An ***AAPTP*** Research Report

Airfield Asphalt Pavement Technology Program

Final Report AAPTP 05-04 Techniques for Mitigation of Reflective Cracks

Principal Investigator

Harold L. Von Quintus, P.E., Applied Research Associates (ARA), Inc.

Contributing Authors

Mr. Jagannath Mallela, ARA, Inc.
Mr. William Weiss, P.E., ARA, Inc.
Dr. Shihui Shen, ARA, Inc.
Dr. Robert L. Lytton, P.E., Consultant, Texas Transportation Institute

APPLIED RESEARCH ASSOCIATES, INC.
100 Trade Centre Dr., Suite 100
Champaign, IL 61820-3915
(217) 356-4500
(217) 356-3088

Monte Symons, Director
Auburn University
277, Technology Parkway
Auburn University, Alabama 36849

20 February 2009

85-02

ACKNOWLEDGMENT OF SPONSORSHIP

This report 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

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policy of Auburn University or the Federal Aviation Administration. This report does not constitute a standard, specification, or regulation. The United States Government does not endorse products or manufacturers. Trademarks or manufacturers' names appear herein only because they are considered essential to the object of this document.

ACKNOWLEDGEMENTS

Dr. Robert L. Lytton, P.E. participated as a consultant on this project. 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.

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

Figure No. **Page No.**

LIST OF FIGURES, Continued

Figure No. **Page No.**

LIST OF TABLES

ABBREVIATIONS

AAPTP	– Airport Asphalt Pavement Technology Program
AASHTO	– American Association of State Highway and Transportation Officials
AC	– Advisory Circular or Asphalt Cement (viscosity grade)
ACF	– Asphalt Concrete Fiberglass
ASTM	– American Society for Testing and Materials
BRE	– Brent Rauhut Engineering
CIPR	– Cold In Place Recycling
CRCP	– Continuously Reinforced Concrete Pavement
CRREL	– Cold Regions Research and Engineering Laboratory
DCP	– Dynamic Cone Penetrometer
DOT	– Department of Transportation
EB	– Engineering Brief
EVA	– Ethylene-Vinyl-Acetate
FAA	– Federal Aviation Administration
FC	– Friction Course
FDR	– Full Depth Reclamation
FHWA	– Federal Highway Administration
FOD	– Foreign Object Debris
FWD	– Falling Weight Deflectometer
GA	– General Aviation
GPR	– Ground Penetrating Radar
HIPR	– Hot In Place Recycling
HMA	– Hot Mix Asphalt
HWD	– Heavy Weight Deflectometer
IRI	– International Roughness Index
ISAC	– Interlayer Stress Absorbing Composite
JPCP	– Jointed Plain Concrete Pavement
JRCP	– Jointed Reinforced Concrete Pavement
LCC	– Life Cycle Cost
LTE	– Load Transfer Efficiency
LTPP	– Long Term Pavement Performance
M-E	– Mechanistic-Empirical
MHB	– Multi-Head Breaker
NAPA	– National Asphalt Pavement Association
NDT	– Nondestructive Testing or Nondestructive Deflection Testing
PCC	– Portland Cement Concrete
PCI	– Pavement Condition Index

PFC	– Porous Friction Course
PG	– Performance Grade
PMA	– Polymer Modified Asphalt
RAP	– Recycled Asphalt Pavement
RPB	– Resonant Pavement Breaker
SAF	– Sand Anti-Fracture
SAMI	– Stress Absorbing Membrane Interlayer
SAPAE	– State Asphalt Pavement Association Executives
SBS	– Styrene Butadiene-Styrene
SBR	– Styrene Butadiene-Rubber
SMA	– Stone Matrix Asphalt
TTI	– Texas Transportation Institute
WHRP	– Wisconsin Highway Research Program

EXECUTIVE SUMMARY

Reflective cracks are a major concern to airport management personnel because they can significantly reduce the service life of hot mix asphalt (HMA) overlays of airside airport pavements. When 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 reflective cracks have to be maintained to prevent the generation of loose aggregate and increased roughness that can be detrimental to aircraft operations. These cracks also allow water to penetrate the underlying layers causing further damage to the pavement structure.

At best, the use of various materials and methods available today only slightly delay or limit the severity of the reflective cracks. One possible reason for this reduced service life of HMA overlays is that the rehabilitation strategy selected for a specific project is insufficient for the condition of the existing pavement. AAPTP Project 05-04 provides guidance and recommendations to the Federal Aviation Administration (FAA) and others related to managing and designing rehabilitation strategies of airside pavements on the selection and use of materials and treatment methods to mitigate the occurrence of reflective cracks in HMA overlays of rigid and flexible pavements. The technical guidance is provided in a separate document—*Technical Guide for Techniques for Mitigation of Reflective Cracks*, dated February 2009.

The 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 Portland cement concrete (PCC), HMA, and cement treated base layers. For purposes of this study those the categories to mitigate reflective cracks were classified into five basic categories for existing flexible and rigid pavements. These categories are listed below.

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.

This study presents a broad overview of the products and processes within each category that have been used to mitigate or delay the occurrence of reflective cracks based on the mechanisms listed above. The study also included a summary and overview of the types of materials and properties, field application techniques, extensiveness of use, and general success rate of each treatment method, as documented in the literature. The present state-of-the-art for mitigating reflective cracks in HMA overlays, however, is to a large degree still based on experience gained from trial and error methods of in service pavements; both for highways and airfields. Thus, the study presents the results from specific airfield and highway projects where different products and processes were used to mitigate reflective cracks.

Climate, structural condition of the existing pavement and overlay thickness are the three parameters that have the greatest effect relative to mitigating reflective cracks. The climatic conditions, especially the temperature conditions (such as freeze-thaw cycles and extremely cold weather conditions) have significant effect on the performance of different interlayer products (such as geotextile and asphalt rubber products) for controlling reflective cracking. In general, all reflective cracking retarding products or processes will perform better in warm and mild climates than in the hard-freeze or freeze-thaw cycling climates. The freeze-thaw cycles in severe cold climates can cause contraction and expansion of water within the pavement, which accelerates the damage from water filtration.

Field site visits were conducted within the study on a number of airfield pavements to investigate the performance of different mitigation strategies and methods. Results from the field or site visits were used to compare the performance characteristics of different mitigation strategies. Site visits included discussions with airport managers, design engineers, and field inspectors.

The data sources used to determine the effectiveness of different treatment methods was extracted from three areas: information and data included in the literature (including the comparative field studies), data and information obtained from airfields and roadway projects that have placed one to multiple treatment methods, and information from the detailed site visits. In order to assess and compare the effectiveness of different reflective crack mitigation strategies, the key evaluation factors were grouped into four major categories: (1) condition of existing pavement, (2) climate, (3) the rehabilitation design thickness, material and construction properties, and (4) the amount of reflective cracks over time. The probability of success and risk factors were used to rate the reflective cracking mitigation methods. The overall rating of a mitigation method was simply determined by multiplying its probability of success and risk values.

The key to designing an adequate rehabilitation strategy over a design period is to select the right or appropriate treatment method for the site and in place pavement structural condition. Decision trees were prepared for selecting appropriate reflective cracking mitigation techniques and methods that depend on the type and condition of the existing pavement. The decision trees were prepared based on the results from previous research studies, forensic investigation of rehabilitation strategies for the methods identified, a detailed survey of various projects, and experience documented in the literature. The decision trees are shown in figures A to C.

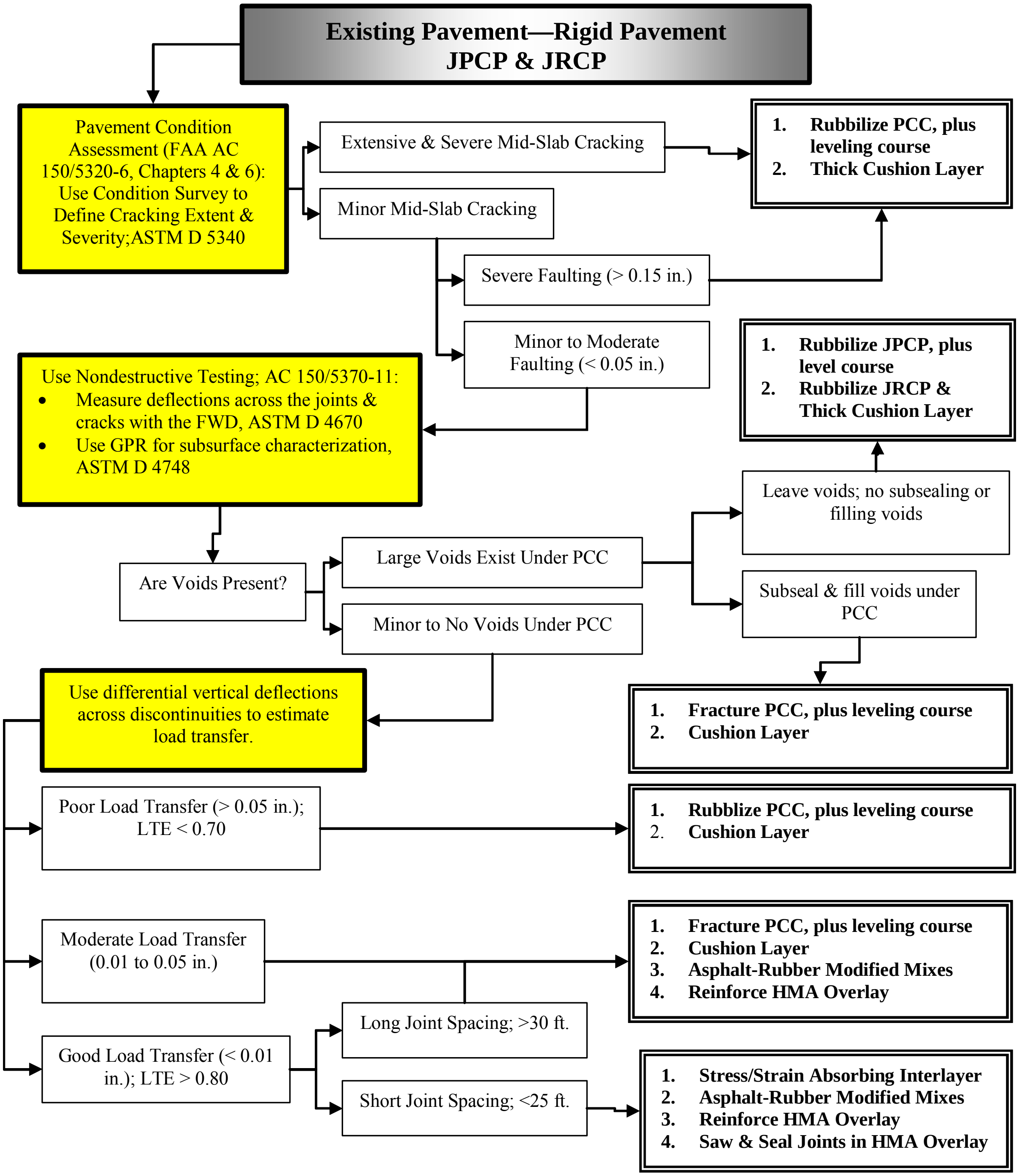


Figure A Decision Tree Providing Guidance to Mitigate Reflective Cracks in HMA Overlays of Existing Rigid Pavements

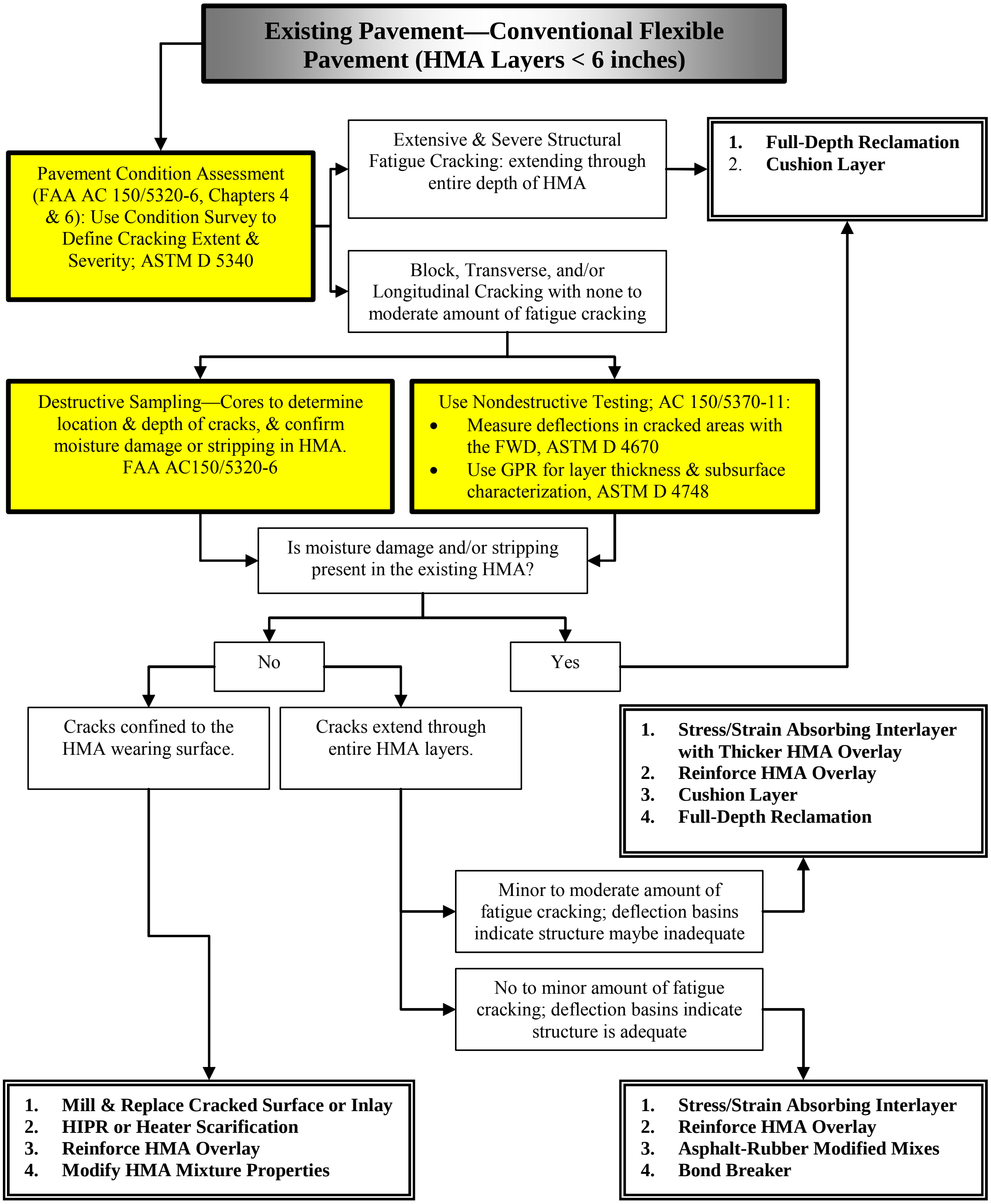


Figure B Decision Tree Providing Guidance to Mitigate Reflective Cracks in HMA Overlays of Existing Conventional Flexible Pavements

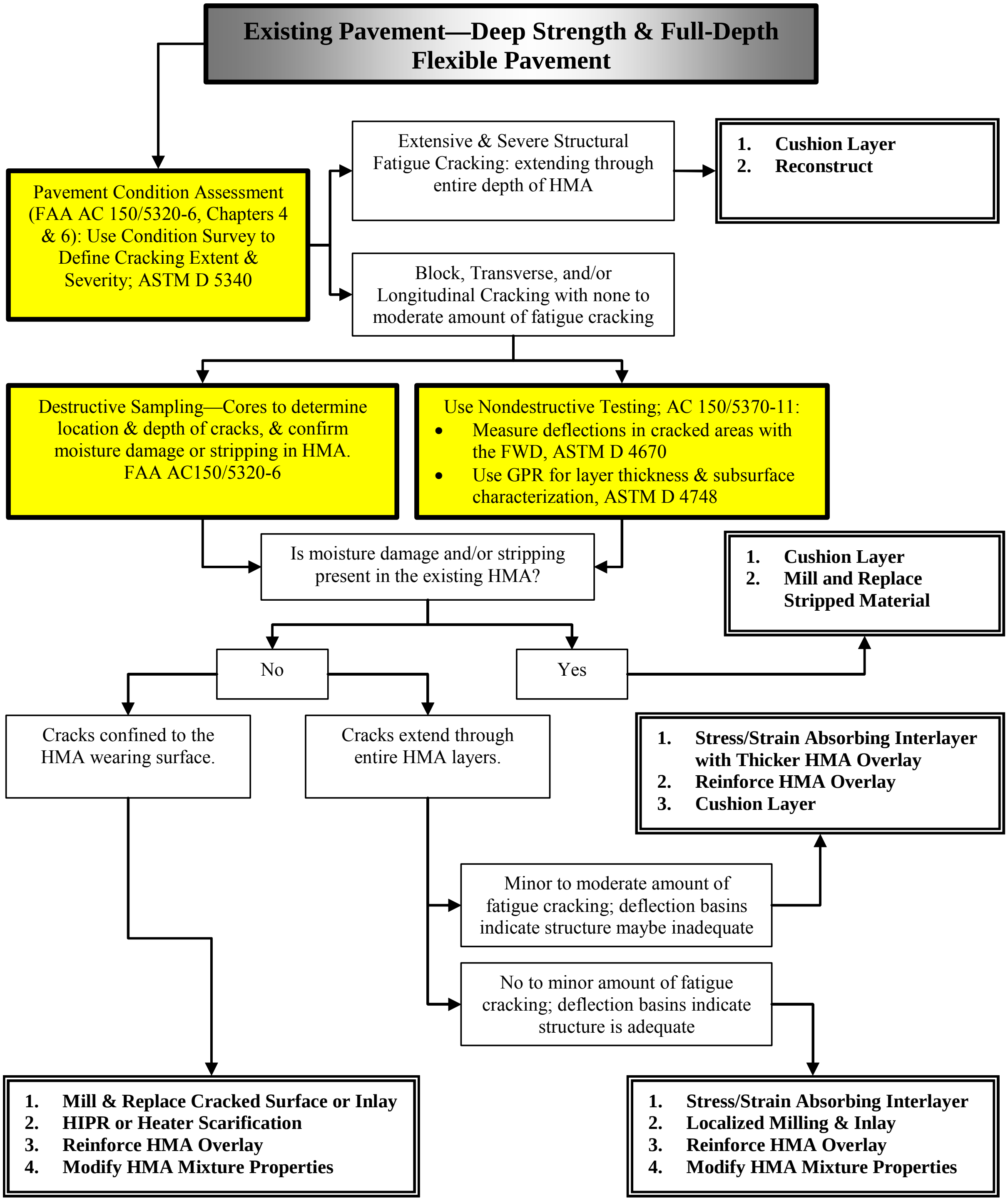


Figure C Decision Tree Providing Guidance to Mitigate Reflective Cracks in HMA Overlays of Existing Deep Strength and Full-Depth Flexible Pavements

The following provides a summary of the results obtained from this study, which were used in preparation of the decision trees.

1. Modification of Existing HMA Pavements:
    - Full-Depth Reclamation—Viable and effective technique; mainly used for flexible pavement that exhibit severe levels of structural cracks.
    - Heater Scarification—Viable, but where cracks are confined to the wearing surface.
    - Hot In Place Recycling—Viable, with the exception of thermal and fatigue cracks that extend through all of the HMA layers.

2. Modification of Existing PCC Pavements:
    - Crack and Seat—Viable, but does not eliminate reflective cracks. This method can be used with other mitigation techniques.
    - Rubblization—Viable and effective technique for PCC pavements that have extensive deterioration. Of the fracturing techniques used to destroy the slab action of the PCC pavement, the state-of-the-practice is moving towards rubblization because it has been shown to be most effective. Change Number 4 to FAA AC 150/5320-6 has switched the preferred fracturing technique for old PCC pavements that are in very poor condition from crack-and-seat to rubblization.

3. Stress or Strain Relieving Interlayer:
    - SAMI—Viable and effective technique for existing flexible pavements that have adequate structural support. SAMI layers, which work on the principal of isolating the horizontal movement of the base pavement from the overlay, have been successfully employed to reduce the rate of reflective cracking when the crack spacing and crack widths are narrow. It has been found, however, that eventually the crack will work through, even with the more compliant SAMI materials. SAMIs can also act as moisture barriers prevent rising water and vapor from the base or subgrade that can cause additional distress in the overlay. Conversely, these materials can reduce water infiltration into the underlying pavement, as fatigue and thermal cracks begin to initiate within the overlay wearing surface. Chip seals and rubber modified asphalt mixtures are specific types of SAMI layers that have provided more consistent positive results for mitigating reflective cracks under appropriate conditions.
    - STRATA & ISAC (proprietary materials)—Viable technique for flexible pavement that have adequate structural support, but these materials have limited performance data available. These materials are also believed to be effective, but life cycle cost analyses must be used to determine whether they are cost effective for a particular pavement condition and climate.

4. Bond Breakers; Thin layers—Viable, but mixed results reported in literature, and are not recommended for use by the authors. Bond breakers have exhibited poor performance when an inadequate HMA overlay thickness is placed, especially in severe climates.

5. Cushion Layers:
    - Unbound Aggregate Base or Crushed Stone Layer—Viable, but mixed results in performance; mainly for PCC pavements. Maintaining adequate clearance or the same elevation of adjacent features (lighting fixtures, etc.) can be a problem. In addition, granular cushion layers also provide a water conduit between the overlay and existing pavement, and are not recommended for use by the authors.
    - Crack Relief Layer—Viable, but requires thicker overlays, has had mixed performance results, and clearance can be a problem. Thick crack relief layers consisting of large-stone, open-graded, asphalt-stabilized layers (defined as cushion courses within this report), which work on the base isolation principle, have not performed as expected in some cases. The stones simply do not act as "ball bearings," as was originally anticipated. Instead, their interparticle friction will eventually transfer horizontal movements of the base pavement to the HMA overlay.

6. HMA Mixture and Layer Modification
    - Rubber Modified Asphalt—Viable and effective in mild and moderate climates. Rubber modified asphalt mixtures have exhibited success in local or regional areas. Some of the earlier failures reported for this material was found to be construction and materials related and located in colder climates. Those rubber modified asphalt mixtures designed with proper strength or stability have delayed reflective cracking much longer than conventional neat asphalts, polymer modified asphalts, and stone matrix asphalt mixtures.
    - Various Modifiers, such as polymer modified asphalt and stone matrix asphalt—Viable, but not effective for most modifiers. This method or treatment should be used in combination with other mitigation techniques to increase the success of other methods.
    - Low Viscosity or Soft Asphalt—Not recommended for use by the authors because of other load related distresses (shoving, rutting, roughness, etc.).
    - Thicker Overlays—Not cost effective. This method should be used in combination with other mitigation techniques, especially for PCC pavements. Thicker overlays do provide better insulation for the PCC slabs.

7. HMA Overlay Reinforcement:
    - Steel or Wire Fabric—Viable, but does not prevent reflective cracks. This type of reinforcement keeps cracks tightly closed with adequate density and good materials. Limited data is available for adverse conditions where de-icing salts and chemicals

have been used (susceptible to corrosion). Steel reinforcement, as well as geogrids discussed below, have been effective in reducing reflective cracks from existing HMA layers. These materials are less effective when the overlay is placed over jointed concrete pavements, but definitely keeps the cracks narrower as they occur. A geogrid or strip reinforcing product must have a higher modulus than the HMA mixture surrounding it, if it is to reinforce the overlay. These products are effective in reinforcing the overlay against horizontal, thermally-induced movements but not against the traffic-induced bending and shearing movements.

- Geogrids—Viable for flexible pavements with adequate strength, and PCC pavements exhibiting limited structural distress.
- Geosynthetics—Viable for flexible pavements with adequate structural strength, but inadequate for PCC pavements. Fabrics will perform best when used over old HMA pavements with closely spaced random or alligator cracks (not caused by base or subgrade failures) with crack widths less than 1/8 in (3 mm). Fabrics do not perform well when placed on old PCC pavement joints/cracks or over wide (greater than 3/8 in [9.5 mm]) transverse or shrinkage cracks in old HMA pavements.

8. Crack Control; Saw and Seal Joints in HMA Overlay—Viable and effective for PCC pavements without structural cracks & adequate support; must accurately locate existing joints in PCC pavement so that saw cut is made directly above joints. Saw and seal of the HMA overlay that matches the joints in the old PCC pavements has met with great success in many places. Several highway agencies have used it as a preferred rehabilitation method. However, in some instances “tenting” of the sealant has been a problem or concern. This concern has resulted in a cautious use of this technique on high-speed facilities, such as interstate highways or airport runways and parallel taxiways.

TECHNIQUES FOR MITIGATION OF REFLECTIVE CRACKS

AAPTP PROJECT 05-04

CHAPTER 1 INTRODUCTION

1.1 Background

Reflective cracks are a major concern to airport management personnel because they can significantly reduce the service life of hot mix asphalt (HMA) overlays of airside airport pavements. When 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 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.

Although the problem of reflective cracks and their impact on pavement performance has been known for decades, established procedures to select, design, and construct effective mitigation strategies have not been adopted widely. The Federal Aviation Administration (FAA) AC-150/5320-6 (FAA, 2006) provides the design recommendations for HMA overlays of existing Portland Cement Concrete (PCC) pavements. It recommends some type of treatment in the form of the following to mitigate or delay HMA reflective cracking:

1. A coarse aggregate HMA binder layer,
2. An engineering fabric,
3. Tensile reinforcement provided by woven fabrics or geogrids, or
4. Rubblization, if the existing PCC pavement condition factor (C_b) falls below 0.75.

Detailed guidance, however, is not provided on what constitutes an appropriate treatment method for a given situation. In addition, the Advisory Circular (AC) does not address HMA overlays of distressed flexible or composite pavements from the standpoint of reflective cracks.

Numerous studies throughout the previous three decades 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.

Despite the significant advances in the understanding of reflective cracking phenomenon, there is still minimal practical technical guidance needed for an airport pavement designer or contractor on assessing when a given pavement can be effectively treated with reflective crack control measures, what constitutes an effective method for a given situation, how to apply the treatment, and how to evaluate the effectiveness of the treatment prior to and after installation/construction of the treatment.

1.2 Purpose of Project

The purpose of Airport Asphalt Pavement Technology Program (AAPTP) Project 05-04 is to provide guidance and recommendations to the FAA and others related to managing and designing rehabilitation strategies of airside pavements to mitigate the occurrence of reflective cracks in HMA overlays of rigid and flexible pavements. Specifically, the project was to provide guidance on assessing the condition of existing pavements, selecting a reliable treatment method and materials for specific pavement conditions, and how to effectively apply the selected treatment method. The purpose of this document is to provide a summary of all project activities and tasks to develop these guidelines and recommendations. The technical guidance is provided in a separate document—*Technical Guide for Techniques for Mitigation of Reflective Cracks*, dated February 2009.

1.3 Scope of Work for Project

The scope of work for AAPTP Project 05-04 included a review of existing performance data for the different methods and materials used to mitigate reflective cracks, and site visits to airfields where these and other materials had been used to mitigate reflective cracks. Specifically, the scope of work included the following tasks.

- Task 1—Review of Existing Literature on Products and Processes to Mitigate Reflective Cracks.
- Task 2—Collect, Evaluate, and Summarize Field Performance Data of Categories of Reflective Crack Mitigation Application to Airfield Pavements. This task included evaluating field performance data from existing studies and visits to selected airfields within this project.
- Task 3—Identify and Provide Recommended Laboratory Tests for Various Reflective Cracking Control Strategies.
- Task 4—Compare and Contrast Various Crack Control Strategies and Identify Benefits and Issues for Each Strategy.

- Task 5—Prepare a Preliminary Technical Guide for Mitigating Reflective Cracking. This technical guide represents a separate document prepared under AAPTP project 05-04, and provides guidance for selecting specific strategies (treatment methods and materials) for increasing the time to the occurrence of reflective cracks in HMA overlays or rigid, flexible, and composite pavements.
- Task 6—Revise Technical Guide and Develop Specifications.

The final tasks (Tasks 7 and 8) of this project were for posting the final technical guide on the Web site authorized by AAPTP for public review, and preparing the draft final and final reports.

1.4 Scope of Report

As noted above, this report provides a summary of all project activities and tasks to develop the technical guide for mitigating reflective cracks. Chapter 2 defines the mechanisms of reflective cracks and the concepts and methods to mitigate these cracks. Chapters 3 through 5 presents and summarizes the data used to evaluate the different mitigation strategies for identifying methods and materials that have had the higher success rates and lower risks for mitigating reflective cracks. Chapter 3 summarizes the historical information on the reflective cracking products and processes, Chapter 4 summarizes both airfield and highway experiences with mitigating reflective cracks, and Chapter 5 presents the results of visits to selected airfields where different methods and materials were used to mitigate reflective cracks. Chapter 6 provides an assessment of the methods and materials that have been used to mitigate reflective cracking, while Chapter 7 summarizes the conclusions and recommendations from this study.

The appendices to the report provide specific information and a summary of the airfield visits presented in Chapter 5. Appendix A includes definitions for selected terms, while Appendix B summarizes details on the design and construction of geogrids as reinforcement in HMA overlays. Appendix C provides the notes and summary information from the site visits to selected airfields.

CHAPTER 2 REFLECTIVE CRACKING MECHANISMS AND 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 and understood for a particular project, a mitigation strategy can be designed so that an economical determination of material properties and treatments can be established. The purpose of this chapter is to present the mechanisms of reflective cracks and generalized concepts and methods that have been used to mitigate these cracks.

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 joints and cracks, and from increased vertical deflections at the joints and cracks. Although reflective cracks are more associated with rigid or composite pavements, they do occur in HMA overlays of flexible pavements.

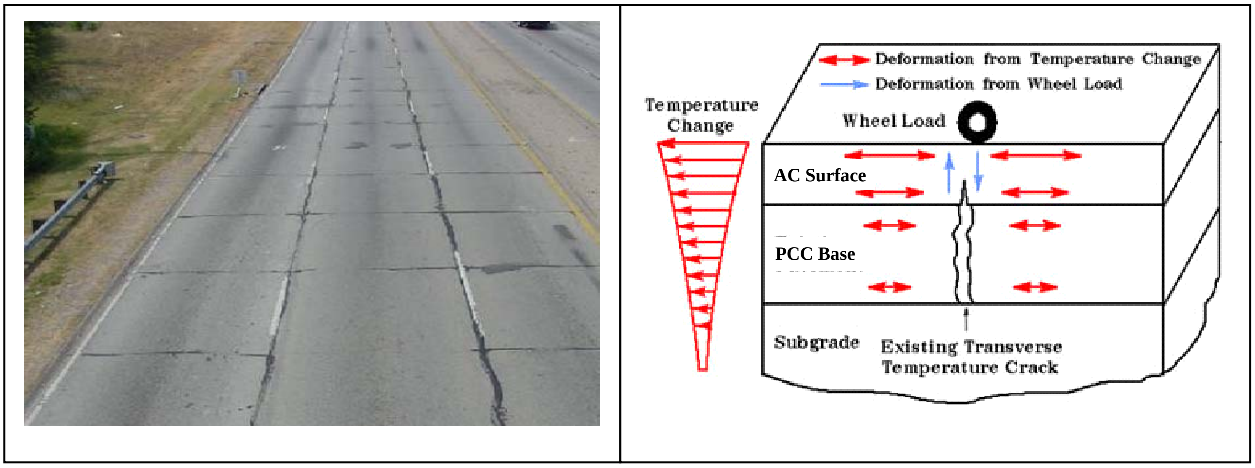
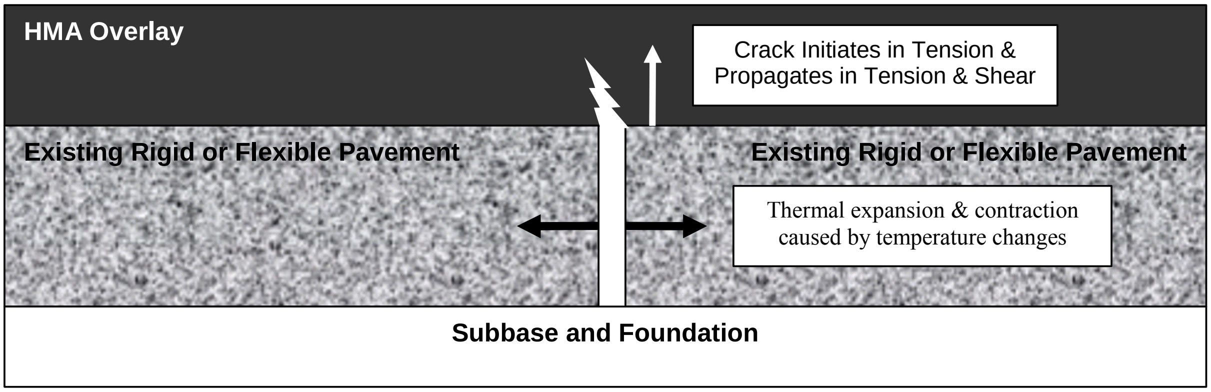
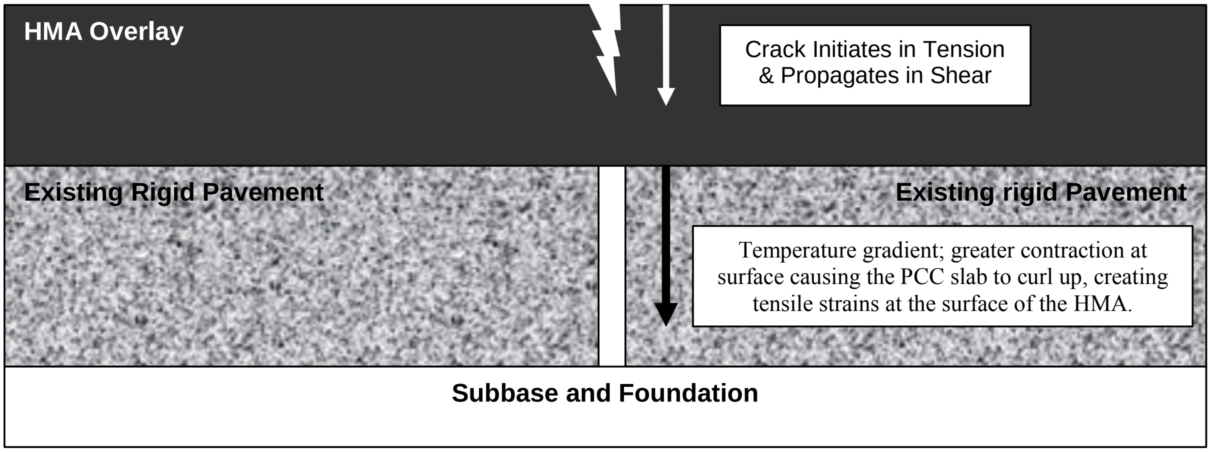


Figure 1 Reflective Cracking in HMA Overlays of PCC Pavements

The most common accepted cause of reflective cracking 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 and from temperature changes in HMA layers that exhibit transverse cracks. The tensile stresses and strains resulting from joint movements become critical in the areas of construction joints and cracks, because of the bond between the overlay and existing pavement (figure 2.a). Reflective cracks resulting from 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 HMA overlay. Thus, all of these factors must be included in the evaluation of the environmental effects or loadings on the HMA overlay.



2.a. Thermally Induced Cracking; Horizontal Movements



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

Figure 2. Mechanisms of Thermally Induced Reflective Cracks of 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 wheel loads that depress abutting slabs or crack faces resulting in shear-stress concentrations in 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 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.

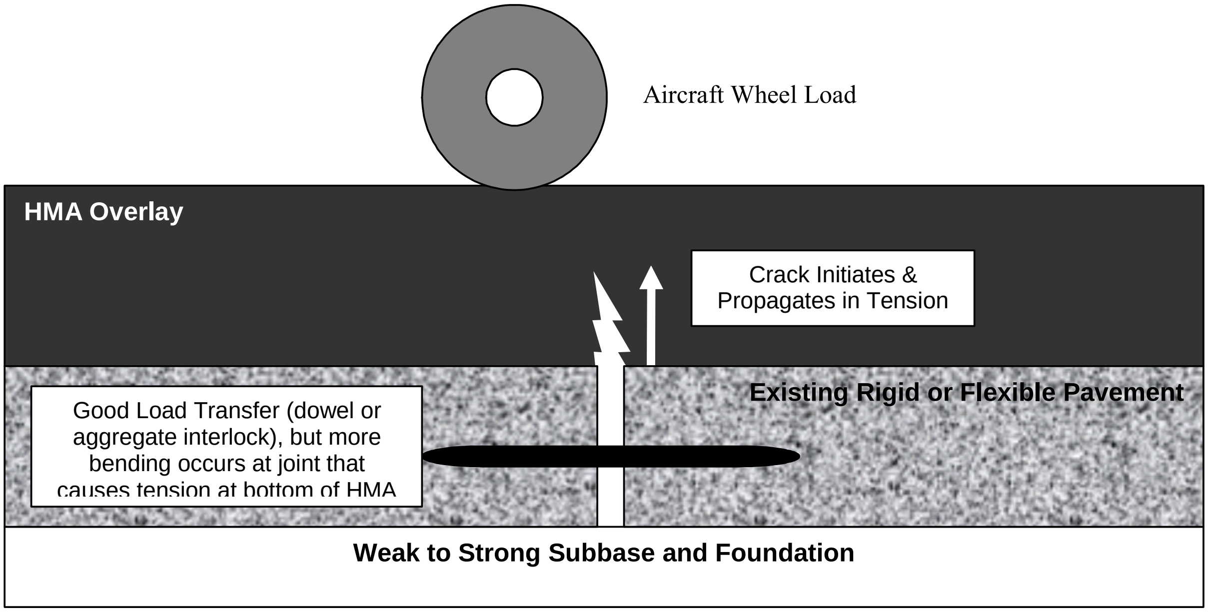
A third mechanism that causes reflective cracks is the curling of PCC slabs during colder temperatures when the HMA overlay is stiff and brittle. Reflective cracks caused by this mechanism initiate at the surface where the majority of mixture aging takes place and propagate downward (refer to figure 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 their propagation is dependent on the overlay thickness, properties of the HMA overlay, type of reinforcement, if used, and foundation support condition.

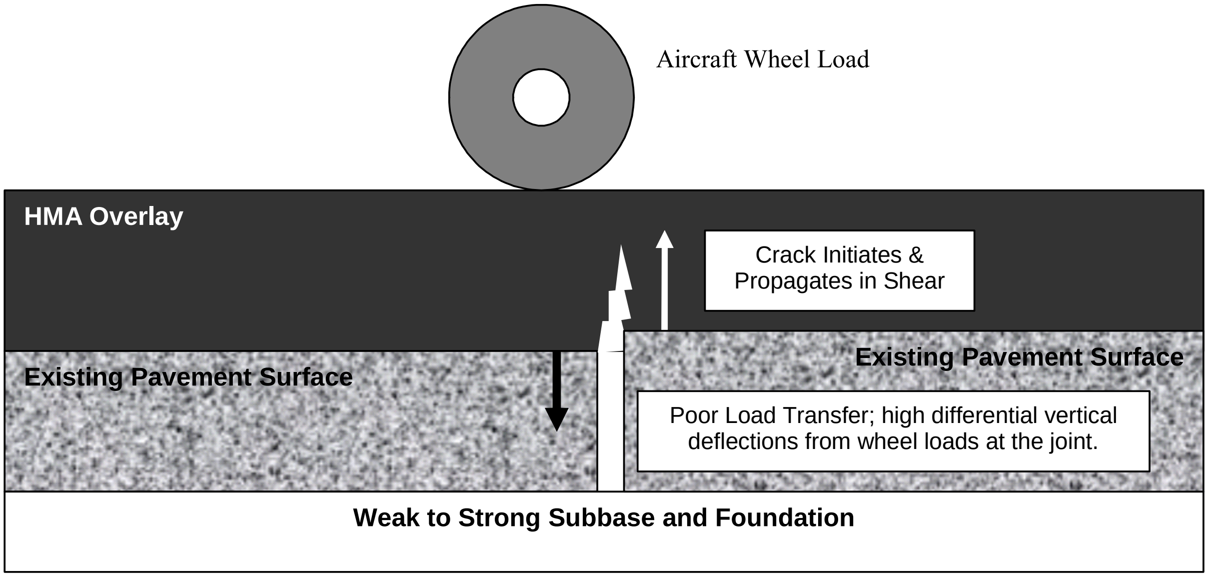
In summary, the commonly attributed factors that cause movements at joints and cracks in the base pavement (termed trigger factors) are low temperatures (temperature drop), wheel loads, freeze-thaw cycles, aging of the HMA near the surface (level of air voids), and shrinkage of PCC, HMA, and cement treated 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 Mitigation Strategies—Concepts and Methods

Numerous materials and methods have been tried to solve the reflective cracking problem with varying degrees of success. These methods include: increased overlay thickness, modification of asphalt and mixture properties, crack arresting (reinforcing) interlayer, stress absorbing membrane interlayer (SAMI), strain tolerant interlayer, treatment at cracks/joints in existing pavements, and fracturing existing PCC pavements (crack/seat, break/seat, and rubblization).



3.a. Traffic Induced Cracking



3.b. Traffic Induced Cracking

Figure 3 Mechanisms of Traffic Induced Reflective Cracks of HMA Overlays

Button and Lytton (2003) classified the methods to address reflective cracking into three major categories: reinforcement of the overlay, stress or stain relieving interlayer, and re-strengthening of cracked pavement before overlaying. For purposes of this report, however, those three were expanded into the following categories.

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.

These categories, discussed in greater detail in Chapter 3, can be used individually or in combination with each other.

2.2.1 Modify/Strengthen Existing Pavement Surface Layer

This treatment method is used to modify or alter the structural properties of the existing pavement layers, which includes pre-overlay repairs to the existing surface. Specifically, these treatments 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. The following summarizes the different methods used to modify/strengthen the existing PCC and HMA pavements.

- 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 concrete pavements to reduce the horizontal movements concentrated at joints and to reduce the curling of the PCC slab at the joints. Break and seat is the terminology used for jointed plain concrete pavements (JPCP), while crack and seat is used for jointed reinforced concrete pavements (JRCP).
    - Rubblization is used to fracture the PCC into small pieces, eliminating the horizontal and differential vertical movements concentrated at 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 stiffer than a good quality crushed stone aggregate base. The back-calculated elastic modulus values reported by Buncher, et al ranged from 100,000 to 400,000 psi (700 to 2,800 MPa).
- Existing HMA Surface:
    - Full-depth reclamation (FDR) is used to remove cracks that extend through all HMA layers. This method is typically restricted to pavements with HMA layers

less than 6 inches (150 mm) in thickness. FDR is also referred to as Cold In Place Recycling (CIPR).
  - Hot In Place Recycling (HIPR) and CIPR methods are also used when the cracks are confined to the HMA wearing surface. The HIPR technique is commonly used for HMA pavements that have adequate structural strength and distresses that are confined to the surface, while the CIPR technique is used for HMA pavements that exhibit structural-load related cracks.
  - 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 is a non-issue.
  - 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

This treatment method is defined as layers greater than 3-inches (75 mm) in thickness that provides structural support to the cracked pavement and separates the existing surface layer and dense-graded HMA overlay. Cushion layers consist of crack relief layers (defined as 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 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 reflective cracks caused by all three failure mechanisms listed above (refer to figures 2 and 3). A disadvantage with using this method is that the cushion layer can hold water because it is permeable. This trapped water can lead to deterioration of the overlay and pavement structure.

2.2.3 Stress or Strain Relieving Interlayer

This treatment method has been defined as layers less than 1-inch (25 mm) in thickness that offers negligible structural support to the pavement. Although most of these methods are less than one inch, some of the proprietary products and stress relieving interlayer do exceed 1-inch. Thus, the definition for these methods (as used in this report) is that they are less than 2 inches (50 mm) in thickness and limit the transfer of horizontal movements concentrated at joints or cracks to the overlay. This category of methods includes bond breakers (stone dust, sand, etc.), chip seals, fabrics, crack relief layers, thin bituminous layers with low viscosity asphalt, and composite layers that separate the existing surface from the HMA overlay. The chip seals and other composite materials included under this category are also referred to as a SAMI.

Conceptually, the use of a SAMI over joints and cracks increases the gauge length for the development of strain—decreasing the potential of reflective cracks caused by environmental loadings and/or dissipates horizontal movements from the existing surface to the HMA 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 vertical deflections) may not be reduced or mitigated. 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 interlay is used in areas where turning and braking movements occur because thin (2 inches [50 mm]) overlays tend to shove under horizontal loading from aircraft.

2.2.4 Overlay Layer/Mixture Modification

This treatment method includes engineered or specialty mixtures with specific properties for the HMA overlay; such as polymer modified asphalt (PMA), stone matrix asphalt (SMA), and rubber modified asphalt mixtures. Increasing the thickness of the HMA overlay is also included within this category. In summary, this treatment method improves the fracture resistance of the overlay and reduces the deterioration around the cracks once they occur. This treatment method does not prevent reflective cracks from occurring but will control or reduce the severity of reflective cracks with time and aircraft operations. In other words, it keeps the crack severity to a low level—assuming good construction methods are followed. The one exception to the above statement is that rubber modified asphalt mixtures have been found to delay the occurrence of reflective cracks.

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 differential vertical movements concentrated 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 crack tight and 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 referred to as 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 PRODUCTS & PROCESSES

The general categories of the concepts and methods used to mitigate reflective cracks were defined in Chapter 2. This chapter presents a broad overview of the products and processes within each category that have been used to mitigate or delay the occurrence of reflective cracks based on the mechanisms defined in Chapter 2. The overview includes the type of materials and properties, field application techniques, extensiveness of use, and general success rate of each treatment method, as documented in the literature.

3.1 Treatment or Modification of Existing Pavement Surface Layer

Modification of the existing pavement surface layer reduces the possibility of reflective cracking by decreasing the extent and severity of stress concentrations to removing the cracks themselves. The specific methods are discussed by existing pavement type, including pre-overlay repairs of the existing pavement.

3.1.1 Pre-Overlay Repairs of Existing Pavement Surface

Although not a cure for reflective cracking, pre-overlay repairs of rigid and flexible pavements provide reasonable results and can be cost-effective when used in conjunction with other methods and techniques to mitigate reflective cracking, especially for rigid pavements. The pre-overlay repair technique depends on the surface condition and distresses, but generally includes undersealing PCC slabs, placing HMA inlay, and/or full-depth patches. FAA AC 150/5380-6 provides guidance in selecting the repair method for different distresses. The decision to make any repairs should be based on cost of the rehabilitation strategy with and without the repairs.

Undersealing PCC Slabs

When placing HMA overlays on top of existing PCC pavements, a key to eliminating reflective cracking is to control the deformation of the PCC slabs and reduce the horizontal and vertical movements in the vicinity of the joint/crack (Mukhtar, 1994). In order to prevent rocking/vertical deformation of the slabs, cement grout or other materials can be injected under the slab to fill any voids. Subsealing voids beneath PCC slabs should be considered when the slabs have yet to exhibit extensive and severe cracking and deterioration from those voids. When voids are filled, uniform support conditions can be used for overlay design.

The process of grout pumping is critical. 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 inch [302 mm] thick slab [Mukhtar 1994]). A higher pressure and excessive amount of grout can result in poorer performance of the HMA overlay than without use of the undersealing material. Overfilled voids can cause the slabs to be lifted, creating voids in other areas under the slab which increase deflections rather than reduce deflections.

