CHAPTER 1 INTRODUCTION

1.1 OVERVIEW

This chapter presents an overview of pavement preservation purpose, concept, benefits, and pavement preservation treatment selection and the optimum timing for a treatment. This chapter also provides a discussion on the fundamentals of flexible pavements, which provides a basic understanding of the factors affecting flexible pavement performance. A brief description of various distresses and distress mechanism associated with flexible pavements is also provided.

1.2 PURPOSE OF PAVEMENT PRESERVATION

In the simplest term, the purpose of pavement preservation is to keep good pavements in good or near new conditions by applying the right maintenance strategies at the right time to extend pavement life and preserve investments. This section briefly describes the definition, concept, benefits of pavement preservation and importance of treatment selection and the optimum timing for the treatments used.

1.2.1 Definition

Pavement preservation, as defined by the FHWA, is a program employing a network level, long-term strategy that enhances pavement performance by using an integrated, cost-effective set of practices that extend pavement life, improve safety and meet motorist expectations (FHWA, 2005). A pavement preservation program consists primarily of three components: preventive maintenance, minor rehabilitation (restoration), and some routine maintenance (FHWA, 2005). A pavement preservation program does not include pavements that require major rehabilitation or reconstruction.

1.2.2 Pavement Preservation Concept

Pavement preservation is a proactive approach in maintaining the existing highways. An effective pavement preservation program addresses pavements while they are still in good condition and before the onset of serious damage. By applying a cost-effective treatment at the right time, the pavement can be restored almost to its original condition. The cumulative effect of systematic, successive preservation treatments is to postpone or delay costly rehabilitation and reconstruction (FHWA, 2005). The pavement preservation treatments restore the function of the existing system and extend its life by reducing aging and restoring its serviceability, not increase its capacity or strength. Performing a series of successive pavement preservation treatments during the life of a pavement is less disruptive to uniform traffic flow than long closures normally associated with reconstruction projects (FHWA, 2005).

Pavement preservation is not simply a maintenance program, but an agency program. Essentials for an effective pavement preservation program include agency leadership, a dedicated annual budget, and support and input from staff in planning, finance, design, construction, materials, and maintenance.

1.2.3 Benefits of Pavement Preservation

An effective pavement preservation program can benefit Caltrans by preserving the roadway network, enhancing pavement performance, ensuring cost-effectiveness by extending pavement life, and reducing user delays by delaying major rehabilitation or reconstruction projects. Some of these benefits may be noticed immediately and some may be realized over time (Galehouse, Moulthrop, and Hicks, 2003).

1.2.4 Treatment Selection and the Optimum Timing for the Treatment

Figure 1-1 shows how a flexible pavement would typically perform under traffic and with time (dotted line). Various types of treatment stages are also shown in the figure. It clearly indicates that the pavement preservation should be carried out at early stage of the pavement life while it is still in good conditions both structurally and functionally. If the pavement is not maintained effectively, it will eventually deteriorate to a point where the only choice is reconstruction which is the most costly option.

