An ***AAPTP*** Research Report

Airfield Asphalt Pavement Technology Program

Technical Guide AAPTP 05-04 — Techniques for Mitigation of Reflective Cracks

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February 20, 2009

85-02

ACKNOWLEDGMENT OF SPONSORSHIP

This technical guide has been prepared for Auburn University under the Airport Asphalt Pavement Technology Program (AAPTP). Funding is provided by the Federal Aviation Administration (FAA) under Cooperative Agreement Number 04-G-038. Mr. Monte Symons serves as the Project Director for AAPTP Project 05-04.

The AAPTP and the FAA thank the Project Technical Panel that willingly gave of their expertise and time for the development of this report. They were responsible for the oversight and the technical direction. The names of those individuals on the Project Technical Panel follow:

1. Monte Symons
2. Rodney Joel
3. Stan Herrin
4. John Harvey
5. Darrell Bryan

ACKNOWLEDGEMENTS

Dr. Robert L. Lytton, P.E. participated as a consultant to the authors of this technical guide. Dr. Lytton reviewed the products from AAPTP Project 05-04 and provided expertise relative to the use of geosynthetic materials as an interlayer and reinforcement in HMA overlays to mitigate reflective cracks. His advice and participation on this project was greatly appreciated.

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TECHNICAL GUIDE
TECHNIQUES FOR MITIGATION OF REFLECTIVE CRACKS

CHAPTER 1 INTRODUCTION

1.1 Background

When hot mix asphalt (HMA) overlays are placed over jointed and/or severely cracked rigid and flexible pavements, the cracks and joints in the existing pavement can reflect to the surface in a short period of time. These cracks allow water to penetrate the underlying layers causing further damage to the pavement structure by destroying the bond between the existing pavement and overlay and causing moisture damage in the HMA layers, as well as weakening the unbound layers. Reflective cracks also pose safety problems for airfield pavements because of their potential to cause foreign object debris (FOD), and loss of ride quality or smoothness. These reflective cracks have to be maintained to prevent the generation of loose aggregate and increased roughness that can be detrimental to aircraft operations.

Numerous studies have attempted to develop methods and materials to prevent these cracks from occurring within the design period. Most of the materials and methods in use today, however, only briefly delay or limit the severity of the reflective cracks. One possible reason for the shortened service life of HMA overlays is that the rehabilitation strategy selected for a specific project is insufficient for the condition of the existing pavement.

1.2 Purpose of Technical Guide

The purpose of this Technical Guide is to provide guidance and recommendations to the Federal Aviation Administration (FAA) and others related to managing and designing rehabilitation strategies of airside pavements for mitigating reflective cracks. This guidance includes selection and use of materials and treatment methods to increase the time to the occurrence of reflective cracks in HMA overlays of rigid, flexible, and composite pavements. The Guide also provides guidance on the cost-effectiveness of different treatments for minimizing reflective cracking from experience gained of various organizations (both airfield and highway uses) and an evaluation of numerous airfields that have used different strategies.

1.3 Definition of Selected Terms

This section of the Guide provides the definition of selected terms related to reflective cracks.

Conventional Flexible Pavements—Flexible pavements that consist of relatively thin HMA surfaces (less than 6 inches [150 mm] thick) and unbound aggregate base layers (crushed stone or gravel, and soil-aggregate mixtures). Conventional flexible pavements may also have a stabilized or treated subgrade layer.

Crack or Break and Seat—The process of cracking or breaking the existing Portland cement concrete (PCC) slabs into short segments, while retaining structural integrity of the slabs. This process results in fine, vertical, transverse cracks in the existing PCC slab thereby reducing the effective length of the slab.

Crack Relief Layer—A specific cushion layer that consists of an open-graded HMA with larger aggregate. These layers have 25 to 30 percent air voids with a nominal maximum aggregate size of 1-inch (25 mm) or more.

Cushion Layer—A pavement layer placed on the existing pavement surface as part of the rehabilitation process that is greater than 3 inches (76 mm) in thickness. This layer absorbs or dissipates horizontal movements and differential vertical deflections that are concentrated at joints and cracks in the existing pavement. Cushion layers can consist of open-graded HMA mixture with large aggregate (crack relief layer, as defined above) or an unbound aggregate/crushed stone base material.

Deep Strength Flexible Pavements—Flexible pavements that consist of a relatively thick HMA surface and a dense-graded HMA or asphalt stabilized base mixture placed over an aggregate base layer. Deep strength flexible pavements may also have a stabilized or treated subgrade layer.

Differential Vertical Deflection—The difference between the deflections measured on opposite sides of a joint or crack. An impulse load is placed on one side of a joint or crack and the deflections are measured on both sides of the discontinuity to determine the amount of load transfer.

Full Depth Reclamation (In-Place Pulverization of Conventional Flexible Pavements)—Cold in-place recycling of the HMA and existing aggregate base layers. Cold in-place recycling as a rehabilitation strategy is considered reconstruction and would be defined as a new or deep-strength flexible pavement.

Full-Depth HMA Pavements—HMA layers placed on a stabilized subgrade layer or placed directly on the prepared embankment or foundation soil. Full-depth HMA pavements do not have an unbound granular or crushed stone base layer.

Gauge Length—The length over which horizontal movements from the underlying pavement are transferred to the HMA overlay. The gauge length can vary from the width of the crack or joint in the existing pavement when full bond is created between the existing pavement surface and HMA overlay to several feet either side of the crack or joint when using an interlayer.

Geogrids—Materials that may be woven or knitted from glass fibers or polymeric (polypropylene or polyester) filaments, or they can be cut or pressed from plastic sheets and then post-tensioned to maximize strength and modulus.

Geotextiles—Materials or fabrics that are woven or non-woven and composed of thermoplastics, such as polypropylene and polyester. The fabrics can also contain nylon, other polymers, natural organic materials or fiberglass. Common geotextiles manufacturer names include Petropave, Paveprep, Petromat, Mirafi, Typar, and Roadglass.

Heater Scarification—A process that heats and scarifies the existing HMA surface to a depth of less than about 1-inch (25 mm). A rejuvenating material is normally added to the scarified material, which is compacted prior to placing the HMA overlay.

Horizontal Movement—The total movement or widening of a joint or crack at the pavement surface that is caused by a drop or decrease in temperature.

Interlayer Stress Absorbing Composite (ISAC)—A composite layer or material combining the benefits from geotextile and SAMI layers. An ISAC system consists of a low stiffness geotextile as the bottom layer, a viscoelastic membrane layer as the core, and a very high stiffness geotextile for the upper layer.

Reflective Cracks—The FAA Advisory Circular (AC) AC-150/5380/6 (FAA, 2007) defines reflective cracking as cracks in the HMA overlay that reflects the crack or joint pattern in the underlying pavement. A more detailed description is that reflective cracks are fractures in an HMA overlay or surface course that are a result of, and reflect, the crack or joint pattern in the underlying layer, and may be either environmental or traffic induced.

Rubblization—The process of breaking or fracturing the existing PCC slabs in place into small, interconnected pieces that have a nominal maximum size between 3 to 8 inches (75 to 200 mm) in diameter. The rubblized PCC slab serves as a high quality granular base for the HMA overlay.

Stress Absorbing Membrane Interlayer (SAMI)—A layer of soft material that is relatively impermeable and applied on the surface of the existing pavement surface prior to placing the HMA overlay. SAMI layers are normally less than 1-inch (25 mm) and can consist of chip seals to thin modified bituminous mixtures.

Stress or Strain Relieving Interlayer (Membrane)—A non-structural layer that is less than 2 inches (50 mm) in thickness and placed on the surface of the existing pavement. This layer absorbs or dissipates horizontal movements that are concentrated at the joints or cracks in the existing pavement. The stress/strain relieving interlayer does not provide structural benefit but dissipates horizontal movements from the existing pavement prior to reaching the HMA overlay. They can consist of chip seals, fabrics, sand, and different stress absorbing membrane interlayer (SAMI).

CHAPTER 2 REFLECTIVE CRACKING MITIGATION STRATEGIES

Reflective cracks must be prevented to retain the structural integrity of the HMA overlay, prevent water intrusion, and maintain a smooth riding surface. Before any attempt can be made to prevent these cracks, the failure mechanisms must be defined. Once the mechanism is defined for a particular project, a mitigation strategy can be designed so that an economical determination of material properties and treatments can be established.

2.1 Mechanisms of Reflective Cracking

The basic mechanisms leading to the occurrence of reflective cracks are horizontal and differential vertical movements between the original pavement and HMA overlay. The classical theory on the cause of reflective cracks is shown in figure 1. Reflective cracks can be caused by horizontal movements from the expansion and contraction of the PCC slabs that are concentrated at the joints and cracks, and from increased vertical deflections at the joints and cracks.

The most common accepted cause of reflective cracks is from horizontal movements concentrated at joints and cracks in the existing pavement, and is referred to as thermally induced cracking (refer to figure 2). These horizontal movements are caused by temperature changes in the PCC slab. This development of reflective cracking due to environmental loadings are dependent upon the magnitude and rate of temperature change, slab geometry, gauge length across the joint or crack, and properties of the resurfacing material or overlay. Because of the bond between the HMA overlay and existing pavement, the tensile stresses and strains produced from joint movements become critical in the areas of the PCC joints and cracks (figure 2.a). Thus, all of these factors must be included in the evaluation of the environmental effects or loadings on the HMA overlay.

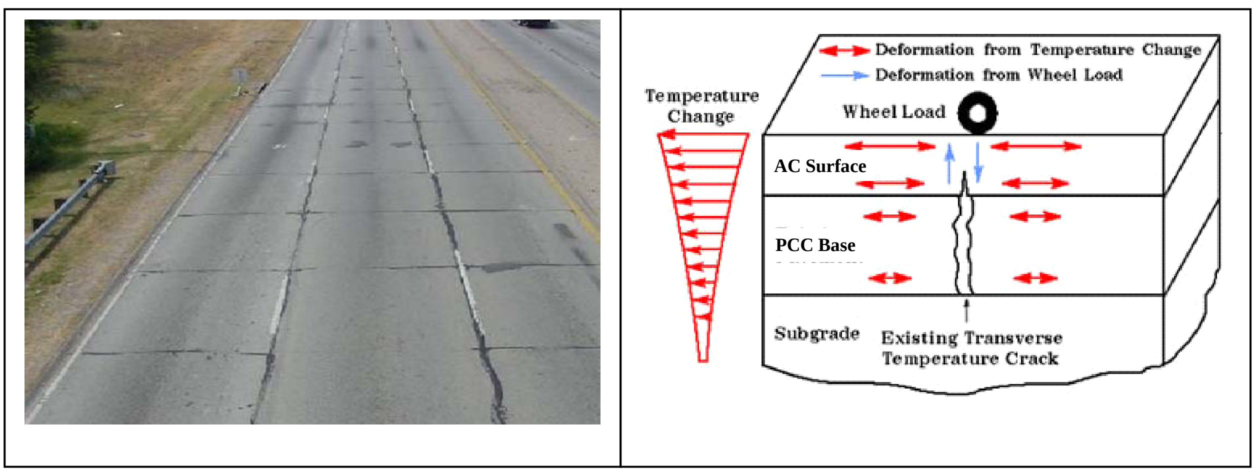
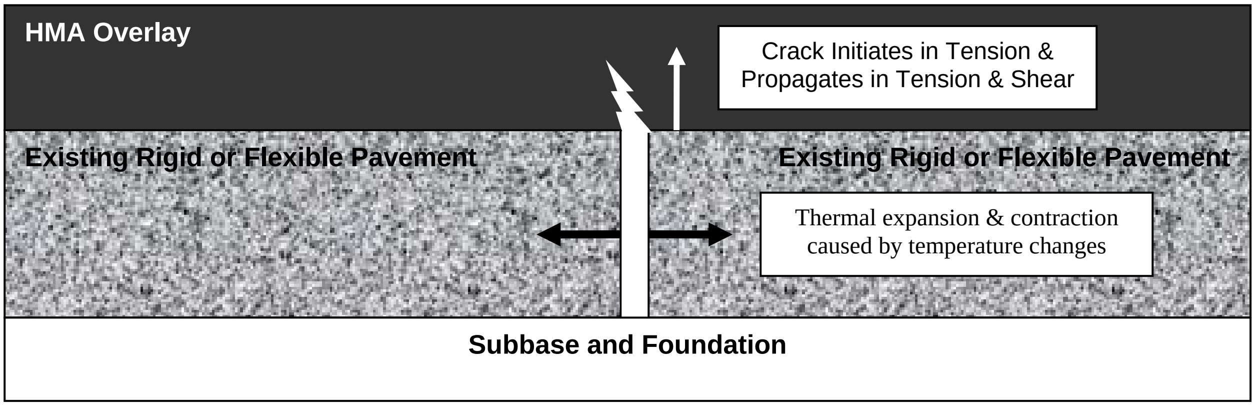
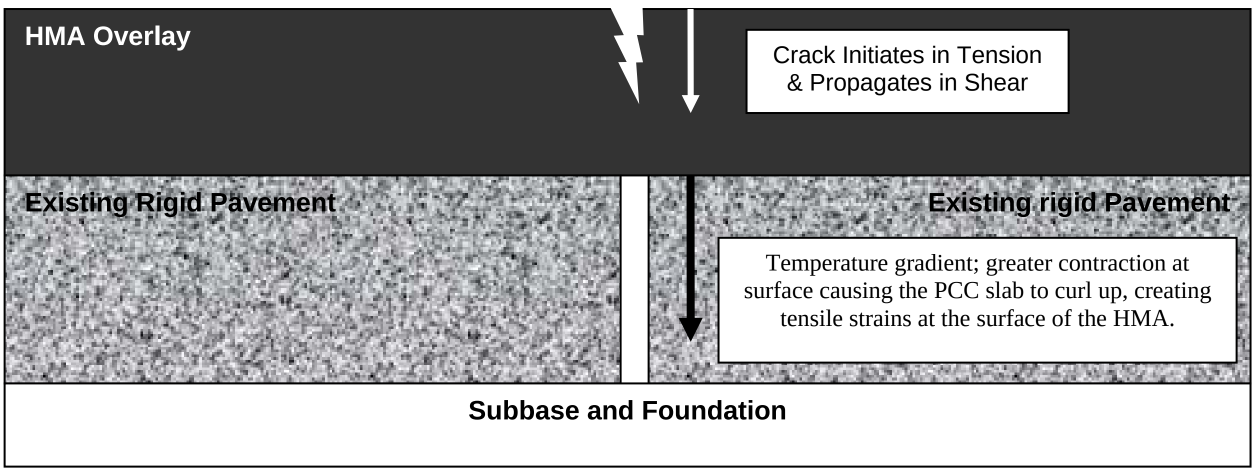


Figure 1. Reflective Cracking in HMA Overlays of PCC Pavements



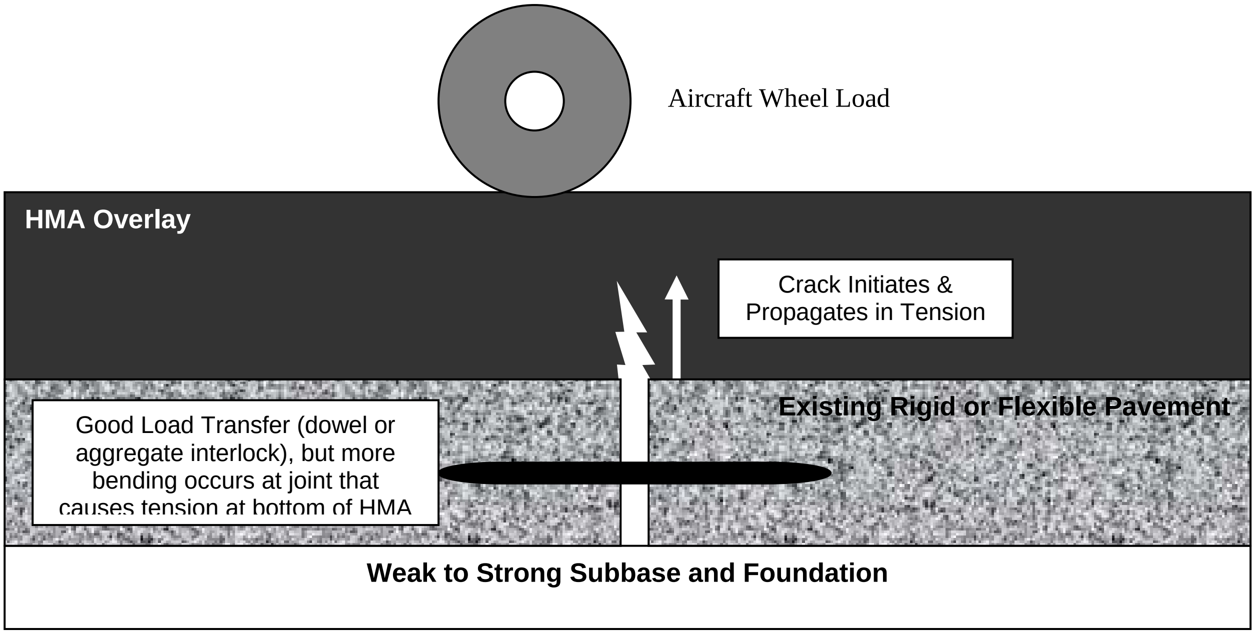
2.a. Thermally Induced Cracking; Horizontal Movements



