INTERIM REPORT

to the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
(NCHRP)

for Project <u>10-82 Performance-Related Specifications for Pavement Preservation Treatments</u>

Submitted by
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on behalf of
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CHAPTER 1 INTRODUCTION

BACKGROUND

Major financial resources are invested in preserving and maintaining the nation's roadways. For example, the Interstate Maintenance Program of the SAFETEA-LU federal highway bill authorized $25.2 billion to preserve the Interstate highway system for the 5-year period 2005–2009. Increasing portions of state, city, and county budgets are being allocated for maintenance. Considering this major investment in pavement preservation, it is imperative that the initial quality and long-term performance of preservation treatments be assured in the best possible way.

In this research project, pavement preservation treatments are defined as treatments applied to slow the deterioration of an existing pavement and improve its functional condition (without substantially increasing structural capacity). Several treatments fit this definition for hot-mix asphalt (HMA) pavement and portland cement concrete (PCC) pavement, including:

- HMA-surfaced Pavement: Crack sealing, slurry seals, chip seals, microsurfacing, cape seal, fog seals, hot in-place recycling, cold in-place recycling, and thin HMA overlays.
- PCC-surfaced Pavement: Joint resealing, crack sealing, joint and spall partial-depth repair, load transfer restoration, diamond grinding, undersealing, and thin HMA overlays.

PROBLEM STATEMENT

Currently, most materials and construction specifications for pavement preservation treatments provide little or no linkage between quality assurance methods and in-service performance of the treatment (short and long-term). This approach to quality assurance is limiting to both contractors and highway agencies because: a) it limits the contractor's ability to innovate and focus on quality characteristics that affect the treatment's in-service performance, and b) it limits the ability of the highway agency to account for the performance lost or gained due to differences in quality between the as-designed treatment and as-constructed treatment. Performance-related specifications (PRS) that specify quality in terms of parameters that correlate with future performance provide an alternative approach that can address these limitations. Significant progress has been made over the past three decades in developing and implementing PRS for new pavements. However, the transportation community is lacking PRS methodology and guidelines for pavement preservation treatments.

RESEARCH OBJECTIVES

The objective of this research is to develop guidelines for use in preparing PRS for pavement preservation treatments. To accomplish this objective, the following issues will be addressed:

- Identify preservation treatments that are suitable for PRS.
- Identify acceptance quality characteristics (AQCs) that correlate with the performance (or longevity) of the pavement, that are measurable, and that can be controlled by the material supplier and/or contractor.
- Develop models for predicting the treatment performance (or longevity) as a function of initial quality (as measured by the AQCs), condition of the existing pavement, and site conditions (climate, traffic loading, etc.).

- Develop a method for determining pay adjustment based on expenses or savings expected to occur in the future as a result of variation from the specified target level of quality.
- Develop guidelines for establishing statistically sound sampling and testing acceptance plans.
- Integrate the AQCs, acceptance sampling plans, performance/longevity prediction models, and pay adjustment methods into a coherent methodology and guidelines for developing PRS for pavement preservation treatments.

RESEARCH TASKS

This research project is divided into two phases consisting of eight primary tasks, as follows:

- Phase I (Tasks 1 through 4): This phase consists of the following four tasks:
    - Task 1— Review Literature and Current Practices.
    - Task 2— Develop a Process for Assessing the Suitability of Preservation Treatments for PRS.
    - Task 3—Prepare a Detailed Outline of the Guidelines and a Plan for Developing them in Phase II.
    - Task 4— Prepare Interim Report.
- Phase II (Tasks 5 through 8): This phase involves the execution of the process for identifying preservation treatments suitable for PRS. A total of six preservation treatments deemed most suitable for PRS will be identified. The guidelines will be developed for these six treatments. Also, this phase includes the development of the guidelines and preparation of a final project report that documents the entire research effort. Phase II tasks are:
    - Task 5— Identify Preservation Treatments for Consideration in the PRS Guidelines.
    - Task 6—Develop PRS Guidelines and Methodology for Pavement Preservation Treatments.
    - Task 7—Prepare Examples to Illustrate Use of the PRS Guidelines and Methodology.
    - Task 8—Prepare Final Report.

This report is the deliverable for Task 4, and it documents the research performed to date.

REPORT ORGANIZATION

This report consists of six chapters. Chapter 1 (this chapter) presents the background of the research problem and describes the research objectives and scope. Chapter 2 presents key findings of a review of the literature on PRS and pavement preservation. Chapter 3 discusses current specifications for pavement preservation treatments (obtained from a sample of state DOTs). Chapter 4 presents a detailed outline of the PRS guidelines and a plan for developing them, taking into account all the knowledge gained in Phase I. Chapter 5 provides a systematic process for assessing the suitability of pavement preservation treatments for PRS based on the Analytic Hierarchy Process (AHP). Finally, Chapter 6 provides a closure to this report.

The report includes four appendixes. Appendix A includes summary tables of current specifications for preservation treatments for HMA-surfaced and PCC-surfaced pavements. Appendix B provides a bibliography of existing performance prediction models for both HMA and PCC pavements. Appendixes C and D contain site condition data for promising HMA and PCC treatment sections obtained from the Long-Term Pavement Performance (LTPP) database.

CHAPTER 2 LITERATURE REVIEW

This chapter presents key findings of the literature review regarding PRS and pavement preservation treatments.

PERFORMANCE-RELATED SPECIFICATIONS

Performance-Related Specifications are quality assurance specifications that describe the desired levels of key materials and construction quality characteristics that have been found to correlate with the long-term performance of the finished product, thus providing the basis for rational acceptance and price adjustments (TRB 2009; Hoerner and Darter 1999). These characteristics should be amenable to acceptance testing at the time of construction (TRB 2009). A systematically complete and scientifically sound PRS should include the following elements (Chamberlin 1995; Hoerner and Darter 1999; Weed 2006):

- Acceptance quality characteristics that correlate with the performance (or longevity) of the pavement, that are measurable, and that can be controlled by the material supplier and/or contractor.
- Pavement performance indicators that are affected by the defined AQCs.
- Statistical acceptance sampling and testing plan (including definition of lots, sublots, and sample size).
- Pay adjustment plan.
- Operating characteristic (OC) curves to evaluate the agency and contractor risks.

The history of PRS for pavements is well documented in the NCHRP Synthesis 212 (Chamberlin 1995). Efforts to develop PRS for highway construction can be dated back to the late 1940s. The New Jersey DOT is a pioneer state agency in developing PRS for new pavements. Weed (1989) provided the prototype PRS, which used total life-cycle cost (LCC) as an overall measure of pavement quality. This approach was modified and adopted in a series of FHWA-sponsored research studies that resulted in guidelines for developing PRS for new PCC pavements and the PaveSpec PRS software (Hoerner and Darter 1999). A follow-up research was sponsored by the FHWA to improve the performance prediction models used in the PRS methodology for PCC pavement and to revise the PaveSpec software (Hoerner et al. 2000), which represent the current PRS methodology and guidelines for new PCC pavement at the national level.

Initial efforts to develop PRS for new HMA pavements began under NCHRP Project 10-26, where Anderson et al. (1990) identified relationships between materials and construction properties and performance of HMA pavements. NCHRP Project 09-20 developed PRS for HMA pavement based on field data from the WesTrack accelerated pavement test sections by examining how deviations in materials and construction properties affected pavement performance (Seeds et al. 1997; Epps et al. 2002). NCHRP Project 09-22 developed a new PRS methodology for new HMA pavement and incorporated a rapid form of AASHTO's mechanistic-empirical models for predicting HMA pavement performance (El-Basyouny and Jeong 2010; Jeong and El-Basyouny 2010), which represent the current PRS methodology and guidelines for new HMA pavement at the national level.

Table 1 compares key aspects of current PRS methodologies for HMA pavement and PCC pavement. While the general PRS framework is similar, the two pavement types have different acceptance quality characteristics and distress types. Also, the two methodologies differ in terms of the basis for computing pay adjustment factors. The HMA PRS methodology determines pay factors based on the difference in expected life between as-designed and as-constructed pavements; whereas, the PCC PRS methodology determines pay factors based on the difference in total LCC between as-designed and as-constructed pavements. Finally, the PCC PRS methodology considers both initial International Roughness Index (IRI) IRI (as an AQC) and is equipped with models to predict IRI (as a performance indicator); whereas the HMA PRS methodology considers pavement smoothness through user-defined pay adjustment factors for various values of initial IRI.

Table 1. Comparison of Current PRS Methodologies for New Pavements.

PRS Aspect	New PCC Pavement	New HMA Pavement
Acceptance Quality Characteristics	• PCC strength (compressive or flexural) • Slab thickness • Air content • Initial smoothness (profile index or IRI) • Consolidation around dowel bars	• Asphalt concrete (AC) layer thickness • Gradation: 3⁄4 in., 3⁄8 in., #4, and #200 • Asphalt content (%) • Gyratory mix air voids (%) • Marshall mix air voids (%) • In situ air voids from cores (%) • Max. theoretical specific gravity of mix (G_{mm})
Predicted Performance	• Transverse cracking • Joint faulting • Joint spalling • International Roughness Index (IRI)	• Bottom-up fatigue cracking • Top-down (longitudinal) fatigue cracking • Permanent deformation (rutting)
Pavement Smoothness	• Initial smoothness is considered as an AQC • Future IRI is predicted as a performance indicator	User-defined pay factors based on initial IRI
Performance Prediction Models	Empirical and Mechanistic-empirical models	Rapid closed-form of AASHTO's mechanistic-empirical models
Basis for Pay Factor	Difference in life-cycle costs between as-designed and as-constructed pavements	Difference in expected lives between as-designed and as-constructed pavements
Composite Pay Factor	• Individual pay factors combined using multiple options (multiplication, average, weighted average, etc.) • Overall pay factor computed based on LCC	Summation of individual pay factors

Currently, most materials and construction specifications for pavement preservation treatments provide little or no linkage between initial quality (material properties, construction quality, and design) and performance of the treatment (short and long-term). This approach to quality assurance is limiting to both contractors and highway agencies because: a) it limits the contractor's ability to innovate and focus on quality characteristics that affect performance, and b) it limits the ability of the highway agency to account for the performance lost or gained due to differences between the as-designed product and as-constructed product. PRS that specify quality in terms of parameters that correlate with future performance provide an alternative approach that can address these limitations. This research effort will develop PRS methodology and guidelines for pavement preservation treatments by building on the existing knowledge in PRS.

PAVEMENT PRESERVATION TREATMENTS

The concept of "pavement preservation" has emerged as a cost-effective alternative to reactive maintenance. Generally, preservation treatments are applied to extend pavement service life, enhance its performance, and reduce its life-cycle cost (Smith 2002; Zhang et al. 2010; FHWA 1999). The cumulative effect of preservation treatments is to postpone costly rehabilitation and reconstruction and consequently reduce the life-cycle cost of pavements. Figure 1 depicts the effect of these treatments on pavement performance and service life.

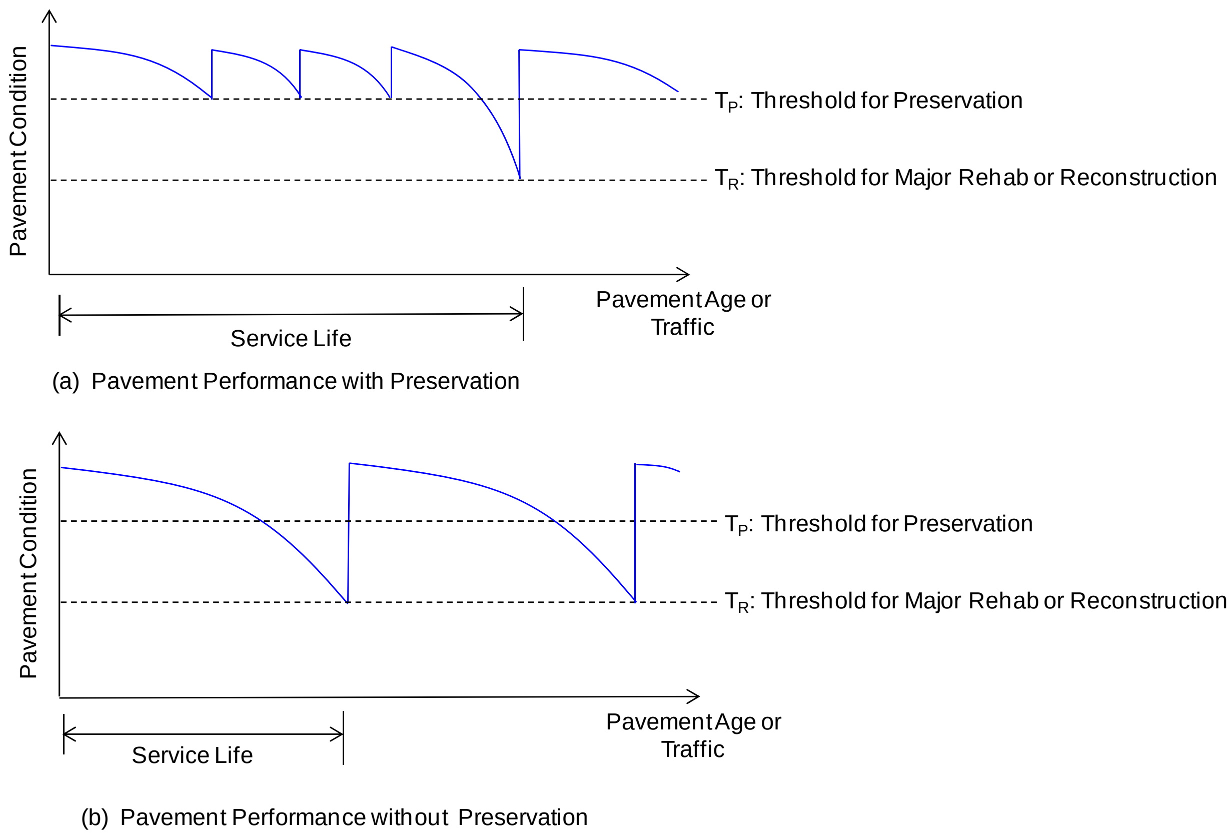


Figure 1. Effect of Preservation Treatments on Pavement Performance and Service Life.

In this research, pavement preservation treatments are defined as "treatments applied to preserve an existing roadway, slow future deterioration, and maintain and improve its functional condition (without substantially increasing structural capacity)." This definition is consistent with the FHWA definition of pavement preservation, which includes preventive maintenance, minor rehabilitation (non structural), and some routine maintenance activities (FHWA 2005). Tables 2 and 3 summarize preservation treatments that meet this definition for HMA-surfaced and PCC-surfaced pavements, respectively.

Table 2. Preservation Treatments for HMA-Surfaced Pavements.

Treatment	Description	Purpose
Chip seals	Application of asphalt (typically an emulsion) to the pavement surface, followed by the application of rolled aggregate chips.	• Seal longitudinal, transverse and block cracking • Inhibit and retard raveling/weathering (loose material must be removed) • Improve friction • Reduce the intrusion of water into the pavement • Minor improvement to ride • Inhibit low severity bleeding • Inhibit moisture infiltration
Fog seals	Very light application of a diluted asphalt emulsion placed directly on the pavement surface with no aggregate.	• Seal fine low severity longitudinal, transverse, and block cracking • Enrich the hardened/oxidized asphalt • Inhibit and retard raveling/weathering
Crack sealing	Application of sealant (thermo-plastic bituminous materials) to "working" cracks that undergo little movement.	• Prevent the intrusion of moisture through existing cracks
Slurry seals	A mixture of well-graded aggregate and asphalt emulsion spread in a thin layer (less than 0.4 in) over the entire pavement surface.	• Inhibit and retard raveling/weathering (loose material must be removed) • Retard asphalt aging, oxidation, and hardening • Inhibit low and medium severity bleeding • Reduce the intrusion of water • Minor improvement to ride • Improve friction (especially at low speeds (below 30 mph)
Microsurfacing	Application of a mixture of polymer-modified emulsified asphalt, mineral aggregate, mineral filler, water, and additives applied in a process similar to slurry seals.	• Inhibit and retard raveling/weathering (loose material must be removed) • Retard asphalt aging, oxidation, and hardening • Inhibit low and medium severity bleeding • Improve friction (especially at low speeds • Reduce the intrusion of water • Improve surface friction • A multiple course of microsurfacing is used to correct pavement surface deficiencies, including rutting and minor surface profile irregularities
Thin HMA Overlay	Application of a thin layer of HMA.	• Remove surface distresses • Significantly improve ride (lower IRI) • Seal pavement from surface water intrusion, reduce transpiration of water upward through pavement

Table 2. Preservation Treatments for HMA-Surfaced Pavements (cont.).

Treatment	Description	Purpose
Cold in-place recycling	Reclaimed asphalt pavement (without heat), combined with new emulsified or foamed asphalt and/or a rejuvenating agent, possibly also with virgin aggregate, and mixed at the pavement site to produce a new cold mix end product. Normally, cold in-place recycling is used in conjunction with an HMA overlay or chip seal.	• Remove low-severity longitudinal, block, and transverse cracking • Remove raveling/weathering • Improve friction • Improve ride quality • Inhibit low and medium severity bleeding
Hot in-place recycling	Softening the existing surface with heat, mechanically removing the pavement surface, mixing it with a recycling or rejuvenating agent, possibly adding virgin asphalt and/or aggregate, and replacing it on the pavement without removing the recycled material from the pavement site. Depth of treatment normally ranges between 0.75 and 2.0 in.	• Remove low-severity longitudinal, block, and transverse cracking • Remove raveling/weathering • Improve friction • Improve ride quality • Inhibit low and medium severity bleeding

Table 3. Preservation Treatments for PCC-Surfaced Pavements.

Treatment	Description	Purpose
Diamond Grinding	Removal of a thin layer of PCC using stacked diamond tipped cutting blades	• Remove faulting • Improve surface rideability • Improve surface friction
Load transfer restoration	Placement of load transfer devices (dowel bars) across joints or cracks in an existing pavement	• Provide reliable load transfer • Reduce or eliminate pumping, faulting, and corner breaks (reducing deflections)
Partial-Depth Repair	Remove and replace relatively small deteriorated areas of PCC (usually < 10 sq. ft) and often only 2 to 3 in deep.	• Repair shallow spalling associated with localized areas of scaling, weak concrete, clay balls, or high steel • Improve ride quality
Undersealing (or Slab Stabilization)	Pressure insertion of flowable material beneath a PCC slab (ACPA 1994)	• Fill underlying voids (not raise slab) • Reduce pavement deflections • Minimize pumping and faulting
Thin HMA Overlay	Application of a thin layer of HMA	• Remove surface distresses • Significantly improve ride (lower IRI) • Seal pavement from surface water intrusion, reduce transpiration of water upward through pavement
Joint Resealing /Crack Sealing	Application of a sealant material in concrete pavement joints and cracks (ACPA 1993)	• Minimize moisture infiltration • Prevent intrusion of incompressibles

The literature contains very little hard data on the extent to which these treatments are used throughout the U.S. Much of the information in this regard is obtained through questionnaires, which can be influenced by the perception of the person who answered the questionnaire. Nonetheless, the results of these questionnaires provide indications of the treatment types that are being used nationwide. Key findings from the literature regarding the use of preservation treatments are summarized below:

- A questionnaire survey of 13 state DOTs concerning HMA preservation treatments found that thin overlay (thickness less than 1.0 inch), microsurfacing (thickness less than 1.0 inch), crack sealing, and chip seal techniques are the most frequently used treatments for HMA-surfaced pavements (Morian 2011). The same survey indicated that chip seal is used primarily on low and medium volume roads (average daily traffic of 5,000 or less vehicles per day).
- A study conducted under the Strategic Highway Research Program 2 (SHRP 2) Project R26 developed guidelines for selecting pavement preservation strategies specifically for high traffic volume roadways (Smith and Peshkin 2011). That study also included a questionnaire survey of highway agencies to identify what preservation treatments are used for high traffic volume roadways. Responses to the questionnaire from 50 highway agencies indicated that crack sealing, cold mill and HMA overlay, and drainage preservation are the most widely used HMA preservation treatments for high volume roads (average daily traffic of 10,000 or more vehicles per day). The same survey indicated that joint reseal, crack sealing, diamond grinding, and partial- and full-depth repairs are the most widely used PCC preservation treatments for high volume roads. The SHRP 2 study used sub-types of treatments. For example, the SHRP 2 study divides microsurfacing into single course and multi-course microsurfacing.
- Montana DOT developed a synthesis of pavement maintenance and preservation through literature review and a web-based email survey that was distributed to all 50 U.S. states, Washington, D.C., and 11 Canadian provinces (Cuelho et al. 2006). Responses to the questionnaire from 34 U.S. states and five Canadian provinces indicated that crack sealing, thin overlays, chip seal, drainage features, and microsurfacing are the most frequently used treatments for HMA-surfaced pavements. The same survey indicated that diamond grinding and dowel bar retrofit are the most commonly used treatments for PCC-surfaced pavements. PCC partial- and full-depth repairs were not included in the Montana survey.
- As part of NCHRP Project 14-14, Peshkin et al. (2004) identified pavement treatments that are used to preserve the system, retard future deterioration, and maintain and improve the functional condition of the system (without substantially increasing structural capacity). For HMA-surfaced pavements, these treatments included crack filling/crack sealing, fog seals, slurry seals, scrub seals, microsurfacing, chip seals, thin overlay, and ultrathin friction courses. For PCC-surfaced pavements, these treatments included joint/crack sealing, diamond grinding, undersealing, and load transfer restoration.
- Although microsurfacing and slurry seal are listed separately in Table 2, NCHRP synthesis 411 found that most state DOT specifications include both microsurfacing and slurry seal together in the same specifications section, with little or no distinction between the two treatments (Gransberg 2010). Gransberg (2010) stated that the International Slurry Surfacing Association advocates categorizing both as “Slurry Systems” while maintaining the distinction that microsurfacing always contains a

polymer-modified emulsion that is designed to break chemically; thus allowing for opening the pavement for traffic within about an hour after application.

- Some highway agencies include additional treatments (beyond those shown in Tables 2 and 3) in their preservation programs. For example, Michigan DOT includes full-depth repair in the preservation program for PCC-surfaced pavements (Galehouse 2002; Buch et al. 2003). Similarly, other highway agencies exclude some of the treatments shown in Tables 2 and 3 from their preservation programs. For example, Florida DOT does not use partial-depth repair for PCC-surfaced pavements.

CONSTRUCTION QUALITY AND IN-SERVICE PERFORMANCE OF ASPHALT PAVEMENT TREATMENTS

The following sections provide discussions of the initial quality and in-service performance of primary treatments for HMA-surfaced pavements.

Chip Seal

A chip seal is a thin coat of asphalt (emulsion, modified or unmodified) followed by a thin layer of aggregate, placed on an existing pavement. Seal coat is the name usually used for this treatment when placed on a base course as part of a construction sequence. A chip seal, as the name implies, seals the underlying pavement from air and water intrusion and corrects and improves surface texture. As with other maintenance treatments, a chip seal has no significant structural impact and has little or no impact on rutting. Key quality indicators for chip seals include:

1. Air and pavement temperature within tolerance.
2. Clean surface, sealed cracks, and patched spot areas.
3. Proper quality, gradation, and quantity of aggregate.
4. Proper type, temperature, and application rate of asphalt binder.
5. Compatibility of binder and aggregate.
6. Construction timing (time between binder application and aggregate spread, time between aggregate spread and rolling).

When placed properly, chip seals are an excellent, cost-effective treatment, especially for lower volume roads.

Slurry Seal and Microsurfacing

Slurry seal and mcrosurfacing consist of a thin (<3/8 inch) mixture of well-graded small sized aggregate (typically less than 1/4 inch), emulsified asphalt binder (and modifiers), squeegeed onto the pavement at ambient temperature. Microsurfacing uses a modified binder and mix design process and provides more stability; which is especially useful when the treatment is used to correct shallow rutting. Both treatments seal and protect the underlying surface, provide improved surface texture, and can improve ride quality. Slurry seals are often used in locations where high traffic volumes make chip seals problematic. Key quality indicators for slurry seals and microsurfacing include:

1. Clean surface, sealed cracks, and patched spot areas.
2. Proper quality and gradation of aggregate.
3. Proper type and percentage of asphalt binder and modifiers, if used.
4. Pavement temperature in the proper range.
5. Stockpile/plant/truck contamination.

6. Proper equipment calibration.

When slurry seals or microsurfacing are used on a cracked pavement, most cracks will reflect through fairly quickly. If the cracks in the existing pavement are wide (>3/8"), a wide crack, or even two cracks will develop, even if the cracks were sealed prior to the application. Some improved performance has been reported when cracks were filled with slurry material (instead of crack filler) prior to covering the surface.

Crack Sealing

Crack sealing is applied to keep air, water, and other foreign material from entering the pavement surface. Crack sealing is the least expensive preservation treatment. Typically, cracks are blown clean of debris with a jet of compressed air (sometimes heated air is used), and an asphaltic material, often with some type of rubber product, is applied at high temperature and squeegeed into the crack, forming a tight waterproof seal. Some agencies rout the crack prior to sealing. Cracks can be filled just below the surface, filled to the top of the surface, or overbanded where the crack is sealed and a thin layer (<1/16") extends beyond the crack for approximately 1 inch on each side. Key quality indicators for crack sealing include:

1. Crack free of debris, clean, and dry.
2. Sealant heated to correct temperature.
3. If crack is heated, the pavement is not burnt.
4. Correct amount of material is applied in each crack.

Thin HMA Overlay

A thin hot-mix overlay is used when the pavement exhibits some functional problems. The overlay is too thin to address structural problems such as fatigue cracking or significant rutting. The situations where this treatment applies are to correct minor ride issues and skid resistance issues (flushing, polished aggregate). A thin overlay is used much like a seal coat or slurry seal, but is normally used on higher volume routes or as an alternative to these treatments. The most critical quality indicators for thin HMA overlays are:

1. Clean surface, sealed cracks, and patched spot areas.
2. Proper quality and gradation of aggregate.
3. Proper type and amount of asphalt binder.
4. Mix temperature at plant, mat temperature on pavement, and rolling temperatures within tolerance.
5. Mat thickness.

HMA overlays have generally provided excellent service life and performance when placed properly on pavements without structural problems.

Cold-in-Place Recycling

Cold-in-place recycling is used to remove and replace the existing HMA pavement when there are problems with the existing surface, but the pavement structure is sound. In this treatment, the existing surface is milled, re-sized, and re-used; modifiers are added (including additional aggregate, emulsion, or some specialized asphalt product); and the pavement re-laid and compacted. A new surface course is usually added. This technique is the best option for surfaces that exhibit considerable cracking (non-fatigue related), aging, or even flushing of the asphalt surface. The mix design of the recycled pavement is very important. Some improvements to the existing profile can be realized and when the new surface is placed, the roadway is nearly equivalent to a new road. The success of cold-in-place recycling is dependent on:

1. Control of milling depth and re-sizing operations.
2. Proper quality, gradation, and quantity of aggregate.
3. Accurate asphalt and modifier quantities.
4. Compaction operations and achieving target density.
5. Curing time prior to placing new surface and opening to traffic.

Hot-in-Place Recycling

Hot-in-place recycling is similar to cold-in-place in that it is used to remove and replace the existing HMA pavement when there are functional problems with the existing surface, but the pavement structure is sound. However, in this treatment the pavement surface is heated prior to milling, no cure time is required, and a new surface is not necessarily placed on top of the layer. Key quality indicators for hot-in-place recycling include:

1. Control of surface heating and milling depth.
2. Proper quality, gradation, and quantity of aggregate added.
3. Accurate asphalt and modifier quantities.
4. Compaction operations and achieving target density.
5. Surface profile control.

CONSTRUCTION QUALITY AND IN-SERVICE PERFORMANCE OF CONCRETE PAVEMENT TREATMENTS

The following sections provide discussions of the initial quality and in-service performance of primary treatments for PCC-surfaced pavements.

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 1/4 in., 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.

Studies of ground pavement surfaces indicate that the depth of texture is strongly dependant on the age or the time since the grinding and indirectly on traffic since grinding. Climate also is a factor as where pavements in wet and dry freeze environments tend to have lower macro texture than those in the non-freeze regions. Ground sections in the wet and dry freeze environments regions would provide on the average 8 years of service life where those in the non-freeze regions provide 12 years of service life on the average. Key quality indicators for diamond grinding include:

1. Consistent transverse profile across the full width of the roadway.
2. Consistent longitudinal profile (particularly across transverse joints).
3. Smoothness.
4. Friction.
5. No adverse tracking issues (appropriate blade spacing and selection according to aggregate hardness).

Load Transfer Restoration (Dowel Bar Retrofitting)

Load transfer restoration (also called dowel bar retrofitting) should be considered when faulting, high deflections, low load transfer efficiency (LTE) of the joint/crack, or reflection cracks in the asphalt concrete overlay (ACOL) are detected. When LTE is lower than 70%, the basin area is less than 25 in., and joints are spalled more than 2 in. wide over more than 20% of the slabs, then restoration of load transfer is recommended.

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. Key quality indicators for load transfer restoration include:

1. Placement and consolidation of the grout.
2. Alignment of the dowel.
3. Alignment and placement of the joint face restoration materials.

Load transfer retrofitting repairs have performed reasonably well, particularly where the grout material has stayed in place and has not prematurely spalled out.

Partial Depth Repair

The objective of partial depth repair is to repair spall distress without removing the entire slab. When 2 inch wide spalls are more than 10% of the crack or joint, partial depth repair is often employed using patching materials for PCC pavement or AC overlaid PCC pavement. The depth of spall should be less than 1/3 the thickness of the slab, and the pavement should have no reinforcing steel exposure. Partial depth repairs should restore the joint face, and the joint should be sealed properly. Key quality indicators for partial depth repairs include:

1. Method of curing.
2. Type of curing.
3. Weather conditions at the time of placing.
4. Strength of the bond at the existing concrete interface.
5. Moisture content and cleanliness of the surface concrete.
6. Drying shrinkage of the repair concrete.

Partial depth repairs have generally provided good service except where curing and bonding to the existing surface was inadequate and premature spalling of the repair shortens its effectiveness.

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, which is one of critical factors in effective undersealing operations. Therefore, Ground Penetrating Radar (GPR) is recommended to both locate and validate that voids have been properly identified and filled. Slab undersealing is recommended when GPR-indicated voided cracks or joints are more than 20% of the inspected section or where unstable bumps or unstable settlement is present.

The success of undersealing is strongly connected to the adequacy of the void filling; many undersealed projects have failed to provide adequate service due to eradicate void filling or filling non-voided areas resulting in uneven or non-supported slabs.

Thin ACOL

A thin AC overlay with petromat 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. Key quality indicators for thin ACOLs include:

1. Existing condition and roughness – amounts and type of cracking.
2. Control of gradation.
3. Temperature of placement.
4. AC content.
5. Compaction.

Routinely, thin ACOLs provide about 5 to 10 years of service life, depending on the above factors until additional faulting and spalling occur in the pavement.

Joint Resealing and Crack Sealing

Crack sealing is recommended when crack width is wider than 0.03 inch. Resealing joints and cracks is recommended when sealants are damaged over more than 20% along the joint or crack to reduce infiltration of moisture and incompressible material over time.

Service life for sealants can be anywhere from 7 to 10 years, performance can be short lived if water is not cleared from the joint prior to placement of the seal. Water trapped by the sealing operation can rapidly deteriorate the bond between the seal and the face of the joint. Thus, trapped subsurface water should be removed before re-sealing operations. Selection of proper sealing material should be based on temperature and moisture conditions. Key quality indicators for joint and crack sealing/resealing include:

1. Moisture in the existing concrete.
2. Clean and dry joint face.
3. Backer rod positioning.
4. Hot applied placement temperature and minimizing over-banding.
5. Removing water from the joint and its vicinity.

CHAPTER 3 CURRENT SPECIFICATIONS FOR PAVEMENT PRESERVATION TREATMENTS

This chapter provides an overview of current specifications for pavement preservation treatments.

AVAILABILITY OF SPECIFICATIONS

Table 4 shows the availability of materials and construction specifications for most commonly-used pavement preservation treatments in a sample of 14 state DOTs. These agencies were selected to provide a broad geographic distribution throughout the United States. It can be seen that most of these agencies have developed specifications for pavement preservation treatments. While these specifications are predominantly method-based, they provide clues of acceptance quality characteristics that can be measured during or immediately after construction. Samples of these specifications were reviewed and summarized. Table 5 lists the specifications reviewed and summarized in this study. A discussion of these specifications is presented in the following section of this report. Appendix A provides the summary tables.

Table 4. Availability of Specifications for Commonly-Used Preservation Treatments at Sample State DOTs.

State DOT	PCC-surfaced Treatments*						HMA-surfaced Treatments*					
	PDR	FDR	DG	LTR	JR	US	CS	SS	CrS	CIR	HIR	TOL
AZ	√	√	√	√	√		√	√	√	√	√	√
CA	√	√	√	√	√	√	√	√	√			√
FL		√	√		√							√
IA	√	√	√		√	√	√	√	√	√	√	√
ID							√					√
KS	√	√	√	√	√	√	√	√	√	√		√
MI	√	√	√	√	√		√	√	√			√
MT							√		√	√		√
NC							√	√	√			√
NY	√		√	√	√	√	√			√	√	√
PA	√	√	√	√	√	√	√	√	√			√
SD	√		√	√	√	√	√		√			√
TX	√	√	√	√	√	√	√		√	√	√	√
WA	√	√	√	√	√		√		√			√

*PDR=Partial-Depth Repair; FDR=Full-Depth Repair; DG=Diamond Grinding; LTR=Load Transfer Restoration; JR=Joint Resealing; US=Undersealing; CS=Chip Seals; SS=Slurry Seal or Microsurfacing; CrS= Crack Sealing; CIR=Cold in-place recycling; HIR=Hot in-place recycling; TOL=Thin HMA Overlay.

The following discussions focus on the materials and construction quality measures used in the reviewed specifications. This review will help identify acceptance quality characteristics that can potentially be used in the PRS guidelines (to be developed later in Phase II of this research project). Additional relevant aspects of the specifications, such as pay adjustment, are also discussed.

Table 5. Specifications Discussed and Summarized in This Report (See Appendix A).

