

# Guide for Mechanistic-Empirical Design

## OF NEW AND REHABILITATED PAVEMENT STRUCTURES

FINAL REPORT

### PART 3. DESIGN ANALYSIS

#### CHAPTER 6. HMA REHABILITATION OF EXISTING PAVEMENTS



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## **PART 3—DESIGN ANALYSIS**

### **CHAPTER 6**

#### **HMA REHABILITATION OF EXISTING PAVEMENTS**

##### **3.6.1 INTRODUCTION**

This chapter describes the mechanistic-empirical design procedures for rehabilitation of existing flexible, rigid, and composite pavements with hot-mix asphalt (HMA). Because many aspects of rehabilitation design are similar to new design, PART 3, Chapter 3 is referenced often to avoid duplication.

###### **3.6.1.1 Scope**

HMA can be used to remedy functional or structural deficiencies of existing pavements. It is important for the designer to consider several aspects, including the type of deterioration present, before determining the appropriate rehabilitation strategy to adopt. Several different rehabilitation options using HMA overlays can be applied to existing pavements to extend their useful service life. These range from thin surface treatments to structural overlays of existing flexible, composite, or rigid pavements and from in-place recycling of existing pavement layers followed by placement of a HMA surface, to reconstruction with HMA as described in PART 3, Chapter 5 of this Guide. These strategies are commonly used to remedy functional, structural, or other inadequacies.

This chapter presents detailed mechanistic-empirical design procedures for HMA overlays of flexible, semi-rigid, composite and rigid pavements. This chapter first provides an overview of the HMA overlay design process, and then describes in detail the design procedures for:

- HMA overlay of existing HMA surfaced pavements, both flexible and semi-rigid.
- HMA overlay of existing PCC pavement that has received fractured slab treatments; crack and seat, break and seat, and rubbilization.
- HMA overlay of existing intact PCC pavement (JPCP and CRCP), including composite pavements or second overlays of original PCC pavements. Note that this Design Guide does not provide for design of JRCP and thus there is no specific overlay design procedure for JRCP. However, some recommendations are provided for approximate overlay design of JRCP considering reflection cracking and distress in the HMA overlay.

The mechanistic-empirical design of rehabilitated pavements using HMA overlays requires an iterative, hands-on approach. The designer must select a proposed trial rehabilitation design and then analyze the design in detail to determine whether it meets the applicable performance criteria (i.e., rutting, fatigue cracking, thermal cracking, and smoothness) established by the designer. If a particular trial rehabilitation design does not meet the performance criteria, the design is modified and reanalyzed until it meets the criteria. The designs that meet the

applicable performance criteria are then considered feasible from a structural and functional viewpoint and can be further considered for other evaluations, such as life cycle cost analysis.

### **3.6.1.2 Organization**

This chapter is organized into the following six sections, following this introduction:

- Section 3.6.2—Overview of the HMA overlay design process.
- Section 3.6.3—Overlay design requirements.
- Section 3.6.4—Overlay design for existing HMA surfaced pavements.
- Section 3.6.5—Overlay design for existing PCC pavements that have received fractured slab treatments prior to overlay placement.
- Section 3.6.6—Overlay design for existing PCC and composite pavements.
- Section 3.6.7—Additional consideration for rehabilitation with HMA overlays.

While considering the information presented in sections 3.6.4 through 3.6.6, it should be noted that, although the methodology described is generally applicable for a wide variety HMA overlay design scenarios, the number of pavement sections used to develop the calibrated performance models for these various configurations were limited due to lack or unavailability of data. This is particularly true for HMA overlays of fractured PCC sections (section 3.6.5). The greatest amount of data were available for HMA overlays of existing HMA pavements (section 3.6.4). Even within this category more data were available for conventional and deep strength HMA pavements and very little data, if any, were available for HMA overlays of existing semi-rigid pavements. In addition, although the methodology described in section 3.6.4 can also be used for the structural design of rehabilitation alternatives that incorporate in-place recycling, the performance models have not been calibrated for these types of pavements. Finally, the design of thin surface treatments is not included in this Guide, while reconstruction is treated as the design of a new flexible pavement and is discussed in detail in PART 3, Chapter 3.

## **3.6.2 OVERVIEW OF REHABILITATION DESIGN PROCESS**

Figure 3.6.1 shows the flow of the HMA rehabilitation design process. Actual structural design of feasible rehabilitation strategies is step 6 of the following procedure:

- Steps 1-4: Evaluation of the existing pavement (PART 2, Chapter 5).
  - Step 1: Determine existing pavement condition.
  - Step 2: Determine causes and mechanism of distress.
  - Step 3: Define problems and inadequacies of existing pavement.
  - Step 4: Identify possible constraints.
- Step 5: Rehabilitation strategy selection (PART 3, Chapter 5).
- Step 6: Rehabilitation design (PART 3, Chapter 6 for HMA rehabilitation).
- Step 7: Perform life cycle cost analysis (as desired).
- Step 8: Determine non-monetary factors that influence rehabilitation (as desired).
- Step 9: Determine preferred rehabilitation strategy (as desired).

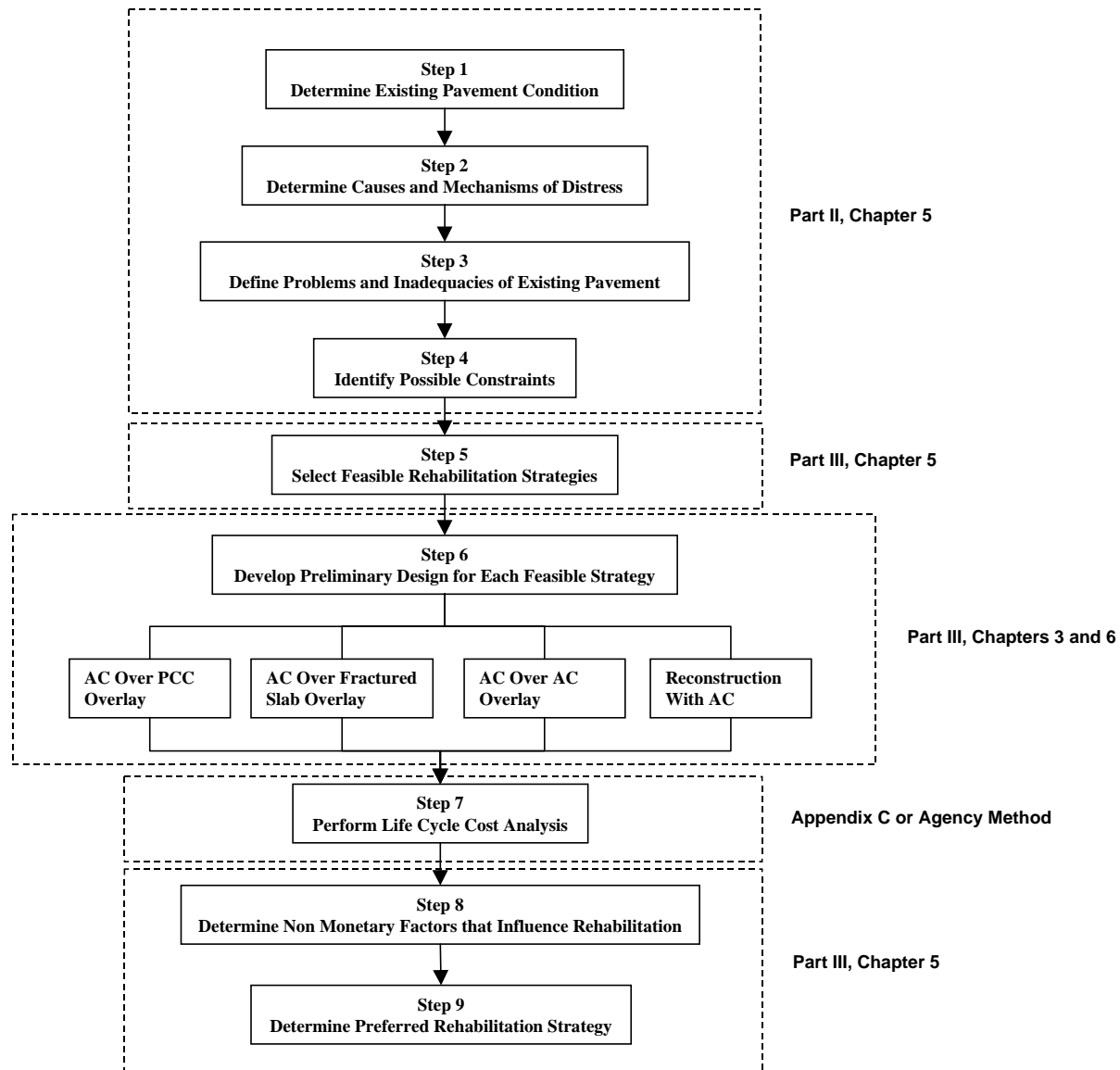


Figure 3.6.1. Summary of HMA rehabilitation design process.

An HMA overlay is a candidate rehabilitation strategy for existing pavements with either HMA or PCC surfaces. The design methods described in this chapter can address HMA overlays of the following types of existing pavements:

- Conventional flexible pavements – thin HMA layer over granular base and subbase.
- Deep strength HMA pavements – thick HMA layers over granular base and subbase.
- Full-depth HMA pavements – flexible pavement consisting only of HMA layers.
- Semi-rigid pavements – HMA surfaced sections having some type of chemically stabilized layer.
- Composite pavements – HMA surface over PCC. These include previous HMA overlays of original PCC pavements.
- PCC pavements – Jointed plain concrete pavements (JPCP), jointed reinforced concrete pavements (JRCP), and continuously reinforced concrete pavements (CRCP).

The procedures provide powerful tools for analysis of a variety of overlay options. The overlay may consist of up to four layers, including three HMA layers and one layer of unbound granular or chemically stabilized material. The procedure can also assess the effects of various types of pre-overlay treatments such as cold milling of existing HMA layers, fracture/rubblizing of existing PCC layers, and in-place recycling of HMA and granular base layers.

Figure 3.6.2 presents a general flow chart for pavement rehabilitation with HMA overlays. As shown in figure 3.6.2, the various combinations of existing pavements and pre-overlay treatments reduce the overlay analyses to three general types:

- HMA overlay of HMA surfaced pavement
- HMA overlay of fractured PCC pavement
- HMA overlay of intact PCC pavement

For existing flexible or semi rigid pavements, the pre-overlay treatments may include nothing, a combination of milling, full or partial depth repairs, or in-place recycling. In either case, the resulting analysis is an HMA overlay of an existing HMA surfaced pavement. The analysis for existing PCC pavements may be either an HMA over PCC analysis or an HMA over fractured slab analysis depending on whether or not crack and seat, break and seat, or rubblization techniques are applied to the existing PCC pavement. Similarly, existing composite pavements may result in either an HMA over PCC analysis or an HMA over fractured slab analysis depending on whether or not the existing HMA surface is removed and the underlying PCC pavement is fractured.

The three overlay analyses predict the same distresses included in PART 3, Chapter 3 for the analysis of new and reconstructed flexible pavements:

- Load associated fatigue of the HMA layers, both top-down and bottom-up cracking.
- Load associated fatigue fracture of any chemically stabilized layer.
- Permanent deformation in HMA layers.
- Permanent deformation in unbound layers.
- Thermal fracture in HMA surface layers.

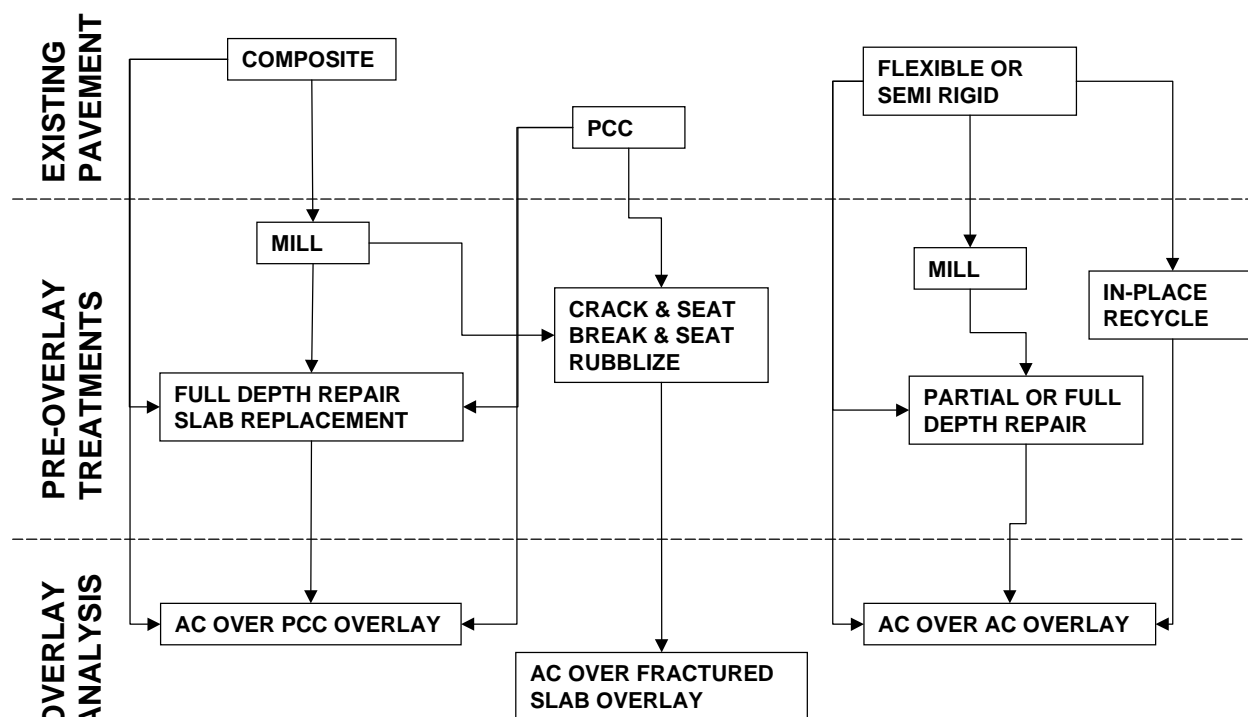


Figure 3.6.2. Flow chart of rehabilitation design options.

The HMA over PCC analysis also considers continued damage of the PCC slab using the rigid pavement performance models presented in PART 3, Chapter 4. The three overlay analyses also provide the capability to address reflection cracking of joints and cracks in PCC pavements and thermal and load associated cracking in HMA surfaced pavements. However, it should be noted here that the reflective cracking models incorporated in the Design Guide were based strictly on empirical observations and were not a result of rigorous M-E analysis. Finally, the predicted distresses are linked to estimates of International Roughness Index (IRI) to form a functional performance criterion that can be considered along with the specific distresses in the design process.

### 3.6.2.1 HMA Overlay of Existing HMA Surfaced Pavements

An HMA overlay is generally a feasible rehabilitation alternative for an existing flexible or semi-rigid pavement except when the conditions of the existing pavement dictate substantial removal and replacement. Conditions when an HMA overlay would not be feasible include:

1. The amount of high-severity alligator cracking is so great that complete removal and replacement of the existing pavement is dictated.
2. Excessive surface rutting indicates that the existing materials lack sufficient stability to prevent recurrence of severe rutting.
3. Existing stabilized bases show signs of serious deterioration and require an inordinate amount of repair to provide uniform support for the overlay.
4. Existing granular base must be removed and replaced due to infiltration and contamination of clay fines or soils.

5. Stripping in existing HMA layers dictates that those layers should be removed and replaced.

In this guide, the design procedure for HMA overlays of existing HMA surfaced pavements considers distresses developing in the overlay as well as the continuation of damage in the existing pavement structure. The overlay generally reduces the rate at which distresses develop in the existing pavement. The design procedure provides for the reflection of these distresses through the overlay layers when they become critical. The condition of the existing pavement also has a major effect on the development of damage in the new overlay layers.

### **3.6.2.2 HMA Overlay of Fractured PCC Slabs**

Reflection cracking is a major distress in HMA overlays of existing PCC pavements. Rubbilizing, crack and seat, and break and seat techniques are used to reduce the size of PCC slabs to minimize the differential movements at existing cracks and joints, thereby minimizing the occurrence and severity of reflection cracks.

The design of an HMA overlay of fractured PCC slabs is very similar to the design of a new flexible pavement structure. The primary design consideration is the estimation of an appropriate elastic modulus for the fractured slab layer. One method to estimate the elastic modulus for the fractured PCC pavement condition is to backcalculate the modulus values from deflection basin measurements on existing projects. The three methods referred to as fractured PCC slabs are defined and used as follows.

- Rubbilizing can be used on all types of PCC pavements in any condition. It is particularly recommended for reinforced pavements. Fracturing the slab into pieces less than 12 inches reduces the slab to a high-strength granular base.
- Crack and seat is used only with JPCP and involves cracking the slab into pieces typically one to three feet in size. To avoid reflection cracking, it has been recommended that no more than 5 percent of the fractured slab have a modulus greater than 1 million psi (*I*). Effective slab cracking techniques are necessary in order to satisfy this criterion.
- Finally, break and seat is used only with JRCP and includes the requirement to rupture the reinforcing steel across each crack or break its bond with the concrete. If the reinforcement is not ruptured or its bond is not broken, the differential movements at working joints and cracks will not be reduced and reflection cracks will occur. The wide range in backcalculated modulus reported for break and seat projects suggest a lack of consistency in the technique, as performed with past construction equipment (*I*). The JRCP frequently retains a substantial degree of slab action because of failure to either rupture the reinforcing steel or break its bond with the concrete. This may also be responsible for the inconsistency of this technique to reduce reflection cracking.

### **3.6.2.3 HMA Overlay of Existing Intact PCC Pavements**

An HMA overlay is generally a feasible rehabilitation alternative for existing PCC and composite pavements provided reflection cracking is addressed in the overlay design. Conditions under which an HMA overlay would not be feasible include:

1. The amount of deteriorated slab cracking and joint spalling is so great that complete removal and replacement of the existing PCC pavement is dictated.
2. Significant deterioration of the PCC slab has occurred due to severe durability problems.

The design procedure presented in this guide for HMA overlay of existing PCC surfaced pavements considers distresses developing in the overlay as well as the continuation of damage in the PCC. For existing JPCP, the joints, existing cracks, and any new cracks that develop during the overlay period are reflected through the HMA overlay using empirical reflection cracking models that can be adjusted for local conditions. A primary design consideration for HMA overlay of existing CRCP is to full-depth repair all working cracks and existing punchouts and then provide sufficient HMA overlay to keep cracks sufficiently tight and exhibit little loss of crack LTE over the overlay design period.

#### **3.6.2.4 Reconstruction**

When the existing pavement deteriorates to the point where the typical rehabilitation strategies are no longer cost-effective, or when the geometrics must be changed, the most feasible rehabilitation strategy may be reconstruction with HMA or PCC. Reconstruction involves removing some or all of the pavement structure and replacing it. The design of reconstructed pavements is similar to that for new pavements; therefore, the design guidelines presented in PART 3, Chapter 3 for flexible pavements and Chapter 4 for rigid pavements should be applied.

### **3.6.3 INPUTS FOR HMA REHABILITATION DESIGN**

Input data used for the design of rehabilitation with HMA presented in this chapter are summarized in table 3.6.1 and categorized as follows:

- General information
- Site/project identification
- Analysis parameters
- Traffic
- Climate
- Drainage and surface properties
- Pavement structure
  - Overlay structure
  - Existing pavement
  - Drainage and surface properties

Several of these inputs are identical to those used for new pavement design (presented in PART 3, Chapter 3) and are not discussed in detail here. However, there are variations in how some inputs are selected for use in rehabilitation design. The focus of this section is to summarize all the inputs required for the design of rehabilitation with HMA overlays using this guide with appropriate commentary on how they relate to the design process. In summary, the designer can choose one of three hierarchical input levels that range from actual testing and field measurements (e.g., laboratory testing of HMA and other materials, on site traffic measurements, and nondestructive testing) to regional or statewide default values.

Table 3.6.1. Design inputs and requirements for rehabilitation design with HMA.

General Description	Variable	Rehabilitation Type		
		HMA Overlay of Existing HMA Surfaced Pavement	HMA Overlay of Fractured PCC Pavement	HMA Overlay of Existing Intact PCC Pavement
General information	Project name and description	Yes	Yes	Yes
	Design life, years	Yes	Yes	Yes
	Existing pavement construction date	Yes	Yes	Yes
	Pavement overlay construction date	Yes	Yes	Yes
	Traffic opening date	Yes	Yes	Yes
	Asphalt Concrete Overlay	Yes	Yes	Yes
Site/project identification	Location of the project	Yes	Yes	Yes
	Project and section identification	Yes	Yes	Yes
	Functional class	Yes	Yes	Yes
Analysis parameters				
	Initial smoothness	Yes	Yes	Yes
	Performance criteria	Yes (table 3.6.3)	Yes (table 3.6.3)	Yes (table 3.6.3)
Climate	Climatic parameters: temperature, moisture, depth to water table, etc. (same inputs required for new pavement designs)	Yes (see PART 2, Chapter 3)	Yes (see PART 2, Chapter 3)	Yes (see PART 2, Chapter 3)
	Hourly profiles of temperature distribution through PCC slab	NA <sup>1</sup>	NA	Yes
	Hourly temperature and moisture profiles (including frost depth calculations) through the other pavement layers	Yes	Yes	Yes
	Temperature at the time of PCC set for JPCP and CRCP overlay design	NA	NA	Yes
	Monthly or semi-monthly (during frozen or recently frozen periods) predictions of layer moduli for asphalt, unbound base/subbase, and subgrade layers	Yes	Yes	Yes
	Mean annual freezing index, number of wet days, number of freeze-thaw cycles	Yes	Yes	Yes
	Mean monthly relative humidity	Yes	Yes	Yes
Traffic	Axle load distribution for each axle type; same input elements required for new pavement designs.	Yes (see PART 2, Chapter 4)	Yes (see PART 2, Chapter 4)	Yes (see PART 2, Chapter 4)
Drainage and surface properties	Pavement surface layer shortwave absorptivity	Yes	Yes	Yes
	Potential for infiltration	Yes	Yes	Yes
	Pavement cross slope	Yes	Yes	Yes
	Length of drainage path	Yes	Yes	Yes
Design Features	PCC pavement type dependent	NA	NA	Yes (see PART3, Chapter 4)

Table 3.6.1. Design inputs and requirements for rehabilitation design with HMA, continued.

General Description	Variable	Rehabilitation Type		
		HMA Overlay of Existing HMA Surfaced Pavement	HMA Overlay of Fractured PCC Pavement	HMA Overlay of Existing Intact PCC Pavement
Layer definition and material properties; PART 2, Chapter 2	Layer number, description, and material type	Yes	Yes	Yes
	Layer thickness	Yes	Yes	Yes
	Layer Interface Condition	Yes	Yes	No
	Elastic (or resilient) modulus and Poisson's ratio, all layers	Yes	Yes	Yes
	Creep-compliance & tensile strength	HMA	HMA	NA
	Flexural, compressive, and tensile strength	NA	NA	PCC
	Ultimate shrinkage	NA	NA	PCC
	Unit weight, all layers	Yes	Yes	Yes
	Coefficient of thermal expansion	HMA	HMA	PCC
	Thermal conductivity, heat capacity, etc.	HMA	HMA	HMA/PCC
	Coefficient of Lateral Pressure, $k_0$	Unbound	Unbound	Unbound
Rehabilitation related inputs for existing flexible pavement <sup>2</sup>	Choice of rehabilitation level	Yes	Yes	No
	At Level 1:	<ul style="list-style-type: none"> <li>Initial permanent strain in each layer from trenching</li> <li>Estimation of initial damage in existing layers through materials testing and non-destructive testing (NDT)</li> </ul>	<ul style="list-style-type: none"> <li>Initial permanent strain in unbound layers from trenching</li> </ul>	
	At Level 2:	<ul style="list-style-type: none"> <li>Estimated initial permanent strain in each layer</li> <li>Estimation of initial damage through observation of fatigue cracking in existing pavement</li> </ul>	<ul style="list-style-type: none"> <li>Estimated initial permanent strain in each layer</li> </ul>	
	At Level 3:	<ul style="list-style-type: none"> <li>Total rutting</li> <li>Subjective rating of pavement condition</li> </ul>	<ul style="list-style-type: none"> <li>Total rutting</li> </ul>	
	Milled Thickness	Yes	NA	NA
	Placement of geotextile prior to overlay	Yes	NA	Yes

Table 3.6.1. Design inputs and requirements for rehabilitation design with HMA, continued.

General Description	Variable	Rehabilitation Type		
		HMA Overlay of Existing HMA Surfaced Pavement	HMA Overlay of Fractured PCC Pavement	HMA Overlay of Existing Intact PCC Pavement
Distress Potential	Medium and High severity sealed longitudinal cracks outside wheel path	Yes	Yes	Yes
	Area of medium and high severity patches, % total lane area	Yes	Yes	Yes
	Potholes, % total lane area	Yes	Yes	Yes
Rehabilitation related inputs for existing rigid pavement <sup>2</sup>	Percentage of slabs with cracks prior to overlay before any restoration work is done plus percentage of slabs replaced on the project historically	NA	NA	Yes (for HMA overlays of JPCP only)
	Percentage of slabs with repairs after any pre-overlay restoration work is performed (includes historically replaced/repared slabs)	NA	NA	Yes (for HMA overlays of JPCP only)
	Number of punchouts per mile	NA	NA	Yes (for HMA overlays of CRCP only)
	Number of punchouts repaired as part of pre-overlay activities per mile	NA	NA	Yes (for HMA overlays of CRCP only)
Foundation Support	Dynamic (FWD) Backcalculated modulus of subgrade reaction, k-value	NA	NA	Optional This value may be entered if known from FWD testing along with the month in which the test was performed. It is used to scale the k-value internally calculated by Design Guide software.

<sup>1</sup> NA = Not applicable.<sup>2</sup> Detailed discussions on the exact inputs pertaining to this category and how they relate to the design procedure are provided under sections 3.6.4 through 3.6.6.

A detailed description of the three input levels is described in PART 1, Chapter 1 and PART 2, Chapters 2 and 4. Detailed descriptions for several of these inputs were presented in previous chapters of this guide as indicated below:

- PART 2, Chapter 1: Subgrade/Foundation Inputs.
- PART 2, Chapter 2: Material Characterization.
- PART 2, Chapter 3: Environmental Effects.
- PART 2, Chapter 4: Traffic Loadings.
- PART 2, Chapter 5: Evaluation of Existing Pavements for Rehabilitation.
- PART 3, Chapter 1: Subdrainage.
- PART 3, Chapter 3: Design of New and Reconstructed Flexible Pavements.
- PART 3, Chapter 4: Design of New and Reconstructed Rigid Pavements.

