NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE 171

FABRICS IN ASPHALT OVERLAYS AND PAVEMENT MAINTENANCE

TRANSPORTATION RESEARCH BOARD
National Research Council

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE 171

FABRICS IN ASPHALT OVERLAYS AND PAVEMENT MAINTENANCE

RICHARD D. BARKSDALE
Georgia Institute of Technology
Atlanta, Ga.

Topic Panel

JAMES F. CONDRON, *Federal Highway Administration*
DANIEL W. DEARASAUGH, JR., *Transportation Research Board*
CURTIS J. HAYES, *Oklahoma Department of Transportation*
PETER KLESCOVIC, *Maryland Highway Administration*
FRANK R. McCULLAGH, *Transportation Research Board*
NELSON PREDOEHL, *California Department of Transportation*

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. JULY 1991

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NOTE: The Transportation Research Board, the National Research Council, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the individual states participating in the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

NCHRP SYNTHESIS 171

Project 20-5 FY 1988 (Topic 20-01)
ISSN 0547-5570
ISBN 0-309-04919-9
Library of Congress Catalog Card No. 90-72110

Price $9.00

Subject Areas
Bituminous Materials and Mixes
General Materials
Maintenance

Mode
Highway Transportation

NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the Federal Government. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

The Transportation Research Board evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to pavement designers, maintenance engineers, and others interested in methods and procedures for reducing reflection cracking of asphalt overlays. Information is provided on the use of paving fabrics and membranes in pavement rehabilitation.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

Reflection cracking of pavement overlays results in decreased pavement performance with respect to ride quality, structural support, skid resistance, and safety. The use of fabrics is one of the alternatives that are available to reduce or delay reflection cracking. This report of the Transportation Research Board describes the experiences of agencies in the use of fabrics and membranes for reduction of reflection cracking.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

ACKNOWLEDGMENTS

This synthesis was completed by the Transportation Research Board under the supervision of Robert E. Skinner, Jr., Director for Special Projects. The Principal Investigators responsible for conduct of the synthesis were Herbert A. Pennock and Sally D. Liff, Senior Program Officers.. This synthesis was edited by Judith Klein.

Special appreciation is expressed to Richard D. Barksdale, Professor of Civil Engineering, Georgia Institute of Technology, who was responsible for the collection of the data and the preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of James F. Condron, Highway Engineer, Federal Highway Administration; Curtis J. Hayes, Branch Manager, Oklahoma Department of Transportation; Peter Klescovic, District Engineer, Maryland Department of Transportation; and Nelson Predoehl, Materials and Research Engineering Associate, California Department of Transportation.

Daniel W. Dearasaugh, Jr., Senior Program Officer, and Frank R. McCullagh, Materials Engineer, Transportation Research Board, assisted the NCHRP Project 20-5 Staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

FABRICS IN ASPHALT OVERLAYS AND PAVEMENT MAINTENANCE

SUMMARY

Reflection cracking of pavement overlays is generally regarded as undesirable. The use of fabrics is among the alternatives that are available to reduce or delay that cracking.

Stress-relieving interlayers (including paving fabrics saturated with asphalt) have been used frequently in an attempt to reduce or delay reflection cracking. Their effectiveness in reducing reflection cracking is related to joint or crack movement in the underlying pavement, crack width, overlay thickness, climate, and traffic volume. Movements affecting reflection cracking include load-induced differential displacement, horizontal movement caused by temperature change, and curling and warping of concrete slabs. Use of an interlayer may enhance overlay performance by relieving stress, by reinforcing the pavement, by reducing water infiltration, or by a combination of these.

When paving fabrics are used in stress-relieving interlayers, there are several characteristics that are of concern. Tack coat application is critical, and tests have been devised to determine the correct quantity. There is some concern that fabrics may shrink when exposed to hot asphalt, and methods are available to test for this. Interface shear strength can be evaluated to be sure that shear stresses from traffic will not cause slippage of an overlay. Permeability tests will reveal whether a fabric saturated with asphalt reduces penetration of water into lower layers.

Various types of fabrics and grids have been used, at least experimentally, as a means of reducing reflection cracking of asphalt concrete overlays over flexible pavements. Functions of these materials are similar to those of other interlayers: relieving stress, reinforcing the pavement, and reducing water infiltration. Fabrics used for full-width applications may be either woven or nonwoven; the latter are most frequently used in stress-relieving interlayers. Specifications have been developed by several agencies for use of fabrics in interlayers.

Construction aspects of fabric interlayers should be given careful consideration. These include pavement preparation, tack coat selection and application, fabric placement, rolling, and whether traffic is allowed on the fabric.

The field performance of overlays using fabric interlayers has ranged from clear successes, in which an overlay with fabric had only a small fraction of the cracking of a control section, to failures in which the overlay with the fabric performed worse than a similar overlay without fabric. The variable performance is related to type and extent of existing pavement distress, remedial work performed before overlay, overlay thickness, variability of pavement strength, and climate. In general, fabric interlayers have performed best when used for load-related fatigue distress and have been ineffective when used to retard thermal cracking. A potential benefit of fabrics is the reduction

of water entering the pavement; however, this benefit needs to be documented with carefully planned field studies.

High-strength and high-stiffness grids and mats have been used for either strip or full-width applications. Performance has been mixed and should not be considered conclusive; more studies are needed, although the high cost of the materials necessitates greatly improved performance.

Heavy-duty membranes and paving fabrics have been used on portland cement concrete (PCC) pavements to reduce reflection cracking of an asphalt concrete overlay. They are usually used as strips placed over the PCC joints, although there have been some full-width applications. In addition to reducing reflection cracking, another benefit expected from the use of fabrics and membranes is the reduction of water entering the pavement, thus reducing pumping, decreasing slab movement, and increasing subgrade strength.

Performance of fabrics and membranes on PCC pavements is poorer than on asphalt pavements. The performance is influenced by large load and thermally induced movements at joints, which impose severe bending, tension, and shear on the overlay. There has been a wide variation in results of experimental studies, in large part caused by variation in the strength of the PCC pavement throughout the length of the projects. On projects in California where fabric use was considered successful, reflection cracking was delayed about a year; no slab or joint repair was done before the overlay. In states where extensive joint repair was done before overlay, use of fabrics or membranes delayed reflection cracking for three to five years.

Fabrics have not been used extensively in maintenance operations. It appears that they can be used successfully when the width of cracks is less than ⅛ in. The major benefit is reduction of water infiltration. Fabrics have been used beneath skin patches and chip seals, membranes have been used as cover over pothole repairs, and fabric membranes have been used as vertical and horizontal moisture barriers. Little published research is available on these applications.

Performance of fabrics used for overlay applications has ranged from successes to failures. Substantial field experience indicates that fabric interlayers used on flexible pavements only delay reflection cracking. The pavements that are candidates are those with fatigue distress not caused by base or subgrade failure and with cracks generally less than ⅛ in. wide. Fabrics are not effective when wide temperature and shrinkage cracks are present. Fabrics should not be used over PCC pavements if vertical joint deflections are greater than 0.008 in. unless corrective measures are taken. Horizontal thermal movement should be less than 0.05 in. Overlay thicknesses should be designed as if no fabric interlayer or strip membrane is present, preferably using a deflection-based design method. Overlay over strip membranes should be at least 2 in. thick.

The costs of fabrics, heavy-duty membranes, and other reflection-cracking-improvement techniques are influenced by the material used, the quantity to be placed, local experience, local labor costs, and the general marketplace. Economically feasible techniques that prevent reflection cracking for the life of an overlay have not been identified. Under favorable conditions a number of methods can delay reflection cracking for two to four years. Reflection cracks are usually sealed through a maintenance program, and the costs of such a program should be considered when making cost comparisons.

A delay in pavement cracking improves ride quality and may provide a benefit through reducing water infiltration into the pavement structure; these benefits are hard to quantify. Also, paving fabrics are not always effective in reducing reflection cracking, and thus the probability of success should be included in economic analyses. Comparisons of total cost over the life of the overlay should be done for the two or three most promising alternatives and compared with conventional overlay procedures. At a minimum, the cost of using fabric interlayers or other techniques should be compared with that of a conventional overlay of similar thickness with a crack-sealing program. Thicker overlays could also be used for cost comparison. A number of studies have found that, even where successful, fabric interlayers are not cost-effective, although they may be cost-effective over flexible pavements if quantifiable benefits can be derived from improvements in aesthetics, improved ride quality, or permeability reduction.

There are alternatives to the use of fabrics and heavy-duty membrane interlayers for reduction of reflection cracking. Among these are increased thickness of asphalt overlay; decreased viscosity of asphalt; additives such as sulfur, carbon black, fibers, polymers, and rubber; use of stress-relieving interlayers such as rubber asphalt or low-viscosity asphalt concrete (AC); aggregate cushion interlayers; steel reinforcement; bond breakers over PCC joints; and modification or rehabilitation of the existing pavement by heater-scarifying, reducing joint spacing by cracking and seating, and sawing and sealing.

Paving fabrics and heavy-duty membranes can be used to delay reflection cracking for a few years. This strategy, like all others, must be engineered carefully and is not a quick, easy solution suitable for all pavements in need of rehabilitation. Generally, the use of paving fabrics for delaying reflection cracking is not justified unless the benefits from permeability reduction are considered. These benefits, however, have not yet been quantified. Both old AC and PCC pavements that are to receive an overlay must be repaired carefully, including replacing failed sections, patching and sealing cracks and joints, and, where required, undersealing. On flexible pavements, under favorable conditions, moderate to significant levels of reflection cracking in AC pavement overlays can be delayed two to four years, and in a few instances as long as five years, by using a full-width paving fabric interlayer. On PCC pavements, paving fabrics and heavy-duty membranes can also be used to delay reflection cracking in PCC pavement overlays by about two to four years under quite restrictive conditions: (a) vertical load-induced Benkelman beam joint movements must be between 0.002 in. and 0.008 in. and (b) horizontal, thermally induced joint movements must be less than 0.05 in.

A considerable amount of research has been conducted to develop techniques for reducing or eliminating reflection cracking. The potential benefits to be realized if reflection cracking is delayed for several years, and the maximum costs that can be justified to achieve this delay, are not entirely clear and need to be established. This would allow future research to properly focus on potentially cost-effective techniques.

CHAPTER ONE

INTRODUCTION

The highways constructed during the late 1950s and 1960s as a part of the Interstate system, and other roads developed to accommodate an expanding economy during that era, have reached the end of their design lives and, as expected, are now rapidly deteriorating. The use of fabrics and grids, developed during the 1970s and 1980s, offers a possible alternative for rehabilitating these highways.

Rehabilitation programs are consuming an increasing percentage of the available transportation system construction funds each year. Selected rehabilitation schemes should return the pavement to a safe condition and provide a high level of serviceability. The rehabilitated pavement should have sufficient structural strength to perform satisfactorily throughout its new design life. These goals must be accomplished at a minimal cost to preserve the limited available funds. Selecting the most economical rehabilitation procedure for a given project requires a thorough understanding of the limitations, performance, and associated costs of each viable design alternative. At the present time, much needs to be learned about the performance of available rehabilitation procedures and their cost-to-benefit relationships.

REHABILITATION METHODOLOGY

A suitable pavement rehabilitation scheme including the use of fabrics, grids, and membranes, just like any other design, must be carefully engineered from its condition evaluation study through its material specifications and construction stages. Finn and Monismith (*1*) identify the following important factors that must be determined and evaluated before selecting a resurfacing or rehabilitation treatment:

- Present pavement condition, in terms of smoothness and distress.
- Traffic, past and future, in terms of volume and vehicle weight.
- Structural evaluation of existing pavement.
- Environment, represented by rainfall and temperature (both high and low regimes).
- Drainage of both surface and subsurface water.
- Terrain features (i.e., mountainous, flat, cut or fill, and transitions).
- Constraints imposed by contiguous structures (i.e., bridges, drainage structures, curbs and gutters, shoulders).
- Design life of the new treatment.
- Materials in the original construction and planned for the rehabilitative treatment.
- Existing pavement age.
- Maintenance history (frequency, cost).

Several important factors deserve special attention when dealing with fabrics and membranes (i.e., the current level of pavement deterioration, traffic volume, and the pavement's current structural strength). Rehabilitation can vary from chip seal resurfacing on a low-volume road to complete reconstruction of a badly deteriorated Interstate pavement. For pavements in reasonably sound condition, subjected to moderate to heavy traffic volumes, a common solution is an asphalt concrete (AC) overlay for the deteriorating pavement.

AC overlay reflection cracking has been a serious concern associated with rehabilitated pavements from as early as 1932, when Gray and Martin (*2*) studied this problem. Their investigation showed that increased overlay thickness delays reflection cracking in asphalt concrete overlays placed on portland cement concrete (PCC) pavements. Using increased overlay thickness is still one of the most effective methods for delaying reflection cracking in AC overlays. Considerable effort has been expended over the years to develop alternative techniques for reducing reflection cracking. Proposed methods for delaying or reducing reflection cracking in overlays for flexible AC and PCC pavements can be grouped into four general categories:

- Add special interlayers under the AC overlay.
- Modify the AC overlay.
- Reinforce the AC overlay.
- Modify or rehabilitate the existing pavement.

Table 1 summarizes, by category, specific methods that have been tried in an attempt to reduce reflection cracking. The success level of these rehabilitation techniques has varied considerably. Consequently, only limited progress in developing special techniques for delaying reflection cracking can be reported to date.

WHAT COST TO DELAY REFLECTION CRACKING?

Everyone agrees that delaying reflection cracking is desirable. Reflection cracking usually results in deteriorating pavement performance in the safety, skid resistance, ride quality, and structural support aspects of the rehabilitated surface. To delay reflection cracking, however, has been relatively expensive and not always successful. An appropriate question is what cost is justified to accomplish this goal. Although largely unanswered at this time, Hughes and McGhee (*3*) describe the results of a survey conducted in 1973 by the Virginia Highway Research Council. The questionnaire survey of about 60 Virginia transportation administrators and engineers investigated the detrimental effects of reflection cracking in overlays placed over PCC pavements and the realistic cost to reduce such cracking. A brief summary of these significant findings is as follows:

- Sixty-seven percent of the respondents felt transverse cracks are moderately detrimental.

TABLE 1
METHODS TRIED FOR REDUCING OR DELAYING REFLECTION CRACKING OF AC PAVEMENT OVERLAYS

A. INTERLAYERS
  1. Stress-Absorbing Interlayer
    a. Asphalt or rubber layer with stone chips (SAMI)
    b. Paving fabric saturated with asphalt
    c. Softer asphalt layer
  2. Cushion Interlayer
    a. Open-graded asphalt concrete mix
    b. Unstabilized granular layer
    c. Asphalt-stabilized soil aggregate
  3. Bond Breakers at Joints of PCC Pavements
    a. Sandcushions, aluminum foil lamina, wax paper, sisal paper, tar paper, polyethylene, polypropylene fabric, galvanized sheet metal

B. MODIFY ASPHALT CONCRETE OVERLAY
  1. Increase asphalt concrete thickness
  2. Modify the asphalt cement
    a. Soft asphalt cement
    b. Rubber asphalt cement (latex and neoprene rubber)
    c. Carbon black with soft asphalt cement
    d. Fiber asphalt cement (asbestos, polyester, poypropylene)
    e. Polymer, sulfur, modified asphalt cement
    f. Dry lime
  3. Saw-cut AC overlay and seal joints

C. REINFORCEMENT OF AC OVERLAY
  1. Steel wire mesh
  2. Expanded metal
  3. Polymer grids
  4. Glass grids

D. MODIFY/REHABILITATE OLD PAVEMENT
  1. Flexible pavement
    a. Maintenance--seal joints, repair raveling, replace structurally failed areas; patches, leveling/scratch courses
    b. Seal coat
    c. Heat scarifier
    d. Hot/cold recycling
  2. PCC pavement
    a. Rehabilitate--underseal, seal joints, replace joints and deteriorated areas, grind surface, install load transfer devices
    b. Reduce joint spacing
      1. Crack and seat
      2. Saw new joints
      3. Rubblize

• Fifty-three percent of the respondents felt that the detrimental effects of cracking influence ride quality and future maintenance.

• The general consensus was that a realistic cost to delay reflective cracking would be the cost to repair the cracks.

A further conclusion drawn from the Hughes and McGhee survey is as follows:

> In areas where no defect other than reflective cracks are present the increased cost may be held to 25% and should extend the life appreciably. Where the present cracking is more extensive, the increased [rehabilitation] cost may amount to 100%, but should, optimistically, double the life of the overlay.

PURPOSE OF SYNTHESIS

In the past, the role of fabrics and membranes in pavement rehabilitation has not been defined clearly and often has been misunderstood. As a result, these materials have been used frequently for conditions where they are not suited, leading to widely variable performance and sometimes disappointing results.

The primary purpose of this synthesis is to summarize the behavior and present use of paving fabrics and heavy-duty membranes in pavement rehabilitation. In addition to fabrics and membranes, polymer and glass grids are also considered briefly. Chapter 2 considers the basic mechanisms associated with the performance of these materials and also discusses laboratory testing especially developed for paving fabrics. The following specific applications of paving fabrics and heavy-duty membranes are discussed in Chapters 3, 4, and 5, respectively:

Resurfacing of flexible (AC) pavements
Resurfacing of rigid (PCC) pavements
Rehabilitation through maintenance

Chapter 6 considers the requirements for an engineered overlay design and for planning experimental test sections using fabrics and membranes. Cost comparisons and life-cycle costs are also discussed. Finally, a brief review of other techniques used for delaying reflection cracking is given in Chapter 7. Chapter 7 summarizes and updates Synthesis 92 (*4*).

CHAPTER TWO

BASIC CONSIDERATIONS IN USING STRESS-RELIEVING INTERLAYERS

Thin stress-relieving interlayers have been used frequently during the past 20 years to try to eliminate or delay reflection cracking. These interlayers generally have consisted of either a paving fabric saturated with asphalt or else an asphalt-rubber membrane. Soft paving-grade asphalts have also sometimes been used as interlayers. Interlayers have the potential for reducing or preventing surface water infiltration through cracks and joints in the pavement. In recent years, both fabrics and polymer grids have been used in an attempt to reinforce overlays to delay reflection cracking. All of the above treatments are usually placed directly on top of the old pavement surface. Sometimes they are laid on a leveling course when a rough surface is being overlaid.

To achieve optimum performance from these special treatments for delaying reflection cracking, the fundamental mechanisms associated with their behavior must be understood. Carefully selected laboratory tests can assist in developing optimum designs in many instances. This chapter's primary emphasis is on paving fabric interlayers, although most of the concepts are also applicable to asphalt-rubber interlayers.

GENERAL FACTORS AFFECTING OVERLAY PERFORMANCE

A growing amount of evidence indicates that overlay reflection cracking, and its reduction when a stress-relieving interlayer or other technique is employed, is closely related to:

- Joint and crack movement in the underlying pavement caused particularly by load, temperature, and moisture, but also possibly caused by other factors such as expansive subgrade materials and frost action.
- Crack width.
- Overlay thickness.
- Climate.
- Traffic volume.

For flexible (AC) pavements, type of distress is the primary factor in determining if an interlayer can potentially delay reflection cracking. For example, load-related fatigue, often evidenced by alligator surface cracking, is one of several types of distress that can be overcome successfully by using a stress-relieving interlayer. A stress-relieving interlayer is not a substitute for the AC overlay's load-carrying capacity. Design thickness of the AC overlay should not be reduced, even when a stress-relieving interlayer is used in an attempt to delay reflection cracking.

FUNDAMENTALS OF REFLECTION CRACKING

Combined Loading Conditions

General movements leading to reflection cracking in overlays, as shown in Figure 1, are:

- Load-induced differential displacements, particularly across cracks and joints.
- Horizontal movements caused by length change resulting from temperature changes.

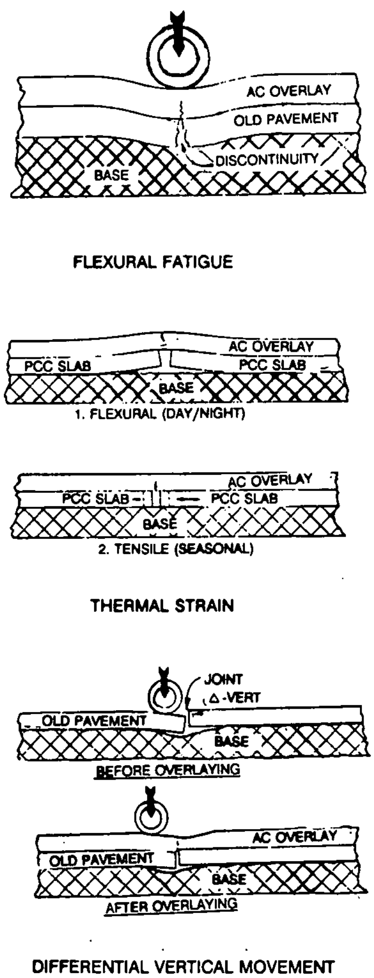

FIGURE 1 Movements of a PCC pavement induced by wheel load and temperature change (after *20*).

• Curling and warping of PCC slabs, caused by the presence of temperature and moisture gradients in the slab.

The simultaneous movement of an overlay caused by wheel loadings, temperature changes, and temperature gradients induces a complex stress state of cyclic bending, tension, and shear within the overlay. This is particularly true for a PCC pavement, in which stresses are caused by a complex sequence of cyclic joint movements caused by wheel loads, long-term temperature changes, and temperature and moisture gradients.

Each wheel loading crossing a joint or crack causes a bending pulse and two shear pulses to be applied to an overlay as shown in Figure 2. Each pavement movement results in a small increase in crack length in the overlay. As the magnitude of movement increases, crack growth occurs faster and overlay reflection cracks appear rapidly.

Wheel loadings caused by a moving vehicle are applied rapidly and result in a fast rate of loading. In contrast, thermally induced curling movements have a frequency of about one cycle per day, whereas movements caused by long-term seasonal temperature change occur over a period of a year. The stiffness of AC subjected to a slow load pulse caused by seasonal temperature change is from 1,000 to 10,000 times less than for a fast pulse caused by traffic loading (*5, 6*). The AC creep and relaxation properties are similarly affected by differences in loading rate.

For PCC pavements in Massachusetts, Tons et al. (*7*) summarize the importance of combined loading effects as follows:

> Although field observations and laboratory measurements show that the main reason for reflection cracking in Massachusetts is the horizontal joint opening or tensional stress, it often can be the combined effects of both horizontal joint opening and vertical deflection movements which cause the cracking. Damaging axial and flexural tension in the resurfacing at a joint affect not only the immediate area above the joint, but also extend some distance on each side. Once a crack has appeared it has a tendency to deteriorate and widen.

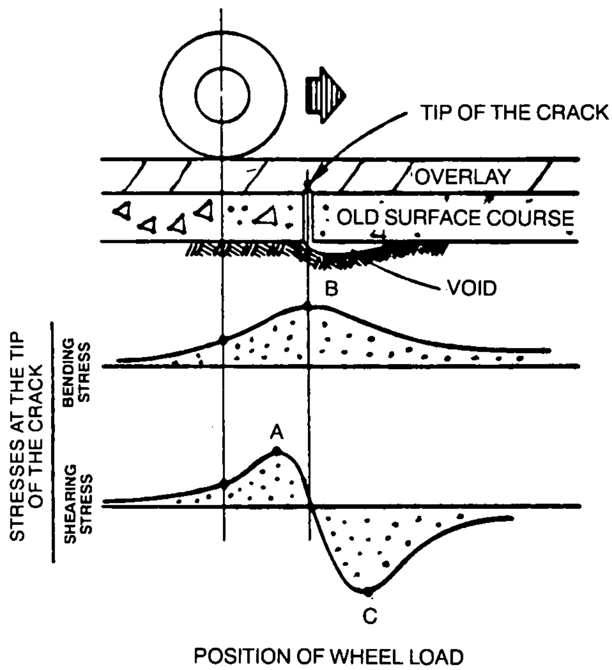

FIGURE 2 Shear and bending stresses induced at a crack caused by a moving wheel load (after *6*).

Performance Mechanisms

The performance of an overlay in conjunction with a fabric, membrane, grid, or asphalt-rubber interlayer may be enhanced by one or a combination of the following mechanisms: (a) stress relief, (b) reinforcement, and (c) reduction of water infiltration. Button and Lytton (*5*), Lytton (*6*), Majidzadeh et al. (*8*), Monismith and Coetzee (*9*), and Yuce et al. (*10*) have all presented excellent descriptions of the fundamental behavior of interlayers such as paving fabrics, heavy-duty membranes, and asphalt-rubber membranes. Button and Lytton (*5*) and Lytton (*6*) summarized three distinct failure modes associated with stress relief and reinforcement:

• Mode I—Stress Relief (*6, 8, 9, 11, 12*). In this mode of failure, the reflection crack propagates rapidly upward from an old crack to the stress-relieving interlayer. The crack stalls at the interlayer for a while, and then propagates from the top of the interlayer upward to the surface. Presence of a soft asphalt-saturated fabric or asphalt-rubber interlayer results in large amounts of plastic deformation when the crack reaches this layer, thus altering the energy balance at the tip of the crack. Because of the low stiffness of the stress-relieving layer, the resulting large strains are stored at low stress levels, retarding, but not preventing, crack propagation. Majidzadeh et al. (*8*) refer to this mechanism of crack stalling as "blunting."

• Mode II—Stress Relief. A Mode II-type failure consists of a crack propagating upward from the bottom of an overlay and temporarily terminating at the stress-relieving interlayer. A crack then begins at the top of the overlay and propagates downward to the stress-relieving interlayer. This failure mode apparently has been observed only by Lytton and his colleagues in the laboratory when the interlayer is located 0.75 in. above the bottom of an asphalt concrete beam representing the overlay. The condition simulated by Lytton is representative of those existing when a paving fabric is placed over a leveling course.

• Mode III—Reinforcement. In a Mode III reinforcement failure, the crack propagates upward to the reinforcing interlayer. The crack then makes a right turn and moves along the interface between the reinforcement and underlying material (*5, 6*). The crack propagates laterally until insufficient energy is left to move any further. Majidzadeh et al. (*8, 12*) describe a Mode III-type failure as the buffer zone concept. Lytton (*6*) has concluded that, for the reinforcing failure to develop, debonding must occur between the lower layer and the reinforcement. Lytton has found in the laboratory that debonding, although desirable under controlled conditions, usually occurs when an AC-10 or AC-20 viscosity-grade asphalt tack coat is used to bond a paving fabric to the asphalt concrete. Laboratory tests also indicate that the required rate of tack coat application must be about 0.15 gal/yd^2 greater than the optimum tack coat application rate. Reinforcing failure has been observed in AC beam specimens only when the stiffness of the fabric or grid is greater than that of the surrounding material and when the reinforcement is sufficiently thick (*6*). If the fabric or grid is not sufficiently stiff, only the stress relief mode can occur.

Required Reinforcement Stiffness

Recent research by Barksdale et al. (*13*) has shown that fabrics having a low stiffness, such as those usually used for interlayers, are not capable of reinforcing an unstabilized aggregate base subjected to low deformation conditions associated with a flexible pavement. To become an important performance mechanism in unstabilized aggregate bases, a paving fabric should be classified as "very stiff" according to the classification system given in Table 2. Grids, because of aggregate interlock, are better for a given stiffness than fabrics; therefore, they should meet the "stiff" classification in Table 2. To be classified as stiff, a fabric or grid must have a stiffness of at least 1500 lb/in.; to be classified as very stiff, 4000 lb/in.

For an asphalt concrete layer, which usually has a higher stiffness than an unstabilized aggregate base, a fabric stiffness of at least 4000 lb/in. appears to be required before reinforcing begins to become an important mechanism. The stiffness of a potential reinforcing element, such as a fabric, is equal to the element's modulus of elasticity times its thickness. Having a high modulus of elasticity alone will not ensure that the material will act as reinforcement.

Large-scale laboratory experiments involving fabrics and grids placed in unstabilized aggregate bases have shown that a geogrid with large openings between the reinforcing members performs as well as a woven fabric having a stiffness of about 2 to 2.5 times that of the geogrid. This important difference in observed performance is caused by aggregate interlock. Aggregate interlock results from the protrusion of aggregates through the large openings in the geogrid. Whether aggregate interlock is an important factor in AC overlays remains to be established.

Crack Propagation

Basic Theory

Several researchers have used fracture mechanics principles to predict the fatigue life of overlays, both with and without stress-relieving or reinforcing interlayers (*6, 8, 12, 14–17*). Unfortunately, at the present time a formal fracture-mechanics analysis is quite time-consuming and involved. Hence, further simplification in the theory is required before it will be suitable for routine design purposes. Majidzadeh et al. (*8, 12*) have considered crack propagation above stress-relieving interlayers. They used the EFRON computer program using finite-element techniques to calculate stresses in the overlay above the crack and then applied the RECK program to evaluate crack propagation. Jayawickrama and Lytton (*17*) and Lytton (*6*), using a beam on an elastic foundation formulation, have developed a simplified mechanistic theory for predicting AC overlay life. This encouraging approach, which uses a computer program called SIMPLE, has been calibrated to observed field performance using 40 flexible pavement sections located in Texas and New Mexico. Monismith and Coetzee (*9*) present a framework for a rational method of fracture analysis for predicting reflection cracking, which also holds promise for use on a microcomputer.

Crack propagation theories have usually been based on the empirical fracture mechanics law for rate of crack propagation proposed by Paris and Erdogan (*18*), which can be expressed as follows:

$$dc/dN = A(K)^n \tag{1}$$

where

c = crack length
N = number of load cycles applied
K = stress intensity amplitude factor at crack tip
A, n = fracture properties of the material

The number of repetitions to cause layer failure can be evaluated by solving equation (1) for dN and then integrating the crack length over the thickness of the overlay for the bending, shearing, and thermal movement conditions that exist in the pavement. The bending, shear, and tensile stresses induced in an overlay usually have been calculated using finite-element theory. The approximate theory of Jayawickrama and Lytton (*17*) offers

TABLE 2
TENTATIVE STIFFNESS CLASSIFICATION OF GEOSYNTHETIC FOR BASE REINFORCEMENT OF SURFACE PAVEMENTS (AFTER *13*)[a]

Stiffness Description	Secant Stiffness @ 5% Strain, s_g (lb/in.)	Elastic Limit (lb/in.)	Tensile Strength (lb/in.)	Failure Elongation (% Initial Length)	Typical Cost Range ($/yd²)
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	0.50-3.00
Very Stiff	4000-6500	≥ 300	350-500 (or more)	5-15	$3.00-$7.00

[a]The properties given in addition to stiffness are typical ranges of manufacturers properties and do not indicate a material specification.

an attractive alternative for practical applications. Equation (1) is evaluated for each type of movement to determine the number of load cycles to cause failure. Lytton (*6*) has concluded that a linear combination of the load cycles to failure for each of these three modes gives a good estimate of overlay life based on correlations with observed field performance.

Stress Intensity at Crack

Equation (1) shows that reflection cracking is related to the stress developed in the overlay at the tip of the crack raised to a power. The presence of a soft interlayer above a crack at the top of the old pavement surface causes a reduction in the tensile stress above the crack. A reduced stress at the tip of the crack in turn decreases the stress intensity factor K. Therefore, a stress-relieving interlayer theoretically has the potential for significantly reducing the rate of crack propagation through an overlay because the stress intensity factor is raised to a power. Schapery (*19*) has shown the factors A and n in equation (1) to be true material constants. They are related to the creep, tensile strength, and fracture properties of the material and can be evaluated by laboratory tests (*6, 8, 9, 11, 12, 14–16*).

PAVING FABRIC AND ASPHALT-RUBBER INTERLAYERS

A stress-relieving interlayer is a soft layer that is usually thin and is placed at or near the bottom of an overlay. The purpose of this soft layer is to reduce the tensile stress in the overlay in the vicinity of the tip of the crack in the underlying old layer and hence "absorb" stress. As discussed previously, a reduction in stress above the crack tip can slow down the propagation of reflection cracks through the overlay under the proper conditions.

One of the most commonly used stress-relieving membrane interlayers consists of a thin rubberized asphalt layer having aggregate chips rolled into it to prevent bleeding and flushing. This stress-absorbing membrane interlayer (often called a SAMI) is usually about 0.25 to 0.375 in. thick. Conventional paving-grade asphalt cements are also sometimes used in constructing this type of interlayer. In recent years, paving fabrics saturated with asphalt have also been employed as a membrane interlayer. Most paving fabric interlayers are about 0.05 to 0.15 in. thick, which is thinner than an asphalt-rubber interlayer.

The stiffness of asphalt-rubber interlayers without the aggregate is about 650 to 7500 lb/in.^{2} at temperatures of 70°F to 75°F and loading rates of 0.05 to 0.02 in./sec (*9*). The aggregate chips placed in the asphalt-rubber interlayer would be expected, however, to increase its stiffness and therefore reduce its effectiveness. The initial modulus of elasticity of paving fabrics in the plane of the fabric is about 400 to 2500 psi when tested at 77°F with a loading rate of 0.2 in./min (*10, 20*).

Finite-Element Analysis—PCC Pavements

Coetzee and Monismith (*21*) and later Monismith and Coetzee (*9*) have theoretically studied the effect of placing a thin asphalt-rubber SAMI between a jointed PCC pavement and an AC overlay. The finite-element theory shows that stresses caused in an AC overlay at the tip of the old crack can be significantly reduced using an ideally performing SAMI. Several other important findings from these theoretical studies include, for load-induced stresses:

- Interlayer stiffness and thickness—Decreasing the asphalt-rubber interlayer stiffness and increasing its thickness, as shown in Figure 3, both have moderately large beneficial effects in reducing the stress at the crack tip. These effects are not nearly as great, however, as the initial reduction in stress caused by using a membrane compared with no membrane at all.
- Crack width—Increasing the crack width had almost no effect on stress when a membrane was used, but a slight effect when one was not present; this theoretical finding appears to be in disagreement with observed field performance.
- Overlay thickness—Thickness of the overlay is very important when a stress-relieving interlayer is not used, with a thicker overlay resulting in a significant reduction in crack tip stress as illustrated in Figure 4.
- Stiffness of overlay—Increasing the stiffness of the AC overlay has an important beneficial effect on stress (the stress is decreased) when an asphalt-rubber interlayer is not present, but only a modest effect when it is.

These theoretical findings suggest that introducing a stress-relieving interlayer has a sound theoretical basis, with the potential for significantly reducing the stress at the tip of a crack and

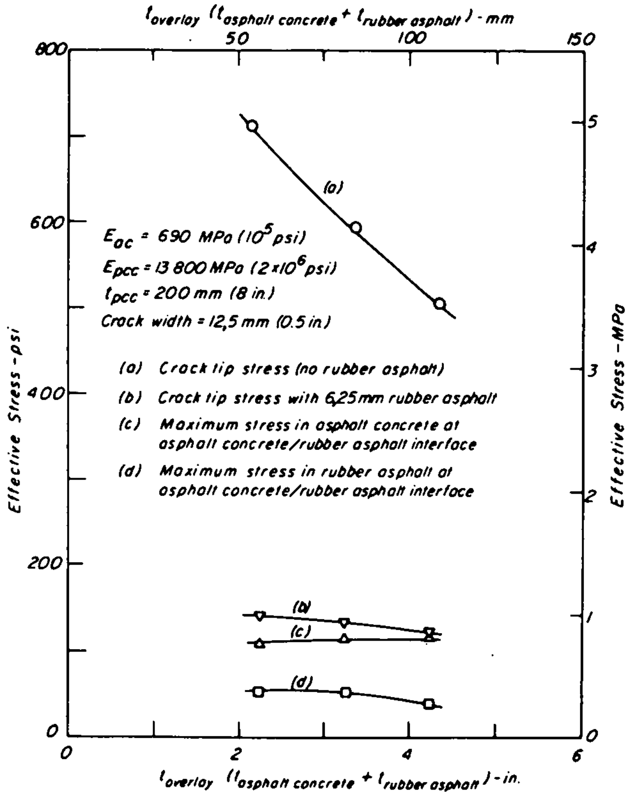

FIGURE 3 Influence of asphalt-rubber interlayer stiffness on effective crack tip stress (after *21*).