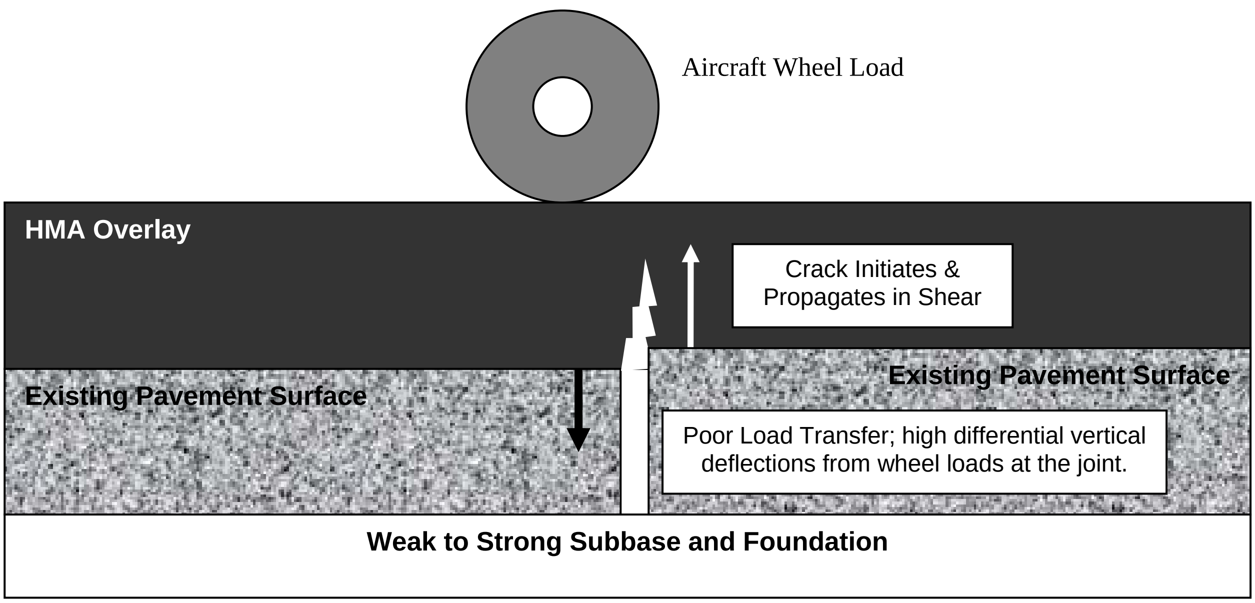
2.b. Thermally Induced Cracking; Curling of PCC Slab

Figure 2. Mechanisms of Thermally Induced Reflective Cracks in HMA Overlays

Reflective cracking can also be caused by differential vertical deflections across the joints and cracks in the existing pavement surface and is referred to as traffic induced cracking (refer to figure 3). Differential vertical deflections concentrated at the joints and cracks are caused by traffic loadings which depress abutting slabs ends resulting in shear-stress concentrations of the HMA overlay at the joints and cracks. The differential vertical deflections can be caused by the gradual reduction of load transfer at the joints and cracks in the PCC pavement or the development of voids beneath the PCC at the joints and cracks. Thus, reflective cracking caused by differential vertical deflections is a shear-fatigue phenomenon and is dependent on the magnitude of the differential vertical deflections across the joint or crack. The factors which are important include the magnitude of the wheel load, amount of load transfer across the joint or crack, and the differential subgrade support under the slab.



3.a. Traffic Induced Cracking



3.b. Traffic Induced Cracking

Figure 3. Mechanisms of Traffic Induced Reflective Cracks in HMA Overlays

A third mechanism that causes reflective cracks is the curling of PCC slabs during colder temperatures when the HMA overlay is stiff and brittle. Reflective cracks caused by this mechanism initiate at the surface where the majority of mixture aging takes place and propagate downward (refer to figure 2.b). The upward curl between adjacent slabs result in tensile stresses at the surface of the overlay, and when the tensile stress exceeds the tensile strength, a crack develops above the joint. HMA mixtures with higher air voids will age faster, resulting in higher modulus values but lower tensile strains at failure; in other words, brittle mixtures susceptible to cracking.

The cause of reflective cracks is a result of the combined effect of these wheel and environmental loadings. The cracks can initiate at the surface or bottom of the HMA overlay, and the rate of propagation depends on the overlay thickness, properties of the HMA overlay, type of reinforcement, if used, and foundation support condition.

In summary, the commonly attributed factors that cause movements at joints and cracks in the base pavement (termed trigger factors) are low temperatures (temperature drop), wheel loads, freeze-thaw cycles, aging of the HMA near the surface (level of air voids), and shrinkage of PCC, HMA, and cement treated base layers. Figure 1 provided an example of extensive reflective cracking in an HMA overlay of a PCC pavement and a conceptual sketch of thermal and wheel loading stresses leading to it (excluding the curling mechanism).

2.2 Concepts and Methods

The concepts used for designing or selecting methods to mitigate reflective cracks can be grouped into five categories, which are listed below and defined within the remainder of this section of the Guide. These categories or concepts are discussed in greater detail in the latter chapters of this Guide and can be used individually or in combination with each other.

Existing PCC or Rigid Pavements	Existing HMA or Flexible Pavements
1. Modify existing PCC surface.	1. Modify existing HMA surface.
2. Overlay layer/mixture modification.	2. Overlay layer/mixture modification.
3. Cushion layers.	3. Stress or strain relieving interlayer.
4. Reinforcement of HMA overlays.	4. Reinforcement of HMA overlays.
5. Crack control method.	5. Crack control method.

2.2.1 Modify/Strengthen Existing Pavement Surface

These treatment methods are used to remove the cracks in the existing pavement surface or adjust the joint condition of PCC pavements so that reflective cracking becomes a non-issue. These treatments include break and seat, crack and seat, and rubblization of PCC pavements, while full-depth reclamation (FDR), mill and replace or inlay, hot in place recycling (HIPR), and heater scarification methods are used for HMA pavements. The following summarizes the conditions where these methods should be considered.

- Existing PCC Surface:
  - Break and seat and crack and seat methods are used to fracture the PCC slab into a shorter joint spacing of jointed plain and reinforced concrete pavements to reduce

    the horizontal movements concentrated at the joints and to reduce the curling of the PCC slab at the joints.
  - Rubblization is used to fracture the PCC into small pieces, eliminating the horizontal and differential vertical movements concentrated at the joints and cracks in the PCC slabs. Although the rubblized PCC layer is similar in response to a good quality crushed stone, Buncher, et al. (2008) reported that the rubblized layer is much stiffer than a good quality crushed stone base material. The backcalculated elastic modulus values reported by Buncher, et al. ranged from 100,000 to 400,000 psi (700 to 2,800 MPa).
- Existing HMA Surface:
  - FDR is used to remove all cracks within the HMA layers. This method is typically confined to pavements with HMA layers less than 6 inches (150 mm) in thickness.
  - Mill and replace or inlay is used when the cracking is confined to the HMA wearing surface. The cracked HMA wearing surface is removed and replaced so that reflective cracking will be a non-issue.
  - HIPR methods are also used when the cracks are confined to the HMA wearing surface.
  - Heater scarification is used when the cracks initiate at the surface and are propagating downward. The heater scarification process does not eliminate the cracks, but reduces the stress concentrations at the tip of the crack and fills the portion of the crack that remains below the scarification depth.

2.2.2 Cushion Layer

These treatments are defined as layers greater than 3-inches (75 mm) in thickness and provide structural support to the pavement. Cushion layers consist of open-graded HMA mixtures with large aggregate and unbound aggregate or crushed stone base materials. Several advantages of using a cushion layer are listed below.

- It insulates the existing PCC slab, decreasing localized horizontal movements and curling at the joints and cracks.
- It reduces horizontal movements transferred from the existing slab to the overlay by breaking or reducing the bond between the overlay and existing pavement.
- It absorbs or distributes some of the differential deflection at joints and cracks because of the increased layer thickness and lower modulus material of the cushion layer.

Theoretically, this treatment method should mitigate reflected cracks caused by all three failure mechanisms listed above (refer to figures 2 and 3).

2.2.3 Stress and Strain Relieving Interlayer

These treatment methods are defined as layers less than 2 inches (50 mm) in thickness, that offer negligible structural benefit to the pavement. Thus, they are referred to as an interlayer or membrane. The specific methods include bond breakers (stone dust, sand, etc.), chip seals, fabrics, and composite layers. The chip seals and other composite materials included under this category are also referred to as a stress absorbing membrane interlayer (SAMI).

Conceptually, the use of a SAMI over joints and cracks increase the gauge length for the development of strain (decreasing the potential of reflective cracks caused by environmental loadings) and/or dissipate horizontal movements from the existing surface to the overlay. There is no increase in the structural capacity of the pavement contributed by the stress/strain relieving interlayer. Thus, traffic induced reflective cracking (caused by differential deflections) may not be improved. These treatments have minimal ability to distribute shear stresses or differential vertical deflections across the joint or cracks in the existing pavement surface.

Caution must be taken when a stress or strain relieving interlayer is used in areas where turning and braking movements occur because thin overlays (2 inches [50 mm] or less) tend to shove under horizontal loading from aircraft.

2.2.4 Overlay Layer/Mixture Modification

This treatment method includes specialty mixtures for the overlay; such as polymer modified asphalt (PMA), stone matrix asphalt (SMA), and rubber modified asphalt mixtures. Increasing the thickness of the HMA overlay is included within this category.

In summary, this treatment method improves the fracture resistance of the overlay and reduces the deterioration around the reflective cracks once they occur. Use of this method does not prevent reflective cracks from occurring, but controls or reduces the severity of reflective cracks with time and aircraft operations. In other words, it keeps the crack severity to a low level. The one exception to the above statement is that rubber modified asphalt mixtures have been found to delay the occurrence of reflective cracks (refer to Chapter 6).

2.2.5 Reinforcement of HMA Overlay

Steel, fabrics, and geogrids have been used as reinforcement in HMA overlays. The purpose of the reinforcement is to distribute the stresses caused by horizontal and vertical movements occurring at the joints and cracks, decreasing the potential of reflective cracking caused by all failure mechanisms. Reinforcement of HMA overlays will not prevent reflective cracks from occurring when large differential vertical movements occur at the joints, but will keep the reflective cracks tight or narrow.

2.2.6 Crack Control Method

Crack control methods are used to control the severity of reflective cracks and not to prevent or delay reflective cracks. The common crack control method is saw and seal joints in the HMA overlay above joints in PCC pavements. Crack control has also been used for existing flexible pavements with regularly spaced transverse cracks, without irregularly shaped cracks. The concept is to control the crack location in the HMA overlay and maintain the joint over time—just like for joints in PCC pavements.

CHAPTER 3 SITE INVESTIGATION AND ASSESSMENT OF CONDITION

3.1 Purpose of Site Investigation

Rehabilitation design requires an evaluation of the existing pavement to provide key information. The purpose of any site investigation is to determine the strength and condition of the existing pavement structure. The first step in the pavement rehabilitation design process involves assessing the overall condition of the existing pavement and fully defining the existing pavement problems. To avoid making an inaccurate assessment of the problem, the engineer needs to collect and evaluate sufficient information about the existing pavement's condition. High-speed nondestructive testing data, such as GPR and deflection basin testing are excellent pavement evaluation tools to assist in making decisions related to timing of the improvement and additional data collection effort needed.

FAA Advisory Circular (AC) 150/5320-6[1] should be followed in assessing the condition of the pavement. The remainder of this chapter of the Guide provides recommendations for the site investigation specifically related to determine the crack features in the existing pavement that are needed to select a mitigation strategy for reflective cracking. Table 1 contains a checklist of factors designed to identify the problems that need to be addressed during rehabilitation design related to reflective cracking potential.

3.2 Field Test Equipment and Pavement Evaluation Levels

A rehabilitation design strategy requires extensive information about the existing pavement. No additional field test equipment is needed for selecting a mitigation strategy for reflective cracking than is used for any pavement evaluation to assess the pavement's structural condition under FAA AC 150/5320-6. The field test equipment used to assess the condition of the pavement related to reflective cracks includes deflection basin measuring device (falling weight deflectometer [FWD])[2], a coring rig, and ground penetrating radar (GPR), as a minimum.[1] The deflection basin measurements are used to calculate the elastic modulus of the structural layers of the pavement structure. FAA AC 150/5320-6 also notes that infrared thermography equipment can be used to determine some physical properties of the pavement, including the capability to detect delamination (debonding) between adjacent layers. Seismic stiffness measuring equipment is another nondestructive testing (NDT) device to evaluate the quality of existing HMA layers of flexible and composite pavements. The seismic test equipment and GPR, in combination with cores, can be used to identify areas with stripping or moisture damage (Von Quintus, et al., 2006 and 2008).

Not all airfield owners or operators, however, will have the funds to complete a full pavement evaluation program for rehabilitation design and in making decisions to mitigate reflective cracks (refer to Chapter 4). The following summarizes the minimum data elements that are needed for different pavement evaluation levels.

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[1] FAA AC 150/5320-6, Airport Pavement Design and Evaluation
[2] FAA AC 150-5370-11, Use of Nondestructive Testing Devices in the Evaluation of Airport Pavements

Table 1. Checklist of Factors for Overall Pavement Cracking Assessment

<table>
<tr><th>Item</th><th>Factors</th><th colspan="2">Description</th></tr>
<tr><td rowspan="5">Structural Adequacy</td><td>Existing Structural Cracks</td><td colspan="2">1 Little or no load/fatigue-related cracking distress
2 Moderate load/fatigue-related distress (possible deficiency in load-carrying capacity)
3 Major load/fatigue-related distress (obvious deficiency in current load-carrying capacity)
4 Load-carrying capacity deficiency: (yes or no)</td></tr>
<tr><td>Nondestructive testing (FWD deflection testing)</td><td colspan="2">1. High deflections or weak layers: (yes or no)
2. Are back-calculated layer moduli reasonable?
3. Are joint/crack load transfer efficiencies reasonable?</td></tr>
<tr><td>Nondestructive testing (GPR testing, in combination with seismic testing)</td><td colspan="2">1. Determine layer/lift thickness.
2. Are voids located beneath PCC pavements?
3. Do any of the HMA layers have stripping or moisture damage (refer to material durability)?</td></tr>
<tr><td>Nondestructive testing (profile testing)</td><td colspan="2">1 Minor Joint/Crack faulting
2 Moderate joint/crack faulting
3 Severe joint/crack faulting</td></tr>
<tr><td>Destructive testing; drill cores from pavement surface.</td><td colspan="2">1. Do the cracks extend through the entire thickness of the HMA layers?
2. Is there good bond between the different HMA layers and lifts?
3. Do the cores show any signs of material durability issues or problems?</td></tr>
<tr><td rowspan="4">Materials Durability; Non-Load Related Distress</td><td>Presence of thermal induced, transverse cracks or mid-slab cracks.</td><td colspan="2">1. Little to no transverse/block or mid-slab cracking.
2. Moderate transverse/block or mid-slab cracking.
3. Extensive transverse/block or mid-slab cracking.</td></tr>
<tr><td>Presence of durability-related distress; D-cracking for PCC & raveling for HMA.</td><td colspan="2">1. Little to no durability-related distress.
2. Moderate durability-related distress
3. Extensive durability-related distress</td></tr>
<tr><td>Base erosion or stripping</td><td colspan="2">1. Little or no base erosion or stripping
2. Moderate base erosion or stripping
3. Major base erosion or stripping</td></tr>
<tr><td>Nondestructive testing (GPR & seismic testing)</td><td colspan="2">Determine areas with material deterioration/moisture damage (stripping)</td></tr>
<tr><th>Item</th><th>Factors</th><th colspan="2">Description</th></tr>
<tr><td rowspan="2">Miscellaneous</td><td><u>PCC joint damage:</u>
• Is there measurable faulting (transverse joints)?
• Is there measurable faulting (centerline joint)?
• Is there joint seal damage (sealant is cracked)?
• Is there joint spalling (transverse), more than 10% of length?
• Is there joint spalling (longitudinal), more than 10% of length?
• Have there been any blowups?</td><td>Yes</td><td>No</td></tr>
<tr><td><u>HMA construction joints:</u>
• Have the construction joints opened or cracked?
• Do the construction joints have secondary cracks?
• Do the construction joints have raveling along the edges?</td><td>Yes</td><td>No</td></tr>
<tr><td colspan="4">NOTE: FAA AC 150/5380-6 (Chapter 4), dated September 2007, provides guidelines for the inspection of airfield pavements; while AC 150/5320-6 (Chapter 6) provides discussion on conducting airfield pavement evaluations for both flexible and rigid pavements.</td></tr>
</table>

Evaluation Level 1— Basic Information or Minimum Data Elements Needed
The following lists the basic and minimum data elements that are needed for selecting an appropriate reflective cracking mitigation strategy for repairing flexible and rigid pavements:

1. Conduct condition surveys to define the type, extent, and severity of cracking, and measure the amount of faulting for jointed PCC pavements.
2. Drill cores and borings to recover materials for visual inspection, layer thickness measurements, and identification of subsurface materials. The cores should also be used to identify material deterioration and to determine whether the cracks are confined to the wearing surface or extend through the entire HMA layer. The depth of cracking and whether the cracks initiated at the surface of the pavement or at the bottom of the HMA layer is important is selecting a cost effective rehabilitation strategy to mitigate reflective cracks.
3. Perform dynamic cone penetrometer (DCP) tests through the cores to measure the strength of the unbound layers or materials for rehabilitation design.

Assumptions that must be made using the minimum data elements:
- The condition survey data, cores, borings, and DCP tests are used to estimate whether the existing pavement is structurally adequate for the existing and future aircraft traffic operations.
- The condition survey data and DCP tests are used to estimate the magnitude of the differential vertical deflections or load transfer across the joints and transverse cracks in the existing pavement.
- The condition surveys, visual examination of cores, and DCP tests are used to estimate whether there are voids or other material problems beneath the pavement surface.
- Climate is used with the joint spacing or average spacing between the transverse cracks to estimate the amount of annual horizontal movements that will be concentrated at the joints and cracks.

