CHAPTER 10
REHABILITATION OF PORTLAND CEMENT CONCRETE PAVEMENT

10.1 Introduction

Prior to 1976, Federal-Aid Interstate funds could be used only for the initial construction of the system. All other non-maintenance work on the Interstate System was funded with Federal-Aid Primary or State funds. The Federal-Aid Highway Act of 1976 established the Interstate 3R program, which placed emphasis on the use of Federal funds for resurfacing, rehabilitation, and restoration. The Federal-Aid Highway Act of 1978 required 20 percent of each State's primary, secondary, and urban Federal-Aid funds be spent on 3R projects. The Federal-Aid Highway Act of 1981 added the fourth R, reconstruction, so existing facilities could be eligible for Federal funding. The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) reclassifies the four Federal-Aid systems (interstate, primary, secondary and urban) into two Federal-Aid systems: the National Highway System (NHS) and the Non-NHS. Although the Interstate System is a part of the NHS, it retains its own identity and will receive separate funding. Due to the passage of 1998 TEA-21, funding is not available for surface transportation improvements but, federal funds are available for matching state and local funds to construct 4R projects (6). The above legislation and funding is the driving force behind the restoration of pavements and specifically this chapter.

This chapter provides a framework and describes the information needed to create cost effective rehabilitation strategies for Portland Cement Concrete Pavement (PCCP). Policy decision making that advocates applying the same standard fixes to every pavement does not produce successful pavement rehabilitation. Successful rehabilitation depends on decisions that are based on the specific condition and design of the individual pavement. Five basic types of detailed project information are necessary: design, construction, traffic, environmental, and pavement condition (1). Once the data is gathered, an evaluation is in order to determine the cause of the pavement distress. Finally, a choice needs to be made to select an engineered rehabilitation technique(s) that will correct the distresses.

10.2 Scope and Limitations

Pavement rehabilitation projects should substantially increase the service life of a significant length of roadway. The guidelines presented in this chapter will focus on restoration. The restoration presented refers to the pavement rehabilitation before an overlay or not needing one after the restoration. In this chapter, the words rehabilitation and restoration are interchangeable; one needs to understand the contents as presented. Resurfacing with an overlay is covered in **CHAPTER 8** and **CHAPTER 9** of this manual. **CHAPTER 8** is the design of flexible overlays. Most of the chapter deals with flexible overlays over flexible pavement, but, the same principles apply to flexible overlays over rigid pavements. **CHAPTER 9** mostly deals with rigid overlays over rigid pavement and the design of concrete overlays. Reconstruction involves complete removal of the pavement structure and would use the same design procedures as in **CHAPTER 7**. Reconstruction techniques offer the choice of selecting virgin or recycled materials. The use of recycled material can often lower project costs (1, 3).

The pavement designer will encounter other definitions relating to rehabilitation. Both definitions will refer to functional and structural conditions. The intent is to show how encompassing rehabilitation is:

- AASHTO defines Preventive Maintenance (PM) as a "planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without substantially increasing structural capacity)" (8).

- The publication *Development of a Pavement Maintenance Program for the Colorado Department of Transportation, Final Report*, CDOT-DTD-R-2004-17, August 2004 suggests this definition for Preventive Maintenance (22).

  "Preventive Maintenance: Work undertaken that preserves the existing pavement, retards future deterioration, and improves the functional life without substantially increasing the structural capacity."

- An AASHTO sponsored working group defined pavement preservation as "the planned strategy of cost-effective pavement treatments to an existing roadway to extend the life or improve the serviceability of the pavement. It is a program strategy intended to maintain the functional or structural condition of the pavement. It is the strategy for individual pavements and for optimizing the performance of a pavement network" (8).

The above definitions stress the point that pavement maintenance and preservation is planned and associated cost effective strategies. The gathering of information, evaluation, and selections of treatments as outlined below are the same if the strategies were or were not planned.

10.3 Colorado Documented Design Methods

By June 1952, 8 inches of concrete pavement over 6 inches of granular subbase was placed on the now northbound lanes of Interstate 25 from Evans Avenue southward through a rural area to the Town of Castle Rock. In 1951 the grading project in preparation for the concrete pavement had a requirement of 90 percent AASHO T 180 Modified Compaction on A-6 and A-7 soils with a swell ranging from 4.3 to 9.9 percent. Shortly after the PCCP was placed, theColorado Department of Highways (CDOH) noticed cracking and warping of the slabs in certain areas. By the following summer, the cracking and rising of the slabs had become severe in these areas. The cracking increased throughout the project from October 1952 of 1,802 linear feet to 13,959 linear feet by September 1958. What followed in 1956/1957 was not a restoration of the existing concrete pavement, but constructing experiential sections to investigate alternatives to mitigate the swell potential on the new future southbound lanes. A number of design philosophies in place now are a result of these experiential sections. The final report was published in 1966 titled, *Pavement Study - Project I 092-2(4)* in cooperation with U.S. Bureau of Public Roads (16). The grading project for the experiential sections required 95 percent AASHO T 99 Standard Compaction as much on the wet side as feasible. Laboratory tests showed the A-7-5(20) soils that swelled 9.9 percent at 90 percent modified compaction swelled to only 2.8 percent at 95 percent standard

compaction. At this time, the Department felt that if the swell of the subgrade soils was less than 3 percent, 4 inches of subbase material plus 8 inches of PCCP would provide sufficient surcharge to nullify the detrimental effect of this small amount of swell. Five test sections were constructed from late 1957 to spring of 1958.

- **Section A:** ½ mile of 8 inch concrete pavement encasing a light welded wire reinforcing fabric placed 2 inches below the concrete surface with a joint spacing of 61.5 feet, concrete pavement was placed over 4 inches of sand subbase treated with 2 percent cement.

- **Section B:** ½ mile of 8 inch concrete pavement encasing a heavy welded wire reinforcing fabric with a joint spacing of 106.5 feet, concrete pavement placed over 4 inches of sand subbase treated with 2 percent cement.

- **Section C:** "Control Section" 1 mile of 8 inch non-reinforced concrete pavement with a joint spacing of 20 feet, placed on 4 inches cement-treated base.

- **Section D:** ½ mile of 10 inch non-reinforced concrete pavement with a joint spacing of 20 feet, placed on 4 inches cement treated base.

- **Section E:** ½ mile of 8 inch concrete pavement with a joint spacing of 20 feet, placed on 20 inches of cemen -treated base

1966 results showed the Section C "Control Section" had less cracking per mile than any other section; Section B had 718 feet/mile, Section D had 502 ft/mi, Section A had 396 feet/mile, Section E had 384 feet/mile, and Section C had 85 feet/mile. The tests sections would never be classified as severe when compared to the cracking of 1952-1957.

A number of important conclusions were presented. The 1966 report concluded remedial measures are necessary for high swelling soils. High swelling soils could be mitigated by applying moisture contents at or near optimum using standard 95 percent of AASHO T 99 standard compaction. If the subgrade soils had a swell less than 3 percent then no mitigation was necessary. DOH Memo #323, 1/5/66, (Construction) Swelling Soils was issued to address the depth of treatments in cuts sections. Refer to Chapter 2 of this Manual and *Chapter 200 of the Field Materials Manual* for additional information; both manuals basically follow Memo #323. Current thinking is to use a moisture content of optimum plus 2 percent and not to use continuously reinforced concrete pavement. Two reasons were presented, first being that for joint maintenance as a whole, cost was about the same for all sections. Second, the extra cost of wire mesh reinforcement was not justified considering rideability. The difference between a present service index of 4.0 and one of 3.4 were both considered acceptable. The maintenance forces provided a practical remedial rehabilitation by placing a thin overlay to improve the appearance and ride. Currently, this is a viable option and the most often used treatment.

In 1983 the Colorado Department of Highways (now referred to as the Colorado Department of Transportation, CDOT) prepared a research report titled *Rehabilitation of Concrete Pavements*, Report No. CDOH-83-1 (9). In 1983, the Colorado Department of Highways conducted an in-

depth evaluation of concrete pavements on the interstate system. The purpose of the evaluation was to determine the condition of the pavements and develop rehabilitation strategies for these concrete pavements in anticipation of increased 4R funds from the Federal Government. The rehabilitation philosophy used in 1983 was to restore all of the concrete pavements to "Like New" condition with a 20-year design life. Design procedures presented at the end of the study were developed utilizing thick concrete and asphalt as a means of achieving the 20-year design life. Nine types of distress were identified and thought to be the most frequently observed on interstate roadways in Colorado. The pavements ages ranged from 4 to 24 years with the average being 18 years. The nine distresses were:

- Reactive aggregate
- Longitudinal cracking
- Transverse cracking
- Rutting
- Depression
- Pumping
- Spalling
- Faulting
- Corner breaks

Reactive aggregates were found to be the most devastating in terms of cost and effective corrective methods. The study recommended fly ash to be use on a routine basis where reactive aggregate problems are known to exist. Currently fly ash is used in CDOT Class P concrete. Rutting was found to be the most prominent in the areas where studded tire traffic volume was higher. Currently the use of studded snow tires is waning; chemical de-icing products such as magnesium chloride and potassium acetate, are taking their place. Pumping was observed only in areas with relatively poor drainage and untreated granular base materials. In these areas the first stage of distress was found to be pumping followed by corner breaks, faulting, and ultimately slab block cracking. Currently pumping and faulting have been reduced by the use of load transfer devices. Dowel bar diameter significantly affects faulting per Long-Term Pavement Performance (LTPP) Tech Brief *LTPP Data Analysis: Frequently Asked Questions About Joint Faulting With Answers From LTPP*, FHWA-RD-97-101 (11). Presently, untreated granular bases are still being used and bases are not being specified with concrete pavement being placed on natural soils. As a reference, refer to AASHTO M155-87(2000) - *Standard Specification for Granular Material to Control Pumping Under Concrete Pavement* for aggregate base requirements. In other instances treated soils such as lime treated subgrade are being specified in swelling soil conditions. Spalling at the joints was observed under two types of conditions. Spalling occurred at plastic parting strip ribbons and where joint filler material was not replaced. Currently, plastic parting strips have been eliminated and the standard for joint saw cutting has been revised using only a narrow single cut instead of two saw cuts with a wider top cut. Longitudinal cracking is still prominent. Two apparent reasons is the slab widths are too wide for the design thickness, and serious construction problems, *Structural Factors of Jointed Plain Concrete Pavements: SPS-2 -- Initial Evaluation and Analysis*, FHWA-RD-01-167. CDOT published a research report *Evaluation of Premature PCCP Longitudinal Cracking in Colorado*, Final Report, Report No. CDOT-DTD-R-2003-1, concluding swelling soils, shallow saw cut depth, and malfunctioning or improperly adjusted paver vibrators creating vibrator trails produces longitudinal cracking (13). The 14 foot wide slabs on

rural interstates did not contribute to the cracking. A regional investigation is looking at the ends of the tie bars where voids occur at the location of longitudinal cracking. Other possible reasons may be wheel loadings applied before the concrete cures or thermal flashing.

Other conclusions were presented in the Report No. CDOH-83-1, 1983. First, rutting of low severity accounted for most of the distressed mileage. Second, reactive aggregates and faulting were most frequently occurring as high severity. Thirdly, medium severity of longitudinal cracking was observed.

The standard concrete pavement joint detail before 1983 required skewed and variable 13-19-18-12 transverse joint spacing and older standards of skewed or non-skewed equal 15 or 20 foot spacing depending on aggregate size. The transverse joints were not doweled except for the first 3 joints after the expansion joint. The saw depth was $^{T}/_{4}$ or older standards of 2 inches minimum. The longitudinal joints had tie-bars at 30 inch centers and size No. 4 for 8 inch thick pavement and No. 5 for thickness greater than 8 inches or older standards of No. 4 at 36 inch spacing. Most of the interstate pavement at that time was 8 inches thick. The design procedure was to obtain design traffic, soil support, concrete strength, and an applied load safety factor. The load safety factor was directly related to high predicted truck traffic.