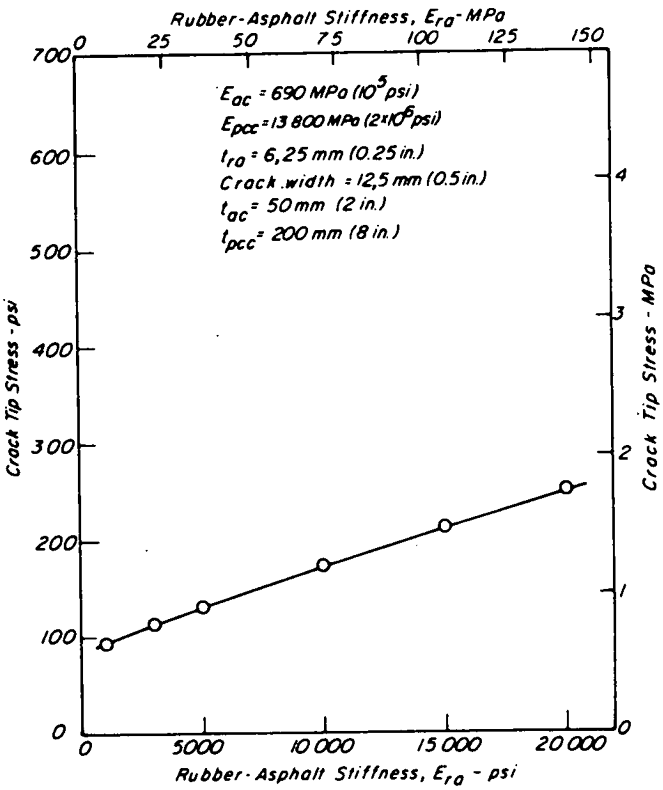

FIGURE 4 Influence of overlay thickness on effective stress at crack tip (after *21*).

hence reducing the rate of crack propagation within the overlay. Of course, many practical problems arise in actually applying the stress-relieving interlayer concept to either a rigid or flexible pavement. Even without an interlayer, the crack tip stress decreases significantly as the stiffness of the original pavement decreases. This theoretical finding gives some justification for using rehabilitation alternatives that reduce the thickness of the old pavement.

SPECIAL PAVING FABRIC TESTS

A detailed discussion of commonly used fabric test methods, including their significance and application, is given in the comprehensive Federal Highway Administration (FHWA) manual by Christopher and Holtz (*22*). Standard test methods typically used in specifying paving fabric are referred to in Appendix A because these methods are not considered in the FHWA manual. The following material characteristics and properties are of special concern when paving fabrics are used as stress-relieving interlayers:

- Tack coat application rate
- Fabric shrinkage at paving temperatures
- Interface shear strength at the interlayer
- Interlayer permeability

These factors have received almost no attention in most literature dealing with fabrics and are therefore discussed in this section.

Tack Coat Application Rate

Applying the correct amount of tack coat is quite critical in achieving optimum performance of a paving fabric, in avoiding problems such as slippage at the interface, and in bonding the overlay to the fabric (*6, 20, 23–28*). Application of too little tack coat causes both a poor fabric bond and poor interlayer performance. Excessive quantities of tack coat material result in slipping and tearing. Tests to determine the correct quantity of tack coat have been developed by Pickett and Lytton in Texas (*5, 27*) and Smith in California (*20, 28*).

Texas Asphalt Retention/Shrinkage Test

The Texas State Department of Highways and Public Transportation asphalt retention and shrinkage test, as currently used, involves immersing 4-in.-x-8-in. fabric specimens in AC-10 viscosity-grade asphalt cement heated to 275°F. The specimens are then removed from the hot asphalt, drained, and heated in naphtha. Finally, the fabric specimens are blotted with paper towels and allowed to air dry. The asphalt retention (oz/ft^2) and percent change in fabric area is then calculated. A wide width tension test is also performed on the specimens. Detailed descriptions of the Texas test methods are given in Appendix A.

Pickett and Lytton (*27*) proposed a slightly different procedure, for use in Texas, involving pressing the asphalt-saturated fabric with a hot iron.

California Melt-Through Test

The California melt-through test was designed by Smith (*20, 28*) to simulate a worst-case field-construction condition; it includes the presence of (a) a thin overlay, (b) low air and overlay mix temperature, and (c) a light compactive effort to the overlay. In summary, the melt-through test consists of spreading a trial layer of asphalt tack over the surface of a 1-ft^2 AC slab at a slab temperature of 40°F. A 5-in. square of paving fabric is then placed on the tack coat. A 4-in.-diameter cylinder of dense-graded asphalt concrete heated to 250°F is set on the fabric for 5 min. While the cylinder of asphalt is on the fabric, three 1500-lb loads are applied and removed within a 5-sec interval to simulate three passages of a 12-ton steel wheel roller.

The required tack coat quantity is estimated visually to be the amount necessary to saturate the fabric, as indicated by a complete darkening of the fabric surface with a slight excess amount visible on the top. This test requires the use of four different trial asphalt tack coat rates to identify the optimum tack coat application. Although the melt-through test nicely simulates cool field conditions (the AC slab is at 40°F), it is time-consuming, and judgment must be exercised to estimate the optimum.

Simplified Approaches

Smith (*20*) has found, by trial and error, the following useful correlation ($r^2 = 0.886$) between the recommended tack coat rate and the product of fabric weight multiplied by the fabric thickness:

$$RTC = 0.05\ (TW)^{0.30} \quad (2)$$

where
RTC = recommended tack coat rate (gal/yd^2)
T = fabric thickness (mils)
W = fabric weight (oz/yd^2)

The recommended tack coat rate includes an allowance of 0.05 gal/yd^2 in excess of the amount determined by the melt-through test to account for absorption (surface hunger) of the underlying pavement. The previous equation is an approximation; Smith recommends rounding the calculated tack rate up to the next higher 0.05 gal/yd^2.

An excellent correlation (r^2 = 0.997) as shown in Figure 5 has been found between the Texas retention test [apparently as performed at 300°F by Pickett and Lytton (*27*)] and the more complex California melt-through test. Up to application rates of about 0.35 gal/yd^2, the Texas method gives lower tack coat rates than does the California test. The slightly lower tack coat application rate given by the Texas method may be applicable to higher summer pavement temperatures.

A motor oil retention test was also developed by Smith (*20, 28*). It simulates field conditions but is easier to perform than the California melt-through test. The motor oil retention test consists of soaking a piece of fabric in 20W motor oil at 70°F for 2 min, removing it, and placing the saturated fabric on a plane inclined at an angle of 7.5°. Excess oil is removed from the fabric by rolling a 3350-g steel cylinder over the fabric six times. The recommended tack coat rate is then empirically related to the percent oil retained as follows (r^2 = 0.996):

$$RTC = 0.05 + MOR/(12 + 1.85\ MOR) \quad (3)$$

where
RTC = Recommended tack coat rate (gal/yd^2)
MOR = Retained motor oil (g)

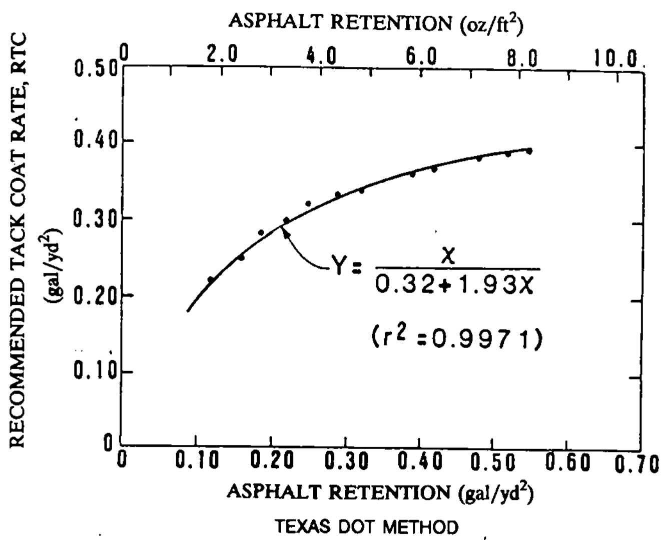

FIGURE 5 California melt-through tack coat rate compared with Texas asphalt retention rate (after *20*).

Fabric Shrinkage

During AC placement, paving fabrics are exposed for short periods of time to temperatures as high as 300°F or more. Button et al. (*29*) in Texas, and later Smith (*20*) in California, found that polypropylene fabrics subjected, as reported by Smith, "to prolonged oven temperatures around 300°F showed the fabric to shrink considerably, embrittle, and even disintegrate in some cases." Shrinkage of a paving fabric causes poor overlay performance, including surface cracking and bonding problems (*23*). In the field, however, a hot tack coat or an AC overlay usually cools quite rapidly. The cooling rate of AC is significantly affected by the initial temperature and thickness of the overlay and by environmental factors such as temperature, sunshine, and wind.

Because of rapid cooling, Smith (*20*) has questioned the validity, as related to field behavior, of the Texas shrinkage test as performed by Button et al. (*29*) at 300°F. To more closely simulate field conditions, Smith places a 6-in.-x-6-in.-x-2-in.-thick block of dense-graded AC, heated to 325°F, against a 1-ft-square fabric specimen. The top of the asphalt concrete block is subjected to a 1500-lb load for 1 min, and the concrete block is removed after 5 min. In this test a tack coat is not applied to the fabric, although it would be desirable to do so.

Using this approach, none of the polypropylene, polyester, or glass specimens tested by Smith experienced significant shrinkage. Some fusing of individual fibers was observed for the two polypropylenes studied. The California shrinkage test results indicate that, for typical overlay conditions, fabric shrinkage should not be a problem for polypropylene fabrics at temperatures around 300°F. This finding is in spite of the fact that polypropylene fabrics melt when exposed for a prolonged time to temperatures between about 315°F and 350°F and are considered to be susceptible to heat shrinkage. Perhaps the severity of the Texas shrinkage test, at least as performed by Button et al. (*29*) and Pickett and Lytton (*27*), has been realized. The temperature of 300°F, originally used by these researchers, has now been reduced to 275°F in the standard Texas test method given in Appendix A. The lack of fabric restraint is also a possible limitation of the Texas shrinkage test. The examination of core samples from the field indicates that fabric shrinkage is not generally a problem.

Interface Shear Strength

A vehicle changing speed on curves and grades, and particularly at intersections, where it stops and starts, transfers important shear stresses to an overlay. The overlay must be capable of transferring these shearing stresses through a stress-absorbing interlayer to the underlying old pavement. As the interlayer becomes softer, and its shear strength lowers, it becomes more effective at delaying reflection cracking. Too great a reduction in interlayer shear strength, however, can result in slippage of the overlay at critical locations. Lytton (*6*) has given a good theoretical discussion of the importance of the paving fabric or grid interlayer shear stiffness and strength on the stress relief and reinforcement failure modes.

To evaluate the shear strength of the interlayer at the interfaces, a simple shear test has been performed by Smith (*20*) and Button et al. (*29*). In this test, failure is forced to occur along the fabric interface. In performing this shear interface test, careful attention must be given to the use of a realistic load rate and temperature, because asphalt is quite sensitive to both.

Button et al. (*29*) developed a test to simulate the effects of a vehicle applying its brakes on the surface of the overlay. A 3-in.-x-3-in.-x-2-in. asphalt concrete specimen is prepared by placing the fabric in the middle of the block and bonding them together with the required amount of tack coat. A static pressure of 67 psi is applied normal to the block and fabric. At the same time, a shear load parallel to the plane of the fabric is applied to cause failure along the interface. Smith (*20*) cut beam fatigue specimens into approximate cubes and performed a somewhat similar shear test.

Both Button et al. and Smith performed the simple shear test for a range of temperatures. Button et al. (*29*) used a rapid load rate of 13 in./sec, which simulates a moving wheel load. Smith (*20*) used a standard laboratory static load rate of 0.05-in./min, which simulates a very slow moving vehicle. The interface shear strengths measured at the faster load rate were on the order of 35 times greater than those found for the slower load rate.

Interlayer Permeability

Laboratory permeability tests have been performed by several investigators, on both laboratory-prepared specimens and field cores, to determine whether a fabric interlayer saturated with asphalt acts as an infiltration-reducing membrane. One apparatus that has been used successfully to evaluate the permeability of both laboratory and field specimens is illustrated in Figure 6. This apparatus was originally developed by the Chevron Oil Company and later adapted by Smith (*20*) for use in testing interlayers. An asphalt tack coat must be applied around the sides of the specimen and tape must be applied around the aluminum dome (Figure 6) to prevent leakage around the outside of a specimen.

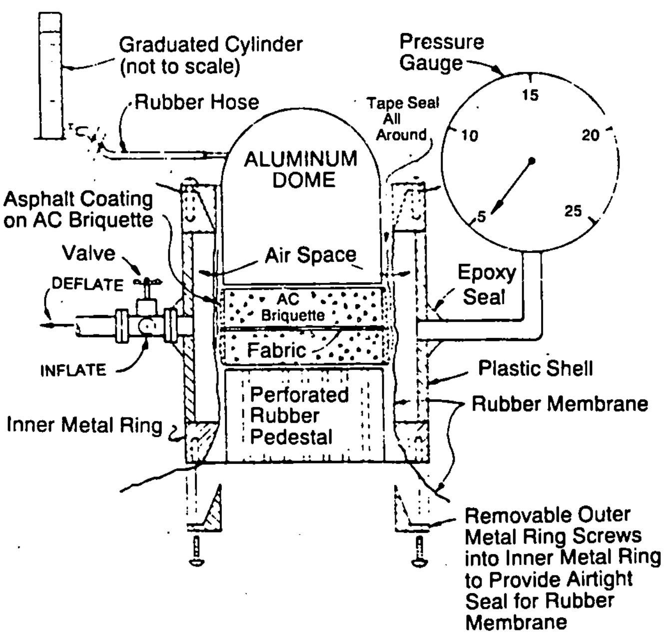

FIGURE 6 Water permeability apparatus for paving fabrics and asphalt-rubber membranes (after *20*).

LABORATORY REFLECTION CRACKING TEST

Laboratory reflection cracking and fatigue tests offer an excellent means of studying the potential relative performance between different candidate techniques for delaying reflection cracking under ideal conditions. Laboratory tests are also useful for optimizing (subject to field verification) the performance of a promising approach. Laboratory tests, however, should be used only as an initial screening technique and not as a replacement for field test sections.

Majidzadeh et al. (*8 12,14*), Button and Lytton (*5*), Smith (*20, 28*), Jayawickrama and Lytton (*17*), Brown et al. (*30*), Germann and Lytton (*16*), and Roland (*31*) have all studied the behavior in the laboratory of paving fabric, asphalt-rubber, and geogrid interlayers, as well as fiber-reinforced asphalt and other materials. In selecting testing equipment and techniques, field conditions must be simulated as close as possible, including applying appropriate relative movements and levels of stress and strain to the model overlay. In these tests, the number of load cycles to the initiation of cracking is determined, and the length of the crack is measured at selected cycles. To allow visual inspection of crack propagation, the sides of the model AC overlay are frequently painted white (*16, 30*) although white spackling has also been used (*20*).

Overlay Crack Reflection Tests

Overlay crack reflection tests are performed by placing a beam or slab of AC representing the overlay over a support simulating a cracked pavement surface. The AC beam may be constructed either with or without a stress-relieving interlayer or reinforcement. Often a cyclic load is applied to the top of the overlay; alternatively, the joint in the simulated underlying cracked pavement is cyclically opened and closed to simulate thermal movement of a PCC slab. A combination of these two testing conditions is also used.

Early overlay reflection and fatigue tests were performed by Luther et al. (*11*) using either a circular AC slab or a beam placed over a concrete slab having a small joint. These early tests demonstrated that reflection cracking is multi-modal, with both shear stress and joint opening being important. Majidzadeh et al. (*8*) performed cyclic load tests on asphalt concrete beams up to 96 in. long, using several types of interlayers. Results were disappointing at a 95 percent confidence level for both high- and low-modulus fabrics and for a fiber-reinforced SAMI used with a simulated flexible pavement. A high-modulus fabric was, however, determined to be beneficial in delaying reflection cracking over PCC pavements.

In tests performed by Germann and Lytton (*16*), the bottom of an AC beam, which simulated an overlay, was epoxy-glued to the top of two horizontal plates. A small space was left between the plates to simulate a joint or crack. A stress-relieving interlayer or reinforcement was placed within the AC beam 0.75 in. above the bottom. To simulate horizontal joint or crack movement, the supporting plates were cycled horizontally back and forth, giving a constant joint opening between 0.01 and 0.07

in. for different tests. Based on the results of several laboratory testing programs, Button and Lytton (*5*) have reached the following conclusions concerning the benefits of using paving fabrics:

> Laboratory tests indicate fabrics will improve the tensile properties of asphalt concrete at low strain levels, increase flexural fatigue life and improve resistance to thermal reflective cracking. These improvements can be maximized when the optimum asphalt tack rate is carefully selected. These data imply that fabrics can function as an effective strain-relieving interlayer in asphalt concrete pavements.

Brown et al. (*30*) supported an AC beam on two pieces of 0.75-in.-thick plywood butted to each other, with a 0.4-in. gap between them. The plywood plates, in turn, rested on a rubber pad. A cyclic load was applied to the top of the beam, causing maximum tensile strains across the joint of about 5000 microstrain. This strain level is about an order of magnitude greater than that usually occurring in the field. Fatigue tests and wheel-tracking tests were also performed, using large slabs of rolled asphalt, both with and without a polymer grid reinforcing. Brown et al. found the optimum location of a polymer grid to be at the top of the cracked surface. Also, the grid caused significant delays in crack propagation times compared with those times found for the unreinforced control specimen. The beneficial effect of the grid reduced as the distance the grid was placed above the cracked surface was increased.

Smith (*20*) developed the interesting testing apparatus shown in Figure 7 to simulate a vehicle moving across a joint or crack at the same time the crack opens and closes. To simulate a moving wheel, load is applied sequentially to each of the four independent loading feet placed on top of the AC beam. The beam simulating the overlay was prepared with Chemcrete in the top half to represent an age-hardened asphalt. A conventional AC mix was used in the bottom half together with a fabric interlayer and tack coat. A 0.125-in.-wide saw cut about 1.25 in. deep was placed at the center of the bottom of the beam between the loading feet. The vertical load was adjusted to apply a radius of curvature of 125 ft, which induced a realistic strain level in the beam.

Smith's test results exhibited a relatively large amount of scatter, always a problem with fatigue and reflection crack tests. Smith attributed the scatter to the random orientation of aggregates, which results in large variations in air voids within the mix. Some of the variation might have been related to the deep saw cut placed in the beam. Several conclusions reached by Smith are summarized as follows: (a) Paving fabrics do not reduce beam deflections and hence are not effective as a structural reinforcement in flexible pavements, (b) paving fabrics generally delay reflection cracking because of the presence of the soft layer, and (c) the fabric stress-relieving interlayer did not delay crack growth through the beam.

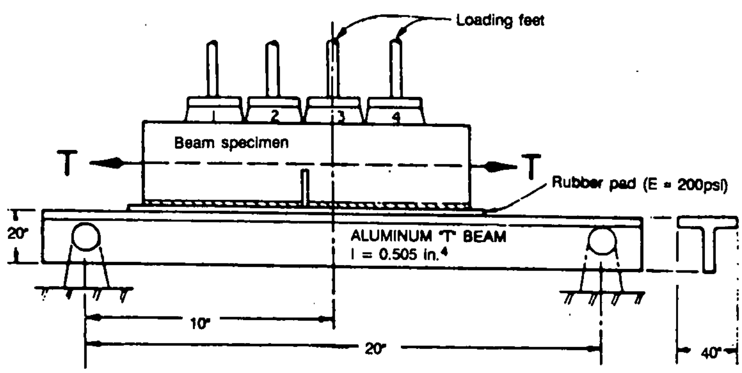

FIGURE 7 California fatigue test apparatus that simulates moving wheel load (after *20*).

CHAPTER THREE

FABRIC AND GRID INTERLAYERS: AC OVERLAYS OVER FLEXIBLE PAVEMENTS

INTRODUCTION

Paving fabrics have received considerable attention in recent years as a potential means of reducing reflection cracking in rehabilitated flexible pavements. The use of fabrics in paving, however, is not new. Beckham and Mills (*32*) describe the use of a cotton fabric in pavement construction in South Carolina in 1935. Numerous experimental sections, using paving fabrics as an interlayer, have been constructed in recent years in an attempt to reduce reflection cracking in overlays. Usually the paving fabric is placed over the full pavement width. More recently, polymer geogrids, fiberglass grids, and woven meshes laminated to rubber-asphalt membranes have been employed primarily in experimental sections. All of these materials are considered in this chapter as potential means to delay overlay reflection cracking.

In some experimental studies, the use of paving fabrics has been quite successful; in other instances, poor performance and some disasters have been observed, particularly when fabrics have been used under conditions that are now known to be unfavorable. This chapter summarizes the present state of the art in surface preparation and in overlay construction using fabrics, the overlay's observed behavior, and the resulting design implications.

SUMMARY OF BEHAVIOR MECHANISMS

The primary mechanisms by which a geosynthetic may function to improve overlay performance are as follows:

- Stress-relieving interlayer
- Reinforcement
- Surface water infiltration-reducing membrane

Currently used geosynthetics attempt to function either as a stress-relieving interlayer or as a reinforcement. At the same time, paving fabrics and membranes may serve as an effective means for reducing water movement. Most older paving fabrics are classified as having a low stiffness, as defined by the classification system presented in Table 2. Because of their low stiffness, paving fabrics must act as a stress-relieving interlayer to achieve a reduction in reflection cracking, as previously discussed in Chapter 2. The behavior mechanisms associated with paving fabrics are therefore similar to those of SAMIs. To be effective, this type of interlayer must be sufficiently soft and thick to reduce the stress above the tips of cracks on the surface of the underlying pavement.

To reinforce the overlay, a geosynthetic must have sufficient thickness and a modulus of elasticity greater than that of the AC overlay (*6*). If this demanding condition is met, the geosynthetic has potential not only to reinforce the overlay but also, at least temporarily, to stop the upward propagation of cracking by turning those cracks laterally. Only polymer geogrids, glass grids, and very heavyweight fabrics can even approach a stiffness great enough to act as a reinforcing element. As discussed in Chapter 2, fabrics must, at a minimum, be very stiff (Table 2) to have the potential to act as a reinforcing element.

FABRIC STRESS-RELIEVING INTERLAYERS

Fabric Selection

Fabric Types

Paving fabrics typically used for full-width applications may be either woven or nonwoven. Nonwoven fabrics are most frequently used in a stress-relieving interlayer. Fabrics made using polypropylene and polyester fibers are the most common. Glass, nylon, or a combination of nylon and polyester or polypropylene fibers have also been used to a limited extent, although they may be more expensive. A number of manufacturing processes result in fabrics that are: (a) needle punched, (b) spun bonded, (c) woven, or (d) combinations of these methods. Punching an existing fibrous web with needles orients the fibers. The spun-bonded process consists of extruding the desired polymer at an elevated temperature through tiny holes called spinnerts. After cooling, the extruded fibers are reoriented and then bonded together by thermal, chemical, or other methods.

A detailed summary of fabric manufacturers, available fabrics, and commonly specified properties for each material is given every year in the December issue of *Geotechnical Fabrics Report* (*33*). The precondition, initial, and secant moduli and Poisson's ratio for selected fabrics are given in Appendix B.

General Factors Affecting Fabric Selection

Christopher and Holtz (*22*) have given an excellent summary of available fabric tests and their significance. Therefore, only material properties of specific importance to reducing overlay reflection cracking are considered here. Important properties of fabrics used as a stress-relieving interlayer include: (a) constructibility, (b) asphalt retention, (c) ductility, (d) durability, and (e) traffic abrasion resistance. Fabric abrasion resistance can vary greatly between fabrics under traffic (*34*).

In Pennsylvania, Maurer and Malasheskie (*35*) developed a construction application rating system that considers product cost, number of required construction steps, ease of application, and potential for related paving problems. For the six materials studied, the ratings varied from 3.04 (best) to 9.65 (worst) as shown in Table 3. The ratings of the fabrics studied varied from 5.5 to 9.65, demonstrating that a significant variation in constructibility can exist between different fabrics. Heat-bonded fabrics were found to be stiffer and to experience the most construction problems. In another study in New York, Fredrick (*36*) found a stiff, woven polypropylene exhibited wrinkling problems when the laydown machine changed direction slightly.

In theory, using a thicker stress-relieving paving fabric interlayer should result in lower stresses at the tip of a crack than using a thinner one. Therefore, the thicker layer should be more effective in delaying reflection cracking. To achieve as thick an interlayer as possible, the fabric must be saturated with asphalt. Therefore, the asphalt retention rate is an important property. Asphalt retention should be at least 0.2 to 0.3 gal/yd^2; it is directly related to the fabric weight and thickness. When used as a stress-relieving interlayer the fabric should generally have a minimum weight of 3.5 oz/yd^2. Both theory and a limited amount of field evidence (*26*) indicate a thicker fabric, with a greater retention of asphalt, may delay cracking longer than a thinner fabric.

Polypropylene fibers melt if subjected to temperatures much greater than about 315°F to 320°F for an extended period of time. A study by Smith (*20*), cited previously, indicates that melting and shrinkage of polypropylene and polyester fabrics should not be a problem for field laydown temperatures less than about 300°F. Laboratory test methods for evaluating asphalt retention rates, fabric shrinkage, and permeability are described in Chapter 2.

Specifications

Numerous states currently have specifications for fabrics used under overlays for both flexible and rigid pavements. These specifications have, in many instances, simply consisted of a manufacturer's specification, sometimes slightly modified, and used as a special provision for a research study. Although manufacturer's specifications can serve as guidelines, general specifications should be developed when fabrics are to be used as a routine rehabilitation alternative. Model generic specifications for full-width paving fabrics, developed by the AASHTO-AGC-ARTBA Task Force 25, which is composed of representatives from state and federal agencies, industry, and universities, are given in Appendix A. Specifications developed by the Texas Department of Highways and Public Transportation are also given, as are the specifications used by the Georgia Department of Transportation for heavy-duty membranes. The specifications give typically used requirements for ductility, strength, weight, permeability, and requirements for other material properties.

Construction

If a fabric interlayer is to be constructed to perform properly without creating any problems, all aspects of the fabric placement operation must be given careful attention. Maurer and Malasheskie (*35*) give the following important considerations for constructing a fabric interlayer properly:

TABLE 3
CONSTRUCTION APPLICATION RATING (ADAPTED FROM *35*)

Material	Rank	Cost ($/yd^2)	No. Steps	Ease of Application[a]	Potential for Related Paving Problems[b]	Total Score[e]
Reepav T-376	6	1.65	2	4	2	9.65
Amopave	2	1.50	2	2	0	5.5
Trevira 115	3	1.70	2	2	0	5.7
Mirafi	5	1.45	2	3	1	7.45
Fiber Pave 3010[c]	4	2.00	2	3	0	7.0
Bonfibers[d]	1	1.04	1	1	0	3.04

[a]Rating system:
1--Easy
2--Moderately Easy
3--Moderately Difficult
4--Difficult

[b]Rating system:
0--None observed
1--One problem observed
2--Two or more problems observed

[c]Fiber-reinforced interlayer
[d]Fiber-reinforced asphalt overlay
[e]Lower score indicates better rating

• The tack coat should be applied at the proper rate and uniformly spread for complete coverage.

• Fabric laydown should be smooth, with minimal fabric wrinkling.

• Coordination of tack coat application and fabric laydown is required for effective tacking to occur.

• Overlapped joint construction is essential to achieve complete coverage.

• The pavement overlay should closely follow fabric placement to avoid potential traffic damage.

In addition, the fabric should be placed as close to the tack coat distributor as possible, except when using an emulsion as a tack material. If the fabric is placed too close to the distributor, however, spray from the hot tack material may damage the fabric. This problem most commonly occurs when the fabric laydown equipment is attached to the distributor. In general, the temperature of the AC overlay should be 300°F to 310°F. In cool weather, the temperature of the AC is often increased, but it should never be higher than 325°F.

Pavement Preparation—Sealing, Patching, and Base Removal

Pavement preparation should include the remedial work necessary to achieve good uniform structural support and to minimize differential crack movements under wheel loadings. The results of pavement surface deflection surveys should be used as the basis for establishing the required remedial work (*25, 35*).

A relatively smooth surface is necessary for laying the fabric tightly without wrinkles. Therefore, a leveling, or scratch, course is required before fabric is placed on rough surfaces. Paving fabrics are also placed directly on milled surfaces using a special rolling to achieve adherence of the fabric to the old surface. Cracks absorb the tack coat, resulting in a deficiency of asphalt where it is most needed (*25*). Pourkhosrow (*34*) has found that open cracks also leave the fabric unsupported in the most critical locations. Therefore, cracks greater than ¼ in. wide (*37*), and preferably even smaller cracks (*38*), should be blown out with air and filled with a suitable sealant. Oklahoma (*34*) has found that wider cracks must be filled with a sealer that hardens rather than the more traditional softer, usually asphalt-based, materials. Pourkhosrow (*34*) recommends air-blown asphalt, polymeric asphalt that hardens, or fly ash or cement grout.

California uses a CRF (a fabric interlayer) crack treatment consisting of 50 percent reclamite and 50 percent emulsion. This sealant breaks surface tension and penetrates small cracks well. However, it requires about a year to cure. Cracks greater than ¼ in. wide are blown out and filled with hot rubberized asphalt sealant. Where an overlay must be placed quickly, a sealant should not be used that requires an extended period of time to cure.

In Colorado, La Force et al. (*38*) describe crack treatment for the Alameda Avenue project as follows:

> Visible cracks were filled using AC-10/crumb rubber crack filler. For this project, the crumb rubber was supplied by Sahuaro Petroleum and Asphalt Company. Using a pressurized tank and a special hand-held nozzle, the crack filler material was extruded on the crack surface, then forced into the crack with a "V" shaped squeegee.

Before the cracks were filled, two passes of a Rotomill PR225 were used to remove the top 3 in. of the old pavement surface. The importance of crack filling is emphasized by the finding of Bushey (*37*) that crack filling alone is an effective technique to delay reflection cracking.

Distressed areas with base or subgrade failures must be removed and replaced as was done in Pennsylvania (*35*). La Force et al. (*38*) concluded that, on the Alameda Avenue project, base problems caused poor performance of the paving fabric.

Tack Coat Selection

A large percentage of projects using paving fabrics have experienced problems related to the tack coat. Selection of the proper tack coat and application rate and the uniform application of the tack coat at the proper rate is undoubtedly one of the most important aspects in the construction and performance of fabric interlayers. A sufficient amount of tack coat must be used to satisfy the fabric asphalt retention requirements and to provide the thick, soft layer necessary to achieve stress relief in the overlay. Also, the needs of the underlying pavement surface and cracks for tack must be satisfied. Up to about 0.05 gal/yd^2 of additional tack coat may be applied when the cracks have not been filled or when the pavement surface has been lightly trafficked and received very little kneading action from tires.

The type of tack coat used has varied greatly, including the use of AC-3, AC-10, AC-20, AC-40, 120-150 penetration-grade asphalt cement, AR 2000, AR 4000, and AR 8000 western paving-grade asphalts, SS-1h emulsified asphalt, and RS-1 anionic emulsion (*24, 34, 35, 39–42*). Both asphalt cement and asphalt emulsions have been used successfully, although AC-10 and AC-20 viscosity-graded asphalt cements and AR 4000 are usually preferred. Emulsified asphalts require a proper curing period, which delays construction and impedes traffic. A large quantity of emulsion is required, which may cause problems with uneven application and runoff. Pourkhosrow (*34*) has found moisture may be trapped at the interface below emulsions, and saturation of the fabric is harder to achieve. Fabric debonding during high winds has been reported to occur by Epps and Button (*23*) when emulsions have been used. In general, cut-back asphalts should not be used, because the solvent can react with the fabric, and solvents remain for extended periods of time.

Quantity of Tack Coat

The quantity of tack coat can be estimated by equation (2) or determined by performing laboratory tests as described in Chapter 2. Table 4 gives recommended asphalt tack coat application rates for selected fabrics and can be used as a general guide. The tack application rates in Table 4 should either be decreased or increased by up to about 0.05 gal/yd^2, depending on the surface condition. Too much tack coat can result in overlay slippage. Dykes (*25*) recommends reducing the quantity of tack coat used by 20 percent on steep grades, in areas of rapid speed changes such as intersections, and on tightly sealed surfaces. On very porous surfaces the quantity should be increased by 20 percent.

Tack Coat Application

The tack coat should be applied using a calibrated distributor truck having a spray bar. Asphalt tack coat application tempera-

TABLE 4
RECOMMENDED TACK COAT RATES FOR SELECTED PAVING FABRICS PLACED ON AN AC LEVELING COURSE (AFTER *20*)

Fabric	Lightest tack coat rate found to be accepatable (gal/yd²)
Amoco 4545	0.30
Bidim C-22	0.25
Bidim C-34	0.35
TrueTex MG75	0.30
TrueTex MG100	0.35
Trevira T1115	0.30
Nicolon 50	0.30
Petromat	0.25
DuPont T376	0.15
Q-Trans-50	0.35
Fibretex 200	0.30

tures are generally about 300°F to a maximum of 325°F. They should be selected considering the environmental conditions at the time of placement, such as the temperature, sunshine, and wind. Common field problems with tack coat applications have included clogged and leaking spray bars or nozzles, application of either too much or too little tack coat material, and nonuniform distribution (*23, 24, 34–36, 39*).

Proper calibration and operation of the distributor is essential to achieve a uniform tack coat placed at the correct rate. Lorenz (*39*) reports excess tack coat being applied in the overlap zone where two passes of the distributor truck had to be made to obtain coverage over the full width of the fabric. Maurer and Malasheskie (*35*) report low application rates being applied at the beginning of a tack coat pass because of the nozzles not being opened at the proper time. Problems have also been reported that were caused by clogged spray nozzles. Epps and Button (*23*) recommend using a minimum tack coat pass at least equal to the length of the fabric roll (usually 300 ft). Even longer lengths are often preferable. Short tack coat application lengths often result in uneven application rates. Epps et al. (*43*) have given detailed guidance for distributor calibration and tack coat application. An inspector's check list for asphalt distributors is included in Table 5.

TABLE 5
INSPECTOR'S CHECKLIST FOR ASPHALT DISTRIBUTOR (ADAPTED FROM *43*)

Asphalt Distributors

1. Do distributors assigned to the job meet specifications requirements?
2. Are heaters and pumps in good operating condition?
3. Are certified calibrations for tank, tachometer, and other measuring devices available?
4. Are spray bars and nozzles in good condition, clean, and correctly adjusted?
5. Have all other adjustments been made in accordance with manufacturer's instructions?
6. Has rate of application (including transverse and longitudinal variation) been checked?
7. Will spray bar height adjustment give required double-lap or triple-lap spray pattern with nozzle set as installed?
8. Does distributor have a means of maintaining constant spray bar height? Is it in good operating condition?