State DOT	PCC-surfaced Treatments						HMA-surfaced Treatments					
	PDR	FDR	DG	LTR	JR	US	CS	SS	CrS	CIR	HIR	TOL
AZ	√	√	√	√	√		√	√	√	√	√	
CA	√	√	√	√	√	√	√	√	√			
FL		√	√		√							√
IA	√	√	√		√	√	√	√	√	√	√	
ID							√					
KS									√			√
MI	√	√	√	√	√		√	√	√			√
MT							√		√	√		
NC							√					
NY	√		√	√	√	√	√			√	√	
PA	√	√	√	√	√	√		√	√			
SD	√		√	√	√	√	√		√			
TX	√	√	√	√	√	√	√		√	√	√	√
WA	√	√	√	√	√		√		√			

CURRENT SPECIFICATIONS FOR HMA-SURFACED PAVEMENT TREATMENTS

Chip Seal

Most of the 14 state DOTs included in this review have standard specifications for chip seals. Some DOTs have multiple specifications for chip seals, depending on the type of material used, and number of layers. Material quality measures include testing of asphalt materials and aggregate. Construction quality measures include application rate of aggregate and asphalt material, and number of roller passes. The most common construction quality measures are the application rates of asphalt and aggregate. Few states have pay adjustment in their specifications based on construction quality. Some DOTs (such as Montana, Michigan, and California DOTs) have a form of warranty for chip seals.

Slurry Seal

Only five of the 14 state DOTs included in this review have separate specifications for slurry seals. Common materials quality measures include testing of asphalt emulsion (generally SS-1h and CSS-1h), fine aggregate and filler (if used), asphalt cement content, and gradation of aggregate. Construction quality measures include slurry spread rate and mix consistency.

Crack Sealing

Ten of the 14 state DOTs included in this review have separate specifications for crack sealing. Materials quality measures refer to the testing of crack sealant materials. Only one state requires the testing of backer rod in their specifications. Construction quality measures include depth of crack cleaned, adhesion and cohesion failure, and missed cracks.

Thin HMA Overlay

Thin HMA overlay treatment refers to plant-mixed asphalt binder and aggregate applied to existing HMA pavement as an overlay with thicknesses typically 1.0 inch, or less and that does not significantly add structural strength to the pavement. Only a few state DOTs have separate specifications specific for this treatment. Most state DOTs include this treatment in their specification for HMA pavement, stone mastic asphalt, open graded friction course, etc. with or without minor modifications. Whereas the same table contains the guide specification for the ultra-thin HMA overlay from Michigan. Typically the construction and materials quality of this treatment include asphalt content, percent passing of aggregate for certain sieve sizes, in-place and laboratory density, and smoothness. State DOTs apply varying pay adjustment schemes (different adjustments for different AQCs).

Cold-in-Place Recycling

Only six of the 14 state DOTs included in this review have separate specifications for cold-in-place recycling. Three states have special specifications and the other two have standard specifications. Materials quality measures include the testing of asphaltic material added as recycling agent or rejuvenator, and the testing of aggregate quality if any additional aggregate is added during the recycling process. Size of pulverizing of existing surface course is one of the construction quality measures. Generally the maximum size allowable during the pulverization ranges from 1 to 2 inches. Other construction related quality measures include smoothness, depth of planning of surface course, and application rate of bituminous materials (recycling agent).

Hot-in-Place Recycling

Only four of the 14 state DOTs included in this review have separate specifications for hot-in-place recycling. Materials quality measures include testing of asphalt materials used as recycling agent and asphalt from existing surface course, quality of virgin HMA (if used). Construction quality measures include smoothness of finished surface, depth of scarification of existing surface course, percentage of recycling agent, percentage of virgin HMA (if used), and placement of construction joint.

CURRENT SPECIFICATIONS FOR PCC-SURFACED PAVEMENT TREATMENTS

Diamond Grinding

Most of the 14 state DOTs included in this review have standard specifications for diamond grinding. Typically, construction quality measures include smoothness, percentage of ground area, height of individual bump, and groove dimensions. California and Arizona also require certain amount of coefficient of friction on ground surface. Smoothness of treated surface is evaluated by measuring profile index or the IRI. Half of the reviewed specifications have a pay adjustment scheme based on the smoothness of treated surface.

Full-Depth Repair

Majority of the 14 state DOTs included in this review have standard specifications for full-depth repair treatment. These specifications have mixed definitions of full-depth repair, depending on the width of patching. The acceptance quality characteristics include smoothness, location of dowel and tie bars, and compressive strength of concrete. Some states have pay adjustment factors based on concrete strength and depth of patching.

Partial-Depth Repair

Ten of the 14 state DOTs included in this review have standard specifications for concrete pavement partial-depth repair. The patching materials consist of different types of cement concrete, epoxy resin, cement grout, and HMA. Typically the DOTs specify several laboratory tests as acceptance criteria for the patching materials. The most common construction quality measure among the reviewed specifications is the depth of saw cutting. Other construction related quality measures include testing of smoothness and sounding. None of the reviewed specifications has a quality-based pay adjustment.

Joint Resealing and Crack Sealing

Ten of the 14 state DOTs included in this review have standard specifications for joint resealing and crack sealing (both transverse and longitudinal cracks). Materials quality measures of joint and crack sealing mainly consist of testing of sealants. Generally, states accept silicone joint sealant or asphalt rubber sealant.

Load Transfer Restoration

Nine of the 14 state DOTs included in this review have standard specifications for dowel bar retrofitting to restore load transfer efficiency. Materials quality measures primarily consist of testing of dowel bar and patching materials. Patching material includes cement concrete, epoxy resin, and grout. Most of states verify the positing of dowel bar as a construction quality measure. Other construction quality is verified for the compressive strength of patching material, and saw cut depth. South Dakota DOT's specifications include a pay reduction if the 24-hour concrete strength does not meet the minimum 4000 psi requirement.

Slab Stabilization (Undersealing)

Seven of the 14 state DOTs included in this review have standard or special specifications for slab stabilization or undersealing of PCC pavement. The grout quality measures include testing such as efflux time, set time, compressive strength, and volume expansion property. Construction quality measures include maximum amount of upward movement of the slab, deflection of slab, and smoothness. South Dakota and Iowa DOTs apply pay reduction if any radial cracking develops during grouting.

CHAPTER 4 OUTLINE AND DEVELOPMENT PLAN FOR PRS GUIDELINES

This chapter presents a detailed outline of the PRS guidelines and a plan for developing them.

OUTLINE FOR PRS GUIDELINES

Figure 2 shows the general framework for developing PRS. This framework will guide the development of the guidelines. In this framework, the highway agency defines a target mean and uniformity and a sampling plan (lots, sublots, and sample size) for each key AQC. Probabilistic performance prediction models are employed to relate these AQCs (along with other design features and site conditions) to in-service performance of the treatment. Treatment life is defined based on the predicted performance as “number of years until user-defined distress threshold values are reached.” The present worth values (PWVs) of the as-designed and as-constructed lots are computed based on their life expectancies and associated costs. Rational pay adjustment factors are then derived based on the difference between the as-designed and as-constructed PWVs.

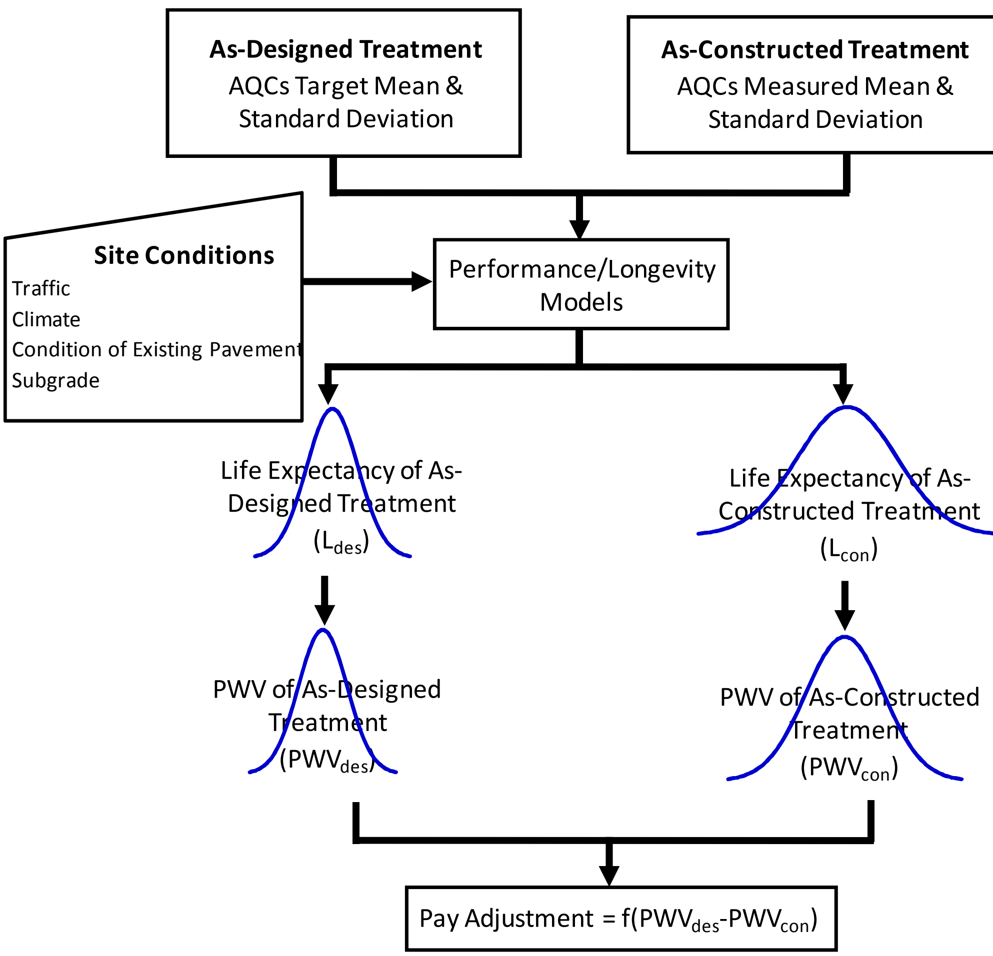


Figure 2. General PRS Framework for Pavement Preservation Treatments.

Figure 3 shows a detailed outline of the PRS guidelines. The guidelines will consist of five chapters and two appendixes, as follows:

- **Chapter 1 – Introduction:** This chapter begins with introducing the primary concepts of both pavement preservation and PRS. Then, it defines the purpose and scope of the guidelines, including identifying treatments that are found to be most suitable for PRS (three treatments for HMA-surfaced pavement and three treatments for PCC-surfaced pavements). Finally, this chapter describes how to use the guidelines to generate PRS.
- **Chapter 2 –PRS Methodology for Pavement Preservation Treatments:** This chapter defines the components and flow of the PRS methodology, including inputs and outputs.
- **Chapter 3 – Guidelines for Determining Acceptance Quality Characteristics for Preservation Treatments:** This chapter identifies key construction and materials acceptance quality characteristics for each treatment deemed suitable for PRS (a total of six treatments). Additionally, this chapter describes testing and measurement methods available for these AQCs. Finally, it provides guidance on selecting appropriate mean and variability target values for each AQC.
- **Chapter 4 – Guidelines for Developing Statistical Acceptance Sampling Plans:** This chapter will provide guidelines for developing and evaluating acceptance sampling plans for use in PRS. The guidelines will address issues related to defining lots, sublots, and sample size, and developing operating characteristic curves that assess the agency's and contractor's risks.
- **Chapter 5 – Guidelines for Applying PRS:** This chapter provides guidance on how to prepare PRS prior to letting preservation projects and how to apply PRS in the field (including implementing sampling plans and pay adjustment schemes).
- **Appendix A – Illustrative Examples of PRS Development:** These examples will be designed to illustrate the use of the PRS guidelines for different preservation treatments (six treatments found most suitable for PRS), pavement types (HMA-surfaced pavement and PCC-surfaced pavement), highway classification (high, medium, and low traffic volumes), and climatic regions.
- **Appendix B –Performance Prediction Models for Preservation Treatments:** Performance prediction models are vital for developing PRS. They provide a necessary link between initial quality and in-service performance. This appendix will describe the developed models, define their inputs and outputs, and assess their sensitivity to key inputs.

Chapter 1 – Introduction

1.1 Background on PRS and Pavement Preservation
1.2 Purpose of Guidelines
1.3 Scope of the Guidelines (Treatments Suitable for PRS)
  1.3.1 HMA-surfaced Pavement Preservation Treatments
  1.3.2 PCC-surfaced Pavement Preservation Treatments
1.4 How to Use the Guidelines

Chapter 2 – PRS Methodology for Pavement Preservation Treatments

2.1 Description of PRS Methodology
2.2 Predicting Treatment Performance
  2.2.1 HMA-surfaced Pavement Preservation Treatments
  2.2.2 PCC-surfaced Pavement Preservation Treatments
2.3 Life Cycle Cost as an Overall Measure of Treatment Quality
  2.3.1 Agency Costs
  2.3.2 User Costs (if found suitable for PRS)
3.4 Development of Pay Factor Curves

Chapter 3 – Guidelines for Determining Acceptance Quality Characteristics (AQCs) for Preservation Treatments

3.1 HMA-surfaced Pavement Preservation Treatments
  3.1.1 Key AQCs
  3.1.2 Testing and Measurement Methods for AQCs
  3.1.3 Determining Target Values for AQCs (mean and variability)
3.2 PCC-surfaced Pavement Preservation Treatments
  3.2.1 Key AQCs
  3.2.2 Testing and Measurement Methods for AQCs
  3.2.3 Determining Target Values for AQCs (mean and variability)

Chapter 4 – Guidelines for Developing Statistical Acceptance Sampling Plans

4.1 Defining Lots and Sublots
4.2 Determining Sample Size
4.3 Defining Acceptable and Rejectable Quality Levels
4.4 Assessing Agency's and Contractor's Risks

Chapter 5 – Guidelines for Applying PRS

5.1 Preparation of PRS Prior to Project Letting
5.2 Applying PRS in the Field

Appendix A – Illustrative Examples of PRS Development

1. Examples for HMA-surfaced Pavement Preservation Treatments
2. Examples for PCC-surfaced Pavement Preservation Treatments

Appendix B – Performance Prediction Models for Preservation Treatments

1. Models for HMA-surfaced Pavement Preservation Treatments
2. Models for PCC-surfaced Pavement Preservation Treatments

Figure 3. Outline for the Guidelines for Preparing PRS for Pavement Preservation Treatments.

PLAN FOR DEVELOPING PRS GUIDELINES

The following sections describe the steps that will be taken in Phase II of the project to develop the PRS guidelines.

Step 1 - Develop Detailed PRS Methodology

Figure 4 shows the methodology for developing PRS. This methodology simulates as-designed and as-constructed lots under PRS. A lot is divided into multiple sublots and samples are taken from each sublot for each AQC. The performance of each sublot is predicted using probabilistic prediction models. The life and PWV distributions of the sublots are combined to arrive at a PWV distribution for the lot. As-constructed lots that represent various quality scenarios (superior to target, inferior to target, or on target) are then simulated by varying the mean and the standard deviation values for each AQC.

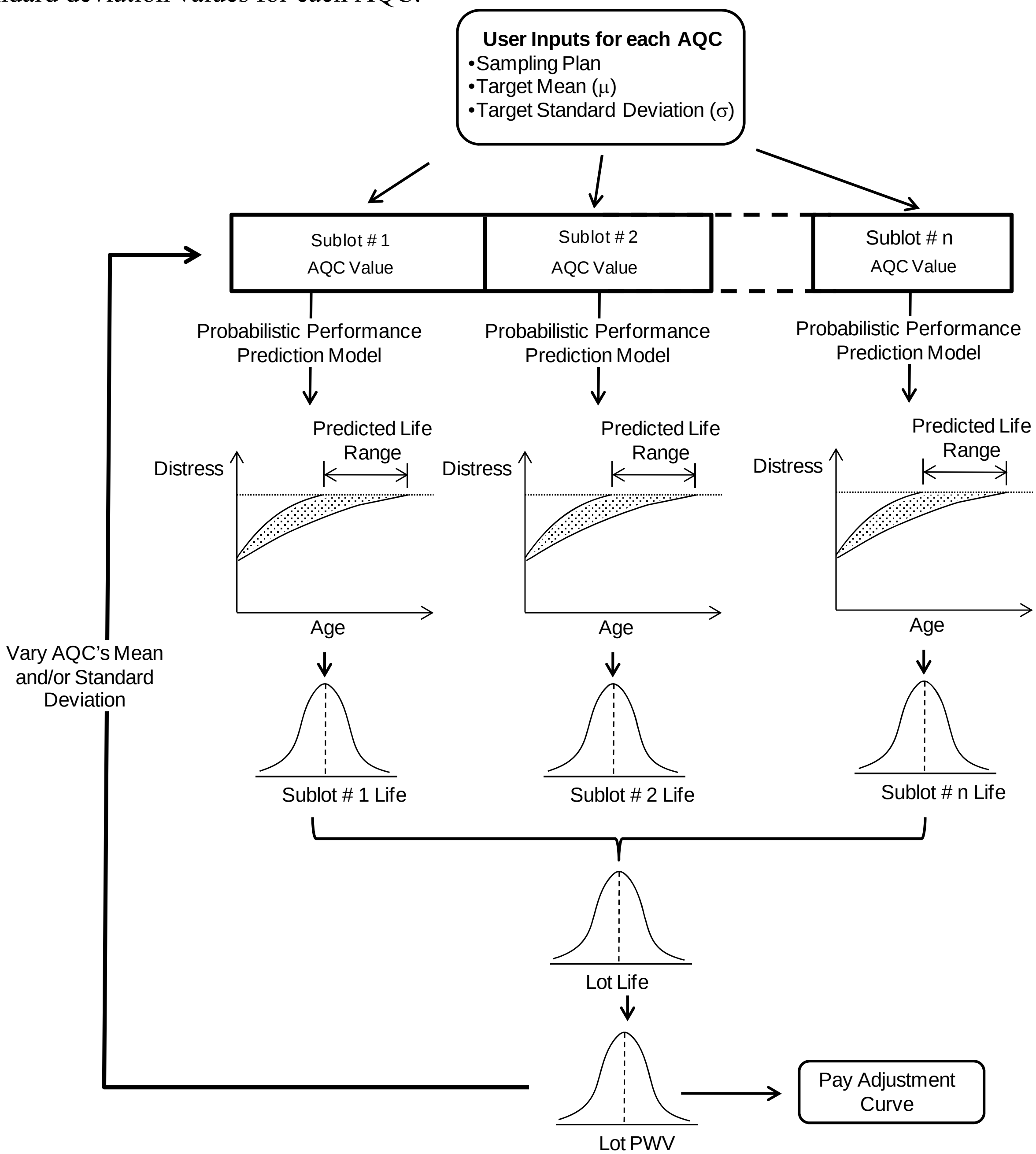


Figure 4. Detailed PRS Methodology for Pavement Preservation Treatments.

Pay factor (PF) is determined for each AQC based on the expected saving (or loss) to the agency throughout an agency-specified life cycle period, as follows:

$$PF = \frac{\left(PWV_d^{\alpha} - PWV_c^{\alpha}\right) \times P}{Bid} \times 100 \qquad (4\text{-}1)$$

where PF = pay factor as a percentage of bid price, %

PWV_d^{α} = present-worth value of as-designed lot at α confidence level

PWV_c^{α} = present-worth value of as-constructed at α confidence level

P = probability of PWV between PWV_d^{α} and PWV_c^{α}

Bid = bid price, $

The above formula is best explained through possible quality scenarios, as follows:

- **Equal Quality:** If the as-constructed lot has mean and standard deviation values equal to those specified by the agency as targets, the as-constructed and as-designed PWV distribution curves will be identical and thus the contractor receives full payment (i.e., PF = 100%).
- **High Quality:** If the as-constructed lot has higher quality than the as-designed lot (i.e., as-constructed mean and/or standard deviation values of the AQC are superior to the agency-specified targets), the as-constructed PWV distribution curve will be shifted to the left of the as-designed PWV distribution curve; and thus the contractor receives a pay increase (i.e., PF > 100%). Figure 5 shows this scenario graphically.
- **Poor Quality:** If the as-constructed lot has lower quality than the as-designed lot (i.e., as-constructed mean and/or standard deviation values of the AQC are inferior to the agency-specified targets), the as-constructed PWV distribution curve will be shifted to the right of the as-designed PWV distribution curve; and thus the contractor receives a pay reduction (i.e., PF < 100%). Figure 6 depicts this scenario graphically.

Figure 7 shows typical PF curves for the above scenarios of quality. The lot composite (overall) pay factor is normally computed as the multiplication or weighted average of the individual pay factors. State DOTs can assign minimum and maximum limits on composite pay factors for practical reasons. For example, the minimum limit can be 90% and the maximum limit 110% of the bid price, representing a 10% maximum incentive or disincentive.

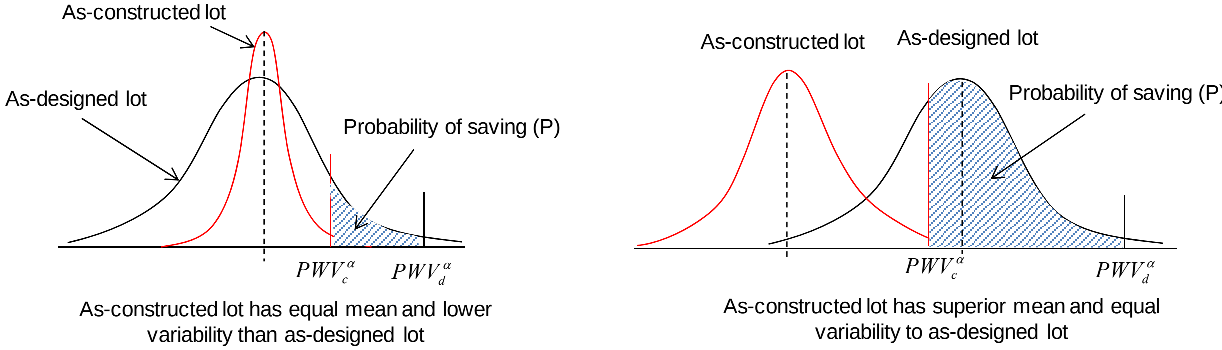


Figure 5. Scenarios of High-Quality Treatment Receiving PF > 100%.

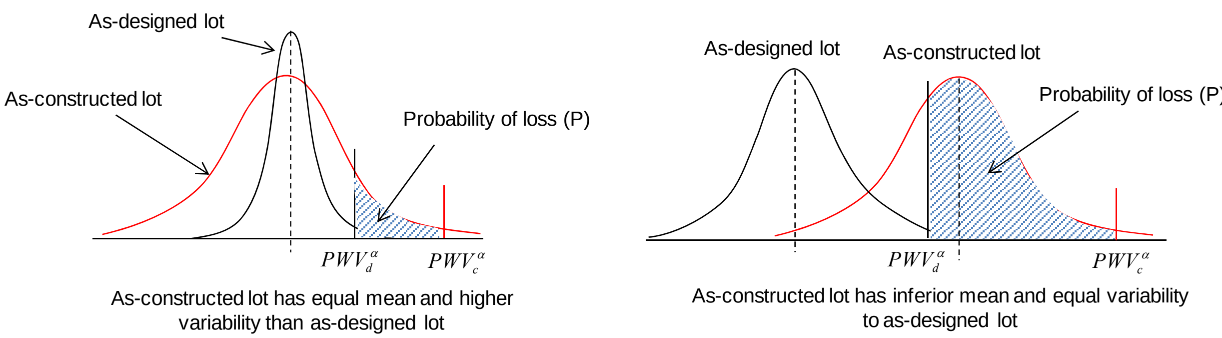


Figure 6. Scenarios of Poor-Quality Treatment Receiving PF < 100%.

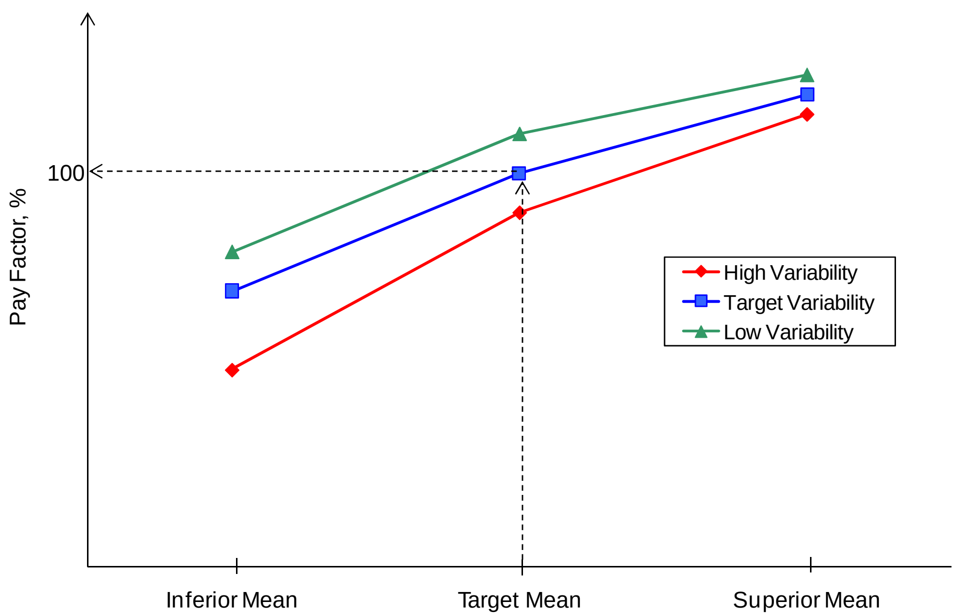


Figure 7. PF for Scenarios of High, Low, and On-Target Quality Levels.

Step 2 – Identify Acceptance Quality Characteristics and Performance Indicators for Selected Pavement Preservation Treatments

AQCs and performance indicators are core elements of PRS. The essence of PRS is that these two elements can be linked through mathematical relationships. As mentioned earlier, AQCs that are amenable to PRS can be described as follows:

- Measurable at the time of construction.
- Can be controlled by the contractor or material supplier.
- Affect the future performance of the preservation treatments.

As discussed in the previous chapter, the availability of these AQCs is a key factor in determining the suitability of treatments for PRS. Existing specifications (summarized in Chapter 2) and existing databases (e.g., the LTPP database) will be used to determine the availability of AQCs for each treatment. Also, existing laboratory and field testing procedures will be evaluated to determine their suitability for measuring AQCs for the selected treatments.

Potential AQCs for various pavement preservation treatments have been identified based on SHRP studies SHRP-H-358 and SHRP-M/FR-92-102 (Smith et al. 1993; Bullard et al. 1992). These potential AQCs for HMA-surfaced and PCC-surfaced pavement treatments are listed as follows:

- HMAC-surfaced Pavement (both flexible and composite pavements).
    - Binder/bituminous material application rate.
    - Binder/bituminous material application temperature.
    - Aggregate application rate.
    - Mineral filler application rate (slurry seal).
    - Percent of cracks sealed.
    - Aggregate maximum size.
    - Aggregate gradation.
    - Aggregate physical properties (cleanliness, shape, toughness, and absorption).
    - Time between application of bituminous material and spreading of aggregate.
    - Number of coverages per roller.
    - Time between final rolling and opening to traffic.
    - Sealant temperature (crack sealing only).
    - Time between crack sealing and opening to traffic (crack sealing only).
    - Initial Smoothness (e.g., International Roughness Index, IRI).
- PCC-surfaced Pavement.
    - Sealant properties (temperature, width, and depth below pavement surface) (crack sealing and joint resealing).
    - Width of crack or joint (crack sealing and joint resealing).
    - Depth of backer rod (joint resealing).
    - Sealant application pressure (crack sealing and joint resealing).
    - Area of removed deteriorated concrete (partial-depth repair).
    - Time of setting of repair material (partial-depth repair, dowel bar retrofitting).
    - Strength of repair material (compressive or flexural) (partial-depth repair).
    - Porosity of repair material.
    - Fracture roughness of repair material.

- Bond shear strength between base concrete and spall repair material (partial-depth repair).
- Consolidation of repair material.
- Compatibility in thermal expansion between the repair material and the original PCC slab (partial-depth repair).
- Initial surface texture (e.g., sand patch test) (diamond grinding).
- Groove characteristics (height, groove, land area, and number of grooves per ft).
- Initial smoothness (e.g., IRI).

The final set of AQCs for the selected six treatments (three treatments for HMA-surfaced pavement and three treatments for PCC-surfaced pavements) will be determined in Subtask 5.2 (Identify Existing Laboratory and Field Tests for the Selected Treatments) of Phase II. Current state DOTs specifications for pavement preservation treatments provide additional guidance for selecting AQCs that are suitable for PRS and at the same time practical to implement (see the next chapter of this report).

Once the AQCs are identified, performance indicators (individual distress type, overall condition indexes, or roughness indexes) that can be linked to these AQCs will be identified. There are dozens of types of distress types and conditions indexes for both HMA and PCC pavements (Huang 2004). Not all of them can be used in PRS for pavement preservation treatments. For preservation treatments, the selection of performance indicators should be done with great caution because each preservation treatment is intended to address very few distress types in the existing pavement. For example, chip seal is intended to address skid resistance, polishing, and a limited amount of cracking. It should not be expected to address rutting, roughness, and high-severity cracking.

Step 3 - Develop Performance Prediction Models for Pavement Preservation Treatments

Performance prediction models are crucial components of PRS. Through these models, the material and construction quality of the treatments (as measured by key AQCs) is related to the in-service performance and life-cycle costs of the treatment. As discussed earlier, the ability to relate AQCs (measured during or immediately after construction) to in-service performance allows for developing rational pay adjustment schemes.

Since, by definition, preservation treatments do not substantially increase the structural capacity to the existing pavement, their performance is affected by both their AQCs and the condition of the original (existing) pavement. For example, the structural layers underneath the treatment govern the initiation and propagation of cracking into the treatment, as illustrated in Figure 8.

Figure 9 displays a conceptual model for predicting treatment performance as a function of condition of the existing pavement, AQCs of treatment, age of treatment, and site conditions (traffic loading, climate, etc.). This concept requires the use of reliable models for predicting the condition of the existing pavement and the availability of field performance data for the preservation treatments. Existing models will be used for predicting the condition of the original pavement. The literature is rich in these models for both HMA and PCC pavements. However, these existing models vary in terms of their type (mechanistic, empirical, or mechanistic-empirical), predicted performance indicators and distress type, and suitability for PRS. Appendix B provides a bibliography of these models. Field performance data for the selected preservation treatments will be obtained from existing databases (such as the LTPP database).

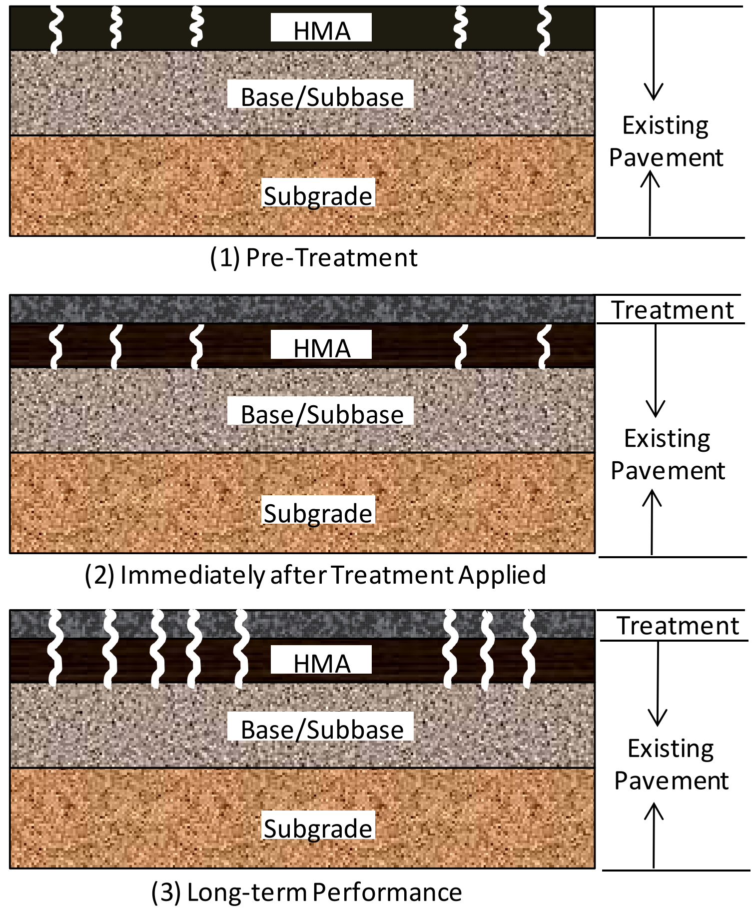


Figure 8. Propagation of Distress before and after Treatment Applied.

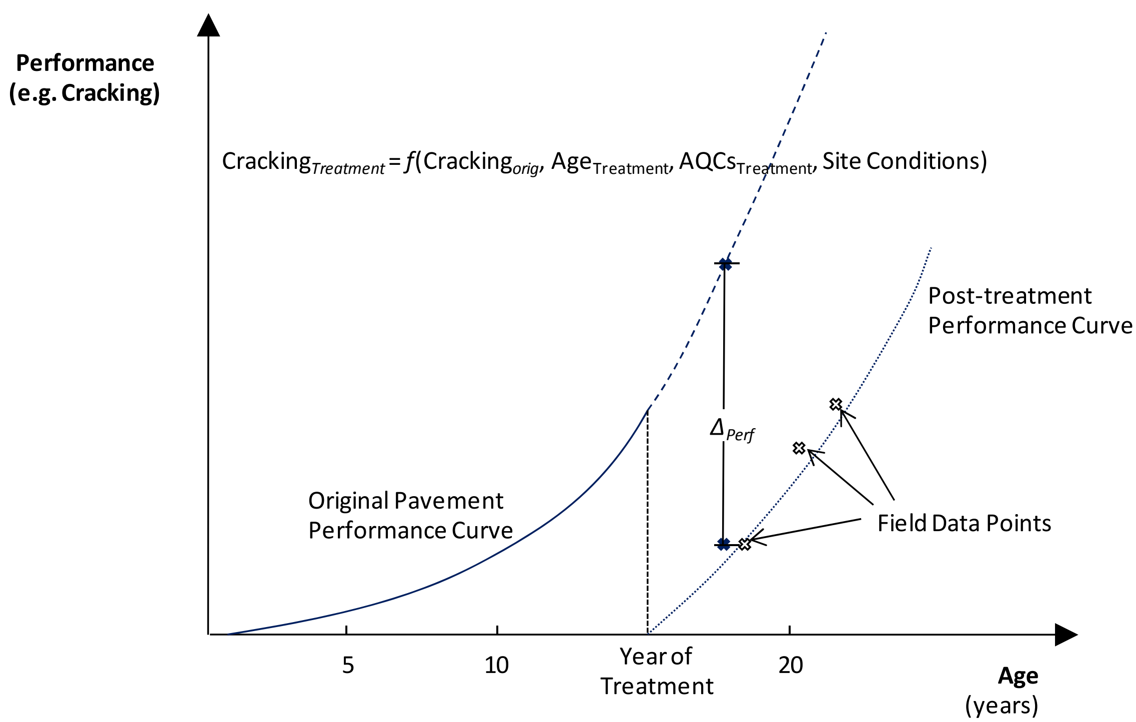


Figure 9. Conceptual Model for Predicting Treatment Performance.

