Continuously Reinforced Concrete Pavement

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Continuously Reinforced Concrete Pavement:

Extending Service Life of Existing Pavements

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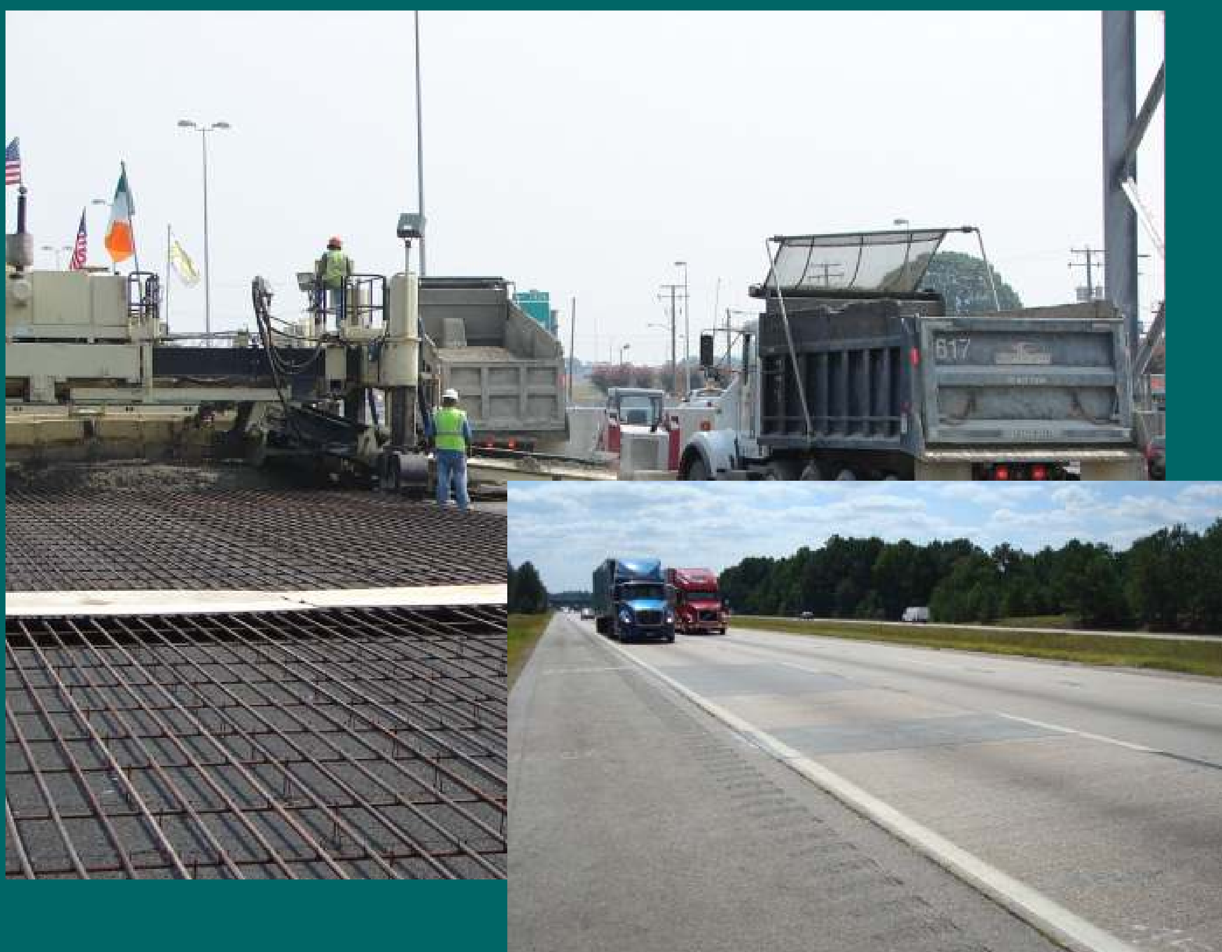

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16. Abstract

The purpose of this guide is to provide information on best practices in rehabilitation strategies for extending the service life of continuously reinforced concrete pavements (CRCP). The procedures described consist of defining the problem, identifying potential solutions, and selecting the preferred rehabilitation alternatives. The rehabilitation strategies described comprise two categories: restoration and resurfacing.

Restoration activities preserve the existing pavement by repairing isolated or localized areas of distress in the CRCP and to prevent their reoccurrence by stopping or delaying the deterioration process. Restoration activities include preventive maintenance and repair methods. Restoration activities can be utilized either before or in conjunction with pavement resurfacing methods.

Resurfacing activities, or overlays, significantly increase the structural or functional capacity of an existing pavement. These treatments are not localized, but are applied over the entire surface of the existing pavement. Overlays are used when restoration techniques are no longer sufficient or cost effective, but before reconstruction is required.

When restoration and rehabilitation treatments are applied correctly and in a timely manner, the service life of an existing CRCP can be extended by 10 to 25 years or more without destroying the structural integrity of the existing CRCP.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1. INTRODUCTION

PURPOSE

The purpose of this guide is to provide the best practices information on rehabilitation strategies for extending the service life of continuously reinforced concrete pavements (CRCP). The procedures described in this guideline consist of defining the problem, identifying potential solutions, and selecting the preferred alternatives.[1,2]

Several guidelines for CRCP repair and rehabilitation strategies have been previously published, such as the *1993 AASHTO Guide for Design of Pavement Structures*; the FHWA series on the performance of CRCP that includes *Volume IV: Resurfacings for CRC Pavements* and *Volume V: Maintenance and Repair of CRC Pavements*; and *The Concrete Pavement Restoration Guide* from the American Concrete Pavement Association. (See references 3, 4, 5, and 6.) The most pertinent sections of these documents, and others, are highlighted in this best practices guide, yielding state-of-the-art rehabilitation procedures for CRCP. The intent is for users of this guide to tailor the discussed rehabilitation strategies to meet their own project needs and priorities.

Potential rehabilitation strategies to extend the service life of existing CRCP are discussed in chapter 4. The decision tree presented in chapter 4 can be used to systematically determine which restoration methods are appropriate based on the pavement's structural and functional condition. The restoration treatments are presented as a function of pavement distresses, and general guidelines for selecting which resurfacing treatment to use are provided.

Rehabilitation treatments to extend the service life of existing CRCP s can be selected from the methods listed in chapters 5 and 6:

- Restoration techniques described in chapter 5 include full-depth repairs (FDRs), partial-depth repairs (PDRs), diamond grinding and grooving, joint resealing, slab stabilization and slab jacking, and cross stitching. Items to consider when selecting the restoration techniques are also presented.

- Resurfacing options, namely bonded concrete overlays (BCOs), unbonded concrete overlays (UBOLs), and hot-mix asphalt (HMA) overlays on intact CRCP are discussed in chapter 6, along with the prerequisites to their proper selection.

- Materials used for full-depth and partial-depth patching and for slab stabilization and jacking are presented in chapter 7.

- State specifications for the repair and rehabilitation of CRCP from Texas and Illinois, the States with the most constructed lengths of CRCP, are summarized in chapter 8. Also summarized in chapter 8 are State specifications from Iowa, Texas, and Illinois for overlays for CRCP.

- Standard details for FDR of CRCP from Texas, Illinois, and Georgia are presented in appendix A.

SCOPE AND TERMINOLOGY

This document is intended to provide guidance in selecting the optimal rehabilitation strategy for a CRCP based on observations of the pavement's structural and functional condition, along with an understanding of pavement engineering. It should be noted that the "engineering" solution for the optimum CRCP rehabilitation may not be the best final solution since other decisionmaking criteria such as traffic and constructability, agency policies, and funding can sometimes control the selection process.

Because rehabilitation terminology varies in the literature, the definitions used in this guide are described here. It is assumed that the rehabilitation strategy is selected at the project level. Rehabilitation strategies describe the type and quantity of treatments that should be used, along with when they should be applied. They can be subdivided into two categories, restoration and resurfacing, as shown in table 1.

- *Restoration:* Restoration activities are designed to preserve the existing pavement by repairing isolated or localized areas of distress in the CRCP and then preventing their reoccurrence by stopping or delaying the deterioration process. Identifying the mechanisms leading to the distresses allows the optimal restoration treatment (or set of treatments) to be used. Preventive maintenance and repair methods fall into the restoration category. Pavement restoration activities can be utilized either before or in conjunction with pavement resurfacing methods.

- *Resurfacing:* Resurfacing activities, or overlays, are designed to significantly increase the structural or functional capacity of an existing pavement. These treatments are not localized, but are applied over the entire surface of the existing pavement. Overlays are used when restoration techniques are no longer sufficient or cost effective, but before reconstruction is required.

Table 1. Framework for rehabilitation activities.[3,7]

Classification	Function	Treatment Types
Restoration (see chapter 5)	Preventive maintenance, preservative or corrective	Retrofitted edge drains Joint or crack sealing Retrofitted concrete shoulders Cathodic protection
	Repair	Full-depth repair Partial-depth repair Diamond grinding and grooving Pressure relief or expansion joints Slab stabilization and jacking Cross stitching
Resurfacing (see chapter 6)	Overlay construction	Hot-mix asphalt overlay Bonded concrete overlay Unbonded concrete overlay

CHAPTER 2. EVALUATING CRCP

To develop the "best" rehabilitation strategy, the condition of the existing pavement must be thoroughly evaluated using visual condition surveys, deflection testing, and profile measurements. The data that should be collected can be divided into the following categories:

- Pavement condition: structural and functional.
- Pavement materials and soils properties: surface, subbase, and subgrade.
- Pavement design.
- Drainage conditions.
- Climatic conditions.
- Traffic volumes and loading.
- Geometric and safety factors.

The condition survey provides information on the pavement structural and functional condition via a visual distress evaluation. This survey also documents any previous maintenance activities performed, and the condition of the shoulders. A drainage survey (including local climatic conditions) should also be conducted at this time, along with the collection of field samples. Subsequent laboratory testing provides information on the properties of the pavement materials and soils. Special considerations to keep in mind when performing the condition survey include the traffic volumes and loads, pavement design, and geometric and safety factors. Deflection tests can be used to measure the load transfer efficiency (LTE) at cracks and joints, and to detect voids under the pavement. The results are also used to backcalculate the thickness and stiffness of the layers comprising the pavement structure. If collected, pavement profile measurements can be used to quantify the pavement smoothness. After all of the data are collected, the data should be analyzed to identify the mechanisms causing the deterioration. With this information, the proper rehabilitation strategy can be selected.

Pavement condition data can be used to assess the variability of pavement performance—assessing the rate of deterioration as it varies from point to point along the highway. A variability assessment can be used to determine whether the entire pavement should be resurfaced or whether only localized areas of restoration are needed. Periodic pavement evaluations are especially beneficial because they reveal the rate of deterioration of the pavement. They also assist in identifying deficiencies before they evolve into more significant structural distresses. Preventive, preservative, or corrective actions can be applied at the most opportune time if periodic surveys are conducted. Quite often, each agency has standard data collection and evaluation procedures that best suit its personnel and equipment resources. (Detailed information on how to perform systematic step-by-step condition surveys can be found in references 1, 3, 8, and 9.)

VISUAL CONDITION SURVEY

Before any rehabilitation project is initiated, a visual condition survey of the pavement should be conducted. The distresses visible on the surface of the pavement provide insight into the current structural and functional condition of the pavement. A visual condition survey is often described in terms of a distress survey, a drainage survey, field sampling and testing, and special considerations. Each of these is elaborated on herein.

Results from a visual condition survey may be presented graphically in the form of strip charts or historical performance charts that detail the condition of the pavement at various points along the project length. When used in conjunction with other field tests listed in this chapter, the pavement performance is more accurately characterized. Methods used to conduct visual condition surveys include windshield surveys, walking the pavement, and automated survey equipment. It may be useful to drive the pavement prior to the visual survey to obtain a sense of the distresses that are likely to exist based on the ride quality.

Distress Survey

A distress is defined as any visible defect or form of deterioration on the surface of a pavement. For CRCP, distresses include punchouts, wide transverse cracks, longitudinal cracks, and crack spalling. Other distresses that are more common to jointed concrete pavement (JCP) may also occur in CRCP, such as faulting, pumping, joint deterioration, blowups, and patch deterioration, Materials-related distresses (MRD) can occur in both pavement types and can include D-cracking, alkali–silica reactivity (ASR), freeze–thaw damage, popouts, scaling, corrosion, swelling, and depressions. The mechanisms behind each distress can be described in terms of traffic loads, climatic conditions, materials incompatibilities, or a combination of all three. The purpose of a distress survey is twofold:

- To document the condition of the pavement.
- To characterize the distresses by type, severity, and amount (relative area).

The *Distress Identification Manual for the Long-Term Pavement Performance Program* is one of the most widely cited distress identification manuals.[10] This manual has standardized definitions of the different distress types, allowing for uniformity in identifying their severity and extent. If the type, severity, and extent of the distress are not accurately noted in the survey, it may prove difficult to optimize the rehabilitation strategy. It is important that the survey team review all current and historical pavement records prior to performing a distress survey so they know what to look for while conducting the survey.

Drainage Survey

Distresses in rigid pavements like CRCP can be caused or accelerated by the presence of excess moisture in the pavement structure. A drainage assessment will reveal if drainage improvements are needed or if the current system is not functioning as designed. Recognizing this, drainage surveys are performed to:

- Identify signs of moisture or moisture-related distresses in the pavement.

- Document the pavement drainage conditions (topography, cross slopes ditches, and drainage inlets and outlets if present).[1]

Field Sampling and Testing

To properly characterize the existing pavement, the distress and drainage surveys should be supplemented with the results from laboratory tests on samples of the pavement structure. Destructive testing of core samples taken from the concrete, subbase, and subgrade allow for a more indepth and accurate analysis of the in-place materials and their engineering properties than the surveys provide. In addition, cores can confirm the layer thicknesses in the pavement structure, and can be used to identify MRDs.

Cores are commonly taken at locations observed to have structural deficiencies. They are also taken to validate or complement nondestructive test (NDT) results. Other guidelines for field sampling and testing include the following:

- For punchouts, wide cracks, and any other structural distresses, cores should be taken at the distress to determine the pavement thickness and concrete strength.

- For deteriorated longitudinal and construction joints, cores should be taken through the joints to determine whether or not they are working. If tie bar corrosion is suspected, the core should be taken through the bar to determine the extent of the corrosion and loss of bond.

- For MRDs, like D-cracking and reactive aggregate, petrographic examination and testing of field samples is recommended.

- For drainage deficiencies or foundation movement, subbase and subgrade samples should be tested to determine their permeability and gradation.[11]

The concrete is primarily sampled to measure its strength and thickness, and to identify any MRD problems. Tests on the subbase and subgrade layers focus on measuring their in-situ strength, resistance to load deformations, and resistance to moisture damage. For more field sampling techniques and an overview of in-situ field and laboratory tests, the reader is referred to reference 1.

Special Considerations

The amount of data to collect in a condition survey depends on the size of the project, its variability, the distresses observed, and the rehabilitation methods being considered. In addition, all constraints that will affect the rehabilitation choice should be identified, including geometric and safety factors, traffic control problems, available materials and equipment, and contractor expertise and manpower. Each of these should be assessed at the time of the condition survey. Larger projects on high-traffic-volume roads require a more comprehensive pavement evaluation because premature failures have a more serious effect on performance.[3] However, there are more safety issues with regard to obtaining field samples on high-traffic-volume roads.

Engineering judgment is needed to ensure that the sampling and testing plan is adequate, while not exceeding budgetary constraints.

Pavement variability is assessed by dividing the project into segments that have the same design features and site conditions. Performance differences are expected between these segments (or units), which fall predominately at intersections or interchanges, bridge approach or leave areas, and cut-and-fill sections. In addition to "between-unit variability," there is also "within-unit variability," which addresses the inherent diversity of response within each unit.[3] Both sources of variability need to be considered in rehabilitation design.

