

# Evaluation and Decision Strategies for the Routine Maintenance of Concrete Pavement

Youn su Jung,<sup>1</sup> Dan G. Zollinger,<sup>2</sup> and Thomas J. Freeman<sup>3</sup>

## ABSTRACT

This paper is to provide assistance for the pavement evaluation and selection of method of repair for routine maintenance relative to the extension of service life. The visual identification of various distress types is discussed, and evaluation techniques using nondestructive testing are introduced that are key to determining proper routine maintenance activities. According to the areas selected from the simplified checklist of visual distress types, ground penetration radar for detecting voids below the slab and the presence of trapped water, falling weight deflectometer for structural condition evaluation, and dynamic cone penetrometer for estimating the in situ strength of base and subgrade soils are used to provide current information on pavement condition for selection of needed repair methods using a simple, systematic decision process. During field investigations, poorly performing areas were identified and possible fixes determined as a means of guideline development. Key routine maintenances activities are categorized in five levels; performance monitoring, preservative, functional concrete pavement repair (CPR), structural CPR, and remove and replace. Each level of maintenance is arranged for the use of repair treatments in a consistent, logical framework to ensure their effective and timely use and employment. Since the decision process is focused on monitoring the early stages of deterioration, it should result in more cost effective maintenance programs.

## INTRODUCTION

Concrete pavement has performed well in urban area and Interstate highway settings for many years because of its inherent stiffness and capability for providing long service life. However, rapidly increasing heavy traffic accelerates pavement deterioration and increases the need for more maintenance than in the past. If proper maintenance is not employed at low levels of deterioration in a timely manner, acute degradation of pavement serviceability will occur and major repair costs may be incurred; therefore, preservative or minor concrete pavement repair (CPR) should be executed strategically at early stages of pavement deterioration to extend pavement life at lower cost.

Figure 1 shows the concept of pavement condition degradation with pavement age. Different stages of maintenance are noted as a means to address specific pavement conditions. Performance monitoring (prior to the pavement condition deteriorating to the level where structural CPR is needed) is extremely important since preservative

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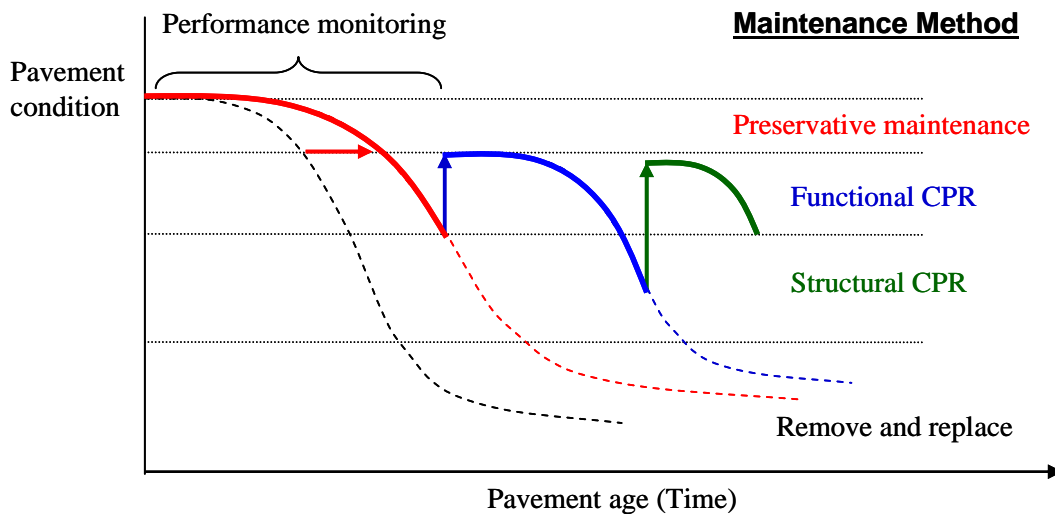
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maintenance is effective in slowing down the rate of degradation and extending pavement life.

Key routine maintenance activities are categorized into five levels:

- Performance monitoring.
- Preservative maintenance.
- Functional CPR.
- Structural CPR.
- Remove and replace.



**Figure 1. Pavement condition and maintenance stages.**

Table 1 outlines a strategic overview of routine maintenance activities in terms of pavement condition, assessment, and recommendations for repairs, and Table 2 summarizes the comparison of selected routine maintenance treatments in terms of repair cost, life extension, and working time. All cost and life extension numbers are averages and may vary from those listed in the table (1).