In 1988, the report titled *Rehabilitation of Concrete Pavements Follow-Up Study*, Report No. CDOH-88-8 was released (10). The Colorado Department of Highways had been working under the guidelines of the previous study for 5 years. The intent was to review the effectiveness and suitability of the concepts developed in 1983. In 1983, approximately 81 miles of concrete were rated in the poor category. Over the period from 1983 to 1988 nearly 64 miles of concrete roadway were rehabilitated; however, the 1988 survey determined that approximately 98 miles of pavement were in the poor category. The rehabilitation philosophy used in 1983 to restore all of the concrete pavements to "Like New" condition with a 20 year design life was modified under this study. With the issuance of the *1986 AASHTO Design Guide*, FHWA allowed the states to use a design life as low as 8 years for rehabilitation. A section of roadway can now be analyzed using both an 8 year and 20 year design life to optimize the expenditure of resources to achieve acceptable levels of service. Examples of the new design procedures were included in the report. A rehabilitation plan was provided for a 10 year effort. Highlights were to start rehabilitating the worst sections first, use the 8 year design concept wherever it was possible, and concentrating on sections having the highest levels of traffic. The focus of the study was to bring forth the rehabilitation by overlay design and not repair the nine distresses individually by restoration techniques.

Following the first report above, the need to showcase the latest state-of-the-art Concrete Pavement Restoration (CPR), a seminar and demonstration project was organized (Demonstration Project No. 69). The seminar was a cooperative effort between CDOH, ACPA and FHWA and was held a day after the AASHTO meeting on October 5, 1983 with approximately 200 state and highway officials and engineers along with industry representatives in attendance. The results of the seminar and notes in the construction of the demonstration were reported in *Evaluation of Concrete Pavement Restoration Procedures and Techniques*, Initial Report, Report No. CDOH-DTP-R-84-5 (14). The demonstration showcased the techniques of full depth repair, partial depth repair, undersealing, grinding, installing load transfer devices, joint sealing, and crack sealing. The site was on eastbound I-70 between Chambers Road and Tower Road. The pavement was 19 years

old, 8 inches of concrete pavement over 6 inches of base course surfacing, 20 foot joint spacing, skewed, with tie bars in the centerline longitudinal joint, no load transfer devices or steel in the transverse joints and with asphalt shoulders. *Concrete Pavement Restoration Demonstration*, Final Report, Report No. CDOH-DTD-R-88-6 (15) reports the subsequent evaluations for a period of three years after construction repair. Generally, most of the restoration techniques did not perform well in this demonstration project.

- **Full-Depth Repair:** 8 out of 13 replacement slabs cracked.
- **Partial-Depth Repair:** All 6 patches showed distress or failed.
- **Undersealing:** Inconsistent data in slab deflections of grouted and non-grouted slabs and how well uniform support was obtained.
- **Faulting and Grinding:** Typically slabs faulted in a third of the unground sections.
- **Load Transfer Device:** The obsolete device worked well especially in conjunction with undersealing.
- **Joint Sealing:** 12 different types of joint sealer were applied, some worked some failed.
- **Crack Sealing:** Routed and sealed with the same sealants used above, overall was not very successful, continued to crack and spall.

The pre-overlay design methods and techniques suggested in this Chapter are based on these reports as well as *Factors for Pavement Rehabilitation Strategy Selection* by the American Concrete Pavement Association (1). The following sections are based on the ACPA publication.

10.4 Project Information

Obtaining specific project information is the first step in the process of rehabilitation. Five basic types of detailed project information are necessary before an evaluation can be made:

- **Design Data:** Includes the pavement type and thickness. The components of the pavement are layer materials, strengths, joint design, shoulder design, drainage system and previous repair or maintenance.
- **Construction Data:** If possible obtain original construction conditions. Field books, daily logs and weather conditions are helpful. Concrete mix designs would show aggregate size and additives that may influence the existing concrete conditions.
- **Traffic Data:** Strategy selection requires past, current, and expected traffic growth. This helps determine the remaining effective structural capacity of the existing pavement. **Section 1.5 Traffic Projections** outlines the methods and procedures to calculate traffic loads.

- **Environmental Data:** Important factors are temperature, precipitation, and freeze-thaw conditions. These factors influence material integrity, structural capacity, and rideability.

- **Distress and/or Condition Data**: A distress survey should report the type, severity and quantity of each distress. A detailed concrete pavement distress/condition survey is required before a rehabilitation project can be evaluated and designed. The types of distress in concrete pavements have to be identified and documented prior to the selection of corrective measures. The cause of distresses is not always easily identified and may consist of a combination of problems. The following types of distress are common to deteriorating concrete pavements: excessive deflection, differential deflection at joints, moisture related distress at cracks and joints, cracking due to reactive aggregate, longitudinal and transverse cracking, spalling, faulting, pumping, rutting, and movement of slabs due to swelling soils. The condition survey should identify and document the types, location, and amount of distress encountered in the design selected for rehabilitation. Photographs are a good way to document many of the distresses mentioned above. **Figure 9.2 Pavement Condition Evaluation Checklist (Rigid)** should be used and placed in the pavement design report. To help determine the type of distress the pavement is exhibiting refer to FHWA *Distress Identification Manual* (4). This manual may be downloaded from the web page: http://www.fhwa.dot.gov/publications/infrastructure/pavements/ltpp/reports/03031/ CDOT has a distress manual documenting pavement distress, description, severity levels, and additional notes (22). The distress manual is presented in Appendix B - Colorado DOT Distress Manual for HMA and PCC Pavements in the publication *Development of a Pavement Maintenance Program for the Colorado Department of Transportation*, Final Report, CDOT-DTD-R-2004-17, August 2004. The report is in pdf format and can be downloaded from the web page http://www.coloradodot.info/programs/research/2004/preventivemaintenance.pdf. In order to determine the pavement distress and condition, a field inspection is mandatory. Isolating areas of distress can pinpoint different solutions for different sections along a project. Non-Destructive Testing (NDT) and destructive testing (i.e. coring and boring) can determine the structural condition and material properties below the surface.

10.5 Pavement Evaluation

The second step is to analyze and evaluate the gathered project information. Pavement evaluation requires a systematic approach to quantify adequately and analyze the many variables that influence the selection of the appropriate rehabilitation technique. More engineering effort may be required for pavement rehabilitation than for new construction because of the additional elements of evaluating the existing pavement. An engineering evaluation must address several key issues such as functional and structural condition, materials condition, drainage conditions, and lane condition uniformity (1, 5, 6).

10.5.1 Functional and Structural Condition

The CDOT Pavement Management System triggers the need for rehabilitation work on automated visual surface distresses in a single lane. The distresses are rated and weighted in an index equation. The equation is weighted heavily to ride, then rut, and then cracking. The index equation is then converted into Remaining Service Life (RSL). Lost in the RSL values is the distinction between functional and structural distress. Be careful on just relying on the rating obtained from pavement management. As of this date, the observed surface distresses are limited to a few of the major pavement distresses. Pavement management will not pick up on Alkali Silica Reactivity (ASR) until the severe stage, showing up as surface cracking. Knowing ASR exists may influence the restoration technique the designer selects. Each distress condition will have its own set of repair techniques. The project pavement design engineer must determine if the pavement condition is in a functional or structural distress.

10.5.2 Structural Condition

Structural deterioration is any condition that reduces the load carrying capacity of a pavement (6, 7). Corner breaks, pumping, faulted joints, and shattered slabs are some examples of structural related distresses. Evaluating the level of structural capacity requires thorough visual survey and materials testing (7). Non-destructive testing is important to characterize both pavement stiffness and subgrade support. Restoration is applicable only for pavements with substantial remaining structural capacity. Pavements that have lost much of their structural capacity require either a thick overlay or reconstruction. To help assess the current structural adequacy of Jointed Plain Concrete Pavement (JPCP), the extent and severity of the distresses can be compared with value ranges provided in **Table 10.1 Structural Adequacy for JPCP**.

Table 10.1 Structural Adequacy for JPCP
(Extracted from March 2004, *Guide for Mechanistic-Empirical Design, Part 2 Design Inputs*, Table 2.5.15 pg. 2.5.61 (17))

Load-Related Distress	Highway Classification	Current Distress Level		
		Inadequate	**Marginal**	**Adequate**
Deteriorated Cracked Slabs medium and high severity transverse and longitudinal cracks and corner breaks (percent slabs)	Interstate/freeway	> 10	5 to 10	< 5
	Primary	> 15	8 to 15	< 8
	Secondary	> 20	10 to 20	< 10
Mean Transverse Joint/Crack Faulting (inches)	Interstate/freeway	> 0.15	0.10 to 0.15	< 0.10
	Primary	> 0.20	0.125 to 0.20	< 0.125
	Secondary	> 0.30	0.15 to 0.30	< 0.15

10.5.2.1 Functional Condition

Functional deterioration is defined as a condition that adversely affects the highway user. Functional distresses include problems which influence the ride quality, but are not necessarily signs of reduced structural capacity. These may include poor surface friction and texture,

hydroplaning and splash from wheel path rutting, and excess surface distortion. Cracking and faulting affect ride quality but are not classified as functional distress. These conditions reduce load carrying capacity as stated above. The integrity of the base, concrete slab, and joint system is compromised under cracking and faulting. To help assess the current functional adequacy of Jointed Plain Concrete Pavement (JPCP), International Roughness Index (IRI) is compared with value ranges provided in **Table 10.2 Functional Adequacy for JPCP**.

Table 10.2 Functional Adequacy for JPCP
(Extracted from March 2004, *Guide for Mechanistic-Empirical Design, Part 2 Design Inputs*, Table 2.5.19, pg. 2.5.65 (17))

Pavement Type	Highway Classification	IRI (inch/mile) Level		
		Inadequate (Not Smooth)	**Marginal** (Moderately Smooth)	**Adequate** (Smooth)
Rigid (JPCP) and Flexible	Interstate/freeway	> 175	100 to 175	< 100
	Primary	> 200	110 to 200	< 110
	Secondary	> 250	125 to 250	< 125

10.5.2.2 Problem Classifications Between Structural and Functional Condition

How would the pavement designer classify lane separation? It could be classified as a functional condition if the lane separation (longitudinal joint width) becomes too excessive where the handling of a motorcycle becomes dangerous or adversely affects the highway user. It becomes a structural condition when the lane separation starts to manifest itself during rain storms when water infiltrates the base by cross slope sheet flow. Also, edge wheel loading next to the lane separation will eventually accumulate stress damage until finally over-stressing to the allowable limit. Even though no cracked slabs are present at the time of the investigation, lane separation will eventually be classified as a structural condition. The pavement designer could then say the integrity of the base, slab, and joint system is compromised.

10.5.2.3 Material Condition and Properties

An evaluation of material condition <u>should not</u> be done using assumed conditions or unknown material strengths. These factors are measurable from actual response to non-destructive and destructive testing methods.

10.5.2.4 Non-Destructive Testing

Non-destructive testing may use three methods of testing to determine structural adequacy (17).

- **Deflection Testing:** Determines high deflections, layer moduli, and joint load transfer efficiencies
- **Profile Testing:** Determines joint/crack faulting
- **Ground Penetrating Radar:** Determines layer thickness

This site specific data obtained from these methods would be a Level 1 input. Deflection testing results are used to determine the following:

- Concrete elastic modulus and subgrade modulus of reaction at center of slab
- Load transfer across joints/cracks (across transverse joints/cracks in wheelpath)
- Void detection at corners
- Structural adequacy at non-distressed locations

In addition to backcalculation of the pavement layer, subgrade properties, and void detection, deflection testing can also be used to evaluate the Load Transfer Efficiency (LTE) of joints and cracks in rigid pavements (18). *Evaluation of Joint and Crack Load Transfer*, Final Report, FHWA-RD-02-088 (19) is a study presenting the first systematic analysis of the deflection data under the LTPP program related to LTE.

$$\mathbf{LTE = (\delta_u / \delta_l) \times 100} \qquad \textbf{Eq. 10-1}$$

Where:

LTE = load transfer efficiency, percent

δ_u = deflection on unloaded side of joint or crack measured 6 inches from the joint/crack

δ_l = deflection on loaded side of joint or crack measured beneath the load plate and center of which is placed 6 inches from the joint/crack

Visual distresses present at the joint or crack should be recorded and quantified. Joint (and crack) distress information is useful in analyzing and filtering the results obtained from the LTE calculation. The load transfer rating as related to the load transfer efficiency is shown in **Table 10.3 Load Transfer Efficiency Quality.**

Table 10.3 Load Transfer Efficiency Quality
(From March 2004, *Guide for Mechanistic-Empirical Design, Part 2 Design Inputs*, Table 2.5.9, pg. 2.5.49 (17))

Load Transfer Rating	Load Transfer Efficiency (percent)
Excellent	90 to 100
Good	75 to 89
Fair	50 to 74
Poor	25 to 49
Very Poor	0 to 24

Crack LTE is a critical measure of pavement condition because it is an indicator of whether the existing cracks will deteriorate further. LTE tests are usually performed in the outer wheelpath of the outside lane. For JPCP, cracks are held together by aggregate interlock; joints designed with load transfer devices have steel and aggregate interlock. In general, cracks with a good load transfer (LTE greater than 75 percent) hold together quite well and do not significantly contribute to pavement deterioration. Cracks with poor load transfer (LTE less than 50 percent) are working

cracks and can be expected to deteriorate to medium and high severity levels, will exhibit faulting over time, and are candidates for rehabilitation.