Fabric Laydown

Just before application of the tack coat, the pavement surface should be swept clean of all loose debris. Construction should be planned so that the fabric laydown operation occurs as near to the distributor truck as possible. Spray from the distributor should not hit the fabric, however, because the high temperature of the tack coat material can damage the fabric. Emulsions should cure for at least 45 min before the fabric is laid down.

A fabric's bonded side is better to drive on than is its fuzzy side. The fabric's fuzzy side, rather than the side with a glaze, should be placed against the old pavement surface. This will provide the highest bond strength and best slippage resistance. The heat set (glazed) side also provides better abrasion resistance if traffic is allowed on the paving fabric. Machine fabric placement by an experienced crew is generally preferable to hand laydown, particularly when the wind is blowing (*34*). Moderate to strong wind causes fabric kiting and inhibits laydown. Pourkhosrow (*44*) found it impossible to avoid wrinkles when the wind velocity was greater than 20 mph. Heavyweight fabrics handle better in a wind than lightweight ones do (*44*).

The fabric laydown machine developed by Phillips Petroleum Company has been used to place fabric on pavement surfaces efficiently and effectively. This machine, shown in Figure 8, is propelled by a large, specially modified garden tractor with smooth tires. The tractor has a modified front-end loader that

FIGURE 8 Paving fabric laydown machine using a modified tractor (courtesy Phillips Petroleum Fibers Corporation).

holds a roll of fabric on a spool. A tension of about 14 psi is applied to the fabric roll to hold it properly in place. A broom, mounted on the tractor, is positioned so that it rides on the newly placed fabric. The broom presses the fabric into the tack coat after it is pulled off the roll. It applies a uniform pressure to the fabric, resulting in a smooth surface without wrinkles, which improves fabric-to-surface adhesion. Other material suppliers have also developed suitable laydown equipment.

Both Pourkhosrow (*44*) and Maurer and Malasheskie (*35*) have found the laydown crew's experience greatly influences the quality and efficiency of the laydown operation. This is true even when a technical representative of the fabric supplier is present. The laydown crew's skill increases rapidly during the first several days of fabric placement.

An excessive amount of tack may cause the paving machine to slip. Slip on one nonwoven fabric occurred on a 2 percent grade when 0.3 gal/yd^2 or more of tack coat was used. A thin layer of bituminous hot mix placed beneath the wheels of the paver usually avoids slipping, which can cause fabric pulling and wrinkling. In one instance, slip of a nonwoven fabric occurred, causing wrinkles even when bitumen was placed beneath the paver (*44*). After the overlay was placed, cracks immediately formed in the surface above the wrinkles.

Fabric wrinkles during placement should be avoided if possible. When they do occur, the wrinkles should be slit and folded over flat. If sufficient tack is not present, wrinkles should be tacked down with either an AC or an emulsion; cut-back asphalt has been found undesirable. At joints, a 4- to 6-in. overlap should be used. On one job in Pennsylvania an inexperienced crew placed the fabric with no overlap at a critical longitudinal joint (*35*).

When the air temperature is 90°F or higher, the tires of the construction traffic, such as asphalt trucks, may pull the asphalt through the fabric, causing the fabric to become saturated in the wheel paths. As a result, the tires become covered with asphalt and may pull up the fabric. In this event, the tack coat quantity should not be reduced. Instead, the corrective measures proposed by Epps and Button (*23*) should be followed to minimize the problem:

- Hand spread a small amount of asphalt concrete on top of the fabric in the wheelpath of the haul vehicles.
- Change to a stiffer grade of asphalt cement for the tack coat material.
- Minimize the number of vehicles moving over the fabric.
- Shorten the distance between fabric placement and the paving machine.
- Application of sand is the least desirable choice. Sand absorbs some of the asphalt, which defeats its purpose. If sand is used, the quantity should be minimized and the grading should be coarse.

Fabric wrinkling is also a problem on curves. To avoid wrinkles on a curve, the fabric must be cut as the direction of the fabric laydown machine changes. Generally, using fabrics on a pavement having numerous sharp curves is not practical.

Pneumatic Rolling

Pressure on the fabric interlayer caused by rolling the AC overlay, combined with high overlay placement temperature, forces the asphalt tack to move upward through the fabric. If sufficient rolling and heat are not applied during overlay compaction, poor fabric interface bond results. When the overlay thickness is less than 1 to 1.5 in., considerably more problems with bonding have been observed. In New York, Fredrick (*36*) reports delamination in areas where the overlay was only $\frac{3}{8}$ to $\frac{1}{2}$ in. thick. In Oklahoma, Pourkhosrow (*44*) found pulled spots where the overlay was less than $\frac{1}{2}$ in. thick. These problems were caused by poor bond resulting from the low heat retention characteristics of a thin bituminous overlay.

Pneumatic rolling, directly on top of the fabric interlayer, is sometimes used to improve fabric saturation and bond with the old pavement. Two to four passes can be used to improve bond; additional passes may cause the tack coat to stick to the roller. Rolling the fabric, or permitting traffic on it, has been observed to improve fabric bond with the old pavement surface. Whether this rolling improves the long-term performance of a 1.5 in. or thicker overlay has not been established.

In Oklahoma, fabric interlayer pneumatic rolling follows the application of a light layer of sand. Pneumatic rolling may be used without sand in Texas. When constructing an overlay thicker than 1.5 in. in warm weather, asphalt cement is drawn into the fabric during the compaction of the overlay, causing fabric saturation. Hence, pneumatic rolling or traffic on the fabric may not be necessary when overlays are greater than 1 to 1.5 in. thick, except when temperatures are below about 80°F. However, pneumatic rolling and/or traffic is required when a fabric is used beneath a chip seal, as will be discussed in Chapter 5.

Traffic

Frequently, traffic is directed onto the fabric before the overlay has been placed. Field experience indicates that many fabrics can withstand traffic abrasion without excessive damage for about one week or more. Fabric abrasion resistance varies greatly by type, and some fabrics may pull, delaminate, or even tear (*24*). In one instance, Bidim showed distress under traffic after only 30 min. Continuous filament (spun-bonded) fabrics of this type have demonstrated delamination problems when traffic is allowed on them.

Tires sometimes tend to pull the fabric up. Usually a light coating of fine sand is spread over the fabric to minimize this problem. A coarse, crushed sand was reported to give better performance than rounded, natural sand in Texas (R. Martin, personal communication, August 1989). The sand application also blots up the asphalt tack, so its use should be minimized; an additional quantity of tack coat can be applied to compensate for blotting.

Fabric should not be placed in the rain, or when rain is expected. Rainfall at this time has resulted in several instances of such severe debonding under traffic that sections of the fabric had to be removed and replaced (*24, 34*). Allowing a contractor to place traffic on the fabric allows considerably more flexibility in construction and can result in reduced construction costs. In general, however, traffic should not be allowed on the uncovered fabric any more than necessary. Sometimes manufacturers warn that skid resistance is reduced when the fabric is wet and hence speed should be reduced.

Distress Caused by Poor Construction

Button (*24*) has observed that fabric interlayer distress caused by poor construction practices usually appears within about one year. An insufficient amount of tack coat results in poor bond and slip in the interlayer, which may appear as crescent-shaped cracks on the surface, as illustrated in Figure 9. Slippage usually occurs at high temperatures, when the asphalt within the interlayer has its lowest shear strength. Slippage generally develops on grades, curves, or at intersections, where the shear stress applied by the tire of a vehicle is greatest. An excessive amount of tack coat can result in flushing and bleeding of asphalt, generally in the wheel paths. Button (*24*) cautions against confusing tack-coat-related problems with those caused by unstable overlay mixes, which can, for example, cause rutting, corrugations, and shoving.

Summation

Several conclusions reached by Lorenz (*39*) in New Mexico nicely summarize construction of paving fabric and asphalt-rubber interlayers:

> Tighter control is needed in construction. . . .Numerous problems occurred during construction of these projects which probably affected the actual performance of the interlayers. To achieve. . .a reduction of reflective cracks, the interlayers must be constructed according to specifications. Interlayers [consisting of a paving fabric or a rubberized asphalt membrane] are highly recommended for reducing reflective cracks in an overlay construction project. For the interlayer to be successful, the existing surface needs to be patched, cleaned, and be free of irregularities and dry. All cracks wider than ½" are to be cleaned and sealed.

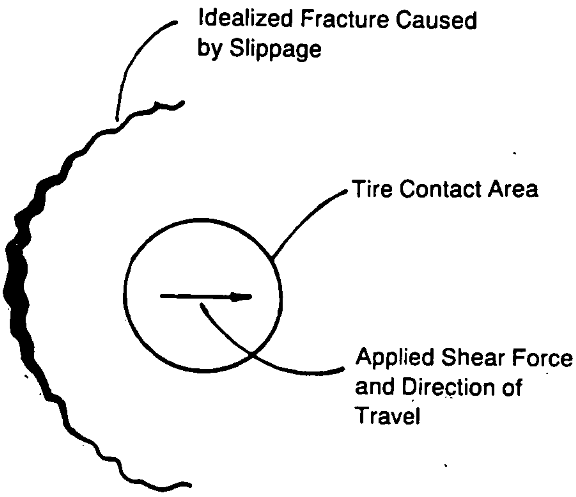

FIGURE 9 Crescent-shaped surface cracks caused by slippage at paving fabric interface (*23*).

Previous Studies

Relatively extensive field performance data have been accumulated that describe the behavior of overlays having paving fabric stress-relieving interlayers (*4, 5, 23–26, 31, 34–36, 38–42, 44–62*). Sherman (*4*) and Jackson (*46*) have given good general summaries of selected studies of both flexible and rigid pavements using fabrics and other techniques to delay reflection cracking. More recently, Ahlrich (*47*) reviewed the performance of both paving fabrics and asphalt-rubber stress-relieving interlayers at 23 test sites. As a part of this study, Ahlrich inspected six experimental test sections located throughout the United States to investigate long-term performance extending past the original test section study period. Epps and Button (*23*) and Dykes (*25*) have given excellent, practice-oriented general reviews of the factors influencing the design and behavior of overlays having fabric interlayers. Topics considered include fabric selection, pavement preparation, fabric placement, economics, specifications, and test methods.

California Investigations

The results of a very extensive series of field studies in California, including the extensive use of fabric interlayers, have been summarized by Predoehl (*26*). Undoubtedly this work constitutes the most comprehensive, integrated data base compiled to date. It includes fabric performance on flexible pavements under moderate- to high-volume traffic, and covers the reasonably wide range of climates encountered in California. The performance data compiled by Predoehl are given in Appendix C.

The California studies involve 29 flexible pavement test sections having an AC overlay with a fabric interlayer. Overlay thicknesses used in these sections vary from 0.7 to 4.2 in. The main emphasis of Predoehl's (*26*) investigations is on the use of paving fabrics as a means of reducing reflection cracking. Important performance data, however, are also given for asphalt-rubber interlayers, asphalt or rubber-asphalt slurry seal interlayers, and open-graded asphalt mixes. The findings from these studies give the best available insight into the long-term performance (up to 13 years) of overlays having fabric interlayers. Many of the experimental findings from this study are included in the next section.

Performance

The observed performance of overlays having fabric interlayers has varied from clear successes, such as the one shown in Figure 10 (*47*), to apparent failures in which the overlay with a paving fabric interlayer showed poorer performance than a conventional AC overlay having the same thickness. The observed highly variable performance of overlays with fabric interlayers and other reflection crack-delaying techniques is strongly influenced by the following important factors:

- Type and extent of existing pavement distress, including crack widths.
- Extent of remedial work performed on the old pavement, such as crack sealing and/or filling, pothole repair, and replacement of failed base areas.
- Overlay design thickness.
- Variability of structural pavement strength from one test section to another test section.
- Climate.

Under favorable conditions, as will be described subsequently, overlays with fabric interlayers would be expected, on the average, to be successful in delaying reflection cracking about 60 percent of the time, based on an interpretation of the data from California (*26*). Where cold climates are present but other factors are favorable, the success rate would be expected to be less. In addition to favorable performance, the economics of using paving fabrics should be evaluated carefully as discussed in Chapter 6.

Distress Type

Fabrics generally have been observed to perform best when used for load-related fatigue distress, as evidenced, for example, by closely spaced alligator cracking (*5, 23, 25, 34, 44, 47*). Fatigue cracks should be less than ⅛ in. for best results; cracks greater than ⅜ in. wide require a rigid filler. Fabrics used to retard thermal cracking have, in general, been found to be ineffective (*4, 14, 23, 26, 34, 44*). Thermal cracking can occur in the overlay itself or cracks can reflect upward from the thermal cracks in the old pavement. Pourkhosrow (*44*) concluded that, in Oklahoma, paving fabrics should only be used for open transverse or longitudinal joints less than ⅜ in. wide. In New Mexico, Lorenz (*39*) found that even in wide joints initially filled with a sealant, large voids as great as 2 in. deep can form. In Oklahoma, a fabric overlay effectively delayed reflection cracking above alligator/random cracking, as shown in Figure 11. The effectiveness of fabrics in reducing reflection cracking above transverse cracks is poor (Figure 11).

Variability of Pavement Structural Strength

The structural strength, and therefore the required overlay thickness, often varies greatly along the pavement. Figure 12 shows a reasonably good correlation between the rate of cracking observed in Pennsylvania by Maurer and Malasheskie (*35*) and the required thickness of the overlay as determined from Road Rater deflection measurements. Cracking rates varied by about 200 percent over the length of the test sections. Most of the past experimental studies involving fabric interlayers, as well as other methods of reducing reflection cracking, have not considered, in

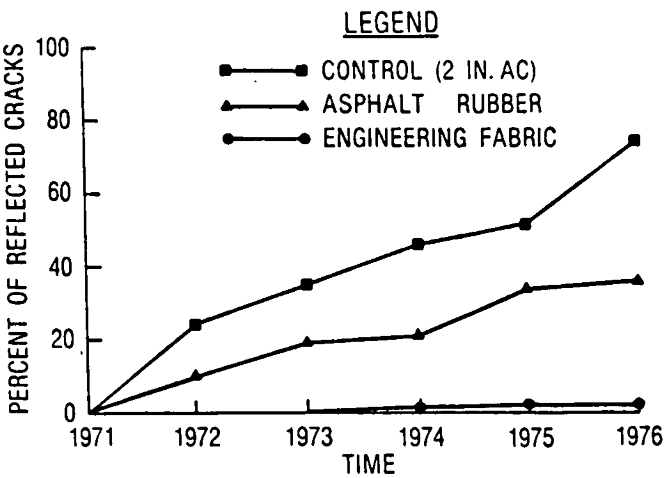

FIGURE 10 Successful application of paving fabric on Interstate 70, Clifton Colo.—2-in. AC overlay (after *47*).

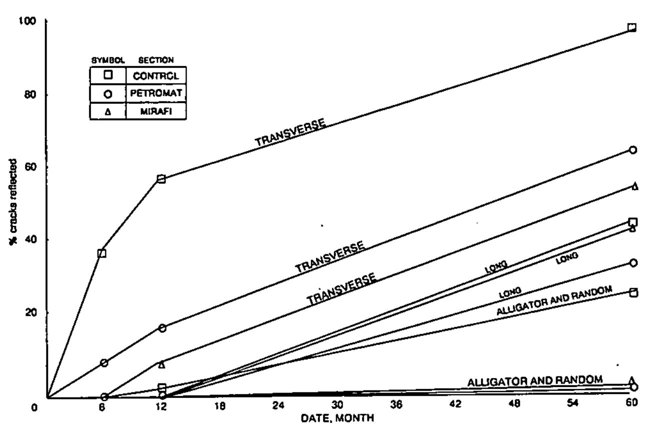

FIGURE 11 Comparison of levels of alligator and random cracking with longitudinal and transverse cracking in Oklahoma (after *44*).

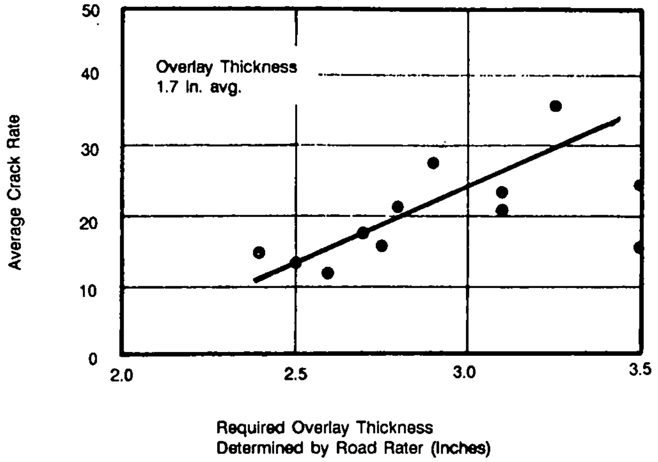

FIGURE 12 Influence of required overlay thickness on average crack rate (data from *35*).

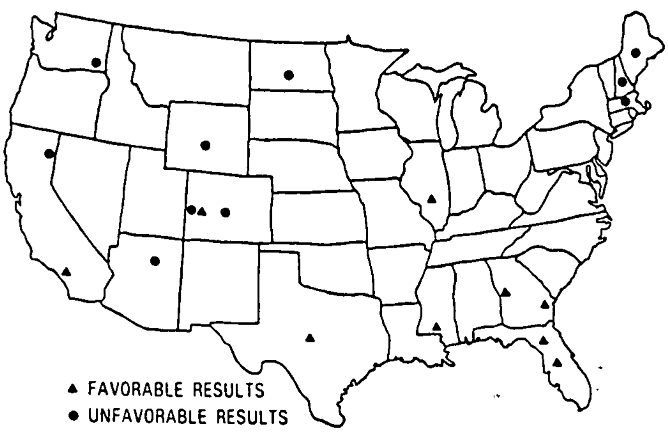

FIGURE 13 Location of selected favorable and unfavorable paving fabric installations in the United States (after *47*).

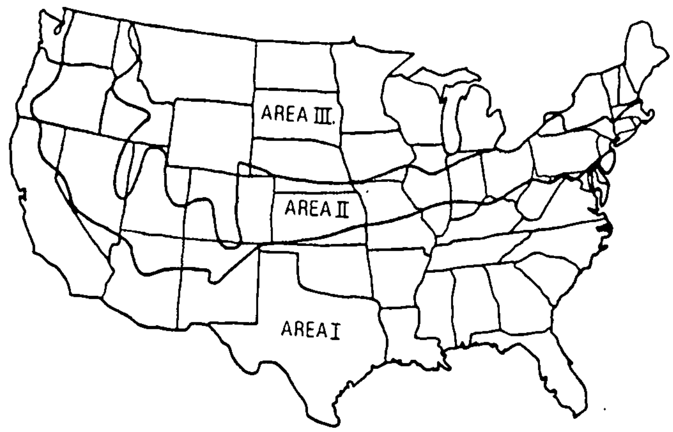

FIGURE 14 Climatic zones as a guide to paving fabric performance of AC pavements (after *47*).

the interpretation of test results, the significant effect of the variation of pavement strength on overlay performance.

Assuming the correlation in Figure 12 is valid, it implies that the rate of cracking is related to the strength of the existing section for a constant overlay thickness. Because of the variation in subgrade strengths, some misleading conclusions have been likely to have been drawn from previous reflection crack studies. In support of the argument that variation in pavement strength within the study area can be quite important, data presented by Lorenz (*39*) in New Mexico indicated that a control section having a 2.5-in.-thick AC overlay performed better than a similar 4-in.-thick control section. This conclusion, of course, is not true if all other factors are equal. A statistical correlation performed by Way (*54*) in Arizona indicated that the test section deflections, as measured by the Benkelman beam, did not have a significant influence on the ranking of the test section. As pointed out by Voss in a discussion of the paper by Way (*63*), however, three of the top five performing overlay treatments used in this study had average deflections almost one-half those of the other sections.

Many early overlay reflection studies documented poorly: (a) the type, level, and extent of structural distress initially present, (b) the variations in structural strength among test sections within a study, and (c) the specific level of remedial work performed on the pavement before the overlay was placed. Because of these deficiencies, drawing specific conclusions from many of the available studies could be quite misleading; therefore, this synthesis does not attempt to do so.

Climate

In general, fabrics and other types of interlayers have performed considerably better in warm and mild climates than in cold ones (*23, 25, 41, 47, 64*). Ahlrich (*47*) has summarized selected pavements that have demonstrated both good and poor performance on a map of the United States, which is shown in Figure 13.

Using this map as a guide, Ahlrich divided the United States into the three climatic zones shown in Figure 14. The potential beneficial effects of reducing water infiltration were not considered in this study. Zone I is the most favorable area for the use of paving fabrics; it includes the warm southern and western states having a mean freezing index equal to or less than zero degree-days. In support of this, Predoehl (*26*) has found that a hot, dry, desert climate may have the best interlayer performance of the environments encountered in California. These findings help to explain the relatively high use of fabrics in states with generally warm, dry climates such as Oklahoma and Texas. The study by Predoehl did not, however, show a clear difference between the widely varying climatic zones of California, and the data were not entirely conclusive concerning the overall effect of climate on performance of paving fabrics. Most of these data, however, were from mild areas, with only one section from a cold climate; none of the sections were in wet areas.

Button (*24*) has described the use of nine types of fabrics at four locations in Texas. These sites would generally be considered as having a favorable climate for fabrics. The results of this study were disappointing; the fabrics were found not to be economically feasible alternatives at the sites studied. The results of these four projects were not, based on past experience, considered by Button as representative of the general performance of fabric interlayers in Texas. The study by Button indicates that other factors discussed in this section are important, even in warm climates generally favorable to the use of paving fabrics.

Zone II, which is also shown in Figure 14, was proposed by Ahlrich (*47*) as a transition zone between the warm climate and the cold regions of the United States. Zone II has a mean freezing index varying from 0 to 500 degree-days. Caution must be exercised when determining if fabric interlayers should be used in this climatic zone.

Ahlrich recommends not using fabric interlayers in Zone III, where the mean freezing index is greater than 500 degree-days. Past experience in cold climates gives some justification for these recommendations, particularly for thermal cracking.

In Pennsylvania, however, Maurer and Malasheskie (*35*) found, in a study involving both flexible and jointed PCC pavements, that after 44 months, the use of paving fabrics resulted in 22 to 45 percent reduction in cracking relative to the control section. The freezing index at this site approached 1000 degree-days. In Pennsylvania, Hoffman (*65*) also found that fabrics reduced reflection cracking in flexible pavements. Thus, it appears that, under favorable conditions, fabric interlayers can reduce reflective cracking even in moderately cold regions.

Effect of Overlay Thickness

The relationship between pavement performance and overlay thickness is quite sensitive to the thickness of the overlay, either with or without a fabric, as illustrated in Figure 15. Because of this variable relationship, caution must be exercised in interpreting the results. These results show, for the flexible pavements overlaid in California, that the benefit of increasing overlay thickness, either with or without a fabric, is significant when the original overlay thickness is small. When a fabric is not used, the benefit of increasing overlay thickness reduces rapidly for overlay thicknesses greater than about 3.0 in. When a fabric is used, the breakpoint for rapidly increasing benefits is probably in the vicinity of 2.0 to 2.5 in. More experimental data are required to better define where the transition occurs. Undoubtedly, the transition from high to low benefits is dependent on many factors, including the existing strength and condition of the pavement and traffic loading.

Table 6 compares the added benefits measured as longer times until significant cracking appears when fabrics are used under various overlay thicknesses.

In overlays having thicknesses varying from 0.72 to 1.44 in., fabrics are most effective in retarding reflective cracking (Figure 15 and Table 6). For these overlays, the average time to significant cracking (greater than 30 percent alligator range B cracking) was 1.6 years for the control without fabric, compared with 6 years for the sections with fabric interlayers (Table 6). As the overlay thickness increases, the benefit of a paving fabric appears, based on the California data, to decrease. The California results suggest, however, for relatively thin overlays that are structurally adequate, a fabric interlayer is equivalent to about 1.0 in. of asphalt concrete.

For the thickest overlays used in the California study, which includes only a limited amount of data, the control sections required 9.8 years to reach a condition of significant cracking, compared with 7.8 years for the paving fabric sections. Thus, for overlays varying from 4 in. to 5.4 in. thick, a paving fabric

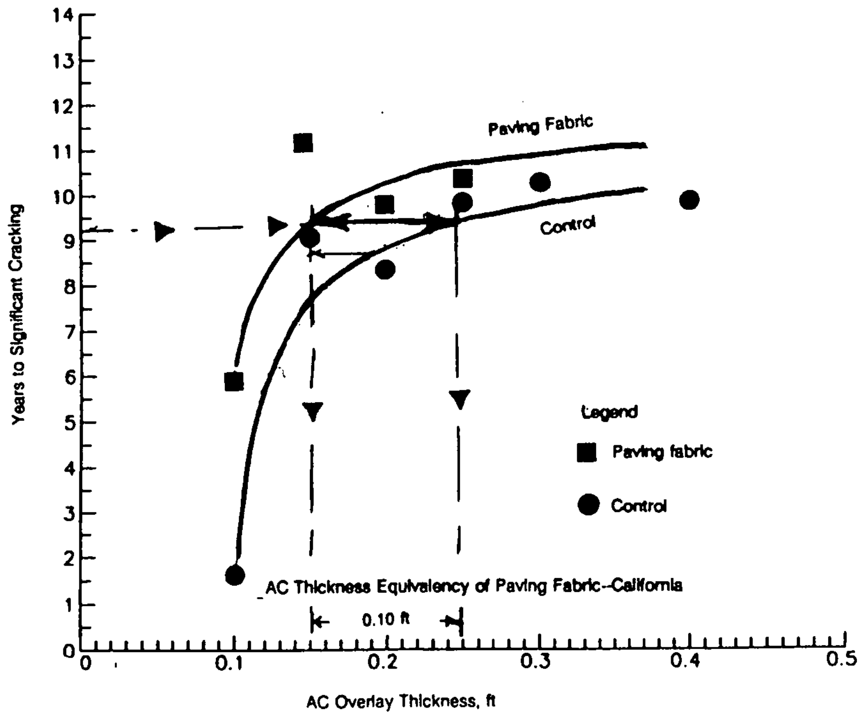

FIGURE 15 Estimated paving fabric equivalency as a function of AC pavement thickness (data from *26*).

TABLE 6
EFFECT OF OVERLAY THICKNESS ON YEARS TO INITIAL, MODERATE, AND SIGNIFICANT CRACKING (AFTER *26*)[a]

Overlay Thickness Range (ft)	0.06-0.12		0.13-0.17		0.18-0.22		0.23-0.27		0.28-0.32		0.33-0.45	
No. of Sections (Locations)	3 (2) C	5 (3) F	4 (4) C	9 (6) F	8 (5) C	8 (5) F	5 (4) C	5 (3) F	5 (4) C	0 (0) F	5 (3) C	2 (1) F
Years to Initial Cracking, Avg.	1.0	3.0	7.2	8.3	4.1	7.1	4.4	6.8	8.2	-	7.9	3.0[b]
Years to Moderate Cracking, Avg.	1.0	4.2	8.5	9.9	5.6	8.4	9.6	8.4	9.4	-	8.5	4.0[b]
Years to Significant Cracking, Avg.	1.6	6.0	9.0	11.1	8.3	9.7	9.8	10.2	10.2	-	9.8	7.8[a]

	Average Thickness	No. of Sections	Initial Cracking	Moderate Cracking	Significant Cracking
Overall Average of Control Overlays	0.24'	29	5.8	7.2	8.5
Overall Average of Overlays W/PRF	0.18'	30	6.4	7.8	9.4

[a]Data summarized from Table C-1.
[b]Values are from a limited number of sections; therefore, they may not be entirely representative.

NOTE: C = control section F = PRF sections

interlayer did not reduce reflection cracking. Indeed, the paving fabric may even have encouraged reflection cracking, although variability of test section strength could also explain this finding and other discrepancies that appear in Table 6.

Thin Overlays

Most researchers have concluded that relatively thick overlays should be used to achieve the most benefit from fabric interlayers. Ahlrich (*47*) recommends using a minimum thickness of 2.0 in. in the warm climate defined by Zone I, and 3 in. to 4 in. in the cooler climate of Zone II. On moderate- to high-volume roads, thin overlays less than 1.5 in. thick have led to premature failure (*24, 36, 44*). Dykes (*25*) recommends using a minimum overlay thickness of 1 in. with a fabric interlayer, whereas Epps and Button (*23*) recommend using 1.5 in.

The above recommendations appear to conflict with the California data indicating that thin overlays perform best (i.e., retard reflection cracking for a longer period of time); however, California recommends that AC overlays over fabric be a minimum of 1.8 in. The important factors to consider are that the overlay (a) must be constructible and (b) must be structurally adequate based on existing conditions. Premature failure appears to be caused, to a large extent, by the very high reflection cracking rate that occurs when a section is significantly underdesigned (Figure 12). The thin overlays (0.7 in. thick) placed in California were laid by maintenance forces and were not designed. Nevertheless, they appear to have been used only for pavement and traffic conditions for which they were adequate.

Stage construction, however, does not work; a thin overlay should not be constructed now with plans for placing another thin overlay in, for example, four years. Past experience suggests that a minimum overlay thickness of 2.0 in. should be used with paving fabrics, at least until adequate construction experience has been gained in placing thin overlays.

Thin Overlay Construction Problems

Overlays less than 1 in. thick cool rapidly and, as a result, are difficult to compact to the required density. A low-density AC results in a low-permeability asphalt overlay that allows water to enter and become trapped on top of a fabric interlayer. Trapped water may lead to stripping and freeze-thaw problems, evidenced by premature cracks that first appear in the wheel paths (*34*). Moisture-related problems have been observed by Epps and Button (*23*), Pourkhosrow (*34*), and Ravn et al. (*49*).

Ravn et al. (*49*) found when a thin 0.75-in. semi-open-graded wearing coarse was placed over a paving fabric interlayer, considerable early distress occurred. This premature distress did not develop in sections having either a SAMI or a 1.5-in. wearing course. Ravn hypothesized that water trapped above the fabric interlayer may have caused the premature distress.

Very thin overlays less than 0.5 in. thick have been pulled up by traffic, apparently because of lack of heat to pull the tack coat through the fabric, which causes inadequate bond (*44, 49*). Also Ravn et al. (*49*) found for a 0.75-in. overlay that was too thin, that spalling occurred at several cracks. Spalling was attributed to the rebound of the fabric over the unfilled crack. To solve this spalling problem, relief joints were sawed on each side of the crack and it was filled with a sealant. To avoid these problems, overlays less than 1.5 in. thick generally are not recommended.

Reducing Water Infiltration

Eliminating water from beneath a pavement can increase its life by a factor of 25 or more. Therefore, providing a seal that will reduce water movement in any pavement, and particularly in badly cracked ones, has the potential for significantly extending its useful life. Marais et al. (*66*) have found that after cracking occurs in a flexible pavement having a thick, unstabilized aggregate base, the rate of rutting increases significantly and general deterioration follows rapidly. Dykes (*25*) cites an example in which the use of an asphalt-saturated paving fabric interlayer had a significant beneficial effect on performance of a badly alligator-cracked pavement. In this instance, water passing through the alligator cracks in the old pavement surface apparently reduced the strength of the base and subgrade. The use of such a membrane should not, however, be considered as a substitute for subsurface drainage where a high groundwater table exists. Some evidence indicates that the presence of such a paving fabric membrane can reduce pumping significantly by eliminating free surface water from beneath the pavement (*24*).

Laboratory research conducted by Smith (*20*) has shown that: (a) most fabric interlayers act as low-permeability membranes, (b) the actual value of permeability can, however, vary considerably depending on the paving fabric used, (c) an asphalt tack coat interlayer without fabric also has low permeability, (d) even though the fabric may be penetrated by sharp aggregate, the permeability apparently does not increase, probably because the asphalt acts as a sealant, and (e) rupture of lightweight fabrics typically used in full-width applications is likely to occur when relative vertical displacements are greater than about 0.011 in. Field measurements made in California show that water infiltration is significantly reduced when a paving fabric is present. The actual beneficial effects of reducing water infiltration in terms of improved pavement performance and increased life have not, however, been quantified through field studies. Open structural materials such as grids, when used alone, do not have the ability to act as an infiltration-reducing membrane.

A number of studies show that a paving fabric membrane generally remains intact in flexible pavements for at least moderate levels of cracking, even though the crack propagates all the way through the overlay (*20, 23, 39, 50*). Spalling, which is more likely to occur in thin overlays, can lead to fabric damage, as found by Maag et al. in Kansas (*50*). Pourkhosrow (*44*) found, in Oklahoma, that when Bidim was placed over moderate to wide unfilled cracks, it stretched and pressed into the crack by traffic. The Bidim became abraded and loose, white, and no longer was considered of sufficiently low permeability. In contrast, Petromat was not torn or ruptured after five years of service and was performing well.

A low-permeability paving fabric can trap water both above and below the interlayer, which can, as already described, lead to instances of premature overlay distress. Moisture that vaporizes and condenses as the dark fabric is heated up can cause blisters (*24*). Paving fabric interlayers have been observed to have a sheet of water above them, resulting in a significant amount of spray from traffic and the potential for lack of skid resistance and hydroplaning problems. The occurrence of these problems has not, however, been reported. A number of researchers have observed that the presence of a fabric interlayer tends to result in tighter reflection cracks. The tighter cracks may be due to the fabric preventing material from entering the cracks in the old pavement and also may be due to reducing water infiltration. Presence of a smaller-width crack could reduce the quantity of infiltration water entering the pavement, even if the fabric is damaged.

Probably the primary benefit from the use of paving fabrics is the potential beneficial effect derived from reducing water infiltration. Documentation showing the benefit derived, however, needs to be developed through carefully planned field studies.

GRIDS AND MEMBRANES

Grids

High-strength and high-stiffness polymer and glass grids and mats have been used on a relatively limited basis for either strip or full-width overlay applications of flexible pavements in formal test sections. In the past, grid systems have been considered as serving primarily as a reinforcing element. To perform as a reinforcing element, the grid (a) must be stretched tight, or even slightly pretensioned, and (b) must have sufficient stiffness. Grid or fabric stiffness is defined as the tensile force applied per unit length of material divided by the resulting displacement. This very important aspect was discussed in Chapter 2. Grids used for overlay reinforcement typically have stiffnesses varying from about 80 to 1000 lb/in. or more. Only the stiffest grids, however, have a potential for acting as a reinforcement in an AC overlay.

Polymer Grids

Polymer grids, often referred to as geogrids, are manufactured from high-density polypropylene or polyethylene. One manufacturing method punches holes in the polymer. The polymer sheets are then stretched in both directions into grids having various weights and configurations with varying aperture shapes and sizes. Orientation of long-chain polymer molecules through stretching results in a stiffer and stronger polymer for a given weight of material. A new generation of steel mesh grids is also available but apparently has not been used yet for overlay applications (*67*).

In the past, the full-width placement of polymer grids formed by the stretching process has been slow and quite labor intensive, as was found by Lund in Minnesota (*40*). Usually one end of the grid is nailed down and the other end stretched, using either a band wrench or more elaborate laydown equipment. Additional nails are placed as required to fasten the grid to the pavement. Stretching helps to hold the grid against the pavement.