**Table 1**  
**Routine Maintenance Strategy Guidelines**

<b>Level of Routine Maintenance</b>	<b>Type of Activity</b>	<b>Type of Condition</b>	<b>Quantifiable Condition Factors</b>	<b>Repair Type and Notes</b>
Performance monitoring	Distress Survey	Pavement age; Portland cement concrete (PCC) >10 years; asphalt concrete overlay (ACOL) > 2 years	Pavement age	Monitor age for pavements more than 10 years old PCC or ACOL pavements more than 2 years old.
	Distress and FWD Survey	Pavement deflection data > 3 years	Recent FWD data	Conduct FWD testing based on visual survey results.
	FWD and GPR Survey; DCP Testing	Pumping with or without staining; missing joint seal material; edge drop-off; shoulder separation	Pumping; joint seals condition; surface dielectric constant (DC) of GPR; penetration ratio (PR) of DCP	Conduct selected FWD and DCP testing based on visual and GPR survey results. PR > 2-in./drop indicates soft subgrade materials, soil modulus < 6,000 lbf/in <sup>2</sup> . GPR is useful to detect subsurface moisture and voided areas. DC > 9 indicate presence of subsurface water.
Preservative	Crack sealing	Working cracks	Crack width > 0.03 in.	Crack sealing for working crack in continuously reinforced concrete (CRC) pavement.
	Reseal joints and cracks	Visible sealant damage on transverse and longitudinal joints and sealed cracks	Sealant age; visible sealant damage—cracking and debonding	Keep joint well width < 1 in.; widened joint wells may be noisy. Trapped subsurface water should be removed before re-sealing operations.
	Transverse grade re-profiling	Trapped surface water in depressed areas	Trapped surface water in depressed areas	Depressed area degrades riding quality and cause impact loading. Trapped surface water can cause safety problem.
	Retrofit edge drains	Standing water; Trapped surface water; Saturated base layer and subgrade	Presence of standing water; Slab staining; Surface DC; Subgrade strength	Edge drain is not recommended if the base is unstabilized, the base contains > 15 percent fines, or the pavement structure is undrainable.
Functional CPR	Partial-depth repair	Spalled joint/crack; deep delamination in CRC pavement	Density, width, and depth of spalling (>2 in.)	Spalling depth should be less than 1/3 the thickness of the slab and no reinforcing steel exposure; deep delamination with no other distress and steel is not corroded.
	Diamond grinding	Rough and noisy patches; faulting; bump	Density of patching; depth of faulting	Restore load transfer before grinding if structurally defected.
	Thin ACOL	Rough and noisy patches; faulting; hard aggregate; settlement	Density of patching; depth of faulting; aggregate type	Employ for hard aggregate pavements. Restore load transfer before the overlay if structurally defected. Use crack attenuating mix and good aggregate.
Structural CPR	Restore load transfer	High deflection; low load transfer efficiency (LTE); reflection crack in ACOL	Faulting; deflection; LTE; crack width and density of spalling in ACOL	Dowel bar retrofit. Check the deflection basin area and LTE of joint/crack. Employ RLT when 2- in.-wide spalled joint in ACOL > 20 percent.
	Cross stitching	Longitudinal crack; separated shoulder joint; low LTE	Width of the crack or shoulder joint separation; lane to shoulder LTE; pumping	Joint seal only when shoulder joint separation < 1/2 in. Cross stitching and joint seal when shoulder joint separation is between 0.5 in. and 1 in. Remove and replace shoulder when joint separation > 1 in. Slab undersealing where pumping and void detected.
	Slab undersealing	Water-filled voids at or under joints; settlement	Presence of voids; slab staining	GPR is recommended to locate holes in a way that will ensure good grout distribution and void filling.
Remove and replace	Full-depth repair	Corner break; shattered slabs; punchouts; broken cluster area	Severity and number of cracks; spalling; faulting	Soft subgrade materials may require removal. Full-depth repair for broken cluster should be extended to one-half of crack spacing between next cracks.

**Table 2**  
**Summary of Routine Maintenance Repairs (1)**

Repair Stage	Repair Type	Object	Limitations	Unit Repair Cost (\$/ft <sup>2</sup> )	Expected Life Extension	Typical Repair Work Time	Recommendations
Preservative	Reseal joints and cracks	Reduce infiltration of moisture and incompressive material. Reduce pumping and faulting.	Questionable for long-term effectiveness	\$0.75–\$1.25/ft (hot pour), \$1.00–\$2.00/ft (silicon)	3–8 years	5,000 ft/day (hot pour)	Select proper sealing material based on temperature and moisture conditions.
	Retrofit edge drains	Provide drainage of surface water. Reduce pumping, faulting, and other moisture damage.	May accelerate deterioration if not maintained well, not recommended if no base or base contains excessive amount of fines (>15 percent passing No. 200 sieve)	\$2.00–\$4.00/ft	Life of existing pavement	1 mi/day	Proper design, construction, and maintenance are essential.
Functional CPR	Partial-depth repair	Repair spall and distress without removing entire slab.	Full-depth repair is needed if the damage extends below 1/3 the slab thickness.	\$325–\$500/yd <sup>3</sup>	3–10 years	4–12 repairs/hr, curing time not included	Partial-depth repairs should restore the joint face and joint should be sealed properly.
	Diamond grinding	Provide smooth riding surface with good texture. Reduce noise.	Roughness will return if underlying causes not addressed.	\$1.80–\$7.80/yd <sup>2</sup>	8–12 years	2,500 yd <sup>2</sup> /day	Grinding should not be employed on pavements with material problems.
	Thin ACOL	Restore functional capacity such as rideability but increase structural capacity insignificantly.	Susceptible to reflection cracking	\$1.45–\$3.25/yd <sup>2</sup> -in	5–15 years	2–4 mi/day/lane	Existing structural distresses must be repaired to avoid premature failure.
Structural CPR	Restore load transfer	Restore load transfer to reduce faulting, pumping, and crack/joint deterioration.	Pavements exhibiting material related distresses such as D-cracking or reactive aggregate are not good for dowel bar retrofitting.	\$25–\$35/dowel	10–15 years	150 joints/day	Diamond grinding is needed to remove existing faulting. Slab stabilization is needed to address loss of support.
	Cross stitching	Hold longitudinal crack or joint together and prevent opening of crack or joint.	Applicable for fair condition and may not prevent secondary cracking or crack propagation.	\$9–\$10/bar	10–15 years	1,500 ft/day	Rehabilitation is required when secondary cracks develop.
	Slab undersealing	Restore uniform support by filling void and reduce corner deflection, pumping, and faulting.	Difficult to identify poorly supported area, restrictions on climatic condition, and can increase damage if slab is lifted.	\$1.30–\$1.40/yd <sup>2</sup>	3–6 years	100 slabs/day	Experienced contractor and proper inspection are essential.
Remove and replace	Full-depth repair	Remove all deterioration in the distress area. Restore load transfer at joints and cracks.	Additional joints introduced by full-depth repairs may add to the pavement roughness.	\$90–\$100/yd <sup>2</sup>	5–15 years	4 to 6 repairs/hr, curing time not included	If deterioration is widespread over the entire project length, an overlay or reconstruction may be more cost effective.

## PAVEMENT CONDITION EVALUATION TECHNIQUES

Pavement condition evaluation is the key to determining proper routine maintenance activities. It is needed to validate the extent of distress-related damage, quality of drainage, and relative base/subgrade layer strength. Pavement distress condition is considered relative to functional and structural performance in the decision process. The following evaluation techniques are recommended for strategic routine maintenance decisions (2): visual survey, ground penetration radar (GPR), falling weight deflectometer (FWD), and dynamic cone penetrometer (DCP).

### Visual Survey

Selected project sites can be scanned to identify distressed areas to select locations for further inspection. There are many well-organized visual pavement condition survey protocols used by highway agencies to monitor and record pavement distresses. However, current survey protocols often require a level of inspection detail greater than what is normally needed for a routine maintenance survey; therefore, a simplified survey list is provided in Table 3 to assist in the collection of routine maintenance information to meet critical decision criteria.