DEFLECTION MEASUREMENT

Deflection testing is an integral part of a comprehensive structural evaluation and rehabilitation assessment of pavements to achieve the following purposes:

- Assess the response of the pavement structure to an applied load.
- Evaluate LTE across cracks and joints.
- Detect voids under the pavement.
- Determine in-situ pavement layer properties via backcalculation, like the concrete's elastic modulus and the modulus of reaction of the support layers (k-value).

Deflections simulate a vertical response of the pavement to traffic loads, indicating uniformity and structural adequacy.[1] The larger the deflection is, the weaker the pavement structure. NDT testing equipment commonly used to measure pavement deflection falls into four general classes: static load deflection, steady-state dynamic load deflection, impulse load deflection, and surface wave propagation—commonly SASW (spectral-analysis-of-surface-waves). The falling weight deflectometer (FWD), which belongs in the impulse load deflection category, is most commonly used. Testing does not disturb the pavement and is very efficient. With the ability to evaluate up to 400 locations per day, it is suitable for assessing pavement variability, particularly variability due to seasonal changes.

To measure the LTE of CRCP cracks, the FWD load should be placed in the outer wheel path approximately 2 ft (0.6 m) from the pavement edge.[1] The center of the load should be near the crack, but not on top of it. If the deflection-based LTE is greater than 75 percent, the crack is performing well; between 50 percent and 75 percent means fair performance; and if less than 50 percent, the crack is no longer performing in an acceptable manner. In this case, the underlying subbase may be pumping, the concrete may be experiencing D-cracking, or there may be a rupture of the bars or insufficient bonding of the reinforcement with the concrete. Quite often, wide cracks will coincide with low load transfer.

Deflection profiles are also useful in locating voids in the pavement structure. A void thicker than 0.05 inch (1.3 mm) is enough to generate high stresses in the slab when loaded.[5] Since a loss of support generally begins under the slab corners on the outside traffic lane, deflection tests should be performed here when temperature-induced curling is at a minimum. High deflections at the outside corners (compared to the inside corner deflections) can indicate a loss of support, as can large deflections at the edge of the slab or across joints and cracks. This information can then be used to identify where slab stabilization is needed. For more information on analyzing deflection results, the reader is referred to references 3 and 12.

CHAPTER 3. MECHANISMS CAUSING CRCP DISTRESSES

The mechanisms that lead to different distresses on CRCP are discussed in this chapter. Quite commonly, traffic loads, climate, material incompatibilities, or a combination of all three cause the distresses recorded in the pavement condition evaluation.[13] More specific mechanisms include the following:

- Vehicles producing significant dynamic loads when they move at high speeds over rough pavements. These dynamic loads accelerate CRCP deterioration, especially at discontinuities like poorly performing cracks or patches.

- Like vehicle loads, temperature and moisture variations also lead to pavement stresses. Temperature changes cause volumetric expansion and curling, while moisture changes can induce warping stresses. Moisture can also enter the pavement structure through wide joints and cracks, causing the support to soften and even pump.

- MRDs lower concrete strength and decrease its integrity. This translates to an increase in pavement deterioration under the same traffic and climatic loading. Typical MRDs include D-cracking, ASR, freeze–thaw damage, and reinforcement corrosion.

The more common distresses found in CRCPs are listed in table 2. The mechanisms behind their formation are indicated, and are primarily caused by traffic loading, climate, or materials issues. Punchouts and wide transverse cracks (which can lead to punchouts) and longitudinal cracking are the most damaging structural distresses. Other distresses that may occur are spalling, faulting, pumping, patch deterioration, and MRD. Distress severity (low, medium, or high) indicates how far the distress has progressed; a high-severity distress will need more rehabilitation than a low-severity one. In the following sections, the mechanisms causing these distresses are discussed. Understanding the distress mechanisms at work will aid in identifying the most appropriate rehabilitation treatments. The likelihood that the repair will fail in the same manner is reduced once the original distress mechanism has been remedied.[5] The rehabilitated pavement will have a longer service life, which translates to a better use of available funds and reduced overall cost.

Table 2. Common CRCP distresses and their mechanisms.[(3)]

Distress Type	Caused by Traffic Loading	Caused by Climate / Materials
Punchout	X	
Cracking		
Wide transverse cracks	X (M,H)	X (L)
Longitudinal cracks		X
Spalling	X	X
Faulting		
Longitudinal joint faulting	X	X
Lane/Shoulder dropoff or heave		X
Erodibility		
Pumping and water bleeding	X (M,H)	X (L)
Joint distress		
Construction joint distress	X	X
Lane/shoulder joint separation		X
Materials-related distresses		
D-cracking		X
Alkali–silica reactivity		X
Popouts		X
Scaling, map cracking, and crazing		X
Corrosión		X
Swell		X
Depression		X
Localized distress		X
Blowup		X
Patch deterioration		
Asphalt patch deterioration	X	
Concrete patch deterioration	X (M,H)	X (L)
Adjacent slab deterioration	X	X

Note: L = low severity, M = medium severity, and H = high severity.

CRACKING

CRC pavements are designed to crack in the transverse direction. Transverse cracks are designed and expected to remain tight, and as such are not considered distress. However, if they widen, some restoration or rehabilitation treatment may be required. The mechanisms causing wide transverse cracks and longitudinal cracks are discussed here.

Wide Transverse Cracks

Medium- and high-severity transverse cracks with crack widths ranging from 0.12 to 0.24 inches (3 to 6 mm), spalls greater than 3 inches (75 mm), and faults greater than 0.24 inches (6 mm) should be repaired immediately. Otherwise, a more extreme method of rehabilitation will be required in the future.[5] These distresses form for various reasons:

- Structural deficiency in the pavement.
- Construction or design defects.
- Localized loss of support.

Low levels of reinforcement in CRCP can cause large crack spacing to develop greater than 10 ft (3 m) in some cases.[14] This crack spacing can sometimes lead to a widening of the transverse cracks and an increase in tensile stress in the reinforcement. If the reinforcement ruptures, the transverse crack will be free to open and close, and will lose much of its load transfer. Water will then readily infiltrate the crack. Even if the reinforcement does not rupture initially, the loss of support and associated high deflections under heavy traffic loads may cause it to rupture eventually. Good construction is important to ensure steel continuity, proper lap length, and good consolidation of the concrete, especially at the construction joints.

Wide transverse cracks can form when reinforcing steel corrodes, which means that the steel reinforcing bars are more likely to rupture. Typically, the steel reinforcement ruptures first in the outside lane. This places more stress on the inner bars, and rupture progresses from the outside inward.[5] To minimize this, transverse crack widths should be limited to 0.02 to 0.04 inch (0.5 to 1 mm) to prevent the infiltration of moisture, deicing salts, and incompressible materials. However, once the wide transverse cracks have formed, FDRs should be used to remedy this distress, along with slab stabilization to correct any associated loss of support, if needed.

Longitudinal Cracks

Longitudinal cracks can form in CRCP because of poor construction techniques or subgrade settlement (figure 1). Late sawcutting or improper placement or omission of the joint separator strip, if used in lieu of sawing, can cause longitudinal cracks to form.[5] Cracks of this nature rarely develop further or cause additional problems. A second mechanism that causes longitudinal cracking is subgrade swell or settlement. These longitudinal cracks commonly widen under repeated loading, allowing water to enter into the pavement structure. Treatment options for longitudinal cracks include sealing, slab stabilization, and complete slab replacement. If transverse reinforcement is present and it shears at the longitudinal crack, the resulting vertical and horizontal separation can be remedied by cross stitching and diamond grinding.

Figure 1. Longitudinal crack in CRCP.

PUNCHOUTS

Punchouts typically occur at the pavement or shoulder edge (figure 2). The primary cause of punchouts is concrete fatigue, which is caused in turn by repeated traffic loading, possibly aggravated by insufficient pavement thickness or a weak foundation.(4) The most commonly cited theory describes how traffic loads induce high-tensile stresses at the top of the slab in the transverse direction (perpendicular to the direction of traffic) between two closely spaced transverse cracks. If the subbase shifts or pumps between the two transverse cracks, the small concrete segment can deflect and bend like a cantilever beam. As the deflections increase, the cracks wear out, and the load transfer decreases. Crack widths subsequently begin to increase, and the transverse cracks eventually spall and fault. Finally, a longitudinal crack develops in this cantilevered section, and a punchout results. Time and traffic increase the severity of a punchout as the distressed area continues to push down into the subbase and subgrade materials. Reinforcement at the segment will permanently deform, and may even rupture. If the reinforcement does not break, deep spalls can form in the concrete above each bar. If steel reinforcement corrodes because of its exposure to moisture and deicing salts, rupture is even more likely.(5) In short, repairs should not be delayed once a punchout forms. Most agencies repair punchouts with FDRs on an as-needed basis.

Figure 2. Punchout.

SPALLING

Spalling of concrete is defined as the cracking, breaking, chipping, or fraying of slab edges within 2.4 inches (60 mm) of a crack or joint (figure 3).[10] In CRCP, spalls are primarily caused by high deflections, infiltration of incompressible materials, weak concrete, or the corrosion of reinforcing steel. Secondary causes include reinforcement misalignment, inadequate concrete cover, and MRDs.[1]

When a heavy wheel load passes over a crack, high deflections occur, and a stress concentration develops at the top of the slab, which can cause the pavement surface to crumble over time. Concrete segments that are curled down have even higher stress concentrations at this location, as do CRCP cracks filled with incompressible materials. Spalling of CRCP can also be linked to weak surface concrete, corrosion of reinforcing steel, and the use of aggregates with high thermal expansion properties. Surface concrete weakens when it experiences a severe loss of moisture, inadequate mixture proportions, or poor finishing. Weak concrete deteriorates more easily. Corrosion of reinforcing steel also can cause spalling because the rust byproduct occupies more volume than the steel. The resulting expansive pressures cause the concrete to spall, especially if the cover is less than 3 inches (75 mm).

Figure 3. Spalling at CRCP transverse cracks.

OTHER MECHANISMS

Pumping and Erosion

Pumping is the ejection of water and support material through pavement joints, cracks, or edges. Primary factors that influence pumping are the erodibility of the support material (silty subbase materials are most susceptible), the presence of free water, and pavement deflections (due to traffic loading). Secondary factors include the permeability of the subgrade material, CRCP crack spacing, and the quality of the lane–shoulder joint seal. Pumping leads to a loss of pavement support and the formation of voids. A void thicker than 0.05 inch (1.3 mm) will cause significant deflections when loaded.[5] In the visual condition survey, pumping can be detected by looking for punchouts, lane–shoulder dropoffs, pavement roughness, and the deposit of subbase materials on the pavement surface or shoulder. If pumping has progressed to the point that voids have formed, their presence can be confirmed by deflection testing or coring.

Corrosion

Reinforcement corrosion may occur in CRC pavements in areas of the country that use extensive amounts of deicing chemicals during the winter months. Because rust occupies a larger volume than intact steel, the concrete cover may prematurely spall and delaminate from the expansive pressures. Likewise, the corroded steel is more likely to rupture because of its reduced cross-sectional area.[5] Wide transverse cracks can form or blowups can develop if incompressible materials fill the crack and the pavement expands. Conventional restoration options for corroded reinforcement are FDRs and pavement resurfacing.

CHAPTER 4. SELECTION CRITERIA FOR THE REHABILITATION OF CRCP

Through use of the pavement condition evaluation tools identified in chapters 2 and 3, the appropriate rehabilitation solution can be more readily identified. Decision trees or matrices are commonly used for this purpose because they link the pavement condition to possible rehabilitation options in a systematic manner. Their flexibility allows them to be applied to pavements with different distresses. Unique rehabilitation alternatives are identified and tailored to each pavement, rather than specifying a single fix that would be applied over and over again.[1] Decision trees do have limitations, however, as they often lead to only a small number of feasible treatments. As a result, a serious effort should be made to identify and consider as many rehabilitation options as possible for any given project. Pavement performance is more likely to improve if a range of different alternatives is considered. It is important to recognize that decision trees are only "tools" for selecting rehabilitation strategies; they are not absolute indisputable methods. Engineering judgment and local experience should always be applied when rehabilitation strategies are being selected. It also may be advisable to conduct an economic analysis to determine the long-term cost of a rehabilitation strategy.

The optimal rehabilitation strategy will repair the distress that is present in the existing pavement to meet all project constraints in a cost-effective manner. "Quick fixes" or cosmetic treatments should only be considered as a temporary solution because they do not mitigate the distress mechanisms. If the root of the problem is not addressed, distresses will only continue to appear over and over again, forcing more lane closures and additional costs onto the highway agency.

In this section, decision trees are presented that can be used to identify optimal rehabilitation strategies for CRCPs, whether they are restoration or resurfacing strategies. It should be noted that these decision trees are only intended to provide general guidance in the selection of rehabilitation strategies and are not designed or intended to cover every possible pavement distress and every possible rehabilitation alternative. The decision trees recommended here also cover only the minimum allowable rehabilitation treatment, and can therefore always be upgraded. Decisionmaking using these trees should be based on an engineering evaluation of the existing pavement. As given here, they do not incorporate related factors like constructability and cost-effectiveness. Users will have to incorporate these additional criteria into their final decision as needed. Similarly, the threshold values provided in the decision trees presented should be carefully evaluated and possibly redefined by each user to match local practice.

DECISION TREE

An overall decision tree to identify possible rehabilitation treatments for CRCPs is illustrated in figure 4. After the need for rehabilitation has been identified, pavement evaluation data is used to determine if restoration treatments or resurfacing options should be applied or if the pavement should be reconstructed. Pavements with good structural capacity may only need restoration treatments. Structurally deteriorated pavements, on the other hand, may require increased structural capacity via resurfacing methods or reconstruction. The decision tree given here uses both condition survey criteria and functional criteria to make a decision. In addition, users can also include structural and functional triggers and limiting values established by the highway agency.

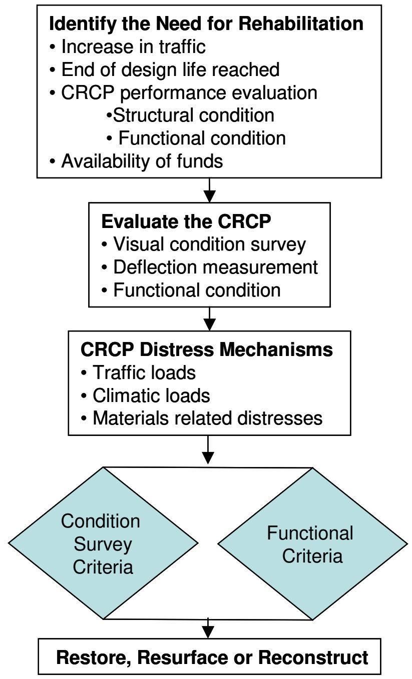


Figure 4. Decision tree for performing restoration or resurfacing activities.

SELECTION OF RESURFACING OPTIONS

When it is decided to resurface the existing pavement, the next decision to make is whether to use an HMA overlay, BCO, or UBOL. As an example, the decision tree in figure 5, from a study conducted for the Texas Department of Transportation (DOT),(13) allows these resurfacing options to be selected using condition survey data, deflection survey data, ride quality data, and a life-cycle cost analysis (LCCA).

The "F/km/yr" criterion referenced in the chart is "failures per kilometer per year." The effectiveness of the different overlay options depends on the structural condition of the existing CRCP. Since thin functional HMA overlays are not a feasible option if the CRCP lacks structural capacity, they should not be used if pavement deflections are too high. However, if the CRCP has sufficient structural capacity, thin HMA overlays can be used to improve surface characteristics including friction and ride quality. The concrete overlays (BCOs and UBOLs) are effective in increasing both the structural and functional capacity of the existing pavement. A UBOL is more appropriate if the existing pavement is extensively deteriorated, while a BCO is the best choice for CRCPs not showing significant distress. Engineering judgment should always be applied when making the final decision.