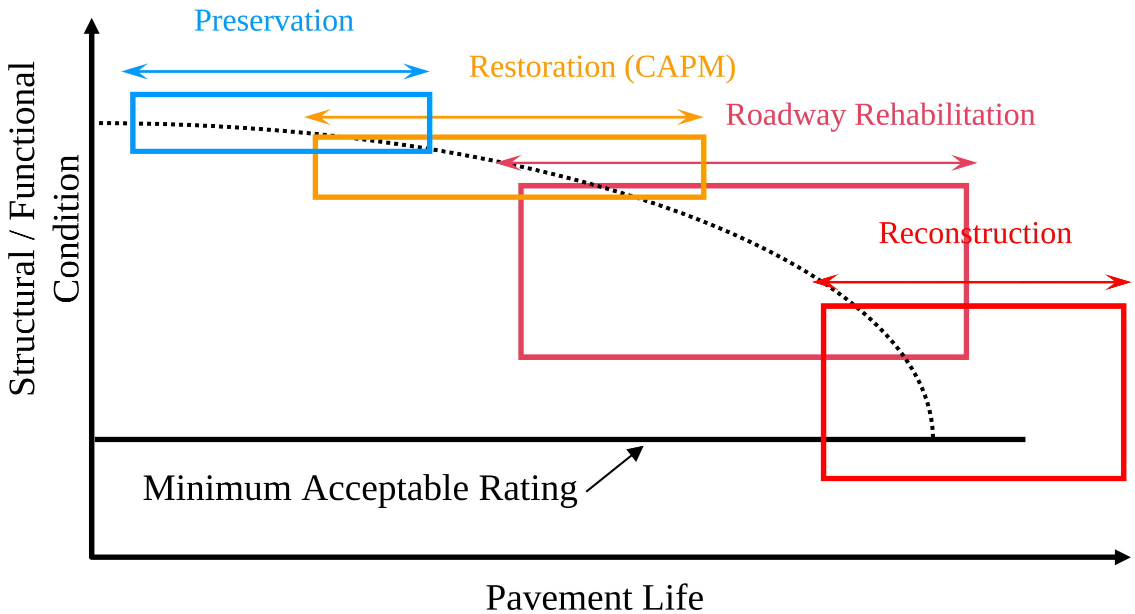

Figure 1-1 Typical pavement performance curve and maintenance/rehabilitation time

The timing of the application of the treatment has a significant influence on the effectiveness of the treatment in prolonging the performance of the pavement; therefore, applying the right treatment to the right pavement at the right time is of the core of pavement preservation. As indicated earlier, by applying cost-effective preservation treatments at the right time, the pavement can be maintained close to its original condition for a longer period of time. Timely application of a successive treatment can maintain the pavement in good condition and prolong the need for more expensive roadway rehabilitation and reconstruction strategies, as shown in Figure 1-2. This figure illustrates the concept of timely application of a treatment is important to maintain the existing pavement condition. The frequency of applying treatment will depend on the type of treatment that has been used and their life expectancy.

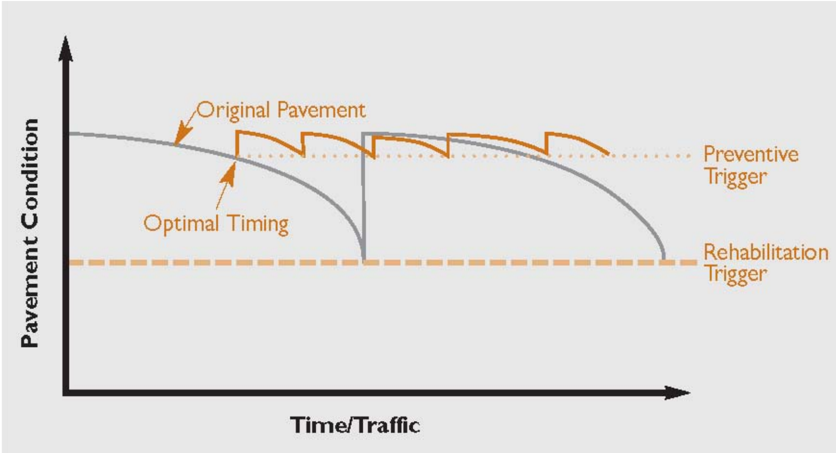

Figure 1-2 Concept of optimal timing for pavement preservation (Galehouse et al, 2003)

The timely application of preservation treatments is important as they not only improve pavement condition but also save money over the life of a pavement. Reconstruction or extensive dig-out and replacement strategies are far more costly than applying pavement preservation treatments. Figure 1-3 shows an example of the relative costs of preventive maintenance treatments in 1998 versus major rehabilitation treatments or reconstruction. When treatments are properly timed, preventive maintenance can produce savings over the life of the pavement (Zaniewski, 1996 and ISSA, 1998). In addition, subsequent maintenance treatments can be applied in a relatively quick manner resulting in fewer disruptions to the traveling public and less exposure to traffic for maintenance employees as compared with major rehabilitation or reconstruction activities.