Deflection basin testing with the Falling Weight Deflectometer (FWD) or Heavy Weight Deflectometer (HWD) has been used to ensure that additional voids are not created during the subsealing or injection process. Ground penetrating radar (GPR) has also been used to confirm the adequacy of the undersealing process. Deflection basin testing and GPR can be used individually or in combination with one another. Using both devices increases the reliability of the results—confirmation of filling the voids beneath the PCC pavement.

HMA Inlay

HMA inlay is considered an alternative pre-overlay repair strategy that has had some success on highways where a previously overlaid jointed PCC pavement has suffered reflective cracking and is about to be overlaid again. The cracks in the original overlay above joints of the underlying PCC slabs are milled out to a width of about 2 feet (0.6 m) and filled with HMA before applying the new HMA overlay. The new infill HMA acts like a SAMI. [SAMIs are discussed in more detail in a latter subsection of this chapter.] Much wider HMA inlays have been used to a limited extent on airside pavements, but performance data are limited. An HMA inlay by itself, however, provides little protection against the occurrence of reflective cracks.

Patches

When placing HMA overlays on existing HMA-surfaced pavements, localized alligator or fatigue cracks (structural cracks that propagate through the HMA layers) can be removed and patched. The foundation layer should be scarified and compacted, if the structural cracks have been caused by weak foundations that are localized to specific areas.

Other Repairs

Other pre-overlay repairs recommended from different studies for existing HMA and PCC pavements include sealing wider transverse cracks (greater than 1/8 inch [3 mm] in width) and placing a leveling course prior to the application of some mitigation methods (Ahlrich, 1986; USACE, 1992). There is general agreement within industry that there is a benefit to the use of leveling courses with appropriate HMA mixture properties. Conversely, the benefit of sealing cracks prior to the rehabilitation strategy is debatable because there is little evidence that shows increased performance (reduced reflective cracking) with and without crack sealing.

3.1.2 Existing HMA Pavements—Mill and Replace Wearing Surface

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, the use of inlays (mill and replace the layers with cracks within the traffic area) can be an economical solution, as noted under pre-overlay repairs.

3.1.3 Existing HMA Pavements—Heater Scarification and Hot In Place Recycling

Heater scarification and HIPR of existing HMA surfaced pavements are hypothesized to be reliable mitigation techniques, because the scarification or recycling process eliminates all cracks at the surface of the pavement. Both techniques are designed or intended for the condition where cracks initiate at the surface of the pavement. The equipment, materials, and construction procedure for both processes is discussed in detail in the FHWA's training course entitled *Asphalt Roadway Rehabilitation Alternatives* (FHWA, 1997).

The heater scarification technique scarifies the existing HMA surface layer to a depth of approximately 0.75-in (19 mm) so that the upper portion of any crack can be removed. The lower portion of the crack is sealed because of the heating process and a rejuvenating agent is applied to soften the surface of the oxidized or aged HMA. An issue with the heater scarification process is the depth of penetration or influence of the rejuvenating material of the intact material. Unlike the scarification process, the deeper the cracks, the thicker the HIPR layer to eliminate those cracks. The HIPR technique has been used to depths of 4 inches (100 mm).

The remixed and re-compacted layer serves as a uniform, uncracked layer above the crack tip. As a consequence, the reflective cracking of the overlay should be delayed. Projects where the heater scarification and HIPR techniques were used, however, have reported mixed results, varying from good to no improvement in mitigating reflective cracks, as compared to control sections. Heater scarification and HIPR have been used more commonly on highway rehabilitation projects and much less frequently on airside pavements.

Heater scarification was used on an airfield pavement in Fort Smith, N.W.T. in 1982 (Anderson et al. 1984). Cores taken through a crack before scarification showed that the crack was sealed approximated two-thirds of the way through the existing HMA. After scarification, the same crack was cored again and was found to have been sealed to the bottom of the existing HMA. However, there was no significant difference in the amount of reflective cracking in the overlays of scarified and non-scarified pavements after the first winter.

The heater scarification method has been widely used in highway pavements as a reflective crack mitigating strategy. Some projects exhibited good results, while others have not. In Arizona, heater scarification with Reclamite plus a 1.3 in (32 mm) wearing course was ranked as the third best among eighteen test treatments (Way 1980). After 6 years only 7.4 percent of reflective cracking was observed. In Quebec, however, scarification with Reclamite plus a 1.3 in. (32 mm) wearing course resulted in 100 percent reflective cracking after only 2 years (Poon 1986). In New Mexico (McKeen et al. 1984), 0.75-in (19 mm) scarification with a rejuvenating agent plus 0.63 in (3 mm) seal coat and 2 inch (50 mm) surface course resulted in 70 percent of reflective cracking within 4 years.

The projects reviewed that included the heater scarification and HIPR techniques suggest that local pavement condition, climate, and whether the cracks extend through all HMA layers are important factors affecting the performance of the HMA overlay. The location of where cracks initiate is the 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 reflect through the overlay, usually in a fairly short period of time.

In summary, the heater scarification and HIPR are considered viable approaches when the cracks are confined to the HMA surface. The HIPR approach is still considered a viable approach even when cracks extend into the lower HMA layers. The deeper the crack, however, the less effective the HIPR approach to mitigate reflective cracks. A major issue or concern when using both processes on airfields is the potential for damage to jet engines from loose aggregate (raveling) if an overlay is not placed on the scarified or HIPR layer.

3.1.4 Existing HMA Pavements—Full-Depth Reclamation or Cold In Place Recycling

FDR or CIPR of existing HMA pavements have been reported to be reliable mitigation treatment methods for all reflective cracking mechanisms, because the process eliminates all cracks. In other words, reflective cracking becomes a non-issue when the FDR or CIPR processes are used. In summary, the existing HMA layers and aggregate base, if needed, are pulverized and mixed in place. A bituminous binder consisting of emulsions or foamed asphalt (with or without cement or lime-fly ash) is added to the pulverized material and compacted. This method strengthens the HMA pavement because all cracks are destroyed in place and the recycled layer compacted forming new intact material. The equipment, materials, and construction process is discussed in more detail in FHWA's training course entitled *Asphalt Roadway Rehabilitation Alternatives* (FHWA, 1997).

FDR is used to rehabilitate structurally deficient flexible pavements or General Aviation (GA) airside facilities with lower aircraft traffic volumes. This technique was successfully used to repair a parallel taxiway at Killeen Municipal Airport in 1984. That taxiway did not exhibit any reflective or load-related cracks for 15+ years. This same technique was successfully used to repair selected low volume Naval Air Station airside pavements in South Texas that were used for touch and go training exercises (Von Quintus, 1984 to 1990).

Montana Department of Transportation (DOT) currently considers FDR as one of their primary repair strategies to upgrade existing lower volume roadways. Of the twelve segments included in a research study, only one exhibited significant levels of cracking (Von Quintus and Moulthrop, 2007). The roadway segments included in that study varied in age from 3 to nearly 20 years.

3.1.5 Existing PCC Pavements—Crack and Seat or Break and Seat of PCC Slabs

The crack 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 JPCP to reduce the effective length of the slab between the joints. As the size of the slabs is effectively reduced, the horizontal strains resulting from thermal movements are distributed more evenly over the pavement and are less likely to cause reflective cracks in the HMA overlay. The cracks induced in the PCC slab should be fine so that aggregate interlock between the newly formed slabs is retained (good load transfer; load transfer efficiency [LTE] values exceed 0.80). 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.

A 1970 New York study (Vyce, 1983) tested and evaluated the crack and seat technique for 9 sections, each 1000 ft (300 m) long. Different combinations of fragment sizes (3, 6, and 10 ft [0.9, 1.8, and 3 m) and overlay thickness (2.5, 3.5, and 4.5 in [64, 89, and 114 mm) were included in the experiment. After 12 years, fewer reflective cracks and better performance was observed in the crack and seat sections, as compared to the control sections. The segment with the smallest fragment size (3 ft) and maximum overlay thickness (4.5 in) exhibited the best results with negligible reflective cracking. The amount of cracking was found to increase as fragment size increased and overlay thickness decreased.

Many other states have reported that the crack and seat method is a promising technique for mitigating reflective cracking, especially during the first few years of service (FHWA, 1987). NAPA, Michigan, and Wisconsin sponsored studies to evaluate the performance of HMA overlays of crack and seat and rubblized PCC pavements (NAPA, 1991; Von Quintus, et al., 2007). These studies concluded that the crack and seat method definitely reduces reflective cracking, but required thicker overlays than previously used. According to FHWA's review report (1987):

- Cracking and seating provides excellent results if the foundation is firm and the broken sections are properly seated and compacted with the help of a pneumatic roller so that no voids are left under the slabs.
- Too small and non-appropriate broken slab size can accelerate the formation of reflective cracking. Voigt et al. (1987) recommended that to achieve the best results, the area of broken slabs should be 4 to 6 sq ft (0.4 to 0.6 sq m) and the length and width of the broken sections should be roughly equal. In warmer regions, the length and width of broken sections could be increased but should not exceed 6 ft (1.8 m) in any case.
- In general, cracking and seating has better results in JPCP than JRCP. In JRCP, the steel, if not cut, creates problems and the PCC slabs may not be properly seated. Rocking and settlement of pavement sections take place due to traffic load, which increases the severity

of reflective cracks.

- Although a thinner HMA overlay on a cracked and seated pavement might be sufficient to inhibit reflective cracking, the extra cracks created in the PCC slab will reduce its load-spreading ability and this must be taken into account in the structural design. A thicker HMA overlay will be required. A thicker overlay not only increases the cost of the project, but also creates clearance issues. Thus, this method should be selected only when the pavement is severely cracked/faulted, no longer behaving as a structural section.

Consequently, it is necessary to establish the balance between the crack spacing, the reduction in stiffness modulus, the overlay thickness and the occurrence of reflective cracks for typical designs of airfield pavements. In summary, crack and seat is considered a viable approach when the existing PCC pavement has extensive deterioration.

3.1.6 Existing PCC Pavements—Rubblization of PCC Slabs

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 (Asphalt Institute web site; Buncher and Jones, 2006). The deflections and weak spots are filled with coarse aggregate and the rubblized material is then compacted with the help of a steel wheel roller (referred to as a V-roller) before placing the HMA overlay.

The rubblizing process reduces the slab to a layer that responds similar to a strong granular base for the overlay and eliminates all reflective cracking concerns. The stiffness of the rubblized PCC layer, however, is stiffer than a crushed stone, as stated in Chapter 2. Buncher and Jones (2006) suggested that the process of rubblization technique is essentially the same for airfields as they are for highways, which consists of the following steps.

- Mill and remove any existing asphalt;
- Install a side drain system;
- Isolate any adjacent sections with full-depth saw cut;
- Rubblize the concrete pavement;
- Cut off and remove any exposed steel reinforcement;
- Remove exposed joint sealing material;
- Roll the rubblized concrete pavement;
- Remove and patch any unstable areas;
- Place asphalt HMA leveling course/HMA overlays;
- Pave transitions to existing pavement surfaces; and
- Adjust shoulders grades as necessary.

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 layer, thereby eliminating the need for new virgin aggregates. Weather delays are minimized since the subgrade is never opened up and exposed to the elements.

There are two basic types of rubblization equipment, the resonant pavement breaker (RPB) and the multi-head breaker (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. According to Buncher and Jones (2006 and 2008), the effects of the different equipment types on the underlying subgrade integrity, rubblized layer permeability, and effective modulus of the rubblized layer have not been properly researched.

Rubblizing the PCC pavement does reduce the structural support of the existing pavement since the PCC slabs are fractured into small pieces. It is hypothesized that the PCC slabs perform as a flexible but interlocked system. Because the structural capacity of the concrete is diminished the thickness of the HMA overlay is greater in comparison to the crack and seat mitigation technique.

A national research study was conducted in 1991 by PCS/Law Engineering (PCS/LAW, 1991) for the National Asphalt Pavement Association (NAPA) and the State Asphalt Pavement Association Executives (SAPAE). In this study, rubblization was considered the best techniques for mitigating the effects of reflective cracks. It was also determined in this study that a properly seated rubblized layer is between 1.5 to 3 times as effective as dense graded aggregate base course in terms of contributing to structural capacity of the rehabilitated pavement.

Various State highway agencies (Illinois, Michigan, Wisconsin, etc.) have also completed studies on the performance of rubblized pavements. All studies have concluded that this rehabilitation strategy provides excellent performance for heavily deteriorated PCC pavements (Von Quintus, et al., 2007; APTech, 2006; FHWA, 2006). Figures 4 through 7 are a series of flow charts or decision trees developed for the Wisconsin DOT in selecting whether the rubblization process is a viable technique for a specific segment of roadway (Von Quintus, et al., 2007).

While rubblization and repaving with HMA was initially developed for highway pavements, this process is becoming a choice of rehabilitation technique for old deteriorated thick PCC airfield pavements. In the past 7 years, more than 1.6 million square feet (0.5 million square meters) of airport PCC pavement had been rubblized, and overlaid with HMA (Buncher and Jones, 2006). These projects range from heavy load military airfields to local GA airfields.

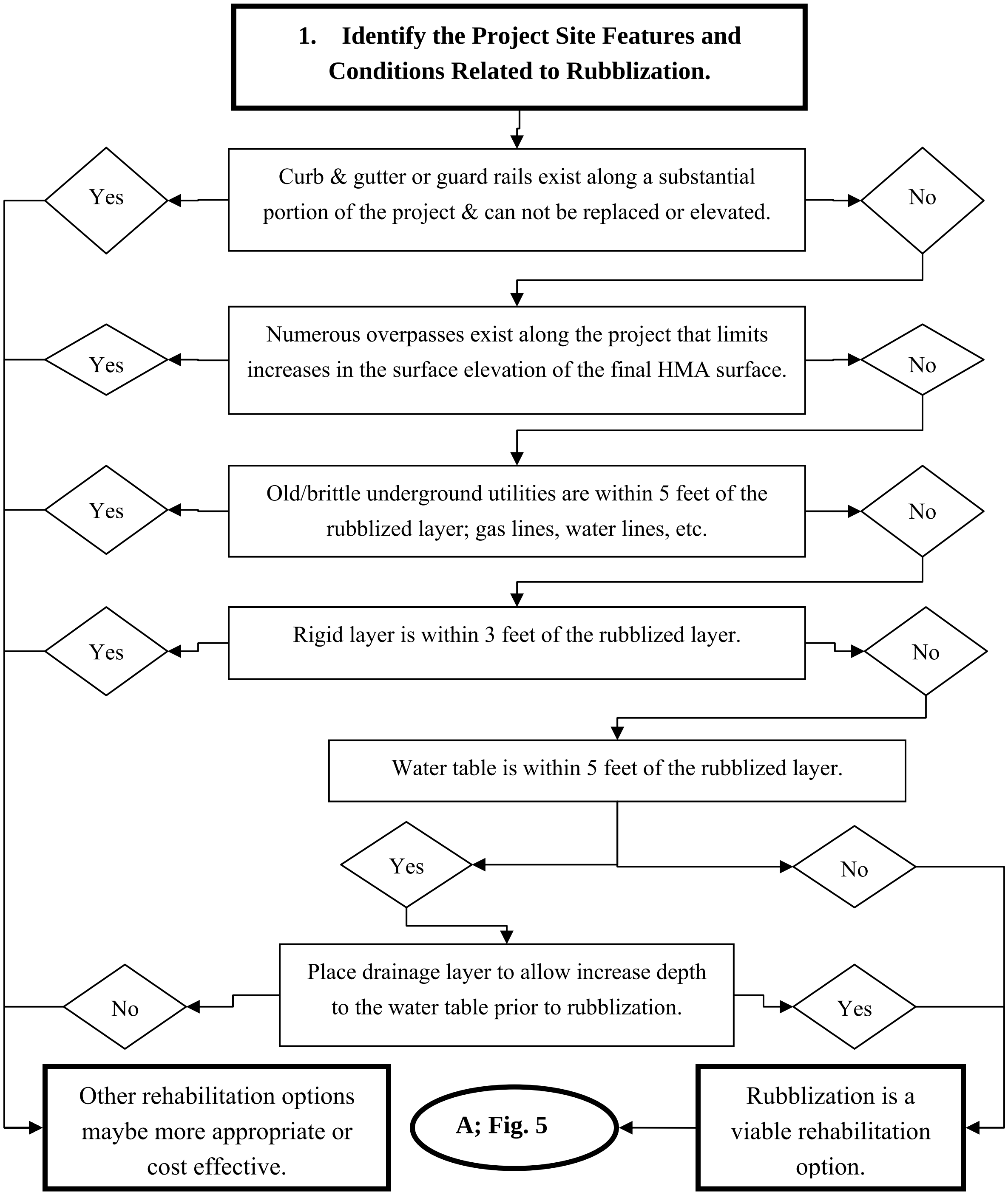


Figure 4. Site Features Conducive to the Selection of the Rubblization Process for Rehabilitating PCC Pavements (After Von Quintus, et al., 2007)

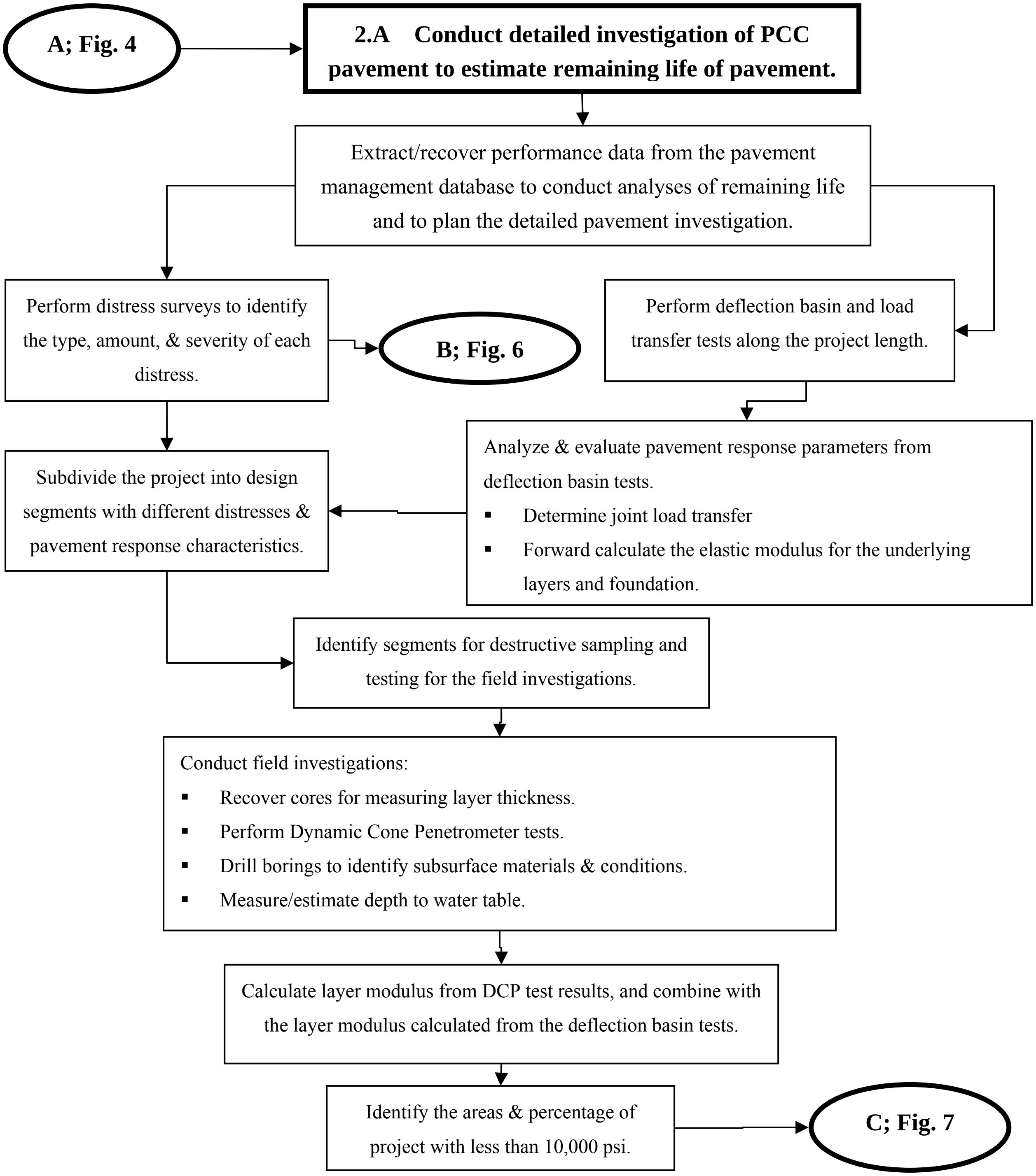


Figure 5. Recommendations for a Detailed Investigation of the PCC Pavement to Estimate Remaining Life and Identifying Site Features and Conditions Conducive to the Rubblization Process (After Von Quintus, et al., 2007)

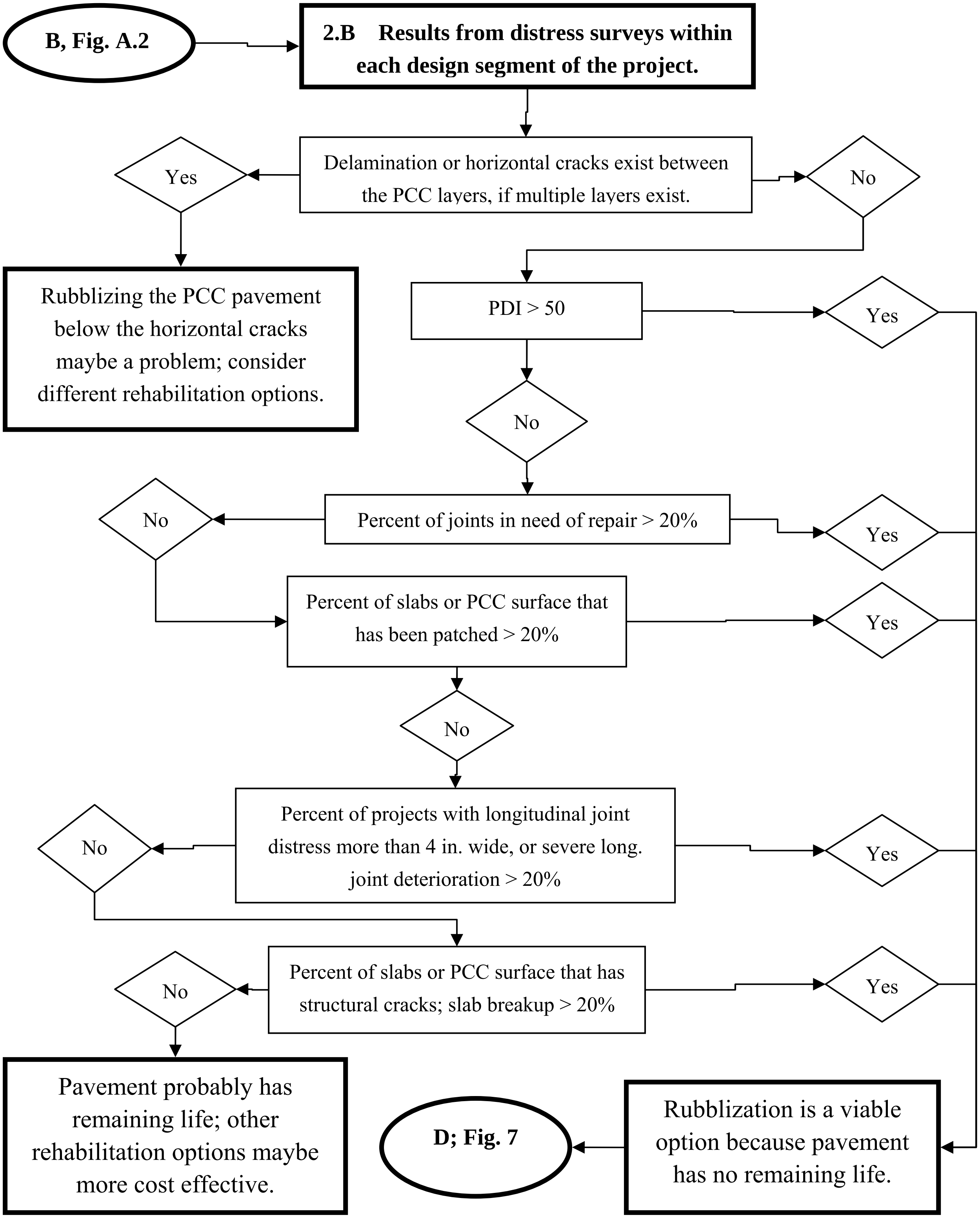


Figure 6. Evaluate Surface Condition and Distress Severities on Selection of Rubblization Option (After Von Quintus, et al., 2007)

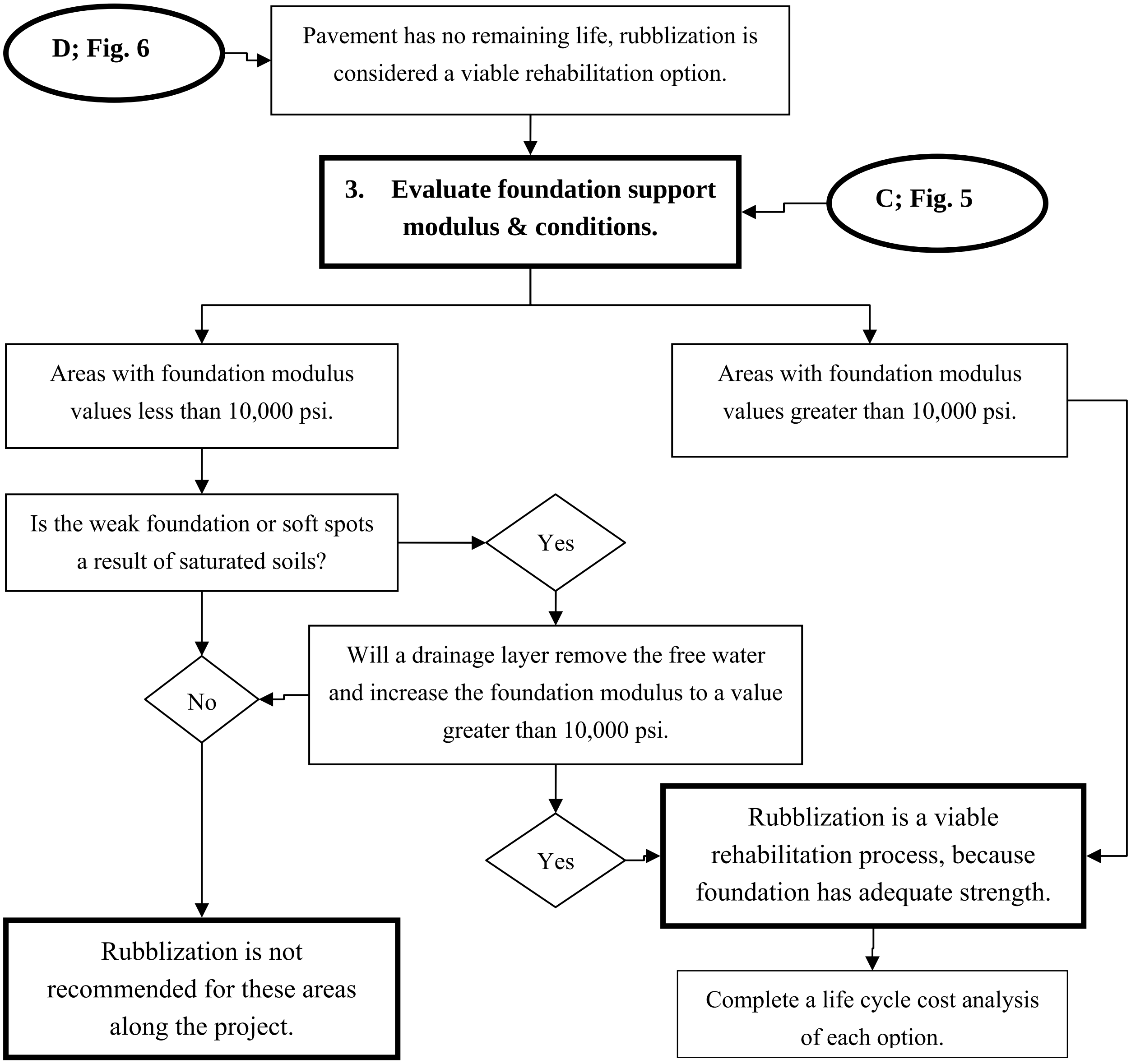


Figure 7. Foundation Support Conditions Related to the Selection of the Rubblization Process (After Von Quintus, et al., 2007)

As reported by Buncher and Jones (2006), the RPB successfully rubblized up to 26 in (0.7 m) of PCC at the Wright-Patterson Air Force Base in 2002. The PCC slabs were broken into particles smaller than 12 in (305 mm) throughout the PCC thickness. A Guillotine Breaker followed by an MHB was used at the Selfridge Air National Guard Base. These two pieces of equipment were used to rubblized up to 21in (0.5 m) of PCC without any problem. In summary, Buncher and Jones (2006) recommended the following specifications for rubblizing PCC airfield pavements.

- Prepare and submit scopes of work plan including a description of the rubblizing and rolling equipment.
- Preparation of the pavement: Remove all HMA layers and saw cut the whole depth to isolate the pavement being rubblized.
- Before an actual rubblization project is started, a test strip (12 by 150 ft [3.6 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.
- Particle size criteria: According to FAA Engineering Brief No. 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 reinforced PCC, the reinforcing steel shall be substantially debonded from the concrete 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.
- Removal of weak areas: The weak areas of the pavement can be replaced with full depth patches, as required by the user agency.

In February 2004, the FAA adopted and published FAA Engineering Brief (EB) No. 66, *Rubblized Portland Cement Concrete Base Course*. This document includes guidance and specifications for rubblizing existing PCC pavement. Recognizing the benefits of rubblization by consultants, highway agencies, equipment manufactures, and the U.S. Air Force, the publication of EB 66 will facilitate even more use of the rubblization technology on airfields. More recently, AAPTP Project 04-01 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 EB #66, Buncher, et al reported that there are no major flaws in that brief and the P-215 specification on rubblization.

In summary, rubblization is definitely considered a viable approach for eliminating reflective cracks in HMA overlays of PCC pavements. This approach is cost effective when the existing PCC pavement is heavily deteriorated (refer to figures 4 through 7).

3.2 Stress or Strain Relieving Interlayer

Stress or strain relieving interlayer systems (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 interlayer over joints and cracks increases the gauge length to dissipate tensile strains—decreasing the potential for reflective cracks caused by environmental and wheel loads.

As defined in Chapter 2, this category provides no increase in the structural capacity of the pavement. The thin layers or membranes dissipate only horizontal movements, and are less than 2 inches (50 mm) in thickness—some of the proprietary interlayer systems and modified mixtures exceed 1 inch in thickness. Earlier documents include cushion courses within this category even though they are reported and hypothesized to dissipate both horizontal and differential vertical movements at joints and cracks. For purposes of this report, cushion courses (greater than 3 inches [75 mm] in thickness) can add structural value to the pavement, and are included in a category by themselves. Different interlayer systems are discussed in the following subsections, while cushion courses are discussed in the next section of this chapter.

3.2.1 Stress Absorption Membrane Interlayer

A SAMI is a layer of thick binder, usually modified, and spread with single size chips that are rolled in prior to placing the overlay. SAMIs provide a flexible layer in the pavement system above the base pavement which is able to deform horizontally without breaking. This allows large horizontal movements to take place in the vicinity of cracks or joints, without transferring those movements to the overlay. In other words, this technique has been found to be effective in dissipating horizontal deformation before it reaches the HMA overlay. SAMI's also provide a waterproofing role to protect the pavement structure and foundation should the overlay crack. Some SAMIs are applied only to the cracks, like a bond breaker, minimizing the materials and installation costs.

Usually a blend of rubber and asphalt is prepared at 400 °F (204 °C) and a 1/4 to 3/8 in (6 to 9.5 mm) thick layer of the rubber asphalt mix (0.4 to 0.8 gal/sq. yd.) is applied to the old pavement surface (Mukhtar 1994). Heated 3/8 in. aggregate chips are then spread over the mix at a rate of 35 to 40 lbs/sq yd (19 to 22 kg/sq m) to prevent bleeding and flushing.

During the years 1972 -1976, SAMIs were tried by Arizona DOT on several projects to reduce reflection cracking (Vallerga et al. 1980). On a Sky Harbor International Airport (Phoenix, Arizona) project, a heavily deteriorated runway with lots of shrinkage cracks (block cracking) and alligator cracking was rehabilitated in 1973 with a SAMI. A plant-mixed asphalt-rubber SAMI system was placed over the entire length of the 3000 ft (914 m) wide runway and then overlaid with a dense-graded P-401 mixture. The SAMI used in the Sky harbor International Airport project consisted 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 14.6 kg/sq m) crushed river gravel with nominal maximum size of 1/4-in.

This runway only exhibited minor problems during extreme hot weather in June, as reported by Vallerga et al. (1980). Some tenderness at aircraft turnoff areas was found which was addressed by flushing the SAMI with lime-treated water to reduce surface temperature. Six and a half years later with over one million take offs and landings of heavy commercial aircraft traffic, the pavement was reported to be in excellent shape and no distress or reflective cracking was observed. A pavement evaluation was conducted by Von Quintus (1982) on the airside pavements at Sky Harbor International Airport. The runway with the SAMI was found to have significantly fewer cracks and consistently lower deflections in comparison to a similar parallel runway that had been overlaid at the same time, but without the use of the SAMI.

Vedros (1979, 1981) reported on some research conducted by the U. S. Army Engineer Waterways Experiment Station to determine the effectiveness of a SAMI and fabric interlayer in stopping reflective cracking. The SAMI consisted of an asphalt-rubber membrane, while a non-woven fabric was placed under a thin HMA overlay (2 in. [50 mm] or less) for different segments. Field tests of two asphalt-rubber membrane formulations and three non-woven fabrics were placed on roadway and airfield pavements at five Army installations across the United States. The construction report covered the construction of the test areas and performance after a 6-month period. A final report was prepared on the performance of each material after a number of years of annual inspections. The research found that the SAMI was an effective strategy for mitigating reflection cracks over the relatively short study period.

Coetzee and Monismith (1979, 1980) used finite element analysis to study the effect of a SAMI between a PCC pavement and HMA overlay. Their findings showed that the stress at a crack tip is reduced significantly when the stiffness of the SAMI is decreased. If a SAMI exists, the thickness of overlay has little influence on the overlay performance and the effect of crack width on the stress at the crack tip is negligible. However, the finite element analysis showed that overlay thickness had some effect when a SAMI was not used. The stress concentration at the crack tip increased as crack width increased, HMA overlay thickness decreased, HMA overlay stiffness decreased, or when the original pavement stiffness was increased.

Paterson (1983) incorporated a SAMI of styrene butadiene-styrene (SBS) elastomer asphalt to a medium-thickness asphalt overlay for the rehabilitation of cracked PCC pavements. This application was also extended to thin overlays with more severe conditions, such as joint movements of up to approximately 0.28-in (7 mm) and airport runway loadings. Finite-element analysis and time-temperature-dependent material properties were used to analyze response and fatigue behavior under daily temperature fluctuation and aircraft dynamic loading in various modes. Results showed the crack resistance of the pavement structure was improved by increasing overlay thickness and stiffness and reducing membrane stiffness. This finding was verified by laboratory tests. Finite element analysis also indicated that a 3.15-in (80 mm) thick composite membrane-overlay system covered by an open-graded HMA overlay can satisfy the design requirements and was comparable to 9.4-in (240 mm) thick conventional HMA overlay for control of crack reflection over a 15-year life. This SAMI system was shown to be safe under all aircraft loading conditions.

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 three (Colorado, Pennsylvania, and Nevada) reported complete failures. As an overall summary, Mukhtar (1994) presented the following results for SAMI application:

- SAMI's cannot prevent reflective cracking but can retard it.
- SAMI's perform better in the overlays on flexible pavements with fatigue cracking than rigid pavements having thermal cracking.
- Treatments applied on the full width and length of pavement produced better results than treatment applied only above the joint/crack area.
- A thicker SAMI is more effective, when placed in the range of 0.25 to 0.375 inches (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 acceleration of vehicles. 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.

Some of the Naval Air Stations located in South Texas that are used for training exercises have exhibited extensive amounts of high severity block cracking along the runways and taxiways. As part of a rehabilitation program in 1983 to 1984, the main runways used for training were found to have adequate structural support, and were rehabilitated because of block cracking and raveling. The rehabilitation strategy included placing a chip seal followed by a 4 inch (100 mm) P-401 overlay. This rehabilitation strategy provided excellent performance with minimal reflection cracking for 10+ years (Von Quintus, 1984-1994).

Overall, SAMI's have been used on many projects and the performance of this technique for mitigating reflective cracks has been good. SAMI's are definitely considered a viable and cost effective mitigation technique when used under the right conditions.

3.2.2 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 HMA pavement. This type of interlayer using geosynthetics (fabrics) is usually included as a separate category of stress and strain relieving interlayer. For this report, 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. Geosynthetics are also included and discussed under section 3.5—HMA Overlay Reinforcement.

As noted in the previous subsection, Vedros (1979) reported on the effectiveness of an interlayer consisting of 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. The fabric interlayer 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.

3.2.3 HMA Interlayer with Material Modification

Soft Asphalt Interlayer

Softer grade asphalt can substantially reduce 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 the appearance of cracking is:

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

Several projects have successfully incorporated the soft asphalt interlayer for controlling reflective cracking. In Arizona (Way, 1980), the 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 finishing course. This structure-material combination was found to be one of the five most effective treatments to reduce reflective cracking. Sherman (1982) reported that a 1971 Wyoming project provided evidence that a 2-in (50 mm) soft asphalt interlayer (viscosity grade, AC 2.5) and crack sealer exhibited the least cracks and was the most effective for reducing reflective cracking.

Rubber Modified Asphalt Interlayer

Rubber modified asphalt is made from mixing relatively high concentrations of reclaimed rubber in hot asphalt. When comparing the amount of reflective cracking alone, an asphalt rubber membrane covered by approximately 0.5 in (12.5 mm) HMA wearing surface was the best among the eighteen treatments tested in Arizona (Way, 1980). The sections with the rubber modified asphalt membrane, however, exhibited shoving which led to a rough ride. The shoving and rough ride was reported to be a big disadvantage of the rubber modified asphalt interlayer.

A rubber modified asphalt interlayer is also included in the SAMI category, which was discussed in the previous section. New Mexico (McKeen et al., 1984) used a factorial design to study the influence of variables such as rubber type, mixing temperature, batch repetition, and test temperature. Four laboratory tests and the field trial were conducted. McKeen, et al (1984) concluded from the field experiment that the mixing time has a significant influence on cracking observed while the rubber type showed no influence on cracking.

In summary, an HMA interlayer with asphalt modification has been reported to be a viable technique to mitigate reflective cracks, if the mixture has been properly designed. This technique is susceptible to shoving when thin HMA overlays (less than 2 inches) are used, especially in areas where horizontal loads occur.

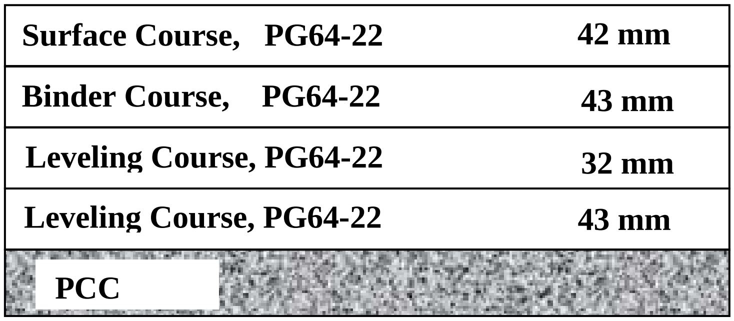
3.2.4 STRATA Crack Relief Interlayer System—A Proprietary Material

STRATA is a relatively new reflective crack relief interlayer system that protects existing pavement structures from water damage and delays reflective cracks. It was developed by SemMaterials (www.SemMaterials.com). 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 PMA produced and compacted at higher asphalt content. The recommended HMA overlay can be Superpave or SMA using SBS polymer modified asphalt binder. The minimum overlay thickness should be determined based on future aircraft traffic.

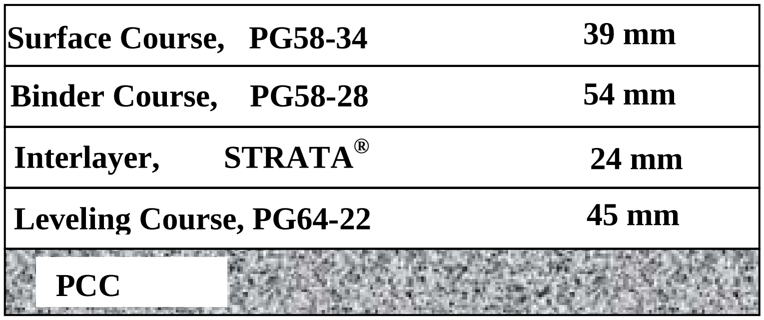
According to SemMaterials, the advantages of STRATA include: 1) significantly delaying reflective cracks longer than fabric and HMA overlays, 2) providing an impermeable interlayer to protect pavement structure from moisture damage, 3) providing a highly fatigue resistant material, 4) ease of mixing,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

The STRATA interlayer system was applied on an Iowa highway project and evaluated by Wagoner et al. (2006). This project is located in northeast Iowa on State Highway 9 (IA-9) near Decorah and was constructed in 2001. The pavement structure consisted of an HMA overlay on top of a jointed PCC pavement. Before the overlay was constructed, the underlying pavement was repaired to provide sufficient support. The highway is a two-lane pavement with an average of 3800 vehicles per day and 18 percent truck traffic. The average 7-day high pavement temperature is 90 °F (32.4 °C) and the low pavement temperature is -25 °F (-31.6 °C).

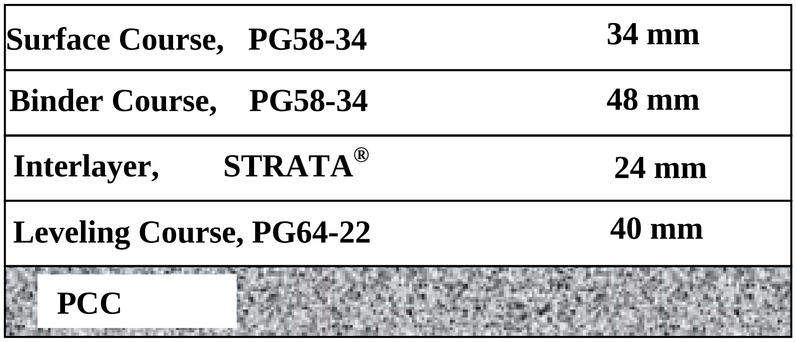
There were three sections on this IA-9 project—a control section, section 1, and section 3 with a nominal overlay thickness of approximately 6.3 inches (160 mm). The detailed structure-material combinations of these sections are shown in figure 8. A STRATA interlayer mixture was placed above the leveling course in sections 1 and 3 to retard reflective cracks and prevent moisture intrusion into the base. The interlayer consisted of a fine, No. 4 nominal maximum aggregate size gradation and 8 percent highly polymer modified binder compacted to 2.7 percent air voids to enhance crack resistance. American Association of State Highway and Transportation Officials (AASHTO) test protocol T321 (2003) beam test was performed at a high strain level (2000 micro strains at 50 °F [10 °C]) to simulate extreme conditions of strain in the area of potential reflective crack locations.



(a) Control section.



(b) Section 1.



(c) Section 3.

Figure 8. Pavement Structure with Asphalt for the Three Pavement Sections of the IA-9 Project (Wagoner et al. 2006)

Annual surveys of the pavement after construction showed that all pavement sections performed well through the first winter without any visual reflective cracks. After the second winter, the control section and Section 1 had approximately 20% reflective cracking, while Section 3 did not have any reflective cracks. For years 3 (February 2004) and 4 (August 2005), the control section and Section 1 showed similar amounts of reflective cracking, approximately 27 percent in February 2004 and 30 percent in August 2005. Section 3 exhibited about 4 percent reflective cracking by February 2004 and about 16 percent by August 2005. It was reported that the STRATA system was beneficial in retarding reflective cracking.

Laboratory testing and finite element analysis were also preformed by Wagoner et al. (2006) to investigate the reflective cracking resistance in conjunction with field observations. From the laboratory tests and analytical studies, Wagoner concluded that the materials utilized in the control section consistently had the highest stiffness, lowest tensile strength, and lowest fracture energy. The control section was reported to have the highest possibility of developing reflective cracking, as compared to pavements with the STRATA interlayer.

In summary, much fewer projects have been used to document the performance of the STRATA material, as compared to the use of the more conventional SAMI's. Based on the results reported to date, STRATA is considered a viable mitigation technique.

3.2.5 Interlayer Stress Absorbing Composite—A Proprietary Material

In 1993, the University of Illinois completed research directed by the Illinois DOT on a prototype Interlayer Stress Absorbing Composite (ISAC). A test section of ISAC was placed on state route IL-38 near Rochelle, IL.

ISAC is a composite layer combining the effect of both geotextile and SAMI, which was developed and evaluated for the purpose of effectively alleviating 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. This system can relieve stress at the crack tip and at the same time provide reinforcement to the HMA overlay. Thus, it could contain the upward propagation of a crack and dissipate the stress at the tip of the joint/crack. As stated by Mukhtar (1994), the design of ISAC system followed the concept that "stress should not be stored indefinitely in the geotextile or the overlay and should be dissipated as it develops".

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, and 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.

In order to evaluate the effectiveness of the ISAC layer to control reflective cracking, a laboratory pavement section with an HMA overlay placed on a jointed PCC slab was constructed and tested in an environmental chamber (Dempsey, 1997 and 2002). A mechanical device was used to simulate thermal strain in the slab and the joint was opened and closed at an extremely slow rate. The testing was conducted at 30°F (-1.1 °C) and strain in the overlay was monitored using a sensitive LVDT device. The force required to pull and push the slab was monitored using a load cell placed between the slab and the hydraulic ram.

Performance of ISAC was evaluated by comparing the cycles to failure of an ISAC treated overlay with a control section without ISAC and with two commercially available products. The base isolation properties of the ISAC system were demonstrated in the laboratory evaluation studies. The laboratory evaluation studies indicated that the ISAC system exhibited superior performance than the control section and the two commercial products tested. Under the same temperature-loading condition, the strain in the overlay was significantly decreased and the number of cycles to failure was greatly increased when comparing with and without ISAC overlay structures. Three years of field performance testing also showed that the ISAC system was highly effective for mitigating reflective cracks in the HMA overlay.

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 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 the 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-reflective cracking products, such as PavePrep and Roadtac. When compared with SAF, the ISAC delayed reflective cracks by about two years. However, the price of the ISAC strips was higher, ranging from $10 to $14 per foot in 2005.

Similar to STRATA, the ISAC material has been used on fewer projects, but is considered a viable mitigation technique based on early performance observations that have been documented in the literature.

3.2.6 Bond Breaker

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 reflective 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 in (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 overlay in the vicinity of the joint or crack—increasing the gauge length of where the reflective crack occurs (Mukhtar, 1994). In other words, 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 reflective cracking will not take place.

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, but developed severe cracking after 3 years. Kentucky experience showed the bond breaker technique only works for a short time. In New York, a project was conducted to evaluate the effectiveness of stone dust bond breaker in retarding reflective cracking. A layer of stone dust (¼ 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 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 for failure of the bond breaker method were suggested by Mukhtar (1994):

- 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 vehicles.
- The effect of 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 stone dust around the joint/crack.

In summary, the performance of bond breakers has been mixed—varying from no benefit to slightly delaying the occurrence of reflective cracks, in comparison to control sections where bond breakers were not used. Where bond breakers are used, a thicker HMA overlay is needed because of the higher tensile strains at the bottom of the overlay and to reduce the potential for shoving and slippage cracks.