10.5.2.5 Destructive Testing

Experience has shown non-destructive testing techniques alone may not always provide a reasonable or accurate characterization of the in-situ properties, particularly for those of the top pavement layer (17). The determination of pavement layer type cannot be made through non-destructive testing. While historic information may be available, the extreme importance and sensitivity calls for a limited amount of coring at randomly selected locations to be used to verify the historic information. Pavement coring, base and subbase thicknesses, and samples are recommended to be collected at an approximate frequency of one sample per one-half mile of roadway. Several major parameters are needed in the data collection process. They are as follows:

- Layer thickness
- Layer material type
- Examination of cores to observe general condition and material durability
- In-situ material properties (i.e. modulus and strength)

Concrete slab durability may have a possible condition of severe D-Cracking and reactive aggregate. Petrographic analysis helps identify the severity of the concrete distresses when the cause is not obvious. Material durability problems are the result of adverse chemical or physical interactions between a paving material and the environment (17). The field condition survey and examination of cores for material durability reinforce each other (see **Table 10.4 Distress Levels for Durability of JPCP**). Listed are durability problems and causes.

- **D-Cracking**: The fracture of layer aggregate particles, and subsequently the PCC mortar, as a result of water freezing and expanding in the pores of moisture-susceptible course aggregate.

- **Freeze-Thaw Damage**: Spalling and scaling in freeze-thaw climates due to inadequate entrained air voids. The lack of entrained air restricts the internal expansion of water in concrete during periods of freezing and thawing.

- **Alkali-Silica Reactivity**: Map cracking and joint deterioration resulting from the reaction of high silica or carbonate aggregates and alkalies (sodium and potassium) in portland cement. The reaction produces a gel that absorbs water and swells, thus fracturing the cement matrix.

- **Steel Corrosion**: Pavements located in regions where de-icing salts are used.

- **Treated Base/Subbase Disintegration**: Stripping of asphalt cement by water in asphalt-treated materials, or the disintegration of cement-treated materials due to freeze-thaw cycles.

- **Unbound Base/Subbase Contamination** by fines from subgrade.

Table 10.4 Distress Levels for Durability of JPCP
From March 2004, *Guide for Mechanistic-Empirical Design, Part 2 Design Inputs*, Table 2.5.22, pg. 2.5.70 (17)

Load-Related Distress	Highway Classification	Current Distress Level		
		Inadequate	**Marginal**	**Adequate**
Patch Deterioration Medium and High Severity (percent surface area)	Interstate/Freeway	> 10	5 to 10	< 5
	Primary	> 15	8 to 15	< 8
	Secondary	> 20	10 to 20	< 10
D-cracking and **ASR**	All	Predominantly medium and high severity	Predominantly low and medium severity	None or predominantly low severity
Longitudinal Joint Spall Medium and High Severity (percent length)	Interstate/Freeway	> 50	20 to 50	< 20
	Primary	> 60	25 to 60	< 25
	Secondary	> 75	30 to 75	< 30
Transverse Joint Spalling Medium and High Severity (joints /mile)	Interstate/Freeway	> 50	20 to 50	< 20
	Primary	> 60	25 to 60	< 25
	Secondary	> 75	30 to 75	< 30
Stripping (treated base/subbase)	All	Unable to recover majority of cores due to disintegration or stripping	Unable to recover some cores due to disintegration or stripping	Cores are predominantly intact
Unbound Granular Base Contamination	All	Contamination of unbound granular base/subbase with fines from subgrade		

For rigid pavements, one of the more significant properties influencing performance is the flexural strength (modulus of rupture) of the concrete. General correlations between splitting tensile strength and flexural strength may be used as a source of input since cores can be obtained from the pavement. Three correlation formulas may be used. The reports cannot be found but the formulas were kept. All are straight line relationships.

1971, Deville
Flexural Strength = 190 + 0.097 × compressive strength **Eq. 10-2**

1979, Mirza
Flexural Strength = 247 + 0.068 × compressive strength **Eq. 10-3**

1996, Lollar – using CDOT Region 1 (prior to 7/1/2013) data for master's degree
Flexural Strength = 217 + 0.75 × compressive strength **Eq. 10-4**

There are many papers, articles, and opinions on the correlation between the different strength test types. ACPA does not recommend any one particular test. The listed national correlations are from ACPA website (see **Table 10.5 Strength Correlation Formulas**) (20): http://www.pavement.com/Concrete_Pavement/Technical/FATQ/Construction/StrengthTests.asp

Table 10.5 Strength Correlation Formulas

Source/Author	Equation (psi)
ACI Journal / Raphael, J.M.	$M_r = 2.3 \times [F_c \wedge (^2/_3)]$
	$F_{st} = 1.7 \times [F_c \wedge (^2/_3)]$
ACI Code	$M_r = 7.5 \times [F_c \wedge (^1/_2)]$
	$F_{st} = 6.7 \times [F_c \wedge (^1/_2)]$
Center for Transportation Research / Fowler, D.W.	$F_{st} = 0.72 \text{ x } M_r$
Center for Transportation Research / Carrasquillo, R.	M_r (3rd point) = 0.86 x M_r (center point)
Greer	$M_r = 21 + 1.254\ F_{st}$
	$M_r = 1.296\ F_{st}$
	$M_r = F_{st} + 150$
Hammit	$M_r = 1.02\ F_{st} + 210.5$
Narrow & Ulbrig	$M_r = F_{st} + 250$
Grieb & Werner	$F_{st} = {}^5/_8\ M_r$ (river gravel)
	$F_{st} = {}^2/_3\ M_r$ (crushed limestone)

Note: When High-Performance Concrete (HPC) is used, the above relationships will not necessarily hold true. The HPC mixes with very low water/cement ratios tend to be more brittle and show different behaviors.
F_{st} = Splitting tensile strength
F_c = Compressive strength
M_r = Modulus of rupture = flexural strength, third-point loading (unless otherwise noted)

In-situ material properties of bases, subbases and soils including soil strength, may be obtained using the Dynamic Cone Penetrometer (DCP). The proposed mechanistic-empirical design guide software allows users to input DCP test results directly or indirectly depending on the models of choice. The pavement design engineer uses the above material properties to obtain a resilient modulus of each layer. The field and laboratory testing would have a hierarchical Level 2 for inputs in the mechanistic empirical design method. Level 3 would use similar values obtained through regional or typical default values.

10.5.3 Drainage Condition

Condition of drainage structures and systems such as ditches, longitudinal edge drains, transverse drains, joint and crack sealant, culverts, storm drains, inlets, and curb and gutters are all important to convene water away from the pavement structure. Visual distress may reveal the types and extents of distresses present in the pavement that are either caused by or accelerated by moisture. Drainage assessment can also be benefited by data obtained from coring and material testing. The permeability and effective porosity of base/subbase materials, as determined through laboratory tests or calculated from gradations, can be used to quantify drainability (17) (see **Table 10.6 Distress Levels for Assessing Drainage Adequacy of JPCP**).

Table 10.6 Distress Levels for Assessing Drainage Adequacy of JPCP
From March 2004, *Guide for Mechanistic-Empirical Design, Part 2 Design Inputs*, Table 2.5.20, pg. 2.5.67 (17)

Load-Related Distress	Highway Classification	Current Distress Level		
		Inadequate	Marginal	Adequate
Pumping All Severities (percent joints)	Interstate/freeway	> 25	10 to 25	< 10
	Primary	> 30	15 to 30	< 15
	Secondary	> 40	20 to 40	< 20
Mean Transverse Joint/Crack Faulting (inches)	Interstate/freeway	> 0.15	0.10 to 0.15	< 0.10
	Primary	> 0.20	0.125 to 0.20	< 0.125
	Secondary	> 0.30	0.15 to 0.30	< 0.15
Durability All Severity Levels of D-Cracking and Reactive Aggregate	All	Predominantly medium and high severity	Predominantly low and medium severity	None or predominantly low severity
Corner Breaks All Severities (number/mile)	Interstate/freeway	> 25	10 to 25	< 10
	Primary	> 30	15 to 30	< 15
	Secondary	> 40	20 to 40	< 20

10.5.4 Lane Condition Uniformity

On many four lane roadways, the outer truck lane deteriorates at a more rapid pace than the inner lane of shoulders. The actual distribution of truck traffic across lanes varies with the roadway type, location (urban or rural), the number of lanes in each direction, and the traffic volume. Because of these many factors, it is suggested the lane distribution be measured for the project under consideration (6). Obtaining the actual truck lane distributions will determine the actual remaining life of the lane under consideration. Significant savings may result by repairing only the pavement lane that requires treatment.

10.6 Pavement Rehabilitation Techniques

Rehabilitation or restoration techniques are methods to preserve the integrity of the concrete pavement system or to bring the pavement system to an acceptable level for future performance. Concrete Pavement Restoration (CPR) is a series of engineered techniques designed to manage the rate of pavement deterioration in concrete roadways. Ideally, CPR is the first rehabilitation procedure applied to the concrete pavement. CPR is a non-overlay option used to repair isolated areas of distress, or to prevent or slow overall deterioration, as well as, to reduce the impact loadings on the concrete pavement without changing its grade (21). If the pavement needs more load carrying capacity or has deteriorated to poorer conditions, other procedures, such as bonded concrete overlay, unbonded concrete overlay, or asphalt overlay may be applied in conjunction with restoration. Pavement rehabilitation work shall not include normal periodic maintenance activities (2). Cleaning of cross culverts, inlets, and underdrain outlets would be considered normal periodic maintenance activities. CPR may be a maintenance activity, contract work by

maintenance purchase order, or contract low bid. Either way, the work performed is identical. A report was published in August 2004 to assist staff maintenance in developing a pavement maintenance program. Refer to Appendix A - Preventive Maintenance Program Guidelines in the publication *Development of a Pavement Maintenance Program for the Colorado Department of Transportation*, Final Report, CDOT-DTD-R-2004-17, August 2004 (22). The report is in pdf format and can be downloaded from the web page
http://www.coloradodot.info/programs/research/pdfs/2004/preventivemaintenance.pdf
Specific maintenance treatments were documented. These same concrete pavement treatments are described in this chapter (see **Figure 10.1 CPR Sequencing**).

- Diamond grinding
- Concrete crack sealing
- Concrete joint resealing
- Partial depth repair
- Full depth concrete pavement repair
- Dowel bar retrofit

Two additional treatments will also be described.

- Cross stitching
- Slab stabilization

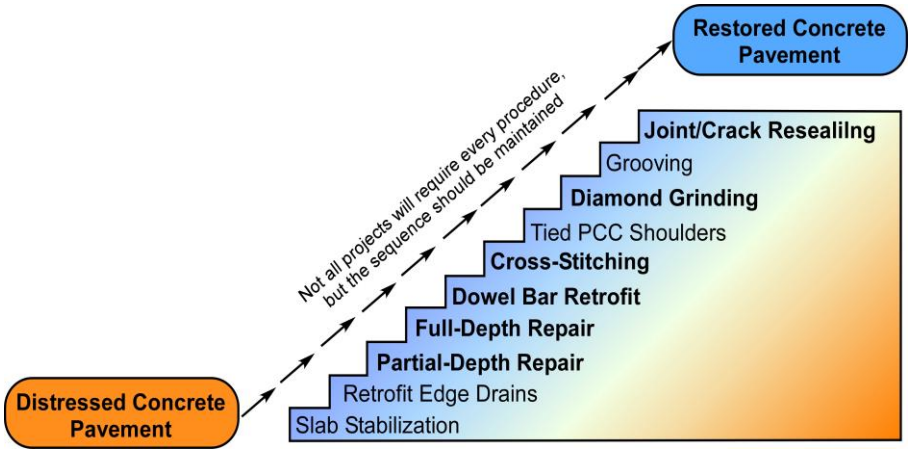
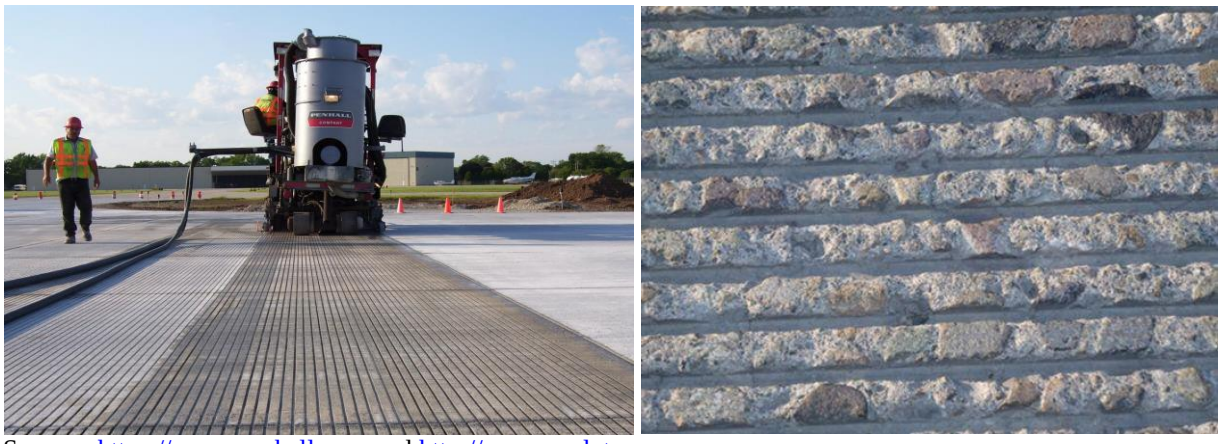