Evaluation Level 2— Pavement Response Measurements or Determining the In Place Structural Condition of Pavement Layers
The following lists the additional information and data elements beyond evaluation level 1 for selecting an appropriate reflective cracking mitigation strategy for repairing flexible and rigid pavements:

4. Perform heavy weight deflectometer (HWD) deflection basin measurements in areas without cracking to determine the structural response of the pavement under different test loads and at different temperatures during the day or night.
5. Perform some deflection basin tests across the joints or cracks in the existing pavement. The deflection basins at the joints and cracks are used to estimate load transfer and measure the differential vertical deflections across the joints and cracks. FAA AC 150-5370-11 provides guidance on the use of nondestructive testing devices for assessing the pavement structural condition; both in measuring the deflections and data analyses for use in rehabilitation design.

Assumptions that must be made using evaluation level 2 data elements:

- The deflection basin measurements made in areas without cracks, as well as across cracks and joints, in combination with the condition surveys are used to estimate whether there are voids beneath the surface and the strength of the supporting layers.
- The deflection basin measurements in areas without cracks and condition surveys are used to estimate whether the existing pavement structure is adequate for the existing and future aircraft traffic operations.
- Climate is used with the joint spacing or average spacing between the transverse cracks to estimate the amount of annual horizontal movements that will be concentrated at the joints and cracks.

Evaluation Level 3— Full Pavement Evaluation to Define the In Place Material/Layer Condition and Design Data

The following lists the additional information and data elements beyond evaluation level 2 for selecting an appropriate reflective cracking mitigation strategy for repairing flexible and rigid pavements:

6. Perform ground penetrating radar (GPR) test to determine the layer thickness deviations, identify whether there are voids beneath the existing pavement, and locate any potential areas with material defects or material degradation problems (for example; HMA stripping or moisture damage). The GPR is also used to determine the magnitude or extensiveness of the voids and material defects. As noted in the introduction paragraph to section 3.2, GPR is used in combination with other devices (such as the HWD or seismic testing equipment) to more accurately estimate the extensiveness of material defects.
7. Conduct laboratory tests of the recovered materials to characterize the bound and unbound layers. The laboratory tests should include volumetric, as well as strength and modulus tests.
8. Measure the horizontal movements across the joints or transverse cracks during daily temperature cycles to estimate the magnitude of annual horizontal movements concentrated at the cracks and joints based on the climate and joint spacing or average spacing between the transverse cracks.
    - At a representative number of joints or cracks, mark either side of the discontinuity at three to four points equally spaced along the joint or transverse crack, and measure the difference between the marks with a micrometer over a range of temperatures during the day or longer period of time. A minimum temperature difference of 20 °F (11 °C) should be used for joint or crack spacing exceeding 20 feet (6 m). Greater temperature differences are usually needed for a shorter joint or crack spacing.
    - Based on the measured horizontal movements over a limited temperature difference, estimate the annual horizontal movements that are expected over time. The expected annual horizontal movements are used to determine the tensile strain at the bottom of the overlay using mechanistic modeling techniques, which are beyond the scope of this Technical Guide.

3.3 Existing Rigid Pavements

The extent of cracking and condition of those cracks and joints in the existing PCC layer need to be determined in selecting the rehabilitation strategy. The type and causes of cracking in PCC pavements are varied and include: mid-slab cracks, corner cracks, D-cracking, and spalling along cracks and joints.

The type and condition of the cracks should be determined in accordance with FAA AC 150/5380-6 and ASTM D 5340.[3] The load transfer should be measured across some of the joints and cracks with the FWD, HWD or an equivalent device. GPR should be used to determine if voids are present under existing PCC slabs.

3.4 Existing Flexible Pavements

The condition and depth of the existing cracks should be determined for selecting a rehabilitation strategy to mitigate reflective cracks. The type and causes of cracking in HMA surfaced pavements are varied and include: fatigue cracking, longitudinal cracking within and outside the wheel paths, transverse cracking, block cracking, edge cracking, and cracking along construction joints. The type and condition of the cracks should be determined in accordance with FAA AC 150/5380-6 and ASTM D 5340.

The depth of the cracks are important relative to flexible pavements and can only be determined though the use of cores. Some cores should be drilled and recovered directly over the cracks to determine the depth of cracking and whether those cracks extend through the entire HMA layers. As part of the coring program, the cores should be visually inspected to estimate the condition of the bond between the different HMA lifts and layers and identify any layers that began to disintegrate under wet coring operations—suggesting moisture damage or stripping.

Nondestructive deflection testing should also be used to measure the deflection basins in areas with fatigue cracking to determine the in place stiffness of the cracked HMA layers. Deflection testing should also be measured across transverse cracks in the same manner as for joints and cracks in PCC surfaces (refer to subsection 3.3).

Another important condition assessment of HMA mixtures is the presence of moisture damage in HMA mixtures. A combination of GPR and seismic testing should be used to determine if stripping or moisture damage is present in the existing HMA layers. Cores are also used to confirm the results from the GPR and seismic tests.

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[3] FAA AC 150/5380-6, Guidelines and Procedures for Maintenance of Airport Pavements; and ASTM D 5340, Standard Test Method for Airport Condition Index Survey

3.5 Existing Composite Pavements and Existing HMA Overlays of Rigid Pavements

The assessment of existing composite pavements or existing HMA overlays of rigid pavements includes the same items for both existing rigid and flexible pavements (refer to subsections 3.3 and 3.4).

CHAPTER 4 IDENTIFICATION OF MITIGATION METHODS

A common reason for failure of the mitigation methods is that they have been used under inappropriate conditions. As an example, using stress/strain relieving layers on jointed plain concrete pavement (JPCP) that have extensive cracking and poor load transfer across the joints. This chapter includes decision trees for selecting appropriate reflective cracking mitigation techniques and methods that depend on the type and condition of the existing pavement. The chapters that follow provide information on the assumptions, properties, and features of the mitigation methods that should be used or considered with the design method in determining the thickness of the HMA overlay.

4.1 Structural Design Method/Procedure

Cracks and joints represent the weakest part of the existing pavement and the first cracks to appear in the overlay will, in most cases, be located over those discontinuities. An appropriate rehabilitation strategy is to design the overlay so that the discontinuities do not cause the overlay to reach a level of cracking or other distresses requiring additional repairs within the design period.

A conservative approach is to decrease the structural support of the existing pavement to a value equivalent to a severely cracked pavement. This conservative approach is generally expensive and the least cost effective. A more cost effective approach is to design the overlay (material types and layer thickness) based on the overall condition of the pavement and use an engineered design methodology that eliminates the mechanisms of reflective cracking (refer to chapter 2) within the design period.

The use of empirical pavement design procedures makes the quantification of the design life difficult to determine. Thus, a more detailed procedure is needed for designing the overlay to mitigate reflective cracks. This Technical Guide does not recommend a specific design procedure, but provides general guidance on how to consider different reflective cracking mitigation strategies so that a cost effective and reliable design can be determined.

The HMA overlay thickness should be determined based on an appropriate overlay design method, including FAA AC 150-5320-6. It is also recommended that mechanistic-empirical (M-E) analysis-based methods be used to confirm the overlay thickness to ensure that the rehabilitation design and reflective cracking mitigation strategy will not exhibit premature distress (cracking, distortions, and mixture disintegration).

4.2 Decision Trees Identifying Appropriate Mitigation Methods

Figures 4 through 6 are decision trees for selecting a mitigation method to minimize the impact of reflective cracking on the rehabilitation design for different types of existing pavements. The decision trees were prepared based on the results from previous research studies, forensic investigations of rehabilitation strategies with the methods identified in Chapter 2, a detailed survey of selected airfield projects, and experience documented in the literature.

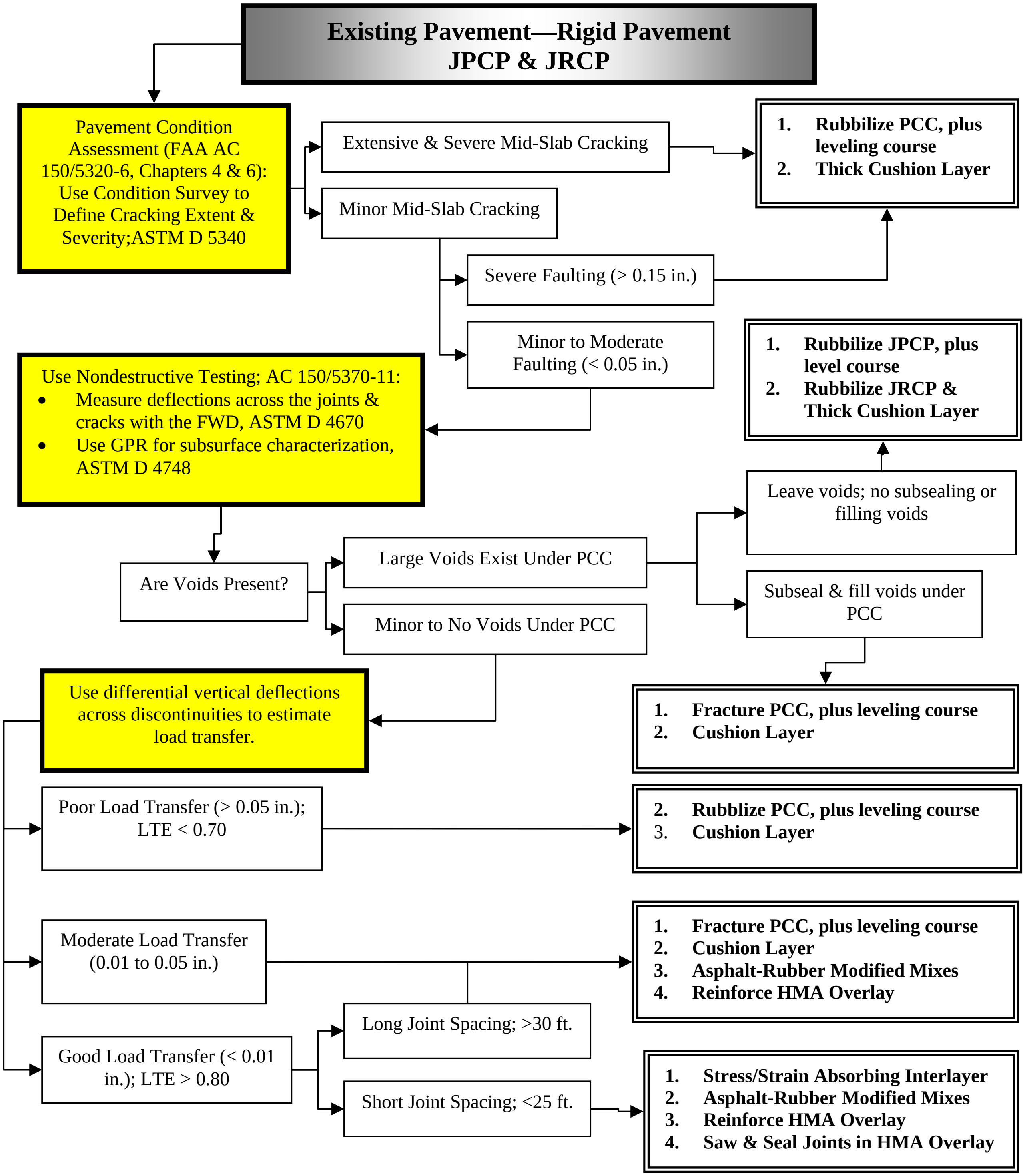

Figure 4. Decision Tree Providing Guidance to Mitigate Reflective Cracks in HMA Overlays of Existing Rigid Pavements

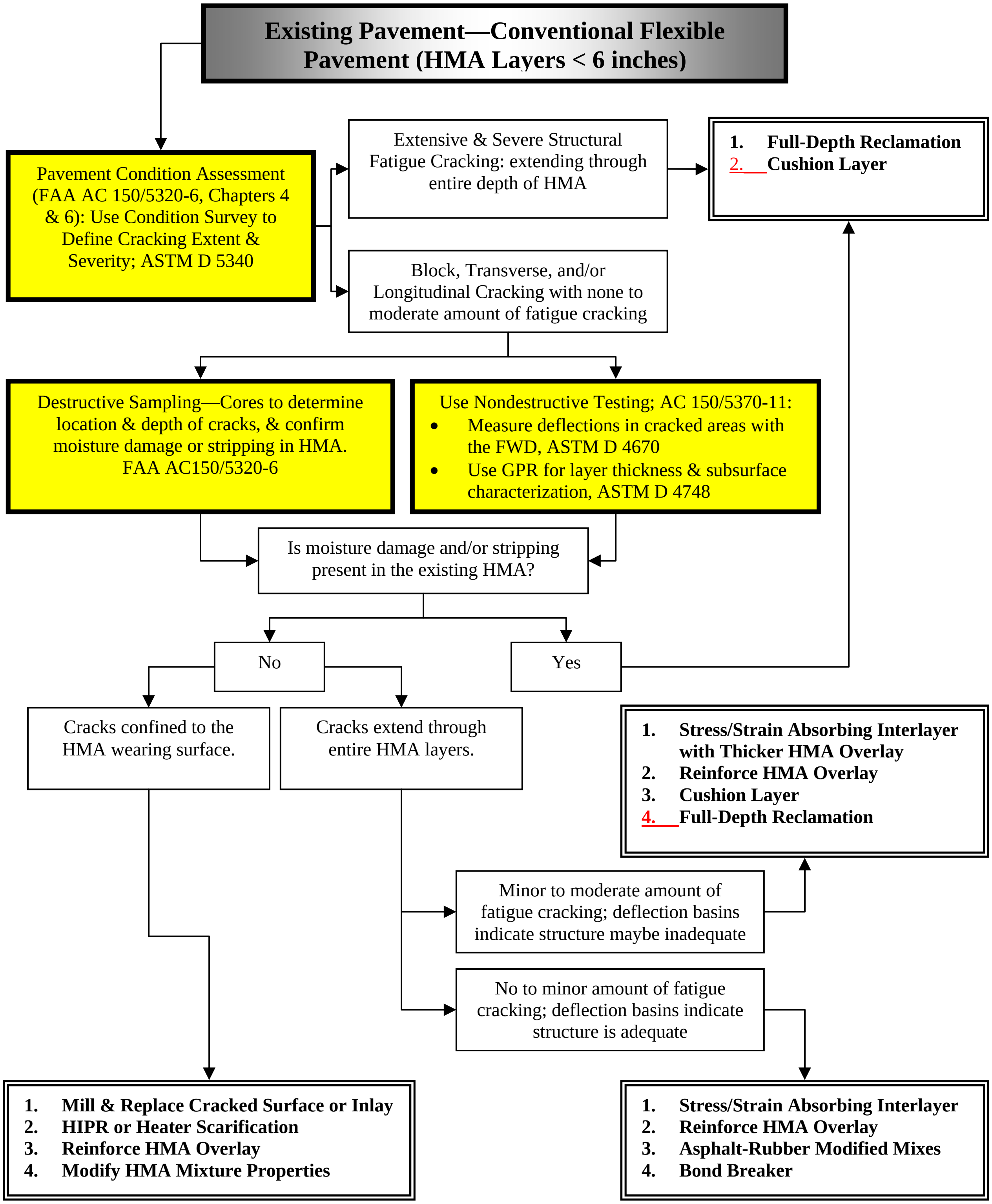

Figure 5. Decision Tree Providing Guidance to Mitigate Reflective Cracks in HMA Overlays of Existing Conventional Flexible Pavements

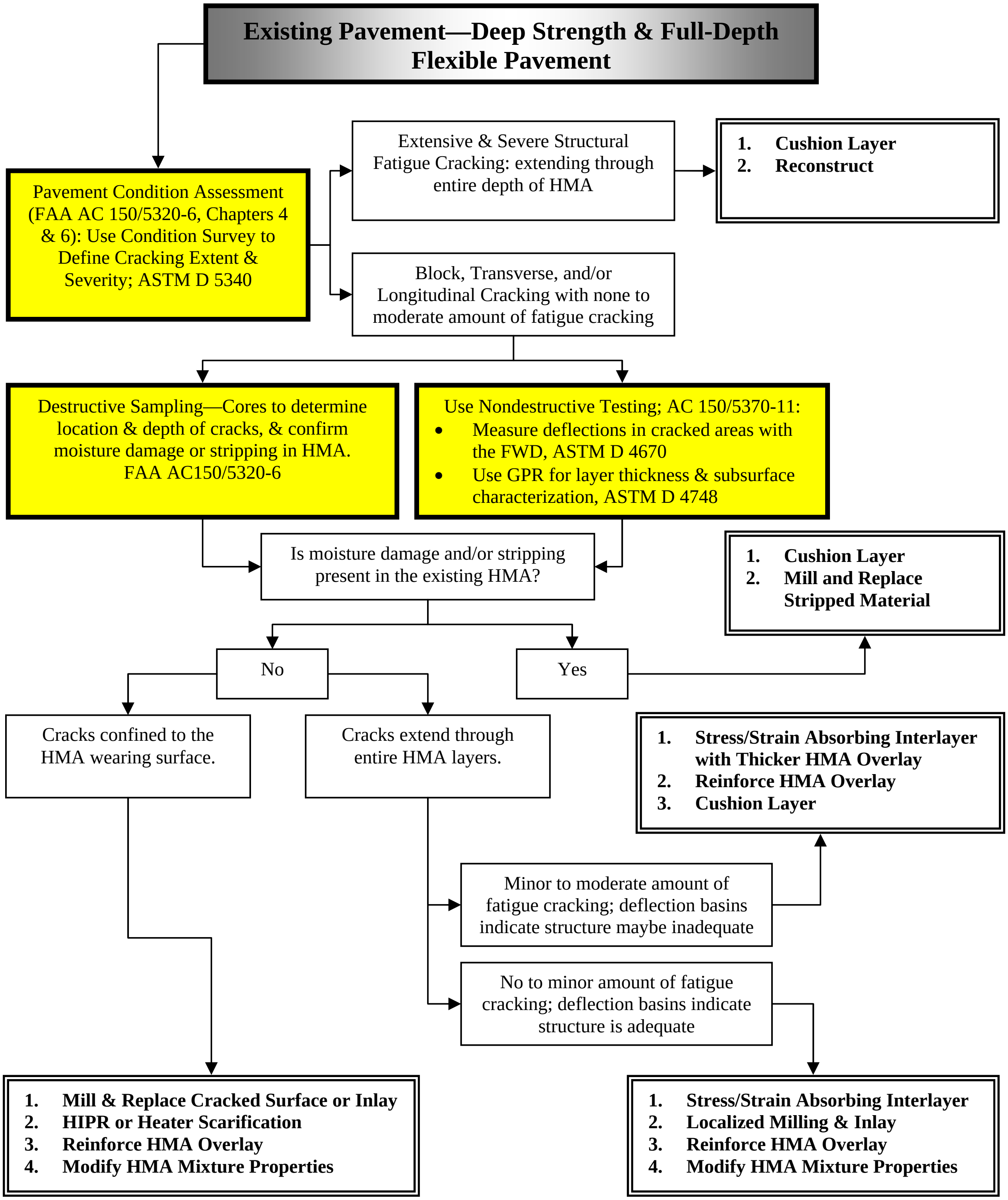

Figure 6. Decision Tree Providing Guidance to Mitigate Reflective Cracks in HMA Overlays of Existing Deep Strength and Full-Depth Flexible Pavements

It should be noted that the reflective cracking mitigation methods can be used individually or in combination with each other. Chapters 5 through 9 provide more information of the combined use of these methods. In addition, these chapters provide information of the probability of success and risk of use between the different methods and the site features that can have an impact on that probability of success. The probability of success and risk for each reflective cracking mitigation strategy were used in preparing the decision trees (figures 4 through 6). These factors are defined below.

