

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE

92

MINIMIZING REFLECTION CRACKING OF PAVEMENT OVERLAYS

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MINIMIZING REFLECTION CRACKING OF PAVEMENT OVERLAYS

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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 its parent organization, the National Academy of Sciences, a private, nonprofit institution, 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 Academy 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 Academy and its 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.

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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 National Academy of Sciences, or the program sponsors.

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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 special interest to pavement designers, materials specialists, maintenance engineers, and others concerned with the performance of pavement overlays. Methods are presented for reducing reflection cracking in overlays.

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 cracks can shorten the service life of overlays on both asphalt and portland cement concrete pavements. This report of the Transportation Research Board contains a discussion of the causes of reflection cracking and provides guidance on the methods of preventing this problem.

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.

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

MINIMIZING REFLECTION CRACKING OF PAVEMENT OVERLAYS

SUMMARY

Reflection cracks are fractures in a pavement overlay that are the result of, and reflect, the crack or joint pattern in the underlying layer. Reflection cracks can cause early deterioration of an overlay, thereby increasing maintenance costs and decreasing the useful life of the overlay.

Reflection cracks are generally assumed to be caused by horizontal and vertical movements of pavement that is being resurfaced. There has been much field experimentation since 1932; however, it is only recently that theoretical studies of reflection cracking have been initiated. The National Experimental and Evaluation Program for Reducing Reflection Cracking in Bituminous Overlays (the NEEP-10 project) has been one of the most extensive projects for testing methods to reduce reflection cracking.

Methods that have been used to minimize reflection cracking of asphalt concrete overlays include (a) greater thickness of overlay, (b) changes in the viscosity of the asphalt, (c) additives incorporated into the asphalt concrete mixture, (d) treatments to the existing pavement before overlaying (seal coats, rejuvenators, heater-scarifying, crack filling, pavement breaking, stabilization, and recycling), and (e) stress-relieving interlayers (asphalt-rubber, membranes, fabrics, low-viscosity asphalt concrete, open-graded asphalt concrete, and aggregate). Results of various tests using these methods are presented in the synthesis.

Portland cement concrete overlays that are bonded or partially bonded to the existing pavement have joints that match the old joints; thus reflection cracking is not a problem. Unbonded portland cement concrete overlays are separated from the old pavement by an interlayer and cracks do not reflect through.

Theoretical approaches to reflection cracking, based on fracture mechanics principles, have provided methods for calculating the maximum stress or strain in an overlay in order to indicate whether or not reflection cracking will occur.

Conclusions of this synthesis include:

- Overlay systems that have retarded reflection cracking of asphalt concrete overlays on old asphalt concrete pavements are low-viscosity asphalt (in the overlay or as an interlayer), heater-scarifier remix of the old surface, asphalt-rubber interlayer, certain fabrics (for other than thermally induced cracks), and overlays thicker than 2 in. (50 mm).
- Overlay systems that have retarded reflection cracking of asphalt concrete overlays on old portland cement concrete pavements are 6-in. (150-mm) thick overlays where vertical movement is not excessive, and stress-relieving layers

such as prefabricated fabric membrane strips or a 3.5-in. (90-mm) layer of open-graded asphalt concrete base.

- For bonded and partially bonded portland cement concrete overlays, new joints should be placed over old joints; unbonded overlays do not require matching joints.

- Additional research and field testing are necessary to verify theoretical approaches as practical design systems.

INTRODUCTION

As many of the nation's Interstate and other highways approach the end of their design life, the need for dependable rehabilitation techniques becomes increasingly important. Rehabilitation procedures include preventing the cracks in existing pavement, either portland cement concrete (PCC) or asphalt concrete (AC), from working through a new pavement layer and prematurely starting the failure process. Such cracks, known as reflection cracks, can lead to raveling and spalling (Figure 1), and can permit water to enter the base and subgrade beneath the pavement.

Reflection cracking has been defined as follows: "Reflection cracks are fractures in an overlay (AC or PCC) that are the result of, and reflect, the crack or joint pattern in the underlying layer, and may be either environmental or traffic induced" (1). Reflection cracks can be found in bituminous layers covering either portland cement concrete or asphalt concrete.