Figure 10.1 CPR Sequencing
Recommended Sequence of Restoration Activities, ACPA, 2006

10.6.1 Diamond Grinding

Diamond grinding and grooving are used to restore the surface of the PCCP. Diamond grinding is the removal of a thin layer of concrete generally about 0.25 inches (6 mm) from the surface of the pavement (36), refer to **Figure 10.2 Photos of Diamond Grinding and Grooving**. Grinding utilizes closely spaced diamond saw blades and corrects surface irregularities, such as cracking, rutting, warping, polishing, and joint faulting. Diamond grooving is the establishment of discrete grooves in the concrete pavement using diamond saw blades. The grooving is placed to break up

the flow of water across the surface. Grooving may be performed longitudinally or transversely however, CDOT's standard is to groove longitudinally (36). Grooving places the diamond blades ¾ inch apart and is used to prevent hydroplaning on wet pavements. Grinding and grooving operations produce a slurry consisting of ground concrete and water. Local environmental regulations should be consulted to determine acceptable disposal solutions. After diamond grinding or grooving, all concrete joints and major cracks must be resealed.



Source: https://www.penhall.com and http://www.wsdot.wa.gov

Figure 10.2 Photos of Diamond Grinding and Grooving

Field studies of diamond ground pavement have indicated that diamond grinding can be an effective long-term treatment. CDOT uses a triangular distribution with a minimum value of 11, the most likely value of 15 years and the maximum value of 17. Additional information may be found in **Section 7.18 Concrete Pavement Texturing, Stationing, and Rumble Strips**.

Cold milling may be done on PCCP, although it is more commonly used on asphalt pavements. Cold milling uses carbide tips to chip off the distressed surface. Cold milling can cause damage to transverse and longitudinal joints. Figure 3 in the publication *Diamond Grinding and Concrete Pavement Restoration* by ACPA (23) shows photographs of the difference between a diamond ground surface and a milled surface. Unless surface unevenness, aggregate fracturing, and joint spalling are tolerable, cold milling should not be allowed as a final surface. One should consider using diamond grinding for the following:

- **Faulting at Joints and Cracks:** Removal of roughness caused by excessive faulting has been the most common need for surface restoration. Trigger values indicate when a highway agency should consider diamond grinding and CPR to restore rideability, see **Table 10.7 Trigger Values for Diamond Grinding**. Limit values for diamond grinding define the point when the pavement has deteriorated so much that it is no longer cost effective to grind, refer to **Table 10.8 Limit Values for Diamond Grinding**. The two tables below show when it is appropriate and how much to diamond grind, and are presented in FHWA technical report titled *Concrete Pavement Rehabilitation Guide for Diamond Grinding*, dated June 2001 (29). The report can be found on the website http://ww.fhwa.dot.gov/pavement/concrete/diamond.cfm.

- **Smoothing Out Rehabilitation Roughness:** When partial-depth and full-depth repairs create differences in elevation between the repair and existing pavement, diamond grinding smoothes out the repair.

- **Wheelpath Rutting:** Diamond grinding removes wheelpath ruts caused by studded tires, improves drainage in wet weather by eliminating pooling of water, and reduces the possibility of hydroplaning.

- **Re-Establish Macrotexture:** Restores a polished surface to provide increased skid resistance, improves cornering friction numbers, and provides directional stability by tire tread-pavement-groove interlock.

- **Reduce Noise Level:** Re-textures worn and tined surfaces with a longitudinal texture and provides a quieter ride. Also removes the faults by leveling the surface, thus eliminating the thumping and slapping sound created by the faulted joints.

- **Removes Slab Warping and Curling:** Long joint spacing and stiff base support may result in curled slabs that are higher at joints than at mid-panel, while warped slabs are higher at the mid-panel. Diamond grinding smoothes out the curled and warped slabs.

- **Minor Cross Slope Changes:** Minor cross slope changes helps transverse drainage and reduces the potential for hydroplaning.

- **Pre-overlay Treatment:** Creates a smooth base surface for thin micro-surfacing overlays.

Table 10.7 Trigger Values for Diamond Grinding

From Table 1, *Trigger Values for Diamond Grinding, Concrete Pavement Rehabilitation – Guide for Diamond Grinding*, June 2001 (29)

Traffic Volumes[1]	**JPCP**			**JRCP**			**CRCP**		
	High	**Med**	**Low**	**High**	**Med**	**Low**	**High**	**Med**	**Low**
Faulting mm-average (inches average)	2.0 (0.08)	2.0 (0.08)	2.0 (0.08)	4.0 (0.16)	4.0 (0.16)	4.0 (0.16)	N.A.		
PSR	3.8	3.6	3.4	3.8	3.6	3.4	3.8	3.6	3.4
IRI m/km (in/mi)	1.0 (63)	1.2 (76)	1.4 (90)	1.0 (63)	1.2 (76)	1.4 (90)	1.0 (63)	1.2 (76)	1.4 (90)
Skid Resistance	Minimum Local Acceptable Levels								

Note: [1] Volumes: High ADT > 10,000; Medium 3,000 < ADT < 10,000; Low ADT < 3,000

Table 10.8 Limit Values for Diamond Grinding
From Table 2, *Limit Values for Diamond Grinding, Concrete Pavement Rehabilitation – Guide for Diamond Grinding*, June 2001 (29)

Traffic Volumes[1]	JPCP			JRCP			CRCP		
	High	**Med**	**Low**	**High**	**Med**	**Low**	**High**	**Med**	**Low**
Faulting mm-average (inches average)	9.0 (0.35)	12.0 (0.50)	15.0 (0.60)	9.0 (0.35)	12.0 (0.50)	15.0 (0.60)	N.A.		
PSR	3.0	2.5	2.0	3.0	2.5	2.0	3.0	2.5	2.0
IRI m/km (in/mi)	2.5 (160)	3.0 (190)	3.5 (222)	2.5 (160)	3.0 (190)	3.5 (222)	2.5 (160)	3.0 (190)	3.5 (222)
Skid Resistance	Minimum Local Acceptable Levels								
Note: [1] Volumes: High ADT > 10,000; Medium 3,000 < ADT < 10,000; Low ADT < 3,000									

For both diamond grinding and grooving, the most important design element is the spacing of the blades on the grinding head. Grinding is made by using 50 to 60 circular saw blades per foot on a shaft to produce the desired texture. Grooving has a different cutting pattern, it has a uniform spacing of 0.75 inches (19 mm) between grooves (see **Figure 10.3 Dimensions for Grinding and Grooving**). **Figure 10.4 Dimensional Grinding Texture for Hard and Soft Aggregate** shows the suggested dimensions for hard and soft aggregates from an earlier publication.

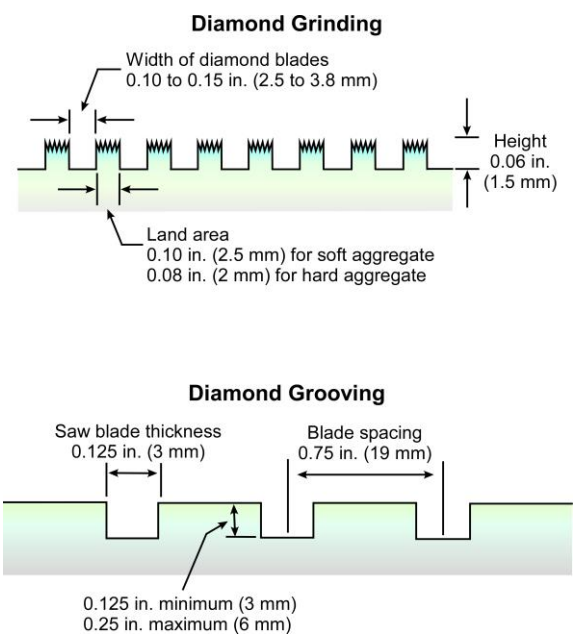
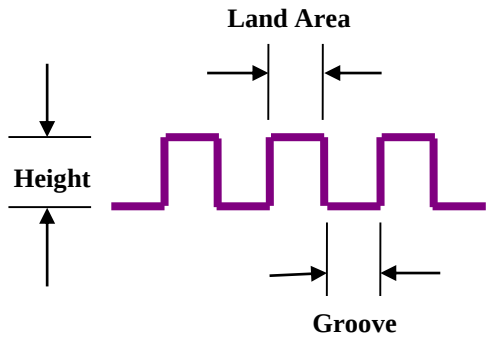


Figure 10.3 Dimensions for Grinding and Grooving
From Figure 7, *Concrete Pavement Rehabilitation and*

Preservation Treatment, November 2005 (36)



	Range of Values mm (in)	*Hard Aggregate mm (in)*	*Soft Aggregate mm (in)*
Grooves	1.0 – 4.0 (0.08-0.16)	2.5 – 4.0 (0.1 – 0.16)	2.5 – 4.0 (0.1 – 0.16)
Land Area	1.5 – 3.5 (0.06-0.14)	2.0 (0.08)	2.5 (0.1)
Height	1.5 (0.06)	1.5 (0.06)	1.5 (0.06)
No. Grooves per meter	164 – 194 (50-60)	174 – 194 (53-60)	164 – 177 (50-54)

Figure 10.4 Dimensional Grinding Texture for Hard and Soft Aggregate
From Figure 7, *Concrete Pavement Rehabilitation -Guide for Diamond Grinding*, June 2001 (29)

CDOT has published research reports on textures of new pavements. Refer to CDOT Final Report CDOT-DTD-R-2005-22 *PCCP Texturing Methods*, dated January 2005 (37) and Final Report CDOT-DTD-R-2006-9, *Implementation of Proven PCCP Practices in Colorado*, dated April 2006 (38).

10.6.2 Concrete Crack Sealing

Crack sealing is a commonly performed pavement maintenance activity that serves two primary purposes. One objective is to reduce the amount of moisture that can infiltrate a pavement structure, thereby reducing moisture-related distresses such as pumping. The second objective is to prevent the intrusion of incompressible materials into cracks so pressure-related distresses (such as spalling) are prevented (6).

Sealants may become ineffective anywhere from 1 to 4 years after placement. However, improvements in sealant materials, an increased recognition of the importance of a proper reservoir design, and an emphasis on effective crack/joint preparation procedures are expected to increase the expected life of sealant installations. At the same time, there is a persistent controversy over whether joint/crack sealing is needed at all (6). CDOT policy is to seal the cracks and not take the position that joint/crack sealing is not necessary.

What to crack seal:

- **Plastic Shrinkage and Working Cracks**: Cracks that remain tight usually do not require sealing. These cracks are typically very narrow (hairline), plastic shrinkage cracks and only penetrate to a partial depth. Once started, any crack may develop full depth through a slab. The crack may begin moving and functioning as a joint. Cracks which function as a joint are "working" cracks and are subject to nearly the same range of movement as transverse and longitudinal joints, therefore require sealing (24). If significant pavement integrity is being lost, then other remedial repairs are needed in conjunction with crack sealing.

- **Number of Cracks in a Slab:** Section 412.16 of CDOT's *Standard Specification for Road and Bridge Construction*, 2011 (40) book specifies when cracks penetrate partial depth they may be epoxy injected with the written approval of the Engineer. New construction and reconstruction that have full depth cracks which separate the slab into two or more parts will not be sealed, rather the slab will be removed and replaced. Rehabilitation treatments are generally designed with a shorter design life than new construction. Thus, when cracks are full depth and the slab is separated into three or more parts the slab should be removed and replaced or repaired. Slabs remaining in place that are cracked will require sealing, as well as, the repaired slabs if appropriate.