Lund (*40*) found that a lightweight polymer grid experienced problems with waving between nail points; stiffer grids are even more susceptible to waving. Therefore, constructibility is an important issue when using stiff reinforcement grid systems. Kennepohl and Lytton (*68*) recommend that a chip seal coat be placed over one type of polymer grid to provide protection from the paving equipment and minimize grid waving. Based on observations from one project, however, Lund (*40*) questions whether a chip seal provides adequate protection of the grid.

Because of problems encountered in the field with geogrid placement, the Tensar Corporation now recommends using a 4.5-oz nonwoven, spun-bonded, needle-punched polyester fabric attached to the grid. This composite system is laid as if it were a paving fabric, using a tack coat. Whether such a composite system acts as a stress-relieving interlayer, reinforcement, or both depends, as discussed in Chapter 2, on the properties of the composite system. Neither polymer nor glass grids acts to reduce permeability; a composite system, such as recommended by Tensar, would.

Glass Grids

Glass grids and meshes consist of bundles of very-small-diameter glass fibers (fiberglass). Small-diameter fibers are used to give flexibility, because large-diameter glass is quite brittle and does not bend. The large surface area of the small glass fibers is apparently subject to attack by polar liquids, including water. Therefore, the glass fibers may be in encapsulated bundles.

Application of glass meshes and mats requires a two- or three-step installation process. The manufacturer's recommendations should be followed. Usually a tack coat, consisting of AC-10 or AC-20 asphalt polymer or emulsified asphalt, is applied to the old pavement surface before the fabric is placed. Some glass mesh manufacturers specify placing a second tack coat on top of the fabric. For one system using a hot polymer asphalt tack coat, the cracks are filled at the same time as the tack coat is placed, thus eliminating one operation.

Performance of Grids and Membranes

Relatively few field data are present in the literature documenting the performance of polymer, glass grids, or fabric membranes, used as strip or full-width treatments to minimize reflection cracking. In an extensive study performed in Arizona, Way (*54*) found that glass matting did not rank in the best-performing 5 out of 18 sections studied (specific rankings were only given for the best 5 treatments).

In Minnesota, Lund (*40*) has described a test section constructed using (a) a 4-oz/yd^2 fabric placed full width, (b) a glass fabric applied as strips having a stiffness of 1000 lb/in., (c) an experimental glass fabric placed full width, and (d) a polymer geogrid with an average strength of 1100 lb/ft. The traffic volume on the two-lane highway was 10,115 ADT, and the overlay was 2 in. thick. The pavement condition was described as good, although some heavily cracked areas were reported to be present. The cracks, described as being fairly tight, were sealed. Although formal crack surveys apparently were not taken, the sections that had special treatment have been reported as showing no significant improvement over the control sections.

In New York, fabric membranes were placed as strips over transverse temperature cracks on two projects. One project was four-lane AC pavement with a traffic volume of 14,100 AADT, the other a rural two-lane pavement with 2,500 AADT. These sections had Benkelman beam deflections of 0.021 and 0.025 in., respectively, before the thin 1-in. overlay was placed. Two polypropylene meshes with rubber-asphalt membranes and a fiberglass woven roping with hot asphalt binder were used in this study. All the underlying cracks protected by these strips were reflected through the protective application by the first spring.

Harmelink (*51*) has described the use of four paving fabrics, a nonwoven glass mat, and a heavy-duty membrane. The project involved widening a 22-ft-wide two-lane pavement to a 64-ft four-lane roadway. Block cracking was present in the old pavement. All materials except the heavy-duty membrane were placed on top of a variable-depth leveling course. A total of 3.5 in. of AC overlay was placed over the leveling course. The heavy-duty membrane, which was 12 in. wide, was laid directly on the old surface over all visible cracks.

Figure 16 shows the reduction in reflection cracking as a percent of that in the control after four years. The glass mat performed best of those mats compared with the control. The glass mat, which was Duraglass 7108, manufactured by the Manville Corporation, also was reported to be the cheapest material tested. However, the glass mat was found to be brittle, breaking at one fold as it was unrolled during hand placement. Vehicle tires caused delamination of Mirafi 140S, Bidim, and Duraglass 7108; Bidim delamination under traffic has also been pointed out by Epps and Button (*23*).

The limited experimental findings about the behavior of grids and membranes should be considered far from conclusive; more well-planned tests are needed. Currently, full-width grids and membranes are being used only in experimental sections. Their high cost necessitates greatly improved performance, which has not been documented to date.

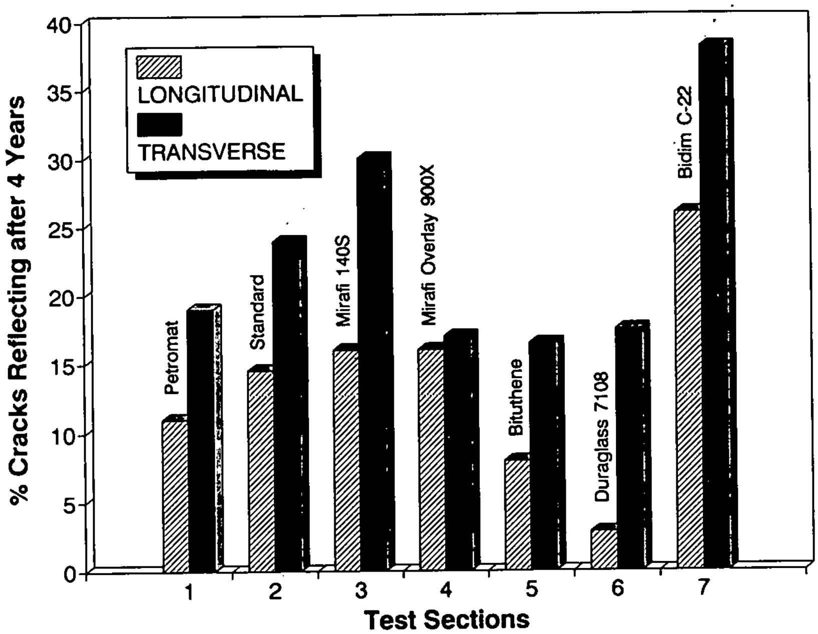

FIGURE 16 Reflection cracking of AC pavement with blocking cracking—paving fabrics and membranes: Colorado (after *51*).

CHAPTER FOUR

FABRICS AND INFILTRATION-REDUCING MEMBRANES IN AC OVERLAYS OVER RIGID PAVEMENTS

INTRODUCTION

Both heavy-duty membranes and paving fabrics have been used on PCC pavements to delay reflection cracking through an asphalt concrete overlay. Heavy-duty membranes (and occasionally paving fabrics) have usually been used as 12- to 24-in.-wide strips placed over transverse and longitudinal PCC pavement joints. The use of strips is sometimes referred to as a strip or "Band-Aid" treatment. Paving fabrics, and in a few instances heavy-duty membranes, have also been placed full width over one or more lanes. Heavy-duty membranes and paving fabrics can, under favorable conditions, which are relatively stringent, serve as both an infiltration-reducing membrane and a stress-relieving interlayer.

One important function of a heavy-duty membrane, like a paving fabric interlayer system, is to prevent surface water from entering the pavement through joints and cracks. If the quantity of surface water entering the pavement is significantly reduced, then the following benefits should be realized:

- Reduction or elimination of pumping.
- Decreased slab movements through reduced fines erosion from beneath the slab; lower moisture gradients might also reduce slab warping.
- Increased subgrade strength through a decrease in moisture.

Improved subgrade strength and slab movement reduction result in reduced stresses and strains in the overlay. A stress and strain reduction, in turn, should lead to a lower crack propagation rate. Joint faulting should also be reduced, leading to better ride quality and higher pavement serviceability. Important factors in assessing the potential benefits derived from the use of heavy-duty membranes and paving fabrics include: (a) the existing structural strength of the concrete pavement as indicated by slab movement, (b) slab preparation, (c) fabric installation, (d) required overlay thickness, (e) climate, and (f) potential economics of using heavy-duty membranes or paving fabrics compared with other acceptable design alternatives. This chapter considers the important factors influencing membrane and fabric performance in terms of available experimental findings from test sections.

HEAVY-DUTY MEMBRANE MATERIALS

Heavy-duty membranes should be selected to serve as both an infiltration-reducing membrane and a stress-relieving interlayer. A heavy-duty membrane is a composite system, usually consisting of a polypropylene or polyester mesh laminated on either one or both sides with a rubber-asphalt membrane. Membranes typically weigh about 50 to 100 oz/yd^2, including the weight of the rubber-asphalt. For comparison, a typical 4 oz/yd^2 paving fabric weighs about 40 oz/yd^2 after saturation with asphalt.

General descriptions, adapted from Zapata et al. (*69*), of several commonly used heavy-duty membranes are as follows:

- Bituthene: A tough reinforcement of polypropylene woven fabric laminated to a thick layer of self-adhesive rubberized asphalt; $\frac{1}{16}$ in. thick.
- PavePrep: A sand asphalt sandwiched between two layers of polyester, one layer woven and one nonwoven spun bonded; $\frac{1}{8}$ in. thick; AC-20 tack required; 100 percent elongation; 13 oz/yd^2.
- Polygard: A high-strength heat-resistant polypropylene fabric embedded in (laminated to) the outer surface of self-adhesive rubberized asphalt; $\frac{1}{6}$ in. thick.
- Petrotrac: A combination of nonwoven polypropylene fabric precoated with rubberized asphalt; it is protected by a release sheet that is removed at the time of membrane installation; 80 mils thick; 80 percent elongation; 50 oz/yd^2 (with release film); no prime is required if temperature > 70°F.

The mastic membrane, which constitutes the most important part of the interlayer, should provide both reduced permeability and be sufficiently soft and thick to act as a stress-relieving interlayer. The fabric is included to protect the membrane and hold the system together. In some systems, the membrane is bonded to the old pavement, when temperatures are greater than about 70°F, by simply removing a protective film from the back of the membrane and laying it over the prepared joint. In other systems, an adhesive tack coat, sometimes proprietary, must be applied to each side of the joint before the membrane is placed.

The manufacturer's recommendations for membrane installation should be followed unless sufficient experience has been gained with a specific product to develop improved installation procedures. Installation specifications are therefore usually similar to those recommended by the manufacturer. The Georgia Department of Transportation is currently using heavy-duty membranes as a routine rehabilitation strategy on PCC overlay projects; material and installation specifications are given in Appendix A.

MEASUREMENT OF JOINT MOVEMENT

The significant effects of load and thermally induced joint movements on PCC pavement overlay performance have become increasingly clear as more knowledge is accumulated about reflection cracking (*26 35, 70, 71*). McGhee (*70, 72*) and later Predoehl (*26*) have clearly demonstrated, by field studies, the importance of load-induced vertical joint movements of PCC pavements.

Thermally Induced Horizontal and Vertical Joint Movement

Thermally induced horizontal joint movements are also important, as demonstrated by the early work of Bone et al. (*73*) and Tons et al. (*7*) in Massachusetts, and the later work in Virginia by McGhee (*70*). Theory indicates that the magnitude of thermally induced horizontal joint movement caused by seasonal changes in temperature is approximately proportional to the joint spacing. Horizontal joint movement is also proportional to the coefficient of thermal expansion. The coefficient of thermal expansion, however, varies with aggregate type, which, therefore, is an important factor in joint movement.

Vertical joint movements are caused by curling and warping of the slab caused, respectively, by temperature and moisture gradients that exist through the slab. A cycle of joint movement caused by curling occurs each day, with daily vertical movements being as great as 0.1 in. or more. Field data from Minnesota (*74*) indicate that the warping of a PCC slab caused by a 1 percent change in moisture through the slab is equivalent to that caused by a 20°F change in temperature. Thermal and moisture-induced joint movements have, in recent years, generally not received the attention they deserve in overlay design.

For the AC mixes used, cracking resulted in Massachusetts at horizontal joint deformations greater than 0.05 in. measured over a 13-in. gage length. Tons et al. (*7*) summarize these findings as follows:

> Although field observations and laboratory measurements show that the main reason for reflection cracking in Massachusetts is the horizontal joint opening or tensional stress, it often can be the combined effects of both horizontal joint opening and vertical deflection movements that cause the cracking. Damaging axial and flexural tension in the resurfacing at a joint affect not only the immediate area above the joint, but also extend some distance on each side. Once a crack has appeared it has a tendency to deteriorate and widen.

Load-Induced Joint Movement

In Virginia, McGhee (*70*) used a Benkelman beam and a dump truck with an 18-kip single-axle loading to effectively measure load-induced vertical joint and crack movements of rigid pavements. Gulden and Brown (*75, 76*) in Georgia and Seeds et al. (*77*) in Arkansas have both measured load-induced vertical deflections using a Dynaflect. Predoehl (*26*), however, has found a poor correlation between vertical joint deflections of PCC pavements measured with a Dynaflect and joint displacements under an 18-kip load. This finding casts doubt on the validity of using a Dynaflect, which applies a small load to the PCC pavement for joint and crack deflection studies.

A modified Benkelman beam developed by the California Department of Transportation (Caltrans) for measuring vertical joint or crack movement is shown in Figure 17. This measurement device consists of a 4.5-ft beam with a 12-lb counterweight. The beam is placed at a crack or joint at right angles to the direction of the pavement. Two dial indicators located 1 ft apart at the end of the beam are used to measure the vertical deflection of each side of the joint as an 18-kip wheel load moves across at 1 to 2 mph. McGhee (*70*) uses a somewhat similar procedure, except a conventional Benkelman beam is used.

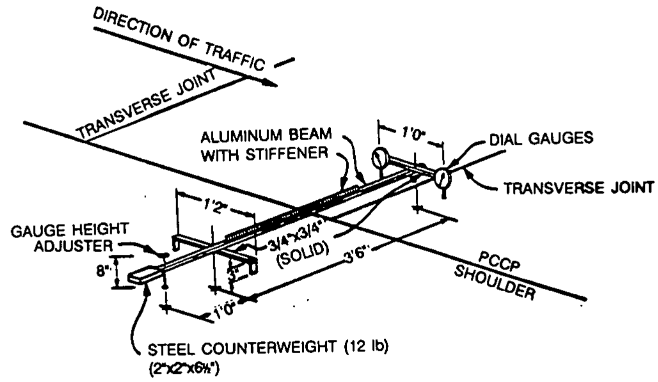

FIGURE 17 PCC joint deflection measurement device (after *26*).

Seeds et al. (*77*) recommend measuring the deflection of every joint if an underseal is considered. Otherwise, the measurement of the deflection of every other joint is suggested, provided the joint spacing is less than 25 ft. For continuously reinforced concrete pavements, Seeds et al. (*77*) recommend measuring the deflection of three to five cracks in a 100-ft interval if undersealing is to be used; otherwise a 200-ft interval is suggested.

Load Transfer and Shear on Joints

Load transfer across a joint is directly related to the differential deflection between the two sides. Joint load transfer efficiency is 100 percent if the deflection on each side is the same when a load is applied to one side. Load is not transferred across the joint if the slab on the other side does not deflect. When a wheel loading is on the edge of the joint, the shear load, V_o, that must be carried by the overlay can be approximated using measured vertical slab movements. Assume two fictitious loads, P_1 and P_2, are applied as shown in Figure 18 to each side of the joint and

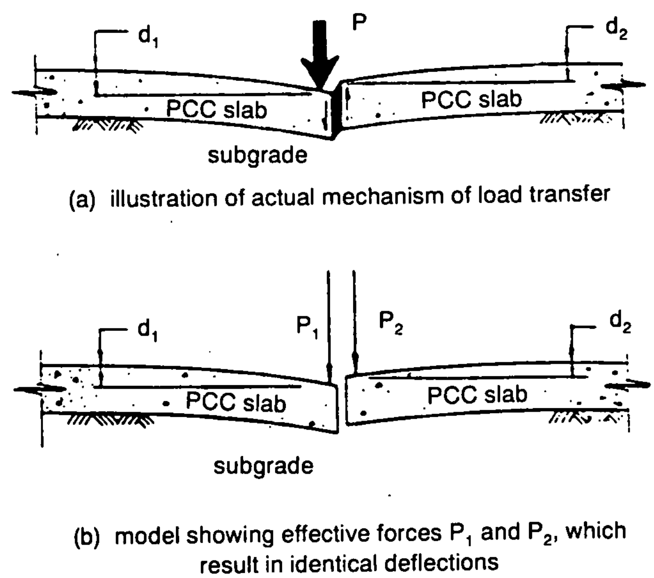

FIGURE 18 Load transfer across a PCC pavement joint (after *77*).

cause the two observed deflections, d_1 and d_2. Then the shear force in the overlay caused by an applied wheel load P is approximately equal to (*77*):

$$V_o = P (d_1 - d_2)/(d_1 + d_2) \quad (4)$$

The derivation of the above expression assumes a linear system and neglects any interaction between the two slabs.

Measurement of Thermal Joint Movements

Thermal joint movements can readily be measured by placing reference points on the pavement across a transverse joint or crack (*70, 77, 78*). Usually the reference points are brass plugs epoxy glued into holes drilled into the pavement. Either a Berry strain gage (*77*) or a special measurement device (*79*) can be used. To achieve a high degree of accuracy, the gage's measurement tips should always be pointed to fit the same way in the cylindrical holes drilled in the center of the brass plugs.

Seeds et al.'s (*77*) overlay design approach requires measuring thermally induced slab movement at five different temperatures on at least two days. More measurements over a longer period are desirable and should be developed, on at least a regional basis, for each slab overlay design. For a study of overlay performance, McGhee (*70*) measured horizontal joint movements in PCC pavements at five consecutive joints in both control and test sections. Measurements were made both before the overlay was placed and for a period of 30 months afterward. Horizontal movements across the old joint were corrected for normal thermal movements of the asphalt concrete overlay. To develop the correction factor, horizontal thermal movements were also made, using the same gage length, on the AC overlay in an uncracked area of the pavement near the joint. Results suggest that the asphalt concrete probably "humped" up over the joint, which has been observed elsewhere in Virginia and in other states.

PCC SLAB PREPARATION

A number of overlays involving heavy-duty membranes and paving fabrics have been successful when load induced slab deflections were small, usually as a result of good slab preparation (*32 35, 69–72, 75, 76, 78, 80*). Gulden and Brown (*76*) and Dykes (*25*) have emphasized the importance of proper PCC slab stabilization to minimize joint movement. An excellent description of restoration methods for jointed concrete pavement has been given by Gulden and Thornton (*81*). Slabs exhibiting excessive joint deflection or rocking should be replaced or undersealed with an acceptable grout. Cement grouts and cement-fly ash grouts are often used for undersealing. Both cement lime fly ash (*75, 76*) and asphalt grouts (*72*) have also been employed. When necessary, slabs should be replaced. Portland cement concrete pavement should be used for slab replacement (*81*).

Unsealed joints and cracks in PCC slabs can lead to AC overlay raveling and an accelerated rate of reflection cracking. Joint resealing can delay the pumping of erodible base materials. Where the sealant has failed, joints should be cleaned out thoroughly and sealed appropriately with suitable joint filler materials. Spalled areas greater than about 3 in. in diameter, particularly if they are to be covered with a membrane or fabric, should be repaired with partial PCC patches or a bituminous material and brought approximately flush with the slab surface. Cracks greater than 0.25 in. wide should also be cleaned out and sealed. Cracks should not be overfilled, and the expansion of some fillers should be considered in overlay design; problems with humping at joints have resulted because of these factors. Crack filling having volatiles should be allowed to cure before the fabric or membrane is placed.

CONSTRUCTION CONSIDERATIONS—INSTALLATION

Full-Width Fabrics

The installation of full-width paving fabrics over rigid pavements is similar to that for flexible pavements, described in detail in Chapter 3. A leveling, or scratch, course of asphalt concrete should be placed over rough PCC pavement surfaces before the fabric is laid. California applies a leveling course when a full-width paving fabric is employed over a PCC pavement. A leveling course was also used in Georgia on an experimental section where 29 percent of the joints were faulted more than 0.25 in. (*75, 76*).

As on flexible pavements, proper tack coat application rate is crucial to a successful paving fabric installation on PCC pavements. Overlay surface cracking has occurred where the fabric was not laid down correctly, wrinkles were not slit properly, and where stretching and slipping occurred under the paver because of wrinkles and poor fabric anchorage (*82*). As crews gain experience, construction-related problems generally decrease.

Strip Membranes

The installation of heavy-duty membranes generally has been found to be relatively easy (*69, 83*), particularly when compared with fabric placement and separate tack in limited widths. Usually the manufacturer's recommendations are followed when installing heavy-duty membranes because of the widely varying products and installation requirements. Heavy-duty membranes may require using either a single-, two-, or three-step installation process, depending on the product.

Because of the differences in materials and installation requirements, the constructibility of heavy-duty membranes should be evaluated in the field. Knight (*78*) has found that six different heavy-duty membranes exhibited quite different application problems, installation rates, installed costs, and traffic resistance, as summarized in Table 7.

Heavy-duty membrane strips should be placed on a clean, dry surface that has been properly prepared. Installation crews for heavy-duty membranes vary from three to as many as eight persons for complicated installation procedures in which high production rates are desired. The paver should not be permitted either to start or stop over a membrane strip; this has been found, both in Georgia (*75, 76*) and Delaware (*84*), to cause AC shoving over the strip. Asphalt concrete bulging over the strip may also occur during construction of the first lift, especially if the lift is 2 in. or less thick. Knight (*78*) in Pennsylvania has found the presence of wide, unfilled joints to result in damage to the membranes during overlay compaction.

TABLE 7
OBSERVED IN-PLACE COST, EASE OF APPLICATION, AND EFFECT OF DIRECT TRAFFIC ON SELECTED HEAVY-DUTY MEMBRANES (AFTER *78*)

Trade Name	Manufacturer	Material Cost Lin./ft[a]	In-Place Cost Lin./ft	Installation Rates	Ease of Application	Effect of Direct Traffic
Polyguard 665 (Section 1)	Polyguard Products, Inc. Pryor, Okla.	$0.39-0.42	$0.85	P 4 min/100ft M 8 min/100ft (2-member crew)	1	2
PavePrep (Section 2)	McAdams Mfg. Co., Inc. Cincinnati, Ohio	$0.83	$1.20	T 37 min/100ft (3-member crew)	4	3
Bituthene S-5300 (Section 3)	W.R. Grace & Co. North Bergen, N.J.	$0.34	$0.55-.065	P 15 min/100 ft M 15 min/100 ft (2-member crew)	2	2
Roadglas (Section 4)	Owens/Corning Fiberglas Granville, Ohio	Fabric $0.22 Binder $0.40 $0.62	$1.27	T 16 min/100 ft (3-member crew) + 20-min wait	3	1
Petrotac (Section 5)	Phillips Fiber Corp. Greenville S.C.	$0.33	$0.47	T 10 min/100 ft (2-member crew)	1	1
Royston #108	Royston Lab, Inc. Pittsburgh, Pa.	$0.54	$0.78	P 7 min/100 ft M 20 min/100 ft (2-member crew)	3	4
#10AR	Royston Lab, Inc. Pittsburgh, Pa.	$0.53	$0.77	M 12 min/100 ft (2-member crew)	2	2

[a]Based on companies' projected cost.
P = Application of primer
M = Application of membrane
T = Combined operation time
Ease of application: 1 = easiest to apply
Effect of direct traffic: 1 = least affected

A minimum membrane overlap of 2.5 in. should be used in the direction of the paving operation. Transverse joints and transverse cracking should be covered before longitudinal joints. The contractor should be responsible for membranes that are damaged or become debonded, either during construction or when subjected to traffic.

Traffic

A limited amount of traffic on heavy-duty membranes and paving fabrics may be acceptable (*75, 76, 78, 84, 85*). Gulden and Brown in Georgia (*75, 76*) have, in fact, found some traffic to result in improved bond to the underlying layer, and to mold the membrane to faulted joints. Observed resistance to traffic of six different membranes is given in Table 7. Fabrics and heavy-duty membranes have successfully withstood traffic for 7 to as many as 11 days without observable damage. However, in one instance, a heavy-duty membrane underwent a loss of adhesion after being open to traffic for several days; moisture and cold weather apparently were contributing factors. To minimize the damage potential both from moisture and traffic, the membrane should, when practicable, be left exposed for three days or less and never for longer than seven days.

PREVIOUS STUDIES

Only a moderate amount of documented field performance data have been developed about the performance of PCC pavements having heavy-duty strip membranes over joints and cracks and for full-width fabric coverage (*26, 35, 69–72, 75, 76, 78, 80, 82–91*). General summaries of observed performance have been given by Sherman (*4*) and Ahlrich (*47*). Predoehl (*26*) recently has presented the findings from five sites involving about 17 paving fabric sections.

PERFORMANCE

The overall probability of reducing reflective cracking by using fabrics and heavy-duty membranes appears, based on past experience, to be lower for PCC pavements than for flexible pavements. The overall poorer performance for PCC pavements is significantly influenced by the large vertical load and thermally induced joint movements that frequently are present. These movements impose severe bending, tension, and shear conditions on the overlay placed above a PCC pavement. As discussed in Chapter 2, joint movement significantly affects crack propagation. Also the wide variation in PCC design details, existing pavement condition, and level of remedial work performed significantly influences joint movements and hence contributes to the observed variability in performance.

Data from California summarized by Predoehl (*26*) for full-width coverage, using several types of paving fabrics placed on a leveling course, suggest that the probability for delaying reflection cracking is on the order of 45 percent for PCC pavements. Sections with fabrics that were considered to perform favorably either had delayed cracking or, more commonly, exhibited reduced levels of cracking compared with the control section(s). For comparison, the probability of delaying reflection cracking using paving fabrics on flexible pavements is on the order of 60 percent for favorable conditions. In the California PCC studies, several types of paving fabrics were used over a leveling course. Where the applications were considered successful, reflection cracking over the PCC pavements typically was delayed for about a year. Except for thin overlays, about 2.4 in. thick, the average time to reach moderate levels of reflection cracking for the pavements typically was seven or more years, indicating a satisfactory overlay design. These pavements apparently did not receive any previous slab or joint repair.

In states such as Pennsylvania, Michigan, and Georgia, where a high level of joint repair apparently is carried out, a limited number of studies show the overall success rate to be reasonably high for reducing the level of reflection cracking for about three to five years. Undoubtedly, careful selection of candidate PCC pavements and type of treatment, together with a high level of joint repair, increases the probability of success. The hypothesis is given that under certain restrictive conditions, described subsequently, the probability of delaying reflection cracking successfully for several years is reasonably similar to that of flexible pavement in warm to moderately cold climates. The studies performed in California suggest that thicker fabric layers (75 to 100 mils compared with 50 ± 10 mils) may be more effective.

Vertical Joint Movements

McGhee (*70*) has found that using a paving fabric or heavy-duty membrane over PCC joints delays reflection cracking better than the control when the Benkelman beam vertical deflection across a joint is less than 0.002 in. Indeed, the Virginia study showed, for a vertical joint deflection of 0.002 in., 29 percent of the fabric-treated joints reflected through the overlay, compared with 54 percent of the control joints. For a condition of no joint movement, the fabric-treated joints did not show any reflection cracking, compared with 44 percent of the control joints. For deflections greater than 0.008 in., reflection cracking occurred regardless of whether a treatment was used.

McGhee (*70*) and McGhee and Hughes (*92*) describe the construction and performance of a composite pavement consisting of a plain concrete base with asphalt concrete surfacing. Findings verified the importance of vertical joint movement. Rutkowski (*71*) found the control section to perform just as well as both those with full-width paving fabrics and with heavy-duty strip membranes. Average joint deflections measured by the Benkelman beam were 0.009 in., which further emphasizes the importance of joint movements. Extensive reflection cracking was reported in all sections after two years. Predoehl (*26*) has concluded:

> It appears that a PRF interlayer should be incorporated in AC overlays over in situ (existing condition—no correction of Δ-vert) PCC pavement where Δ-vert is more than 0.003 inches but no more than 0.008 inches. Where Δ-vert is 0.008 inches or greater, PRF interlayers are ineffective, and it appears that a minimum AC overlay thickness of 0.40 feet is needed to retard significant cracking for the 10-year design period. It also appears that the 10-year design period can be obtained without using PRF where Δ-vert is less than 0.003 inches.

Horizontal Joint Movement

Limited measurement data reported by McGhee (*70*) indicate that horizontal joint movements greater than about 0.04 in. have a significant effect on reflection cracking. This preliminary finding indicating the importance of horizontal joint movements is supported by the early 1954 work of Bone et al. (*73*) and reiterated in 1961 by Tons et al. (*7*). This work showed that horizontal joint movements in Massachusetts are a predominant factor in reflection cracking of conventional AC overlays. Overlay reflection cracking almost always occurred where the joints opened more than 0.05 in. Typical measured joint movements, however, were between about 0.10 and 0.18 in., which helps to explain the observed occurrence of reflection cracking. Bone et al. (*73*) also found that laboratory AC specimens could withstand deformations no greater than 0.05 in. without cracking.

Based apparently upon laboratory studies Lytton (*6*) has concluded:

> There are three ranges of thermal opening: (a) from 0 to 0.03 in., where no geotextile is needed; (b) from 0.03 to 0.07 in., which is the effective range of geotextiles; and (c) greater than 0.07 in., which is an opening movement which geotextiles cannot normally withstand.

The findings of Bone et al. (*73*) and Lytton (*6*) support the tentative results from McGhee concerning the importance of joint opening.

Variability of Experimental Results

As was found for flexible pavements, experimental studies involving the use of paving fabrics and heavy-duty membranes over PCC pavements have shown widely varying and often erratic results. One important cause of this variability is undoubtedly the variation in structural strength of the PCC pavement throughout the length of the experimental studies. Structural strength is influenced by slab thickness, subbase and subgrade strength, and erosion of material from beneath the pavement caused by pumping. The resultant effect of these factors is, to at least a large degree, evidenced by vertical joint movement under load, joint faulting, and the general condition of the pavement. Transverse joint spacing is directly related to horizontal joint movements and hence is also related to overlay performance. Azab et al. (*91*) found significant variation in performance between two similar control sections in a study involving heavy-duty membranes. In another study, Mullen and Hader (*82*) used statistical principles to lay out the test sections. They included replicate test and control sections to provide a statistically sound interpretation of the findings. Mullen and Hader concluded that "'joint' cracking appears to vary much more with location along the highway than with the different overlay treatments used in this experiment."

The significant effect of variable conditions along experimental sections has, in the past, received far too little attention. As a result, the interpretation and synthesis of the majority of existing experimental studies is greatly clouded by the potential for structural and environmental variability throughout the project's length. For these reasons, only somewhat generalized conclusions can be drawn from the available experimental results, because of the potential for variability, differences in joint movements, and greatly varying thicknesses of the overlay compared with that required for a reasonable overlay life.

Tests in Georgia (*76*) have shown Bituthene to give good results, whereas in Pennsylvania (*91*) Polyguard 665 and Pave-Prep were found to perform satisfactorily. Roadglas performed well over transverse joints in Michigan (*86*); over longitudinal joints, Bituthene, V-78, and Roadglas strips all performed well. Full-width Petromat, when placed 3 in. up in a 5.25-in.-thick overlay, showed reasonably good performance in Minnesota (*80*), but was not as effective as either a SAMI or saw-cutting additional transverse joints, which performed best.

Climate

Past experience indicates that heavy-duty membranes and paving fabrics, when used over PCC pavements, in general perform better in warm climates than in cold ones (*4, 47*). Ahlrich (*47*) recommends not using fabrics on either flexible or PCC pavements where the mean freezing index is greater than 500 degree-days, illustrated as Area III in Figure 14. Thermally induced joint movements appear to be greater in cold than warm climates if other factors are the same (*79*). Also, problems with pumping and the resultant load-induced joint movements are, in general, probably more common in the North Central and eastern sections of the United States. This is probably because of high volumes of heavy truck traffic and moderate amounts of rainfall. Where joint movements are limited, fabrics and heavy-duty membranes have performed reasonably well, delaying reflection cracking for three to perhaps five years.

Acceptable performance has been observed in reasonably cold climates for two projects in Pennsylvania (*35, 78, 91*) and on one project in Michigan (*69, 86*). Full-width paving fabrics on PCC pavements in Michigan met with mixed results (*69*). In Wisconsin (*71*), after six years little difference existed between reflection cracking of transverse control joints and joints treated with paving fabrics and membranes. Although vertical joint movements were excessive, the level of reflection cracking was reduced for several years.

These limited results, which considered the effects only of cracking, indicate the effect of climate alone is not entirely clear at this time and requires further study. The results, however, do suggest that joint movement is probably at least as important as climate.

Full-Width or Strip Coverage

One of the more comprehensive studies of PCC pavement reflection cracking has been performed in Georgia by Gulden and Brown (*75, 76*). Both full-width paving fabric coverage, heavy-duty membranes strips, and other techniques were compared with control performance for AC overlay thicknesses of 2, 4, and 6 in. The heavy-duty membrane strips were 18 in. wide. A high level of slab repair was carried out before construction, including replacing broken slabs and, where required, undersealing slabs. Proof rolling was used to identify slabs with excessive movement. The full-width paving fabrics were placed on a leveling course. For all three overlay thicknesses, the heavy-duty membranes strips performed better than the two types of full-width paving fabrics used as illustrated in Table 8. The heavy-duty membrane performed best when used below the 6-in.-thick overlay.

For a thin 2-in. AC overlay used in North Carolina, Mullen and Hader (*82*) concluded, based on joint cracking data, that a significant difference did not exist between strip and full-width coverage. Because of the presence of a thin overlay, the effect of membrane type may have been hidden because of the high crack rate and slight differences between the test sections. Limited studies performed in California using heavy-duty strip membranes are inconclusive (*26*).

When joint movements are excessive, neither full-width paving fabrics nor heavy-duty membranes are likely to be effective.

Overlay Thickness

As overlay thickness decreases, the rate of reflection cracking increases in the overlay as illustrated in Table 8. Gulden and Brown (*76*) recommend, for conditions in Georgia, a minimum overlay thickness of 4 in., together with a comprehensive repair program to reduce slab movement, when a heavy-duty membrane is used to control reflection cracking. This recommendation applies for relatively severe conditions leading to pumping and faulting problems. A study in Pennsylvania conducted by Knight (*78*) and Azab et al. (*91*) supports this finding. In California, where faulting and pumping problems may be less severe than in Georgia, Predoehl (*26*) recommends using a minimum overlay thickness of 4.8 in. without a fabric or membrane to retard reflective cracking for 10 years.

One study suggests that a PCC pavement that has previously been overlaid one or more times provides more favorable conditions, apparently in terms of increased strength, for the use of a relatively thin overlay. Full-width paving fabrics were used successfully in Pennsylvania, which has a relatively severe climate, with a thin 1.5-in. overlay (*35*). This overlay was placed

TABLE 8
NUMBER OF YEARS TO 10 PERCENT CRACKING AND RATE OF INCREASE FOR AC OVERLAYS OF PCC PAVEMENTS IN GEORGIA (AFTER *76*)

	Overlay Thickness (inches)								
	2			4			6		
Type Treatment	1[a]	2[b]	3[c]	1[a]	2[b]	3[c]	1[a]	2[b]	3[c]
Bituthene	2	42%	39%	3	25%	20%	>8		
Mirafi	1	69%	17%	2	24%	46%	5	23%	
Petromat	1	59%	12%	2	19%	32%	4	23	
Edgedrains	0	80%	14%	0	51%	27%	2	26%	43%
Control	0	91%	7%	1	58%	11%	4	24	
Arkansas Base[d]	Item 1 3 years Item 2 36%								

[a]Number of years without significant occurrence of cracking (≤ 10%)
[b]Rate of increase for first two-year interval after significant cracking occurs.
[c]Rate of increase for second two-year interval.
[d]The Arkansas base is 3.5 in. thick and the overlay is also 3.5 in. thick. Refer to Chapter 7 for a discussion of this type of base.

over an old 12-in. PCC pavement that had previously been overlaid with 2.5 in. of asphalt concrete. A reasonably high level of maintenance, however, appeared to have been performed on this pavement before application of the fabric.