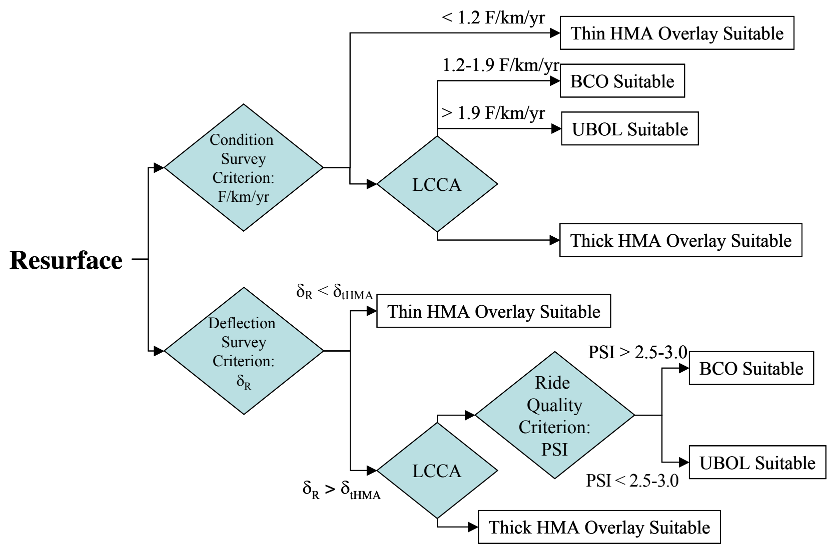


Figure 5. Decision tree to determine the optimal resurfacing treatment.[(13)]

F/km/yr = failures per kilometer per year; PSI = present serviceability index

DEFLECTION SURVEY CRITERIA

Deflection tests can indicate the structural capacity of a pavement. If deflections are high, the pavement possesses reduced structural integrity compared to a structurally sound CRCP with low deflections. For CRCP, a deflection ratio (δ_R) has been used as a measure of the pavement structural capacity. The ratio is defined as the deflection at a crack divided by the deflection at mid-slab (between two transverse cracks) as follows:

$$Deflection\ Ratio\ (\delta_R) = \frac{Deflection\ at\ Crack}{Deflection\ at\ Midslab} = \frac{\delta_{crack}}{\delta_{midslab}} \quad \textbf{(1)}$$

The deflection criteria included in the decision tree can be used to determine whether HMA overlays, BCOs, or UBOLs are the optimal solution (figure 5). The allowable deflection ratio for HMA overlays (δ_{tHMA}) is less than the ratio allowed for BCOs (δ_{BCO}). Similarly, the deflection ratio allowed for BCOs is less than that for UBOLs (δ_{UBOL}). UBOLs provide more structural support than BCOs. These limiting deflections are summarized as follows:

$$\delta_{tHMA} < \delta_{BCO} < \delta_{UBOL} \quad \textbf{(2)}$$

Thin HMA overlays (1.5 to 2 inches (40 to 50 mm)) do not provide a significant amount of structural support. However, they may be the ideal rehabilitation option if placed in a timely manner on a structurally sound CRCP that has only profile (smoothness) irregularities. If the CRCP is rough and has a high deflection ratio, a thin HMA overlay may alleviate some of the dynamic impact loads, but the structural deficiency will still have to be addressed at a later date. Typically, all major structural failures should be fixed before placing a thin HMA overlay. If not, reflection cracks may appear soon after its placement.

Based on local practice, agencies can determine their own deflection criteria. These thresholds are a function of the pavement deflection ratio and the traffic-induced stresses with and without the overlay.

SELECTION OF RESTORATION OPTIONS

Depending on the pavement condition survey and functional criteria, restoration techniques may be applied to improve the pavement performance. The decision matrix presented in table 3 shows the repair and preventive alternatives available for CRCP structural and functional distresses. If the distress severity is low, only preventive techniques are required.

Table 3. Repair and preventative techniques for CRCP structural and functional distresses.[3,5,15]

Distress	Repair Technique	Preventive Technique
Structural Distresses		
Pumping	Slab stabilization Full-depth repair	Reseal joints Retrofit edge drains Retrofit concrete shoulders
Wide transverse cracks	Full-depth repair	Slab stabilization
Longitudinal cracking	Full-depth repair Cross stitching	Reseal joints Cross stitching Slab stabilization
Joint or crack spalling	Full-depth repair (spall depth > D/3) Partial-depth repair (spall depth < D/3)	Reseal joints
Blowup	Full-depth repair	Pressure relief joints at CRCP ends Reseal joints
Punchouts	Full-depth repair	Slab stabilization Retrofit concrete shoulders
Patch deterioration	Full-depth repair Diamond grinding	Reseal joints
Functional Distresses		
Faulting	Diamond grind	Slab stabilization Reseal joints Retrofit edge drains Retrofit concrete shoulders
Scaling	Partial-depth repair (spall depth < D/3) Diamond grinding	Reseal joints
Surface polishing	Diamond grinding / grooving	

Note: D = slab thickness

CHAPTER 5. CRCP RESTORATION

Restoring CRCP can delay the placement of costly overlays or total pavement reconstruction. For restoration techniques to be most effective, they should be engineered and constructed properly. Timing of the treatment application is also critical. If the "window of opportunity" is missed, performance trends show that the distresses will deteriorate at an accelerated rate. This chapter presents the considerations used to select the optimal CRCP restoration techniques and describes six different restoration techniques.

CONSIDERATIONS IN CRCP RESTORATION

To evaluate the feasibility of using different restoration alternatives, the structural and functional condition of the CRCP needs to be considered, as does the cost-effectiveness of the various alternatives. These two tasks can be summarized as follows:

1. *Structural and functional condition*. The best restoration techniques not only repair the existing structural and functional distresses, but also prevent or postpone their reoccurrence so that the pavement can be used as originally designed.(3) Restoration techniques used on a project need to address the cause of the distresses.(3) As a result, for each structural and functional distress, one or more restoration alternatives might need to be applied (see Table 3).

2. *Cost-effectiveness*. The cost-effectiveness of using various restoration techniques depends on the quantities required, and the timing of their use.(5) On a structurally adequate pavement, several repair and preventive maintenance methods can be used cost effectively to correct CRCP distress. Using these methods will increase the probability that the pavement will reach its intended design life or beyond. On a structurally inadequate pavement, restoration treatments are likely not an option. In this case, a more involved rehabilitation strategy, like resurfacing, should be used because the restoration techniques do not increase the pavement structural capacity.

RESTORATION TECHNIQUES AND PROCEDURES

In this section, the techniques used to restore CRCP are presented. FDRs and PDRs are categorized as corrective techniques. They repair a given distress and improve the pavement serviceability. Other restoration activities are slab stabilization and jacking, diamond grinding and grooving, and cross stitching. The purpose of each of these restoration methods is detailed, as are the CRCP distresses they repair or prevent. Their application procedures are also briefly described. It will be noted that the sequence of performing these restoration techniques is very important to the success of the pavement rehabilitation. For example, slab stabilization, if needed, should precede FDRs and PDRs. Cross stitching and all other activities except joint resealing should be done prior to diamond grinding. Joint resealing is the last treatment to be applied.(3)

Full-Depth Repairs

FDRs are used to repair severely deteriorated punchouts, joints, or cracks in CRCP when normal maintenance procedures can no longer correct them. They restore locally damaged areas to near-original condition with similar rideability and structural integrity. A limitation of FDRs is that they do not increase the pavement's overall structural capacity. In rehabilitation projects, FDRs are typically the most prevalent and largest cost item. Because of this, many highway agencies tend to delay their installation. This delay leads to an increased rate of pavement deterioration and even more costly rehabilitation in the future.(3) Ideally, FDRs should be constructed at the earliest appropriate time to be most cost effective, and to obtain the best long-term performance.

While FDRs are primarily used to repair punchouts in CRCP, they can also repair the following distresses:

- Wide transverse cracks (medium and high severity).
- Longitudinal cracks (high severity).
- Localized distresses, like spalls, that extend through more than one-third the slab thickness (medium and high severity).
- Blowups (low, medium and high severity).
- D-cracking (as a stopgap measure) (high severity).
- Deteriorated previous repairs (high severity).(1)

FDRs are not considered a long-term solution for MRDs such as ASR and D-cracking.

FDRs are composed of reinforced cast-in-place concrete. When properly constructed, they will permanently repair the distressed area, and will perform as well as the adjacent material. HMA is sometimes used as a temporary fix until a permanent concrete repair can be installed.(5) HMA patches should not be left in place as permanent patches.

Typical FDR construction follows the steps described below:

1. *Define the patch area.* The patch boundaries should completely encompass all existing deterioration. Distresses may be larger on the bottom of the pavement than they are on the surface by up to 3.3 ft (1 m) on any side.(1) The boundaries should also encompass any subbase voids created by pumping. Likewise, the patch should be large enough to prevent rocking and longitudinal cracking. A minimum patch length of 4 to 6 ft (1.2 to 1.8 m) by one half-lane to one full-lane width has been found to provide the necessary stability.(5) Patch boundaries should not be closer than 18 inches (0.46 m) to an existing transverse crack or joint as a guide. Methods used to define FDR patch areas in CRCP are shown in figure 6.

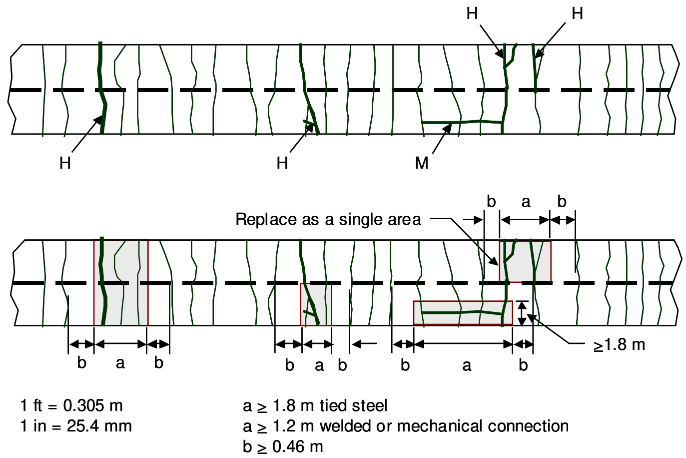


Figure 6. Placement of FDRs in CRCP.[1]

2. *Saw and remove the concrete.* Full-depth saw cuts are typically used to separate the deteriorated concrete from the surrounding concrete in the longitudinal direction.[3] In the transverse direction, both partial-depth and full-depth saw cuts may be required (figure 7). The final decision will depend on whether the reinforcement will be installed using tied laps, mechanical couplers, single or double welds, or by drilling and grouting. Tied laps require the most existing steel exposure, 24 inches (610 mm) of overlap for the splice (figure 8). Mechanical couplers require 1 to 2 inches (25 to 50 mm) of overlap, while single 0.25-inch (6-mm) welds require 8 inches (200 mm), and double welds require 4 inches (100 mm). All of these dimensions indicate how far the partial-depth saw cut should be from the full-depth saw cut. Jackhammers or manual methods can then be used to remove the concrete from around the reinforcing bars. Care must be taken that the steel is not nicked or bent in the process, since the patch concrete may spall as a result. The dimensions of the FDR should be extended if this does occur. This construction practice is time consuming, labor intensive, and very costly. An alternate method used in Texas that saves time is to drill holes in the sawed face and use epoxy to anchor new reinforcing bars directly into the existing concrete. The reinforcing steel in the repair is then spliced to the inserted rebars.

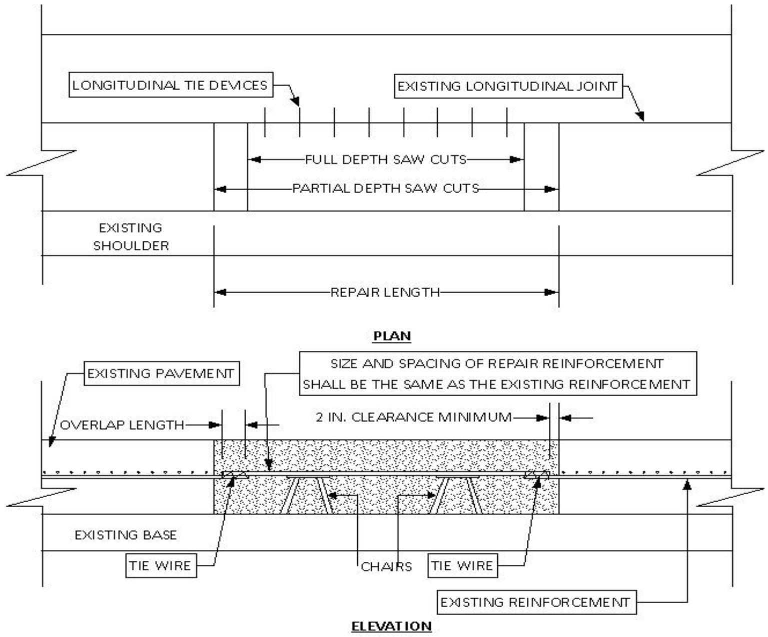


Figure 7. Schematic of conventional FDR on CRCP.[(16)]

Figure 8. Exposed steel for splicing new rebars in CRCP.

Once the FDR boundaries have been sawed, the concrete should be removed within 2 days or else pumping and punching of the subbase may occur. Lift-out or breakout methods can be used to remove the distressed concrete. The lift-out method is preferred because it does not damage the subbase and is faster.[(1)] With the breakout method, the concrete is broken into small fragments and removed. This method can damage the subbase, but is sometimes preferable since it is not always possible to use the lift-out method.

3. *Prepare the patch area.* After concrete removal, the subbase has to be prepared. Any loose material or excessive moisture should be removed. If damaged, the subbase should be backfilled, leveled to the height of the adjacent material, and compacted similarly.[5]

4. *Install reinforcement.* The FDR should be reinforced with longitudinal steel bars that match the existing reinforcement's grade, quality, and size. Maintaining continuity in the CRCP reinforcement is considered to be critical to the long-term performance of the FDR by most highway agencies (figure 9). Tied splices, welded splices, mechanical connections, or drilling and grouting the reinforcement into the existing concrete have been used to maintain the continuity of the reinforcement. Performance problems have been reported by some agencies with the use of mechanical couplers as well as with drilled and grouted reinforcement. A study conducted by the Pennsylvania DOT in the late 1980s, however, reported good performance with mechanical couplers after 5 years. The recommendation was not to use mechanical couplers as a replacement for tied reinforcement in the patches due to the cost.[17] Since 1994, the Texas DOT (TxDOT) has used the drill-and-grout method, which is discussed in more detail below. The longitudinal steel should be supported on chairs to avoid bending and sagging, and the concrete cover should be at least 2.5 inches (60 mm) thick. Illinois also uses supplemental transverse steel in the patch to guard against longitudinal cracking and punchouts.[5]

Figure 9. Maintaining reinforcing steel continuity in CRCP.[1]

The Illinois DOT published a report in 1998 detailing the results of a 20-month study of full-depth CRCP patching techniques.[18] The results showed that the addition of transverse reinforcing steel greatly reduced failures. Patches with mechanical bar couplers showed failures within 1 month. The patches that used the drilled in reinforcing steel to which the longitudinal reinforcing was tied had a failure rate of 45 percent during the study period.

The TxDOT Method

The TxDOT Pavement Design Guide manual requires the drill-and-grout method for full-depth CRCP repair.[19] Texas Tech University completed a research study for TxDOT in 2012 to evaluate the performance of FDR.[20] The full-depth-cut method with drilled-in reinforcing steel was placed in the TxDOT specifications in 1994 due to limitations on the allowable repair time. The majority of the patches installed with the new requirements are performing well, but a substantial number of the patches were showing distress and required additional repairs.[20] The performance of this method was examined in the research study with field investigations and laboratory testing with the objective to determine the causes and recommend improvements.

The laboratory investigation included pull-out test, various epoxies, and injection methods. The field investigation consisted of FWD testing and removing and examining failed patches. The majority of the distress occurred in the existing pavement side of the patch. The FWD testing showed a minimal increase in deflections at patches that performed well but a substantial increase at the failed patches. Since the cut face of the concrete is smooth, load transfer at a patch is carried by the reinforcing steel and base support. It is therefore crucial that the drilled and epoxied steel bars are properly placed. The field investigation showed lack of bond between the reinforcing steel and the concrete, which can largely be attributed to poor installation practices (figure 10).