These chapters should be referenced for more comprehensive descriptions of the required inputs.

### 3.6.3.1 General Information

General information is described in table 3.6.2. The inputs range in simplicity from project name to rehabilitation strategy type—a key input parameter since most of the subsequent input data depends on the selected rehabilitation strategy.

Table 3.6.2. General information required for HMA rehabilitation design.

Input Variable	Description/Source of Information
Project name and description	<ul style="list-style-type: none"> <li>• User input</li> </ul>
Design life	<ul style="list-style-type: none"> <li>• Expected rehabilitation design life</li> </ul>
Existing pavement construction date	<ul style="list-style-type: none"> <li>• Month in which existing pavement was constructed</li> <li>• Year in which existing pavement was constructed</li> </ul>
Pavement overlay construction date	<ul style="list-style-type: none"> <li>• Month in which HMA overlay construction is expected</li> <li>• Year in which HMA overlay construction is expected</li> </ul>
Traffic opening date	<ul style="list-style-type: none"> <li>• Expected month in which rehabilitated pavement will be opened to traffic</li> <li>• Expected year in which rehabilitated pavement will be opened to traffic</li> </ul>
Asphalt Concrete Overlay	<ul style="list-style-type: none"> <li>• HMA overlay of existing HMA surfaced pavement <ul style="list-style-type: none"> <li>○ Includes conventional, deep-strength, full-depth, and semi-rigid pavements.</li> </ul> </li> <li>• HMA overlay of fractured PCC slabs <ul style="list-style-type: none"> <li>○ Includes HMA overlays of fractured JPCP and CRCP.</li> </ul> </li> <li>• HMA overlay of existing intact PCC pavement <ul style="list-style-type: none"> <li>○ Includes HMA overlays of intact JPCP and CRCP.</li> </ul> </li> </ul>

### 3.6.3.2 Site/Project Identification

These inputs simply identify the following features with regard to the project being designed:

- Location of the project.
- Project identification – Project ID, Section ID, begin and end mile posts, and traffic direction.

### 3.6.3.3 Analysis Parameters

The analysis parameters include the various performance criteria that the designer will use to evaluate the acceptability of the design. The user has the flexibility to select the distresses and the performance criteria to be used in the analysis. If smoothness is selected as a performance criteria, the program prompts the designer for an initial smoothness and automatically includes evaluation of the distresses needed as input to the IRI prediction equations. The inputs to the IRI prediction equation are presented in section 3.6.3.3.

#### Initial Smoothness

Recommendations for initial smoothness, as measured by IRI, are the same as those for new construction (refer to PART 3, Chapter 3). They depend greatly on the project smoothness specifications.

#### Distress/Performance Criteria

Performance criteria are definitions of the maximum amounts of individual distress or smoothness acceptable to the highway agency at a given reliability level. Performance indicators used for HMA rehabilitation design are as follows:

- Rutting caused by permanent deformation in asphalt, unbound aggregate, and soil layers.
- Longitudinal cracking or top-down fatigue cracking of the HMA surface.
- Alligator cracking or bottom-up fatigue cracking of new and existing HMA layers, and chemically stabilized layers.
- Transverse cracking due to thermal fracture, reflection joints and existing cracks, and load associated fatigue of existing JPCP.
- Punchout failures of existing CRCP.
- Smoothness, which is presented and discussed in the next subsection.

Performance criteria are a user input and depend on local design and rehabilitation policies. The designer can select one, two, or all the performance criteria available to evaluate a design and make modifications, if necessary. See PART 3, Chapter 3 for detailed recommendations.

Table 3.6.3 summarizes the distress and/or performance measures by overlay analysis type that can be used as performance criteria. In addition to the distresses normally associated with HMA surfaced pavements, the overlay analysis includes degradation of the modulus of chemically stabilized layers with additional traffic. A brief description of each of these distresses or performance measures is provided below. Subsequent sections of this chapter describe critical locations for computation of distresses by type of overlay analysis.

Table 3.6.3 Summary of distresses for HMA overlay analysis.

<b>Distress</b>	<b>HMA over HMA</b>	<b>HMA over Fractured PCC</b>	<b>HMA over Intact PCC</b>
Terminal Smoothness/IRI	Yes	Yes	Yes
Longitudinal Cracking	Yes	Yes	Yes
Bottom-up Fatigue (Alligator) Cracking <sup>1</sup>	Yes	Yes	Yes
Thermal Cracking	Yes	Yes	Yes, Unless Bonded to JPCP or CRCP
Rutting in HMA Layers	Yes	Yes	Yes
Rutting in Unbound Layers	Yes	Yes	When Used in Overlay Layers
CSM <sup>1</sup> Modulus Reduction	Yes	NA	NA
CSM Fatigue Cracking <sup>2</sup>	Yes	NA	NA
PCC: CRCP Punchouts	NA	NA	CRCP only
PCC: JPCP Transverse Cracking	NA	NA	JPCP only
Reflection Cracking	Yes	NA	Yes

<sup>1</sup> Alligator cracking is not expected to be a major distress type in these pavement systems unless in some special cases where the HMA overlay debonds with the PCC or when relatively thicker overlays are placed.

<sup>2</sup> CSM = Chemically stabilized material (e.g., cement-treated, lime flyash, soil cement bases or subbases). Note that the fatigue cracking prediction procedures for CSM layers are uncalibrated.

### *Terminal Smoothness*

The smoothness of the HMA overlay as measured by the IRI is a functional criterion used in evaluating different rehabilitation design strategies for overlays placed on both flexible and rigid pavements. The regression equations used to predict the increase in IRI with time during the HMA overlay design life are discussed in greater detail in a latter section of this chapter. The IRI value at which the agency considers unacceptable to the public and schedules some type of major rehabilitation or repair is defined as the terminal smoothness.

### *Longitudinal Cracking*

Longitudinal cracking is the manifestation of top-down fatigue cracking in HMA layers. It is only considered for the top layer of the HMA overlay. A detailed description of the longitudinal cracking model is presented in PART 3, Chapter 3.

### *Alligator Cracking*

Alligator cracking is the manifestation of bottom-up fatigue cracking in asphalt bound layers. It is evaluated for the lowest HMA layer in the overlay, any HMA layer immediately above an unbound layer, and the existing HMA layer in flexible pavements. It is also evaluated in the existing HMA surface for semi-rigid pavement structures. A detailed description of the alligator cracking model is presented in PART 3, Chapter 3.

## Thermal Cracking

Transverse thermal cracking is evaluated for the top HMA layer of the overlay. The thermal fracture analysis is performed independently of the load associated distress analysis using the model, TCMODEL, developed under the Strategic Highway Research Program and enhanced in work performed under National Cooperative Highway Research Program (NCHRP) Project 9-19 (2). A detailed discussion of the thermal fracture analysis is included in PART 3, Chapter 3. Thermal cracking is not evaluated when the HMA overlay is bonded directly to an existing JPCP or CRCP slab; cracking for these conditions is treated as reflection cracking (discussed in more detail in section 3.6.3.3).

## Rutting

Rutting results from the accumulation of permanent deformation in asphalt bound and unbound aggregate and soil layers. The models used to predict rutting are functions of material type and are described in detail in PART 3, Chapter 3. Rutting in both the overlay and the existing pavement are evaluated for all asphalt and unbound layers, except when the layer is beneath an existing PCC slab that will not receive a fractured slab treatment.

As shown in figure 3.6.3, rutting in existing layers accumulates at a reduced rate during the overlay period due to the hardening effect of traffic prior to the overlay. The amount of rutting in each layer of the existing pavement at the time of the overlay is used to estimate previous traffic and to predict additional rutting in the existing layers.

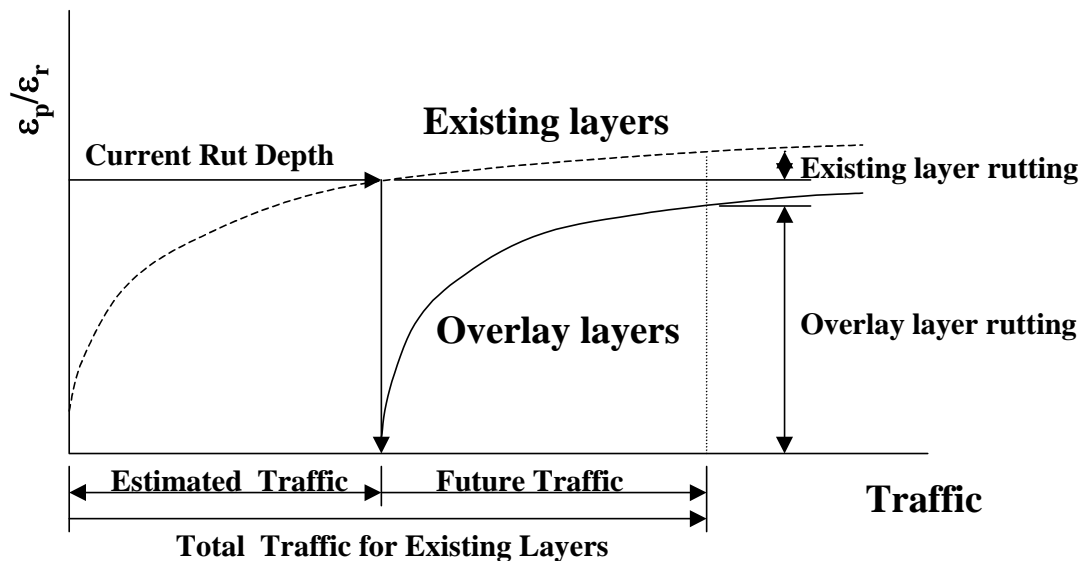


Figure 3.6.3. Effect of pre-overlay traffic on accumulation of rutting.

### Modulus Reduction

In the overlay analysis, the modulus of certain bound layers of the existing pavement is characterized by a damaged modulus representative of the conditions at the time of overlay placement. The modulus of chemically stabilized materials is reduced due to traffic induced damage during the overlay period. The modulus reduction is not applied to JPCP and CRCP pavements as these are modeled exactly as they are in PART 3, Chapter 4 and Chapter 7 as intact slabs with accumulated damage from previous traffic. Cracks in these slabs are considered as reflective transverse cracks through the HMA overlay.

The modulus reduction is shown schematically in figure 3.6.4. Equation 3.6.1 presents the general form of the modulus as a function of damage:

$$E = E_{\min} + \frac{(E_{\max} - E_{\min})}{1 + e^{a+b(d)}} \quad (3.6.1)$$

Where:

- $E$  = Modulus of chemically stabilized material, psi.
- $E_{\min}$  = Minimum modulus, psi.
- $E_{\max}$  = Maximum modulus, psi.
- $a$  and  $b$  = Fitting parameters.
- $d$  = Fatigue damage in chemically stabilized material.

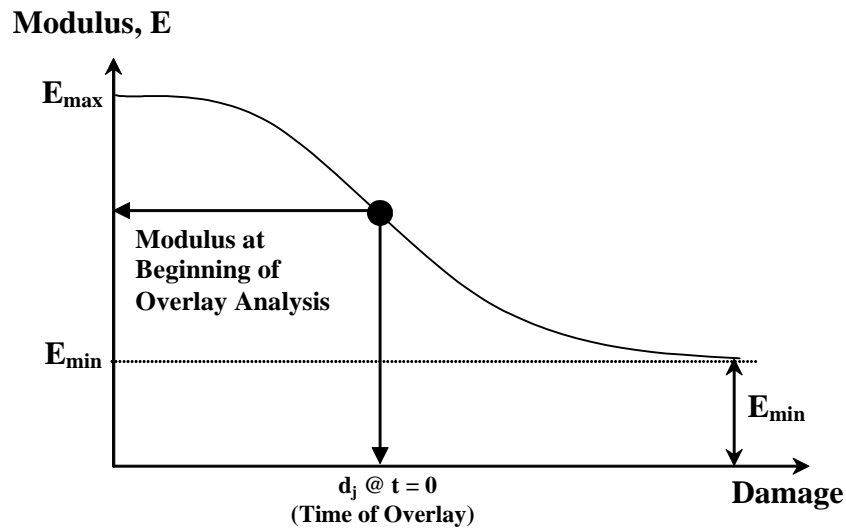


Figure 3.6.4. Modulus reduction for a damaged chemically stabilized layer.

Table 3.6.4 summarizes the parameters of the model for chemically stabilized materials. The maximum modulus is a function of material quality and age, and can be estimated using the relationships provided in PART 2, Chapter 2.

Table 3.6.4. Parameters for modulus reduction of cementitious layers, equation 3.6.1.

Parameter	Cement Treated Material <sup>1</sup>
$E_{\max}$ , psi	PART 2, Chapter 2
$E_{\min}$ , psi	50,000
A	-4
B	14

<sup>1</sup> These values pertain to cement treated base or subbase materials.

### *CSM Fatigue Cracking*

A ladder cracking pattern in pavements that include chemically stabilized layers is the manifestation of fatigue damage in the stabilized material. A detailed description of the cement-treated base (CTB) fatigue damage model is provided in PART 3, Chapter 3. Note that fatigue cracking in CSM layers is not calibrated in the Design Guide procedure.

### *Reflection Cracking*

Reflection cracking is a major distress mode in HMA overlays of both flexible and PCC pavements. The basic mechanism of reflection cracking is the propagation of cracks through the overlay due to movements in the vicinity of cracks and joints in the existing pavement. This movement may be vertical due to loading, horizontal due to temperature changes, or more probably a combination of both. Load-induced movements are influenced by the thickness of the overlay and the thickness, modulus, and load transfer in the existing pavement. Temperature induced movements are influenced by daily and seasonal temperature variations, the coefficient of thermal expansion of the existing HMA and PCC layers and the spacing of cracks.

The complex combination of tensile and shear strains at the bottom of the overlay cause cracks to initiate at the bottom of the HMA layer. With time, the cracks propagate upward through the HMA overlay. As the process continues, multiple reflection cracks will form and eventually portions of the HMA overlay will spall and dislodge from the pavement surface. Even with periodic or routine maintenance (crack sealing), reflection cracks eventually lead to a reduction of pavement smoothness and shorten the life of the overlay.

The overlay design procedure allows the designer to consider two types of reflection cracks: reflection of cracks that exist on the surface prior to overlay placement and those that develop in the existing surface after overlay placement. The prediction process for each type is discussed in the following subsections.

**Existing Cracks in Pavement Surface – Prior to Overlay Placement.** The current state of mechanistic-empirical modeling of reflection cracking is limited. To address this critical distress mode, a simplified empirical model is included for the overlay analysis. The model predicts the percentage of cracks that propagate through the overlay as a function of time using a sigmoidal function. Equation 3.6.2 presents the general form of the sigmoidal model:

$$RC = \frac{100}{1 + e^{a+bt}} \quad (3.6.2)$$

where:

$RC$  = Percent of cracks reflected, %.

$t$  = Time, years.

$a$  and  $b$  = Fitting parameters.

The parameters of the model are a function of overlay thickness, the type of existing pavement, and for PCC pavements, load transfer at joints and cracks. The regression fitting parameters included in this guide are summarized in table 3.6.5, which are hard coded in the software. The designer cannot directly alter these parameters as inputs, but can change them in the software. An agency should use historical data to develop a local reflection cracking model for each pavement type and rehabilitation strategy.

Table 3.6.5. Reflection cracking model parameters, equation 3.6.2.

Pavement Type	Parameters	
	A	b
Flexible	$3.5 + 0.75(h_{ac})$	$-0.688584 - 3.37302(h_{ac})^{-0.915469}$
Rigid, Good Load Transfer	$3.5 + 0.75(h_{ac} - 1)$	$-0.688584 - 3.37302(h_{ac} - 1)^{-0.915469}$
Rigid, Poor Load Transfer	$3.5 + 0.75(h_{ac} - 3)$	$-0.688584 - 3.37302(h_{ac} - 3)^{-0.915469}$

Notes:

1.  $h_{ac}$  = thickness of overlay in inches.
2. In the Design Guide approach, it is assumed that a properly installed fabric is equivalent to 2 inches of HMA overlay. This is purely based on empirical considerations.
3. Minimum recommended  $h_{ac}$  is 2 inches for existing flexible pavements, 3 inches for existing rigid pavements with good load transfer, and 4 inches for existing rigid pavements with poor load transfer.

The empirical model for reflective cracking is used for estimating the amount of cracking from a non-surface layer that has reflected to the surface after a certain period of time. The model is used for reflection of fatigue and thermal cracks from stabilized layers, as well as for joints and cracks from overlaid rigid pavements.

**Cracks Occurring in Existing Pavement Layers After Overlay Placement.** Even after overlay placement, the underlying bound layers (including all asphalt bound and chemically stabilized layers) undergo additional fatigue damage with continued traffic loading, and will eventually crack. The continual fatigue damage accumulation of these layers is considered in the overlay analysis procedures of this guide. For any given month  $m$ , the total fatigue damage is estimated by equation 3.6.3.

$$D_m = \sum_{i=1}^m \Delta D_i \quad (3.6.3)$$

Where:

$D_m$  = Damage for month  $m$ .

$\Delta D_i$  = Increment of damage in month  $i$ .

The area of fatigue cracking for the underlying layer at month  $m$  ( $CA_m$ ) is given by equation 3.6.4.

$$CA_m = \frac{100}{1 + e^{6-6 \times D_m}} \quad (3.6.4)$$

For each month  $i$ , there will be an increment of damage  $\Delta D_i$  which will cause an increment of cracking area  $\Delta CA_i$  to the stabilized layer. To estimate the amount of cracking reflected from the stabilized layer to the surface of the pavement for month  $m$ , the reflective cracking model is applied incrementally, as follows:

$$TRA_m = \sum_{i=1}^m RC_{m-i} \times \Delta CA_i \quad (3.6.5)$$

Where:

$TRA$  = Total reflected area for month  $m$ .

$RC_{m-i}$  = Percent cracking reflected for Age =  $m - i$ ; (Age in years).

$\Delta CA_i$  = Increment of fatigue cracking for month  $i$ .

The reflective cracking model is applied to each increment of fatigue cracking area because the time elapsed for each of these increments is different. The model included in this guide is based on engineering judgement and a limited amount of published data from Georgia (3). Figure 3.6.5 compares the rigid pavement reflection cracking model (equation 3.6.5) for good load transfer with published data from Georgia. The beneficial effect of fabrics is incorporated in the model by assuming that a properly installed fabric is equivalent to 2 inches of HMA.

Figure 3.6.6 compares the recommended reflection cracking models by pavement type and joint load transfer for 4 and 8 inch overlays. The reflection cracking model predicts fewer reflection cracks as the thickness of the overlay increases. It also predicts that reflection cracking will occur quicker in rigid pavements compared to flexible pavements, and in rigid pavements with poor load transfer compared to rigid pavements with good load transfer.

### *JPCP Fatigue Damage*

In the HMA overlay of JPCP analysis, fatigue damage will continue to accumulate in existing JPCP (only at a reduced rate depending on overlay thickness and modulus) based on the cracking model described in PART 3, Chapter 4. This model assumes that the slabs remain intact and their elastic modulus does not reduce. However, fatigue cracks generated by this model will then reflect through the HMA overlay based on the approximate reflection cracking model described in the preceeding section.

Bottom-up transverse cracking typically occurs in the center portion of slabs between the transverse joints (4). It begins as an initial hairline crack at the bottom of the slab and eventually propagates to the top of the slab and across the slab. This fine crack will deteriorate over time and traffic, resulting in a loss of load transfer across the crack. Loss of load transfer results in significant differential vertical movement across the crack when subjected to heavy wheel loads.

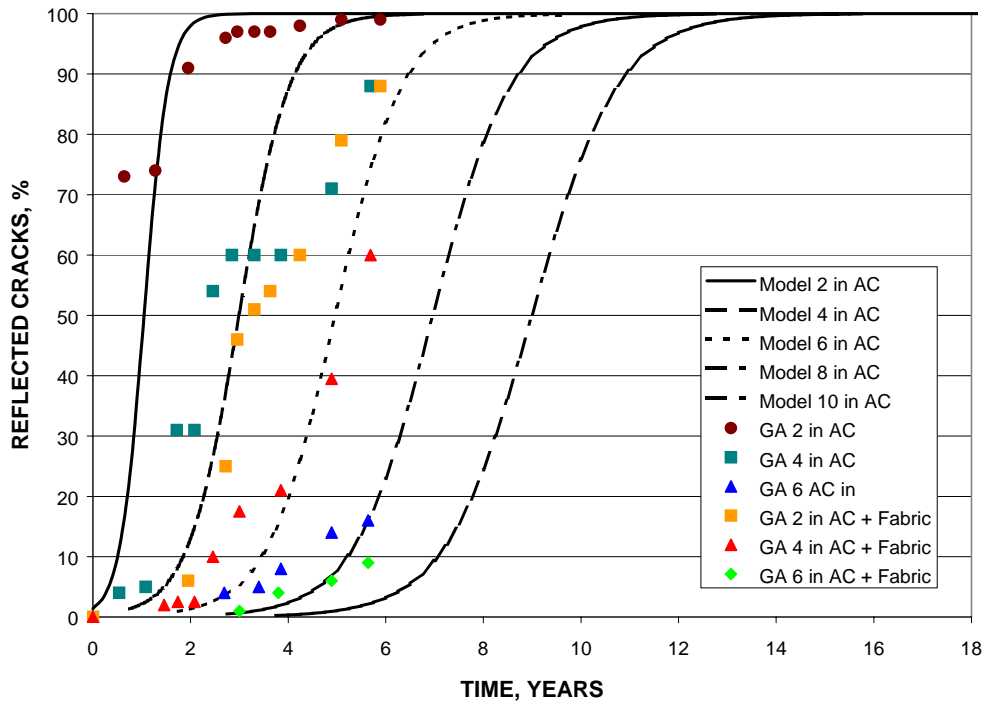


Figure 3.6.5. Reflection cracking model for rigid pavements with good load transfer showing Georgia field data.

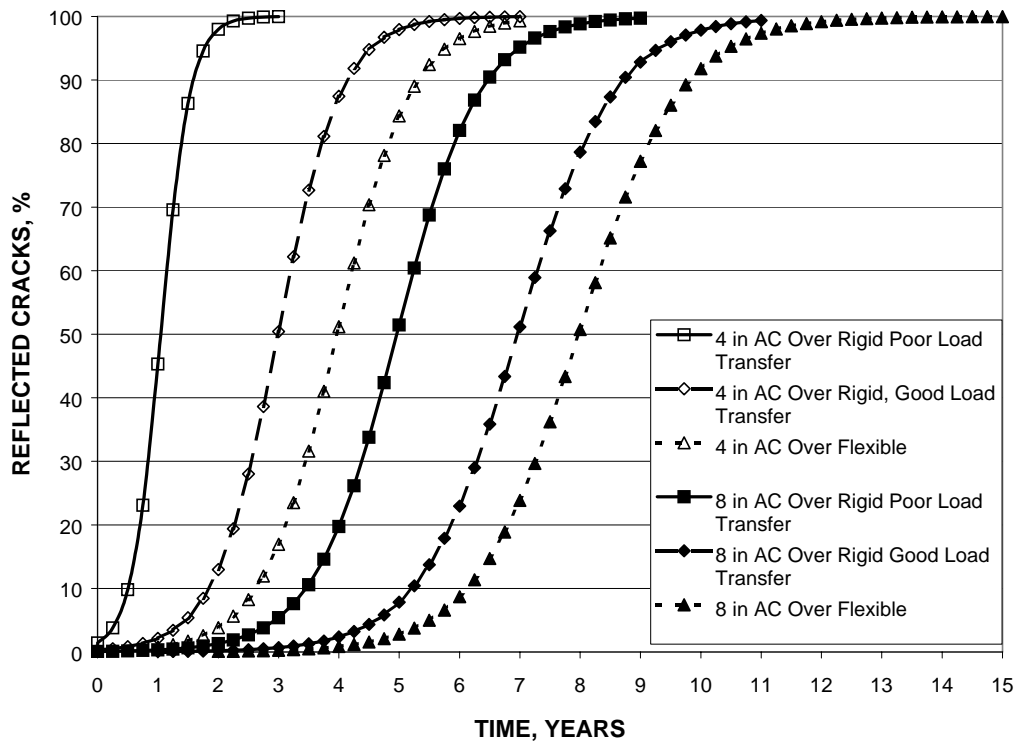


Figure 3.6.6. Comparison of reflection cracking model by overlay thickness, pavement type, and load transfer.

These slab movements generate high shear stresses at the bottom of the HMA overlay that cause the development of reflection cracks in the HMA. These cracks will reflect through the HMA overlay over time as discussed in section 3.6.3.3 and eventually cause loss of ride quality (increase in IRI) and increased maintenance. PCC bottom-up transverse cracking is thus an important structural deterioration mode of JPCP overlaid with HMA.

It should be noted that transverse cracking can also be caused by foundation settlements, lockup of joints, and inadequate joint forming after placement. However, this type of transverse cracking is not considered in this section because its cause is mostly construction-related (lack of quality control). This section deals only with bottom-up transverse cracking caused by repeated loading, superimposed by positive temperature gradients through the slab (which increases the tensile stress at the bottom of the slab). Top down JPCP cracking does not occur due to the HMA overlay and the subsequent reduction in negative thermal gradients through the slab which reduce tensile stresses at the top of the slab.

HMA overlays will greatly reduce both the thermal gradients and the stresses in the existing JPCP. In the JPCP fatigue analysis, the effect of the overlay on the thermal gradients is evaluated with the Enhanced Integrated Climatic Model (EICM) and the trial overlay structure. The effect of the overlay on the bending stresses is considered by computing bending stresses using an equivalent slab thickness approach. The equivalent slab thickness is a function of the thickness and modulus of the overlay layers.

**Factors Affecting Bottom-Up Transverse Cracking.** The following factors have been shown analytically and in field tests to affect bottom-up transverse cracking of JPCP slabs with HMA overlays (4,5,6,7):

- HMA stiffness.
- JPCP slab modulus and strength.
- JPCP slab size.
- Existing JPCP shoulder type (tied PCC shoulders or otherwise).
- Foundation modulus.
- Climate (including temperature profiles for both HMA and PCC layers).
- Permanent curl/warp equivalent temperature for the PCC slab.
- Shrinkage of PCC slab.