In California and Georgia, placement of a paving fabric or heavy-duty membrane together with a thin overlay about 2 in. thick should delay reflection cracking for about one to three years as shown in Tables 8 and 9. Overlays less than 2 in. thick tend to "hump" over strip membranes during overlay placement. The probability of delaying reflection cracking may reduce with decreasing overlay thickness.

Reduced Transverse Joint Spacing

Horizontal joint movements caused by temperature changes are theoretically approximately proportional to transverse joint spacing. Therefore, horizontal joint movements can be reduced significantly by sawing additional transverse joints in the pavement or by cracking and seating, which is briefly reviewed in Chapter 7. In one study, Allen (*80*) found that sawing a 39.3-ft PCC panel into 6.5-ft lengths was quite effective for reducing reflection cracking. Sawing the panels into 6.5-ft slabs, without any other treatment, was more effective than using two saw cuts per panel with either a full-width paving fabric or one or two strips of a glass membrane. The 39.3-ft panels were reinforced with temperature mesh. The saw cuts were about 4 in. deep, which severed the steel reinforcement.

Cracking and seating alone was more beneficial for delaying reflection cracking than using a full-width paving fabric without cracking and seating (*26*). Also, preliminary findings in California suggest that when a paving fabric is used together with cracking and seating, cracking and seating has the dominant beneficial effect on performance.

Longitudinal Joints

Longitudinal centerline, shoulder, and widening joints on PCC pavements usually undergo less movement than transverse joints. As a result, fewer problems generally are experienced with reflection cracking over longitudinal joints. Paving fabrics and heavy-duty membranes therefore have a higher probability of being successful over longitudinal joints. Studies in Virginia (*72*), Delaware (*84*), Iowa (*87*), Minnesota (*83*), and Michigan (*69, 86*) indicate that when strip membranes are used, varying levels of reduction in reflection cracking are achieved compared with no treatment. Therefore, when reflection cracking of longitudinal joints is anticipated to be a problem, the use of heavy-duty membranes and fabrics offers one acceptable alternative for delaying reflection cracking, provided that joint movements are within acceptable levels. Although effective, Heins (*87*) recommended discontinuing the use of fabrics over longitudinal joints in Iowa because reflection cracking was found not to be a problem (probably because of small longitudinal joint movement). A similar conclusion was reached by Knight (*78*) in Pennsylvania.

Very Stiff Membranes

Some very stiff, high-modulus, heavy-duty membranes have moved the cracking from immediately over the old joint out to the sides of the membrane. This behavior is similar to that observed when steel reinforcement strips have been used.

TABLE 9
EFFECT OF PAVING FABRIC ON YEARS TO INITIAL AND SIGNIFICANT CRACKING OF PCC PAVEMENTS IN CALIFORNIA (AFTER 26)

		Average Years to Cracking[a]						
Thickness (ft)		0.20	0.25	0.30	0.35	0.40	0.45	0.50
Years to Initial Cracking	C	1.0	6.3	2.5	9.5+	7.0+	8.8+	7.0+
	F	3.0	7.0	5.5	9.0+	8.1+	8.6+	8.5+
Years to Significant Cracking	C	1.0	7.3+	5.0+	10.0+	7.0+	8.8+	7.0+
	F	5.0	7.2+	8.1+	9.2+	8.4+	8.8+	8.5+

[a]Averages with pluses include values for AC overlays that have not yet reached this condition. The values indicate current average years of service.

NOTES: (1) Overlays consisted of AC--dense graded (DG) or a combination of DGAC +0.10-ft surface course of open-graded AC (OGAC).
(2) C = control sections.
F = PRF sections (only full-width PRF sections; does not include strip-type fabrics such as Bituthene and Varistrate).

Reducing Water Infiltration

Cores taken from a number of PCC pavements indicate that reflection cracking does not generally tear a fabric interlayer or membrane (*70–72, 86*). Knight (*78*), however, took cores through reflection cracks and found some heavy-duty membranes are damaged by hot asphalt concrete shoving the membrane into an open joint:

> Two of the membranes cored, Polyguard 665 and Royston 10AR, were intact and were performing as waterproofing membranes; two, Bituthene S-5300 and Roadglas, were damaged during the rolling operation and were not waterproof.

This finding clearly demonstrates that joints must be filled with a suitable material before fabric or membranes is placed. Oklahoma (*34*) has found that crack joints greater than ⅜ in. wide must be filled with hard or stiff material. Asphalt-rubber, etc. will not work properly when used in these wide joints. Fly ash grout and fast-setting polymer slurry seal material have been used in Oklahoma with success. Predoehl (*90*) also concluded that wide cracks can damage fabrics, as can vertical joint deflections greater than 0.01 in. in magnitude. McGhee (*72*) and Gulden and Brown (*75*) have observed that reflection cracks above PCC pavements appear to remain tighter when a membrane is present. McGhee (*70*) also found evidence that a membrane may reduce pumping. Whether the fabric or membrane improves ride quality or results in a higher present serviceability index (PSI) has not been clearly established. A study by Rutkowski (*71*) in Wisconsin found that the decrease in PSI with time was not affected by the presence of fabrics and membranes; they also were relatively ineffective in delaying reflection cracking.

CHAPTER FIVE

FABRICS IN MAINTENANCE OF FLEXIBLE PAVEMENTS

INTRODUCTION

Maintenance strategies such as use of paving fabrics have the potential for significantly extending a deteriorated pavement's useful life. Reduction of water infiltration by fabrics is very likely the most important mechanism leading to improved pavement performance when paving fabrics are used in rehabilitation. Using paving fabrics when overlaying low-volume roads probably has the most potential, although fabrics can also be used as a maintenance strategy for high-volume roads.

South Carolina, Texas (Brownwood District), California, and Oklahoma are among the few state transportation agencies identified that currently use fabrics in maintenance activities. At this time, counties and cities are perhaps making more use of fabrics than state agencies are. Unfortunately, almost no published research is currently available documenting the use and performance of fabrics in pavement maintenance. Therefore, the preliminary findings presented in this chapter are based, to an important extent, on discussions with engineers involved in maintenance activities. Paving fabric uses in maintenance including chip seals, patching, and special water infiltration-reducing applications are described in this chapter.

FUNDAMENTALS

Reducing Water Infiltration

Experience has shown that the rate of flexible pavement deterioration increases rapidly after surface cracking begins, as illustrated in Figure 19. Usually this deterioration takes the form of rutting and additional alligator surface cracking, which is soon followed by more serious problems, including potholes and raveling. Rapid deterioration after cracking is particularly pronounced when the pavement structure includes an unstabilized aggregate base. A membrane placed near the surface in a distressed area, under the proper conditions, has the potential for significantly reducing the quantity of surface water entering the pavement in the distressed area. Hence, using membranes such as paving fabrics has the potential for greatly increasing the maintenance activity's effectiveness. Figure 19 illustrates the importance of taking timely corrective maintenance action.

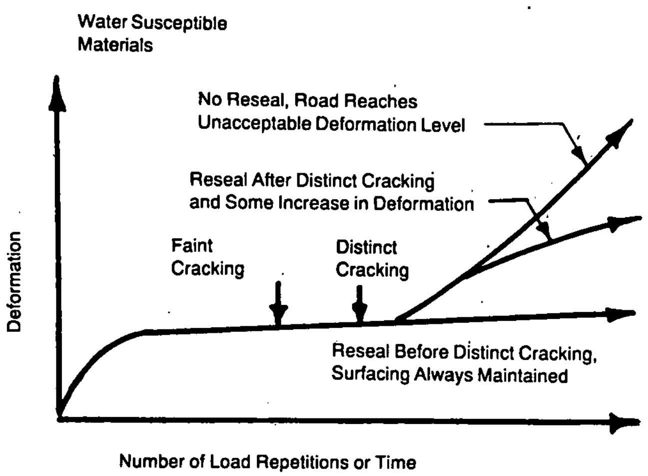

FIGURE 19 Influence of surface cracking on rutting of flexible pavement with unstabilized granular base (after *66*).

Fabric Use

Paving fabrics should not be considered as a maintenance cure-all for severely deteriorated pavements. In general, paving fabrics should not be used in maintenance if cracking is not present or if the weak areas of the pavement have been removed and replaced (R. Martin, personal communication, August 1989). The exception is when future water-reduction benefits are desired. Overlays should be designed to have adequate structural strength using a deflection-based procedure as will be discussed in Chapter 6. The use of paving fabrics should only be considered where the cracks are tight, with crack width preferably less than ⅛ in. Cracks greater than ⅜ in. should not be treated with fabrics without previous crack treatment. Cracks ⅜ in. or wider prevent asphalt from "wicking" in the fabric across a crack or joint. This leaves the crack or joint open to surface water infiltration immediately after the old crack reflects through the overlay.

Areas badly cracked because of fatigue are ideal candidates for improvement using paving fabrics in maintenance. Such areas typically have alligator or block cracking with low levels of rutting. Use of paving fabrics is not recommended in areas where an unstable layer (i.e., weak base or subgrade) is the cause of the problem. Fabrics can, however, be used to advantage in maintenance where a base or subgrade failure occurred after fatigue-related surface cracking permitted water to infiltrate through the cracks. This condition is not, however, easy to identify.

Water Infiltration Reduction and Stress Relief

Considerable field and laboratory data show that an asphalt-saturated paving fabric can serve as a low-permeability membrane as discussed in Chapters 3 and 4. Even an asphalt tack coat without fabric, if uniform and thick enough, has a low permeability (*20*). An asphalt-saturated fabric can also perform, under the proper conditions, as a stress-relieving interlayer, as discussed in Chapter 2. A stress-relieving interlayer reduces the stress at the tip of the crack, and as a result, retards reflection cracking. Theory shows that more reduction in reflection cracking should occur as the stress-relieving interlayer becomes softer and thicker.

MAINTENANCE APPLICATIONS—PATCHES, CHIP SEALS, AND LEVELING COURSES

Fabrics can be used in maintenance in areas exhibiting fatigue distress and where surface water infiltration is causing pumping. The fabric is placed over the distressed area on the surface of the old pavement and then covered with either a patch, chip seal coat, or leveling course. The type of maintenance selected depends on the type and level of pavement deterioration. Maintenance strategies used by Martin (R. Martin, personal communication, August 1989) in Texas for different types of distress are illustrated in Figure 20. For good performance, the selected

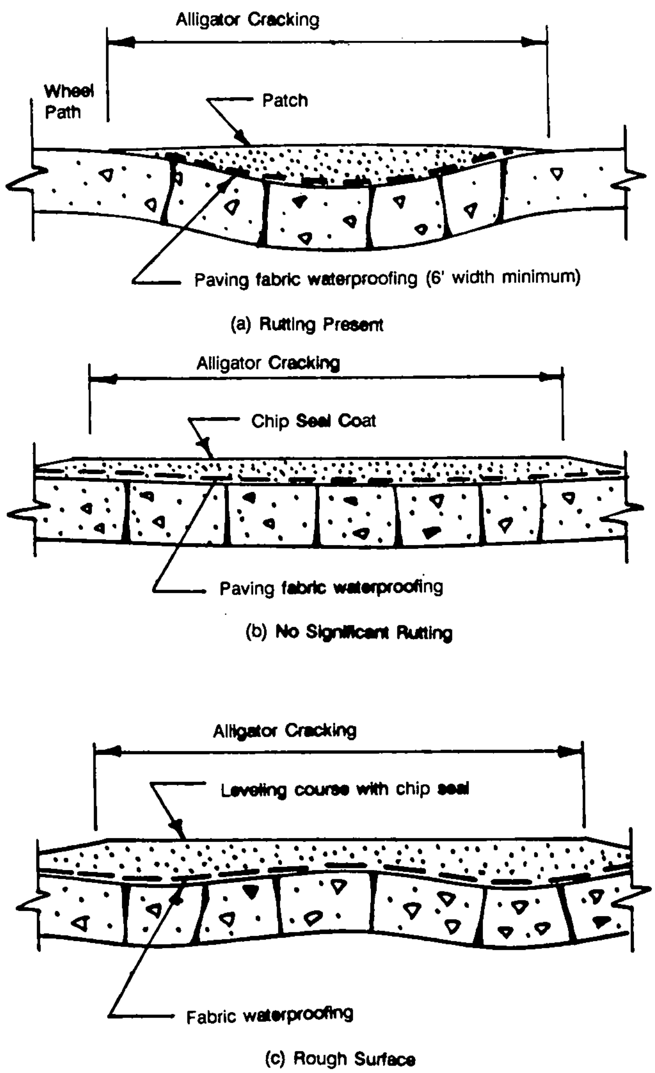

FIGURE 20 Use of paving fabrics as an infiltration-reducing membrane by the Texas Department of Highways and Public Transportation—Brownwood District.

paving fabric maintenance procedure must be carefully engineered just like any other design activity.

Before fabric placement, the deteriorated pavement should be prepared and the fabric placed as discussed in Chapter 3. For proper fabric application, the old pavement surface must be dry and the pavement temperature greater than 45°F.

Tack Coat

Applying the proper amount of tack coat is very critical to successfully using fabrics in maintenance, just as it is in conventional overlay applications. Too little tack coat results in bond failure and reduced stress-relieving ability, whereas too much tack results in overlay slippage. The required quantity of tack can be readily estimated using equation (2) or Table 4. Laboratory tests described in Chapter 2 can also be performed to determine required tack quantity. The theoretical quantity of tack coat to be applied must be adjusted to account for surface texture, oxidation (whether the asphalt on the old surface appears alive or not), and whether the cracks have been filled.

For maintenance applications, the Brownwood District in Texas varies the tack coat application rate transversely across the pavement to reflect variations in surface dryness (R. Martin, personal communication, August 1989). The pavement in the wheel paths is worked and hence is more "alive" and "wetter" than between the wheel paths. Therefore, the Brownwood District typically applies 20 to 30 percent more tack coat outside the wheel paths.

An uneven distribution of tack can be applied using a specially modified spray bar on a distributor truck. The nozzles on the spray bar located between the wheel paths can be drilled out slightly to give increased flow. Varying the rate of tack coat application has been found to be particularly important where the traffic volume is relatively high. Caution should be exercised if an uneven distribution of tack is used; improper application can cause problems. For any surface treatment less than 1.5 in. thick, the fabric should be rolled or else trafficked because of the lack of heat retention in the layer.

Patching

Paving fabrics apparently have not been used extensively in patching applications. The Texas Department of Highways and Public Transportation is probably one of the larger users. Caltrans has experimented with using paving fabric beneath a small patch over alligator-cracked areas (R. Kelly, personal communication, August 1989). Although this approach is reported to work satisfactorily, it is quite manpower- and equipment-intensive. Where small areas are to be repaired, a heavy-duty membrane can be used, eliminating the need for a tack coat application.

Weld County, Colorado

In Weld County, Colorado, a paving fabric is routinely used by the county (D. Scheltinga, personal communication, August 1989) beneath relatively large skin patches. Paving fabrics are placed only over alligator-cracked areas that are in an advanced state of deterioration. Such deterioration must not be related to a structural failure of the base or subgrade. This fabric-patching procedure has now been carried out successfully for four years with only one fabric patch repair being required. Typical traffic volumes on the two-lane roads where paving fabrics are used in Weld County vary from about 200 to 1200 vehicles per day, with trucks accounting for about 5 to 10 percent of the traffic.

A loaded truck is used to proof roll the alligator-cracked area to visually determine if the problem is structurally related. When excessive deformations are observed, the structurally failed areas are removed and replaced. A fabric is not used in repairing structurally failed areas. Where a fabric is laid, a patch about 1.25 to 1.5 in. thick is placed over the fabric. Usually the patch extends over the entire width of the pavement to improve ride quality. A chip seal is then placed over the entire length of the pavement segment being rehabilitated, including the patched area. A rubberized RC-800R cut-back asphalt is used for the chip seal; this material has been reported to remain plastic and to be self-healing under traffic.

Removal of Asphalt Concrete

The California Department of Transportation sometimes uses paving fabrics in maintenance even when the asphalt concrete surfacing and base have failed. The bad material is broken and dug out of the distressed area, typically about 200 ft to 1 mile in length. A contractor usually places the fabric with a roller mounted on a tractor. The state maintenance crews then apply the paving by hand.

Chip Seals

Chip Seals without Fabrics

Chip seal treatments have frequently been placed on old pavement surface without a paving fabric being placed beneath them. This layer has sometimes been called a stress-absorbing membrane (SAM), although its ability to delay reflection cracking by absorbing the strain caused by stress is questionable. The 17 asphalt-rubber chip seal projects included in the National Experimental and Evaluation Program were reported generally to have outperformed the control sections in delaying fatigue cracking (*93*). The chip seals, however, were found to be ineffective in delaying transverse and longitudinal reflection cracking. During hot weather, asphalt-rubber has been found to have better healing properties than conventional asphalt cement (*93*).

In Kansas (*94*), a seal coat worked well on one project, but a comparison was not made with one having asphalt-rubber. A hot asphalt-rubber chip seal in California (*45*) reflected almost all cracks within five years but was effective in binding the surface together. In Georgia, Gulden (*95*) concluded that an asphalt-rubber seal coat performed better than a double surface treatment, which served as the control. The asphalt-rubber seal coat did not perform as well as a triple surface treatment. These treatments were found to be effective in reducing fatigue alligator cracking. None of the treatments studied by Gulden (*95*) were found to be capable of bridging over weak areas. Gulden also concluded that the asphalt-rubber distributor, chip spreader, and roller should all be located close together during construction.

Chip Seals with Paving Fabrics

Chip seals placed over a paving fabric have been used by several states as a maintenance strategy for reducing pavement permeability and reducing reflective cracking. States using this technique include Texas, Oklahoma, and South Carolina (*34, 96,* R. Martin, personal communication, August 1989). Martin (R. Martin, personal communication, August 1989) uses a chip seal/paving fabric treatment only on the surface of relatively low-volume roads having less than about 4000 cars per lane per day. Chip seals should be limited to use on low-volume roads. Common problems resulting in poor chip seal performance have been identified by Martin as follows:

- Applying too much aggregate: Aggregate should not be stacked on the surface. The quantity of aggregate to be used should be determined by laboratory testing (*97*).
- Incorrect quantity of asphalt: This problem can be corrected by laboratory testing and proper evaluation of the roadway surface.

Pourkhosrow (*34*) has found in Oklahoma that, in one test section, a chip seal used with Petromat exhibited good performance for five years. The best-performing Petromat section retarded reflection cracking and did not tear or rupture. Cores taken over cracks showed that the Bidim used in this study was disturbed, stretched and ruptured at alligator cracks, and torn at transverse cracks. Both fabrics were found to ravel at wrinkles and transverse joints. Oklahoma is now reporting good success with fabrics and chip seals using polymer-treated emulsions.

In South Carolina, a fabric chip seal placed over a lightly traveled roadway that had been patched extensively has performed well for three years (*96,* Z.C. Barker, personal communication, September 1989). Success using fabric chip seals has also been reported in Texas by Martin (R. Martin, personal communication, August 1989). One formal study performed in Texas, however, showed chip seal performed poorly compared with a fabric and 1.25 in. of asphalt concrete (*24*). The best performance, however, was observed when a fabric and chip seal were both used under a 1.25-in. AC overlay. These results suggest that using a chip seal for this project may not have been appropriate because of insufficient strength of the old roadway.

Fabric Chip Seal Construction—Brownwood District, Texas

Fabric Installation The Brownwood District in Texas typically permits traffic on the fabric for two to three days after placement. For fabric under chip seal coats, traffic appears necessary to achieve a good bond with the old pavement and to draw the asphalt tack into the paving fabric to saturate it. A pneumatic roller can be used for these purposes, but appears to be less popular than allowing traffic on the fabric. Sand is spread on the fabric surface once or twice during this period to prevent tires from pulling the fibers. Initially, 10 to 15 lb/yd^2 is placed from a sand spreader mounted on the back of a truck. Another application of sand is applied later if the surface becomes black, indicating asphalt bleeding. Manufactured (crushed) sand has been found to perform better than natural sand. Excess loose sand should be swept off the fabric before placing the chip seal (R. Marienfeld, personal communication, August 1989).

Chip Seal A board test can be used to determine the correct amount of aggregate for the chip seal to avoid aggregate loss and to determine the proper amount of asphalt to fill the voids in the aggregate (*97*). The board test consists of placing the chip seal aggregate one rock thick over a 3-ft-x-3-ft board. The quantity of asphalt needed to fill the voids in the aggregate chips is then calculated. Usually a $\frac{3}{8}$-in. Texas grade 4 chip is used. This design technique has worked well in the Brownwood District for many years (R. Martin, personal communication, August 1989).

If the asphalt tack comes to the surface, the quantity of asphalt in the seal coat application is reduced by between 0.04 to 0.05 gal/yd^2, depending upon the appearance of the surface just before shooting. A modified CRS-2P asphalt having 3 percent polymer is used sometimes. The polymer-modified cationic CRS asphalt has been found (R. Martin, personal communication, August 1989) to adhere better to both the aggregate and surface, particularly if it rains within a few hours after the seal coat is placed.

Potholes

Paving fabrics and heavy-duty membranes are seldom being used by state transportation agencies to repair potholes. Limited success has been reported with the use of self-adhesive, heavy-duty membranes as an infiltration-reducing layer for pothole repair. Usually, heavy-duty membranes are used during poor weather when conventional maintenance practices are impracticable. The pothole is first filled with a suitable material. Then a heavy-duty membrane, which acts as an infiltration reducer, is placed over the material. An AC surfacing frequently is omitted, particularly in poor weather. To install the self-adhesive heavy-duty membrane properly, the surface must be dry and at a temperature of at least 70°F. In cold weather, when this type of repair is perhaps most applicable, a blow torch or other heat source is required to bring the surface to the required temperature and, when required, to dry it.

Special Fabric Applications

Temporary Patch

Continuous sheet asphalt roofing has been used as a temporary patch in Texas over relatively small distressed areas (J.W. Button, personal communication, September 1989). The patch is placed during weather conditions when routine maintenance is not practicable. This quick-repair patch is placed with the sand side up and usually is not covered with an AC surface. The roofing, which is saturated with asphalt, serves as an effective infiltration-reducing membrane similar to an asphalt-saturated fabric. The roofing material, however, does not hold up for extended periods of time under traffic and hence serves only as a temporary maintenance procedure.

Horizontal and Vertical Moisture Barriers

In areas where expansive clays or dispersive soils are found, both seasonal and long-term changes in moisture can cause severe pavement distortion and cracking, resulting in reduced ride quality. If the variation in moisture content over time can be minimized, many problems associated with expansive clays can be reduced. In Texas, vertical impervious fabric membranes have been constructed along the edge of roadways (R. Marienfeld, personal communication, August 1989). The vertical membranes have been used, together with a fabric/chip seal or fabric/overlay, to minimize moisture change as shown in Figure 21. For complete replacement rehabilitation or new construction, a horizontal moisture barrier is sometimes placed directly on the subgrade instead of using a paving fabric.

Low-Cost Pavement

Because of capillary tension, cohesive soils exhibit a high strength as long as they remain dry. Low-cost roads are being constructed in Hope, Arkansas, by Holt (G. Holt, personal communication, September 1989), using a clay gravel as the construction material. The clay gravel is first well compacted. The surface is then primed with about 0.35 gal/yd^2. After curing, about 0.3 gal/yd^2 of CRS-2 emulsified asphalt is placed. Paving fabric is immediately laid on the unbroken emulsion, using a special tractor similar to the one described in Chapter 3. After allowing traffic on the fabric for about two to three weeks, a chip seal is placed. The surface of the fabric is covered with about 0.4 gal/yd^2 of CRS-2, and the chip seal is spread and rolled with a pneumatic roller. Good performance has been reported for this pavement over the past four years, including withstanding approximately a 10-in. rainfall and a 10-in. sleet storm (G. Holt, personal communication, September 1989).

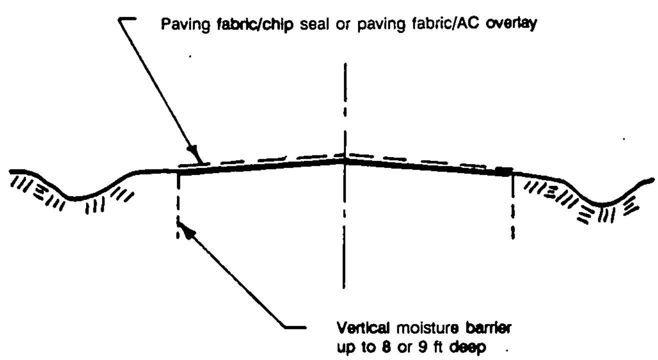

FIGURE 21 Use of moisture barrier as maintenance strategy for expansive clays.

CHAPTER SIX

EVALUATION, DESIGN, AND LIFE-CYCLE COSTS

INTRODUCTION

When paving fabrics and heavy-duty membranes have been used for overlay applications, a wide range of performance has resulted, including numerous successes and some disasters. In recent years, the mechanisms and restrictions associated with using fabrics and membranes gradually have become much better defined. Several important behavioral limitations restrict the use of fabrics and membranes to the reasonably well-defined pavement conditions discussed in Chapters 3 and 4. These findings should be taken into account when planning a rehabilitation strategy. This chapter discusses performance evaluations of overlay designs using fabric and membrane interlayers for routine overlays and experimental test sections. Finally, the very important topic of rehabilitation costs and life-cycle cost comparisons is considered for fabric and membrane applications.

GENERAL FABRIC OVERLAY DESIGN CONSIDERATIONS

A good general discussion of overlay design can be found in Synthesis 116 (*1*). A carefully planned and executed study is required to develop an engineered overlay design using a fabric or membrane that has a high probability of success. For either flexible or rigid pavements the existing pavement condition must be clearly defined, and the type and extent of existing distress fully established, before paving fabrics and membranes can be considered as feasible alternatives.

Flexible Pavements

Substantial field experience indicates that fabric interlayers only delay reflection cracking. Pavements for which cracking can potentially be delayed by using an interlayer exhibit fatigue distress that is not caused by a base or subgrade failure. Surface cracks should be tight and generally less than ⅛ in. wide; no improvement in performance is likely if cracks are greater than ⅜ in. wide. Cracks greater than ⅜ in. wide should be filled with a rigid filler such as a cement grout. Observed field performance shows fabrics are not effective where wide transverse temperature and shrinkage cracks are present.

The recommended steps in developing an overlay design for flexible pavements where a paving fabric is a potential candidate are as follows:

• *Pavement Condition Evaluation.* The results of a general pavement condition survey are valuable in establishing, in a rational manner, the type, severity, and extent of pavement distress. Such information is needed to develop required repair strategies along the pavement (*35*). The condition survey is also useful in developing an overlay design strategy.

Candidate pavements should be divided into segments, and a thorough visual evaluation made of each segment to determine the type, extent, and severity of cracking and to classify the other distress present as: alligator cracking, block cracking, transverse cracks, joint cracking, patching, potholes, widening drop-offs, etc. Crack widths should be measured. The classification system for cracks shown in Table 10 is suitable for use in determining paving fabric applications.

A number of simplified, easy-to-apply systems are available for performing a pavement condition survey (*1, 98–100*). The end result of the pavement condition evaluation should be a rating of the distress level along the length of the pavement under study. A tentative conclusion should then be drawn as to whether paving fabrics are suitable as a potential candidate for inclusion in the rehabilitation scheme. If a formal pavement condition evaluation is not performed, at a minimum, the type, extent, and level of cracking should be established.

• *Structural Strength.* The overall structural strength of the pavement should be evaluated along its length, using suitable nondestructive techniques, such as the Benkelman beam, falling-weight deflectometer, Dynaflect, or Road Rater. Chapters 2 and 3 provide a discussion of failure mechanisms. More surface curvature measurements are desirable. Such measurements were performed by Gulden (*95*) for a rehabilitation study.

• *Base/Subgrade Failure.* Areas that have experienced base or subgrade failures should be identified. Benkelman beam pavement deflections greater than about 0.025 in. are one indication that base/subgrade failures may have occurred; excessive rutting is another. When nondestructive testing devices are not available, proof loading the pavement with a loaded truck has also been used to identify structurally weak areas.

Reflection cracking will not be significantly delayed by using stress-relieving interlayers such as paving fabrics in areas that have base/subgrade failures. If base failure areas are limited, they should be repaired by removal and replacement. If base failure areas are extensive, rehabilitation alternatives other than fabrics should be considered. If all failed base/subgrade areas

TABLE 10
CRACK WIDTH CLASSIFICATION (AFTER *44*)

Crack Classification	Crack Width (in.)
1. Very light	0-1/8
2. Light	1/8-3/8
3. Medium	3/8-5/8
4. Heavy	>5/8

are repaired and other types of distress are not present, the use of paving fabrics probably will not improve performance.

- *Remedial Pavement Treatment.* The results of the pavement condition survey and deflection measurements should be used to develop a pavement repair strategy for each segment. A cumulative pavement rating development using the Systematic Technique to Analyze and Manage Pennsylvania's Pavements system apparently proved quite effective for assessing the level of repair required for each pavement segment in one fabric overlay study (*35*). Remedial treatments for flexible pavements are briefly reviewed in Chapter 3.
- *Overlay Design.* A realistic overlay thickness must be selected to ensure a reasonable overlay life. Using paving fabrics with thin, underdesigned overlays, which lead to significant reflection cracking in three to five years or less, will not justify the use of a paving fabric. Specific overlay design methods are discussed in a subsequent section.
- *Performance Monitoring.* To develop a data bank of performance histories when paving fabrics, heavy-duty membranes, grids, or other unverified techniques are used, some limited level of performance monitoring during the life of the overlay is highly desirable. Using a control section without the fabric membrane, grid, or other technique, with all other items equal, will provide valuable comparative data for future decisions. Although quantitative measurements are always highly desirable, a visual assessment of cracking classification can be made for routine projects; quantitative studies should be made for research projects. Table 11 gives the crack classification system used by California; other systems are also available.

TABLE 11
CRACK CLASSIFICATION SYSTEMS USED IN CALIFORNIA (AFTER *26*)

Initial Cracking:	This category establishes an age when the amount of cracking is more than just an isolated crack or two but is not very extensive. It is defined as having between 5% and 10% alligator (load-related) cracking (Type B) or one transverse crack (non-load-related) per station (100 ft) in the test area.
Moderate Cracking:	This category represents a mid-range of cracking distress. Moderate cracking is defined as 20% ± 9% alligator cracking (Type B) or two through 4 transverse cracks per 100 ft.
Significant Cracking:	This category represents a condition that generally signifies that reconstruction or restoration is required. The condition is based on Caltrans priority criteria that give the highest priority to load-related cracking and a bad ride. Significant cracking is defined as 30 percent or greater alligator cracking (Type B) or five or more transverse cracks per 100 ft.

PCC Pavements

The process for determining candidate PCC pavements for use with overlays having a paving fabric or heavy-duty membrane interlayer is generally similar to that previously described for flexible pavements. As discussed in Chapter 4, vertical joint deflection surveys should be performed; proof rolling of PCC slabs is also a valuable technique to determine if undersealing is required. Neither full-width paving fabric interlayers nor heavy-duty membranes should be used when vertical joint deflections are greater than about 0.008 in. unless corrective measures, such as undersealing, are taken to reduce joint movements. Horizontal thermal joint movement should be less than about 0.05 in. Because horizontal joint movement is approximately proportional to slab length, thermal joint movements will be greater as the joint spacing increases. Careful attention must be given to carrying out required remedial measures, including joint cleaning and resealing, patching, undersealing, slab replacement, etc., as discussed in Chapter 4.

Ride Quality

Any performance evaluation scheme should include ride quality. Just having cracks does not necessarily mean that ride quality is low. The cracks can be sealed and the pavement can continue to be used if ride quality is high.

DESIGN OF EXPERIMENTS WITH FABRIC AND HEAVY-DUTY MEMBRANE INTERLAYERS

The interpretation of past experimental studies involving fabric interlayers is greatly complicated because relevant variables now understood to be important were all too frequently not considered in the experiment design. To avoid this problem in the future, the investigative approach given in the previous section should be followed carefully and the results documented. Control sections should be constructed with all experimental projects. Little is learned from a study if the conditions under which it was performed are not thoroughly known.

Reducing Water Infiltration

Fabric interlayers and heavy-duty membranes have been found to reduce water infiltration. The benefits derived from an asphalt-saturated fabric acting to reduce water infiltration may be more important than those derived from the mechanism of stress relief. Unfortunately, documented evidence does not exist that quantifies the benefits obtained from using these materials to reduce water infiltration. This important aspect of performance evaluation should be incorporated into future studies.

Constructibility

Based on observations and assessments made during construction, a rating system should be developed to establish the installation cost and constructibility of new fabric, membrane, and other techniques used to retard reflection cracking. The rating system should consider the following important factors established by Knight (*78*) and Maurer and Malasheskie (*35*):

- Material and installation costs.
- Number of installation steps.
- Ease of application.
- Potential for field problems occurring during or immediately after construction.
- Effects of traffic and/or exposure on the material.

Appropriate weightings should be assigned to each of these factors, and an overall rating developed for every product investigated. Different products have been found to exhibit widely varying behavior, as previously illustrated in Table 7. A constructibility rating system is an effective tool in developing overall evaluations of new materials. Different methods of construction could, however, affect the constructibility rating of a fabric.

Variability

Variation in structural strength of the old pavement along the length of a test section is always a serious problem in attempting to interpret test results. This problem is clearly shown by the comprehensive studies of Mullen and Hader (*82*) and Knight (*78*). Finn and Monismith (*1*) summarize, in their Appendix C, a procedure, developed for the FHWA by Austin Research Engineers, Inc. (*101*), to determine if the strength of adjacent test sections, based on deflection measurements, is statistically different.

Even when statistical techniques are used to evaluate the differences in strength, experimental layouts should include more control sections (or untreated joints) than generally used in the past. The use of a single control section has proved to be inadequate in defining the reductions in reflection cracking provided by special treatment techniques. Azab et al. (*91*) recommend that the length of treated and untreated joints should be the same within each section of a PCC pavement for reliable comparisons. Ideally, the number of control sections in a flexible pavement should approach the number of test sections. Experimental designs that permit a statistical analysis of the results, such as the study performed by Mullen and Hader (*82*), are encouraged. Both treated and control sections should be long enough to be tested for ride quality.

Observation Period

Performance evaluations of experimental sections using interlayers or other special treatments for delaying reflective cracking should last for the life of the overlay or until no further need exists for continuing the study. Observation periods of two to three years are inadequate for properly engineered experiments. Even observations for four years can lead to somewhat misleading conclusions (*91*).

Usually the initial formal study lasts for about three to four years. After this period, additional performance evaluations should be made every few years and summarized, for example, in a short letter or memo report. When the overlay has almost reached the end of its life cycle, a more formal summary report should be written. This general approach has been used effectively by Predoehl (*26*) for observation periods extending up to about 12 years and also by Zapata (*86*) and Azab et al. (*91*) for shorter periods of time.