Figure 10. Lack of bond between inserted rebar and concrete.[20]

The study showed that proper installation of the reinforcing bars is very important. Proper installation practices are similar to the installation requirements of dowels in jointed pavement FDRs.

- The holes must be only slightly larger than the rebar size (rebar size +1/8 inch) (+3 mm)).
- The holes must be free of dust, moisture, and grease.
- The epoxy must be placed at the back of the hole to avoid air pockets when inserting the bar. Dipping the bar in epoxy and pushing it into the hole is bad practice.
- There must be enough epoxy in the hole to fill the entire void around the bar. The viscosity of the epoxy must be sufficient to prevent run-out.
- The epoxy must be left to set before the reinforcing steel is attached and concrete is placed in the patch.
- Drilling holes with the hammer drill rather than a rotary drill is the fastest method and does not affect bond strength.

- The holes should be a minimum length of 6 inches (150 mm) for adequate pull-out resistance.

The South Carolina DOT Method

In the mid 1990s, the South Carolina DOT (SCDOT) decided not to replace the steel at all in FDRs. SCDOT previously had been drilling and grouting the reinforcing bars into the existing concrete and found that the concrete often ruptured at one end of the patch within a year or two because the grouted bars were pulling loose. SCDOT's current repair detail for CRCP is shown in figure 11. The key details of the South Carolina method are as follows:

1. Repairs are full-lane width and mostly in a single lane only, typically the outside lane of a two-lane, one-direction roadway. However, a few repairs have been carried out in two lanes of a three-lane roadway.

2. The repair area full-depth perimeter cuts are made.

3. Longitudinal steel continuity is not maintained in the repair area. In fact, longitudinal steel is not used in the repair area.

4. Tie bars are used along the centerline longitudinal joint for longer patches. Tie bars are spaced at nominally 30-inch (762-mm) spacing, but the spacing may be varied to avoid any cracking in the adjacent lane and to be at least 15 inches (375 mm) away from the repair area's transverse joints.

5. Dowel bars are placed at middepth at a nominal spacing of 12 inches (300 mm), starting and ending about 12 inches from the corners of the repair area. The dowel bar spacing is adjusted to miss any longitudinal steel in the existing pavement.

6. Intermediate transverse joints are required for repair lengths greater than 16 ft (4.9 m). Dowel baskets are used at these intermediate joints, with dowels spaced at 12 inches (300 mm). The intermediate joints are sawed to a depth of one-third of the depth of the repair area and sealed.

Overall, the jointed FDRs are performing well at several projects in South Carolina. A windshield survey conducted in 2010 on the repairs on I-95 indicated that the FDRs using this method were still in good condition after 5 years of service under heavy truck traffic.[16] The subbase for I-95 is a cement-stabilized soil.

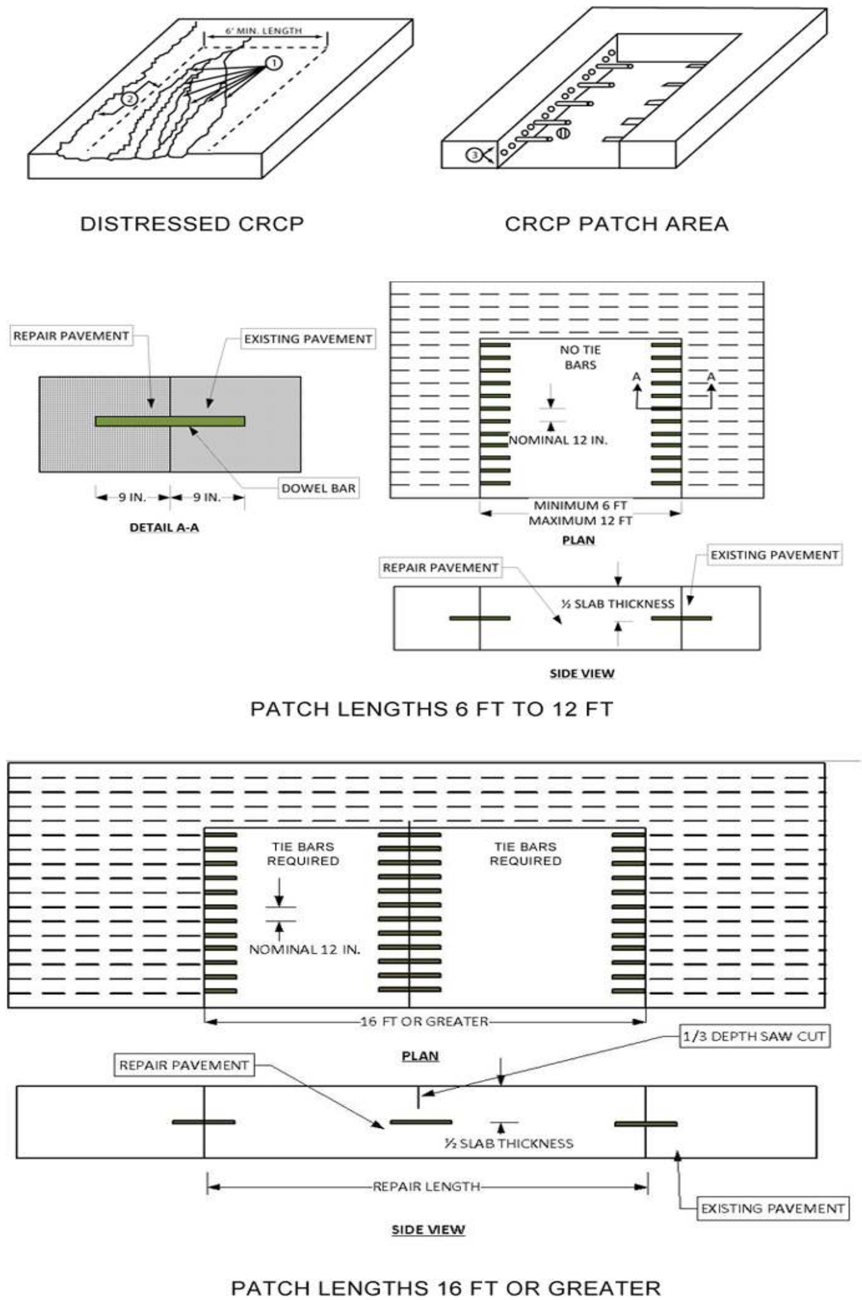


Figure 11. Details of the South Carolina jointed FDR of CRCP.[(16)]

A number of FDR repairs of CRC have also been made on I-77. Both full-lane-width and half-lane-width patching have been done on this pavement. Almost all of the repairs are performing well based on a windshield survey conducted in the fall of 2012 (figure 12 and figure 13).

Figure 12. Full-lane-width FDR on I-77 in South Carolina.

Figure 13. Half-lane-width FDR on I-77 in South Carolina.

The SCDOT FDR method allows for the consideration of using precast concrete panels instead of the conventional cast-in-place method. This technique is more fully discussed in a report that was prepared for the Strategic Highway Research Program 2 on precast concrete pavement technology.[21] The use of precast panels and positive load transfer along the transverse joints of the repair area can ensure repair area concrete durability and long-term performance of the transverse joints under heavy truck traffic. The precast panel repairs can be performed during the nighttime and the repair areas can be opened to traffic the next morning. The specific items to be considered for use of precast concrete panels for FDR of CRCP are as follows:

1. Concrete removal and base preparation steps should follow standard procedures for jointed FDR, except that the repair area boundary should be selected so that the transverse joints are at least 24 inches (600 mm) from the nearest crack and at least 12 inches (300 mm) from the nearest transverse reinforcement.

2. The location of the dowel bar slots in the precast panel should be laid out to ensure that the slots and the companion drilled-and-grouted dowel bars will not interfere with the longitudinal steel.

3. The gap around the perimeter of the panel can be filled with an approved rapid-setting cementitious grout.

4. The transverse and the longitudinal joints should be sawed and sealed.

5. *Place and finish the concrete.* Conventional concrete mixtures are most commonly used for FDRs, but rapid-setting mixtures can also be used if the pavement needs to be opened to traffic as quickly as possible (chapter 7). Prior to placing the concrete, the patch area should be cleaned to ensure that a strong bond develops between the new concrete and the existing concrete. Vibrating the fresh concrete around the patch edges and reinforcement will also ensure their intimate contact. The repair should be finished to match level and texture of the adjacent concrete.

6. *Cure the concrete.* To cure the newly placed patch, curing compound is most commonly applied at 150 ft^2/gal (3.7 m^2/L), approximately two times the “normal” rate.[1] Wet burlap, polyethylene sheeting, or insulation blankets can also be used. Like all concrete work, the curing should be applied as soon as possible after finishing ensuring good strength and durability. Local experience should also be followed regarding what time of the day and during what season the patch should be constructed. Typically, patches placed in the afternoon during the spring or fall perform well since they have the opportunity to gain sufficient strength before significant stresses begin to develop.

7. *Saw and seal the joints.* The longitudinal joints and any construction joints should be sealed to reduce the likelihood of moisture and incompressible infiltration.

The need for high-quality FDR construction cannot be overemphasized. Inadequate design, poor construction quality, and poor installation procedures will lead to premature patch failure (figure 14).

Figure 14. Failure of FDR.

Distresses commonly seen in FDRs include irregular transverse cracks, edge punchouts, and longitudinal joint failure, pumping, and spalling. Distresses that can occur in the adjacent slab segments include spalling, wide cracks, edge punchouts, and blowups. When the distress extends over multiple lanes, the lanes can be repaired independently. A separation fiberboard should be placed along the longitudinal joint during construction. Furthermore, the FDR saw cuts do not need to match across the lanes, but a small offset should be avoided. If there is a blowup in the adjacent lane while placing the FDR, repair work should be delayed until cooler weather.

Partial-Depth Repairs

PDRs are sometimes used to repair localized surface distresses of less than 10 ft^2 (0.9 m^2) that exist in the upper one-third of the CRCP thickness (figure 15). This commonly includes spalls, scaling, and popouts. PDRs retard future deterioration and maintain the pavement's functional condition without increasing its structural capacity. These repairs are not appropriate if the deterioration extends below the upper third of the slab; FDRs should be used in these cases. The Illinois DOT does not routinely use PDRs on CRCP. Small spalls are left untreated, and HMA is used in larger spalls as a temporary repair. TxDOT uses PDRs on shallow spalls. The TxDOT *Pavement Design Guide* defines shallow spalls as less than 4 inches (100 mm) in depth.(19)

Figure 15. Shallow spall.(19)

The mechanisms that cause spalls to form are listed in chapter 3. It should be stressed that not all spalls should be repaired with PDRs. In particular, spalls caused by reinforcement misalignment, D-cracking, reactive aggregate, and freeze–thaw damage should not be repaired with a PDR.[(1] In these cases, the PDR will not address the underlying mechanism and the spall will likely form again in the future. However, if the spall is the result of incompressible material entering the construction joint or reinforcement corrosion, a PDR can repair and prevent the spall from forming again. Studies conducted by TxDOT concluded that spalling can occur from early-age delamination due to evaporation-induced stress gradients resulting in a shearing action near the surface of the pavement.[(22)] An investigation of the cause of the occurrence of spalling should be done prior to making any decision regarding the method of repair.

Repairing spalls at the longitudinal joints or the transverse construction joints allows the joint sealant reservoir to be reformed. When the joint is properly sealed, the amount of moisture and incompressible material that infiltrate will be reduced. Spalling will only increases in severity as more incompressible materials fill the joint.

PDRs are also commonly used on deteriorated pavements prior to resurfacing. When this is the case, the PDR's surface finish is not as important, and the joints do not need to be resealed. The overlay will protect the repair from load and environmental stresses. However, if the pavement will not be subsequently resurfaced, the PDR should be placed with the highest quality of workmanship. TxDOT has developed specifications (720, ss3203, ss3256) for PDRs.

The following steps are typically followed when constructing high-quality PDRs:[(23,24)]

1. *Locate the unsound concrete.* PDRs preserve the pavement by replacing the localized areas of poor concrete with new, high-quality concrete. Sounding is a technique commonly used to identify delaminated areas and unsound concrete.

2. *Identify the repair dimensions.* The full extent of a distress is not always visible from the surface of the pavement. To account for this, the repair area is usually extended 3 to 4 inches (75 to 100 mm) beyond the visible area. Repairs are commonly square or rectangular, with recommended minimum dimensions of 4 by 12 inches (100 by 300 mm). If two or more spalls have formed on the same transverse construction joint, the entire joint should be repaired because one large patch is better than several small patches. Repairs should not be placed if the deteriorated area is less than 6 inches (150 mm) long by 1.5 inches (35 mm) wide.

3. *Remove the concrete.* The deteriorated concrete can be removed by sawing the repair boundary and chipping out the deteriorated concrete with a light pneumatic hammer or by using a carbide-tipped milling machine. The bottom of the repair should consist of sound concrete. Reinforcement can sometimes be visible depending on the location of the steel and the depth of the deterioration. Care must be taken not to damage the reinforcing bars.

4. *Clean the repair area.* Sandblasting or high-pressure water blasting can be used to remove loose particles, oils, dust, and other contaminants from within the repair area. Air blowing typically follows to ensure that all dust and debris have been removed. If the repair area is 3 ft (1 m) or larger, it is recommended that No. 5 hook bars be drilled and

grouted into the bottom of the repair area at 1-ft (300-mm) intervals in both transverse and longitudinal directions.[9] If reinforcing steel is exposed, sandblasting will be necessary to remove the cement paste from around the bar.

5. *Place the joint insert.* PDRs at construction joints and longitudinal joints in CRCP need a compressible insert placed to prevent the adjacent concrete from bearing directly onto the newly placed concrete. If the insert is not placed, the repair may fail quickly, popping out or delaminating.

6. *Apply the bonding agent.* Cement grouts or epoxy agents can be used to bond the patch material to the existing concrete. The entire surface area of the repair should be covered with a thin uniform coating of the bonding agent to be most effective. If the bonding agent is a cement grout, the patch material should be placed as soon as possible so the bonding agent does not dry out. Highway agencies often use fast-setting proprietary patching materials from an approved list. If this is the case, the manufacturer's instructions for preparation must be followed.

7. *Place the patching material.* Because PDRs require only a small amount of patching material, they are typically mixed on site in small mobile drums or paddle mixers. The patching material is shoveled into the area and then vibrated to eliminate all voids. TxDOT also has a specification for a fiber-reinforced polymer patching material (ss7622). Guidance on the selection of the patching material is discussed in chapter 7.

8. *Finishing.* The patch should be finished to match the elevation of the surrounding pavement. Troweling from the center of the repair area to the edges will ensure a smooth transition and good bonding.

9. *Curing.* The patch needs to be properly cured with a curing compound, moist burlap, or polyethylene sheeting because its surface area is large compared to its volume. Moisture loss and shrinkage cracks are more likely to form due to improper curing. To accelerate the repair material's strength development, insulation mats can be placed over the patch. Follow the manufacturer's directions for proprietary materials

10. *Seal the joint.* Sealing the joint is the final step. It ensures that incompressible materials and moisture do not re-enter the joint and cause additional damage.

PDRs have performed well in some States, while other States have discontinued their use because of poor performance.[1] Before doing PDRs, local experience and past performance should be evaluated. The most frequent reasons for failure are poor construction techniques and inappropriate site placement.

Diamond Grinding and Grooving

Diamond grinding and grooving serve two very different purposes. Diamond grinding is primarily designed to smooth the pavement surface, restoring its rideability. Diamond grooving is intended to restore the macrotexture depth. Diamond grinding typically involves removing a thin layer of the concrete surface, 0.19 to 0.25 inches (4 to 6 mm), to decrease the magnitude of joint or crack faulting, wheel path rutting caused by studded tires, and surface irregularities. It also improves the pavement surface texture, reduces road noise, smooths out roughness caused by repairs, and can improve drainage by restoring the transverse cross slope if needed. A pavement can typically be ground up to three times before its fatigue life is significantly compromised by a reduction in thickness.