**Computing Structural Responses.** The pavement structural response of interest for JPCP bottom-up cracking of HMA overlaid JPCP is the maximum bending stress at the bottom surface of the existing JPCP layer. Maximum bending stress at the bottom of the JPCP layer is computed using the following input data:

- HMA overlay thickness.
- HMA overlay modulus.
- JPCP slab thickness.
- JPCP slab modulus of elasticity.
- JPCP slab Poisson's ratio.
- JPCP slab unit weight.

- JPCP slab coefficient of thermal expansion.
- Base thickness.
- Base modulus of elasticity.
- Interface condition between the PCC slab and base.
- Base unit weight (required only if the PCC slab and base interface is bonded).
- JPCP joint spacing.
- Modulus of subgrade reaction.
- Lane-shoulder LTE.
- Longitudinal joint lane-lane LTE (for JPCP with widened lanes).
- Temperature profiles throughout the HMA overlay and JPCP slab.
- Axle type (single, tandem, or tridem).
- Axle weight.
- Number of axle load applications.
- Tire pressure and wheel aspect ratio (length-to-width ratio).
- Axle position (distance from the critical slab edge).

The following assumptions are made in the bottom-up transverse cracking analysis for HMA overlays of JPCP:

- The interface between the HMA overlay and existing PCC slab is bonded.
- The interface between the PCC slab and the underlying material is unbonded.
- The coefficients of thermal expansion of the HMA overlays and the existing JPCP slab are different.
- The coefficients of thermal expansion of the existing JPCP and all underlying layers are equal.
- Deflection LTE of the longitudinal lane-to-lane joint is 70 percent for non-widened lane pavements.
- The LTE of the transverse joints does not affect the critical tensile stresses at the bottom of the PCC slab and hence 85 percent is used for doweled pavements and 50 percent is used as a standard for nondoweled pavements.

As damage is accumulated incrementally and pavement design features, material properties, and climate vary for the different time increments, the critical pavement response parameter—maximum bending stress at the bottom surface of the PCC surface layer—must be computed for each analysis increment throughout the rehabilitation design life. For HMA/JPCP analysis, stresses and strains are computed using the standard input parameters listed above and by converting the HMA/JPCP structure into an equivalent structure as shown in figure 3.6.7. Stresses computed in the equivalent structure can be related to the stresses in the actual structure through closed form solutions. The equivalent structure shown in figure 3.6.7 is based on the following assumptions:

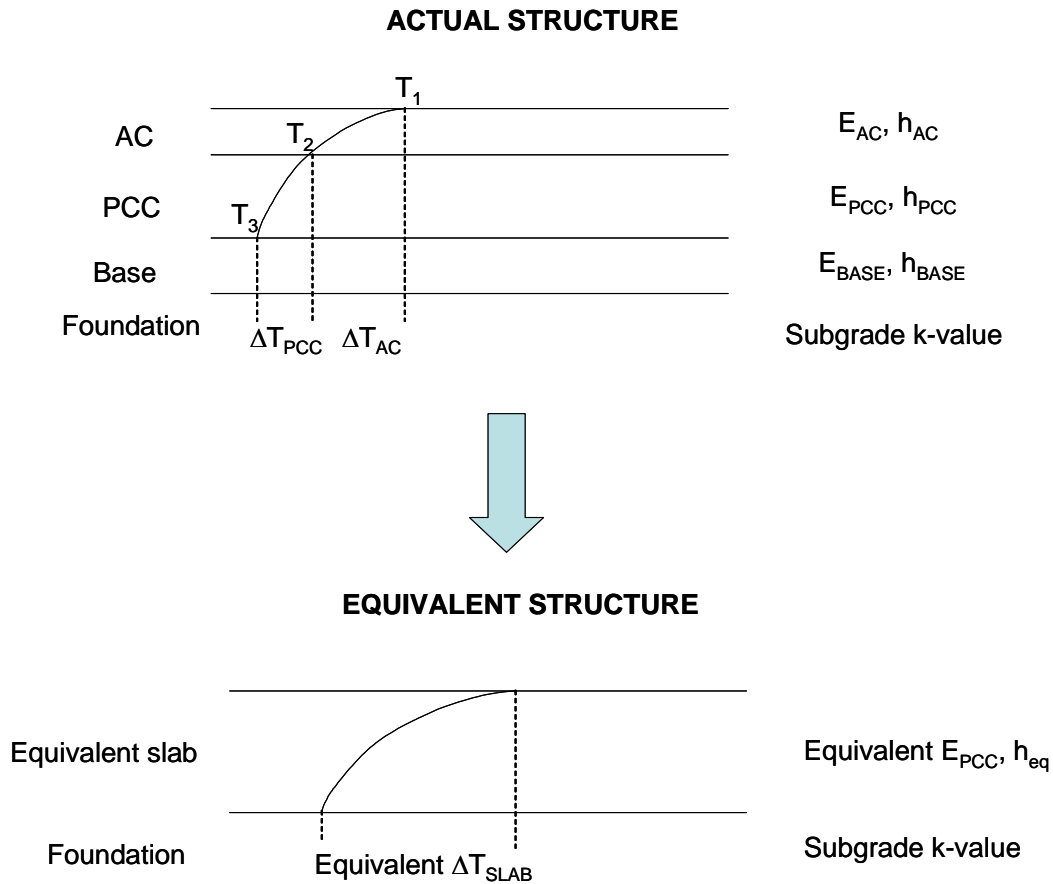


Figure 3.6.7. Schematic of HMA/JPCP structure and equivalent JPCP structure used in analysis.

- The equivalent temperature gradient must induce the same magnitude of moments in the equivalent structure as induced in the JPCP slab.
- The deflection basin of the equivalent structure is the same as the original structure under the same conditions of axle and temperature loading.

The following HMA/PCC properties are modified to establish the equivalent structure:

- Layer thickness.
- Layer modulus.
- Temperature gradients.

For this guide, structural responses in the equivalent pavement structure (critical stresses and strains in the pavement due to traffic loads and climatic effects) are computed using rapid solution neural networks models that are based on finite element structural analyses. The neural network models were developed specifically for the rehabilitation strategies covered by this guide and were developed using a range of traffic loading, site properties, and design features typical for rehabilitated pavements. A detailed description of the software and neural networks developed for computing structural responses is presented in PART 3, Chapter 4 and Appendix QQ.

### *CRCP Punchout Damage*

For HMA overlay of CRCP, punchout fatigue damage accumulates much more slowly than before the overlay as described in in PART 3, Chapter 4. The effect of the overlay on the thermal gradients is determined by the EICM using the trial overlay structure. The overlay reduces the negative thermal gradients reducing the critical top of slab tensile stress that results in punchouts. More importantly, the overlay reduces the opening of the transverse cracks and thus the deterioration or loss of LTE of the cracks. The effect of the overlay on the bending stresses is included by computing bending stresses using the equivalent slab thickness approach. The equivalent slab thickness is a function of the thickness and stiffness of the overlay layers. These effects reduces the rate of punchout development. The development of punchouts in the existing CRCP is assumed to cause an immediate reflection crack in the HMA overlay.

**Factors Affecting CRCP Punchouts.** CRCP punchouts are the result of a combination of the following factors:

- Irregular transverse crack spacing with large number of narrow (2 ft or less) cracked PCC segments.
- Application of repeated heavy axle loads to the CRCP.
- Loss of load transfer across the transverse cracks (crack width is a most important factor).
- Free moisture beneath the CRCP (within the underlying layers).
- Inadequate CRCP slab thickness.
- Erosion of the layers underlying the CRCP slab (base/subbase, or subgrade) resulting in high deflections.

CRCP punchouts are also influenced by the following:

- Amount of reinforcement in the CRCP slab.
- CRCP slab thickness.
- Base layer type and durability.
- Subgrade type (fine or coarse).
- Location of applied loads (lateral placement of vehicle loads near unsupported pavement edges increases the likelihood of punchouts).
- Slab edge support (e.g., lack of widened paving lanes, tied PCC shoulders, or edge beams increases the likelihood of punchouts).
- Climate (e.g., precipitation, freezing index, and number of freeze-thaw cycles).
- Subsurface drainage facilities (presence of adequate drainage or otherwise).
- Construction conditions (including concrete set temperature and built-in “construction” curling/warping, drying conditions).

A detailed description how these factors influence punchout development and progression is presented PART 3, Chapter 4.

**Computing Structural Responses.** The pavement structural response of interest for CRCP punchouts of HMA overlaid CRCP is the maximum transverse tensile stress at the surface of the PCC (in the transverse direction) between two closely spaced transverse cracks. Maximum

transverse tensile stress at the surface of a narrow concrete segment is computed using the following input data:

- HMA overlay thickness.
- HMA overlay modulus.
- CRCP slab thickness.
- CRCP modulus of elasticity.
- CRCP Poisson's ratio.
- CRCP unit weight.
- CRCP coefficient of thermal expansion.
- Base thickness.
- Base modulus of elasticity.
- Interface condition between the PCC slab and base.
- Crack spacing.
- Subgrade stiffness (coefficient of subgrade reaction).
- Crack LTE (affected largely by crack width and crack spacing).
- Difference in top and bottom PCC slab surface temperature.
- Axle type (single or tandem).
- Axle weight.
- Axle position (distance from the critical slab edge) – varied between 0 and 18 in from the longitudinal edge.

For CRCP punchout analysis, the following is assumed:

- A bonded interface is assumed between the HMA overlay and the CRCP.
- An unbonded interface is assumed between the PCC slab and the base.
- The coefficients of thermal expansion of the HMA overlay and CRCP layer are different.
- The coefficients of thermal expansion of the CRCP layer and all underlying layers are the same.
- Deflection LTE of the longitudinal lane-to lane joint is 50 percent.

The critical pavement response parameter— maximum transverse tensile stress at the top of the PCC layer (in the transverse direction between two closely spaced transverse cracks)—must be computed for each analysis increment throughout the rehabilitation design life. These incremental computations are necessary because damage is accumulated incrementally and pavement design features, material properties, and climate vary for the different time increments. For HMA/CRCP analysis, stresses and strains are computed using the standard input parameters listed above and by converting the HMA/CRCP structure into an equivalent structure. The HMA/CRCP equivalent structure is determined using the same procedure as for HMA/JPCP pavements, described previously in section 3.6.3.3.2.9 of this chapter.

### Smoothness Prediction

The basic design premise for this guide is that incremental increases in surface distress cause an incremental decrease in surface smoothness or decrease in ride quality, as measured by IRI.

Appendix OO provides a detailed discussion on the development of these regression prediction equations. The following lists the regression equations used in this guide based on a functional design requirement.

#### *HMAC Overlays of Flexible Pavements*

$$IRI = IRI_0 + 0.011505(t) + 0.0035986(FC) + 3.4300573 \left( \frac{1}{(TC_s)_{MH}} \right) + 0.000723(LC_s)_{MH} + 0.0112407(P)_{MH} + 9.04244(PH) \quad (3.6.6)$$

Where:

$IRI_0$	= Initial IRI at the time of HMA overlay placement, m/km.
$t$	= Time after overlay placement, years.
$FC$	= Total area fatigue cracking, % of wheel path area.
$(TC_s)_{MH}$	= Average spacing of medium and high severity transverse cracks, m.
$LC_s$	= Medium and high severity sealed longitudinal cracks in the wheel path, m/km.
$(P)_{MH}$	= Area of medium and high severity patches, % of total lane area.
$(PH)$	= Pot holes, % of total lane area.

#### *HMAC Overlays of Rigid Pavements*

$$IRI = IRI_0 + 0.0082627(t) + 0.0221832(RD) + 1.33041 \left( \frac{1}{(TC_s)_{MH}} \right) \quad (3.6.7)$$

Where:

$RD$	= Average rut depth, mm.
All other variables as described previously.	

Note that some of the terms in equations 3.6.6 and 3.6.7 call for distresses grouped by severity level (medium- or high-severity distresses). Recall that the Design Guide approach does not discriminate between levels of severity when predicting distress quantities. However, this is not expected to influence the results significantly since most of the terms in question are user inputs (e.g., sealed longitudinal cracks in wheel path, patching, etc.). The only quantity that is likely affected is the transverse crack spacing which is directly predicted by the Design Guide software.

#### **3.6.3.4 Traffic**

Traffic data is one of the key data elements required for the analysis and design of rehabilitated pavement structures. The design procedures for all the different types of rehabilitation with HMA are based on future traffic estimates. Estimates of load spectra for single, tandem, tridem, and quad axles are used to characterize the truck traffic for rehabilitation designs. This load spectra includes the counts of number of axles within a series of load groups in a given time interval. Each load group covers a specified load interval for a specific axle. Detailed guidance on traffic inputs required for rehabilitation design is presented in PART 2, Chapter 4. Further

information on traffic inputs is provided in PART 3, Chapter 3 relative to HMA surfaced pavements. Traffic inputs for rehabilitation design are identical to those for new design.

### **3.6.3.5 Climate**

Environmental conditions have a significant effect on the performance of HMA rehabilitated pavements. The interaction of the climatic factors with pavement materials and loading is fairly complex. Factors such as precipitation, temperature, freeze-thaw cycles, and depth to water table affect pavement and subgrade temperature and moisture content, which in turn, directly affect the load-carrying capacity of the pavement layers and ultimately pavement performance. In this guide, the temperature and moisture profiles in the pavement structure and subgrade are determined using the EICM. The EICM software is linked to the Design Guide software as an independent module through interfaces and design inputs. Detailed guidance on environmental inputs required for pavement design is presented in PART 2, Chapter 3. Further information specifically for flexible pavements is given in PART 3, Chapter 3 and for rigid pavements is given in PART 3, Chapter 4.

### **3.6.3.6 Pavement Structure**

The design of structural HMA overlays is an iterative process. An initial trial overlay design is first selected and analyzed. If the trial design does not meet one or more of the performance criteria (identified in section 3.6.3.3), it must be modified and reanalyzed. This process continues until the rehabilitation design meets all performance criteria.

To begin the process, the designer must specify the thickness and material properties for the overlay and the existing pavement structure, taking into account planned pre-overlay treatments such as milling, in-place recycling, or rubblizing. The maximum number of overlay layers that can be specified is four. This includes up to three HMA layers, and one unbound or chemically stabilized layer. The total number of layers of the existing pavement and the overlay is limited to 14, as described in PART 3, Chapter 3. A further limitation for existing HMA surfaced pavements is that only one existing HMA layer can be specified.

The capability for multiple HMA layers in the overlay enables the designer to assess the merits of different HMA mixtures. For example on a high volume urban freeway with slow moving traffic during peak periods, consideration may be given to the following overlay structure and strategy:

- 1/2 in. polymer modified stone matrix asphalt (SMA) wearing surface. The stone on stone contact and high mastic stiffness in this mixture provides excellent resistance to rutting. The high binder content and polymer-modified binder also provides excellent resistance to thermal cracking and surface initiated fatigue (top-down) cracking. In addition, the mixture's open texture is beneficial for reducing noise and splash and spray.
- 3/4 in. HMA intermediate course designed to a high number of gyrations. This type mixture will have relatively low asphalt content and be highly resistant to rutting.
- 1 in. HMA base course designed to a low number of gyrations. This mixture will have relatively high asphalt content and be resistant to bottom-up fatigue cracking.

## Overlay Structure

Figure 3.6.8 shows the type of overlay structures that can be analyzed. However, it should be noted that, in order to keep the number of layers and evaluation locations within the limits of the mechanistic response calculation models considered in the Design Guide procedure (e.g., JULEA), several layers may need to be combined when using the computer software. The “Rules of Simulation” section in PART 3, Chapter 3 explains how various layers can be combined and provides other pertinent information to set up trial design structures for overlay analysis.

AC 1	AC 1	AC 1	AC 1
AC 2	AC 2	AC 2	AC 2
AC 3/ATB	AC 3/ATB	GB	AC 3/ATB
Existing Pavement	GB	AC 3/ATB	CTB
	Existing Pavement	Existing Pavement	Existing Pavement
Case 1	Case 2	Case 3	Case 4

Figure 3.6.8. Example overlay design options.

Case 1 in figure 3.6.8 is a standard overlay incorporating up to three HMA mixtures or layers. Case 1 may also be used to represent in-place recycling of an existing HMA surface and granular base using an asphalt emulsion prior to placing the overlay. Cases 2 and 3 represent an overlay where an unbound granular layer is used for reflection crack control in an overlay of a PCC pavement. These cases may also be used in forensic analysis to evaluate the effect of moisture damage in lower asphalt bound layers. Cases 2 and 3 may also be used to convert an existing flexible pavement into a sandwich type pavement. Sandwich pavements may be a cost effective alternative for substantial strengthening of an existing pavement on a soft subgrade. Finally, Case 4 represents in-place recycling of an existing HMA surface and possibly granular base using cement stabilization.

For the overlay layers, methods for determining appropriate material properties are described in detail in PART 2 – DESIGN INPUTS, Chapter 2. For most materials, the designer can choose from three hierarchical input levels that include: laboratory testing, correlations with easily measured material characteristics, and default values.

## Existing Pavement

A critical element in the HMA overlay design method is the characterization of the existing pavement section, including the effect of pre-overlay treatments. Pre-overlay treatments include operations such as full or partial depth patching, cold milling of existing HMA layers, fracture/rubblizing of existing PCC layers, and in-place recycling of HMA and granular base

layers. General recommendations for evaluating existing pavements for rehabilitation are discussed in PART 2, Chapter 5. All pavement properties should be representative of the conditions expected immediately before rehabilitation.

A three level hierarchical system is provided for characterization of the existing pavement structure. Table 3.6.6 summarizes the recommended methods for estimating critical design input parameters for existing pavement layers. Poisson's ratio for all levels is estimated using the recommendations included in PART 2, Chapter 2.

Level 1 characterization generally uses data from non-destructive testing (NDT) for estimating layer modulus values and detailed condition survey data for characterizing damage in the existing pavement. Level 2 combines the use of correlations between modulus and easily measured material characteristics with detailed condition survey data. Finally, Level 3 uses typical published or recommended values for modulus and information from general pavement ratings for estimating damage. Details of the recommended methods for each layer are discussed in more detail in sections 3.6.4, 3.6.5, and 3.6.6.

#### Drainage and Surface Properties

Information required under this category includes the following elements, which were previously defined and discussed in PART 3, Chapter 3:

- Pavement surface layer shortwave absorptivity.
- Potential for infiltration.
- Pavement cross slope.
- Length of drainage path.

### **3.6.4 HMA OVERLAY OF EXISTING HMA SURFACED PAVEMENTS**

#### **3.6.4.1 Introduction**

An HMA overlay is generally a feasible rehabilitation alternative for an existing flexible or semi-rigid pavement except when the conditions of the existing pavement dictate substantial removal and replacement. Conditions when an overlay would not be feasible include:

1. The amount of high-severity alligator cracking is so great that complete removal and replacement of the existing pavement is dictated.
2. Excessive surface rutting indicates that the existing materials lack sufficient stability to prevent recurrence of severe rutting.

Table 3.6.6. Summary of existing layer characterization for HMA rehabilitation analysis.

Layer Material	Input	Hierarchical Level		
		1	2	3
Subgrade	Modulus	NDT	Simple Test Correlations	Soil Classification
	Initial Permanent Strain ( $\epsilon_p$ )	Trench Data	User Input	User Input
Unbound Base or Subbase	Modulus	NDT	Simple Test Correlations	Soil Classification
	Initial ( $\epsilon_p$ )	Trench Data	User Input	User Input
Chemically Stabilized Materials	Damaged Modulus	NDT	Estimated from Undamaged Modulus	Estimated from Undamaged Modulus
	Undamaged Modulus	Compressive Strength of Field Cores	Estimated from Compressive Strength of Field Cores	Estimated form Typical Compressive Strength
	Fatigue Damage	% Alligator Cracking from visual condition survey	% Alligator Cracking from visual condition survey	Pavement Rating
Asphalt Concrete	Damaged Modulus	NDT	Estimated from Undamaged Modulus (reduction factor from measured alligator cracking)	Estimated from Undamaged Modulus (reduction factor from pavement rating)
	Undamaged Modulus	HMA dynamic modulus model Project Specific Inputs Agency Historical Inputs	HMA dynamic modulus model with Project Specific Inputs	HMA dynamic modulus model with Agency Historical Inputs
	Fatigue Damage	Damaged modulus is measured by NDT	% Alligator Cracking from visual condition survey	Pavement Rating
	Initial $\epsilon_p$	Trench Data (each layer)	User Input (by layer)	Total rutting at surface

Note: Recommended values of Poisson's ratio for various material types are included in PART 2, Chapter 2.

3. Existing stabilized bases show signs of serious deterioration and would require an inordinate amount of repair to provide uniform support for the overlay.
4. Existing granular base must be removed and replaced due to infiltration and contamination by a soft subgrade.
5. Stripping in an existing HMA layer dictates that it should be removed and replaced.

#### **3.6.4.2 Subsurface Drainage Considerations**

Evaluation of the adequacy of drainage at the project location and an investigation of the role of poor drainage on pavement deterioration is an important consideration prior to placing the HMA overlay on the fractured slab. Properly installed and maintained retrofit drainage systems play an important role in achieving the design life of the HMA overlays. This is especially true when retrofit drains are being considered in pavements subjected to excessive moisture damage.

PART 3, Chapter 1 describes a systematic approach for drainage considerations in rehabilitated pavements starting from the assessment of drainage needs to integrating pavement drainage design with structural design.

#### **3.6.4.3 Pre-Overlay Treatments**

Various pre-overlay treatments and repairs should be performed to address deterioration of the existing pavement, improve surface smoothness, and provide uniform support for the overlay. Deterioration in the existing pavement includes visible distress as well as damage that is not visible at the surface but which may be detected by nondestructive testing. Various nondestructive testing techniques and their application to pavement evaluation were discussed in PART 2, Chapter 5.

Determining how much of the distress should be repaired before the overlay is placed requires a careful mix of experience and engineering judgment. If the distress in the existing pavement is likely to affect the performance of the overlay within a few years, it should be repaired prior to overlay placement. Premature distress in the overlay is often the result of deterioration in the existing pavement that was not repaired properly prior to placing the overlay.

The pavement evaluation described in PART 2, Chapter 5 quantifies the major distresses in the existing pavement. Guidance on the use of various repair treatments is also presented and discussed in PART 3, Chapter 5. The sections below discuss pre-overlay treatments that should be considered for HMA overlays of flexible, semi-rigid, and composite pavements.

##### **Pre-Overlay Repair Options for Alligator Cracking**

Alligator cracking is the result of fatigue damage in the HMA layer. Localized areas of medium and high severity alligator cracking indicate poor support conditions. These areas could receive full depth repair prior to overlay placement. The repairs may also include removal of any soft base, subbase or subgrade material. If the pavement will be cold milled, the full depth repairs could be made before milling operations to provide a smooth surface for overlay placement.

### Pre-Overlay Repair Options for Longitudinal Cracking

Longitudinal cracking in the wheel paths is usually the result of top-down fatigue damage in the HMA layer. Since these cracks initiate at the surface and propagate downward, cold-milling to the depth of the cracks is recommended for pavements exhibiting medium to high severity longitudinal wheel path cracking.

Cracking may also occur along longitudinal joints in the existing HMA surfaced pavement. This type of cracking is usually the result of poor compaction near the longitudinal joint during construction. These cracks are often accompanied by raveling or development of adjacent longitudinal cracks in the poorly compacted area adjacent to the joint. Partial depth repair of such distress will need to be performed prior to the overlay, otherwise these cracks will reflect through the overlay.

### Pre-Overlay Repair Options for Transverse Cracking

Transverse cracks in flexible pavements are usually the result of thermal fracture of the HMA surface. Unless treated, these cracks will reflect through the overlay even when the appropriate grade of binder is selected for the HMA overlay layers. Cold milling can address those cracks that have not propagated through the existing HMA layers. Thermal cracks that have propagated through the existing HMA layers require either full depth repair or the application of specially designed reflection crack control treatments. The performance of reflection crack control treatments is highly dependent on pavement strength and environment conditions and the quality of the application. Agency experience remains the best source of information on the performance of reflection crack control treatments.

### Pre-Overlay Repair Options for Rutting

Rutting in an existing HMA surfaced pavement may occur in any asphalt bound or unbound aggregate and soil layers. The cause of rutting in an existing flexible pavement must be determined before an overlay is designed. Although recent research suggests that it may be possible to identify the source of the rutting from surface profile measurements, trenching of the existing pavement remains the only definitive method for determining the cause of the rutting (3,11). An overlay may not be appropriate if severe rutting is occurring due to instability in any of the existing pavement layers. Cold milling can be used to remove the rutted surface and any underlying asphalt bound layer that is unstable.

### Cold Milling

In recent years, cold milling has become a common pre-overlay treatment for existing HMA surfaced pavements. Current equipment can remove as much as 3 to 4 inches of HMA in a single pass. Removal of a portion of the existing cracked and hardened HMA surface by cold milling frequently improves the performance of an HMA overlay. Cold milling also increases the smoothness of the existing pavement by removing rutting and other surface distortions. Other advantages of cold milling include:

- Restoring the curb line of asphalt pavements in urban areas.
- Restoring cross-slope of asphalt pavements to improve drainage.
- Maintaining vertical clearances.
- Hot recycling of existing pavement materials.
- Maintaining pavement surface elevation.

Unless dictated by other reasons, the depth of milling should not extend below the depth of cracks in the HMA surfaced pavement.

### In-Place Recycling

In-place recycling should be considered as an alternative to reconstruction for those cases where an HMA overlay is not feasible due to the extent of repair that would be required to provide uniform support conditions. Recent equipment advances provide the capability to recycle pavements in-place to a depth of 8 to 12 inches. Asphalt emulsions or foamed asphalt can be used to produce an HMA base and various cementitious stabilizers can be used to produce a semi-rigid base. Both of these options can be considered directly in the overlay analysis.

#### **3.6.4.4 Performance Criteria**

Performance criteria are definitions of the maximum amounts of individual distress or smoothness acceptable to the highway agency at a given reliability level. Performance indicators used for HMA rehabilitation of existing HMA surfaced pavements are listed below.

- Rutting
- Alligator cracking
- Longitudinal cracking
- Transverse cracking
- Smoothness

Performance criteria are a user input and depend on local agency design standards as described in section 3.6.3 of this chapter.

#### **3.6.4.5 Design Reliability**

When the means for all design inputs are used, the predicted performance indicators (pavement distresses and smoothness) are at the 50 percent reliability. The performance of the pavement in terms of the key performance indicators can be also be obtained at any higher desired level of reliability as described in PART 3, Chapter 3, PART 1, Chapter 1, and Appendix BB.