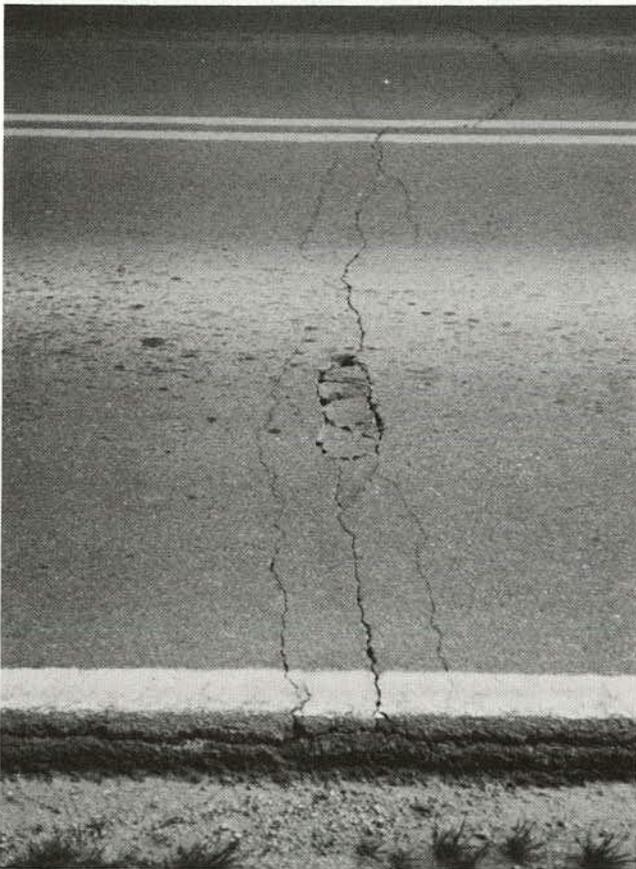


FIGURE 1 Reflection crack with secondary cracking and the beginning of a spalled area [PCC covered with a 2-in. (50-mm) AC overlay].

In 1974 a pavement rehabilitation workshop, conducted by the Transportation Research Board and sponsored by the Federal Highway Administration (FHWA), was held in San Francisco (2). In the section of the workshop dealing with reflection cracking, the following conclusions were reached concerning the significance of such cracking (3):

Problems associated with cracks in existing pavement reflecting through new surfacings are important considerations in pavement rehabilitation and can play an important part in the degree of success obtained in the rehabilitation process. This is particularly true in the case of rehabilitation with bituminous concrete overlays, which has been and continues to be, the predominant form of rehabilitating highway pavements. Reflection cracks can be the source of early deterioration in bituminous concrete overlays, causing accelerated maintenance and reducing the useful service life of the rehabilitated pavement. Deterioration in the form of raveling and spalling of the surfacing occurs at reflection cracks in bituminous concrete resurfacing of flexible pavements. In addition to these, closely spaced parallel cracks and tenting, or humps, often occur at reflection cracks in bituminous concrete resurfacings over existing rigid pavements. Another concern is intrusion of water into the crack opening, which can cause loss of bond between the surface and pavement and can result in pumping and a decrease of subgrade support. Many remedies have been proposed and tried over the years, but as yet there is no proven method that can be used to guard against reflection cracking in bituminous concrete overlays.

Reflection cracking in portland cement concrete (PCC) overlays is an important consideration in this method of rehabilitation, which has been used some in the highway field and to a much greater extent in airport work. The research work in this area, however, has been more fruitful, and methods have been developed and are being used to successfully control reflection cracking in PCC overlays of rigid pavements.

MECHANICS OF REFLECTION CRACKING

The basic mechanisms generally assumed to lead to reflection cracking are the vertical and horizontal movements of the pavement being resurfaced. Vertical movements are differential movements at the crack in the underlying pavement and are caused by moving loads; horizontal movements are due to expansion and contraction caused by temperature change and/or moisture change. The horizontal movement of cracked slabs under a bonded bituminous surface causes high tensile stresses in the immediate area over the crack. Because an AC surface is generally stiffer at lower temperatures, it can withstand only small temperature-induced stresses. In addition to temperature changes in the underlying slab, total movement at the crack is affected by slab length, moisture changes, and, to some extent, the stiffness properties of the overlying material.