Diamond grinding is most effective when used in conjunction with other rehabilitation techniques since it does not improve the pavement's structural capacity or address the mechanisms causing the distresses.[3] It should not be used on pavements experiencing MRDs. Caution should be exercised if the pavement being ground contains coarse aggregate that is susceptible to polishing under traffic. Exposing this aggregate could result in surface friction problems over time.

Diamond grinding is commonly considered based on the pavement's roughness values. An example of such "trigger" values is shown in table 4, but each agency should follow its own established smoothness criteria

Table 4. Example of trigger and limit values for diamond grinding.[1]

	Measure	Traffic, ADT		
		> 10,000	3,000 to 10,000	< 3,000
Trigger values	IRI, m/km (in./mi)	1.0 (63)	1.2 (76)	1.4 (90)
	PSR	3.8	3.6	3.4
Limit values	IRI, m/km (in./mi)	2.5 (160)	3.0 (190)	3.5 (222)
	PSR	3.0	2.5	2.0

ADT = average daily traffic; IRI = International Roughness Index; PSR = present serviceability rating.

Diamond grooving is designed to increase the macrotexture of the pavement surface. It is usually performed on pavements with a history of wet-weather accidents or hydroplaning. The accidents typically occur on horizontal curves or at interchanges. Localized grooving at these locations will improve their tire–pavement interaction and the safety of the pavement. While both longitudinal and transverse grooves drain water from the pavement, longitudinal grooving is more commonly used because it produces less tire–pavement noise and is much less costly than transverse grooving. Transverse grooving removes water efficiently from the pavement surface, but also significantly increases tire–pavement noise. The texture is more or less permanent on the concrete pavements unless studded tires are used. Only structurally sound pavements should be diamond grooved.

Joint and Crack Sealing

Joint and crack sealing is a rehabilitation method designed to reduce the infiltration of free water and incompressible materials into joints and cracks. Moisture infiltration can lead to support layer softening and pumping around the joints. In CRCP, moisture commonly infiltrates at the longitudinal lane-shoulder joints, longitudinal joints between traffic lanes, and transverse construction joints.[3,5] All of these joints should be sealed. The hairline transverse cracks in

CRCP should not be sealed. The use of epoxy sealing for wider transverse cracking has been done by some agencies (figure 16). Epoxy sealing of wide transverse cracks was studied in Illinois with poor results.[25] The study recommended that epoxy crack sealing not be done. If transverse cracks are exhibiting significant distresses, like faulting and spalling, other distress mechanisms are likely at work, and more extensive rehabilitation, not just sealing, should be conducted. Working transverse construction joints less than 0.5 inch (13 mm) wide can be sealed, but once their crack width is greater than 0.5 inch (13 mm), an FDR should be considered.

Figure 16. Epoxy sealing of CRCP cracks.

Slab Stabilization and Slab Jacking

Slab stabilization is the pressure filling of voids at the slab/subbase interface with a grout or other material. These voids are typically the result of subbase pumping. Stabilization is intended to improve the pavement's performance by preventing further pumping, reducing deflections, and returning the slab back to full support without raising it. Slab stabilization is also commonly referred to as pressure grouting, subsealing, or undersealing. In CRCP, voids may develop along the pavement edge and can contribute to punchout formation.

The effectiveness of slab stabilization depends on when it is performed, the accuracy with which the voids have been detected, the amount of stabilization materials used, and the construction procedures. The optimal time to stabilize is when there is a loss of support at the joints and working cracks, but before visible damage (like faulting or punchouts) is apparent. Voids are commonly detected in visual distress surveys and by deflection testing. Slab stabilization is more of an art than a science; it should only be performed by experienced contractors.[5] The construction process consists of selecting an appropriate hole pattern, drilling the holes, mixing the grout or foam (or other material), pumping it beneath the pavement, plugging the holes until it sets, and patching the holes before the pavement is opened to traffic.

Slab jacking (figure 17) is designed to physically raise depressed areas of the slab back to their original profile, thereby restoring ride. The depressed areas are associated with foundation settlement, culverts, and bridge approaches. The slab-jacking construction procedure is similar to slab stabilization. Care should be taken not to overly strain the pavement at any one place, so at each hole it should not be raised by more than 0.25 inch (6 mm) at one time.

Figure 17. Pavement-raising operation in Louisiana.

Cross Stitching

Cross stitching is typically used to repair low-severity longitudinal cracks that are not working.[1] Commonly, 0.75-inch-diameter (19-mm) deformed tie bars spaced at 20 to 30 inches (500 to 700 mm) are grouted into holes drilled at 30° and 45° to the pavement surface.[26] Properly drilled holes, alternated on either side of the crack, will intersect the crack at mid-depth. Cross stitching effectively prevents all vertical and horizontal movement and crack widening. The tight crack maintains good load transfer and slows the rate of deterioration.

CHAPTER 6. CRCP RESURFACING

Both rigid and flexible overlays can be placed to increase the life of an existing CRCP. Proper resurfacing selection requires an understanding of the mode of failure that is occurring in the pavement. For example:

- *Structural overlays* are used when the existing pavement no longer provides the necessary level of service, either because the traffic loads have increased, its design life has been reached, or it has deteriorated extensively. Structural overlays are typically used when the preventative maintenance and restoration treatments are too expensive or are no longer cost effective at slowing down the rate of pavement deterioration.

- *Functional overlays* can be considered as an alternative to diamond grinding to improve the pavement ride quality and surface friction (skid resistance), conditions that directly affect highway users. They are typically placed on structurally adequate pavements.

In this chapter, four different types of overlays that can be used on existing CRCP are presented. Considerations in the overlay selection process are discussed, and the four resurfacing methods and their design procedures are described. BCOs and UBOLs are typically used to increase the CRCP's structural capacity. The flexible overlay designs include HMA layers placed on intact CRCP. In these cases, overlays can be used to increase either the pavement's structural or functional capacity.

CONSIDERATIONS IN OVERLAY SELECTION

When resurfacing an existing CRCP, primary issues to consider in the overlay selection process are constructability, performance life, cost-effectiveness, and suitability based on the condition of the existing pavement (table 5). In addition, the purpose of the overlay should be clearly defined, whether it is to provide structural support, functional support, or both.[1,2,3] The following considerations should be made:

- *Purpose of the overlay.* Thin overlays (less than 3 inches (75 mm)) can increase the existing functional capacity of the pavement, while thicker overlays are needed to correct structural deficiencies.

- *Constructability.* Vertical clearance, traffic management, and the method of construction all influence the overlay's constructability and can dictate the type of resurfacing used (table 5). For example, UBOLs add significant thickness to the pavement and should not be used if overhead clearance is an issue. Traffic control may be an issue if travel lanes cannot be closed for an extended period of time.

- *Performance*. Each of the resurfacing methods can provide good long-term performance if properly constructed. The number of repairs required, and the materials used for resurfacing, should be selected to satisfy the intended life of the overlay.

- *Cost-effectiveness.* The cost-effectiveness of an overlay should be assessed using an LCCA. The more pre-overlay repairs performed at the time of construction, the more expensive the resurfacing option is. However, if the expected life of the overlay is substantial, it may be a competitive option.

- *Condition of the existing pavement.* Pre-overlay repairs, reflection cracking, drainage, climatic conditions, materials durability, and overlay design all need to be considered prior to selecting the resurfacing method.

Additional considerations are as follows:

- Pre-overlay repairs should be performed on some distresses that have developed in the existing pavement. The number of pre-overlay repairs required depends on the type of overlay selected and the condition of the existing pavement (table 5). Cracks in the underlying pavement can reflect through the overlay. Bonded concrete and HMA overlays are especially susceptible to reflective cracking.

- Climatic conditions at the time of construction greatly influence the resurfacing layer material properties and performance. For example, the interfacial bond strength of a BCO to the underlying pavement is a function of the climatic conditions at the time of construction.(4)

- MRDs in the existing CRCP (e.g., D-cracking, reactive aggregate, or freeze–thaw damage) influence overlay performance. BCOs should not be considered when the existing pavement has evidence of MRD.

The considerations listed above play a dominant role in overlay selection. However, the final selection may be controlled by other factors, such as pavement widening, shoulder construction, overlay design, and user costs.

Table 5. Constructability, performance, and cost-effectiveness of BCOs, UBOLs, and HMA overlays on CRCP.[1,2]

		BCOs	UBOLs	HMA Overlay on Intact CRCP
Constructability	Vertical clearance	Not a problem (typically 50 to 100 mm (2 to 4 inches) thick)	May be a problem (typically 180 to 250 mm (7 to 10 inches) thick)	May or may not be a problem, depends on the overlay thickness
	Traffic control	May be difficult to construct under traffic	May be difficult to construct under traffic	Not difficult to construct under traffic
	Construction	Special equipment and experienced operators needed	No special equipment required	No special equipment required
Performance	Existing CRCP condition	Good condition with no MRD	All conditions (good to bad)	Good condition, may accelerate MRDs
	Extent of repair	Repair all deteriorated joints and cracks	Repair limited to severe damage	Repair all deteriorated joints and cracks
	Future traffic	Any traffic level	Any traffic level	Any traffic level
	Historical reliability	Fair to poor*	Good	Good
Cost-Effectiveness	Initial cost	Depends on pre-overlay repair, but usually high	Higher than conventional HMA overlay	Depends on the pre-overlay repairs
	Life-cycle cost analysis	Competitive if future life is substantial	Competitive	Cost effective unless the pavement is in poor condition

**Fair to poor performance attributed to placing BCOs on pavements not suitable for their use.*

RESURFACING TECHNIQUES AND PROCEDURES

The resurfacing techniques discussed in this section include bonded concrete, unbonded concrete, and HMA overlays on intact CRCP. Even though HMA overlays are most commonly used, highway agencies are increasingly investigating concrete overlays because of their long-term performance with minimal maintenance.[1] In each section, the performance and design methods available for each type of overlay are described, as are the number of pre-overlay repairs required, construction methods, and the propensity for reflection crack formation. A good reference for information on concrete overlays is ACI 325-13R, "Concrete Overlays for Pavement Rehabilitation."[27] The information in this document is based largely on the information contained in reference 2 of this guide.

Reflection cracking is one of the more predominate distresses that affect CRCP overlays when using HMA and bonded concrete overlays. Movement in the underlying joints and cracks produces stress concentrations at the bottom of the overlay, directly above the discontinuities. Temperature changes produce thermal stresses, while traffic loadings produce shear and bending stresses at these locations. Reflection cracks propagate upward from the overlay interface, and eventually appear on the pavement surface. To reduce reflection cracking, several options are available. Fabrics, stress-relieving interlayers, stress-absorbing interlayers, and crack-arresting interlayers can be placed at the interface to physically arrest the reflection cracks.[1,13] In addition, repairing the existing pavement can reduce the potential for reflection cracking.

In the design of overlays, a structural deficiency approach (AASHTO 93) has commonly been used by agencies. The approach is that with time and traffic loading, the pavement's capacity and condition decreases. At the time that an overlay is considered, a new required structural capacity is calculated based on the expected future traffic loadings. The required overlay thickness is then determined by taking into account the remaining structural capacity and the thickness that is needed for the overlay to obtain the new structural requirement of the total pavement system.

In 2011, AASHTO adopted a new pavement design program, DARWIN-ME, that uses mechanistic principles. The new design method has some limitations for overlays since the minimum allowable thickness for concrete overlays is 6 inches (150 mm) for JCP and 7 inches (175 mm) for CRCP. The structural design of overlays is not covered in this document.

BONDED CONCRETE OVERLAY ON CRCP

BCOs are good options for CRC pavements that are in good condition but require increased functional or structural capacity. BCOs provide a suitable riding surface and increase the structural capacity of the pavement. It is the interfacial bond between the overlay and the underlying CRCP that allows them to act as a monolithic structure, which in turn increases the pavement structural capacity. While some BCOs have performed well for more than 20 years, their historical performance has been mixed (table 5).[2] This disparity can likely be attributed to variability in the interfacial bond strength and in the condition of the existing pavement. If the BCO is used on a properly selected project and well-constructed with good interfacial bond, it will last longer and provide a higher level of serviceability than will a conventional HMA overlay. However, if the interface delaminates, the BCO performance will be reduced. Bonded concrete overlays will also not perform as intended if placed on CRCP that is too deteriorated or that has not been adequately repaired prior to resurfacing. The condition of the existing CRCP needs to be carefully evaluated for suitability prior to selecting a BCO as the method of choice. Texas and Iowa have been using these overlays to rehabilitate their concrete pavements since the 1970s.[28]

BCOs are very susceptible to reflection cracking, and nearly all cracks in the existing CRCP will eventually reflect through the overlay. Structural distresses in the existing CRCP should be repaired prior to placing a BCO to minimize their reflection. A list of pre-overlay distresses to repair is provided in table 6. All distresses that compromise the CRCP load-carrying capacity or exacerbate reflection cracking should be repaired with FDRs, PDRs, slab stabilization, slab jacking, or cross stitching. If the existing pavement has evidence of MRDs, a BCO should not be used.

A bonded concrete mill and fill could be considered for a CRCP that has extensive shallow spalling at the cracks, as shown in figure 3. A concrete mill-and-fill project was constructed in Kansas in 2008. The pavement was a jointed reinforced concrete pavement (JRCP), milled 2 inches (50 mm) deep and inlayed with concrete. The Kansas DOT estimated that the inlay will extend the surface life of the original pavement by 15 years or more.(29) The joints were re-established, but that would not be necessary for a CRCP. Preliminary testing is necessary to establish the location of the reinforcing steel in the existing concrete. The mill-and-fill method has been used successfully on deteriorated bridge decks where the concrete is removed to below the steel to anchor the overlay and provide additional bonding.

Table 6. Pre-overlay distresses to repair prior to BCO placement (D = slab thickness).(2,3,30)

Distress Types	Repair Methods
Wide transverse cracks	FDR
Longitudinal cracks	FDR Cross stitching Reflective crack control
Punchouts	FDR
Spalled joints and cracks	PDR (if spall depth < D/3) FDR (if spall depth > D/3)
Deteriorated repairs: HMA patches, exceptionally wide joints, and existing expansion joints	FDR
Pumping / Faulting	FDR Retrofit edge drains Slab stabilization
Settlement / Heaves	Slab jacking Localized reconstruction

A BCO was recently installed on a section of U.S. Route 58 in Virginia. A summary of the project characteristics is shown in table 7, and photographs of the project are shown in figure 18 and figure 19.(31)

Table 7. Bonded overlay on U.S. Route 58 in Virginia.

Existing CRCP	
Constructed	1988
CRCP thickness, in.	8
Traffic (2008 annual average daily traffic)	8,300 with 14% trucks
Pavement roughness, IRI, in./mi (2012)	110 to 163
Bonded Overlay	
Constructed	2012
Overlay length, mi	2.6
Thickness, in.	4
Average bond strength, lbf/in^2	225

Figure 18. a) Surface preparation for bonded overlay on U.S. Route 58 in Virginia; b) Closeup view of surface after preparation.

Figure 19. Bonded overlay on U.S. Route 58 in Virginia, as constructed.

UNBONDED CONCRETE OVERLAY ON CRCP

UBOLs are the most commonly placed concrete overlays. They are a long-term rehabilitation solution that can provide a level of service and performance comparable to that of newly constructed portland cement concrete (PCC) pavements. UBOLs are used when the existing CRC pavement is in fair to poor condition, but the overlay performs well because a separation layer is placed between the overlay and the underlying pavement. This separation layer makes the UBOL relatively insensitive to the deficiencies in the existing pavement. The separation layer is designed to:(2)

- Isolate the overlay from the underlying pavement.
- Prevent or reduce the development of reflection cracks in the overlay (a stress relief layer).

- Provide uniform support to the overlay.

The separation layer also provides friction and a certain amount of bonding between the UBOL and underlying pavement, which contributes to the composite behavior of the resulting pavement. JCPs are the most popular type of unbonded overlays—even for existing CRCP. Their thickness should be at least 6 to 11 inches (150 to 280 mm). CRCP unbonded overlays should be 7 inches (180 mm) or thicker for good performance. If the overlay is less than 6 inches (150 mm) thick, the UBOL has been found not to perform well.(2) UBOLs significantly increase the thickness of the mainline pavement (table 5). New shoulders, interchange ramps, and guardrails may need to be constructed as a result. This should be considered when assessing the economic feasibility of the UBOL option.