- The probability of success for the treatment methods were defined based on the performance data documented in the literature and from surveys of selected airfields where multiple methods were used to mitigate reflective cracks. This factor is normally determined from the survivability or probability of failure relationship for a specific treatment method. Table 2 is a summary of the success rate scale (probability of success) that was used in quantifying the different treatment methods for different existing pavement conditions.

- Confidence or risk factors are used as a tool to indicate the uncertainty associated with the results obtained for treatment methods that have not been used extensively and do not have an extensive database substantiating their use. The confidence factor accounts for the uncertainty associated with results obtained for methods that are not yet in routine use by industry and for which long-term performance data do not yet exist. Confidence factors are defined on a scale of 0 to 1. A confidence factor equal to 0 implies that there is no confidence that the treatment method will perform as expected or designed. Conversely, a confidence factor of 1 means that there is full confidence that the method will perform as expected in mitigating reflection cracks. In other words, the method is routinely used and appropriate performance data are available. Table 3 summarizes the risk categories and values used in comparing the different treatment methods.

After one or multiple rehabilitation design strategies have been selected, an economic analysis should be completed to determine the life cycle costs (LCC) of each strategy to aid in the selection of the optimum strategy. Report FAA-RD-81-78 describes the economic analysis for airport pavement rehabilitation alternatives (*Economic Analysis of Airport Pavement Rehabilitation Alternatives*, Epps and Wootan, October 1981). Appendix 1 (entitled Economic Analysis) of FAA AC 150/5320-6 includes examples of an economic analysis using the principles and procedures outlined within that report. The difficulty in comparing the LCC of different reflective cracking mitigation methods is estimating the expected service life of the rehabilitation strategy and when reflective cracks and other distresses start to appear. The remaining chapters provide discussion and information on the different methods to estimate those inputs for the LCC analysis.

Table 2. Success Categories Used to Rate Reflective Cracking Mitigation Methods

Percent of Projects Reported Exhibiting Premature or Accelerated Reflective Cracking	Probability of Success Category and Value	
<2 (few projects exhibiting premature reflective cracking)	Very High	1.0
2 to 10	High	0.9
10 to 25	Moderate	0.75
25 to 50	Low	0.6
>50 (extensive number of projects exhibiting premature reflective cracking)	Very Low	0.5

Table 3. Risk Categories Used to Rate Reflective Cracking Mitigation Methods

Number of Projects for Site Parameters	Number of Years in Use				
	<5	5 to 10	10 to 15	15 to 20	>20
<10	Very High	Very High	High	Moderate	Low
10 to 20	Very High	High	Moderate	Low	Low
20 to 50	High	Moderate	Low	Low	Very Low
>50	High	Moderate	Low	Very Low	Very Low

Risk Category—The following defines typical values associated with each category of risk:
Very Low = 1.0
Low = 0.9
Moderate = 0.75
High = 0.6
Very High = 0.5

4.3 Pre-Overlay Repair Considerations of Localized Cracks and Other Distresses

Although not a cure for reflective cracking, pre-overlay repair of rigid and flexible pavements provides good results and can be cost effective when used in conjunction with other methods and techniques to mitigate reflective cracking, especially for rigid pavements. If cracks and other distresses in the existing pavement are localized to specific areas, the designer should consider making localized repairs to remove those cracks. FAA AC 150/5380-6 provides guidance in selecting the repair method for different distresses. The decision to make any pre-overlay repairs should be based on cost of the rehabilitation strategy with and without the repairs. The localized repair of cracks and other distresses can consist of the following:

- Existing HMA Surfaces: Mill a width of 2-feet (0.6 m) on either side of the crack or construction joint to remove the surface initiated cracks (or area that has become debonded) and replace with an approved or appropriate patching material; or full-depth patches of localized areas when those cracks extend through the entire HMA layers.
- Existing PCC Surfaces: Remove and replace localized slabs with cracking; and make joint repairs to localized areas with joint spalling, D-cracking, and/or faulting. For PCC pavements with joint faulting greater than 0.15 inches (4 mm) but without voids beneath those joints, another option is to install dowels along the joint prior to placing the HMA overlay. For this condition, the surface of the PCC near the joints should be ground to

create a level surface prior to placing the overlay. The dowels will reduce the differential vertical deflections across the transverse joint, but will not reduce the horizontal movements concentrated at the joint from temperature changes.

- Existing HMA Overlays of PCC Pavements: If an existing HMA overlay has exhibited reflective cracks and there is concern that the overlay is becoming or has exhibited debonding from the underlying layer, mill and remove the existing HMA overlay to expose the PCC surface. For this case, figure 4 should be the decision tree to be used after the existing HMA overlay has been removed. In addition, the above repair options for existing PCC surfaces would also apply to this type of pavement.

More importantly, a key to eliminating reflective cracking in HMA overlays of PCC pavements is to control or reduce the differential vertical deformations across the joint/crack. If voids are identified during the site investigation resulting in larger differential vertical deflections, they should be filled as part of the rehabilitation project. Cement grout or other materials can be injected under the slab to fill the voids prior to overlay, in order to prevent any rocking/vertical deformation of the slabs. The subsealing/filling void process by itself, however, does not mitigate reflective cracks—filling the voids is not a mitigation method. This void filling/injection process should be used in combination with other mitigation methods, as shown in figure 4. Subsealing voids beneath PCC slabs should be considered when the slabs have yet to exhibit extensive and severe cracking and deterioration. When voids are filled, uniform support conditions can be used for overlay design.

The process of grout pumping or undersealing the PCC pavement is critical. A high pressure and an excessive amount of grout can result in poorer performance of the overlay than without use of the undersealing material. The overfilled voids can cause the slabs to be lifted creating voids in other areas under the slab, which will increase deflections rather than reduce deflections. Pressure applied to the injected grout should not exceed the pressure exerted by the weight of the slab (about 1 psi [7 kPa] for a 12 in. [302 mm] thick slab).

CHAPTER 5 MODIFICATION OF EXISTING PAVEMENT

This category of treatments is used to change the structural characteristics of the existing pavement surface by strengthening or weakening and altering the physical features of the surface layer and/or pavement. These treatments are used to remove cracks in the existing pavement surface and adjust the joint condition of PCC pavements so that reflective cracking becomes a non-issue. These treatments include break and seat, crack and seat, and rubblization, while full-depth reclamation, mill and replace, hot in place recycling, and heater scarification methods are used for HMA pavements. Subsealing and filling voids beneath the PCC slabs was discussed in the previous chapter as a pe-overlay repair activity and is not a mitigation strategy.

Rubblization of the PCC slabs and full-depth reclamation of HMA layers have the highest reliability in eliminating reflective cracks, because those cracked surfaces are completely destroyed.

5.1 Existing Rigid Pavements

Crack or Break and Seat PCC Surface

The crack or break and seat technique produces shorter slabs (2 to 6 ft. [0.6 to 1.8 m] in length), while retaining structural integrity by inducing fine, vertical, transverse cracks in the jointed concrete pavement. The break and seat method refers to jointed plain concrete pavement (JPCP), while the crack and seat method refers to jointed reinforced concrete pavements (JRCP). The fracturing process reduces the effective length of the slab between the contraction joints. Figure 7 shows the equipment used to fracture the PCC slab and the transverse cracks that are created.

Figure 7. Crack and Seat or Break and Seat Equipment for Fracturing PCC Slabs

In summary, hairline cracks are induced in the PCC slab so that load transfer between the newly formed shorter slabs should be good because of aggregate interlock. In addition, the fractures shorten the length of the slab so that the horizontal movements resulting from thermal variations are distributed more evenly over the pavement and are less likely to cause reflective cracks in the

HMA overlay. After cracking, the PCC segments are firmly seated by a heavy pneumatic tire roller to ensure that there are no voids beneath the PCC segments prior to overlay placement. A bituminous leveling course should be placed when the surface profile is distorted after the seating process. The leveling course will permit more uniform density and compaction of the HMA overlay mixture.

Benefits of Crack or Break and Seat Methods

Because there are no hauling or disposal costs and none of the existing pavement system is discarded, cracking or breaking and seating the PCC saves natural resources, saves landfill space, expedites construction, and is environmentally, friendly and cost-effective as a rehabilitation technique. The existing PCC pavement stays in place and becomes the base for the new HMA overlay, thereby reducing or eliminating the need for new virgin aggregates. Weather delays are minimized since the subgrade is never opened up and exposed to the elements.

Construction Equipment and Issues

The type of equipment for cracking or breaking the PCC slabs is referred to as a guillotine breaker (refer to figure 7). This equipment imparts an impact force on the PCC surface that cracks the PCC through its entire depth. The equipment must transfer the energy entirely into the pavement to ensure proper breaking of the PCC slabs. A pneumatic-tire roller with a gross weight of 25+ tons is used to seat the fractured slab and ensure that no voids exist under the fractured slabs. Some issues that may affect the performance and adequacy of the crack or break and seat methods include:

- If the fractured slabs are not properly seated, voids will remain or be created under the shorter slab lengths. Any voids under the fractured slabs can be a potential problem to long term performance, as noted in the next bullet.
- In general, breaking and seating has better results in JPCP than cracking and seating for JRCP. In JRCP, the steel, if not cut, can prevent the PCC slabs from being properly seated. Rocking and settlement of pavement sections take place under repeated aircraft loadings reducing the time that reflective cracks start to appear and increasing the severity of those cracks. The differential vertical deflections across joints and some of the cracks can be fairly high. If this condition exists, the rehabilitation process to mitigate reflective cracks should include the use of subsealing those voids or placing a cushion layer over the fractured slabs to reduce differential vertical deflections.
- Although a thinner HMA overlay on a cracked or break and seated pavement might be sufficient to inhibit reflective cracking, the cracks created in the PCC slab reduce its load-spreading ability that must be taken into account in the structural design. A thicker HMA overlay may be required than resulting from use of the FAA procedure (FAA AC 150/5320-6), which increases the cost of the rehabilitation project.
- The bond between the HMA overlay and fractured PCC slab has an impact on the overlay thickness. A tack coat is used to achieve a bond between the overlay and fractured PCC. However, a bond breaker can also be used to reduce the transfer of horizontal movements from the fractured PCC to the HMA overlay. When a bond breaker is used, a thicker overlay is needed to prevent fatigue and slippage cracks from occurring in the HMA overlay.

The overlay design is a balance between the crack spacing, the reduction in stiffness modulus, the overlay thickness, and the occurrence of reflective cracks for rehabilitation designs of airfield pavements.

Rubblize PCC Slabs

Rubblization and repaving with HMA was initially developed for highway pavements, but is becoming a choice of rehabilitation technique for old deteriorated thick PCC airfield pavements. In the past 7 years, more than one-half million square meters of airport PCC pavement has been rubblized, and overlaid with HMA. These projects range from heavy load military airfields to local general aviation (GA) airfields that handle small aircraft.

Rubblization is defined by the Asphalt Institute as the process of breaking or pulverizing the existing PCC pavement in place into small, interconnected pieces (having a nominal maximum size between 3 in. [75 mm] and 8 in. [200 mm]) that serve as a base course for the HMA overlay. Weak spots are filled with coarse aggregate and the rubblized material is then compacted with the help of a steel roller before placing the HMA overlay. The rubblizing process reduces the slab to a material that is stronger than a crushed stone base (Buncher, et al., 2008) for the overlay and eliminates all reflective cracking concerns.

In February 2004, the FAA adopted and published *FAA Engineering Brief No. 66, Rubblized Portland Cement Concrete Base Course*, which includes guidance and specifications for rubblizing existing PCC pavement. More recently, AAPTP Project 04-01 has provided updated guidelines for the rubblization process for airfields (Buncher, et al., 2008). Although there are slight differences in the allowable particle size range of the rubblized layer between AAPTP Project 04-01 and FAA Engineering Brief No. 66, the final report for AAPTP Project 04-01 noted that there are no major flaws in FAA Engineering Brief No. 66 and the P-215 specification on rubblization.

Benefits of Rubblization

Because there are no hauling or disposal costs and none of the existing pavement system is discarded, rubblization saves natural resources, saves landfill space, expedites construction, and is environmentally, friendly and cost-effective as a rehabilitation technique. The existing PCC pavement stays in place and becomes the base for the new HMA pavement, thereby reducing or eliminating the need for new virgin aggregates. Weather delays are minimized since the subgrade is never opened up and exposed to the elements.

Rubblization Construction Equipment

The type of equipment for rubblization should be a pavement breaker machine that delivers adequate energy to rubblize the full depth of the slab and break all existing slab action. PCC thickness in excess of 20 inches (508 mm) has been successfully rubblized. The equipment must transfer the energy entirely into the pavement to ensure proper breaking of the PCC slabs.

FAA permits the use of either resonant pavement breaker (RPB) or multi-head breaker (MHB) for the rubblization process. Figure 8 shows the RPB used for rubblizing PCC slabs, while Figure 9 shows the MHB. These two types of equipment operate in different modes to achieve the required rubblization of the PCC pavement. The RPB is a high frequency, low amplitude process while the MHB is a low-frequency, high-amplitude process. Both types of equipment have been used with success. All references to a resonant frequency breaker imply a self-contained, self-propelled resonant frequency breaking unit. Likewise all references to a multiple head breaker imply a self-contained, self-propelled multiple-head impact hammer. The equipment used on FAA projects is summarized below.

- ***Resonant Breaker Machine:*** The machine should be capable of producing low-amplitude (1 inch maximum) blows of 2000 pounds force, and delivering blows to the existing PCC surface at a rate of not less than 44 cycles per second. If necessary, the breaker should be equipped with a screen to protect nearby structures, vehicles or aircraft from flying chips during the fracturing process.

- ***Resonant Breaker Seating Equipment:*** A smooth double steel drum vibratory roller with a gross weight of at least 10 tons is used, and operated in the high frequency, low amplitude vibratory mode to seat the rubblized pavement and provide a smoother surface for the HMA overlay.

- ***Multi-Head Breaker Machine:*** The machine should be capable of rubblizing a minimum width of 13 feet (4 m) per pass. Pavement-breaking hammers are to be mounted laterally in pairs, with adjustable heights and with half the hammers in a forward row and the remainder diagonally offset in a rear row so there is continuous breakage from side to side. The breaker can be equipped with a screen to protect personnel and vehicles from flying chips during the fracturing process.

- ***Multi-Head Breaker Seating Equipment:*** A Z-grid Roller with a gross weight of at least 10 tons, will be operated in the vibratory mode, to settle and seat the rubblized pavement, and provide a smooth surface for the HMA overlay. A pneumatic-tire roller with a gross weight of 10 to 25 tons is used to further settle and seat the rubblized pavement for slab thickness of 8 to 12 inches (203 to 305 mm) or higher. Finally, a smooth steel drum vibratory roller with a gross weight of at least 10 tons and operated in the vibratory mode is used to settle the rubblized pavement, and provide a smooth surface for the HMA overlay.

Construction Activity Sequence

The process of rubblization is essentially the same for airfields as for highways. The typical rubblization construction sequence is listed below.

- Locate, evaluate, and mark any underground utilities. Ensure that the utilities have sufficient cover to protect them from the vibrations and deflections from the rubblization equipment.
- Install edge drains, if needed, and allow sufficient time for water to drain prior to rubblization.