Traffic crossing a crack can induce a differential vertical movement. The amount of such movement depends on aggregate interlock at the crack as well as on the amount of curl developed in underlying PCC slabs. The results of an experiment in Virginia (4) indicated that the amount of reflec-

tion cracking in a particular PCC roadway depended on the amount of differential movement as determined by deflection measurements.

BACKGROUND

Until the 1970's, most of the field research on reduction of reflection cracking was based on (a) increased thickness, (b) cushion courses, (c) treatment of existing slabs, or (d) reinforcement of AC surface. One of the first AC overlays of PCC pavement was the placement of a thin resurfacing layer [1 to 1.5 in. (25 to 38 mm) thick at the edges and 3 in. (75 mm) in the center] on Union Street in Schenectady, New York, in 1909 (5). In 1930 the Portland Cement Association reviewed the performance of 200 miles (320 km) of PCC overlays placed in California between 1919 and 1930 (5), and reported that, depending on traffic and deterioration of the roadway, 4 or 5 in. (100 or 125 mm) of PCC resurfacing was required in order to prevent reflection cracking.

The problem of reflection cracking is not new and has been under study since 1932. In that year, the Highway Research Board conducted a symposium on "Resurfacing Portland Cement Concrete Pavements," which included reflection cracking experiences. Experience of that period was summarized in papers by Fleming (5) and Gray and Martin (6). Since then, much field experimentation has been done, but only in recent years have theoretical approaches been studied.

Bone et al. (7) concluded in 1954 that the horizontal movement of slabs was the predominant factor in reflection cracking. They found a seasonal length variation of 0.10 to 0.18 in. (2.5 to 4.6 mm) per 57 ft (17 m) (at the time of the experiments this was the distance between expansion joints in Massachusetts). The results of their work also indicated that the AC surfacing used at that time, when made into test specimens 13 in. (330 mm) in length, would not tolerate strains in excess of 0.05 in. (1.3 mm) without cracking. The results were verified by field measurements, which revealed that cracking had occurred in nearly every case where the surfacing had stretched more than 0.05 in. in 13 in.

The first systematic field study to evaluate factors affecting AC resurfacing of concrete pavements was reported in 1955 by Crump and Bone (8). The results of their study of 25 test sections, each 1000 ft (305 m) long, led to two significant conclusions (8):

1. The successive record of various sections showed a definite progressing of reflection cracking in the early years. Different types of cracking develop at different rates but all types increase with each additional climatic cycle. For instance, by the third year many pavements had cracks over more than 75% of the length of the transverse joint. A few reached 95 to 100% in three or four years. Successive surveys, then, show a progressive growth of crack width after each annual temperature cycle rather than an increase in length of cracking.
2. Resurfacings laid in the fall do not usually crack until their second winter. Those laid in the spring or summer almost always begin to crack during the first winter. After about 2 years the cracking was about equal on both types.

In 1963 Vicelja (9) reported to the Association of Asphalt Paving Technologists the results of a 4-yr study in Los Angeles of the effectiveness of expanded wire-mesh rein-

forcement, aluminum foil, wax paper, and stonedust in breaking the bond over existing PCC shrinkage cracks. Of particular interest was the use of an 18-in. (450-mm) swath of stonedust to reduce bond at the crack. This treatment was successful in retarding reflection cracking. Kanarowski (10) also summarized the performance of bond breakers, including stonedust, used by nine agencies. Two agencies reported the process as very good to excellent; the others reported the process to be ineffective.