Example Performance Prediction Models

As a proof of concept, this performance modeling approach was tested on three LTPP SPS-3 chip seal sections and two LTPP SPS-6 diamond grinding sections. These examples are provided to help assess the feasibility of the proposed modeling approach. The performance of the original pavement in these examples is predicted using the mechanistic-empirical pavement design guide (MEPDG) models (ARA 2004). In Phase II of the project, additional models will be evaluated and the best available models for predicting the performance of the original pavement will be used.

Example Performance Prediction Model for Chip Seal

The original HMA sections (located in Alabama, Minnesota, and Oklahoma) were treated with chip seal in 1990. Table 6 presents a summary of the original pavement design and site characteristics of these three sections.

The data shown in Table 6 were used as inputs to the MEPDG 1.1 software to predict longitudinal cracking in the original HMA pavements. Default values for some MEPDG inputs were used for variables that are not available in the LTPP database for these sections (e.g., traffic adjustment factors). Note that the MEPDG can predict a variety of distresses and IRI. However, only longitudinal cracking is used in this example.

Table 6. LTPP SPS-3 Chip Seal Sections Used for Testing Proposed Performance Prediction Modeling Approach.

Attributes	Alabama A350	Minnesota D350	Oklahoma B350
Site Information:			
Site Location	AL-152, Montgomery	US-169, Princeton	OK-3E, Seminole
Year of Most Recent Construction/Rehabilitation	1972	1980	1978
Functional Class	Urban Principal Arterial	Rural Principal Arterial	Rural Minor Arterial
Latitude, Longitude	(32.42, -86.26)	(45.59, -93.60)	(35.21, -96.67)
Initial Two-Way AADTT	550	320	600
Comp. Traffic Growth Factor	8%	4%	4%
Mean Annual Air Temp (ºF)	65.2	44.1	60.61
Freezing Index (ºF-days)	38.67	1667.91	151.55
Mean Annual Rainfall (in)	41.06	22.74	31.12
Layer Characteristics:			
AC Layer #*1*:			
Thickness (in)	1.0	0.8	1.5
Asphalt Binder Grade	Pen85-100	Pen85-100	Pen85-100
Eff. Binder Content (%)	5.0	5.4	11.6
Air Voids (%)	6.0	7.2	7.0
Cum. Retained % ¾″ Sieve	0	0	0
Cum. Retained % 3/8″ Sieve	23	1	23
Cum. Retained % #4 Sieve	40	28	35
% Passing #200 Sieve	6	2	8

Attributes	Alabama A350	Minnesota D350	Oklahoma B350
AC Layer #2:			
Thickness (in)	3.0	4.0	8.8
Asphalt Binder Grade	Pen85-100	Pen120-150	Pen85-100
Eff. Binder Content (%)	5.0	7.0	11.0
Air Voids (%)	6.0	4.0	3.7
Cum. Retained % ¾″ Sieve	10	0	20
Cum. Retained % 3/8″ Sieve	34	18	50
Cum. Retained % #4 Sieve	42	40	57
% Passing #200 Sieve	2	4	6
AC Layer #3:			
Thickness (in)	6.5	-	-
Asphalt Binder Grade	Pen85-100	-	-
Eff. Binder Content (%)	5.0	-	-
Air Voids (%)	8.0	-	-
Cum. Retained % ¾″ Sieve	14	-	-
Cum. Retained % 3/8″ Sieve	36	-	-
Cum. Retained % #4 Sieve	54	-	-
% Passing #200 Sieve	1	-	-
Base/Subbase:			
Material Type	Soil-aggregate mixture	A-1-b	A-1-a
Thickness (in)	6.0	6.0	12.0
Modulus (input) (psi)	10,000	38,000	29,500
Plasticity Index	1	1	0
Liquid Limit	6	11	6
% Passing #200 Sieve	8.7	6.9	12
% Passing #4 Sieve	44.7	63	41
Subgrade:			
AASHTO Soil Class	A-7-6	A-2-4	A-1-a
CBR (%)	9	-	-
Modulus (psi)	10,426 (calculated)	30,000 (input)	29,500 (input)
Plasticity Index	17	2	0
Liquid Limit	47	14	6
% Passing #200 Sieve	76.6	14.1	12
% Passing #4 Sieve	97.7	87.2	41

Figure 10 shows the MEPDG-predicted longitudinal cracking curve (for the original pavement) and the field-measured longitudinal cracking values for the three HMA sections. In all the three graphs, the green-triangle point represents the field-measured longitudinal cracking immediately before chip seals were applied in 1990. The red-square points represent the field-measured longitudinal cracking data in subsequent years after the chip seal applications. As the field survey was carried out once every two years or even at a longer time intervals, these data points were not evenly distributed. The blue lines represent MEPDG-predicted longitudinal cracking in the original pavement (if the treatment was not applied). Ultimately, mathematical relationships will be developed to link key chip seal quality characteristics (along with other variables that describe the original pavement and site conditions) to the magnitude of reduced distress throughout the treatment life. Table 7 shows chip seal quality characteristics available in the

LTPP database that can potentially be used to develop these relationships. This example indicates that the proposed modeling approach is promising and merits pursuing.

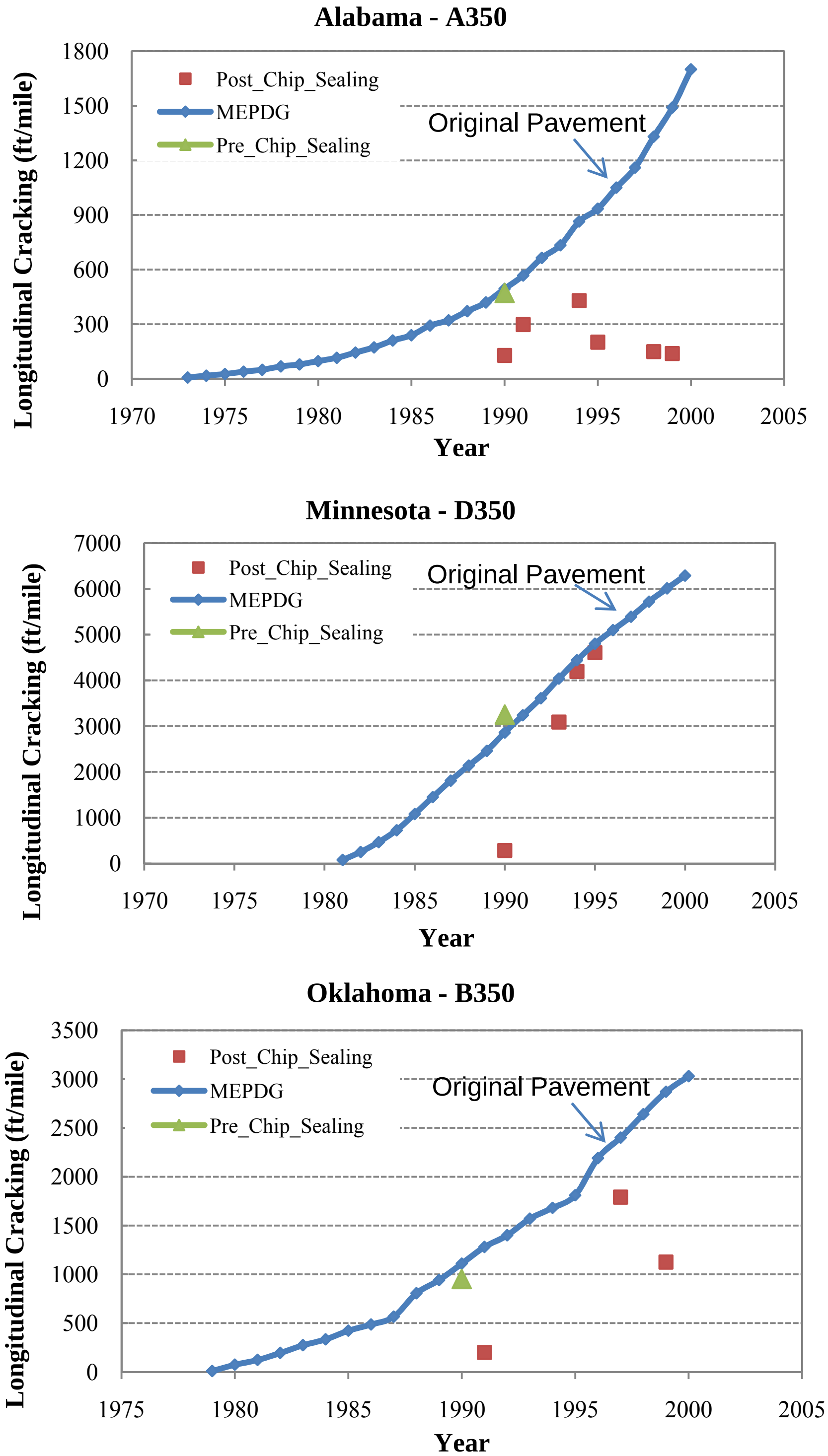


Figure 10. MEPDG-Predicted and Field-Measured Longitudinal Cracking for Three LTPP SPS-3 Chip Seal Sections.

Table 7. Materials and Construction Quality Characteristics for Chip Seal of the Three LTPP SPS-3 Sections.

Attributes	Alabama A350	Minnesota D350	Oklahoma B350
Date of Chip Sealing	8/7/1990	7/31/1990	9/10/1990
Thickness (in)	0.3	0.3	0.3
Asphalt Binder:			
Asphalt Type	Emulsified CRS-2	Emulsified CRS-2	Emulsified CRS-2
Specific Gravity	-	-	1.022
% Residue by Distillation	66.0	66.8	64.8
Ductility	80	52	80
Penetration	129	127	105
Solubility	99.94	99.67	99.97
Viscosity at 50ºC (s)	118	55	185
Aggregate:			
Aggregate Type	Crushed river gravel	Granite	Crushed river gravel
Flakiness Index	10	17	17
Avg. Least Dimension (in)	0.24	-	0.24
Bulk Specific Gravity	2.58	-	2.58
Moisture Content (%)	0.4	1.0	0.4
% Passing ½″ Sieve	100	100	99
% Passing 3/8″ Sieve	79	67	69
% Passing #4 Sieve	9	4	2
% Passing #8 Sieve	6	3	0
% Passing #200 Sieve	1.9	0.9	0
Construction:			
Air Temperature (ºF)	100	76	93
Relative Humidity (%)	58	32	49
Surface Condition	Slightly flushed	Normal	Slightly oxidized
Est. % of Cracks Sealed	0	20	90
Target Application Rate of Aggregate (lb/sq yd)	22	25	22
Application Rate of Cover Aggregate in WP (lb/sq yd)	23.2	25.2	22
Application Rate of Cover Aggregate b/t WP (lb/sq yd)	21.2	24.9	20
Time Before Rolling (sec)	20	20	25
Roller Coverages	5	5	5
Time Before Open (hr)	2.6	-	2.3

Example Performance Prediction Model for Diamond Grinding

In these examples, the original PCC sections (located in Pennsylvania and Tennessee) were treated with diamond grinding in 1992 and 1996, respectively. Table 8 presents a summary of the original pavement design and site characteristics of these two sections.

Table 8. LTPP SPS-6 Diamond Grinding Sections Used for Testing Proposed Performance Prediction Modeling Approach.

Attributes	Pennsylvania 42 0605	Tennessee 47 0605
Site Information:		
Site Location	I-80, Centre County	I-40 Madison County
Year of Original Construction	1968	1964
Functional Class	1 (Rural Principal Arterial–Interstate)	1 (Rural Principal Arterial–Interstate)
Latitude, Longitude	40.97, -77.79	35.72, -88.64
Initial Two-Way AADTT	4220	5560
Mean Annual Air Temp (ºF)	48.6	59.0
Freezing Index (ºF-days)	712.4	189.7
No. of Days below 32 ºF in a Year	133	75
Mean Annual Rainfall (in)	39.6	53.8
Average No. of Wet Days	180	154
Diamond Grinding Date	9/17/1992	6/7/1996
Layer Characteristics:		
PCC Slab:		
Type	JRCP	JPCP
Thickness (in)	10.1	9.0
Dowel Diameter (in)	1.25	No Dowels
Contraction Spacing (ft)	61.5	25
Base:		
Type	Crushed Stone	Soil Cement
Thickness (in)	11	7.5
Subgrade:		
Type	Fine-Grained Soils: Silt	Fine-Grained Soils: Lean Inorganic Clay
AASHTO Soil Class	A-7-5	NA
CBR (%)	7	NA

The data shown in Table 8 were used as inputs to the MEPDG 1.1 software to predict faulting in the original PCC pavements. Similar to the chip seal examples, default values for some MEPDG inputs were used for variables that are not available in the LTPP database for these sections (e.g., traffic adjustment factors). Only joint faulting is used in this illustrative example.

Figure 11 shows the MEPDG-predicted average joint faulting curve (for the original pavement) and the field-measured faulting values for the two PCC sections. In the Pennsylvania section, the green-triangle point represents the field-measured faulting immediately before diamond grinding was applied in 1992 (this data point was missing for the Tennessee section). The red-square points represent the field-measured average faulting in subsequent years after the diamond grinding was applied. The blue lines represent MEPDG-predicted average faulting in the original pavement (if the treatment was not applied). The next step is to develop mathematical relationships that link key diamond grinding quality characteristics (along with other variables that describe the original pavement and site conditions) to the magnitude of reduced distress throughout the treatment life. Table 9 shows diamond grinding quality characteristics available in the LTPP database that can potentially be used to develop these relationships. Again, these two examples demonstrated that the proposed modeling approach is promising and merits pursuing.

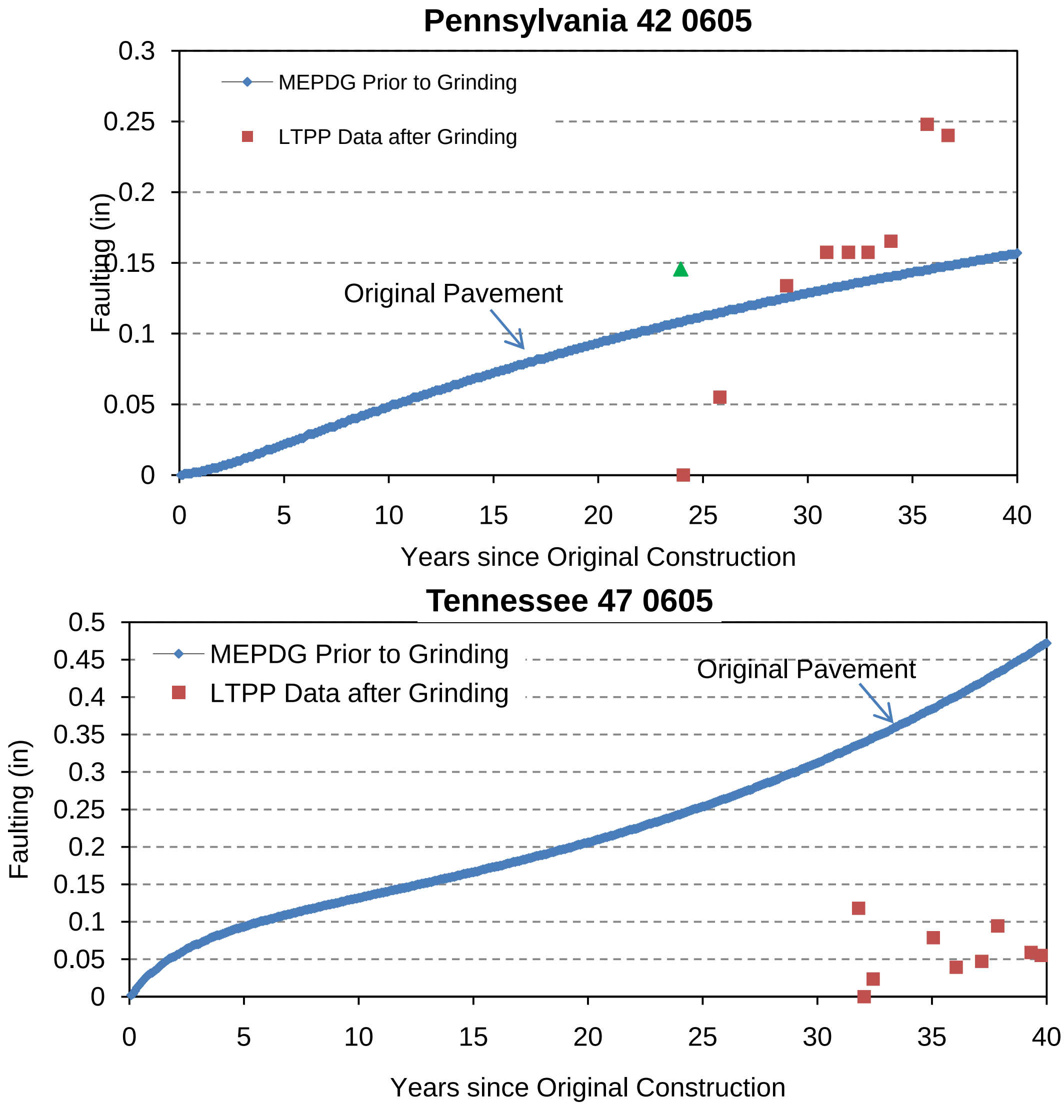


Figure 11. MEPDG-Predicted and Field-Measured Joint Faulting for Two LTPP SPS-6 Diamond Grinding Sections.

Table 9. Construction Quality Characteristics for Diamond Grinding of the Two LTPP SPS-6.

Attributes	Pennsylvania 42 0605	Tennessee 47 0605
Pre-Grinding IRI (in/mi)	220	NA
Post-Grinding IRI (in/mi)	89.7	49
Reduction in IRI (in/mi)	130.3	NA
Head Width (in)	36	38
Groove Width (in)	0.1	0.1
Blade Spacing (in)	0.1	0.1
Average Depth (in)	0.06	0.1

Probabilistic Models

Since the available data can be noisy (i.e., highly variable with no clear patterns) and incomplete, it is best to use probabilistic modeling techniques for predicting in-service performance of treatments. Bayesian models are a promising technique in this situation. These models are generally developed by combining observed data and expert knowledge using Bayesian Networks (BNs). BNs are a formalism (founded in probability theory) for modeling problems involving uncertainty (Pearl 1988). A BN (which can often be understood in terms of cause-effect relationships) can be used for computing any probabilistic statement (conditional or not) of the involved variables. The influences and probabilistic interactions among variables that affect treatment performance can potentially be described in a BN. One feature that makes BNs particularly attractive in this case is that it is possible to start by defining a probability distribution from one source (e.g., expert knowledge), and then refining it later using another source (e.g., field data).

The structure of a BN can be designed using knowledge of known causal dependences, influences, or correlations. All or part of these relationships may be derived from knowledge of domain experts, obtained from descriptions in the literature, or extracted from field data. Figure 12 shows a simple generic example BN. For example, the goal variable (X7) depends on the mediating variables (X5 and X6) and the mediating variable X5 is influenced by another mediating variable (X3). For each node (i.e., variable), there is a conditional probability function that relates this node to its parents. For instance, the probabilistic relationship between X4 and its parent X3 is the conditional probability distribution of X4 given X3 [i.e., P(X4|X3)].

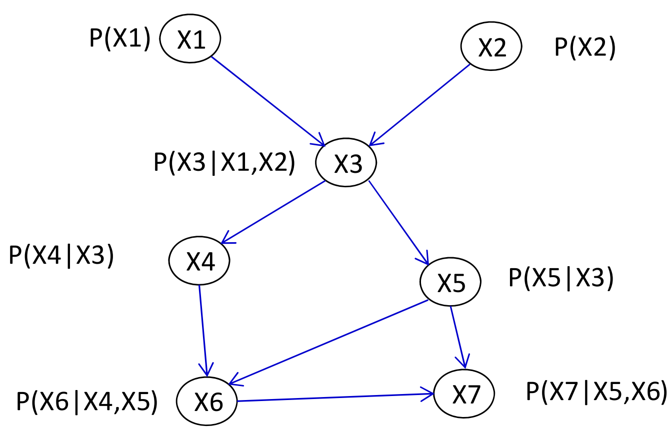


Figure 12. Example Generic BN with Seven Variables.

Hajek and Bradbury (1996) described a Bayesian statistical analysis methodology for pavement deterioration modeling in the Canadian Strategic Highway Research Program (C-SHRP). In this application, several distress prediction models were constructed initially based on field data alone using linear regression techniques. After evaluation, the best one was selected for further analysis. Subsequently, five experts with 10 to 30 years of relevant experience and knowledge of past pavement surface failures containing steel slag aggregate were requested to rate the level of distress at different ages with different traffic and asphalt binder contents using a scale from 0 (no distress) to 10 (sufficient distress that unmistakably requires a rehabilitation treatment). Separate matrices for cracking and raveling were used since the distress index was considered as a linear function of cracking and raveling. The distress index (DI) matrices were then obtained by adding two matrices (each having 18 cells) coded by each expert. After carrying out a sensitivity analysis of these models, the final distress prediction model was selected. Hajeck and Bradbury (1996) stated that "the C-SHRP Bayesian statistical analysis software provides a unique feature that enables the user to obtain a probability density function for regression coefficients (for the data-based, expert-based, and combined models) and plot them in one composite figure for easy comparison."

Data Availability and Quality

The LTPP database will be the primary source of data for developing performance prediction models for preservation treatments (a total of six treatments seemed most suitable for PRS). Ideally, the database should include treatment type, treatment year, treatment construction and materials quality characteristics, pre-treatment conditions, site conditions (traffic loading, climatic factors, subgrade type, etc.), and treatment performance (measured distresses and roughness).

The research team has identified several promising sections for potential use in this research project. These sections were part of the LTPP experiments SPS-3, SPS-4, SPS-5, and SPS-6. The maps in Figures 13 and 14 show the number of these promising sections (grouped by state and treatment type) for HMA-surfaced and PCC-surfaced pavement, respectively.

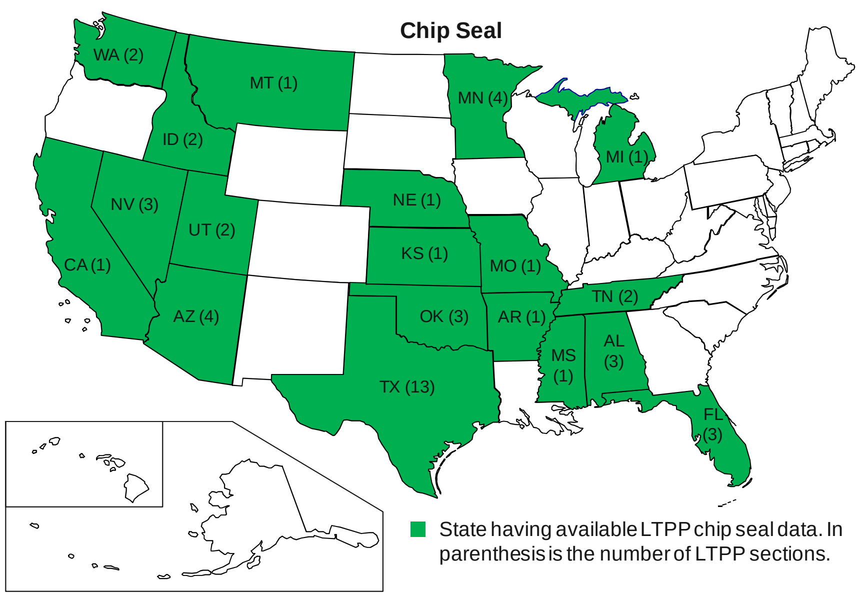


Figure 13. Promising LTPP Sections of Preservation Treatments for HMA Pavement.

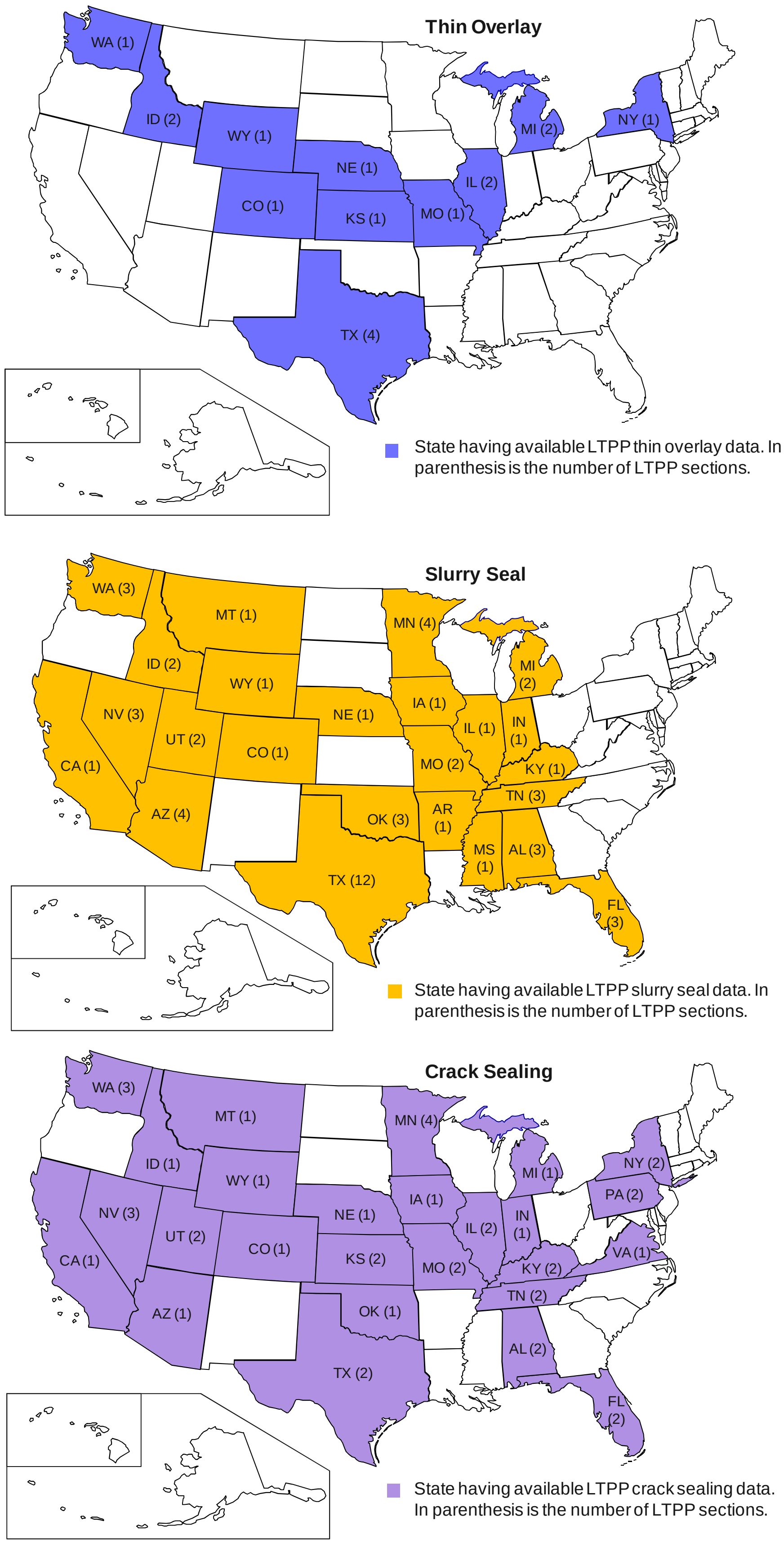


Figure 13. Promising LTPP Sections of Preservation Treatments for HMA Pavement (cont.).

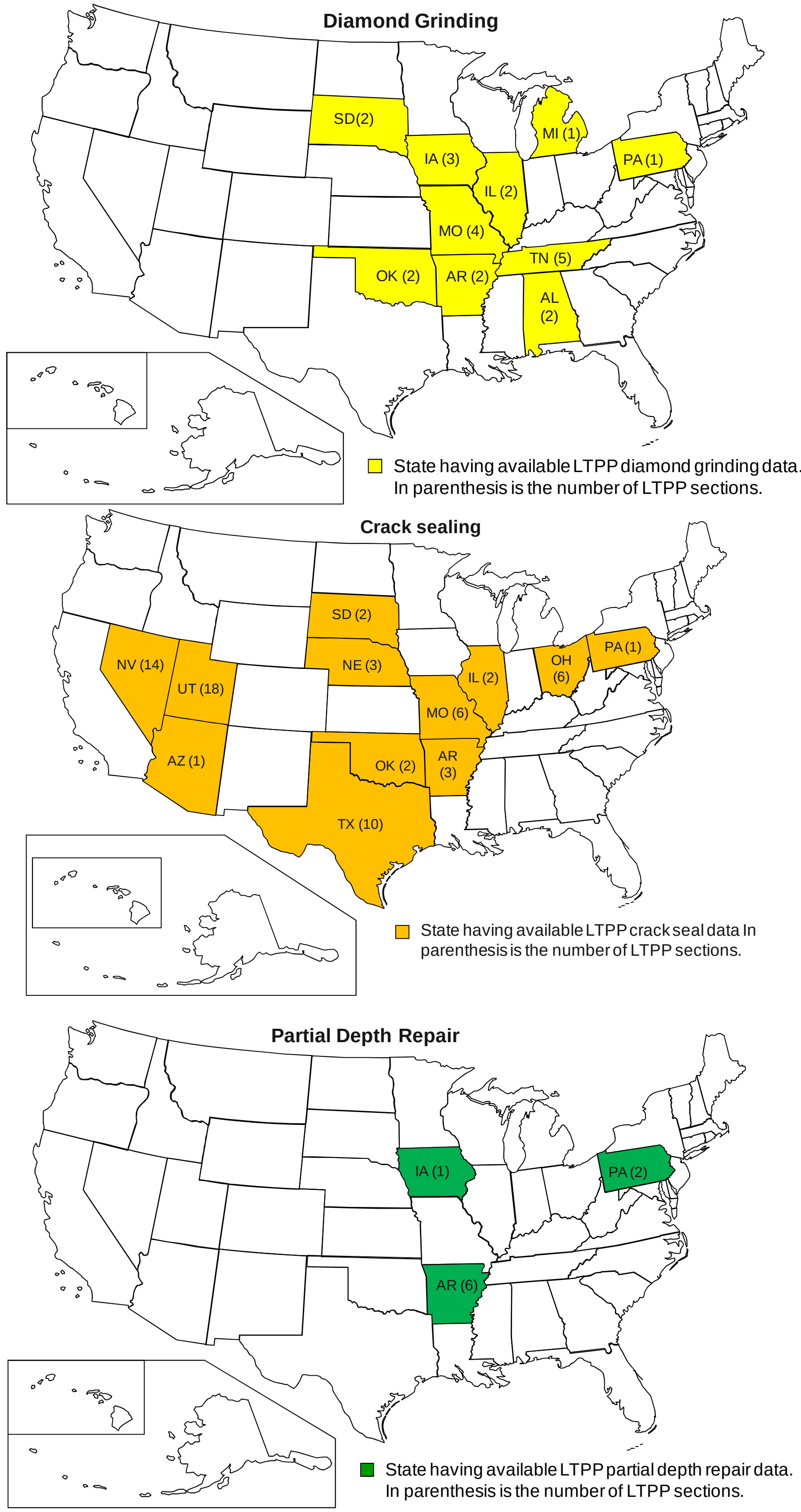
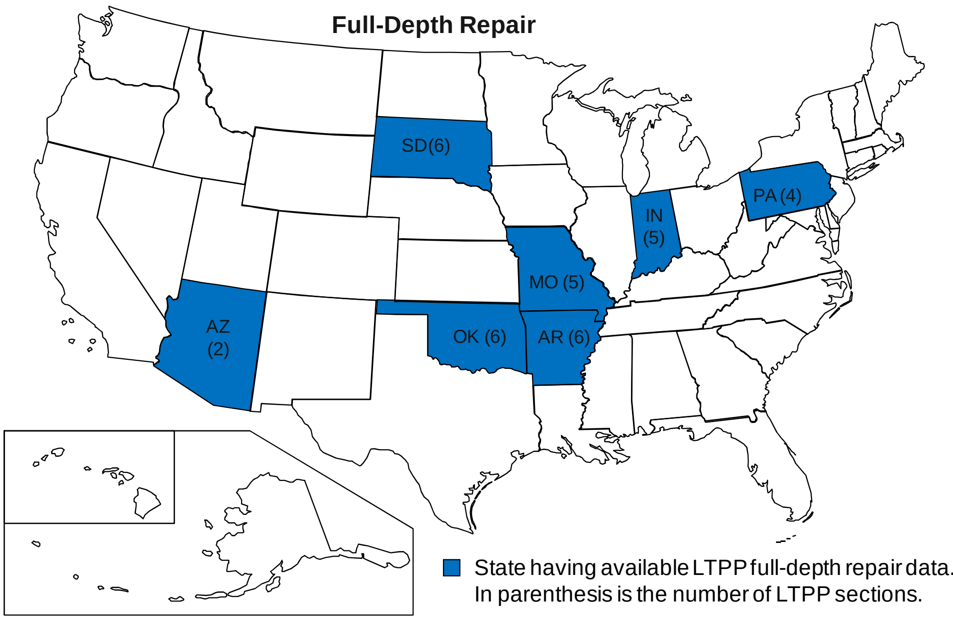
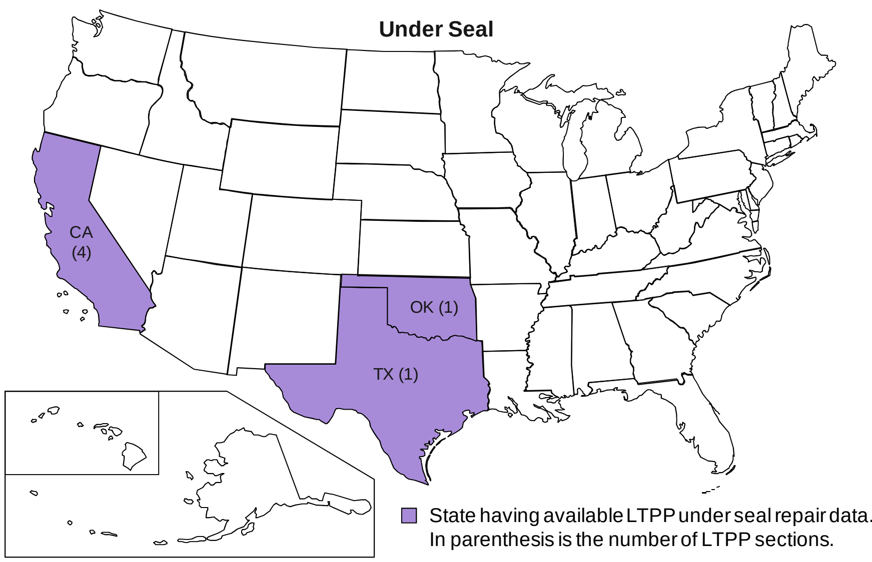


Figure 14. Promising LTPP Sections of Preservation Treatments for PCC Pavement.