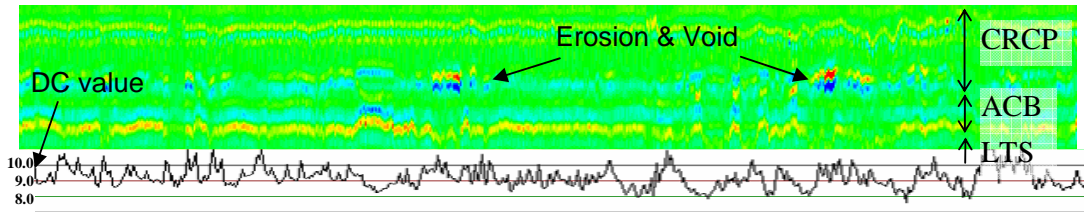
**Table 3**  
**Pavement Condition Survey Form for Routine Maintenance**

No.	Check list	Further Inspection (Circle all that apply)
1	Pavement age (yr.) and aggregate type (hard or soft)	
2	Year of recent pavement distress survey (yr.)	
3	Year of recent pavement deflection survey (yr.)	
4	Joint sealant age (yr.)	
5	Sealant damage of transverse joint or crack (%)	
6	Sealant damage of longitudinal joint or crack (%)	
7	Sealant damage of sealed crack (%)	
8	Trapped surface water in depressed area	
9	Standing water or slab staining	GPR, DCP
10	Pumping with or without staining	GPR, DCP
11	Bump (stable or unstable, depth, in.)	GPR, DCP
12	Settlement (stable or unstable, depth, in.)	GPR, DCP
13	Joint spall (width, depth, % of joint spall > 2 in.)	FWD
14	Crack spall (width, depth, % of crack spall > 2 in.)	FWD
15	Deep spall (depth, in.)	FWD, GPR, DCP
16	Patching (number/mi)	FWD, GPR, DCP
17	Faulting (depth, in.)	FWD, GPR, DCP
18	Transverse crack (width, number/slab)	FWD, GPR, DCP
19	Longitudinal crack (width, number/slab)	FWD, GPR, DCP
20	Shoulder separation (width, in.)	FWD, GPR, DCP
21	Corner break (spall width, fault depth, % of slab)	FWD, GPR, DCP
22	Deep delamination (depth, in.)	Steel corrosion
23	Punchout (spall width, fault depth, % of slab)	FWD, GPR, DCP
24	Reflection crack in ACOL (spall width, fault depth, number/mile)	FWD, GPR, DCP

FWD = falling-weight deflectometer; GRP = ground-penetrating radar; DCP = dynamic cone penetrometer

## GPR Testing

GPR testing is a fast and effective test method to determine base conditions such as voids and the presence of water trapped in and between underlying pavement layers. Moreover, GPR survey can be used for PCC pavement layer thickness estimation, layer interface condition assessment, and dowel misalignment evaluation. In pumping areas, dowel locations, voids, and subsurface water under the slab could be detected using an air-coupled system vehicle or ground coupled, as shown in Figure 2. Although no standard procedures have been documented for detection of voids under the concrete slab using GPR, image analysis or dielectric constant (DC) analysis could be used to detect void and subsurface moisture for the routine maintenance purpose.



**Figure 2. Example of the GPR testing image.**

### *Image Analysis*

Detection of voids under the concrete slabs may require determination by trained personnel, but generally the following can help to analyze GPR images. In the color image, blue strips represent voids and red strips represent moisture, while in the gray scale image, black strips represent voids and white strips represent moisture. Intervallic blue dots (black in the gray scale image) indicate dowel locations.

### *DC Analysis*

The DC value of GPR is shown as blue line below the layer image in Figure 2. It can be used to detect subsurface moisture. DC values range from 1 (air) to 81 (distilled water), and generally DC of aggregate base is around 6 to 7. In the pavement system, DC is an efficient indicator of the presence of subsurface water if the DC of base or subgrade is higher than 9.

## FWD Testing

Load transfer efficiency (LTE) and deflection testing can be used as simple means of determining routine maintenance needs. Deflection test using FWD can evaluate the structural condition of pavement such as layer stiffness, LTE, and loss of support below the slab. Therefore, the areas selected from the checklist of visual survey items needs to be evaluated relative to structural capacity for such stiffening measures as load transfer retrofitting. Highly spalled or faulted joints and cracks should be tested to evaluate LTE and continuity of support. Moreover, deflection and basin area determinations at the center of slab should be carried out occasionally as a reference of good support conditions.

### *LTE Testing*

LTE testing is recommended to check the structural capacity of joints or cracks. Deflections on loaded and unloaded side of a joint or crack are measured, and used to determine the LTE as follows:

$$\text{LTE} = \frac{d_U}{d_L} \times 100 \quad (1)$$

Where, LTE = Load transfer effectiveness, percent

$d_U$  = Deflection on the unloaded side of the joint or crack, mils

$d_L$  = Deflection at the loaded side of the joint or crack, mils

It is recommended that testing be completed when the ambient air temperature is above 80 °F (27 °C), and below 60 °F (16 °C). Above 80 °F (27 °C), the LTE is generally over 90 percent for temperature expanded concrete pavement; load transfer retrofitting could be considered if it is determined that the joint or crack LTE is lower than 70 percent a substantial amount of time which can be more easily detected at temperatures below 60 °F (16 °C).

### *Deflection Testing*

Deflection basin area is a simple means to detect possible deteriorated areas. The locations which show low deflection basin areas could be interpreted as problematic as the same meaning of a low LTE. The typical range of basin area for rigid pavements is between 24 and 33 in., and load transfer retrofitting may be recommended when basin area is lower than 25 in. Deflection basin area can be calculated as follows (3):

$$\text{Basin area} = \frac{6(d_0 + 2d_1 + 2d_2 + d_3)}{d_0} \quad (2)$$

Where, Basin area = FWD deflection parameter, in.