#### **3.6.4.6 Characterization of Existing Pavement**

A critical factor in the design of an HMA overlay is the characterization of the existing pavement structure. This section provides specific recommendations for obtaining layer modulus values and defining initial conditions for existing flexible and semi-rigid pavements. General

recommendations for evaluating existing pavements for rehabilitation are discussed in PART 2, Chapter 5.

A three input level hierarchical system is provided for characterization of the existing pavement structure. Table 3.6.7 summarizes the recommended methods for obtaining the design inputs for the different pavement layers in existing flexible and semi-rigid pavements for each input level, as summarized below (the information in this table is a subset of the information presented in table 3.6.6 and has been summarized for convenience).

- Level 1 characterization generally uses data from nondestructive deflection testing (NDT) for estimating layer modulus and detailed condition survey data for characterizing damage in the existing pavement.
- Level 2 combines the use of correlations between modulus and easily measured material characteristics with detailed condition survey data.
- Level 3 uses typical published or recommended values for modulus and information from general pavement ratings for estimating damage.

The following sections describe the hierarchical approaches recommended for each pavement layer.

#### Subgrade and Unbound Base and Subbase

For subgrade, unbound base, and unbound subbase materials, data on the modulus of the layer and the current level of permanent deformation in each layer are needed for the overlay analysis. Poisson's ratio for all levels is estimated using the recommendations included in PART 2, Chapter 2.

#### *Elastic Properties*

**Level 1.** Backcalculated elastic moduli from NDT are recommended for a Level 1 characterization of the modulus of subgrade and unbound base and subbase layers for HMA overlay analyses. Information on backcalculation of layer modulus values is included in PART 2, Chapter 5.

Backcalculated modulus values require adjustment to obtain modulus values that are consistent with laboratory determined values. The basis for the calibration of the performance models was laboratory determined modulus values. The NDT backcalculated moduli are generally higher than those determined from laboratory testing. Adjustment factors of 0.40 for subgrade soils and 0.67 for granular bases and subbases have been used to correct NDT backcalculated moduli to those derived from laboratory repeated load resilient modulus tests. However, table 3.6.8 provides more detailed information and can be used as a guide in converting backcalculated modulus values to laboratory derived values for the in place material. Table 3.6.8 was developed using level E data (the highest quality data) from the LTPP database (12,13,14).

Table 3.6.7. Recommended methods for characterizing existing HMA surfaced pavement layers.

Layer Material	Input	Hierarchical Level		
		1	2	3
Subgrade	Modulus	NDT	Simple Test Correlations	Soil Classification
	Initial $\epsilon_p$	Trench Data	User Input	User Input
Unbound Base or Subbase	Modulus	NDT	Simple Test Correlations	Soil Classification
	Initial $\epsilon_p$	Trench Data	User Input	User Input
Chemically Stabilized Materials	Damaged Modulus	NDT	Estimated from Undamaged Modulus	Estimated from Undamaged Modulus
	Undamaged Modulus	Compressive Strength of Field Cores	Estimated from Compressive Strength of Field Cores	Estimated form Typical Compressive Strength
	Fatigue Damage	% Alligator Cracking	% Alligator Cracking	Pavement Rating
Existing Asphalt Layers	Damaged Modulus	NDT	Estimated from Undamaged Modulus	Estimated from Undamaged Modulus
	Undamaged Modulus	HMA dynamic modulus model with Project Specific Inputs	HMA dynamic modulus model with Project Specific Inputs	HMA dynamic modulus model with Agency Historical Inputs
	Fatigue Damage	% Alligator Cracking from Visual Condition Surveys	% Alligator Cracking from visual condition surveys	Pavement Rating
	Initial $\epsilon_p$	Trench Data	User Input	User Input

Note: Recommended values of Poisson's ratio for various material types are included in PART 2, Chapter 2.

Table 3.6.8. Average backcalculated to laboratory determined elastic modulus ratios (12,13,14).

Layer Type	Location	Mean $E_R/M_R$ Ratio
Unbound Granular Base and Subbase Layers	Granular base/subbase between two stabilized layers (cementitious or asphalt stabilized materials).	1.43
	Granular base/subbase under a PCC layer.	1.32
	Granular base/subbase under an HMA surface or base layer.	0.62
Embankment and Subgrade Soils	Embankment or subgrade soil below a stabilized subbase layer or stabilized soil.	0.75
	Embankment or subgrade soil below a flexible or rigid pavement without a granular base/subbase layer.	0.52
	Embankment or subgrade soil below a flexible or rigid pavement with a granular base or subbase layer.	0.35

$E_R$  = Elastic modulus backcalculated from deflection basin measurements.

$M_R$  = Elastic modulus of the in-place materials determined from laboratory repeated load resilient modulus test.

**Level 2.** Any of the correlations between modulus and easily measured material properties may be used in a Level 2 characterization. Dynamic Cone Penetrometer (DCP) testing is, however, highly recommended for a Level 2 characterization of unbound layers for HMA overlay analysis. The use of the DCP in pavement evaluation was discussed in PART 2, Chapter 5. From the DCP penetration resistance, the resilient modulus can be estimated using equations 3.6.8 and 3.6.9.

$$M_r = 2550(CBR)^{0.64} \quad (3.6.8)$$

$$CBR = \frac{292}{PR^{1.12}} \quad (3.6.9)$$

Where:

$CBR$  = California Bearing Ratio, %.

$PR$  = DCP Penetration Resistance, mm/blow.

$M_r$  = Resilient modulus for in-situ conditions, psi.

**Level 3.** Unbound layer moduli for a Level 3 characterization are obtained from tabular values based on classification. These are presented in PART 2, Chapter 2.

#### *Initial Permanent Strain*

An important input for the rehabilitation analysis is an estimate of the permanent strain accumulated in the unbound layers before the overlay. Rutting in existing layers will accumulate at a reduced rate during the overlay period due to the hardening effect of traffic prior to the overlay. For all levels, the input will be the rut depth in each pavement layer. For Level 1, the rutting in each layer should be measured by performing trench surveys at representative locations in the project. For Levels 2 and 3, the initial rutting is a user input.

Table 3.6.9 presents the average percentage of surface rutting obtained from forensic studies, engineering experience, and trench studies performed by different agencies when the supporting layers have been properly compacted. Similar data should be developed by an agency in estimating initial rut depths for Level 2 and 3. It should be noted that the percentage of surface rutting measured at the AASHO Road Test for the different pavement layers and subgrade was significantly different than the values summarized in table 3.6.9, because of the lower compaction requirements in the granular base and subbase materials (15).

Table 3.6.9. Average percentage of surface rutting for different pavement layers and subgrade.

Layer	HMA Surface Thickness		
	Less Than 4 in.	4 – 8 in.	Greater Than 8 in.
Asphalt Concrete	70	80	100
Granular Base	15	10	0
Granular Subbase	10	5	0
Subgrade	5	5	0

### Chemically Stabilized Materials

For overlay design of pavements with existing chemically stabilized materials, the modulus and the level of fatigue damage in the chemically stabilized layer are critical input parameters. Poisson's ratio for all levels is estimated using the recommendations included in PART 2, Chapter 2.

For overlay design, the modulus of chemically stabilized layers of the existing pavement must account for the damage already induced in this layer by pre-overlay loading. Additionally, further degradation of the modulus of the chemically stabilized layer with traffic is accounted for in the overlay analysis. As discussed in PART 3, Chapter 3, the modulus of the chemically stabilized layer will reduce as a function of damage from the initial intact modulus to that of a good quality crushed aggregate base. The initial intact modulus is a function of material quality and can be estimated from unconfined compressive strength data. Equation 3.6.10 presents the change in modulus as a function of damage. This is shown graphically in figure 3.6.9.

$$E_{CTB} = 50,000 + \frac{(E_{max} - 50,000)}{1 + e^{[-4+14(d_{CTB})]}} \quad (3.6.10)$$

Where:

- $E_{CTB}$  = Modulus of chemically stabilized layer, psi.
- $E_{max}$  = Intact modulus, psi.
- $d_{CTB}$  = Damage in chemically stabilized layer.

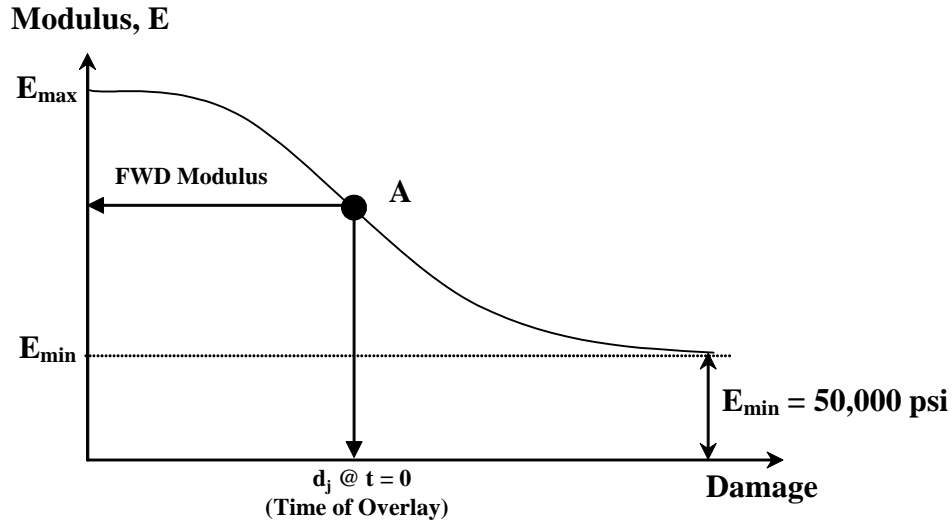


Figure 3.6.9. Modulus reduction for chemically stabilized layers with damage.

From equation 3.6.10, two of three parameters are needed to define the modulus relationship for chemically stabilized layers: intact modulus,  $E_{max}$ , current damage,  $d_{CTB}$ , or the modulus at the current damage level,  $E_{CTB}$ .

**Level 1.** For a Level 1 characterization, the modulus at the current damage level and the intact modulus are used. The modulus at the current damage level is obtained from NDT data. The intact modulus is obtained from the compressive strength of intact cores removed from undamaged areas of the pavement. The compressive strength correlations described in PART 2, Chapter 2 should be used to estimate the initial intact modulus. With  $E_{CTB}$  and  $E_{max}$  known, equation 3.6.10 can be solved to obtain the current damage level as shown in figure 3.6.9.

The backcalculated modulus is used as the modulus at the beginning of the overlay analysis. It is further reduced during the overlay period in accordance with equation 3.6.11 and the damage obtained from tensile stresses computed at the bottom of the chemically stabilized layer.

$$C_{CTB} = \frac{100(C_s)}{RC} \quad (3.6.11)$$

Where:

- $C_{CTB}$  = Percent alligator cracking in the chemically stabilized layer.
- $C_s$  = Percent alligator cracking observed at the pavement surface.
- $RC$  = Percent of cracks reflected computed from equation 3.6.2.

**Level 2.** For a Level 2 characterization, estimates of the intact modulus,  $E_{max}$ , and the current damage,  $d_{CTB}$ , are used. The intact modulus is estimated as described above for Level 1 using the compressive strength of intact cores removed from undamaged areas of the pavement. The current damage in the chemically stabilized layer is estimated from the alligator cracking data obtained from a detailed pavement condition survey as described below.

1. Knowing the age of the pavement and the thickness of the HMA surface, the reflection cracking model, equation 3.6.2, is used to estimate the percent of cracks in the chemically stabilized layer that have reflected through the HMA surface,  $RC$ .
2. The cracking in the chemically stabilized layer is then obtained from the measured alligator cracking at the surface of the HMA layer using equation 3.6.11.
3. The damage is then obtained from equation 3.6.12, which is the calibrated transfer function for alligator cracking for chemically stabilized materials described in PART 3, Chapter 3. This is shown schematically in figure 3.6.10.

$$C_{CTB} = \frac{100}{1 + e^{a+b(d_{CTB})}} \quad (3.6.12)$$

Where:

- $C_{CTB}$  = Percent alligator cracking in the chemically stabilized layer.  
 $d_{CTB}$  = Damage computed in chemically stabilized layer.  
 $a, b$  = Field calibrated fitting parameters.

With the intact modulus and current damage level known, the modulus at the beginning of the overlay analysis can be obtained from equation 3.6.10. It is further reduced during the overlay period in accordance with equation 3.6.10 and the damage obtained from tensile stresses computed at the bottom of the chemically stabilized layer.

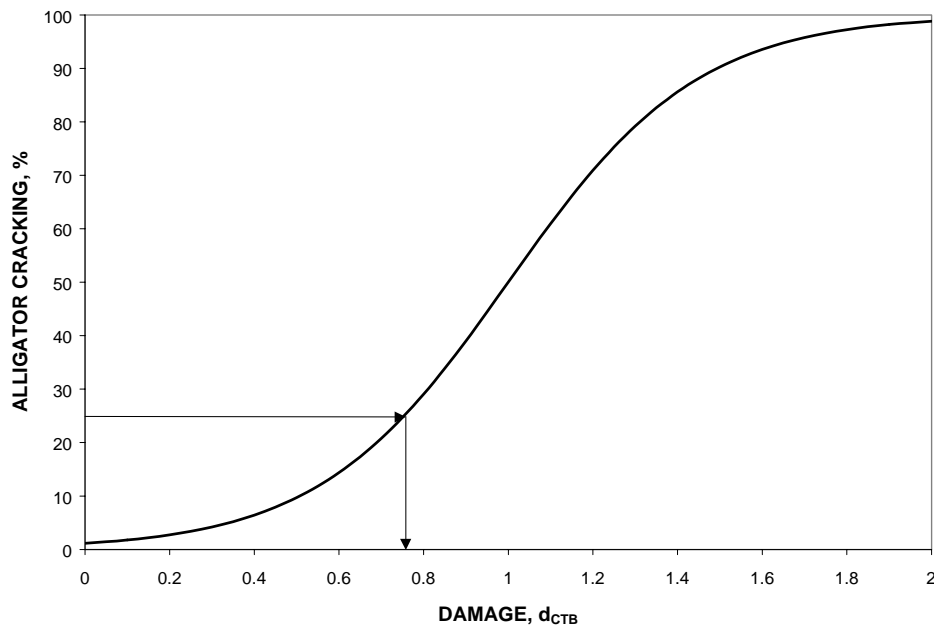


Figure 3.6.10. Alligator cracking transfer function for chemically stabilized materials.

**Level 3.** Estimates of the intact modulus,  $E_{max}$ , and the current damage,  $d_{CTB}$ , is also used in the Level 3 characterization. The intact modulus is obtained from correlation to compressive strength using typical compressive strengths based on material description. This is the same method used in a Level 3 characterization for new design, and is described in PART 2, Chapter

2. The current damage is obtained from a general condition rating of the pavement given in table 3.6.10. With the intact modulus and current damage level known, the modulus at the beginning of the overlay analysis can be obtained from equation 3.6.10. It is further reduced during the overlay period in accordance with equation 3.6.10 and the damage obtained from tensile stresses computed at the bottom of the chemically stabilized layer.

Table 3.6.10. Damage for chemically stabilized layers based on pavement condition rating.

Category	Damage
Excellent	0.00 – 0.20
Good	0.20 – 0.40
Fair	0.40 – 0.80
Poor	0.80 – 1.20
Very Poor	> 1.20

### Asphalt Concrete

Existing asphalt bound layers will be treated as a single layer in the overlay design. Thus, the designer must select material properties for existing HMA layers that are representative of the mixtures that will remain in-place after the application of pre-overlay treatments, such as milling or full depth repairs. Three input parameters are needed for the overlay analysis: modulus, current level of fatigue damage, and current permanent strain. Like chemically stabilized materials, the modulus and level of fatigue damage are related. Poisson's ratio for all levels is estimated using the recommendations included in PART 2, Chapter 2.

### *Modulus and Fatigue Damage*

As discussed in detail in PART 2, Chapter 2, the modulus of all asphalt bound layers is characterized by a master curve that accounts for changes in the modulus with temperature, loading rate, and age. Equation 3.6.13 presents the form of the master curve.

$$\log(E^*) = \delta + \frac{\alpha}{1 + e^{\beta + \gamma \log(t_r)}} \quad (3.6.13)$$

Where:

- $E^*$  = Asphalt concrete modulus, psi.
- $\delta$  = Regression parameter ( $10^\delta$  = minimum modulus).
- $\alpha$  = Range.
- $t_r$  = Reduced time (function of rate of loading, temperature, age, and depth), sec.
- $\beta$  and  $\gamma$  = Regression parameters.

For overlay analysis, a master curve adjusted for pre-overlay damage will be used. The damage adjusted master curve is obtained by applying equation 3.6.14 to the  $E^*$  computed from the original master curve. Figure 3.6.11 shows the effect of damage on the master curve for a typical HMA mixture.

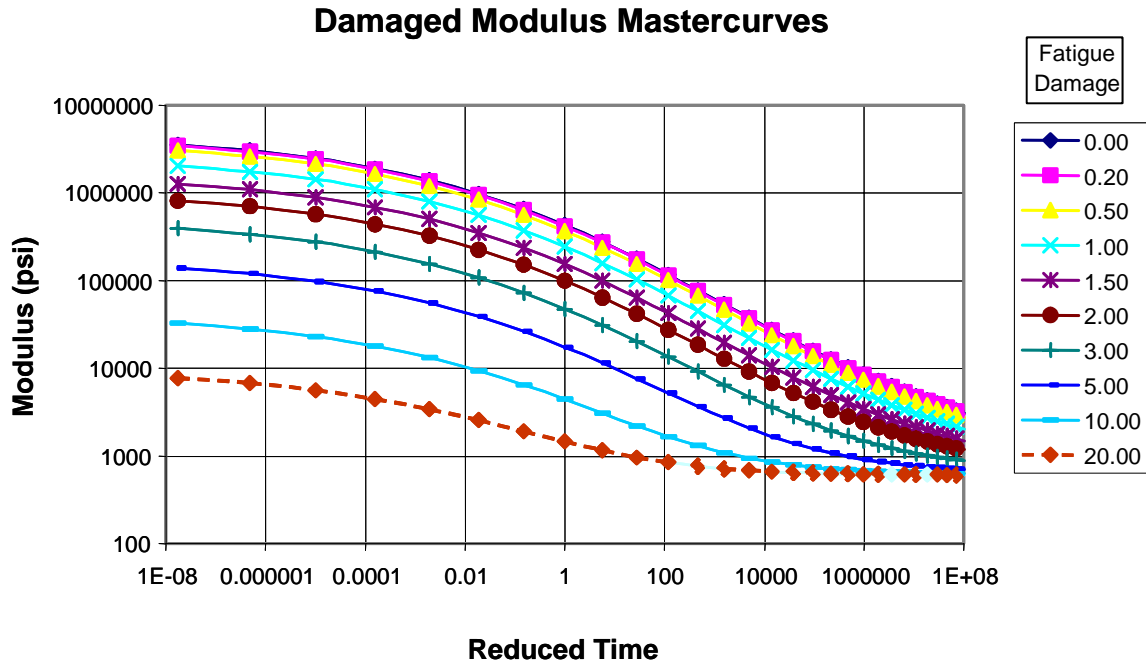


Figure 3.6.11. Damaged HMA modulus master curve.

$$E^*_{dam} = 10^\delta + \frac{E^* - 10^\delta}{1 + e^{-0.3 + 5 \times \log(d_{AC})}} \quad (3.6.14)$$

Where:

- $E^*_{dam}$  = Damaged modulus, psi.
- $\delta$  = Regression parameter (from equation 3.6.13).
- $E^*$  = Undamaged modulus for a specific reduced time (from equation 3.6.13).
- $d_{AC}$  = Fatigue damage in the HMA layer.

As described below, three hierarchical levels have been developed for determining the damage in the HMA layer.

**Level 1.** The Level 1 characterization requires field cores to obtain the undamaged modulus master curve and backcalculated modulus from NDT analysis to obtain the initial damage level and damaged modulus master curve. From standard forensic tests on the field cores, the parameters needed for the Dynamic Modulus predictive equation can be measured and are listed below:

- Air void content
- Asphalt content
- Gradation
- A and VTS parameters for the ASTM viscosity temperature susceptibility relationship as determined from recovered binder

These volumetric and recovered binder parameters are then used in the Dynamic Modulus predictive equation to establish the undamaged master curve. PART 2, Chapter 2 presents a detailed discussion on the application of the Dynamic Modulus predictive equation. An optional, less reliable method for determining the undamaged modulus master curve is to use historical agency data in the Dynamic Modulus predictive equation.

The damaged modulus for the reduced time representative of the temperature and loading conditions for the NDT equipment is obtained directly from the NDT analysis. Knowing the damaged and undamaged modulus values, equation 3.6.14 is solved for the fatigue damage,  $d_{AC}$ . The process is shown schematically in figure 3.6.12.

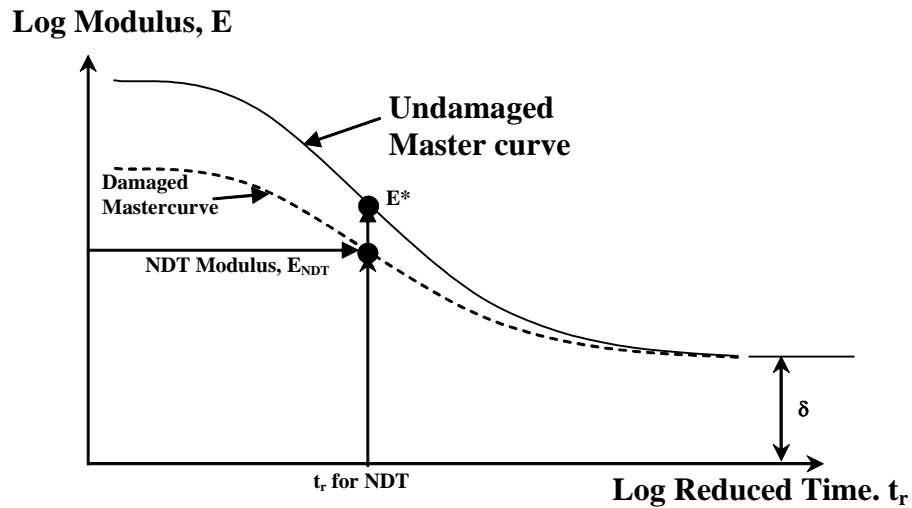


Figure 3.6.12 HMA layer damage computation, Level 1.

An important consideration in the application of the level 1 characterization is the computation of the reduced time representative of the NDT loading conditions. This is accomplished using equation 3.6.15, which is the reduced time relationship described in detail in PART 2, Chapter 2.

$$\log(t_r) = \log(t) - 1.255882(\log(\eta) - \log(\eta_{Tr})) \quad (3.6.15)$$

Where:

- $t_r$  = Reduced time for NDT loading, seconds.
- $t$  = NDT loading time, seconds.
- $\eta$  = Binder viscosity at the NDT test temperature.
- $\eta_{Tr}$  = Binder viscosity at the master curve reference temperature (70 °F).

The binder viscosity at the NDT test temperature and the master curve reference temperature can be determined from the ASTM viscosity temperature susceptibility relationship given in equation 3.6.16.

$$\log \log \eta = A + VTS \log T_R \quad (3.6.16)$$

Where:

- $\eta$  = Binder viscosity.
- $T_R$  = Temperature in ° Rankine.
- $A$  = Viscosity temperature susceptibility intercept.
- $VTS$  = Viscosity temperature susceptibility slope.

**Level 2.** Level 2 characterization for an existing asphalt layer uses field cores to obtain the undamaged modulus as described above for level 1. The initial damage and the damaged modulus master curve are then developed from an estimate of fatigue damage obtained from a detailed pavement condition survey as described below.

The amount of alligator cracking measured at the pavement surface is used to solve for the HMA damage,  $d_{AC}$  in equation 3.6.17, which is the calibrated transfer function for alligator cracking for HMA described in PART 3, Chapter 3.

$$C_{AC} = \frac{100}{1 + e^{c+d(d_{AC})}} \quad (3.6.17)$$

Where:

- $C_{AC}$  = Percent alligator cracking in the chemically stabilized layer.
- $D_{AC}$  = Damage computed in chemically stabilized layer.
- $c, d$  = Field calibrated fitting parameters.

This is shown schematically in figure 3.6.13. With the undamaged modulus master curve and current damage known, the damaged modulus master curve is obtained from equation 3.6.14.

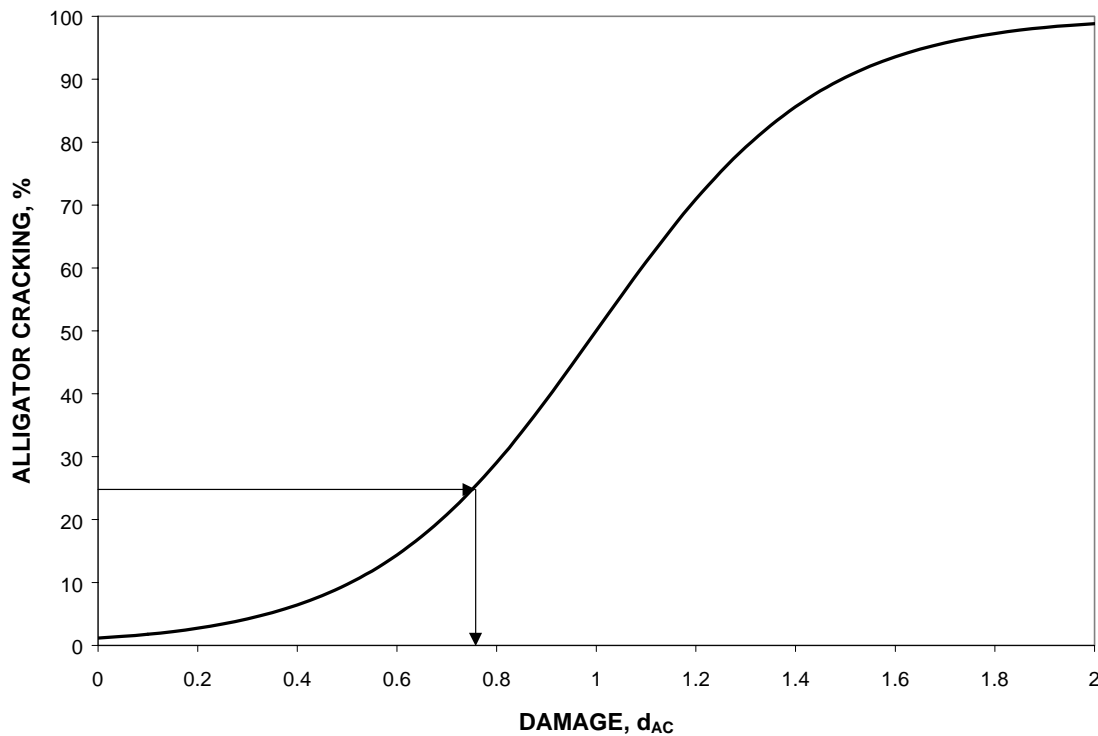


Figure 3.6.13. Alligator cracking transfer function for HMA.