3.3 Cushion Courses or Layers

Cushion courses, for use in mitigating reflective cracks, are defined as open-graded HMA or crack relief layers and unbound aggregate base layers. The open-graded HMA or crack relief mixtures have 25 to 30 percent air voids, but generally require thinner dense-graded HMA overlays than when an unbound aggregate base is used as the cushion course. The unbound aggregate base layers 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 that other related features (such as lighting) be raised accordingly.

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.

Aggregate cushion layers have been used as a reflective cracking mitigation technique of PCC pavement since the 1950s and are still used to date. Two problems associated with cushion courses include: the total overlay thickness being generally much greater than for some of the other mitigation strategies causing clearance problems, and the cushion course being 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 of overlays in some cases. The clearance or elevation issue (bridges, curb & gutter, guard rails, etc.) with the use of thicker layers is another reason why this technique has been used less frequently in recent years for roadway rehabilitation projects.

In northern Ontario Canada, air-blown asphalts LV 15-200 and LV 85-100 were used in an HMA overlay (Gaw, et al., 1976). In order to isolate the performance of air-blown asphalts from the influence of varying conditions of the underlying pavement, a cushion layer of 12 in (0.3 m) granular material was placed over the cracked pavement prior to placing the overlay. After three years of service with minimum temperatures reaching -36 °F (-38 °C), the air-blown asphalt sections showed no significant transverse or reflective cracking and their performance were better than that of the non-air-blown asphalt HV 150-200. Although this project was developed to study the benefits of air blown asphalt, it also demonstrated the benefit of granular cushion courses to mitigate reflective cracking.

The use of an open-graded HMA or crack relief layer as a stress relief layer placed on the existing pavement is recommended as a method to inhibit reflective cracking in FAA AC-150/5320-6. The large percentage of the interconnecting air voids in open-graded mixture dissipates the stress, caused by the movement of the underlying PCC slabs, 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.

Different aggregate sizes (air voids) offer different protection against reflective cracking from both horizontal strain and vertical strain modes and different aggregate interlock for load transfer. Larger aggregates are normally used in the crack relief layer over existing PCC pavements that that have longer slabs and larger horizontal movements at the joints. Smaller aggregate crack relief layers are used for PCC pavements with shorter slabs or for flexible pavements.

Open-graded mixtures as an interlayer and defined as 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 reflective cracking in both rigid and flexible pavements.

When using the mitigation strategy for maximum benefit, it is usually recommended that the existing pavement be treated by undersealing, if voids are beneath the PCC slabs and, removing/replacing all badly cracked and depressed areas before the open-graded HMA is placed. 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. According to Hensley (1980), the selection of an open-graded mix gradation should be based on the expansion-contraction characteristics of the pavement to be overlaid.

Larger aggregates and voids (Grade A, as defined in the Asphalt Institute’s Technical Bulletin #4) usually offer the greatest protection against reflective cracking from both horizontal and differential vertical movements (Asphalt Institute, 2004). 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 continuously reinforced concrete pavement (CRCP) where the horizontal movements are uniformly distributed. A Grade C gradation is also used for existing flexible pavements and uniformly cracked CRCP.

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 and used in Arkansas. All crack-relief aggregates should consist of 100 percent crushed from a hard durable aggregate source. An intermediate course placed directly on the crack relief mixture provides an adequate working table for the surface to be placed which bridges the surface voids of the crack-relief layer. The binder course should be specified to be coarse enough to prevent material from penetrating the voids of the open-graded mixture.

3.4 HMA Mixture Modification

This category of reflective crack mitigation method includes those treatments that 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.

The crack resistance of HMA depends on the asphalt grade, content, elastic characteristics, and temperature susceptibility. These properties affect the HMA mix'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. These properties can be achieved by modifying the asphalt and/or increasing the film thickness of less viscous (softer) asphalts.

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 (Tuckett, et al., 1970). 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 HMA tensile strain at failure for the softest asphalt. In summary, HMA mixture modification and use of thicker overlays by themselves is not considered a cost-effective technique to mitigate reflective cracks, with the exception of rubber modified asphalt mixes that have exhibited positive results in reducing reflective cracks. The different materials/mixtures included within this category are briefly discussed in the following subsections.

3.4.1 Thick HMA Overlay

In general, increasing thickness of the HMA overlay can reduce the load-associated damage by reducing the effect of poor load transfer across a crack or a joint in the underlying pavement, and thus, can effectively improve the pavement performance. Sherman (1974 and 1982) suggests that the overlay thickness required to retard the reflective cracks depends on four factors:

1. Type of pavement being overlaid – HMA or PCC; HMA overlay thickness of flexible pavements is generally less than that for JPCP or JRCP.
2. 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.
3. Climate; the greater the variations in seasonal and daily temperatures, the greater the HMA overlay thickness.
4. Number and weight of axle loads; the higher wheel loads or weights and the higher the traffic volume, the greater the overlay thickness.

The greatest benefit from the use of thicker overlays of PCC slabs, however, is the ability of the HMA to insulate the PCC, reducing the amount of curling and temperature variations. High quality dense graded HMA and low viscosity asphalt should be used as concluded by NEEP-10 final report in 1984 (Tyner, et al., 1981). A study done by Gulden and Brown (1984) in Georgia found that the occurrence of reflective cracks decrease considerably as overlay thickness increases. They recommended a minimum overlay thickness of 100 mm (4 in) when no other treatment is used.

The Texas DOT sponsored studies in the latter 1960's through the 1970's on the use of thick HMA overlays of PCC pavements to mitigate reflective cracks. The overlay thickness on these projects varied from 2 to 6 inches (50 to 150 mm). The 2-inch overlays exhibited a high percent of reflective cracks within the first year, while the thicker overlays did delay the reflective cracks. However, most of the thicker overlay sections exhibited a high amount of reflective cracks prior to 10 years. The Georgia DOT found similar results from field observations of HMA overlay placed over PCC pavements. In general, one-inch (25 mm) of added HMA overlay will delay the reflective cracks by about 2 years.

Simply increasing the overlay thickness is not a cost effective approach. In specific, Mukhtar (1994) reported that a thicker overlay is the easiest but usually the most expensive alternative. Zhou and Sun (2000) also report that only increasing overlay thickness of composite pavements (HMA over PCC) may not be an economical solution. Increasing the HMA overlay thickness will result in additional project expenditures because of clearance (bridges, curb & gutter, guard rails, etc.) and shoulder elevation problems.

The New York DOT (Vyce, 1983; Noonan, et al., 1980) reported that their 7 in (178 mm) thick HMA overlays of PCC pavements cracked completely after 5 years. The continued deterioration of the reflective cracks was less in the following 4 years for the thick overlays in comparisons to their thinner overlays. The reason for the high extent of reflective cracks for the thick overlays was related to the length of the PCC slabs (78 to 100 ft [24 to 30 m]) and high seasonal temperature variations (100 °F [38°C]).

The results of several reflective cracking studies, where the overlay varied from 1.5 to 10 in (38 to 254 mm), all showed some degree of reflective cracking (Van Breeman, 1963; and Housel, 1962). From these previous studies, it is safe to conclude that simply increasing overlay thickness will not eliminate reflective cracks, and may only slightly delay their occurrence.

3.4.2 Soft or Low Viscous Asphalt

The brittleness of HMA at low temperature is one of the major reasons for the cracking in HMA pavements. Based on previous research, Huffman (1978) stated that "asphalt stiffness can play a significant role in the amount of reflective cracking. However, eventually after sufficient asphalt aging, significant reflective cracking will occur."

The use of soft asphalts, however, is not recommended because of the potential for bleeding and rutting. If softer asphalts are used in the first lift placed, the upper HMA layer must be thick and stiff enough to resist rutting within the softer layer. On a positive point, one study conducted in Iowa showed that the use of softer asphalt allows the reflective cracks that occur during cold weather to heal themselves during the summer months (Roberts, 1954).

3.4.3 Modified Asphalt

The major objective 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. 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. (Kanarowski, 1972; and Mellott, 1975). 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.

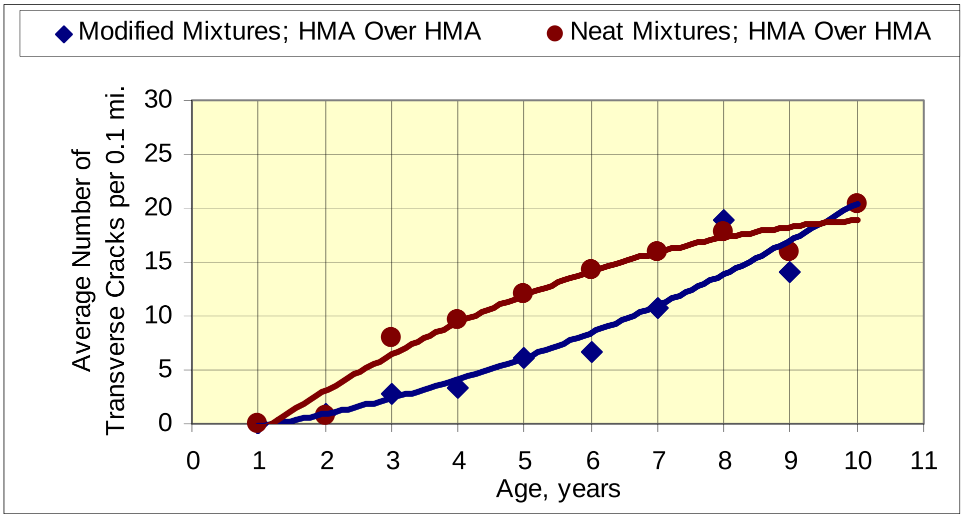
Although the results are diverse, most of the results reviewed suggest that fillers or additives alone will not improve the performance (delaying reflective cracks) of an HMA overlay over the long term. Stated differently, the use of HMA mixture modification by itself is not a cost effective approach to mitigate reflective cracks. As an example, Figure 9 shows the results from a comparison of transverse cracks in HMA overlays of flexible and rigid pavements for neat and polymer modified overlays (Von Quintus and Mallela, 2005). The HMA overlays of the flexible pavements show no long term benefit, while the HMA overlays of rigid pavements do show a long term benefit. Conversely, similar studies conducted for the Arizona DOT and Wisconsin DOT found just the opposite.

The following subsections provide a brief summary of past studies to mitigate reflective cracks that are related to type of modified asphalt.

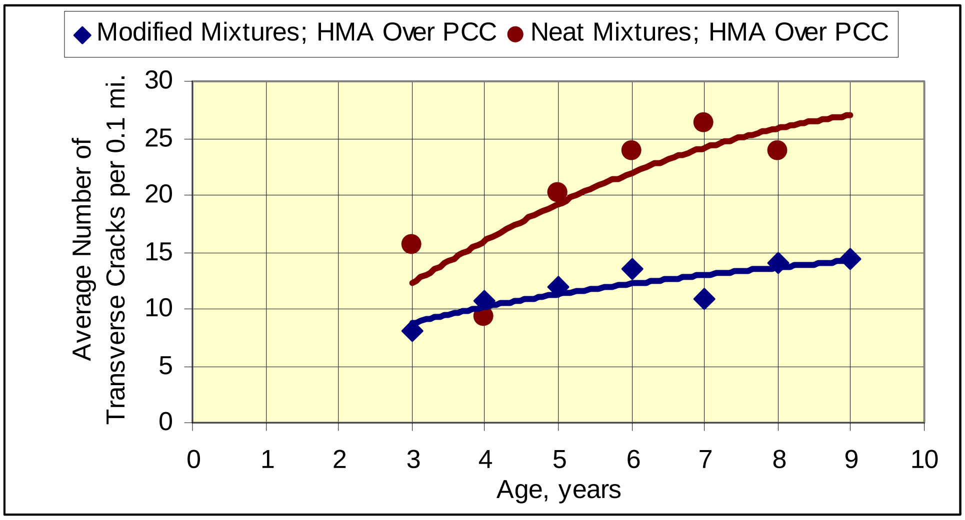
Polymer Modified Asphalt

Blending certain percentages of styrene-butadiene-styrene (SBS), ethylene-vinyl-acetate (EVA), or styrene butadiene-rubber (SBR) 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 asphalts. More importantly, PMA has increased resistance to cracking. Some applications of the PMA to reduce the reflective cracking have been documented by Ellis et al. (2003) at UK military airfields, which are discussed in more detail in Chapter 4.

Von Quintus, et al., (2007) evaluated and compared the performance of overlays with conventional-neat mixtures to those with PMA mixtures of existing flexible and rigid pavements. The comparison of field performance clearly showed a substantial benefit (reduced levels of distress) with the use of PMA mixtures. This study, however, did not consider reflective cracking of the overlay—it was based on thermal or transverse cracks, fatigue cracks, rutting and International Roughness Index (IRI).



(a) HMA Overlays of Flexible Pavements.



(b) HMA Overlays of Rigid Pavements.

Figure 9. Average Number of Transverse Cracks Measured Along a Project with Age for Different HMA Mixtures (after Von Quintus and Mallela, 2005)

Rubber Modified Asphalt

Rubber particles, when mixed with asphalt at 374 °F (190 °C), swell to about twice their original volume and become softer and more elastic. Such change gives additional "stretchability" to the HMA mixture, enabling it to withstand higher strains without breaking. Although the crack tendency can be improved, that modification with rubber can be detrimental to stability, if not properly designed. Some agencies have reported good performance with the use of HMA mixtures modified with reclaimed or crumb rubber (Arizona DOT [Way, 1980]), while others have reported problems (Alaska DOT [Raad, et al., 1997]). Many of the earlier problems were investigated and found to be related to construction issues and/or material defects. Thus, the use of rubber modified asphalt mixtures in the wearing course should be used with caution and require 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 was discussed under the previous section on Stress and Strain Relieving Interlayer.

Reclaimed rubber asphalt was used by the State of Connecticut to increase the flexibility of HMA through two mechanisms (Stephens, 1982): a) less temperature sensitivity of the modified asphalt so that softer asphalt can be used, and b) increased asphalt film thickness. Stephens (1982) reported that rubber modified asphalt was used in nine test sections with different pavement distress, traffic levels, and base pavement types (composite [HMA over PCC], HMA, and PCC pavements). These mixtures were Connecticut DOT approved, with either one percent rubber and 0.25 percent additional asphalt, or two percent rubber and 0.5 percent more asphalt. Results showed that sections overlaid with one percent rubber modified asphalt, on average, have fewer cracks than the non-rubberized section. Sections with two percent rubber modified asphalt, however, had more cracks than the non-rubberized section.

Conversely, cores taken by the City of Phoenix, Arizona from HMA overlays modified by rubber found that wide transverse cracks in the existing HMA pavement had not reflected into the HMA overlay in over 5+ years of performance. Climate and materials are believed to be the reason for the diverse differences in performance.

Sulfur Asphalt

Different additives can be used to improve asphalt rheology properties. 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 (Poon, 1986).

Hignell et al. (1972) described the sulfur-modified HMA as an ideal mixture which is optimum for both low temperature and high temperature conditions. Meyer et al. (1977) also found that adding sulfur to asphalt would increase the stability and stiffness of the HMA at high temperatures and at the same time maintain the low temperature property of the asphalt. Sulfur asphalts behave 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.

The stiffness of sulfur asphalt at higher temperatures is determined by the amount of sulfur added. Based on the performance of sulfur asphalt in test sections, Fromm et al. (1981) found that the sulfur HMA mixture had better resistance to thermal cracking and rutting in comparison to a conventional HMA mixture without sulfur. Reflective cracking, however, was not included within that study.

On a negative note, sulfur fumes during paving can be a problem if the mixture temperature is above 266°F (130 °C), according to that same study by Fromm et al. (1981). Hydrogen sulfur and sulfur dioxide were considered the main component of the fumes, even though their concentrations were far below toxic level.

Carbon Black

The use of carbon-black to modify asphalt has been studied by Rostler et al. (1972, 1977). 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 increases the tensile strength of the HMA mixture. Increasing the tensile strength of HMA should delay the occurrence of reflective cracking.

Laboratory studies on the behavior of HMA mixtures with carbon black reinforcement were reported by Yao and Monismith (1986). Test results showed 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 un-reinforced mixtures.

Yao and Monismith (1986) concluded that if in-service asphalt responds in a manner similar to that used in this study, soft asphalt may be used to mitigate low temperature cracking yet provide improved resistance to rutting at high pavement temperatures. The study also suggested that in hot climates, the addition of carbon black microfiller to relatively hard asphalts may be useful in reducing the rutting potential for heavily trafficked pavement sections.

Other Additives

Other additives such as asbestos fibers, shingles, and metal additives are also found to be successful in modifying asphalt. Most of the studies reviewed on the use of other additives included a comparison of mixture properties measured in the laboratory. Few of these projects included a comparison of field performance data, and of those, almost none were focused on reflective cracking. Asbestos fortified HMA mix was rated as one of the five treatments that significantly reduced the reflective cracking in Arizona (Way 1980). However, the application of asbestos in HMA overlays has been abandoned because asbestos has been identified as a carcinogenic substance.

Kennedy et al. (1981) found that adding a small amount of metal can trigger the polymerization of the asphalt and improves HMA performance. Laboratory tests showed that the temperature susceptibility, indirect tensile strength and bending strength were all improved due to this modification. Kennedy et al. (1985) further reported that by using manganese metal additive, the modified HMA mixture was found to have increased stiffness, strength, and stability at high temperature and decreased low temperature stiffness. The tensile strength of the modified mixture at low temperatures, however, appeared to be lower than for conventional mixtures.

3.5 HMA Overlay Reinforcement

HMA overlay reinforcement that has 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.

3.5.1 Steel Reinforcement

Steel reinforcement is one of the oldest interlayer systems used in HMA. 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, similar to PCC (Busching and Elliott, 1970). In other words, the reinforcing elements with high tensile strength can be used to strengthen the tension ability of the HMA mixtures. The 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 (Zube, 1956; Chastain and Mitchell, 1963; and Smith, 1977). Both welded wire fabric and expanded metal reinforcement has been used.

According to Busching and Elliott (1970), 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 in areas where braking and acceleration occur, reducing the potential for slippage cracks. The primary disadvantage is that water within the HMA mixture can cause the steel to corrode in as little as four years of service.

Steel and wire mesh reinforcement was used in the HMA overlays of many military airfield pavements during the 1950's and 1960's. However, the construction and performance of these overlays have not been adequately documented. As an example, one of the major runways at San Antonio International Airport was found to have steel reinforcement (welded wire fabric) in an 8-inch (203 mm) HMA overlay over a JPCP based on cores recovered from the runway during a pavement evaluation for a rehabilitation design study. The steel reinforcement did not prevent the reflection cracks, but did hold the cracks tightly together (Von Quintus, 1984).

Brown et al. (2001) investigated the effectiveness of different reinforcement or interlayer systems, such as geogrid, steel reinforcement, and glass fiber for retarding reflective cracks in HMA overlays based on British experience. The interface shear strength and stiffness for un-reinforced and reinforced samples were evaluated by applying a repeated load shear test and their fatigue behavior was evaluated by a semi-continuous fatigue test. Thermal loading due to the expansion and contraction of a PCC base was also simulated in the laboratory for comparing the performance of different interlayer systems. Results of this study indicated that steel reinforcement provides interface shear stiffness comparable to the non-reinforced case. Steel reinforcement might improve the fatigue life by a factor up to three. It was also found that steel reinforcement had good results in reducing reflective cracks due to the thermal movements of the PCC slabs.

Although the original steel reinforcement was gradually abandoned in the US due to its difficulty in installation starting from the early 1970's, some modifications to producing the steel mesh and installing it were made in the early 1980's which helped regain interest to this reinforcement interlayer system in Europe (especially in Belgium and the Netherlands). A comparison of the original welded steel mesh with the new woven wire mesh was given by Al-Qadi et al. (2003), as shown in table 1. 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 are discussed in the next subsection.

Table 1. Comparison Between the Original Wire Mesh and the Current Steel Mesh (Al-Qadi et al. 2003)

Criterion	Original Mesh (1950-1970)	New Mesh (1980-2000)
Product	Welded wire	Coated woven wire mesh
Product Shape	Rectangular	Hexagonal
Sensitivity to rust	Yes	No
Installation	Rigid	Allows horizontal movement
Unrolling Process	Manually	Using a roller
Creeping of the mesh	Installed loose	Wire tension may be relieved during construction
Fixation	Hog rings	Nails or other pertinent methods (slurry seal)
Cost ($\$/m^2$)*	0.20-0.70	3.5-6.0

* No inflation rate is applied

The application of steel reinforcement netting interlayer in the field has been widely used and well documented throughout the world. Vanelstraete and Francken (1996) from Belgium investigated the effectiveness of steel reinforcement in mitigating reflective cracks based on laboratory tests. A type of thermal test was used, in which an HMA overlay on top of an interlayer system and a cracked concrete slab was subjected to horizontal (thermal) opening and closing cycles until the crack reflects to the surface of the overlay. Different interlayer systems (e.g. steel reinforcement, SAMI, geogrid, non-woven and woven geotextile) were tested. The study concluded that the use of steel reinforcement provided better performance than the control case as well as the other interlayer systems.

Steel reinforcement experience in Finland has been summarized by Makela et al. (1999) based on the evaluation of ten different sites, where steel reinforcement was used to enhance the bearing capacity of the road and to prevent pavement damage from frost heave. The steel reinforcement was installed at two different locations within the same pavement structure (inside the base layer, and on top of the existing pavement prior to the overlay installation). Also, rectangular rather than hexagonal steel mesh was used. Furthermore, the reinforcement is not placed in the transverse direction, but in the longitudinal direction (parallel to the direction of traffic). The authors reported that at all ten test sites, steel reinforcement effectively prevented frost damage (which usually appears as longitudinal cracks in the pavement surface), while the control section exhibited significant damage.

In the United States, the steel reinforcement netting interlayer system was first introduced and 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 the other three projects. 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. From the field survey results, all four projects showed good effect of steel reinforcement on reducing the reflective cracks.

If a thick layer of slurry seal is used, the imprint of the mesh should be clear to prevent bleeding. Other benefits of using a slurry seal include; 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. The maximum speed suggested, if construction vehicles are allowed to travel on the slurry seal-mesh interlayer, is 25 mph (40 km/hr).

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).

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 roller 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 is to pretension the steel, which was used successfully on a project in Atlanta, Georgia.

3.5.2 Geosynthetics (Fabrics, Grids, Composites, Membranes)

Geosynthetics are defined as fabrics, geogrids, 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 (70 kg/mm), “Very Stiff’ classification in table 2. 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 of Chapter 3.

Table 2. Tentative Stiffness Classification of Geosynthetics (Barksdale et al. 1989)

Stiffness Description	Secant Stiffness @ 5% Strain, Sc (lbs/in.)	Elastic Limit (lbs/in.)	Tensile Strength (lbs/in.)	Failure Elongation (% Initial Length)	Typical Cost Range ($/sq yd)
Very low	<800	10-30	50-150	10-100	0.30-0.50
Low	800-1500	15-50	60-200	10-60	0.40-0.50
Stiff	1500-4000	20-400	85-1000	10-35	0.5-3.00
Very Stiff	4000-6500	>=300	350-5000	5-15	3.00-7.00

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 reflective 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 reflective cracking in HMA overlays has ranged from successes to failures. 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.

Fabrics/Geotextiles

Fabrics or geotextiles for reflective cracking mitigation started to enter the marketplace in the 1970s. 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.

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.

Although fabrics will not eliminate reflective cracking completely, they are recommended by FAA circular AC-150/5320-6 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. 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/sq. yd. (70 to 130 gm/sq. m.).

(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 0.15 to 0.30 gal/sq. yd. (0.7 to 1.4 liters/sq. m.) 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 the following relationship to estimate the amount of tack coat needed for geotextiles.

$$RTC = 0.05(TW)^{0.30} \tag{1}$$

Where:
RTC = recommended tack coat rate (gal/sq. yd.)
T = Geotextile thickness, mils
W = Geotextile weight (oz/sq. yd.)

A study evaluating the performance of geotextiles was reported on by New York State DOT (Vyce, 1983). For the existing pavements with a 2.5 in (64 mm) thick overlay placed in January 1974, 100 joints were monitored as control joints, 50 were covered with 7.5 ft (2 m) wide geotextile strips and 50 used 15 ft (4.6 m) geotextile strips. By December 1974, the control joints developed significant cracking. However, the joints with 15 ft wide geotextile strips showed little cracking. By January 1975, 80 to 89 percent cracking developed on all the sections and by February 1975, all sections had developed more than 95 percent cracking. Vyce concluded that geotextile reinforcement did not work when the joint movement was more than 0.25 in (6 mm) The New York study, however, only included slab lengths that varied from 78 ft to 100 ft (24 to 30 m) and seasonal temperature variations of about 100 °F (38 °C).

Fabrics have been used in many airport pavement projects for mitigating the reflective cracks and protecting lower layers from water damage. Thomas (1985) reported several applications of synthetic fabrics on state and interstate highways as well as on airport runways. Fabrics were placed over a tack coat to prevent reflective cracks in an HMA overlay placed over deteriorating rigid pavements. Routinely repairs and maintenance were normally performed to ensure better performance of these overlays.

Other studies have also found marginal results 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 inches [50 mm]), but for thicker overlays their performance has been successful for the most part.

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 1/4 to 2 inches (6 to 50 mm) wide (Button and Lytton, 2003). Geogrids provide crack mitigation by providing tensile reinforcement to the HMA layer. FAA (2006) allows the use of geogrids as a countermeasure to retard reflective cracking.

Reinforcing geogrids 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—reducing the initiation of reflective cracks. Kennepohl and Lytton (1984) used the Texas Transportation Institute's Overlay Tester and computer analyses to simulate the crack growth due to thermal contraction. This laboratory study indicated that the presence of the reinforcing geogrid did improve the fracture resistance of the HMA mixture.

Tensar, a high strength plastic geogrid was introduced in late 1980 and has been evaluated by Kennepohl et al. (1984, 1985) and others. This material is made from polypropylene and is biaxial oriented to give strengths in the order of mild steel in both directions. In this study, Tensar geogrids were found to be effective as a reinforcement of the HMA layer. Laboratory tests were also used to evaluate the fatigue strength of Tensar geogrid reinforced HMA. The results showed that a 6-inch (150 mm) reinforced HMA layer could carry as many load cycles as a 10-inch (250 mm) un-reinforced HMA layer.

Higher-strength, higher-stiffness geogrids 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. Sprague et al. (1998) described the mechanisms that lead to the enhanced performance of reinforced overlays, and hypothesized that the high stiffness geogrids 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 delays reflective cracking indefinitely, provided they are constructed properly. Sprague et al. (1998) also pointed out, however, that evaluating the appropriate reinforcing material should rely on the uniform definition and measurement of stiffness for the geosynthetic, so that materials can be properly compared.

According to published literature (Shoesmith and Emery, 1985), Glasgrid, a material made of fiberglass, is another promising reinforcing product because it has high modulus, low percentage of elongation, and is relatively cheap. Flexural tests of Glasgrid showed 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. Only the reinforcement layer was delaminated horizontally from the underneath layer. These cracking phenomena and failure modes were actually desirable in overlay construction. Field trials of this Glasgrid were carried out in a number of places. One successful example is an experimental sections constructed in Alberta in 1985 incorporating both Tensar and Glasgrid.

Ellis, et al., also reported on the use of geogrid reinforcement materials on various military airfields in the UK (Ellis, et al., 2002). The different geogrids that were used include: (1) a polyester grid with a 1.5 in (40 mm) square mesh size, (2) a fiberglass grid with a 0.5 in (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. Achieving good performance with geogrids as a reinforcement of HMA overlays requires the proper choice of geogrid geometry, good construction practices, and the selection of the materials to meet the in-service stresses imposed by the traffic and thermal loads that the geogrid must resist. A summary of the design and construction factors that are important to performance are provided in Appendix B.

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, similar to the ISAC material previously discussed. 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).

Ramsamooj theoretically compared an HMA-fiberglass composite overlay (referred to as ACF) to the 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 (1,380 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.

Later, Ramsamooj (2001) designed a new fiberglass composite overlay with a granite riding surface to eliminate reflective cracks from existing JPCP. Laboratory testing and analytical fracture mechanics solution were performed to evaluate the materials resistance to thermal, bending, and shear stress under cyclic loading. A 0.6 in (15 mm) thick E-glass mat-reinforced polyester (0/90° woven fabric, 18.3 percent volume fraction) was used over the joints covering a length of 7.9 in (20 cm) on either side. This laminate has the strength and flexibility to carry very heavy gear loads and tire pressures across the joints. Within a distance of approximately 20-in (51 cm) from the joint, the thickness of the fiberglass/polyester laminate is decreased gradually to 0.075-in (2 mm) and formed a hybrid composite with a thin HMA layer. The overlay was designed to withstand the thermal and aircraft stresses for about one million cycles of loading, which is considerably more economical than for a conventional HMA overlay.

Membranes

Membranes are special cases of composites and consist of a polypropylene or polyester mesh laminated on either one or both sides with an impermeable rubber-asphalt membrane (Button and Lytton, 2003). The specific applications of the membranes in relieving stress and controlling reflective cracking have had limited use.

3.6 Crack Control—Sawing and Sealing Joints in HMA Overlay

Under this strategy, a joint is sawed in the HMA overlay directly above the joint in the existing PCC pavement. A major advantage of providing such controlled crack relief is that this controlled saw cut can be more effectively sealed than a self-propagating zig-zag reflection crack. Sealing the saw cut prevents water and incompressible materials from penetrating the pavement, as well as reduces spalling and crack deterioration—assuming good compaction and materials that are not susceptible to moisture damage.

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.

Different agencies such as New York (Vyce, 1983), New Jersey, and Connecticut (Knight, 1983) tried the overlay joint sawing and sealing method with success. In the New York project, however, only 174 out of 683 saw cuts were properly located over the concrete joints. All of the 174 saw cuts that were properly located remained intact without any joint deterioration even after 7 years of service. Similar results were obtained in the New Jersey and Connecticut projects.

Numerous research studies have concluded that the sawing and sealing method 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 (Knight, 1983). Shorter slab length requires a large amount of sawing and sealing, which may not be cost effective.

3.7 Summary of Performance Reported in Literature

The following provides a summary of the results that have been reported in the literature to mitigate reflective cracking.

1. Modification of Existing HMA Pavements:
    - Full-Depth Reclamation—Viable and effective technique; mainly used for flexible pavement that exhibit severe levels of structural cracks.
    - Heater Scarification—Viable, but where cracks are confined to the existing surface.

  - Hot In Place Recycling—Viable, with the exception of thermal and fatigue cracks that extend through the entire HMA layers.
2. Modification of Existing PCC Pavements:
   - Crack and Seat—Viable, but does not eliminate reflective cracks; can be used with other mitigation techniques.
   - Rubblization—Viable and effective technique for PCC pavements that have extensive deterioration.
3. Stress or Strain Relieving Interlayer:
   - SAMI—Viable and effective technique for existing flexible pavements that have adequate structural support.
   - STRATA & ISAC—Viable technique for flexible pavement that have adequate structural support, limited performance data available.
4. Bond Breakers; Thin layers—Viable, but mixed results reported in literature.
5. Cushion Layers:
   - Aggregate Layer—Viable, mainly for PCC pavements; clearance can be a problem.
   - Crack Relief Layer—Viable, but requires much thicker overlays; clearance can be a problem.
6. HMA Mixture Modification
   - Various Modifiers—Viable, but not effective; Use in combination with other mitigation techniques.
   - Thicker Overlays—Not cost effective; Use in combination with other mitigation techniques, especially for PCC pavements.
7. HMA Overlay Reinforcement:
   - Steel or Wire Fabric—Viable, does not prevent reflective cracks but keeps cracks tightly closed with adequate density and good materials; limited data for adverse conditions where de-icing salts and chemicals have been used (susceptible to corrosion).
   - Geosynthetics—Viable for flexible pavements with adequate structural strength, but inadequate for PCC pavements.
   - Geogrids—Viable for flexible pavements with adequate strength, and PCC pavements exhibiting limited structural distress.
8. Crack Control; Saw and Seal Joints in HMA Overlay—Viable and effective for PCC pavements without structural cracks & adequate support; must accurately locate existing joints in PCC pavement so that saw cut is made directly above joints.

Chapter 4 Historical Performance and Experiences with Mitigating Reflective Cracks

The present state-of-the-art for mitigating reflective cracks in HMA overlays is to a large degree still based on experience gained from trial and error methods of in service pavements; both for highways and airfields. This chapter presents the results from specific airfield and highway projects where different products and processes were used to mitigate reflective cracks.

4.1 Airfield Projects and Comparative Studies

4.1.1 U.S. Army Corps of Engineers

Eaton and Godfrey reported on a study that was initiated in 1977 by the U.S. Army Corps of Engineers (USACE), Cold Regions Research and Engineering Laboratory (CRREL). The purpose of the study was to monitor and evaluate the rate of reflective cracking of an HMA overlay placed on a severely cracked runway at Thule Air Base in Greenland (Eaton and Godfrey, 1980). The HMA overlay was produced with AC 2.5 viscosity-graded asphalt that was placed at varying thickness along the runway.

In the summer of 1978, the Thule Air Base project was expanded to include the use of geotextiles. Fabrics were placed under another HMA overlay with AC 2.5 viscosity graded asphalt on severely cracked portions of the taxiway system. The purpose of this project was to evaluate overlay performance with fabrics in combination with soft asphalt under severe environmental conditions. The fabrics used in this project included: Phillips Fibers Corporation 4 and 6 oz/yd^2 Petromat and the Monsanto 6 and 8 oz/yd Bidim fabrics.

Eaton and Godfrey (1980) reported that 71 percent of the cracks reflected through the first year and 105 percent through the second year for the overlays with less than 2 inches (50 mm) in thickness. For the overlays with thicknesses greater than 3 inches (75 mm), 46 percent of the cracks reflected within the first year and 57 percent reflected in the second year. Thermal contraction was reported to be the reason for the severe cracking. Results from this study suggest that thicker overlays provide better performance, as found in many other studies (refer to Chapter 3). For the thicker overlays with fabrics, the 4 oz/sq yd geotextile had 34 percent more cracking than the 8 oz/sq yd geotextile. The fabrics, however, remained intact and served as a water proofing membrane or barrier in all areas with reflective cracks.

After the Thule Air Base study, the USACE began to collect performance data on other airfields within the U.S. Ahlrich (1986) completed an evaluation of overlays placed with paving fabrics under different climate conditions based on some case studies from airfields in the U.S. From these field results, Ahlrich concluded that the paving fabrics and rubber modified asphalt performed considerably better in warm and mild climates than in cold ones. This finding is similar to that found by other researchers (Epps and Button, 1984; Vedros, 1981; Amini, 2005). Ahlrich (1986) developed a map with climatic zones which was later adopted by the USACE in 1992 as a guide for using paving fabric (geotextiles) to retard reflective cracking. This study divided the United States into three climatic zones, as shown in figure 10 an defined below.

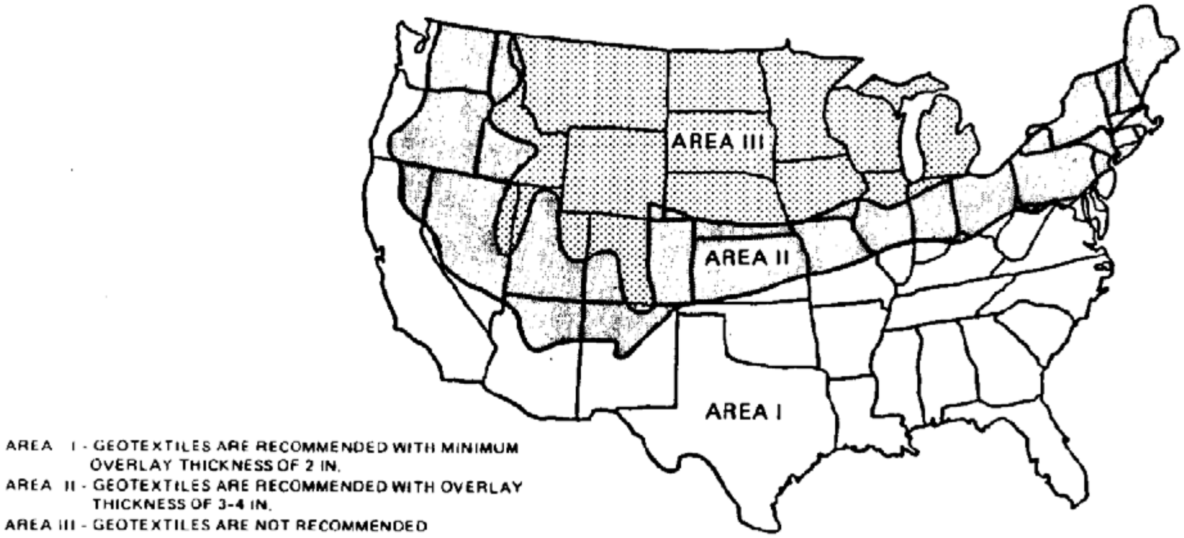


Figure 10. Location Guide for the Use of Geotextiles in Retarding Reflective Cracking (Ahlrich 1986; USACE, 1992)

- Area I includes climates similar to the warm southern and western states that has a mean air freezing index below 0. Fabrics used in this climate provided the most favorable results when a minimum of 2 inches (50 mm) of HMA is used on top of the fabrics for existing flexible pavements. A minimum of 4 inches (100 mm) of HMA is recommended when using paving fabrics in HMA overlays placed on existing PCC pavements in the same climate and geographic location.
- Area II includes areas within the central states and has a mean air freezing index between 0 and 500. Fabrics used within this climate should provide satisfactory results when geotextiles are used with at least a 3 inch (75 mm) HMA overlay placed on existing flexible pavements and a minimum 4 inch overlay for existing PCC pavements.
- Area III includes climates of the northern states that can experience extreme cold weather with a mean air freezing index above 500. Fabrics used within this climate exhibited the least favorable results and were not recommended for use as a strategy to retard reflection cracking for both existing flexible and rigid pavements.

Furthermore, Ahlrich (1986) recommended that rubber modified asphalt SAMI treatment be used for existing flexible pavements with a minimum overlay thickness of 2 inches in Area I and 3 inches in Area II. The rubber modified asphalt technique was not recommended for use on existing HMA pavements in Area III and on existing PCC pavements in any of the areas.

In summary, the use of paving fabrics (geotextile) is most effective in warm climates in controlling thermal cracking and reflective cracking. In cold region with freeze-thaw cycles, geotextiles mainly work as a waterproofing membrane to control moisture infiltrating into the lower layers and minimize the freeze-thaw damage—improving overall pavement performance.

Based on the Ahlrich study (1986), the USACE made some recommendations for the application of geotextiles in their design manual (USACE, 1992). The existing pavement should be prepared with either crack sealing (for cracks larger than 1/8 in [3 mm]) or a leveling course to ensure a suitable surface. A tack coat should be used before the geotextile is placed. Because low viscosity (or higher penetration grade) asphalts were found less likely to exhibit reflective cracks, the USACE recommended using the lowest viscosity grade asphalt that would provide sufficient stability at high temperatures.

4.1.2 Willow Run Airport, Michigan (Housel, 1962)

Willow Run Airfield was built during World War II (1941) by Ford Motor Company for production of the B-24 Liberator aircraft. Since 1955, several projects were conducted to address the badly cracked taxiway and main aprons.

HMA resurfacings were found to provide effective results of reducing the need for frequent maintenance for the areas where there was excessive cracking in the PCC pavements. In one test area, an increase thickness of one inch, or 33 percent, the HMA resurfacing reduced the reflected cracking about 8% of the total lineal feet of joints and cracks, and from 20 to 25 percent of the reflected cracking in the area of the standard 3-inch overlay. Better resistance to reflective cracking was found when using the 3-inch HMA overlay.

Welded wire fabric was found to have substantial benefit in reducing crack reflection when used as reinforcement in the HMA mixture. It creates a new pattern of cracks described as translated cracks in which wider crack openings such as joints were distributed by the reinforcing over the area covered in a large number of finer cracks.

4.1.3 State of Art (McLauglin, 1979)

McLauglin completed a study in 1979 of the methods and practices to reduce reflective cracking of HMA overlays, as well as the more analytical and laboratory tools for evaluating those methods and practices. Information concerning different techniques, their successes, failures and uncertainties were obtained from interviews with field personnel and different research agencies. Data were obtained directly from construction records, site visits, and published materials.

4.1.4 New Hanover County Airport (1978)

New Hanover County Airport, in Wilmington, North Carolina, overlaid their 20 year-old runway and adjacent taxiways in the summer of 1977 to provide greater load resistance to the increasing jet traffic. The runway rehabilitation was designed for supporting the heaviest medium range commercial jet aircrafts.

Protection against reflective cracks was provided by nonwoven polypropylene fabric combined with asphalt to form a stress relieving membrane. Before the installation of the fabric, the cracks in the runway were routed out and filled. A tack coat of asphalt was applied followed by the application of the fabric on either side of the centerline along the entire runway length and width, except for three control strips. Finally, the HMA overlay was placed. It was reported that this stress relieving membrane strategy performed satisfactory over the design period.

4.1.5 Suffolk Municipal Airport, Virginia (Rada and Witczak, 1987)

A study was conducted for three different pavement sections at Suffolk Municipal Airport, Virginia in order to evaluate and provide design guidelines for cracked and seated airfield pavements. Nondestructive testing (NDT) was used to determine the in-situ pavement properties and visual surveys were conducted to assess the condition of the existing pavements. From this study, Rada and Witczak (1987) concluded that: (1) crack and seat technique can be effective in reducing reflective cracking, but not eliminating it; (2) the strength of the PCC layer is significantly reduced after cracking and seating and hence, thicker HMA overlays are required; and (3) a greater degree of cracking before placing the overlay is helpful. This study recommended using the "modified FAA flexible pavement procedure" for the design of HMA overlays as an interim procedure, and using NDT testing as a construction quality control device during breaking of the PCC slabs.

4.1.6 Yellowknife N.W.T. Airfield Runway, Canada (Poon, 1986)

A test section on a Yellowknife, N.W.T. airfield runway at Canada was constructed in 1983 using non-woven polyester fabric (Mirafi P50 and P250) to inhibit reflective cracking. Poon concluded that an open graded HMA interlayer and an overlay of low consistency asphalt or modified asphalt is a more effective method to mitigate reflective cracks than the non-woven polyester fabric.

4.1.7 New Mexico Airports (McKeen and Pavlovich, 1989)

A field trial was conducted on Apron A at Kirtland Air Force Base, New Mexico, for the purpose of correlating interlayer material characteristics with field performance when used as a SAMI. The original pavement was built in 1940 with 1.5 in (38 mm). HMA over a cement treated base. This apron had exhibited extensive longitudinal, transverse and alligator cracking.

Two surface treatments (heater scarification and slurry sealing), three asphalt rubber mixing times (0.25, 1.0, 4.0 hours), three types of rubber, and two control sections with no asphalt rubber SAMI were placed. One control section (I) was cold milled to remove the entire existing pavement, then built entirely of new material from the base up. The other control section (II) was heater scarified and overlaid with 3 inches (75 mm) of HMA. The asphalt-rubber sections were first heater scarified, and then the SAMI was placed followed by the 3-inch overlay.

An evaluation of the cracking after two years of construction indicated that asphalt rubber mixing time significantly affected the level of cracking. Lower mix time resulted in less cracking. Rubber type had no influence on cracking. Control section I exhibited lots of load related cracking from heavy fuel truck traffic. Conversely, the entire apron and control section II exhibited little traffic related distress. The study concluded that the wide variation in cracking in control section II and the higher amount of traffic related cracking in control section I do not necessarily indicate a better performance of SAMI than the control sections, because of the confounding factors within this field trial.

4.1.8 William Hobby Airport, Texas (Little, 1991)

A 7-inch (2.8 cm) overlay of polyethylene-modified rich asphalt mixture (using the Novophalt process) was placed at the William Hobby Airport in Houston, Texas in December 1998 and compared to traditional Marshall and Hveem designed mixtures. Little (1991) evaluated the effectiveness of using PMA mixtures to resist reflective cracking, thermal cracking, and permanent deformation.

Based on the results of laboratory tests, the binder-rich polyethylene-modified HMA mixture was found to be significantly less sensitive to permanent deformation, had greater resistance to fracture, but was very sensitive to the initial level of compaction. The laboratory testing included compressive uniaxial creep compliance testing, uniaxial repeated-load permanent deformation testing, tensile creep testing, tensile strength testing, and resilient modulus tests. Little concluded from these data and other data reported in the literature that binder-rich polyethylene-modified HMA mixtures can perform successfully in certain specialized applications with acceptable resistance to permanent deformation, superior resistance to fracture (reflective cracking and thermal cracking), and superior durability of the low-permeability, asphalt-rich mixture.

4.1.9 United Kingdom Military Airfields (Ellis, et al., 2003)

To evaluate the performance of different "anti-reflection cracking systems," Ellis et al. (2003) reported on the results from different projects carried out at a number of military airfields in the United Kingdom (UK). The first attempt was to use increased HMA overlay thickness for structural strengthening and better thermal insulation of the PCC to reduce thermal movements. This approach considerably increased the project costs, because of other related construction activities in raising the elevation of the pavement's surface.

Alternative techniques were tried in 1989 by six UK military airports for inhibiting reflective cracking in HMA overlays on existing JPCP. These alternative techniques included reinforcement geogrid, SAMIs, modified HMA overlay, alternative overlay materials, crack and seat treatment of the PCC slabs, and HMA inlay over the joints.

The different geogrids used were: HaTelit 40/17 which is a polyester grid of 1.5 in (40mm) square mesh size, Glasgrid 8501 which is a fiberglass grid with 0.5 inch (12.5mm) square grid size and BituforTM system that incorporates Mesh Track MT1, a galvanized hexagonal steel mesh with dimensions 3 by 4.6 in (80 by 118mm) and a series of transverse reinforcing strands, which is bonded to the underlying surface with a specified slurry surfacing. The SAMIs used in the trial at RAF Finningley, Fiberscreed RC 100, is a polymer modified rubberized bituminous compound containing chopped fibers, selected granite aggregate and other fillers. It was applied hot, using a screed box to fill the voids in the cracks and joints and form the membrane in one operation. At RAF Finningley, two different HMA overlay materials were used. One had an additional friction course (FC) surface layer, while the other one had a dense bitumen macadam base course.

The performance of test sections were compared to control areas constructed with conventional Marshall designed HMA overlay, with or without a FC. The performance of all trials that were constructed is summarized in table 3 (Ellis, et al., 2003). From these trial projects Ellis suggested that the use of porous friction course (PFC) as the surfacing material on runway can effectively reduce the occurrence of reflective cracking. Both a Stress SAMI and an SBS modified Marshall designed HMA wearing course overlay applied to a cracked flexible composite pavement can reduce the amount of reflective cracking by about 80 per cent, as well as the severity of cracks. However, the use of both SBR and EVA modified Marshall designed HMA wearing courses did not show significant improvement in inhibiting reflective cracking.

Incorporating a polyester geogrid or a fiberglass grid below 4 inches (100mm) of Marshall-designed HMA overlay exhibited fewer reflective cracks after seven years in service. The geogrid was suggested to be installed on an HMA regulating layer rather than directly on a milled surface under an HMA overlay. The crack and seat technique provided successful experience to JPCP with cracked size between 10 x 10 ft and 10 x 20 ft (3 x 3m and 6 x 6m). Control sections showed that smaller bay sizes (10 x 10 ft) gave a significantly lower risk of reflective cracking when overlaid. One of the most important recommendations made by Ellis et al., however, was to use detailed visual inspection, core sampling and GPR to make correct decisions and select treatments for preventing and mitigating reflective cracks in airfield pavements.