Another early attempt to reduce reflection cracking was the use of wire reinforcement in the asphalt resurfacing layer. The ineffectiveness of this treatment was reviewed in 1968 by Kanarowski (10) who summarized the experiences of 20 agencies in using wire reinforcement in AC overlays placed on PCC. The author found that performance ranged from poor to excellent, with Illinois reporting good performance after 11.5 yr of service. He concluded that the method of placing the welded wire fabric was an important factor in the performance of the material. Recent literature does not report the use of wire reinforcing in AC overlays. It apparently is no longer (or rarely) used because of unsatisfactory experience or excessive cost.

A method consisting of breaking old concrete pavement into smaller segments using heavy pneumatic rollers of 50+ tons (45+ mg) was employed to reduce the effect of expansion and contraction of the concrete slab. Kanarowski (10), in summarizing the experiences with this method, reported that all five states reporting apparently had success in retarding reflection cracking using heavy rollers to break and seat the PCC pavement. Reported results ranged from good to excellent for resurfaced pavements 5 to 10 yr old.

An attempt in Illinois to apply a systematic approach to the design of AC overlays and to include a factor for reflection cracking was reported by Elliott (11) in 1971. The study results indicated that the AASHTO present serviceability index (PSI) equation for flexible pavements was applicable for measuring performance of resurfaced pavements if the cracking term was adjusted. Therefore modifications were made to include a cracking term similar to that used in the rigid pavement PSI equation. The formula developed by Illinois is as follows:

$$\text{PSI} = 10.91 - 3.90 \log \overline{RI} - 0.01 (C + P)^{1/2} - 1.38 \overline{RD}^2 - 0.09 (C')^{1/2}$$

where

$$\begin{aligned} \overline{RI} &= \text{roughness index measured by Illinois roadmeter,} \\ C &= \text{measure of alligator cracking,} \\ P &= \text{measure of patching,} \\ C' &= \text{measure of reflective cracking, and} \\ \overline{RD} &= \text{measure of rut depth.} \end{aligned}$$

Nomographs have been constructed to determine the structural number (SN_R) of the road. These nomographs use terminal PSI values of 2.0 and 2.5, design traffic loading [18 kip (80 kN) equivalent axle loadings over the design period], and CBR of the underlying soil. The required thickness of resurfacing can then be determined using the thickness of the existing pavement components. The thickness (D_F) of the first resurfacing is determined by the equation:

$$D_F = \frac{SN_R - 0.26D_C}{0.40}$$

where

D_C = thickness of PCC pavement, and
 SN_R = structural member.

For the second resurfacing the thickness (D_s) is determined by the equation:

$$D_s = \frac{SN_R - (0.25 D_F + 0.17 D_C)}{0.40}$$

The limitations placed on the design system are a minimum thickness of 3 in. (75 mm) for primary and Interstate roads, and 2.5 and 1.5 in. (64 and 38 mm) for roads of lesser traffic or importance. The reason for the minimum is that a degree of smoothness is required and Illinois contends that two-course AC construction is required to obtain this riding quality.

In 1956 Roggeveen and Tons (12) reported on experiments with three rubber additives:

1. *Emulsified rubber asphalt*. Five percent (of the weight of final asphalt content) of rubber latex was added and mixed with heated aggregate.

2. *CRS synthetic rubber*. A powder with 100 percent passing No. 20 (850 μ m) sieve was cooked into the asphalt at 225° F (107° C) in the amount of 7.5 percent by weight.

3. *Natural rubber crumbs*. Crumbs were added directly into the pugmill in the amount of approximately 7.5 percent by weight of asphalt in the top course and 5.75 percent in the binder course.

Roggeveen and Tons concluded that 80 percent of the total transverse cracks reflected through in 4 yr and 90 percent after 6 yr whether or not rubber additives were added to the asphalt.

A similar study conducted by the Road Research Laboratory in England (13) also showed that small percentages of rubber in asphalt concrete do not prevent reflection cracking.

Experience in California reported by Skog and Munday in 1966 (14) showed that a rubber additive did not reduce reflective cracking. In this case, 4 percent rubber solids (styrene-butadiene latex) was added to the mix. Cracks began to appear after 2 yr, whereas the control section had cracks within 10 months. Ultimately, however, the rubberized section cracked to a greater degree than the control. It was pointed out in the report that the properties of the rubber asphalt are influenced by the properties of the base asphalt and the type of rubber.