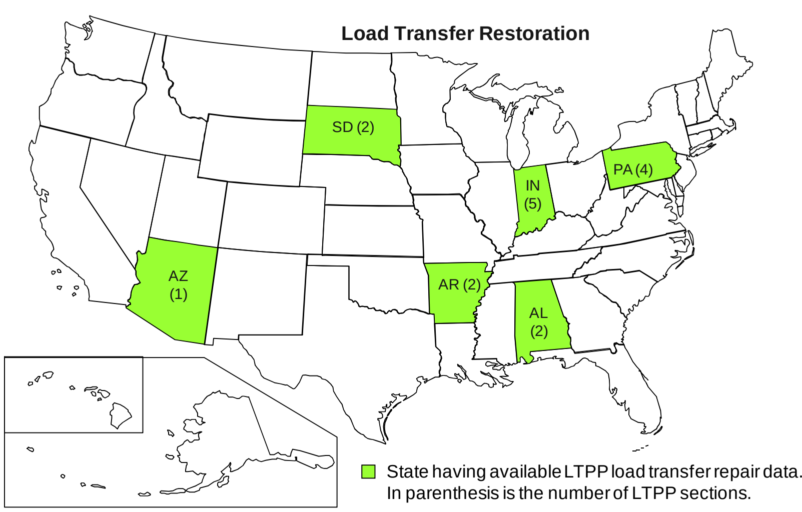


Figure 14. Promising LTPP Sections of Preservation Treatments for PCC Pavement (cont.).

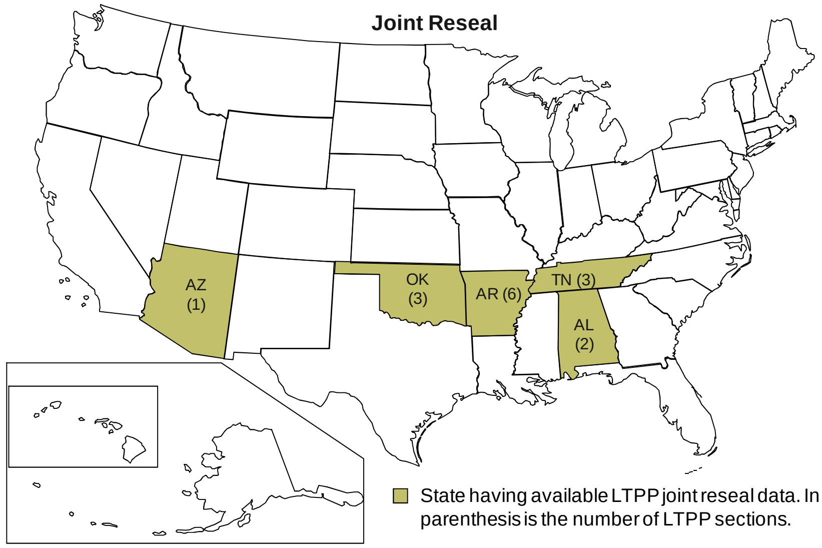


Figure 14. Promising LTPP Sections of Preservation Treatments for PCC Pavement (cont.).

Appendixes C and D provide more information about these sections. The research team will continue to evaluate the quality of these data in greater detail. If ultimately this data set was found to be insufficient, the research team will seek to obtain supplementary data from individual state DOTs. Based on the literature review, candidate states include Arizona (Scofield and Epps 1999), California, Iowa (Jahren et al. 1999), Michigan, New York, North Carolina, South Dakota (Wade et al. 2001), and Texas (Freeman 1999; Syed et al. 1998; Tang and Zollinger 1997).

Step 4 - Develop a Procedure for Designing and Evaluating Acceptance Sampling Plans

The Transportation Research Circular E-C137 (TRB 2009) defines an acceptance plan as "an agreed-upon procedure for taking samples and making measurements or observations on these samples for the purpose of evaluating the acceptability of a lot of material or construction." A sound statistical sampling plan is essential for unbiased PRS. A procedure for designing and evaluating acceptance sampling and testing plans will be developed and integrated into the PRS methodology and guidelines. Key components of this procedure include:

- **Lot:** This is the amount of treatment that may be accepted (sometimes with pay adjustment) or rejected based on the deviation of the as-constructed quality level from the as-designed quality level. Thus, payments are made on a lot-by-lot basis. A lot represents the amount treatment produced by essentially the same process. The lot size is measured in different units, depending on the treatment. For example, a diamond grinding lot may be measured in lane-miles; whereas a slurry seal lot may be measured in tonnage.
- **Sublots:** Typically, each lot is divided into 3-5 sublots for sampling stratification purposes. Thus, sublots should be of approximately equal size. Also, as discussed earlier, the proposed PRS methodology is based on predicting performance on a sublot-by-sublot basis.
- **Sample size:** Sample size refers to the number of tests or measurements taken randomly from the lot. Since a lot is divided into sublots, at least one unit of the sample is taken from each sublot. However, it is important that each sample unit (i.e., a test or measurement) be taken at randomly-selected location within the sublots. Randomness of sampling is a vital assumption upon which statistical acceptance procedures are based.

- **Acceptable Quality Level (AQL):** This is the true quality level of a lot that the buyer (e.g., state DOT) is willing to accept at full payment to the contractor.
- **Rejectable Quality Level (RQL):** This is the true quality level of a lot that the buyer (e.g., state DOT) considers so deficient that replacement or corrective action is warranted.
- **Maximum Allowable Quality Level (often referred to as M):** A lot is rejected if the sample percent within limits (PWL) is less than M [or if the sample percent defective (PD) exceeds M]. Traditionally, M is set between RQL and AQL as an additional reliability to the constructed product and to provide balanced contractor and agency risks (AASHTO 2005 and AASHTO 1995).

Operating characteristic (OC) curves and expected pay curves will be used to evaluate acceptance sampling plans. These curves allow for determining the buyer's and seller's risks associated with the sampling plan (Weed 1994; Chamberlin 1995). The seller's risk (α) is the risk of erroneously rejecting or assigning a payment decrease to a lot that indeed should be accepted or assigned a pay increase. The buyer's risk (β) is the risk of erroneously accepting or not assigning a payment decrease to a lot that indeed should be rejected or assigned a pay decrease. The seller's risk represents the contractor's risk and the buyer's risk represents the highway agency's risk. Figure 15 shows a graphical representation of an OC curve.

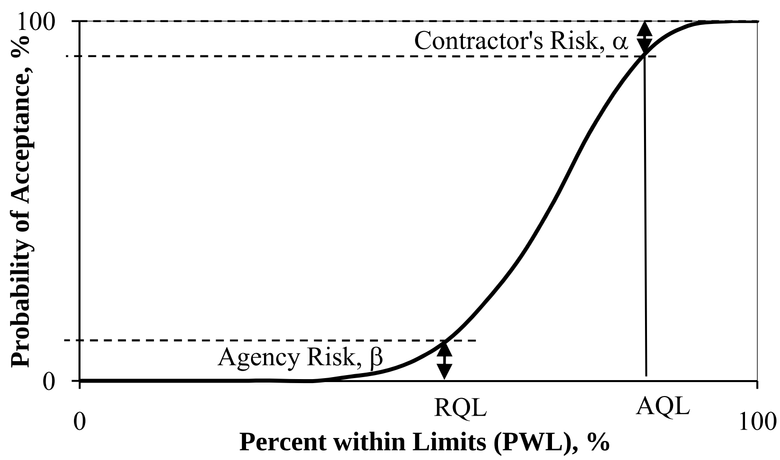


Figure 15. Typical OC Curve.

The theoretical basis of statistical sampling plans is well-documented in the literature [see for example the Standard Recommended Practice for Acceptance Sampling Plans for Highway Construction (AASHTO Designations: R 9-90 and R 9-05), Buratti et al. 2004, and Duncan 1986]. The research team will build on this knowledgebase to develop specific guidelines for developing acceptance plans for pavement preservation PRS.

Step 5 – Evaluate and Refine the PRS Methodology and Guidelines

Since the final guidelines will be developed based on the PRS methodology discussed earlier, it is important to evaluate this methodology as a whole system (not as separate components). The research team will integrate the PRS methodology into a simulation-based software tool, so that it can be tested, verified, and refined (as needed). This software tool will be developed as a research tool (not as a commercial software application). A comprehensive sensitivity analysis will be designed and performed on the methodology to uncover errors, understand its limitations, and improve it.

Finally, the PRS methodology and guidelines will be demonstrated through illustrative examples. These examples will be designed to illustrate the use of the PRS guidelines for different preservation treatments (six treatment found most suitable for PRS), pavement types (HMA-surfaced pavement and PCC-surfaced pavement), highway classification (high, medium, and low traffic volumes), and climatic regions.

CHAPTER 5 A PROCESS FOR ASSESSING THE SUITABILITY OF PAVEMENT PRESERVATION TREATMENTS FOR PRS

This chapter presents a process for assessing the suitability of pavement preservation treatments for PRS using the Analytic Hierarchy Process.

ANALYTIC HIERARCHY PROCESS

Several multi-criteria decision analysis and ranking methods have been identified for possible use in ranking preservation treatments based on their suitability for PRS. These methods include the Analytic Hierarchy Process, Direct Weighting Method, Observer-Derived Weights Method, Multi-Attribute Utility Theory, Swing Weighting Method, and Indifference Trade-off Weighting Method. The details of these methods are available in the literature (see for example, Sinha et al. 2009; Huber 1974; Hobbs 1980; Keeney and Raiffa 1993). Based the pros and cons of these methods, as identified in the literature, AHP has been selected for assessing the suitability of pavement preservation treatments for PRS. AHP has been selected for the following primary reasons:

- Its ability to handle multi-criteria decision-making problems.
- Its ability to consider both qualitative and quantitative input parameters.
- Its computational process is robust, and at the same time, is relatively simple to perform.

AHP was originally developed in the early 1970s to deal with unstructured decision-making problems in contingency planning at the Department of Defense (Saaty 1980; Saaty 1990b). AHP requires formulating the decision problem in a hierarchal fashion. The hierarchy consists of the decision objective at the highest level, a set of alternatives, at the bottom or last level, and a set of evaluation criteria at mid-level that relate the alternatives to the objective. The evaluation criteria can be broken down into multiple sub-criteria, depending on the complexity of the decision problem.

The elements at each level are placed in a pairwise matrix, where each element is compared against each other element. The pairwise comparisons are made using a predefined importance rating scale (Saaty 1990b). This importance rating scale ranges from 1 to 9. The odd numbers (1, 3, 5, 7, and 9) represent the primary importance intensity values, while the even numbers, 2, 4, 6, and 8 represent intermediate importance intensity values. Table 10 illustrates this rating scale.

The elements are not compared to the decision as a whole; rather they are compared with each other to determine how they compete for importance in making the final decision. The pairwise comparison builds an $n \times n$ judgment matrix (called A matrix); where n is the number of elements being compared.

Table 10. AHP Relative Importance Rating Scheme.

Importance Intensity	**Relative Importance (from Saaty 1990a)**	**Explanation**
1	Equal importance	Two factors contribute equally to the objective.
3	Moderate importance of one over another	Experience and judgment strongly favor one factor over another.
5	Essential or strong importance	Experience and judgment strongly favor one factor over another.
7	Very strong importance	A factor is strongly favored and its dominance demonstrated in practice.
9	Extreme importance	The evidence favoring one factor over another is of the highest order of affirmation.

A consistency ratio (CR) is used to assess the consistency of the evaluator in making the pairwise comparisons. The CR is computed as follows:

$$CR = \frac{CI}{RI} \tag{5-1}$$

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \tag{5-2}$$

Where CI = consistency index; n = size of judgment matrix; λ_{max} = maximum eigenvalue; and RI is the Random Consistency Index obtained by computing the CI value for randomly generated matrices. RI can be obtained by approximating RI values for matrices of order 1 to 10 using a sample size of 500 (Saaty 1980), as shown in Table 11.

Table 11. Average RI Values (from Saaty 1980).

Size of Matrix	**Average RI**
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Saaty (1990b) suggests that the CR should be less than 10%. This CR threshold value essentially implies that the method allows for up to 10% error in human judgment during the pairwise comparison phase.

Once the judgment matrix passes the consistency check, the weights associated with the elements being compared are computed in a process known as "synthesis." This process involves computing the principal eigenvector associated with the maximum eigenvalue for the pairwise matrix A. This principal eigenvector is normalized to create a relative ratio scale that can be used as the priority weight vector (called w) or more simply put, weights associated with each element being compared. The calculation of an eigenvalue and eigenvector are not discussed here for brevity; but they can be found in most algebra textbook. A priority weight vector w is established for each criterion, sub-criterion, as well as the alternatives under each sub-criterion.

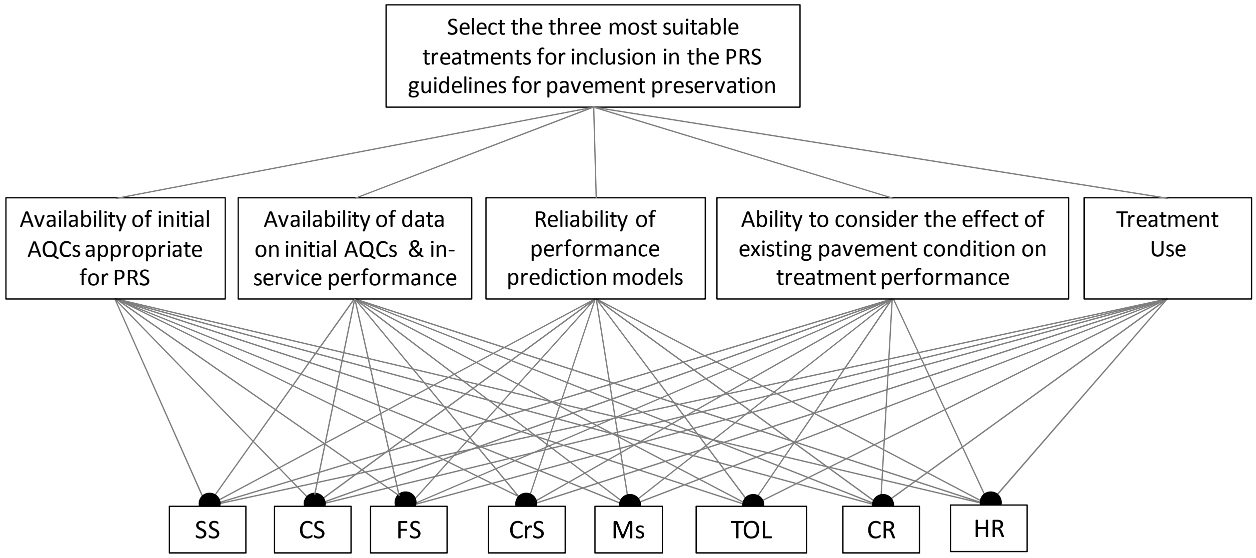
AHP STRUCTURE

Figures 16 and 17 show the decision hierarchy for assessing the suitability of pavement preservation treatments for PRS for HMA-surfaced and PCC-surfaced pavements, respectively. Each hierarchy consists of the following layers:

- Objective (Level 1): The objective is "to select the three most suitable treatments for inclusion in the PRS guide for pavement preservation."
- Evaluation Criteria (Level 2): The evaluation criteria consist of five factors, as follows:
  - Availability of initial AQCs.
  - Availability of data that can be used for correlating initial AQCs with in-service performance.
  - Reliability of performance prediction models that link initial AQCs to in-service performance.
  - Ability to consider the effect of existing pavement condition on treatment performance.
  - Industry and DOT willingness to accept and implement PRS.
- Treatment (Level 3): For HMA-surfaced pavements, eight treatments are included at this level of the hierarchy. For PCC-surfaced pavements, seven treatments are included.

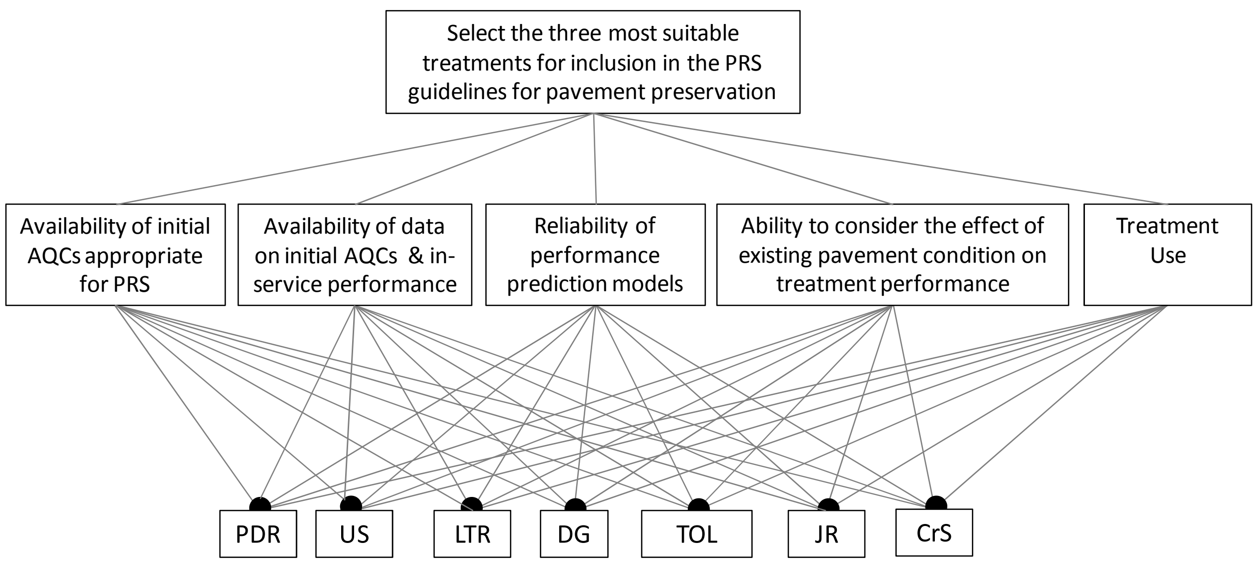
The decision-making task is to determine the three most suitable treatments for PRS, considering the above evaluation criteria.

A judgment matrix for the evaluation level (Level 2) will be established to determine a priority weight for each evaluation criterion. Also, judgment matrixes will be established for the preservation treatments based on each evaluation criterion (i.e., five judgment matrixes for HMA-surfaced pavement and five judgment matrixes for PCC-surfaced pavements). Finally, a priority score will be computed for each treatment based on the pairwise comparisons of all judgment matrixes. Treatments with the highest three priority scores (for each pavement type) will be deemed as most suitable for PRS. This process is best demonstrated through an example, as discussed in the following section of this chapter.



SS=Slurry Seals; CS=Chip Seals; FS=Fog Seals; CrS=Crack sealing; Ms=Microsurfacing; TOL=Thin HMA Overlay; CR=Cold in-place recycling; HR=Hot in-place recycling

Figure 16. AHP for Assessing the Suitability of HMA Pavement Preservation Treatments for PRS.



PDR=Partial-Depth Repair; US=Undersealing (or Slab Stabilization); LTR=Load Transfer Restoration; DG=Diamond Grinding TOL=Thin HMA Overlay; JR=Joint Resealing; CrS= Crack Sealing

Figure 17. AHP for Assessing the Suitability of PCC Pavement Preservation Treatments for PRS.

DEMONSTRATION EXAMPLE

(This example is hypothetical and is intended for demonstration purposes only.)

Figure 18 shows Level 2 judgment matrix for the demonstration example. In this hypothetical example, the result of comparing "suitability of initial AQCs for PRS" to "availability of data on initial AQCs & in-service performance" is 2, which indicates that the importance of "suitability of initial AQCs for PRS" to the evaluator is two times that of the "availability of data on initial AQCs & in-service performance." On the other hand, the result of comparing "availability of data on initial AQCs & in-service performance" to "treatment use" is 1/2, which indicates that the importance of "availability of data on initial AQCs & in-service performance" is half that of the "treatment use."

Evaluation Criteria	Suitability of initial AQCs for PRS	Availability of data on initial AQCs & in-service performance	Availability and reliability of performance prediction models	Ability to consider the effect of existing pavement condition on treatment performance	Treatment Use
Suitability of initial AQCs for PRS	1	2	4	3	2
Availability of data on initial AQCs & in-service performance		1	5	4	1/2
Availability and reliability of performance prediction models			1	1/2	1/5
Ability to consider the effect of existing pavement condition on treatment performance				1	1/7
Treatment Use					1

Figure 18. Level 2 Judgment Matrixes for the Demonstration Example.

The CR of this example judgment matrix is 6.8% (computed using Equations 5-1 and 5-2), which is less than the 10% threshold value. Thus, the matrix passes the consistency check and the priority weights can be computed. The final weights for the evaluation elements are calculated using the synthesis procedure mentioned earlier and are shown in Table 12.

Table 12. Weights for Each Evaluation Criterion in the Demonstration Example.

Evaluation Criterion No.	Evaluation Criterion	Priority Weight
1	Suitability of initial AQCs for PRS	0.35
2	Availability of data on initial AQCs & in-service performance	0.21
3	Availability and reliability of performance prediction models	0.05
4	Ability to consider the effect of existing pavement condition on treatment performance	0.07
5	Treatment Use	0.32

Figure 19 shows five hypothetical judgment matrixes for the PCC-surfaced pavement preservation treatments (Level 3 in the AHP hierarchy). The CR values for these hypothetical matrixes range between 4% and 7.1%, which are less than the 10% threshold value. Thus, these matrixes pass the consistency check and a weight can be computed for each treatment based on each evaluation criterion. Table 13 shows these weights.

Comparisons based on suitability of initial AQCs for PRS (CR=6.2%)

Treatment	Partial-Depth	Undersealing	Load transfer	Diamond	Thin HMA	Crack	Joint
Partial-Depth Repair	1	1/2	2	2	1/2	2	2
Undersealing		1	1/3	2	1/2	4	3
Load transfer restoration			1	2	1/3	3	3
Diamond Grinding				1	1/5	2	2
Thin HMA Overlay					1	5	5
Crack Sealing						1	1/2
Joint Resealing							1

Comparisons based on availability of data on initial AQCs & in-service performance (CR=4%)

Treatment	Partial-Depth	Undersealing	Load transfer	Diamond	Thin HMA	Crack	Joint
Partial-Depth Repair	1	2	1/2	1/3	1/2	1/7	1/3
Undersealing		1	1/2	1/3	1/5	1/7	1/5
Load transfer restoration			1	1/2	1/2	1/3	1/4
Diamond Grinding				1	1/2	1/3	1/4
Thin HMA Overlay					1	1/3	1/3
Crack Sealing						1	2
Joint Resealing							1

Comparisons based on availability and reliability of performance prediction models (CR=6.2%)

Treatment	Partial-Depth	Undersealing	Load transfer	Diamond	Thin HMA	Crack	Joint
Partial-Depth Repair	1	5	1/2	1/2	1/3	2	1/2
Undersealing		1	1/3	1/3	1/4	1/3	1/4
Load transfer restoration			1	1/2	1/2	3	2
Diamond Grinding				1	2	5	3
Thin HMA Overlay					1	4	3
Crack Sealing						1	1/2
Joint Resealing							1

Comparisons based on ability to consider the effect of existing pavement condition on treatment performance (CR=7.1%)

Treatment	Partial-Depth	Undersealing	Load transfer	Diamond	Thin HMA	Crack	Joint
Partial-Depth Repair	1	2	1/2	1/3	1/4	3	1/3
Undersealing		1	1/2	1/3	1/5	2	1/5
Load transfer restoration			1	1/2	1/2	3	2
Diamond Grinding				1	3	5	3
Thin HMA Overlay					1	3	2
Crack Sealing						1	1/2
Joint Resealing							1

Comparisons based on treatment use (CR=4.5%)

Treatment	Partial-Depth	Undersealing	Load transfer	Diamond	Thin HMA	Crack	Joint
Partial-Depth Repair	1	5	2	2	5	1/3	1/2
Undersealing		1	1/3	1/5	1/2	1/7	1/5
Load transfer restoration			1	1/2	1/2	1/5	1/2
Diamond Grinding				1	2	1/3	1/2
Thin HMA Overlay					1	1/7	1/5
Crack Sealing						1	2
Joint Resealing							1

Figure 19. Level 3 Judgment Matrixes for the Demonstration Example.

Table 13. Weights for Each Treatment Based on Each Evaluation Criterion in the Demonstration Example.

Treatment	Evaluation Criterion No.				
	1	2	3	4	5
Partial-Depth Repair	0.15	0.05	0.11	0.08	0.16
Undersealing	0.16	0.04	0.04	0.06	0.03
Load transfer restoration	0.18	0.08	0.16	0.15	0.07
Diamond Grinding	0.08	0.11	0.28	0.31	0.11
Thin HMA Overlay	0.32	0.13	0.24	0.22	0.06
Crack Sealing	0.05	0.33	0.06	0.05	0.35
Joint Researing	0.06	0.26	0.12	0.14	0.21

The final step in the process is to apply the weights for each evaluation criterion to each of the treatment priority vectors and sum across to determine a priority score for each treatment. Table 14 shows the treatment priority scores. For this hypothetical demonstration example, Thin HMA Overlay, Crack Sealing, and Joint Resealing have the highest three priority scores.

Table 14. Treatments Priority Scores for the Demonstration Example.

Treatment	Priority Score (0-1.0)
Partial-Depth Repair	0.13
Undersealing	0.08
Load transfer restoration	0.12
Diamond Grinding	0.12
Thin HMA Overlay	0.19
Crack Sealing	0.21
Joint Researing	0.16

AHP EVALUATORS

The pairwise comparisons can be made through direct interviews or survey questionnaires of evaluators who are familiar with the decision problem. However, to obtain reliable comparisons; the evaluators must have sufficient information on the factors they are asked to consider. For example, the evaluators must have a good understanding of what makes an AQC suitable for PRS to be able to compare the importance of "suitability of initial AQCs for PRS" to each other element in the judgment matrix. Also, the evaluators must have a good understanding of existing data on each treatment to be able to compare treatments based on "availability of data." Therefore, it is proposed that these comparisons be made by the research team and possibly members of the project panel.

CHAPTER 6 CLOSURE

This interim report provides a summary of the work that has been completed to date and a plan for future work to be completed under NCHRP project 10-82 (Performance-Related Specifications for Pavement Preservation Treatments). The objective of this research is to develop guidelines for use in preparing performance-related specifications for pavement preservation treatments.

Chapter 1 discusses the background of the research problem, and describes the research objectives and the need for the PRS guidelines. It also presents the scope of work for this research project, in terms of the phases and tasks.

Chapter 2 summarizes key findings of a very extensive literature review undertaken in Task 1 of the project. Numerous publications related to pavement preservation (design, construction, materials, and performance), PRS for pavements, and pavement performance prediction modeling were gathered and reviewed in this task.

Chapter 3 discusses current specifications for pavement preservation treatments, with emphasis on acceptance quality characteristics that are measured during or immediately after construction. This work was undertaken in Task 1 of the project.

Chapter 4 presents a detailed outline of the PRS guidelines and a step-by-step plan for developing them. The plan describes a detailed PRS methodology, including a promising approach for modeling the performance of preservation treatments. Additionally, examples are presented and potential data sources for developing these models are identified in this chapter.

Chapter 5 provides a systematic process for assessing the suitability of pavement preservation treatments for PRS based on the Analytic Hierarchy Process. A total of six preservation treatments deemed most suitable for PRS will be identified using this process. The guidelines will be developed for these six treatments.

The report includes four appendixes. Appendix A includes summary tables of current specifications for preservation treatments for HMA-surfaced and PCC-surfaced pavements. Appendix B provides a bibliography of existing performance prediction models for both HMA and PCC pavements. Appendixes C and D contain site condition data for promising HMA and PCC treatment sections obtained from the Long-Term Pavement Performance database.

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Appendix A. Current Specifications of Pavement Preservation Treatments

Table A-1. Current Specifications for Chip Seals.

State	Materials Quality Measures (Pre-construction)		During and Post-construction Quality Measures	Payment Methods	Comment
	Material Type	Quality Measure			
Michigan	Asphalt Emulsion (HFRS-2M, or CRS-2M)	Viscosity	Asphalt emulsion application rate Aggregate application rate Aggregate Gradation	Payment = Contracted unit price × Area of Application	MIDOT's Standard Specification Item 508, Year 2003
		Storage Stability			
		Demuslsibility			
		Sieve Test (% particle larger than certain sieve			
		Penetration (on residue)			
		Float Test			
		Elastic Recovery (on residue)			
	Coarse Aggregate	Aggregate Wear Index (AWI)			
		Moisture Content			
		Gradation			
		Crushed Material (percent)			
		LA Abrasion Loss			
		Soft Particle Percent			
		Flat & Elongated Aggregate percent			
Arizona	Asphalt Emulsion (CRS-2)	Viscosity	Asphalt emulsion application rate Number of roller passes	Payment = unit bid price × tons of emulsion + unit bid price × cu yd of cover mat + unit bid price × cu yd of blotter mat (if any)	AZDOT's Standard Specification Item 404, Year 2008
		Residue			
		Settlement percent (5 days)			
		Classification (uncoated particle minimum)			
	Coarse Aggregate	Gradation			
		Abrasion			
		Carbonates			
		Crushed particle percentage			
		Flakiness index			
		Bulk Specific Gravity			
		Water absorption			
	Blotter Material (if any)	Gradation			
California	Asphalt Emulsion	Viscosity	Asphalt emulsion application rate (Separately in trans. & long. Aggregate Application Rate	Payment = unit bid price × tons of emulsion + unit bid price × tons of aggregate	CalTrans' Standard Specification Item 37, Year 2006
		Settlement percent (5 days)			
		Storage Stability			
		Sieve Test (% particle larger than certain sieve			
		Residue (percent)			
		Penetration (on residue)			
	Aggregate (different size grades)	Gradation			
		Crushed particle percentage			
		LA Abrasion Loss			
		Film Stripping			
		Cleanliness Value			
Montana	Bituminous Material (CRS-2)	Viscosity	Bituminous Material Application rate Aggregate Application rate	Payment = unit bid price × amount of bituminous material (gal, or ton) + unit bid price × amount of aggregate (sq yd)	MTDOT's Standard Specification Item 409, Year 2006
		Sieve Test (% particle larger than certain sieve			
		Settlement percent (5 days)			
		Storage Stability			
		Penetration (on residue)			
		Residue (percent)			
		Demuslsibility			
		Ductility (on reside)			
	Aggregate	Gradation			
		Plasticity Index			
		Abrasion Loss			
		Clay content			
		Crushed particle percentage			
Iowa	Bituminous Material (CRS-2, or Cutback)	Viscosity	Application Rate of Bituminous Application Rate of Aggregate	Payment = unit bid price × amount of bituminous material (gal) + unit bid price × amount of aggregate (sq yd) + Unit bid price × amount of emulsion used in dust control (gal, if any)	IADOT's Standard Specification Item 2307, Year 2010
		Sieve Test (% particle larger than certain sieve			
		Settlement percent (5 days)			
		Storage Stability			
		Penetration (on residue)			
		Residue (percent)			
		Demuslsibility			
		Ductility (on reside)			
	Aggregate	Gradation			
		Clay content			
		Frictional classification			
		Abrasion Loss			
		Freeze-Thaw Loss			
		Shale Content			
	Asphalt Emulsion (for dust				

Table A-1. Current Specifications for Chip Seals (cont.).

State	Materials Quality Measures (Pre-construction)		During and Post-construction Quality Measures	Payment Methods	Comment
	Material Type	Quality Measure			
North Carolina	Bituminous Material (CRS-2, RS-2, CMS-2, MS-2)	Viscosity	Application Rate of Bituminous Application Rate of Aggregate	Payment = Unit bid price × sq yd of treatment	NCDOT's standard Specification Item 660, Year 2006
		Sieve Test (% particle larger than certain sieve			
		Settlement percent (5 days)			
		Storage Stability			
		Penetration (on residue)			
		Residue (percent)			
		Demulsibility			
		Ductility (on reside)			
		Particle charge test			
	Aggregate	Gradation			
		Fractured Face percentage			
		Soundness			
		Abrasion loss			
	Blotter Material	Gradation			
New York	Bituminous Material (CRS-2, RS-2, HFRS-2)	Viscosity	Application Rate of Bituminous Application Rate of Aggregate	Payment = Unit bid price × sq yd of treatment + Unit bid price × gal of bituminous material	NYDOT's Standard Specification Item 410, Year 2008
		Sieve Test (% particle larger than certain sieve			
		Settlement percent (5 days)			
		Storage Stability			
		Penetration (on residue)			
		Residue (percent)			
		Demulsibility			
		Ductility (on reside)			
		Particle charge test			
	Aggregate	Gradation			
		Crushed particle percentage			
		Flat & Elongated Aggregate percent			
		Soundness			
		Freeze-Thaw Loss			
		LA Abrasion Loss			
	Polymer Modifier				
South Dakota	Asphalt Material	Viscosity	N/A	Payment = Unit bid price × tons of asphalt + Unit bid price × tons of aggregate	SDDOT's Standard Specification Item 360, Year 2008
		Sieve Test (% particle larger than certain sieve			
		Settlement percent (5 days)			
		Storage Stability			
		Penetration (on residue)			
		Residue (percent)			
		Demulsibility			
		Ductility (on reside)			
		Particle charge test			
		Performance Grading			
	Aggregate	Plasticity Index			
		L.A. Abrasion Loss			
		Soundness			
		Crushed Particle Percentage			
		Flakiness Index			
Washington	Cationic Emulsified Asphalt	Viscosity	Application Rate of Asphalt Material Application Rate of Aggregate Number of roller passes	Payment =∑(Respective unit bid price × Respective Quantity)	WADOT's Standard Specification Item 5-02, Year 2010
		Storage Stability			
		Demulsibility			
		Coating Ability and Water Resistance			
	Aggregate	LA Abrasion Loss			
		Degradation Factor			
		Gradation			
Texas	Asphalt Material	Viscosity	Application Rate of Bituminous Application Rate of Aggregate Number of roller passes	Payment = Unit bid price × tons of asphalt + Unit bid price × cu yd of aggregate	TxDOT's Standard Specification Item 316, Year 2004
		Sieve Test (% particle larger than certain sieve			
		Settlement percent (5 days)			
		Storage Stability			
		Penetration (on residue)			
		Residue (percent)			
		Demulsibility			
		Ductility (on reside)			
		Particle charge test			
		Performance Grading			
	Aggregate	Gradation			
		Surface Aggregate Classification (SAC)			
		LA Abrasion Loss			
		Flakiness Index			
		Micro-Deval Loss			
		Soundness			
		Deleterious material content			
		Coarse aggregate angularity			
		Water absorption (for light weight agg)			
		Unit weight (for light weight agg)			
Idaho	Asphalt	Viscosity	Application rate of cover material (aggregate) Application Rate of Asphalt Material	Payment = Unit bid price × tons of asphalt + Unit bid price × cu yd of aggregate+ Unit bid price × miles of brooming	IDDOT's Standard Specification Item 403, Year 2004
		Sieve Test (% particle larger than certain sieve size)			
	Aggregate	Gradation			
		Cleanliness Value			
		LA Abrasion Loss			
		Crushed particle percentage			
		Asphalt film retention			

Table A-2. Current Specifications for Thin HMA Overlay.