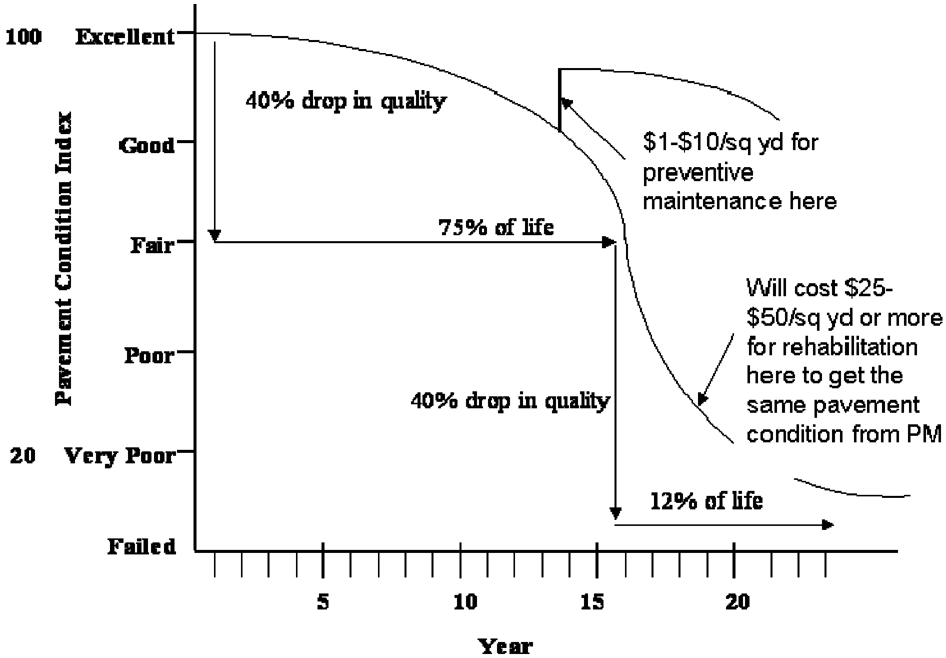

Figure 1-3 The Cost of NOT carrying out maintenance in a timely way

1.3 FUNDAMENTALS OF FLEXIBLE PAVEMENTS

1.3.1 Function of Pavements

Pavements are constructed to serve two primary functions. First , they serve the traveling public by providing a smooth, skid-resistant surface upon which vehicles may safely travel. Second, they must be structurally capable of withstanding the traffic and environmental loadings that are imposed upon them. A pavement may be considered failed if it does not adequately serve either one of these two functions.

Flexible pavements are one of several pavement types. They are the most common pavement types and are typically built with a hot-mix asphalt (HMA) surface or an asphalt surface treatment. A flexible pavement is very effective in providing load-carrying capacity, resisting distortion, providing a smooth riding surface, minimizing the intrusion of moisture from the surface, resisting traffic wear, and retaining anti-skid properties.

Flexible pavements typically consist of several layers of paving materials, as illustrated in Figure 1-4, which are built on natural soil, normally referred to as the subgrade soil. The top portion of the subgrade soil is compacted prior to placing the subbase or base. The subgrade soil ultimately carries all traffic loads. Thus, the function of a flexible pavement structure is to support a wheel load on the pavement surface and to spread or distribute the applied loads to the subgrade soil without exceeding its strength or that of various overlying pavement layers. Therefore, layers near the surface are generally constructed with paving materials of increasing quality and load-carrying capability.