$d_0, d_2, d_3, d_4$  = Deflection at 0, 1, 2, and 3 ft from the loading position, mils

### **DCP Testing**

DCP testing indicates the in situ strength of base and subgrade soils. The test provides a correlation between the strength of the soil and its resistance to penetration. It is a fast and easy test method and can be used to make a rough estimate the elastic modulus of each layer and sublayer for evaluation purposes. Conduct DCP testing on selected areas where visual and GPR surveys indicate the evidence of pumping or subsurface water. Equation 3 shows the relationship between the penetration ratio and elastic modulus of soils (4).

$$\begin{aligned} E &= 2550 \times \text{CBR}^{0.64} \\ \text{CBR} &= 292 / \text{PR}^{1.12} \end{aligned} \quad (3)$$

Where, E = Elastic modulus, lbf/in<sup>2</sup>

CBR = California bearing ratio

PR = Penetration ratio, mm/blow

A plot of the DCP data is useful to find the slope of the linear trendline. Typical flexible base modulus is 60,000 to 80,000 lbf/in<sup>2</sup> (413.69 to 551.58 MPa ) or PR is 1 to 2 mm/blow (0.05 to 0.1 in./blow). The PR value higher than 2 in./blow indicates very soft subgrade materials which implies the soil modulus < 6,000 lbf/in<sup>2</sup>(41.37 MPa).

## REPAIR DECISION FLOWCHART FOR ROUTINE MAINTENANCE

Based on the pavement condition evaluation, the following decision flowchart provides guidance for effective routine maintenance. The decision flowchart is self-explanatory and provides guidance for effective routine maintenance.

### Performance Monitoring

Performance monitoring is basic and is the most important step to achieve effective routine maintenance for extending pavement service life. General pavement information needs to be assembled. Pavement age, aggregate type, traffic conditions, weather, and usual construction issues help decision makers understand the current pavement distress. In Figure 3, if pavement age is more than 10 years for PCC or 2 years for AC overlaid pavement, the pavement condition survey is recommended to be updated. Based on visual survey results, distressed areas may need further testing using pavement condition evaluation techniques such as FWD, GPR, and DCP to evaluate the structural condition. When pumping evidence is monitored, GPR surveying is especially useful to detect subsurface moisture and voided areas. FWD and DCP testing is useful to score the pavement's structural condition for selecting proper maintenance repairs.

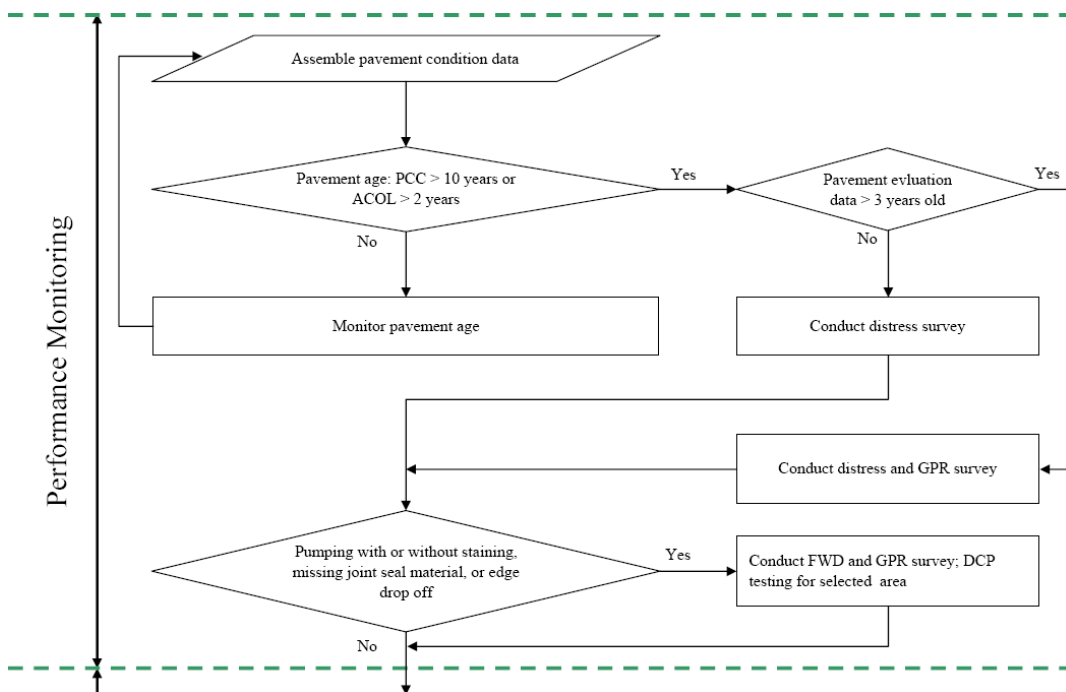


Figure 3. Routine Maintenance Decision Flowchart – Performance Monitoring.

### Preservative Maintenance

Preservative maintenance is focused on providing minor treatment to minimize potential moisture damage, which is one of the most significant causes of deterioration of a concrete pavement system. The condition of the joint and crack seals and overall pavement drainage are key factors to prevent moisture damage due to water infiltration, and decision making is guided as in Figure 4.

## Reseal Joints and Cracks

Crack and joint sealing condition is the first thing to check in a visual survey. Crack sealing is recommended when crack width is wider than 0.03 in. (0.8 mm) or reflection cracking occurs on asphalt concrete overlay (ACOL) to prevent infiltration of water and incompressible materials. Resealing joints and cracks is recommended when sealants are damaged more than 20 percent along the joint or crack to reduce infiltration of moisture and incompressible material over time.

This treatment can reduce pumping and faulting potential. Selection of proper sealing material should be based on temperature and moisture conditions; trapped subsurface water should be removed before re-sealing operations. Moreover, keep the joint well width smaller than 1 in. (25 mm) since widened joint wells may be noisy and degrade rideability (5).

## Transverse grade re-profiling

If depressed or uneven areas are present along the longitudinal pavement edge, transverse grade re-profiling should be considered to enhance the functional condition or reduce blocked drainage of the surface water. Standing surface water could be a source of infiltration that may eventually lead to further settlement, and depressed areas induce degrading of riding quality, impact loading, and create safety issues.

## Retrofit Edge Drains

If geometry and circumstances facilitate drainage, retrofitting the edge drain is recommended when water under the slab is identified or when the DC value is higher than 9 and the subgrade PR is smaller than 2 in. (51 mm) per blow. However, edge drainage is not recommended if the base is unstabilized and contains more than 15 percent fines (passing No. 200 sieve) or if the pavement structure is undrainable. Proper design, construction, and maintenance are essential because edge drainage may accelerate deterioration of the base and subgrade if not well-maintained (6).