**Level 3.** No testing is required for the level 3 characterization of existing asphalt bound layers. The undamaged modulus is obtained from the Dynamic Modulus predictive equation using typical volumetric and binder properties for the mixture type in the existing pavement. The current damage is obtained from a general condition rating of the pavement given in table 3.6.11. With the undamaged modulus master curve and current damage known, the damaged modulus master curve is obtained from equation 3.6.14.

Table 3.6.11. Damage for HMA based on pavement condition rating.

Category	Damage
Excellent	0.00 – 0.20
Good	0.20 – 0.40
Fair	0.40 – 0.80
Poor	0.80 – 1.20
Very Poor	> 1.20

#### *Initial Permanent Strain*

An important input for the rehabilitation analysis is an estimate of the permanent strain accumulated in the asphalt bound layers before overlay placement. Rutting in existing layers will accumulate at a reduced rate during the overlay period due to the hardening effect of traffic prior to the overlay. For all levels, the input will be the rut depth in the layer. For level 1, the rutting should be measured by performing trench surveys at representative locations in the project. For levels 2 and 3, the initial rutting is a user input. Table 3.6.9 listed the average percentage of surface rutting in different layers obtained from trench studies performed by various agencies and based on engineering experience. The designer should use similar data developed by the agency, however, barring any trench data, table 3.6.9 can be used in estimating initial rut depths for input levels 2 and 3.

#### **3.6.4.7 Trial Section**

The trial overlay section should be selected considering the condition of the existing pavement, the expected future traffic, and the pre-overlay treatments that will be applied. The overlay may consist of up to four layers, including three asphalt layers and one layer of unbound granular or chemically stabilized material. Figure 3.6.8 shows the types of overlay structures that are applicable to HMA overlays of existing HMA surfaced pavements.

The initial thickness of the various overlay layers should be selected based on experience. Since the guide provides the option to analyze the thickness for one of three layers of the overlay, the designer can quickly optimize the thickness of the overlay layers. Methods for determining appropriate material properties for the overlay materials are described in detail in PART 2, Chapter 2. For most materials, the designer can choose from three input levels that include: laboratory testing, correlations with easily measured material characteristics, and default values.

### 3.6.4.8 Distress Prediction

Several distresses are considered in the structural HMA overlay design and analysis. Table 3.6.12 summarizes the distresses applicable to overlays of flexible and semi-rigid pavements. The models used for the prediction of structural distresses (i.e., excluding smoothness prediction) in the overlaid pavement are basically the same as those described in PART 3, Chapter 3 with some modifications to the rates of distress accumulation in the existing layers as noted in the following paragraphs. The designer may use one or more of these distresses as performance criteria.

Table 3.6.12 Summary of distresses and other factors for HMA overlay of flexible and semi-rigid pavements.

Distress	Symbol (in figure 3.6.14)	HMA Surfaced Pavement Type	
		Flexible	Semi-Rigid
Longitudinal Cracking	D <sub>1</sub>	Yes	Yes
Alligator Cracking	D <sub>2</sub>	Yes	Yes
Thermal Cracking	D <sub>3</sub>	Yes	Yes
Rutting in HMA Layers	D <sub>4</sub>	Yes	Yes
Rutting in Unbound Layers	D <sub>5</sub>	Yes	Yes
CSM <sup>1</sup> Modulus Reduction	D <sub>6</sub>	When included in overlay section	Yes
CSM Fatigue Cracking	D <sub>7</sub>	When included in overlay section	No
Reflection Cracking	D <sub>9</sub>	Yes	Yes

<sup>1</sup> CSM = Chemically Stabilized Material.

For overlaid pavements, the distress analysis includes consideration of distresses originating in the overlay structure and the continuation of damage in the existing pavement. Tables 3.6.13 and 3.6.14 summarize the distresses computed in the overlay and the existing pavement for various overlay and existing pavement types. These are discussed in greater detail in the next subsections of this chapter.

The distresses can also be combined to predict the IRI for the rehabilitated pavement using predictive equation 3.6.6. The IRI provides a functional performance criterion that can be used in assessing the acceptability of a given rehabilitation design. The applicability of equation 3.6.6 in assessing the acceptability of a design is also discussed in the following subsections for different rehabilitation designs.

#### Case 1 Conventional HMA Overlay

The conventional HMA overlay shown as Case 1 in figure 3.6.8 is a candidate rehabilitation strategy for existing flexible and semi-rigid pavements. It is also the type of pavement that results from in-place recycling using asphalt emulsion or foamed asphalt. Figure 3.6.14 presents typical flexible, semi-rigid, and in-place recycled structures that may result from the use of a

Table 3.6.13 Summary of distress computation locations for the overlay.

<b>Distress</b>	<b>Case 1</b>	<b>Case 2</b>	<b>Case 3</b>	<b>Case 4</b>
Longitudinal Cracking	Top Layer	Top Layer	Top Layer	Top Layer
Alligator Cracking	Bottom HMA Layer	Bottom HMA Layer	1 <sup>st</sup> HMA Layer Above Granular Layer; Bottom HMA Layer	Bottom HMA Layer
Thermal Cracking	Top Layer	Top Layer	Top Layer	Top Layer
Rutting in HMA Layers	All HMA Layers	All HMA Layers	All HMA Layers	All HMA Layers
Rutting in Unbound Layers	NA	Granular Layer	Granular Layer	NA
CSM Modulus Reduction	NA	NA	NA	CTB Layer
CSM Fatigue Cracking	NA	NA	NA	CTB Layer
Reflection Cracking	Top Layer	Top Layer	Top Layer	Top Layer

<sup>1</sup> NA = Not applicable.

Table 3.6.14 Summary of distresses computation locations for existing pavement in HMA overlay of flexible and semi-rigid pavements.

<b>Distress</b>	<b>Flexible</b>	<b>Semi Rigid</b>
Alligator Cracking	Existing HMA Layer	Existing HMA Layer
Rutting in HMA Layers	Existing HMA Layer	Existing HMA Layer
Rutting in Unbound Layers	All Unbound Layers	All Unbound Layers
CSM Modulus Reduction	N/A	CSM Layer

NEW SURFACE AC	D <sub>1</sub> D <sub>3</sub> D <sub>4</sub> D <sub>9</sub>
NEW INTERMEDIATE AC	D <sub>4</sub>
NEW LEVEL AC	D <sub>2</sub> D <sub>4</sub>
EXISTING AC	D <sub>2</sub> D <sub>4</sub>
EXISTING GRANULAR SUBBASE	D <sub>5</sub>
SUBGRADE	D <sub>5</sub>

**EXISTING FLEXIBLE**

NEW SURFACE AC	D <sub>1</sub> D <sub>3</sub> D <sub>4</sub> D <sub>9</sub>
NEW INTERMEDIATE AC	D <sub>4</sub>
NEW LEVEL AC	D <sub>2</sub> D <sub>4</sub>
EXISTING AC SURFACE	D <sub>2</sub> D <sub>4</sub>
EXISTING CHEMICALLY TREATED BASE	D <sub>6</sub> D <sub>7</sub>
SUBGRADE	D <sub>5</sub>

**EXISTING SEMI-RIGID**

NEW SURFACE AC	D <sub>1</sub> D <sub>3</sub> D <sub>4</sub>
NEW INTERMEDIATE AC	D <sub>4</sub>
IN-PLACE RECYCLED WITH AC	D <sub>2</sub> D <sub>4</sub>
EXISTING GRANULAR SUBBASE	D <sub>5</sub>
SUBGRADE	D <sub>5</sub>

**IN-PLACE RECYCLED**

Figure 3.6.14. Example Case 1 overlay pavement structures.

conventional HMA overlay. The overlay analysis allows up to three different asphalt materials in the overlay structure. This provides the designer the capability to directly assess the effects of different HMA mixtures such as polymer modified surface courses to resist rutting or rich fine graded leveling courses to resist cracking.

As shown in figure 3.6.14, distresses in the overlay section are computed at the same locations for all Case 1 overlay structures. Longitudinal, thermal, and reflection cracking are computed for the top layer of the overlay. The longitudinal and thermal cracking are based on the incremental damage calculated in this layer using the models described in PART 3, Chapter 3. Reflection cracking is computed by applying the empirical reflection cracking model discussed in section 3.6.3.3 to the cracking at the surface of the existing pavement. Fatigue damage is evaluated in the bottom HMA layer of the overlay using the bottom-up fatigue cracking model described in PART 3, Chapter 3. Rutting in the overlay structure is evaluated by considering permanent deformations in all asphalt and unbound layers using the rutting model described in PART 3, Chapter 3.

The continuation of damage in the existing pavement structure depends on the composition of the existing pavement after accounting for the effect of pre-overlay treatments such as milling or in-place recycling. For existing flexible and semi-rigid pavements where asphalt bound layers remain in-place, fatigue damage will continue to develop in those layers in the existing structure.

The HMA fatigue damage model described in PART 3, Chapter 3 is based on the undamaged modulus of the HMA. Thus, the strains for the analysis of fatigue in the existing HMA are based on the undamaged modulus determined using the methods described previously. All other stresses and strains in the overlay and the existing pavement are computed using the damaged modulus as determined from pavement evaluation data using the methods described previously. As a result, the evaluation of Case 1 overlays of pavements with existing HMA layers requires the structure to be analyzed twice for each loading and environmental condition. In the first analysis stresses and strains are computed at all critical locations using the damaged HMA modulus. For the second analysis, strains in the existing HMA layer are calculated using the undamaged modulus. These strains are used to predict the continuation of fatigue damage in the existing HMA layer.

Fatigue damage will also continue to develop in the chemically stabilized layer of existing semi-rigid pavements using the model described in PART 3, Chapter 3. This damage will result in further reduction of the modulus of the chemically stabilized layer, as described previously.

Permanent deformations in all asphalt bound and unbound layers of the existing pavement are included in the predicted rutting for the rehabilitated pavement. As described earlier, rutting in the existing pavement layers will accumulate at a lower rate than new materials due to the hardening effect of past traffic.

Equation 3.6.6 is used when assessing the functional performance of HMA overlays on existing flexible pavements, semi-rigid pavements, and in-place recycled pavements. However, most all of the LTPP test sections that were used to develop equation 3.6.6 consisted of HMA overlays of

conventional, deep-strength, and full-depth flexible pavements. Agencies should confirm the applicability of equation 3.6.6 to HMA overlays of semi-rigid and in-place recycled pavements.

### Case 2 and 3 HMA Overlay With Unbound Granular Layer

An unbound granular layer may be included with an HMA overlay to control reflection cracking in existing semi-rigid pavements and severely thermal cracked flexible pavements. In this case, the unbound layer would generally be placed directly on top of the existing pavement as shown in figure 3.6.15.

NEW SURFACE AC	D <sub>1</sub> D <sub>3</sub> D <sub>4</sub>	NEW SURFACE AC	D <sub>1</sub> D <sub>3</sub> D <sub>4</sub>
NEW INTERMEDIATE AC	D <sub>4</sub>	NEW INTERMEDIATE AC	D <sub>4</sub>
NEW BASE AC	D <sub>2</sub> D <sub>4</sub>	NEW BASE AC	D <sub>2</sub> D <sub>4</sub>
NEW GRANULAR BASE	D <sub>5</sub>	NEW GRANULAR BASE	D <sub>5</sub>
EXISTING AC	D <sub>2</sub> D <sub>4</sub>	EXISTING AC SURFACE	D <sub>2</sub> D <sub>4</sub>
EXISTING GRANULAR SUBBASE	D <sub>5</sub>	EXISTING CHEMICALLY TREATED BASE	D <sub>6</sub>
SUBGRADE	D <sub>5</sub>	SUBGRADE	D <sub>5</sub>
<b>EXISTING FLEXIBLE</b>		<b>EXISTING SEMI-RIGID</b>	

Figure 3.6.15. Example Case 2 overlay pavement structures.

An unbound layer in the overlay may also be considered when strengthening an existing flexible pavement to accommodate substantially heavier traffic. The resulting sandwich pavement structure is an efficient use of materials. The HMA layers carry tension and provide confinement for the unbound granular layer. This confinement increases the modulus of the granular layer above that normally associated with an unbound granular layer on a subbase or subgrade. Depending on the thickness and condition of the existing asphalt bound layers, the unbound layer may be placed directly on the existing HMA surface or a layer of new HMA may be placed prior to placing the unbound layer, as shown in figure 3.6.16. An unbound layer may also be included to improve drainage in a flexible pavement after removing existing HMA layers. Figure 3.6.17 shows an example of the structure resulting from this type of partial reconstruction.

Figures 3.6.15, 3.6.16, and 3.6.17 show the locations where distresses will be predicted for both the overlay and existing pavement structures. It is assumed that the unbound granular layer will stop the reflection of cracks from the existing structure. Thus, reflection cracking is not considered as a distress in Case 2 and 3 overlays.

NEW SURFACE AC	$D_1 D_3 D_4$
NEW INTERMEDIATE AC	$D_4$
NEW GRANULAR BASE	$D_5$
NEW BASE AC	$D_2 D_4$
EXISTING AC	$D_2 D_4$
EXISTING GRANULAR SUBBASE	$D_5$
SUBGRADE	$D_5$
<b>EXISTING FLEXIBLE</b>	

Figure 3.6.16. Example Case 3 overlay pavement structure.

NEW SURFACE AC	$D_1 D_3 D_4$
NEW INTERMEDIATE AC	$D_4$
NEW BASE AC	$D_2 D_4$
NEW GRANULAR BASE	$D_5$
EXISTING GRANULAR SUBBASE	$D_5$
SUBGRADE	$D_5$
<b>EXISTING FLEXIBLE</b>	

Figure 3.6.17. Example Case 2 partial reconstruction pavement structure.

Longitudinal and thermal cracking in the top layer of the overlay are evaluated for all Case 2 and 3 overlays based on the incremental damage calculated in this layer using the models described in PART 3, Chapter 3. Bottom-up fatigue damage in the overlay structure of Case 2 and 3 overlays is evaluated in the HMA layer immediately above the new unbound granular layer using the models described in PART 3, Chapter 3.

Bottom-up fatigue damage is also evaluated in layers below the new unbound granular layer where tensile strains are expected to develop. Although fatigue cracks from these layers will not propagate to the surface due to the presence of the unbound granular layer, fatigue failure of these layers will result in loss of support or stiffness for the overlay structure and must be avoided.

For Case 2 overlays of existing flexible pavements, fatigue damage is evaluated in the HMA layer of the existing pavement. For Case 2 overlays of existing semi-rigid pavements, fatigue damage is evaluated in the existing chemically stabilized layer and the existing HMA surface. The modulus of the existing chemically stabilized layer is reduced as a function of damage as described previously.

For Case 3 overlays, fatigue damage is evaluated in the existing HMA layer and the bottom HMA layer of the new pavement. The HMA fatigue damage model described in PART 3, Chapter 3 is based on the undamaged modulus of the HMA layers. Thus, strains for the analysis of fatigue in the existing HMA are based on the undamaged modulus determined using the methods described previously. All other stresses and strains in the overlay and the existing pavement are computed using the damaged modulus as determined from pavement evaluation data using the methods described previously. As a result, the evaluation of Case 2 and 3 overlays of pavements with existing HMA layers requires the structure to be analyzed twice for each loading and environmental condition. In the first analysis stresses and strains are computed at all critical locations using the damaged HMA modulus. For the second analysis, strains in the existing HMA layers are calculated using the undamaged modulus. These strains are used to predict the continuation of fatigue damage in the existing HMA layers.

For all Case 2 and 3 overlays, permanent deformations in each asphalt bound and unbound layers of both the overlay and the existing pavement are included in the predicted rutting for the rehabilitated pavement. Rutting is predicted using the models described in PART 3, Chapter 3. As discussed earlier, rutting in the existing pavement layers will accumulate at a lower rate than new materials due to the hardening effect of past traffic.

Functional performance of HMA overlays with a granular layer is assessed with equation 3.6.6. However, none of the LTPP test sections that were used to develop equation 3.6.6 fell within this rehabilitation strategy. Agencies should confirm the applicability of equation 3.6.6 to the rehabilitation strategy where a new granular layer is placed with the HMA overlay.

When the existing flexible pavement is partially reconstructed (figure 3.6.17), the functional performance of this rehabilitation strategy is assessed using the IRI regression prediction equation for new conventional flexible pavements, provided in PART 3, Chapter 3.

#### Case 4 HMA Overlay With Chemically Stabilized Layer

Case 4 overlays include a chemically stabilized layer at the bottom of the overlay structure. The most likely scenario for this type of overlay is in-place recycling of an existing pavement using cement or a combination of lime and flyash as a stabilizing agent. Figure 3.6.18 shows an example of a pavement structure resulting from this form of in-place recycling and the types of

NEW SURFACE AC	$D_1 D_3 D_4 D_7$
NEW INTERMEDIATE AC	$D_4$
NEW BASE AC	$D_2 D_4$
IN-PLACE RECYCLED WITH CEMENT OR LIME FLYASH	$D_6$
EXISTING GRANULAR SUBBASE	$D_5$
SUBGRADE	$D_5$

### IN-PLACE RECYCLED

Figure 3.6.18. Example Case 4 overlay for in-place recycling.

distresses that can be predicted. This case is much like the design of a new pavement, except the evaluation of rutting in the rehabilitated pavement accounts for the hardening effect of past traffic.

Longitudinal and thermal cracking are evaluated in the top layer of the overlay. The longitudinal and thermal cracking are based on the incremental damage calculated in this layer using the models described in PART 3, Chapter 3.

Fatigue damage is evaluated in the lowest asphalt bound layer of the overlay and the chemically stabilized layer using the models described in PART 3, Chapter 3. The damage computed in the chemically stabilized layer will also result in further reduction of the modulus of the chemically stabilized layer as described previously.

Permanent deformations in all asphalt bound and unbound layers of the overlay and existing pavement are included in the predicted rutting for the rehabilitated pavement. As described earlier, rutting in the existing pavement layers will accumulate at a lower rate than new materials due to the hardening effect of past traffic.

Functional performance of HMA overlays with an in-place chemically stabilized layer as part of the rehabilitation is assessed using the IRI regression prediction equation for new semi-rigid pavements, provided in PART 3, Chapter 3. However, none of the LTPP test sections that were used to develop this prediction equation fell within this rehabilitation strategy. Agencies should confirm the applicability of this equation to HMA overlays with an in-place chemically stabilized layers.

#### 3.6.4.9 Trial Design Performance Evaluation and Design Modifications

Performance evaluation is basically the comparison of the predicted distress (over the rehabilitation design life at a predetermined level of reliability) and the user input performance

criteria, which are basically the critical distresses values that would trigger rehabilitation. Design performance criteria are required to help ensure that the HMA overlays will perform adequately over the design period. These values are chosen by the designer and should not be exceeded at the specified level of design reliability at any given time over the rehabilitation design life. If these values are exceeded, the designer should modify the HMA overlay structure and associated properties (e.g., layering, layer thicknesses, materials properties) iteratively until satisfactory results are obtained.

Guidance on how to alter the trial design to meet performance criteria are provided in PART 3, Chapter 3 for new and reconstructed pavements on an individual distress basis. These guidelines are equally applicable for HMA overlaid sections. The only caveat being that the designer's options to modify the trial design are restricted to the overlay structure alone. However, in order to properly modify the trial design in the event it does not meet the preset performance criteria, it is essential to understand the impact of the various overlay structural features on the predicted distress quantities. Some examples of the sensitivity of the predicted distresses to various design features in pavements constructed with conventional HMA overlays are presented in the following paragraphs.

Figures 3.6.19 through 3.6.22 present the sensitivity of the predicted alligator cracking, total rutting, transverse cracking (thermal), and smoothness to HMA overlay thickness for a conventional HMA overlay (Case 1). It can be noted from the figures that, as expected, the overlay thickness has a major impact on the predicted bottom-up (alligator cracking) and total rutting. Transverse cracking and smoothness are also lower at higher overlay thickness levels.

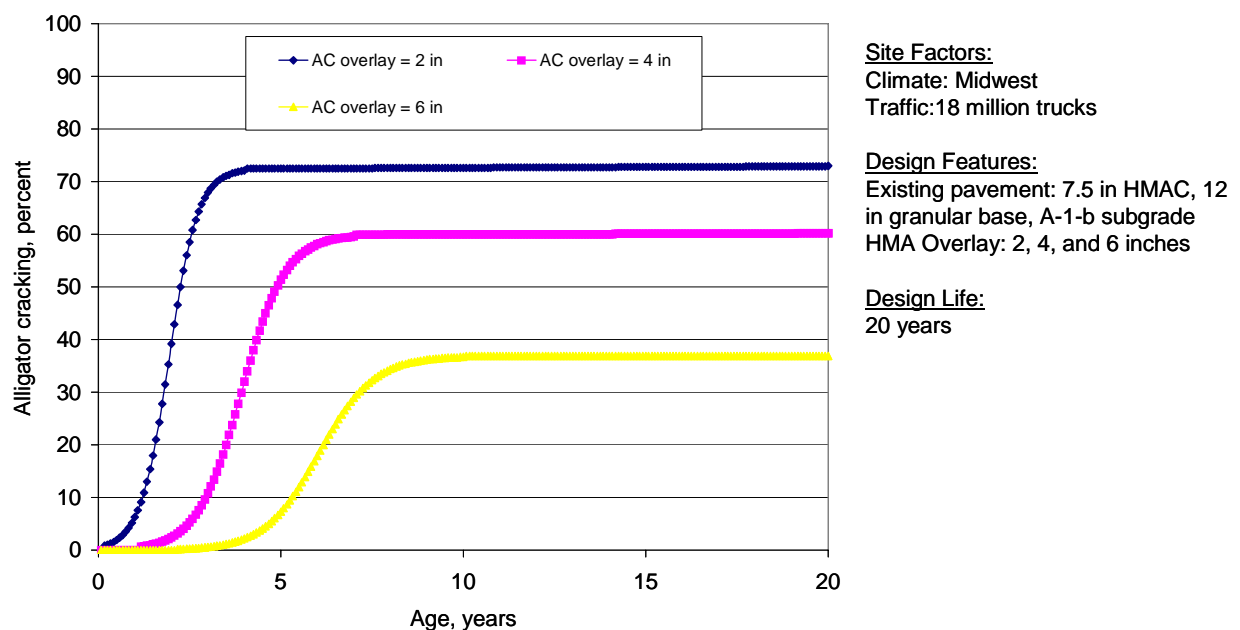


Figure 3.6.19. Conventional HMA Overlay Example – Effect of HMA overlay thickness on bottom-up (alligator) cracking.

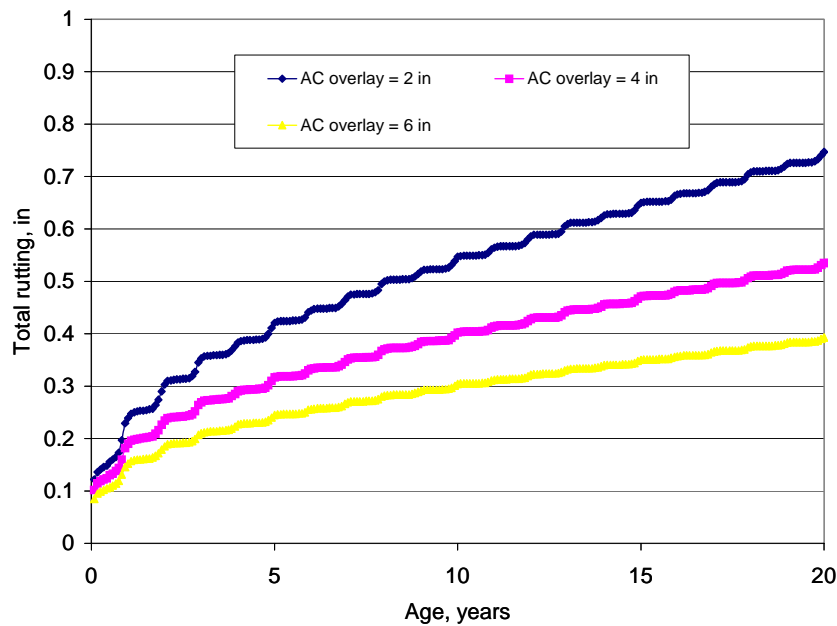


Figure 3.6.20. Conventional HMA Overlay Example – Effect of HMA overlay thickness on total rutting.

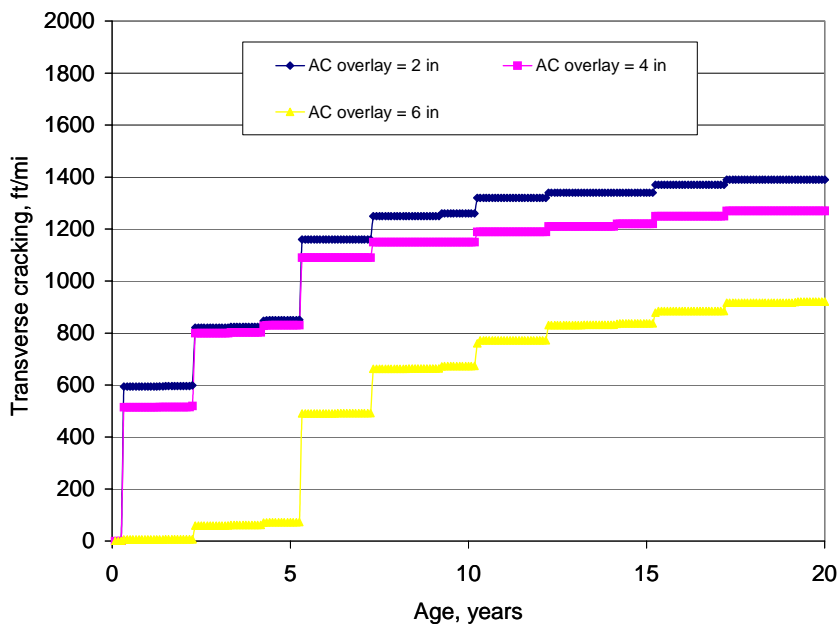


Figure 3.6.21. Conventional HMA Overlay Example – Effect of HMA overlay thickness on transverse (thermal) cracking.