State	Materials Quality Measures (Pre-construction)		During and Post-construction Quality Measures	Payment Methods	Comment
	Material Type	Quality Measure			
Michigan	Bond Coat (SS1h)	N/A			MIDOT's Special Specifications, Year 2005
	HMA Mixture	Marshall air voids		Payment = contracted unit price × sq yd of application	
		Voids of Mineral Aggregate			
		Marshall Stability	Tack coat application rate		
		Marshall Flow Value	HMA application rate		
		Percent Fines (passing #200 sieve)	Asphalt Content		
	Aggregate	Percent Crushed Face	Air Void		
		LA Abrasion Loss	Aggregate Gradation (#8, #30, and #200 Sieve)	Or, Payment = contracted unit price for special mix × tons of mix used	
		Aggregate Wear Index			
		Aggregate Angularity Index			
		Gradation			
	Asphalt	Performance Grading*			
Texas	Asphalt	Performance Grading*		Payment = contracted unit price × tons of HMA used	TxDOT's Standard Specification Item 341, Year 2004
	Aggregate	SAC AQMP			
		Deleterious material			
		Decantation, %, max	Asphalt Binder Content (Pb)		
		Micro-Deval abrasion loss	No. 8 Sieve (P_{-8})		
		Los Angeles abrasion loss	No. 200 Sieve (P_{-200})		
		Magnesium sulfate soundness	In place Air Voids (V_a)		
		Coarse aggregate angularity	Laboratory-Modeled Density (G_{mb})		
		Flat and elongated particles	International Roughness Index		
		Linear shrinkage	Joint Density (In-place)		
		Sand equivalent			
		Gradation			
Kansas	Asphalt	Performance Grading*		Payment = contracted unit price × tons of HMA used	KSDOT's Standard Specification Item 602, Year 2007
	Aggregate	Gradation			
		Plasticity Index			
		Clay Content	Air Voids (Va) at Ndesign		
		Coarse aggregate angularity	Density (Gmb)		
		Fine Aggregate angularity	Thickness		
		Soundness	Profile Index		
		Abrasion loss			
		Flat and elongated particles			
		Linear shrinkage			
Florida	Asphalt	Performance Grading*		Payment = contracted unit price × tons of HMA used	FLDOT's Standard Specification Item 334, Year 2007
	Aggregate	Gradation			
		Sand equivalent	Asphalt Binder Content (Pb)		
		Clay Content	No. 8 Sieve (P-8)		
		Coarse aggregate angularity	No. 200 Sieve (P-200)		
		Fine Aggregate angularity	Air Voids (Va) at Ndesign		
		Soundness	Density (Gmb)		
		Abrasion loss	Smoothness using Straightedge		
		Flat and elongated particles			
		Linear shrinkage			
		Shale content			

* Performance grading of Asphalt refers to all the superpave binder testing performed on original, RTFO aged, and PAV aged binder to determine its high and low temperature properties and thereby classify them into PG grade.

Table A-3. Current Specifications for HMA Cold-in-Place Recycling.

State	Materials Quality Measures (Pre-construction)		During and Post-construction Quality Measures	Payment Methods	Comment
	Material Type	Quality Measure			
Arizona	Emulsified Binder Agent	Viscosity	Pulverizing size (below 1.5 inch) Emulsified binder agent percentage Number of roller pass Smoothness using straightedge (longitudinal	Payment = Unit bid price of recycling × Sq yd of treatment + unit bid price × Tons of emulsified asphalt	AZDOT's Special Specification Item 408COREC, Year 2006
		Residue percentage from distillation			
		Penetration			
		Ductility of residue			
		Float (residue's ability to flow at high temp)			
		Elastic Recovery (on residue)			
		Sieve Test (% particle larger than certain sieve			
	Recycled Asphalt Pavement	Moisture Content of combined mix			
Texas	Emulsion	Viscosity	Pulverizing size (below 1.0 inch) Cross Slope Smoothness using straightedge Depth of Planning	Payment = Unit bid price of recycling × Sq yd of treatment + unit bid price × Tons of emulsified asphalt + Unit bid price × cu yd of aggregate	TxDOT's Special Specification Item 3209, Year 2010
		Penetration			
		Sieve Test (% particle larger than certain sieve			
		Float (residue's ability to flow at high temp)			
		Coating Ability and water resistance			
		Storage Stability			
	Additive (Lime)	Gradation			
		Active Lime content			
	Aggregate (if any)	Surface Aggregate Classification			
		Micro-Deval Abrasion Loss			
		Magnesium Sulphate Soundness			
	Recycled or Combined Asphaltic Mixture	Mixture Design			
		Moisture Content of combined mix			
		Emulsion content			
		Gradation of Pulverized pavement			
		Hamburg Wheel Tracking Testing			
		Indirect Tensile Strength			
		Compacted Density			
Iowa	Asphalt Stabilizing Agent (HFMS-2s, CSS-1, or Foamed asphalt using PG binder)	Performance Grading	Asphalt stabilizing agent application rate Depth of Planning Profile Index Cross Slope Percentage Cross Slope Percentage	Payment = Unit bid price of recycling × Sq yd of treatment + unit bid price × Tons of emulsified asphalt	IADOT's Standard Specification Item 2318, Year 2010
		Sieve Test (% particle larger than certain sieve			
		Viscosity			
		Penetration (on residue			
		Storage Stability			
	Recycled Asphalt Pavement	Gradation			
		Mixture Design			
		Density			
		Moisture Content			
New York	Recycled or combined Asphalt Pavement	Mixture Design	Pulverizing size (below 2.0 inch) Thickness of compacted layer Smoothness using straightedge (longitudinal	Pay = unit price of treatment × sq yd of treatment + unit price bituminous material × gal used + unit price of aggregate × tons used	NYDOT's Special Specification Item 405.0201-02 M , Year 2009
		Gradation			
	Aggregate (if any)	LA Abrasion Loss			
		Freeze Thaw Loss			
		Crushed particle percentage			
		Flat & Elongated Particle			
		Magnesium Sulphate Soundness			
	Additive (if any)	N/A			
	Bituminous Material	N/A			
Montana	Bituminous Material	Viscosity	Smoothness using straightedge (longitudinal Application rate of Bituminous Materials	Pay = unit price of treatment × sq yd of treatment + unit price bituminous material × gal used + unit price of aggregate × tons used	MTDOT's Standard Specification Section 406, Year 2006
		Sieve Test (% particle larger than certain sieve			
		Settlement percent (5 days)			
		Storage Stability			
		Penetration (on residue)			
		Residue (percent)			
		Demuslsibility			
		Ductility (on reside)			
	Aggregate (if any)	Gradation			
		Plasticity Index			
		Abrasion Loss			
		Clay content			
		Crushed particle percentage			
	Recycled Asphalt Pavement	N/A			

Table A-4. Current Specifications for HMA Hot-in-Place Recycling.

State	Materials Quality Measures (Pre-construction)		During and Post-construction Quality Measures	Payment Methods	Comment
	Material Type	Quality Measure			
Texas	Recycling Agent	Viscocisity	Placement of longitudinal joint Ride Quality	Payment = Unit bid price × sq yd of treatment	TxDOT's Standard Specification 358, Year 2004
		Sieve Test (Percentage of particle larger than ceratin			
		Residue percent by evaporation			
		Flash point temperature			
	Virgin Hot Mix Asphalt (if	Mixture Design			
	Surface Course Materials	N/A			
Iowa	Surface Course Materials	N/A	Depth of Scarification Construction Joint location	Payment = Unit bid price × sq yd of treatment + Unit bid price × tons of	IADOT's Standard Specification 2309, Year 2010
	Hot Mix Asphalt (overlay)	Mixture Design			
New York	Surface Course Materials	Penetration grade of extracted binder from existing	Construction Joint location Percentage of Virgin HMA Application Rate of Recycling	Pay = unit price of hot-in-place recycle area of treatment + unit price virgin HMA × tons used	NYDOT's Special Specification Item Item 402.607201-02, Year 2009
	Recycling Agent	N/A			
	Virgin HMA	Mixture Design			
	Combined HMA	Penetration grade of extracted binder from combined			
		Determination of lab compacted density			
Arizona	Recycling Agent	Viscosity	Depth of Scarification Application Rate of Recycling Percentage of Virgin HMA	Pay = unit price of hot-in-place recycle area of treatment + unit price virgin HMA × tons used + Unit price of recycling agent × tons used	AZDOT's Special Specification for Hot-in-Place Recling, Year 2006
		Residue percentage from distillation			
		Penetration			
		Ductility of residue			
		Float (residue's ability to flow at high temp)			
		Elastic Recovery (on residue)			
		Sieve Test (% particle larger than certain sieve size)			
	Surface Course Materials	N/A			
	Virgin HMA	Mixture Design			
	Combined HMA	N/A			

Table A-5. Current Specifications for Slurry Seal.

State	Materials Quality Measures (Pre-construction)		During and Post-construction Quality	Payment Methods	Comment
	Material Type	Quality Measure			
CA	Aspahlt Emulsion (QS1h, or CQS1h)	Viscosity @ 25ºC and/or 50ºC	Slurry spread rate (lb/sq.yd)	Payment = Contracted unit price × tons of slurry seal materials (asphaltic emulsion + aggregate)	CalTran's Standard Specifications Item 37, Year 2006
		Settlement percent (5 days)			
		Storage Stability Test, 1day, %			
		Sieve Test, %			
		Demuslsibility, 35 ml, 0.02 N $CaCl_2$, %			
		Coating Ability and Water Resistance			
		Particle charge test (for cationic asphalt emulsion and polymer modified asphalt emulsion)			
		Cement mixing test, %			
		Residue by distillation, %			
		Ash content (for polymer modified asphalt emulsion only)			
		Residue by evaporation, %			
		Penetration (on residue) @ 25ºC			
		Ductility (on reside), 50mm/min, mm			
		Solubility in trichloroethylene (on residue), %			
	Fine Aggregate	Gradation			
		Sand Equivalent			
		Durability Index			
	Mix Design	Slurry seal consistency, mm			
		Wet stripping			
		Compatibility			
		Cohesion test, kg-mm within one h			
		Wet track abrasion, g/m^2			
AZ	Asphalt Emulsion (QS-h)	Viscosity @ 77^0F	Slurry spread rate (lb/sq.yd)	Payment = unit bid price × sq yd of slurry seal	AZDOT's Standard Specification Item 404, Year 2008
		Residue by evaporation, %			
		Sieve Test, % retained on #20			
		Particle Charge, Electroplate			
		Penetration (on residue) @ 77^0F			
		Solubility in trichloroethylene (on residue), %			
		Ductility (on reside) @ 77ºF, cm			
	Fine Aggregate	Gradation			
		Sand Equivalent (minimum 45)			
		Abration Loss (maximum 75 gm per sq ft)			
	Mix	Slurry Seal Mixing Test, sec			
		Slurry Seal Setting Test			
		Slurry Seal Water Resistance Test			
IA	Aspahlt Emulsion (CSS-1h or SS-1h)	Sieve Test	Mix Consistency	Payment = unit bid price × gallon of emulsion + unit bid price × tons of aggregate	IOWA DOTs' Standard Specification Item 2319, Year 2010
		Aggregate Compatibility			
		Absolute Viscosity			
		Asphalt Binder Content			
	Aggregate	Gradation			
		Abrasion, maximum			
		Alumina, maximum			
		Sand Equivalence, minimum			
		Organic Materials, maximum			

Table A-5. Current Specifications for Slurry Seal (cont.).

State	Materials Quality Measures (Pre-construction)		During and Post-construction Quality	Payment Methods	Comment
	Material Type	Quality Measure			
MI	Asphalt Emulsion (CSS-1h)	Viscosity @ 25^{0}C and/or 50^{0}C	Asphalt Cement Content Aggregate Gradation	Payment = unit bid price × sq. yd of slurry seal	MDOT's Standard Specification Section 506, Year 2003
		Storage Stability Test, 1day, %			
		Demuslsibility			
		Sieve Test, % max			
		Miscibility with Water			
		Residue by distillation, %			
		Penetration (on residue)			
		Float Test (on residue)			
		Ductility (on residue)			
		Solubility in trichloroethylene (on residue), %			
		Ash Content (on residue), %			
		Specific Gravity			
		Toughness/Tenacity			
		Elastic Recovery			
		Gradation			
	Fine Aggregate	L.A. Abrasion, %			
		Angularity Index			
		Sand Equivalence			
		Consistency Test			
	Mix	Set Time			
		Cure Time			
		Wet track abrasion			
PA	Emulsified Asphalt (SS-1h or CSS-1h)	Percent Bitumen Residue by Mass	Control the temperature of componented mixture (b/t 50F and 125F)	Payment = Unit bid price × sq yd of treatment	PADOT's standard Specification Item 482, Year 2007
		Specific Gravity @ 60F			
	Fine Aggregate	Gradation			
		Material Finer than #200 Sieve			
		Minimum Strength Ratio			
		Soundness Test			
	Filler	Gradation			
	Mix	Proportioning			

Table A-6. Current Specifications for HMA Crack Sealing.

State	Materials Quality Measures (Pre-construction)		During and Post-construction Quality Measures	Payment Methods	Comment
	Material Type	Quality Measure			
AZ	Asphalt cement (PG 58-22)	Solubility in Trichloroethylene, %, minimum	Depth of cracks cleaned (minimum twice the clear opening of the crack)	Payment = Contracted unit price × Linear foot	AZDOT's Standard Specification Item 404, Year 2008
		Softening Point, °C, minimum			
		Elastic Recovery @ 10°C, %, minimum			
		Phase Angle (δ) @ 70°C @ 10 rad/sec, degrees, maximum			
		Basis of Conversion, avg gallons per ton @ 60°F			
	Rubber (100-percent vulcanized granulated)	Gradation			
		Specific Gravity			
	Mix	Proportioning (75 ± 2 asphalt, 25 ± 2 rubber)			
CA	Crack Treatment Material (asphalt)	Softening Point, ^{0}C, minimum	Extent of treatment below the specified level two days after crack sealing (no more than 1/4 inch)	Payment = unit bid price × lane-mile	CalTrans' Standard Special Provisions (SSPs) Item 37.400, Year 2006
		Cone Penetration @ 77°F, maximum			
		Resilience @ 77°F, unaged, %			
		Flexibility			
		Tensile Adhesion, %, minimum			
		Specific Gravity, maximum			
		Asphalt Compatibility			
		Sieve Test, % passing			
	Sand applied to tacky crack treatment material	Gradation			
IA	Joint Filler and Sealer (depending on the type of joint, either contraction or expansion)	Poured Joint Sealer (contraction joint): ASTM D 6690 Type IV test	Sealant excess on each side the crack edge (no more than 1/2 inch)	Payment = unit bid price × mile of pavement or shoulders	IOWA DOTs' Standard Specification Item 2541, Year 2010
		Backer Rod (contraction joint): absorption < 5%			
		Resilient Filler (expansion joint): AASHTO M 213			
		Flexible Foam (expansion joint): ASTM D 1752			
KS	Hot Joint Sealing Compound	Bond	N/A	Payment = unit bid price × linear foot	KDOT's Standard Specification Item 835, Year 2007
		Flow, maximum			
		Resilience, %			
		Penetration @ 0^{0}F			
	Fiber-Reinforced Asphalt	Seperation			
		Elastic Recovery @ 25^{0}C, %, minimum			
	Rapid-Set Concrete Patching Material	Freeze-Thaw Durability, %, minimum			

Table A-6. Current Specifications for HMA Crack Sealing (cont.).

State	Materials Quality Measures (Pre-construction)		During and Post-construction Quality Measures	Payment Methods	Comment
	Material Type	Quality Measure			
KS	Hot Joint Sealing Compound	Bond	N/A	Payment = unit bid price × linear foot	KDOT's Standard Specification Item 835, Year 2007
		Flow, maximum			
		Resilience, %			
		Penetration @ 0^0F			
	Fiber-Reinforced Asphalt	Seperation			
		Elastic Recovery @ 25^0C, %, minimum			
	Rapid-Set Concrete Patching Material	Freeze-Thaw Durability, %, minimum			
MI	Polymer Modified Asphalt Cement	Penetration @ 25 ºC	Adhesion failure Cohesion failure Missed crack	Payment = unit bid price × roadbed mile	MDOT's Standard Specification Section 505, Year 2003
		Softening Point, ^{0}C, minimum			
		Viscosity @ 60ºC (on aged residue)			
	Polyester Fibers	Length			
		Crimps			
		Tensile Strength			
		Denier			
		Specific Gravity			
		Melting Temperature			
		Ignition Temperature			
MT	Crack Sealant	Cone Penetration @ 77F	N/A	Payment = Unit bid price × pound (kg) of material placed	MTDOT's standard Specification Item 403, Year 2006
		Cone Penetration @ 0F, min			
		Flow @ 60^0C, maximum			
		Resilience @ 77^0F, %			
		Bond @ 20F			
		Recommended Pour Temperature			
		Safe Heating Temperature			
		Asphalt Compatibility			
	Backer Rod	ASTM D-5249, Type 1			
PA	Asphalt Rubber Sealing Compound	Tensiel Stress at 150% Elongation, psi, max	N/A	Payment = unit bid price × linear foot	PADOT's Standard Specification Item 469, Year 2008
		Elongation at Maximum Tensile Strength, %, min			
		Extrusion Rate, grams/second, min			
		Specific Gravity			
		Durometer Hardness			
		Shelf Life, days, min			
		Ozone and Ultraviolet Resistance			
		Flow			
		Bond to Cement Mortar, psi, min			
		Tack Free Time, minutes, max			
		Movement Capability and Adhesion			
	Ruberized Joint Sealing Material	Cone Penetration @ 77^0F			
		Flow @ 60ºC, maximum			
		Resilience @ 77^0F, unaged, %			
		Ductility @ 77F, maximum			
		Bond, non-immersed @ 0F			
		Asphalt Compatibility @ 140F			
		Sealant Life at Application Temperature, minimum			
SD	Sealant	Penetration @ 77F	N/A	Payment = unit bid price × pound (kg) of sealant used	SDDOT's Standard Specification Item 350, Year 2004
		Bond at -20F			
		3 Cycles, 200% Extension			
		Unit Weight, lbs/gal (no greater than 9.36)			
TX	Polymer Modified Asphalt Emulsion	Rotational Viscosity	N/A	Payment = Unit bid price × foot, gallon, pound, or lane mile	TxDOT's Standard Specification Item 712, Year 2004
		Sieve Test			
		Storage Stability			
		Residue by Evaporation			
		Penetration (on residue)			
		Softening Point (on residue)			
		Ductility (on residue)			
	Rubber-Asphalt Crack Sealer	Crumb Rubber Modifier (CRM) Content, Grade A or B			
		Virgin Rubber Content			
		Flash Point			
		Penetration			
		Softening Point			
		Bond			
WA	Rubberized Asphalt	Cone Penetration, 130 max	N/A	Payment = unit bid price × linear foot	WSDOT's Standard Specification Item 9-04.10, Year 2010
		Softening Point			
		Resilience			
		Bond			
		Asphalt Compatibility			
		Minimum Application Temperature			
		Maximum Heating Temperature			

Table A-7. Current Specifications for PCC Joint Resealing and Crack Sealing.

State	Materials Quality Measures (Pre-construction)		During and Post-construction Quality Measures	Payment Methods	Comment
	Material Type	Quality Measure			
Texas	Joint sealant and filler	N/A		Payment = Unit bid price for clean and seal joints and crack × linear ft of crack and	Special Specification 7435, Year 2004
	Backer Rod				
Washington	Hot poured Joint Sealant	Cleveland Open Cup Flash Point	Height of sealant in joint	Payment = Unit bid price × linear ft of joints sealed	WADOT's standard specification 5-01, 2010
		Cone Penetration			
	Poured Rubber Joint Sealer	Viscosity			
		Curing Time			
		Bond Strength			
		Durometer Hardness			
	Asphalt Filler	When a strip 2-inches wide and 24-inches long is freely supported 2-inches from each end and maintained at 70°F, it shall support a weight of 100 grams placed at the center of the strip without deflecting downward from a horizontal position more than 2-inches within a period of 5 minutes			
South Dakota	Hot Poured Elastic Joint Sealer	cone penetration		Payment = Unit bid price × linear ft of joints sealed	SDDOT's standard specification Item 390
		Flow			
		Bond Strength			
		Resilience			
	Low Modulus Silicone Sealant:	Tensile Stress			
		Elongation			
		Durometer Hardness			
		Bond Strength			
		Tack free time			
Pennsylvania	Joint Sealant	Tensile Stress		Payment = Unit bid price × linear ft of joints sealed	PADOT's Standard Specification Section 513, Year 2007
		Elongation			
		Durometer Hardness			
		Bond Strength			
	Rubberized Joint Sealing Materials	Cone Penetration			
		Flow			
		Resilience Recovery			
		Bond Strength			
	Backer Rod	N/A			
Arizona	Joint Sealant Materials	Sand Gradation	Height of sealant in joint	Payment = Unit bid price × linear ft of joints sealed	Arizona DOT's Specification for Joint and Crack Resealing Section 402-6
		Epoxy-resin to Sand ratio			
Iowa	hot poured joint sealer		Sealant dimension in the joint	Payment = Unit bid price for sealer material × lb of sealer + unit bid price fro cleaning	Iowa DOT's Standard Specification Section 2542, Year 2010
	elastomeric joint seals				
Michigan	Hot-Poured Joint Sealant		Height of sealant in joint	Payment = Unit bid price × linear ft of joints sealed	Michigan DOT's Standard Specification Item 603, Year 2003
	Backer Rod				
New York	Silicone Joint Sealant			Payment = Unit bid price × linear ft of joints sealed	NYDOT's special specification ITEM 18502.701002 M, Year 1996
California	Silicone Joint Sealant	Tensile Stress	Failure of the joint material in either adhesion or cohesion of the material will be cause for rejection.	Payment = Unit bid price × linear ft of joints sealed	CalTrans' Standard Special Provision 41-210, Year 2007
		Elongation			
		Bond Strength			
		Durometer Hardness			
	Asphalt Rubber Joint Sealant	Cone Penetration			
		Resilience Recovery			
		Softening Point			
	Backer Rod				
Florida	Low Modulus Silicone Sealant:			Payment = Unit bid price × linear ft of joints sealed	FDOT's Standard Specification Item 350-12.7, Year 2010
	Hot-Poured Type Sealant				

Table A-8. Current Specifications for PCC Partial-Depth Repair.

State	Materials Quality Measures (Pre-construction)		During and Post-construction Quality Measures	Payment Methods	Comment
	Material Type	**Quality Measure**			
Texas	Concrete Patch Materials	Flexural Strength Test in 5 hr Compressive Strength test at 7 days and 28 days Shrinkage Test	Minimum depth of patching saw cut	Payment = Unit Bid Price × Cubic ft of Concrete Patch Material	Repair of Spalling Item 720, Year 2004
	Polymeric Patch Materials	N/A		Payment = Unit Bid Price × Gallons of Polymeric Patch Material	
Washington	Concrete patching material	Compressive Strength (3 hr and 24 hr) Bonding Strength Shrinkage Test	Minimum depth of patching saw cut	NA	WADOT's Standard Specification Item 5-01, Year 2010
Iowa	Portland cement concrete patching material	Set time Air content Compressive Strength	Minimum depth of patching saw cut	Payment = Unit Bid Price X Area of Patch	Iowa DOT's specifications Partial Depth Repair (Item 2530), Year 2010
	Hot mix asphalt (HMA)	N/A		Payment = Unit Bid Price X Area of Patch + Unit price × Weight of HMA Patch Material	
South Dakota	Bonding Mortar for Concrete Patches	N/A	Minimum depth of patching saw cut Sounding (pre-repair) and Resounding (post-repair) Test	Payment = Unit Bid Price for Saw and Seal × Length of Joints Repaired Payment = Unit bid price for Type A spall repair × square ft spall repaired Payment = Unit bid price for Type B spall repair × length of spall repaired	SDDOT's Standard Specification Item 390, "Concrete Spall Repair", Year 2004
	Concrete Patches	Air content			
	Epoxy Resin Mortar	N/A			
	Silicone Sealant	N/A			
Pennsylvania	Type 1 repair with Class AA Cement Concrete, Modified.	Compressive Strength	Minimum depth of patching saw cut Resounding test	Payment = Unit bid price for saw and seal × length of joints repaired	PADOT's Standard Specification Section 525 for Concrete Spall Repair, Year 2007
	Type 2 repair with Class AA Cement Concrete, Special.	N/A			
	Type 3 repair with Rapid Set Concrete Patching Materials.	N/A		Payment = Unit bid price for spall repair × square ft spall repaired	
	Type 4 repair with Latex Modified Concrete.	N/A			
	Type 5 repair with Thin Bonded Portland Cement Concrete Inlay	N/A			
New York	Transit Mix High Early Strength Concrete.	Compressive Strength Air Content Moisture content of aggregate	Minimum and maximum saw cut depth	Payment = Unit bid price for spall repair × square ft spall repaired	NYDOT's Item 502.4MR00018 Partial-Depth Repairs, Year 2003
	Concrete Repair Material or Rapid Hardening Concrete Repair Material	N/A			NYDOT's Item 502.46010018 Partial-Depth Repair using epoxy resin, Year 2003
	Rapid Hardening Polymer Concrete.	N/A			
	Epoxy Resin System	N/A			
Arizona	Accelerated Strength Port land Cement Concrete Patch Material	Compressive strength test (6 hr)	Minimum saw cut depth for patching	Payment = Unit bid price for spall repair × square ft spall repaired	AZDOT's Standard Specification Item 402-2, Year 2008
	Rapid Setting Patch Materials	compressive strength (6 hr)			
	Epoxy Resin Grout Patch Material	epoxy binder to aggregate ratio			
	Flexible Epoxy Patching Material	Tensile Strength Tensile Elongation Tensile Bond Strength Hardness			
Michigan	Patching Concrete	Cement Content Air Content (5.5±1.5%) Flexural Strength (at traffic opening time)	Smoothness test using straight edge	Payment = Unit bid price for pavement repair × square yard of area repaired	MIDOT's Standard Specification Item 603, Year 2003
California	Fast-Setting Grout	Compressive Strength (3 hr and 24 hr) Flexural Strength Bond Strength Drying Shrinkage Setting time	Minimum saw cut depth for patching	Payment = Unit bid price for pavement repair × square yard of area repaired	CalTrans' Standard Special Provision 41-150, Year 2007
	Silicone Joint Sealant	Tensile Strength Elongation Bond Strength Durometer Hardness			

Table A-9. Current Specifications for PCC Full-Depth Repair.

State	Materials Quality Measures (Pre-construction)		During and Post-construction Quality Measures	Payment Methods	Comment
	Material Type	Quality Measure			
Texas	Hydraulic Cement Concrete	Flexural Strength		Payment = Unit Bid price × sq yd of repaired surface area	TxDOT's Item 361, Year 2004
		Compressive Strength			
	Reinforcement.	Yield Strength			
		Pullout Strength			
	Asphalt Concrete	N/A			
Washington	Concrete patching material	Compressive Strength (3 hr, 24 hr)	Placement of dowel and tie bar Smoothness using straight edge Placement of dowel and tie bar Profile Index	Payment = Unit Bid price × sq yd of repaired surface area	WADOT's Standard Specification Item 5-01, Year 2010
		Shrinkage			
		Freeze-Thaw			
		Bond Strength			
	Portland Cement Concrete	Air Content			
		Compressive Strength			
Pennsylvania	Cement Concrete Class AA	Compressive Strength (7 hr, 28 day)	Ride acceptance using straight edge Compressive Strength before opening to	Payment = unit bid price × corresponding items measured	PADOT's Standard Specification Item 516, Year 2007
		Air Content			
	Reinforcement.	N/A			
	Dowels	N/A			
Arizona	Accelerated Strength Concrete	Compressive Strength (6 hr)	Depth of patch	Payment = Unit Bid price × sq yd of repaired surface area	AZDOT's Standard Specification Item 402-3, Year 2008
	Tie bar	Yield Strength			
	Joint sealant	Yield Strength			
Michigan	Patching Concrete	Cement Content	Smoothness test using straight edge	Payment = Unit Bid price × sq yd of repaired surface area + (price for additional items)	MIDOT's Standard Specification Item 603, Year 2003
		Air Content (5.5±1.5%)			
		Flexural Strength (at traffic opening			
	Reinforcement.	N/A			
	Dowel bar	N/A			
Florida	Portland Cement Concrete	Compressive Strength at 6 hr and 24	Smoothness test using 10 ft straight edge, Maturity Method Testing before opening to	Payment = Unit Bid price × Cu yd of concrete placed	FLDOT's Standard Specification Section 353,
		Air Content (1 to 6%)			
California	Rapid Strength Concrete	Modulus of Rupture Strength (7 day)	Smoothness test using straight edge Co-efficient of Friction Groove dimension	Payment = Unit Bid price × Cu yd of concrete placed	CalTrans' Standard Special Provision 40-020, Year 2009
	Hydraulic Cement	Contraction in air			
		Mortar expansion in water			
		Soluble chloride			
		Soluble sulfates			
		Thermal stability			
		Compressive strength @ 3 days			
	Hot mix Asphalt	Asphalt Content			
Iowa	Portland Cement Concrete	Air Content	Patch thickness Smoothness of patch using straightedge Core density (HMA) Profile Index (for patch longer than 50 ft)	Payment = Unit bid price × sq yd of Payment = Unit bid price × tons of	IADOT's specifications Full Depth Finish Patch (Item 2529), Year 2010
		Cement Content			
	Hot mix Asphalt	N/A			
	Dowel bar and tie bar	N/A			

Table A-10. Current Specifications for Load Transfer Restoration (Dowel Bar Retrofitting).

State	Materials Quality Measures (Pre-construction)		During and Post-construction Quality Measures	Payment Methods	Comment
	Material Type	Quality Measure			
Arizona	Dowel Bar	Tensile Strength	Positioning of Dowel Bar	Payment = unit bid price × ft of joint repair	AZ DOT's Standard Specification (Section 402-6-C)
	Epoxy resin	Epoxy resin to sand ratio			
Pennsylvania	Dowel bar	Yield Strength	Positioning of Dowel Bar, Compressive Strength of patching material	Payment = unit bid price × number of dowel bar installed	PADOT's Standard Specification Item 527, Year 2007
		Epoxy coating thickness			
	Rapid Set Concrete Patching Material	Shelf life			
South Dakota	Dowel Bar	N/A	Positioning of Dowel Bar Compressive Strength (6 hr, 24 hr)	Payment = unit bid price × number of dowel bar installed	SDDOT's Special Provision for PPCP Dowel Bar Retrofit, Year 2001
	Concrete patching material	Compressive Strength (3 hr and 24 hr)			
		Final Set time			
		Flexural Strength (if aggregate added)			
		Bond Strength			
Texas		Tensile Strength	Estimate Concrete Strength by Maturity Method Compressive Strength of patching material	Payment = unit bid price × number of dowel bar installed	TxDOT's Special Specification 3012, Year 2004
	Class HES Concrete	Compressive Strength	Positioning of Dowel Bar		
Washington	Concrete patching material	Compressive Strength (3 hr and 24 hr)	Positioning of Dowel Bar	Payment = unit bid price × number of dowel bar retrofitted	WA DOT's Specification for Dowel Bar Retrofit (Section 5-01), Year 2010
		Shrinkage			
		Bond Strength			
		Freeze-Thaw Loss			
	Dowel Bar	Thickness of epoxy coating			
		Tensile Strength			
New York	Retrofit LTDs (Dowel Bar)	Yield Strength	Positioning of Dowel Bar	Payment = unit bid price × number of dowel bar retrofitted	NYDOT,s Special Specification Item 502.70010018, Year 2003
		Corrosion Abrasion			
		Load Deflection			
		Pull-Out			
	Backfill Materials (Patching materials)	Compressive Strength (3 hr and 24 hr)			
		Shrinkage			
		Freeze-Thaw Loss			
		Bond Strength			
	Joint Forming Materials	Dimension			
Michigan	Dowel Bar	Tensile Strength (yield)		Payment = unit bid price × number of dowel bar retrofitted	MIDOT's Special Provision for Dowel Bar Retrofit, Year 2000
		Thickness of epoxy coating			
	Concrete patching material	N/A			
California	Dowel Bar	N/A	Saw cut depth within certain tolerance Placement of dowel bar within certain tolerance Verification of grinding on grouted area Verification of dowel bar positioning by coring	Payment = unit bid price × number of dowel bar retrofitted	CalTrans' Standard Special Provision 40-015, Year 2009
	Bond Breaker	N/A			
	Fast Setting Grout	Compressive Strength (3 hr and 24 hr)			
		Flexural Strength			
		Bond Strength			
		Drying Shrinkage			
		Setting time			
	Silicone Joint Sealant	Tensile Strength			
		Elongation			
		Bond Strength			
		Durometer Hardness			

Table A-11. Current Specifications for PCC Diamond Grinding.