- **Crack Load Transfer Rating**: Refer to **Section 10.5.2.1 Non-destructive Testing** for guidance on LTE and when to remove and replace or repair the slab parts, or when to crack seal a good LTE crack.

Cracks are not straight and are therefore more difficult to shape and seal. Special crack saws are now available to help the operator follow crack wander. The saws have special blades with 7 to 8 inch diameters and are more flexible. The saws are supported by three wheels, the pivot wheel allows the saw to follow the crack. The desire is to obtain the same shape factor at the working cracks that is developed at the joints. Routers were used extensively in the past to create the seal reservoir. The trend now is to use special crack saws. It is believed better reservoir results and increased productivity are obtained with these special crack saws. **Figure 10.5 Photos of Crack Sealing**. Crack sealing requires all of the cleaning steps used in joint resealing, which includes the use of a backer rod and uniform sealant installation (24). This treatment procedure follows the concept of the joint details and sealants as specified in CDOT Standard Plan M-412-1 Concrete Pavement Joints, sheet 5 of 5. CDOT publication *Development of a Pavement* Preventive *Maintenance Program for the Colorado Department of Transportation* (22) follows the Standard Plan M-412-1 concept. This treatment using silicone sealant is recommended when the existing concrete surface is the new riding surface. A project special provision is required to outline the method of construction and payment. Section 408, Joint and Crack Sealant in the *Standard Specification for Road and Bridge Construction*, 2011 (40) book consists of work with hot poured joint and crack sealant. Section 408 does not require routing or sawing to develop a seal reservoir. This treatment is recommended when an overlay is required. When routed or sawed cracks with a backer rod is required, use Colorado Procedure CP 67-02 *Standard Method of Test for*

Determining Adhesion of Joint Sealant to Concrete Pavement as the test method for crack sealing adequacy.

Source: http://cimlinepmg.com and http://2.bp.blogspot.com

Figure 10.5 Photos of Crack Sealing

Estimating crack sealant is based on the severity level of cracking. These are estimated quantities only and were used in HMA crack sealing projects. The quantities shown are for information only and are only listed as an aid to the pavement designer for comparison purposes (see **Table 10.9 Hot Poured Crack Sealant Estimated Quantities**).

Table 10.9 Hot Poured Crack Sealant Estimated Quantities

Cracking Severity Level	Crack Sealant (tons) per lane mile
Heavy	2
Medium	1
Light	0.50
Very Light	0.25

10.6.3 Concrete Joint Resealing

Joint resealing is a commonly performed pavement maintenance activity that serves two primary purposes. One objective is to reduce the amount of moisture that can infiltrate a pavement structure, thereby reducing moisture-related distresses such as pumping. A second objective is to prevent the intrusion of incompressible materials into joints so pressure-related distresses (such as spalling) are prevented (6), refer to **Figure 10.6 Photos of Concrete Joint Resealing.**

Source: https://www.fhwa.dot.gov and http://www.pavementinteractive.org

Figure 10.6 Photos of Concrete Joint Resealing

Sealants may become ineffective anywhere from 1 to 4 years after placement. However, improvements in sealant materials, an increased recognition of the importance of a proper reservoir design, and an emphasis on effective crack/joint preparation procedures are expected to increase the expected life of sealant installations. At the same time, there is a persistent controversy over whether joint/crack sealing is needed at all (6). CDOT policy is to seal the joints/cracks and not take the position that joint/crack sealing is not necessary. The above objectives and effectiveness are the same as stated in the section of concrete crack sealing and are reiterated here for emphases.

What to joint seal:

- **Joint Load Transfer Rating**: Refer to **Section 10.5.2.1 Non-destructive Testing** for guidance on LTE and when to improve the LTE or when to reseal the joint.

- **Joint Spalling:** Studies show joint sealing and resealing reduces joint spalling by keeping out incompressibles even on short-panel pavements (24). Joint resealing is still recommended, even on pavements supported by permeable base layers.

- **Type of Joints:** Joint resealing is to be done on transverse and longitudinal joints. If the shoulder is of HMA, the interface joint should also be resealed.

Existing sealant distresses (24):

- **Adhesion Loss:** The loss of bond between the sealant material and the concrete joint face.

- **Cohesion Loss:** The loss of internal bond within the sealant material.

- **Oxidation/Hardening**: The degradation of the sealant as a result of natural aging, long-term exposure to oxygen, ozone, ultra-violet radiation, and/or the embedment of incompressibles into the sealant material.

Resealing is necessary when sealant distress affects the average sealant condition and results in significant water and incompressible infiltration. The basis of this determination is typically engineering judgment. ACPA has suggested guidelines to assist in the engineering judgment (see **Table 10.10 Sealant Severity Level**). The length of the deterioration defines the severity level of deterioration along each surveyed joint.

Table 10.10 Sealant Severity Level

Severity Level	Length in Percent
Low	< 25
Moderate	≥ 25 to < 50
High	≥ 50

Every joint need not be surveyed to determine the average sealant condition, rather a statistical sampling can be performed. Random and area sampling frequencies are provided for a statistical significant survey. The area of sampling represents the average condition of the joints, therefore the selected area should be representative of the total length of the roadway in question. Longitudinal joints should be sampled at the same time the transverse joints are surveyed (see **Table 10.11 Sealant Survey Sampling Frequency**).

Table 10.11 Sealant Survey Sampling Frequency

Joint Spacing (feet)	Measurement Interval	Number of Joints (per mile)	Area (percent)
< 12	Every 9th joint	+85	20
12 - 15	Every 7th joint	85 - 70	20
15 - 20	Every 5th joint	70 - 50	20
20 - 30	Every 4th joint	50 - 35	20
30 +	Every 4th joint	35	20

Joint resealing requires removing the old sealant, reshaping the reservoir, and cleaning the reservoir. Removal of the old sealant may be done manually, use of a small plow, cutting with a knife, or sawing method. Shaping the reservoir may be done using saw blades. Cleaning must remove dust, dirt, or visible traces of the old sealant. A backer rod is required, followed by a uniform sealant installation process (24). The joint resealing procedure follows the concept of the joint details and sealants as specified in CDOT's Standard Plan M-412-1 Concrete Pavement Joints, sheet 5 of 5. CDOT publication *Development of a Pavement* Preventive *Maintenance Program for the Colorado Department of Transportation* (22) follows the Standard Plan M-412-1 concept as well. The joint resealing treatment using silicone sealant is recommended when the

existing concrete surface is the new riding surface. A project special provision is required to outline the method of construction and payment for joint resealing. Section 408, Joint and Crack Sealant in CDOT's *Standard Specification for Road and Bridge Construction*, 2011 (40) book consists of work with hot poured joint and crack sealant. This treatment is recommended when an overlay is required. Use Colorado Procedure (CP) 67-02 Standard Method of Test for Determining Adhesion of Joint Sealant to Concrete Pavement as the test method for joint resealing adequacy. The frequency of the test is documented in the Frequency Guide Schedule for Minimum Material Sampling, Testing, and Inspection chapter of the current *CDOT Field Materials Manual*.

10.6.4 Partial Depth Repair

Partial-depth repair restores localized surface distress, such as spalling at joints and/or cracks in the upper one third to one half of a concrete pavement. Spalling is the breaking, cracking, chipping, or fraying of the slab edges that occurs within 2 inches of joints and cracks or their corners. Spalls that are smaller than 2 inches by 6 inches do not affect ride quality and do not need partial depth repair. Another localized surface distress may be severe scaling. A partial depth repair patch is usually very small (26) and should be done after slab stabilization, refer to **Figure 10.7 Photos of Partial Depth Concrete Repair**.

Source: http://www.roadsbridges.com and https://www.wbdg.org

Figure 10.7 Photos of Partial Depth Concrete Repair

When not to use partial depth repairs (26):

- When spalls extend more than 6 to 10 inches from the joint and are moderately severe. These types indicate more deterioration is likely taking place below the surface and full depth repair is more appropriate.

- A partial depth repair cannot correct a crack through the full thickness of the slab. Partial depth repair is not recommended when the deterioration is greater than $^1/_3$ to $^1/_2$ the slab depth.

- A partial depth repair is not appropriate for distresses such as D-Cracking. These distresses are not confined to the surface.

- Partial depth repairs should not be used when spalls are caused by corrosion of metal.

- Pavements with little remaining structural life are not good candidates for partial depth repairs.

Guidelines on repair sizes (26):

- A patch typically covers an area less than 1¼ square yards and is only 2 to 3 inches deep.
- Patch boundaries should be square or rectangular and are easily shaped by saw cutting.
- Use a minimum length of 12 inches
- Use a minimum width of 4 inches
- Extend the patch limits beyond the distress by 3 to 4 inches
- Do not patch if the spall is less than 6 inches long and 1½ inches wide
- If two patches will be less than 2 feet apart, combine them into one large patch.
- Repair the entire joint length if there are more than two spalls along a transverse joint.
- During removal of the concrete, the patch depth is determined.

The recommended concrete removal method is by sawing and chipping. First, saw cuts are made around the perimeter of the repair area. The vertical faces provide a sufficient depth to prevent spalling of the repair material. Saw cuts should be at least 1½ inches deep, preferably more. Then chipping can be done with light (less than 30 pounds) pneumatic hammers until sound and clean concrete is exposed. For best results, use 15 pound hammers or lighter. Spade bits are preferred, light hammers with gouge bits can damage sound concrete. However, if the depth of the patch exceeds about ½ of the slab thickness or exposes any dowel bars, switch to a full depth repair. Chipping without sawing the perimeter has shown that when a thin or feathered concrete edge is along the perimeter it is prone to spalling and debonding. All loose particles, oil (from pneumatic tools), dust, and joint sealant materials must be thoroughly removed to create a good bond. Patches that cross or abut a working joint/crack require a compressible insert. The primary function is to keep the adjacent concrete from bearing against the new patch. The compressible insert provides space for when the slabs thermally expand. This is the primary reason for failure of partial depth repairs. The compressible insert should extend about one inch below and three inches beyond each patch area. At no time should the patch material be permitted to flow into or across the joint or crack. Curing is very important because the partial depth repair's large surface-area-to-volume ratio makes them susceptible to rapid heat and moisture loss. After the patch material has hardened, the reservoir may need to be reformed by saw cutting and then resealed. Patch material may be found in CDOT's Approved Products List website under Concrete; Repair/Patching; Rapid Set, Horizontal. It is best to use the patch material manufacturer’s recommended bonding agent and follow their instructions. Depending on the specified patch material, opening to traffic may be specified by minimum strength or time after completing the patch repair. Care should be taken to ensure manufacturers water/cement ratios are achieved, as additional water will result in dramatically reduced strength and durability.

10.6.5 Full Depth Concrete Pavement Repair

Full depth repair or patching entails removing and replacing slab portions (full depth patching) or the complete slab to the bottom of the concrete (27). Sometimes the repair must go into the base and subbase layers. Full depth repairs improve pavement rideability and structural integrity. The most common distress for using full depth repair is joint deterioration, this includes any cracking, breaking or spalling of the slab edges. Below surface cracking and spalling requires full depth repairs. Any crack may develop full depth through a slab and may begin moving and functioning as a joint. Cracks which function as joints are "working" cracks. Working cracks are subject to nearly the same range of movement as transverse and longitudinal joints and therefore require sealing (24). However, once the cracks develop severe spalling, pumping or faulting it would be necessary to restore the pavement's structural integrity. Corner breaks and intersecting cracks in slabs are also candidates for full depth repairs. Refer to **Figure 10.1 CPR Sequencing** when other techniques are applied in conjunction with full depth repairs. The other techniques are cross stitching, retrofit dowel bars, and tied PCC shoulders or curb and gutter. Full depth repair should be done after partial depth repair and slab stabilization, refer to **Figure 10.8 Photos of Full Depth Concrete Repair**. If during a partial depth repair the distress is more extensive than originally thought then a full depth repair may be substituted.

Source: www.dhctexas.com and www.infrastructures.com

Figure 10.8 Photos of Full Depth Concrete Repair

When to use full depth repair (27):

- When spalls extend more than 6 to 10 inches from the joint and are moderately severe, they indicate more deterioration is likely taking place below the surface. Full depth repair is more appropriate for these types of distresses.

- When transverse joints or transverse cracks deteriorate with a moderate severity level of faulting equal to or greater than ¼ inches, other techniques and full depth repair is appropriate.