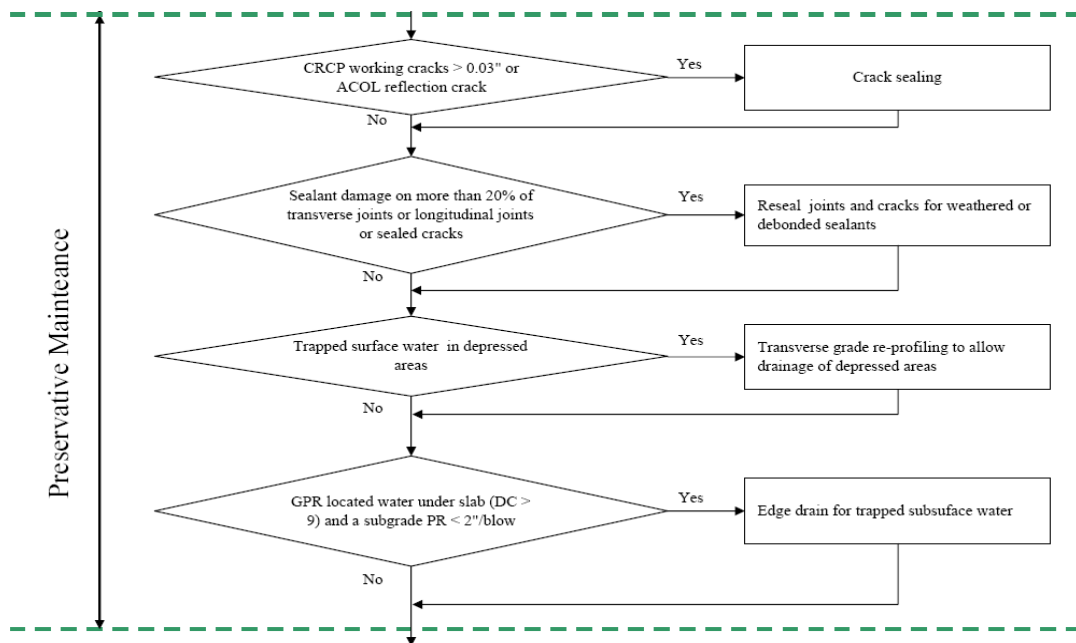


Figure 4. Routine Maintenance Decision Flowchart – Preservative Maintenance.

## Partial-Depth Repair

The objective of partial-depth repair is to repair spall and distress without removing the entire slab. When spalls 2 in. (51 mm) wide are more than 10 percent of the crack or joint, partial-depth repair should be employed using proper patching material for PCC pavement and AC-overlaid PCC pavement. The depth of spall should be less than one-third the thickness of the slab, and the pavement should have no reinforcing steel exposure. Partial-depth repair also can be applied for deep delamination up to half of the CRC pavement thickness if the remaining slab is strong with no other distress and the steel is not corroded. Partial-depth repairs should restore the joint face, and the joint should be sealed properly (6, 7).

## Diamond Grinding

Rough and noisy patches, faulting, and bumps can be eliminated cost-effectively using diamond grinding. When patches are more than 10 per mile and faulting is more than 0.25 in. (6 mm), diamond grinding provides a smooth riding surface with good texture and reduces noise. When stabilized bumps or settled areas are present, diamond grinding can also be effective. However, roughness will return if underlying causes are not addressed; therefore, restoration of load transfer before grinding is recommended. Grinding should not be used for pavements with material problems or if the aggregate type is too hard to grind economically (6).

## Thin ACOL

A thin AC overlay with a paving fabric can be used to restore the functional capacity of a pavement and improve rideability. Employing a thin AC overlay for hard aggregate pavements may be a good alternative to diamond grinding. Existing structural distresses must be repaired and restored before the overlay is placed. This is important particularly if the pavement is structurally deficient to avoid premature failure. Use of a crack-attenuating mix with good aggregate is recommended to minimize reflection cracking.

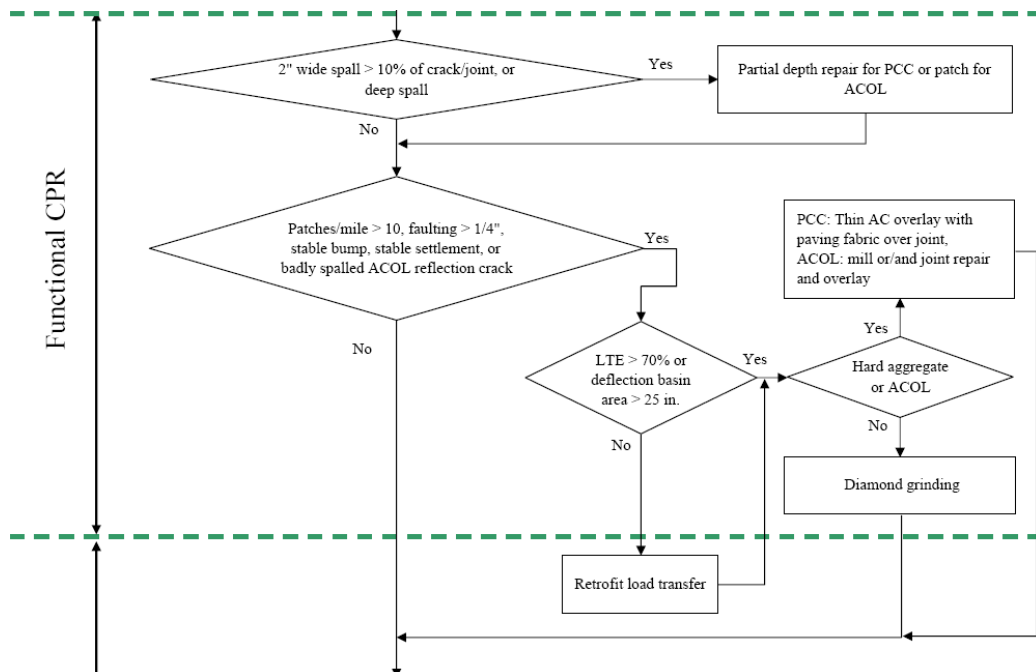


Figure 5. Routine Maintenance Decision Flowchart – Functional CPR.