Table 3. In-Service Performance of Anti-Reflection Cracking Trials on UK Military Airfields (Ellis et al. 2002)

Technique	Location	Performance Summary
Crack and seat	RAF Coningsby	No reflection cracks in test or control sections after 6 years.
	RAF Lyneham	Taxiways, 4 years since maintenance, no reflection cracks to date.
Geogrid	RAF Northolt	Glasgrid installed below 100mm new Marshall asphalt base course and wearing course – needs to be laid on smooth surface, significant cracking after 7 years (20-30%). The length of transverse cracking per linear meter of taxiway is the same as the control.
	RAF Northolt	Mesh Track installed between concrete and 70mm Marshall asphalt overlay, severe cracking within 6 months, not recommended. A complete bay pattern above large slabs, fewer above 3m x 3m slabs.
	RAF Brize Norton	Glasgrid and HaTelit installed, after 7 years test sections showing fewer cracks than associated controls.
Geogrid	RAF Finningley	Fibrescreed on top of new base course performing not better than the associated control section, though there is no detailed information available to confirm that the Fibrescreed was correctly installed. Fibrescreed joint repair under the centre-line and SBS modified Marshall asphalt work – significantly less cracks than control.
Friction course	RAF Finningley	Friction course on Marshall asphalt on DBM base course – slightly delays cracking compared to control. Friction course prior to regulating gives significantly better results than the control.
Asphalt inlay over joints	RAF Marham	After 5 years cracking at trench edges: full with slurry seal and partial with the thin wearing courses.
Modified asphalt	RAF Brize Norton	Brize Norton – Marshall asphalt wearing course incorporating SBR and EVA modifier, after 7 years, modified asphalt same as control, with reflection cracks.

4.1.10 Pavement Evaluation & Rehabilitation Design and Pavement Monitoring Studies, (Von Quintus, 1982-1990)

Pavement evaluation and rehabilitation design studies were completed by Brent Rauhut Engineering, Inc. (BRE) for numerous airfields in the southwest (Texas and Arizona) from 1982 to 1990. These rehabilitation design studies included repair recommendations and monitoring the performance of those repairs. Most of these projects were mentioned and discussed in Chapter 3 for a review of selected products and processes. The following simply summarizes the findings from these design studies and construction experiences.

- Welded Wire Fabric used as reinforcement in HMA overlay. This treatment method was used on Runway 4R-22L at San Antonio International Airport in the 1960's and provided good performance for over 20 years. Although it did not prevent reflective cracks from occurring, this method did keep the cracks tight preventing deterioration around the edges of the cracks. The success of this method was attributed to the use of quality aggregates and HMA mixtures, good construction or low air voids, and a mild climate where salt and other de-icing chemicals are not used.
- Chip Seals Placed Prior to the HMA Overlay. This treatment method was used on runways and taxiways at different Naval Air Station airfields in south Texas which exhibited extensive and high severity block cracking. The chip seals were placed by local contractors experienced in constructing chip seals. The airfields where this method was used have relatively low aircraft traffic volumes and are mainly used for pilot training. The treatment method provided good performance with minimal reflective cracks occurring within 10 years. The existing pavements, however, were found to have adequate structural strength for the training operations and mild climate.
- SAMI Placed Prior to HMA Overlay on a Pavement with Adequate Strength. This treatment method was used at Sky Harbor International Airport and provided excellent performance for over 10 years. Based on a pavement evaluation study, the amount of cracking and deflections were significantly less than the amount of cracking and deflections measured on a parallel runway that was overlaid at the same time but without a SAMI, as compared the runway that received the SAMI layer.
- SAMI Placed Prior to HMA Overlay on a Pavement with Inadequate Strength. A SAMI and 1.5-inch (38 mm) HMA overlay were placed on the taxiways and apron areas at the Addison Airport near Dallas, Texas in 1983. The existing pavement structure had areas of extensive fatigue cracking and depressions (inadequate foundation strength). The SAMI and thin overlay exhibited fatigue cracking within 2 years in all areas of fatigue cracking and localized depressions.
- FDR of Flexible Pavements. This treatment method was used on multiple GA airfields (Killeen Municipal Airport, Tyler Municipal Airport, McKinney Municipal Airport, etc.) and different Naval Air Station airfields in south Texas. The airside pavements where this method was used exhibited extensive load-related cracks. The performance of this method was found to be excellent with minimal distress for 15+ years.

4.2 Highway Projects and Comparative Studies

4.2.1 Oregon DOT

Reflective cracking due to shrinkage and brittleness in HMA pavements had been a big concern over the years for the Oregon DOT. It can seriously degrade an HMA overlay before it is near its design life. Geosynthetics have been used in some projects to minimize the tension transferred to the overlay from the existing pavement to impede the reflection of existing transverse cracks to the overlay.

In one project located on US Highway 97 between mile points 213.58 and 217.64, the Oregon DOT installed a test section consisting of 120 transverse cracks treated with five different geosynthetic types, 22 transverse cracks treated with crack filling only and a control section of 20 untreated transverse cracks. Both the test and control sections were constructed over an open-graded HMA pavement. The overlay was also an open-graded mix. The geosynthetics were found to be beneficial in reducing reflective cracks by introducing an interlayer within the overlay to dampen the tensile stress, relieving strain, and providing tensile reinforcement to the HMA. No significant difference was reported between the different geosynthetics.

4.2.2 Texas DOT

The Texas DOT started using chip seals to serve as a SAMI prior to overlaying existing HMA pavements in the mid-1970s. After about 2 years of service, the Department began to observe a higher percentage of premature failures. The reason for these premature failures was attributed to the SAMI trapping moisture in the existing HMA layer (high air voids), which was susceptible to stripping or moisture damage. Intact cores of the existing HMA layer could not be recovered because most of the asphalt binder had been stripped from the aggregate. Thus, the premature failures were not attributed directly to the SAMI. One beneficial result from these premature failures was that the Department recognized the importance of detailed pavement evaluations for rehabilitation design and identifying existing moisture sensitive mixtures prior to overlay.

Several projects were also conducted in the Texas DOT from 1979 to 1981 to evaluate the performance of different geotextiles in overlays (Button 1990). The properties of these geotextiles were summarized by Button (1990), and are presented in table 4. Based on the continued monitoring of these projects for 9 years, Button (1990) concluded that the geotextile may significantly retard the reflective cracking, particularly in the first three to four years. Premature failure, however, was possible when used in thin overlays (less than 1.5 in [38 mm] thick) placed over geotextiles on high volume roads. Asphalt imbedded geotextiles remained intact even after moderate cracking, which can reduce the flow of surface water into the base and reduce pumping.

Texas Transportation Institute (TTI) researchers in cooperation with Texas DOT and construction contractors installed multiple end-to-end geosynthetic test pavements in three different climatic regions (Button and Chowdhury, 2006). The products evaluated were selected to represent the three major categories of geosynthetics (fabrics, grids, and composites) that are often used to address reflective cracking.

The three test locations selected in coordination with Texas DOT were the Pharr District (McAllen), the Waco District (Marlin), and the Amarillo District (northeast of Amarillo). These regions provide mild, moderate, and cool climates, respectively, relative to Texas for the long-term evaluation. Pharr and Amarillo provided flexible pavements while Waco provided a rigid pavement. Table 5 presents a summary of the three test pavements, and figures 11 to 13 show the plan views of each test section and project.

Table 4. Physical Description of Geotextiles Used in Texas Study (Button, 1990)

Geotextile Type	Nominal Weight (oz/sq yd)	Nominal thickness (mils)	Material	Construction type	Filament type	Fiber bonding
Bidim C-22	4	60	Polyester	Nonwoven	Continuous	Needle Punched (N. P.)
Bidim C-34	8	90	Polyester	Nonwoven	Continuous	N. P.
Old Petromat	4	-	Polypropylene	Nonwoven	Staple	N. P. & Heat bonded 2 side
New Petromat	4	-	Polypropylene	Nonwoven	Staple	N. P. & Heat bonded 1 side
Petromat 8 oz	8	-	Polypropylene	Nonwoven	Staple	N. P. & Heat bonded 1 side
Bidim C-28	6	75	Polyester	Nonwoven	Continuous	N. P.
Reepav 3 oz	3	15	Polyester	Nonwoven	Continuous	Spun-bonded & heat bonded
Reepav 4 oz	4	17	Polyester	Nonwoven	Continuous	Spun-bonded & heat bonded
Crown Zellerbach	5	60	Polypropylene	Nonwoven	Continuous	Spun-bonded & N. P.
Mirafi 900 X	5	-	Polyester/Poly propylene	Woven	Continuous	Woven

Table 5. Summary of Test Pavements (Button and Chowdhury, 2006)

District	Highway Name	Pavement Type	Average Daily Temperature Range (°F)	Annual Rainfall / Precipitation (inch)	Traffic (2005)	
					AADT	ESAL
Amarillo	SH 136	Flexible	23 – 92	18	4000	1933
Pharr	FM 1926	Flexible	48 – 96	24.0	27500	1279
Waco	BU 6	Flexible over Jointed concrete	34 - 97	36.0	3100	791

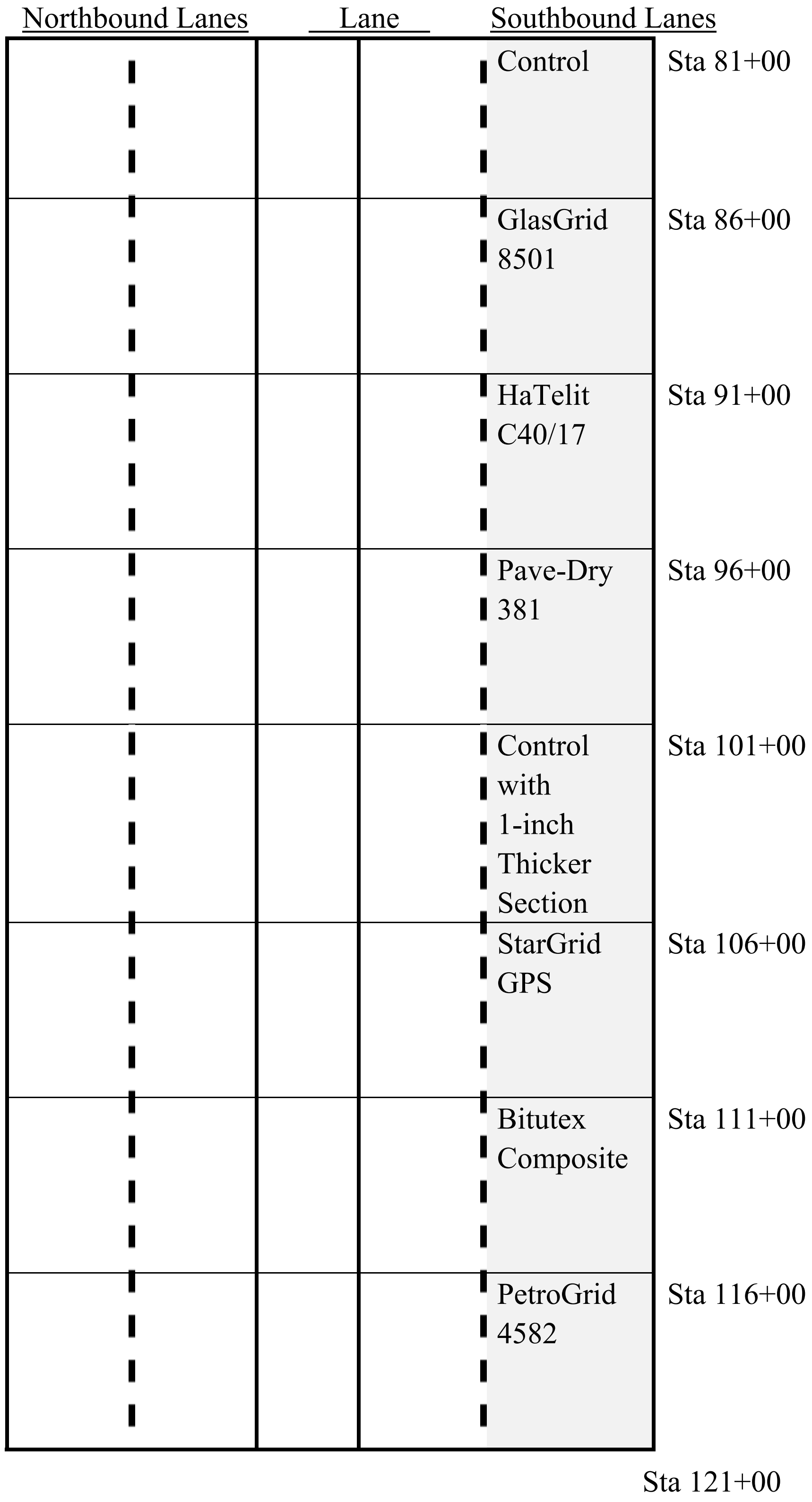
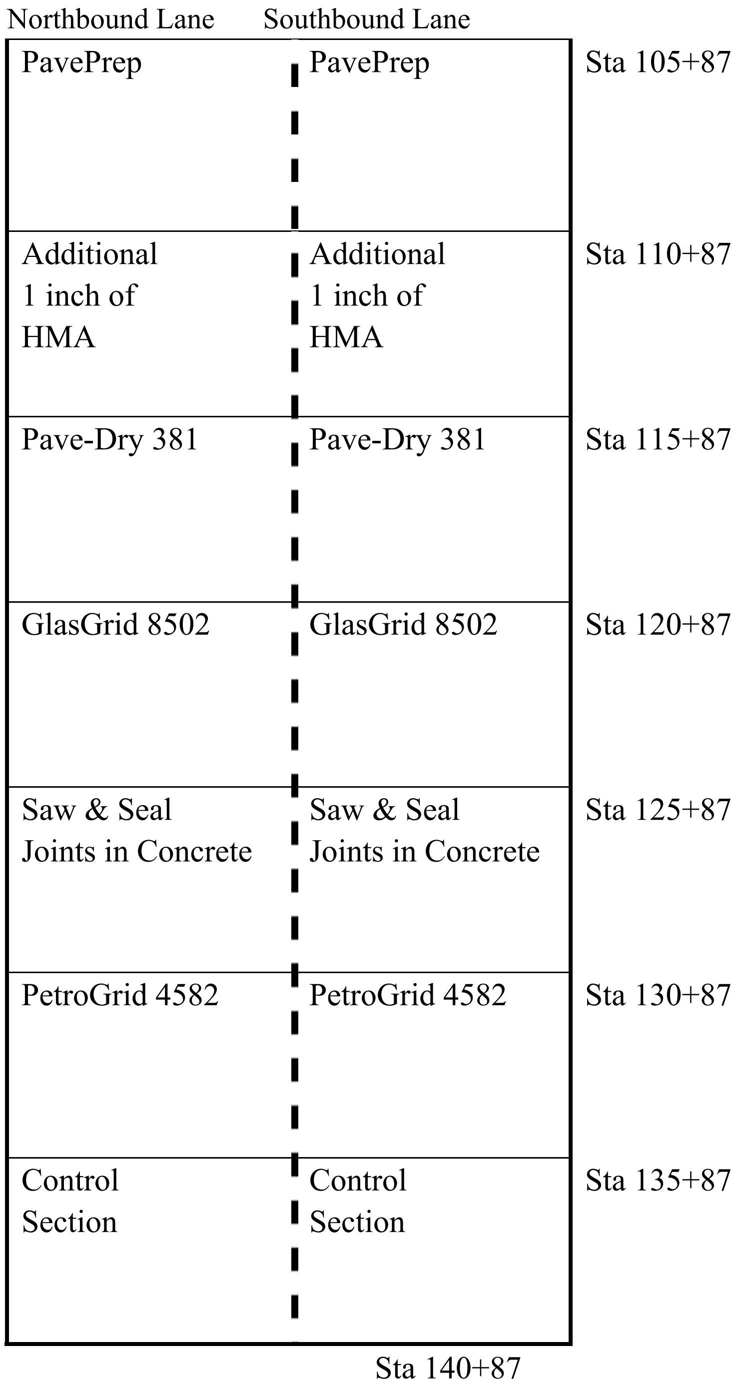


Figure 11. Plan View of Test Pavements Placed in McAllen — Pharr District



Northbound Lane	Southbound Lane	
PavePrep	PavePrep	Sta 105+87
Additional 1 inch of HMA	Additional 1 inch of HMA	Sta 110+87
Pave-Dry 381	Pave-Dry 381	Sta 115+87
GlasGrid 8502	GlasGrid 8502	Sta 120+87
Saw & Seal Joints in Concrete	Saw & Seal Joints in Concrete	Sta 125+87
PetroGrid 4582	PetroGrid 4582	Sta 130+87
Control Section	Control Section	Sta 135+87
		Sta 140+87

Figure 12. Plan View of Test Pavements Placed in Marlin – Waco District

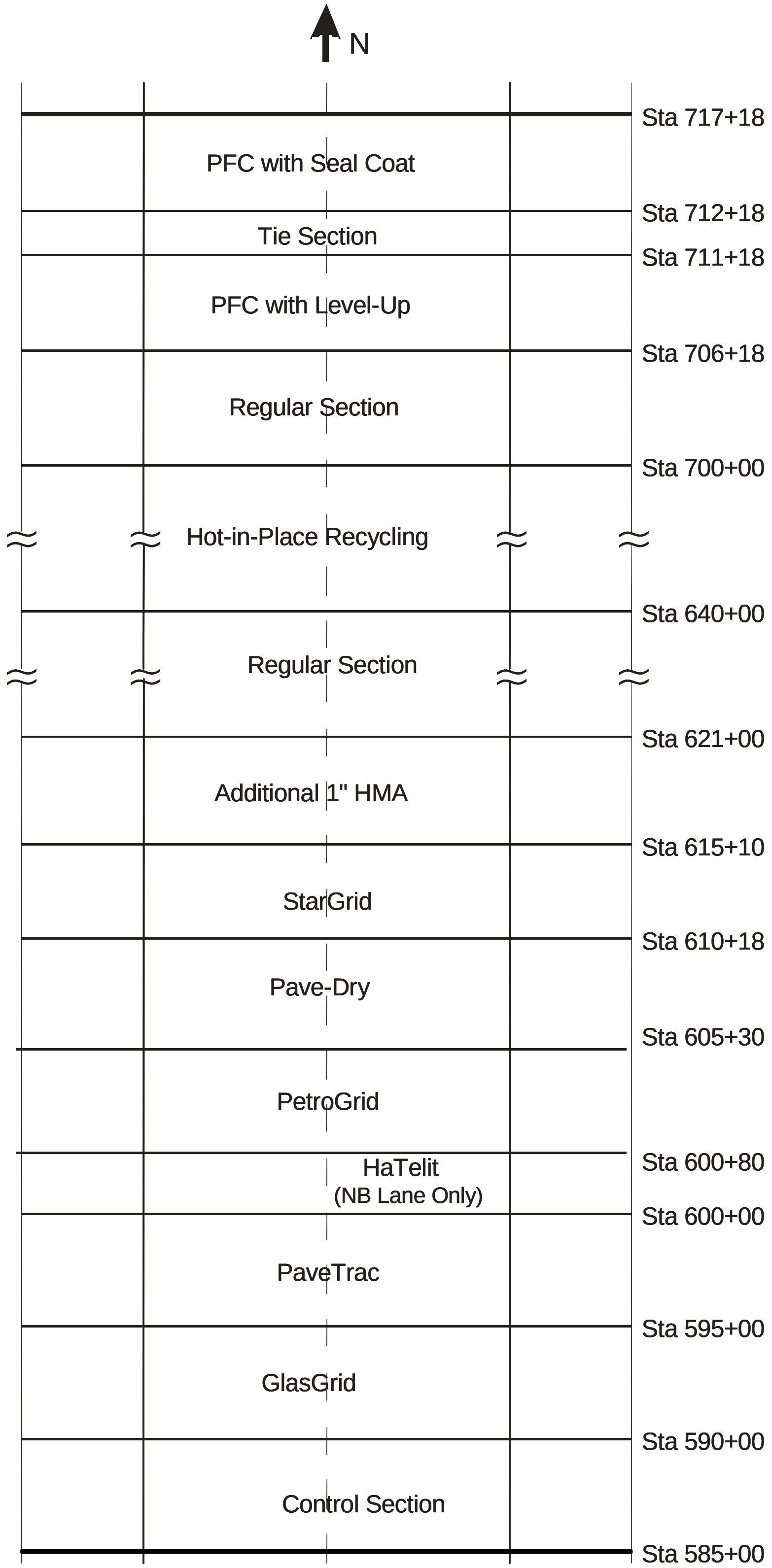


Figure 13. Plan View of Test Pavement Placed in Amarillo—Amarillo District

TTI Researchers evaluated these test pavements each spring since 2001, because most cracks appear during cooler weather. After three to four years (depending on the date of construction), the oldest project (Pharr District) exhibited minimal to no cracking, while the Amarillo District project only had a small percentage of reflective cracking. The Waco District project, however, exhibited significant amount of reflective cracks. The Waco project had the lower traffic level and was in the mild climate category (refer to table 5). The reason for the much higher amount of reflective cracks was attributed to the existing JPCP.

Cost of selected geosynthetic materials and their installation were also discussed by Button and Chowdhury (2006). Based on first cost alone, installation of an inexpensive fabric must increase the service life of an overlay by more than 15 percent to be cost effective. On a similar basis and, of course, depending on the actual geosynthetic product and installation cost, a more expensive grid or composite material may need to double the service life of an overlay to be cost effective.

4.2.3 New Mexico DOT (Lorenz, 1987)

Different interlayer products were tried by New Mexico including Mirafi 140, Petromat, asphalt-rubberized membranes, and the Arkansas crack relief mix. Each is described below.

- Mirafi 140 is a non-woven geotextile uniquely constructed from two types of continuous filament fibers which includes homo-filament polypropylene and hetro-filament polypropylene covered with a nylon sheath. During the manufacturing process the hetro-filaments were heat bonded or fused together at their intersections.
- Petromat is a non woven geotextile manufactured by Philips Fibers Corps. A needle punching process is used to make polypropylene geotextile with low strain properties.
- Two types of SAMIs were used. Sahuaro SAMI is a blend of 25 percent vulcanized granulated rubber and 75 percent 120 to 150 penetration asphalt cement prepared at 350 °F (177 °C). This blend was diluted with Kerosene at 5.5 to 7.5 percent by volume and was applied at the rate of 0.6 percent gal/sq. yd. followed by chips at an average rate of 38 lbs/sq yd. Arizona SAMI was produced by an Arizona Refining Company. Twenty percent replasticized-rubber was blended with 2 percent extender oil, and 78 percent of 85 to 100 penetration reclaimed asphalt cement and was heated at 410 °F (210 °C). The blend is applied at the rate of 0.63 gal/sq. yd. and chips are spread over the membrane at an average rate of 38 lbs/sq. yd.
- Arkansas Mix, a specially designed open-graded HMA material with a coarse-graded aggregate less than 2 in (50 mm) size and 3 percent AC-20 asphalt, was applied as an interlayer to reduce reflective cracking.

The effect of the various treatments were continuously monitored and evaluated. As summarized by Lorenz (1987), a thicker overlay may reduce reflective cracking but it would not be as cost effective as the geotextile or rubberized asphalt membrane. Petromat gave the best performance among all other geotextiles tested. The effect of Arizona SAMI and Sahuaro SAMI was comparable to that of Petromat. It was concluded from the study that the interlayer did not prevent reflective cracks, but does retard reflective cracks and that delay reduces maintenance costs.

4.2.4 California DOT

California conducted a study on 29 flexible pavement sections using a geotextile interlayer with an HMA overlay. The overlay thickness varied from 0.7 to 4.2 in (18 to 107 mm). A rubber-asphalt interlayer was also used on some of the pavement sections. The long term performance of these overlays (up to 13 years) was evaluated, and the results were reported by Predoehl (1989), which are summarized in tables 6 and 7.

Table 6. Performance of Overlays with Geotextiles in California (Predoehl, 1989)

Overlay Thickness (inches)	Average Years to Cracking:			
	Initial Cracking		Significant Cracking	
	Control	Geotextile	Control	Geotextile
2.5	1	3	1	5
3.0	6.3	7	7.3	7.2*
3.5	2.5	5.5	5	8.1*
4.0	9.5	9	10*	9.2*
5.0	7*	8.1*	7*	8.4*
5.5	8.8*	8.6*	8.8*	8.8*
6.0	7*	8.5*	7*	8.5*

*1.5-inch surface course of open graded HMA added.

Table 7. Average of the Results for Geotextiles in California (Predoehl, 1989)

Type of Treatment	Average Thickness, inches	No of Sections	Average Years to Cracking:		
			Initial Cracking	Moderate Cracking	Significant Cracking
Control	2.9	29	5.8	7.2	8.5
Geotextile	2.2	30	6.4	7.8	9.4

As summarized by tables 6 and 7, different results were achieved when geotextiles were used. Some were moderately successful while others showed poorer performance than the control pavements. In total, approximately 60 percent of the geotextiles used in California for controlling reflective cracking were successful. Predoehl (1989) suggested possible reasons for the diversity in results and limited benefit as: the different type and extent of existing pavement distress including the crack width; amount of pre-overlay repairs carried out on the old pavement such as crack sealing/filling, pot hole repair, replacement of rocking slabs, etc.; designed overlay thickness; variability in strength/material properties of the PCC slab; and temperature variability and other climate influences or factors.

4.2.5 Belgium (Vanelstraete and Francken; 1996, 2000)

From 1989 to1995, different interlayer systems including non-woven geotextiles impregnated with modified bitumen, geogrids and steel reinforcing netting were used at different sites in Belgium to prevent reflective cracking. Six of these projects were carefully evaluated and the effect of each treatment was monitored and summarized by Vanelstraete and Francken (1996, 2000), as summarized in table 8. Based on the observations and field investigation, Vanelstraete and Francken (1996, 2000) concluded that:

Table 8. Summary Results of the Sites and Inspections (Vanelstraete and Francken 2000)

Project Year repair	Crack and seat	Type of interlayer	Overlay	Equivalent reflected cracking				
				‘94	‘95	‘96	‘97	’98 and ‘99
Tournai 1989	No	Steel reinforcement netting, nailed	8cm dense mix + surface dressing	1%	-	-	1%	1%
N415 1991	No	Steel reinforcement netting, nailed	10 cm dense + 4cm porous mix	No	-	-	4%	11%
N499 1991	No	Steel reinforcement netting, in slurry (elastomer), 24-26kg/m^2	4 cm porous mix	7%	25%	46%	66%	77%
Aalter 1992	Yes	Steel reinforcement netting, in slurry, 24-26kg/m^2	9 cm dense mix	No	0.1%	-	1%	1%
Genappe 1993	No	Nonwoven polyester, 1.5kg/m^2 modified binder	4 cm ultrathin layer	-	17%	-	45%	55%
Berlare 1995	Partly*	Steel reinforcement netting, in slurry* (elastomer) 17kg/m^2 no interface	4 cm SMA	No	No	No	No	-

*There are six sections. Refer to reference (Vanelstraete and Francken 1996, 2000) for detailed information.

- The thickness of overlay is an important factor even with the use of an interlayer system. The highest percentage of reflective cracks was observed in a pavement with 1.5 in (4 cm) thick overlay on PCC slabs, whereas no reflective cracking appeared on a 5.5 in (14 cm) thick overlay.
- The vertical movements at the crack edges of the PCC should be limited by using the crack and seat method before placing the overlay system.
- Cavities under the interlayer product should be avoided. The existence of voids may result in inadequate compacted spots and potholes shortly after rehabilitation. Interlayer systems may not be placed on unstable or moving (parts of) under layers.
- When all the rules mentioned above have been respected, the projects with steel reinforcement nettings presented excellent performance, even 10+ years after repair.
- From the six projects evaluated, steel reinforcement netting used in the overlay combined with the crack and seat method were effective in mitigating reflective cracks.

4.2.6 Long-Term Pavement Performance Test Sections

The Long Term Pavement Performance (LTPP) program includes segments of roadways across North America that have been monitored since 1989. The program includes both new and rehabilitated test sections. The LTPP database includes detailed measurements of cracking (condition survey data) on each test section with time. Some of the rehabilitation projects do include a variety of reflective cracking mitigation strategies.

The more common reflective cracking mitigation strategy included within these experiments for HMA overlays of flexible pavements includes the use of HMA mixture/layer modification, geosynthetics (fabrics; geogrids are not included), and SAMIs, while crack and seat and rubblization are the more common methods for existing rigid pavements. The experiments in the LTPP program that are related to reflective cracking include:

- GPS-6B—HMA Overlay on HMA Pavement; detailed distress surveys available prior to overlay placement.
- GPS-6C—HMA Overlay with HMA mixture/layer modification on HMA Pavement, without Milling.
- GPS-6S—HMA Overlay on HMA Pavement with Milling and/or Fabric Pretreatment.
- GPS-7C—HMA Overlay with HMA mixture/layer modification on PCC Pavement, with CPR or No Pretreatment.
- GPS-7F—HMA Overlay on PCC Pavements, with Slab Fracture Pretreatment.
- SPS-5—Rehabilitation of Flexible Pavements with HMA Overlays: with and without Recycled Asphalt Pavement (RAP) in the mixture and with and without milling. No reflective cracking mitigation strategies are included in the core experiment; HMA mixture/layer modification is included in some of the supplemental test sections.
- SPS-6—Rehabilitation of Rigid Pavements: some test sections include HMA overlays of intact, crack and seat, and rubblized PCC slabs.

The LTPP HMA overlay test sections that have data are shown in table 9. Some of these test sections have extensive cracking, while others have exhibited no cracking. The test sections included in the program, however, were not selected to specifically study the effects of different mitigation strategies. The difficulty in using these test sections for detailed analyses is that the cracking is reported as transverse, longitudinal, edge, block, and fatigue. It is difficult to accurately determine whether all or only some of the cracks are reflective, or were caused by delamination or debonding between HMA layers, thermal cycling or low temperatures, and/or load related surface-initiated cracking mechanisms, with the exception of the HMA overlays of PCC pavements. Forensic investigations of these test sections were not included as part of the LTPP database and program.

Table 9. HMA Overlay Test Sections Included in the LTPP Program with Reflective Cracking Mitigation Strategies, as Defined in Chapter 2

Category	Description	Total Test Sections	No. of Test Sections at Each Climatic Zone			
			WF	DF	WNF	DNF
HMA/Overlay	HMA, then HMA overlay	110	59	16	33	0
HMA/Mill/Overlay	HMA, then Mill+HMA Overlay	133	109	---	---	---
CRCP/Overlay	CRCP, then HMA Overlay	26	21	---	---	---
JPCP/Overlay + JRCP/Overlay	JRCP, then HMA Overlay	55	54	---	---	---
Total Sections that Include the Use of Reflective Cracking Mitigation Strategies		19	15	16	33	0

As an example, the Texas SPS-5 project did not exhibit any cracking prior to overlay or rehabilitation. After 8 years of performance, the test sections with HMA overlays exhibit significant amounts of fatigue, transverse, longitudinal, and edge cracks. Forensic investigations of these test sections were not included as part of the LTPP database and program. Thus, whether these cracks are reflective cracks or were caused by other mechanisms is unknown.

4.2.7 New York City Experimental Test Sections

Several crack control treatments were investigated by Mallela and Von Quintus (2004) as part of an experimental study to determine cost-effective materials and methods to minimize reflective cracks in composite pavements in New York City. The as-constructed experimental plan included the following variables:

- PCC base joint spacing (two levels – 15 and 20 feet [4.6 and 6 m]).

- Saw and seal.
- Petrotac fabric (two levels differentiated by placement).
- Paveprep fabric.
- ISAC fabric.
- Glasgrid (two levels).

Control sections without any treatments were also built for each of the two different PCC base joint spacing as baseline references. Evaluations, in the form of ten visual condition surveys and five FWD surveys, were conducted over 60 months to monitor the performance of these sections. Performance was measured in terms of crack initiation, crack length, and crack severity, as well as load transfer deterioration across reflective cracks. The time history of reflective crack development as a percentage of total joint length is shown in figures 14 and 15 for the 20-ft (6 m) sections 15-ft (4.6 m) sections, respectively.

In summary, the saw and seal crack control strategy is providing the better performance. None of the geogrids or geosynthetics significantly reduced the amount of reflective cracks. The most surprising observation from this experiment was that a significantly lower percentage of reflective cracking was exhibited for nearly all treatment methods for the 20-ft (6 m) test sections rather than the 15-ft (4.6 m) test sections.

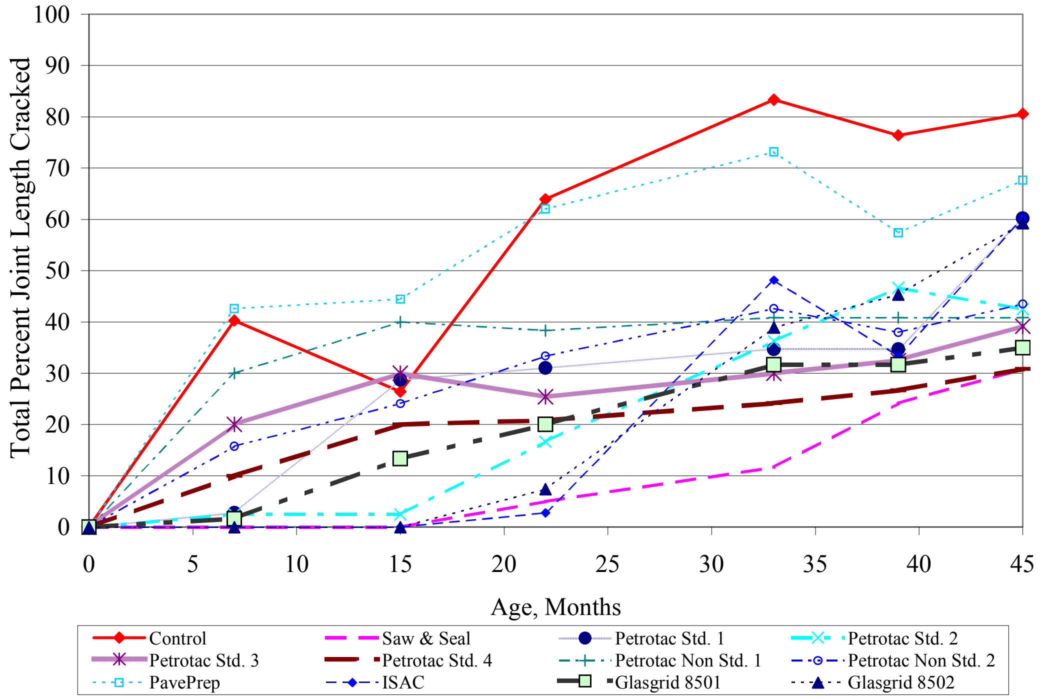


Figure 14. Time History of Reflection Crack Development as a Percentage of Total Joint Length for the 20-ft Sections (Joint Series 1-12); after Mallela and Von Quintus, 2004

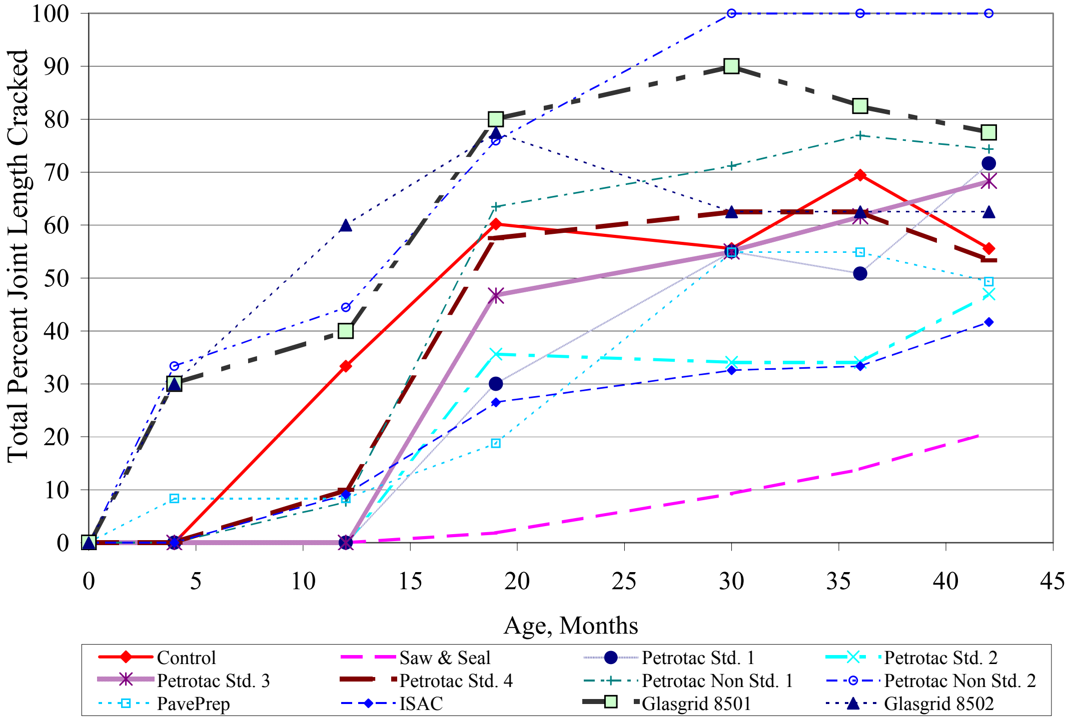


Figure 15. Time History of Reflection Crack Development as a Percentage of Total Joint Length for the 15-ft Sections (Joint Series 1-12); after Mallela and Von Quintus, 2004

4.3 Summary of Comparative Studies

Based on the comprehensive review of the different reflective cracking mitigation strategies applied by various airport and highway projects under different conditions, the following summary was obtained:

- No pavement rehabilitation technique has been shown to prevent reflective cracking, with the exception of rubblizing PCC pavements and full-depth reclamation for flexible pavements. However, several techniques have demonstrated the ability to reduce reflective cracking when designed and constructed properly. The performance and effectiveness of all reflective cracking mitigation strategies is heavily dependent on construction quality (good compaction—low air voids), good workmanship, and use of HMA mixtures for the overlay that are not susceptible to moisture damage.

- Climate, structural condition of the existing pavement and overlay thickness are the three parameters that have the greatest effect relative to mitigating reflective cracks.

- A major element for selecting, designing, and constructing a rehabilitation strategy is adequately determining the structural condition of the existing pavement and other site condition features to determine the reflective cracking mechanisms that must be addressed.

- The climatic conditions, especially the temperature conditions (such as freeze-thaw cycles and extremely cold weather conditions) have significant effect on the performance of different interlayer products (such as geotextile and asphalt rubber SAMI products) for controlling reflective cracking (Amini, 2005). The freeze-thaw cycles in severe cold climates can cause contraction and expansion of water within the pavement, which accelerates the damage from water filtration.

- One reason for the poor performance of some of the thinner reflective cracking mitigation methods is that the HMA overlay was too thin for the aircraft traffic, climate, and on-site conditions.

- Poor load transfer and voids beneath a crack or joint in the old PCC pavement will allow traffic loads to accelerate the rate of reflective cracking. Joints and cracks with load transfer efficiencies greater than 80 percent have the higher success rates in retarding reflective cracking.

- All reflective cracking retarding products or processes will perform better in warm and mild climates than in the hard-freeze or freeze-thaw cycling climates.

- Fabrics will perform best when used over old HMA pavements with closely spaced random or alligator cracks (not caused by base or subgrade failures) with crack widths less than 1/8 in (3 mm). Fabrics do not perform well when placed on old PCC pavement joints/cracks or over wide (greater than 3/8 in [9.5 mm]) transverse or shrinkage cracks in old HMA pavements.

- Fabrics and SAMIs that act as moisture barriers prevent rising water and vapor from the base or subgrade that can cause additional distress in the pavement layers. These materials also prevent water infiltration into the underlying pavement, as fatigue and thermal cracks begin to initiate within the overlay wearing surface.

- Steel reinforcement and geogrids have been effective in reducing reflective cracks from existing HMA layers. These materials are less effective when the overlay is placed over jointed concrete pavements, but definitely keeps the cracks narrower as they occur. A grid or strip reinforcing product must have a higher modulus than the HMA mixture surrounding it, if it is to reinforce the overlay. These products are effective in reinforcing the overlay against horizontal thermally induced movements but not against the traffic-induced bending and shearing movements.

- Widely spaced cracks or joints, which are characteristic of old PCC pavements, will have large thermal movements and may be addressed with a strip product or grid placed between a leveling course and the surface course of the overlay. If they are placed directly on the base material, they may not provide the desired benefit.

- SAMI layers, which work on the principal of isolating the horizontal movement of the base pavement from the overlay, have been successfully employed to reduce the rate of reflective cracking when the crack spacing and crack widths are smaller. It has been found that eventually the crack will work through, even with the more compliant SAMI materials.

- Thick crack relief layers consisting of large-stone, open-graded, asphalt-stabilized layers (defined as cushion courses within this report), which also work on the base isolation principle, have not performed as expected in some cases. The stones simply do not act as “ball bearings,” as was originally anticipated. Instead, their interparticle friction eventually transmitted horizontal movements of the base pavement into the overlay.

- Saw and seal of the HMA overlay to match the joints in the old PCC pavements has met with great success in many places. Several highway agencies have used it as a preferred rehabilitation method. However, in some instances “tenting” of the sealant has been a problem or concern. This concern has resulted in a cautious use of this technique on high-speed facilities such as interstate highways or airport runways and parallel taxiways.

- Of the fracturing techniques used to destroy the slab action of base PCC pavement, the state-of-the-practice is slowly moving towards rubblization because it has been shown to be most effective. ARA (Von Quintus, et al., 2007) completed a rubblization study under the Wisconsin Highway Research Program (WHRP) and found that the rubblization process was successful in eliminating the occurrence of reflective cracks after the Department increased the minimum HMA overlay thickness for constructability reasons. Also, Change Number 4 to FAA AC 150/5320-6 has switched the preferred fracturing technique for old PCC pavements that are in very poor condition from crack-and-seat to rubblization (FAA, 2006).

CHAPTER 5—AIRPORT PROJECT REVIEWS AND SITE VISITS

Field site visits were conducted on a number of airfield pavements to investigate the performance of different mitigation strategies and methods. The purpose of Chapter 5 is to present the preliminary investigation and process to determine the candidate airfields to visit and to summarize the results from the site visits.

5.1 Identification and Preliminary Investigation of Airfields

The data gathered from a review of the literature was the first step in identifying civilian (commercial and GA) and military airports in the U.S. that have used multiple reflective crack mitigation strategies for existing flexible and rigid pavements. Chapters 3 and 4 provided a summary of some of the airfields where different products and processes have been used to mitigate reflective cracks.

The second step for selecting potential airfields for the site visits was to contact appropriate airfield personnel that were knowledgeable of the rehabilitation projects. This initial contact via telephone revealed that a number of airports had some experience with applying different types of reflective crack control treatments. Those airports where multiple treatments had been used were considered a high priority for the site visits.

Design and construction data were initially requested and reviewed for each project, where available, to select projects for the more detailed evaluation and site visits. Those airports for which design and construction information was unavailable were not considered a high priority for the site visits. The specific data items that were obtained as part of this initial contact included:

- Reflective cracking observations over time (both in length or amount and severity)—This data element was considered mandatory, but was available for only a limited number of projects. Two reasons for this limited number of projects include: detailed data are not maintained over time at the facility, and many of the projects where personnel have sufficient knowledge about the project are relatively new.
- Reflective cracking mitigation strategies deployed and year of HMA overlay placement.
- HMA overlay design (thickness, mixture types, etc.).
- Type of existing pavement and structure (layer thickness, slab dimensions, mixture types, base type, etc.).
- Pavement condition evaluation reports prior to overlay (types and extents of cracking prior to overlay, differential vertical displacements across joints and cracks, etc.)—Pavement condition index (PCI) values were available for many of the airfields,

but detailed condition surveys were limited. The amount of reflective cracks was based on day-to-day observations of airfield personnel knowledgeable of the facility.

- Subgrade type.
- Airfield climate or general location (city and state).
- Airfield and facility usage type (i.e., apron, runway, taxiway).

This initial search included more than 85 airports/projects from 17 states in the United States, representing diverse climate zones, as shown in figure 16. Both civilian (commercial and GA) and military airports were covered. Some of the airports included in Chapters 3 and 4 are not included in figure 16, because access to those facilities was unavailable for the detailed site visits.

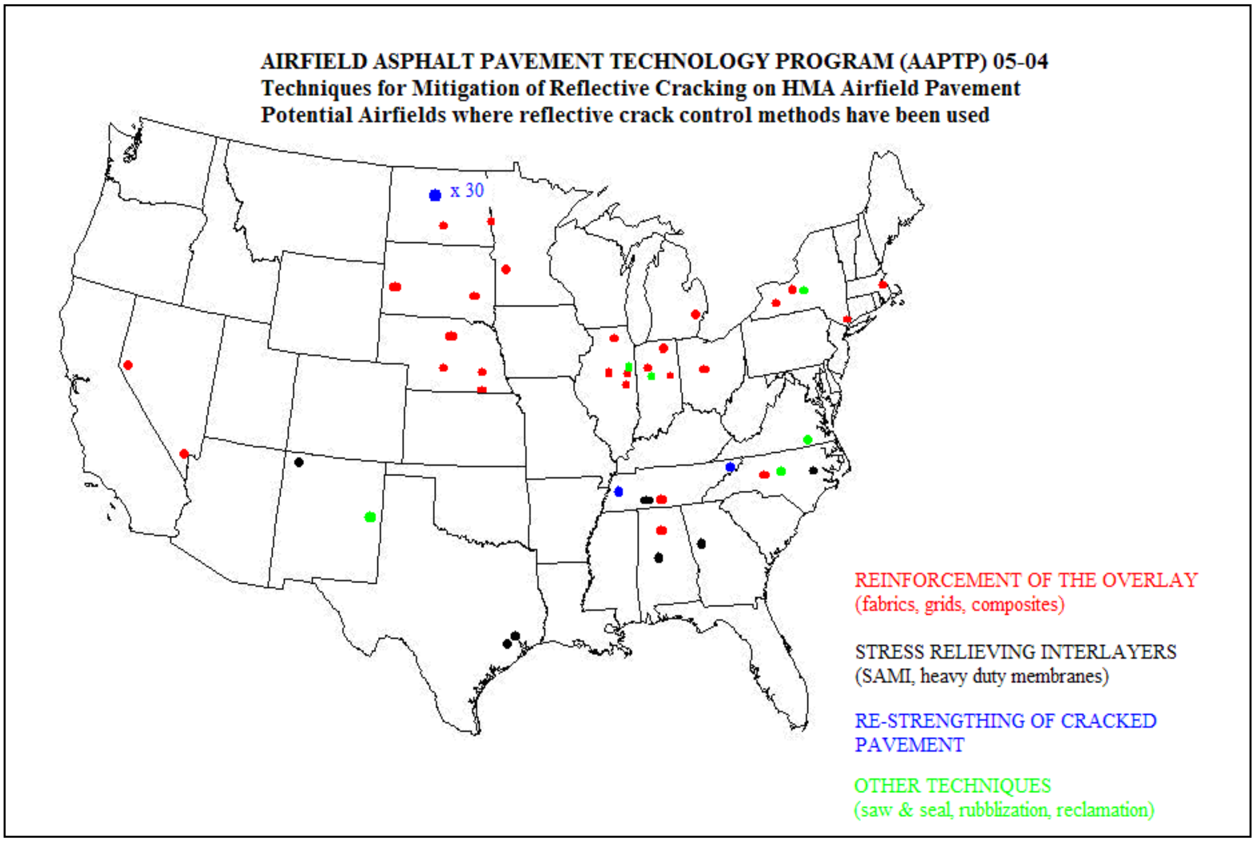


Figure 16. Airfields where Reflective Crack Control Methods have been Used

As shown in figure 16, there are large geographical areas where reflective cracking mitigation strategies have not been used or sufficiently documented. Based on the climate zones shown in figure 10, however, a sufficient number of airfields are located within each of the three climate zones recommended for use by Ahlrich (1986).