- When longitudinal joints or cracks deteriorate with a high severity level of faulting of ½ inches, or are wider than ¼ inches, then full depth repair and other techniques are to be used.

- New construction and reconstruction with full depth cracks that separate the slab into two or more parts will not be sealed, and the slab will be removed and replaced. Rehabilitation treatments are generally designed with a shorter design life than new construction, thus, when cracks are full depth and the slab is separated into three or more parts, the slab should be removed and replaced or repaired.

To size the repair, the pavement designer must know the mechanisms of the observed distresses. Generally the visible surface distresses show the minimum amount of repair area affected.

Guidelines on patch repair sizes (27):

- When the erosion action of pumping is present then the repair size should go beyond the limits of any base/subbase voids.

- The below slab deterioration may have to extend 3 feet beyond the visible distress in freeze-thaw climates.

- Parallel full lane width patching has been found to perform better than having interior corners of a partial width patch.

- If dowels (load transfer devices) are present, a minimum longitudinal patch length of 6 feet from the joint is acceptable to prevent the slab patch rocking and to provide room for equipment such as dowel hole drill rigs. If the other side of the transverse joint does not need repair with a minimum patch width, extend the patch beyond the joint about 12 to 15 inches to remove the existing dowels and install new dowels.

- If no dowels are present, a minimum longitudinal patch length of 8 to 10 feet may be used. The extra length will provide more load distributing stability on the base/subgrade. If the minimum width patch falls within 6 feet of a joint that does not need repair, extend the patch to the transverse joint.

Combining two smaller patches into one large patch can often reduce repair costs. When costs of the additional removal and patch material of a large patch is equivalent to the increased costs for additional sawing, sealing, drilling and grouting dowels, and/or chipping the patch thickness face of two smaller patches, a minimum cost effective distance has been calculated. When two patches will be closer than the distances as shown in **Table 10.12 Minimum Cost Effective Distance Between Two Patches**, it is probably more effective to combine them. Longitudinal patches

should be wide enough to remove the crack and any accompanying distress. One should locate the longitudinal joint beyond the wheel paths to avoid edge loading.

Table 10.12 Minimum Cost Effective Distance Between Two Patches
(Extracted from Table 2, Minimum Cost-Effective Distance Between Two Patches, *Guidelines for Full-Depth Repair*, Publication TB002.02P, American Concrete Pavement Association, 1995)

Slab Thickness (inches)	Patch Lane Width (feet)			
	9	**10**	**11**	**12**
8	15	13	12	11
9	13	12	11	10
10	12	11	10	9
11	11	10	9	8
12	10	9	8	8
15	8	8	7	6
Note: Table does not apply to longitudinal patches.				

Slab Removal: Full depth saw cuts are to be made on all four sides to create a smooth, straight, vertical face. The saw cuts may require a full depth cut through the existing joint reservoir. These cuts may have to sever the existing tie bars for longitudinal cuts and dowel bars in the transverse cuts. The smooth faces improve the accuracy of new tie and dowel bar placement. Carbide tooth wheel saws can cause micro cracks in the surrounding concrete. It is recommended to use diamond bladed wheel saws. The preferred method to remove the existing deteriorated slab is to lift it out. A number of means to lift the slab out by the contractor are is available, refer to **Figure 10.9 Photos of Concrete Slab Removal**. It may be necessary to provide additional saw cuts to facilitate the slab removal. Another method to remove the slabs after saw cutting is to break the deteriorated concrete into small fragments by drop hammers, hydraulic rams or jackhammers. The drawback to the break up method is it often damages the base/subbase and requires more patch preparation. Generally buffer cuts minimize the potential of damaging the surrounding concrete. These buffer cuts help absorb the energy and reduce spalling from the pavement breakers.

Source: http://epg.modot.org and http://kenco.com

Figure 10.9 Photos of Concrete Slab Removal

Patch Preparation: Sometimes it is necessary to remove and replace soft areas in the base/subbase. Good compaction is often difficult to achieve in the patch areas. It may be advantageous to fill the disturbed base/subbase areas with patching concrete. Flow-fill is ideal for utility excavations, Refer to **Figure 10.10 Photos of Compaction of Subbase and Flowfill Placement**. Flow-fill mix design properties are documented in Section 206.02 of CDOT's *Standard Specifications for Road and Bridge Construction* specifications (40).

Source: http://wikipave.org

Figure 10.10 Photos of Compaction of Subbase and Flowfill Placement

Install Load Transfer: Load transfer devices (dowel bars) should conform to the size and placement as specified on CDOT *Standard Plans, M & S Standards*, July 2012, M-412-1 Concrete Pavement Joints. Dowel bars slip into holes drilled into the transverse edge of the existing slabs. Dowel drill rigs with gangs of drills are preferred to control drill alignment and wandering. Either standard pneumatic or hydraulic percussion drills are acceptable. Both can drill a typical dowel

hole in about 30 seconds. Standard pneumatic drills may cause slightly more spalling on the existing slab face. Hole diameter is dependent on the type of anchoring material used. Cement type grouts require about $^{1}/_{4}$ inch larger hole and epoxy materials should be $^{1}/_{16}$ inch larger than the nominal dowel diameter. A grout retention disk made of nylon or plastic shall be used for all dowel bars placed in the existing pavement (see **Figure 10.4 Grout Retention Disk**). An anchoring material should be used and not a compression fit. Adhesive anchoring materials are listed on CDOT's website for approved products conforming to AASHTO M 235. After drilling the dowel holes, the holes should be cleaned with compressed air and anchoring material applied as per the manufacturer's directions. Do not use any method that pours or pushes the material into the hole. To provide a good bearing surface and bond, insert the dowel with a twisting motion of about one revolution to evenly distribute the material around the dowels circumference. Apply a bond breaker coating onto the other half of the dowel bar that is to be imbedded in the fresh concrete.

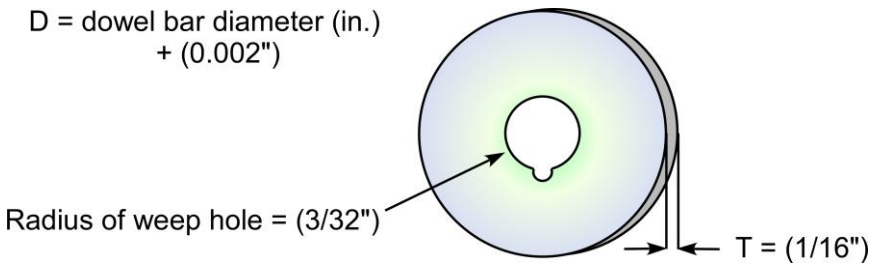


Figure 10.11 Grout Retention Disk

<u>Install Tie Bars:</u> Tie bar installation is similar to the load transfer devices. The size and placement is specified on CDOT's *Standard Plans, M & S Standards*, July 2012, M-412-1 Concrete Pavement Joints. Tie bars are placed in the longitudinal joint face of existing slabs, refer to **Figure 10.12 Photos of Tie Bar Installation During Concrete Repair**. Full slab replacements and repairs greater than 15 feet require tie bars where previous tie bars existed. Hand held drills are acceptable because alignment is not critical. Tie bar requirements and pull out testing is specified in Section 412.13 of CDOT's *Standard Specifications for Road and Bridge Construction* (40). For repairs less than 15 feet long a bond breaker board (¼ inch fiberboard) may be placed along the longitudinal face. For urban area repairs around maintenance access units (manholes) do not install tie bars, instead place a bond breaker board around the perimeter. Tie bars are used to tie the curb and gutter to the travel lanes. The curb and gutter acts as lateral support similar to widened and tied shoulders.

Source: http://www.minnich-mfg.com and http://www.dot.state.oh.us

Figure 10.12 Photos of Tie Bar Installation During Concrete Repair

Concrete Material: All concrete pavement full depth patch repairs should use a concrete material and not asphaltic materials (HMA). Asphalt patches heave and compress during warm weather when the existing concrete slabs expand. Generally, full depth repairs are done under traffic conditions and time is of the essence. Class E concrete is used for fast track pavements and is specified in Section 601.02 of CDOT's *Standard Specifications for Road and Bridge Construction* (40) or as revised.

Finishing: Strike-off, consolidation, floating, and final surface finish is specified in Section 412.12 of CDOT's *Standard Specifications for Road and Bridge Construction* (40). The surface texture should be similar to the surrounding pavement.

Curing: The type and placement method of membrane curing compounds and/or curing blankets for Class P and Class E concretes are specified in Section 412.14 of CDOT's *Standard Specifications for Road and Bridge Construction* (40).

Smoothness: If many closely spaced patches are required, consider specifying the pavement smoothness specification. The requirements are specified in Section 105.07 of CDOT's *Standard Specifications for Road and Bridge Construction* (40). If diamond grinding is required, the grinding should precede joint sealing.

Joint Sealing: The final step is to saw the joint sealant reservoirs of the transverse and longitudinal joints, clean, and apply the joint sealant, refer to **Section 10.6.3 Concrete Joint Resealing**).

Strength or Time Method on Opening to Traffic: CDOT utilizes strength requirements or maturity relationships to determine when to open the roadway repair to traffic. Both methods are

specified in Section 412.12 of CDOT's *Standard Specifications for Road and Bridge Construction* (40).

Precast Panels: CDOT has been utilizing precast panels for full depth repairs. Each panel is custom cast to fit the patch repair dimensions. The removal of the existing slab(s) is the same as above. The advantage of this method is being able to open the roadway to traffic in a shorter length of time than the above conventional method. This operation is well suited for nighttime work on busy daytime highways, see **Figure 10.13 Photos of Precast Concrete Panel Repair**. Refer to CDOT Final Report CDOT-DTD-R-2006-8 *Precast Concrete Paving Panels: The Colorado Department of Transportation Region 4 Experience*, 2000 to 2006, dated August 2006 (39). An example of a project's complete plans and specifications utilizing precast panels is available in Region 4, Project Number MTCE 04-061R, Region 4 FY06 I-25 MP 244 to MP 270 Concrete Slab Replacement, Subaccount Number M4061R.

Source: www.fhwa.dot.gov

Figure 10.13 Photos of Precast Concrete Panel Repair

10.6.6 Dowel Bar Retrofit

Dowel bar (load transfer devices) retrofit is a technique that increases the load transfer capability from one slab to the next through shear action (28). Slots are cut into the existing pavement at the transverse joints/cracks with slot cutting diamond saw (preferred method). Generally, three slots per wheel path are cut to a depth that allows the dowel bar to sit half way down in the slab with a half-inch of clearance to the bottom of the slot. Epoxy coated dowels must be a minimum of 14 inches long so at least six inches will extend on each side of the joint or crack. A non-metallic expansion cap is placed on one end of the dowel and the dowel is placed on non-metallic chairs for clearance. Horizontal and vertical alignments are critical. Refer to the Details Illustrating Dowel Placement Tolerances in CDOT's *Standard Plans, M & S Standards*, July 2012, M-412-1 Concrete Pavement Joints drawings. The slots are then backfilled using the same materials that would be used for partial depth repairs. The retrofit should last the remaining life of the pavement. Refer to **Figure 10.1 CPR Sequencing** when other techniques are applied in conjunction with dowel bar retrofit. The other techniques are cross stitching and tied PCC shoulders or curb and

gutter. Dowel bar retrofit should be done after full or partial depth repair, slab stabilization, and before diamond grinding.

When to use dowel bar retrofit (28):

- Generally load transfer devices should be installed at transverse joints and transverse working cracks with poor load transfer but otherwise little or no deterioration.

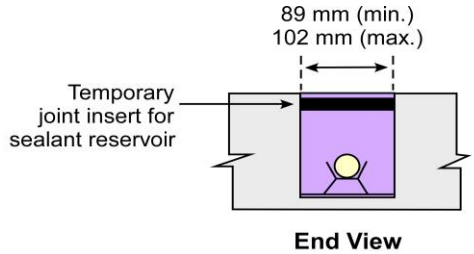
- Pavements exhibiting D-Cracking are not good candidates for load transfer restoration because the concrete in the vicinity of the joints and cracks is likely to be weakened, thus retrofit load transfer devices would not have sound concrete on which to bear. For D-Cracked pavements with concrete deterioration only in the vicinity of joints and cracks, full depth repair is more appropriate.