Figure 8. Resonant Frequency Pavement Breaker for Rubblizing PCC Slabs

Figure 9. Multiple-Drop Hammer for Rubblizing PCC Slabs

- Preparation of the existing pavement:
    - Isolate any adjacent sections from the pavement being rubblized with full-depth saw cuts.
    - Remove any existing HMA overlays or patches. The millings from any existing HMA layers can be used in the leveling course.
- Before the actual rubblization project is initiated, include a test section or control strip for the rubblization process to optimize or confirm the equipment and procedures.
    - A test strip (12 ft by 150 ft [4 m by 45 m]) should be constructed using the proposed equipments and a test pit may need to be excavated and inspected. The particle size and debonding of the steel reinforcement can be investigated.
    - Test pits should be required whenever the pavement cross section changes or every 35,880 to 47,840 sq yd (30,000 to 40,000 sq m) depending on the size of the project.
- Rubblize the PCC pavement—adjusting equipment and procedures, as necessary.
    - Particle size criteria: According to EB 66 (2004), the rubblized PCC should have at least 75 percent (as determined by visual observation) particles smaller than 3 in (75 mm) at the surface and 12 in (300 mm) in the bottom half. For JRCP, the reinforcing steel shall be substantially debonded from the PCC and left in place, unless protruding above the surface. PCC pieces below the reinforcing steel shall be reduced to the greatest possible extent, and no individual piece shall exceed 15 in (380 mm) in any dimension.
    - Rollers: The type of rollers (type, minimum roller weight, and number of roller passes) should be determined according to the method of rubblizing.
- Cut off and remove any exposed steel reinforcement and joint sealing material.
- Roll and seat the rubblized PCC.
- Remove and replace material in any unstable area. The weak areas of the pavement can be replaced with full depth patches.
- Place a leveling course that can consist of a fine-graded HMA or unbound aggregate material.
- Place HMA overlay in appropriate lift thicknesses.
- Pave transitions to existing pavement surfaces and adjust shoulder grades as necessary.

For the resonant breaking process, rubblization should start at a free edge or previously broken edge and progress toward the opposite side or longitudinal centerline of the slab. In areas where the HMA overlay will be placed before the rubblization is complete, the rubblization should extent to a minimum of 6 in (150 mm) beyond the edge of the HMA to provide relief and transition into the next section to be rubblized.

Installation of Edge Drains

Rubblizing the PCC slabs significantly increases the permeability of the PCC layer. Any water infiltrating the rubblized layer should be quickly removed through the use of edge drains, especially for pavements supported by fine-grained soils with low permeability. Edge drains may not be required in areas with coarse-grained soils that have high permeability.

Edge drains should be used in all rubblized projects to drain any saturated foundation layer. These drains can be placed continuously or intermittently along the project. Their use and location should be based on engineering judgment to remove water from the pavement structure. When used, edge drains should be installed prior to the rubblization process to ensure that there is sufficient time to allow the subbase and subgrade to drain and dry out (usually 2 weeks before rubblization starts).

Leveling Course or Cushion Layer

The surface of the rubblized PCC layer cannot be bladed with a motor grader. A leveling course is typically needed to restore the grade and make profile corrections. The leveling course material can consist of crushed aggregate, milled or recycled asphalt pavement (RAP), or a fine-graded HMA mixture that is workable. A 2 to 4 in (50 to 100 mm) should be included in the design to fill in depressions or low spots along the rubblized surface. This leveling course also acts as a cushion layer for the HMA overlay. If a workable, fine-graded HMA mixture (a HMA mixture with higher asphalt content) is used, the designer should ensure that there is sufficient cover so that rutting does not become a problem within that workable layer.

Design Features and Properties for Fractured PCC Slabs

Rubblizing the PCC pavement reduces the structural support of the existing pavement since the PCC slabs are fractured into small pieces. In summary, the rubblized PCC slabs perform as a flexible but interlocked system. The following lists some of the design features that must be considered for the overlay design relative to structural support in reducing load related fatigue cracks, rather than for reflective cracking.

- ➔ The HMA overlay thickness placed above the rubblized layer is greater in comparison to the crack or break and seat methods; because the structural capacity of the PCC is reduced to material similar to a high quality crushed stone base material. For fractured PCC slabs (break or crack and seat and rubblization), the minimum HMA overlay thickness recommended is 4 inches (100 mm).
    - o Rubblized PCC—Assume that rubblized PCC is similar in response to a high quality crushed stone base material. AAPTP Final Report 04-01 provides the recommended CBR equivalency factors for the rubblized layer recommended for use in rehabilitation or overlay design. The back-calculated elastic modulus values reported in that document vary from 100,000 to 400,000 psi (700 to 2,800 MPa), and are PCC layer dependent (modulus values increase with increasing rubblized PCC thickness).
    - o Crack and Seat or Break and Seat—Assume that the fractured PCC is equivalent to a stabilized subbase material.

- ➔ The important property needed for the rehabilitation design is the in place modulus of the fractured PCC layer. The National Asphalt Pavement Association (NAPA) and AAPTP Project 04-01 provide guidelines on elastic modulus values for the fractured layer (break and seat, crack and seat, and rubblized PCC). The values suggested for use in the NAPA report are high—resulting in relatively thin HMA overlays (less than 4 inches [100 mm] in thickness). Deflection basins have been measured on the first lift of HMA placed on the fractured PCC. For rubblized PCC slabs, the in place modulus values range from 30 to 100+ ksi (200 to 700+ MPa), while for break or crack and seat slabs these values range from 75 to 200+ ksi (500 to 1,400+ MPa). For thick PCC slabs

JRCP, the PCC is usually divided into two layers for the back-calculation process. As noted above, AAPTP Project 04-01 provides CBR equivalency factors for the rubblized layer for the design of rehabilitation projects of rigid pavements using this process. The back-calculated elastic layer modulus values are dependent on the project specifications, PCC layer thickness, and whether the PCC slabs are reinforced.

- ➔ Another important property needed for the rehabilitation design is the condition of the bond between the HMA overlay and fractured PCC slab. Most design procedures assume that there is good bond between the different layers. A bond breaker interlayer should not be used between the HMA overlay and fractured PCC, unless the overlay exceeds 4 inches (100 mm). A cushion course or level up layer should be used between the overlay and rubblized PCC layer.

Performance Issues and Probability of Success

A national research study was conducted in 1991 by PCS/Law Engineering (PCS/LAW) for NAPA and the State Asphalt Pavement Association Executives (SAPAE) related to the performance of fractured PCC slabs in mitigating reflective cracks. This study and others have found that the cracking or breaking and seating methods provide good results if the foundation is firm and the broken sections are properly seated with the help of a heavy pneumatic roller so that no voids are left under the slabs. Rubblization, however, was considered the best method for mitigating reflective cracks. The following provides an estimate of the probability of success between the rubblization and crack or break and seat methods.

- ➔ Rubblization—High probability of success with low risk. In fact, reflective cracks should be a non-issue for this method. The HMA overlay should meet the design life expectations. This method, however, requires the use of thicker HMA overlays.
- ➔ Crack or Break and Seat—Moderate probability of success with moderate risk. Some reflective cracks from longitudinal joints and cracks can start to occur within the design life of the HMA overlay of JRCP and JPCP. In addition, some reflective cracks of transverse joints of JRCP can be expected. To increase the probability of success using this method for JRCP, other mitigation methods should be used in combination with the break and seat method. The other methods for both JRCP and JPCP include the use of a cushion layer or stress absorbing membrane interlayer (refer to Chapter 7).
    - o Used in combination with a cushion layer—high probability of success with low risk.
    - o Used in combination with a stress absorbing membrane interlayer—high probability of success with moderate risk. The overlay thickness should be determined assuming zero bond or interface friction between the overlay and fractured PCC using a equivalent cracked condition of the existing PCC slab.
    - o Used in combination with a bond breaker interlayer—moderate probability of success with moderate risk. A thicker HMA overlay is needed for this case to ensure that fatigue and slippage cracks and shoving do not occur within the design period. The overlay thickness should be determined assuming zero bond or interface friction between the overlay and fractured PCC.

5.2 Existing Flexible Pavements

Modification of the existing flexible pavements can be divided into three different strategies or methods that depend on the depth of the existing cracks. These three methods are listed below.

1. Existing cracks are confined to the wearing or surface layer: milling and inlaying of the cracked HMA layer is a simple and cost effective solution.
2. Existing cracks extend below the wearing surface: hot-in place recycling or heater scarification methods become the preferred solutions.
3. Cracks extend completely through the HMA layers: full-depth reclamation should be considered, depending on the total thickness of the HMA layers.

The following subsections overview each of these mitigation methods for flexible pavements.

Mill and Replace Wearing Surface or Inlay

When the cracks in the existing pavement are confined to the wearing surface or upper HMA layers, those layers can be milled and replaced, so reflective cracking becomes a non-issue. For runways and other facilities with wide paving widths, the use of inlays (mill and replace the layers with cracks within the traffic area) can be an economical solution. This method becomes the selection of choice because reflective cracking is a non-issue with the removal of surface initiated cracking.

Hot In Place Recycling and Heater Scarification

The hot-in place recycling (HIPR) and heater scarification methods do strengthen the HMA pavement because cracks are removed and replaced with intact material. Figures 10 and 11 show the equipment used for the HIPR and heater scarification processes, respectively. The HIPR method is hypothesized to have a higher reliability because the recycling or remixing process eliminates all cracks that initiate at the surface of the pavement prior to placing the HMA overlay.

The heater scarification technique scarifies the existing pavement surface to a depth of approximately 0.75-in (19 mm) so that the upper portion of any crack can be removed along with any crack sealant. The lower portion of the crack can be sealed through the heating process. The remixed and re-compacted layer becomes a uniform uncracked layer above the crack tip. As a consequence, the reflective cracking of the HMA overlay should be delayed.

The projects reviewed that included the heater scarification technique suggest that local pavement condition, climate, and whether the cracks exist through the entire layer are important factors affecting the performance of the overlay. In summary, the location of where cracks initiate is an important factor in terms of selecting a reflective crack mitigation strategy. Cracks that initiate at the bottom of the HMA layer are generally wider at the bottom than at the mid-depth of the HMA. In addition, any crack (caused by the environment or wheel loads) through the entire HMA layer will cause stress concentrations at the crack tip. These cracks will eventually reflect through the overlay, usually in a fairly short period of time.

Figure 10. Hot In Place Recycling Method of Flexible Pavement

Figure 11. Heater Scarification of HMA Surfaced Pavements

Full-Depth Reclamation

The full-depth reclamation (FDR) method is a cold in place recycling (CIPR) method. Figure 12 shows the equipment used for the CIPR process. In summary, the existing HMA layers are pulverized in place eliminating all cracking. A bituminous binder consisting of various emulsions or foamed asphalt (with or without cement or lime-fly ash) is normally added to the pulverized material which is compacted. This method strengthens the HMA pavement because cracks are removed in place and that material is compacted forming new intact material. This method is hypothesized to be a reliable technique because the reclamation/recycling process eliminates all cracks in the existing HMA layers, and reflective cracking becomes a non-issue. The equipment, materials, and construction process is discussed in more detail in the FHWA's training course entitled Asphalt Roadway Rehabilitation Alternatives (1997).

Figure 12. Cold In Placed Recycling Method of Flexible Pavements

Benefits for Modification of Existing Flexible Pavement

FDR, CIPR, HIPR, and heater scarification do not require any hauling or disposal costs because none of the existing pavement system is discarded. This use of the entire in place pavement saves natural resources, saves landfill space, expedites construction, and is environmentally, friendly and cost-effective as a rehabilitation technique. The existing HMA remains in place and becomes the base for the HMA overlay, thereby reducing the need for new virgin aggregates. Weather delays are also minimized since the subgrade is never opened up and exposed to the elements.

Design Features and Properties

Modification of the existing flexible pavement strengthens the in place layers in most situations because the cracks are being removed and replaced with intact material. The two properties needed for the CIPR, HIPR, and heater scarified mixture are the modulus and strength. The following lists some of the design features or assumptions that should be considered for the overlay design.

- ➔ Mill and Inlay—Existing flexible pavement is found to be structurally adequate so the HMA surface layers that are cracked are removed and replaced. Reflective cracking becomes a non-issue. If the existing pavement structure requires a thicker HMA for future aircraft operations, the overlay thickness is determined assuming that the in place HMA (existing HMA minus the milled material) is in good condition.
- ➔ HIPR—Properties of the HIPR are assumed to be equivalent to the new HMA dense-graded mixture or in place layers that have yet to exhibit any cracking, in accordance with FAA standards. The overlay thickness for future aircraft operations would be determined as for the mill and inlay method. This assumes that the HIPR process is recycling and remixing the layers that exhibit cracking. Reflective cracking becomes a non-issue.
- ➔ FDR—Properties of this layer depend on the type of material being recycled and the type of modifiers/additives used in the full-depth reclamation process. The type of modifiers or additives used includes; emulsions, foamed asphalt, lime, fly-ash, and cement. If properly constructed, this material can be equivalent from a good quality crushed stone base to a stabilized base layer, depending on the type of modifier used in the reclaimed layer. The resulting stiffness or strength of this layer has a significant impact on the required HMA overlay thickness from a load related fatigue cracking standpoint, but reflective cracking is a non-issue because the HMA layer with full-depth cracking is being remixed and compacted in place.

Construction Considerations

Full-Depth Reclamation

Highly variable thickness of the existing HMA layers can be an issue during construction. The CIPR can become contaminated with fines and other materials in areas with thinner HMA layers. Thus, the type of material directly below the existing HMA is a factor in selecting this method. The rehabilitation design should take this condition into account through the site investigation (refer to Chapter 3). In addition, the bituminous material that is added to the mixture during the FDR process needs to cure to allow any moisture used during recycling to evaporate. As an example, when emulsions are used, the CIPR is normally allowed to “cure” for an extended period of time prior to compaction.

Mill and Replace Existing HMA and Inlays

An important construction consideration is to ensure that the surface of the milled layer has been properly cleaned so that a good bond is obtained between the overlay and existing surface. Another construction consideration is to inspect the surface after milling to ensure that the cracks were in fact confined to the wearing surface. If many cracks propagate through the surface, a change in the rehabilitation design may be needed. It might be necessary to increase the depth of milling or include a stress/strain absorbing interlayer to mitigate those cracks from reflecting to the surface.

Performance Issues and Probability of Success

The following provides an estimate of the probability of success for those methods used for modification of the flexible pavement.

- ➔ FDR—High probability of success with low risk, for smaller or general aviation airports. In fact, reflective cracks should be a non-issue for this method assuming that the CIPR process includes the depth of cracking. This rehabilitation strategy has been used much less on facilities of larger airports because the existing HMA layers are generally thicker than 6 inches (150 mm). For larger airports, this strategy would have a high risk category. However, full-depth reclamation has been successfully accomplished with depths up to 12 inches (300 mm). The HMA overlay should meet the design life expectations. This method is normally restricted to flexible pavements with HMA layers totaling less than 6 inches in thickness.
- ➔ Mill and Replace Existing HMA and Inlays—High probability of success with low risk. Reflective cracks should be a non-issue for this method, because the cracks are confined to the surface layer or wearing course. The HMA overlay should meet the design life expectations, as long as adequate bond or interface friction is retained between the milled surface and HMA overlay. The only performance issue for the use of inlays is that reflective cracks will occur in the area outside the inlay and eventually will propagate across the pavement. The time for the reflective cracks to propagate into the inlay area is highly variable and would require a detailed theoretical analysis.
- ➔ HIPR—High probability of success with moderate risk, assuming that all of the cracks are included in the HIPR process. An issue or risk with using this method is that the hardening or aging of the asphalt in the existing HMA layer can result in thermal cracking. These thermal cracks, however, would not be reflective cracks. Rejuvenating additives or softer asphalts are used in the HIPR mixture to minimize the occurrence of thermal cracking, but that can increase the potential for rutting and shoving.
- ➔ Heater Scarification—Moderate probability of success with high risk. The heater scarification process will not eliminate the cracks that propagate into the lower layers of the existing HMA and those cracks will eventually propagate through the HMA overlay. Thicker HMA overlays are usually required with the heater scarification process when the existing cracks extend into the lower HMA layers. The overlay thickness would be dependent on the number of aircraft operations and in place modulus of the scarified layer and existing HMA layers that exhibit cracking.

5.3 Composite Pavements or Existing HMA Overlays of PCC Pavements

HMA inlays are an alternative strategy that have met with some success on highways where a previously overlaid JPCP or JRCP has suffered reflective cracking and is about to be overlaid again. The cracks in the original overlay above joints in the underlying PCC slabs are milled out to a width of about 2-feet (0.6 m) and inlayed with HMA before applying a new surfacing. The new infill asphalt acts like a SAMI.

CHAPTER 6 OVERLAY LAYER/MIXTURE MODIFICATION

This category of reflective crack mitigation techniques includes those methods to improve the fracture resistance properties of HMA mixtures, as well as using thicker HMA overlays. The objective of increased HMA overlay thickness is to reduce the stress and strain in the overlay to acceptable limits for delaying reflective cracks, while the objective of HMA mixture modification is to improve the mixture properties to withstand the higher stress and strain values above the cracks or joints in the existing pavement.

6.1 Thick HMA Layers

Increasing thickness of the HMA overlay reduces the load-associated damage by reducing the effect of poor load transfer across a crack or a joint in the underlying pavement, and thus, improve pavement performance. The greatest benefit from the use of thicker overlays on rigid pavements, however, is the ability of the HMA to insulate the PCC, reducing the amount of curling and temperature variations. The overlay thickness required to retard the reflective cracks depends on four factors:

a) Type of pavement being overlaid – HMA or PCC (HMA overlay thickness of flexible pavements is generally less than that for JPCP or JRCP).
b) Type of distress of the pavement – alligator cracking, block cracking, transverse cracking, longitudinal cracking, or PCC joint cracking (Thicker overlays are generally needed for any type of transverse crack or joint because of the horizontal movements).
c) Climate (The greater the variations in seasonal and daily temperatures, the greater the HMA overlay thickness).
d) Number and weight of axle loads (The higher wheel loads or weights and the higher the traffic volume, the greater the overlay thickness).