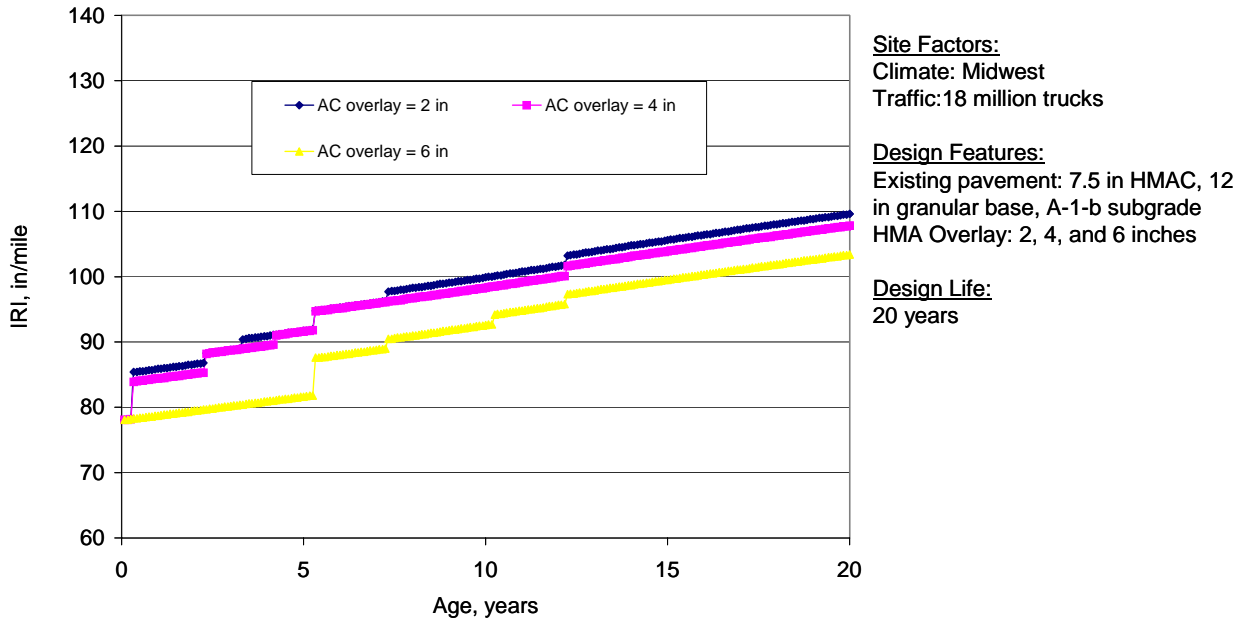


Figure 3.6.22. Conventional HMA Overlay Example – Effect of HMA overlay thickness on IRI.

Figures 3.6.23 through 3.6.25 present the effect of existing pavement condition (just prior to overlay) on overlay fatigue cracking, rutting, and smoothness performance. Note that the pavement condition prior to overlay has a large impact on fatigue cracking. This is once again as expected since a poorer underlying pavement condition rating translates to a lower modulus in existing the HMA layers and higher initial fatigue damage and therefore higher amount of bottom-up cracking. The bottom-up cracking predicted is due to continued fatigue in the existing HMA layers and reflected alligator cracking.

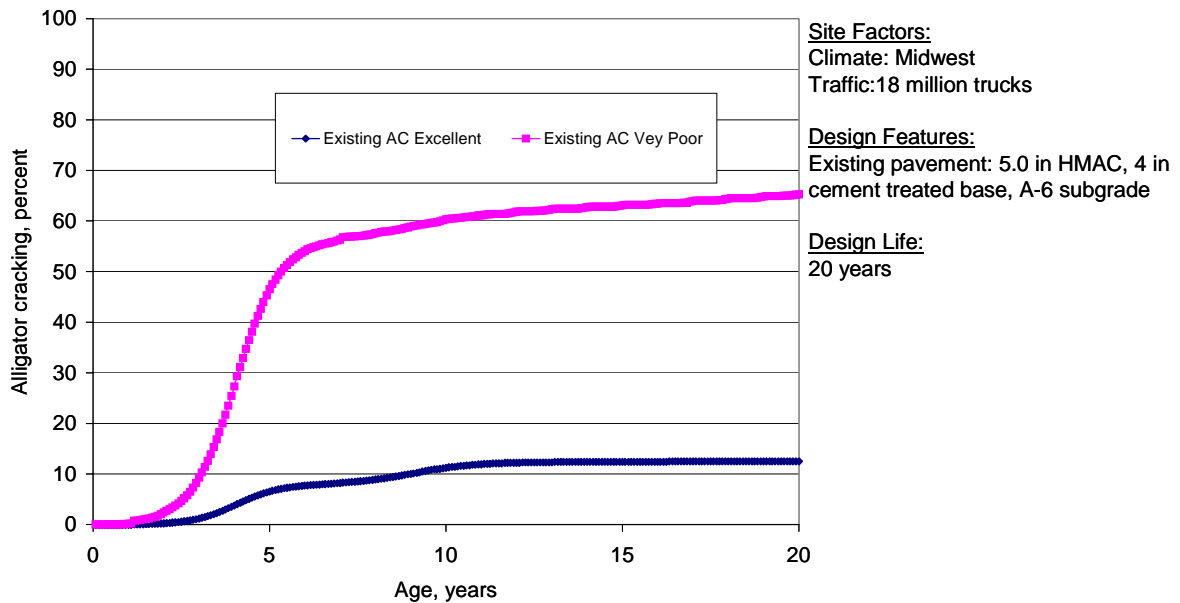


Figure 3.6.23. Conventional HMA Overlay Example – Effect of existing pavement condition on bottom-up (alligator) cracking.

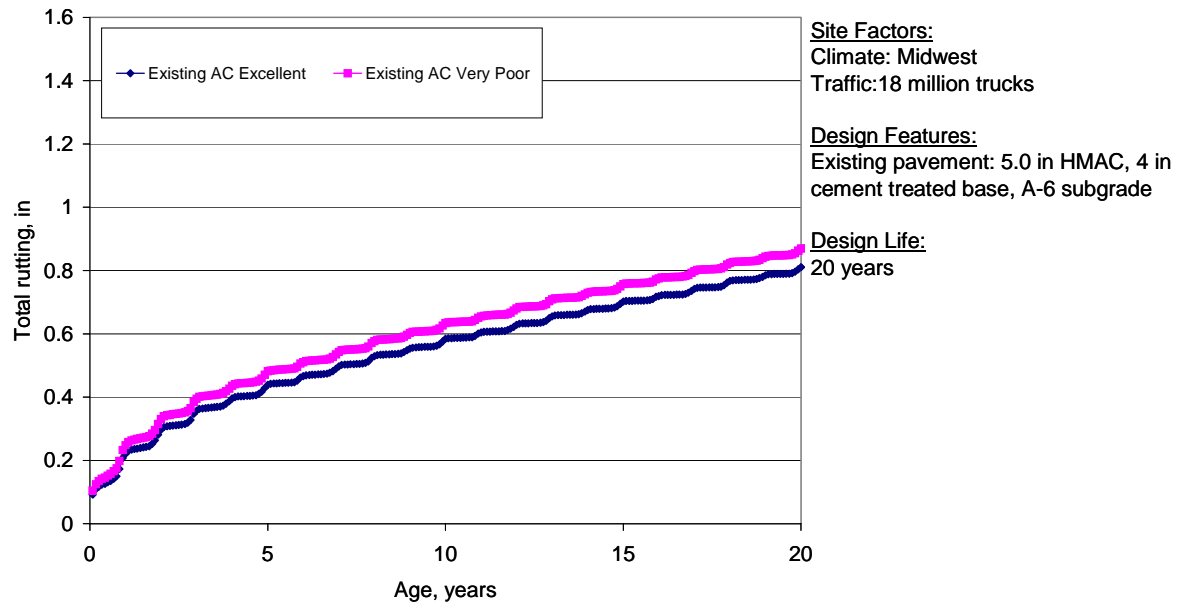


Figure 3.6.24. Conventional HMA Overlay Example – Effect of existing pavement condition on total rutting.

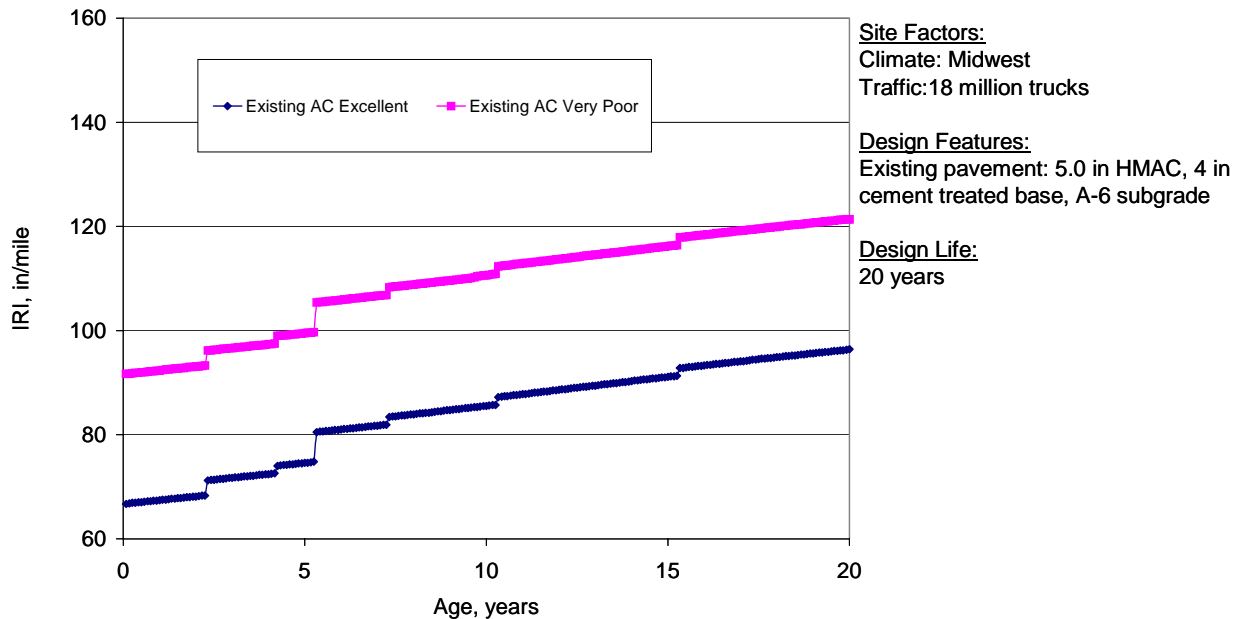


Figure 3.6.25. Conventional HMA Overlay Example – Effect of existing pavement condition on IRI.

### **3.6.5 HMA OVERLAY OF FRACTURED SLAB**

#### **3.6.5.1 Introduction**

Reflection cracking is a major distress in HMA overlays of existing PCC pavements. Rubbilizing, crack and seat, and break and seat techniques are used to reduce the size of PCC slabs to minimize the differential movements at existing cracks and joints, thereby minimizing the occurrence and severity of reflection cracks.

Rubbilizing can be used on all types of PCC pavements in any condition. It is particularly recommended for reinforced pavements. Fracturing the slab into pieces less than 12 inches reduces the slab to a high-strength granular base. Deflection testing of several rubbilized projects has shown a wide range in backcalculated modulus values among different projects, from less than 100,000 psi to several hundred thousand psi, and within-project coefficients of variation of as much as 40 percent (*I*).

Crack and seat is used only with JPCP and involves cracking the slab into pieces typically one to three feet in size. Field testing of several crack and seated JPCP projects showed a wide range in backcalculated modulus values among different projects, from a few hundred thousand psi to a few million psi, and within project coefficients of variation of 40 percent or more (*I*). To avoid reflection cracking, it has been recommended that no more than 5 percent of the fractured slabs have a modulus greater than 1 million psi. Effective slab cracking techniques are necessary in order to satisfy this criterion.

Break and seat is used only with JRCP and includes the requirement to rupture the reinforcing steel across each crack or break its bond with the concrete. If the reinforcement is not ruptured or its bond is not broken, the differential movements at working joints and cracks will not be reduced and reflection cracks will occur. Deflection testing of several break and seat projects showed a wide range in backcalculated modulus values ranging from a few hundred thousand psi to several million psi, and within-project coefficients of variation of 40 percent or more (*I*). The wide range in backcalculated modulus values reported for break and seat projects suggests a lack of consistency in the technique as performed with past construction equipment. Even though cracks are observed, the JRCP frequently retains a substantial degree of slab action because of failure to either rupture the reinforcing steel or break its bond with the concrete. This may also be responsible for the inconsistency of this technique in reducing reflection cracking.

#### **3.6.5.2 Subsurface Drainage Considerations**

Evaluation of the adequacy of drainage at the project location and an investigation of the role of poor drainage on pavement deterioration is an important consideration prior to placing the HMA overlay on the fractured slab. Properly installed and maintained retrofit drainage systems play an important role in achieving the design life of the HMA overlays. This is especially true when retrofit drains are being considered in pavements subjected to excessive moisture damage.

PART 3, Chapter 1 describes a systematic approach for drainage considerations in rehabilitated pavements starting from the assessment of drainage needs to integrating pavement drainage design with structural design. An important consideration when considering retrofit drains in conjunction with HMA overlays of fractured PCC slabs is the potential for the fines generated during the slab fracturing process (particularly during rubblization) to clog the edgedrain system. A careful evaluation of the potential for clogging is required and the components of the drainage system should be chosen accordingly to ensure the functionality of the drainage system. Further, since the slab fracturing process will provide a fairly open graded system, the installed drains should be designed with adequate hydraulic capacity to handle the potential rate and quantities of outflow.

### **3.6.5.3 Pre-Overlay Treatments**

These slab fracturing techniques are a type of pre-overlay treatment. When slab fracturing is to be performed on an existing composite pavement, the HMA surface should be removed by cold milling to expose the underlying PCC. Better efficiency and control of the slab fracturing process is obtained when existing HMA layers are removed. Any conditions that may not provide uniform support after the slab fracturing process should be repaired prior to placement of the overlay. Detailed guidance on the equipment used to obtain the desired degree of slab fracturing can be obtained from NAPA IS-117 (1).

### **3.6.5.4 Performance Criteria**

Performance criteria are definitions of the maximum amounts of individual distress or smoothness acceptable to the highway agency at a given reliability level. Performance indicators used for HMA rehabilitation design using fractured slab treatments are listed below.

- Rutting
- Alligator cracking
- Longitudinal cracking
- Transverse cracking
- Smoothness

Performance criteria are a user input and depend on local agency design standards as described in section 3.6.3 of this chapter.

### **3.6.5.5 Design Reliability**

When the means for all design inputs are used, the predicted performance indicators (pavement distresses and smoothness) are at the 50 percent reliability. The performance of the pavement in terms of the key performance indicators can also be obtained at any higher desired level of reliability as described in PART 3, Chapter 3, and PART 1, Chapter 1.

### 3.6.5.6 Characterization of Existing Pavement

Table 3.6.15 summarizes the recommended methods for obtaining design inputs for the various pavement layers for fractured slab analyses. This section provides specific recommendations for obtaining a design modulus for the fractured slab layer, a critical factor in the design of the HMA overlay. The designer should refer to section 3.6.4.5 of this chapter for recommended methods for characterizing other layers of the existing pavement. General recommendations for evaluating existing pavements for rehabilitation are discussed in PART 2, Chapter 5.

#### Characterization of Fractured Slab

Two input levels, Level 1 and Level 3, are provided for characterization of the modulus of the fractured slab. Recommended values of Poisson's ratio for various material types are included in PART 2, Chapter 2.

##### *Level 1*

Table 3.6.16 presents recommended design values for the modulus of the fractured slab,  $E_{fs}$ , for Level 1 characterizations. These recommended design values are functions of the anticipated variability of the slab fracturing process. When using these design values, the user must perform NDT of the fractured slab to ensure that not more than 5 percent of the in-situ fractured slab modulus values exceed 1000 ksi. When Level 1 is used, the design values may be used for all methods of fracture. The possible combinations are listed below.

Existing PCC	Fracture Method
JPCP	Crack and Seat or Rubbilize
JRCP	Break and Seat or Rubbilize
CRCP	Rubbilize

The recommended design values were developed based on NDT data on fractured slab projects contained in NAPA IS-117 (I). For the three levels of control, the mean fractured slab modulus necessary to achieve less than 5 percent exceeding 1000 ksi were determined. To be conservative, the final recommended design fractured slab modulus values use a 75 percent reliability.

##### *Level 3*

Table 3.6.17 presents recommended design values for the modulus of the fractured slab,  $E_{fs}$ , for Level 3 characterizations. These values are functions of the fracture method used and the nominal fragment size. The recommended design values were developed by applying conservatism to the relationship of  $E_{fs}$  versus nominal fragment size published in the 1986 AASHTO Design Guide and NAPA IS-117 (I). The design values are conservative and Level 3 should not be used with JRCP unless the user can insure that full debonding of the steel and concrete occurs.



Table 3.6.15. Recommended methods for characterizing existing layers for fractured slab analysis.

Layer Material	Input	Hierarchical Level		
		1	2	3
Subgrade	Modulus	NDT	Simple Test Correlations	Soil Classification
	Initial $\epsilon_p$	Trench Data	User Input	User Input
Existing Unbound Base or Subbase	Modulus	NDT	Simple Test Correlations	Soil Classification
	Initial $\epsilon_p$	Trench Data	User Input	User Input
Existing Asphalt Base or Subbase	Dynamic Modulus	NDT	HMA dynamic modulus model with Project Specific Inputs	HMA dynamic modulus model with Agency Historical Inputs
	Initial $\epsilon_p$	Trench Data	User Input	User Input
Fractured Slab	Modulus	Tabulated with NDT Quality Assurance (see table 3.6.16)	None	Tabulated Based on Process and Crack Spacing (see table 3.6.17)

Note: Recommended values of Poisson's ratio for various material types are included in PART 2, Chapter 2.

Table 3.6.16. Recommended fractured slab design modulus values for Level 1 characterization.

Expected Control on Slab Fracture Process	Anticipated Coefficient of Variation for the Fractured Slab Modulus, %	Design Modulus, ksi
Good to Excellent	25	600
Fair to Good	40	450
Poor to Fair	60	300

Table 3.6.17. Recommended fractured slab design modulus values for Level 3 characterization.

Type Fracture	$E_{fs}$ , ksi
Rubbilization	150
Crack and Seat	—
12 in crack spacing	200
24 in crack spacing	250
36 in crack spacing	300

Note: For JRCP Level 1 should be used unless agency experience dictates otherwise.

### 3.6.5.7 Trial Section

A series of HMA base, intermediate, and wearing layers comprise the typical overlay of fractured PCC slabs. However, an unbound granular layer may be considered on top of the fractured slab to provide additional assurance that reflection cracking will be eliminated. These two trial sections are shown as Case 1 and Case 2 in figure 3.6.8. The initial thickness of the various overlay layers should be selected based on experience. Since the design software provides the option to analyze three thicknesses for one of the layers of the overlay, the designer can quickly optimize the thickness of the overlay layers. Methods for determining appropriate material properties for the overlay materials are described in detail in PART 2, Chapter 2. For most materials, the designer can choose from three input levels that include: laboratory testing, correlations with easily measured material characteristics, and default values.

### 3.6.5.8 Distress Prediction

Several distresses are considered in the structural HMA overlay design and analysis. Table 3.6.18 summarizes the distresses applicable to fractured slab overlays. The designer may use one or more of these distresses as performance criteria. For overlaid pavements, the distress analysis includes consideration of distresses originating in the overlay structure and the continuation of damage in the existing pavement for the applicable layers. Tables 3.6.19 and 3.6.20 summarize the distresses computed in the overlay and the existing pavement for fractured slab analyses. These are discussed in greater detail in the next subsections of this chapter.

Table 3.6.18 Summary of distresses for HMA overlay of fractured slab.

Distress	Symbol	HMA Over Fractured Slab
Longitudinal Cracking	D <sub>1</sub>	Yes
Alligator Cracking	D <sub>2</sub>	Yes
Thermal Cracking	D <sub>3</sub>	Yes
Rutting in HMA Layers	D <sub>4</sub>	Yes
Rutting in Unbound Layers	D <sub>5</sub>	Yes

Table 3.6.19 Summary of distress computation locations for the overlay.

Distress	Case 1	Case 2
Longitudinal Cracking	Top Layer	Top Layer
Alligator Cracking	Bottom HMA Layer	Bottom HMA Layer
Thermal Cracking	Top Layer	Top Layer
Rutting in HMA Layers	All HMA Layers	All HMA Layers
Rutting in Unbound Layers	NA	Granular Layer

Table 3.6.20 Summary of distress computation locations for existing pavement in HMA overlay of fractured slab.

Distress	Fractured Slab
Rutting in HMA Layers	HMA Base if Present
Rutting in Unbound Layers	All Unbound Layers

The distresses can also be combined to predict the IRI for the rehabilitated pavement using the predictive equations presented in section 3.6.3.3 of this chapter. The IRI provides a functional performance criterion that can be used in assessing the acceptability of a given rehabilitation design.

#### Case 1 Conventional HMA Overlay

The conventional HMA overlay, shown as Case 1 in figure 3.6.8, is the principal overlay structure used with fractured slab techniques. Figure 3.6.26 shows an example Case 1 overlay of a fractured slab and the types of distresses that can be predicted. The design of this pavement structure is very similar to that for a new deep strength flexible pavement.

NEW SURFACE AC	D <sub>1</sub> D <sub>3</sub> D <sub>4</sub>
NEW INTERMEDIATE AC	D <sub>4</sub>
NEW BASE AC	D <sub>2</sub> D <sub>4</sub>
FRACTURED SLAB	
EXISTING GRANULAR SUBBASE	D <sub>5</sub>
SUBGRADE	D <sub>5</sub>

#### **CASE 1 FRACTURED SLAB**

Figure 3.6.26. Example Case 1 fractured slab overlay structure.

The design analysis for HMA overlays on fractured slabs can consider the following distresses.

- Longitudinal and thermal cracking in the overlay.
- Alligator cracking in the overlay.
- Rutting in the overlay and existing pavement.

Reflection cracking is not considered in the fractured slab analysis. The guidance on slab fracturing presented earlier is assumed to eliminate the occurrence of reflection cracking.

Longitudinal and thermal cracking are evaluated in the top layer of the overlay based on the incremental damage calculated in this layer using the models described in PART 3, Chapter 3. Fatigue damage is evaluated in the bottom HMA layer of the overlay using the bottom-up fatigue cracking model described in PART 3, Chapter 3. Rutting in the rehabilitated structure is evaluated by considering permanent deformations in all HMA and unbound layers using the rutting model described in PART 3, Chapter 3. Rutting is not evaluated in the fractured slab layer.

Functional performance of HMA overlays over fractured PCC pavements are assessed using equation 3.6.7. However, only a few of the LTPP test sections that were used to develop equation 3.6.7 fell within this rehabilitation strategy. Agencies should confirm the applicability of equation 3.6.7 to the rehabilitation strategy of fracturing the PCC pavement.

#### Case 2 HMA Overlay With Unbound Granular Layer

An unbound granular layer may be considered as part of the fractured slab overlay structure to further reduce the possibility of reflection cracking particularly with break and seat operations. The unbound granular layer would be placed directly on top of the fractured slab. Figure 3.6.27 presents an example structure and shows the distresses that will be considered.

NEW SURFACE AC	D <sub>1</sub> D <sub>3</sub> D <sub>4</sub>
NEW INTERMEDIATE AC	D <sub>4</sub>
NEW BASE AC	D <sub>2</sub> D <sub>4</sub>
NEW GRANULAR BASE	D <sub>5</sub>
FRACTURED SLAB	
EXISTING GRANULAR SUBBASE	D <sub>5</sub>
SUBGRADE	D <sub>5</sub>

**CASE 2 FRACTURED SLAB**

Figure 3.6.27. Example Case 2 fractured slab overlay structure.

The analysis of Case 2 overlays of fractured slabs, including functional assessment, is the same as that described in the previous section for Case 1 with the additional requirement that rutting in the new granular base is evaluated.

#### **3.6.5.9 Trial Design Performance Evaluation and Design Modifications**

As explained in section 3.6.4.9, performance evaluation is basically the comparison of the predicted distress (over the rehabilitation design life at a predetermined level of reliability) and

the user input performance criteria, which are basically the critical distresses values that would trigger rehabilitation. If the preset performance criteria are exceeded, the designer should modify the HMA overlay structure and associated properties (e.g., layering, layer thicknesses, materials properties) iteratively until satisfactory results are obtained. Guidance on how to alter the trial design to meet performance criteria are provided in PART 3, Chapter 3 for new and reconstructed pavements on an individual distress basis. The same concepts can be extended to alter the various types of HMA overlay trial designs that can be considered for fractured PCC pavements.

### **3.6.6 HMA OVERLAY OF INTACT PCC PAVEMENT**

#### **3.6.6.1 Introduction**

This section covers the design of HMA overlays of PCC pavement and HMA overlays of existing composite pavements when slab fracture techniques are not used. For these conditions an HMA overlay is generally a feasible rehabilitation alternative provided reflection cracking is addressed in the overlay design. Conditions under which an HMA overlay would not be feasible include:

1. The amount of deteriorated slab cracking and joint spalling is so great that complete removal and replacement of the existing PCC pavement is dictated.
2. Significant deterioration of the PCC slab has occurred due to severe durability problems. If the PCC slab is deteriorated by durability problems, a special evaluation and overlay design will be needed to ensure the thickness is adequate to protect the surface of the PCC from further disintegration and reflection through the overlay.

#### **3.6.6.2 Subsurface Drainage Considerations**

Evaluation of the adequacy of drainage at the project location and an investigation of the role of poor drainage on the deterioration of the existing pavement is an important consideration prior to placing the HMA overlay on the fractured slab. Properly installed and maintained retrofit drainage systems play an important role in achieving the design life of the HMA overlays. This is especially true when retrofit drains are being considered in pavements subjected to excessive moisture damage.

PART 3, Chapter 1 describes a systematic approach for drainage considerations in rehabilitated pavements starting from the assessment of drainage needs to integrating pavement drainage design with structural design.

#### **3.6.6.3 Pre-Overlay Treatments**

##### Repairs

Full depth repair of working cracks, heaves, deteriorated joints and slabs, and punchouts should be performed prior to placement of the overlay. Full-depth repairs and slab replacements in

JPCP and JRCP should be PCC, doweled or tied to provide load transfer across repair joints. Some agencies have placed full depth asphalt concrete repairs in JPCP and JRCP prior to overlay placement. However, this has often resulted in rough spots in the overlay, opening of nearby joints and cracks, and rapid deterioration of reflection cracks at the patch boundaries.