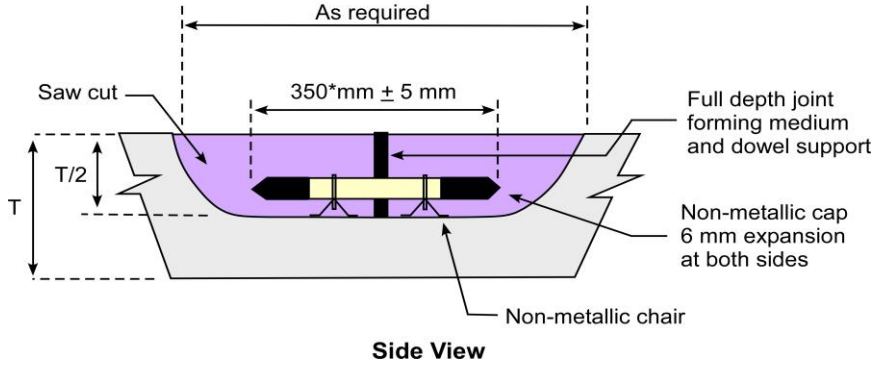
- Pavements with distress caused by Alkali-Silica Reaction (ASR) or Alkali-Carbonate Reaction (ACR) are not good candidates for load transfer restoration either.

The load transfer rating as related to the load transfer efficiency is shown in **Table 10.3 Load Transfer Efficiency Quality**.

Dowel bars are between 1 and 1½ inches in diameter. The larger diameter dowel bars are used in thicker pavements (>10 inches). Dowel bars are spaced 12 inches on center in sets of three or four per wheel path. Edge spacing from the longitudinal joint to the first dowel bar varies. The edge distance is dependent on whether tie bars are located at the longitudinal joint. Use 12 inches if tie bars are not present and 18 inches if they are.

Refer to **Figure 10.14 Typical Dowel Bar Retrofit Installation** for a conceptual drawing of the retrofit installation. See **Figure 10.15 Typical Dowel Bar Retrofit Sequencing of the**





Installation for the installation procedure and **Figure 10.16 Photos of Dowel Bar Retrofit Processes**. Apply a bond breaker coating (i.e. a light coating of grease or oil) to the dowel bars along their full length to facilitate joint movement. Bond breaker application is specified in Section 709.03 of CDOT's *Standard Specifications for Road and Bridge Construction* specifications (40).

Note: For pavements with poor support conditions slightly longer bars should be considered.

Figure 10.14 Typical Dowel Bar Retrofit Installation
Modified from Figure 4-9.3, *Dowel Bar Load Transfer Device Techniques for Pavement Rehabilitation*, 1998 (6)

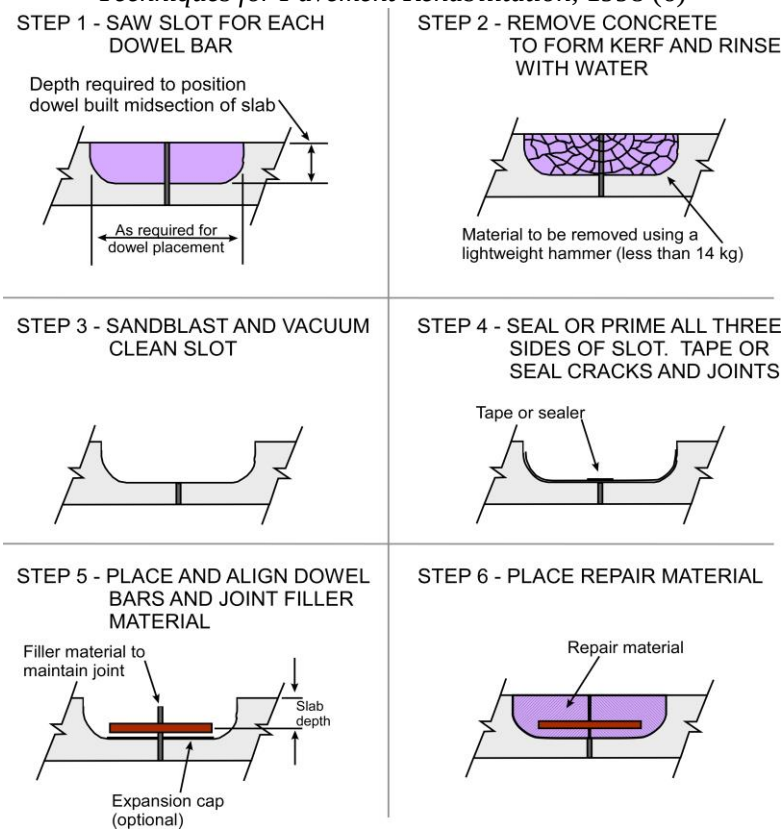
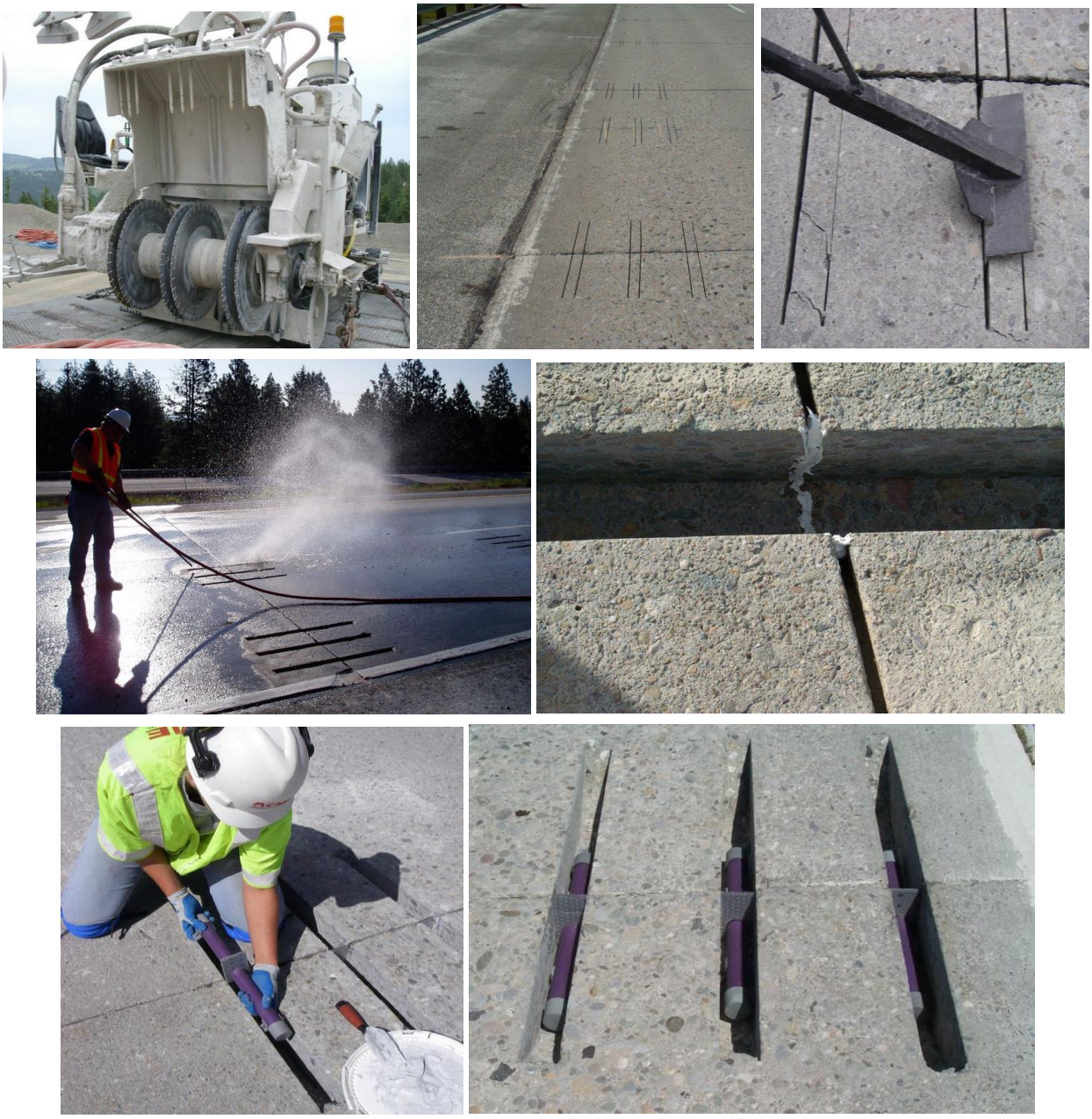


Figure 10.15 Typical Dowel Bar Retrofit Sequencing of the Installation
From Figure 4-9.7, *Construction Procedures for Retrofitted Dowel Bar Installation Techniques for Pavement Rehabilitation* 1998 (6)



Source: http://www.pavementinteractive.org

Figure 10.16 Photos of Dowel Bar Retrofit Processes

Photos of cutting equipment for dowel slots, three cut slots, breaker bar used to remove concrete from the slots, cleaning slots with water, caulking dowel bar slot, inserting dowel assemblies, and dowel bar assembly, respectively

10.6.7 Cross Stitching

Cross stitching longitudinal discontinuities, such as joints and cracks, is a repair technique to facilitate lateral load transfer of an otherwise unsupported free edge. The free edge is where the most critical loadings occur in the slab. This free edge condition may exist at a lane-to-lane or lane-to-shoulder joint. Working longitudinal cracks may also develop and create an unsupported

free edge condition. The cross stitching will help maintain the aggregate interlock in this situation if the crack doesn't widen too much. Cross stitching uses deformed tie bars inserted into holes drilled across a joint/crack at an angle. As observed on a CDOT project, if the angle is less than 35° from the horizontal the contractor has problems drilling the holes. The tie bars are placed and staggered with each other on each side of the joint/crack for the length of the discontinuity. The tie bars prevent joints and cracks from vertical and especially horizontal movement or widening. In new construction, tie bars are placed in plastic concrete to keep the joints tight in the hardened state and incompressibles and sheet flow of water into the base. The cross stitching repair technique for joints is to prevent further lane or shoulder separation and minimize the settlement of the slabs. Generally, this technique is used where the overall pavement condition, joints, and cracks are in good condition. If the joints and cracks are spalled too much, other rehabilitation repair methods may be appropriate.

Another similar technique is slot stitching which uses a modified dowel bar retrofit method. Slots are cut across the joints/cracks, deformed bars are placed in the slots, and the slots are backfill similar to dowel bar retrofit. If an overlay is not being placed after the repair, then cross stitching has a more pleasing appearance than slot stitching. If an overlay will be placed, either method is acceptable, see **Figure 10.17 Photos of Cross Stitching** and **Figure 10.18 Photos of Slot Stitching**.

Source: http://waterproofing-world.blogspot.com and http://www.concreteisbetter.com

Figure 10.17 Photos of Cross Stitching

Photos show drilling the hole, drilling and measuring a hole, inserting bars into holes (not fully inserted in photo), and finished cross stitching, respectively

Source: http://www.rekma.net

Figure 10.18 Photos of Slot Stitching

Both rehabilitation techniques are discussed in *Stitching Concrete Pavement Cracks and Joints*, Publication Special Report SR903P, ACPA and IGGA, 2001 (30). The publication illustrates the cross stitching bar dimensions, locations of drilled holes, and slot layouts. Be aware that if diamond grinding is performed after cross stitching, then the placement of the bars should be deep enough so they are not impacted by the grinding machining. The amount of anchor adhesive cover over the bars should be sufficient to protect the bars from the elements. Project plans should detail the appropriate stitching method.

Refer to **Figure 10.1 CPR Sequencing** when other techniques are applied in conjunction with the cross/slot stitching. Cross/slot stitching should be done after full/partial depth repair and slab stabilization and before diamond grinding and crack/joint sealing. Cross/slot stitching should last the remaining life of the pavement.

A special note is in order to understand the significance of tying the longitudinal joints and cracks. In the Section 3.4.3.8 Pavement Design Features, subheading Edge Support of the *Guide for Mechanistic-Empirical Design*, Final Report, NCHRP Project 1-37A (17) explains the structural effects of the edge support features are directly considered in the design process. The Design Guide evaluates the adequacy of the trial design through the prediction of key distresses and smoothness. The design process uses the Load Transfer Efficiency (LTE) equation for transverse joints related to shoulder type (HMA vs. PCC), tied PCC shoulders, or widen slabs. The distresses are percent slabs cracked and faulted joints versus time and are compared to the user defined allowable reliability limits. It appears that the Design Guide assumes all lane-to-lane joints are tied, but the designer has a choice on lane-to-shoulder jointing. LTE design input features are as follows:

- **Tied PCC Shoulder:** For tied concrete shoulders, the long-term LTE between the lane and shoulder must to be provided. The LTE is defined as the ratio of deflections of the unloaded versus loaded slabs. The higher the LTE, the greater the support provided by the shoulder to reduce critical responses of the mainline slabs. Typical long-term deflection LTE are:

  - 50 to 70 percent for monolithically constructed and tied PCC shoulder
  - 30 to 50 percent for separately constructed tied PCC shoulder

- **Untied Concrete Shoulders:** or other shoulder types do not provide significant support, therefore, a low LTE value should be used (i.e. 10 percent due to the support from extended base course).