Just increasing the HMA overlay thickness, however, is an ineffective approach. In specific, a thicker overlay is the easiest, but it only briefly delays the occurrence of reflective cracks and is usually the least cost effective alternative. One common rule-of-thumb is that one added inch of HMA will further delay reflective cracks by 2 years. An adequately designed overlay in combination with the use of other mitigation methods has had success.

6.2 Modified Asphalt and Specialty Mixtures

The crack resistance of HMA depends on the asphalt grade, content, elastic characteristics, and temperature susceptibility. These asphalt properties, as well as air voids and density of the mixture, affect the HMA's ability to absorb stresses generated at cracks and the self-healing properties, as well as its resistance to aging that causes the asphalt to become brittle with time. Improved fracture properties can be achieved by modifying the asphalt, using softer asphalts, and/or increasing the film thickness of asphalt. A high quality dense graded HMA with low viscosity asphalt is recommended by NEEP-10 final report in 1984 (Tyner et al. 1981).

There has been some experimentation with the use of different asphalt grades and admixtures for controlling reflective cracks, but the results have generally been unfavorable. This finding is understandable because the amount of strain that must be endured in localized areas at the joints and cracks is much greater than the tensile strain at failure for the softest asphalt. Thus, use of modified asphalt mixtures does not prevent and may not even delay the occurrence of reflective cracks, but can reduce the severity of the reflective cracks once they occur. Compaction of the modified mixtures is an important factor related to the overall performance of these mixtures.

6.2.1 Soft or Low Viscosity Asphalt
The brittleness of HMA at low temperature is one of the major reasons for cracking in HMA pavements. Soft or low viscosity asphalt mixtures have been used with initial success, because asphalt stiffness plays a significant role in the occurrence of reflective cracks. The lower the viscosity of the asphalt, the fewer reflective cracks because higher tensile strains prior to cracking. Reflective cracking, however, will occur as the asphalt ages near the surface and becomes brittle with time.

The use of soft asphalt in the wearing surface should not be used because of the increased potential for bleeding and rutting. If softer asphalts are used in the lower layer or lift (i.e.; defined as an interlayer, refer to subsection 7.1.4), the upper HMA layers must be thick and stiff enough to resist rutting within the softer layer.

6.2.2 Specialty Mixtures
The specialty mixture that has been used to improve pavement performance is SMA. This mixture has a gap-graded gradation with fibers and/or modifiers and thicker asphalt films surrounding the aggregate particles. This type of mixture has been found to be very resistant to rutting and cracking as a wearing surface. However, this mixture, as well as the other modified mixtures, does not have adequate fracture resistant to mitigate or delay reflective cracking by itself. SMA and other PMA mixtures will reduce the severity of the reflective cracks, but not significantly delay those cracks from occurring.

Open-graded asphalt mixtures, as a wearing surface have been used to a limited extent to “hide” the reflective and other types of cracking once they occur. These types of mixtures, however, do not delay reflective cracks and are not recommended because of the potential loss or raveling of the coarse aggregate particles (potential for FOD) surrounding the cracks.

Another type of specialty mixture is an open-graded (high permeability) crack relief layer that is placed over the existing pavement surface. Crack relief layers are considered a cushion layer and are discussed in the next chapter (subsection 7.2).

6.2.3 Modified Asphalt Mixtures
The purpose of asphalt modification is to use asphalts with good temperature performance at both low and high temperatures. Asphalt that is stiff at high pavement temperatures and soft at low temperatures will provide better performance, everything else being equal. Different additives can be used to improve the asphalt rheology properties. Laboratory and field studies have shown that the HMA strength and/or tensile strain at failure can be increased with the use of different additives; limestone dust, asbestos fibers, polymer, etc. In addition, the use of natural

rubber and neoprene in various amounts to increase the extensibility of the asphalt has been used with limited success.

Although the results are diverse, most of the results suggest that fillers or additives alone do not significantly delay reflective cracking, but are beneficial in keeping those cracks at a low severity for a longer period of time. The following paragraphs discuss those modified mixtures that have been used in combination with other treatment methods to mitigate reflective cracks.

6.2.3.1 Polymer Modified Asphalt Mixtures

Blending certain percentages of styrene-butadiene-styrene (SBS), ethylene-vinyl-acetate (EVA), or SBR (styrene-butadiene-rubber) polymers to selected asphalts produces a material that is less temperature susceptible and has higher viscosity at ambient temperature when compared to unmodified or neat asphalt mixtures. PMA has increased resistance to thermal and fatigue cracking. PMA mixtures by themselves will not prevent reflective cracking, but will reduce the severity of the reflected cracks over time. PMA mixtures have been used in combination with other treatment methods to reduce reflective cracking.

6.2.3.2 Rubber-Asphalt Mixtures

Rubber particles, when mixed with asphalt at 375+ °F (190+ °C), swell to about twice their original volume and become softer and more elastic. Such change gives additional “extensibility” or ductility to the HMA mixture, enabling it to withstand higher strains without breaking. Although the crack tendency can be improved, that modification with rubber-asphalt can be detrimental to stability, if not properly designed. The use of rubber-asphalt mixtures in the wearing surface or structural layers has been good for preventing reflective cracking in some areas (such as Arizona DOT and California DOT), while poor performance has been reported by others (such as the Alaska DOT and Oregon DOT). Many of the earlier problems were investigated and found to be related to construction issues and/or material defects. Thus, the use of asphalt-rubber modified mixtures in the wearing surface should be used with caution and requires experience in the design of those mixtures. There are more projects, however, where this type of mixture has been used as a stress relieving interlayer to successfully mitigate reflective cracking. This type of mixture used as an interlayer and its benefits are discussed under the next chapter; Stress and Strain Relieving Interlayer.

6.2.3.3 Sulfur Asphalt Mixtures

Sulfur, when added, can control the occurrence of reflective cracks and also reduces the total cost of HMA as some of the higher priced asphalt is replaced by relatively cheaper sulfur. Adding sulfur to asphalt does increase the stability and stiffness of the HMA at high temperatures and at the same time maintain the low temperature property of the asphalt. In other words, sulfur-asphalt behaves as soft asphalt at low temperatures and harder asphalt at high temperatures. Thus, sulfur added to the asphalt should have less cracking at low temperatures, as well as less rutting at high temperatures.

On a negative note, sulfur fumes during paving can be a problem if the mixture temperature is above 266 °F (130 °C). Hydrogen sulfur and sulfur dioxide are considered the main component of the fumes, even though their concentrations are normally below toxic level.

6.2.3.4 Other Asphalt Modified Mixtures
The use of carbon-black to modify asphalt has been studied by Rostler et al. (1972, 1977) and others. It was found that carbon black can be used as a reinforcement agent for asphalt to decrease its temperature susceptibility and retard the hardening of the asphalt during production. Carbon black modification also increases the tensile strength of the HMA mixture. Previous test results have shown that the addition of carbon black in the form of Microfil 8 in the amounts of 15 to 20 percent by weight of the asphalt reduced the influence of temperature on the physical response characteristics of the mixture. At high temperatures, creep characteristics at long loading times were improved; while at low temperatures, creep response remained the same as conventional neat HMA mixtures.

For asphalt that is waxy and has low viscosity, air blowing (i.e.; oxidation) can be one possible solution to improve its temperature susceptibility through increasing its Penetration Index (PI). It has been reported that air-blown asphalt has better resistance to aging for some asphalts, as noted above.

6.3 Design Features and Properties

To mitigate reflective cracking using HMA mixtures with improved fracture properties, the softer or low viscosity asphalt mixtures should be only used in the first layer placed on the existing pavement surface. Additional layers placed should have sufficient thickness to protect the softer layer from rutting and shoving under aircraft movements. Thus, this softer layer will act like a cushion layer, which is discussed in the next chapter.

As noted above, the specialty and modified mixtures (PMA and SMA) may not delay the occurrence of reflective cracks but can keep the cracks in a low severity level for a longer period of time. These mixtures should be used with other reflective cracking mitigation methods.

The existing pavement should represent an equivalent cracked condition in determining the overlay thickness to resist load related fatigue cracking for the future aircraft operations. Multiple studies have been completed that provide evidence that the use of SMA and PMA mixtures do reduce surface distress (rutting, fatigue cracking, and thermal cracking) in comparison to dense-graded neat HMA mixtures. One of the more recent studies was sponsored by the Asphalt Institute (2005). These studies can be used in deciding whether SMA and PMA mixtures have increased resistance to fracture and distortion for structural design purposes or to assume that they are equivalent to conventional neat HMA mixtures. The resulting HMA overlay thickness should be determined in accordance with FAA approved procedures.

6.4 Construction Considerations

If standard construction practices are followed as established by industry, there should be no construction difficulties or issues related to using this method. However, there are production, transport, and placement issues when using selected asphalt modified mixtures. These issues are material or modifier dependent. As an example, pneumatic rubber tired rollers can not be used in the primary or breakdown position when using some highly polymer modified mixtures, because the rubber tires pick up the material during the rolling process.

In addition, the production and placement temperatures become extremely important when using some modified mixtures so that adequate densities can be obtained. Without adequate compaction, insufficient fracture properties will be obtained eliminating the benefit of using some modified mixtures. Thus, the material manufacturer's recommendations should be followed when using asphalt modification methods.

6.5 Performance Issues and Probability of Success

The probability of success for this method in delaying reflective cracks is low. In actuality, these methods by themselves are not considered cost effective in mitigating reflective cracks. The asphalt modification methods, however, do have one distinct benefit or advantage: improved mixture fracture properties (assuming adequate compaction) will keep the reflective cracks at a low severity level for a longer period of time.

A critical performance issue with using soft or low viscosity asphalt mixtures is that the stability of these mixtures is low. This type of mixtures can shove and rut under heavy aircraft traffic. As noted above, if this method and material is used, the HMA overlay should be designed to ensure that there is sufficient thickness above the softer layer to prevent rutting and shoving in the soft HMA mixture and slippage cracks in the HMA overlay. The overlay thickness of the stiffer HMA mixtures is aircraft wheel load, structure, and climate dependent. There are mechanistic-empirical based procedures that have been used but which have not been adopted by FAA. In summary, 4 inches (100 mm) of dense-graded mixtures with adequate stability should be sufficient on general aviation facilities, while 6 inches (150 mm) should be sufficient for heavier aircraft of the larger commercial aviation airports.

The following provides an estimate of the probability of success for those methods used for the overlay layer and mixture property modification.

- ➔ Thick HMA Layers—Very low probability of success with low risk, when used by itself. Simply using thicker HMA overlays is not considered a cost effective solution or good investment of resources. Thicker HMA overlays can be used to increase the probability of success for some of the other mitigation methods.
- ➔ Modified Asphalt and Specialty Mixtures—Low probability of success with high risk. Similar to using thick HMA layers, modified mixtures will not delay reflective cracks by themselves. Modified mixtures can be used to increase the probability of success for some of the other mitigation methods. The modified mixtures that have resulted in better performance characteristics for flexible pavements and HMA overlays include SMA, PMA, and asphalt-rubber mixtures. The severity of reflective cracking that occurs in PMA and SMA wearing surfaces have been found to be low for a longer period of time in comparison to conventional neat HMA mixtures. It should be noted that asphalt rubber modified mixtures have provided good performance in delaying reflective cracks in localized areas; for example Arizona and California.

CHAPTER 7 STRESS AND STRAIN RELIEVING INTERLAYER

Stress or strain absorption interlayer systems, such as SAMI, STRATA, and crack relief layers are designed to dissipate energy by deforming, horizontally or vertically, because of their low stiffness. Conceptually, the use of stress or strain relieving/absorbing interlayer over joints and cracks increase the gauge length for the development of strain, decreasing the potential for reflective cracks caused by environmental and wheel loads.

This mitigation method is classified into two types: an interlayer that is less than about 2 inches (50 mm) in thickness, defined as stress absorbing membrane interlayer, and those that are greater than 3 inches (75 mm), defined as cushion or crack relief layers. The thin layers or membranes (majority of these are less than 1 inch [25 mm] in thickness) dissipate only the horizontal movements and does not increase the structural capacity of the pavement, while the thicker cushion layers are hypothesized to dissipate both horizontal and differential vertical movements at joints and cracks.

A third type is also included within this chapter and is defined as a bond breaker interlayer. Bond breakers dissipate (do not transfer) horizontal movements from the existing pavement surface to the HMA overlay. All three types are discussed in the following subsections. It is emphasized that HMA overlays of 4 inches (100 mm) or greater should be used when an interlayer is used in areas with turning or braking movements of aircraft, because of the increased horizontal forces applied at the surface of the pavement resulting in slippage cracks or shoving.

7.1 Stress Absorbing Membrane Interlayer

Stress absorbing membrane interlayer (SAMI) is a layer of soft material applied on the existing pavement surface prior to placing the overlay. SAMI’s provide a flexible layer in the rehabilitation design above the base pavement that is able to deform horizontally without breaking. This allows large horizontal movements to take place in the vicinity of the cracks or joints, thus dissipating the stress before it reaches the overlay. SAMI’s do not dissipate large differential vertical deflections across joints or cracks in existing rigid and flexible pavements. Thus, they are typically used to mitigate thermally induced reflective cracks.

They also provide a waterproofing role to protect the pavement structure and foundation should the overlay crack. Some SAMI’s are applied only to the cracks, like a bond breaker, thus minimizing the cost of materials and installation.

Wood (1984) reported the application of SAMI in seven states to retard reflective cracking. Four states (Alabama, Arizona, Arkansas and New York) achieved good performance, while the other three (Colorado, Pennsylvania, and Nevada) reported complete failures. As an overall summary, the following results for SAMI application were presented:

- SAMI’s cannot prevent reflective cracking, but can retard it.
- SAMI’s perform better in overlays on flexible pavements with fatigue cracking than for rigid pavements having thermal or mid-slab cracking.

- Treatments applied on the full width and length of pavement has produced better results than treatment applied only above the joint/crack area.
- A thicker SAMI is more effective, when placed in the range of ¼ to 3/8 in (6 to 9.5 mm).
- A SAMI with lower stiffness was more effective. However, the stiffness should not be so low as to promote slippage between layers under horizontal loads caused by braking and turning of aircraft. Stiffness of the SAMI used in the past has varied from 6500 to 7500 psi (45 to 52 MPa) at temperatures of 70 to 75 °F (21 to 24 °C) when no aggregate is used.

The overlay thickness above a SAMI should be determined using an equivalent cracked condition of the existing pavement to account for the increased deflections at the cracks and joints. In addition, zero bond or interface friction (no shear restraint between the layers) should be used between the overlay and existing pavement for determining the overlay thickness. The use of no interface friction is a conservative estimate of the actual condition.

7.1.1 Chip Seals

Chip seals are a SAMI layer that consists of a thick layer of binder, usually modified, and spread with single size chips that are rolled into the binder using a pneumatic rubber tired roller. Chip seals are applied over the entire area being overlaid. The thick binder layer and aggregate chips do not prevent or reduce the horizontal movements at cracks and joints, but dissipate those movements and are not transferred to the HMA overlay.

A plant-mixed asphalt-rubber chip seal has been also used. For example, this chip seal have been used extensively at Sky harbor International Airport. The chip seal consists of 0.5 gal/yd^2 (2.3 liter/m^2) asphalt-rubber blend of 75 percent 120-150 Pen asphalt and 25 percent ground rubber tire tread, and 24 to 27 lb/yd^2 (13 to 14.5 Kg/m^2) crushed river gravel with nominal maximum size of ¼ inch. Chip seals that have been used at other locations consist of a 1/4 in. to 3/8 in thick layer of the rubber-asphalt mix (0.4 to 0.6 gal per sq yd [1.8 to 2.7 liter/m^2]). Heated 3/8 inch aggregate chips are spread over the mix at a rate of 35 lbs/yd^2 to 40 lbs/yd^2 (19 to 21.5 Kg/m^2) to prevent bleeding and flushing.

7.1.2 STRATA—A Proprietary Material

The STRATA, developed by SemMaterials (www.SemMaterials.com), is a relatively new reflective crack relief interlayer system which protects existing pavement structures from water damage and delays reflective cracks. It includes a highly flexible, impermeable HMA interlayer and overlay. The HMA interlayer is normally very thin (1-in [25 mm]), with fine aggregates and highly elastic polymer modified asphalt (PMA) produced and compacted at higher asphalt content. The HMA overlay can be a well-graded Superpave mixture or gap-graded SMA using SBS polymer modified asphalt binder. The minimum overlay thickness should be determined based on aircraft traffic operations.

According to SemMaterials, the advantages of STRATA include: 1) significantly delaying reflective cracks longer than fabric and HMA overlays, 2) providing an impermeable interlayer to protect pavement structure from moisture damage, 3) providing a highly fatigue resistant material, 4) ease of mixing, placement, and compaction through the use of conventional HMA paving equipment, and 5) savings in construction time and facilitating easy maintenance of pavement. Field results show that the STRATA system does delay thermally induced and to some extent traffic induced reflective cracks much longer than the use of thicker HMA overlays.