The projects shown in figure 16 include most of the treatment categories listed in Chapters 2 and 3 of this report, as well as a variety of design, construction, and site factors for both rigid and flexible pavements. The following provides a summary of the distribution of locations between climate and reflective cracking mitigation strategy.

Percent of Projects Within Each Area			
Major Reflective Crack Mitigation Strategy	Climate Zone (refer to figure 10)		
	Area I; Warm Climates	Area II; Mild Climates	Area III; Cold Climates
Crack Control; Saw & Seal	5.1	5.1	0.0
Reinforcement of Overlay; fabrics, grids, composites	8.5	20.3	16.9
Stress Relieving Interlayer (SAMI)	13.6	6.8	0.0
Re-Strengthening of Cracked Pavement	11.9	1.7	3.4
Rubblization, Crack & Seat, Reclamation	1.7	1.7	3.4

As shown, there are combinations of climate and existing pavement type where some mitigation strategies have not been used or their use has been limited based on historical experience. It should also be noted that there are airfields where reflective cracking mitigation strategies have been used but those rehabilitation projects have since been removed and replaced or personnel knowledgeable with them are no longer at the facility. For example; some of the small naval air stations in south Texas, Sky Harbor International Airport, and San Antonio International Airport. The major findings from this initial project selection process are summarized below.

- **Alabama—**Two airfields in Alabama were found to have projects of interest: Huntsville International Airport and Tuscaloosa Municipal Airport.
  - Huntsville International Airport—A small amount of composite, believed to be GeoTac, was placed in 2003 over PCC joints towards the edge of the runway and covered by a 1 inch (25 mm) HMA overlay. No significant distress or reflective cracks have occurred within 3 years of performance.
  - Tuscaloosa Municipal Airport—A single bituminous surface treatment was placed as a bond breaker for both existing rigid and flexible pavements but is more characteristic of a SAMI. The HMA overlay was placed over the surface treatment, which has performed very well in mitigating reflective cracks.

- **Georgia—**At Georgia's LaGrange-Callaway Airport, a single layer of bituminous surface treatment was used as a bond breaker on top the existing flexible pavement. No performance data were reported by or available from the stakeholders interviewed.

- **Illinois—**The Illinois Division of Aeronautics has tried different types of anti-reflective cracking products for their airports. The ones identified are listed below.

  - ISAC was used at Champaign (Willard), Rantoul, and Dekalb airfields in 1999. These ISAC systems were applied on both existing PCC and HMA pavements and covered with HMA overlays. The thickness of the overlay varied between each airfield. Two years after overlay placement, no cracks have been observed and the pavements are performing well.
  - PavePrep fabric was also used at Willard Airport in 1999 as an interlayer between a 2 inch (50 mm) HMA overlay and existing 20 inch (8 cm) PCC pavement. PavePrep is high density mastic laminated with tough woven polyester designed specifically to withstand the loads encountered by highway/airport traffic and stress concentrations at pavement joints and cracks. Good results with no cracks were reported on this project by Willard Airport in 2001.
  - The Peoria Airport rehabilitated a taxiway, which was a flexible pavement with wide environmental transverse cracks (greater than 1-inch [25 mm] in width) spaced approximately 80 ft. apart. Two techniques were used to rehabilitate the taxiway.
    - One technique used in the repair strategy consisted of first milling the top 2 inches of the existing HMA layer over the entire surface. An additional 2 inch deep by 48 inch (1.2 m) wide area was milled at each transverse crack. The milled area over the crack was filled with "bituminous interstabilizing layer" and a 60 inch (1.5 m) wide Glasgrid was installed over this material. After the Glasgrid was installed, a 4.5-inch (11.4 cm) HMA overlay was placed over the entire area. Placing ISAC fabric on the wide transverse cracks prior to the HMA overlay was considered, however, a study conducted by the University of Illinois determined that the distance between cracks was too great for the ISAC fabric to work effectively.
    - A second technique used on this taxiway consisted of placing a 5/8 inch (15.9 mm) PFC directly on the previous surface prior to placing a 4.5 inch HMA overlay.

- **Indiana**—Three airports (Elkhart, Anderson, and Purdue Airport) used PavePrep fabric on their existing flexible pavements to retard reflective cracking.
  - The Elkhart Airport project performed poorly. It was reported that the PavePrep material absorbed lots of moisture and became debonded from the existing HMA pavement and 1 inch overlay. The thin HMA overlay could be one reason why the overlay lost its bond to the underlying layer.
  - On the Anderson Airport project, after placing the fabric, a 4.5 to 6.5 inch HMA overlay was placed. The overlay "looks good," as stated by Mr. Bret Campbell from Butler, Fairman, & Seufert Company.
  - At the Purdue Airport, two different techniques were used to mitigate the reflection of cracks in the existing HMA pavement.

  - PavePrep fabric was placed on the existing pavements of the taxiway connectors. Both good and bad results have been observed. Ken Ross from NGC Corporation suggested that some of the applications may retard reflective cracking by 2 years.
  - CIPR or the pulverization technique was also used at the Purdue Airport for a runway rehabilitation project. The previous 9.5 inch (24 cm) asphalt surface was pulverized, shaped, and compacted to grade. A 4.0 inch (10 cm) HMA overlay was then placed on the pulverized surface. Full-width transverse saw cuts were made at 100 ft (30 m) intervals to allow for horizontal movement in the HMA overlay. Performance of this rehabilitation project has been good. From this experience, Ken Ross suggests that the optimum distance between control joints is 100 to 500 ft (30 to 152 m).

- **Massachusetts**—Boston Logan Airport installed Petrotac fabric to keep water from infiltrating the lower pavement layers. Petrotac consists of Amoco's Petromat®, a needle-punched non-woven polypropylene fabric, coated with asphalt and a rubberized asphalt adhesive. A release sheet, which is removed prior to placement, covers the adhesive. Cracking and other distresses have occurred in different areas of the project. It has been hypothesized that the distress is a result of moisture damage or stripping in the existing HMA layers.

- **Michigan—**In 2002, Selfridge Air National Guard Base Runway 1-19 was rubblized prior to placing a 7 inch (18 cm) HMA overlay. No serious reflective cracks have been recorded and only 2 or 3 isolated areas have slight "speed bumps" in areas where utilities trenches cross under the runway. Overall performance has been good.

- **Minnesota**—Madison Airport had severe transverse cracking on Runway 13-31. Prior to placing a 1.5 to 3.0 in (3.8 to 7.6 cm) HMA overlay in 2004, the Airport milled down 4 in. along the transverse cracks, placed a 2 ft (0.6 m) wide fabric, and filled the milled areas with HMA. Reports indicate that the edges of the milled areas have reflected through the overlay and that it was difficult to achieve the desired density in the milled areas.

- **Nebraska**—Lincoln Airport reported bad experience during construction and poor overlay performance when using PavePrep composite to reduce reflective cracking. The material got caught in the paver during HMA placement on numerous occasions.

- **New Mexico**—In 1998, Cannon AFB used the saw and seal technique for HMA overlays of an existing JPCP pavement. The technique is reported to have performed well. No cracks were observed, with the exception of some small cracks within a few inches of the saw cut in the HMA overlay. The joint seal materials were replaced in 2005.

- **New York**—Ledgedale Airpark runway was overlaid in 2003. The PavePrep fabric was placed as an interlayer. This runway had been widened from an earlier project. The PavePrep fabric was applied to the 3200 ft (1 km) longitudinal joint at the former edge of the runway, as well as along wide transverse cracks. Shawn Brey from Passero mentioned the fabrics performed “OK.”

- **North Carolina**—Different reflective crack mitigation strategies were tried at multiple airfields in North Carolina. The reflective crack mitigation strategies included: fabrics, full-depth reclamation, bond breaker consisting of a single bituminous surface treatment, and double and triple bituminous surface treatments. For very wide cracks, 12 to 18 in (30 to 46 cm) wide fabric strips were used, which resulted in material debonding between the base and upper layers.

  The process of full-depth reclamation involved milling HMA, reclaiming the base and some subgrade soils in place in localized areas. Where the subgrade soils were reclaimed, lime or cement was mixed in place. In general, this rehabilitation strategy of the existing pavements and treated by reclamation performed very well.

  Another technique involved placing a double or triple bituminous surface treatment prior to an HMA overlay. The existing cracks were first sealed. A surface treatment was then applied, followed by a 2 to 3 in. HMA overlay. NCDOT sometimes mills 2 in. of the existing HMA prior to sealing cracks. This technique appeared to have some benefit in reducing reflective cracking, as reported by Department of Aviation personnel.

- **North Dakota**—Different rehabilitation projects of the runways at Mandan Airport compared three types of treatments: PavePrep, Glasgrid, and mill and fill. Airport personnel ranked the performance of each treatment strategy to mitigate reflective cracks as follows: PavePrep is better than Glasgrid, and glasgrid is better than mill & fill with HMA.

  Geogrid and Petromat were also used at Fargo airport (ND). Good performance was reported for both the geogrid and petromat rehabilitation projects.

  North Dakota’s experience of filling the cracks with polypatch has also been reported as being successful. The pavements where this material has been used have exhibited better performance than other pavements treated with PavePrep, Glasgrid, or mill & fill techniques. Polypatch was suggested to be a good material, especially when lots of underlying pavement movement was expected.

- **South Dakota**—Two recent airfield rehabilitation projects in South Dakota used the PavePrep fabric placed on existing flexible pavements. These two airfields included Mitchell Airport and Black Hills Airport.
    - The Mitchell Airport was overlaid in 2006. PavePrep was selected and used because of the width and severity of the existing cracks. A 2 in. HMA overlay was placed over the PavePrep. No reflective cracking after the first year of service.
    - The Black Hills Airport was repaired in 2004. PavPrep was placed over all cracks that were wider ¾ in (19 mm). The existing pavement was milled to a depth of 1.5 in (3.8 cm) over a width of 24 in (0.6 m) along the wider cracks. The PavPrep fabric was installed in the milled areas prior to filling with a traditional HMA mixture. No HMA overlay was placed on the fill or level-up material.

  South Dakota has traditionally placed the HMA overlay in one 2 in (50 mm) lift. They have recently changed that policy to placing two-1.5 in (38 mm) lifts and believe the benefits from this change include fewer reflective cracks and a smoother pavement after construction. Since 1998, South Dakota has also repaired transverse cracks with widths greater than 2 in. (environmental cracks that appear approximately every 80 ft [24 m]) using full-depth repair. This technique involved saw cutting the limits of the repair area, reworking the base material, and then placing the HMA patch material. The repairs have "worked great" according to the State. This repair technique typically does not include an overlay because the pavement is in relatively good condition (only transverse cracks that are environment and are not wheel load associated) or there is a lack of funds.

- **Texas—**A SAMI was installed on George Bush Intercontinental Airport (Houston) Runway 9-27 in 2007. This product consists of a crumb rubber modified asphalt and HMA, and a single surface treatment. This project was recently completed—no performance data are available.

- **Tennessee**—Poor performance was reported at Smyrna Airport when applying fabrics over PCC joints prior to placing a thin HMA overlay in 1993. The design thickness was 1.5 inches, but the thicknesses measured at random locations were reported to be 0.75 to 1 inch (19 to 25 mm). The bond breaker mitigation technique with a single bituminous surface treatment, however, was reported to have worked very well. Records also indicate that sealed cracks with a sand-asphalt mix treatment was utilized by Tri-Cities Regional Airport, Reelfoot Lake Airport, and Nashville International Airport parking lot in 2004, 2006, and 1998, respectively. Performance data from these airfields were unavailable for use on this study.

5.2 Candidate Projects For Site Visits

Key issues or questions were used to identify a shortlist of projects from the larger pool of candidate airfield pavement rehabilitation projects. The questions were established in alignment with the general and specific project objectives presented in Chapter 1 and include:

a. What are the important material and construction considerations for the different reflective cracking control products?
b. Did the mitigation strategies delay reflective cracks, and were they considered successful?
c. How does the existing pavement type affect the selected treatments and their performance?
d. Does structural condition of the existing pavement affect the rate of reflective cracking and their performance for the different treatment categories?
e. Does climate have an effect on the rate of reflection cracking for the different treatment categories?
f. Does the level of aircraft operations have an effect on the rate of reflective cracking for the different treatment categories?

Project selection followed a two-step process. The first step involved grouping the projects on the basis of the data gathered from literature and interviews with key personnel knowledgeable of the rehabilitation projects (discussed under the previous section of this chapter). Table 10 shows the template created to aid in grouping the potential projects based on key factors or variables. Those factors and levels are listed below.

- Climate—3 categories (in accordance with figure 10 to evaluate the success of different methods to mitigate thermally induced reflective cracks; refer to figure 2).
    - Hard freeze climate (northern tier airfields in the U.S.).
    - Freeze-thaw climate (airfields in the mid-western U.S.).
    - Warm climates (airfields in the southern and western U.S.).
- Aircraft loadings—2 categories (based on aircraft weight and number of operations, low volume GA airfields and those with high volume traffic to evaluate the success of different methods to mitigate traffic induced reflection cracks; refer to figure 3).
    - High – Airfield features with larger aircraft and a larger number of operations.
    - Low – Airfield features with lighter aircraft and a small number of operations.
- Treatment type—3 categories (initially selected based on the categories recommended by Button and Lytton, because these are the ones that have been used at a higher frequency).
    - Reinforcement products/processes.
    - Stress-relieving products/processes.
    - Crack control techniques.
- Rehabilitation type—2 levels.

  - ➢ HMA overlays of PCC.
  - ➢ HMA overlays of HMA.
- Reflective cracking—2 levels.
  - ➢ Present or exhibited (the amount of cracking was not included as a primary factor).
  - ➢ Absent, no reflective cracking observed (few projects fell within this category).

Table 10. Analysis Template Used in Identifying and Selecting Airport Projects

Rehabilitation Type	Reflection Crack Control Strategy	Aircraft Loadings	Climate		
			Hard-Freeze	Freeze-Thaw	Warm
HMA/PCC	Reinforcing	Low	1.a	2.a	3.a
		High	1.b	2.b	3.b
	Stress-Relieving	Low	4.a	5.a	6.a
		High	4.b	5.b	6.b
	Crack Control	Low	7.a	8.a	9.a
		High	7.b	8.b	9.b
HMA/HMA	Reinforcing	Low	10.a	11.a	12.a
		High	10.b	11.b	12.b
	Stress-Relieving	Low	13.a	14.a	15.a
		High	13.b	14.b	15.b
	Crack Control	Low	16.a	17.a	18.a
		High	16.b	17.b	18.b

Note: The definitions of "wet" and "freeze" climatic conditions were based on the Federal Highway Administration's (FHWA's) Long-Term Pavement Performance (LTPP) criteria. According to these criteria, a wet climate is defined as one receiving greater than 20 in. (50 cm) of mean annual precipitation and freezing climate is defined as one where the cumulative annual freezing index is greater than 150 °F-days (83 °C-day).

In the second step, projects were selected for detailed investigation, according to the following items.

- Select a reasonable number of projects within each climatic regime, such that at least two treatment types are included for further review per location, if available.
- From the available design and construction data for each project, establish the ranges of the key variables of interest (e.g., cross-section details, material parameters, construction parameters, and climatic variables [e.g., milling and other pre-overlay repairs]).
- For a group of projects exhibiting extensive reflective cracking with identical rehabilitation type and reflective crack control strategy, select two or more companion sections to enable an evaluation of:

- The effect of climatic parameters.
- The effect of condition of base pavement prior to overlay.
- The effect of design factors, e.g., HMA overlay thickness, HMA overlay properties (conventional, SMA, PMA, etc.), joint spacing in the base pavement, load transfer in the base pavement, etc.
- The effect of airport classification or aircraft type on reflective cracking.
- The effect of construction factors, e.g., tack coat application, rubblization technique, saw and seal technique.

The project selection process was formulated to determine the performance effectiveness or rate of reflective cracking of various crack control strategies under different site conditions. This information was to provide insight into the mechanism of reflective cracking and to refine the technical guidance of various reflective cracking mitigation strategies.

5.2.1 Experimental Plan: Grouping or Stratification of Projects

The project short-listing procedure was applied to the database of airfield pavement sections assembled in the preliminary project identification. Table 11 shows the number of reflective cracking control projects identified for the analysis matrix. As shown, the analysis template has many cells without any projects and is considered an unbalanced factorial or sampling template.

Table 11. Number of Control Projects Included in the Analysis Template

Rehabilitation Type	Major Reflection Crack Control Strategy	Aircraft Loadings	Climate		
			Hard-Freeze	Freeze-Thaw	Warm
HMA/PCC	Reinforcing	Low	0	1	2
		High	1	2	2
	Stress-Relieving	Low	0	2	0
		High	0	1	2
	Crack Control	Low	0	2	4
		High	1	1	2
HMA/HMA	Reinforcing	Low	5	4	1
		High	0	1	0
	Stress-Relieving	Low	0	0	0
		High	0	0	1
	Crack Control	Low	31	0	>5
		High	0	0	0

5.2.2 Projects Selected and Data Collection

Table 12 lists the projects with reflective cracking and the reasons cited for their occurrence. It also shows the eleven reflective cracking mitigation projects that were selected for detailed investigation and identifies the reasons for selecting or not selecting the projects.

Table 13 summarizes, by existing pavement type, crack control strategy, traffic levels and climate conditions, the candidate reflective cracking mitigation projects selected for evaluation. As shown, these selected projects are representative and suitable in terms of location (nearby), climatic parameters (covering most climate conditions), base condition (include both PCC and HMA base pavement), airport classification (including both low and high traffic levels), and the different reflective cracking control mechanisms (stress reinforcing, stress relieving, and crack control). The locations of the eleven airport projects selected for further field investigation are shown in figure 17. These projects provided sufficient data and information to investigate the reasons for reflective cracking and to develop appropriate guidance that either prevent or retard reflective cracking.

After the projects were selected, project specific data was requested from the various stakeholders for each airfield. In most cases, both a local point of contact (airport personnel) and an engineer representative were identified for further interviews. The individuals contacted and interviewed had knowledge of the existing pavement condition prior to overlay, as well as construction observation experience when the pavement was repaired. In addition, at least one contact at each airfield was interviewed that could also comment on the effectiveness of the mitigation technique (periodical inspection of the performance of the repaired pavement). The means of collecting the data occurred via a combination of interviews (phone and/or in person), e-mails, and construction documents. Discussions with the stakeholders also provided important insights into the construction processes and undocumented factors that may have contributed to the success or failure of a mitigation technique.

5.3 Site Visits and Field Notes

Site visits were made to the majority of the reflective crack control projects selected for detailed investigations. Site visits included discussions with airport managers, design engineers, and field inspectors. A summary of the notes compiled after each site visit and the location of the specific reflective cracking mitigation methods at each airfield is provided in Appendix C. Figure 18 shows photographs of the reflective crack severities that were recorded for use within this study. Table 14 summarizes more information about each of the projects included in the site visits.

Table 12. List of Candidate Reflection Cracking Projects and Those Selected for Detailed Investigation

Project No.	Airport Name	Rehab. Type	Year of Overlay	Climate	Aircraft Loading	Reflection Cracking Mitigation Strategy	Project Selected
1	Champaign (IL) Willard	HMA/PCC	1999	F-T	GA/Com.	Includes two strategies: stress relieving interlayer (ISAC), reinforcing (PavePrep fabric), 2 traffic levels.	Yes
2	Rantoul (IL)	HMA/PCC (WWII)	1999	F-T	GA	Three treatments (ISAC, rubblization, & saw and seal)	Yes
3	Smyrna (TN)	HMA/PCC	1993-94	Warm	GA	Two treatments (double bituminous surface treatment [DBST] as a SAMI, reinforcing fabric).	Yes
4	Purdue (IN)	HMA/HMA	1997	F-T	GA	Two treatments (pulverization or CIPR, Paveprep fabric reinforcing).	Yes
5	Cannon AFB (NM)	HMA/PCC	1998	Warm	Military	The only airport using saw and seal technique in this region.	Yes
6	George Bush Intercontinental (Houston, TX)	HMA/HMA	1999	Warm	Com.	Only stress relieving project (SAMI) with HMA over existing HMA pavement.	Yes
7	Peoria (IL)	HMA/HMA	2001	F-T	GA/Com.	Using Glasgrid fabric reinforcing technique, two traffic levels.	Yes
8	Mandan (ND)	HMA/HMA	1998	H-F	GA	Several treatment techniques were used (PavePrep fabric reinforcing, Glasgrid reinforcing, and Mill & Fill with HMA crack control).	Yes
9	Fargo (ND)	HMA/HMA	1996	H-F	GA	Two reinforcing products (Geogrid and Petromat). This project is similar as project 8, and was not selected.	No

Project No.	Airport Name	Rehab. Type	Year of Overlay	Climate	Aircraft Loading	Reflection Cracking Mitigation Strategy	Project Selected
10	Dayton International (OH)	HMA/PCC	2007	F-T	GA/Com.	Two projects: one using fabric reinforcing ("Center One" apron); the other upcoming project using membrane and fabric on taxiway.	Yes
11	Willow Run Airfield (Detroit, MI)	HMA/PCC	1955, 1960	H-F	GA	Using HMA overlay and welded wire fabric reinforcing; the only reinforcing project in H-F climate. Project was not selected because of missing historical and other data.	No
12	Huntsville International (AL)	HMA/PCC	2003	Warm	Com.	Composite over PCC covered by thin HMA overlay (1 inch), the only stress relieving project in warm climate visited.	Yes
13	Selfridge Air National Guard Base (MI)	HMA/PCC	2002	H-F	Military	Rubblization, the only crack control project in H-F climate with sufficient data and information.	Yes
14	Reno International (NV)	HMA/PCC	Before 1978	Warm	Com.	Reinforcing steel fiber used inside of the PCC. This project was not selected because it was not clear if reinforcing was in HMA overlay or just using reinforced PCC pavement.	No
15	Wright-Patterson AFB (Dayton, OH)	HMA/PCC	---	F-T	Military	Rubblization; the only crack control project in F-T climate. This project was not selected considering its similar treatment and climate condition as project 2.	No
16	Wilmington International Airport (NC)	HMA/---	Summer 1977	Warm	Com.	Several techniques were used; stress relieving (SAMI) and Nonwoven polypropylene fabric reinforcing. The project was not selected as the existing pavement type was unknown.	No

Table 13. List of Candidate Reflection Cracking Mitigation Projects in Different Traffic Traffic Levels and Climate Conditions

Table 13. List of Candidate Reflection Cracking Mitigation Projects in Different Traffic Levels and Climate Conditions

Rehabilitation Type	Reflection Crack Control Strategy	Aircraft Loadings	Climate		
			Hard-Freeze	Freeze-Thaw	Warm
HMA/PCC	Reinforcing	Low	0[a]	1[b]	3
		High	11	1, 10	14
	Stress-Relieving	Low	0	12	0
		High	0	1	12
	Crack Control	Low	0	2, 4	3
		High	13	15	5
HMA/HMA	Reinforcing	Low	8, 9	4, 7	3
		High	0	7	0
	Stress-Relieving	Low	0	0	0
		High	0	0	6
	Crack Control	Low	8	0	3
		High	0	0	0

[a] 0 indicates no project was found in this category.

[b] other numbers (except 0) in the cells corresponding to the project number shown in table 11.

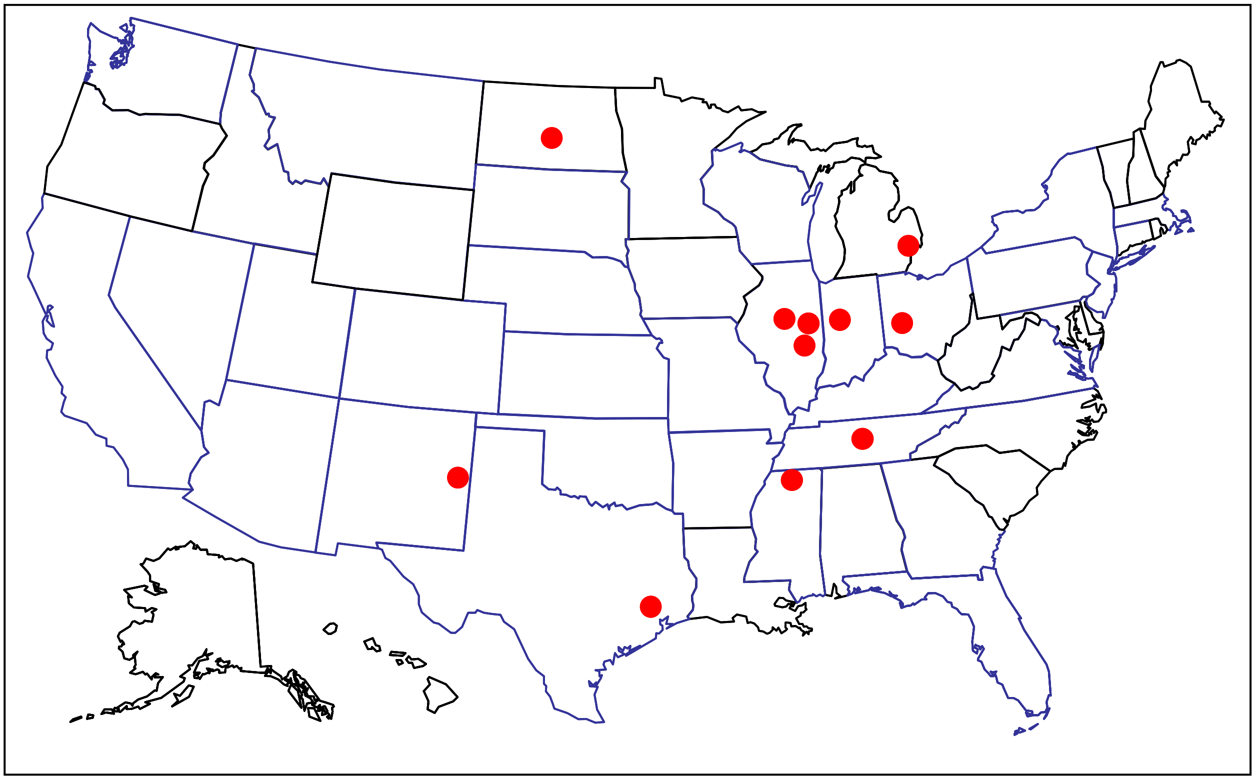
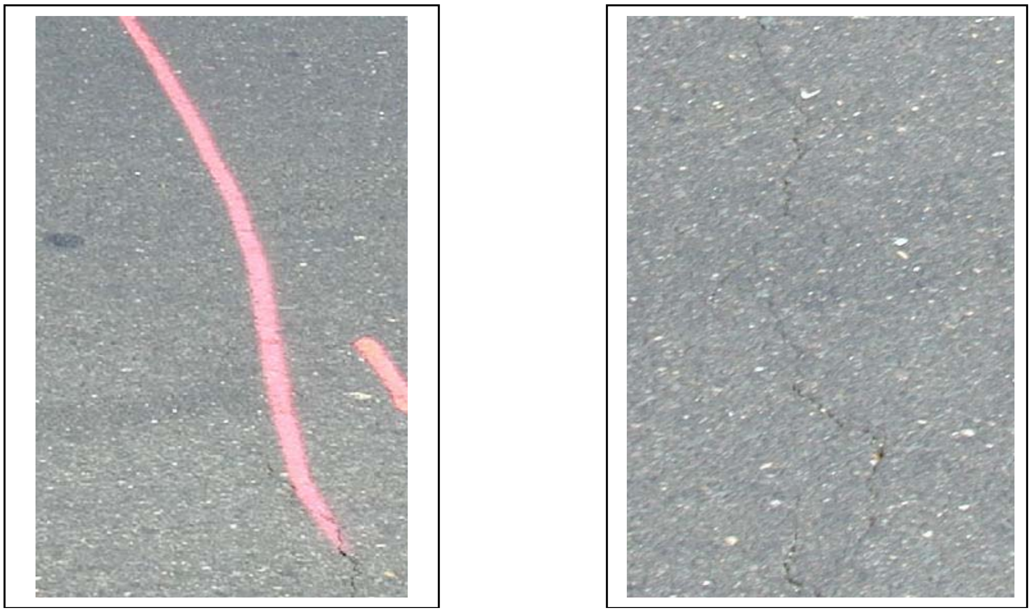


Figure 17. Location of Projects Selected with Reflective Cracking



Hairline Reflective Crack—Crack difficult to see and may not be continuous.

Hairline to Low Severity Reflective Crack—Crack can be seen and extends across paving width.

Low to Moderate Severity Reflective Crack—Crack easily seen and extends across entire pavement width; secondary cracks beginning to occur.

Moderate to High Severity Reflective Crack—Crack has started to deteriorate, secondary cracks have occurred.

Figure 18 Reflective Crack Severity Levels Used in Recording Data on Crack Progression During the Site Visits

Table 14. Summary of Short-Listed Airports and Mitigation Techniques Used

Airport	Climate	Aircraft Loading	Base Pavement	Mitigation Section (work performed prior to overlay)	Control Section	Year	HMA Overlay Thickness	Detailed Inspection Results	2007 Site Visit Comments
Mitigation Technique – Reinforcement of the Overlay (fabrics, grids, composites)									
Champaign	F-T	GA/Com.	PCC	1. Placed 1.5" HMA (1998) 2. Tacked ISAC over trans. jnts. (95% had reflected through)	2" to 8.5" HMA overlay with and without ISAC at trans. joints	1999	6.5"	Mitigation section - 2002 PCI = 89 Control sections - 2002 PCI = 86, 92	• Less cracking compared to Paveprep section • Transverse cracks are 0.25" or less
Champaign	F-T	GA/Com.	PCC	1. Placed 1.5" HMA (1998) 2. Tacked Paveprep over trans. jnts. (95% had reflected through)	---	1999	6.5"	2002 PCI = 89	• More cracking compared to ISAC section • Transverse cracks are 0.25" or less
Rantoul	F-T	GA	PCC	1. Tacked ISAC to all PCC joints	2.5" to 3.0" HMA overlay without ISAC	1999	2.5" to 3.0"	Mitigation sections - 2004 PCI = 90, 100 Control sections - 2002 PCI = 77, 81	• ISAC has kept the trans joints from reflecting through • Some heaves (swells) have occurred, usually aligned over expansion jnt. in PCC or utility trench
Smyrna	Warm	GA	PCC	1. Paveprep placed on all PCC joints and cracks > 0.5" wide	1.5" to 2.0" HMA overlay without Paveprep	1993, 1994	1.5"	Mitigation sections - 1999 PCI = 83, 88, 78 Control section - 1999 PCI = 87	• All joints have reflected through • Some have progressed to medium or high severity
Purdue	F-T	GA	HMA	For cracks > 0.5" wide: 1. Cleaned, sealed, and had Paveprep placed on top	---	1997	4"	2006 PCI = 73, 73, 69, 85	• Cracking at low severity • Portion of mitigation sections were milled/overlaid in 2001
Peoria	F-T	GA/Com.	HMA	1. Milled off 6" of existing HMA	---	2001	6"	2005 PCI = 88, 92	• Isolated transverse cracks, all low severity, and 15' to 30' across, do not coincide with pre-overlay cracks (i.e.; not reflective) • Paving lane joint cracks are low severity
Peoria	F-T	GA/Com.	HMA	1. Milled 2" off old surface 2. Milled 2" x 48" off over wide (> 1") trans. cracks 3. Filled in milled area with a bit. interstabilizing layer 4. Placed 60" wide Glasgrid over milled area	---	2001	4.5"	2005 PCI = 88, 94, 93	• Nearly every pre-overlay trans. crack has reflected through, typically as one crack at low severity, average around 35' across • The 3 pre-overlay cracks that were not treated with the interstabilizing layer have reflected through and average 55' across

Airport	Climate	Aircraft Loading	Base Pavement	Mitigation Section (work performed prior to overlay)	Control Section	Year	HMA Overlay Thickness	Detailed Inspection Results	2007 Site Visit Comments
Mandan	H-F	GA	HMA (8")	1. Milled 2.5" x 24" off over transverse cracks 2. Tacked bottom of milled area 3. Installed Paveprep or Glasgrid fabric in milled channel 4. Tacked edges of channel and top of fabric 5. Placed and compacted HMA in milled area	1. Milled 2.5" x 24" off over transverse cracks 2. Tacked bottom and edges of milled area 3. Filled in milled channel with HMA 4. Placed 2" HMA leveling course 5. Placed double layer chipseal (0.5" total)	1998	Double layer chipseal (0.5" total)	Mitigation section - 2004 PCI = 78 Control section – 2004 PCI = 82	• Paveprep locations typically had one main crack • Glasgrid locations often contained one main crack, plus a second crack above the edge of the milled area • The higher construction cost of Paveprep locations ($7.00/ft), might be offset by lower maintenance cost on fewer and less severe cracks compared to Glasgrid locations ($6.20/ft) • The control section
Mandan	H-F	GA	HMA (8")	1. Milled 2.5" x 24" off over transverse cracks 2. Tacked bottom and edges of milled area 3. Placed and compacted HMA in milled area	---	1998	Double layer chipseal (0.5" total)	Mitigation section - 2004 PCI = 78	• Least effective and lowest construction costs ($2.80/ft) • Usually had three cracks, or one very wide (up to 3") crack • Some settlement has impacted ride quality
Mandan	H-F	GA	HMA (8")	1. Milled 2.5" x 36" off over transverse cracks 2. Milled a second pass at 18" x 2.5" centered within the first milled area 3. Tacked bottom and edges of milled areas 4. Placed and compacted HMA in bottom milled area 5. Placed and compacted HMA in top milled area	---	1998	Double layer chipseal (0.5" total)	Mitigation section - 2004 PCI = 78	• Used this repair type on the most severe cracks in base pavement • Higher construction cost ($5.80/ft) offset by lower maintenance cost since the resulting cracks have been low severity
Fargo	H-F	GA	HMA (2")	1. Routed and sealed all cracks 2. Placed tack coat 3. Placed 0.5" to 0.75" HMA leveling course 4. Placed Geogrid 8501 or Petromat 4599	---	1996	1.75" to 2.0"	Geogrid 1998 PCI = 93 2004 PCI = 75 Petromat 1998 PCI = 95 2004 PCI = 70	• Difficult to distinguish any difference in the performance of the overlay over each fabric • Lots of L&T cracking with cracks as wide as 1" with secondary cracking • Stakeholders felt that current conditions were manageable and that the fabric has added life to the overlay
Mitigation Technique – Stress Relieving Interlayer (SAMI, heavy duty membranes)									
Smyrna	Warm	GA	PCC	1.) tack coat on PCC 2.) placed double layer chip seal (DBST) (0.5" total	2.0" HMA overlay without chip seal	1994, 1995, 2000	1.5"	Mitigation sections 1999 PCI = 95, 100	• DBST was "day-lighted" by extending beyond the limits of the HMA overlay • 1994 project: joints have reflected through

Airport	Climate	Aircraft Loading	Base Pavement	Mitigation Section (work performed prior to overlay)	Control Section	Year	HMA Overlay Thickness	Detailed Inspection Results	2007 Site Visit Comments
				thickness)				Control section 1999 PCI = 87	and are low severity • 1995 project: some joints have not reflected through; those that have are low severity
Peoria	F-T	GA/Com.	HMA	1. Tacked surface 2. Placed 5/8" porous friction course (PFC)	---	2001	4.5"	2005 PCI = 90	• 3 out of 4 pre-overlay cracks have reflected through • Cracks have not reached full width across taxiway and remain at low severity
Houston	Warm	Com.	HMA	1. Placed 0.5" SAMI 2. Placed 5" HMA overlay	5" HMA overlay without the SAMI layer	1999	5"	Mitigation sections 2001 PCI = 97 Control sections 2001 PCI = 98	
Mitigation Technique – Re-strengthening of Cracked Pavement									
Various ND and MN airports	H-F	GA	HMA	1. Filled cracks with Polypatch	---	---	Varies	---	• Did not visit airports where this technique has been used • Both States report that this material "has performed best," also good when a lot of movement is expected
Various SD airports	H-F	GA	HMA	1. Saw cut full depth and removed old asphalt 2. Reworked and compacted the base 3. Patched area with HMA	---	Since 1998	Varies, sometimes no overlay	---	• Did not visit airports where this technique has been used • State reports that this techniques "has worked great" on wide cracks
Tri-Cities & Reelfoot airports (TN)	Warm	GA	HMA	1. Fill and seal cracks with a sand asphalt mix	---	---	varies	---	• Did not visit airports where this technique has been used
Mitigation Technique – Other Techniques (saw and seal, rubblization, reclamation)									
Rantoul	F-T	GA	PCC (8" with reinforcing wire mesh)	1. Rubblized PCC to three different max sizes: 18", 9", 3"	---	1999	2.5" to 3.0"	(18" rubblized) 2004 PCI = 88, 95 (9" rubblized) 2004 PCI = 93, 100 (3" rubblized) 2004 PCI = 93, 100	• The 18" and 9" rubblized sections have several locations with heaves • Some cracks line up with old PCC joints visible on shoulder • The 3" rubblized section has no reflective cracks or heaves
Rantoul	F-T	GA	PCC (8" with reinforcing wire mesh)	1. Saw and seal after HMA overlay	---	1999	2.5" to 3.0"	2004 PCI = 77, 81	• Sealant has failed • No secondary cracking near saw cuts (Note: saw seal joints are sometimes considered a sealed/unsealed crack depending on the condition of the joint material)

Airport	Climate	Aircraft Loading	Base Pavement	Mitigation Section (work performed prior to overlay)	Control Section	Year	HMA Overlay Thickness	Detailed Inspection Results	2007 Site Visit Comments
Purdue	F-T	GA	HMA (9.5”)	1. Pulverized, shaped, and compacted old asphalt surface 2. After overlay: saw cut full-width 0.5” wide transverse joints at 100 ft intervals	---	1997	4.0”	2006 PCI = 77	• Most cracking is at the paving lane seams • Some random longitudinal cracks are present • Very few transverse cracks, what ones exists start in a longitudinal direction and curve in the trans. Direction
Cannon AFB	Warm	Military	PCC (8”)	1. After overlay: saw cut full-width 0.5” wide transverse joints at 100 ft intervals	---	1998	4.0”	2000 PCI = 82, 83	• Visited this airport in 2000 • Airfield staff report that the joint seal material was replaced in 2006 • No cracks, except for some small cracks within a few inches of the joints (Note: saw seal joints are sometimes considered a sealed/unsealed crack depending on the condition of the joint material)
Selfridge ANG	H-F	Military	PCC (13” to 21”)	1. Rubblized PCC 2. Placed 4” crushed PCC leveling course	---	2002	7”	---	• Did not visit this airport • Base personnel report that no reflective has occurred • Report that 2 or 3 areas have non-visible speed bumps that can be felt at certain speeds, these areas are over utility trenches that cross the runway

Chapter 6 Assessment of Reflective Cracking Mitigation Strategies

Based on information and data presented in Chapters 3 through 5, none of the reflective cracking mitigation strategies consistently prevented reflective cracks within the design period, with the exception of FDR for existing flexible pavements and rubblization for rigid pavements. This chapter provides an assessment of the reflective cracks mitigation strategies to determine the key factors related to the occurrence or rate of occurrence of reflective cracks for different site conditions and materials.

6.1 Data Sources

The data sources used to determine the effectiveness of different treatment methods was extracted from three areas: information and data included in the literature, including the comparative studies (Chapters 3 and 4); data and information obtained from airfields and roadway projects that have placed one to multiple treatment methods (Chapters 4 and 5); and information from the site visits (Chapter 5).

6.2 Evaluation Factors/Parameters—Stratification of Projects

In order to assess and compare the effectiveness of different reflective crack mitigation strategies, the key evaluation factors were grouped into four major categories: (1) condition of existing pavement, (2) climate, (3) the rehabilitation design thickness, material and construction properties, and (4) the amount of reflective cracks over time.

6.2.1 Condition of Existing Pavement

The condition of the existing pavement is usually defined by the type, magnitude, and severity of distress, the condition of the joints or cracks, material degradation properties, structural response of the pavement (deflection basin measurements), and the horizontal movements at joints and cracks. Unfortunately, most of these data elements were unavailable for the existing pavements of the projects listed in Chapter 5 and included in the site visits. Thus, the structural condition of the existing pavements was defined by two categories: (1) structurally adequate and (2) inadequate for the existing aircraft operations and site conditions.

The data elements that were used to determine the structural condition were limited to the PCI and magnitude of cracking prior to rehabilitation. Table 15 provides a description of the different categories that were used to stratify or group the projects into similar conditions. It was assumed that the differential vertical deflections across joints or cracks were minimal for the structurally adequate condition of the existing pavements and excessive for those existing pavements classified as structurally inadequate.

6.2.2 Climate

Climate, in accordance with figure 10, was used to estimate the magnitudes of horizontal movements at joints or cracks. The horizontal movements at joints and cracks were assumed to be minimal in Area I, moderate for Area II, and excessive for Area III (refer to table 15).

Table 15. Site Conditions Used to Stratify the Existing Projects into Similar Groups for Data Analyses

Reflective Cracking Mechanism	Existing Pavement	Condition	Classification	Design Feature of Existing Pavement
Traffic Induced	Flexible	Fatigue or load-related cracks	Structurally Inadequate	Excessive differential vertical deflections; large shear displacements at cracks.
		No load-related cracks	Structurally Adequate	Minimal differential vertical deflections; low shear displacements at cracks.
	Rigid	Mid-slab cracks & spalling at cracks & joints	Structurally Inadequate	Excessive differential vertical deflections; large shear displacements at joints and cracks; poor load transfer.
		No load-related cracks & spalling	Structurally Adequate	Minimal differential vertical deflections; low shear displacements at joints; good load transfer.
Thermal Induced	Flexible & Rigid	Thermal cracks & joints	Climate, Area III	Large horizontal movements at cracks and construction joints.
			Climate, Area II	Moderate horizontal movements at cracks & construction joints.
			Climate, Area I	Limited horizontal movements at cracks & construction joints.

6.2.3 Rehabilitation Design Parameters—Thickness and Properties

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 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 rehabilitation design period is a parameter needed to judge the significance of performance differences between control sections and those with different mitigation strategies. Most of the design periods reported for these projects was 20 years. Thus, a 20-year design period was assumed for all of the projects. In addition, it had to be assumed that all rehabilitation designs with different reflective cracking strategies were structurally equivalent for the same design period.

The HMA overlay thickness was determined for most projects in accordance with FAA AC 150-5320-6. The use of empirical pavement design procedures makes the quantification of the design life difficult to determine. Mechanistic-Empirical (M-E) analysis-based methods can be used to confirm or evaluate the overlay thickness to ensure that the rehabilitation design and reflective cracking mitigation strategy would not exhibit premature distress within the rehabilitation design period (cracking, distortions, and mixture disintegration). M-E based design procedures were not used to evaluate each rehabilitation design and project because sufficient structural response data were unavailable. Thus, climate, design aircraft, and number of aircraft operations were used in comparing structural rehabilitation designs between different repair strategies for different facilities (aprons, taxiways, and runways).

6.2.4 Performance Data—Amount of Reflective Cracks and PCI

Pavement condition data was obtained from the site visits when available. Two measures of performance were used to assess and compare the reflective crack mitigation methods between each other and to the control section: (1) the amount or length of reflective cracks with time which was the preferred data element and (2) PCI.

The PCI procedure is the universally accepted method for assessing the condition of airfield pavements and is documented in FAA AC150/5380 and ASTM D5340. During a PCI inspection distress types, their severities, and quantities are recorded in representative areas called sample units. The raw distress data is input into a software program specifically designed for calculating the PCI, such as MicroPAVER. The final PCI for a sample unit is a number between 0 and 100, with 100 representing a pavement with no visible signs of distress. Since the PCI is directly related to the amount of distress on a pavement, the method provides a means to track deterioration over time and with increasing aircraft operations.

The PCI is used to determine the overall performance and deterioration of airfield pavements. The disadvantage of using this method is that the PCI value by itself is a measure of the overall performance of the pavement and does not permit an analysis of an individual distress, such as reflective cracks.

6.3 Data Analyses

PCI data were available for 18 of the 22 short listed projects that were provided in tables 13 and 14. The PCI inspection typically occurred several years after the mitigation technique had been in place thereby providing a means to compare the condition of the mitigation and control sections. When the age versus PCI data was plotted, the trend or performance model for the data set provides an estimate of the rate of deterioration. Table 16 presents the summarized PCI performance by mitigation technique.

Cracking data were used as the basis for analysis. The results of the site visits, however, were insufficient to determine the most effective treatment. Many of the rehabilitation projects are relatively new being less than 5 years in age and have an insufficient number of distress measurements, as shown in table 16. As such, data from the three sources noted above were used to rate and compare the different mitigation strategies for assessing the success rate, overall performance, construction difficulties encountered, and advantages and disadvantages.

Table 16. PCI Performance by Mitigation Technique

Mitigation Technique	No. of Short-Listed Sections/No. of Sections with PCI Data	Mitigation PCI Deterioration Rate (PCI pts/year)	Control PCI Deterioration Rate (PCI pts/year)
Reinforcement of Overlay (fabrics, composites)	11/11	2.9	3.5
Stress-relieving Interlayer (SAMI)	3/3	Not enough PCI data points	
Re-strengthening of Cracked Pavement	3/0	No PCI data points	
Other (saw & seal, rubblization, pulverization)	5/4	2.2	No PCI data points

In summary, there were insufficient cracking and PCI data to determine the service life-to-design life ratio and to generate survivability or probability of failure curves for the different reflective cracking mitigation methods for existing flexible and rigid pavements (refer to Chapter 2). Many of the projects listed in Chapter 5 were newer rehabilitation projects with limited distress or insufficient data to determine and compare deterioration between repair strategies. More importantly, insufficient data were available for review to determine why the viable methods were found to be ineffective or did not provide adequate performance – delay reflective cracks. Thus, a rating procedure was used to compare the different mitigation strategies. This rating procedure is defined and discussed in the following sections of this chapter.

6.4 Rating of Mitigation Strategies

Probability of success and risk factors were used to rate the reflective cracking mitigation methods and are defined in this section of the report. The overall rating of a mitigation method is simply determined by multiplying the probability of success and risk values.

6.4.1 Probability of Success

The probability of success for the treatment methods were defined based on the performance data documented in the literature and from the site visits. This factor is normally determined from the survivability or probability of failure relationship for a specific treatment method. Table 17 is a summary of the success rate scale (probability of success) that was used in quantifying the different treatment methods. Projects with accelerated reflective cracks is defined as moderate to high severity cracks (refer to figure 18) that occur within 25 percent of the rehabilitation design life.

6.4.2 Risk or Confidence in Mitigation Strategy

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 normally 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 reflective cracks. In other words, the method is routinely used and appropriate performance data are available.

The risk of using different mitigation strategies is an important parameter in assessing and comparing strategies that have been in use for different periods of time. Table 18 summarizes the risk categories and values used in comparing the different treatment methods.

Table 17. 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 18. 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					

6.5 Probability of Success and Risks—Potential Performance Issues

Table 19 summarizes the overall rating for each reflective cracking mitigation strategy. It should be noted that the higher rating does not necessarily mean that the strategy listed is the most cost effective repair method for the conditions noted. The following subsections define and discuss the individual categories and combination of methods to increase the probability of success and lower the risk of exhibiting reflective cracks for different site and design conditions.