For the most part, UBOLs require fewer pre-overlay repairs than BCOs. But if severe distresses exist in the underlying pavement that will affect the overlay support, they should be completely repaired. Unbonded overlays that perform best have been found to have uniform support. This means that all distresses that deflect, or deform vertically, should be repaired (table 8). Punchouts and wide transverse cracks with significant differential deflection should be repaired to avoid their reflection through the overlay, and any unstable slab segments should be stabilized.

Thicker separation layers can be used to level out settlements and heaves and to fill severely spalled areas. Unbonded overlays are also applicable for existing pavements exhibiting MRD.

Table 8. Required pre-overlay repairs to the CRCP prior to placing a UBOL.(2,3,32)

Distress Types	Repair Methods
Wide transverse cracks with significant differential deflection	FDR
Punchouts	FDR
Unstable slabs with large deflections	FDR Slab stabilization Retrofit edge drains
Severely spalled joints or cracks	FDR HMA filling
Pumping / Faulting (> 6 mm (0.25 in.))	Retrofit edge drains Slab stabilization
Settlement	Level-up with HMA
Poor joint / crack load transfer	Repair not necessary, but a thicker separation layer should be considered

A UBOL was recently installed on a section of U.S. Route 58 in Virginia. A summary of the project characteristics is shown in table 9, and photographs of the project are shown in figure 20 and figure 21.(31)

Table 9. Unbonded overlay on U.S. Route 58 in Virginia.

Existing CRCP	
Constructed	1988
CRCP thickness, in.	8
Traffic (2008 average annual daily traffic)	8,300 with 14% trucks
Pavement roughness, IRI, in./mile (2012)	110 to 163
Unbonded Overlay	
Constructed	2012
Overlay length, miles	2.2
Thickness, in.	7
AC interlayer	Porous friction course
AC interlayer thickness, in.	1
Overlay jointing layout	6 by 6 ft

Figure 20. Unbonded overlay on U.S. Route 58 in Virginia. Placement of AC porous friction course.

Figure 21. Unbonded overlay on U.S. Route 58 in Virginia, as constructed, with 6 ft by 6 ft joint layout.

HMA OVERLAY ON CRCP

HMA overlays are a commonly used method for resurfacing CRCPs.[13] They are capable of increasing the functional characteristics (and possibly structural capacity) of existing CRCPs provided the existing pavement is structurally sound and preventive maintenance activities are still cost effective. Functional HMA overlays are thin, typically 1 to 3 inches (25 to 75 mm), while structural HMA overlays are thicker, about 4 to 8 inches (100 to 200 mm) or more. Thin HMA overlays do not contribute significantly to the underlying pavement structural capacity, but they do provide the following benefits:

- They enhance the ride quality (reducing the dynamic impact loading) and can improve skid resistance if a problem exists.
- HMA overlays can be swiftly constructed.
- Additional HMA overlays can be used to provide structural support when traffic volumes increase.

If the CRCP is in fair to good condition and only a few repairs need to be made, HMA overlays can be used. However, the pavement should be resurfaced before the number of distresses becomes significant. A list of distresses and their repair treatments is given in table 10. Punchouts, wide transverse cracks, spalled joints, and deteriorated cracks and repairs can reflect through the overlay and should be repaired with FDRs or PDRs. Also, any existing HMA patches should be removed and repaired with concrete. As long as the repairs are made prior to overlay placement, reflection crack control methods are generally not necessary except along longitudinal joints. If the number of distresses is excessive, a different resurfacing option such as UBOLs should be considered. Also, thin HMA overlays should not be placed on concrete pavements with MRD.

Table 10. Distresses to repair in CRCP prior to placing an HMA overlay.[3,15]

Distress Types	Repair Methods
Wide transverse cracks	FDR
Punchouts	FDR
Spalled joints / Deteriorated transverse cracks	FDR PDR
Deteriorated repairs HMA patches and exceptionally wide joints	FDR
Pumping / Faulting	Retrofit edge drains
Settlement / Heaves	HMA level-up, slab jacking, or localized reconstruction

PERFORMANCE OF OVERLAYS

The typical lifespans of the three types of overlays used to rehabilitate CRCP (BCO, UBOL, and HMA overlays on intact CRCP) are listed in table 11. As can be seen, HMA overlays on CRCP can last from 10 to 15 years. UBOLs have the longest lifespan, up to 30 years or more. BCOs can perform up to 25 years.

Table 11. Typical life of HMA and PCC overlays on CRCP.[2,33]

Overlay	Typical Life (years)
BCO on CRCP	15–25
UBOL on CRCP	20–30
HMA overlay on CRCP	10–15

CHAPTER 7. MATERIALS FOR RESTORATION AND RESURFACING

The materials used to restore and resurface CRCP are of prime concern to engineers. In this chapter, resurfacing materials, patching materials, and innovative materials are presented. Material selection is primarily based on the following three criteria:

1. *Application.* Materials used to resurface a pavement are not the same as those used to repair it because of different construction techniques and constraints including project size, cost, and the allowable time for lane closures.

2. *Material durability.* Materials have to be durable enough to perform satisfactorily under changing climatic conditions for the duration of the rehabilitation treatment.

3. *Time of opening to traffic.* The time a pavement should be opened to traffic dictates the type of material selected. The material needs to be able to sustain traffic loads by opening time.

A common recommendation is to select the most conventional material that meets the demands of the project.

Fast-track paving, also called accelerated rigid pavement techniques, can be used to facilitate construction when the pavement being rehabilitated is an urban highway, urban intersection, commercial area, or a single-access road. These pavements have high user costs associated with them due to lane closures.(1) To reduce the closure time, fast-setting concrete mixtures can be placed and their strength monitored with NDT methods like maturity. The time of opening to traffic, when the concrete is strong enough to support the traffic loads, can be determined using a fatigue analysis that accounts for the anticipated traffic loads, the slab thickness and strength, and the modulus of subgrade reaction (k-value). Many States have developed their own criteria for early opening to traffic. FHWA has also developed guidelines for the absolute minimum concrete strength allowed for opening to traffic as follows:

- For low to moderate levels of traffic, many projects open at flexural strengths as low as 290 lbf/in^2 (2,000 kPa) (third point) or 350 lbf/in^2 (2,400 kPa) (center point). However, a third-point flexural strength of 350 to 450 lbf/in^2 (2,400 to 3,100 kPa) may be more appropriate.

- For heavy traffic, flexural strength of at least 450 lbf/in^2 (3,100 kPa) (third point) or 540 lbf/in^2 (3,700 kPa) (center point) will provide reasonable protection against a single heavy load.(1)

It is also recommended that traffic not be allowed within 2 ft (0.6 m) of the pavement edge until the concrete strength has increased further. Typically, higher strengths are needed at the time of opening for repairs (like FDRs and PDRs) than for overlays to limit damage from a single heavy load. Materials used for pavement rehabilitation that are not mentioned in this chapter, that is, the types of reinforcement (reinforcing steel, dowel bars, and tie bars) and the methods of curing, are the same as those used to construct new concrete pavements.

PATCHING MATERIALS

Full-Depth Repairs

For concrete repairs, most patching mixtures fall into one of the following time to opening categories: 4 to 6 hours, 12 to 24 hours, and 24 to 72 hours (table 12). Accelerators permit opening within 4 to 6 hours. Without the accelerator, opening increases to 12 to 72 hours. The mixtures recommended entrained air content is 6.5±1.5 percent in freeze areas and less in no-freeze zones. Slump should range from 2 to 4 inches (50 to 100 mm). Typical FDR mixture designs can be obtained elsewhere.[1] Proprietary mixtures like sulfo-aluminate cements and certain blended cements can achieve opening times of 2 hours. Manufacturer's instructions and placing limits (like maximum temperatures) need to be carefully followed when using admixtures and proprietary materials.

Table 12. Opening-to-traffic times for typical FDR concrete mixtures.

Full-Depth Repair Mixture Design	**Time to Opening** (hours)
Certain blended cements	2–4
Sulfo-aluminate cements	2–4
Type III cement with non-calcium-chloride accelerator	4–6
Type III cement with calcium chloride accelerator	4–6
Type I cement with calcium chloride accelerator	6–8
Type III cement with Type A water reducer	12–24
Type I cement without fly ash (air entrained)	24–72

Partial-Depth Repairs

A number of repair materials are available for PDRs, each with different chemical and physical properties. PDRs can be constructed out of rapid-setting hydraulic cement, magnesium phosphate, polymeric, or modified bituminous materials. Cementitious materials are used most commonly in PCC pavements, with high-density, low-slump (0 to 0.5 inch (0 to 12 mm)) PCC or mortar mixtures providing the most successful performance provided they are properly placed, consolidated, and cured.[3] Concrete mixtures are advantageous because of their low cost, long working times, availability, and ease of use. However, if the patch needs to be opened to traffic in a couple of hours, a polymer concrete may be used instead. This material is a mixture of polymer resin, aggregate, and an initiator. Polymer concrete patches have good adhesion and strength development, but are often expensive and sensitive to installation procedures.

A study conducted for TxDOT made recommendations on material properties to consider for the success of spall repairs.[22] Another report from TxDOT gives guidance on implementing the best practices for spall repair, which is crucial to the long-term performance.[24] The laboratory study and the field study found that that the low-modulus materials were more durable for concrete repair. The materials in figure 22 were evaluated in the Texas study.[22,24]

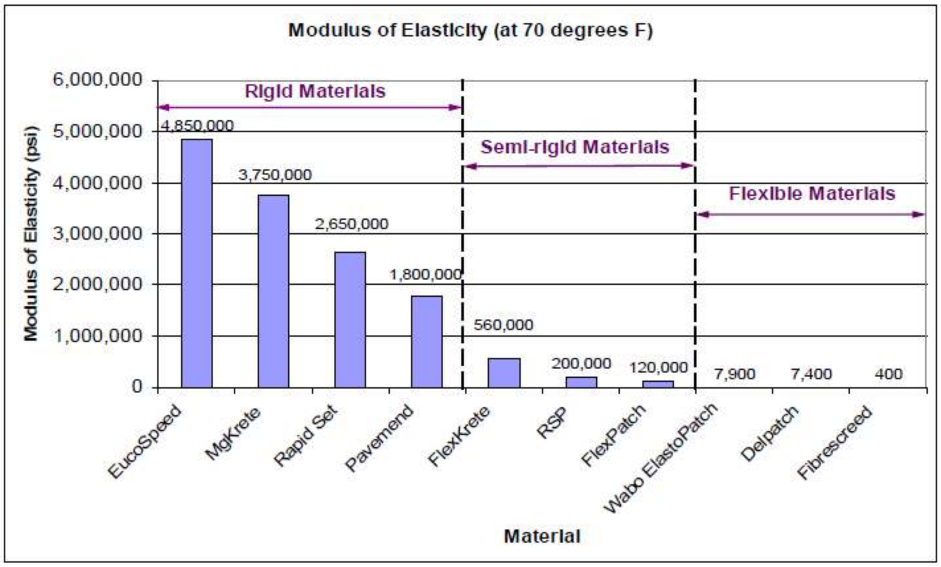


Figure 22. Materials evaluated in TxDOT study.[22,24]

Many other proprietary materials are available and are often contained on a highway agency's approved products list. Low-modulus materials did not reflect the cracks while high-modulus materials did, but both types of materials performed well in the Texas study. The repair materials can be grouped into three categories, rigid, semi-rigid, and flexible, with magnesium phosphates representing the more rigid materials and the polymer concretes representing the more flexible materials. Materials which have a large amount of shrinkage or a high coefficient of thermal expansion (CTE) should have a low modulus to accommodate for the volume changes that can occur. Likewise materials with a high modulus should have a low amount of shrinkage and a CTE similar to that of its substrate to avoid the high internal stresses that can occur due to an associated change.[22]

Compatibility properties should be considered when making a selection regarding a spall repair material. If the spall repair is done as part of an overlay, a rigid cementitious material is recommended with CTE properties similar to the existing concrete. If the CRCP will not be overlaid, an elastomeric flexible polymer-based material is recommended.[24]

Joint / Crack Sealing Materials

A wide variety of materials are available for joint and crack sealing. Thermoplastic and thermosetting materials are most common:[1]

1. *Thermoplastic.* Thermoplastic materials are either hot-poured or cold-applied. Hot-poured thermoplastic materials soften on heating and harden on cooling, and typically perform for 4 to 8 years. Cold-applied sealants are seldom used except on low-volume roads and city streets.

2. *Thermosetting.* Thermosetting materials are either chemically cured materials or solvent release materials. Silicone is a commonly used chemically cured material, and it

commonly performs for about 8 years or more. Solvent release materials are rarely used on pavements and are very costly.

MATERIALS FOR SLAB STABILIZATION AND SLAB JACKING

Materials used for slab stabilization include cement grouts, and polyurethane foam.[5] They are selected for their ability to fill voids and set before opening to traffic. A common cement-grout mixture design contains one part cement to three parts pozzolan (fly ash) or lime dust with enough water to achieve the required consistency. Additives include superplasticizers, water reducers, fluidifiers, expanding agents, and accelerators. The grout should be tested in the laboratory prior to use to ensure materials compatibility. Grouts are commonly specified for a 7-day compressive strength of 600 lbf/in^2 (4,134 kPa) by ASTM C 109.[3] The cement grout used for slab jacking is typically stiffer than the one used for slab stabilization.

CHAPTER 8. SPECIFICATIONS SUMMARY

Specifications developed for the restoration and resurfacing of CRCP are presented in this section. Restoration activities, like FDR, PDR, slab stabilization, and diamond grinding, are commonly used. A comprehensive list of restoration specifications by State can be found at the Web site http://www.igga.net/specs.html. Since Texas and Illinois have constructed the largest number of CRCPs in the United States, their specifications for FDRs are summarized and presented here. The TxDOT specifications for PDRs and slab stabilization are also summarized. The specifications for resurfacing using BCOs (Texas) and UBOLs (Iowa) are summarized in terms of the materials, construction procedures, and equipment used.

RESTORATION

Full-Depth Repair

Illinois DOT Specification

FDRs for CRCP are classified as Class A Patches in Section 442 of the Illinois DOT specification.[34] The standard specification can be accessed at http://dot.state.il.us/desenv/hwyspecs.html. This site should be visited to obtain the most recent version of Section 442 and any special provisions that may have been issued. The Illinois DOT standard detail drawing is contained in appendix A.

The deteriorated area of pavement that will be removed must first be scored with a concrete saw, wheel saw, or jackhammer. This operation can be done up to 3 days ahead of time when the pavement is under traffic. If a wheel saw is used, it can done 1 day ahead of time and the cuts must be filled with a cold bituminous mix. Only sound concrete should remain. The exterior transverse saw cuts are made perpendicular to the centerline of the patch without cutting the longitudinal reinforcement, while maintaining a minimum distance of 18 inches (450 mm) from the end of the patch to the nearest transverse crack. This minimum distance can be reduced to 6 inches (150 mm) if the pavement appears to be sound, at the discretion of the Engineer. The interior saw cuts will allow the proper length of steel to be exposed and shall be to a depth to completely sever the longitudinal reinforcement. The longitudinal edges of the patch are formed with full-depth saw cuts. Patches are typically one half-lane width or one full-lane width. When the longitudinal edge of the patch is adjacent to a concrete shoulder, a full-depth saw cut should be made at the shoulder–pavement joint to sufficiently sever the tie bars. Another full-depth saw cut is then made 4 inches (100 mm) from the edge of the shoulder. The concrete between these two saw cuts is removed with a hand-held hammer and hand tools prior to removing the remaining concrete. The remaining concrete should be removed by lifting, being careful not to disturb the subbase or spall the adjacent pavement. If it is not practical to lift the panel, it can be broken into small pieces and removed. If the subbase has been disturbed or removed in excess of the pavement thickness, it should be replaced with like material, compacted and restored to the existing line and grade. A bond breaker can then be applied to separate it from the concrete.