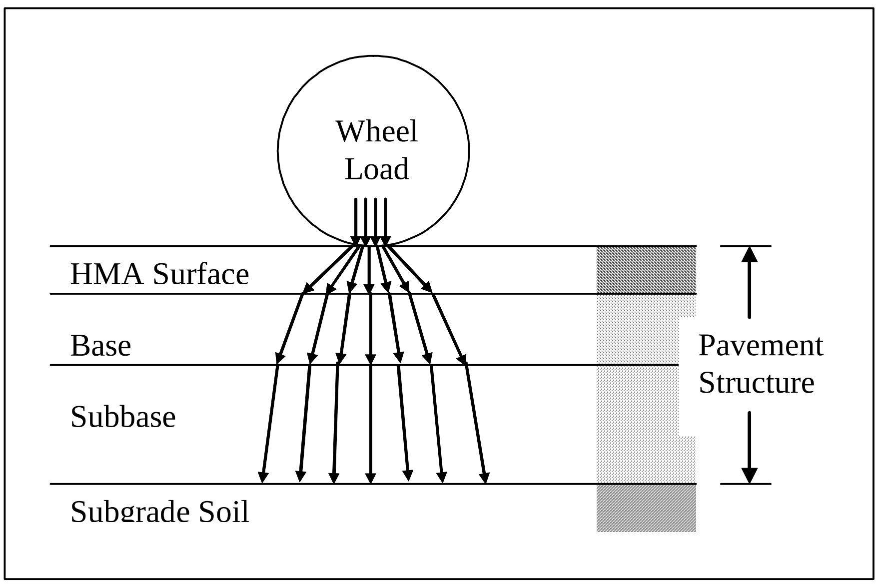

Figure 1-4 Typical flexible pavement structure and stress distribution (NHI, 2001)

1.3.2 Factors Affecting Pavement Performance

There are a number of factors that contribute to pavement distress and loss in performance. The key factors that can be affect pavement performance and/or impact pavement preservation treatment selection include:

- Subgrade Soil
- Pavement Materials Characteristics
- Traffic Loading
- Environment

Subgrade Soil

Pavement structures must rely upon the strength and stiffness of the underlying subgrade soil for support. As shown in Figure 1-4, one of the functions of a pavement structure is to distribute the stress from applied wheel loads to such an extent that the subgrade soil is protected from overstress. Because of this load distribution function, it is easy to understand why weak soils require thicker pavements than strong soils to provide the same protection against overstress due to traffic loadings.

From a pavement design and engineering standpoint, there are two general characteristics of the soil that are of interest, its classification and either its strength or stiffness. Soil classification provides the engineer with a good idea of the gradation and constituents of the subgrade soil. The strength of a material refers to the amount of load or stress it can withstand before failing (either through fracture or high deformation). The stiffness of a material refers to its capacity to resist deformation under applied loading. The two properties are distinctly different; however, they are highly correlated and often used as surrogates for one and other. The primary measures of soil strength include the California Bearing Ratio (CBR) and the unconfined compressive strength. The primary measures of stiffness are Hveem stabilometer (R-value) and elastic (or resilient) modulus. Although many of these measures have been adequate in the past for strength and stiffness characterization, the current trend is to consider more fundamental engineering properties, such as the elastic (or resilient) modulus. The resilient modulus is a measure of the pavement's response under load, and is thus better suited for long-term pavement performance prediction. Caltrans uses the R-value, unconfined compressive strength (for lime-treated subbases only), and the Gravel Factor (G_f) for pavement design purposes (Caltrans 2006).

Pavement Materials Characteristics

There are many materials that are used in the construction of a pavement. Typically, the individual ingredients or constituents fall under one of four different categories:

- Asphalt Cement
- Aggregate
- Modifiers for Asphalt Cement (e.g., Rubber and Polymers)
- Additives or Stabilizing Agents for Aggregates (e.g., Lime and Cement)

When the various ingredients are combined in proper proportions, they produce mixes (e.g., HMA, stabilized bases/subbases) that ultimately make up the structural components of the pavement. Obviously, high quality materials, good mixing and construction practices, and good quality control/quality assurance will help maximize the ultimate load-carrying capacity of the pavement.