7.1.3 Interlayer Stress Absorbing Composite—A Proprietary Material

Interlayer Stress Absorbing Composite (ISAC) is a composite layer combining the effect of both geotexile and SAMI, which was developed and evaluated for the purpose of effectively alleviating or mitigating the problem of reflective cracks (Mukhtar, 1994; Dempsey, 1997 and 2002). The ISAC system consists of a low stiffness geotextile as the bottom layer, a viscoelastic membrane layer as the core, and a very high stiffness geotextile for the upper layer. The design of ISAC system followed the concept that stress can not be stored indefinitely in the geotextile or the HMA overlay and should be dissipated as it develops. This system can relieve stress at the crack tip and at the same time provide reinforcement to the overlay.

The low modulus, low stiffness non-woven geotextile (meeting AASHTO M-288-92) at the bottom of the composite interlayer serves three functions: a) contain the rubber asphalt membrane, b) fully bond with the existing pavement with the help of a tack coat, c) accommodate large strain at the joint/crack so as to allow horizontal movement of the underlying pavement without breaking its bond with the slab. This design system has been confirmed in the laboratory, but has not been used extensively in the field. Three years of field performance testing in limited applications has shown that the ISAC system is effective for mitigating reflective cracks.

In 1993, the University of Illinois completed research directed on a prototype ISAC. A test section of ISAC was placed on IL 38 near Rochelle, IL. Five ISAC test sections were placed between 1997 and 2000 (Vespa, 2005). Some of these ISAC sections contain other reflective crack control methods, such as Sand Anti-Fracture (SAF) layer and strip and area-wide reflective crack control fabric. For all five test sections, the formation of reflective cracks and the subsequent deterioration of these cracks were delayed at ISAC treated joints and cracks. This delay ranged from over one year to close to three years when compared to the untreated and other crack control methods. The ISAC areas performed consistently better than other anti-reflection cracking products such as PavePrep and Roadtac. When compared with SAF, the ISAC delayed reflective cracks by about two years. The price of the ISAC strips ranged from $10 to $14 per foot in 2005.

7.1.4 HMA Interlayer with Material Modification

7.1.4.1 <u>Soft Asphalt Interlayer</u>

Softer grade asphalt can substantially alter the elastic modulus of the HMA mixes thus reducing the crack tip stress. As suggested by Carpenter et al. (1976), the best overlay design to reduce cracking is:

a) A thin layer with soft asphalt (low viscosity) and low modulus of elasticity to serve as a stress relieving medium.
b) A layer with soft asphalt (low viscosity) and a high modulus of elasticity. Although this arrangement will hasten the propagation of unseen cracks through the surface of old pavement, it will slow them down considerably through the stress-relieving layer.

Several projects have successfully incorporated the soft asphalt interlayer for controlling reflection cracking. In Arizona (Way, 1980), a 200-300 penetration asphalt from the Los Angeles Basin (low temperature susceptibility) was used in a 1.26-in (32 mm) HMA overlay and then covered with an approximately 0.5-in (12.5 mm) HMA wearing surface. This structure-material combination was found to be one of the five most effective treatments to reduce reflection cracking. Sherman (1982) reported on a project in Wyoming that included the use of a 2-in (50 mm) soft asphalt interlayer (viscosity grade, AC 2.5) and crack sealer. This system exhibited the least amount of cracking and was the most effective for reducing reflective cracking.

7.1.4.2 Asphalt-Rubber Interlayer
An asphalt-rubber interlayer is also included in the SAMI layer category. Asphalt rubber is made from mixing relatively high concentrations of reclaimed rubber in hot asphalt. When comparing the amount of reflection cracking alone, asphalt rubber membrane covered by a approximately 0.5 in (12.5 mm) HMA wearing surface was the best among the eighteen treatments tested in Arizona (Way 1980). However, shoving occurred and led to an undesirably rough ride which was a disadvantage of the asphalt rubber interlayer. Increasing the thickness of the HMA overlay would reduce the potential for shoving.

New Mexico (McKeen et al., 1984) studied the influence of variables such as rubber type, mixing temperature, batch repetition, and test temperature on cracking resistance. Four laboratory tests and a field trial were conducted. Results from a field experiment showed that the mixing time has a significant influence on cracking observed, while the rubber type showed no influence on cracking.

7.1.4.3 Polymer Modified Interlayer
Another type of SAMI used to mitigate reflective cracks consist of a thin SBS elastomer asphalt included in a medium-thickness HMA overlay for the rehabilitation of cracked concrete pavements (Patterson, 1983). This application has been also used below thin overlays with more severe surface conditions, such as joint movements of up to approximately 0.28-in. (7 mm) under airport runway loadings. Results showed the crack resistance of the pavement structure was improved by increasing overlay thickness and stiffness and reducing the membrane stiffness. Theoretical analyses of this system indicated that a 3.15-in (89 mm) thick composite membrane-overlay system covered by an open-graded HMA overlay can satisfy the design requirements and is comparable to 9.4-in (240 mm) thick conventional overlay for control of crack reflection over a 15-year life. This type of SAMI layer was shown to be safe under all aircraft loading conditions, and has been successfully used.

7.1.5 Fabrics—Geosynthetics
Another type of interlayer used on both roadways and airfield pavements consists of a thick asphalt-rubber membrane and non-woven fabric that are placed directly on the surface of the existing pavement. This type of interlayer using geosynthetics (fabrics) is usually included in a separate category of stress and strain relieving interlayer. For this guide, it is included under the SAMI systems because it is designed to dissipate energy by deforming horizontally in combination with the fabric that increases the tensile strength of the interlayer system.

The effectiveness of this stress-absorbing layer system in stopping reflective cracking from occurring in the HMA overlay was evaluated by the U. S. Army Engineer Waterways Experiment Station (Vedros, 1979). This layer consisted of an asphalt-rubber membrane and a non-woven fabric placed below a thin HMA overlay (2 in. [50 mm] or less). Field tests of two asphalt-rubber membrane formulations and three nonwoven fabrics were placed on roads and airfield pavements at five Army installations in various areas of the United States. This system has been found to significantly delay reflective cracks from existing flexible pavements, but has been less effective when placed over existing JPCP or JRCP.

A construction issue related to the use of fabrics is that wrinkles can occur in the fabric during placement. Where wrinkles occur during placement, cracks have been reported to occur in the HMA overlay.

7.1.6 Advantages and Issues

The major advantage of the different SAMI layers is that the elevation of the final pavement surface is minimized. More importantly, most of the SAMIs included within this treatment method are an effective mitigation strategy for the condition where the primary mechanism causing reflective cracks are horizontal movements concentrated at the joints and cracks (refer to figures 4 through 6). Chip seals are the more commonly used SAMI for mitigating reflective cracks, while the proprietary materials have been used the least. Both have been successful when used under the right conditions. Those methods that have resulted in good performance for mitigating reflective cracks are chip seals, asphalt rubble interlayer, and the proprietary materials (STRATA and ISAC). Fabrics or Geosynthics placed directly on the existing PCC pavement surface have resulted in variable performance and their performance is climate dependent.

The major issues with the use of these materials is that they do not provide structural support to the overlay and are ineffective in reducing reflective cracks caused by differential vertical deflections at joints and cracks in the existing pavement. Another major concern with the use of SAMI layers is that they can be impermeable and trap water in the HMA overlay mixtures that have not been properly compacted. HMA mixtures with air voids exceeding 8 percent can exhibit moisture damage both below and above the SAMI layer. Thus, the in place density and air void level are important for the existing HMA layers and HMA overlay.

These products also require some minimum HMA overlay thickness to prevent the occurrence of shoving and slippage of the overlay in areas subjected to turning and braking movements of aircraft. That minimum overlay thickness is interlayer, aircraft load, and climate dependent and should be determined using mechanistic-based structural design procedurese. More importantly, all of these methods (including chip seals) require special materials, workmanship, and knowledge for their placement.

7.1.7 Design and Construction Features

As noted above, the overlay thickness above a SAMI should be determined using an equivalent cracked condition of the existing pavement to account for the increased deflections at the cracks and joints. Zero interface friction should also be simulated between the overlay and existing pavement in determining the overlay thickness. The use of no interface friction is a conservative estimate of the actual condition. The other important feature with this reflection cracking mitigation strategy is that the materials and construction procedures for the proprietary products listed should follow the manufacturer's materials and construction specifications.

7.2 Cushion or Crack Relief Layer

Two types of cushion layers have been used for mitigating reflective cracks: crushed stone or unbound aggregate base layers and open-graded HMA or crack relief layers. The open-graded HMA, historically defined as crack relief mixtures, have 25 to 30 percent air voids and generally require thinner dense-graded HMA overlays as compared to an unbound aggregate base. The unbound aggregate base layers, however, are less expensive than for the crack relief layers that are stabilized with asphalt. Aggregate base course cushion layers have been used more extensively for roadway rehabilitation projects than for airfields. This method is not currently used as extensively as it has been used in the past because of the increase in surface elevations. Increasing the surface elevation on airfields requires the other related features (such as lighting) to be also raised accordingly.

The use of an open-graded HMA or crack relief layer as a stress relief layer placed on the existing pavement is recommended by FAA circular AC-150/5320-6 (1995) as a method to inhibit reflection cracking. Because of the large percentage of the interconnecting air voids in open-graded mixtures, the stress caused by the movement of the underlying PCC slabs can be relieved before it causes concentrated stress in the upper dense-graded HMA layers of the overlay. The existence of large air voids absorbs the crack energy and arrest crack development in the overlay.

Crack relief layers have been used in Tennessee for more than 30 years and in Arkansas for more than 20 years. Good results and construction experiences were presented by Hensley (1980). In the state of Arkansas alone, over 200 two-lane miles of open graded mixtures as part of the rehabilitation strategy have been placed. The performance of this overlay strategy has been good and shows that this mitigation method is viable for reducing reflection cracking in both rigid and flexible pavements.

7.2.1 Advantages and Issues

Advantages of cushion layers are that these thicker layers: (1) help insulate the existing pavement, decreasing localized horizontal movements, (2) reduce horizontal movements transferred from the existing pavement to the overlay, and (3) absorbs some of the differential vertical deflections across the joints and/or cracks in the existing pavement. Thus, this treatment method should mitigate reflective cracks caused by both horizontal and differential vertical movements across joints and cracks. Several sources of information report that the use of cushion courses rate from poor to excellent in eliminating reflective cracks.

Two problems associated with cushion courses include: the total overlay thickness is generally much greater than for some of the other mitigation strategies, and the cushion layer is a potential water conduit or reservoir between the overlay and existing pavement. This potential drainage problem may be the reason why this mitigation strategy has resulted in poor performance in some cases. Positive drainage must be maintained in case rains occur during construction that could fill the voids in the crack relief layer.

7.2.2 Design and Construction Features

When using a cushion layer for maximum benefit, the existing pavement should be treated by undersealing, if voids are beneath the PCC slabs and, removing/replacing all badly cracked and depressed areas before the cushion layer (open-graded HMA or unbound aggregate base material) is placed.

7.2.2.1 Crack Relief Layer (Permeable Asphalt Treated Base)

For the design of open-graded or crack relief mixtures, no standard procedure exists. However, a low amount of asphalt (a harder grade is preferred) is used with a 2 to 3 in (50 to 75 mm) top size aggregate with low fines content. The in place air voids of the crack relief layers are generally greater than 20 percent.

Different aggregate sizes (air voids) offer different protection against reflection cracking from both horizontal and vertical deformations and different aggregate interlock for load transfer. Larger aggregates and voids (Grade A, as defined in the Asphalt Institute's Technical Bulletin #4) usually offer the greatest protection against reflection cracking from both horizontal and differential vertical movements (Asphalt Institute, 2005). Open-graded mixtures with smaller aggregate size and slightly less air voids (Grade C, Asphalt Institute crack relief layer) is recommended for use when short slabs are involved or on CRCP where the horizontal movements are uniformly distributed. A Grade C gradation is also used for existing flexible pavements.

Regardless of the type grading selected, a minimum of 3.5-in (89 mm) open graded course plus a 2-in (50 mm) intermediate course and a 1-in (25 mm) surface course are recommended. All crack-relief aggregates should consist of 100 percent crushed from a hard durable aggregate source. The intermediate course placed directly on the crack relief mixture provides an adequate working table for the surface to be placed on and bridges the surface voids of the crack-relief layer. The intermediate course should be specified to be coarse enough to prevent material from penetrating the voids of the open-graded mix.

7.2.2.2 Crushed Stone or Granular Aggregate Base

For unbound aggregate base cushion layers, the amount of fines should be limited to values less than 10 percent and those fines should be non-plastic. An issue or problem that occurs with the use of this type of cushion layer is that construction equipment (the delivery trucks and paver) can disturb the surface of the material resulting in variable overlay thicknesses. Layers with variable thickness can be difficult to compact to an adequate density. Another issue related to the use of granular base materials as the cushion layer is that all adjacent features along the air-side pavements need to be raised to the same or similar elevation. As a result, the open-graded or permeable asphalt base mixture (crack relief layer) is more commonly used.

7.3 Bond Breaker Interlayer

A type bond breaker material can be placed on the pavement surface adjacent to the pavement joint/crack before placing an overlay in order to prevent reflection cracking. These materials usually include wax paper, aluminum foil, roofing paper, or a thin layer of sand/stone dust. The width of such a bond breaker strip varies from 2 to 24 inches (50 to 610 mm) on either side of the joint/crack.

The mechanism of the bond breaker technique is to reduce the stress concentration by preventing a bond forming between the old pavement and the overlay in the vicinity of the joint/crack. The area of stress in the HMA overlay can be extended from about 0.25 in (6 mm) immediately above the concrete joint to a length of several feet. By using this procedure, the strain in the overlay can be reduced so that the reflection cracking will not take place within the design period.

Wood (1984) reported several applications of the bond breaker technique. In Virginia, one project did not develop any cracking for 9 years whereas the other two, initially preformed well, developed severe cracking after 3 years. Kentucky experience showed the bond breaker technique only worked for a short time. In New York, a project was conducted to evaluate the effectiveness of stone dust bond breaker in retarding reflection cracking. A layer of stone dust (¼ in [6 mm] in thickness) was spread at 40 different locations adjacent to the joints before placing the overlay. It was found that after 4 years all of the test sections exhibited cracks that were ¼ to ½ inch (6 to 12 mm) in width. Cores taken from the field showed that no free stone dust was present. Some asphalt flow had occurred causing the stone dust, HMA overlay, and the PCC slab to bond together. Possible reasons reported for failure of the bond breaker method included:

- Because of the small width of the un-bonded portion, the bond breaker only breaks the bond very close to the joint/crack and provides limited degree of stress relief.
- Wax paper or aluminum foil can not transfer enough shear force to the underlying pavement, it only breaks the bond. Therefore, slippage may occur under the accelerating, decelerating, or sharply turning condition of the moving aircraft.
- The effect of sand and stone dust is not durable. Asphalt can still create a bond with the stone dust and the underlying pavement. It is also difficult to spread a uniform thickness of the sand or stone dust around the joint/crack.

7.4 Performance Issues and Probability of Success

In summary, a stress and/or strain relieving interlayer can be an effective mitigation method when the existing pavement has good support conditions and minimal differential vertical deflections across joints and cracks. The probability of success for this method in mitigating reflective cracks is summarized below.

➔ STRATA and Other Proprietary Materials—High probability of success with moderate risk. These materials have been found to provide good performance in delaying reflective cracks much longer than other conventional methods. The higher risk identified for this material is that there are few performance data to confirm the use of these mixtures over longer periods of time.

➔ SAMI: Sufficient thickness of the HMA overlay needs to be placed to ensure that shoving and slippage cracks do not occur in areas with horizontal loads from aircraft operations. In other words, the HMA overlay placed over these materials needs to be thick enough to reduce the potential for shoving and slippage cracks and limit the amount of fatigue cracking to a specific amount over the design period.

- Chip Seals as a SAMI—Moderate probability of success with a low risk when used on flexible pavements with good support conditions. Chip seals should not be used to mitigate reflective cracks on jointed concrete pavements with faulting.
- Modified HMA Interlayer as a SAMI:
  - Asphalt Rubber Interlayer—High probability of success with a moderate risk.
  - Polymer Modified Interlayer—Moderate probability of success with a moderate risk.
  - Soft Asphalt Mix Interlayer—Low probability of success with a high risk.
- Fabrics as a SAMI—Moderate probability of success with a high risk when used on flexible pavements with good support conditions. The reason for the higher risk is a result on some of the construction problems (such as wrinkles in the fabric) and difficulties with using the fabrics and other similar materials. Fabrics, as a SAMI, are not recommended for jointed concrete pavements.

➔ Cushion Layer: Two types of cushion layers have been used to increase the structural strength and mitigate reflective cracks.

- Crack Relief Layer (Open-Graded HMA Mixtures)—Moderate probability of success with low risk. As noted above, the key to success of this method is to ensure that the mixture has reasonable stability so that it will remain undisturbed under construction traffic, but will not transfer any of the horizontal movements of the existing pavement to the overlay. The risk of using this method is that the permeability of the crack relief layer can retain water and cause moisture damage in the dense-graded HMA overlay with time.
- Cushion Layer: Unbound Aggregate Base Layer—Moderate probability of success with moderate risk.

➔ Bond Breaker Interlayer (excluding cushion layers that are much thicker)—Low probability of success with a high risk. As such, a bond breaker interlayer should not be used as a method to mitigate reflective cracking. If a bond breaker interlayer is used, thicker HMA overlays should be used to reduce the probability of slippage cracks and mix shoving.

CHAPTER 8 REINFORCEMENT OF HMA OVERLAY

The different types of HMA overlay reinforcement that have been used to mitigate reflective cracks can be grouped into two materials: steel and Geosynthetics. The strategy of overlay reinforcement is used to increase the tensile strength of the overlay and to hold the cracks tightly together once they occur.