State	Materials Quality Measures		During and Post-construction Quality Measures	Payment Methods	Comment
	Material Type	Quality Measure			
Arizona	N/A	N/A	Groove Dimension Profile Index Percentage of ground area Minimum Coefficient of friction	Payment = Unit bid price × square yard of treatment	Arizona Standard Specification (Section 402-4) Year 2008
California	N/A	N/A	Uniformity of transverse slope Profile Index Minimum Coefficient of friction	Payment = Unit bid price × square yard of treatment	California Standard Specification (Section 42-2) Year 2006
Florida	N/A	N/A	Smoothness Test using straight edge Profile Index	Payment = Unit bid price × square yard of treatment	Florida Standard Specification (Section 352) Year 2010
Iowa	N/A	N/A	Profile Index Height of individual bump Uniformity of transverse slope Percentage of ground area	Payment = Unit bid price × square yard of treatment	Iowa Special Specification (Section 2532) Year 2010
Michigan	N/A	N/A	Percentage of ground area Smoothness Test using straight edge Dimension of Groove Faulting height near transverse cracks	Payment = Unit bid price × square yard of treatment	Michigan Standard Specification (Section 603.03) Year 2003
New York	N/A	N/A	Percentage of ground area Profile Index	Payment = Unit bid price × square yard of treatment	New York's Specification for Diamond Grinding (Special Item 502.81010018
South Dakota	N/A	N/A	Profile Index Height Individual Bump	Payment = Unit bid price × square yard of treatment	South Dakota's Specification for Diamond Grinding (Special Provision
Texas	N/A	N/A	Groove Dimension Profile Index	Payment = Unit bid price × square yard of treatment	Texas' Special Specification (Special Specification 3088)
Washington	N/A	N/A	Percentage of ground area Groove Dimension Profile Index Smoothness Test using straight edge	Payment = Unit bid price × square yard of treatment	Washington State DOT's Specification (Item 5-01.3(9)) Year 2010
Pennsylvania	N/A	N/A	Groove depth and spacing Uniformity of cross slope (Transverse direction) Roughness test in longitudinal direction (IRI)	Payment = Unit bid price × square meter of ground area	PADOT's Specification for Diamond Grinding (Item 514) Year 2007

Table A-12. Current Specifications for PCC Slab Stabilization (Undersealing).

State	Materials Quality Measures (Pre-construction)		During and Post-construction Quality Measures	Payment Methods	Comment
	Material Type	Quality Measure			
Pennsylvania	Grout Slurry	Expansion Test Initial setting time Compressive Strength (7 day)	Maximum upward movement of the slab Smoothness Deflection Test	Payment = unit price of cement × weight of cement + unit price of drill hole × no of holes + unit price of deflection testing × no of testing	PADOT's specifications for Concrete Pavement Slab Stabilization Item 679, Year 2007
Texas	Grout Slurry	Efflux Time Initial setting time Compressive Strength (7 day)	Maximum upward movement of the slab Deflection Test	Payment = unit price of grout slurry × cubic ft of cement or fly ash + unit price of drilled hole × no of holes	TxDOT's Special specification 3004: pressure Grouting, Year 2004
South Dakota	Grout Slurry	Efflux Time Compressive Strength (7 day)	Maximum upward movement of the slab Deflection Test	Payment = unit price of cement × cubic ft of cement + unit price of drill hole × no of holes + unit price of deflection testing × no of testing	South Dakota's Item 391, Year 2004
Iowa	Grout Slurry	Efflux Time	Maximum upward movement of the slab	Payment = unit price of cement × ton of cement + unit price of drill hole × no of holes filled + 50% of unit price of drilled holes × no of inspection holes	Iowa's Standard Specification Section 2539, Year 2010
New York	Grout Slurry			Payment = unit bid price × cubic meter of grout filling	New York's special specification Item 01501.12 M, Year 1997
California	Grout Slurry	Set Time Compressive Strength Efflux Time	Maximum allowable upward movement of the slab	Payment = unit bid price × no of holes + unit bid price for grout × weight of cement or fly ash	CalTrans' Standard Specification 41-1, Year 2006

Appendix B. Bibliography of Current Pavement Performance Prediction Models

PERFORMANCE MODELS FOR HMA PAVEMENT TREATMENTS

An extensive literature review has been conducted by the research team to search for existing pavement preservation performance prediction models. It was found that significant efforts had been put into developing promising prediction models for HMA pavement preservations. Though some of the efforts have proposed rational performance prediction models, none of them has the ability correlating initial materials and construction properties with future performance of preservation treatments. A summary of reviewed performance prediction models for HMA pavement preservations is presented below. Figure B-1 graphically shows potential influential factors that have an important effect on preservation treatment performance. These factors are categorized into four groups, materials-related, construction-related, traffic-related, and environment-related.

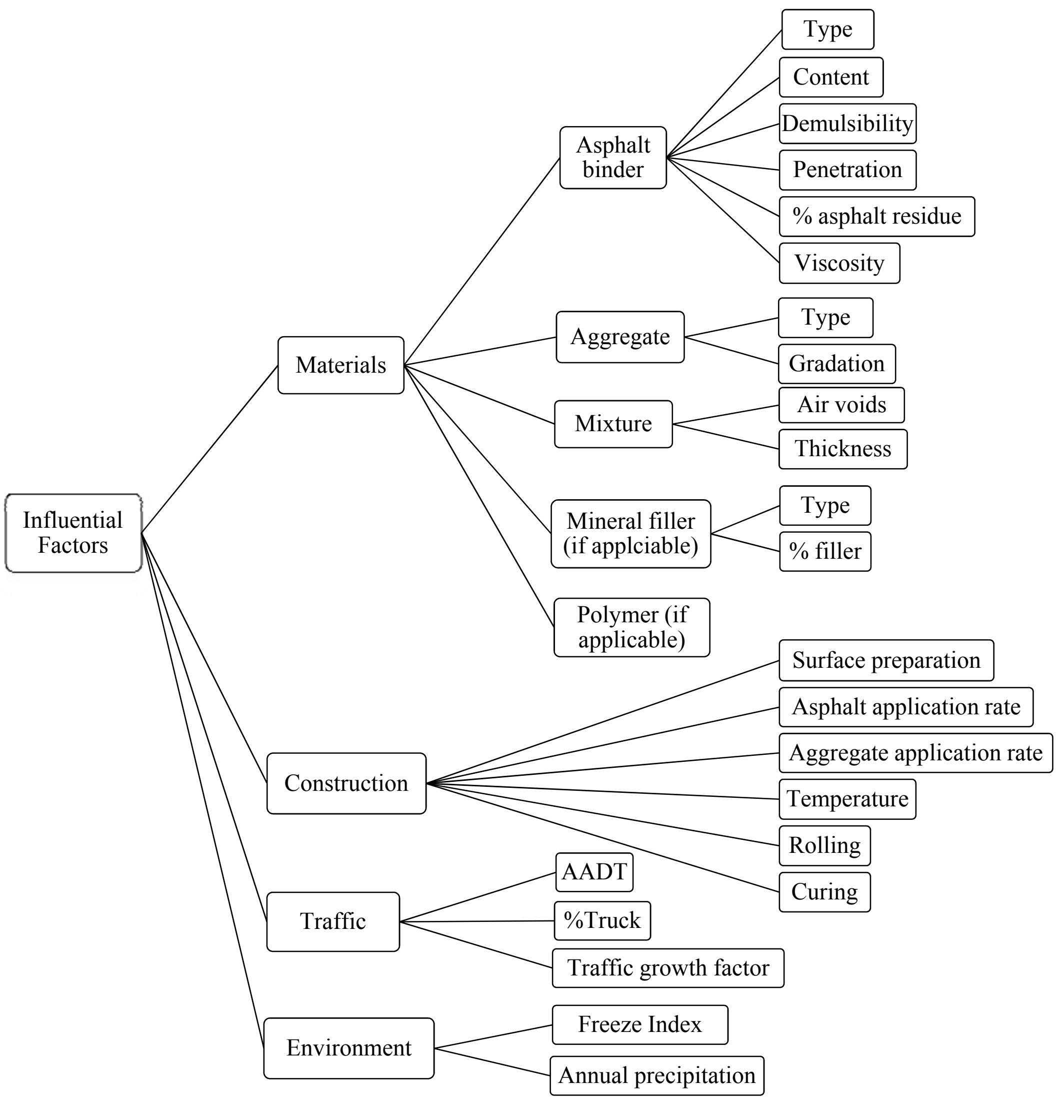


Figure B-1. Influential Factors on HMA Pavement Preservation Treatments

Morian, Gibson, and Epps, 1998

Morian et al. (1998) performed a 5-year study using the long-term pavement performance (LTPP) data. Linear regression models were developed for predicting the pavement rating score (PRS) as a function of a group of traffic, environment, and site-specific variables. PRS is a composite 0-100 scale performance indicator, computed based upon distress conditions including fatigue cracking, longitudinal cracking, transverse cracking, and patching. Regression models were developed for thin overlay, slurry seals, crack seals, and chip seals, having the following forms:

Thin Overlay: $$PRS = 43.3476 + 1.88071(EZ) + 6.137(Age) + 4.37(IC) + 6.122(SG)$$

Slurry Seal: $$PRS = 23.426 + 4.42829(EZ) + 6.92985(Age) + 6.92985(IC)$$

Crack Seal: $$PRS = 26.7872 + 6.54727(EZ) + 11.23(IC)$$

Chip Seal: $$PRS = 45.26 + 4.37(Age) + 9.79(IC) - 9.21(SA) + 10.43(SG)$$

where,

EZ = Environmental zone (dry-no freeze, dry-freeze, wet-no freeze, wet-freeze),
Age = Year of pavement preservation treatment,
IC = Original pavement condition level (good, fair, and poor),
SA = Pavement structural adequacy (structural number ratio either greater than or less than one),
SG = Subgrade type (fine verses coarse).

Hajek and Bradbury, 1999

The Canadian Strategic Highway Research Program (C-SHRP) employed Bayesian statistical analysis methodology for modeling pavement deterioration (Hajek and Bradbury 1999). In this application, distress prediction models were first constructed based on data alone using linear regression. The researchers then selected the best models for further analysis, in which experts with extensive experience in pavement were requested to rate the level of distress at different age with different traffic and asphalt content using a 0-to-10 scale. Based on experts input, prior models were developed using the C-SHRP Bayesian analysis software, and then posterior models were developed from the prior models and field data using "N-prior" analysis option built in the analysis software. Final distress prediction model was selected based on sensitivity analysis. The final model has the following form:

$$DI = 127 + 5.64(Age) - 18.5(AC) - 5.88\log(Traffic)$$

Where,

DI = Distress index,
Age = Age of the pavement surface course,
AC = Design percentage by mass of asphalt cement content in the surface course,
Traffic = AADT volume per lane.

Eltahan, Daleiden, and Simpson, 1999

Eltahan et al. (1999) employed the Kaplan-Meier method to develop a model that predicts the probability of treatment failure at a given time as expressed in the following form.

$$F(t_r) = 1 - \left\{ \frac{n-1}{n} \times \cdots \times \frac{n-(r-1)}{n-(r-1)+1} \times \frac{n-r}{n-r+1} \right\}$$

where,

$F(t_r)$ = The probability of treatment failure at a given time,
n = The total number of sections,
r = The rank of the section at a given time.

This model was said to be applicable for crack sealing, thin overlay, chip seals, and slurry seals.

Jahren, Cawley, Ellsworth, and Bergeson, 1999

Jahren (1999) proposed a simple linear regression model to predict the service life of cold in-place asphalt recycling treatments. In their model, the performance indicators depend solely on treatment age as follows:

$$PSI = 91.7 - 4.19(Age)$$

$$PCI = 114.97 - 4.84(Age)$$

$$\frac{PSI + PCI}{2} = 101 - 4.56(Age)$$

where,

PSI = Pavement serviceability index,
PCI = Pavement condition index.

Temple, Shah, Paul, and Abadie, 2002

Temple et al. (2002) provided a power form model to predict pavement performance [in terms of pavement condition index (PCI)] for Louisiana's chip seal and microsurfacing program. The proposed power model has the following form:

$$PCI = 100 - bx^m$$

where,

b = slope coefficient,
x = pavement age (months),
m = parameter controlling curvature of the PCI curve.

Morian, Oswalt, and Deodhar, 2004

Morian et al. (2004) provided a simple linear regression model to predict reflective cracking in HMA pavements treated with cold in-placed recycling combined with a reflective crack control technique. Their model has only one independent variable, age; therefore, reflective cracking is just a predicted increasing straight line with the age of treatment.

Labi, Mahmodi, Fang, and Nunoo, 2007

Labi et al. (2007a&b) fitted exponential equations using performance indicators [e.g., IRI, rutting, and pavement condition rating (PCR)] for microsurfacing and thin HMA overlay, which have the following general form:

$$PI = e^{\beta_1 + (\beta_2 \times AATT + \beta_3 \times AFDX) \times t}$$

where,

$AATT$ = Annual average daily truck traffic,
$AFDX$ = average annual freeze index,
t = the time at which the performance is being estimated.

Liu, Hossain, and Miller, 2009

Liu et al. (2009) proposed linear models predicting distresses development on HMA pavements treated with chip seals. The covered distresses included IRI, rutting, transverse cracking, and fatigue cracking. These linear models are summarized as follows:

Roughness: $IRI = 3.97091 + 0.89323(InitIRI) + 2.87797(Age) + 1.29244(FC)$

Rutting: $RUT = 0.03621 + 0.76501(InitRUT) - 0.00404(FC)$

Transverse Cracking: $TCR = -0.0765 + 0.7833(InitTCR) + 0.0175(Age) + 0.0561(FC)$

Fatigue Cracking: $FCR = -0.24839 + 0.49664(InitFCR) + 0.00008(ESAL) + 0.15381(FC)$

where,

InitIRI = First year IRI value after chip-sealing,
InitRUT = First year rut depth after chip-sealing,
InitTCR = First year transverse crack value after chip-sealing,
InitFCR = First year fatigue crack value after chip-sealing,
Age = Year of chip seal treatment,
FC = Highway functional class (interstate, US, and state highways),
ESAL = Cumulative equivalent 18-kip single axle loads.

MEPDG, 2004

The mechanistic-empirical pavement design guide (MEPDG) employs several pavement distress prediction models to estimate distress development in newly constructed or overlaid HMA pavements. The distresses that can be predicted in MEPDG include fatigue cracking (both alligator and longitudinal), thermal cracking (transverse), performance deformation (rutting), and smoothness (IRI).

Fatigue Cracking

In MEPDG the estimation of fatigue damage is based upon Miner's Law, as following:

$$D = \sum_{i=1}^{T} \frac{n_i}{N_i}$$

where,

D = damage,
T = total number of periods,
n_i = actual traffic for period i, and
N_i = traffic allowed under conditions prevailing in i.

The number of load repetitions to fatigue cracking can be predicted as a function of the tensile strain and mix stiffness (modulus). In MEPDG, the national field calibrated model has the following form:

$$N_f = 0.00432 k_1^{'} C \left(\frac{1}{\varepsilon_t}\right)^{3.9492} \left(\frac{1}{E}\right)^{1.281}$$

where,

N_f = number of load repetitions to fatigue cracking,
$k_1^{'}$ = correction factor for asphalt layer thickness effects,

ε_t = tensile strain at the critical location,
E = stiffness of the material,

C = laboratory to field adjustment factor, and $C = 10^{4.84\left(\frac{V_b}{V_a+V_b} - 0.69\right)}$,
where,
V_b = effective binder content (%), and
V_a = air voids (%).

The "$k_1^{'}$" value has different computation forms for bottom-up cracking and top-down cracking:

a. For bottom-up cracking (alligator cracking):

$$k_1^{'} = \frac{1}{0.000398 + \frac{0.003602}{1+e^{(11.02-3.49 h_{ac})}}}$$

b. For top-down cracking (longitudinal cracking):

$$k_1^{'} = \frac{1}{0.01 + \frac{12.0}{1+e^{(15.676-2.8186 h_{ac})}}}$$

where, h_{ac} = total thickness of the asphalt layers in inch.

The $k_1^{'}$ value ranges from 0 to 2,500 for bottom-up cracking and from 0 to 100 for top-down cracking, as shown in Figure B-2.

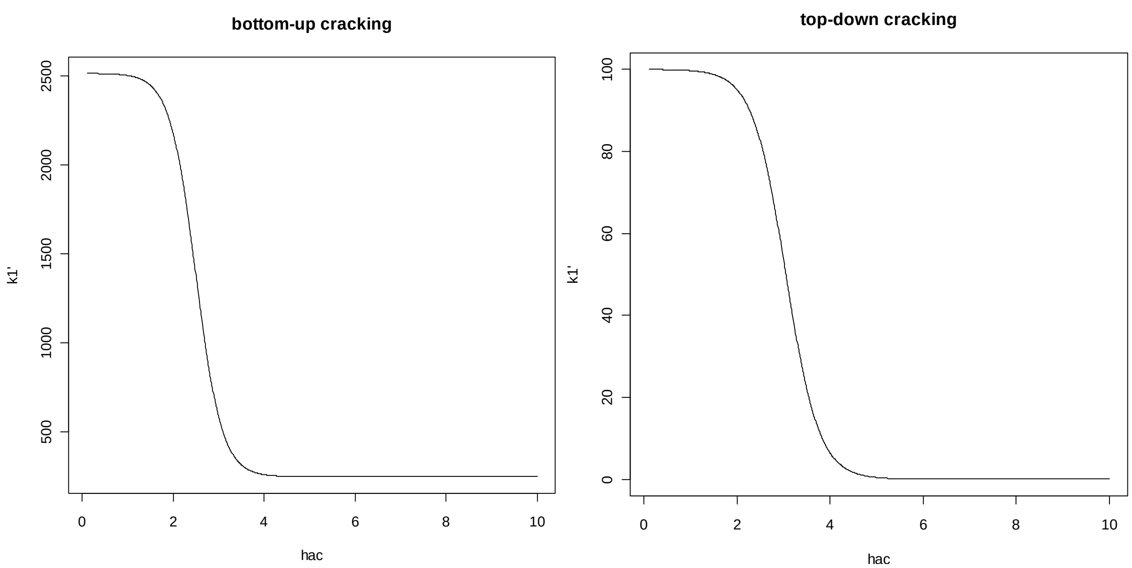


Figure B-2. $k_1^{'}$ versus h_{ac} for Bottom-up and Top-down Cracking

The fatigue damage can then be calculated into fatigue cracking using a transfer function, which has the following forms:

a. For bottom-up cracking (% of total lane area):

$$FC_{bottom-up} = \frac{1}{60}\left(\frac{6000}{1+e^{C_1 * C_1^{'} + C_2 * C_2^{'} * \log 10(D*100)}}\right)$$

where,

$FC_{bottom-up}$ = bottom-up fatigue cracking, percent lane area,
D = bottom-up fatigue damage (obtained from Eq. 2),
C_1 = 1.0,
$C_1^{'} = -2 * C_2^{'}$,
$C_2 = 1.0$,
$C_2^{'} = -2.40874 - 39.748 \times (1 + h_{ac})^{-2.856}$.

b. For top-down cracking (feet/mile):

$$FC_{top-down} = 10.56\left(\frac{1000}{1 + e^{7.0-3.5*\log10(D*100)}}\right)$$

where,
$FC_{top-down}$ = top-down fatigue cracking, ft/mile,
D = top-down fatigue damage.

Thermal Cracking

In MEPDG, the amount of thermal (transverse) cracking expected in the pavement system is predicted by relating crack depth to the amount of cracking as follows:

$$C_f = \beta_1 * N\left(\frac{\log C / h_{ac}}{\sigma}\right)$$

where,
C_f = observed amount of thermal cracking,
β_1 = regression coefficient from field calibration,
$N(z)$ = standard normal distribution evaluated at (z),
σ = standard deviation of the log of the depth of cracks in the pavement,
C = crack depth, and
h_{ac} = thickness of asphalt layer.

Using the Paris Law, the amount of crack propagation induced by a given thermal cooling cycle is predicted by the following expression:

$$\Delta C = A \Delta K^n$$

where,
ΔC = change in the crack depth due to a cooling cycle,
ΔK = change in the stress intensity factor due to a cooling cycle,
A, n = fracture parameters for the asphalt mixture, which can be derived from the following equations:

$$n = 0.8\left(1 + \frac{1}{m}\right)$$

where,
m is the slope of the compliance curve.

and

$$A = 10^{\beta*\left[4.389-2.52*\log\left(E*\sigma_m*n\right)\right]}$$

where,
E = mixture stiffness,

σ_m = undamaged mixture tensile strength,
β = calibration parameter.

Permanent Deformation

In MEPDG pavement permanent deformation is the total rutting in the pavement structure (asphalt surface, granular base/subbase, and subgrade). Thus, the total rutting can be expressed by the following equation:

$$RD_{Total} = RD_{AC} + RD_{GB} + RD_{SG}$$

Pavement structure is divided into a number of sublayers. The plastic strain in each sublayer is evaluated, and the overall performance deformation is the accumulation of the product of plastic strain and thickness of individual sublayers as follows.

$$RD = \sum_{i=1}^{\#of\ sublayers} \varepsilon_p^i h^i$$

where,

RD = Pavement permanent deformation,
ε_p^i = Total plastic strain in sublayer *i,*
h^i = Thickness of sublayer *i*.

For asphalt mixtures, the plastic strain has the following model form:

$$\frac{\varepsilon_p}{\varepsilon_r} = k_1 * 10^{-3.4488} T^{1.5606} N^{0.479244}$$

where,

ε_p = Accumulated plastic strain at N repetitions of load,
ε_r = Resilient strain of the asphalt material as a function of mix properties, temperature and time rate of loading,
N = Number of load repetitions,
T = Temperature (degree F), and
k_1 = Correction factor for the confining pressure at different depths of pavement and it is a function of total asphalt layers thickness (h_{ac}) and *depth* to computation point, expressed as follows:

$$k_1 = \left(C_1 + C_2 * depth\right) * 0.328196^{depth}$$

where,

$$C_1 = -0.1039 * h_{ac}^2 + 2.4868 * h_{ac} - 17.342$$

$$C_2 = 0.0172 * h_{ac}^2 - 1.7331 * h_{ac} + 27.428$$

For granular base or subbase, the permanent deformation is estimated using the following model:

$$\delta_a\left(N\right) = \beta_{GB}\left(\frac{\varepsilon_0}{\varepsilon_r}\right) e^{-\left(\frac{\rho}{N}\right)^{\beta}} \varepsilon_v h$$

where,

δ_a = Permanent deformation for the layer/sublayer,
N = Number of traffic repetitions,

β_{GB} = National calibration factor of 1.673,
ε_0, ρ, and β = Material Properties,
ε_r = Resilient strain imposed in laboratory tests,
ε_v = Average vertical resilient strain in the layer/sublayer obtained from the primary response model, and
h = Thickness of the layer/sublayer.

The rutting model for all subgrade soils has exactly the same form as granular base or subbase, except that a 1.35 national calibration factor is used.

Smoothness (IRI)

In MEPDG, smoothness loss is correlated to some other forms of distress, including rutting, transverse cracking, alligator cracking, longitudinal cracking, block cracking, and site conditions. A collection of IRI models have been developed for different types of bases and subbases.

For unbound aggregate bases and subbase, the IRI model has the following form:

$$IRI = IRI_0 + 0.463\left[SF\left(e^{\frac{age}{20}} - 1\right)\right] + 0.00119\left(TC_L\right)_T + 0.1834\left(COV_{RD}\right) + 0.00384\left(FC\right)_T$$
$$+ 0.00736\left(BC\right)_T + 0.00115\left(LC_{SNWP}\right)_{MH}$$

where,

IRI = IRI at any given time,
IRI_0 = Initial IRI,
$e^{\frac{age}{20}} - 1$ = Age term, where *age* is expressed in years,
$\left(TC_L\right)_T$ = Total length of transverse cracks (low, medium, and high severity levels),
COV_{RD} = Coefficient of variation of the rut depths,
$\left(FC\right)_T$ = Fatigue cracking in wheel path,
$\left(BC\right)_T$ = Area of block cracking,
$\left(LC_{SNWP}\right)_{MH}$ = Length of moderate and high severity sealed longitudinal cracks outside wheel path, and
SF = Site factor, expressed as

$$SF = \left(\frac{R_{SD} * \left(P_{.075} + 1\right) * PI}{2 * 10^4}\right) + \left(\frac{\ln\left(FI + 1\right) * \left(P_{.02} + 1\right) * \ln\left(R_m + 1\right)}{10}\right)$$

where,

R_{SD} = Standard deviation of monthly rainfall,
$P_{.075}$ = Percent passing 0.075-mm sieve,
PI = Percent plasticity index of the soil,
FI = Average annual freeze index,
$P_{.02}$ = Percent passing 0.02-mm sieve,
R_m = Average annual rainfall.

For asphalt treated bases, the IRI model is as follows:

$$IRI = IRI_0 + 0.0099947(Age) + 0.0005183(FI) + 0.000235(FC)_T$$
$$+18.36\left[\frac{1}{(TC_s)_H}\right] + 0.9694(P)_H$$

where,

$(TC_s)_H$ = Average spacing of high severity transverse cracks,

$(P)_H$ = Area of high severity patches,

All other variables are as previously defined.

For chemically treated bases, the IRI model is as follows:

$$IRI = IRI_0 + 0.00732(FC)_T + 0.07647(SD_{RD}) + 0.0001449(TC_L)_T$$
$$+0.00842(BC)_T + 0.0002115(LC_{NWP})_{MH}$$

where, all the variables are as previously defined.

PERFORMANCE MODELS FOR PCC PAVEMENT

Concrete Pavement Faulting

The presence of water, the erodibility of a subbase material, the magnitude of load-inducted deflection, and the number of loads are factors that influence the development of faulting. However, existing models for faulting scarcely address these factors fully. Below are models listed in the literature that potentially could be used to predict faulting performance of PCC preservation treatments.

Markowl, 1984

An empirical model (see equation below) based on AASHO road test data related slab thickness to equivalent single axle load (ESAL) and subbase drainage conditions (Van Wijk 1985). The model is simple, but does not consider many important factors. The pumping index indicates the potential of erosion that increases with cumulative number of ESAL and diminishing drainage conditions but decreases quickly with an increase in slab thickness. Drainage adjustment factor is considered based on subbase permeability.

$$P_i = m \cdot \sum ESAL \cdot f_d$$
$$\log m = 1.07 - 0.34D$$

where, P_i = pumping index

D = slab thickness (in.)

$ESAL$ = equivalent 80 kN (18,000 lb) single axle loads

f_d = drainage adjustment factor

= 0.2 for good drainage (k =10,000 ft/day)

= 0.6 for fair drainage (k = 100 ft/day)

= 1.0 for poor drainage (k = 0.1 ft/day)

k = subbase permeability

Larralde, 1984

Another empirical model was developed based on the AASHO road test data relating erosion to the amounts of deformation energy imposed by the application of load (Van Wijk 1985). The deformation energy was computed using finite element modeling; a pumping index is normalized to eliminate the effect of slab length and reinforcement. The model in the following equation is empirical in nature and consequently does not consider many important factors related to erosion.

$$NPI = \exp\left[-2.884 + 1.652 \cdot \log\left(\frac{\sum ESAL \cdot DE}{10{,}000}\right)\right]$$

where, *NPI* = normalized pumping index of volume of pumped material (in.^{3})
ESAL = equivalent 80 kN (18,000 lb) single axle loads
DE = deformation energy per one application of ESAL
= $\log(\mathrm{DE}) = 3.5754 - 0.3323\,\mathrm{D}$
D = slab thickness (in.)

Rauhut, 1982

In this model, the level of pumping damage was empirically related, based on nonlinear regression analysis of the Concrete Pavement Evaluation System (COPES) database, to many comprehensive factors such as precipitation, drainage, subbase type (stabilized or not), subgrade type (soil type), load transfer, slab thickness, freezing index, Thornthwaite moisture index, and traffic. The first equation below is separated for jointed plain concrete pavement (JPCP), and jointed reinforced concrete pavement (JRCP), as follows (Van Wijk 1985):

$$\mathrm{g} = \left(\frac{\mathrm{ESAL}}{\rho}\right)^{\beta}$$

JPCP

$$\ln\rho = 1.39 \cdot \mathrm{DRAIN} + 4.13$$

$$\beta = \frac{0.772(\mathrm{D} - 2.3)^{1.61}}{\mathrm{PPTN}} + 0.0157 \cdot \mathrm{JLTS} \cdot \mathrm{D} + 0.104 \cdot \mathrm{STAB} + 0.17 \cdot \mathrm{DRAIN} + 0.137 \cdot \mathrm{SOILTYP} - 0.247$$

JRCP

$$\ln\rho = 1.028 \cdot \mathrm{STAB} + 0.0004966 \cdot \mathrm{D}^{3.47} - 0.01248 \cdot \mathrm{FRINDEX} + 1.667 \cdot \mathrm{CBR} + 5.476$$

$$\beta = -0.01363 \cdot \mathrm{DMOIST} + 0.02527 \cdot \mathrm{D} - 0.423$$

where, g = amount of distress as a fraction of a pumping level of 3 (severe)
DRAIN = 0; no underdrains, 1; underdrains
PPTN = average annual precipitation (cm)
JLTS = 0; undowelled, 1; dowelled
STAB = 0; unstabilized subbase, 1; stabilized subbase
SOILTYP = 0; granular foundation soil, 1; coarse foundation soil
DMOIST = Thornthwaite moisture index
FRINDEX = freezing index
CBR = California bearing ratio of foundation soil
D = slab thickness (in.)

Van Wijk, 1985

The following equations were developed to include factors derived from field data to make improvement over the Larralde model to predict the volume of eroded material as a function of the deformation energy produced by traffic. The effect of many factors on pumping such as subbase and subgrade type, drainage, load transfer, and climate condition are considered in this model. Since this model is empirical in nature, its application is limited to the variable ranges included in the data base.

$$P = 36.67 \cdot NPI$$

$$NPI = F \cdot \exp\left[-2.884 + 1.652 \cdot \log\left(\frac{\sum ESAL \cdot DE}{10{,}000}\right)\right]$$

where, P = volume of pumped material (ft^3/mile)

NPI = normalized pumping index ($in.^3$)

DE = deformation energy per application (in.-lb)

$\log(DE) = 3.5754 - 0.3323\,D$

D = slab thickness(in.)

F = f_{JPCP} if nonreinforced PCC, f_{JRCP} if reinforced PCC

P = volume of pumped material (ft^3/mile)

$f_{JPCP} = f_{sbl} \cdot f_d \cdot f_{lt} \cdot f_{prec} \cdot f_{sg}$

f_{sbl} = subbase adjustment factor: 1; unstabilized

0.65+0.18 log(ΣESAL); stabilized

f_d = drainage adjustment factor: 1; poor drainage

0.91+0.12 log(ΣESAL)-0.03D; fair drainage

0.68+0.15 log(ΣESAL)-0.04D; good drainage

0.01; excellent drainage

f_{lt} = load transfer adequacy adjustment factor: 1; with dowel

1.17-0.68 log(ΣESAL)-0.078D; without dowel

f_{prec} = rainfall adjustment factor:

0.89+0.26 log(ΣESAL)-0.07D; dry climates

0.96+0.06 log(ΣESAL)+0.02D; wet climates

f_{sg} = subgrade adjustment factor: 1; granular subgrades

0.57+0.21 log(ΣESAL); coarse subgrade

$f_{JRCP} = f_{sb2} \cdot f_e$

f_{sb2} = subbase adjustment factor: 1; unstabilized

0.91-0.02 log(ΣESAL); stabilized

f_e = adjustment for climate:

0.011+0.003 log(ΣESAL)-0.001D; dry, warm climates

1.44-0.03 log(ΣESAL)-0.06D; wet, warm climates

1.04-0.32 log(ΣESAL)-0.08D; dry, cold climates

0.54-0.85 log(ΣESAL)-0.19D; wet, cold climates

Jeong and Zollinger, 2001

A mechanistic empirical model (see below) was developed using the water induced shear stresses model proposed by Van Wijk (1985). Key factors such as vehicle load and speed, load transfer, number of applications, and climatic conditions are included in the model to predict erosion. Erosion potential increases with higher initial edge gap and liftoff distance due to the effect of upward curling along slab corners and edges inducing shear stress on the base layer by pumping of trapped water. The magnitude of shear stress depends on the dynamic viscosity of water governed by water temperature and the speed of slab deflection. Higher slab deflection velocity and lower viscosity of water result more erosion of the base while better load transfer cuts down erosion rate as detailed in equation. The accuracy of the model should be calibrated using performance data such as that may be available in the Long-Term Pavement Performance (LTPP) database (Jeong and Zollinger, 2003). This model can account for abrasive erosion due friction between concrete and subbase layer.

$$f = f_0 e^{-\left(\frac{\rho}{N_i}\right)^a}$$

Where, ν_0 = ultimate erosion depth (L)

N = number of axle loads per load group

ρ = calibration coefficient based on local performance

a = $a'\alpha_f$

a' = environmental calibration coefficient

α_f = inverse of the rate of void development

$$= \left[\frac{\partial f_i}{\partial t}\right]^{-1} = \left[\frac{Log^{-1}(a_m \tau + b_m)}{\gamma_b}\right]^{-1} = \left[\frac{\beta}{\gamma_b}\right]^{-1}$$

τ = shear stress = $\frac{\eta B}{\delta_{void}}\left(1 - \frac{LTE}{100}\right)$

η = dynamic viscosity of water ($FL^{-2}t$)

$$= \left\{2056.82 + 10.56T - 284.93\sqrt{T} - 265.02e^{-T}\right\}10^{-6}$$

T = Water temperature (°C)

B = $V_{z_i} \sin\theta + 6V_{z_i}\left[\frac{\sin\theta}{2} + \frac{\cos^2\theta}{\sin\theta}\right]$ (L/t)

δ_{void} = Void space below slab for water movement

θ = Slab angle = $\tan^{-1}\left[\frac{z_o}{s}\right]$

z_o = Edge gap (L) = $\frac{(1+\nu)}{H}\Delta\varepsilon_{tot}\ell^2$

$$V_{z_i} = \frac{\delta_{int}}{s/V_i}$$

$$\delta_{int} = \frac{P_i}{8k\ell}\left\{1 + \left[0.3665\log\left(\frac{a_L}{\ell}\right) - 0.2174\left(\frac{a_L}{\ell}\right)^2\right]\right\}$$

a_L = loaded radius (L)

P_i = axle load (F)
s = slab liftoff distance (L) = $\sqrt{2}\ell(\gamma - 1)$
$\gamma = \sqrt{\dfrac{z_o}{w_o}}$
$w_o = \dfrac{\rho H}{k}$

PCA Design Method

In this procedure, subbase erosion is related to pavement deflection (at the slab corner) due to axle loading. The following equations were developed based on the results of the AASHO Road Test for allowable load repetitions and erosion damage (Huang 2004):

$$\log N = 14.524 - 6.777(C_1 P - 9.0)^{0.103}$$

$$\text{Percent erosion damage} = 100\sum_{i=1}^{m}\frac{C_2 n_i}{N_i}$$

where, N = allowable number of load repetitions based on a PSI of 3.0
C_1 = adjustment factor (1 for untreated subbase, 0.9 for stabilized subbase)
P = rate of work or power = $268.7\dfrac{p^2}{hk^{0.73}}$
p = pressure on the foundation under the slab corner in psi, $p = kw$
k = modulus of subgrade reaction in psi/in
w = corner deflection in inches
h = thickness of slab in inches
m = total number of load groups
C_2 = 0.06 for pavement without concrete shoulder, 0.94 for pavements with tied concrete shoulder
n_i = predicted number of repetitions for ith load group
N_i = allowable number of repetitions for ith load group

Prepared sets of tables and charts are used to address doweled and aggregate interlock joints either with or without concrete shoulders. Since the erosion criterion was developed primarily from the results of the AASHTO Road Test using a specific subbase which was highly erodible, the application of the model has found limited use as far as application to different subbase types. Nonetheless, this procedure represents a significant advancement in the mechanistic analysis of pavement support condition in design.