Structural (or physical) characteristics of the pavement system have a significant impact on pavement performance. Structural characteristics for HMA pavements primarily include the layer types and their thicknesses. These characteristics can be controlled during the design and construction process. Another factor that influences pavement material properties and consequently affects pavement performance is the variation in material properties that occurs in construction and rehabilitation operations. For example, failure to achieve proper compaction, variable moisture conditions during construction, uniformity and quality of paving materials, and as-built layer thicknesses all directly affect performance.

Traffic Loading

Pavements are designed and constructed to withstand the stresses and strains caused by repeated wheel loadings that are sustained over the course of their life. Therefore, it is important to have a good knowledge of the amount of traffic loading expected on a pavement. The proper structure design of a pavement relies upon developing an accurate forecast of future loadings, which should include the following:

- Average Daily Traffic, ADT (initial number of vehicles per day)
- Future Projections (annual growth rate by vehicle type)
- Truck Factors or Load Equivalency Factors (to convert the distribution of vehicle loads into an equivalent number of load applications that can be used for design)
- Lane Distribution (percent of trucks in design lane)
- Directional Distribution (percent of trucks in design direction)

These factors are combined with the design period (up to 40 years for long-life pavements) to derive the 18,000 lb equivalent single axle load (ESAL) applications that must be sustained by the "design lane" (i.e., that lane of the pavement that carries the most ESAL applications and for which the pavement structure or overlay will be designed). The Caltrans flexible pavement design method converts the ESAL applications to a Traffic Index (TI) for pavement structural section design (Caltrans, 2006).

Environment

Moisture and temperature are two key environmental factors that have a significant impact on pavement performance:

- **Moisture:** Moisture enters a pavement structure through cracks in the surface, laterally from poor draining ditches, and from the underlying water table through capillary action. The presence of moisture in the soil and underlying layers of the pavement structure weakens those materials and thereby reduces their load-carrying capacity. The presence of moisture in an HMA layer can lead to a phenomenon known as stripping, which is the separation of asphalt cement from aggregate particles in the mix. Moisture in the soil in regions where freezing occurs can result in differential frost heave and thaw weakening. In addition, moisture changes in some clay soils can cause volume changes and pavement distortion and roughness. Because of the effects of moisture on pavement performance, significant attention should be given to drainage during pavement design and construction.

- **Temperature:** At high temperatures, asphalt cement softens and is more likely to experience permanent deformation (rutting) under wheel loading. At low temperatures, HMA will shrink (due to thermal contraction) and contribute to transverse (thermal) cracking. Also, at low to intermediate temperatures, HMA can become brittle and susceptible to fatigue cracking.

1.4 FLEXIBLE PAVEMENT DISTRESSES

Typical pavement structures include hot mix asphalt (HMA) layer(s), with or without any untreated or treated aggregate base layers, over the subgrade soil. Flexible pavement preservation typically includes thin overlays or seal coats.

In general, thin overlay, as defined in this Guide, is a non-structural layer and is applied as a maintenance treatment, either corrective or preventive. Seal coats are intended to improve the functional performance. The pavement distresses and distress mechanisms for flexible pavements can generally be classified into the following categories:

- Cracking
- Deformation
- Deterioration
- Mat Problems
- Problems associated with seal coats

Determination of applying a specific type of treatment will depend upon the types of distress, extent and severity of the distresses. In general, pavement preservation treatments should be applied to pavements with little or minor distresses to preserve the pavements while they are still in a good condition.

Distress photos shown in this chapter are from "*Guide to the Investigation and Remediation of Distress in Flexible Pavements*" (Caltrans, 2003) and "*Distress Identification Manual for the Long-Term Pavement Performance Program*" (FHWA, 2003).

1.4.1 Cracking

Longitudinal – Cracks that are approximately parallel to pavement centerline and are not in the wheel path. Longitudinal cracks are non-load associated cracks. Location within the lane (wheel path versus non-wheel path) is significant. Longitudinal cracks in the wheel path are normally rated as Alligator 'A' cracking.