OVERLAY DESIGN

Overlay design procedures that can reliably consider the effects of fabrics and heavy-duty membranes suitable for routine use are not currently available. Design procedures that can handle stress-relieving interlayers or reinforcement effects require the use of a relatively complex, theoretically based methodology. Significant progress is being made in the development of mechanistically based overlay design methodologies as discussed in Chapter 2. An in-depth review of several theoretical procedures has been given by Majidzadeh et al. (*8*), whereas Finn and Monismith (*1*) have presented a general review.

A simplified, theoretically based overlay design procedure for PCC pavements has been developed for the FHWA and is described by McCullough and Seeds (*102*) and Treybig et al. (*103*). This approach has been modified for use in Arkansas by Seeds et al. (*77*). This method is the only technique currently suitable for routine design. The method is computer based but does not require the use of the finite-element method. It has been generalized into charts for conditions existing in Arkansas (*77*). Measured vertical and horizontal PCC slab joint movements and joint and crack spacings are required. The effects of stress-relieving interlayers and bond breakers can at least approximately be included. One of several important limitations to this approach, as pointed out by Finn and Monismith (*1*), is the simplifying assumptions made in analyzing fatigue caused by the tensile and shear strains developed in the overlay. Incorporation of the rational but relatively simple-to-apply crack propagation concepts of Button and Lytton (*5*) and Lytton (*6*) has the potential to significantly improve this overlay design approach.

Overlay Thickness

The overlay thickness for both flexible and rigid pavements having a fabric interlayer or heavy-duty strip membrane should be determined as if the interlayer is not present (*6, 23, 25*). An excellent general review of overlay design procedures has been given by Finn and Monismith (*1*). Deflection-based overlay design methods have been found to give better results than other techniques and are recommended for flexible pavements (*1*). The deflection-based overlay design procedure used by California for 13 different sites involving stress-relieving interlayers gave remarkably consistent results, as indicated by the data presented by Predoehl (*26*). As more experience is gained, some reduction in overlay thickness for flexible pavements may be permissible, particularly for thin overlays that have been engineered to carry the required traffic. Under no circumstance should an overlay less than 2 in. thick be placed over strip membranes.

LIFE-CYCLE COSTS

Careful economic comparisons should be made between special methods for delaying reflection cracking, such as paving fabrics and membranes, and other suitable alternatives. Other alternatives include additional overlay thickness and maintenance sealing of cracks and joints after reflection cracking has developed. Even relatively simple cost comparisons and evaluations, which may incorporate some crude assumptions concerning performance, are usually extremely helpful in identifying potential alternatives that may be cost-effective.

Costs

The in-place costs of paving fabrics, heavy-duty membranes, and other reflection-cracking-improvement techniques are greatly influenced by: (a) the specific material used, (b) the quantity to be placed, (c) local experience with its installation, (d) local labor costs, and (e) the general condition of the marketplace. The general marketplace constraints have a significant effect on material price. For example, the in-place cost of paving fabrics in recent years has been falling, apparently because of stiff competition and, perhaps, improved contractor experience and acceptance of geosynthetics.

The 1989 in-place cost of a 4- to 5-oz nonwoven paving fabric and tack coat was about \$0.60/yd^2 for large jobs to \$1.25/yd^2 for small jobs. For comparison, a SAMI cost about \$1.75 to \$2.25/yd^2 and 1 in. of asphalt concrete base was about \$1.50 to \$2.00/yd^2 for large jobs and more for small ones. The typical in-place cost of a 50- to 100-oz/yd^2 heavy-duty infiltration-reducing membrane was about \$0.60 to \$1.00/ft^2. The installed cost of most glass grid membranes was about \$1.50 to \$2.00/ft^2. For comparison, the cost of cracking and seating PCC panels was about \$0.30 to \$0.85/yd^2, and that of sawing additional joints was about \$1.00 to \$1.50/lineal ft.

The relative 1984 cost of a wide range of selected rehabilitation techniques is given in Table 12. These costs should serve only as a general, relative guide for performing preliminary life-cycle cost comparisons of different alternatives. Where possible, these costs should be adjusted for local conditions and material costs existing at the time of the analysis. A useful rule of thumb, based on typical in-place costs, is that a full-width paving fabric installed is roughly equivalent to the cost of about 0.5 to 0.6 in. of asphalt concrete.

Basis of Comparison

Economically feasible techniques that prevent reflection cracking for the life of an overlay have not been identified. A number of methods that can potentially delay reflection cracking, including stress-relieving fabric interlayers and heavy-duty membranes, are available. An overlay using fabrics and membranes under favorable conditions can delay moderate levels of reflection cracking for about two to four years, compared with a similar overlay without them. Reflection cracks and joints are usually sealed through a maintenance program. Such maintenance costs are reasonably easy to quantify, and must be considered when different design alternatives are analyzed for cost-effectiveness.

A delay in pavement cracking by use of special techniques such as interlayers or even thicker overlays improves the aesthetics of the pavement and may have a beneficial effect on ride quality. Also, important benefits may be derived from the reduced water infiltration provided by fabrics and heavy-duty membranes. Whether these hard-to-quantify beneficial effects are considered in an economic analysis must be decided by the designer; in the past they have not been taken into account. A comprehensive pavement management program should help in evaluating the effects fabrics and membranes have on ride quality.

Paving fabrics, as well as other improvement techniques, are not always effective in reducing reflection cracking. Therefore, an estimate of the probability of success should be included in all economic analyses. Preliminary results for full-width flexible pavements suggest that, under favorable conditions, the probability that a fabric will be successful is on the order of 60 or 65 percent. The probability for success may increase as a better understanding of paving fabrics is gained.

Equivalent Cost Comparisons

A simple approach frequently used for cost comparisons is to determine an equivalency between two alternatives and directly compare their costs. Results from California indicate that, under favorable conditions, a paving fabric interlayer for flexible pavements may be equivalent to about 1.24 in. of AC. Using typical in-place costs, the fabric interlayer is slightly cheaper than 1.2 in. of additional AC, assuming a 100 percent probability for success. Considering about a 60 percent level of probability, the economic advantage of using paving fabrics appears to be doubtful unless the potential benefits of reduced water infiltration and improved ride quality are considered. California is not using fabrics today with the same regularity as in past years.

Alternatively, a thinner overlay without fabric should be considered. If a 2.0-in.-thick AC overlay is used, based on the California data summarized in Figure 15, significant cracking should occur only about two years sooner than if a 3.0-in.-thick overlay without fabric, or a 1.8-in.-thick overlay with fabric, is used. Hence, the use of either a thicker overlay or a fabric is questionable. Note that the structural section developed from the pavement design should never be reduced because a fabric is incorporated. A 3-in. design thickness based on load requirements must be built as a 3-in. AC with or without fabric.

Life-Cycles and Cost-Effectiveness

Cost comparisons can also be made between different rehabilitation strategies, either for the life of the overlay or the full remaining life of the pavement after the overlay is placed. Most cost comparisons are performed over the life of the overlay. Such an analysis is considerably simpler to perform than is an analysis performed over the remaining life of the pavement. The projected maintenance times and costs are also easier to define. Most researchers have used the overlay life for cost comparisons.

The total cost associated with overlay construction and maintenance should be estimated for at least the two or three most promising alternatives identified by field experiments, and then compared with conventional overlay procedures. Considerable insight into the economics of overlay design alternatives can be gained through the use of historic cost and performance data gathered from other studies, such as the data summarized in Chapters 3 and 4 (*26, 35, 76, 78, 91*). The use of fabric interlayers, heavy-duty membranes, and other techniques should, at a minimum, be compared with the cost of using an overlay of similar thickness with a crack-sealing maintenance program. Thicker overlays can also be used as a basis for comparison.

Crack treatment has been found to be relatively cheap compared with other alternatives such as fabrics (*35*). Indeed, even when successful, several studies have found that fabric interlayers are not cost-effective for use in overlays on both flexible (*35*) and rigid (*35, 87, 91*) pavements. Zapata (*86*) is one of the few researchers to conclude that the economics for the use of heavy-duty membranes are favorable. At this time, the use of fabrics with overlays on flexible pavements appears to be cost-effective only if quantifiable benefits are derived from other factors such as aesthetics, improved ride quality, or reduced water infiltration. These factors should be included in the overall evaluation of paving fabrics as soon as they can be quantified. Insufficient data are currently available to draw conclusions concerning the use of fabrics or heavy-duty membranes with overlays on PCC pavements.

TABLE 12
TYPICAL RELATIVE 1984 COSTS OF SELECTED REHABILITATION ALTERNATIVES (AFTER *23*)

	In-place costs, $/yd^2	
Rehabilitation Alternative	Range	Representative
Asphalt Concrete-Asphalt Cement Binder	1.40-1.95[a]	1.70[a]
Asphalt Concrete-Sulphur, Chemcrete, or polymer-modified binder	1.80-2.50[a]	2.20[a]
Asphalt Concrete/Asphalt-Rubber Binder	2.50-3.50[a]	3.00[a]
Aggregate Base	0.30-0.45[a]	0.37[a]
Pavement Recycling (hot and cold)	1.10-1.60[a]	1.40[a]
Chip Seal-Asphalt Cement Binder	0.60-1.10	0.85
Chip Seal-Asphalt-Rubber Binder	1.50-2.25	1.85
Heater Scarification	0.50-1.50	0.90
Fabric (conventional) (includes tack coat)	0.65-1.50	1.00
Cracking & Seating PCC	0.25-0.75	0.50
PCC Joint Repair	3.00-4.50	3.75
Pothole Repair	0.25-0.45[b]	0.35[b]
Dig Out and Repair	0.50-1.00[c]	0.75[c]

[a] \$/yd^2/in. thickness.
[b] One percent of area repaired 4 in. thick. Prices are for yd^2 of surface maintained.
[c] Five percent of area repaired 6 in. thick. Prices are for yd^2 of surface maintained.

CHAPTER SEVEN

SUMMARY OF OTHER METHODS FOR REDUCING REFLECTION CRACKING

The use of fabrics and heavy-duty membranes as a means of reducing overlay reflection cracking and improving overlay performance was discussed in Chapters 2 through 6. Although fabrics and heavy-duty membranes can, under the proper conditions, delay reflection cracking, their use has some rather restrictive requirements. Other more economical or desirable techniques may exist, depending on the conditions of each project. Approaches used for minimizing reflection cracking were summarized in Table 1. Progress is being made in developing improved techniques for delaying reflection cracking, and understanding of existing methods is constantly being improved. The purpose of this chapter is to summarize and update the findings given in Synthesis 92 (*4*).

AC OVERLAY

Thickness

The relative movement at joints and cracks under an overlay has a dominant effect on the severity and rate of reflection cracking. As the thickness of the overlay is increased, more load is transferred across a crack or joint, resulting in smaller shear and bending stresses and a smaller rate of crack propagation. As a result, more time occurs before load-related reflection cracks appear on the overlay's surface. A comprehensive study in Georgia by Gulden and Brown (*75, 76*) showed that a 20 percent level of cracking occurred in six years for a 6-in.-thick AC overlay on a PCC pavement, but in only two years for a 4-in. overlay; a 2-in. overlay cracked almost immediately after construction. The studies performed in Georgia (*75, 76*), as well as work in Florida (*55*) and California (*26, 56*), show that a relatively small increase in overlay thickness is considerably more effective in retarding reflective cracking when an appropriately designed thickness of overlay is initially present. In California, Predoehl (*26*) has found that a minimum AC overlay thickness of 4.8 in. is required to delay reflection cracking for 10 years. Gulden and Brown (*75, 76*) recommend a minimum thickness of 4 in. of AC. This thickness applies when no major structural problems exist and the old pavement has been repaired properly.

For flexible pavements, Sherman (*4*) concludes, based on limited data, that a minimum AC thickness of 2 in. is necessary to substantially delay reflection cracking where alligator cracking is present. If a base failure is present, a 2-in. overlay is not sufficient. Where block cracking is present, a minimum thickness of 3 in. is desirable; 3.5 in. is suggested by Sherman (*4*) as being necessary to delay reflection cracking over cement-treated bases for at least six years. The actual overlay thickness used should be engineered considering all pertinent factors, using a deflection-based procedure (*1*).

Asphalt Viscosity

Numerous studies have shown that the use of softer asphalt cements delays both reflection (*104–110*) and transverse thermal cracking. Way (*54, 104, 105*) found that reflection cracking is less likely as long as the viscosity of the asphalt remains below 4.0 megapoises (or an equivalent penetration of about 45). Work in Canada (*111*) indicates that air-blown asphalts can be used at low temperatures to improve viscosity-temperature relationships. Air-blown asphalts have a potential for allowing the use of harder grades of asphalts in cold climates while maintaining high viscosities in hot weather. Ravn et al. (*49*) found in Minnesota that a thin, 1.5-in.-thick AC overlay constructed using a soft 200-300 penetration-grade AC is more effective in delaying reflective cracking than several other methods, including a paving fabric and SAMI interlayer.

Additives

Sulfur extended asphalts (SEA), carbon black, and fibers all improve the temperature susceptibility characteristics of asphalt (*4, 112–114*) and provide better resistance to rutting at higher temperatures. In Minnesota, Ravn et al. (*49*) found that adding carbon black or sulfur (SEA) to a 200-300 penetration-grade asphalt reduced rutting by almost 50 percent compared with using just the soft asphalt. These test sections performed the best of all sections studied with respect to delaying reflection cracking. Of practical importance, the 200-300 penetration asphalt with carbon black or SEA was more economical than either the paving fabric or SAMIs included in the study.

Polyester, polypropylene, and asbestos fibers have also been added to the asphalt cement with varying degrees of success (*5, 35, 46, 115*). Maurer and Malasheskie (*35*) found in Pennsylvania that 6 lb of polyester fibers per ton of AC gave uniformly better performance, regardless of the initial condition of the section, than four paving fabrics and a fiber-reinforced interlayer. The fiberized AC mix had the lowest cost and was easiest to adapt to normal paving operations. Polypropylene fibers melt at about 315°F to 350°F, whereas polyester fibers can withstand heat up to about 480°F to 500°F. Fibers have, in general, been found to be more effective in cold climates than warm ones (*5*).

Dry lime, polymer asphalt, and rubberized asphalts have also been used in attempts to reduce reflection cracking (*46, 116–118*). Shuler et al. (*116*) have found that improved performance is generally observed when 1 percent by weight of finely ground rubber is added to an AC mix. However, using 3 percent ground rubber less than 0.25 in. in size generally does not improve performance. A latex-modified AC wearing course and SAMI have been used on an overlay in Pennsylvania (*119*).

STRESS-RELIEVING INTERLAYERS

Asphalt-Rubber Interlayers

Stress-relieving membrane interlayers (SAMIs) received considerable interest during the 1970s and early 1980s. A SAMI is constructed by placing a seal coat, usually consisting of rubber-asphalt, on the surface of the old pavement and then rolling in aggregate chips. The SAMI is covered with a conventional overlay (*93, 105, 108, 117, 120–127*). Under favorable conditions, an asphalt-rubber stress-relieving interlayer has a high probability of delaying serious reflection cracking for about three to five years. Favorable conditions for flexible pavements include the presence of tight fatigue cracks not related to base failure. SAMIs tend to perform slightly better than fabric interlayers and hence may be able to withstand slightly greater deflections. A PCC pavement's load-related joint movements must be on the order of 0.002 in. to 0.008 in. for a SAMI to function successfully (*26, 70*). The requirements for a successful SAMI are similar to those for a paving fabric interlayer, which were considered in detail in Chapters 3 and 4.

Excellent general reviews of the practical aspects of design, construction, and performance of SAMIs have been given by Morris and McDonald (*125*), Sherman (*4*), Shuler et al. (*116*), and the National Association of Australian State Road Authorities (*93*). The results of an extensive study by Predoehl (*126*) of asphalt-rubber interlayers involving 10 different test sites is summarized as follows (a fabric interlayer is called a PRF):

- Based on crack evaluations of nine test sites evaluating AC overlays over SAMI and PRF interlayers, and control AC overlay sections, it appears that initial cracking is retarded approximately two to four years in AC overlays over SAMI and PRF interlayers compared with similar AC thickness overlay control sections.
- AC overlays over SAMI sections appear to show more of a reduction in cracking except for thin overlays (0.10 ft or less) than overlays over PRF interlayers and control AC overlays. AC overlays over both SAMI and PRF interlayers exhibit less transverse cracking than control overlays.
- AC overlays over SAMIs exhibited bleeding and rutting more frequently than AC overlays over PRF interlayers. None of the control AC overlays exhibited any bleeding or rutting.
- It appears that SAMIs and PRF interlayers provide approximately the same benefits, i.e., stress relief and waterproofing. It also appears that SAMIs and PRF interlayers could be used interchangeably dependent upon each strategy's advantages and disadvantages.

For an overlay of a PCC pavement in Minnesota, Allen (*83*) found that an asphalt-rubber SAMI did better than a paving fabric interlayer. Neither was as effective as reducing the joint spacing without providing any other special treatment (Figure 19). In Washington State, Peters and Schultz (*127*) found that an asphalt-rubber SAMI performed much better than the control. The asphalt-rubber SAMI, however, performed similarly to a paving-grade asphalt SAMI (39 percent reflection cracking compared with 41 percent). The asphalt-rubber SAMI appeared to perform better with alligator cracks, whereas the paving asphalt SAMI did better with longitudinal cracks. Shuler et al. (*116*) recommend not using a SAMI directly under an open-graded friction course. In Oklahoma, however, Way (*54*) found this type of treatment to perform best out of 18 sections. For good performance and to avoid excessive loss of aggregate, SAMIs should be designed so that only a single aggregate layer is placed for each application, with slightly higher embedment than for a seal coat (*116*).

Low-Viscosity AC Interlayers over AC

A low-viscosity asphalt interlayer performs following mechanisms similar to those followed by a SAMI or paving fabric interlayer. The asphalt interlayer usually is considerably thicker than a membrane interlayer but may not be as soft. By using a soft asphalt in just one lift, the total overlay rutting is significantly reduced compared with using the soft asphalt for the full depth. Way (*54*) found a low-viscosity asphalt interlayer to perform better than paving fabrics but not as well as the following treatments: asphalt-rubber under an open-graded friction course, asbestos asphalt concrete, heater scarification with additive, and asphalt-rubber seal coat. A 2-in.-thick soft AC 2.5 asphalt concrete interlayer used by Wyoming has also reduced reflection cracking (*128*).

AGGREGATE CUSHION INTERLAYERS

Both open-graded unstabilized and asphalt-stabilized aggregate cushion interlayers have been used successfully over both AC and PCC pavements receiving overlays (*2, 4, 35, 55, 57, 75, 76, 107, 129, 130*).

Open-Graded Asphalt-Stabilized Cushion

Tennessee and Arkansas both use open-graded, asphalt-stabilized aggregate cushion interlayers. In Arkansas both AC and PCC pavements are overlaid using a 3.5-in.-thick asphalt stabilized cushion with a minimum of 3 in. of additional AC cover. More than 200 two-lane miles are in use in Arkansas on Interstate and primary routes with good results being reported (*129*). Experience in Arkansas, as reported by Hensley (*129*), indicates that cushion gradings "with the larger aggregates and voids offers the most protection against reflection cracking" and the large aggregate "interlock to provide load transfer across the joint."

Gulden and Brown (*76*) describe Georgia's use of a 3.5-in.-thick Arkansas-type cushion. The cushion consists of 2-in. nominal size aggregate stabilized with 2 percent asphalt and overlaid with 3.5 in. of AC. With respect to reflection cracking, Gulden and Brown report the 3.5-in.-thick cushion "performed somewhat better than the 4-in. sections with fabric treatments over the years and not as good as the 6-in. overlay sections. Also, rutting in the Arkansas base test section was considerably less than rutting levels measured on the other test sections."

A 1.5-in. open-graded cushion interlayer used in Canada (*131*) performed poorly over a cracked AC pavement. In Florida (*55*), a thin open-graded cushion interlayer was used beneath a 2-in.-thick AC overlay placed over an AC pavement; only a small benefit was observed compared with the control section.

Unstabilized Aggregate Cushions

In Washington State, reflection cracks have been controlled successfully using an unstabilized aggregate cushion as a routine design option for a number of years. A 4.2-in.-thick crushed aggregate cushion is used beneath a total of 4.2 in. of asphalt concrete (*127*). Copple and Oehler (*132*) have found that 4- to 8-in.-thick soil-aggregate cushions are able to reduce reflection cracking even over jointed PCC pavements in poor condition. In one study, an asphalt-stabilized gravel performed slightly better after five years than a nonstabilized gravel cushion. Both sections performed considerably better than the control. Studies in both California (*130*) and Canada (*106, 131*) substantiate these findings. In California, Forsyth and Munday (*130*) conclude that 6 in. or more of aggregate cushion is required to eliminate reflection cracking; some reflection cracking develops with the use of 4-in. layers. In Canada, a 6-in. granular cushion performed better than a 3-in. cushion. Cracking and seating of the old pavement, however, was determined to be both more effective and economical than an aggregate cushion.

Required Thickness and Limitations

These results suggest that a cushion interlayer about 3.5 in. or more thick is required to absorb the movements usually developed in the pavement. Both unstabilized and asphalt-stabilized aggregate cushions have the disadvantage of requiring greater total layer thicknesses. Additional thickness often results in problems with overhead clearance, adjustment of appurtenance elevations, and side slope geometry. Unstabilized aggregate cushions can take traffic immediately, which offers some advantage where traffic is heavy. A positive method must be provided for draining open-graded cushions, which act as a water reservoir. If adequate drainage is not provided, excess pore water pressure can lead to premature failure (*129, 130*).

STEEL REINFORCEMENT OF AC OVERLAYS

Considerable interest was shown in the use of welded-wire-mesh reinforcement in AC overlays during the 1950s and 1960s. Bushing et al. (*133*), in a state-of-the-art review, identify studies using wire mesh or other types of steel reinforcement performed in Minnesota, Michigan, Illinois, Pennsylvania, Wisconsin, New York, Texas, Massachusetts, Ontario, and New Jersey. Bushing et al. (*133*) conclude, "Previous tests and results were fragmented and exhaustive; however, it was generally concluded that experience did not produce positive support for use of metal reinforcement."

A study by Kanarowski (*134*) involving 27 test sites indicates continuous reinforcement of the overlay to be effective on the average for 3.9 years, whereas wire-mesh strips placed just over the PCC joints were effective, on the average, for only 1.9 years.

Some success has been observed in southern Canada (*135*) and elsewhere (*132*) when the wire mesh is placed on an AC leveling course, compared with directly on the old PCC surface. Tons et al. (*7*) and Smith and Gartner (*136*) observed better performance with the use of continuous-wire-mesh reinforcement compared with strips. In New York (*137*), strips over transverse joints delayed reflection cracks up to four years on three of four projects. However, when the joint spacing was more than 90 ft, reinforcement was not effective.

Three- to 4-ft-wide wire-mesh strips placed over joints move the reflection cracking over to the edge of the reinforcing; strips 5 to 10 ft wide may also develop edge cracking (*7*). Continuous-wire-mesh reinforcing may develop a wave in front of the paver. In Michigan, Copple and Oehler (*132*) observed that "extensive corrosion and fragmentation of reinforcing steel, a performance factor not mentioned in the literature, was encountered even where the overlay surface was in good condition." Tons et al. (*7*) conclude that performance of a wire-mesh-reinforced overlay is dependent on horizontal and relative vertical movement at joints and cracks.

BOND BREAKERS OVER TRANSVERSE PCC JOINTS

A bond breaker is intended to prevent the transmission of horizontal shear stress between the overlay and the underlying PCC slab for a short distance on each side of a transverse joint. If this objective is achieved, the average tensile strain in the overlay at a joint caused by thermally induced horizontal joint movements is reduced. Numerous types of bond breakers have been used, as previously summarized in Table 1. A study conducted by Kanarowski (*134*) indicates that sand and stone dust or screenings perform best, with the average effectiveness being 3.7 and 3.2+ years, respectively, based on results from eight test sites. A single study indicated that wax paper 0.004 in. thick was effective less than four years. The other bond-breaking techniques summarized in Table 1 were effective, on the average, 1.6 years or less. Hughes (*138*) found a sand bond breaker to be only partially successful. The sand was placed about 0.25 in. thick on top of a tack coat. Because the tack coat increases interface friction, it may have at least partially defeated the purpose of using a bond breaker.

On Route 13 in Virginia, McGhee (*70*) found a good correlation between vertical joint movement and performance. Sanded joints that did not move under a wheel loading were 76 percent effective after six years but only 7 percent effective when differential joint movements were 0.006 in. After nine years, 94 percent of the joints exhibited reflection cracking.

MODIFICATION/REHABILITATION OF OLD PAVEMENT

Methods for modifying and rehabilitating old pavements are summarized in Table 1. A good general review of these methods has been given by Sherman (*4*), and Gulden and Thornton (*81*) present an excellent description of restoration methods for jointed-concrete pavements. Proper pavement repair to minimize overlay movement is a very necessary part of any rehabilitation method that uses the existing pavement for structural support (refer to Chapters 3 and 4).

Heater-Scarifier Process

The heater-scarifier and milling processes have received considerable interest and increasing use in recent years (*4, 54, 139*).

The heater-scarifier process consists of heating and scarifying the upper 0.75 to 1 in. of the old AC pavement, adding a rejuvenating agent, and recompacting the disturbed material. Usually additional AC is placed over the recompacted layer. Important advantages of using these approaches include:

- The total thickness of uncracked asphalt above the cracked surface is greater than that of conventional overlays having an equal depth of new material.
- The crack width at the bottom of the heater-scarified or milled layer is often smaller than at the top of the old surface, which can potentially result in slower crack propagation. Also, the required amount of surface preparation is reduced.

These methods result in less grade change and hence fewer problems with clearances. Theory also indicates that the presence of a lower-stiffness, cracked underlayer, such as would result from the milling and heater-scarification processes, may help to delay reflection cracking. Heater scarification is now a standard rehabilitation strategy in Arizona and has been in use since 1975. Way (*54*) found, in a study involving 18 test sections, that heater scarification with the addition of the rejuvenator Reclamite ranked third. The best-performing section was an asphalt-rubber SAMI, which after six years had only 2 percent reflection cracking compared with 7 percent for the heater-scarifier section. The heater-scarifier section, however, exhibited quite favorable cost-to-performance ratios compared with the SAMI section in this early study.

Milling is now used as a standard rehabilitation strategy in Arizona. Typically, about one-half of the old asphalt is removed by milling. Usually this thickness is 2 to 3 in., but as much as about 7 in. has been removed by milling. Milling is reported (*54*) to reduce visible surface cracking substantially in the old pavement to be overlaid.

Surface Seal Coats on AC Pavements

Seal coats applied to the surface of AC pavements are reviewed in Chapter 5.

Reduced PCC Joint Spacing—Cracking and Seating

The objective of the cracking and seating technique is to crack a PCC slab into about 3.5- to 5-ft pieces and to seat them firmly on the subgrade. A 50-ton pneumatic roller, hydraulic hammer, pneumatic breaker, resonance pavement breaker, and headache ball have all been used to crack the pavement (*134, 140, 141*). In addition to cracking the pavement, the 50-ton roller also seats the slab firmly against the subgrade to minimize movement. Although an effort is made to create only hairline cracks in the panels, some loss of structural strength of the PCC pavement panels also occurs. Cracking and seating effectively reduces vertical load-induced joint displacements by providing better slab contact with the subgrade. It also reduces horizontal thermal movements by significantly decreasing joint spacing. Cracking and seating has been shown to be much more effective for plain PCC pavements than for continuously reinforced ones.

This approach also minimizes slab rocking and curling and warping caused by thermal and moisture gradients. In Louisiana, Lyon (*142*) found that cracking and seating the pavement is considerably more effective than cracking alone, and that three coverages by a heavy roller gives less reflective cracking than two.

Since 1984, California has used cracking and seating on more than 50 projects. The cracking and seating strategy has been found to be very effective in delaying reflection cracking over transverse joints and cracks. Usually an insignificant amount of longitudinal and alligator reflection cracks develop when cracking and seating is used. In California, at least 4.2 in. of AC overlay is required over the cracked and seated pavement.

In Minnesota, Allen (*80*) found that sawing (apparently without seating) a 39.25-ft PCC slab into 6.5-ft sections resulted after four years in 10 percent cracking, compared with 70 percent for the control as shown in Figure 19.

Saw and Seal

Some states are now considering a technique called "saw and seal." The saw and seal approach is used when reflection cracks are anticipated and other techniques for delaying cracking have not been used. Soon after the overlay is placed, saw cuts are made in the asphalt overlay where reflective cracks are anticipated, such as over transverse joints in PCC pavements. These saw cuts are then sealed with flexible joint seal materials. This technique should be included in economic evaluations.

CHAPTER EIGHT

CONCLUSIONS AND RECOMMENDATIONS

For many years, states have been expending considerable resources to find new, relatively inexpensive techniques for significantly delaying or preventing reflection cracking of asphalt overlays over AC and PCC pavements. An ideal solution for reflection cracking has not been found and is not likely to be in the near future. Like any rehabilitation technique, overlays containing fabrics and membranes should be placed as soon as possible after deterioration begins.

PAVING FABRICS AND HEAVY-DUTY MEMBRANES

Paving fabrics and heavy-duty membranes can be used to delay reflection cracking for a few years. This strategy, like all others, must be carefully engineered and is not a quick, easy solution suitable for all pavements in need of rehabilitation. Generally, the use of paving fabrics for delaying reflection cracking is not justified unless the benefits from reducing water infiltration are considered. These benefits, however, have not yet been quantified. Both old AC and PCC pavements that are to receive an overlay must be carefully repaired, including replacement of failed sections, patching and sealing of cracks and joints, and, where required, undersealing.

Flexible Pavements

Under favorable conditions, moderate to significant levels of reflection cracking in AC pavement overlays can be delayed two to four years, and in a few instances, as long as five years by using a full-width paving fabric interlayer. Favorable conditions for the use of full-width paving fabrics with flexible pavements include:

- The presence of fatigue (load)-related failure frequently evidenced by alligator cracking.
- Tight surface cracks, usually less than $\frac{1}{8}$ in. wide; improvement where cracks are greater than $\frac{3}{8}$ in. wide is unlikely.
- The AC overlay must be engineered to be structurally capable of handling the anticipated loadings. A deflection-based procedure should give the best overlay thickness determination for each pavement subsection.
- Paving fabrics are usually ineffective for controlling thermal cracks, because those cracks are usually $\frac{1}{2}$ to 1 in. or more wide.

The requirements for an asphalt-rubber SAMI should be similar to those given above for paving fabrics. A limited amount of field evidence suggests that a SAMI may be slightly more effective than a paving fabric in delaying reflection cracking. Whether the additional cost of using a SAMI is justified is doubtful.

PCC Pavements

Paving fabrics and heavy-duty membranes can also be used to delay reflection cracking in PCC pavement overlays by about two to four years under the following quite restrictive conditions:

- Vertical load-induced Benkelman beam joint movements must be between 0.002 in. and 0.008 in. (California has found that a full-width fabric delays cracking when these joint movements are between 0.003 and 0.008 in. For greater joint movements, a fabric did not help, and for lesser movements, a fabric was not required.)
- Horizontal, thermally induced joint movements must be less than 0.05 in.

Although conflicting experimental findings exist, a limited amount of evidence suggests that heavy-duty membranes placed over joints may perform better than full-width paving fabrics. Thermally induced joint movements increase with increasing PCC panel length. Joint movements can be decreased by cracking and seating or by sawing additional transverse joints. Using paving fabrics or heavy-duty membranes together with decreased PCC pavement joint spacing does not, however, appear to offer any advantage over just cracking and seating or additional saw cut joints. Fabrics are used to reduce water infiltration because of the cracks created by the cracking and seating techniques.

The movements at longitudinal pavement shoulder and widening joints are usually less than at transverse joints of PCC pavements. Paving fabrics and heavy-duty membranes have been used effectively to delay reflection cracking when longitudinal pavement shoulder joint cracking is a problem for either PCC or AC pavements. Longitudinal joint movement should be within the limits given above for transverse joints.

RECOMMENDATIONS

Methods for Reducing Reflection Cracking

The economics associated with existing techniques for reducing reflection cracking indicate that a crack-treatment program for pavements having light to moderate levels of cracking is usually more cost-effective than other available methods. Many approaches, such as the use of full-width paving fabrics or SAMIs, require additional construction steps. These additional construction operations may result in reduced performance levels because of field-related construction problems.

For these reasons, it is considered appropriate to focus more attention on the use of asphalt stress-relieving interlayers (SRIs). This type of interlayer can be placed as a conventional construction lift. Use of overlays or interlayers consisting of a modified asphalt should also be considered.

Potential materials to be studied include soft, low-viscosity asphalt cement mixes with additives such as carbon black, sulfur, or, perhaps, fibers. Fiber-reinforced asphalt deserves further consideration, particularly in northern areas. All of these materials have recently been found to offer potential for temporarily delaying reflection cracking at a lesser cost than most other promising techniques. Undoubtedly, other potentially effective additives or combinations of additives exist that also deserve investigation.

Heater scarification, usually with the addition of new overlay material, also is a feasible alternative to conventional overlay construction. Heater scarification is now used in Arizona as a standard and has several important advantages, including reduced change in grade and the presence of smaller cracks on the surface to be overlaid. Theory also suggests that as the thickness of the old pavement is decreased, reflection cracking may be reduced for a given overlay thickness because of a decrease in old pavement stiffness.

Research—What Price for Reducing Reflection Cracking?

A considerable amount of research has been conducted to develop techniques for reducing or eliminating reflection cracking. The potential benefits to be realized if reflection cracking is delayed for several years, and the maximum costs that can be justified to achieve this delay, are not entirely clear and need to be established. This would allow future research to properly focus on potentially cost-effective techniques.

Research on Benefits Resulting from Reducing Water Infiltration by Fabrics

In the presence of small movements, paving fabrics and heavy-duty membranes can act as effective infiltration-reducing interlayers. Although these interlayers reduce reflection cracking, their use is hard to justify economically unless the potential benefits resulting from reducing water infiltration are taken into account. The reduction in surface water infiltration into the base and subgrade has the potential to significantly improve pavement performance. Actual benefits derived from reducing infiltration need to be quantified to allow life-cycle cost comparisons.