## **Structural CPR**

The objective of structural CPR is to eliminate the cause of structural distresses and retrofit structural joint capacity to extend pavement service life. Structural CPR at the optimal time should increase pavement life. Generally, structural CPR needs functional CPR at the same time to achieve adequate results. Figure 6 shows guideline for structural CPR.

## **Retrofit Load Transfer**

Retrofit load transfer should be considered when faulting, high deflections, low LTE of the joint/crack, or reflection cracks in the ACOI are detected. When LTE is lower than 70 percent, the basin area is less than 25 in. (635 mm), and joints are spalled more than 2 in. (51 mm) wide over more than 20 percent, then restoration of load transfer is recommended to address faulting, pumping, and crack or joint deterioration. Pavements exhibiting material-related distresses such as D-cracking or reactive aggregate are not candidates for retrofit load transfer. Before and after restoring load transfer, slab stabilization may be needed to address loss of support and diamond grinding needed to remove the existing faulting (6).

## **Cross Stitching**

Cross stitching holds the longitudinal crack or joint together and prevents opening and closing over time. Cross stitching should be considered when longitudinal cracks or shoulder joints separate wider than 0.5 in. (13 mm). In the case of shoulder joint separation, cross stitching and joint sealing are recommended when shoulder joint separation is between 0.5 in. (13 mm) and 1 in. (25 mm) wide. For joint sealing to be effective, the shoulder joint separation should remain smaller than 0.5 in. (13 mm) (8).

## **Slab Undersealing**

Slab undersealing is used to restore uniform support by filling voids and reducing corner deflection, pumping, and faulting. Experienced contractors and proper inspection are essential to properly identify and underseal damaged areas. Therefore, GPR is recommended to locate holes in a way that will ensure good grout distribution and void filling. Slab undersealing is recommended when GPR-indicated voided cracks or joints are more than 20 percent of the inspected section or where unstable bumps or unstable settlement is present (6).

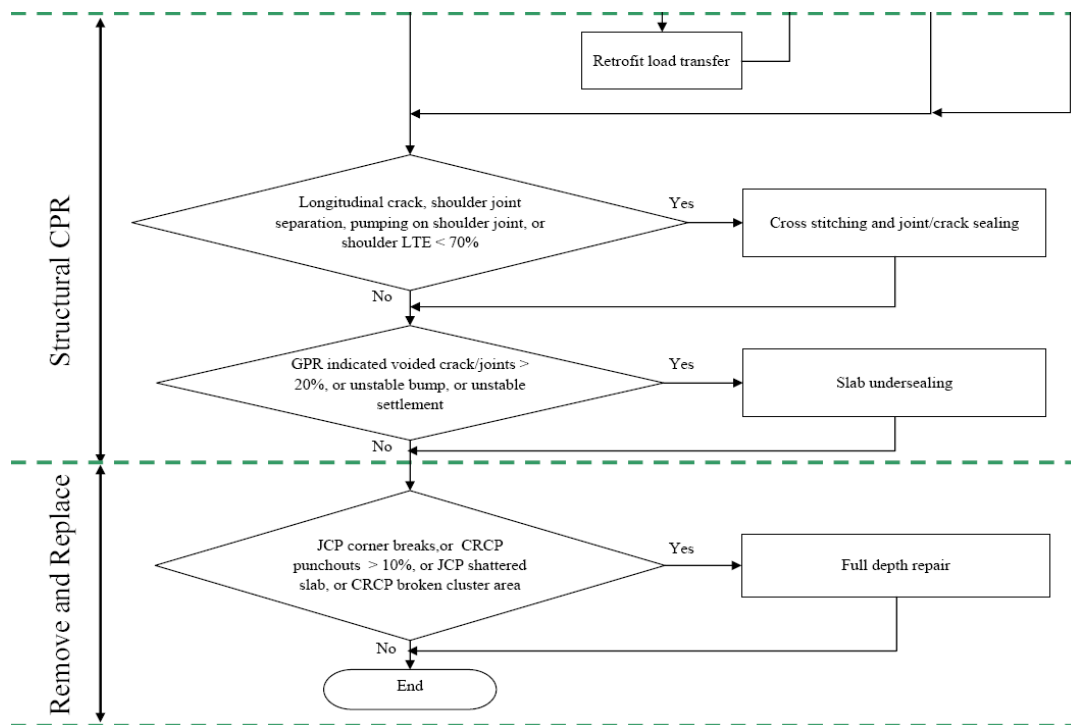
## **Remove and Replace**

Remove and replace is the most expensive repair solution and extreme stage of repair of PCC pavement and is used when other maintenance techniques are not appropriate. Since full-depth repair can be time-consuming, precast concrete panels are recommended to reduce traffic congestion costs. Figure 6 shows guidelines for remove and replace.

## **Full-Depth Repair**

Full-depth repair removes all deterioration in the distress area and restores load transfer at joints and cracks. This repair method should be considered when corner breaks are more than 10 percent or the slab is shattered in JC pavement and when punchouts are more than 10 percent in CRC pavement. Soft subgrade materials may require removal and full-depth repair, particularly in areas where cluster cracking is present. Grinding may be used to

improve roughness created by placement of the FDR. If the deterioration is widespread over the entire project length, an overlay or reconstruction may be more cost-effective (6).