Table 19. Overall Rating of Reflective Cracking Mitigation Methods

Method		**Existing Pavement**	**Climate**	**Rating of:**			**Notes or Assumptions**
				Success	**Risk**	**Value**	
Modification of Existing Pavement	Rubblization	PCC	All	Very High	Low	0.90	Strength of foundation is important.
	Crack & Seat	PCC	All	Moderate	Low	0.68	
	Full-depth reclamation & CIPR	HMA	All	Very High	Very Low	1.0	
	HIPR or Heater Scarification	HMA	All	Moderate	Low	0.68	Cracks confined to surface layer or wearing surface.
	Mill & Inlay	HMA	All	High	Very Low	0.90	
HMA Overlay Mixture Modification	Thick HMA Overlay	HMA	All	Moderate	Moderate	0.56	Existing pavement structurally adequate.
		PCC	Area I	Very Low	Low	0.45	Slabs intact & structurally adequate.
			Areas II & III	Very Low	High	0.30	
	Modified HMA & Specialty Mixture	HMA	All	Low	Low	0.54	Existing pavement structurally adequate.
		PCC	Area I	Low	Moderate	0.45	
			Areas II & III	Very Low	Moderate	0.38	
Stress & Strain Relieving Interlayer	Strata	PCC	All	Moderate	High	0.45	Slabs intact & structurally adequate.
	SAMI		All	Low	High	0.36	
	ISAC		All	High	Very High	0.45	
	Fabrics		All	Very Low	High	0.30	
	Strata	HMA	All	Very High	Moderate	0.75	Existing pavement structurally adequate.
	SAMI		All	High	Low	0.81	
	ISAC		All	Very High	Very High	0.50	
	Fabrics		All	Moderate	Low	0.68	
	Bond Breaker	PCC & HMA	All	Low	High	0.36	
Cushion Course	Crack Relief Layer	PCC & HMA	All	Moderate	Low	0.68	
	Aggregate Base	PCC	All	Moderate	Moderate	0.56	
Reinforce Overlay	Welded Wire Fabric	PCC & HMA	Area I	Moderate	Moderate	0.56	
			Areas II & III	Low	High	0.36	
	Geogrid	PCC & HMA	Area I	High	Moderate	0.68	
			Areas II & III	Low	High	0.36	
	Composite Materials	PCC & HMA	Area I	Moderate	Moderate	0.56	
			Areas II & III	Low	High	0.36	
Crack Control	Saw & Seal	PCC	All	Very High	Very Low	1.0	Existing pavement structurally adequate.

NOTE: The success and risk categories listed above are based on the individual methods. A combination of strategies could be used to increase the success and risk rating of each method.

6.5.1 Modification of Existing Pavements

PCC Pavements

A national research study was conducted in 1991 by PCS/Law Engineering for NAPA and 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 roller so that no voids are left under the slabs.

Rubblization, however, was considered the best method for mitigating reflective cracks. It was also determined that a properly seated and compacted rubblized layer is between 1.5 to 3 times as effective as dense graded aggregate base course in terms of contributing to structural capacity of the rehabilitated pavement. The following provides an estimate of the probability of success between the rubblization and crack or break and seat methods.

- ➔ Rubblization (figure 19)—Very 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. The HMA overlay thickness should be determined using a reduced modulus of the PCC slabs. The authors of this report recommend average values of 50,000 to 80,000 psi (345 to 550 MPa) for use in design. These values are significantly less than the values recommended for use by Buncher, et al (2008) and given in Chapter 2. The lower modulus values recommended by the authors of this report are based on the back-calculated elastic modulus of the rubblized layer from numerous highway and airfield projects around the U.S.
- ➔ Crack or Break and Seat (figure 20)—Moderate probability of success with low risk. Some reflective cracks from longitudinal joints and cracks can start to occur early 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 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. The other methods for both JRCP and JPCP include the use of a cushion layer or thicker stress/strain relieving interlayer (refer to Chapter 7).
    - o Used in combination with a cushion layer—very high probability of success with low risk.
    - o Used in combination with a stress/strain relieving interlayer (specifically a SMAI)—high probability of success with moderate risk.
    - o Used in combination with a bond breaker (interlayer)—low 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. Based on the past experiences reported with this combination of methods, it would be better to use a cushion course rather than a bond breaker interlayer over the crack or break and seat method of PCC slabs.

HMA Pavements

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 FDR, 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.

a. Resonant Frequency Pavement Breaker

b. Multiple-Drop Hammer

c. Compacted Surface of Rubblized PCC Slabs

Figure 19 Equipment Used to Rubblize Deteriorated PCC Slabs

Figure 20. Crack and Seat or Break and Seat Equipment for Fracturing PCC Slabs

- FDR or CIPR—Very high probability of success with a very low risk. Properties of this layer depend on the type of material being recycled. In general, this material can be assumed to be equivalent to a stabilized base layer with the appropriate stabilizing agent (emulsion or foamed asphalt with and without cement or lime-fly ash). Reflective cracking is a non-issue because the HMA layers with full-depth cracks are being recycled, remixed, stabilized, and compacted in place.
- HIPR and Heater Scarification—Moderate probability of success with a low risk, when the cracks are confined to the wearing surface. If the cracks extend into the lower HMA layers, this method drops to a low probability of success with a low risk. 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. The overlay thickness for future aircraft operations would be determined as for the mill and inlay method noted below. This assumes that the HIPR process is recycling and remixing the layers that exhibit cracking. Reflective cracking becomes a non-issue for the HIPR process when all cracks are confined to the layers that are included within the HIPR depth.
- Mill and Inlay—High probability of success with a very low risk, assuming the cracks are confined to the wearing surface. If the cracks extend into the lower HMA layers the rating is the same as for the HIPR and heater scarification method. This method assumes that the existing flexible pavement is structurally adequate so the HMA surface layers that are cracked are removed and replaced. For this condition, 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.

6.5.2 HMA Overlay Mixture Modification

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 following provides an estimate of the probability of success for those methods used for the overlay 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. Thicker HMA overlays can be used to increase the probability of success when used in combination with some of the other mitigation methods.
- ➔ Modified Asphalt and Specialty Mixtures—Moderate probability of success with moderate 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 rubber modified asphalt 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. The rubber modified asphalt mixtures have been more successful when used in the warmer, Area I climate (refer to figure 10).

6.5.3 Stress and Strain Relieving Interlayer

In summary, a stress and 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 ISAC: Proprietary Materials—Very high probability of success with high 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 over the design period.
  - o Fabrics as a SAMI (figure 21)—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

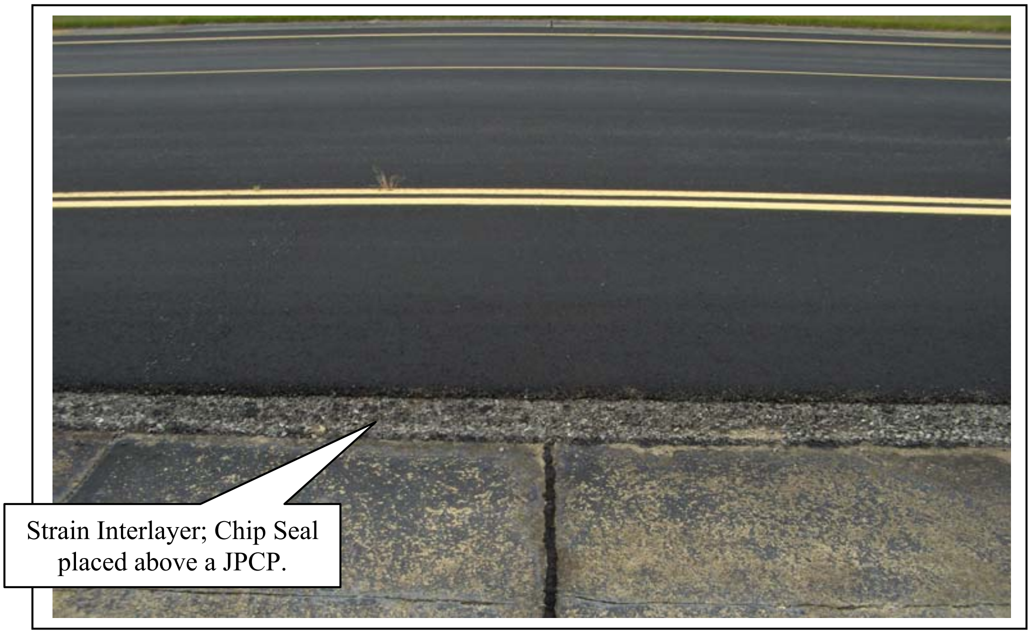
in the fabric) and difficulties with using the fabrics and other similar materials. Fabrics, as a SAMI, are not recommended for jointed concrete pavements.
  - Chip Seals as a SAMI (figure 22)—High probability of success with a moderate risk when used on flexible pavements with good support conditions. Chip seals are not recommended for use on jointed concrete pavements.
  - Modified HMA Interlayer (rubber modified asphalt)—High probability of success with a moderate risk when used on flexible pavements with good support conditions.

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

Figure 21 Geosynthetics Interlayer Used in a Stress/Strain Interlayer

6.5.4 *Cushion Course or Layer*

- 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.
- Unbound Aggregate Base Layer—Moderate probability of success with moderate risk.



Strain Interlayer; Chip Seal placed above a JPCP.

Figure 22 Stress or Strain Relieving Interlayer Placed Above a JPCP

6.5.5 Reinforcement of HMA Overlay

In general, the reinforced HMA overlays do not prevent reflective cracks, but control the width of the cracks. In addition, reinforced HMA mixtures are not recommended for use on overlays of JRCP and JPCP, especially when large differential vertical deflections occur at joints and cracks (poor load transfer across cracks and joints). 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—High probability of success with moderate 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—Moderate probability of success with a high risk. As such, composite materials are not recommended for use by the authors 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.

6.5.6 Crack Control Methods

When used under the appropriate conditions, this method has a very high degree of success with a very low risk (figure 23). The one performance issue is that the sawed and sealed joints in the HMA overlay will need to be resealed with time. There is insufficient performance data to determine the period of time between joint reseal applications. However, previous experience suggests that the joints should last for 10+ years, assuming good materials (not susceptible to moisture damage) and good compaction. Airport maintenance should plan or develop a schedule for inspecting the joints over time.

Figure 23 Saw and Seal Method for Crack Control

6.6 Decision Trees for Identifying Appropriate Mitigation Methods

The key to designing an adequate rehabilitation strategy over a design period is to select the right treatment method for the right condition application. Decision trees were prepared for selecting appropriate reflective cracking mitigation techniques and methods that depend on the type and condition of the existing pavement. Figures 24 through 26 are decision trees for selecting a mitigation method to minimize the impact of reflection cracking on the rehabilitation design for different types and conditions of existing pavements.

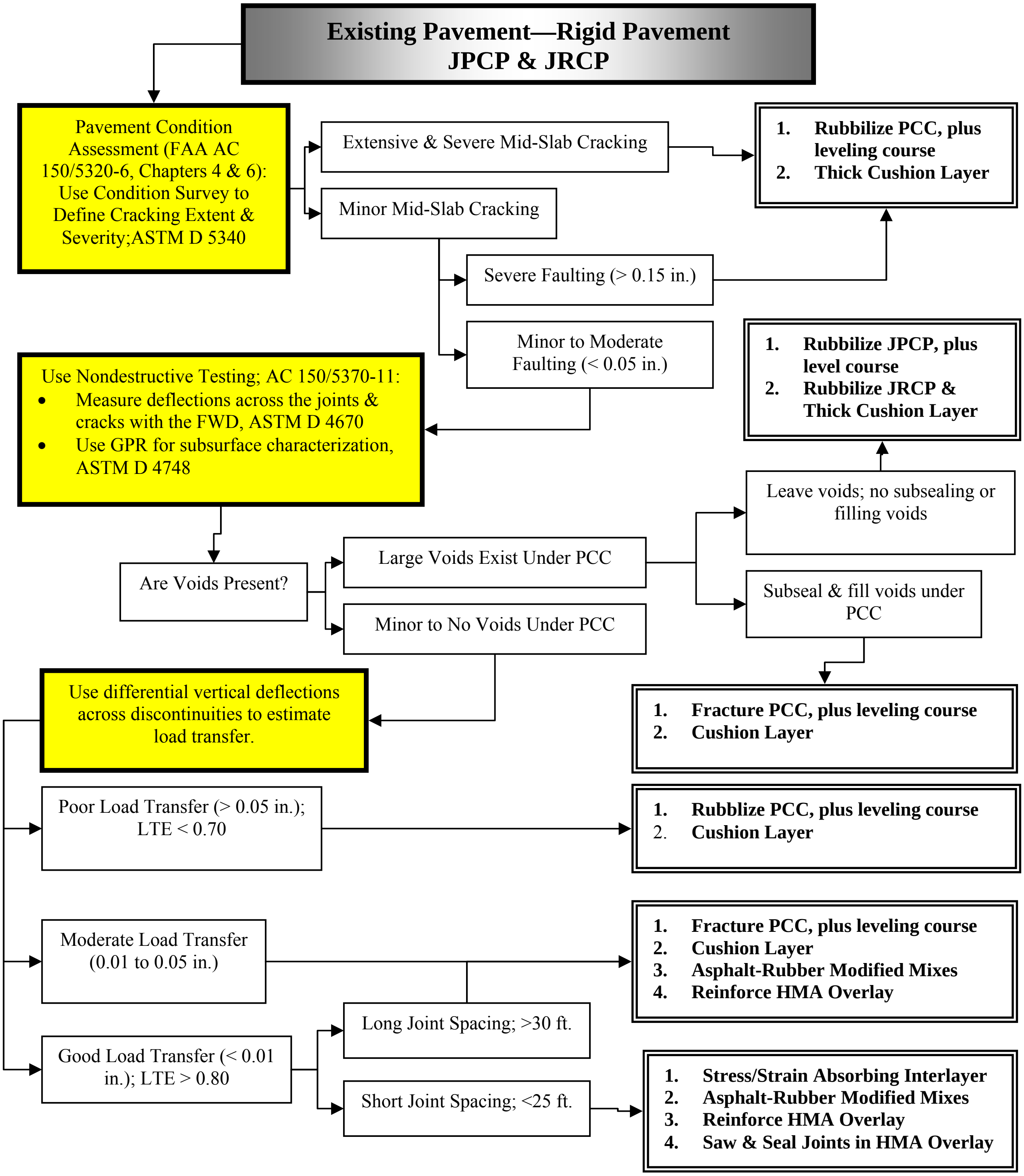


Figure 24 Decision Tree Providing Guidance to Mitigate Reflective Cracks in HMA Overlays of Existing Rigid Pavements

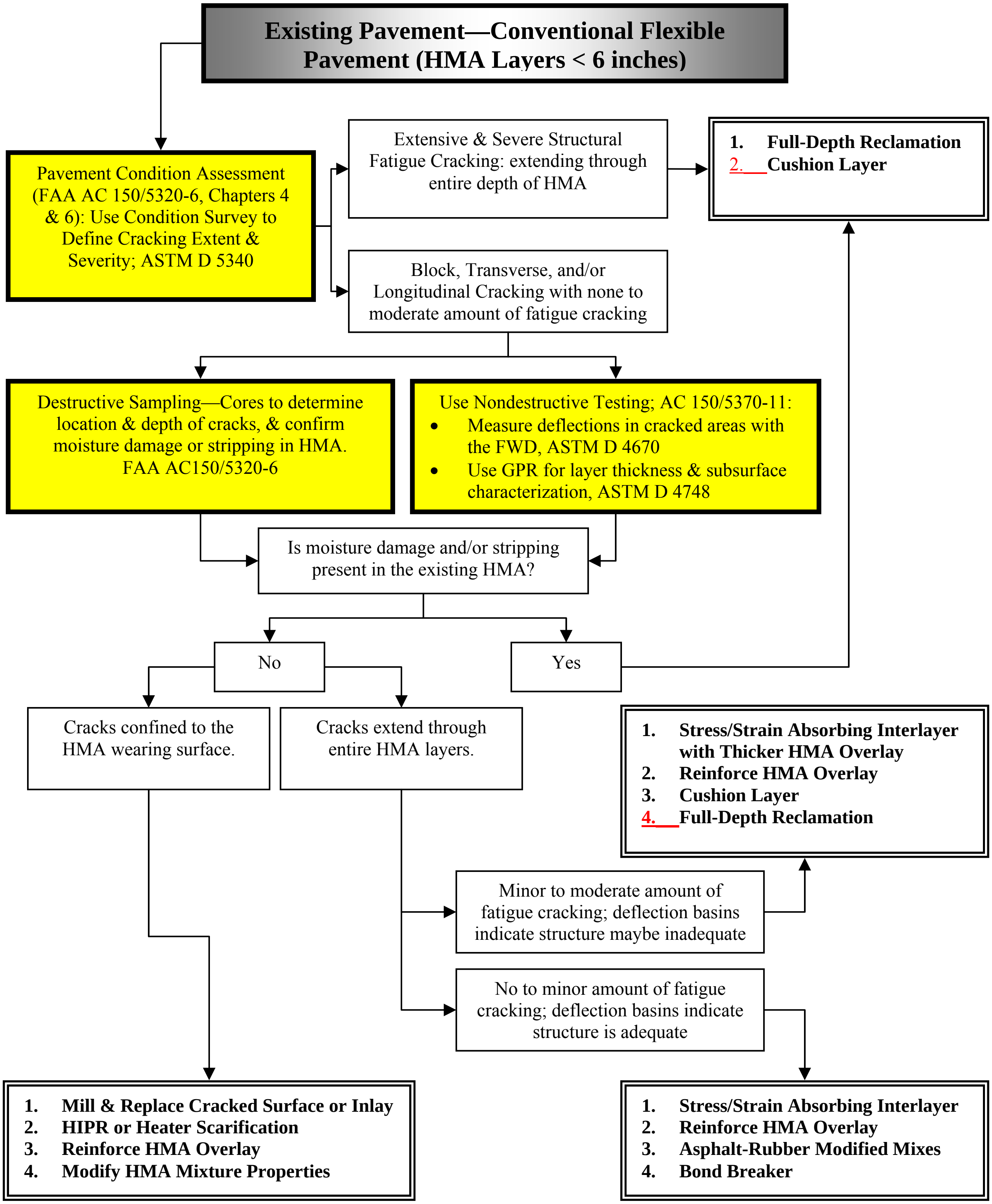


Figure 25 Decision Tree Providing Guidance to Mitigate Reflective Cracks in HMA Overlays of Existing Conventional Flexible Pavements

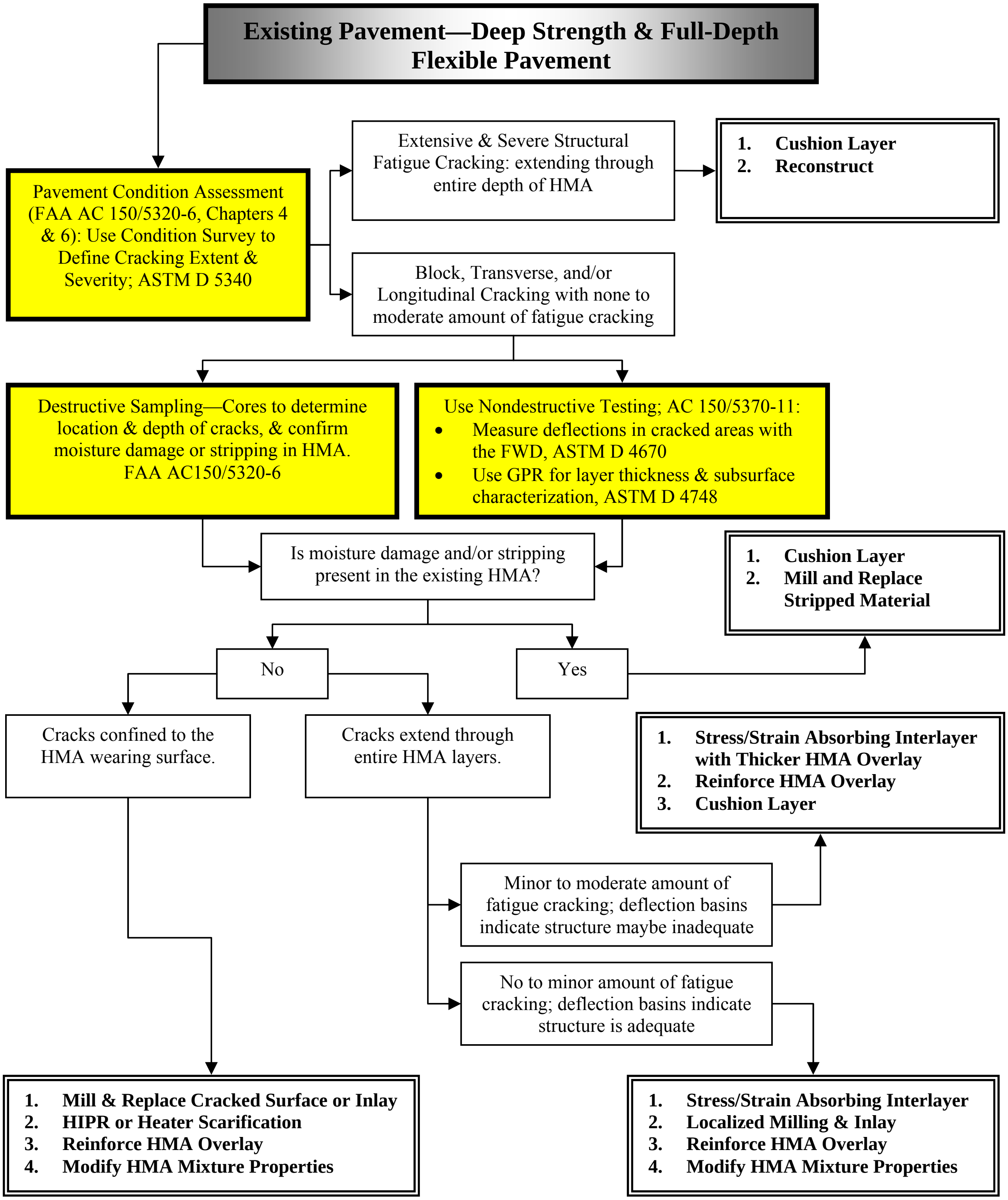


Figure 26 Decision Tree Providing Guidance to Mitigate Reflective Cracks in HMA Overlays of Existing Deep Strength and Full-Depth Flexible Pavements

The decision trees were prepared based on the results from previous research studies, forensic investigation of rehabilitation strategies for the methods identified in Chapter 2, a detailed survey of various projects, and experience documented in the literature. A minimum rating of 0.65 was used in identifying the applicable mitigation strategies.

It should be noted that the reflective cracking mitigation methods can be used individually or in combination with each other. After one or multiple rehabilitation design strategies have been selected, an economic analysis should be completed to determine the life cycle cost (LCC) of each strategy to select the least costly one. Report FAA-RD-81-78 describes the economic analysis for airport pavement rehabilitation alternatives (Epps and Wootan, 1981). 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 section provides some discussion and information on the benefits and limitations of different methods for use in LCC analysis.

6.7 Advantages/Benefits and Disadvantages/Limitations

6.7.1 Modification of Existing Pavements

PCC Pavements

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.

Similar to the rubblization process, 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 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.

The disadvantage or limitation of both processes is that the foundation must have adequate support (the resilient modulus of the foundation should be greater than 3,000 psi [20 MPa], a laboratory equivalent value). Soft foundations or shallow water table depths (less than 5 feet [1.5 m] from the surface) have resulted in problems trying to reduce the size of the fractured PCC particles (refer to figures 4 through 7 in Chapter 3).

HMA Pavements

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.

6.7.2 HMA Overlay Mixture Modification

The HMA overlay mixture modification method (PMA, SMA, rubber modified asphalt mixtures) has one distinct benefit or advantage when used with some of the other mitigation methods: 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 mixture 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.

6.7.3 Stress and Strain Relieving Interlayer

The use of a SAMI will absorb horizontal movements concentrated at joints and cracks. One of the advantages of using a stress and strain relieving interlayer (SAMI or rubber modified asphalt interlayer) is that the added elevation of the overlay is minimized. In addition, many of the SAMI systems (non-proprietary materials) can be placed by local contractors.

The disadvantage is that the interlayer can result in shoving and slippage cracks of the overlay in areas subjected to turning and braking movements of aircraft, if an adequate HMA overlay thickness is not placed. The interlayer has minimal beneficial effect on reducing reflective cracks caused by differential vertical movements.

6.7.4 Cushion Course or Layer

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.

Three problems or concerns associated with cushion courses include: the total overlay thickness is generally much greater than for some of the other mitigation strategies; the cushion layer is a potential water conduit or reservoir between the overlay and existing pavement; and the thicker overlay system requires that the elevation of all adjacent structures and facilities be raised. 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.

6.7.5 Reinforcement of HMA Overlay

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 disadvantage of this method is that future repair alternatives exclude milling the HMA overlay below or near the depth of reinforcement.

Although fabrics will not eliminate reflective cracking completely, they are recommended by FAA circular AC-150/5320-6 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. More importantly, the fabric can trap water in an HMA overlay that was not properly compacted and has excessive air voids that will result in potential moisture damage of the overlay.

6.7.6 Crack Control

There are three critical issues with the use of the crack control method of saw and seal joints in the HMA overlay. The first issue is that the HMA must be sawed directly above the joint in the underlying PCC pavement. Offsets by as little as two inches can result in a secondary crack adjacent to the saw cut, which will cause the mixture between the saw cut and crack to ravel out in a short period of time. The second issue is that the HMA mixture must be allowed to cool so that the HMA mixture does not ravel or become damaged during the sawing operation in very hot weather. The third issue is that the joint cut in the HMA overlay will need to be sealed with time, just like for jointed PCC pavements.

6.8 Summary—Selecting Reflective Cracking Mitigation Strategies

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 JPCP that have extensive cracking and poor load transfer across the joints will be an ineffective treatment method for mitigating reflective cracks. The decision trees provided in figures 24 to 26 were prepared to guide the user in selecting a reflective cracking mitigation strategy that has the highest probability of success when used under appropriate conditions. The HMA overlay thickness should be determined based on the number of expected aircraft operations, climate, condition of the existing pavement, and other site features, as noted under subsection 6.2.3.

Designing a proper rehabilitation alternative, requires extensive information on the existing pavement. The authors recommend that a detailed pavement investigation be completed (refer to FAA AC 150/6320-6) to determine and assess the structural condition of the existing pavement. This recommendation was also made by numerous other authors of the studies referred to in Chapter 4. Not all airfield owners or operators, however, will have the funds to complete a full pavement evaluation program for rehabilitation design in making the decisions noted in those decision trees. The following summarizes the minimum data elements that are needed for different pavement evaluation levels.

Evaluation level 1, Basic Information—The 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.

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 (refer to figure 10) 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—In Place Structural Characterization of Pavement Layers

The following lists the additional information and data elements beyond evaluation level 1 that are needed 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 daily cycles.
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 determine the load transfer and differential vertical deflections across the joints and cracks.

Assumptions that must be made using the minimum 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 (refer to figure 10) 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—Define the Material/Layer Characteristics and Design Data

The following lists the additional information and data elements beyond level 2 that are needed 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.
7. 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.
8. 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.

Chapter 7 Summary—Conclusions and Recommendations

7.1 Conclusions

In summary, there is no material or treatment method that will prevent reflective cracks from occurring under all conditions, with the exception of FDR for flexible pavements and rubblization for rigid pavements. FDR for flexible pavements and rubblization for rigid pavements, however, will not always be a cost-effective rehabilitation strategy. In order to select and design an adequate and cost effective rehabilitation strategy, a detailed pavement evaluation program is needed to determine the site features and condition of the existing pavement to identify the reflective cracking mechanism that must be designed for. The HMA overlay thickness and reflective cracking strategy should be determined based on the number of expected aircraft operations, climate, and other site features.

At best, the use of various materials and methods available today only slightly delay or limit the severity of the reflective cracks. One possible reason for this reduced service life of HMA overlays is that the rehabilitation strategy selected for a specific project is insufficient for the condition of the existing pavement. AAPTP Project 05-04 provides guidance and recommendations to the FAA and others responsible for managing and designing rehabilitation strategies of airside pavements. This guidance includes selection and use of materials and treatment methods to mitigate the occurrence of reflective cracks in HMA overlays of rigid and flexible pavements. The technical guidance is provided in a separate document—*Technical Guide for Techniques for Mitigation of Reflective Cracks*, dated August 2008.

This report presented a broad overview of the products and processes within each category that have been used to mitigate or delay the occurrence of reflective cracks based on the mechanisms presented in Chapter 2. The overview includes the type of materials and properties, field application techniques, extensiveness of use, and general success rate of each treatment method, as documented in the literature. The present state-of-the-art for mitigating reflective cracks in HMA overlays, however, is to a large degree still based on experience gained from trial and error methods of in service pavements; both for highways and airfields. More importantly, the performance and effectiveness of all reflective cracking mitigation strategies is heavily dependent on construction quality (good compaction—low air voids), good workmanship, and use of HMA mixtures for the overlay that are not susceptible to moisture damage.

Climate, structural condition of the existing pavement and overlay thickness are the three parameters that have the greatest effect relative to mitigating reflective cracks. The climatic conditions, especially the temperature conditions (such as freeze-thaw cycles and extremely cold weather conditions) have significant effect on the performance of different interlayer products (such as geotextile and rubber modified asphalt and other SAMI products) for controlling reflective cracking. In general, all reflection cracking retarding products or processes will perform better in warm and mild climates than in the hard-freeze or freeze-thaw cycling climates. The freeze-thaw cycles in severe cold climates can cause contraction and expansion of water within the pavement, which accelerates the damage from water filtration.

The key to designing an adequate rehabilitation strategy over a design period is to select the right treatment method for the right condition application. One reason for the poor performance of some of the thinner reflective cracking mitigation methods is that the HMA overlay was too thin for the aircraft traffic, climate, and on-site conditions. As such, decision trees (figures 24 to 26) were prepared for selecting appropriate reflective cracking mitigation techniques and methods that depend on the type and condition of the existing pavement. These decision trees were based on the results from previous research studies, forensic investigation of rehabilitation strategies for the methods identified, a detailed survey of various projects, and experience documented in the literature.

The following provides a summary of the results that were used in preparing the decision trees and have been reported in the literature to mitigate reflective cracking.

1. Modification of Existing HMA Pavements:
   - Full-Depth Reclamation—Viable and effective technique; mainly used for flexible pavement that exhibit severe levels of structural cracks.
   - Heater Scarification—Viable, but where cracks are confined to the existing surface.
   - Hot In Place Recycling—Viable, with the exception of thermal and fatigue cracks that extend through the entire HMA layers.

2. Modification of Existing PCC Pavements:
   - Crack and Seat—Viable, but does not eliminate reflective cracks. This method can be used with other mitigation techniques.
   - Rubblization—Viable and effective technique for PCC pavements that have extensive deterioration. Of the fracturing techniques used to destroy the slab action of base PCC pavement, the state-of-the-practice is slowly moving towards rubblization because it has been shown to be most effective. Change Number 4 to FAA AC 150/5320-6 has switched the preferred fracturing technique for old PCC pavements that are in very poor condition from crack-and-seat to rubblization.

3. Stress or Strain Relieving Interlayer:
   - SAMI—Viable and effective technique for existing flexible pavements that have adequate structural support. SAMI layers, which work on the principal of isolating the horizontal movement of the base pavement from the overlay, have been successfully employed to reduce the rate of reflective cracking when the crack spacing and crack widths are smaller. It has been found that eventually the crack will work through, even with the more compliant SAMI materials. SAMIs can also act as moisture barriers prevent rising water and vapor from the base or subgrade that can cause additional distress in the pavement layers. These materials also prevent water infiltration into the underlying pavement, as fatigue and thermal cracks begin to initiate within the HMA overlay.
   - STRATA & ISAC—Viable technique for flexible pavement that have adequate structural support, but these materials have limited performance data available. These materials are also believed to be effective, but LCC analysis must be used to determine whether they are cost effective for a particular pavement condition.

4. Bond Breakers; Thin layers—Viable, but mixed results reported in literature. Bond breakers are not recommended for use by the authors, especially in severe climates.

5. Cushion Layers:
   - Aggregate Layer—Viable but mixed performance results;, mainly for PCC pavements. Clearance can be a problem, causing adjacent facilities and features to be raised. Granular cushion layers also provide a water conduit between the overlay and existing pavement, and are not recommended for use by the authors.
   - Crack Relief Layer—Viable, but requires much thicker overlays and has mixed performance results; clearance can be a problem. Thick crack relief layers consisting of large-stone, open-graded, asphalt-stabilized layers (defined as cushion courses within this report), which work on the base isolation principle, have not performed as expected in some cases. The stones simply do not act as "ball bearings," as was originally anticipated. Instead, their interparticle friction will eventually transmit horizontal movements of the base pavement into the HMA overlay.

6. HMA Mixture Modification
   - Rubber Modified Asphalt Mixtures—Viable and effective in mild and moderate climates.
   - Various Modifiers, such as PMA and SMA—Viable, but not effective. This method or treatment should be used in combination with other mitigation techniques to increase the success of other methods.
   - Low Viscosity or Soft Asphalt Mixtures—Not recommended for use by the authors because of other load related distresses (shoving, rutting, roughness, etc.)
   - Thicker Overlays—Not cost effective. This method should be used in combination with other mitigation techniques, especially for PCC pavements. Thicker overlays do act as an insulator for the PCC slabs.

7. HMA Overlay Reinforcement:
   - Steel or Wire Fabric—Viable, but does not prevent reflective cracks. This type of reinforcement keeps cracks tightly closed with adequate density and good materials. Limited data is available for adverse conditions where de-icing salts and chemicals have been used (susceptible to corrosion). Steel reinforcement, as well as geogrids discussed below, have been effective in reducing reflective cracks from existing HMA layers. These materials are less effective when the overlay is placed over jointed concrete pavements, but definitely keeps the cracks narrower as they occur. A geogrid or strip reinforcing product must have a higher modulus than the HMA mixture surrounding it, if it is to reinforce the overlay. These products are effective in reinforcing the overlay against horizontal, thermally-induced movements but not against the traffic-induced bending and shearing movements.
   - Geogrids—Viable for flexible pavements with adequate strength, and PCC pavements exhibiting limited structural distress.
   - Geosynthetics—Viable for flexible pavements with adequate structural strength, but inadequate for PCC pavements. Fabrics will perform best when used over old HMA

pavements with closely spaced random or alligator cracks (not caused by base or subgrade failures) with crack widths less than 1/8 in. Fabrics do not perform well when placed on old PCC pavement joints/cracks or over wide (greater than 3/8 in.) transverse or shrinkage cracks in old HMA pavements.

8. Crack Control; Saw and Seal Joints in HMA Overlay—Viable and effective for PCC pavements without structural cracks & adequate support; must accurately locate existing joints in PCC pavement so that saw cut is made directly above joints. Saw and seal of the HMA overlay that matches the joints in the old PCC pavements has met with great success in many places. Several highway agencies have used it as a preferred rehabilitation method. However, in some instances "tenting" of the sealant has been a problem or concern. This concern has resulted in a cautious use of this technique on high-speed facilities, such as interstate highways or airport runways and parallel taxiways.

7.2 Recommendations

As stated in Chapter 6, there were insufficient cracking data to complete a detailed analysis and comparison of the different mitigation methods for determining which ones were effective and ineffective under varying conditions. Detailed pavement evaluation programs were also unavailable or had not been completed for most of the projects included in the detailed site visits. Thus, the evaluation of mitigation strategies and preparation of the decision trees provided in Chapter 6 were based on information from the interviews conducted within this study and site visits (refer to Chapter 5) and projects documented in the literature (refer to Chapters 3 and 4).

Many of the projects documented in the literature have insufficient data that are needed for a complete and detailed analysis of the overlay performance. Thus, the decision criteria included in the decision trees recommended for use from this study should be checked and confirmed to determine their statistical significance. To confirm that decision criteria and other findings reported within this study requires that the Technical Guide be used to design new and/or evaluate the performance of existing reflective cracking mitigation methods. The following provides recommendations for confirming the Technical Guide and its recommendations to mitigate reflective cracks.

1. Many of the airfields where multiple reflection cracking mitigation strategies were used are relatively new, being less than 5 years in age, and have yet to exhibit distress, including reflective cracks. These airside pavements need to be continually monitored to track pavement distress and performance over time, as noted below. This time-history data and basic pavement condition information can be used in future studies to confirm the decision criteria included in the Technical Guide. An advertisement should be sent to those airfields that have used multiple rehabilitation strategies to mitigate reflective cracking, as a minimum. Those contacted within this study would be the preferred airfields to start with. Using these additional data and other airfields to confirm the decision criteria of the Technical Guide would minimize the number of airfields, treatment methods, and different conditions for future projects. The key issue is to make sure that the data are stored for future use.

2. Determining and assessing the condition of the existing pavement is an important parameter is selecting a reflective cracking mitigation method. As a minimum, pavement investigations are needed to determine the basic information for future studies to evaluate the effectiveness of treatments under a range of existing pavement conditions. Without this basic information, the probability of success of a particular reflective cracking method can not be estimated or determined. Too few of the airfields visited and surveyed within this study included this basic information. Results from more pavement investigations for forensic studies or pavement rehabilitation designs should be documented and stored for future use.

3. PCI data were available on a limited number of airfields to determine the deterioration rates of different reflective cracking mitigation techniques. However, the PCI values by themselves do not capture the increase in reflective cracks over time and does not isolate deterioration caused by different distresses, unless the raw condition survey data are available. Thus, the PCI values, as well as the condition surveys themselves are needed over time to track the growth of reflective crack and other distresses individually. These data also need to be stored for future use.

4. The severity of reflective cracks needs to be included in the data collection procedures. Simply knowing the amount of reflective cracks is insufficient in comparing the different mitigation methods. For example, the saw and seal method for reflective crack control results in 100 percent reflective cracks after overlay placement – sawed joints above the joints in the jointed concrete pavement. The issue is; how to compare the performance of the sawed and sealed joints to the use of a SAMI layer to mitigate reflective cracks. The severity of the discontinuity needs to be included in the data collection process for these types of comparisons. The severity of the reflected cracks and sawed joints needs to be monitored over time for an accurate evaluation and comparison of the different reflective cracking mitigation categories. Figure 18 provided a picture of the different severity levels used within this study. Unfortunately, too few airfields were surveyed for this study. More airfields should collect the reflective crack severity level for tracking their deterioration over time and with aircraft operations.

REFERENCES

(1978). "Bracing for the Bigger Jets: Reinforced Runway, and Taxiways at Wilmington, N. C." *Journal of Airport Services Management*, Vol. 18(No. 8), pp. 14-15.

Ahlrich, R. C. (1986). "Evaluation of Asphalt Rubber and Engineering Fabrics as Pavement Interlayers." *Final Report, Miscellaneous Paper GL-86-34, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS*.

Al-Qadi, I. L., Elseifi, M., and Leonard, D. (2003) "Development of an Overlay Design Model for Reflective Cracking with and without Steel Reinforcing Netting." *Journal of the Association of Asphalt Paving Technologists*, Lexington Kentucky, Vol. 72, pp.388-423.

Al-Qadi, I. L., and Elseifi., M. A. (2004) "Field Installation and Design Considerations of Steel Reinforcing Netting to Reduce Reflection of Cracks." *Proceedings of the International RILEM Conference No. 37, Cracking in Pavements – Mitigation, Risk Assessment, and Prevention*, Limoges, France, pp. 97-104.

Amini, F. (2005). "Potential Applications of Paving Fabrics to Reduce Reflective Cracking." *Final Report FHWA/MS-DOT-RD-05-174*, Department of Civil & Environmental Engineering, Jackson State University, In Cooperation with the Mississippi Department of Transportation and the U.S. Department of Transportation Federal Highway Administration.

Anderson, K. O., et al. (1984). "Rehabilitation of Asphalt Pavments on Airports in the Canadian Western Region." *Proceedings of the Twenty-ninth Annual Conference of Canadian Technical Asphalt Association*, pp. 250-270.

APTech (2006). “Evaluation of Rubblized Pavement Sections in Michigan Constructed Between 1988 and 2002,” Final Report, Prepared for Antigo Construction, Inc., Applied Pavement Technologies, Urbana, Illinois.

Asphalt Institute (2005). “Quantifying the Effects of PMA for Reducing Pavement Distress.” Information Series 215, Lexington, Kentucky.

Asphalt Institute (2004). “Portland Cement Concrete Pavement Rehabilitation: Crack Relief Layer.” Technical Bulletin #4, Lexington, Kentucky.

Asphalt Institute (AI), “About Rubblization”. Internet URL: http://www.asphaltinstitute.org/upload/About_Rubblization.pdf

Baek, J., and Al-Qadi, I. L. (2006) "Effectiveness of Steel Reinforcing Interlayer Systems on Delaying Reflective Cracking." *Meeting Today's Challenges with Emerging Technologies, 2006 Airfield and Highway Pavements Specialty Conference*, Atlanta, Georgia, USA.

Barksdale, R. D., Brown, S. F., and Chan, F. (1989). "Potential Benefit of Geosynthetics in Flexible Pavements." *NCHRP Report 315*, Transportation Research Board, National Research Council, Washington D. C.

Bernard, F. (1996). "Canadian Climate Tests Paving Fabric's Performance." *Geotechnical Fabrics Report*, Vol. 14, No. 3, pp. 30-33.

Brown, S. F., Thom, N. H., and Sanders, P. J. (2001). "A Study of Grid Reinforced Asphalt to Combat Reflection Cracking." *Journal of the Association of Asphalt Paving Technologists*, Vol. 70, pp. 543-571.

Buncher, M., and Jones, H. W. (2006). "Rubblization of Airfield Pavements: State of the Practice." *Transportation Research E-Circular No. E-C087: Rubblization of Portland Cement Concrete Pavements*, pp. 42-59.

Buncher, Mark, et al., (May 2008). “Development of Guidelines for Rubblization” Final Report AAPTP Project 04-01, Federal Aviation Administration, Airport Asphalt Pavement Technology Program, Auburn University, Alabama.

Busching, H. W., Elliott, E. H., and Reyneveld, N. G. (1970). "A State-of-the-Art Survey of Reinforced Asphalt Paving." *Journal of the Association of Asphalt Paving Technologists*, Vol. 39, pp. 766-797.

Button, J. W. (1990). "Overlay Construction and Performance Using Geotextiles." *Journal of Transportation Research Record: Transportation Research Board*, No. 1248.

Button, J. W., and Lytton, R. L. (2003). "Guidelines for Using Geosynthetics with HMA Overlays to Reduce Reflective Cracking." *Report 1777-P2, Project Number 0-1777*, Texas Department of Transportation, Austin, TX.

Button, J. W., and Chowdhury, A. (2006). "Field Tests Using Geosynthetics in Flexible and Rigid Pavements to Reduce Reflection Cracking." *FHWA/TX-06/0-1777-2*, Texas Department of Transportation Research and Technology Implementation Office, Austin, Texas.

Carpenter, S. H., Chang, H., and Lytton, R. L. (1976). "Prediction of Thermal Reflection Cracking in West Texas." *Research Report 18-3, Study 2-8-73-18*, Texas Transportation Institute.

Chastain, W. Jr., and R.H. Mitchell (1963). “Evaluation of Welded Wire Fabric in Bituminous Concrete Resurfacing.” Highway Research Record Number 61, Highway Research Board, Washington, DC.

Clark, M. F., and Culley, R. W. (1976). "Evaluation of Air-blown Asphalts to Reduce Thermal Cracking of Asphalt Pavements." *Proceedings of the Association of Asphalt Paving Technologists*, Vol. 45, pp. 530-551.

Coetzee, N. F., and Monismith, C. L. (1979). "Analytical Study of Minimization of Reflection Cracking in Asphalt Concrete Overlays by Use of a Rubber Asphalt Interlayer." *Journal of Transportation Research Record: Transportation Research Board 700: Pavement Evaluation and Overlay Design: A symposium and Related Papers, Transportation Research Board*, No. 700, pp. 100-108.

Cook, John and Sally Ellis (2005). "Reflection Cracking on Airfield Pavements – A Design Guide for Assessment, Treatment Selection, and Future Minimisation." Design Maintenance Guide 33. Defence Estates, Ministry of Defence, Transport Research Laboratory, TRL Limited.

Dempsey, B. J., and Mukhtar, M. T. (1997) "Interlayer Stress Absorbing Composite in AC Overlays." *Aircraft/Pavement Technology In the Midst of Change*, pp. 244-258.

Dempsey, B. J. (2002). " Development and Performance of Interlayer Stress-Absorbing Composite in Asphalt Concrete Overlays." *Transportation Research Record No. 1809, Transportation Research Board, National Research Council, Washington D. C.*, No. 1809, pp. 175-183.

Eaton, R. A., and Godfrey, R. N. (1980). "Reflection Cracking Studies at Thule Air Base, Greenland Using AC 2.5 and Fabrics." *The Proceedings of the Association of Asphalt Paving Technologists*, pp. 381-396.

Ellis, S. J., and Cook, J. (2003) "Minimization of Cracks on Composite Airfield Pavements in the UK." *Proceedings of the XXIInd PIARC World Road Congress*, 11p.

Ellis, S.J., P.C. Langdale, and J. Cook (2002). "Performance of Techniques to Minimise Reflection Cracking and Associated Developments in Pavement Investigation for Maintenance of UK Military Airfields." Paper presented for the 2002 Federal Aviation Administration Airport Technology Transfer Conference.

Epps, J.A. and W. Wootan (1981). "Economic Analysis of Airport Pavement Rehabilitation Alternatives." Publication Number FAA-RD-81-78, Federal Aviation Administration, Washington, DC.

Epps, J. A., and Button, J. W. (1984). "Fabrics in Asphalt Overlays-Design, Construction and Specifications." *Report No. 261-3F, Texas Transportation Institute*.

Housel, W. S. (1962). "Design, Maintenance and Performance of Resurfaced Pavements at Willow Run Airfield." *Highway Research Board Bulletin*.

Elseifi, M., and Al-Qadi, I. L. (2005). "Modeling and Validation of Strain Energy Absorber for Rehabilitated Cracked Flexible Pavements." *Journal of Transportation Engineering, ASCE*, Vol. 131(No, 9), pp. 653-661.

FAA. (2003). "Guidelines and Procedures for Maintenance of Airport Pavements." *AC-150/5380-6*, Federal Aviation Administration, U.S. Department of Transportation.

FAA (2004). “Rubblized Portland Cement Concrete Base Course.” *Engineering Brief No. 66*

FAA. (2006). "Airport Pavement Design and Evaluation." *AC-150/5320-6*, Federal Aviation Administration, U.S. Department of Transportation.

Fromm, H. J., Bean, D. C., and Miller, L. (1981). "Sulphur-Asphalt Pavements Performance and Recycling." *Proceedings of the Association of Asphalt Paving Technologists*, Vol. 50, pp. 98-115.

Federal Highway Administration (FHWA) (1987). "Crack and Seat Performance." *Review Report*, Demonstration Projects Divisions and Pavements Divisions.

Federal Highway Administration (1997). “Asphalt Roadway Rehabilitation Alternatives – A Training Course.” Publication Number FHWA-SA-97-048, Washington, DC.

Gaw, W. J., Buress, R. A., Young, F. D., and Fromm, H. J. (1976). "A Laboratory and Field Evaluation of Air-Blown, Low Viscosity Waxy Asphalts from Western Canada Crudes." *Proceedings of the Twenty-first Annual Conference of Canadian Technical Asphalt Assocation*, pp. 193-224.

Gulden, W., and Brown, D. (1984). "Overlays for Plain Jointed Concrete Pavements." *Research Project No. 7502*, Office of Materials and Research, Georgia Department of Transportation.

Hensley, M. J. (1980). "Open-Graded Asphalt Concrete Base for the Control of Reflective Cracking." *Proceedings of the Association of Asphalt Paving Technologists*, Vol. 49, pp. 368-380.

Hignell, E. T., Hajek, J. J., and Haas, R. C. G. (1972). "Modification of Temperature Susceptibilities of Asphalt Paving Mixtures." *Proceedings of the Association of Asphalt Paving Technologists*, Vol. 41, pp. 524-561.