NEEP-10 PROJECT

On May 12, 1980, the FHWA issued an Informational Memorandum CMPB-16-70 announcing the National Experimental and Evaluation Program for Reducing Reflection Cracking in Bituminous Overlays. The project became known as the NEEP-10 Project. Briefly, the scope of the project included:

1. Test sections of 1000 ft (300 m) minimum for each type of treatment.

2. Treatments limited to the following except when approved by the Office of Engineering and Operations:

- a. Application of Reclamite or other rejuvenating agents either sprayed on the existing pavement or, if warranted, heating and scarifying the surface before applying the rejuvenating agent and overlay.
- b. Use of Structofors, a proprietary synthetic fabric.
- c. Use of Petromat, a nonwoven polypropylene mat material.
- d. Placement of the so-called "plant-mix seal" or other special plant-mix before placement of the remaining overlay.
- e. Placement of an asphalt emulsion seal before placement of the overlay.

3. Control sections using the state's normal construction.

4. A condition survey and structural analysis for the existing pavement and a structural analysis for the various sections of the new and total pavement structure. A detailed crack condition survey of each test area was required as was a detailed crack condition survey for the existing pavement where the normal nontest overlay was to be placed.

5. Projects that permit designs as nearly uniform as possible.

6. Evaluation period to be concluded within 2 yr (additional time may be warranted).

7. Approval for tests on the Interstate system under certain conditions.

8. Comparison of the performance and cost effectiveness of the individual experimental overlay sections and the state's normal overlay section.

Supplemental memoranda issued on October 13, 1970, and July 15, 1971, include the following items:

1. Use of Petroset AT Geotechnic Emulsion for rubberizing asphalt pavements.

2. Use of a Strain Relieving Layer (SRI) (15).

PURPOSE OF SYNTHESIS

Since the issuance of the 1970 NEEP-10 memorandum, much experimentation in reducing reflection cracking has been carried out, including work conducted by states, counties, and cities. The purpose of this synthesis is to report on the findings of many of the field tests as well as on some of the theoretical approaches.

FACTORS AFFECTING THE RESULTS OF FIELD EXPERIMENTS

Variability of Roadbed Performance Within Experimentation Limits

One of the most important findings of the NEEP-10 experiments is the variability that can exist within a given length of roadway. The North Carolina experiment (16; appendix) is an example of the existence of this variability. In this experiment, it was assumed that the selected pavement was suffi-

ciently uniform and that reliable information could be obtained concerning the effectiveness of the various interlayer materials in retarding reflection cracking. The test clearly showed that some treatments worked well in certain areas, but in others they were no better than the materials they were being tested against. From this road test it was concluded that none of the materials was completely successful and that performance depended on location in the road. This experience demonstrates that decisions on the performance of new materials or processes should not be based solely on small, single test sections; tests should be done under various conditions and with replicate sections, as was the case with the North Carolina experiment.

Climate

Climate is also a significant factor. Climate variations have been observed to greatly affect the performance of fabric interlayers over AC. For example, greater success is reported in the milder climates of California, Florida, and Texas. In addition to geographic variation, there can be large climatic variations at a single location. Maximum and minimum temperatures, rainfall, and snow can vary widely from year to year and can radically affect the performance of a road or a test section.

Roadbed Preparation

Experiments, such as the NEEP tests, should be carried out with some type of uniform road preparation, such as crack filling or, in the case of PCC, stabilizing slabs to reduce vertical movement at joints. To accomplish this requires some measurements. For example, deflection measurements at the joint of concrete slabs can help to determine the load transfer at the joints, and deflection measurements on AC can delineate weak areas in the pavement structure and help to determine if the pavement conditions are uniform.

However, in areas where water infiltrates cracks and joints or percolates from outside the pavement or even through the pavement, there can be large changes in deflection, which may be measured at the time of a deflection survey. A deflection survey conducted in a dry period may or may not be representative of deflections of the road during wet conditions.