REFERENCES

1. Finn, F.N. and C.L. Monismith, *NCHPP Synthesis of Highway Practice 116: Asphalt Overlay Design Procedures,* Transportation Research Board, National Research Council, Washington, D.C. (December 1984) 66 pp.
2. Gray, B.E. and G.E. Martin, "Resurfacing with Bituminous Types of Surfaces," in *HRB Proceedings,* Vol. 12, Highway Research Board, National Research Council, Washington, D.C. (1932) pp. 177–192.
3. Hughes, C.S. and K.H. McGhee, "Results of Reflective Crack Questionnaire Survey," Report No. VHRC 72-R25, Virginia Highway Research Council (February 1973).
4. Sherman, G., *NCHRP Synthesis of Highway Practice 92: Minimizing Reflection Cracking of Pavement Overlays,* Transportation Research Board, National Research Council, Washington, D.C. (September 1982) 38 pp.
5. Button, J.W. and R.L. Lytton, "Evaluation of Fabrics, Fibers and Grids in Overlays," *Proceedings,* 6th International Conference on Structural Design of Asphalt Pavements, Vol. 1, Ann Arbor, Mich. (July 1987) pp. 925–934.
6. Lytton, R.L., "Use of Geotextiles for Reinforcement and Strain Relief in Asphalt Concrete," *Geotextiles and Geomembranes,* Vol. 8 (1989).
7. Tons, E., A.J. Bone, and V.J. Roggeveen, "Five-Year Performance of Welded Wire Fabric in Bituminous Resurfacing," in *HRB Bulletin 290: Developments in Salvaging Old Pavements by Resurfacing,* Highway Research Board, National Research Council, Washington, D.C. (1961) pp. 15–38.
8. Majidzadeh, K., G.J. Ilves, and V.R. Kumar, "Improved Method to Eliminate Reflection Cracking," Report No. FHWA/RD-86/075, Federal Highway Administration, Washington, D.C. (September 1985).
9. Monismith, C.L. and N.F. Coetzee, "Reflection Cracking: Analysis, Laboratory Studies and Design Considerations," *Proceedings,* AAPT, Vol. 49 (1980) pp. 268–313.
10. Yuce, R., P.A. Seddon, and C.L. Monismith, "A Study of Fabrics in Asphalt Concrete Overlays on Portland Cement Concrete Pavements, Part 1: Analytical Study of Overlays with Fabrics," University of California, Berkeley (June 1983).
11. Luther, M.S., K. Majidzadeh, and C-W. Chang, "Mechanistic Investigation of Reflection Cracking of Asphalt Overlays," in *Transportation Research Record 572: Pavement Design, Performance, and Rehabilitation,* Transportation Research Board, National Research Council, Washington, D.C. (1976) pp. 111–122.
12. Majidzadeh, K., G.J. Ilves, and V.R. Kumar, "Mechanistic Methodology for Airport Pavement Design with Engineering Fabrics: Vol. II: Advanced Concepts, Validation, and Criteria," Report No. DOT/FAA/PM-84/9, Federal Aviation Administration, Washington, D.C. (May 1986).
13. Barksdale, R.D., S.F. Brown, and F. Chan, *NCHRP Report 315: Potential Benefits of Geosynthetics in Flexible Pavements,* Transportation Research Board, National Research Council, Washington, D.C. (November 1989) 56 pp.
14. Majidzadeh, K.C., C. Buranarom, and M. Karakouzian, "Application of Fracture Mechanics for Improved Design of Bituminous Concrete," Report No. FHWA-RD-76-91, Federal Highway Administration, Washington, D.C. (June 1976).
15. Majidzadeh, K. and D.V. Ramsamooj, "Development of Testing Procedures and a Method to Predict Fatigue Failures of Asphalt Concrete Paving Surfaces," Project 2873, The Ohio State University Research Foundation (March 1971).
16. Germann, F.P. and R.L. Lytton, "Methodology for Predicting the Reflection Cracking Life of Asphalt Concrete Overlays," Report No. FHWA/TX-79/09 + 207-5, Texas State Department of Highways and Public Transportation, Austin, Tex. (March 1979).
17. Jayawickrama, P.W. and R.L. Lytton, "Methodology for Predicting Asphalt Concrete Overlay Life Against Reflective Cracking," *Proceedings,* 6th International Conference on Structural Design of Asphalt Pavements, Vol. 1, Ann Arbor, Mich. (July 1987) pp. 912–924.
18. Paris, P.C. and F.A. Erdogan, "Critical Analysis of Crack Propagation Laws," *Transactions of the ASME, Journal of Basic Engineering, Series D,* No. 3 (1963).
19. Schapery, R.A., "A Theory of Crack Growth in Viscoelastic Media," Report No. MM 2764-73-1, Mechanics and Materials Research Center, Texas A&M University (1973).
20. Smith, R.D., "Laboratory Testing of Fabric Interlayers for Asphalt Concrete Paving," Report No. FHWA/CA/TL-84/06, California Department of Transportation, Translab (June 1984).
21. Coetzee, N.F. and C.L. Monismith, "Analytical Study of Minimization of Reflection Cracking in Asphalt Concrete Overlays by Use of a Rubber-Asphalt Interlayer," in *Transportation Research Record 700: Pavement Evaluation and Overlay Design: A Symposium and Related Papers,* Transportation Research Board, National Research Council, Washington, D.C. (1979) pp. 100–108.
22. Christopher, B.R. and R.D. Holtz, *Geotextile Engineering Manual,* Federal Highway Administration, Washington, D.C. (1985).
23. Epps, J.A. and J.W. Button, "Fabrics in Asphalt Overlays—Design, Construction and Specification," Report No. 261-3F, Texas Transportation Institute (November 1984) 73 pp.
24. Button, J.W., "Overlay Construction and Performance Using Geotextiles," in *Transportation Research Record 1248: Geosynthetics, Geomembranes, and Silt Curtains in Transportation Facilities,* Transportation Research Board, National Research Council, Washington, D.C. (1989) pp. 24–33.
25. Dykes, J.W., "Use of Fabric Interlayers to Retard Reflective Cracking," *Proceedings,* AAPT, Vol. 49 (1980) pp. 354–368.
26. Predoehl, N.H., "Evaluation of Paving Fabric Test Installations in California—Final Report," draft, California Department of Transportation, Translab (1989).

27. Pickett, D.L. and R.L. Lytton, "Laboratory Evaluation of Selected Fabrics for Reinforcement of Asphalt Concrete Overlays," Report No. FHWA/TX-84/20 + 271-1, Texas Transportation Institute (August 1983).
28. Smith, R.D., "Laboratory Testing of Fabric Interlayers for Asphalt Concrete Paving: Interim Report," in *Transportation Research Record 916: Engineering Fabrics in Transportation Construction,* Transportation Research Board, National Research Council, Washington, D.C. (1983) pp. 6–18.
29. Button, J.W., J.A. Epps, and R.L. Lytton, "Laboratory Evaluation of Fabrics for Reducing Reflection Cracking," Report No. RF 3424-3, Texas Transportation Institute, Texas A&M University (January 1983).
30. Brown, S.F., J.M. Brunton, and D.A.B. Hughes, "Polymer Grid Reinforcement of Asphalt," *Proceedings,* AAPT, Vol. 54 (1985) pp. 18–44.
31. Roland, J.J., "Beam Tests for Fabrics Used in Reduction of Reflection Cracking," Iowa Department of Transportation (April 1981).
32. Beckham, W.K. and W.H. Mills, "Cotton-Fabric-Reinforced Roads," *Engineering News Record,* Vol. 115, No. 14 (1935).
33. *Geotechnical Fabrics Report,* Vol. 5, No. 7 (December 1987) pp. 36–68.
34. Pourkhosrow, G., "Nonwoven Polyester and Polypropylene Engineering Fabrics in Oklahoma Pavements," Oklahoma Department of Transportation (May 1985) 20 pp.
35. Maurer, D.A. and G.J. Malasheskie, "Field Performance of Fabrics and Fibers to Retard Reflective Cracking," Report No. 83-8, Pennsylvania Department of Transportation (1988).
36. Fredrick, D.A., "Stress-Relieving Interlayers for Bituminous Resurfacings," Report No. 113, New York State Department of Transportation (April 1984) 37 pp.
37. Bushey, R.W., "Experimental Overlays to Minimize Reflection Cracking," Report No. FHWA-CA-TL-3167 76-28 (interim report), California Department of Transportation, Translab (September 1976).
38. La Force, R.F., H.N. Swanson, and D.E. Donnelly, "Reflection Cracking Treatments, Alameda Avenue, Project 002612," Report No. CDH-DTP-R-80-11, Colorado Department of Highways, Denver, Colo. (October 1980).
39. Lorenz, V.M., "New Mexico Study of Interlayers Used in Reflective Crack Control," in *Transportation Research Record 1117: Pavement Evaluation and Rehabilitation,* Transportation Research Board, National Research Council, Washington, D.C. (1987) pp. 94–103.
40. Lund, S.M., "Reflective Crack Study Construction Report," Minnesota Department of Transportation (January 1985).
41. MacMaster, J.B., "Control of Reflection Cracking by Use of a Pavement Material," Report EM-11, Ontario Ministry of Transportation and Communications, Engineering Materials Office (January 1978).
42. Zapata, C.A., "Performance Evaluation of 'Mirafi 140' Fabric as Overlay Reinforcement to Control Reflection Cracking," Report No. R-1125, Michigan Transportation Commission, Testing and Research Division (July 1979).
43. Epps, J.A., B.M. Galloway, and C.H. Hughes, *Field Manual on Design and Construction of Seal Coats,* Annual Report 214-25, Texas Transportation Institute, Texas A&M University, College Station, Tex. (July 1981).
44. Pourkhosrow, G., "The Evaluation of Non-Woven Fabrics: Petromat and Mirafi," Report No. FHWA/OK 8266, Oklahoma Department of Transportation (May 1982) 25 pp.
45. Predoehl, N., "1988 Report of Construction Evaluated Research (CER) Projects Featuring Pavement Reinforcing Fabric (PRF) Interlayers in AC Overlays of Distressed Flexible Pavements," (memorandum), California Department of Transportation, Office of Transportation Laboratory (May 4, 1989).
46. Jackson, R.D., "Use of Fabrics and Other Measures for Retarding Reflective Cracking of Asphaltic Concrete Overlays," Report No. WES/MP/GL-80-2, FAA/RD-80/8, Waterways Experiment Station (March 1980) 22 pp.
47. Ahlrich, R.C., "Evaluation of Asphalt Rubber and Engineering Fabrics as Pavement Interlayers," Misc. Paper GL-86-34 (Untraced Series N-86) (November 1986) 7 pp.
48. Parcells, W.H., R.G. Magg, J.A. Thissen, and R.F. Heinen, "Addendum to May 1983 Report of Petromat Performance on Flexible and Composite Pavements," final report, Kansas Department of Transportation (1985).
49. Ravn, T., R. Cassellius, and R. Olson, "Methods and Materials for Reducing Crack Reflectance," Report No. FHWA/MN/RD/05, Minnesota Department of Transportation (December 1987).
50. Maag, R.G., J.A. Thissen, and R.F. Heinen, "Petromat Performance on Flexible and Composite Pavements," Kansas Department of Transportation (May 1983).
51. Harmelink, D.S., "Reflective Cracking—Fabrics," Report No. CDOH-DTP-R-86-11, Colorado Department of Highways (June 1986).
52. Swanson, H.N., "Evaluation of Reflection Cracking for Bituminous Overlays on Concrete Pavements," final report, Colorado Department of Highways (October 1983).
53. *Report on Performance of Fabrics in Asphalt Overlays* (Developed in conjunction with National Experimental and Evaluation Program Project No. 10), Experimental Application and Evaluation Branch, Demonstration Projects Division, Federal Highway Administration (September 1982).
54. Way, G.B., "Prevention of Reflective Cracking in Arizona," *Proceedings,* AAPT, Vol. 49 (1980) pp. 314–330.
55. Fish, G.W. and R.L. McNamara, "Reduction of Reflection Cracking in Bituminous Overlays," Payne's Prairie Experimental Project, Research Report 176A, Office of Materials and Research, Florida Department of Transportation (September 1976).
56. Skog, J.B., J.A. Matthews, G.W. Mann, and D.V. Roberts, "Statewide Flexible Pavement Performance and Deflection Study," Report No. FHWA-CA-TL-78-28, California Department of Transportation, Translab (December 1978).
57. Donnelly, D.E., P.J. McCabe, and H.N. Swanson, "Reflection Cracking in Bituminous Overlays," Report No. CDOH-P&R-R-76-6, Colorado Department of Highways (1976).
58. "A Survey of Reflective Crack Retardation by Fabric Materials in Texas," Report No. 606-2, Texas Department of Highways and Public Transportation (August 1977).
59. Huffman, M.D., "Comparison of Reflective Crack Retardation by Fabric Material (Petromat), Open-Graded Fric-

tion Courses, and Conventional Hot Mix," Experimental Project 606-3, Texas Department of Highways and Public Transportation (February 1978).

60. Swanson, H., D. Donnelly, and R.F. La Force, "Reflection Cracking Evaluation, Kannah Creek, Colorado Project FC 050-1(8)," final report, Colorado Department of Highways (June 1980).
61. "Reflective Cracking Study, Houlton, Maine," Experimental Project report, final report, Maine Department of Transportation (September 1979).
62. "Experimental Use of Pavement Reinforcing Fabrics to Reduce Reflective Cracking," Final Report 80-4, Vermont Agency of Transportation (January 1981).
63. Voss, D.A., "Discussion of 'Prevention of Reflective Cracking in Arizona,'" *Proceedings,* AAPT, Vol. 49 (1980) p. 323.
64. Vedros, P.J., "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, Miss. (1981).
65. Hoffman, G.L., "Reinforcing Fabric for Bituminous Resurfacing," Research Project 73-20, Bureau of Bridge and Roadway Technology, Pennsylvania Department of Transportation (August 1981).
66. Marais, G.P., J.H. Maree, and E.G. Kleyn, "The Impact of HVS Testing on Transvaal Pavement Design," *Annual Transportation Convention,* Vol. 3, Pretoria, South Africa (August 9–13, 1983) 32 pp.
67. van Gurp, C.A.P.M., A.P.M. Christ, and R.L.M. van Hulst, "Reinforcement at Asphalt-Granular Base Interface," *Journal of Geotextiles and Geomembranes,* Vol. 8 (1989).
68. Kennepohl, G.J.A. and R.L. Lytton, "Pavement Reinforcement with Geogrids for Reflection Cracking Reduction," *Proceedings,* Paving in Cold Areas, Mini-Workshop, Canada/Japan Science and Technology Consultations, Technical Memorandum of PWRI No. 2136 (October 1984) pp. 863–882.
69. Zapata, CA., M.A. Chiunti, and L.J. Pearson, "Performance Evaluation of Plastic Fabrics as Overlay Reinforcement to Control Reflection Cracking," Research Report No. 1243, Michigan Transportation Commission, Research Laboratory Section (April 1984).
70. McGhee, K.H., "Efforts to Reduce Reflective Cracking of Bituminous Concrete Overlays of Portland Cement Concrete Pavements," Report No. VHTRC 76-R20, Virginia Highway and Transportation Research Council, Charlottesville, Va. (November 1975).
71. Rutkowski, T.S., "Reduction of Reflective Cracking in Asphalt Concrete Overlays of Rigid Pavement," Report No. 77-4, Wisconsin Department of Motor Vehicles (June 1985).
72. McGhee, K.H., "Control of Reflection Cracking in a Fabric-Reinforced Overlay on Jointed Portland Cement Concrete Pavement," Report No. VHTRC 83-R8, Virginia Highway and Transportation Research Council, Charlottesville, Va. (August 1982).
73. Bone, A.J., L.W. Crump, and V.J. Roggeveen, "Control of Reflection Cracking in Bituminous Resurfacing over Old Cement and Concrete Pavements," in *HRB Proceedings,* Vol. 33, Highway Research Board, National Research Council, Washington, D.C. (1954) pp. 345–354.
74. Carlson, R.W., "Drying Shrinkage of Concrete as Affected by Many Factors," *Proceedings,* ASTM, Vol. 38, Part II (1938) pp. 419–437.
75. Gulden, W. and D. Brown, "Treatments for Reduction of Reflective Cracking of Asphalt Overlays on Jointed-Concrete Pavements in Georgia," in *Transportation Research Record 1007: Nondestructive Pavement Evaluation and Overlay Design,* Transportation Research Board, National Research Council, Washington, D.C. (1985) pp. 26–36.
76. Gulden W. and D. Brown, "Overlays for Plain Jointed Concrete Pavements," Research Project No. 7502, Office of Materials and Research, Georgia Department of Transportation (1984).
77. Seeds, S.B., B.F. McCullough, and R.F. Carmichael, "Asphalt Concrete Overlay Design Procedure for Portland Cement Concrete Pavements," in *Transportation Research Record 1007: Nondestructive Pavement Evaluation and Overlay Design,* Transportation Research Board, National Research Council, Washington, D.C. (1985) pp. 26–36.
78. Knight, N., "Heavy Duty Membranes for the Reduction of Reflective Cracking in Bituminous Concrete Pavements," Report No. FHWA/PA-85-006, Pennsylvania Department of Transportation (August 1985) 32 pp.
79. Barksdale, R.D. and R.G. Hicks, *NCHRP Report 202: Improved Pavement-Shoulder Joint Design,* Transportation Research Board, National Research Council, Washington, D.C. (June 1979) 103 pp.
80. Allen, H.S., "Methods and Materials for Reducing Crack Reflectance," Report No. FHWA-MN-RD-84-09, Minnesota Department of Transportation (January 1985) 32 pp.
81. Gulden, W. and J.B.Thornton, "Restoration Methods for Jointed Concrete Pavements," Project No. 7504, Office of Materials and Research, Georgia Department of Transportation (May 1985).
82. Mullen, W.G. and R.J. Hader, "Effectiveness of Fabric and Non-Fabric Treatments in Controlling Reflective Cracking," *Proceedings,* AAPT, Vol. 49 (1980) pp. 397–415.
83. Allen, H.S., "Evaluation of Fabric Strip Repair to Reduce Longitudinal Crack Reflectance," Special Study 372, Minnesota Department of Transportation (1985).
84. Mills, D.R. and T. Keller, "Reflection Crack Control in Hot Mix Overlays (Bituthene and Polygard Waterproofing Membranes)," Final report, Department of Highways and Transportation, Materials Research, State of Delaware (January 25, 1982).
85. Predoehl, N., "1988 Report of Construction Evaluated Research (CER) Projects Featuring Pavement Reinforcing Fabric (PRF) Interlayers in AC Overlays over Distressed Rigid (PCC) Pavements," (memorandum), California Department of Transportation, Office of Transportation Laboratory (May 25, 1989).
86. Zapata, C.A., "Experimental Fabrics on I-94 BL, City of Kalamazoo," (memorandum) (March 7, 1984 and July 19, 1985).
87. Heins, D., "A Study on the Use of Fabric to Retard Reflective Cracking over Widening Joints," Iowa Department of Transportation, Ames, Iowa (July 1989).

88. Hens, A.T. and G.N. Cirasole, "Evaluation of Synthetic Fabrics to Reduce Reflective Cracking of Bituminous Concrete Overlays," Report No. FHWA/MD-88/15, Maryland Department of Transportation (November 1987).
89. Knight, N.E. and G.L. Hoffman, "Heavy Duty Membranes for the Reduction of Reflective Cracking on Bituminous Concrete Overlays," *Pavement Maintenance and Rehabilitation,* ASTM STP 881 (1985) pp. 51–64.
90. Predoehl, N., "1988 Report of Construction Evaluated Research (CER) Projects Studying the Effects of Pavement Reinforcing Fabric (PRF) Interlayers on Asphalt Concrete (AC) Overlays over Cracked and Seated (C&S) Distressed Portland Cement Concrete (PCC) Pavements," (memorandum), California Department of Transportation, Office of Transportation Laboratory (June 21, 1989).
91. Azab, M.A., R.D. Helwig, and G.J. Malasheskie, "Heavy Duty Membranes for the Reduction of Reflective Cracking in Bituminous Concrete Overlays—Follow Up Report," Research Report 79-6, Engineering Technology Division, Pennsylvania Department of Transportation (1987).
92. McGhee, K.H. and C.S. Hughes, "Installation Report, The Use of Fabric Reinforced Overlays to Control Reflective Cracking of Composite Pavements," Virginia Highway and Transportation Research Council, Charlottesville, Va. (February 1973).
93. "Report on Strain Alleviating Membranes Incorporating Rubber Modified Bitumen Binders," National Association of Australian State Road Authorities, Milsons Point, New South Wales (1984) 83 pp.
94. "Asphalt-Rubber for Stress Absorbing Membrane to Retard Reflective Cracking," final report, Kansas Department of Transportation (June 1989).
95. Gulden, W., "Evaluation of Asphalt-Rubber Seal Coats and Interlayers for Rehabilitation of Flexible Pavements," Report No. 02-76, Georgia Department of Transportation (September 1982).
96. "Renovation in Rock Hill," *Dixie Contractor* (December 5, 1986) p. 22.
97. Hank, R.J. and M. Brown, "Aggregate Retention Studies of Seal Coats," *Proceedings,* AAPT, Vol. 18 (1949) pp. 261–277.
98. *Pavement Condition Manual,* Pennsylvania Department of Transportation (September 1983).
99. "PACES, Pavement Condition Evaluation System," Georgia Department of Transportation (June 1983).
100. "Asphalt Overlays for Highway and Street Rehabilitation," Manual Series No. 17, The Asphalt Institute (June 1983).
101. ARE, Inc., "Asphalt Concrete Overlays of Flexible Pavements," Report No. FHWA-RD-75-76, Vol. II (June 1975).
102. McCullough, B.F. and S.B. Seeds, "Field Validation of an Overlay Design Procedure to Prevent Reflection Cracking," *Proceedings,* 5th International Conference on the Structural Design of Asphalt Pavements, Vol. I, the Netherlands (August 1982) pp. 780–791.
103. Treybig, H.J., B.F. McCullough, P. Smith, and H. Von Quintus, "Overlay Design and Reflection Cracking Analysis for Rigid Pavements, Vol. 1: Development of New Design Criteria," Report No. FHWA-RD-77-66 (August 1977).
104. Way, G., "Prevention of Reflection Cracking in Arizona: Minnetonka-East (A Case Study)," Arizona Department of Transportation (May 1976).
105. Way, G.B., "Prevention of Reflection Cracking: Minnetonka-East-1979 Addendum," No. 1979 G.W.I., Arizona Department of Transportation (August 1979).
106. Haas, R.C.G. et al., "Low Temperature Pavement Cracking in Canada—The Problem and Its Treatment," *Proceedings,* Canadian Good Roads Association (1970) pp. 69–96.
107. Phang, W.A. and K.O. Anderson, "The Thermal Cracking Problem and Pavement Rehabilitation," *Pavement Rehabilitation: Proceedings of a Workshop,* Report No. FHWA-RD-74-60, Federal Highway Administration, Washington, D.C. (June 1974) pp. 158–169.
108. McLeod, N.W., "A Four Year Survey of Low Temperature Transverse Pavement Cracking on Three Ontario Test Roads," *Proceedings,* AAPT, Vol. 41 (1972).
109. Nouneldin, M.S. and P.G. Manke, "Applications of the Stiffness Concept to Transverse Pavement Cracking in Oklahoma," *Proceedings,* AAPT, Vol. 47 (1978).
110. Kandhal, P.S., "Low Temperature Shrinkage Cracking of Pavements in Pennsylvania," *Proceedings,* AAPT, Vol. 47 (1978).
111. Clark, M.F. and R.W. Culley, "Evaluation of Air Blown Asphalts to Reduce Thermal Cracking of Asphalt Pavements," *Proceedings,* AAPT, Vol. 45 (1976) pp. 530–551.
112. Yoo, Z. and C.L. Monismith, "Behavior of Asphalt Mixture with Carbon Black Reinforcement," *Proceedings,* AAPT, Vol. 55 (1986) pp. 564–585.
113. Kennepohl, G.J. and L.J. Miller, "Sulphur-Asphalt Binder Technology for Pavements," in *New Uses of Sulfur-II,* D.J. Brown ed., American Chemical Society *Advances in Chemistry Series* No. 165 (1978).
114. Rostler, F.S., R.M. White, and E.M. Dannenberg, "Carbon Black as a Reinforcing Agent for Asphalt," *Proceedings,* AAPT, Vol. 46 (1977) pp. 376–410.
115. Mills, D.R. and T.J. Keller, "Delaware's Evolution of Three Reflective Crack Retardant Systems in Bituminous Overlay Construction," FHWA Experimental Project No. 608, Delaware Division of Highways (September 1988).
116. Shuler, T.S., R.D. Pavlovich, and J.A. Epps, "Field Performance of Rubber-Modified Asphalt Paving Materials," in *Transportation Research Record 1034: Asphalt Materials, Mixes, Construction, and Quality,* Transportation Research Board, National Research Council, Washington, D.C. (1985) pp. 96–102.
117. Strong, M.P., "The Evolution of Rubber Asphalt Surface Treatment in Preventing Fatigue Crack Reflection in Bituminous Overlay Construction," final report, North Carolina Department of Transportation (April 1983).
118. Szatlcowski, W.S., "Resistance to Cracking of Rubberized Asphalt: Full-Scale Experiment on Trunk Road A6 in Leicestershire," Report No. LR308, Transport and Road Research Laboratory (1970) 15 pp.
119. Morian, D.A. and J.L. Arellano, "Field Evaluation of Latex-Modified Asphalts," Research Project 83-42, Pennsylvania Department of Transportation (July 1987).
120. Elliott, R.P., "Thickness Design Procedure for Bituminous Resurfacing of Portland Cement Concrete Pavements," Research and Development Report No. 30, Illinois Division of Highways (November 1971).

121. Huff, B.J. and B.A. Vallerga, "Characteristics and Performance of Asphalt-Rubber Material Containing a Blend of Reclaim and Crumb Rubber," in *Transportation Research Record 821: Bituminous Mixes, Concrete Pavements and Structures, Testing, and Construction Prices,* Transportation Research Board, National Research Council, Washington, D.C. (1981) pp. 29–37.
122. Green, E.L. and W.J. Tolonen, "The Chemical and Physical Properties of Asphalt-Rubber Mixtures. Final Report, Part 1—Basic Material Behavior," Report No. ADOT-RS-14(162), Arizona Department of Transportation (July 1977).
123. Jimeniz, R.A., "Testing Materials for Asphalt-Rubber. Final Report—Phase 1," Report No. ADOT-RS-15(164), Arizona Department of Transportation (July 1978).
124. Lansdon, H.G., "Construction Techniques of Placement of Asphalt-Rubber Membranes," presented at the 13th Annual Paving Conference, University of New Mexico (January 1976).
125. Morns, G.R. and C.H. McDonald, "Asphalt-Rubber Stress-Absorbing Membranes: Field Performance and State of the Art," in *Transportation Research Record 595: Asphalts, Aggregates, Mixes, and Stress-Absorbing Membranes,* Transportation Research Board, National Research Council, Washington, D.C. (1976) pp. 52–58.
126. Predoehl, N.H., "An Evaluation of the Effectiveness of Stress Absorbing Membrane Interlayers (SAMI)," (memorandum), Office of Transportation Laboratory, California Department of Transportation (September 13, 1989).
127. Peters, A.J. and R.L. Schultz, "Asphalt-Rubber Binder Stress Absorbing Membrane Interlayer," Report No. WA-RD-128.1, Washington State Department of Transportation (July 1987).
128. "Soft Asphalt Cushion and Rubberized Crack Filler for Minimizing Reflective Cracking," No. I-80-5(43)323, Happy Jack-East, Wyoming Highway Department (1975).
129. Hensley, M.J., "Open Graded Asphalt Concrete Base for the Control of Reflection Cracking," *Proceedings,* AAPT, Vol. 49 (1980).
130. Forsyth, R.A. and H.A. Munday, Jr., "The Effectiveness of Flexible Base Cushion Courses over Old Pavements," California Division of Highways Laboratory (January 1966).
131. Kher, R., "Road Test to Determine Implications of Preventing Thermal Reflection Cracking in Asphalt Overlays," in *Transportation Research Record 632: Design and Performance of Pavement Overlays,* Transportation Research Board, National Research Council, Washington, D.C. (1977) pp. 37–44.
132. Copple, F. and L.T. Oehler, "Michigan Investigation of Soil-Aggregate Cushions and Reinforced Asphaltic Concrete for Preventing or Reducing Reflection Cracking of Resurfaced Pavements," in *Highway Research Record No. 239: Design and Performance of Pavement Systems: 12 Reports,* Highway Research Board, National Research Council, Washington, D.C. (1968) pp. 120–131.
133. Bushing, H.W., E.H. Elliott, and N.G. Reyneveld, "A State-of-the-Art Survey of Reinforced Asphalt Paving," *Proceedings,* AAPT, Vol. 39 (1970) pp. 766–798.
134. Kanarowski, S.M., "Study of Reflection Cracking in Asphaltic Concrete Overlay Pavements—Phase I," Report No. AFWL-TR-71-142, Air Force Weapons Laboratory (March 1972) 102 pp.
135. Brownridge, F.C., "An Evaluation of Continuous Reinforcement in Bituminous Resurfacing," *Proceedings,* AAPT, Vol. 33 (1964) pp. 459–501.
136. Smith, L.L. and W. Gartner, "Welded Wire Fabric Reinforcement for Asphaltic Concrete," in *HRB Bulletin 322: Repair of Concrete Pavements,* Highway Research Board, National Research Council, Washington, D.C. (1962) pp. 1–20.
137. "Wire Mesh Reinforcement of Bituminous Concrete Overlays, Phase I," Research Project No. 17, Bureau of Physical Research, New York Department of Public Works (October 1966) 41 pp.
138. Hughes, C.S., Series of memoranda to E. Shelburne, Virginia Highway and Transportation Research Council (April 1965 through October 22, 1965).
139. Burgin, E.W., "Heater Scarification and Pavement Rejuvenation," presented at the 14th Annual Paving Conference, University of New Mexico (1977).
140. Kipp, O.L. and C.K. Preus, "Minnesota Practices on Salvaging Old Pavements by Resurfacing," in *HRB Proceedings,* Vol. 30, Highway Research Board, National Research Council, Washington, D.C. (1950) pp. 260–273.
141. Velz, P.G., "Effect of Pavement Breaker Rolling on Crack Reflectance in Bituminous Overlays," in *HRB Bulletin 290: Developments in Salvaging Old Pavements by Resurfacing,* Highway Research Board, National Research Council, Washington, D.C. (1961) pp. 39–50.
142. Lyon, J.W., "Heavy Pneumatic Rolling Prior to Overlaying: A 10-Year Project Report," in *Highway Research Record No. 327: Pavement Rehabilitation and Design Overlays: 8 Reports,* Highway Research Board, National Research Council, Washington, D.C. (1970) pp. 45–49.

APPENDIX A
SELECTED FABRIC SPECIFICATIONS

SPECIFICATION FOR PAVING FABRICS–TASK FORCE NO. 25–FHWA

1. DESCRIPTION

This work shall consist of furnishing and placing a reinforcing fabric between pavement layers for the purpose of incorporating a waterproofing and stress relieving membrane within the pavement structure. The work shall be performed in accordance with these specifications, applicable plans, or as designated by the Engineer.

2. MATERIALS

2.1 Paving Fabric: The fabric used with this specification shall be constructed of nonwoven synthetic fibers; resistant to chemical attack, mildew and rot; and shall meet the following physical requirements:

Property	Requirement	Test Method
Tensile Strength, lbs.	80 Minimum	INDA Method 1
Elongation-at-Break, %	40	INDA Method 1
Asphalt Retention, gals/sq. yd.		INDA Method 8

Minumum value is defined as: The average of the specimen test values of any roll tested shall be in excess of the lot mean value less 2 standard deviations.

Lot is defined as: Units of production as defined by the manufacturer.

Lot mean value less 2 standard deviations $\geq$ minimum value

and, $\bar{x}$ roll tested $\geq$ x lot mean less 2 standard deviations $\geq$ minimum value and $\geq$ specification minimum value.

2.2 Asphaltic Sealant: The material used to seal the fabric and bond it to adjoining pavement layers shall be a paving grade asphalt recommended by the fabric manufacturer and approved by the Engineer, or as designated by the Engineer. Typical sealants are:

Type	Grade	Specification
Uncut Asphalt Cement	Pen/Viscosity (1)	AASHTO M-20/M-226

Note - Emulsions may be used as an asphaltic sealant providing the necessary precautions are taken:

1) The air temperature shall be 60°F and rising
2) The pavement surface shall be completely dry
3) The application rate shall be adjusted to compensate for the water content of the emulsion

Although emulsions are acceptable, asphalt cements are preferred. Emulsions contain 40%± water. The time required for the water to evaporate (break time) may result in costly construction delays.

(1) Penetration or viscosity grade as determined by the Engineer.

2.3 Aggregate: Although not always required, quantities of washed concrete sand may be needed to facilitate movement of construction equipment over asphalt saturated fabric during construction.

3. EQUIPMENT

3.1 Asphalt Distributor: The distributor must be capable of spraying the asphalt sealant at a prescribed uniform application rate. No drilling or skipping is permitted. The distributor should be equipped with a hand spray having a single nozzle and positive shut-off valve.

3.2 Fabric Handling Equipment: Mechanical laydown equipment shall be capable of laying the fabric smoothly, without wrinkles and folds. Manual laydown should be broomed thoroughly to insure wrinkle-free installation.

3.3 Miscellaneous Equipment: Stiff bristle brooms to smooth the fabric, scissors or blades to cut the fabric, and brushes for applying asphalt sealant at fabric overlaps (as required) shall be provided. Pneumatic rolling equipment to smooth the fabric into the sealant and sanding equipment may be specified for certain jobs.

4. CONSTRUCTION METHODS/REQUIREMENTS

4.1 Fabric Packaging and Storage: Fabric rolls shall be furnished with suitable wrapping for protection against moisture and sunlight. Each roll shall be labeled or tagged to provide product identification sufficient for inventory and quality control purposes. Rolls shall be stored in a manner which protects them from the elements. If stored outdoors, they shall be elevated and covered with a tarpaulin.

4.2 Weather Limitations: Neither the asphalt sealant nor fabric shall be placed when weather conditions, in the opinion of the Engineer, are not suitable. Air and pavement temperatures should be sufficient to allow adequate "tack" from the asphalt sealant to hold the fabric in place. For most asphalt cements air temperature should be 50 F and rising.

4.3 Surface Preparation: The surface on which the fabric is to be placed shall be free of dirt, water, and vegetation. Cracks exceeding 1/8 inch in width will be filled with a suitable crack filler as directed by the Engineer.

4.4 Application of Asphaltic Sealant: The asphaltic sealant must be uniformily spray applied to the prepared pavement surface at the rate recommended by the fabric manufacturer and approved by the Engineer.

"Asphalt Retention" referred to in the specification is the "thirst" of the paving fabric and is an index to the amount of asphalt cement needed to fill the voids and make the fabric impermeable. "Asphalt Retention" is only a property of the fabric itself.

In the intended use asphalt cement is applied to the pavement. The quantity (usually expressed in gallons per square yard) of asphalt cement should be enough to satisfy the sum of fabric "thirst", pavement "hunger", and hot-mix "appetite". Pavement "hunger" is mainly a function of the pavement surface roughness and texture, and hot-mix "appetite" depends upon the character of the hot-mix and the paving process. In general practice a judgement is made as to what constitutes adequate satisfaction of the combined "thirst", "appetite", and "hunger", but in no case should it be less than 0.2 gallons per square yard.

Consider variables in pavement texture and precision of distributor truck operation, however, a rate less that 0.20 gallons per square yard should never be specified. Otherwise, the objective of obtaining a tightly bonded waterproof membrane may not be achieved. Within street intersections, on steep grades, or in other zones where vehicle speed changes are commonplace, the normal application rate shall be reduced by about 20 percent, or as specified by the manufacturer. Application

of the sealant will be by distributor equipment wherever possible, with hand spraying kept to a minimum. Temperature of the asphalt sealant must be sufficiently high to permit a uniform spray pattern. For asphalt cements, the minimum recommended temperature is 290 F. To avoid damage to the fabric, however, distributor tank temperatures should not exceed 325 F if the fabric is to be oversprayed.
The target width of asphalt sealant application shall be fabric width plus 6 inches. The asphalt sealant should be applied no further in advance of fabric placement than the distance which the contractor can maintain free of traffic.
Asphalt "drools" or spills must be cleaned from the road surface to avoid flushing and possible fabric movement at these asphalt-rich areas.
When asphalt emulsions are used, the emulsion must be cured (essentially no moisture remaining) prior to placing the fabric and final wearing surface.