AASHTO Design Method

Potential loss of support (LS) due to foundation erosion is utilized as input to effectively reduce the modulus of subgrade reaction in the thickness design procedure relative to four different contact conditions (i.e. with LS = 0, 1, 2, and 3). The best case is LS = 0, when the slab and foundation are assumed to be in full contact, while the worst case is LS = 3, when an area of slab is assumed not to be in contact with the subgrade (thus reduced values of k-value are in effect).

In Table B-1, the possible ranges of LS factors for different types of subbase materials are provided to adjust the effective modulus of reaction. The subjectivity of the model reduces its sensitivity to material factors associated with erosion leading to inconsistency and limiting applicability. Load transfer coefficient and drainage coefficient are also indirectly related with erosion; a lower deflection caused by better load transfer would reduce shear stress at the interface between the slab and base/subgrade as well as a shorter time of water presence due to better drainage may decrease the potential for pumping. Therefore, major factors causing erosion can be considered in the design.

Table B-1 Typical Ranges of LS Factors for Various Types of Materials (Huang 2004).

Type of material	Loss of support
Cement-treated granular base (E = $1x10^6$ to $2x10^6$ psi)	0.0 to 1.0
Cement aggregate mixtures (E = 500,000 to $1x10^6$ psi)	0.0 to 1.0
Asphalt-treated bases(E = 350,000 to $1x10^6$ psi)	0.0 to 1.0
Bituminous-stabilized mixture (E = 40,000 to 300,000 psi)	0.0 to 1.0
Lime-stabilized materials (E = 20,000 to 70,000 psi)	1.0 to 3.0
Unbound granular materials (E = 15,000 to 45,000 psi)	1.0 to 3.0
Fine-grained or natural subgrade materials (E = 3,000 to 40,000 psi)	2.0 to 3.0

Mechanistic-Empirical Pavement Design Guide (MEPDG)

The MEPDG addresses erosion in modeling faulting distress (see equations below) (ARA 2004). Classes of erodibility are formulated based on a modification of the Permanent International Association of Road Congresses (PIARC) specifications relative to material type and stabilizer percent. Five levels of erosion resistance are listed in Table B-2 distinguish between materials types based on stabilizer type and content (asphalt or portland cement) as well as long-term compressive strength (later than 28 days). Prediction of erodibility is closely associated with the stabilized material compressive strength and is readily available in most databases.

Moreover, the presence of permeable drainage layer (treated or untreated granular material with permeability > 300 ft/day) and/or a geotextile fabric between the treated base and subgrade are design features to enhance design. Each class of erosion is assumed to offer 5 times the resistance to erosion than the next class. (i.e., class 1 materials are five times more erosion resistant than class 2 and so on). However, the guide do not address the degree of friction between the concrete and the base layer or its contribution to erosion of interface via shear stress. Field performance has been satisfactory even though lower strength materials have been used with low friction interface bases.

$$FAULTMAX_i = FAULTMAX_0 + C_7 * \sum_{j=1}^{m} DE_j * Log(1 + C_5 * 5.0^{EROD})^{C_6}$$

$$FAULTMAX_0 = C_{12} * \delta_{curling} * \left[Log(1 + C_5 * 5.0^{EROD}) * Log(\frac{P_{200} * WetDays}{P_5}) \right]^{C_6}$$

where, $FAULTMAX_i$ = maximum mean transverse joint faulting for month i, in.
$FAULTMAX_0$ = initial maximum mean transverse joint faulting, in.
$EROD$ = base/subbase erodibility factor
DE_i = differential deformation energy accumulated during month i.
$EROD$ = base/subbase erodibility factor
C_{12} = $C_1 + C_2 * FR^{0.25}$
C_i = calibration constants
FR = base freezing index defined as percentage of time the top base temperature is below freezing (32 °F) temperature.
$\delta_{curling}$ = maximum mean monthly slab corner upward deflection PCC due to temperature curling and moisture warping.

PS = overburden on subgrade, lb
P200 = percent subgrade material passing #200 sieve
WetDays = average annual number of wet days (greater than 0.1 in. rainfall).

Table B-2 MEPDG recommendations for assessing erosion potential of base material (ARA 2004).

Erodibility Class	**Material Description and Testing**
1	(a) Lean concrete with approximately 8 percent cement; or with long-term compressive strength > 2,500 psi (>2,000 psi at 28-days) and a granular subbase layer or a stabilized soil layer, or a geotextile fabric is placed between the treated base and subgrade, otherwise class 2. (b) Hot mixed asphalt concrete with 6 percent asphalt cement that passes appropriate stripping tests and aggregate tests and a granular subbase layer or a stabilized soil layer (otherwise class 2). (c) Permeable drainage layer (asphalt treated aggregate or cement treated aggregate and with an appropriate granular or geotextile separation layer placed between the treated permeable base and subgrade.
2	(a) Cement treated granular material with 5 percent cement manufactured in plant, or long-term compressive strength 2,000 to 2,500 psi (1,500 to 2,000 psi at 28-days) and a granular subbase layer or a stabilized soil layer, or a geotextile fabric is placed between the treated base and subgrade; otherwise class 3. (b) Asphalt treated granular material with 4 percent asphalt cement that passes appropriate stripping test and a granular subbase layer or a treated soil layer or a geotextile fabric is placed between the treated base and subgrade; otherwise class 3.
3	(a) Cement-treated granular material with 3.5 percent cement manufactured in plant, or with long-term compressive strength 1,000 to 2,000 psi (750 psi to 1,500 at 28-days). (b) Asphalt treated granular material with 3 percent asphalt cement that passes appropriate stripping test.
4	Unbound crushed granular material having dense gradation and high quality aggregates.
5	Untreated soils (PCC slab placed on prepared/compacted subgrade)

Pavement Macro-Surface Texture Model for Diamond Grinding

Data collected from studies of ground pavement surfaces indicate that the depth of texture is strongly dependant on the age or the time since the grinding and indirectly on traffic since grinding (Rao et al. 1999). Climate also seemed to be a factor as where pavements in wet and dry freeze environments tended to have lower macro texture than those in the non-freeze regions.

Pavement grinding on sections in the former regions would provide on the average 8 years of service life where those in the latter would provide 12 years of service life on the average. Several factors were considered in the development of the following macro-texture model listed as:

- Time since grinding
- Traffic (both passenger and truck) since grinding
- Geographic location
- Annual temperature and moisture levels
- Freezing Index
- Blade spacing

The model for the mean texture depth (MTD) is:

$$MTD = 0.152(1-0.233*Freeze)*Age + 0.887$$

where

Age = Time since grinding (0.5 to 16 years)

Freeze = Dummy variable for freeze climate region (0 = wet non-freeze or dry non-freeze, 1 = wet freeze or dry freeze region)

Prediction of Joint/Crack Spalling in PCC Pavement

Spalling is considered as one of the most important distress types of PCC pavement that affects the performance and functionality of a concrete pavement. Therefore it is useful to predict spalling in order to estimate future related maintenance i.e. partial depth repair or full depth repair and to examine how construction factors may affect pavement performance relative to spalling.

Spalling is the breakdown or dislodging of concrete segments along or within 6 to 12 inches of a joint or crack in a concrete slab. There are two main steps associated with spalling.

Step1: Initiation of delamination cracks: a significant contributor to spalling is the existence of shallow, horizontal delaminations that are oriented parallel to the alignment of a transverse crack or joint and at a shallow depth below the surface of the pavement. The formation of delamination has been researched for several years and has been found to be affected by a variety of factors but the most prevalent of them is the quality of the curing process and the evaporation of pore water from the concrete. If the moisture gradient due to evaporation is sufficiently severe it can create horizontal shear stresses and also cracks (Figure B-3.a).

Step 2: The bending moment stress: the presence of delaminations in the vicinity of transverse cracking (in CRC pavement) can eventually lead to the development of spall damage due to repeated traffic loading or any number of mechanisms causing inplane bending stress in the delaminated segments (Figure B-3.b).

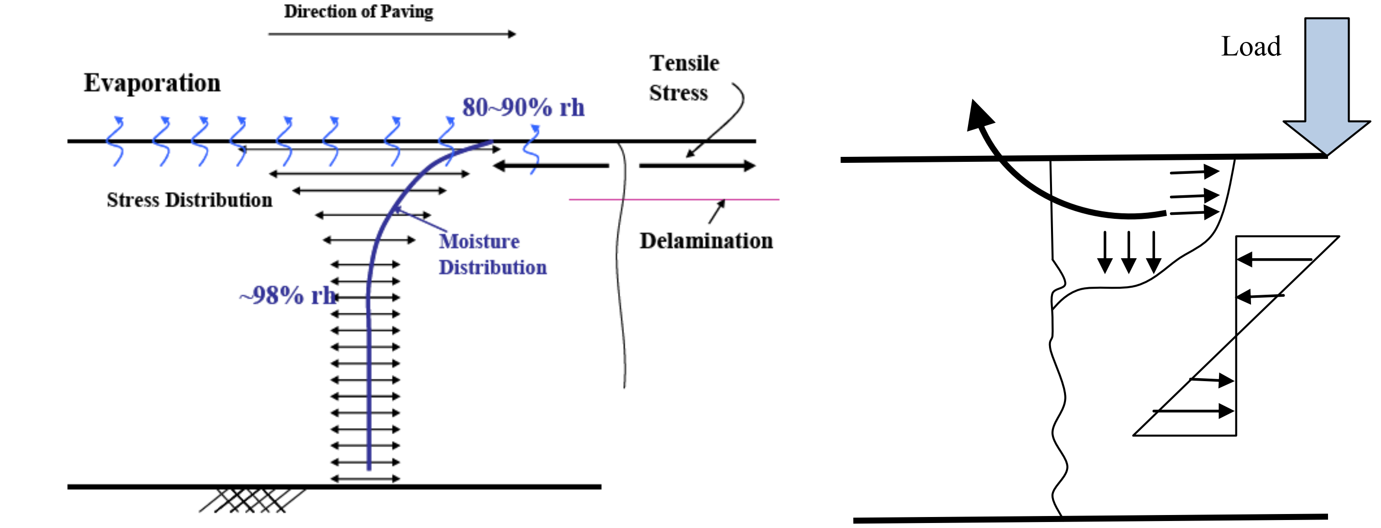


Figure B-3 a) Initiation of delamination cracks, b) The bending moment stress.

MEPDG Spall Model

Spalling is represented, however discretely, in the MEPDG design procedure. It has only been recently that any design procedure has attempted to address spall distress with a design methodology. The spalling model is used to determine a component of roughness along transverse joints used to determine the given level of IRI with the following model:

$$SPALL = \left[\frac{Age}{Age+0.01}\right]\left[\frac{100}{1+1.005^{(-12*Age+SCF)}}\right]$$

where

SPALL	= % Joints spalled (medium and high severities)
Age	= Pavement age, yrs
SCF	= Scaling factor based on site, design, and climate
	= -1400+350(%Air)∗(0.5 + Preform) + 3.4f'_c(0.4) – 0.2(FTCYC∗Age) + 43h_{PCC} – 536W/C
%Air	= Percent air in PCC
Preform	= 1 if performed sealant; 0 if not
f'_c	= PCC compressive strength, psi
FYCYC	= Average number of freeze-thaw cycles
h_{PCC}	= Slab thickness, in
W/C	= water-cementitious ratio

Mechanistic Spall Stress and Performance Modeling

A spalling stress model by Tang et al. (1997) and Jeong, Zollinger (2001) serves as a means to determine tensile stress caused by passing wheel loads leading to spall development. The Tang model for spall stress (σ_{spall}) is illustrated in Figure 2, which has since been modified from the original expression to account for tensile stress effects due to vertical shear on the crack face due to load transfer. As can be observed in Figure B-4, several key parameters are included in the model and are re-defined as follows:

$$\sigma_{spall} = \left[\left(\tau_p - \tau_f \right) \frac{\ell^*}{t} + \frac{\tau_f}{\tan\theta} \right] + \frac{6M}{t^2}$$

where,

τ_p = shear stress from tire loading
τ_f = friction resistance at bottom of spall
l* = length of spall
θ = angle of spall fracture
M = spall bending moment due to shear from load transfer

The bracketed term in the equation can be used to calculate the stress that a passing wheel load causes on the surface concrete leading to chipping and shallow spalling. In case of spalling the second term principally applies.

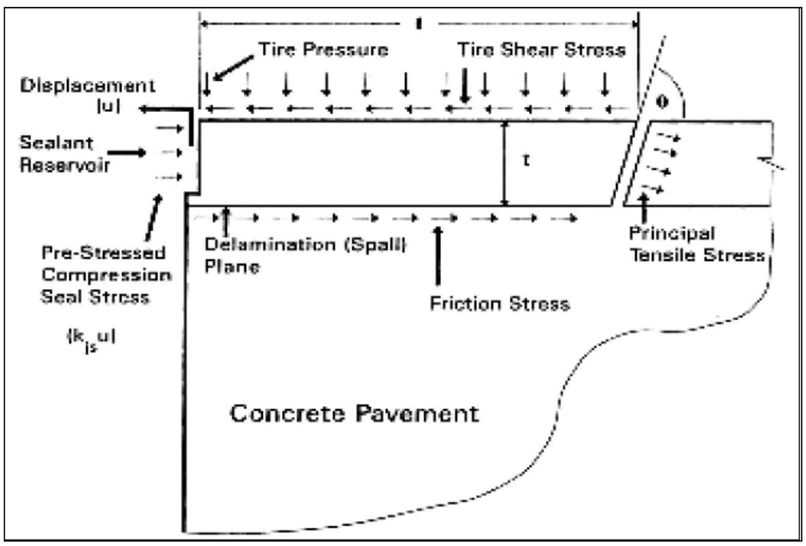


Figure B-4. Concrete Pavement Spall Mechanism and Model. (Zollinger et al. 1994)

The bending stress, the main factor causing spall formation, can be easily calculated as a function of the load transfer of the transverse crack as imposed by $\Delta\delta$ which is deflection between loaded slab and unloaded slab. Since the bending moment is primarily affected by the aggregate interlock along the transverse crack, the spalling stress (σ_{spall}) depends both on the induced bending moment and indirectly on slab thickness through its effect on the LTE of the transverse crack.

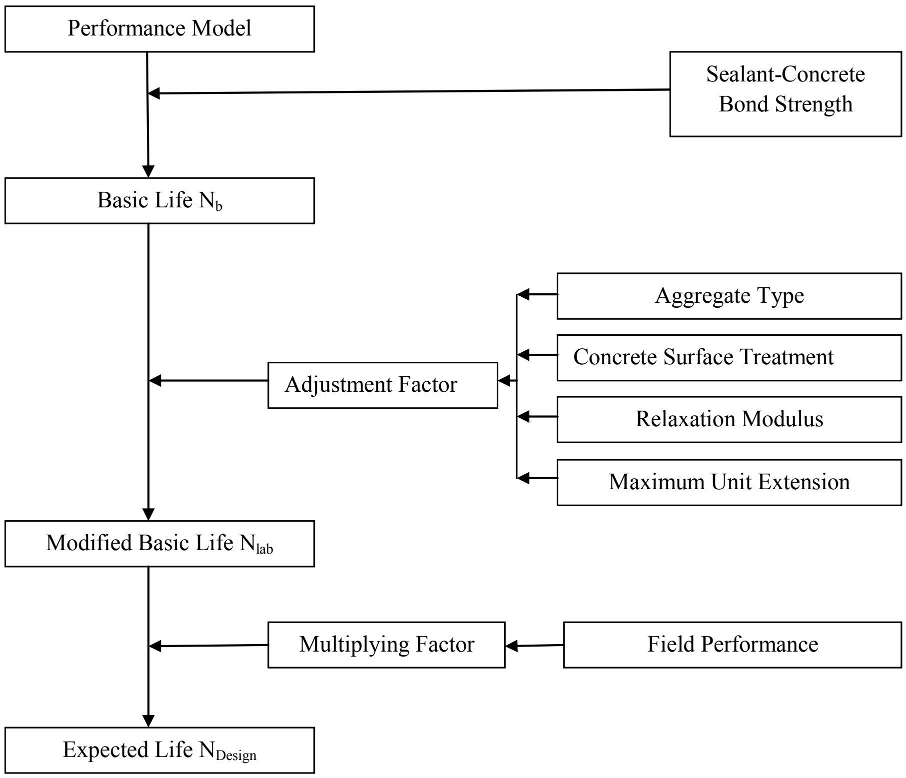
$$M = \frac{E_c t^3 \Delta\delta}{4\left(\ell^*\right)^2}$$

where,

*l** = length of delamination (assumed to be 3 inches),
$\Delta\delta$ = delamination opening at the face of the crack due to movement across the joint or crack reflected in the load transfer efficiency,
t = depth of spalling (in), and
E_c = concrete modulus (psi)

Estimation of service life of the joint sealant

A performance based model is presented to estimate the service life of the joint sealant in a pavement concrete in terms of the number of openings and closing of the joint. The model is based on laboratory and field data for various joint sealants. Below is the flowchart of service life estimation procedure for joint sealant. As it has been shown there are two modifications to account for joint sealant material type and field conditions.



Estimation of Service Life

A simple equation form was adopted to estimate the number of temperature cycles a joint seal can undergo prior to developing bond failure with the concrete joint well.

$$N_{Lab} = f_1 \frac{\sigma_b}{E} \varepsilon_S^{f_2} \varepsilon_L^{f_3}$$

where

N_{Lab} = Number of cycles failure observed under laboratory standard condition,
E = Long term relaxation modulus at 25°C and 20% unit extension,
σ_b = Bond strength,
ε_s = Seasonal opening,
ε_L = Maximum joint opening due to load
f_1, f_2, f_3 = Constants

Standard conditions mean that (1) the ambient temperature is 25°C; (2) the maximum extension level is 20%, (3) limestone is used as the coarse aggregate in the PCC mix, and (4) concrete surface is sand blasted and then cleaned before the sealant is applied. Table 1 shows the coefficients in performance model for three different sealant materials,

The base life is obtained under specific lab conditions which are referred as standard conditions but when the conditions are different, adjustment should be made to modify the base life for the standard conditions to the modified base life. Main factors that affect the service life of the joint sealants include aggregate type, surface preparation, relaxation modulus of the sealant and strains due to seasonal changes and load. The adjustment is made through the following equation:

$$N_{\text{mod}} = a_m N_{lab}$$

$$a_m = a_1 \cdot a_2 \cdot a_3 \cdot a_4$$

where

N_{mod} = Modified base life in number of cycles to failure
N_{lab} = Base life under standard conditions and
a_m = Overall adjustment factor (component factors listed in Tables B-3 through B-6)

a_1 is adjustment for aggregate,a_2 is adjustment for preparation technique and a_3 is adjustment factor for long term relaxation modulus and a_4 is the adjustment factor for the expected maximum unit extension level.

In order to formulate a reasonable estimate the service life of a joint seal it is important to ascertain the effect of different variables such as geographical location of site, traffic volume, etc on performance. This is done by assuming that the field performance trends well with a weibull distribution and that such a curve can be constructed to fit the observed data points thus characterizing the performance of the sealant at particular field site over time.

This effort will require that field data be collected and analyzed for the determination of the two Weibull distribution parameters called the shape (γ) and scale factors (λ). Using the Weibull relationship, load cycles can be related to the damage level (as measured in terms of full depth debonding failure) as:

$$N_f = \frac{1}{\lambda}\left[-\ln\left(d_b\right)\right]^{\frac{1}{\gamma}}$$

where

N_f = number of load cycles
γ = shape factor
λ = scale factor
d_b = percentage of the sealant in the joint length where full depth debonding has occurred.

Table B-3 Adjustment factor for aggregate type.

Aggregate Type	Adjustment factor a_1		
	Sealant Type 1	Sealant Type 2	Sealant Type 3
Limestone	1	1	1
River Gravel	1.15	1.16	1.19

Table B-4 Adjustment factor for preparation technique.

Surface Preparation	Adjustment factor a2		
	Sealant Type 1	Sealant Type 2	Sealant Type 3
Sand Blast	1	1	1
Water Blast+ Sand Blast	1	0.973	0.917
Sand Blast + Primer	1	1	1.26

Table B-5 Adjustment factor for relaxation modulus.

Unit Extension Level	Adjustment factor a_3		
	Class 1	Class 2	Class 3
Above the Standard	0.9	0.9	0.9
Equal	1	1	1
Below the Standard	1.1	1.1	1.1

Table B-6 Adjustment factor for unit extension level.

Unit Extension Level	Adjustment factor a_4		
	Class 1	Class 2	Class 3
10%	1.91	1.33	1.75
20%	1	1	1
30%	0.75	0.9	0.63
40%	0.51	0.75	0.47

The relationship between N_f and d_b can be determined for each pavement and sealant type. Based on tests data from Phoenix, Arizona γ=0.522 and lnλ =19.39 for silicon based sealants and γ=.83 and lnλ =17.78 for asphalt base sealants for dry, on freeze areas. These values can be used where the climate is similar to Arizona.

For a chosen maximum value of d_b referred to as d_{bmax} corresponding life N_{fc} can be determined easily as:

$$N_{f_c} = \frac{1}{\lambda}\left[-\ln\left(d_{b\ \max}\right)\right]^{\frac{1}{\gamma}}$$

where N_{fc} is the number of cycles to failure corresponding to $d_{b\ max}$

For a given design unit extension level, $\varepsilon_{d,}$ the life can be determined using the following equation:

$$N_{f\ design} = \frac{N_{\mathrm{mod}}\left(\varepsilon_d\right)}{MF_c}$$

where

$N_{f\ design}$ = Expected design life at the field conditions

$N_{f\ lab}\left(\varepsilon_d\right)$	= Expected life at the extension level of ε_d in the libratory
MF_c	= Multiplying factor, $MF_c = \dfrac{N_{mod}\left(\varepsilon_f\right)}{N_{f_c}\left(d_{b\ max}\right)}$
ε_f	= Sealant strain level in the field section
$d_{b\ max}$	= Maximum allowable debonding

Delamination Modeling

Shear stress (or delamination stress) can be determined based on slab curling and warping behavior under the effect of drying shrinkage and temperature change. Slab warping (mainly driven by differential drying shrinkage) can occur in two stages as denoted by Zollinger et al. (1994) and delineated by separation of the slab corner from the subbase (i.e. liftoff) versus where the slab remains in contact with the subbase (i.e. zero liftoff).

Medium-thick plate theory provides the basis for several boundary conditions that were considered in the development of the coefficient equations summarized in Table 3. Two sets of solutions of the coefficient equations were developed depending whether the bottom of the slab was in contact with the subgrade or base support.

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Appendix C. Promising HMA Treatment Sections from the LTPP Database.

Chip Seal

Section ID	State	County	Route No.	Freezing Index	Annual Prec., in	AADTT, Trucks/day	Const. Date	Seal Thick, in	HMA Thick*, in	Base Thick, in	Base Type	Subgrade Type
A350	Utah	GARFIELD	89	302	9.47	131	7/18/1990	0.2	7.1	9.5	A-1-a	Silty Sand
B350	Utah	SEVIER	89	242	9.39	158	7/18/1990	0.3	5.5	5.5	A-1-a	Silty Sand
C350	Arizona	PIMA	19	0	14.58	1082	9/6/1990	0.3	8	6	A-1-a	Clayey Sand
M350	Texas	DUVAL	59	1	26.46	310	10/18/1990	0.2	1.5	8	A-2-4	Clay (Liquid Limit > 50)
B350	Oklahoma	SEMINOLE	3E	77	37.91	273	9/10/1990	0.3	10.3	N/A	N/A	Sand
A350	Washington	SPOKANE	195	281	16.79	288	8/12/1990	0.2	3.6	11.4	A-1-a	Gravel
A350	Oklahoma	JACKSON	62	57	27.88	381	9/12/1990	0.3	10	6	Cement-Treated Subgrade Soil	Clay (Liquid Limit > 50)
A350	Arizona	MOHAVE	93	0	5.97	957	9/11/1990	0.2	3.5	16	A-1-a	Sandy Clay
A350	California	BUTTE	32	0	35.00	143	8/21/1990	0.3	4.8	15	A-1-a	Poorly Graded Gravel
L350	Texas	EL PASO	62	5	9.70	275	9/20/1990	0.2	1.5	8.5	A-2-4	Sand
H350	Texas	GRIMES	105	6	43.81	233	10/11/1990	0.2	1	8	A-1-a	Clay (Liquid Limit > 50)
B350	Arizona	MOHAVE	40	2	8.84	1423	8/27/1990	0.3	6	9	A-1-b	Clayey Sand
Q350	Texas	MILLS	84	17	29.15	216	9/25/1990	0.3	1.5	12	Crushed Stone, Gravel or Slag	Clayey Gravel
J350	Texas	WILSON	181	2	29.91	205	10/16/1990	0.2	3	6	A-1-a	Sandy Clay
I350	Texas	WALKER	30	8	47.59	207	10/10/1990	0.1	8	12	Other	Clay (Liquid Limit > 50)
C350	Oklahoma	KAY	60	134	34.69	243	9/7/1990	0.3	12.5	6	A-6	Silty Clay
G350	Texas	RUSK	322	18	48.68	222	10/5/1990	0.2	1.5	12	A-2-4	Sand
F350	Texas	VAN ZANDT	19	29	43.26	317	10/4/1990	0.3	1.5	6	A-1-a	Sandy Clay
B350	Idaho	JEFFERSON	20	598	12.89	539	8/5/1990	0.2	4.8	4.8	A-1-a	Clayey Gravel
N350	Texas	KENEDY	77	0	27.61	654	10/19/1990	0.4	2.5	8	A-2-4	Sand
A350	Idaho	JEROME	93	282	10.57	189	7/30/1990	0.2	4.2	12	A-1-a	Silt
A350	Montana	JUDITH BASIN	87	662	16.94	173	8/10/1990	0.2	3	10.5	A-1-a	Silty Clay
C350	Florida	VOLUSIA	442	0	53.23	223	8/17/1990	0.3	1.3	8.7	A-1-b	Sand
B350	Washington	DOUGLAS	2	269	9.87	46	8/13/1990	0.5	1.8	3.6	A-1-a	Gravel
A350	Alabama	MONTGOMERY	152	7	54.07	745	8/7/1990	0.3	10.5	6	Soil-Aggregate Mixture	Sandy Clay
A350	Mississippi	COVINGTON	84	10	57.61	260	8/23/1990	0.3	8.5	4.5	A-2-4	Silty Sand
B350	Nevada	ELKO	80	312	6.94	627	7/29/1990	0.2	9.8	4	A-1-a	Gravel

Section ID	State	County	Route No.	Freezing Index	Annual Prec., in	AADTT, Trucks/day	Const. Date	Seal Thick, in	HMA Thick*, in	Base Thick, in	Base Type	Subgrade Type
E350	Texas	GARZA	84	55	20.62	447	9/14/1990	0.3	6.5	7.5	A-2-6	Clayey Sand
B350	Texas	KAUFMAN	175	22	38.81	549	9/26/1990	0.3	9.5	10	A-2-5	Clay (Liquid Limit > 50)
B350	Florida	CLAY	17	0	50.51	711	8/16/1990	0.4	3	12	Sand	Sand
A350	Nevada	WASHOE	650	105	7.80	120	8/22/1990	0.3	7.8	12	A-1-a	Clayey Silt
A350	Arkansas	BENTON	71	128	44.46	1244	9/5/1990	0.2	16.5	N/A	N/A	Clay (Liquid Limit > 50)
K350	Texas	BEXAR	1560	4	33.31	148	10/15/1990	0.3	1	9	A-2-6	Clay (Liquid Limit > 50)
C350	Alabama	HOUSTON	84	7	56.43	438	8/9/1990	0.3	3.7	6	A-1-a	Clayey Sand
C350	Nevada	ELKO	80	368	9.27	581	7/28/1990	0.4	8.8	54	A-1-a	Sandy Silt
D350	Arizona	SANTA CRUZ	19	0	15.37	1288	9/6/1990	0.2	11	7	A-1-a	Gravel
A350	Florida	NASSAU	200	1	50.89	391	8/13/1990	0.3	4	12	Soil-Aggregate Mixture	Sand
B350	Tennessee	DE KALB	56	108	56.34	97	8/2/1990	0.3	5.6	8	Crushed Stone, Gravel or Slag	Rock
C350	Tennessee	ANDERSON	75	89	55.13	3282	8/3/1990	0.3	11.3	10	Crushed Stone, Gravel or Slag	Silty Clay
D350	Texas	MITCHELL	20	32	20.78	1126	9/18/1990	0.1	11	6	A-2-6	Sandy Clay
A350	Missouri	MILLER	54	200	40.28	499	8/19/1990	0.3	9	4	Crushed Stone, Gravel or Slag	Sandy Clay
A350	Minnesota	BELTRAMI	71	1466	25.85	117	7/28/1990	0.2	3	4	A-3	Sand
D350	Minnesota	MILLE LACS	169	1065	30.19	152	7/31/1990	0.3	4.8	6	A-1-b	Sand
B350	Minnesota	BELTRAMI	2	1465	25.89	351	7/28/1990	0.1	6.8	12	Gravel (Uncrushed)	Sand
C350	Minnesota	OTTER TAIL	10	1296	26.57	275	7/30/1990	0.2	9.5	N/A	N/A	Sand
A350	Nebraska	FURNAS	6	360	23.18	140	7/17/1990	0.2	7	N/A	N/A	Silt
A350	Kansas	FRANKLIN	68	249	37.17	145	7/12/1990	0.2	11.5	N/A	N/A	Silty Clay
B350	Alabama	WASHINGTON	43	4	64.38	280	8/21/1990	0.3	7	5	A-1-b	Silty Sand
B350	Michigan	MECOSTA	131	600	35.02	288	8/8/1990	0.3	6	18	A-1-a	Sandy Clay

* The HMA thickness refers to the total thickness of all the HMA layers (i.e., the original HMA surface and HMA overlay(s) applied later).

Thin Overlay

Section ID	State	County	Route No.	Freezing Index	Annual prec., in	AADTT, Trucks/day	Const. Date	Overlay Thick, in	HMA Thick*, in	Base Thick, in	Base Type	Subgrade Type
A310	New York	WASHINGTON	4	573	40.53	693	8/16/1990	1	10.5	12	Crushed Stone, Gravel or Slag	Sand
B310	Idaho	JEFFERSON	20	598	12.89	539	9/24/1990	1.1	4.8	4.8	A-1-a	Clayey Gravel
Q310	Texas	MILLS	84	17	29.15	216	9/25/1990	0.9	1.5	12	Crushed Stone, Gravel or Slag	Clayey Gravel
B310	Michigan	MECOSTA	131	600	35.02	288	10/2/1990	1.3	6	18	A-1-a	Sandy Clay
G310	Texas	RUSK	322	18	48.68	222	10/14/1990	1.2	1.5	12	A-2-4	Sand
A310	Michigan	MONTCALM	131	559	35.22	550	10/2/1990	1.3	7.5	18	Sand	Sand
A310	Illinois	CLINTON	50	218	39.74	461	7/31/1991	0.5	11	12	A-4	Clay (Liquid Limit > 50)
B310	Illinois	STEPHENSON	20	632	34.90	498	8/12/1991	1.2	13	N/A	N/A	Silty Clay
J310	Texas	WILSON	181	2	29.91	205	10/30/1990	0.9	3	6	A-1-a	Sandy Clay
B310	Wyoming	SWEETWATER	28	1116	8.21	116	7/26/1990	0.9	3.5	8	A-1-a	Sandy Silt
A310	Colorado	DELTA	50	219	9.49	391	10/15/1990	1.4	4.5	18	A-1-a	Clay (Liquid Limit > 50)
B310	Washington	DOUGLAS	2	269	9.87	46	9/19/1990	1.3	1.8	3.6	A-1-a	Gravel
A310	Idaho	JEROME	93	282	10.57	189	8/13/1990	1	4.2	12	A-1-a	Silt
A310	Nebraska	FURNAS	6	360	23.18	140	10/16/1990	1	7	N/A	N/A	Silt
A310	Kansas	FRANKLIN	68	249	37.17	145	10/30/1990	1.2	11.5	N/A	N/A	Silty Clay
L310	Texas	EL PASO	62	5	9.70	275	4/15/1991	1	1.5	8.5	A-2-4	Sand
B310	Missouri	COLE	3	221	39.66	88	10/5/1990	1.8	7	4	A-1-a	Clayey Gravel

* The HMA thickness refers to the total thickness of all the HMA layers (i.e., the original HMA surface and HMA overlay(s) applied later).