Construction Problems

Construction practices can also affect the results of field experiments. When a new product or process is introduced, it takes a certain period of time for contractors and engineers to gain sufficient knowledge of placement to ensure that a uniform pavement can be produced and the performance can be compared to that of pavements placed using other products or processes. For example, various tack coats have been tried in the placement of fabrics: emulsified asphalt was used initially, but later it was found that a penetration-grade asphalt provided the best method of sticking the fabric in place. Other construction problems can arise in the placement of the overlay itself. Because the softer asphalts reflect cracks at a slower rate than the harder asphalts, overheating of an AC mixture can harden the asphalt at a rapid rate and accelerate reflection cracking.

Although compaction was not mentioned as a variable in the NEEP-10 projects, in a project placed in Yosemite Valley (17), which demonstrated a superior performance by a fabric interlayer, it was found that the density of the AC layer over the fabric was 3 lb/ft³ (48 kg/m³) greater than that over the controls. Although the results may actually represent the true performance of the fabric, the conclusions are clouded by the difference in density of the AC overlay. If comparable field tests are to be meaningful, it is essential that adequate testing be done before the overlay and that construction practices be as uniform as possible for all segments of the test.

ASPHALT CONCRETE OVERLAYS

THICKNESS OF OVERLAY

Based on data from various field tests, the thickness of overlay required to retard reflection cracking would appear to be a variable that depends on several factors: (a) type of pavement being overlaid (AC or PCC); (b) type of distress (alligator cracking, block cracking, transverse thermal cracks, longitudinal cracks, or PCC joint cracks); (c) climate; and (d) number and weight of axle loads.

Experiments with AC overlays on PCC in Virginia (4) demonstrate the effects of differential movement at joints or cracks. This differential movement is influenced by the amount of aggregate interlock or the presence of dowels in transferring load from one slab to the next. Also, heavier axle loads cause greater differential deflections than lighter loads. The results of differential movement from heavy loads can be seen on PCC multilane pavements where faulting caused by pumping is noticeably higher in truck lanes than in lanes used predominantly by passenger cars and light trucks. It can be assumed that the thicker the overlay, the greater the load transfer capabilities over the crack and the longer its life before cracks will be reflected to the surface. An example of the effect of trucks is the experimental, ongoing overlay project on PCC on Highway 101 in San Luis Obispo County, California, an area with a mild climate. A 3.6-in. (91-mm) overlay of dense-graded AC and a 0.7-in. (18-mm) AC friction course were placed in 1972 over the subsealed PCC pavement. By 1979 the truck lanes of the four-lane highway showed approximately 25 percent reflection of the transverse cracks. The inner lanes with predominantly passenger-car and light-truck traffic had no transverse cracks.

A NEEP-10 project is now under study in Georgia (18, 19). After two winters the AC overlays on PCC had 12 percent transverse reflection cracks through a 6-in. (150-mm) overlay, 93 percent through a 2-in. (50-mm) overlay, and 86 percent through a 4-in. (100-mm) overlay. After 4 yr of traffic, 24 percent of the PCC cracks had reflected through the 6-in. AC overlay, 95 percent through the 4-in. overlay, and 100 percent through the 2-in. overlay. In the same 4-yr period, only 7 percent of the length of cracks reflected through the 6-in. control, 62 percent through the 4-in. AC, and 98 percent through the 2-in. AC. These results demonstrate that the thicker overlay is delaying the reflection of cracks. A brief description of this ongoing Georgia project is given in the appendix. This experiment should provide valuable data on the life expectancy of various thicknesses of overlays, which, in turn, will allow more reliable cost analyses of various rehabilitation strategies.

Both Florida (20) and California (21) have included extra-thickness sections of AC overlays on AC pavement in NEEP-10 projects. The Florida experiment demonstrated that an additional 1 in. (25 mm) of pavement provides some benefit. However, because the condition of the pavement before the overlay was 934 ft² (87 m²) of cracking for the 2-in.