Figure 1-5 Longitudinal Cracks

Fatigue – Cracks in asphalt layers that are caused by repeated traffic loadings. The cracks indicate fatigue failure of the asphalt layer. Hence, the term fatigue cracking is used. When cracking is characterized by interconnected cracks, the cracking pattern resembles that of an alligator's skin or chicken wire. Therefore, it is also referred to as alligator cracking.

Figure 1-6 Fatigue Cracks

Transverse – Cracks that are predominately perpendicular to pavement centerline and are not located over portland cement concrete joints.

Figure 1-7 Transverse Cracks

Reflective – Cracks in HMA overlay surfaces that occur over joints in concrete or over cracks in HMA pavements.

Figure 1-8 Reflective Cracks

Block – A pattern of cracks that divides the pavement into approximately rectangular pieces. Rectangular blocks range in size from approximately 0.1 square yard to 12 square yards.

Figure 1-9 Block Cracks

Edge – Crescent-shaped cracks or fairly continuous cracks that intersect the pavement edge and are located within 2 feet of the pavement edge, adjacent to the unpaved shoulder. Includes longitudinal cracks outside of the wheel path and within 2 feet of the pavement edge.

Figure 1-10 Edge Cracks

1.4.2 Deformation

Rutting – Longitudinal surface depression that develops in the wheel paths of flexible pavement under traffic. It may have associated transverse displacement.

Figure 1-11 Rutting

Corrugations – Transverse undulations appear at regular intervals due to the unstable surface course caused by stop-and-go traffic.

Figure 1-12 Corrugations

Shoving – A longitudinal displacement of a localized area of the pavement surface. It is generally caused by braking or accelerating vehicles, and is usually located on hills or curves, or at intersections. It also may have vertical displacement.

Figure 1-13 Shoving

Depression – Small, localized surface settlement that can cause a rough, even hazardous ride to motorists.

Figure 1-14 Depression

Overlay Bumps – In newly overlaid pavements, bumps occur where cracks in old pavements were recently filled. This problem is most prevalent on thin overlays.

Figure 1-15 Overlay Bumps

1.4.3 Deterioration

Delamination – Loss of a large area of pavement surface. Usually there is a clear separation of the pavement surface from the layer below. Slippage cracking may often occur as a result of poor bonding or adhesion between layers.

Figure 1-16 Delamination

Potholes – Bowl-shaped holes of various sizes in the pavement surface. Minimum plan dimension is 6 inches.

Figure 1-17 Potholes

Patching – Portion of pavement surface, greater than 0.1 sq. yard, that has been removed and replaced or additional material applied to the pavement after original construction.

Figure 1-18 Patching

Raveling – Wearing away of the pavement surface in high-quality hot mix asphalt concrete that may be caused by the dislodging of aggregate particles and loss of asphalt binder.

Figure 1-19 Raveling

Stripping – The loss of the adhesive bond between asphalt cement and aggregate, most often caused by the presence of water in asphalt concrete, which may result in raveling, loss of stability, and load carrying capacity of the HMA pavement or treated base.

Figure 1-20 Stripping

Polished Aggregate – Surface binder worn away to expose coarse aggregate.

Figure 1-21 Polished Aggregate

Pumping – Seeping or ejection of water and fines from beneath the pavement through cracks.

Figure 1-22 Pumping

1.4.4 Mat Problems

Segregation – Separation of coarse aggregate from fine aggregate as a result of mishandling of the mix at several points during mix production, hauling, and placing operations. Segregation leads to non-uniform surface texture and non-uniform density.

Figure 1-23 Segregation (HMA)

Checking – Short transverse cracks, usually 1 inch to 3 inches in length and 1 inch to 3 inches apart, which occur in the surface of the HMA mat at some time during the compaction process. The cracks do not extend completely through the depth of the course, but are only 3/8 to ½ inch deep.

Figure 1-24 Checking

Bleeding – Excess bituminous binder occurring on the pavement surface. May create a shiny, glass-like, reflective surface that may be tacky to the touch. Usually found in the wheel paths.