Full depth repairs in CRCP should be PCC and should be continuously reinforced with steel, which is tied or welded to reinforcing steel in the existing slab to provide load transfer across joints and slab continuity. Full depth asphalt concrete repairs should not be used in CRCP prior to placement of an HMA overlay, and any existing asphalt concrete patches should be removed and replaced with continuously reinforced PCC.

Installation of edge drains, maintenance of existing edge drains, or other subdrainage improvements should be done prior to placement of the overlay if pumping or significant faulting is present. If joints are contaminated with incompressibles, they should be cleaned and resealed prior to placement of the overlay. An HMA leveling course should be used to smooth faulting and fill localized settlements.

### Reflection Crack Control

In an HMA overlay of JPCP and JRCP, reflection cracks typically develop relatively soon after the overlay is placed. The rate at which they develop and deteriorate depends on a number of factors including:

- Thickness of the overlay.
- Traffic.
- Stiffness and load transfer in the existing pavement.
- Daily and seasonal temperature variations.
- Coefficient of thermal expansion of the existing pavement.
- Spacing of joints and cracks.

Proper repair of deteriorated joints and working cracks with full-depth doweled or tied PCC repairs reduces the rate of reflection crack occurrence and deterioration provided good load transfer is obtained at the full-depth repair joints. Other pre-overlay efforts that will discourage reflection crack occurrence and subsequent deterioration include subdrainage improvement, subsealing slabs which have lost support, and restoring load transfer at joints and cracks with dowels grouted in slots.

A variety of reflection crack control measures have been used in attempts to control the rates of reflection crack occurrence and deterioration. Any of the following treatments may be employed in an effort to control reflection cracking in an overlay of JPCP or JRCP:

1. *Sawing and sealing joints in the HMA Overlay.* This technique has been very successful when applied to HMA overlays of jointed PCC pavements when the sawcut matches the joint.
2. *Increasing HMA overlay thickness.* Reflection cracks will take more time to propagate through a thicker overlay and deteriorate more slowly.

3. *Granular interlayers.* Large sized stone layers placed between the jointed pavement and the HMA overlay.
4. *Proprietary Fabric treatments and Stress Absorbing Membrane Interlayers (SAMIs).* A number of products are available that claim to reduce reflection cracking in HMA overlays of jointed PCC pavements.

Reflection cracking can have a considerable—often controlling—influence on the life of an HMA overlay of JPCP or JRCP. Deteriorated reflection cracks decrease a pavement's serviceability and also require frequent maintenance such as sealing, milling, and patching. Reflection cracks also permit water to enter the pavement structure, which may result in loss of bond between the HMA and PCC layers, striping in the HMA, progression of “D” cracking or reactive aggregate distress in PCC slabs, and softening of the base and subgrade. For this reason, reflection cracks should be sealed as soon as they appear and resealed periodically throughout the life of the overlay. Sealing low severity reflection cracks may also be effective in retarding their progression to medium and high severity levels.

With an HMA overlay of CRCP, permanent repair of punchouts and working cracks with tied or welded reinforced PCC full depth repairs will delay the occurrence and deterioration of reflection cracks. Improving subsurface drainage conditions and subsealing in areas where the slab has lost support will also discourage reflection crack occurrence and deterioration. Reflection crack control treatments are not necessary for HMA overlays of CRCP, except for longitudinal joints, when continuously reinforced PCC repairs are used to repair deteriorated areas and cracks.

#### **3.6.6.4 Performance Criteria**

Performance criteria are definitions of the maximum amounts of individual distress or smoothness acceptable to the highway agency at a given reliability level. Performance indicators used for HMA rehabilitation of intact PCC pavement are as follows:

- Rutting
- Longitudinal cracking
- Transverse cracking
- Reflection cracking
- Smoothness

Performance criteria are a user input and depend on local agency design standards as described in section 3.6.3 of this chapter.

#### **3.6.6.5 Design Reliability**

When the means for all design inputs are used, the predicted performance indicators (pavement distresses and smoothness) are at the 50 percent reliability. The performance of the pavement in terms of the key performance indicators can be also be obtained at any higher desired level of reliability as described in PART 3, Chapter 3, PART 1, Chapter 1, and Appendix BB.

### 3.6.6.6 Characterization of Existing Pavement

Table 3.6.21 summarizes the recommended methods for obtaining design inputs for the various pavement layers for HMA overlay of intact PCC pavements. This section provides specific recommendations for obtaining design values for the existing PCC layer. The designer should refer to section 3.6.4.6 of this chapter for recommended methods for characterizing other layers of the existing pavement. General recommendations for evaluating existing pavements for rehabilitation are discussed in PART 2, Chapter 5.

For JPCP and CRCP analyses several inputs are needed. These include the elastic modulus, modulus of rupture, and current fatigue damage level of the PCC for use in the JPCP and CRCP damage analyses. This Design Guide does not consider JRCP directly for structural analysis and design, and thus no fatigue damage analysis is possible. Actually, the reinforcement will generally hold any newly formed crack tight and it will not reflect through the surface. Existing cracks that are deteriorated should be repaired prior to the overlay. An HMA overlay can be approximately designed for JRCP by considering HMA reflection cracking from joints.

Three input levels are available for these inputs as described in the sections that follow. Recommended values of Poisson's ratio for various material types are included in PART 2, Chapter 2.

#### PCC Properties for PCC Damage Analysis

##### *Level 1*

For Level 1 characterizations, the elastic modulus and the modulus of rupture for the PCC are measured on cores and beams sawed from representative locations in the project. The elastic modulus is measured on the core specimens in accordance with ASTM C 469, *Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression*. The modulus of rupture is measured on the beam samples in accordance with AASHTO T97, *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)*.

##### *Level 2*

For Level 2 characterizations, the elastic modulus and the modulus of rupture for the PCC are estimated from the compressive strength of cores drilled from representative locations in the project. The compressive strength is determined in accordance with AASHTO T22, *Compressive Strength of Cylindrical Concrete Specimens*. Recommended models relating elastic modulus and modulus of rupture to compressive strength are presented in PART 2, Chapter 2.

##### *Level 3*

For Level 3 characterization, either the 28-day flexural strength (modulus of rupture) or 28-day compressive strength are needed to be input.

Table 3.6.21. Summary of existing layer characterization for HMA overlays of PCC pavements.

Layer Material	Input	Hierarchical Level		
		1	2	3
Subgrade	Modulus	NDT	Simple Test Correlations	Soil Classification
Existing Unbound Base or Subbase	Modulus	NDT	Simple Test Correlations	Soil Classification
Existing Asphalt Base or Subbase	Dynamic Modulus	NDT	HMA dynamic modulus model with Project Specific Inputs	HMA dynamic modulus model with Agency Historical Inputs
Jointed Plain Concrete Pavement (JPCP)	Elastic Modulus for PCC	Field Core (lab testing) or Backcalculated FWD (adjusted)	Estimated from Compressive Strength of Field Cores	Estimated from Historical Compressive Strength Data
	Modulus of Rupture	Field Beam (lab testing)	Estimated from Compressive Strength of Field Cores	Estimated from Historical Compressive Strength Data
	Past Fatigue Damage	% Slabs Cracked	% Slabs Cracked	Pavement Rating
Continuously Reinforced Concrete Pavement (CRCP)	Elastic Modulus for PCC	Field Core (lab testing) or Backcalculated FWD (adjusted)	Estimated From Compressive Strength of Field Cores	Estimated from Historical Compressive Strength Data
	Modulus of Rupture	Field Beam (lab testing)	Estimated From Compressive Strength of Field Cores	Estimated from Historical Compressive Strength Data
	Past Fatigue Damage	Punchouts & Repairs /mile	Punchouts & repairs /mile	Pavement Rating
Jointed Reinforced Concrete Pavement (JRCP)	Elastic Modulus for PCC	Field Core (lab testing) or Backcalculated FWD (adjusted)	Estimated from Compressive Strength of Field Cores	Estimated from Historical Compressive Strength Data

Note: Recommended values of Poisson's ratio for various material types are included in PART 2, Chapter 2.

Optionally, the 28-day elastic modulus of the in-place concrete can also be input, if available, to more accurately determine the strength-modulus ratio. If this is not available, standard strength-modulus relationships described in PART 2, Chapter 2 can be used to estimate the elastic modulus. The estimated 28-day modulus of rupture and elastic modulus values should be increased using the PCC strength and modulus gain models described in PART 2, Chapter 2 for Level 3 to account for the age/maturity of the existing PCC pavement at the time of the HMA overlay.

### Existing PCC Damage

An estimate of the existing damage in the PCC slab at the time of the overlay is needed for the JPCP and CRCP damage analyses. For these pavements, damage will continue to develop in the PCC after the overlay but at a slower rate. Since JRCP is not included in the design procedures of this Design Guide, no damage analysis can be performed for JRCP. If fatigue cracking occurs in JRCP, it is assumed that the reinforcing steel will maintain load transfer across the crack minimizing the potential for the propagation of cracks through the HMA overlay.

#### *Level 1 and Level 2*

For Level 1 and Level 2 characterizations, the damage in the existing PCC slab is estimated based on detailed condition survey information. Tables 3.6.22 and 3.6.23 present recommended initial damage estimates based on the amount of cracked slabs for JPCP, and the number of punchouts per mile for CRCP. The initial damage estimate should consider the effects of planned pre-overlay repairs, such as slab replacement and punchout repairs.

Table 3.6.22. Initial cracking damage estimates.

<b>Distress (Percent Slabs Cracked)</b>	<b>Damage</b>
0	0.100 - 0.250 <sup>1</sup>
10	0.270
20	0.438
30	0.604
40	0.786
50	1.000

<sup>1</sup> Assumed default value.

Table 3.6.23. Initial punchout and associated damage estimates.

<b>No. of Punchouts per Mile</b>	<b>Damage</b>
0	0.10 - 0.15 <sup>1</sup>
2	0.22
4	0.34
6	0.44
8	0.53
10	0.62
> 10	> 0.62

<sup>1</sup> Assumed default value.

### Level 3

For Level 3 characterizations, the current damage is obtained from a general condition rating of the pavement given in table 3.6.24.

Table 3.6.24. Damage for JPCP and CRCP based on pavement condition rating.

Category	Damage
Excellent	0.10 - 0.25 <sup>1</sup>
Good	0.50 - 0.67
Fair	1.00
Poor	> 1.00
Very Poor	> 1.00

<sup>1</sup> Assumed default value.

### 3.6.6.7 Trial Section

Case 1 and Case 2 in figure 3.6.8 are the types of overlay sections that are appropriate for HMA overlay over intact PCC pavements. Case 1 is a conventional HMA overlay consisting of up to three different HMA mixtures or layers. Case 2 includes an unbound granular layer for reflection crack control.

### 3.6.6.8 Distress Prediction

Several distresses are considered in structural HMA overlay design and analysis. Table 3.6.25 summarizes the distresses applicable to HMA rehabilitation of intact PCC pavements. The designer may use one or more of these distresses as performance criteria. For overlaid pavements, the distress analysis includes consideration of distresses originating in the overlay structure and the continuation of damage in the existing pavement. Tables 3.6.26 and 3.6.27 summarize the distresses computed in the overlay and the existing PCC pavement. These are discussed in greater detail in the next subsections of this chapter. The distresses can also be combined to predict the IRI for the rehabilitated pavement using predictive equation 3.6.7. The IRI provides a functional performance criterion that can be used in assessing the acceptability of a given rehabilitation design.

Table 3.6.25 Summary of distresses for analysis of HMA over PCC.

Distress	Symbol	HMA over PCC
Longitudinal Cracking	D <sub>1</sub>	Yes
Alligator Cracking	D <sub>2</sub>	When Unbound Granular Layer is Included in Overlay or When HMA and PCC Interface Debonding is Modeled
Thermal Cracking	D <sub>3</sub>	Only CRCP
Rutting in HMA Layers	D <sub>4</sub>	Only Overlay Layers
Rutting in Unbound Layers	D <sub>5</sub>	Only Overlay Layers
CTB Modulus Reduction	D <sub>6</sub>	If Layer Present in Existing Pavement
PCC Damage	D <sub>8</sub>	JPCP and CRCP
Reflection Cracking	D <sub>9</sub>	Yes

Table 3.6.26 Summary of distresses computation locations for the overlay.

<b>Distress</b>	<b>Case 1</b>	<b>Case 2</b>
Longitudinal Cracking	Top Layer	Top Layer
Alligator Cracking	For JPCP Only	HMA Layer Above Granular Layer
Thermal Cracking	CRCP Only	Top Layer
HMA Rutting	All HMA Layers	All HMA Layers
Unbound Layer Rutting	NA	Granular Layer
Reflection Cracking	Top Layer	NA

Table 3.6.27. Summary of distress computation locations for existing pavement in HMA overlay of PCC pavement.

<b>Distress</b>	<b>PCC</b>	<b>Composite</b>
Alligator Cracking	N/A	When JPCP is Present
Rutting in HMA Layers	N/A	Existing HMA Layers
CTB Modulus Reduction	CTB Layer if Present	CTB Layer if Present
PCC Damage	JPCP and CRCP	JPCP and CRCP

### Overlays of JPCP

#### *Case 1 Conventional HMA Overlay*

The conventional overlay shown as Case 1 in figure 3.6.8 is the principal overlay structure used in HMA overlays of PCC. Up to three different HMA materials can be analyzed in the Case 1 overlay structure. This provides the designer the capability to directly assess the merits of different HMA mixtures. Figure 3.6.29 shows an example Case 1 overlay of JPCP. The distresses that can be predicted are:

- Longitudinal cracking of the HMA overlay.
- Rutting of the HMA overlay.
- Reflection cracking of existing joints and cracks.
- Fatigue damage in the existing JPCP.
- Reflection cracking of JPCP fatigue cracks that develop during the overlay period.
- Alligator cracking in the overlay.

Longitudinal (top-down) cracking is evaluated in the top layer of the overlay based on the incremental damage calculated in this layer using the models described in PART 3, Chapter 3. Rutting in the overlay is evaluated by considering permanent deformations in all HMA layers using the HMA rutting model described in PART 3, Chapter 3. Two types of reflection cracking are considered using the empirical delay functions described in section 3.6.3.3. The first is reflection of joints and cracks identified in the existing pavement during the distress survey. The second is new fatigue cracks in the JPCP resulting from continuation of fatigue damage in the existing pavement.

NEW SURFACE AC	$D_1 D_4 D_9$
NEW INTERMEDIATE AC	$D_4$
NEW BASE AC	$D_2 D_4$
EXISTING JPCP	$D_8$
EXISTING GRANULAR SUBBASE	
SUBGRADE	

#### CASE 1 JPCP

Figure 3.6.29. Example Case 1 JPCP overlay structure.

Fatigue damage in the JPCP is predicted using the JPCP fatigue models described in PART 3, Chapter 4 and section 3.6.3.3. The overlay is converted to an equivalent PCC thickness for evaluation of load induced stresses in the existing JPCP. The damage in the PCC slab is the mechanistic parameter that represents the occurrence and coalescing of micro-cracks to form larger cracks at the bottom of the existing PCC slab. This mechanistic parameter is related to the physical distress of bottom-up transverse cracking. Bottom-up transverse cracking is predicted through calibrated models that relate cumulative fatigue damage to distress when this cracking becomes visible at the pavement surface.

Equation 3.6.19 is used for predicting bottom-up cracking:

$$CRK = \frac{100}{1 + FD^{-1.68}} - CRK_{REPAIRED} \quad (3.6.19)$$

Where:

- $CRK$  = Percent slabs cracked.
- $FD$  = Fatigue damage, percent.
- $CRK_{REPAIRED}$  = Amount of cracks repaired during pavement restoration.

$CRK_{REPAIRED}$  accounts for repairs made to the existing JPCP slab prior to overlay as shown in figure 3.6.30. Equation 3.6.19 was calibrated with field data from LTPP and other sources.

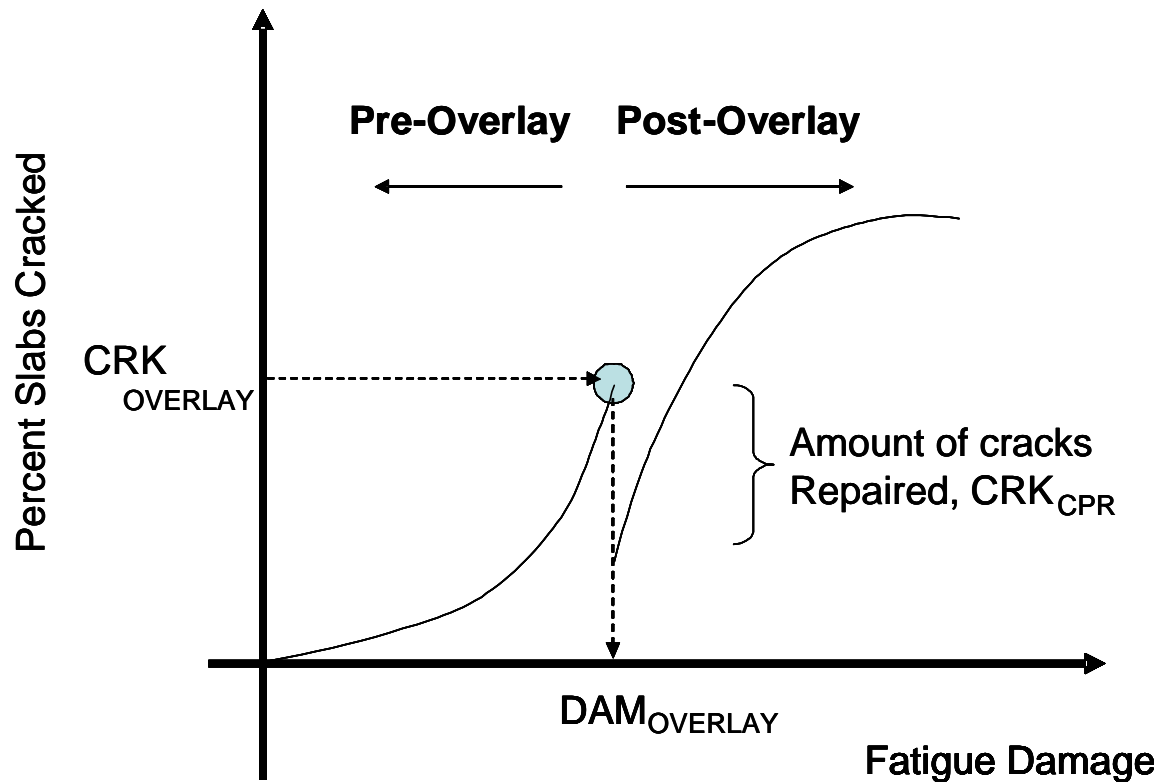


Figure 3.6.30. Schematic showing the effect of pre-overlay repair on predicted cracking where some cracked slabs were replaced during pre-overlay repair.

The guide assumes that thermal cracking will not develop in this type of overlay. Reflection cracking of joints and cracks in the existing JPCP will minimize the potential for thermal fracture of the asphalt layer.

Functional performance of HMA overlays over intact JPCP slabs is assessed using equation 3.6.7.

#### *Case 2 HMA Overlay With Unbound Granular Layer*

The use of an unbound granular layer in the overlay structure may be considered to minimize reflection cracking. In this case, the granular layer would be placed directly above the existing PCC pavement. Figure 3.6.31 shows an example Case 2 overlay of an existing JPCP. For Case 2 overlays, reflection cracking in the HMA layer is not considered because it is assumed that the granular layer will prevent the joints and cracks from reflecting through the HMA layers. The distresses that can be predicted are:

- Longitudinal cracking of the HMA overlay.
- Thermal cracking in the overlay.
- Alligator cracking in the overlay.
- Rutting of the overlay.
- Fatigue damage in the existing JPCP.

NEW SURFACE AC	$D_1 D_3 D_4$
NEW INTERMEDIATE AC	$D_4$
NEW BASE AC	$D_2 D_4$
NEW GRANULAR BASE	$D_5$
EXISTING JPCP	$D_8$
EXISTING GRANULAR SUBBASE	
SUBGRADE	

#### CASE 2 JPCP

Figure 3.6.31. Example Case 2 JPCP overlay structure.

Longitudinal and thermal cracking are evaluated in the top layer of the overlay based on the incremental damage calculated in this layer using the models described in PART 3, Chapter 3. Fatigue damage is evaluated in the bottom HMA layer of the overlay using the bottom up fatigue cracking model described in PART 3, Chapter 3. Rutting in the rehabilitated structure is evaluated by considering permanent deformations in all HMA and unbound layers using the rutting models described in PART 3, Chapter 3. Fatigue damage in the JPCP is predicted using the JPCP fatigue model described in PART 3, Chapter 4. The overlay is converted to an equivalent PCC thickness for evaluation of load induced stresses in the existing JPCP. Tension will not develop at the bottom of the HMA overlay to initiate and propagate bottom-up fatigue cracking of the overlay due to the high modulus of the PCC unless the layers become unbonded.

Functional performance of HMA overlays with a new granular layer over intact JPCP slabs is assessed in accordance with equation 3.6.7. However, none of the LTPP test sections that were used to develop equation 3.6.7 fell within this rehabilitation strategy. Agencies should confirm the applicability of equation 3.6.7 to the rehabilitation strategy when a new granular layer and HMA layers are placed over intact PCC slabs.

#### *Overlay of JPCP Composite Pavements*

The design of HMA overlays of composite pavements with JPCP base, or second overlays of JPCP is very similar to that described above for the initial overlay, including the assessment of functional performance. Figure 3.6.32 presents example Case 1 and Case 2 overlay structures and the damage that can be predicted assuming the existing HMA surface is not removed.

NEW SURFACE AC	D <sub>1</sub> D <sub>4</sub> D <sub>9</sub>	NEW SURFACE AC	D <sub>1</sub> D <sub>3</sub> D <sub>4</sub>
NEW INTERMEDIATE AC	D <sub>4</sub>	NEW INTERMEDIATE AC	D <sub>4</sub>
NEW BASE AC	D <sub>2</sub> D <sub>4</sub>	NEW BASE AC	D <sub>2</sub> D <sub>4</sub>
EXISTING AC	D <sub>2</sub> D <sub>4</sub>	NEW GRANULAR BASE	D <sub>5</sub>
EXISTING JPCP	D <sub>8</sub>	EXISTING AC	D <sub>4</sub>
EXISTING GRANULAR SUBBASE		EXISTING JPCP	D <sub>8</sub>
SUBGRADE		EXISTING GRANULAR SUBBASE	
		SUBGRADE	
<b>CASE 1 JPCP</b>		<b>CASE 2 JPCP</b>	

Figure 3.6.32. Example composite JPCP overlay structure.

### Overlays of JRCPP

This Design Guide does not include the design of JRCPP and thus only an approximate overlay design can be analyzed. An approximate design of HMA overlay of JRCPP can proceed the same as that described for JPCP with the exception that fatigue damage and reflection of new fatigue cracks in the JRCPP pavement are not considered. All existing working transverse cracks must be full-depth repaired with doweled repairs. The reinforcing steel in JRCPP will keep any new fatigue cracks that develop closed and provide a high level of load transfer across the cracks. An HMA overlay can be approximately designed for JRCPP by considering HMA reflection cracking from joints.

### Overlays of CRCP

Except for longitudinal joints, reflection cracking of HMA overlays of CRCP does not generally occur when existing punchouts and deteriorated cracks are properly repaired with continuously reinforced PCC. Thus a conventional HMA overlay, Case 1 in figure 3.6.8 is the primary HMA overlay structure used to rehabilitate CRCP. The overlay analysis allows up to three different HMA layers to be included in the Case 1 overlay.

Figure 3.6.33 presents example HMA overlay structures for existing CRCP. The distresses that can be predicted are:

- Longitudinal cracking of the HMA overlay.
- Thermal cracking of the HMA overlay.
- Rutting of the HMA overlay.
- Punchout damage in the existing CRCP.

NEW SURFACE AC	$D_1 D_3 D_4$	NEW SURFACE AC	$D_1 D_3 D_4$
NEW INTERMEDIATE AC	$D_4$	NEW INTERMEDIATE AC	$D_4$
NEW BASE AC	$D_4$	NEW BASE AC	$D_4$
EXISTING CRCP	$D_8$	EXISTING AC	$D_4$
EXISTING GRANULAR SUBBASE		EXISTING CRCP	$D_8$
SUBGRADE		EXISTING GRANULAR SUBBASE	
		SUBGRADE	
<b>INITIAL OVERLAY</b>		<b>SUBSEQUENT OVERLAYS</b>	

Figure 3.6.33. Example HMA overlay structures for CRCP.

Longitudinal and thermal cracking are evaluated in the top layer of the overlay based on the incremental damage calculated in this layer using the models described in PART 3, Chapter 3. Rutting in the rehabilitated structure is evaluated by considering permanent deformations in all HMA layers using the rutting model described in PART 3, Chapter 3.

Punchout damage in the CRCP is predicted using the CRCP punchout model described in PART 3, Chapter 4. A punchout in the underlying CRCP requires the loss of crack load transfer across two closely spaced cracks, therefore, sufficient overlay thickness must be provided to minimize deterioration of transverse cracks. The HMA overlay will reduce the negative thermal gradient through the CRCP (upward curl) and also the amount of crack opening and thus loss of crack LTE. The thicker the HMA overlay the less crack deterioration will occur over the design life of the overlay. Crack width must be maintained below 0.02-in (at steel level) and crack LTE must be above 95 percent during the coldest months of the year. The effect of punchout repairs prior to overlay on predicted punchouts is shown in figure 3.6.34.

The elastic modulus of the CRCP is determined the same way as for JPCP for all levels as summarized in table 3.6.21. For analysis, the overlay is converted to an equivalent PCC thickness for evaluation of load induced stresses in the existing CRCP. The fatigue analysis is carried out the same way as described in PART 3, Chapter 4 for CRCP design. Tension will not develop at the bottom of the HMA overlay to initiate and propagate bottom-up fatigue cracking of the overlay due to the high modulus of the PCC unless the layers become unbonded.

Functional performance of HMA overlays over intact CRCP is assessed using equation 3.6.7.