**Figure 6. Routine Maintenance Decision Flowchart – Structural CPR and Replace.**

### EXAMPLE FIELD EVALUATION

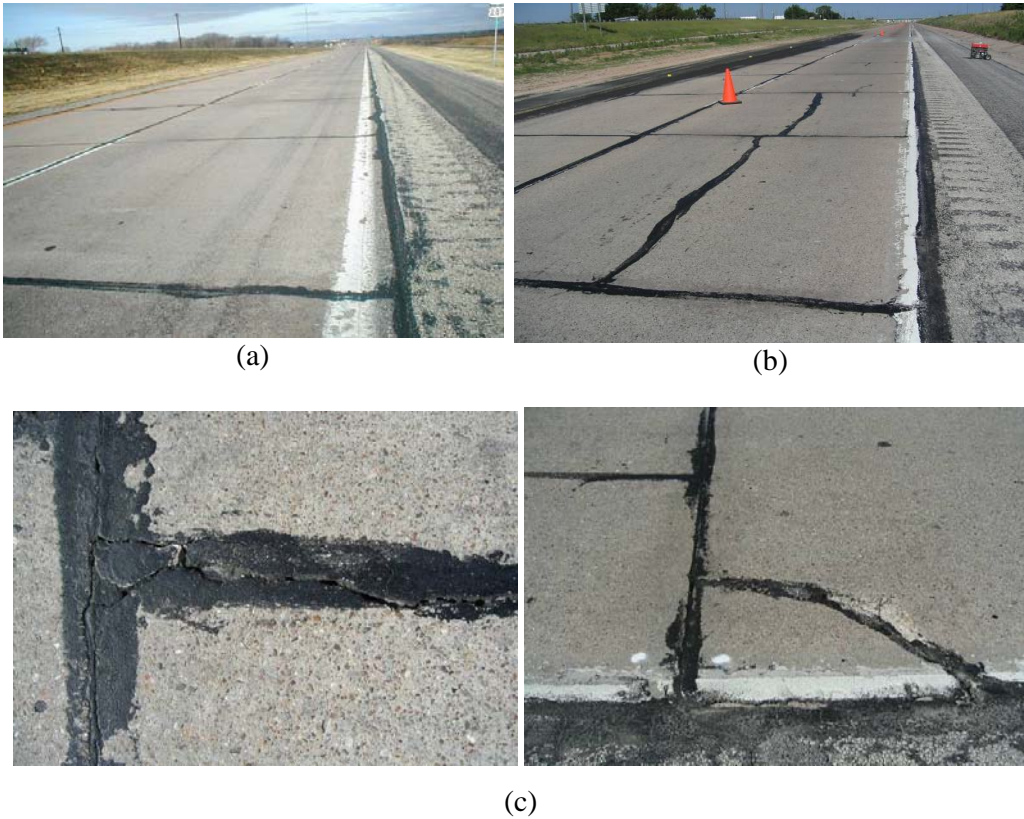
US-287 northbound JC pavement sections near Vernon, Texas, were sampled, and Figure 7 shows good and poor condition sections based on visual distress survey results. Both sections, located 3 mi (4.8 km) apart, consist of 10-in. (254-mm), 15 ft (4.6-m), jointed concrete pavement. The significant difference between them is that the good condition section has better joint sealing than the poor condition section. The crack and joint sealing in the poor condition section is severely damaged (or improperly resealed) in many areas, and the shoulder joint is wide, as shown in Figure 7.

FWD test results in Figure 8-a show no significant difference in LTE and BA between good and poor condition areas (visually decided). Both good and poor sections have lower than 70 percent of LTE with high standard deviation and an apparent restoration of load transfer to prevent further deterioration. As mentioned previously, a good joint sealing condition may result in relatively good performance even though the level of LTE is low.

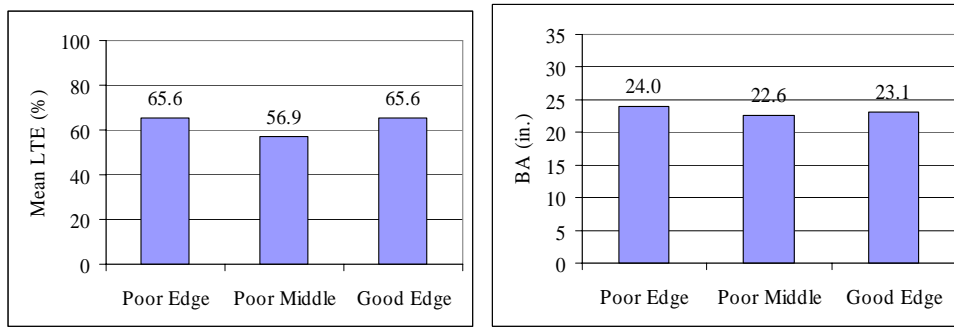
DCP test results shown in Figure 8-b indicate a weak subbase condition for both sections in the Vernon area. It is noted, however, that the modulus of the good performing area is lower than the modulus in the poorly performing area. A possible reason is that the good condition section has experienced less erosion and lower pumping damage due to good joint sealing but the poor condition section has experienced more damaged due to surface water infiltration through opened cracks and joints.

Figure 8-c shows the core hole over a longitudinal crack location in the poor condition section. A horizontal crack at mid-depth and erosion in the base layer are noted. Eroded

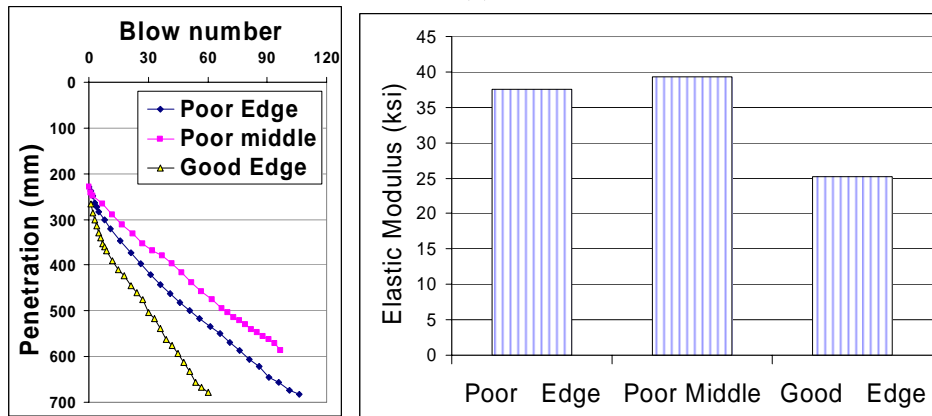
finer materials were detected, and the erosion depth was about 1 to 1.5 in. (25 to 28 mm) in the poor condition section. Since the aggregate type of the poor condition section is river gravel, the crack/joint opening with a higher curling effect may have contributed to pumping and erosion damage to the subbase material. The good condition section showed a smaller depth of erosion. As feasible maintenance means, joint resealing, slab undersealing, and edge drainage may be needed to fill voids under the slab and reduce further moisture damage to the base and subgrade.