- **Widened Slabs:** Improve JPCP performance by effectively moving the mean wheel path well away from the pavement edges where critical loadings occur. The design input for widened slab is the slab width which can range from 12 to 14 feet.

10.6.8 Slab Stabilization and Slabjacking

The purpose of slab stabilization (also called subsealing, undersealing, or pavement grouting) is to stabilize the pavement slab by the pressurized injection of a cement grout, pozzolan-cement grout, bituminous materials, or polyurethane mixture through holes drilled in the slab. The cement grout will, without raising the slab, fill the voids under it, displace water from the voids, and reduce the damaging pumping action caused by excessive pavement deflections. Slab stabilization should be accomplished as soon as significant loss of support is detected at slab corners. Symptoms of loss of support include increased deflections, transverse joint faulting, corner breaks, and the accumulation of fines in or near joints or cracks on traffic lanes or shoulders (31, 32).

When to use slab stabilization (33):

- Slab stabilization should be performed only at joints and working cracks where loss of support is known to exist. Symptoms of support loss include:

  - Increased deflections
  - Transverse joint faulting
  - Corner breaks
  - Accumulation of underlying fine materials in or near joints or cracks on the traffic lane or shoulder

- Slab stabilization should be performed before the voids become so large in area that they cause pavement failure. The only exception is when the pavement is to be overlaid with asphalt or concrete. In this case, slab stabilization is necessary, regardless of pavement condition. Slab stabilization is particularly important for asphalt overlays which have little resistance to shearing forces and reflect the underlying foundation problems.

Refer to **Figure 10.19 Typical Slab Stabilization Hole Layout** for a typical application and hole layout. Refer to **Figure 10.1 CPR Sequencing** when other techniques are applied in conjunction with slab stabilization. Slab stabilization should occur before partial depth repair and other repairs. The slab stabilization technique is detailed and discussed in *Slab Stabilization Guidelines for*

Concrete Pavements, Publication TB018P, ACPA, 1994 (32). The 20 page publication discusses void detection, materials, equipment, installation, post-testing, and opening to traffic.

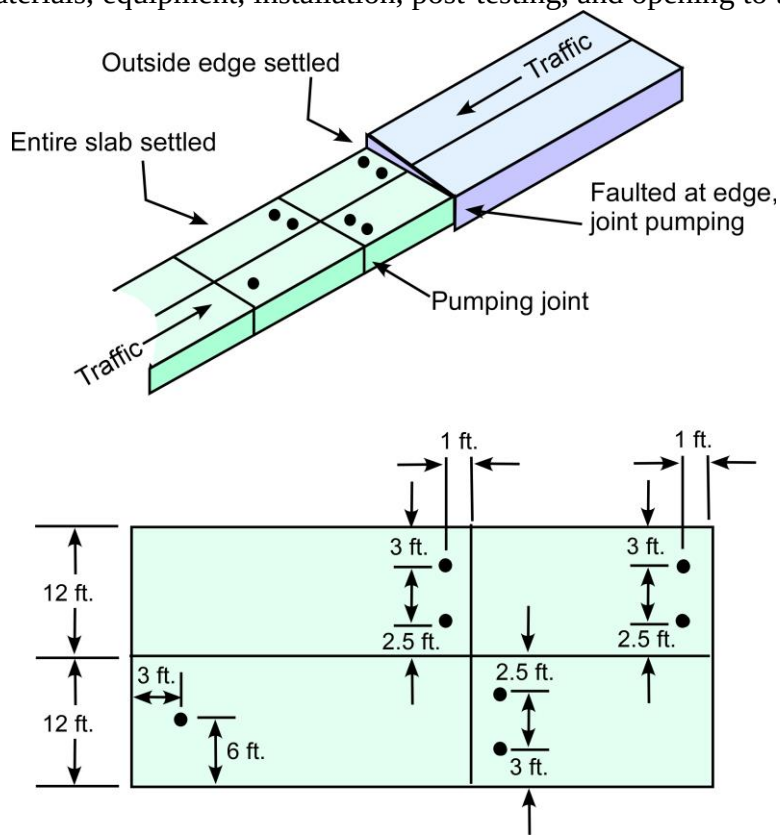


Figure 10.19 Typical Slab Stabilization Hole Layout
From Figure 4-7.6, *Location of Holes Depending on Defect to be Corrected*
Techniques for Pavement Rehabilitation, 1998 (6)

The purpose of slabjacking is to raise a slab in place permanently, prevent impact loading, correct faulty drainage, and prevent pumping at transverse joints by injection of a grout, pozzolan-cement grout or polyurethane mixture under the slab. The grout fills voids under the slab, thereby restoring uniform support. Slabjacking should be considered for any condition that causes nonuniform slab support, such as embankment settlement, settlement of approach slabs, settlement over culverts or utility cuts, voids under the pavements, differences in elevation of adjacent pavements, joints in concrete pavements that are moving or expelling water or soil fines, and pavement slabs that rock or teeter under traffic (31, 32). The performance of pavements subjected to slabjacking is somewhat dependent upon the origin of the corrected defect. For example, an embankment that slowly continues to settle will require periodic slabjacking. Periodic slabjacking may also be required on bridge approach slabs due to poor drainage design and improper embankment compaction (34). An example of a suggested slab jacking pumping sequence that provides a general guideline for obtaining satisfactory results is presented in manual *Techniques for Pavement Rehabilitation 1998* (6). It must be remembered that the sequence must be modified to meet the specific needs of a given project. Refer to **Figure 10.20 Typical Slab Raising in Slabjacking** and **Figure 10.21 Typical Slabjacking Hole Layout** for a typical application using a stringline

and hole layout. **Figure 10.22 Photos of Slab Jacking** shows examples of slabjacking on a roadway project(s).

An example of a project's complete plans and specifications utilizing slab jacking is available. The project was in Region 4, Project Number MTCE 04-061R, Region 4 FY06 I-25 MP 244 to MP 270 Concrete Slab Replacement, Subaccount Number M4061R. It used water blown formulation of high density polyurethane.

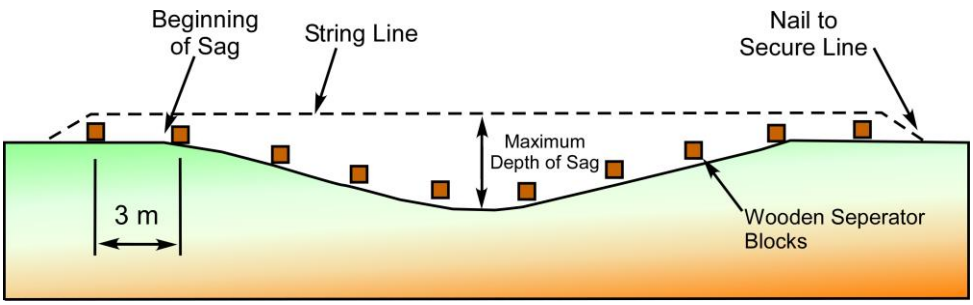


Figure 10.20 Typical Slab Raising in Slabjacking
From Figure 4-7.9, *String Line Method of Slab Jacking Techniques for Pavement Rehabilitation*, 1998 (6)

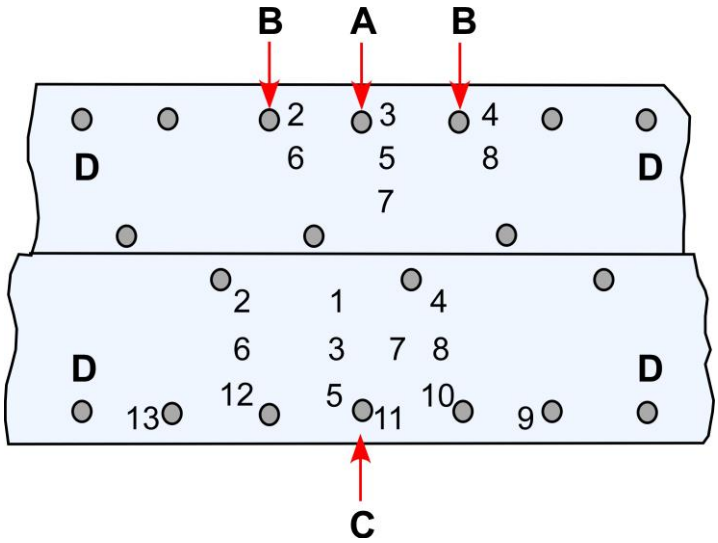


Figure 10.21 Typical Slabjacking Hole Layout
From Figure 4-7.7, *Location of Holes and the Order of Grout Pumping to Correct Settlement Techniques for Pavement Rehabilitation*, 1998 (6)

Source: http://www.roadsurgeons.com.au and http://www.tluckey.com

Figure 10.22 Photos of Slabjacking

Photos show drill pattern and injection, final patching of injection holes, close-up of injection, and close-up of injection material oozing from the pavement seams and reduced vertical differential of the slabs.

10.7 Selecting the Appropriate Pavement Rehabilitation Techniques

Table 10.13 Guidelines for PCC Treatment Selection is from a complete bound report titled *Development of a Pavement Preventive Maintenance Program for the Colorado Department of Transportation*, October 2004, by Larry Galehouse (35). **Note:** The Final Report CDOT-DTD-R-2004-17, August 2004 (22) is not as complete as the October 2004 bound report. The tabular guidelines only include CDOT's treatments as reported in the bound report. Refer also to **Table 10.13 Guidelines for PCC Treatment Selection** for additional treatments and repairs.

Table 10.13 Guidelines for PCC Treatment Selection
From Table Guidelines for Pavement Treatment Selection, *CDOT Preventive Maintenance Program Guidelines*, October 2004 (35)

Pavement Distresses	Parameter	Rigid Treatments					
		Diamond Grinding	Concrete Crack Resealing	Concrete Joint Resealing	Partial Depth Repair	Dowel Bar Retrofit	Full Depth Concrete Pavement Repair
Corner Breaks	Low	⊘	P	⊘	✓	⊘	✓
	Moderate	⊘	P	⊘	✓	⊘	✓
	High	✓	✓	⊘	✓	⊘	
Durability Cracking (“D” Cracking)	Low	⊘	✓	⊘	✓	⊘	✓
	Moderate	⊘	✓	⊘	✓	⊘	✓
	High	⊘	⊘	⊘	⊘	⊘	P
Longitudinal Cracking	Low	⊘	P	⊘	⊘	⊘	✓
	Moderate	✓	P	⊘	P	⊘	✓
	High	P	P	⊘	P	⊘	✓
Transverse Cracking	Low	⊘	P	⊘	✓	✓	✓
	Moderate	✓	P	⊘	P	✓	✓
	High	P	P	⊘	P	✓	✓
Joint Seal Damage	Low	⊘	⊘	✓	⊘	⊘	⊘
	Moderate	⊘	⊘	P	⊘	⊘	⊘
	High	⊘	⊘	P	⊘	⊘	⊘
Longitudinal Joint Spalling	Low	⊘	⊘	P	⊘	⊘	⊘
	Moderate	⊘	⊘	P	P	⊘	✓
	High	⊘	⊘	P	P	⊘	✓
Transverse Joint Spalling	Low	⊘	⊘	P	P	⊘	✓
	Moderate	⊘	⊘	P	P	⊘	✓
	High	⊘	⊘	P	P	⊘	P
Map Cracking and Scaling	Low	⊘	⊘	⊘	✓	⊘	✓
	Moderate	⊘	⊘	⊘	P	⊘	✓
	High	⊘	⊘	⊘	⊘	⊘	⊘
Polished Aggregate	Significant	P	⊘	⊘	⊘	⊘	⊘
Condition Factors							
Traffic AADT-T	< 400	✓	✓	✓	✓	✓	✓
	400 - 6,000	✓	✓	✓	✓	✓	✓
	> 6,000	✓	✓	✓	✓	✓	✓
Ride	Poor	P	⊘	⊘	✓	⊘	✓
Rural	Minimum Turning	✓	✓	✓	✓	✓	✓
Urban	Maximum Turning	✓	✓	✓	✓	✓	✓
Drainage	Poor	⊘	⊘	⊘	⊘	⊘	⊘

P – Preferred Treatment Option
✓ – Acceptable Treatment Option
⊘ – Not Recommended

References

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