The concrete between the exterior and internal saw cuts, in the reinforcement splicing area, is to be removed by hand-held hammers and hand tools. It is important not to undercut the concrete that is to remain in place. The face of the concrete below the partial-depth saw cut should be slightly inclined into the patch. If more than 10 percent of the reinforcing steel is damaged during the contractor's operations, the patch will need to be lengthened to provide adequate steel for splicing. If less than 10 percent of the steel is damaged, the lap steel can be repaired by welding. The steel should be examined for any evidence of distress, like rusting.

Half-lane patches that are 20 ft (6 m) or longer should be tied to the adjacent concrete of the existing pavement, the concrete shoulder, and the curb and gutter with No. 20 (No. 6) bars 24 inches (600 mm) long, embedded 8 inches (200 mm) at 24-inch (610-mm) centers. The tie bars are only needed when the patches are more than 20 ft (6 m) in length. The FDRs longitudinal reinforcing steel should be tied together using two secure ties for each lap splice. The steel should also be supported on chairs such that the unsupported length does not exceed 4 ft (1.2 m). If the subbase is uneven, HMA, PCC, or a sand-cement grout can be used to place the reinforcement within the specified tolerances. For full-width patches, the longitudinal joint at the lane line should be sawed. A form not less than 0.25 inches (6 mm) in thickness also needs to be installed along the lane line that matches the depth of the pavement. If more than two lane widths of a CRCP are to be patched and extreme daily temperature variations are anticipated, the patch and 200 ft (60 m) of pavement on each side should be cured with wet straw and burlap or an approved insulation material. Temperature limitations for placing the concrete patching material are provided, as are limitations on the air and ground temperatures. The methods of consolidating, finishing, and curing are also provided. The centerline joint and any longitudinal joint adjacent to the shoulder should be sealed after patching.

TxDOT Specification

The TxDOT specification for FDR is Section 361 of the Standard Specifications. Several special provisions have been issued modifying the standard specifications. The specification can accessed at http://www.dot.state.tx.us/business/specifications.htm. This site should be visited to obtain the most recent version of Section 461 and any special provisions that may have been issued. The TxDOT FDR standard detail is contained in appendix A.

The minimum repair area is at least 6 ft (1.8 m) long and a minimum of one half-lane width. Full-depth saw cuts are made with a caution not to spall or fracture the adjacent concrete. The sawcutting is allowed to be done ahead of time up to 7 days before removal and replacement. Loose or damaged base material is removed and replaced or repaired with an approved base material to the original top of the base grade. A polyethylene sheet at least 4 mils thick is placed as a bond breaker at the interface of the base and new pavement. If concrete is used as the base material, it must attain adequate strength to prevent displacement when the pavement concrete is placed. New deformed reinforcing steel bars have to be of the same size and spacing as the bars that are removed. Holes are drilled into the existing concrete and tie bars are epoxied into the holes with an embedment of at least 12 inches (300 mm). Grout retention disks are required to keep the epoxy from flowing out. Supports are required to hold the new reinforcing steel, tie bars, and dowel bars firmly in place. It must be demonstrated, through simulated job conditions, that the bond strength of the epoxy-grouted tie bars meets pull-out strength of at least three-quarters of the yield strength of the tie bar when tested in accordance with ASTM E 488 within 18 hours after grouting. Embedment depth must be increased, and retesting must be done when necessary to meet testing requirements. Tie-bar testing must be performed before repair work is started. Contraction joints in the repair area are required to be sawed and sealed.

If the time frame designated for opening to traffic is less than 72 hours after concrete placement, Class HES concrete is used, designed to attain a minimum average flexural strength of 255 lbf/in^2 (1,780 kPa) or a minimum average compressive strength of 1,800 lbf/in^2 (12,420 kPa) within the designated time frame.

Special Provision 361-009 requires that holes be drilled with a maximum diameter 1/8 inch (3 mm) larger than the tie bars or as recommended by the epoxy manufacturer. Oversized-diameter holes require using the next larger bar size or bond-strength testing simulating the oversized hole. The method of placing the epoxy is also described by requiring that it be placed at the base of the drilled hole, filling the hole as the applicator is removed to the face of the saw cut. Sufficient epoxy must be discharged so that excess of epoxy will be forced out the front of the hole when positioning the tie bars. It is not allowed to epoxy-coat the bars outside of the drilled hole.

Partial-Depth Repair

The Texas specification for spall repair is Item 720 in the Standard Specifications, but Texas also has developed a number of special specifications—3256, 3203, and others—for PDRs. Many of the special specifications are for one-time use. The specifications can be accessed at http://www.dot.state.tx.us/business/specifications.htm.

Spalls, or partial-depth failures, are defined as deteriorated areas of the pavement up to 1.5 inches (38 mm) deep. The perimeter of the damaged area should be sawcut and the deteriorated concrete removed by chipping hammers or scarifying equipment. The surface of the patch area should have uniform roughness suitable for bonding. Prior to placing the concrete patch material, each repair face should be blast-cleaned and painted with a rich cement grout to ensure maximum bond. The concrete patching material's mixture design has the following requirements:

- Cement Type III.
- Slump from 1 to 2 inches (25 to 50 mm).
- Minimum cement content: 24 lb/ft^3 (390 kg/m^3).
- Minimum flexural strength in 12 hours: 400 lbf/in^2 (2,758 kPa).
- Maximum water-to-cementitious materials ratio: 0.49.
- Fineness modulus: 2.6 to 2.8.
- Entrained air content: 3 to 6 percent.

Limits are also placed on the coarse and fine aggregate gradations, and the chemical admixtures used. The concrete should be screeded to the elevation of the old pavement and finished with a broom texture. Curing compound should be applied before the concrete's initial set has been reached. PDRs should not be placed if the air temperature is below 41 °F (5 °C). If the air temperature is above 70 °F (21 °C), the concrete should be placed within 30 minutes of adding the chemical admixtures. Existing joints should be replaced where necessary. If the edge of the patch abuts a shoulder or median, the patch alignment and grade should match the adjoining pavement.

Special Specification 7622 is for the use of fiber-reinforced-polymer patching material. The binder may be liquid asphalt or polymer-based, unless otherwise restricted by the plans, and may be provided separately or premixed with the other components of the patching material. The removal, cleaning, and preparation of the spall area is the same as for using a cementitious material. The manufacturer's directions need to be followed in applying a primer and in mixing and placing the patching material.

Slab Stabilization

TxDOT has developed several special specifications (ss3004 and ss3255) for pressure-grouting concrete pavements and raising or undersealing concrete slabs. The materials used include a cement grout and a high-density polyurethane product. The mixture design for the cement grout is usually Type I or II portland cement, fly ash, fluidizer, and water, with one part cement to three parts fly ash. The fluidizer is designed to inhibit early stiffening, to keep the solids in suspension, and to prevent all setting shrinkage. The material's consistency is measured using a flow cone. The grout's 7-day compressive strength should not be less than 200 lbf/in^2 (1,380 kPa). Contractors are required to use crews experienced in pressure grouting and undersealing. Holes 0.5 to 1.5 inches (13 to 38 mm) in diameter are drilled perpendicular to the pavement, 3 to 6 ft (1 to 2 m) apart. The grout is pumped until the slab starts to rise or until it flows from an adjacent hole. This ensures that all cavities or voids are filled and that the slab has been raised the required amount. For CRCP, the contractor should select a pumping pattern that ensures that the pavement is raised to within ± 0.25 inch (6 mm) of the stringline; laser-leveling units are commonly required. Then the holes are plugged until the grout has set. The contractor is required to repair any damage to the pavement, like cracking, caused by the construction process. All traffic should be kept off the slab until the grout has reached initial set, between 1 and 4 hours. Likewise, pressure grouting cannot be performed when the pavement surface temperature is below 34 °F (1 °C) or if the base or subgrade is frozen.

If a foam is used for the raising or undersealing of slabs, it must be a closed-cell, hydro-insensitive, high-density polyurethane foam system with a minimum free-rise density of 3.0 lb/ft^3 (48 kg/m^3), and a minimum compressive strength of 50 lbf/in^2 (345 kPa) The high-density polyurethane should set and obtain 90 percent of its ultimate compressive strength within 15 minutes of injection. The holes drilled for injection cannot be larger than 3/4 inch (19 mm) in diameter, and the final elevations must be within 1/4 inch (6 mm) of the proposed profile elevations.

RESURFACING

Bonded Concrete Overlay

In Texas, a special provision to Item 360, Concrete Pavement, was developed for BCOs with or without monolithic curbs on previously placed concrete pavements. For this application, the PCC defined in Item 421 can be supplemented with steel or polypropylene fibers. If the CRCP has been overlaid with HMA, the HMA must be removed by rotomilling. To prepare the surface of the existing concrete pavement, shot-blasting equipment is recommended, but hydrocleaning equipment can be substituted if it produces the required surface texture and cleanliness. To prevent the possibility of surface contamination, the BCO paving operation must begin within 24 hours of shot blasting or hydrocleaning. Immediately prior to the paving operation, the entire surface should be air blasted. The minimum surface texture of the existing pavement is specified, as are the curing methods for the newly placed BCO. If the evaporation rate exceeds 0.2 lb/ft^2/hr (0.98 kg/m^2/hr), fogging or wet-mat curing should be used. If it exceeds 0.1 lb/ft^2/hr (0.49 kg/m^2/hr) and is less than 0.2 lb/ft^2/hr (0.98 kg/m^2/hr), evaporation retardant can be applied in addition to a membrane curing compound. The time of placement is limited, and special placement measures are required when the temperature gradient 24 hours after placement is expected to exceed 26 °F (14 °C). The pavement is to remain closed a minimum of 12 hours after placement and can be opened only when the concrete's splitting tensile strength is at least 500 lbf/in^2 (3,450 kPa). The pavement should be cleaned and all joints sealed prior to opening it to traffic.

Unbonded Concrete Overlay

The Iowa DOT developed a Supplemental Specification for Portland Cement Concrete Overlay (SS-01030) with an effective date of April 20, 2004. This specification can be used for a UBOL on an existing pavement when a stress relief layer has been placed or on an existing concrete pavement overlaid with HMA. The stress relief layer is to be 1 inch (25 mm) of HMA. The HMA must meet the Iowa requirements (Section 2303) using a PG 58-28 binder, a target air void content of 3.0 percent, and a specified aggregate gradation. The surface of the composite pavement must be prepared using scarifying, shot-blasting, or sandblasting equipment. This is not necessary for newly placed HMA layers. Prior to placing the UBOL, all high spots in the HMA should be trimmed, it should be properly compacted using static steel-wheeled rollers, and it should be cleaned with power brooms. The HMA layer should be dry when the UBOL is placed to allow absorption of the concrete mortar. If the surface temperature of the HMA is greater than 110 °F (40 °C), water can be applied to cool it, provided it is dry before the concrete is placed. If the surface temperature is less than 100 °F (38 °C), water does not need to be applied. The UBOL paving operations are limited when the HMA surface temperature is greater than120 °F (50 °C) and when the air or pavement temperature is below 40 °F (4 °C). The time of opening to traffic can be determined using the maturity method at temperatures below 55 °F (13 °C). The UBOL is required to provide a certain level of smoothness. If the UBOL joint spacing is smaller than a normal lane width, the joints shall be 0.125 inch (3 mm) wide and no cleaning or sealing is required. This specification also provides methods of measuring the quantity of the various construction items and the basis of payment.

CHAPTER 9. SUMMARY

The purpose of this guide is to provide best practices information on rehabilitation strategies for extending the service life of CRCP. The procedures described in this guideline consist of defining the problem, identifying potential solutions, and selecting the preferred alternatives. Several guidelines for CRCP repair and rehabilitation have been published previously. This best practices guide highlights the most pertinent sections of these documents, and others, yielding state-of-the-art rehabilitation procedures for CRCP. The information is presented with the intent that users of the guide will tailor the discussed rehabilitation strategies to meet their own project needs and priorities.

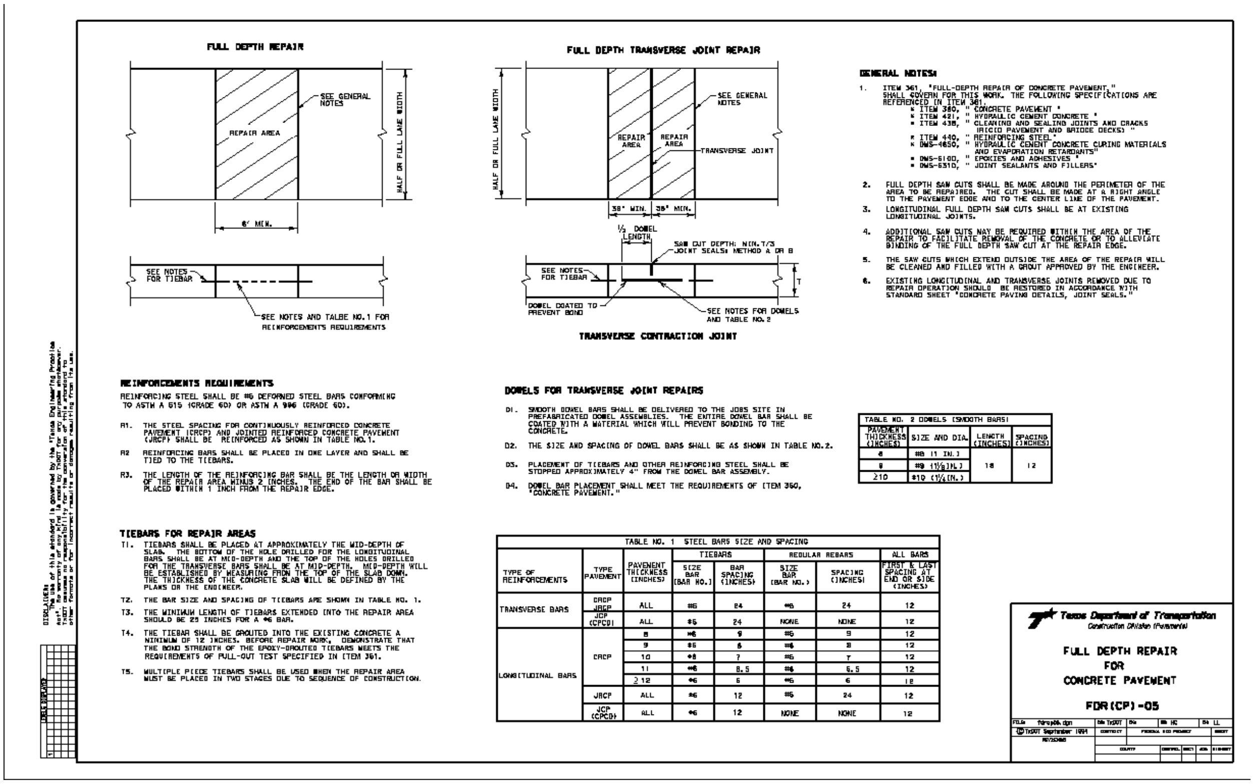
The rehabilitation treatments to extend the service life of existing CRCP include both restoration and resurfacing techniques:

- Restoration techniques, including FDRs, PDRs, diamond grinding and grooving, joint resealing, slab stabilization and slab jacking, and cross stitching.

- Resurfacing options, namely, BCOs, UBOLs, and HMA overlays on intact CRCP.

When the restoration and rehabilitation treatments are applied correctly and in a timely manner, the service life of an existing CRCP can be extended by 10 to 25 years or more without destroying the structural integrity of the existing CRCP.