8.1 Steel Reinforcement

One of the oldest interlayer systems used in HMA is steel reinforcement. The idea, which appeared in the early 1950s, was based on the general concept that if HMA is strong in compression and weak in tension, then reinforcement could be used to provide more resistance to tensile stress. In other words, the reinforcing elements with high tensile strength can be used to increase the tensile strength of HMA mixtures. Steel reinforcement has been placed in narrow strips over the joints and cracks in the PCC pavement or continuously over the entire length of the project. Both welded wire fabric and expanded metal reinforcement has been used.

Steel and wire mesh reinforcement was used in the HMA overlays of many military airfield pavements during the 1950's and 1960's. The steel reinforcement did not prevent the reflection cracks, but did hold the cracks tightly together, similar to its function in JRCP. The use of steel reinforcement was gradually abandoned in the U.S. due to its difficulty in installation starting from the early 1970's and potential for corrosion.

Modifications to producing and installing the steel mesh, however, were made in the early 1980's which helped regain interest to this reinforcement interlayer system in Europe (especially in Belgium and the Netherlands). More importantly, synthetic fiber fabric has been studied and used as a reinforcement material to combat the corrosion problem. The use of synthetic fiber fabrics as a reinforcing material in HMA is discussed in the next subsection.

The applications of steel reinforcement netting interlayer in the field have been widely used and well documented throughout the world. Different interlayer systems (e.g. steel reinforcement, SAMI, geogrid, non-woven and woven geotextile) have been tested and evaluated. Most study results comparing different reinforcing materials have concluded that the use of steel reinforcement provided better performance than the control case as well as other interlayer systems.

In the U.S., the steel reinforcement netting interlayer system was first installed at the Virginia Smart Road in 1999 (Al-Qadi and Elseifi 2003, 2004). In addition, four projects with steel reinforcing netting were completed in 2001: three in Pennsylvania (SR-180, Turnpike MP85-88, and SR3013), and one in Delaware (Wilson Road). Nailing was used in the Pennsylvania Turnpike project, and slurry seal was applied as an intermediate layer on top of the mesh in other three projects. From the field survey results, all four projects showed good effect of steel reinforcement on reducing the reflection cracks of deteriorated pavements.

8.1.1 Advantages and Issues
The advantages of the steel reinforcement include: (1) increased tensile and shear strength, and resistance to cracking; (2) coherence of the pavement even after cracking; (3) increased resistance to fatigue failure and greater pavement flexibility; (4) potential material savings and enhanced performance; and (5) increased resistance to rutting caused by lateral flow of material. In addition, the reinforcement reduces the horizontal displacement at areas where braking and acceleration occur, reducing the potential for slippage cracks. The primary disadvantage is that water within the HMA mixture causes the steel to corrode in as little as four years of service. Another major disadvantage is that HMA overlays reinforced with steel cannot be milled.

8.1.2 Design Features
The steel mesh product consists of a double-twist, hexagonal mesh with variable dimensions, and steel wires (either circular or torsional flat-shaped) placed transverse at regular intervals. No welding is used in this generation of steel reinforcement, which reduces installation difficulties and any variation in HMA densities caused earlier by welded reinforced steel. As noted above, the steel netting can be fixed to existing pavement by nails and/or a slurry seal layer. Studies based on finite element (FE) analysis indicate that properly installed steel reinforcement netting can retard crack initiation and crack propagation by 10-40% and 40-170%, respectively. This benefit range depends on overlay thickness and stiffness of surrounded material (Al-Qadi et al. 2003, Elseifi and Al-Qadi 2005).

8.1.3 Construction Features and Issues
For successful installation of the steel reinforcement netting, Al-Qadi et al. (2003) suggested that the mesh should be laid perfectly flat and any folds or wrinkles should be avoided. A loader or pneumatic compactor may be driven on top of the steel mesh to remove any existing tensions from the steel mesh as well as reduce the natural curvature of the roll. Other than this, any stretching or tensioning the steel mesh is not needed. However, one of the installation techniques suggested pretensioning the steel, which was used successfully on a project in Atlanta, Georgia. Pretensioning of the steel has not been widely used.

Both nailing and slurry seal held the mesh in place effectively. The use of either one is determined by the pavement type, severity of the deterioration, water table level and drainage. If a thick layer of slurry seal is used, the imprint of the mesh should be clear to prevent bleeding. Other benefits such as preventing water from penetrating into the underlying layer, improving bonding between the interlayer and the existing pavement, and facilitating the placement of the top layer can be achieved when a slurry seal is used. The maximum speed suggested running on the slurry seal-mesh interlayer is 25 mph (40 km/hr).

8.2 Geosynthetics

Geosynthetics are defined as fabrics, grids, or composites. These materials are hypothesized to improve HMA overlay performance through the following mechanisms: reinforcing the overlay, relieving the stress/strain concentrations at joints and cracks, and reducing surface water infiltration to the lower layers.

As a reinforcement material, Barksdale et al. (1989) recommends that the geosynthetics must have a secant stiffness greater than 4000 lb/in (71,400 kg/m). Secant stiffness is the modulus of elasticity times the thickness of the geosynthetic. Geosynthetics with lower stiffness will act as a stress relieving interlayer in the pavement and reduce the stress at the tip of the joint/crack. Most of the geosynthetic materials are used as a reinforcing material, and are thus discussed within this subsection.

Geosynthetic products are the more popular and marketed options in dealing with reflective cracks. However, the individual products within this category have different conceptual approaches to delay the occurrence of reflection cracking. In the following paragraphs, a brief definition and various engineering applications of the more common products within this category is provided. In summary, the performance of geosynthetics in mitigating reflection cracking in HMA overlays has ranged from successes to failure. Most studies have concluded that the cost effectiveness of geosynthetics in mitigating reflective cracks is marginal at best. However, these materials do keep the widths of the reflective cracks narrower during the winter months when used as a reinforcing material.

8.2.1 Fabrics/Geotextiles

Fabrics or geotextiles for reflective cracking mitigation started to enter the marketplace in the 1970’s. These materials may be woven or nonwoven and are typically composed of thermoplastics such as polypropylene or polyester but can also contain nylon, other polymers, natural organic materials, or fiberglass (Button and Lytton, 2003). Fabrics or geotextiles provide reinforcement to the HMA overlay to relieve the stress by providing physical restraint to resist the formation of cracks in the overlay as the cracks and joints in the base pavement open. Some of the common geotextiles currently being used are, Petropave, Paveprep, Petromat, Mirafi, Typar, and Roadglass.

Fabrics have been used in many airport pavement projects for mitigating the reflective cracks and protecting lower layers from water damage. Several applications of synthetic fabrics have been used on state and interstate highways as well as on airport runways. Most studies or uses have resulted in marginal performance for the use of geotextiles in retarding reflective cracks. Amini recently reported on the effectiveness of paving fabrics to reduce reflective cracks in the U.S. and foreign countries (Amini, 2005). One of his conclusions was that paving fabrics offer little benefit for thin overlays (less than 2.0 in [50.8 mm]), but for thicker overlays their performance has been successful for the most part.

8.2.1.1 <u>Benefits and Issues</u>

Although fabrics will not eliminate reflection cracking completely, they are recommended by FAA circular AC-150/5320-6 (2006) as a method to protect the existing pavement and foundation as well as provide some degree of water-proofing beneath reflective cracks. The water-proofing capability of fabrics appears to be their most significant contribution, as long as the capacity of the fabric to resist rupture is not lost. Fabrics, however, may not be a good method when excessive deflections, substantial thermal stresses, and/or poor drainage condition exist.

8.2.1.2 <u>Construction Features and Issues</u>

Usually a leveling course is applied to the surface of the existing pavement on which a tack coat is sprayed before placing the geotextile material. The geotextile layer is then placed and covered with another tack coat, prior to placing the HMA wearing surface. Laboratory bending beam fatigue tests exhibited higher fatigue life when the geotextile was placed within the lower third of the overlay, rather than at the bottom of the overlay.

FAA (2006) suggests that the following conditions be followed when including a fabric in a structural overlay:

(1) The fabric should have a tensile strength of at least 90 lbs (41 kg) when tested in accordance with ASTM D 1682 and a density in the range of 3 to 5.5 ounces per square yard (70 to 130 grams per square meter).
(2) Fabric membranes should not be used where the horizontal displacements exceed 0.05 inch (1.3 mm) or where vertical displacements will exceed 0.02 inch (0.5 mm). Fabric should not be used when the overlay thickness is less than 3 inches (75 mm) or more than 7 inches (178 mm).
(3) The proper amount of tack coat applied to the fabric is critical. A sufficient amount of tack coat will ensure proper bond between fabric, overlay and the underlying pavement and also make the pavement impervious. Too much tack coat reduces the shear resistance at the interface which may result in slippage and tearing at critical locations where vehicles accelerate, decelerate, or make sharp turns. Emulsified asphalt applied at a rate of from 0.15 to 0.30 gallons per square yard (0.7 to 1.4 liters per square meter) is recommended by FAA. The optimum amount of tack coat depends on the type of fabric and the surface on which the fabric is placed. Smith (1984) recommended using the following relationship to estimate the amount of tack coat needed for geotextiles:

$$RTC = 0.05(TW)^{0.30}$$

Where:
RTC = Recommended tack coat rate (gal/sq yd)
T = Geotextile thickness
W = Geotextile weight (oz/sq yd)

However, it is common practice to follow the manufacturer's recommendation for type and application rate for the tack coat used to ensure a proper bond between the fabric and existing pavement surface or between adjacent lifts of the HMA overlay.

8.2.2 Geogrids

Geogrids first emerged in the 1980s. They may be woven or knitted from glass fibers or polymeric (polypropylene or polyester) filaments, or they may be cut or pressed from plastic sheets and then post-tensioned to maximize strength and modulus. Geogrids are strip products and typically have rectangular openings from ¼ inch to 2 inches (6 to 51 mm) wide (Button and Lytton, 2003). Grids provide crack mitigation by providing tensile reinforcement to the HMA layer. FAA (2006) allows the use of grids as a countermeasure to retard reflection cracking.

Reinforcing grids are designed to enhance the tensile strength of an HMA overlay by absorbing the horizontal tensile stresses above the concrete joints and distributing them over a wider area. As a result, the stress concentrations in the HMA above the joints, caused by the contraction of the PCC slabs with decreasing temperature, should be reduced by the presence of the Geogrid and hence this should reduce the initiation of reflective cracks.

Higher-strength, higher-stiffness grids and fabrics have been incorporated into HMA overlays in recent years to provide an even higher level of crack retardation, and in some cases waterproofing. These new reinforcing materials rely on their high modulus structure to reinforce the HMA, while interrupting reflective crack propagating from the old surface. It is hypothesized that the high stiffness grids and fabrics allowed the crack energy to be intercepted and reoriented horizontally. This reorientation of the crack turns a reflective crack into a horizontal plane beneath the geogrid and delay reflective cracking indefinitely, provided they are constructed properly.

Tensar is a proprietary material made from polypropylene and is biaxial oriented to give strengths in the order of mild steel in both directions. Tensar grids have been found to be effective as a reinforcement of the HMA layer, as long as the grid size is larger than the nominal maximum size of the aggregate. Laboratory tests have been also used to evaluate the fatigue strength of Tensar grid reinforced HMA. The results showed that a 6-inch (152 mm) reinforced HMA layer could carry as many load cycles as a 10-inch (250 mm) un-reinforced HMA layer.

Glasgrid is another proprietary material made of fiberglass. It has high modulus, low percentage of elongation, and is relatively cheap. Flexural tests of Glasgrid have shown that the reinforced prisms were about two and a half times stronger in flexural than un-reinforced prisms. In addition, the cracks did not propagate through reinforced prism overlay after fracture and the Glasgrid was still fully bound to the base of the overlay, holding the fragments together. Field trials of this Glasgrid have been carried out in a number of places. One successful example is an experimental sections constructed in Alberta in 1985 incorporating both Tensar and Glasgrid.

Geogrid reinforcement materials have been used on various military airfields in the UK (Ellis, et al., 2002). The different Geogrids that have been used include: (1) a polyester grid with a 0.4 inch (40 mm) square mesh size, (2) a fiberglass grid with a 0.5 inch (12.5 mm) square mesh size, and (3) a galvanized hexagonal steel mesh. When placed properly within the HMA overlay, the Geogrids have been successful in reducing the effect of reflective cracks on overlay performance. In other words, the reinforcement did not prevent reflective cracks but did keep them as hairline cracks over a longer period of time.

8.2.3 Composites

Composites consist of fabric laminated onto a grid. The fabric permits adhesion of the composite onto a pavement surface, and the grid provides strength and stiffness. These are considered a new generation product and often are custom designed for a specific product. They combine the advantages of both a grid and a fabric when designed and installed correctly. The FAA allows the use of composites as countermeasure to retard reflection cracking (FAA, 2006).

HMA/fiberglass composite overlays (ACF) have been compared to standard FAA specification for rehabilitation of an airport runway using a 12 in (30 cm) overlay (Ramsamooj, 1998). The aircraft used in the study was a Boeing 777 with a 6-wheel gear load, each wheel weighing 64 kips (284 kN) with a tire pressure of 200 psi (1380 kPa). Both aircraft loading and thermal stresses were considered in the theoretical comparison. Wire mesh reinforcement at the mid depth of the HMA was used above the cracks and joints to enhance the shear strength of the overlay. The results showed that the standard overlay would develop reflective cracking after 6.5 years, and complete failure of the subgrade under the joints and cracks was expected after 10.5 years. The new ACF overlay appeared capable to sustain aircraft loadings throughout the entire design life of the PCC runway. Limited use and performance data are unavailable on these composite systems.

8.3 Performance Issues and Probability of Success

In general, the reinforced HMA overlays do not prevent reflective cracks, but control the width of the cracks. In addition, reinforced HMA mixtures should not be used in HMA overlays of JRCP and JPCP, especially when large differential vertical deflections and faulting occur at joints and cracks. The probability of success for this method in mitigating reflective cracks is summarized below.

- ➔ Steel Reinforcement—Moderate probability of success with high risk, especially in cold climates where salts are used during the winter months. The high risk identified for these materials is that corrosion is still a potential problem when using this type of reinforcement material.

- ➔ Geotextile/Fabrics Used as the Reinforcing Material—Moderate probability of success with a moderate risk when used on flexible pavements. The reason for the higher risk is a result on some of the construction problems (such as wrinkles) and difficulties with using the fabrics and other similar materials.

- ➔ GeoGrids used as the Reinforcing Material—Moderate probability of success with low risk when used on flexible pavements. Of the geosynthetic materials, the Geogrids have provided the better performance in delaying reflective cracks and keeping those cracks narrow once they occur.

- ➔ Composite Materials and Reinforced Systems—Low probability of success with a high risk. As such, composite materials should not be used as a method to mitigate reflective cracking. The reason for this recommendation is that there is too little data on long term performance to determine whether this material can mitigate and/or control reflective cracks.

CHAPTER 9 CRACK CONTROL

Under this strategy, a straight clean joint is sawed in the HMA overlay directly above the joint in the existing PCC pavement and then sealed—just like for a PCC pavement. An advantage of providing such controlled crack relief is that the controlled saw cut is more effectively sealed than a self-propagating zigzag reflection crack. Sealing the saw cut prevents water and incompressible materials from penetrating the pavement as well as reduces raveling and crack deterioration.

Numerous studies have concluded that the “sawing and sealing” is an effective way to avoid further deterioration of a reflected cracking, if applied appropriately. The “sawing and sealing” method is best suitable for JRCP with longer slab length with no mid slab cracking. Shorter slab length requires a large amount of sawing and sealing which may not be cost effective. In general, the typical cost for the sawing and sealing is $1.25 to $1.50 per linear foot based on selected projects in 2005.

9.1 Design Issues, Features and Properties

For this treatment to work, the saw cut in the overlay must match the location of the joint in the existing pavement within a high degree of tolerance (± 1 in [25 mm]). Mismatched joints usually reflect as another crack adjacent to the saw cut joint reservoir. Joints in the existing pavement can be marked using pins prior to overlay and then the overlay sawed at the joint. In addition, the existing PCC pavement must have adequate structural strength for future traffic levels.

The saw cut or reservoir dimension is an important factor in terms of the performance of the joint seal. The standard reservoir dimension established for jointed concrete pavements can be used for HMA mixtures. A minimum 4-inch overlay should be required when using the crack control method.

ASTM D 6690, Hot-Applied Rubber-Asphalt, is a type of sealant that can be used to seal the sawed joint.

9.2 Construction Issues

Three construction issues are associated with using this method and are listed below.

1. Adequate density must be obtained in the HMA overlay to ensure sufficient strength and durability. Any sawed joint in an area with lower densities and /or segregation will start to ravel and deteriorate with time.
2. The HMA mixture must be allowed to cool so that the stiffness of the material is high enough so the mixture will not be damaged during the sawing operation. In addition, do not open the newly sawed overlay to aircraft traffic operations before installing the sealant. In addition, do not overfill the joint. It is best to leave the sealant slightly recessed by about 1/16 to 1/8 on an inch (1.5 to 3 mm).
3. The third but most important construction issue is that the saw cuts must match the joints in the jointed concrete pavement within ± 1 inch, as noted above. If the saw cuts do not

match the joints, one or two secondary cracks that are parallel to the sawed joint will occur under repeated aircraft loadings. These secondary cracks can result in severe raveling and joint deterioration.

9.3 Performance Issues and Probability of Success

When used under the appropriate conditions, this method has a high degree of success. The one performance issue is that the sawed and sealed joints in the HMA overlay will need to be sealed with time. There is insufficient performance data to determine the period of time between different joint seal applications. However, previous experience suggests that the joints should last for 5+ years. Airport maintenance should plan or develop a schedule for inspecting the joints over time.

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