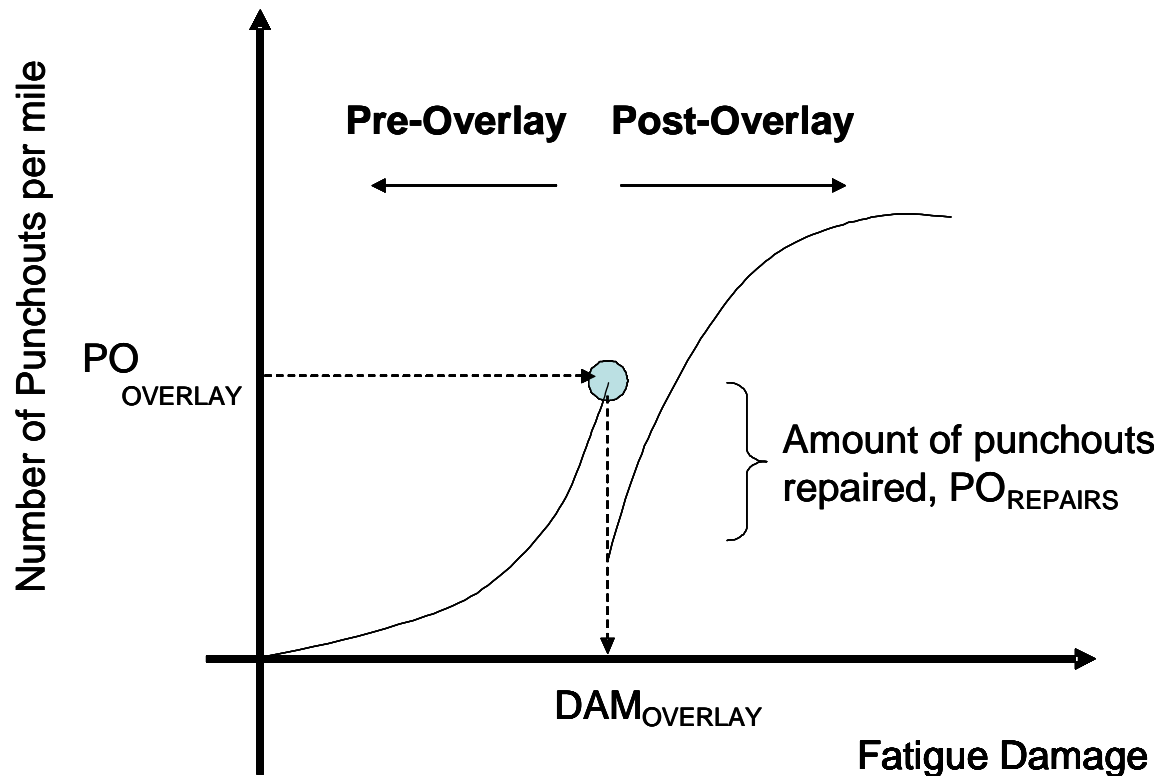


Figure 3.6.34. Effect of repair on punchout prediction including full depth repair.

### 3.6.6.9 Trial Design Performance Evaluation and Design Modifications

As explained in section 3.6.4.9, performance evaluation is basically the comparison of the predicted distress (over the rehabilitation design life at a predetermined level of reliability) and the user input performance criteria, which are basically the critical distresses values that would trigger rehabilitation. If the preset performance criteria are exceeded, the designer should modify the HMA overlay structure and associated properties (e.g., layering, layer thicknesses, materials properties) iteratively until satisfactory results are obtained.

In HMA overlays of intact PCC pavements, the primary distresses of concern are HMA rutting, HMA transverse (thermal) cracking, reflection cracking, and smoothness. Figures 3.6.35 through 3.6.38 present how cracking in the existing JPCP slab – a critical design input – affects these distresses. As expected the damage in the underlying slab has the greatest impact on the predicted quantities of bottom-up (alligator) cracking.

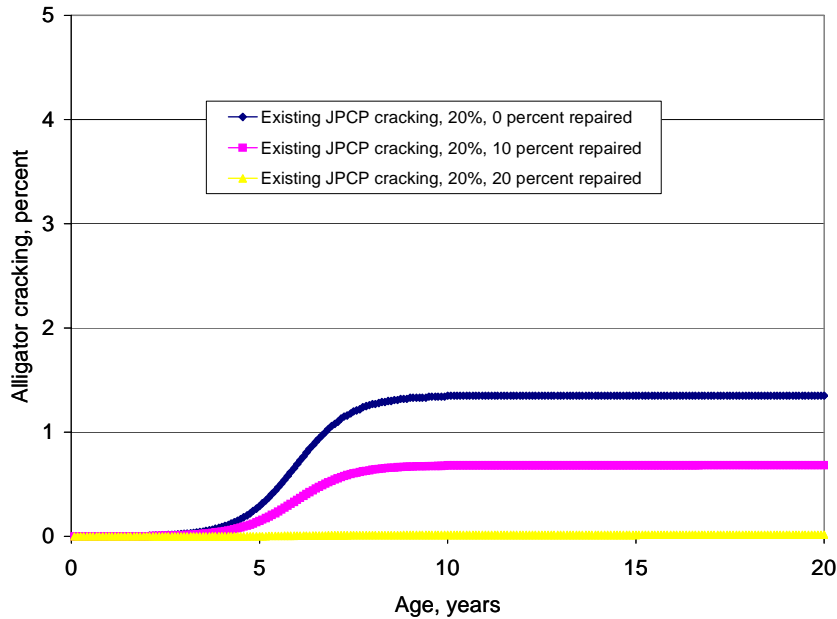


Figure 3.6.35. Conventional HMA Overlay of Intact JPCP – Effect of existing pavement condition on bottom-up (alligator) cracking.

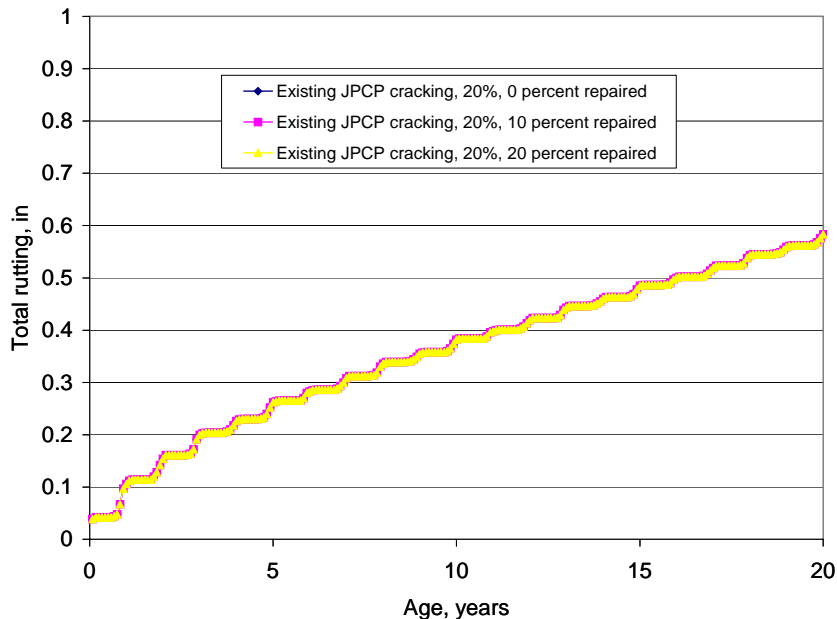


Figure 3.6.36. Conventional HMA Overlay of Intact JPCP – Effect of existing pavement condition on total rutting.

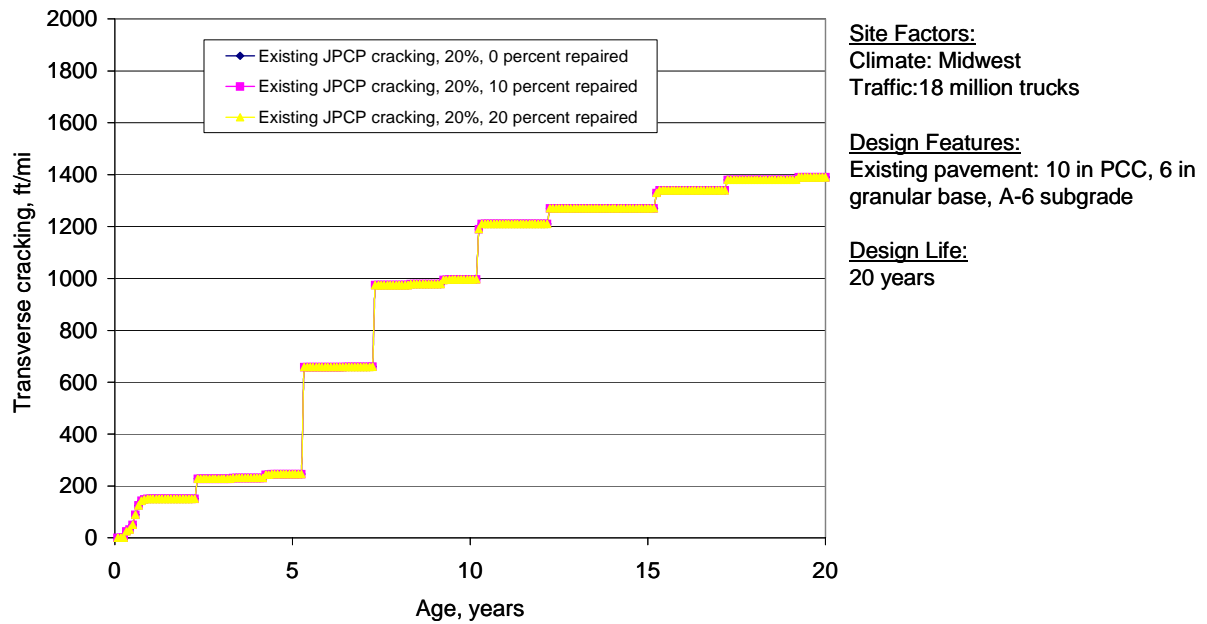


Figure 3.6.37. Conventional HMA Overlay of Intact JPCP – Effect of existing pavement condition on transverse cracking.

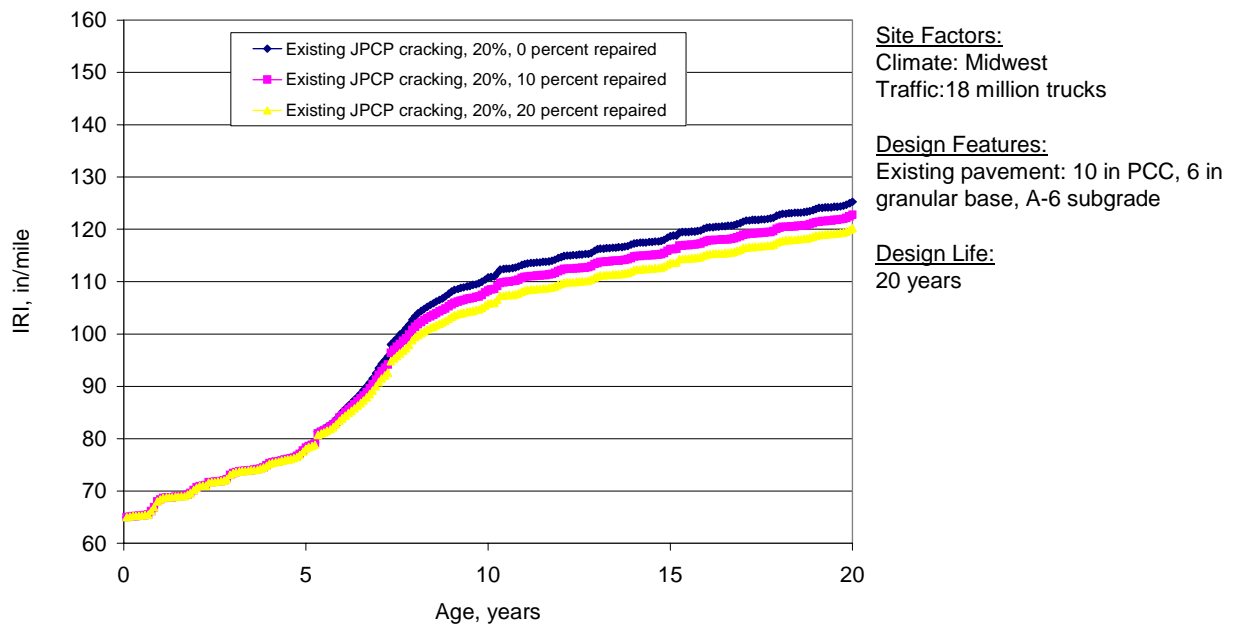


Figure 3.6.38. Conventional HMA Overlay of Intact JPCP – Effect of existing pavement condition on IRI.

### **3.6.7 ADDITIONAL CONSIDERATIONS FOR REHABILITATION WITH HMA OVERLAYS**

There are several important considerations that must be addressed as part of rehabilitation design to ensure adequate performance of the rehabilitation design throughout its design life. These issues include:

- Shoulder reconstruction.
- Lane widening.
- Subdrainage improvement.
- Preoverlay repairs of concrete pavements
- Preoverlay repairs of HMA pavements
- Reflection crack control .
- Use of cold inplace recycling.
- Use of hot inplace recycling

These design considerations are described in the following sections.

#### **3.6.7.1 Shoulder Reconstruction**

Utilize the information on the design of shoulders presented in PART 3, Chapter 2 of this guide.

#### **3.6.7.2 Lane Widening**

Since there is no way to incorporate load transfer into the longitudinal joint formed between the existing pavement and the lane widening, it is important that the joint not be located in the wheel path. In some cases, it may be necessary to remove a portion of the existing lane to assure that the joint is not in the wheel path. Extreme care in the construction/laydown phase should be conducted so that a well bonded hot joint (longitudinal) is created with the existing and new lane being constructed. If the new HMA will be a multi-lift layer, longitudinal joints between lifts should be staggered by approximately 12 inches. This method of construction also ensures that the surface infiltration of moisture is minimized through the avoidance of a cold joint.

Care should be taken to maintain longitudinal cross drainage in the base. In many cases, the new lane becomes the truck lane resulting in the asphalt pavement layer being thicker than the existing section. This may require the addition of additional drainage features such as a drainable base under the lane addition.

#### **3.6.7.3 Subdrainage Improvement**

Utilize the information on the design of subsurface drainage systems described in PART 3, Chapter 1 of this guide.

#### 3.6.7.4 Pre-Overlay Repairs of Concrete Pavements

When there are areas with severe concrete breakup or loss of load transfer, full-depth repairs may be required. Full-depth repairs are cast-in-place repairs that extend over the entire depth of an existing pavement slab. Typically, full-depth repairs are a minimum of 2 m (6 ft) long and extend across the entire lane width. For JPCP and JRCP, distress types that may warrant full-depth repairs are blowups, corner breaks, and those associated with load transfer deterioration. For CRCP, distress types that may warrant full-depth repairs are blowups, punchouts, and construction joint problems. For pavements that are severely distressed over a large area, other rehabilitation techniques such as crack and seat, break and seat, or rubblization should be considered.

It is important that proper load transfer be provided at the transverse joints for all full depth concrete patches. This accomplished through the use of steel dowel bars with a minimum diameter of 32 mm (1.25 in) as shown in Figure 3.6.39.

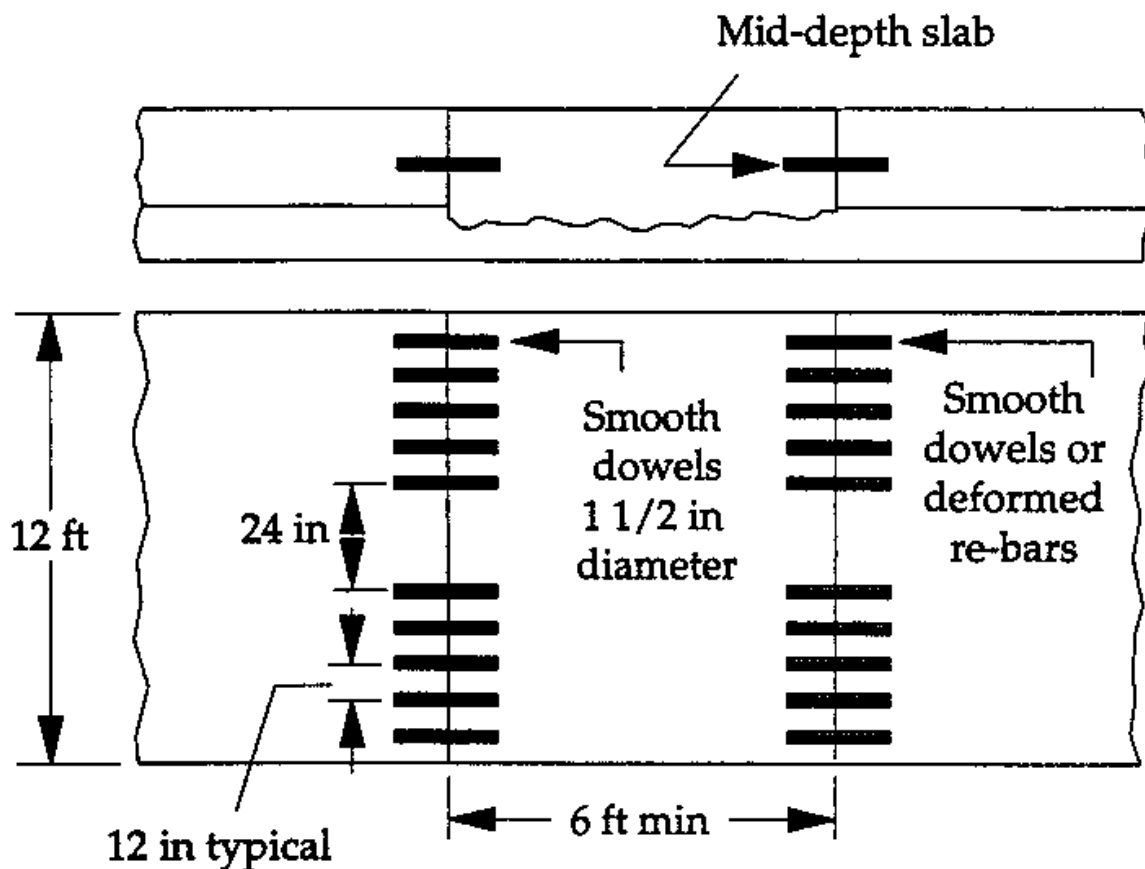


Figure 3.6.39. Typical layout for full-depth repair of jointed PCC

For CRCP, the reinforcing steel should match the existing steel in grade, quality, size, and number. The new reinforcement should end at least 50 mm (2 in) from the joint faces and should be either tied, mechanically connected, or welded to the existing reinforcement. If the reinforcement is welded or mechanically connected, a tied lap must be provided in the middle of

the repair to permit small movements and prevent buckling of the bars. Chairs or other means of support can be used to prevent the steel from sagging during placement of the PCC. A minimum cover of 65 mm (2.5 in) should be provided.

HMA should not be used for full depth patches on PCC pavements. Such patches tend to act as extended expansion joints and provide non-uniform support for overlays. When used with overlays of PCC pavement, full depth HMA patches become areas of early distress, roughness, and excessive reflective cracking.

Where small shallow areas of deteriorated PCC are present, the deteriorated concrete should be removed and HMA used to level the area prior to the overlay.. Partial depth repairs offer an alternative to full depth repairs in areas where slab deterioration is located primarily in the upper one-third of the slab and where existing load transfer devices (if any) are still functional. Failure to repair spalled areas before placing an overlay often results in reflective cracks through the HMA surfacing layers.

In cases where extensive slab deterioration is present or where the slabs are rocking due to the loss of foundation support, slab fracturing techniques present the most effective mode of rehabilitation. Three specific fractured slab techniques are currently used: cracking and seating, breaking and seating, and rubblizing. These techniques have the following unique characteristics:

- Cracking and seating is performed on JPCP to reduce the effective slab length and reduce slab movement.
- Breaking and seating is conducted on JRCP to shorten the slab lengths and reduce slab movement. However, greater impact energy is required to rupture the steel in the slab or break the bond between the steel and concrete. Success of this fracturing process is directly associated with the degree of success achieved in the steel rupturing process and/or debonding the steel-concrete interface.
- Rubblizing is the fracturing of a pavement slab into extremely small pieces that typically approach base aggregate size. It is generally performed on badly deteriorated PCC pavements or pavements suffering from chemical attack.

#### **3.6.7.5 Pre-Overlay Repairs of HMA Pavements**

The ultimate success of preoverlay repairs of HMA pavements is to insure that even limited crack core studies are conducted to assess if cracking is simply occurring on the surface or if it is through the entire surface layer.

All areas of high-severity alligator cracking must be repaired. Localized areas of medium-severity alligator cracking should be repaired unless a paving fabric or other means of reflective crack control is used. The repair must include removal of any soft subsurface material.

High-severity linear cracks should be patched or milled to the crack depth if they are found to be surface (top down) cracks. Linear cracks that are open greater than 6 mm (0.25 in) should be

filled with a sand-asphalt mixture or other suitable crack filler. Some method of reflective crack control is recommended for transverse cracks that experience substantial opening and closing. Cracks that are open less than 6 mm (0.25 in) and cracks that do not experience substantial opening and closing do not require any preoverlay repairs.

Rutting is removed by milling only (for deeper ruts) or placement of a leveling course (for shallower ruts because the leveling course cannot be compacted in deep ruts). If rutting is severe (greater than 6 mm [0.25 in]), an investigation into which layer is causing the rutting should be conducted to determine whether an overlay is feasible. Failure to correct the cause of the problem can lead to premature failures in the overlay.

Depressions, humps, and corrugations require investigation and treatment of their causes. Usually, removal and replacement will be required.

### **3.6.7.6 Reflection Crack Control**

The basic mechanism of reflection cracking is strain concentration in the overlay due to movement near cracks in the existing surface. Bending or shearing induced by loads or horizontal contraction induced by temperature changes can cause this movement. Load-induced movements are influenced by the thickness of the overlay and the thickness and stiffness of the existing pavement, as well as the loading characteristics of the vehicle. Temperature-induced movements are influenced by daily and seasonal temperature variations, the coefficient of thermal expansion of the existing pavement, and the spacing of cracks.

Preoverlay repair (patching and crack filling) may help delay the occurrence and deterioration of reflection cracks. Additional measures to control reflective cracking have been beneficial in some cases. These measures include the following:

- Increased HMA overlay thickness reduces bending and vertical shear under loads and reduces temperature variation in the existing pavement. Thus, thicker HMA overlays are more effective than thinner overlays in delaying the occurrence and deterioration of reflection cracks. However, increasing the HMA overlay thickness may not be a cost effective method to control reflection cracks.
- Sawing and sealing joints in the HMA overlay at locations coinciding with straight cracks in the underlying HMA layer may be effective in controlling the deterioration of reflection cracks. This technique has been very effective when applied to HMA overlays of jointed PCC pavements when the sawcut matches the joint or straight crack within 25 mm (1 in).
- Synthetic fabrics and SAMIs have had limited effectiveness in controlling reflection of low- and medium-severity alligator cracking. They may also be useful for controlling reflection of temperature cracks, particularly when used in combination with crack filling. They generally are less effective, however, to retard reflection of cracks subject to substantial horizontal or vertical movements.

- Crack relief layers thicker than 80 mm (3 in) have been effective in controlling reflective cracking subject to large horizontal or vertical movements. These crack relief layers are composed of open-graded coarse aggregate and a small percentage of asphalt cement. However, the approach is difficult to construct, raises the new grade, and may be costly.

Reflection cracking can have a considerable, often controlling, influence on the life of an HMA overlay. Deteriorated reflection cracks detract from a pavement's serviceability and require frequent maintenance, such as sealing and patching. Reflection cracks also allow water to enter the pavement structure. Water in the pavement may result in loss of bond between the HMA overlay and existing HMA surface, stripping in either layer, and softening of the granular layers and subgrade. Therefore, reflection cracks should be sealed when they appear and resealed periodically throughout the life of the overlay. Sealing low-severity reflection cracks may also be effective in retarding their progression to medium and high severity levels.

### **3.6.7.7 Cold In-Place Recycling**

Cold in-place recycling can be used as a pre-treatment of badly deteriorated existing HMA pavements. The full-depth option of cold in-place recycling has the ability to treat all forms of distress as the entire asphalt-treated portion of the pavement is pulverized and recycled. Thus full-depth recycling eliminates reflection cracking. Cold in-place recycling is among the most economical forms of pavement recycling for a relatively large number of projects. Cold in-place recycled materials have been used for subbases, bases, and surfaces. The most common use to date has been for base courses. Although stabilization with bituminous materials is the most popular process, literature indicates that lime, portland cement, flyash, and calcium chloride have also been used (16, 17).

Two forms of cold in-place recycling with bituminous binders have evolved in the United States: full-depth and partial-depth. Full-depth (reclamation/stabilization) cold in-place recycling is a rehabilitation technique in which the full flexible pavement structure and predetermined portions of the base material are uniformly crushed, pulverized, and mixed with a bituminous binder, resulting in a stabilized base course. Additional aggregate may be transported to the site and incorporated in the processing. This process is normally performed to a depth of 100 to 300 mm (4 to 12 in) (16).

Partial-depth cold in-place recycling is a rehabilitation technique that reuses a portion of the existing asphalt-bound materials. Normal recycling depths are 50 to 100 mm (2 to 4 in). The resulting bituminous-bound recycled material is often used as a base course, but can be used as a surface course on low to medium traffic volume highways. When this form of cold in-place recycling is performed on an old uniform pavement, a higher-quality end product is expected (16).

### **3.6.7.8 Hot In-Place Recycling**

When the existing pavement surface layer is badly cracked, oxidized, or deformed, hot in-place recycling may be a pretreatment option. The use of hot in-place recycling operations dates to the 1930s with the development of heater-planer equipment in California (18,19). Since the 1930s, a wide variety of hot in-place recycling equipment has been developed and improved. Heater-scarifying equipment was developed by the 1960s and heater-remixing equipment was developed in the 1980s and 1990s. Heater-scarifiers were developed to heat, scarify, and reprofile the pavement. Over the years, equipment has been developed which allows for a greater depth of heating and scarification, as well as improved pavement smoothness associated with the laydown operation. Typical heater-scarification operations heat and scarify to depths of 10 to 25 mm (0.4 to 1 in). The use of hot millers in place of scarifiers and improved heaters has increased depth and versatility of the equipment.

Hot in-place recycling repaving equipment was developed in the 1950s and 1960s. A layer of hot-mix asphalt is applied on top of a heated and scarified layer. A single- or two-pass equipment operation can be used in the process, and scarification depths of 10 to 25 mm (0.4 to 1 in) are typical.

Hot in-place remixing operations were developed in the 1980s and 1990s. This equipment heats, scarifies, or hot mills the existing equipment, mixes new materials, and lays the combined recycled and new mixtures. Removal depths from 10 to 50 mm (0.4 to 2 in) are typical.

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