Figure 1-25 Bleeding (HMA)

1.4.5 Problem Associated Seal Coats

Rock Loss – Wearing away of the pavement surface in seal coats.

Figure 1-26 Rock loss

Segregation – Separation of coarse aggregate from fine aggregate as a result of mishandling of the mix at several points during mix production and placing operations. Segregation leads to non-uniform surface texture.

Figure 1-27 Segregation (seal coats)

Bleeding/Fat Spot – Excess binder occurring on the surface treated pavements. May create a shiny, glass-like, reflective appearance. Fat spots are localized bleeding.

Figure 1-28 Bleeding/fat spot (seal coats)

Delamination – Loss of portion of pavement surface treatment. Usually there is a clear separation of the surface treatment from the layer below.

Figure 1-29 Delamination (seal coats)

Distress types under each category along with primary mechanisms for each distress are summarized in Table 1-1. Note that many of these types of distress also occur on HMA patched or recycled surfaces and mechanisms for causing these distresses are similar to those of HMA.

Table 1-1 Distress Type and Mechanism

TYPE		MECHANISM
CRACKING	**Longitudinal**	Poorly constructed paving joint, shrinkage of surface layer due to temperature cycling or hardening of the asphalt. Longitudinal cracking can be load or non-load related depending on the location of the crack within the travel lane. Longitudinal crack in the wheel path also refers to the initial stage of fatigue (alligator) cracking. Note: longitudinal cracking due to thermal and/or shrinkage will be considered under the transverse and block-cracking categories.
	Fatigue	Repeated applications of tensile strain due to wheel loading cause the initiation (and propagation) of a crack at the bottom of the HMA layer. A secondary type of fatigue cracking is that which occurs in thick HMA layers from the top-down. This surface-initiated fatigue cracking is associated with the state of stress directly below a tire and usually takes much longer to appear than bottom-up cracking in thinner HMA layers.
	Transverse	Inadequate bonding between paving lanes due to poor construction techniques (improper joint compaction), shrinkage of asphalt surface due to low temperatures or hardening of asphalt cement, or reflective cracks caused by cracks below the surface. Transverse cracks caused by low temperature are referred to as thermal cracks which are due to contractive forces and restraint, supplied by 1) friction on the bottom of the HMA surface and 2) the continuity of the HMA layer itself, that causes the tensile stress to build up to such a point that it can exceed the tensile strength of the HMA layer thus initiating cracking.
	Reflective	Typically appears in an overlay as a result of movements in a crack or joint in the underlying pavement. Development is especially likely when the pavement below is a PCCP with long joint/crack spacings and poor load transfer.
	Block	Shrinking and hardening of the asphalt due to age and/or environment (temperature).
	Edge	Excessive vehicle loading (stress) at pavement edge. The problem is usually related to poor geometry, inadequate shoulders, and/or poor drainage near the pavement edge.

Table 1-1 Distress Type and Mechanism

TYPE		MECHANISM
DEFORMATION	**Rutting**	Excessive vertical compressive stresses on the HMA surface, base and subgrade soil causing non-recoverable permanent deformation in one or all layers in the pavement structure.
	Corrugations	Plastic movement in the HMA surface layer caused by traffic action on HMA with too much asphalt, too much fine aggregate, or smoothed course aggregate. Appearance is that of a washboard and it has a definite influence on ride quality.
	Shoving	Plastic movement in the HMA surface layer caused by traffic action on HMA with too much asphalt, too much fine aggregate, or smoothed course aggregate. The distress usually appears in localized areas and the deformation can be longitudinal as well as vertical.
	Depression	Localized consolidation or movement of the supporting layers beneath the surface course due to weakness or instability of the material.
	Overlay Bumps	Excessive uneven stress concentration at the crack caused by unstable crack filler, unstable HMA with low shear strength, and excessive moisture in the crack.
DETERIORATION	**Delamination**	Loss of bond between the surface and the layer below causing surface layer to be easily peeled off.
	Potholes	Traffic loads causing pavement disintegrates because of inadequate strength in one or more layers of the pavement, usually accompanied by the presence of water.
	Patching	Crack, settlement, or distortion in patched areas when the underlying cause of the original pavement defect is not corrected or that the utility trench was not properly backfilled forming a weak support underneath.
	Raveling	The result of a loss of adhesion between the asphalt binder and the aggregate causing the loss of material from pavement surface.
	Stripping	The presence of a prolonged high-moisture condition (together with an aggregate with a high-stripping potential) in asphalt bound layers leads to the debonding of the asphalt binder from the aggregate particles.
	Polished Aggregate	Surface binder worn away to expose aggregate due to traffic action and/or mix properties.
	Pumping	Seeping or ejection of water and fines from beneath the pavement through cracks or joints under the applications of heavy vehicle loadings.