APPENDIX A. STANDARD DETAILS FOR CRCP REPAIR



GENERAL NOTES:

1. ITEM 361, "FULL-DEPTH REPAIR OF CONCRETE PAVEMENT," SHALL GOVERN FOR THIS WORK. THE FOLLOWING SPECIFICATIONS ARE REFERENCED IN ITEM 361.
   - ITEM 360, " CONCRETE PAVEMENT "
   - ITEM 421, " HYDRAULIC CEMENT CONCRETE "
   - ITEM 438, " CLEANING AND SEALING JOINTS AND CRACKS (RIGID PAVEMENT AND BRIDGE DECKS) "
   - ITEM 440, " REINFORCING STEEL"
   - DMS-4650, " HYDRAULIC CEMENT CONCRETE CURING MATERIALS AND EVAPORATION RETARDANTS"
   - DMS-6100, " EPOXIES AND ADHESIVES "
   - DMS-6310, " JOINT SEALANTS AND FILLERS"
2. FULL DEPTH SAW CUTS SHALL BE MADE AROUND THE PERIMETER OF THE AREA TO BE REPAIRED. THE CUT SHALL BE MADE AT A RIGHT ANGLE TO THE PAVEMENT EDGE AND TO THE CENTER LINE OF THE PAVEMENT.
3. LONGITUDINAL FULL DEPTH SAW CUTS SHALL BE AT EXISTING LONGITUDINAL JOINTS.
4. ADDITIONAL SAW CUTS MAY BE REQUIRED WITHIN THE AREA OF THE REPAIR TO FACILITATE REMOVAL OF THE CONCRETE OR TO ALLEVIATE BINDING OF THE FULL DEPTH SAW CUT AT THE REPAIR EDGE.
5. THE SAW CUTS WHICH EXTEND OUTSIDE THE AREA OF THE REPAIR WILL BE CLEANED AND FILLED WITH A GROUT APPROVED BY THE ENGINEER.
6. EXISTING LONGITUDINAL AND TRANSVERSE JOINTS REMOVED DUE TO REPAIR OPERATION SHOULD BE RESTORED IN ACCORDANCE WITH STANDARD SHEET "CONCRETE PAVING DETAILS, JOINT SEALS."

REINFORCEMENTS REQUIREMENTS

REINFORCING STEEL SHALL BE #6 DEFORMED STEEL BARS CONFORMING TO ASTM A 615 (GRADE 60) OR ASTM A 996 (GRADE 60).

R1. THE STEEL SPACING FOR CONTINUOUSLY REINFORCED CONCRETE PAVEMENT (CRCP) AND JOINTED REINFORCED CONCRETE PAVEMENT (JRCP) SHALL BE REINFORCED AS SHOWN IN TABLE NO.1.

R2 REINFORCING BARS SHALL BE PLACED IN ONE LAYER AND SHALL BE TIED TO THE TIEBARS.

R3. THE LENGTH OF THE REINFORCING BAR SHALL BE THE LENGTH OR WIDTH OF THE REPAIR AREA MINUS 2 INCHES. THE END OF THE BAR SHALL BE PLACED WITHIN 1 INCH FROM THE REPAIR EDGE.

TIEBARS FOR REPAIR AREAS

T1. TIEBARS SHALL BE PLACED AT APPROXIMATELY THE MID-DEPTH OF SLAB. THE BOTTOM OF THE HOLE DRILLED FOR THE LONGITUDINAL BARS SHALL BE AT MID-DEPTH AND THE TOP OF THE HOLES DRILLED FOR THE TRANSVERSE BARS SHALL BE AT MID-DEPTH. MID-DEPTH WILL BE ESTABLISHED BY MEASURING FROM THE TOP OF THE SLAB DOWN. THE THICKNESS OF THE CONCRETE SLAB WILL BE DEFINED BY THE PLANS OR THE ENGINEER.

T2. THE BAR SIZE AND SPACING OF TIEBARS ARE SHOWN IN TABLE NO. 1.

T3. THE MINIMUM LENGTH OF TIEBARS EXTENDED INTO THE REPAIR AREA SHOULD BE 25 INCHES FOR A #6 BAR.

T4. THE TIEBAR SHALL BE GROUTED INTO THE EXISTING CONCRETE A MINIMUM OF 12 INCHES. BEFORE REPAIR WORK, DEMONSTRATE THAT THE BOND STRENGTH OF THE EPOXY-GROUTED TIEBARS MEETS THE REQUIREMENTS OF PULL-OUT TEST SPECIFIED IN ITEM 361.

T5. MULTIPLE PIECE TIEBARS SHALL BE USED WHEN THE REPAIR AREA MUST BE PLACED IN TWO STAGES DUE TO SEQUENCE OF CONSTRUCTION.

DOWELS FOR TRANSVERSE JOINT REPAIRS

D1. SMOOTH DOWEL BARS SHALL BE DELIVERED TO THE JOBS SITE IN PREFABRICATED DOWEL ASSEMBLIES. THE ENTIRE DOWEL BAR SHALL BE COATED WITH A MATERIAL WHICH WILL PREVENT BONDING TO THE CONCRETE.

D2. THE SIZE AND SPACING OF DOWEL BARS SHALL BE AS SHOWN IN TABLE NO.2.

D3. PLACEMENT OF TIEBARS AND OTHER REINFORCING STEEL SHALL BE STOPPED APPROXIMATELY 4" FROM THE DOWEL BAR ASSEMBLY.

D4. DOWEL BAR PLACEMENT SHALL MEET THE REQUIREMENTS OF ITEM 360, "CONCRETE PAVEMENT."

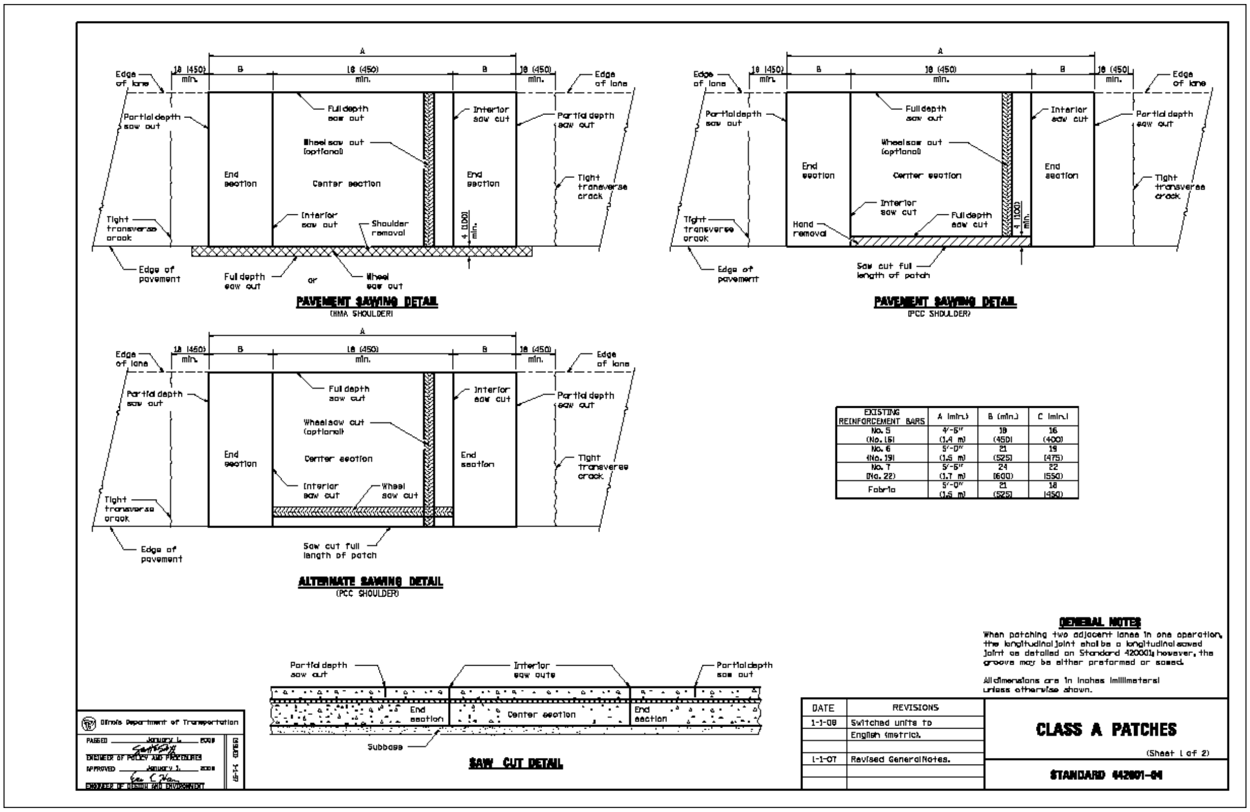
TABLE NO. 2 DOWELS (SMOOTH BARS)

PAVEMENT THICKNESS (INCHES)	SIZE AND DIA.	LENGTH (INCHES)	SPACING (INCHES)
8	#8 (1 IN.)	18	12
9	#9 (1 1/8 IN.)		
≥10	#10 (1 1/4 IN.)		

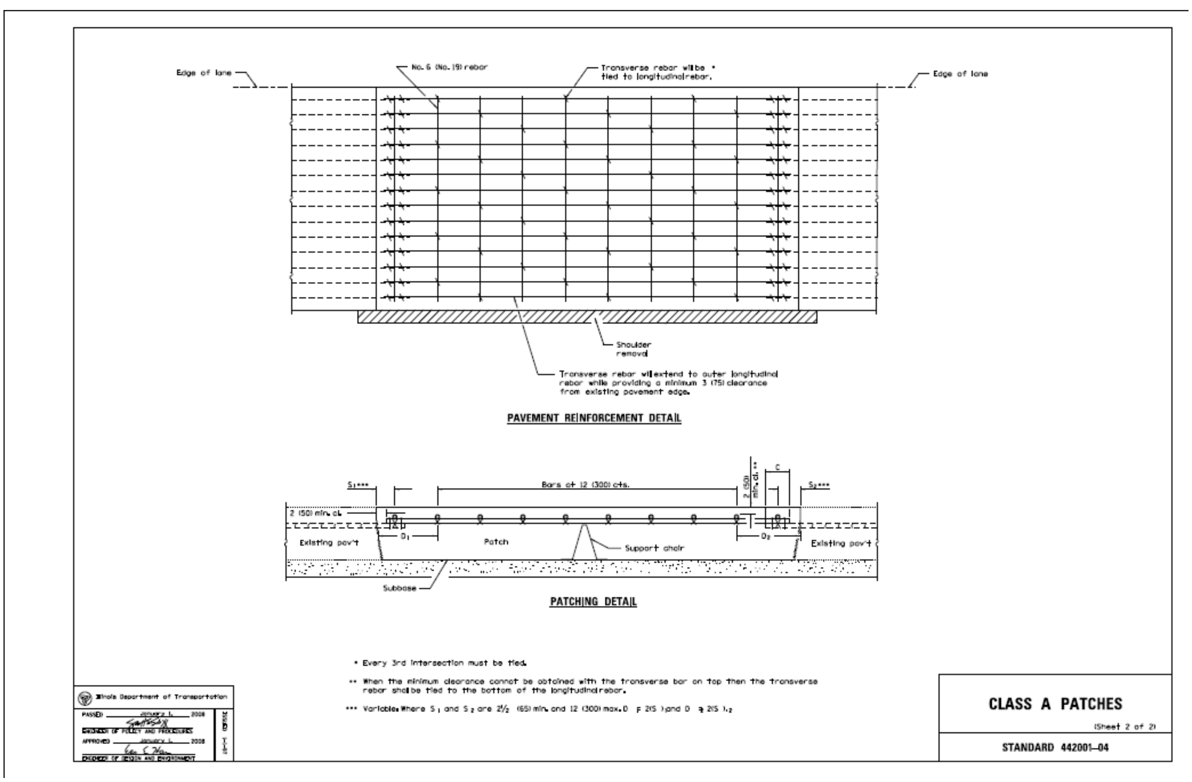
TABLE NO. 1 STEEL BARS SIZE AND SPACING

TYPE OF REINFORCEMENTS	TYPE PAVEMENT	PAVEMENT THICKNESS (INCHES)	TIEBARS: SIZE BAR (BAR NO.)	TIEBARS: BAR SPACING (INCHES)	REGULAR REBARS: SIZE BAR (BAR NO.)	REGULAR REBARS: SPACING (INCHES)	ALL BARS: FIRST & LAST SPACING AT END OR SIDE (INCHES)
TRANSVERSE BARS	CRCP JRCP	ALL	#6	24	#6	24	12
	JCP (CPCD)	ALL	#6	24	NONE	NONE	12
LONGITUDINAL BARS	CRCP	8	#6	9	#6	9	12
		9	#6	8	#6	8	12
		10	#6	7	#6	7	12
		11	#6	6.5	#6	6.5	12
		≥12	#6	6	#6	6	12
	JRCP	ALL	#6	12	#6	24	12
	JCP (CPCD)	ALL	#6	12	NONE	NONE	12

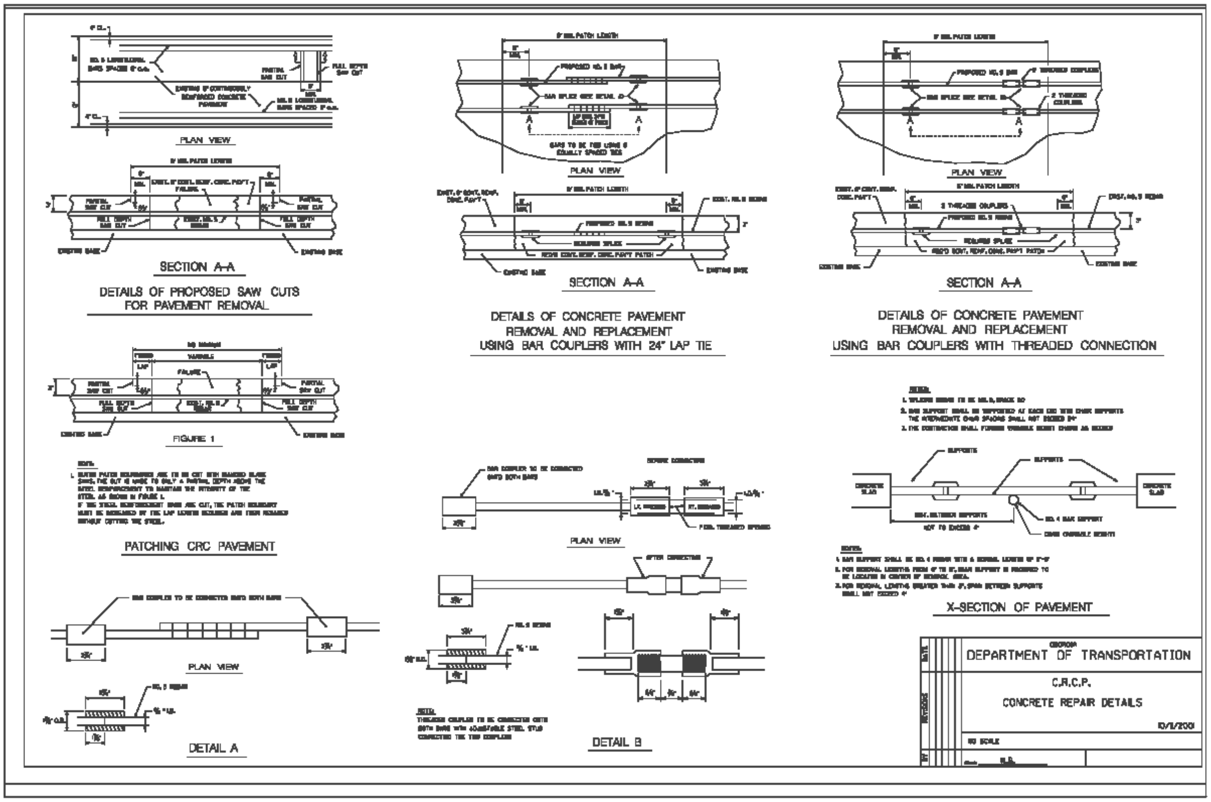
Texas DOT Full-Depth Repair Detail for Concrete Pavement



Illinois DOT Full-Depth Repair Detail for CRC Pavement (page 1 of 2)



Illinois DOT Full-Depth Repair Detail for CRC Pavement (page 2 of 2)



Georgia DOT CRCP Concrete Repair Details

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