4.5 Fabric Placement: The fabric shall be placed into the asphaltic sealant with minimum wrinkling, prior to the time the asphalt has cooled and lost tackiness. As directed by the Engineer, wrinkles or folds shall be slit and layed flat. Brooming and/or pneumatic rolling will maximize contact with the pavement surface.
Overlap of fabric joints may be minimal, but must be sifficient as determined by the Engineer to insure full closure of the joint. Transverse joints should be lapped in the direction of paving to prevent edge pick-up by the paver. Fabric overlaps of several inches may, in the judgement of the Engineer, require additional asphalt sealant to insure proper bonding of the double fabric layer. Removal and replacement of fabric that is damaged after placement is the responsibility of the contractor.

4.6 Fabric Trafficking: Trafficking the fabric, if approved by the Engineer, may be permitted for emergency or construction equipment only.

4.7 Asphalt Overlay: Placement of the hot-mix overlay will normally closely follow fabric laydown. No more fabric than can be overlayed that working day will be placed. In the event asphalt bleeds through the fabric before the hot-mix is placed, it may be necessary to blot the sealant by spreading sand or hot-mix over the affected areas. This will prevent any tendency for construction equipment to pick up the fabric when driving over it. Turning of the paver and other vehicles must be gradual and kept to minimum to avoid movement or damage to the membrane. Most satisfactory laydown of the hot-mix can be accomplished at temperatures below 300 F. In no case should temperature of the mix exceed 325 F.

The thickness of the overlay should be sufficiently thick to prevent excessive shear forces at the overlay fabric interface. Experience has shown that the minimum compacted thickness recommended is one and one-half inches compacted. The overlay thickness should be increased to account for surface irregularities, or deficiencies in existing pavement such as insufficient pavement thickness. Occasionally, a separate truing and leveling course of asphalt concrete is necessary prior to the overlay sequence (tack coat, fabric, asphalt concrete).

If the fabric has been sanded and opened to traffic, excess sand is broomed from the fabric prior to surfacing. If, in the judgement of the Engineer, the fabric surface appears dry and lacks tackiness following exposure to traffic, a light tack coat may be applied prior to placing the overlay.

5. METHOD OF MEASUREMENT

6. BASIS OF PAYMENT

TEXAS PAVING FABRIC SPECIFICATIONS: ITEM 3002

1. DESCRIPTION. This item shall consist of furnishing and placing a fabric underseal in accordance with the details shown on the plans and the requirements of these specifications. This underseal shall consist of a single application of asphalt covered with one layer of the fabric with or without sand or screenings.

2. MATERIALS. The woven or non-woven fabric shall be constructed exclusively of man-made thermoplastic fibers. These fibers may be oriented in the fabric in either a random or an aligned orientation and the fibers may be either continuous throughout the fabric. The fabric itself shall be mildew resistant, rot-proof, and shall be satisfactory for use with asphalt cements.

a. Physical Requirements. The fabric supplied shall meet the following additional requirements when sampled and tested in accordance with the methods specified.

TEST	METHOD	REQUIREMENT	
Original Physical Properties		Minimum	Maximum
1. Fabric weight, oz/yd^2:	ASTM D 1910 paragraph 37 or 38	4.0	9.0
2. "Apparent elongation" at "breaking load" on warp-wise specimens, percent:	ASTM D 1682, Grab Method G as modified by paragraph F. Testing Requirements of this specification.	50	150
3. "Apparent elongation" at "breaking load" on filling-wise specimens, percent:	" " "	50	150
4. "Breaking load," on warp-wise specimens, pounds:	ASTM D 1682, Grab Method G as modified by paragraph F. Testing Requirements of this specification.	45	
5. "Breaking load," on filling-wise specimens, pounds:	" " "	80	
6. Asphalt retention, oz/ft^2:	paragraph F. Testing Requirements of this specification.	0.5	8.5

7. Change in area caused by asphalt retention test and subsequent asphalt removal. Reported as change in area of specimen measured after test as compared to area of specimen before test, percent:	paragraph F. Testing Requirements of this specification.	±15

8. Physical Properties After 275°F Asphalt Retention Test and Subsequent Asphalt Removal. Fabric samples so treated shall when tested in accordance with the methods prescribed for tensile and elongation tests comply with the minimum and maximum strength requirements as set forth for "as-received" samples under "Original Physical Properties" with a 10% tolerance allowed.

b. Packaging Requirements. The fabric shall be packaged in standard-width rolls of specified length. The fabric itself shall be uniformly wound onto suitable cylindrical forms or cores to aid in handling and unrolling. Each roll of fabric and the form or core upon which it is rolled shall be packaged individually in a suitable sheath, wrapper, or container to help protect the fabric from damage due to ultraviolet light and moisture during normal storage and handling.

c. Identification Requirements. Each roll shall be labeled or tagged in such a manner that the information for sample identification and other quality-control purposes can be read from the label without opening the roll packaging. Each roll shall be identified by the manufacturer as to lot number or control number, date of manufacture, tare weight of core plus wrapper, width and length of fabric on the roll, plus the gross weight of the entire package, which is to include fabric, core, wrapping sheath or container tags, etc.

d. Sampling Requirements. Each roll may be subject to a fabric-weight determination on a per-roll basis. In addition, individual test samples shall be cut from at least one roll selected at random from each 100 rolls or fraction thereof representing each shipment. Individual samples shall be no less than 1 ft in length by full-roll width.

e. Basis for Rejection. Should any individual roll fail to meet the fabric-weight requirement when the entire roll is weighed, then that roll is subject to rejection. Should any individual sample selected at random from 100 rolls (or fraction thereof) fail to meet any specification requirement, then that roll shall be rejected and two additional samples shall be taken, one from each of two other additional rolls selected at random from the same 100-roll lot (or fraction thereof). If either of these two additional samples fail to comply with any portion of the specification, then the entire quantity of rolls represented by that sample shall be rejected.

f. Testing Requirements. Fabric-weight determinations may be made upon complete rolls of fabric. In addition the individual test samples selected in accordance with the sampling procedure outlined may be used for fabric-weight determination. If individual test samples are used for fabric-weight determination, then all 19 of the 4 X 8 inch specimens required for testing of a roll shall be selected from the one-foot by roll-width test sample and the 19 individual test specimens shall be weighed and the average weight expressed in ounces per square yard and calculated and reported on that basis.

The determination of the "breaking load" and the "apparent elongation" at "breaking load" shall be made in accordance with ASTM D 1682 entitled "Standard Methods of Test for Breaking and Elongation of Textile Fabrics" using Grab Method G with a constant rate of traverse so that the breaking load is reached in 20 seconds plus or minus three seconds. Modified jaws are to be used in which the 1 inch x 2 inch jaw faces are serrated with approximately 0.5 millimeter deep serrations in a horizontal direction when the jaws are pulled vertically. The continuous teeth or serrations are to be pointed slightly upward on the jaw faces as the jaws are positioned in the testing machine. Original Physical Property test specimens as placed in the testing machine shall be rectangular and measure four by eight inches. When placed in the 1 inch x 2 inch modified jaws the fabric shall extend one-half inches on either side of the one-inch wide by two-inch high jaws.

Five individual specimens shall be chosen for determination of original physical properties, tensile and elongation testing in the warp-wise direction and eight individual specimens shall be chosen for testing in the filling-wise direction. It is important that these specimens be chosen at random from each individual test sample of at least one foot in length by full-roll width selected at random in accordance with the prescribed sampling procedure. The average test value obtained on the five specimens and the average test value for the eight specimens tested shall be reported as the final test values for those tests in the warp and fill directions respectively. Additional individual specimens shall be selected for those tests involving hot asphalt.

Asphalt retention and potential change of area of the fabric shall be determined as follows:

Three warp-wise specimens of four by eight inch dimension and three filling-wise specimens of like dimension shall be selected at random from the individual one foot wide by roll width test sample. These test specimens shall be individually weighed to the nearest 0.1 gram and then submerged for 30 minutes in the specified asphalt cement maintained at a temperature of 275 $\pm$ 4 F. in a mechanical convection oven. After the required submersion the test specimens shall be removed and hung to drain in the oven for an additional 30 minutes at 275 $\pm$ 4 F. The samples shall then be removed from the oven and allowed to drain for one hour at a temperature of 76 $\pm$ 4 F.

The asphalt cement used for this test shall meet the detailed requirements for viscosity grade AC-10 of the Texas State Department of Highways and Public Transportation Specification Item, "Asphalts, Oils and Emulsions" with the additional requirement that the viscosity at 275 F. shall be within the range of 2.3 to 2.8 stokes. After the one hour at 76 $\pm$ 4 F. the asphalt coated specimens shall be weighed to the nearest 0.1 g and then placed in naphtha heated to 110 $\pm$ 5 F. for 30 minutes. Fresh naphtha contained in trays at the specified temperature may be alternated as necessary during the 30 minute period to effect removal of the asphalt cement from the specimens. Specimens will be blotted with paper towels and allowed to air dry to effect naphtha removal. The area of the specimens will then be measured for the determination of percent change in area. Asphalt retention and change in area will be calculated as follows:

$$\text{asphalt retention, oz./sq.ft.} = \frac{\text{wt. in grams asphalt} \times 0.0352739}{\text{area of specimen after test in in}^2 \div 144}$$

$$\text{change in area, \%} = 100 - \left[\frac{\text{area of specimen after test in in}^2}{\text{original area of specimen in in}^2} \times 100\right]$$

Load test specimens which have been previously subjected to the 275 F. Asphalt Retention Test and Asphalt Removal procedures shall be centered in the jaws of the tensile testing machine. The three inch jaw separation will be maintained. If the original 4 X 8 inch specimen has expanded or chrunk in size the required fabric spacing around the jaws will of necessity not be maintained. Specimens will be centered and 3 inch jaw separation maintained.

3. CONSTRUCTION METHODS. The area on which the underseal is to be placed shall be clean of dirt, dust or other deleterious material by sweeping or other approved methods. Asphaltic materials of the type and grade shown on the plans shall be applied on the clean surface by an approved type of self-propelled pressure distributor so operated as to distribute the material in the quantity specified, evenly and smoothly under a pressure necessary for proper distribution. The Contractor shall provide all necessary facilities for determining the temperature of the asphaltic material and all of the heating equipment and in the distributor for determining the rate at which it is applied and for securing uniformity at the junction of two distributor loads. The distributor shall have been recently calibrated and the Engineer shall be furnished an accurate and satisfactory record of such calibration.

This underseal shall not be applied when the air temperature is below 60 F and is falling, but it may be applied when the air temperature is above 50 F and is rising, the air temperature being taken in the shade away from artificial heat. The underseal shall also not be applied when the temperature of the surface on which the underseal is to be placed is below 50 F. Neither the asphalt nor the fabric shall be placed when general weather conditions, in the opinion of the Engineer, are not suitable.

After beginning the work, should the yield on the asphaltic material appear to be in error, the distributor shall be calibrated in a manner satisfactory to the Engineer before proceeding with the work.

Asphaltic material shall be applied ahead of the placement of the fabric in widths 10 inches wider than the fabric. The asphaltic material shall be applied at the approximate rate shown on the plans or as directed by the Engineer.

String lines will be set for alignment as required by the Engineer.

Immediately upon application of the asphalt, the fabric shall be aligned and carefully broomed and/or rolled into the asphalt with equipment approved by the Engineer. In the event the initial alignment is not satisfactory and causes the fabric to wrinkle during placement, the fabric shall be cut and realigned overlapping the previous material and proceeding as before. All transverse joints shall be overlapped a minimum of 6 inches. In lapping joints, the top fabric shall be folded back to allow application of a light coat of asphalt. The top fabric is then folded back onto the asphalt and broomed and squeegeed out smoothly. Rolling and/or brooming the fabric into the asphalt at the joints shall be accomplished in such a way that the air bubbles which form under the fabric will be removed. This may be accomplished by brooming from the center of the fabric toward the outer edges. The fabric shall be neatly cut and contoured at all joints as directed by the Engineer.

If the edges of the fabric tend to be displaced because of air currents, the Engineer may require that the edges be secured to the pavement at 15-foot intervals. In the event this procedure does not prove satisfactory, then work will be suspended until conditions are more favorable.

Adjacent panels of the fabric shall overlap a minimum of 4 inches. Additional asphalt shall be applied to make these longitudinal joints.

Turning of equipment shall be gradual and kept to a minimum to avoid damage to the fabric. On typical sections not receiving a seal coat, the surface of the underseal fabric shall be covered with a thin layer of clean sand or clean crusher screenings at a rate sufficient to absorb the excess asphalt. The sand and/or crusher screenings shall be approved by the Engineer. On typical sections to be seal coated only sufficient sand shall be spread ahead of the tires to prevent sticking.

All storage tanks, piping, retorts, booster tanks and distributors used in storing or handling asphalt material shall be kept clean and in good operating condition at all times, and they shall be operated in such a manner that there will be no contamination of the asphaltic material with foreign material. It shall be the responsibility of the Contractor to provide and maintain, in good working order, a recording thermometer in the storage heating unit at all times.

The Engineer will select a temperature of application based on the temperature viscosity relationship that will permit application of the asphalt within the limits recommended in the item, "Asphalts, Oils and Emulsions". The recommended range for the viscosity of the asphalt is 50 seconds to 60 seconds Saybolt Furol. The Contractor shall apply the asphalt at a temperature within 15 F of the temperature selected.

4. MEASUREMENT. Asphaltic material will be measured at the point of application on the road in gallons at the applied temperature. The quantity to be paid for shall be the number of gallons used as directed in the accepted underseal.

The fabric underseal shall be paid for by the square yard based on the calculated quantity shown on the contract plans with no allowance made for overlapping at joints.

5. Payment. The work performed and materials furnished, as prescribed by this item, and measured as provided under "Measurement", will be paid for at the unit prices bid for "Asphalt" and "Fabric Underseal", which price shall each be full compensation for cleaning and preparing the existing pavement; for furnishing, preparing, hauling and placing all materials, including sand or crusher screenings; for all freight involved; for all manipulation, including rolling and brooming and for all labor, tools, equipment and incidentals necessary to complete the work.

Where a seal coat is proposed, "Aggregate" and "Asphalt" for the seal coat will be measured and paid for under the Item, "Seal Coat".

Where an asphaltic concrete pavement is proposed, "Aggregate" and "Asphalt" for the asphaltic concrete pavement will be measured and paid for under the appropriate asphaltic concrete pavement item.

GEORGIA DEPARTMENT OF TRANSPORTATION SPECIFICATIONS FOR PLACING HEAVY-DUTY MEMBRANES

SECTION 445—WATERPROOFING PAVEMENT JOINTS AND CRACKS

445.01 DESCRIPTION: This Work consists of the waterproofing of joints and cracks in the pavement by cleaning the existing surface and placing a membrane over the joints and random cracks as shown on the Plans.

445.02 MATERIALS: Membranes shall meet the requirements of Subarticle 888.02.

445.03 CONSTRUCTION: The Membrane shall be placed on joints and random cracks as shown on the Plans. The membrane shall be placed on joints and cracks on both the mainline and ramp pavements which are to be resurfaced unless otherwise noted on the Plans. Placement of the membrane will be done only when the temperature is above 40°F. and the pavement surfaces are dry and free of any dirt or debris.

The surface will be primed in accordance with the manufacturer's recommendations prior to placement of the membrane. The primer will be placed on the surface at the rate specified by the manufacturer of the primer, will extend 1" wider than the membrane, and will be allowed to dry until tack-free before applying the membrane. Primer will be placed on both Portland Cement Concrete and old Asphaltic Concrete surfaces. The need for primer on new asphaltic concrete surfaces will be determined by the Engineer. Sections which are primed shall be covered with membrane within the same day or repriming will be required.

Any spall greater than 3" in diameter which will cause a failure of the material to bond to the pavement or will leave a cavity under the material shall be corrected prior to the placement of the membrane. Spalls shall be repaired using asphaltic concrete meeting the requirements of Section 400 or other materials such as cold mixes approved by the Engineer.

The Membrane shall be installed in widths of 11-3/8" minimum and shall be centered over the joint or crack within a 1" tolerance. Transverse joints and cracks shall be sealed first, starting at the outside edge of the pavement and extending the full length of the joints. The longitudinal joint(s) will be sealed after the transverse joint, with the membrane being placed in the opposite direction that the project will be paved. Laps will be permitted in both the transverse and longitudinal membrane with a minimum overlap of 2-1/2".

The Membrane will be installed straight and wrinkle-free with no curled or uplifted edges. Any wrinkles over 3/8" in width shall be slit and folded down. After the membrane has been placed, it shall be pressed against the concrete or asphalt surface by means of a hand roller or other suitable equipment to insure proper bonding. Special attention should be given to insure that the edges and corners of the strips are bonded securely to the surface. Any strips with loose edges or corners shall be rebonded or replaced prior to placement of the overlay at the expense of the Contractor.

All Membrane shall be surface dry before placement of the asphaltic concrete overlay.

Traffic will be allowed to use the section after placement of the membrane and prior to placing the paving for a maximum period of seven calendar days. Any damaged or disbonded membrane must be replaced prior to paving at no cost to the Department.

445.04 MEASUREMENT: The quantity of membrane, complete in-place and accepted, will be measured in linear feet. The length for transverse joints waterproofed will be based on the typical cross section in the Plans, except that, where widening occurs for extra lanes, field measurements will be made as required to determine the exact length waterproofed. The length for longitudinal joints and random cracks waterproofed will be that actually measured in-place along the centerline of the joint on the surface of the pavement. No allowance will be made for laps.

445.05 PAYMENT: Payment will be made at the Contract Unit price per linear foot of joint and crack waterproofed, which will include cleaning the surface and furnishing and placing the primer and Membrane.

Payment will be made under:

Item No. 445. Waterproofing Pavement Joints
and Cracks (width) .... per Linear Foot

GEORGIA DEPARTMENT OF TRANSPORTATION MATERIAL SPECIFICATIONS FOR HEAVY-DUTY MEMBRANES

888.02 WATERPROOFING MEMBRANE FOR PAVEMENT JOINTS AND CRACKS:

A. General: The waterproofing membrane shall incorporate a high strength heat resistant mesh embedded in a layer of self adhesive rubberized asphalt. The membrane shall contain a minimum of 14 percent synthetic rubber by weight of the membrane. The combined amount of asphalt and plasticizer oils must be a minimum of 60 percent of the total weight of the membrane. The total weight of the membrane for this purpose shall not include the weight of any reinforcement or fabric. Primer shall be supplied by the manufacturer of the membrane or other approved equal which is compatible with the membrane.

B. Physical Properties: The membrane shall meet the following physical properties:

Thickness of rubber-asphalt membrane	0.065" minimum
Water Permeability	500,000 ohms/ft^2 minimum
Breaking Factor	50 lbs/in minimum
Heat Resistance	300°F minimum without membrane damage and retain minimum 500,000 ohms/ft^2 resistivity
Puncture Resistance (Mesh)	200 lbs minimum
Elongation of mesh	15% minimum
Pliability 1/4" Mandrel 180° bend at -15°F ± 2°F	No cracks in mesh or rubberized asphalt
Adhesion	No adhesion failure of membrane at 100 lbs minimum

C. Tests: Method of tests shall be in accordance with the following:

Water Permeability	GHD 69
Breaking Factor	ASTM D-882 (Method A)
Heat Resistance	GHD 69
Puncture Resistance	ASTM E-154
Elongation of Mesh	ASTM D-882
Pliability 1/4" Mandrel 180° bend at -15°F ± 2°F	ASTM D-146
Adhesion	GHD 69

D. Acceptance: Membranes which meet the requirements of this specification are contained on a qualified products list. Membranes which meet this specification, but fail to perform adequately in actual use shall be removed from the qualified products list.

APPENDIX B

SELECTED PAVING FABRIC MODULI AND POISSON'S RATIOS (AFTER *10*)

Type of Fabric	Thickness of Fabric (in.)	Direction of Test	Number of Tests	Average Modulus During Preconditioning (M_{PRE})	Average Modulus During Initial Loading (M_1)	Average Average Secant Modulus (M_s)	Average Poisson's Ratio
Quline	0.105	Y	2	310	426	170	0.17
	0.105	X	2	352	427	615	0.14
Petromat	0.040	Y	2	1771	1874	1479	0.24
	0.040	X	2	2133	2501	2066	0.23
Truetex MG 75	0.056	Y	2	1468	2184	2937	0.24
	0.056	X	2	879	1611	1405	0.22
Bidim-22	0.051	Y	1	1886	1894	2589	0.27
	0.051	X	1	478	1000	1560	0.41
Fibretex 200	0.073	Y	1	200	356	404	0.31
	0.073	X	1	615	778	848	0.23
Trevira	0.051	Y	1	548	961	1194	0.43
	0.051	X	2	950	2066	1704	0.38
Truetex MG 100	0.088	Y	2	265	512	622	0.24
	0.088	X	2	767	1478	1943	0.25
Amopave	0.040	Y	2	1632	2069	2316	0.21
	0.040	X	2	2530	2448	1784	0.24
Quline (impregnated with AR-4000)	0.125	Y	2	248	909	214	0.16
	0.125	X	2	340	878	516	0.16
Petromat (impregnated with AR-4000)	0.070	Y	2	1317	2492	1147	0.21

APPENDIX C

SUMMARY OF CALIFORNIA PAVING FABRIC OVERLAY STUDY OVER AC PAVEMENTS (*26*)

Location (Nomenclature) (A) Bushey Section	Overlay Construction Date (Climate Data)	Section (length-feet)	Overlay Thickness (feet)	Initial* Cracking (Years)	Moderate** Cracking (Years)	Significant*** Cracking (Years)	Cracking by Type (Final)**** Alligator %	Transverse No/100 ft	Longitudinal Ft/100 ft	Final Evaluation Year
BRAWLEY (A) (11-Imp-115-21.2/23.4) Contract 11-157314	8-1974 Desert climate	Control (3696)	0.39	12+	12+	12+	0	0	0	1986
ADT=820(1985) % Trucks = 82 (1984) # of trucks/day = 672	Very hot dry summers. Mild dry winters.	Control (528)	0.27	12+	12+	12+	0	0	0	↓
	Rainfall = 3 in/yr	Petromat (528)	0.25	12	12	12+	0	2	0	↓
		Petromat (422)	0.24	12	12+	12+	0	1	0	↓
		Petromat (422)	0.16	12	12	12+	20	3	0	↓
		Control (528)	0.24	4	11	12	40	0	30	↓
		Control (264)	0.36	12+	12+	12+	0	0	0	↓
BRAWLEY II (11-Imp-86-18.5/18.75) Contract 11-157374	4-1978 Desert climate. Very	(Control (106)	0.30	5	6	7+	0	3	20	1985
Project CA-77-18 ADT = 8700 (1985) % Trucks = 10 (1984)	hot dry summers. Mild dry winters.	Control (106)	0.15	5	7	7+	20	0	0	↓
# of trucks/day = 870	Rainfall = 3 in/yr	Petromat (106)	0.15	7+	7+	7+	0	0	0	↓

Location (Nomenclature) (A) Bushey Section	Overlay Construction Date (Climate Data)	Section (length-feet)	Overlay Thickness (feet)	Initial* Cracking (Years)	Moderate** Cracking (Years)	Significant*** Cracking (Years)	Cracking by Type (Final)**** Alligator %	Transverse No/100 ft	Longitudinal Ft/100 ft	Final Evaluation Year
CHIRIACO SUMMIT (11-Riv-10-81.8/85.8) Contract 11-154214	4-1978 Desert climate.	Control (1056)	0.21	2	5	9	70	0	0	1988
Project CA-77-12 ADT = 8700 (1985) % Trucks = 44 (1984)	Very hot dry summers. Mild dry winters.	Control (3696)	0.27	4	10+	10+	11	0	0	↓
# of trucks/day = 3828	Rainfall = 4 in/yr	SAMI (2640)	0.21	10+	10+	10+	0	0	0	↓
		SAMI (2640)	0.13	6	10+	10+	0	0	0	↓
		SAM (4435)	0.03	2	4	5	100	-	-	↓
		Petromat (2376)	0.21	5	10+	10+	13	1	Trace	↓
		Petromat (1214)	0.13	5	5	10+	22	0	Trace	↓
		Mirafi 140 (317)	0.21	10	10+	10+	5	1	0	↓
		Mirafi 140 (370)	0.13	9	10	10+	20	0	0	↓
COLFAX (A) (03-Pla-80-31.3/33.2) Contract 03-156414	7-1974 Mountain climate.	Control (1487)	0.19	3	4	12	38	7	38	1986
ADT = 24,000 (1985) %Trucks = 14 (1984) # of trucks/day = 3360	Cold wet winters. Rainfall = 45 in/yr	Petroset (1230)	0.19	6	12+	12+	1	1	39	↓
		Control (783)	0.20	3	4	10	44	10	13	↓
		Petromat (1000)	0.21	8	8	10	15	5	18	↓
		0.10' DGAC over 0.10 OGAC (OGAC Interlayer) (1088)	0.19	4	8	8	45	7	38	↓

Location (Nomenclature) (A) Bushey Section	Overlay Construction Date (Climate Data)	Section (length-feet)	Overlay Thickness (feet)	Initial* Cracking (Years)	Moderate** Cracking (Years)	Significant*** Cracking (Years)	Cracking by Type (Final)**** Alligator %	Transverse No/100 ft	Longitudinal Ft/100 ft	Final Evaluation Year
		0.20' DGAC over 0.10 OGAC (OGAC interlayer) (1045)	0.26	6	8	12+	9	4	0	↓
		Control (1005)	0.31	8	10	12+	4	2	0	↓
		Control (1600)	0.21	6	7	8	26	6	50	↓
DOYLE (A) (02-Las-395-29.8/31.5) Contract 02-101804 ADT = 3600 (1985) % Trucks = 12 (1984) # trucks/day = 432	8-1972 High mountain climate. Mild summers. Cold winters. Rainfall = 12 in/yr	Rubberized slurry interlayer (1000)	0.08	1	2	3+	6	2	5	1975
		Slurry interlayer (1000)	0.08	1	1	1	0	10	4	↓
		Control (800)	0.08	1	1	1	6	8	5	↓
		Petroset (1000)	0.08	1	1	1	0	10	5	1978
		Control (1000)	0.20	6+	6+	6+	0	0	0	↓
		Cracks sealed with Petrolastic plus heavy tack coat (1000)	0.08	1	1	6+	0	3	3	↓
		Control (800)	0.08	1	1	1	2	10	14	↓
		Petromat (1000)	0.08	1	2	6+	1	2	12	↓

Remark: Half of test sections chip sealed approximately 2.5 years after construction, remainder after six years.

Location (Nomenclature) (A) Bushey Section	Overlay Construction Date (Climate Data)	Section (length-feet)	Overlay Thickness (feet)	Initial* Cracking (Years)	Moderate** Cracking (Years)	Significant*** Cracking (Years)	Cracking by Type (Final)**** Alligator %	Transverse No/100 ft	Longitudinal Ft/100 ft	Final Evaluation Year
GILROY (04-SCI-101-1.5/4.2) Contract 04-392154	7-1976 Valley climate.	Petromat (1000)	0.15	5	9	12	28	6	66	1988
Project CA-76-06 ADT = 36,000 (1985) %Trucks = 10 (1984)	Cool winters. Hot dry summers.	Petromat (4160)	0.20	6	11	12	20	8	33	↓
# of trucks/day = 3600	Rainfall = 20 in/yr	Control (800)	0.30	10	11	11	70	6	0	↓
		Petromat (3400)	0.20	10	12	12	42	3	25	↓
		Control (1100)	0.30	10	12+	12+	11	0	0	↓
		Petromat (1360)	0.20	12	12	12+	20	1	0	↓
		Petromat (1000)	0.15	5	9	12+	12	4	5	↓
LONG BEACH (07-LA-47-3.6/7.2) Contract 07-286604	6-1976 Southern coastal	Petromat (300)	0.17	10	12	13	0	9	0	1989
Project CA-76-08 ADT = 29,000 (1985) % Trucks = 17 (1984)	climate. Mild, wet winters. Mild summers.	Control (300)	0.17	10	12	13+	0	4	0	↓
# of trucks/day = 4930	Rainfall = 12 in/yr	Petromat (500)	0.17	10	12	13+	0	4	0	↓

Remark: Slight alligator cracking in 1986 covered with slurry seal in 1988. No alligator cracking visible in 1989. Transverse cracks only 8" to 24" long from curb; not out in lane.

Location (Nomenclature) (A) Bushey Section	Overlay Construction Date (Climate Data)	Section (length-feet)	Overlay Thickness (feet)	Initial* Cracking (Years)	Moderate** Cracking (Years)	Significant*** Cracking (Years)	Cracking by Type (Final)**** Alligator %	Transverse No/100 ft	Longitudinal Ft/100 ft	Final Evaluation Year
PASADENA (07-LA-11)(110)-31.7/31.9)	6-1977 Coastal valley climate.	Petromat (755)	0.17	9	10	11	14	6	53	1988
Contract 07-241004 Project CA-77-02 ADT = 31,000 (1985) % Trucks = 0 (1984) # of trucks/day = 0	Mild wet winters. Mild summers. Rainfall = 20 in/yr	Control (215)	0.17	9	10	10	59	5	100	↓
PASO ROBLES (05-SLO-46-36.0.37.8) Contract 05-217704	2-1977 Valley climate. Hot dry summers.	Control (300)	0.45	4	5	9+	27	3	10	1986
Project CA-76-04 ADT = 9100 (1985) % Trucks = 20 (1985)	Cool wet winters. Rainfall = 14 in/yr	Petromat (300)	0.35	3	4	5	38	0	50	↓
# of trucks/day = 1820		Petromat (300)	0.35	3	4	9+	11	0	47	↓
		Petromat (300)	0.25	3	4	9	36	3	35	↓
		Petromat (300)	0.25	4	5	9+	36	3	35	↓
		Control (300)	0.35	5	6	9+	0	0	7	↓
Remark: Chip sealed 1983 (6 years after construction).										
RAINBOW 11-SD-15-51.30/53.1 Contract 11-164634	5-1978 Southern coastal climate.	Petromat (211)	0.10	5	6+	6+	1	1	0	1984
Project CA-77-21 ADT = 23,000 (1982) % Trucks = 10 (1984)	Mild, wet winters. Mild summers.	Control (211)	0.27	5	6+	6+	10	0	0	↓
# of trucks/day = 2300	Rainfall = 20 in/yr	Control (211)	0.17	5	5	5	30	0	0	↓

Overall Summary: Petromat section was superior to thicker control sections.

Location (Nomenclature) (A) Bushey Section	Overlay Construction Date (Climate Data)	Section (length-feet)	Overlay Thickness (feet)	Initial* Cracking (Years)	Moderate** Cracking (Years)	Significant*** Cracking (Years)	Cracking by Type (Final)**** Alligator %	Transverse No/100 ft	Longitudinal Ft/100 ft	Final Evaluation Year
REDDING 02-SHA-273-14.5/15.0 Contract 2-145004	6-1979 Valley climate. Cool, wet winters.	Control (400)	0.25	3	7	9+	0	2	0	1988
Project CA-78-14 ADT = 20,000 (1985) % Trucks = 7 (1984)	Hot, dry summers. Rainfall = 38 in/year	SAMI (550)	0.25	3	9	9+	0	2	5	↓
# of trucks/day = 1400		Petromat (500)	0.25	3	9	9+	0	3	11	↓

Overall Summary: Original pavement PCC. Second AC overlay. All sections nearly equal in appearance at 9 years. Petromat does not appear to retard transverse cracking any better than SAMI or no PRF (control).

Location (Nomenclature) (A) Bushey Section	Overlay Construction Date (Climate Data)	Section (length-feet)	Overlay Thickness (feet)	Initial* Cracking (Years)	Moderate** Cracking (Years)	Significant*** Cracking (Years)	Cracking by Type (Final)**** Alligator %	Transverse No/100 ft	Longitudinal Ft/100 ft	Final Evaluation Year
RIO VISTA 10-SOL-12-23.88/24.0 Contract 10-257744	9-1978 Valley climate. Cool wet winters.	Control (113)	0.06	1	1	3	100	0	0	1986
Project CA-78-16 ADT = 5500 (1985) % Trucks = 14 (1984)	Hot, dry summers. Rainfall = 16 in/year	Bidim C-22 (150)	0.06	3	4	7	100	0	0	↓
# of trucks/day = 770		Bidim C-34 (85)	0.06	5	7	7	100	0	0	↓
		Petromat (152)	0.06	3	4	4	100	1	0	↓
		Heavy Tack Coat (100)	0.06	2	2	4	100	3	0	↓

Overall Summary: This entire section was chip sealed in 1983 (5 years after construction.)

Location (Nomenclature) (A) Bushey Section	Overlay Construction Date (Climate Data)	Section (length-feet)	Overlay Thickness (feet)	Initial* Cracking (Years)	Moderate** Cracking (Years)	Significant*** Cracking (Years)	Cracking by Type (Final)**** Alligator %	Transverse No/100 ft	Longitudinal Ft/100 ft	Final Evaluation Year
VISTA 11-SD-78-7.06/7.34 Contract 11-158814	8-1976 Southern coastal climate.	Petromat (200)	0.20	4	4	7	47	0	10	1984
Project CA-76-07 ADT = 54,000 (1985) % Trucks = 6 (1984)	Mild, wet winters. Mild summers.	Control (200)	0.40	6	7	7	50	0	0	↓
# of trucks/day = 3240	Rainfall = 13 in/yr	Control (200)	0.30	7	8	8	35	0	0	↓
		Control (200)	0.20	5	6	7	75	0	0	↓
		Control (200)	0.20	4	4	8	35	0	10	↓

<u>Overall Summary:</u> Possibly underdesigned AC overlay since all sections failed prior to 10 year design life.

Location	Date (Climate Data)	Section (length-feet)	Overlay Thickness (feet)	Initial* Cracking (Years)	Moderate** Cracking (Years)	Significant*** Cracking (Years)	Alligator %	Transverse No/100 ft	Longitudinal Ft/100 ft	Final Evaluation Year
WESTWOOD 7-LA-2,405-3.6/4.0 30.6/31.0	11-1977 Southern coastal	Control (190)	0.20	4	5	6	60	10	100	1986
Contract 7-188104 Project CA-76-13 ADT = 42,000 (1985) % Trucks = 6.2 (1984) # of trucks/day = 2604	climate. Mild, wet winters. Mild summers.	Petromat (200)	0.20	5	5	6	70	10	100	↓

<u>Overall Summary</u> Petromat appeared to retard cracking for approximately 1 year, but was ineffective in reducing cracking after it started.

* Initial Cracking = 5% to 10% alligator cracking or 1 transverse crack/100 feet.
** Moderate Cracking = 20± 9% alligator cracking or 2 to 4 transverse cracks/100 feet.
*** Significant Cracking = >30% alligator cracking or >5 transverse cracks/100 feet.
**** Alligator cracking: percent of wheel path cracking.

THE TRANSPORTATION RESEARCH BOARD is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. It evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 270 committees, task forces, and panels composed of more than 3,300 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, the Association of American Railroads, the National Highway Traffic Safety Administration, and other organizations and individuals interested in the development of transportation.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Frank Press is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Robert M. White is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Samuel O. Thier is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Frank Press and Dr. Robert M. White are chairman and vice chairman, respectively, of the National Research Council.

TRANSPORTATION RESEARCH BOARD
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

ADDRESS CORRECTION REQUESTED