Housel, W. S. (1962). "Design, Maintenance and Performance of Resurfaced Pavements at Willow Run Airfield." *Highway Research Board Bulletin*.

Huffman, J. E. (1978). "Reflection Cracking and Control Methods." *Proceedings of the Twenty-third Annual Conference of Canadian Technical Asphalt Association*, pp. 434-443.

Kanarowski, Stanley W. (1972). “Study of Reflection Cracking in Asphaltic Concrete Overlay Pavements – Phase I.” Report Number AFWL-TR-71-142. U.S. Army Engineer Construction Engineering Research laboratory, Air Force Weapons laboratory Kirtland AFB, New Mexico.

Kennedy, T. W., Cummings, L. O., and White, T. D. (1981). "Changing Asphalt Through New Chemistry." *Proceedings of the Association of Asphalt Paving Technologists*, Vol. 50.

Kennedy, T. W., and Moulthrop, J. (1985). "Properties of Modified Asphalt-Aggregate Mixtures Involving a Metal Complex Catalyst." *Proceedings of the Canadian Technical Asphalt Associate*, Vol. 30, pp. 76-101.

Kennepohl, G., and Lytton, R. L. (1984). "Pavement Reinforcement with Tensar Geogrids for Reflection Cracking Reduction." *Proceeding of Paving in Cold Areas (PICA), Canada/Japan Science and Technology Consultations*, pp. 863-882.

Kennepohl, G., Kamel, N., Walls, J., and Haas, R. (1985). "Geogrid Reinforcement of Flexible Pavements: Design Basis and Field Trials." *Proceedings of the Association of Asphalt Paving Technologists*, Vol. 54.

Knight, N., and Hoffman, G. (1983) "Heavy Duty Membrane for the Reduction of Reflective Cracking in Bituminous Concrete Overlays." *Symposium title: Pavement Maintenance and Rehabilitation*, 32 p.

Little, D. N. (1991). "Performance Assessment of Binder-Rich Polyethylene-Modified Asphalt Concrete Mixtures (Novophalt)." *Journal of Transportation Research Record: Transportation Research Board*, No. 1317, pp. 1-9.

Lorenz, V. M. (1987). "New Mexico Study of Interlayers Used in Reflection Cracking Control." *Presented at the Annual Meeting of the Transportation Research Board.*

Lytton, Robert L. (2008). Excel Spreadsheets for Determining the Geogrid Design Relationships and Graphs for HMA Overlays, Excel computational spreadsheet prepared for AAPTP project 05-04.

Majidzadeh, K., Ilves, Sklyut, H., and Kumar, V. R. (1984). "Mechanistic Methodology for Airport Pavement Design with Engineering Fabrics Volume I: Theoretical and Experimental Base." *DOT/FAA/PM-84/9,I Final Rpt.*, Corp. Authors/Publisher: Resource International, Incorporated; Federal Aviation Administration.

Makela, H., Lehtonen, J., and Kallio, V. (1999). "Finnish Experiences in Preventing Frost Damages of Roads by Using Steel Meshes." *Geotechnical Engineering for Transportation Infrastructure*, Rotterdam, Finland, pp. 1335-1340.

Mallela, Jagannath and Harold L. Von Quintus (2004). "Investigation of Reflective Crack Control Measures for AC Overlays of PCC Pavements." Final Report, City of New York, Department of Design and Construction, Division of Infrastructure, New York.

McCullagh, Frank R. (1973). "Reflection Cracking of Bituminous Overlays on Rigid Pavements." Special Report 16, Engineering Research and Development Bureau, New York State Department of Transportation.

McGhee, K.H. (1975). "Efforts to Reduce Reflective Cracking of Bituminous Concrete Overlays of Portland Cement Concrete Pavements." Virginia Highway and Transportation Research

Council, VHTRC 76-R20.

McKeen, R. G., Newcomb, D. E., and Hanson, D. I. (1984). "Material Characterization and Design Considerations for Membrane Interlayers." *Proceedings of the Association of Asphalt Paving Technologists*, Vol. 53, Scottsdale, Arizona., pp.304-320.

McKeen, R. G., and Pavlovich, R. D. (1989). "Monitoring of Test Sections Designed to Reduce Reflection Cracking." *NMERI-WA5-13(.5.13); ESL-TR-87-44*, New Mexico Engineering Research Institute.

McLaughlin, A. L. (1979). "Reflection Cracking of Bituminous Overlays for Airport Pavements; A State of the Art." *FAA-RD-79-57 Final Rpt.*, Federal Aviation Administration.

Mellott, Dale B. (1975). "Asbestos Fibers in ID-2A Bituminous Concrete – Phase II." Research Report No. 70-12. Pennsylvania Department of Transportation, Bureau of Materials, Testing and Research.

Monismith, C. L., and Coetzee, N. F. (1980). "Reflection Cracking: Analysis, Laboratory Studies and design Considerations." *Proceedings of the Association of Asphalt Paving Technologists*, Vol. 49, pp. 268-313.

Mukhtar, M. T. (1994). "Interlayer Stress Absorbing Composite (ISAC) for Mitigating Reflection Cracking in Asphalt Concrete Overlays," Ph.D., University of Illinois at Urbana-Champaign, Urbana, IL.

NAPA, (2004). Guidelines for the Use of HMA Overlays to Rehabilitate PCC Pavements, National Asphalt Pavement Association, Information Series 117, Maryland.

Noonan, J. E., and McCullagh, F. R. (1980). "Reduction of Reflection Cracking in Bituminous Overlays on Rigid Pavements." *Report No. 78*, New York State Department of Transportation.

Paterson, W. (1983). "Design Study of Asphalt Membrane-Overlay for Concrete Runway Pavement." *Transportation Research Record No. 930, Transportation Research Board, National Research Council, Washington D. C.*, No. 930, pp. 1-11.

Pavement Consultancy Services, A Division of Law Engineering Inc. (1991). "Guidelines and Methodologies for the Rehabilitations of Rigid Highway Pavements Using Asphalt Concrete Overlays." A national research study conducted (1991) by PCS/Law Engineering (PCS/LAW) for the National Asphalt Pavement Association (NAPA) and the State Asphalt Pavement Association Executives (SAPAE).

Predoehl, N. H. (1989). "Evaluation of Paving Fabric Test Installation in California Final Report." *Draft*, California Department of Transportation, Translab.

Poon, S. C. (1986). "Reflection Cracking on Asphaltic Concrete Runway Overlays in Cold Areas," MS thesis, University of Alberta (Canada).

Raad, L., S. Saboundjian, P. Sebaaly, J. Epps, B. Camilli, and D. Bush (1997). “Low Temperature Cracking of Modified AC Mixes in Alaska, Executive Summary,” Final Executive Summary, Report SPR-95-14, INE/TRC 97.05, Alaska Department of Transportation and Public Facilities, Federal Highway Administration.

Rada, G. R., and Witczak, M. W. (1987). "Performance of Cracked and Seated Rigid Airport Pavements. Final Report." Corp. Authors/Publisher: Pavement Consultancy Services, Incorporated; Federal Aviation Administration.

Ramsamooj, D. V., and Gabriel, J. (1998) "Airport Rehabilitation Using Asphalt Concrete/Fiberglass Composite Overlays." *Second International Conference on Composites in Infrastructure*, pp. 621-633.

Roberts, S.E. (1954). “Cracks in Asphalt Resurfacing Affected by Cracks in Rigid Bases.” Proceedings, Highway Research Record, Vol. 33, Highway Research Board, Washington, DC (pp. 341-344).

Rolt, J., M.S. Hasim, M. Hameed, and Z. Suffian (1996). “The Prediction and Treatment of Reflection Cracking in Thin Bituminous Overlays.” Second Malaysian Road Conference, Paper Number PA 3174/96, Transport Research Laboratory, Crowthorne Berkshir United Kingdom.

Rostler, F. S., White, R. M., and Cass, P. J. (1972). "Modification of Asphalt Cements for Improvement of Wear Resistance of Pavement Surfaces." *FHWA-RD-72- 24 Final Report; FCP 34A1-063*.

Rostler, F. S., White, R. M., and Dannenberg, E. M. (1977). "Carbon Black as a Reinforcing Agent for Asphalt." *Proceedings of the Association of Asphalt Paving Technologists*, Vol. 46, pp. 376-410.

Sherman, George B (June 1974). “Reflection Cracking,” Pavement Rehabilitation: Proceedings of a Workshop, Report Number FHWA-RD-74-60. Federal Highway Administration, Washington, DC.

Sherman, G. (1982). "Minimizing Reflection Cracking of Pavement Overlays." *Transportation Research Board, NCHRP Synthesis of Highway Practice 92*.

Shoesmith, R., and Emery, J. (1985) "Glasgrid Pavement Reinforcement." *Roads and Transportation Association of Canada Annual Conference*, Vancouver.

Smith, Richard D. (1963). “Prevention of Reflection Cracking in Asphalt Overlays with Structufors, Petromat, and Cerex.” Research Report Number HR-158, Iowa Research Board, Ames, Iowa.

Smith, R. D. (1984). "Laboratory Testing of Fabric Interlayers for Asphalt Concrete Paving." *Report No. FHWA/CA/TL-84/06*, California Department of Transportation, Translab.

Sprague, C. J., Allen, S., and Tribbett, W. (1998). "Tensile Properties of Asphalt Overlay Geosynthetic Reinforcement." *Journal of Transportation Research Record: Transportation Research Board No. 1611*, pp. 65-69.

Stephens, J. E. (1982). "Field Evaluation of Rubber-Modified Bituminous Concrete." *Journal of Transportation Research Record: Transportation Research Board*, No. 843, pp. 11-21.

Thomas, H. L. (1985). "Synthetic Fabrics and "Earthworks"." *Research and Development*, Vol. 27(No. 7), pp. 66-68.

Tuckett, G.M., G.M. Jones, and G. Littlefield (1970). “The Effects of Mixture Variables on Thermally Induced Stresses in Asphalt Concrete.” Proceedings, Association of Asphalt Paving Technologists, Vol. 39 (pp. 703-744).

Tyner, H. L., Gulden, W., and Brown, D. (1981) "Resurfacing of Plain Jointed Concrete Pavements." *Paper presented at the Transportation Research Board Annual Meeting*, Washington D. C.

USACE (US Army Corps of Engineers (1992). “Pavement Design for Roads, Streets, Walks, and Open Storage Areas.” TM 5-822-5 (Chapter 14), Hyattsville, MD.

Vanelstraete, A., and Francken, L. (1996) "Laboratory Testing and Numerical Modeling of Overlay Systems on Cement Concrete Slabs." *Proceedings of the 3rd International RILEM Conference - Reflective Cracking in Pavements*, pp. 211-220.

Vallerga, B. A., Morris, G. R., Huffman, J. E., and Huff, J. (1980). "Applicability of Asphalt-Rubber Membranes in Reducing Reflection Cracking." *Proceedings of the Association of Asphalt Paving Technologists*, Vol. 49, pp. 330-353.

Vedros, P. (1979). "Evaluation of the Effectiveness of Membranes for Prevention of Crack Reflection in Thin Overlays." *WES-MP-GL-79-4*, Corp. Authors/Publisher: Waterways Experiment Station.

Vedros, P. J. (1981). "Evaluation of Membrane Interlayers for Prevention of Crack Reflection in Thin Overlays." *Miscellaneous Paper GL-81-8, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.*

Van Breeman, William (1963). “Discussion of Possible Designs of Composite Pavement.” Highway Research Record 37, Highway Research Board, Washington, DC.

Vespa, J. W. (2005). "An Evaluation of Interlayer Stress Absorbing Composite (ISAC) Reflective Crack Relief System." *Final Report, FHWA/IL/PRR 150; Physical Research No. 150*, Illinois Department of Transportation.

Voigt, G. F., Carpenter, S. H., and Darter, M. I. (1987). "Rehabilitation of Concrete Pavements, Volume 2 - Overlay Rehabilitation Techniques." Federal Highway Administration Contract No. DTFH61-85-C-00004.

Von Quintus, Harold L., et al (2003). "Quantification of the Effects of Polymer-Modified Asphalt to Enhancing HMA Performance," Report Number 5504-2/1, Affiliate Committee, Asphalt Institute; Lexington, Kentucky.

Von Quintus, Harold L. and Jagannath Mallela (2005). "Reducing Flexible Pavement Distress in Colorado Through the Use of PMA Mixtures." Report Number 16729, Colorado Asphalt Pavement Association, Englewood, Colorado.

Von Quintus, Harold L., et al. (2007). "Guidance, Parameters, and Recommendations for Rubblized Pavements,: Report Number WHRP 06-13; Wisconsin Highway Research Program (SPR# 0092-05-07), Wisconsin Department of Transportation, Division of Transportation Infrastructure Development; Madison, Wisconsin.

Von Quintus, Harold L. and James S. Moulthrop (2007). "Performance Prediction Models: Volume I – Research Report," Publication Number FHWA/MT-06-014/8158-1, Montana Department of Transportation, Helena, MT.

Von Quintus, Harold L.; Pavement Evaluation and Rehabilitation Design Projects, Brent Rauhut Engineering, Inc.:

- (1983) "Pavement Evaluation and Rehabilitation Recommendations," Sky Harbor International Airport, Phoenix, Arizona.
- (1983) "Runway 3R-21L Pavement Improvements," San Antonio International Airport.
- (1984) "Subsurface Investigations and Recommendations for Rehabilitation of Runway 12L-30R," San Antonio International Airport, Texas.
- (1984) "Subsurface Investigations and Pavement Testing of Taxiway G," San Antonio International Airport, Texas.
- (1984) "Runway and Taxiway Pavement Improvements," McKinney Municipal Airport.
- (1984) "Pavement Improvements," Killeen Municipal Airport, Texas.
- (1985) "Repair Recommendations for Runways 17-35 and 13-31," NALF Cabaniss, Texas.
- (1985) "Pavement Repairs for Runways 1-19 and 13-31," NALF Orange Grove; NAS Corpus Christi, Texas.
- (1985) "Airfield Pavement Improvements," Lone Star Steel Airport; Lone Star, Texas.
- (1986) "Repair/Overlay of Runways 17-35 and 13-31, NALF Waldron; NAS Corpus Christi, Texas.

Vyce, J. M. (1983). "Reflection Cracking in Bituminous Overlays on Rigid Pavements." *Report No. FHWA/NY/RR-83/109*. Federal Highway Administration, Washington, DC.

Wagoner, M. P., Buttlar, W. G., Paulino, G. H., and Blankenship, P. (2006) "Laboratory Testing Suite for Characterization of Asphalt Concrete Mixtures Obtained from Field Cores." *Journal of the Association of Asphalt Paving Technologists*, pp. 815-851.

Way, G. B. (1980). "Prevention of Reflective Cracking in Arizona." *Proceedings of the Association of Asphalt Paving Technologists*, Vol. 49, pp. 314-329.

Wood, W. A. (1984). "Reducing Reflection Cracking in Bituminous Overlays." Final Summary Report, National Experimental and Evaluation Program Project No. 10, Federal Highway Administration Report Number FHWA-FP-85-02, Washington, DC.

Yao, Z. and C.L. Monismith (1986). “Behavior of Asphalt Mixtures with Carbon Black Reinforcement (with Discussion).” Proceedings, Association of Asphalt Paving Technologists (pp. 564-585).

Zube, E. (1956). “Wire Mesh Reinforcement in Bituminous Resurfacing.” Highway Research Board Bulletin 131, Highway Research Board, Washington, DC (pp. 1-8).

[THIS PAGE INTENTIONALLY LEFT BLANK.]

Appendix A Definition of Selected Terms

Appendix A 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 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 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 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 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—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. 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 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 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 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).

Appendix B Geogrid Design/Construction Details

B.1 Geogrid Materials and Geometry Related to Performance

Geogrids can successfully reinforce against the horizontal stresses caused by thermal contraction and they will help to reinforce the overlay against the traffic stresses provided that there is good load transfer across each crack or joint in the old pavement. The only way that a geogrid can reinforce the overlay is if it has been "locked in" to the asphalt mix of the overlay. A geogrid is locked in to the mix by allowing the aggregates within the overlay mix to interpenetrate through the grid both from the top and the bottom of the grid. This is done by sandwiching the grid between a leveling course placed on the old pavement surface and a surface course which is compacted over the geogrid. As recommended by Lytton (2008), the strand spacing of the geogrid should be selected to allow aggregate interpenetration. As a rule of thumb, the strand spacing should be about twice the maximum size of the aggregate used in the overlay mix.

If the geogrid is placed directly on the old pavement, then the aggregate from the old pavement surface cannot lock in the grid from below. Experience has shown that when this happens, the overlay and geogrid will move back and forth on top of the old pavement surface, and horizontal traffic stresses will grind the geogrid into powder. As explained later, there are several practical construction reasons why it is a good idea to sandwich a geogrid between a leveling course and a surface course, and enhanced performance is only one of them.

The geogrid opening should be about twice the maximum size of the aggregate used in the overlay mix. The cross-sectional area of the strands in each direction must be chosen principally for the thermal contraction and stress conditions that they must resist. This means ideally that there should be a different strand cross-sectional area in each direction. As a practical matter, it may be necessary to choose a geogrid that has the same cross-sectional area and strand spacing in both directions. In this case, the geogrid spacing and cross-sectional area must be chosen to resist the stresses and displacements in the most critical direction.

The geogrid material properties that are important to its performance of are its modulus at the temperature and loading rate that is imposed by the thermal stresses in the overlay, its tensile strength, and its thermal coefficient of expansion. The geogrid will have another modulus at the loading rates that are imposed by the passing traffic, but as explained above, the effectiveness of geogrid reinforcing against traffic stresses depends mainly upon the level of load transfer across the cracks or joints in the old pavement.

The modulus of a geogrid is measured at the level of horizontal strain that it will have under the thermal design conditions. This strain level is reached when the reflective crack has penetrated to the surface of the overlay and the designer must be able to depend upon the geogrid to have sufficient tensile strength to hold the crack together to prevent further traffic deterioration and increase of crack severity. The thermal coefficient of expansion of the grid material should either match or be less than that of the surrounding HMA. Most geogrid materials have thermal coefficients that are lower than the surrounding HMA and the problems caused by a thermal mismatch are rarely encountered.

The HMA overlay properties that are important are the moduli under thermal and traffic design conditions, its thermal coefficient of expansion, as noted above, as well as its thermal insulating qualities, the log slope of the relaxation modulus curve for the HMA and the thickness of the HMA overlay. The properties of the underlying cracked or jointed old pavement surface are the crack or joint spacing and its thermal coefficient of expansion.

B.2 Selection of Geogrid Material

A design process for selecting the appropriate geogrid for a specific overlay was developed by Lytton (2008), which makes use of three geogrid-overlay design charts through seven steps. [The geogrid overlay design charts are prepared through an excel spreadsheet calculation table using the standard design equations for geogrids.]

- Step 1—Select a trial overlay thickness, *Ho*, which is the sum of the thickness of the leveling course on which the geogrid is placed and the thickness of the HMA overlay placed over the geogrid.
- Step 2—Estimate the stiffness of the HMA mix under long term thermal loading, such as will occur overnight when the overlay becomes thermally stressed.
- Step 3—Use figure 27 to determine the temperature ratio of the average temperature change in the overlay to the design surface temperature change.
- Step 4—Use the tensile strain (excel calculation table) to compute the geogrid thermal strain level. This requires the input of the crack or joint spacing in the surface of the old pavement, the average temperature change ratio from Step 3, the overlay thickness, and an estimated thermal coefficient of expansion of the old pavement. This value is typically 4x10^-5/°F for HMA layers and 6.5x10^-6/°F for PCC materials.
- Step 5—Select a trial geogrid and calculate the product of the design thermal strain level from Step 4 and the geogrid material ratio: *Eg/(s*t)*; where: *Eg* = Material modulus of the geogrid; *s* = Geogrid strand spacing; and *t* = Geogrid thickness.
- Step 6—Enter Figure 28 with the product computed in Step 5 along the horizontal axis and go vertically upward to the proper curve for the slope of the log creep compliance curve, *m*, of the HMA mixture to be used in the overlay. Go horizontally from this point to find the life extension ratio. This is how much longer the overlay can be expected to last with the trial geogrid than without it.
- Step 7—Enter Figure 29 with the same product computed in Step 5 along the horizontal axis and go vertically upward to reach the proper curve for the ratio of overlay stiffness-to-grid material stiffness, *EoHo/Eg*, and then from this point, go horizontally to find the required ratio of the geogrid strand area, *a*, to its strain spacing, *s*. If the *a/s* ratio is not provided by the trial geogrid selected in Step 5, then assume another trial geogrid and repeat steps 5 through 7 until a satisfactory geogrid is found.

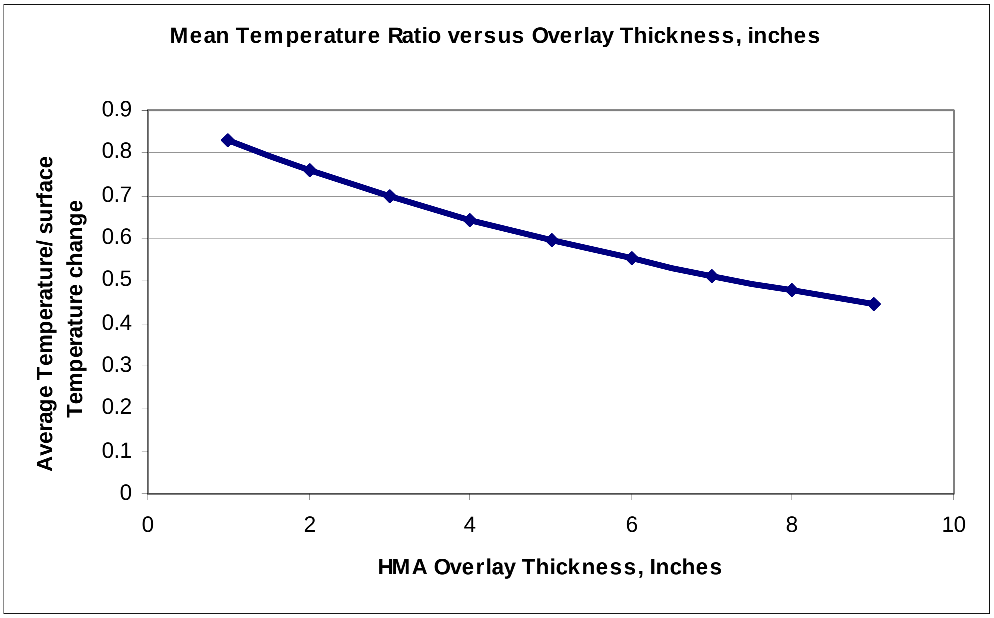


Figure 27. Determine the temperature ratio of the average temperature change in the overlay to the design surface temperature change (Lytton, 2008)

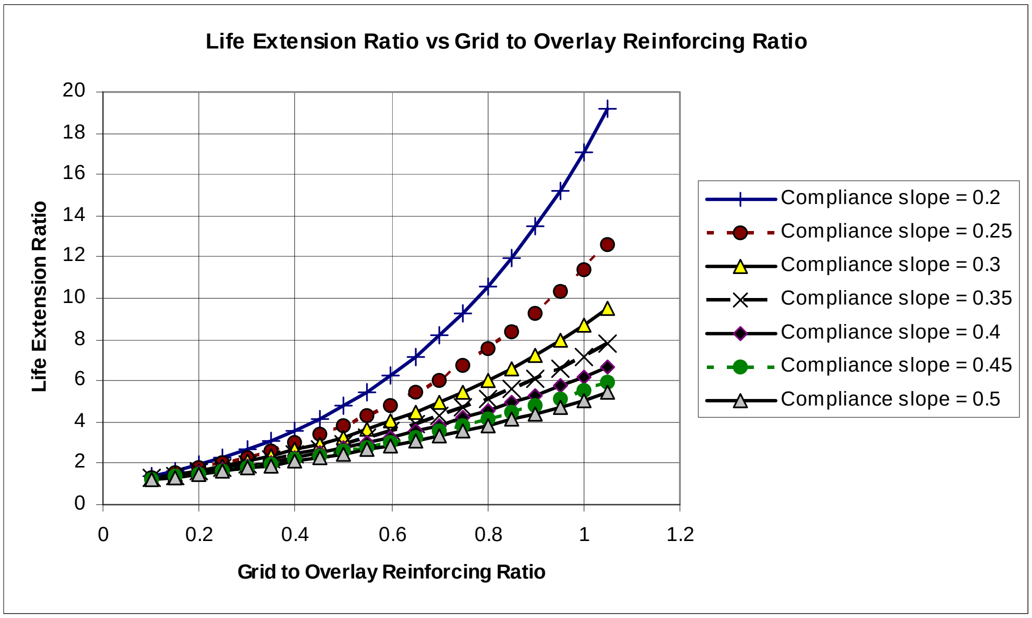


Figure 28. Determination of the Life Extension Ratio for Geogrid Reinforced HMA Overlays

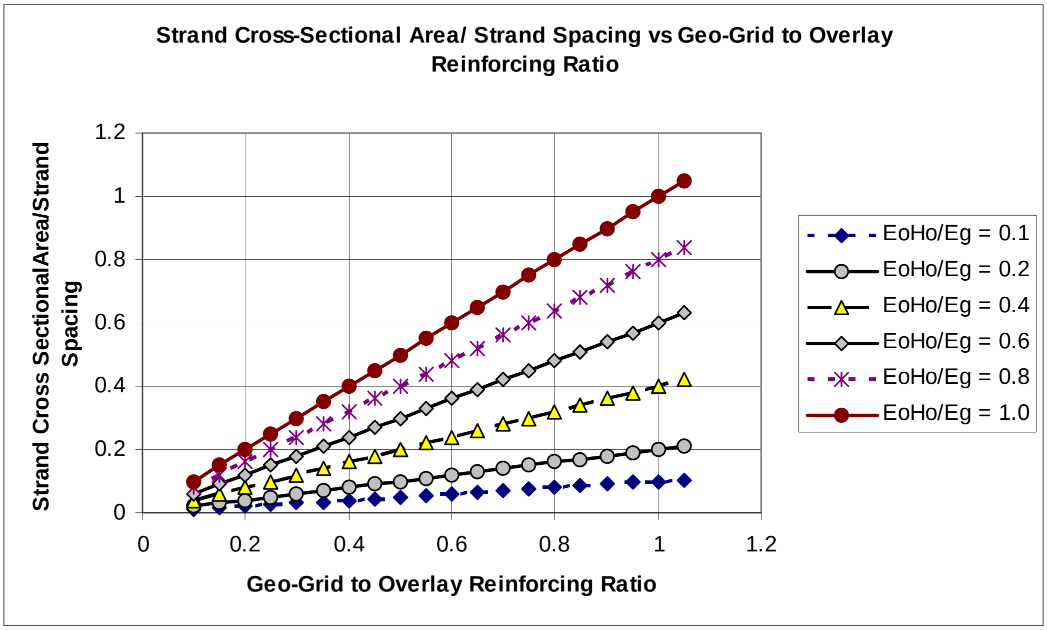


Figure 29. Determination of Required Ratio of the Geogrid Strand Area to Strand Spacing

A larger life extension ratio can be chosen by selecting a geogrid with a larger material modulus, *Eg*, or a smaller strand spacing, *s*, or a smaller thickness, *t*. There is a limit to this which is set by the size of the aggregates that must interpenetrate the grid and lock it into place. There is another limit which is set by the need to have a substantial strand cross-sectional area to resist the thermal stresses that will be imposed by the contraction of the overlay and the old cracked or jointed pavement beneath it.

B.3 Construction Methods

The practical importance of a leveling course in prolonging the service life of a geogrid reinforced overlay stems from several aspects of construction and performance. First of all, the leveling course provides a smooth surface on which to lay down the geogrid allowing the geosynthetic or geogrid to be laid down without wrinkles. Secondly, having fresh HMA mix above and below the geogrid allows the aggregates to interpenetrate the grid and lock it into the material of the asphalt overlay. If the geogrid is placed down on the surface of the old pavement, it cannot be successfully locked into the overlay and will be ground down by the horizontal displacement of the geogrid relative to the old pavement that is caused by passing traffic. Thirdly, the leveling course reduces the level of strain imposed by the thermal contractions of the underlying old pavement surface that the geogrid must resist. Fourthly, the geogrid imbedded in the overlay with the leveling course below and the overlay above it provides an overall higher stiffness to the overlay.

The usefulness of an adhesive below the grid is principally to hold the geogrid in place during the construction of the overlay and to allow the aggregates to lock the geogrid into place.

The interpenetration of the aggregates through the geogrid not only locks it into place and assures reinforcing against thermal contraction of the overlay when a crack eventually reflects through to the overlay surface. The interpenetration also makes the overlay more durable against a rapidly increasing severity of any reflective crack. The HMA overlay thickness is the sum of the thicknesses of the leveling course and the overlay. This total thickness, reinforced with an adequately placed geogrid, will last much longer than the same overlay (thickness and material) but without any geogrid reinforcement.

Appendix C Detailed Site Visits and Notes

Appendix C is a summary of the notes taken during the more detailed site visits to selected airfields and discussions with airport personnel regarding the reflective cracking mitigation methods that had been used. Selected photographs of typical reflected cracks and the general condition of the feature being surveyed are also provided for some of the airfields. An airport diagram showing the specific airfield feature (runway and/or taxiway) with the control and/or mitigation strategy is also included as part of Appendix C.

Site Visit To: **Champaign, IL Willard Airport**
Date of Visit: **August 9, 2007**
Attendees: **Bill Weiss (ARA), Jag Mallela (ARA), Stan Herrin (CMT)**

Site Visit Observations: Runway 14L/32R
After a planned PCC overlay did not work, a 1.5-inch HMA overlay was placed on runway 14L/32R in late 1998 so that the runway was available during the winter months. In 1999, ISAC (23,134 ft) or Paveprep (23,134 ft) was placed on the transverse joints (95% had reflected through), then a nominal 6.5" asphalt overlay was placed. The pavements that intersect this runway offer transition overlays and provide control sections. The thin HMA overlays at this airport leave little chance for most, if not all joints to reflect through at some point. It should also be noted that the Paveprep material was installed directly on the PCC, instead of between lifts of the overlay as recommended by the manufacture.

Paveprep Section

- Some transverse joints have low severity (≤ ¼ inch wide) cracks.
- More transverse joints have cracks in the portion of the runway that was extended in 1974. Construction records indicate 20- 21 inches PCC.
- Fewer transverse joints have cracks in the original portion of the runway which also contains 20- 21 inches PCC, but was constructed as two lifts, one in 1948, the second in 1974

ISAC Section

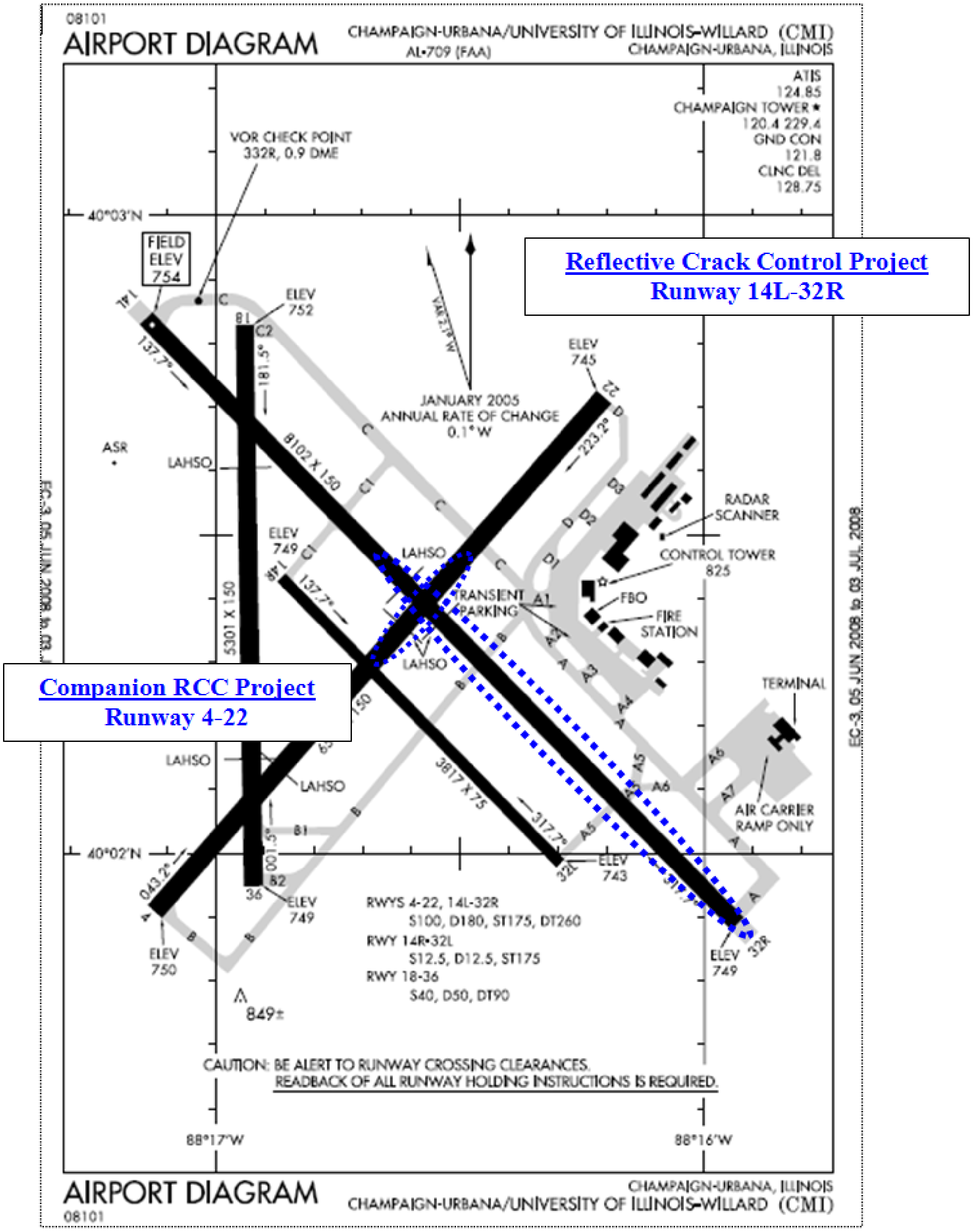
- Less cracking overall compared to the Paveprep section
- Transverse cracks are low severity

Control Section (Runway 4/22)

- A variable thickness (2- 9 inches) transition overlay with and without ISAC at the transverse joints

Willard Airport – PavePrep Section

Willard Airport – ISAC Section



Reflective Crack Control Project
Runway 14L-32R

Companion RCC Project
Runway 4-22

Figure 30 Location of pavement projects evaluated at University of Illinois Willard Airport (map courtesy of FAA Aviation System Standards).

Site visit to Fargo (FAR) Airport, ND
September 24, 2007
Attendees: Bill Weiss (ARA), Mark Holzer (ND Aeronautics), Steve Synhorst and John Scrapper (engineers with Ulteig Engineering)

Runway 13/31

Runway 13/31 (3,800' x 150') at FAR was rehabilitated in 1996 using 2 types of crack control fabrics (Geogrid 8501 and Petromat 4599) prior to placing a thin HMA overlay (2.0" nominal) over the entire surface. The previous surface was reported to be 2" AC, over 5" stabilized base, over 18" granular subbase; a 1994 PCI survey ranged from 17 to 33 PCI for the main features on this runway. Each fabric was installed as detailed below:

- Center 50' of runway – routed and sealed all cracks, placed tack coat, placed ½" to ¾" HMA leveling course, placed Geogrid 8501 (thought it was 8' wide rolls), then placed 1 ¾" to 2.0" HMA surface.

- Outer edges of runway (50' each side) – routed and sealed all cracks, placed tack coat, placed ½" to ¾" HMA leveling course, placed Petromat 4599 (thought it was 8' wide rolls), then placed 1 ¾" to 2.0" HMA surface.

Traffic on this runway is limited to small GA aircraft due to the short length of the runway.

Construction observations – John Scrapper was present during construction and reported no difficulties for the contractor in placing the fabrics. John reported that several of the transverse cracks in the previous surface had subsidence near the crack edges, but had swelled up on both sides of the crack forming a slight speed bump. The contractor bladed the swelled areas off prior to placing the leveling course.

Site visit observations – There was lots of cracking (longitudinal and transverse) found with some cracks as wide as 1" with secondary cracking. However, airport operations and the Ulteig engineers feel that the current conditions were still manageable. Considering the age (11 years) and thinness (2") of the overlay, they view the runway to be in "pretty good" shape. New, unsealed cracks have developed since the last crack sealing effort. Nearly all of the existing cracks could also be resealed soon. Only one transverse crack exhibited slight swelling on the overlaid surface. The large reduction in the occurrence of swelling compared to the original surface may have something to do with making it harder for surface moisture to reach the subbase layers.

The general consensus was that both fabrics added benefit to the project by extending the life of the overlay. It was difficult to distinguish any difference in the performance of the pavement over each fabric. Detailed results from the most recent PCI inspection will be researched to see if differences exist between the keel and the outer edges.

Site visit to Mandan (Y19) Airport, ND
September 24, 2007
Attendees: Bill Weiss (ARA), Mark Holzer (ND Aeronautics), Jim Lawler (Mandan Airport Manager), and Tom Neigum (engineer with Kadrmas, Lee & Jackson)

Runway 13/31

Runway 13/31 at Y19 was rehabilitated in 1998 using 4 types of pre-overlay repairs prior to placing a double layer chip seal (0.5" total) over the entire surface. This site documents very well the location for each repair type making it easy to track the performance for each type. Tom Neigum and Jim Lawler were both present during the project in 1998 and have faithfully spray painted each repair area by type. The crack repair types were randomly assigned to cracks that were approximately the same condition, except Type 4 which were used on the worst cracks. All pre-overlay repair areas have reflected through the chip seal overlay; recent maintenance efforts have crack sealed these cracks. The details of each repair type are provided below as well as in the following figure.

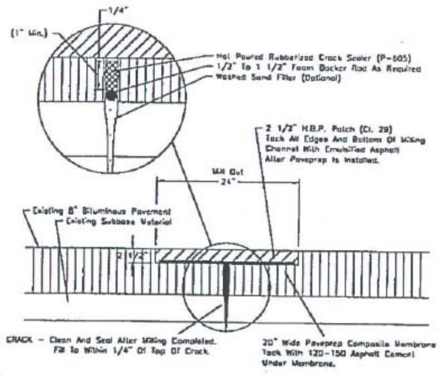
- Type 1 – milled 2.5" deep x 24" wide over transverse cracks, tacked bottom of milled area (if non-adhesive Paveprep used), installed **Paveprep** in milled channel, tacked edges of milled area and Paveprep surface, filled in milled channel with hot-mix asphalt, placed double layer chip seal over entire runway

- Type 2 - milled 2.5" deep x 24" wide over transverse cracks, tacked bottom of milled area, installed **Glasgrid** in milled channel, tacked edges of milled area and Glasgrid surface, filled in milled channel with hot-mix asphalt, placed double layer chip seal over entire runway

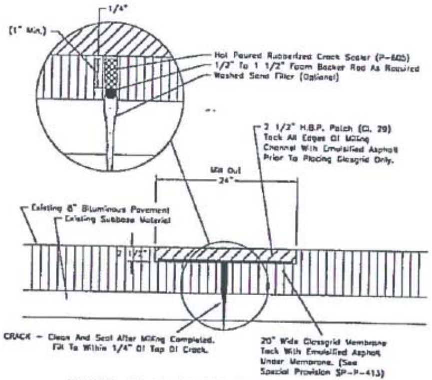
- Type 3 - milled 2.5" deep x 24" wide over transverse cracks, tacked bottom of milled area, filled in milled channel with hot-mix asphalt, placed double layer chip seal over entire runway

- Type 4 – "upside down wedding cake," milled 2.5" deep x 36" wide over transverse cracks, then milled to subgrade (2.5" in plans) x 18" wide centered in initial milled channel, tacked bottom of milled area, filled in both milled channels separately with hot-mix asphalt, placed double layer chip seal over entire runway

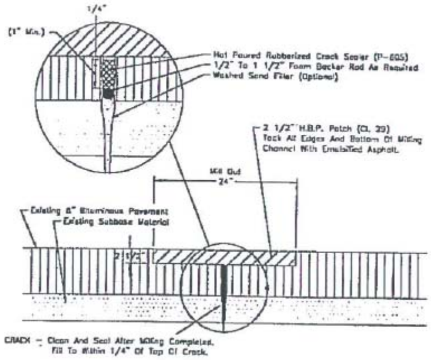
Another "test section" of note on this runway is a 600' long portion where a thin asphalt leveling course (nominal 2") was placed on the old surface prior to the chip seal layer. Only type 3 crack repairs were performed within this section.



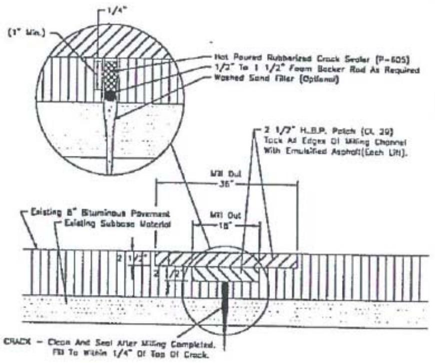
TYPE 1 CRACK REPAIR DETAIL



TYPE 2 CRACK REPAIR DETAIL



TYPE 3 CRACK REPAIR DETAIL



TYPE 4 CRACK REPAIR DETAIL

Construction Observations

The contractor performing the work had no previous experience working with the Paveprep or Glasgrid materials but figured out the installation process fairly quickly. It was estimated that an additional 3 to 5 days was added to the overall project time for the milling and material placement. It appeared that the self-adhesive version of Paveprep was the easiest to work with. Although the crack repair details specified that the milled crack was to be sealed, the cracks were nearly indistinguishable after milling 2.5" into the pavement. In addition, the router chosen for the job would not fit within the milled areas so no routing or crack sealing was performed on the cracks after the milling process.

The spreading of the tack coat had to be performed carefully so that just the bottom of the milled areas were coated. It was found that if the tack coat got on the non-milled areas it was difficult to keep the patch material from also adhering to these areas as well. The challenge in placing the patch material in the milled areas was to arrive at the correct amount of material so that after compaction the patched area would be flush with the surrounding pavement. Under filling the milled area made it hard to achieve density and caused a slight depression. KLJ directed the contractor to compact the patched areas to approximately ¼" higher than the surrounding pavement to allow for settlement over time.

The current ride on the runway feels some roughness over the repaired areas, but this appears to be related to crack width more than movement of the patched material.

Due to the wandering pattern of some of the transverse cracks, it was difficult to keep the crack centered within the milled area. What tended to happen was the crack meandered within the milled areas, and at times, would be right at the edge of the milling limits. The closer the crack and edge of the milling became, the less effective the repair technique – basically merging two reflective cracks into one larger crack at the surface.

Site Visit Observations

Regardless of technique, the cracks at Mandan have all reflected through the ½" chip seal since the 1998 project.

- Type 1 (Paveprep) – 300' project quantity, $7.00/ft construction cost
    - Most of the Type 1 repair areas have one main crack which has been routed and sealed. From a maintenance perspective, this repair area has been easier to maintain since it has resulted in a single crack that costs about $0.50/ft to seal.

- Type 2 (Glasgrid) – 525' project quantity, $6.20/ft construction cost
    - The Type 2 repairs often contained one main crack, plus a second crack above the edge of the milled area. It appears the Paveprep is performing better than the Glasgrid based on the amount and severity of cracks within each of these repair areas.

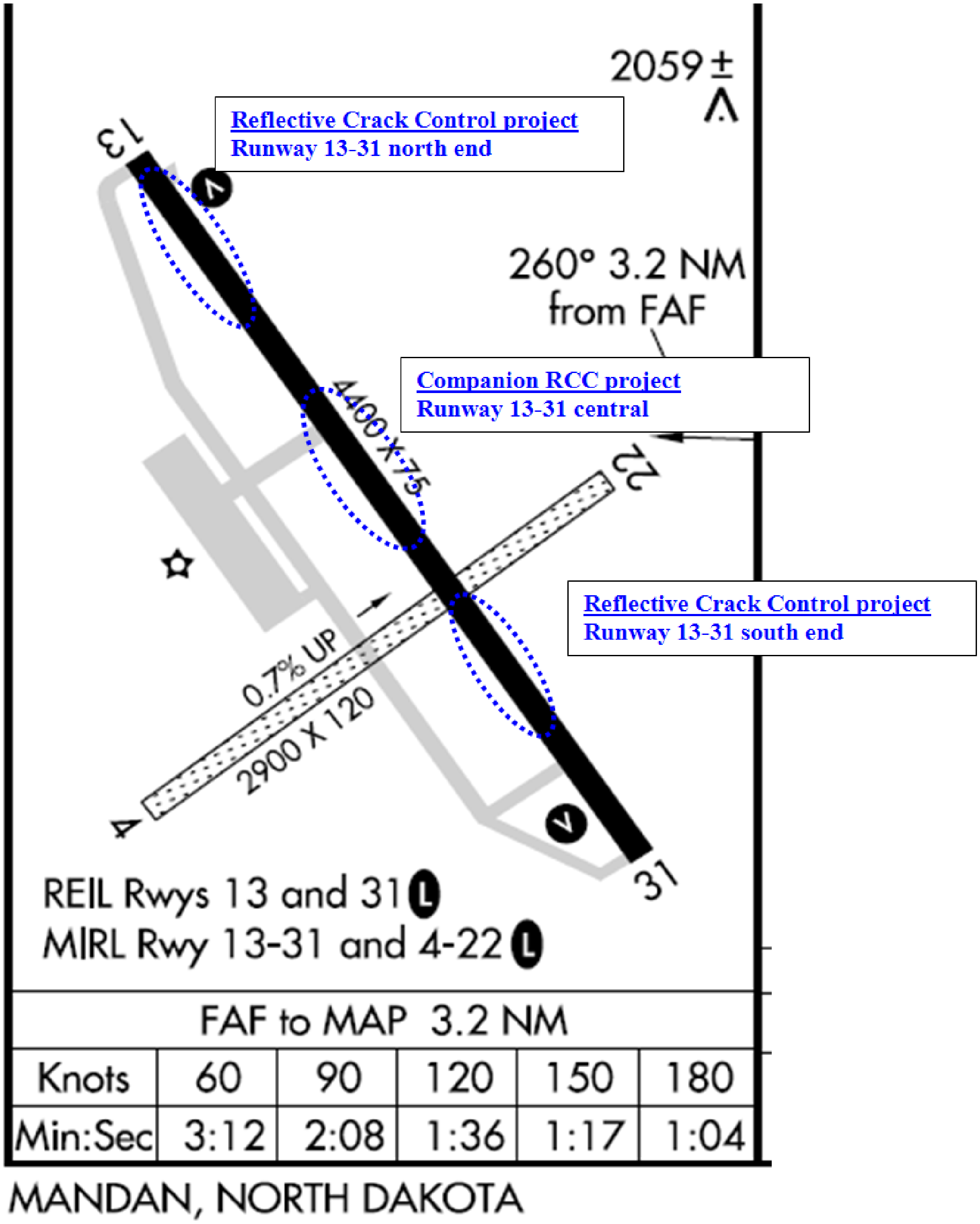
- Type 3 (Mill and Fill only) – 9,973' project quantity, $2.80/ft construction cost
    - The reflective cracks located in Type 3 repair areas were typically in worse condition compared to the other repair types. The main crack tended to be wider, thereby causing roughness.