Table 1-1 Distress Type and Mechanism

TYPE		MECHANISM
MAT PROBLEMS	**Segregation**	Improper mix handling during lay down of HMA causing coarse aggregate separated from fine aggregate and the compacted mix does not have desired density and uniformity.
	Checking	Primarily caused by two factors: excessive deflection of the pavement structure under compaction equipment and one or more deficiencies in the asphalt mix design. Incorrect mix design could result in a tender mixes that has very low resistance to deformation under horizontally applied shearing loads after compaction has been completed. The tender mixes normally resulted from a lack of inter-particle friction or shear strength and were generally material properties and/or construction related.
	Bleeding	Excessive asphalt in the mix relative to the void space in the mineral aggregate, therefore, the air voids in the mix are too low and the excess asphalt is forced to the pavement surface causing bleeding.
SEALS COATS	**Rock Loss**	Lack of bonding between aggregate and binder, plus traffic action causing rock breaking away from the compacted mixture. This problem occurs in chip sealed pavements.
	Segregation	Materials not properly mixed and placed during construction therefore not having a desired uniformity, strength and ability to sustain traffic action.
	Bleeding / Fat Spots	Due to excess binder.
	Delamination	Loss of bond between the surface treatment and the existing surface causing surface treatment material separated from the existing pavement surface.

1.5 DISTRESS TREATMENTS

One of the purposes of this guide is to provide guidance on selecting the most appropriate strategies to address various pavement distresses described earlier by applying pavement preservation treatments. Chapter 3 of this guide presents a framework for treatment selection while various treatment strategies are described in details in Chapters 4 through 13.

For distresses that are related to the existing pavement structure, pavement preservation treatments will not be appropriate; separate rehabilitation design(s) will need to be developed on a project basis. Nevertheless, the distress mechanisms described in the guide will still be useful for the development of the rehabilitation design. Tables 1-2 provides general guidelines for appropriate pavement preservation treatments of various types of distresses.

Table 1-2 General Treatment Guidelines for HMA Distress

CATEGORY	TYPE	DISTRESS SEVERITY LEVEL		
		LOW	MEDIUM	HIGH
Cracking	Longitudinal	Yes	No	No
	Fatigue	Yes	No	No
	Transverse	Yes	No	No
	Reflective	Yes	No	No
	Block	Yes	No	No
	Edge	Yes	No	No
Deformation	Rutting	Yes	No	No
	Corrugations	Yes	No	No
	Shoving	Yes	No	No
	Depression	Yes	No	No
	Overlay Bumps	Yes	No	No
Deterioration	Delamination	Yes	No	No
	Potholes	Yes	No	No
	Patching	Yes	No	No
	Raveling	Yes	No	No
	Stripping	No	No	No
	Polished Aggregate	Yes	No	No
	Pumping	No	No	No
Mat Problems	Segregation	Yes	No	No
	Checking	Yes	Yes	No
	Bleeding	Yes	No	No
Seals Coats	Rock Loss	Yes	Yes	Yes
	Segregation	Yes	Yes	Yes
	Bleeding / Fat Spots	Yes	Yes	No
	Delamination	Yes	No	No

1.6 REFERENCES

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