(50-mm) control section compared to 2150 ft² (200 m²) of cracking for the 3-in. (75-mm) overlay section, the effect of thickness in this case is not the same as it would be in a comparison of pavements with comparable distress. The thicker section showed 15 percent less cracking than the original pavement after 7 yr, whereas the 2-in. control section showed 33 percent more cracking than the original pavement.

An experimental project (21) on Interstate 15 near Riverside, California, included a 1-in. (25-mm) overlay and a 4.2-in. (107-mm) overlay, both constructed on an AC pavement in September 1972. In this area with a mild winter climate, the primary failure was alligator cracking; approximately 2 yr after construction, the 1-in. overlay section showed 98 percent reflection of the alligator cracks. The 4.2-in. overlay section showed no reflection cracks after 6 yr. Average daily traffic was 13,500 with 10 percent truck traffic.

Another NEEP-10 project (21), located on Interstate 80 near Colfax, California, consisted of a structural section of 3.6-in. (91-mm) thick AC over an 8-in. (200-mm) cement-treated base over an 8-in. (300-mm) granular subbase. In 1972 longitudinal and transverse cracks were visible on the existing AC surface throughout most of the project and some structural cracks existed in the outer wheel tracks. The transverse cracks were spaced at about 10- to 20-ft (3- to 6-m) intervals. In July 1974 the project was covered with experimental sections of 2.4-in. (61-mm) and 3.6-in. (91-mm) AC. By 1980, 20 transverse cracks per 1000 ft (66 cracks/1000 m) had appeared through the 2.4-in. section, but the 3.6-in. section was still free of cracks. The cracking in the 2.4-in. overlay was not serious enough to require an additional overlay. The project is located in a mountainous area at an elevation of about 2,500 ft (760 m) and is subject to occasional snowfall. Average daily traffic in 1979 was 20,000 with 13 percent truck traffic.

In another project (21), located on Highway 395 near Doyle, California, the AC pavement had severe block cracking in addition to transverse and longitudinal cracks. There was some spalling and the pavement was rough riding. In 1972 the pavement was covered with a 1-in. (25-mm) AC overlay, and several test sections were installed, including one section with an additional 1.4 in. (36-mm) thickness for a total of 2.4 in. (61 mm) AC. Six years after the start of the project, the section with the thicker AC had only 2 percent reflection cracks, whereas one of the two nearest 1-in. controls had severe distress after 4 yr and the other showed 30 percent reflection cracking at the end of the 6-yr experiment. The area has an annual temperature varying from 20° to 100° F (-7° to 38° C) with an average rainfall of 15 in. (380 mm) per year. Average daily traffic in 1977 was 3500 with 16 percent truck traffic.

Based on the few experiments reviewed here, it appears that an AC thickness of 2 in. (50 mm) minimum is necessary to substantially delay reflection of alligator cracking. A thick-

ness of 3 in. (75 mm) minimum is desirable over block cracking. If cement-treated base is involved, the small amount of evidence available indicates the need for 3.5-in. (90-mm) thick overlay to delay reflection cracking for at least 6 yr. The amount of traffic, climate, AC pavement deflection, differential deflection at PCC joints, and quality of the overlay all affect the actual life of a specific project.

VISCOSITY OF ASPHALT

A significant factor in retarding reflection cracking is the viscosity of the asphalt binder at the time it is placed on the road. The temperature susceptibility of this asphalt, the climate surrounding it, the amount used, and its ability to resist hardening all affect the rate of crack progression through an AC mat.

In conjunction with the federal NEEP-10 project, in 1972 the Arizona DOT placed a series of 18 test sections on a severely cracked AC pavement on Interstate 40 near Winslow. The types of installation and their performance are described in the appendix [see Way (22, 23) for a more complete description]. The tests were conducted in an area at an elevation of 5,000 ft (1500 m) and with a temperature range of 0° to 100° F (−18 to 38° C), and an annual rainfall of less than 8 in. (200 mm). Average daily traffic was 10,000. Among the conclusions reported are the following (23):

It was found that basic asphalt properties influenced the reduction of reflection cracking more than any other property. It was found that the 4.0 megapoise at 77° F viscosity (equivalent penetration about 45, absolute unaged viscosity of 3000 poises at 140° F) was critical to crack initiation. That is, the longer an asphalt can maintain a viscosity below 4.0 megapoise, the less likely reflective cracks will occur. Actual physical crack formation and intensity is triggered by cold temperatures. As such, once the asphalt reaches the 4.0 megapoise level, it becomes highly susceptible to cracking. This being the case, it is an important consideration that all system designs use the lowest viscosity asphalt commensurate with strength requirements, and to use it in such a way as to retard aging as much as possible.