**Figure 7. Test sections in Vernon: (a) good condition, (b) poor condition, (c) crack and deteriorated joint sealing in poor condition section.**



(a)



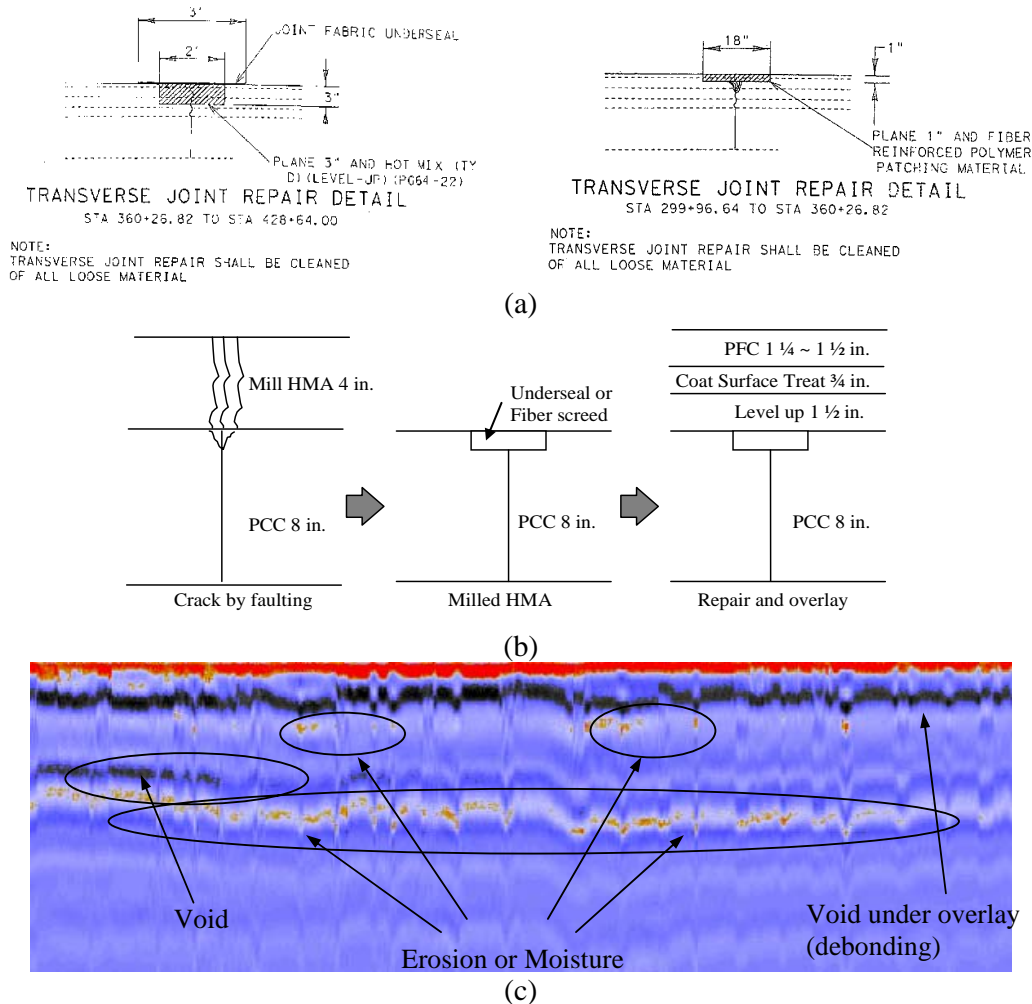
(b)



(c)

**Figure 8. US-287 sample section: (a) load transfer efficiency and basin area, (b) elastic modulus of subbase, (c) coring in poor condition section.**

AC-overlaid JC pavement on US-59 in Legget, Texas, was tested using rolling dynamic deflectometer (RDD) and GPR. Interesting repairs were under taken during rehabilitation work carried out in 2002 consisting of the replacement of an existing AC overlay where the joints in the JC pavement were repaired using two different materials: fiber-reinforced polymer and HMA with a fabric underseal, as shown in Figure 9 (9). The pavement surface condition was visually good, and there was virtually no distress over the repair section after 5 years of service. However, the first section showed an LTE of 65 percent, while the second section showed an LTE of 81 percent based on RDD results as well as a high possibility of debonding and moisture presence between the overlay and the jointed pavement in the GPR image (shown in Figure 9-c). Moreover, eroded or wet conditions under the PCC slab were detected by the GPR. According to the decision criteria, these sections should be monitored routinely for reflection cracking and sealed in a timely manner as preservative maintenance to prevent rapid joint deterioration.



**Figure 9. US-59 ACOL joint repairs: (a) standard plans, (b) repair steps, (c) GPR image.**

## CONCLUSIONS

There are many well-organized visual pavement condition survey protocols used by highway agencies to monitor and record pavement distresses. However, current survey protocols often require a level of inspection detail greater than what is normally needed for a routine maintenance survey; therefore, simplified survey tables have been provided.

Based on the areas selected from the checklist of visual survey, deflection testing using FWD can evaluate the structural condition of pavement such as layer stiffness, LTE, and loss of support below the slab. GPR testing determines base conditions such as voids and the presence of water trapped in and between underlying pavement layers. Moreover, GPR survey can be used for PCC pavement layer thickness estimation, layer interface condition assessment, and dowel misalignment evaluation. DCP testing indicates the in situ strength of base and subgrade soils. It is a fast and easy method to estimate layer stiffness which is useful to estimate the effective stiffness and thickness of the pavement system.

In the field tests, the poor condition section showed more joint and crack seal deterioration than the good condition section. FWD data show no difference between good and poor

condition sections, but the LTE and basin areas are low, possibly requiring retrofit load transfer. DCP test results show how good joint sealing can effectively prevent pumping and erosion damage since the good condition area has lower subbase erosion by well-maintained joint sealing. AC overlaid sections showed no reflection cracking at the surface but did show low LTE, voids under the slab, and wet base conditions indicative of a high potential for rapid deterioration when reflection cracking takes place. Certain conditions are to be met to justify the use of retrofit load transfer and edge drains as a long-term maintenance solution but routine monitoring and timely sealing of joints and cracks should extend good conditions cost effectively.

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