- Type 4 (Upside down wedding cake) – 200' project quantity, $5.80/ft construction cost
    - This type of repair was only performed on the worst cracks in the old surface. For example, one Type 4 repair was performed on a crack directly over a conduit trench. The repairs have performed pretty well considering the cracks that they replaced. Typically the repair area had one main crack plus a crack over the edge of the milled area.

The 600' long section of the runway that had a leveling course (nominal 2") placed before the chip seal is performing well. Only Type 3 repairs were performed in this section prior to the asphalt leveling course. The Type 3 repairs in this section were all in better shape than the ones in the other sections of the runway where the chip seal was applied directly to the old surface.

Jim Lawler thinks the overall condition of the repair areas are in better shape in the keel section of the runway than on the outer edges of the runway. This appeared to be true and could be caused by the kneading action of the traffic.

Mandan Airport – General View of Runway and Reflective Cracking



Reflective Crack Control project
Runway 13-31 north end

Companion RCC project
Runway 13-31 central

Reflective Crack Control project
Runway 13-31 south end

FAF to MAP 3.2 NM

Knots	60	90	120	150	180
Min:Sec	3:12	2:08	1:36	1:17	1:04

Figure 31 Location of pavement projects evaluated at Mandan Airport (map courtesy of FAA Aviation System Standards).

Site visit to Greater Peoria Regional Airport, IL
August 28, 2007
Attendees: Bill Weiss (ARA), Sean Smith (CMT)

Taxiway E

Taxiway E at Peoria was rehabilitated in 2001 with 3 distinct sections.

- Section 1 had 6" of the existing asphalt pavement milled off, then replaced with 6" of new asphalt;
- Section 2 had 2" of the old asphalt milled off of the entire surface, then milled (2" deep x 48" wide) off over wide (> 1") transverse cracks, then added a bituminous interstabilizing layer in crack milling, then "Glasgrid" (60" wide) over the crack milling, and 4.5" asphalt overlay over the entire pavement;
- Section 3 had 5/8" porous friction course added directly to the previous asphalt surface, then overlaid with 4.5" asphalt

The construction plans documented (by station) the location of the pre-construction wide transverse cracks within each of the 3 sections.

Site visit observations

Section 1 (Station 15+15 to 21+50)

- Mostly low severity cracks (≤ ¼" wide) at asphalt paving lane joints
- No random transverse cracks yet
- North lane has some random longitudinal cracking

Section 1 (Station 49+00 to 55+00)

- Mostly low severity cracks (≤ ¼" wide) at asphalt paving lane joints
- Found transverse cracks, all low severity, and 15' to 30' across, did not seem to coincide with previous transverse cracks

Section 2 (22+00 to 28+50, 32+50 to 48+00, 58+00 to 71+12)

- Nearly every pre-construction transverse crack has reflected through, typically as one crack at low severity, average around 35' across
- 3 pre-construction cracks were not treated with the interstabilizing layer; today these cracks have reflected through and average 55' across
- Mostly low severity cracks (≤ ¼" wide) at asphalt paving lane joints
- Also found occasional transverse cracks at locations not coinciding with pre-construction cracks; these cracks were typically 15' across and low severity
- Some random longitudinal cracking (low severity) found

Section 3 (28+50 to 32+50)

- 3 out of the 4 pre-construction transverse cracks have reflected through (all < 25' across)

- Some random longitudinal cracking (low severity) found

General Assessment
The deep mill (6”) and inlay (6”) for Section 1 appears to have eliminated the transverse cracks from the old surface reflecting through into the new surface. If the cracks in the previous surface were of the top-down variety, the depth of the milling has apparently removed the likelihood of having transverse reflective cracking. However, the new inlay could crack transversely but at locations independent of the previous cracks. It is unknown if the longitudinal paving lane joints were offset with respect to the joints in the old asphalt surface.

The treated (interstabilizing layer + Glasgrid) transverse cracks have reflected through in Section 2, but remain low severity and reflect through at a slower rate compared to the non-treated cracks within this section. Based on the wandering pattern of the existing cracks, it appears that the crack is over another crack and is not over the edge of the milled area.

Reflection cracks have occurred at 3 out of the 4 pre-construction documented crack locations in Section 3. The existing cracks have not reached full width across the taxiway and remain at low severity.

The techniques used in Sections 2 and 3 appear to ultimately allow reflective cracks to develop, but at more manageable state (crack width is < ¼”) and perhaps at a slower rate compared to a pavement with no pre-overlay repairs.

Peoria Regional Airport –
Control Section

Peoria Regional Airport –
Glasgrid Section

Peoria Regional Airport –
Strain Relieving Interlayer
Section

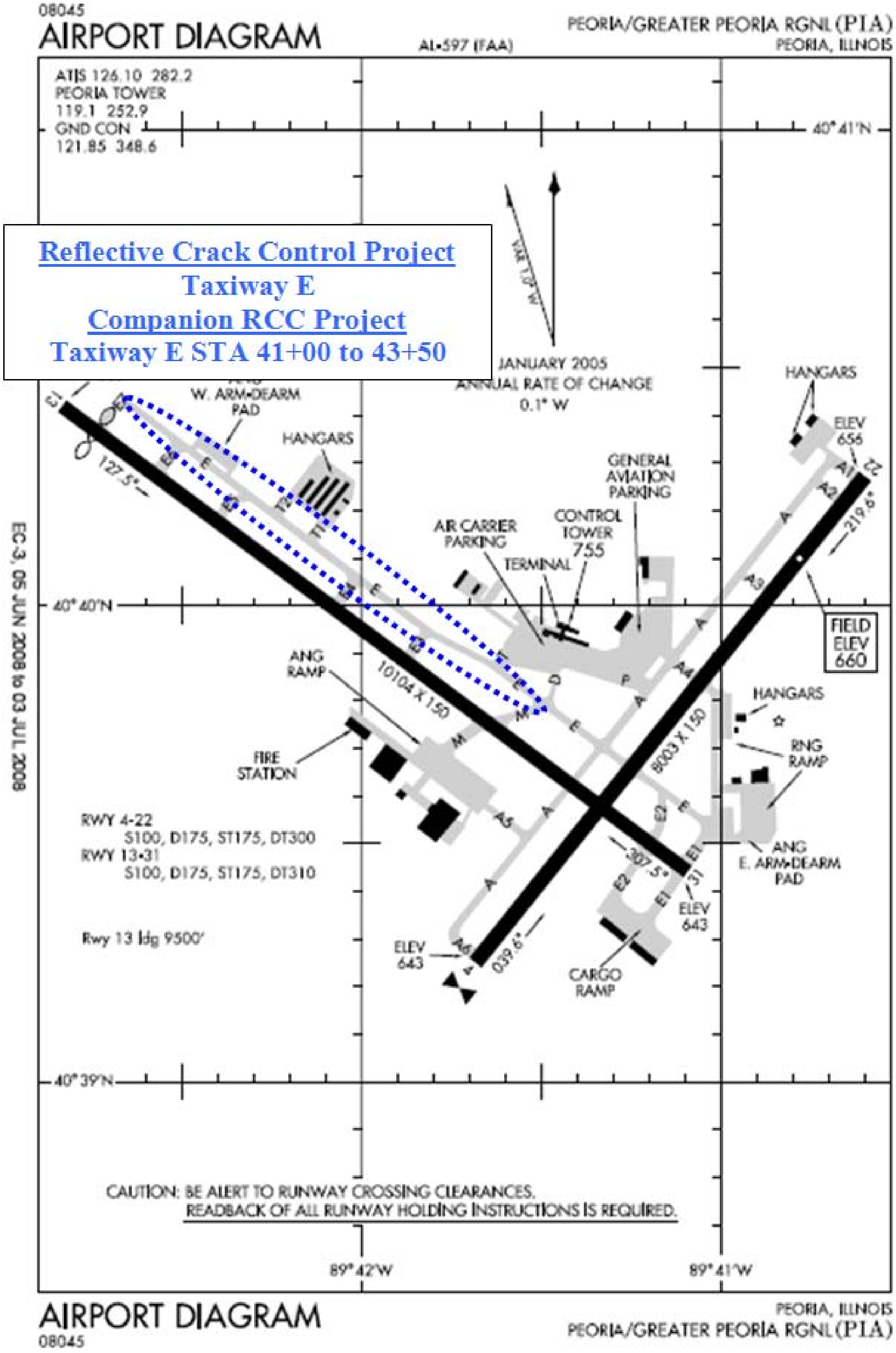


Figure 32 Location of pavement projects evaluated at Peoria Airport (map courtesy of FAA Aviation System Standards).

Site visit to Purdue University Airport (West Lafayette, IN)
August 27, 2007
Attendees: Bill Weiss (ARA)

Runway 10-28

Runway 10-28 is 6,600' x 150' and serves as the main runway at LAF. In 1997, the asphalt pavement (avg. 9.5") was pulverized, shaped, and compacted to grade. A 4.0" asphalt overlay was then placed on the pulverized surface which is still in place today. Full-width transverse saw cuts were made at 100' intervals on the runway to allow for expansion/contraction in the asphalt overlay.

Construction observations

From correspondence with Fred Loeffler of R.W. Armstrong: The general condition of the old HMA surface prior to pulverization-

> "The condition of the asphalt varied from poor to good. The pavement had two binder layers and a surface layer with some cores having a wedge course. The upper (surface) layer was typically in good condition however lower layers crumbled when removed from the core tube in half of the samples taken. There was, however, transverse cracks that were ½" or wider spaced at about 30 ft intervals throughout the entire length of the runway. The cracks went down to the subgrade."

Site visit observations (runway)

- The majority of cracking is at the longitudinal pavement lane seams
- Some random longitudinal cracks are present
- Very few transverse cracks, what ones exist start in a longitudinal direction and curve in the transverse direction
- The full-width transverse saw cut joints are performing well, no secondary cracking was found near the joints, original saw cut width was ½", measured most joints at between ¾" to 1.5" wide, a typical joint will be narrower near the centerline and wider near the edge of the runway
- Most prevalent distress on runway is weathering & raveling (mostly low severity) over the entire surface, the saw cuts for the grooving have worn edges
- 2006 PCI for the runway is 77

Taxiway connectors

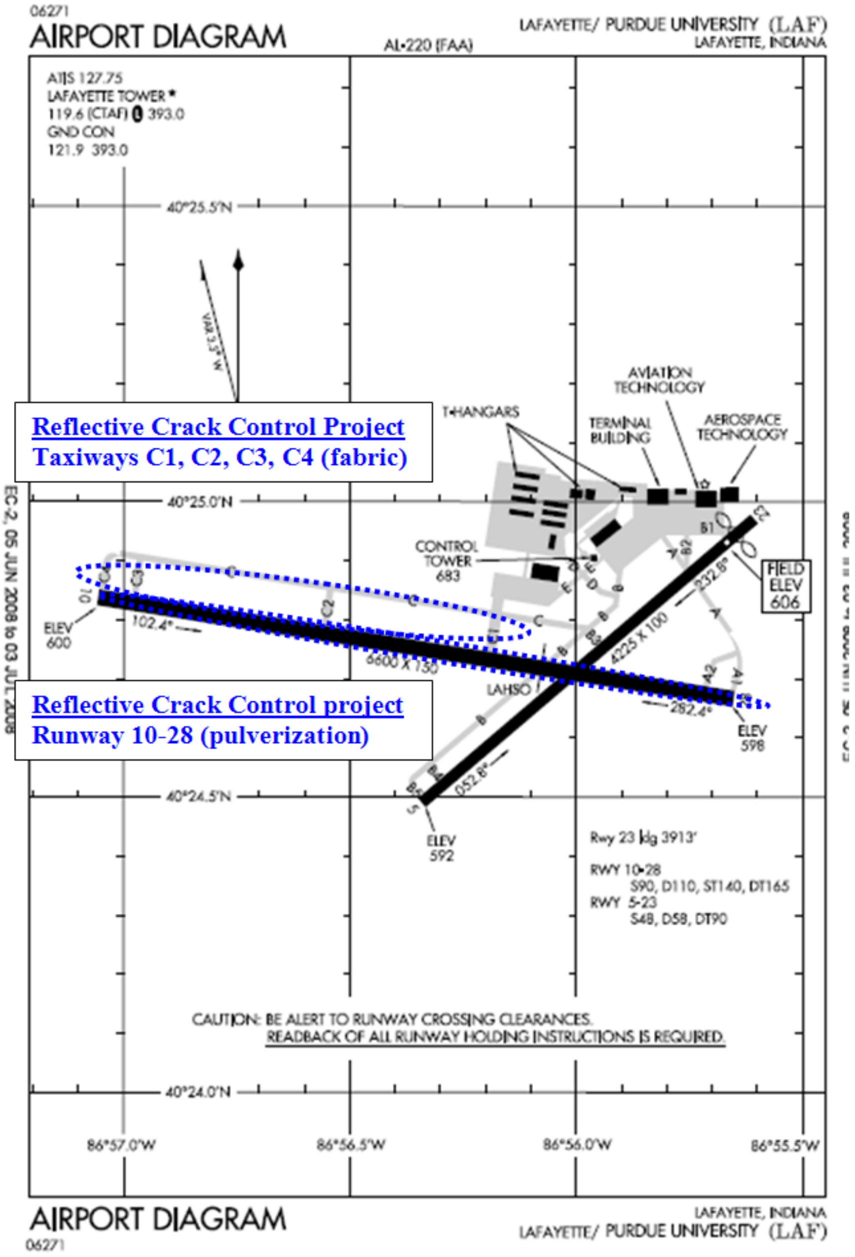
Portions of the adjoining taxiway connectors were not pulverized prior to the asphalt overlay. Cracks greater than ½" wide were cleaned, sealed, and had "PavePrep" placed over the crack prior to the overlay. The exact location of where the PavePrep material was installed is unknown. The current condition of the taxiway connectors is approximately the same as the runway (low severity cracking, weather & raveling) with PCI's ranging from 69 to 85 with an average of 75.

General Assessment

It appears the combination of the pulverization of the old asphalt surface and placing saw cuts at 100' intervals has virtually eliminated the occurrence of transverse cracking on this pavement. The majority of the longitudinal cracking is occurring at paving lane seams as expected for original or overlaid asphalt pavements.

Purdue University Airport – PavePrep Section with 4-inch P-401 Overlay for Taxiway Rehabilitation.

Purdue University Airport – Full-Depth Reclamation for Runway Rehabilitation.



Reflective Crack Control Project
Taxiways C1, C2, C3, C4 (fabric)

Reflective Crack Control project
Runway 10-28 (pulverization)

Figure 33. Location of pavement projects evaluated at Purdue Airport (map courtesy of FAA Aviation System Standards).

Site visit to Rantoul, IL Airport
August 9, 2007
Attendees: Bill Weiss (ARA), Jag Mallela (ARA), Stan Herrin (CMT)

Runway 18/36
West of centerline is polymer modified surface course; east of centerline is regular bituminous surface course without polymer. Overlay was constructed in 1999.

Original PCC is exposed and serves as shoulders for the 75’ wide runway.

Site Visit Observations:

Control section
- No cracking visible over PCC joints (1940’s era PCC, 8” thick with reinforcing wire mesh, 15’ long x 12.5’ wide slab size). HMA overlay thickness varies 2.5- 3.0”
- Low severity cracks (≤ ¼” wide) at asphalt paving lane joints

Saw and Seal section
- Measured longitudinal and transverse saw cut joints at 5/8” wide (1/2” wide at construction)
- Sealant is failing, exposed backer rod
- No visible secondary cracking at sawn joints
- Low severity cracks (≤ ¼” wide) at asphalt paving lane joints
- HMA overlay thickness varies 2.5” to 3.0”

ISAC section (placed on all PCC joints)
- Centerline is continuous low severity crack (paving lane joint + PCC joint)
- Low severity crack 14’ long at transition from saw & seal section to ISAC section
- Very slight snow blow scrapes at some transverse joints towards edge of runway
- Full-width heave over PCC transverse joint, approx ¼- ½” high, appears to be over regularly spaced expansion joint in PCC
- Typical slab size changes from 15’ long to 30’ long within this section
- More heaves (approx ½” high), but in an isolated area (11’ x 7’) not resembling a “speed bump,” area lines up with mid-panel and longitudinal joint
- Another heave of the “speed bump” variety (approx ½ - ¾” high), located only on the east side of the runway
- HMA overlay thickness varies 2.5” to 3.0”

18” Rubblized section
- Far east PCC longitudinal joint has very slight snow blow scrape in asphalt
- HMA paving lane joint has low severity crack with some secondary cracking
- Centerline is low severity crack

- "Speed bump" heave over utility trench
- Airport has milled off some heaves, crack in middle of milled areas evidence that rubblized PCC still functioning as a joint
- Ride had some random slight roughness
- HMA overlay thickness is 5"

9" Rubblized section

- Fairly random heaves over one transverse joint, high spots 1- 2," all on west side of runway
- One 6' low severity crack over longitudinal PCC joint
- Small heave (1/4") and reflective crack over transverse joint, outer 20' of runway
- Small isolated bumps within 5' of centerline, but not over a joint
- HMA overlay thickness is 5"

3" Rubblized section

- No cracks (except paving lane joints) or swells, but ride has some slight roughness
- HMA overlay thickness is 5"

General assessment

After 8 years the control section still has no cracking at the transverse joints. Even with the smaller slab size (15' long x 12.5' wide), one would still expect the joints to reflect through a 2.5" to 3" overlay, typically within the first 3 to 4 years.

The saw and seal section is also performing well in regards to controlling the location of the cracking. The sealant material has failed with the initial signs of failure occurring within 2 years after construction. Obviously, one of the keys to the performance of a saw and seal section is maintaining the joints to keep surface water from reaching the lower layers. So far the joints do not exhibit any subsidence or secondary cracking, but this is anticipated if the sealant is not replaced soon.

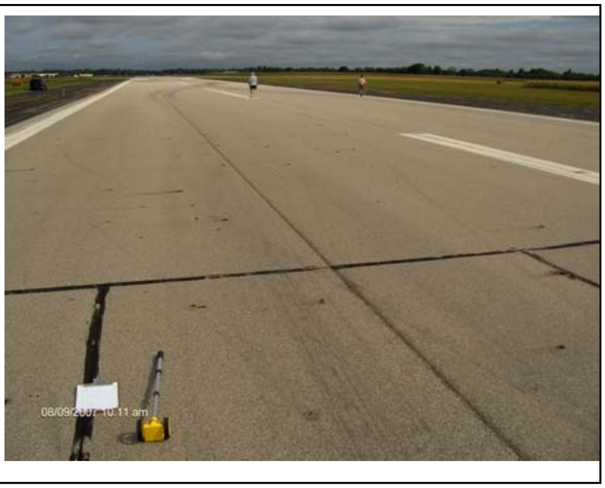
The ISAC section has kept the transverse joints from appearing, with the exception of some isolated heaves that have formed a crack. The heaves are mostly aligned with either an expansion joint in the underlying PCC or utility trench.

The 3 rubblized sections show a range of conditions corresponding to the designed maximum size of the particles. Thus far, the smaller the rubblized particle size, the better the condition of the asphalt. The 18" rubblized section has small amounts of cracking (non-paving lane joint) mostly related to heaves. The Airport staff has milled some of these heaved areas in order to restore the profile. In some cases, the crack associated with the heave continues into the milled pavement and is over a joint in the old PCC, indicating that the rubblized PCC is still performing like a joint in this area. It is important to remember that reinforcing wire mesh was found in this PCC. The 9" rubblized section also contained isolated heaves and associated cracking. The 3" rubblized section did not have cracking (except paving lane joints) or visible heaving. The ride characteristics (from a vehicle) over the rubblized sections all indicate some perceivable roughness, more so in the 18” and 9” sections. It appears that the smaller sized rubblization technique will add benefit to the final product based on the overall condition of the asphalt so far.

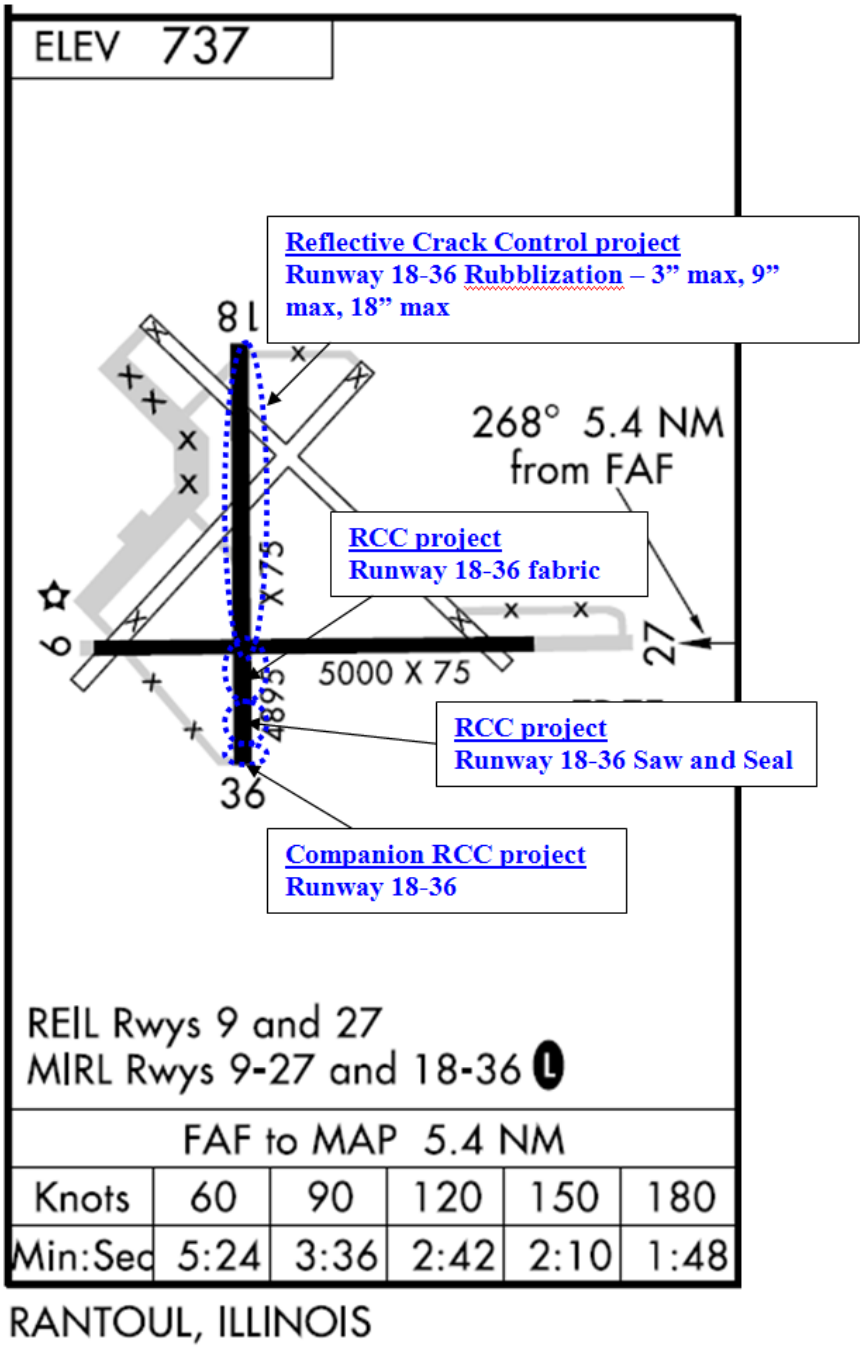
Rantoul Airport – Control Section

Rantoul Airport – Rubblized Section

Rantoul Airport – Saw and Seal Section



Rantoul Airport – ISAC Section; After Saw & Seal Section



FAF to MAP 5.4 NM					
Knots	60	90	120	150	180
Min:Sec	5:24	3:36	2:42	2:10	1:48

Figure 34. Location of pavement projects evaluated at Rantoul Airport (map courtesy of FAA Aviation System Standards).

Site visit to Smyrna (MQY) Airport, TN
October 5, 2007
Attendees: Bill Weiss (ARA), Dave Schilling (PBS&J), Lois Vallance (Smyrna Airport Manager), and John Black (Smyrna Executive Director)

Various Pavements at MQY

The original PCC pavements at MQY were built during the 1940's and have had thin asphalt overlays placed on top throughout the years. Located just south of Nashville, the traffic mix at MQY varies from GA traffic and private jets, all the way up to cargo carriers. Two different approaches have been used at MQY to mitigate reflective cracking, each are described below along with a control section.

- **Paveprep** – In 1993 and 1994 Paveprep was installed directly on all PCC joints and cracks > 0.5" wide prior to placing a thin (1.5") asphalt overlay on 4 taxiways. The Paveprep was 12- to 18" wide. The joints were routed prior to placing the Paveprep. The overlaid width of the taxiway is narrower than the original PCC taxiway width, thereby exposing the PCC joints on the "new" shoulder.

- **DBST –** After placing a tack coat on the PCC, a double layer chip seal (DBST) was placed with an approximate thickness of 0.5." A thin (1.5") asphalt overlay was then placed on top of the DBST. The DBST layer was "day-lighted" by extending it beyond the limits of the asphalt layer. The overlaid width of the taxiway is narrower than the original PCC taxiway width, thereby exposing the PCC joints on the "new" shoulder. This approach was used on projects in 1994, 1995, and 2000.

- **Control** – Thin (1.5- 2.0") asphalt overlays were placed directly on the PCC in 1983, 1993, and 1994.

So far the DBST sections are performing better than the Paveprep and control sections. There is less overall cracking in the DBST section and the severity of the cracks is mostly low. The Paveprep and control sections are in approximately the same condition based on the percentage of reflective cracks and their severity.

Construction Observations

For the 1993 project the Paveprep material was placed without difficulties, but initially was getting stuck to the equipment tires during the asphalt overlay placement. The installed Pavprep material was exposed for several days before the overlay was placed.

The only noted DBST issue involved a taxiway where too much tack coat was placed prior to placing the DBST and asphalt overlay layers. The excess tack has bled through the asphalt layer at a density that could cause slick spots.

Site Visit Observations

The thin overlays placed on top of the DBST and Pavprep layers leaves little margin for either material to mitigate reflective cracking for very long. However, the severity of the individual cracks still provides an indication of how effective the material is performing.

- Paveprep
    - The 1993 projects (Taxiways H, G, and D) involving Paveprep had all of the joints reflect through. Some cracks had progressed to medium and high severity causing FOD issues. On Taxiway H, the asphalt lift had worn away in spots exposing the Paveprep material. The nominal asphalt design thickness of 1.5" was actually measured at ¾ to 1" thickness at these areas. In addition, the area surrounding this taxiway has poor drainage characteristics. Located just north of Taxiway H, Taxiway G was in better condition, probably because the asphalt overlay was closer to the design thickness of 1.5," and better drainage characteristics. Taxiway D was where portions of the installed Paveprep material became stuck to equipment tires. Because of this, not all joints had the Paveprep in place when the asphalt overlay was placed. Currently the cracks are mostly low severity, with some at medium severity.

    - The 1994 project on Taxiway A involved placing two lifts of asphalt. After placing the first lift of asphalt, slight bumps were felt over the Pavprep locations so it was decided that a second lift would be placed in order to eliminate this roughness. The total HMA overlay thickness is estimated to be 1.5" to 2." All joints and cracks have reflected through, most still at low severity.

    - An interesting note on the Paveprep sections is that the installation of the Paveprep was stopped at the edge of the taxiways (double yellow lines), but the asphalt overlay continued to taper out on the PCC shoulder for several more feet. Currently, the cracks over the Paveprep joints appear approximately the same compared to the cracks in the shoulder where no Paveprep was installed.

- DBST
    - The first installation of DBST occurred in 1994 on Taxiway F. The joints that have reflected through are low severity; however, the main concern on this taxiway is a subsurface drainage issue that is causing pumping. Also, this taxiway had too much tack coat applied prior to placing the DBST layer, which has bled through to the asphalt surface in spots.

    - In 1995 the DBST was placed in Taxiway J. This section has performed the best with some joints not reflected through at all and only low severity reflective cracks at other joints. It is easy to see the PCC joint locations because the edges of the PCC taxiway now serve as shoulders. The ride remains good on this taxiway.

    - In 2000, the DBST was placed on an apron area. This apron is surrounded by other pavement sections so the DBST was not day-lighted as on the taxiway sections. Also, the design thickness of the asphalt overlay was 3" (2 lifts). The apron is currently in excellent condition with only isolated low severity cracks.

- Control Section
    - HMA overlays were placed directly on the PCC surface on Taxiway F (1983) and Taxiway A (1994). The 1.5” to 2” thick overlays have reflected through the joints and cracks from the underlying PCC. For Taxiway F, the longitudinal and transverse reflective cracks are mostly low severity, except where they intersect and resemble medium to high severity. The reflective cracks on Taxiway A are all low severity cracks.

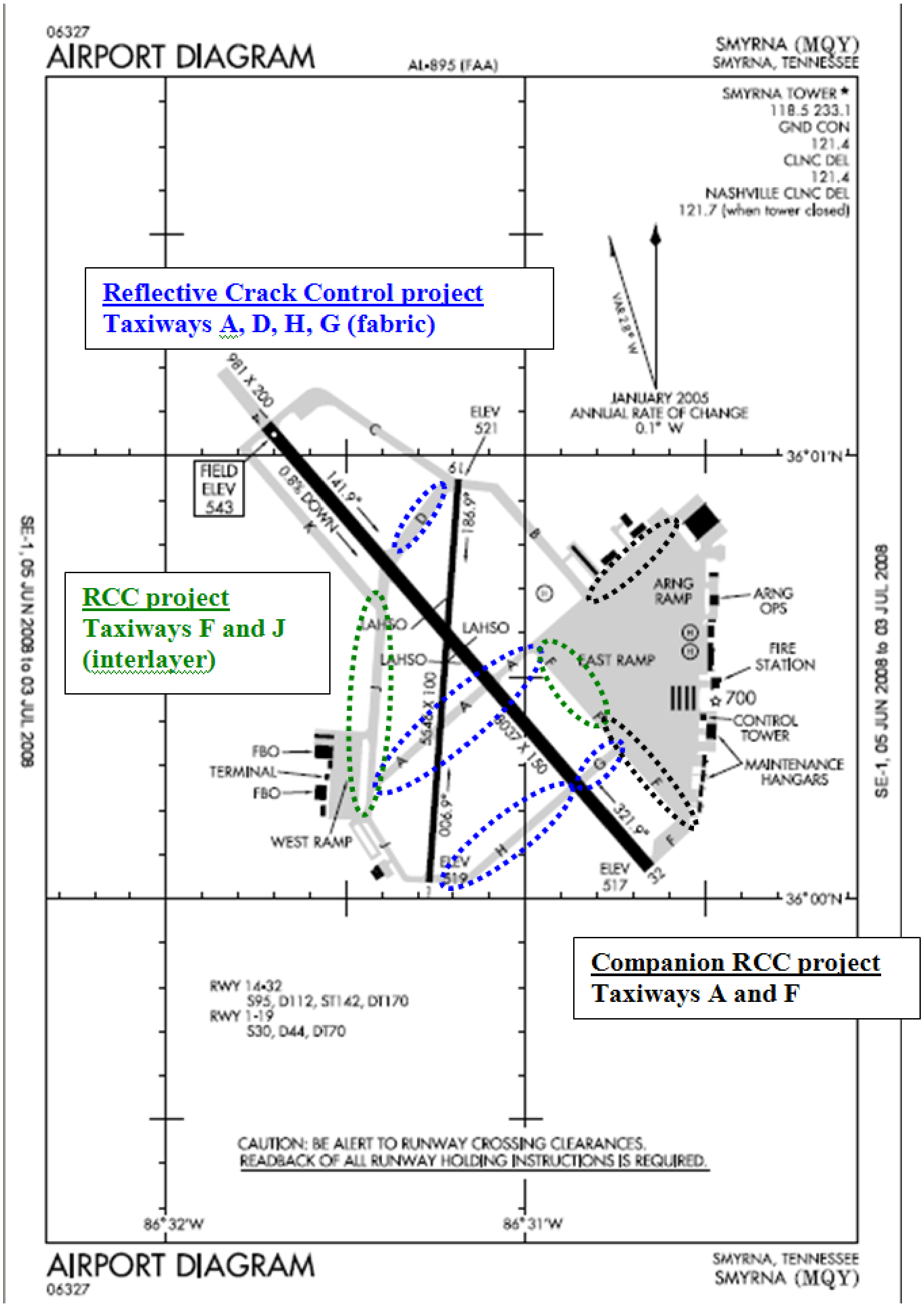


Figure 35 Location of pavement projects evaluated at Smyrna Airport (map courtesy of FAA Aviation System Standards).

PavePrep Characteristics

Paveprep was used on many of the airfields reviewed. Considering the popularity of "PavePrep" material, experienced PavePrep users (designers and contractors) were interviewed during this study. Their comments on the application, installation, and performance of PavePrep are summarized below.

a) Placement criteria

PavePrep installation is fast and economical requiring no special equipment. Unroll at the job site and apply. Use PavePrep on milled and unmilled surfaces with the application of a paving grade asphalt tack coat. PavePrep SA (Self Adhesive) comes with a peel-and-stick adhesive on the application side and does not require a tack coat for most surfaces.

Depending on the severity of pavement cracks, different types of repair prior to overlay is suggested and listed as follows:

A. Minor crack – apply crack seal (too small for backer rod typically)
B. 1/4" crack and/or secondary cracking – apply crack seal (no backer rod typically)
C. 1" wide crack – apply backer rod, crack seal, PavePrep
D. Cracks > 1" wide – full depth repair including PavePrep

PavePrep performance is optimized on pavement surfaces that do not exhibit structural deficiencies or drainage problems. When there is extensive block cracking or random cracking in the existing pavement, or the area has a high water table, PavePrep material is not recommended. Instead, the designers and contractors opted to mill the existing pavement, and place a 3 to 4 in HMA overlay. This occurred in 2003 at North Vernon Airport (IN) and was reported to be in great shape.

b) Constructability

Several issues can be common and critical during the construction process, such as construction traffic, density, and timing. The self adhesive PavePrep (PavePrep SA) can sometimes get stuck to the tires of construction trucks delivering the HMA to the paver or the paver itself. Bret Campbell's successful experience is to place PavePrep first, then apply a tack coat to the PavePrep material. Spray diesel fuel to the truck tires and paver wheels ahead of the overlay. The diesel fuel is applied using bug spraying equipment and acts as a bond breaker between the construction equipment and the PavePrep material.

Bret Campbell believes that the PavePrep material really acts as a "cushion" for the vibratory roller compacting the first lift of HMA. Densities were lower over the PavePrep locations and the contractor was unable to achieve the specified density until the third lift of HMA was placed. The initial HMA lifts had a crack pattern that resembled "checking" over the width of the PavePrep material (typically installed at 12 to 18 in wide).

Since the typical contractor would prefer to install all of the PavePrep first, and then commence with all of the paving, this scenario would usually result in PavePrep that is installed, but has not been overlaid and remains exposed overnight. The concern here is humidity or rain could be absorbed by the PavePrep material during this time. Moisture trapped in the PavePrep would have a detrimental effect on the long term performance of the overlay.

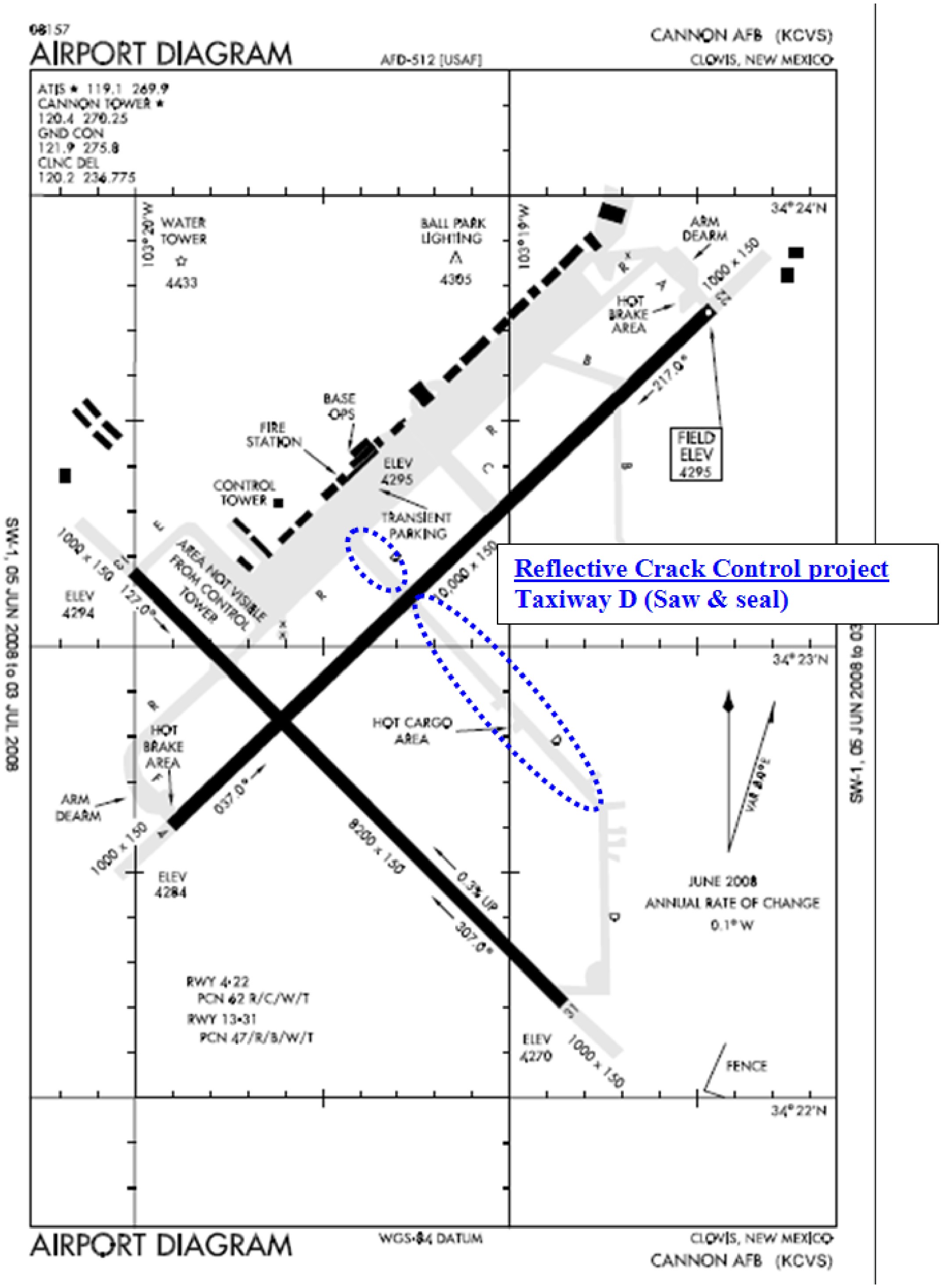
c) Roughness

Bret Campbell from Butler, Fairman, & Seufert noted that the ¼ in thickness (specification says it's 0.135 in) of the PavePrep material could be detected with a 16 ft straight edge set at 1/16 in. The "bump" could be felt in a vehicle, but more so in an aircraft. At sunrise or sunset the bump would be more visible because of the shadows. This is built-in roughness and is noticeable as soon as the pavement is open to traffic. The thicker the overlay, the less rough it is and user does not feel that roughness as much.

d) Good Practice

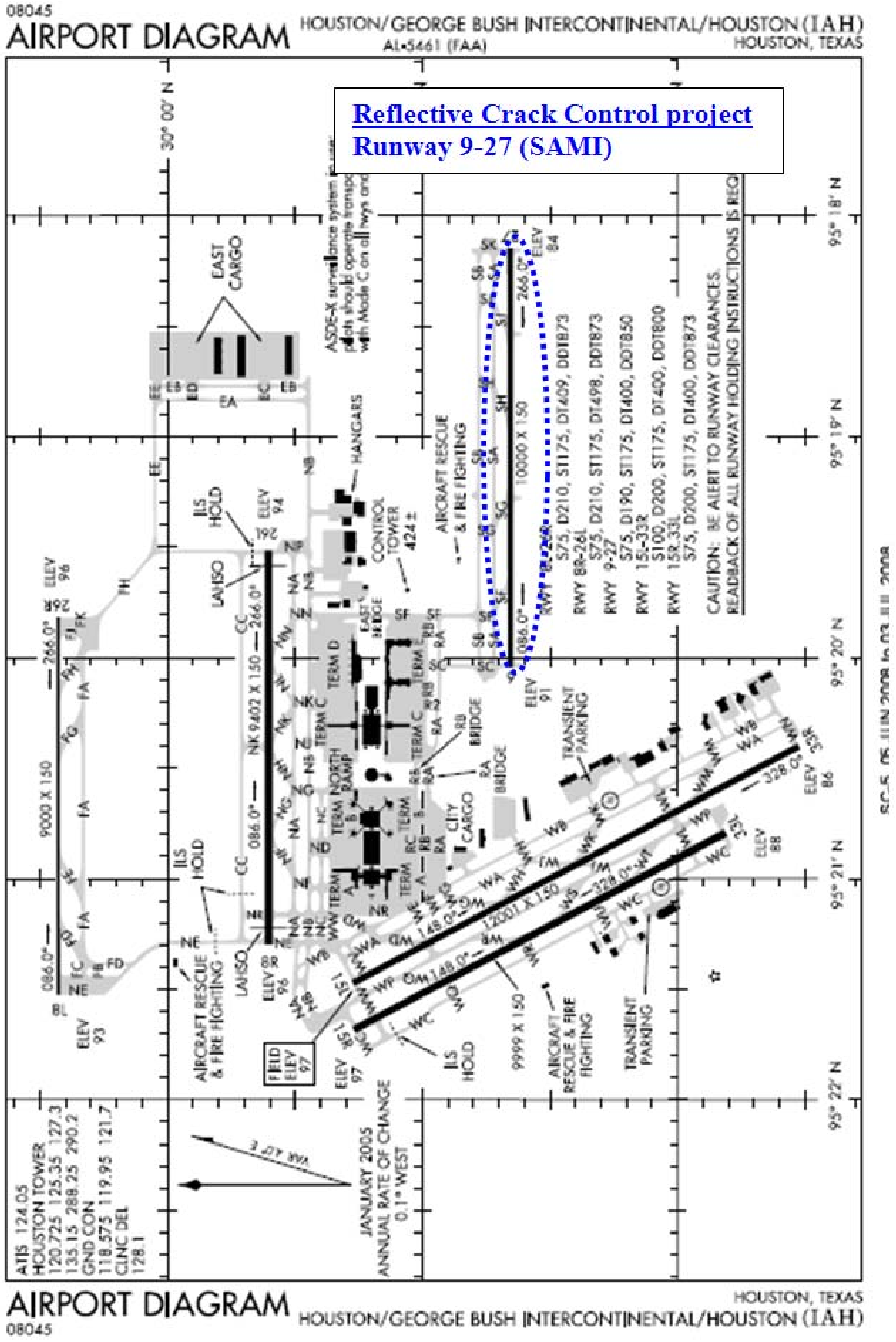
A policy adopted by one design firm is to not place any paving lane joint/seam closer than 1 ft from a PavePrep location (this may only apply to the lift placed on top of the PavePrep). This needs to be communicated early in the process so the contractor and Engineer know to adjust paving widths and patterns in the field. Also, they always offset the joints between successive lifts of the HMA overlay. The objective is to make it as difficult as possible for the water to make it through the pavement cross section.

The remainder of Appendix C includes airport diagrams for some of the other airfields that were included in the interviews, but the distress surveys were conducted by different airport personnel, so the notes were not included within the appendix.



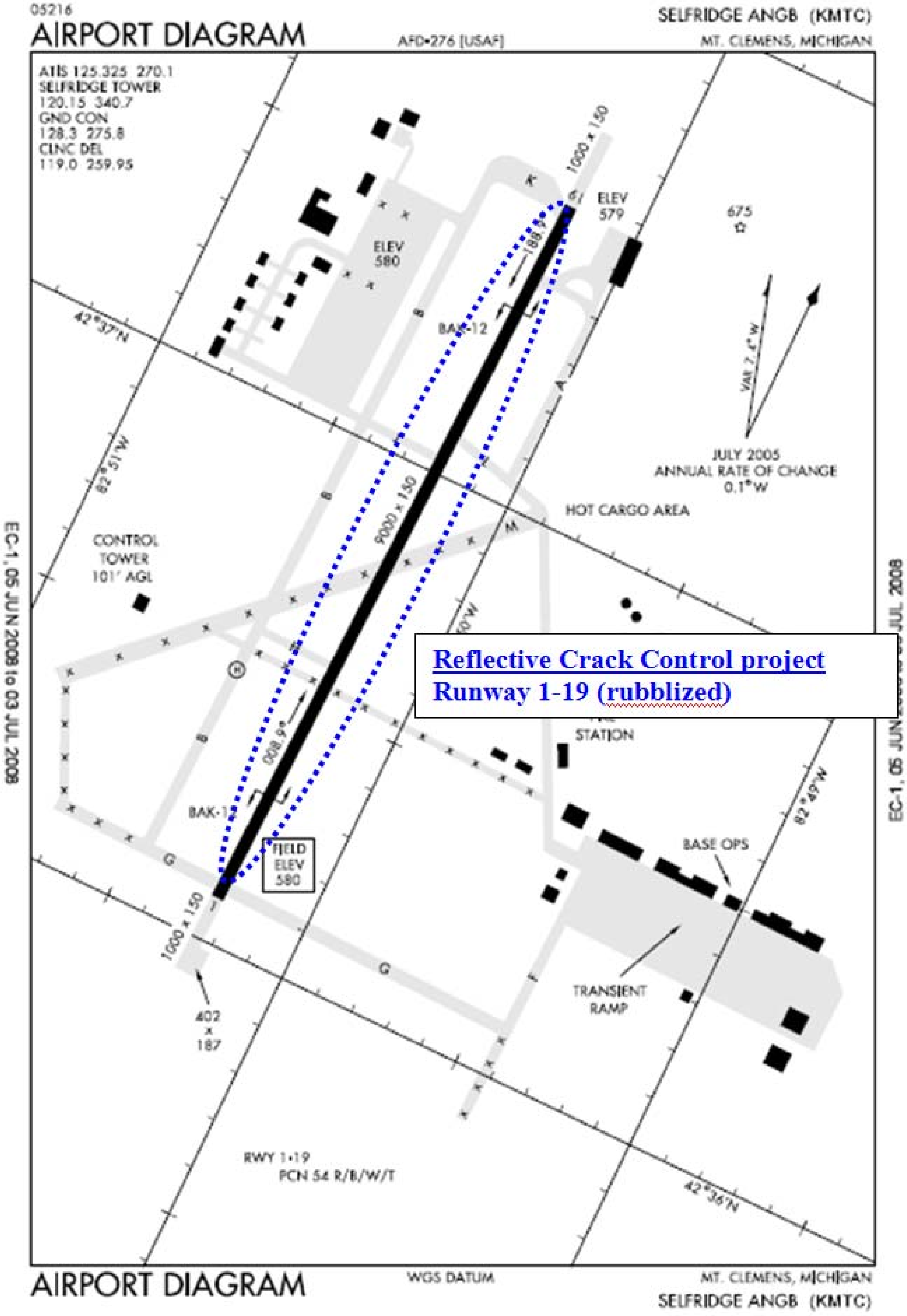
Reflective Crack Control project
Taxiway D (Saw & seal)

Figure 36. Location of pavement projects evaluated at Cannon AFB (map courtesy of FAA Aviation System Standards).



Reflective Crack Control project
Runway 9-27 (SAMI)

Figure 37 Location of pavement projects evaluated at Houston George Bush Intercontinental Airport (map courtesy of FAA Aviation System Standards).



Reflective Crack Control project
Runway 1-19 (rubblized)

Figure 38 Location of pavement projects evaluated at Selfridge ANGB (map courtesy of FAA Aviation System Standards).

[This page intentionally left blank.]