Slurry Seal

Sec. ID	State	County	Route No.	Freezing Index	Annual prec., in	AADTT, Trucks/day	Const. Date	Seal Thick, in	HMA Thick*, in	Base Thick, in	Base Type	Subgrade Type
B320	Missouri	COLE	3	221	39.66	88	8/18/1990	0.1	7	4	A-1-a	Clayey Gravel
M320	Texas	DUVAL	59	1	26.46	310	10/18/1990	0.1	1.5	8	A-2-4	Clay (Liquid Limit > 50)
A320	Nebraska	FURNAS	6	360	23.18	140	7/17/1990	0.1	7	N/A	N/A	Silt
A320	Utah	GARFIELD	89	302	9.47	131	7/2/1990	0.2	7.1	9.5	A-1-a	Silty Sand
A320	Michigan	MONTCALM	131	559	35.22	550	8/7/1990	0.1	7.5	18	Sand	Sand
H320	Texas	GRIMES	105	6	43.81	233	10/11/1990	0.2	1	8	A-1-a	Clay (Liquid Limit > 50)
D320	Arizona	SANTA CRUZ	19	0	15.37	1288	9/6/1990	0.1	11	7	A-1-a	Gravel
B320	Washington	DOUGLAS	2	269	9.87	46	8/13/1990	0.2	1.8	3.6	A-1-a	Gravel
B320	Wyoming	SWEETWATE R	28	1116	8.21	116	7/26/1990	0.2	3.5	8	A-1-a	Sandy Silt
B320	Nevada	ELKO	80	312	6.94	627	7/29/1990	0.1	9.8	4	A-1-a	Gravel
C320	Alabama	HOUSTON	84	7	56.43	438	8/9/1990	0.2	3.7	6	A-1-a	Clayey Sand
C320	Florida	VOLUSIA	442	0	53.23	223	8/18/1990	0.2	1.3	8.7	A-1-b	Sand
A320	Washington	SPOKANE	195	281	16.79	288	8/12/1990	0.2	3.6	11.4	A-1-a	Gravel
A320	Tennessee	CANNON	96	88	55.97	71	7/30/1990	0.3	8.6	5	Crushed Stone, Gravel or Slag	Silty Clay
I320	Texas	WALKER	30	8	47.59	207	10/10/1990	0.2	8	12	Other	Clay (Liquid Limit > 50)
A320	Mississippi	COVINGTON	84	10	57.61	260	8/23/1990	0.3	8.5	4.5	A-2-4	Silty Sand
A320	Nevada	WASHOE	650	105	7.80	120	8/22/1990	0.3	7.8	12	A-1-a	Clayey Silt
C320	Washington	CLARK	14	23	62.28	128	8/15/1990	0.2	8.4	3.6	A-1-a	Gravel
B320	Texas	KAUFMAN	175	22	38.81	549	9/26/1990	0.2	9.5	10	A-2-5	Clay (Liquid Limit > 50)
B320	Florida	CLAY	17	0	50.51	711	8/16/1990	0.3	3	12	Sand	Sand
D320	Minnesota	MILLE LACS	169	1065	30.19	152	7/31/1990	0.3	4.8	6	A-1-b	Sand
C320	Minnesota	OTTER TAIL	10	1296	26.57	275	7/30/1990	0.1	9.5	N/A	N/A	Sand
E320	Texas	GARZA	84	55	20.62	447	9/14/1990	0.2	6.5	7.5	A-2-6	Clayey Sand
C320	Oklahoma	KAY	60	134	34.69	243	9/7/1990	0.2	12.5	6	A-6	Silty Clay

Sec. ID	State	County	Route No.	Freezing Index	Annual prec., in	AADTT, Trucks/day	Const. Date	Seal Thick, in	HMA Thick*, in	Base Thick, in	Base Type	Subgrade Type
A320	Florida	NASSAU	200	1	50.89	391	8/13/1990	0.2	4	12	Soil-Aggregate Mixture	Sand
A320	California	BUTTE	32	0	35.00	143	8/21/1990	0.3	4.8	15	A-1-a	Poorly Graded Gravel
A320	Alabama	MONTGOMER Y	152	7	54.07	745	8/7/1990	0.2	10.5	6	Soil-Aggregate Mixture	Sandy Clay
J320	Texas	WILSON	181	2	29.91	205	10/16/1990	0.1	3	6	A-1-a	Sandy Clay
A320	Arkansas	BENTON	71	128	44.46	1244	9/5/1990	0.2	16.5	N/A	N/A	Clay (Liquid Limit > 50)
B320	Arizona	MOHAVE	40	2	8.84	1423	8/27/1990	0.2	6	9	A-1-b	Clayey Sand
B320	Alabama	WASHINGTO N	43	4	64.38	280	8/21/1990	0.2	7	5	A-1-b	Silty Sand
F320	Texas	VAN ZANDT	19	29	43.26	317	10/4/1990	0.1	1.5	6	A-1-a	Sandy Clay
C320	Arizona	PIMA	19	0	14.58	1082	9/5/1990	0.1	8	6	A-1-a	Clayey Sand
A320	Missouri	MILLER	54	200	40.28	499	8/19/1990	0.1	9	4	Crushed Stone, Gravel or Slag	Sandy Clay
B320	Idaho	JEFFERSON	20	598	12.89	539	8/1/1990	0.1	4.8	4.8	A-1-a	Clayey Gravel
A320	Idaho	JEROME	93	282	10.57	189	7/30/1990	0.2	4.2	12	A-1-a	Silt
A320	Arizona	MOHAVE	93	0	5.97	957	8/24/1990	0.1	3.5	16	A-1-a	Sandy Clay
A320	Colorado	DELTA	50	219	9.49	391	8/31/1990	0.2	4.5	18	A-1-a	Clay (Liquid Limit > 50)
A320	Indiana	SPENCER	64	185	48.04	1078	8/16/1990	0.2	15.8	N/A	N/A	Silty Clay
B320	Kentucky	BARREN	PRK WY	118	53.43	230	8/15/1990	0.2	15	N/A	N/A	Clay (Liquid Limit > 50)
A320	Iowa	SAC	196	711	30.93	77	8/23/1990	0.2	9	6	Gravel (Uncrushed)	Sandy Clay
C320	Nevada	ELKO	80	368	9.27	581	7/28/1990	0.4	8.8	54	A-1-a	Sandy Silt
A320	Montana	JUDITH BASIN	87	662	16.94	173	8/7/1990	0.2	3	10.5	A-1-a	Silty Clay
B320	Utah	SEVIER	89	242	9.39	158	7/5/1990	0.1	5.5	5.5	A-1-a	Silty Sand
K320	Texas	BEXAR	1560	4	33.31	148	10/15/1990	0.2	1	9	A-2-6	Clay (Liquid Limit > 50)
A320	Oklahoma	JACKSON	62	57	27.88	381	9/12/1990	0.2	10	6	Cement-Treated Subgrade Soil	Clay (Liquid Limit > 50)
D320	Texas	MITCHELL	20	32	20.78	1126	9/18/1990	0.1	11	6	A-2-6	Sandy Clay

Sec. ID	State	County	Route No.	Freezing Index	Annual prec., in	AADTT, Trucks/day	Const. Date	Seal Thick, in	HMA Thick*, in	Base Thick, in	Base Type	Subgrade Type
B320	Oklahoma	SEMINOLE	3E	77	37.91	273	9/10/1990	0.2	10.3	N/A	N/A	Sand
G320	Texas	RUSK	322	18	48.68	222	10/5/1990	0.1	1.5	12	A-2-4	Sand
A320	Illinois	CLINTON	50	218	39.74	461	8/17/1990	0.2	11	12	A-4	Clay (Liquid Limit > 50)
Q320	Texas	MILLS	84	17	29.15	216	9/25/1990	0.1	1.5	12	Crushed Stone, Gravel or Slag	Clayey Gravel
C320	Michigan	CLARE	61	717	31.13	63	8/9/1990	0.1	2.3	15	A-1-a	Sand
C320	Tennessee	ANDERSON	75	89	55.13	3282	8/3/1990	0.1	11.3	10	Crushed Stone, Gravel or Slag	Silty Clay
B320	Tennessee	DE KALB	56	108	56.34	97	8/1/1990	0.2	5.6	8	Crushed Stone, Gravel or Slag	Rock
L320	Texas	EL PASO	62	5	9.70	275	9/20/1990	0.1	1.5	8.5	A-2-4	Sand
B320	Minnesota	BELTRAMI	2	1465	25.89	351	7/28/1990	0.1	6.8	12	Gravel (Uncrushed)	Sand
A320	Minnesota	BELTRAMI	71	1466	25.85	117	7/28/1990	0.2	3	4	A-3	Sand

* The HMA thickness refers to the total thickness of all the HMA layers (i.e., the original HMA surface and HMA overlay(s) applied later).

Crack Sealing

Sec. ID	State	County	Route No.	Freezing Index	Annual prec., in	AADTT, Trucks/day	Const. Date	HMA Thick*, in	Base Thick, in	Base Type	Subgrae Type
A330	Alabama	MONTGOMERY	152	7	54.07	745	8/7/1990	10.5	6	Soil-Aggregate Mixture (Predominantly Fine-Grained Soil)	Sandy Clay
A330	Arizona	MOHAVE	93	0	5.97	957	8/24/1990	3.5	16	A-1-a	Sandy Clay
A330	California	BUTTE	32	0	35.00	143	8/21/1990	4.8	15	A-1-a	Poorly Graded Gravel
B330	Colorado	BENT	50	219	13.10	260	7/24/1990	11.5	N/A	N/A	Clay (Liquid Limit > 50)
C330	Florida	VOLUSIA	442	0	53.23	223	8/17/1990	1.3	8.7	A-1-b	Sand
A330	Illinois	CLINTON	50	218	39.74	461	8/17/1990	11	12	A-4	Clay (Liquid Limit > 50)
B330	Illinois	STEPHENSON	20	632	34.90	498	8/2/1990	13	N/A	N/A	Silty Clay
A330	Indiana	SPENCER	64	185	48.04	1078	8/16/1990	15.8	N/A	N/A	Silty Clay
A330	Iowa	SAC	196	711	30.93	77	7/10/1990	9	6	Gravel (Uncrushed)	Sandy Clay
B330	Kansas	FORD	400	204	23.18	336	7/14/1990	8	39	Clayey Sand	Sandy Clay
B330	Minnesota	BELTRAMI	2	1465	25.89	351	7/28/1990	6.8	12	Gravel (Uncrushed)	Sand
A330	Missouri	MILLER	54	200	40.28	499	8/19/1990	9	4	Crushed Stone, Gravel or Slag	Sandy Clay
B330	Missouri	COLE	3	221	39.66	88	8/18/1990	7	4	A-1-a	Clayey Gravel
A330	Nebraska	FURNAS	6	360	23.18	140	7/17/1990	7	N/A	N/A	Silt
A330	Nevada	WASHOE	650	105	7.80	120	8/22/1990	7.8	12	A-1-a	Clayey Silt
B330	Nevada	ELKO	80	312	6.94	627	7/29/1990	9.8	4	A-1-a	Gravel
B330	Oklahoma	SEMINOLE	3E	77	37.91	273	9/10/1990	10.3	N/A	N/A	Sand
B330	Pennsylvania	TIOGA	49	467	37.28	76	10/2/1990	6.5	17	Gravel (Uncrushed)	Silty Clay
A330	Tennessee	CANNON	96	88	55.97	71	7/30/1990	8.6	5	Crushed Stone, Gravel or Slag	Silty Clay
C330	Tennessee	ANDERSON	75	89	55.13	3282	8/3/1990	11.3	10	Crushed Stone, Gravel or Slag	Silty Clay
D330	Texas	MITCHELL	20	32	20.78	1126	9/18/1990	11	6	A-2-6	Sandy Clay
L330	Texas	EL PASO	62	5	9.70	275	9/20/1990	1.5	8.5	A-2-4	Sand
A330	Utah	GARFIELD	89	302	9.47	131	7/2/1990	7.1	9.5	A-1-a	Silty Sand
B330	Utah	SEVIER	89	242	9.39	158	7/5/1990	5.5	5.5	A-1-a	Silty Sand

Sec. ID	State	County	Route No.	Freezing Index	Annual prec., in	AADTT, Trucks/day	Const. Date	HMA Thick*, in	Base Thick, in	Base Type	Subgrae Type
A330	Virginia	PRINCE GEORGE	95	55	48.57	2523	9/18/1990	9.9	6	A-1-a	Silt
A330	Washington	SPOKANE	195	281	16.79	288	8/12/1990	3.6	11.4	A-1-a	Gravel
B330	Washington	DOUGLAS	2	269	9.87	46	8/13/1990	1.8	3.6	A-1-a	Gravel
C330	Washington	CLARK	14	23	62.28	128	8/15/1990	8.4	3.6	A-1-a	Gravel
A330	Kansas	FRANKLIN	68	249	37.17	145	7/13/1990	11.5	N/A	N/A	Silty Clay
B330	Michigan	MECOSTA	131	600	35.02	288	8/7/1990	6	18	A-1-a	Sandy Clay
C330	Alabama	HOUSTON	84	7	56.43	438	8/9/1990	3.7	6	A-1-a	Clayey Sand
B330	Florida	CLAY	17	0	50.51	711	8/16/1990	3	12	Sand	Sand
C330	Idaho	JEFFERSON	15	637	12.02	250	7/31/1990	9.6	7.2	A-1-b	Silty Sand
A330	Kentucky	OWSLEY	11	164	50.12	46	8/14/1990	6.3	8	Crushed Stone, Gravel or Slag	Clay (Liquid Limit > 50)
B330	Kentucky	BARREN	PRK WY	118	53.43	230	8/15/1990	15	N/A	N/A	Clay (Liquid Limit > 50)
A330	Minnesota	BELTRAMI	71	1466	25.85	117	7/28/1990	3	4	A-3	Sand
C330	Minnesota	OTTER TAIL	10	1296	26.57	275	7/30/1990	9.5	N/A	N/A	Sand
D330	Minnesota	MILLE LACS	169	1065	30.19	152	7/31/1990	4.8	6	A-1-b	Sand
A330	Montana	JUDITH BASIN	87	662	16.94	173	8/8/1990	3	10.5	A-1-a	Silty Clay
C330	Nevada	ELKO	80	368	9.27	581	7/28/1990	8.8	54	A-1-a	Sandy Silt
A330	New York	WASHINGTON	4	573	40.53	693	9/6/1990	10.5	12	Crushed Stone, Gravel or Slag	Sand
B330	New York	ST LAWRENCE	3	945	43.78	68	9/4/1990	8.5	12	Gravel (Uncrushed)	Sand
A330	Pennsylvania	NORTHUMBER LAND	147	302	43.22	681	9/10/1990	8.7	19	A-1-a	Clayey Gravel
B330	Wyoming	SWEETWATER	28	1116	8.21	116	7/26/1990	3.5	8	A-1-a	Sandy Silt

* The HMA thickness refers to the total thickness of all the HMA layers (i.e., the original HMA surface and HMA overlay(s) applied later).

Appendix D. Promising PCC Treatment Sections from the LTPP Database.

PCC Diamond Grinding

Section ID	State	County	Route Number	Freezing Index (C-Days)	Annual Prec. (in)	AADTT	Cons. Date	PCC Thickness (in)	Base Type	Base Thickness (in)	Subgrade Material
0602	Alabama	Etowah	59	43.07	54.87	NA	5/1/1966	10.2	GB	6	Sandy Lean Clay
0605	Alabama	Etowah	59	43.07	54.87	NA	5/1/1966	10.2	GB	6	Sandy Lean Clay
A602	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	10.2	TB	6	Silty Clay
A605	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	10	TB	6.3	Clayey Sand
0605	Illinois	Champaign	57	346.55	39.89	2340	6/1/1964	10	GB	8	Silty Clay
0661	Illinois	Champaign	57	346.55	39.89	2340	6/1/1964	10.1	GB	8	Silty Clay
0602	Iowa	Polk	35	618.17	33.30	2220	11/1/1965	10.2	GB	4	Sandy Clay
0605	Iowa	Polk	35	618.17	33.30	2220	11/1/1965	10	GB	6.1	Sandy Clay
0605	Iowa	Polk	35	618.17	33.30	2220	11/1/1965	10	GB	6.1	Sandy Clay
0605	Michigan	Bay	10	519.76	30.96	760	6/1/1958	9	GB	4	Silty Clay
0602	Missouri	Harrison	35	424.8	37.40	1570	7/1/1975	9.2	GB	3.4	Sandy Clay
0605	Missouri	Harrison	35	424.8	37.40	1570	7/1/1975	9.1	GB	5	Sandy Clay
A602	Missouri	Washington	8	203.39	42.24	310	7/1/1969	7	GB	4	Sandy Fat Clay
A605	Missouri	Washington	8	203.39	42.24	310	7/1/1969	7.2	GB	4.5	Gravelly Fat Clay
0602	Oklahoma	Kay	35	132.67	34.53	1490	11/1/1962	8.8	GB	16.5	Clay
0605	Oklahoma	Kay	35	132.67	34.53	1490	11/1/1962	9	GB	14.8	Clay
0605	Pennsylvania	Centre	80	378	39.56	4220	9/1/1968	10.1	GB	11	Silt
0602	South Dakota	Brown	12	1014.33	21.37	150	4/1/1973	6.5	TB	3.4	Lean Inorganic Clay
0605	South Dakota	Brown	12	1014.33	21.37	150	4/1/1973	7.2	TB	4.3	Lean Inorganic Clay
0602	Tennessee	Madison	40	87.63	53.84	5560	6/1/1964	8.9	TB	6	Poorly Graded Sand-Silt
0603	Tennessee	Madison	40	87.63	53.84	5560	6/1/1964	9	TB	7.5	Lean Inorganic Clay
0604	Tennessee	Madison	40	87.63	53.84	5560	6/1/1964	9	TB	6.6	Sandy Lean Clay
0605	Tennessee	Madison	40	87.63	53.84	5560	6/1/1964	9	TB	7.5	Lean Inorganic Clay
0606	Tennessee	Madison	40	87.63	53.84	5560	6/1/1964	9.2	TB	7.5	Lean Inorganic Clay

PCC Crack Seal

Section ID	State	County	Route Number	Freezing Index (C-Days)	Annual Prec. (in)	AADTT	Cons. Date	PCC Thickness (in)	Base Type	Base Thickness (in)	Subgrade Material
0605	Arizona	Coconino	40	260.66	20.67	2240	9/1/1966	8.3	TB	3.9	Sandstone
A410	Arkansas	Lonoke	67	52.36	50.08	NA	NA	9.7	GB	3.9	Silty Gravel with Sand
B410	Arkansas	Jefferson	65	40.05	51.53	NA	NA	9.4	TB	6.9	Silty Sand
C410	Arkansas	Sebastian	540	59.57	43.40	NA	NA	9.3	TB	8.3	Sandy Silt
0660	Illinois	Champaign	57	346.55	39.89	2340	6/1/1964	10.1	GB	7.5	Silty Clay
0661	Illinois	Champaign	57	346.55	39.89	2340	6/1/1964	10.1	GB	8	Silty Clay
0602	Missouri	Harrison	35	424.8	37.40	1570	7/1/1975	9.2	GB	3.4	Sandy Clay
A410	Missouri	Daviess	35	420.93	37.38	NA	NA	8.8	GB	4.2	Fat Inorganic Clay
A602	Missouri	Washington	8	203.39	42.24	310	7/1/1969	7	GB	4	Sandy Fat Clay
A605	Missouri	Washington	8	203.39	42.24	310	7/1/1969	7.2	GB	4.5	Gravelly Fat Clay
B410	Missouri	Jasper	71	172.56	46.74	NA	NA	9.4	GB	3.5	Lean Clay with Sand
B411	Missouri	Jasper	71	172.56	46.74	NA	NA	9.4	GB	3.5	Lean Clay with Sand
A410	Nebraska	Lancaster	77	445.57	29.12	NA	NA	8.4	TB	2.2	Fat Inorganic Clay
B410	Nebraska	Hall	80	459.53	26.76	NA	NA	12	GB	5.9	Poorly Graded Sand
C410	Nebraska	Dakota	129	652.25	26.03	NA	NA	9.2	TB	3.1	Lean Inorganic Clay
A451	Nevada	Elko	80	467.42	10.69	NA	NA	9.7	TB	5.6	Silty Gravel
A452	Nevada	Elko	80	467.42	10.69	NA	NA	9.7	TB	5.6	Silty Gravel
A453	Nevada	Elko	80	467.42	10.69	NA	NA	9.7	TB	5.6	Silty Gravel
A454	Nevada	Elko	80	467.42	10.69	NA	NA	9.7	TB	5.6	Silty Gravel
A455	Nevada	Elko	80	467.42	10.69	NA	NA	9.7	TB	5.6	Silty Gravel
A456	Nevada	Elko	80	467.42	10.69	NA	NA	9.7	TB	5.6	Silty Gravel
A457	Nevada	Elko	80	467.42	10.69	NA	NA	9.7	TB	5.6	Silty Gravel
A458	Nevada	Elko	80	467.42	10.69	NA	NA	9.7	TB	5.6	Silty Gravel
A459	Nevada	Elko	80	467.42	10.69	NA	NA	9.7	TB	5.6	Silty Gravel
A460	Nevada	Elko	80	467.42	10.69	NA	NA	9.7	TB	5.6	Silty Gravel
A461	Nevada	Elko	80	467.42	10.69	NA	NA	9.7	TB	5.6	Silty Gravel
A462	Nevada	Elko	80	467.42	10.69	NA	NA	9.7	TB	5.6	Silty Gravel
A463	Nevada	Elko	80	467.42	10.69	NA	NA	9.7	TB	5.6	Silty Gravel
A464	Nevada	Elko	80	467.42	10.69	NA	NA	9.7	TB	5.6	Silty Gravel
A410	Ohio	Greene	675	296.91	39.43	NA	NA	10.1	TB	4.2	Silty Gravel with Sand
A411	Ohio	Greene	675	296.91	39.43	NA	NA	10.2	TB	4.1	Silty Gravel with Sand
A412	Ohio	Greene	675	296.91	39.43	NA	NA	10.3	TB	3.6	Silty Gravel with Sand
B410	Ohio	Belmont	7	286.09	39.08	NA	NA	9.1	TB	4.5	Clayey Gravel with Sand

Section ID	State	County	Route Number	Freezing Index (C-Days)	Annual Prec. (in)	AADTT	Cons. Date	PCC Thickness (in)	Base Type	Base Thickness (in)	Subgrade Material
B411	Ohio	Belmont	7	286.09	39.08	NA	NA	9.1	TB	4.3	Clayey Gravel with Sand
B412	Ohio	Belmont	7	286.09	39.08	NA	NA	9	TB	4.2	Clayey Gravel with Sand
A410	Oklahoma	Pontotoc	3W	64.17	40.35	NA	NA	9.2	TB	2.2	Lean Clay with Sand
A420	Oklahoma	Pontotoc	3W	64.17	40.35	NA	NA	9.2	TB	2.2	Lean Clay with Sand
A410	Pennsylvania	Lycoming	180	308.92	42.72	NA	NA	10.5	GB	12	Gravelly Silt with Sand
0602	South Dakota	Brown	12	1014.33	21.37	150	4/1/1973	6.5	TB	3.4	Lean Inorganic Clay
0605	South Dakota	Brown	12	1014.33	21.37	150	4/1/1973	7.2	TB	4.3	Lean Inorganic Clay
A410	Texas	Dallas	348	21.32	35.58	NA	NA	9.3	TB	3.5	Fat Inorganic Clay
A420	Texas	Dallas	348	21.32	35.58	NA	NA	9.3	TB	3.5	Fat Inorganic Clay
B410	Texas	Jefferson	90	2.35	57.66	NA	NA	10.4	TB	4.3	Lean Inorganic Clay
B420	Texas	Jefferson	90	2.35	57.66	NA	NA	10	TB	4.3	Lean Inorganic Clay
C410	Texas	Wilbarger	287	49.87	26.85	NA	NA	10	GB	6.2	Silty Sand
C420	Texas	Wilbarger	287	49.87	26.85	NA	NA	10	GB	6.2	Silty Sand
D410	Texas	Liberty	146	2.84	57.28	NA	NA	11.4	TB	6.4	Sandy Silt
D420	Texas	Liberty	146	2.84	57.28	NA	NA	11.4	TB	6.4	Sandy Silt
E410	Texas	Jasper	96	7.31	60.39	NA	NA	9.6	TB	7.6	Clayey Sand
E420	Texas	Jasper	96	7.31	60.39	NA	NA	9.6	TB	7.6	Clayey Sand
D410	Utah	Salt Lake	154	192.87	17.59	NA	NA	10.1	TB	5.4	Clayey Gravel with Sand
D440	Utah	Salt Lake	154	192.87	17.59	NA	NA	10.1	TB	5.4	Clayey Gravel with Sand
D441	Utah	Salt Lake	154	192.87	17.59	NA	NA	10.1	TB	5.4	Clayey Gravel with Sand
D443	Utah	Salt Lake	154	192.87	17.59	NA	NA	10.1	TB	5.4	Clayey Gravel with Sand
D444	Utah	Salt Lake	154	192.87	17.59	NA	NA	10.1	TB	5.4	Clayey Gravel with Sand
D445	Utah	Salt Lake	154	192.87	17.59	NA	NA	10.1	TB	5.4	Clayey Gravel with Sand
D446	Utah	Salt Lake	154	192.87	17.59	NA	NA	10.1	TB	5.4	Clayey Gravel with Sand
D448	Utah	Salt Lake	154	192.87	17.59	NA	NA	10.1	TB	5.4	Clayey Gravel with Sand
D451	Utah	Salt Lake	154	192.87	17.59	NA	NA	10.1	TB	5.4	Clayey Gravel with Sand
D454	Utah	Salt Lake	154	192.87	17.59	NA	NA	10.1	TB	5.4	Clayey Gravel with Sand
D455	Utah	Salt Lake	154	192.87	17.59	NA	NA	10.1	TB	5.4	Clayey Gravel with Sand
D459	Utah	Salt Lake	154	192.87	17.59	NA	NA	10.1	TB	5.4	Clayey Gravel with Sand
E445	Utah	Wasatch	40	445.33	19.24	NA	NA	9.7	TB	4.8	Silty Gravel with Sand
E446	Utah	Wasatch	40	445.33	19.24	NA	NA	9.7	TB	4.8	Silty Gravel with Sand
E456	Utah	Wasatch	40	445.33	19.24	NA	NA	9.7	TB	4.8	Silty Gravel with Sand
E459	Utah	Wasatch	40	445.33	19.24	NA	NA	9.7	TB	4.8	Silty Gravel with Sand
E461	Utah	Wasatch	40	445.33	19.24	NA	NA	9.7	TB	4.8	Silty Gravel with Sand
E462	Utah	Wasatch	40	445.33	19.24	NA	NA	9.7	TB	4.8	Silty Gravel with Sand

PCC Full-Depth Repair

Section ID	State	County	Route Number	Freezing Index (C-Days)	Annual Prec. (in)	AADTT	Cons. Date	PCC Thickness (in)	Base Type	Base Thick. (in)	Subgrade Material
0605	Arizona	Coconino	40	260.66	20.67	2240	9/1/1966	8.3	TB	3.9	Sandstone
0606	Arizona	Coconino	40	260.66	20.67	2240	9/1/1966	8.5	TB	3.9	Silty Sand with Gravel
A601	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	9.8	TB	6.7	Clay
A602	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	10.2	TB	6	Silty Clay
A603	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	10	TB	6	Sandy Lean Clay
A604	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	10.1	TB	6.2	Silty Clay
A605	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	10	TB	6.3	Clayey Sand
A606	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	10.2	TB	5.7	Sandy Lean Clay
0602	Indiana	Marshall	31	447.71	38.41	1110	1/1/1972	10.3	TB	4	Sandy Clay
0604	Indiana	Marshall	31	447.71	38.41	1110	1/1/1972	10	TB	3.4	Sandy Clay
0605	Indiana	Marshall	31	447.71	38.41	1110	1/1/1972	10	TB	4	Sandy Clay
0606	Indiana	Marshall	31	447.71	38.41	1110	1/1/1972	11	TB	4.2	Sandy Clay
0661	Indiana	Marshall	31	447.71	38.41	1110	1/1/1972	10.2	TB	4	Sandy Clay
A602	Missouri	Washington	8	203.39	42.24	310	7/1/1969	7	GB	4	Sandy Fat Clay
A603	Missouri	Washington	8	203.39	42.24	310	7/1/1969	7.3	GB	3.8	Gravelly Fat Clay
A604	Missouri	Washington	8	203.39	42.24	310	7/1/1969	7.5	GB	4	Sandy Fat Clay
A605	Missouri	Washington	8	203.39	42.24	310	7/1/1969	7.2	GB	4.5	Gravelly Fat Clay
A606	Missouri	Washington	8	203.39	42.24	310	7/1/1969	7.3	GB	4	Sandy Fat Clay
0601	Oklahoma	Kay	35	132.67	34.53	1490	11/1/1962	9	GB	16.5	Clay
0602	Oklahoma	Kay	35	132.67	34.53	1490	11/1/1962	8.8	GB	16.5	Clay
0603	Oklahoma	Kay	35	132.67	34.53	1490	11/1/1962	9	GB	15.2	Clay
0604	Oklahoma	Kay	35	132.67	34.53	1490	11/1/1962	9	GB	15.2	Clay
0605	Oklahoma	Kay	35	132.67	34.53	1490	11/1/1962	9	GB	14.8	Clay
0606	Oklahoma	Kay	35	132.67	34.53	1490	11/1/1962	9.1	GB	14.8	Clay
0603	Pennsylvania	Centre	80	378	39.56	4220	9/1/1968	10.1	GB	10	Silt
0604	Pennsylvania	Centre	80	378	39.56	4220	9/1/1968	10.3	GB	10	Silt
0605	Pennsylvania	Centre	80	378	39.56	4220	9/1/1968	10.1	GB	11	Silt
0606	Pennsylvania	Centre	80	378	39.56	4220	9/1/1968	10.1	GB	9	Silt
0602	South Dakota	Brown	12	1014.33	21.37	150	4/1/1973	6.5	TB	3.4	Lean Inorganic Clay
0603	South Dakota	Brown	12	1014.33	21.37	150	4/1/1973	7.2	TB	4.3	Lean Inorganic Clay
0604	South Dakota	Brown	12	1014.33	21.37	150	4/1/1973	7.1	TB	3.9	Lean Inorganic Clay
0605	South Dakota	Brown	12	1014.33	21.37	150	4/1/1973	7.2	TB	4.3	Lean Inorganic Clay
0606	South Dakota	Brown	12	1014.33	21.37	150	4/1/1973	7.3	TB	4.9	Lean Inorganic Clay
0661	South Dakota	Brown	12	1014.33	21.37	150	4/1/1973	7.3	TB	5.5	Lean Inorganic Clay

Partial-Depth Repair

Section ID	State	County	Route Number	Freezing Index (C-Days)	Annual Prec. (in)	AADTT	Cons. Date	PCC Thickness (in)	Base Type	Base Thickness (in)	Subgrade Material
A601	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	9.8	TB	6.7	Clay
A602	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	10.2	TB	6	Silty Clay
A603	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	10	TB	6	Sandy Lean Clay
A604	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	10.1	TB	6.2	Silty Clay
A605	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	10	TB	6.3	Clayey Sand
A606	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	10.2	TB	5.7	Sandy Lean Clay
0605	Iowa	Polk	35	618.17	33.30	2220	11/1/1965	10	GB	6.1	Sandy Clay
0603	Pennsylvania	Centre	80	378	39.56	4220	9/1/1968	10.1	GB	10	Silt
0604	Pennsylvania	Centre	80	378	39.56	4220	9/1/1968	10.3	GB	10	Silt

Underseal

Section ID	State	County	Route Number	Freezing Index (C-Days)	Annual Prec. (in)	AADTT	Cons. Date	PCC Thickness (in)	Base Type	Base Thickness (in)	Subgrade Material
A421	California	San Diego	8	0.62	15.10	NA	NA	8.1	TB	5.4	Silty Sand with Gravel
A423	California	San Diego	8	0.62	15.10	NA	NA	8.1	TB	5.4	Silty Sand with Gravel
B421	California	San Joaquin	5	0.36	12.10	NA	NA	11.7	TB	4.8	Clayey Gravel with Sand
B423	California	San Joaquin	5	0.36	12.10	NA	NA	11.7	TB	4.8	Clayey Gravel with Sand
A420	Oklahoma	Pontotoc	3W	64.17	40.35	NA	NA	9.2	TB	2.2	Lean Clay with Sand
B420	Texas	Jefferson	90	2.35	57.66	NA	NA	10	TB	4.3	Lean Inorganic Clay

PCC Load Transfer Restoration

Section ID	State	County	Route Number	Freezing Index (C-Days)	Annual Prec. (in)	AADTT	Cons. Date	PCC Thick. (in)	Base Type	Base Thick. (in)	Subgrade Material
0605	Alabama	Etowah	59	43.07	54.87	NA	5/1/1966	10.2	GB	6	Sandy Lean Clay
0606	Alabama	Etowah	59	43.07	54.87	NA	5/1/1966	10.3	GB	6	Clayey Gravel
0605	Arizona	Coconino	40	260.66	20.67	2240	9/1/1966	8.3	TB	3.9	Sandstone
A605	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	10	TB	6.3	Clayey Sand
A606	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	10.2	TB	5.7	Sandy Lean Clay
0602	Indiana	Marshall	31	447.71	38.41	1110	1/1/1972	10.3	TB	4	Sandy Clay
0604	Indiana	Marshall	31	447.71	38.41	1110	1/1/1972	10	TB	3.4	Sandy Clay
0605	Indiana	Marshall	31	447.71	38.41	1110	1/1/1972	10	TB	4	Sandy Clay
0606	Indiana	Marshall	31	447.71	38.41	1110	1/1/1972	11	TB	4.2	Sandy Clay
0661	Indiana	Marshall	31	447.71	38.41	1110	1/1/1972	10.2	TB	4	Sandy Clay
0603	Pennsylvania	Centre	80	378	39.56	4220	9/1/1968	10.1	GB	10	Silt
0604	Pennsylvania	Centre	80	378	39.56	4220	9/1/1968	10.3	GB	10	Silt
0605	Pennsylvania	Centre	80	378	39.56	4220	9/1/1968	10.1	GB	11	Silt
0606	Pennsylvania	Centre	80	378	39.56	4220	9/1/1968	10.1	GB	9	Silt
0605	South Dakota	Brown	12	1014.33	21.37	150	4/1/1973	7.2	TB	4.3	Lean Inorganic Clay
0606	South Dakota	Brown	12	1014.33	21.37	150	4/1/1973	7.3	TB	4.9	Lean Inorganic Clay

PCC Joint Reseal

Section ID	State	County	Route Number	Freezing Index (C-Days)	Annual Prec. (in)	AADTT	Cons. Date	PCC Thick. (in)	Base Type	Base Thick. (in)	Subgrade Material
0602	Alabama	Etowah	59	43.07	54.87	NA	5/1/1966	10.2	GB	6	Sandy Lean Clay
0605	Alabama	Etowah	59	43.07	54.87	NA	5/1/1966	10.2	GB	6	Sandy Lean Clay
0605	Arizona	Coconino	40	260.66	20.67	2240	9/1/1966	8.3	TB	3.9	Sandstone
A601	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	9.8	TB	6.7	Clay
A602	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	10.2	TB	6	Silty Clay
A603	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	10	TB	6	Sandy Lean Clay
A604	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	10.1	TB	6.2	Silty Clay
A605	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	10	TB	6.3	Clayey Sand
A606	Arkansas	Jefferson	65	38.38	50.18	1170	12/1/1978	10.2	TB	5.7	Sandy Lean Clay
0601	Oklahoma	Kay	35	132.67	34.53	1490	11/1/1962	9	GB	16.5	Clay
0602	Oklahoma	Kay	35	132.67	34.53	1490	11/1/1962	8.8	GB	16.5	Clay
0605	Oklahoma	Kay	35	132.67	34.53	1490	11/1/1962	9	GB	14.8	Clay
0601	Tennessee	Madison	40	87.63	53.84	5560	6/1/1964	9	TB	6	Poorly Graded Sand with Silt
0602	Tennessee	Madison	40	87.63	53.84	5560	6/1/1964	8.9	TB	6	Poorly Graded Sand with Silt
0605	Tennessee	Madison	40	87.63	53.84	5560	6/1/1964	9	TB	7.5	Lean Inorganic Clay