Additional evidence concerning the effect of asphalt viscosity on retarding crack formation can be found in studies conducted in Canada (24–26), Oklahoma (27), and Pennsylvania (28). These studies reported a reduction in transverse thermal cracking using asphalts of lower viscosity in cold climates. Work done in Saskatchewan, Canada (29) indicates the possibility of air blowing asphalts to improve viscosity-temperature characteristics, which would allow the use of harder grades of asphalt in cold climates while still adhering to the viscosity requirements of cold weather.

Hignell et al. (30) reported in 1972 on work with asbestos and concluded that the low-temperature properties of all types of mixtures are primarily a function of the type of asphalt used; and that at medium to high temperatures, asbestos-fiber modification can significantly improve mixture stiffness properties.

Although these later studies deal mainly with cold-weather cracking of AC pavements, the horizontal stresses due to temperature are the same as those that develop in overlays on existing pavements. Along with the results obtained in Arizona (22), the results of these studies reinforce considera-

tion of asphalt viscosity in an AC overlay as a major factor in the retardation of reflection cracking.

EFFECT OF ADDITIVES

In an attempt to improve the performance of AC, additives have been incorporated to change the characteristics of the asphalt or the mixture of asphalt and aggregate. One of these additives is sulfur. Laboratory tests (31) of sulfur-asphalt mixtures have shown that the viscosity-temperature relationships of the asphalt are changed so that a soft (300-400 penetration) asphalt containing sulfur will have about the same mixture stiffness at below freezing and higher stiffness at 100° F (38° C) as compared to the same asphalt without sulfur. As shown in the Arizona experiments (23, 32), viscosity of the binder is an important factor in overlay performance. However, softer asphalts tend to be less stable at high summer temperatures and have a greater rutting potential than the harder grades. It is possible that the use of sulfur provides a mixture of sufficient stiffness for summer temperatures as well as reduced cold-weather stiffness to resist reflection cracking in the winter.

Asbestos is another additive that has been used in various experimental sections. Asbestos fibers allow the use of additional asphalt in the AC overlay mixture, which should result in lower void content and retarded hardening of the asphalt. This, in turn, should result in delayed reflection cracking. In tests conducted in Arizona (22, 23), 3.2 percent asbestos and an additional 2 percent asphalt was used in one test section. At the conclusion of the project in 1978, this section was rated as the second best performer insofar as reflection cracking was concerned, and also had the smallest rut depth of any of the 18 test sections. It should be noted that because of environmental considerations, asbestos is no longer used in many areas.

In a study conducted in Canada in 1972 (30), the following conclusions were reported:

At low temperatures, the properties of all types of mixtures are primarily a function of the asphalt type used; but, at medium to high service temperature, asbestos fiber modification can significantly improve mixture properties, in comparison to "standard conditions" and to mineral filler modification.

A major implication of this finding is that where a softer asphalt is to be used for low-temperature cracking conditions, asbestos fiber modification may be useful. Such modification may not appreciably alter low-temperature stiffness but it will increase medium to high service temperature stiffness and thereby possibly avoid violation of fatigue and permanent deformation requirements.

A third means of improving asphalt properties has been proposed by the Chem-Crete Corporation of Menlo Park, California (33). This process consists of the addition of a small amount of metal, which triggers a polymerization of the asphalt and changes the chemistry of some of the carbon groups found in asphalt. The process is currently being field tested, but no conclusive data has been reported.

Laboratory tests (34) have shown that the temperature susceptibility of the asphalt can also be improved when carbon black is used as a filler in asphalt concrete. However, field trials are necessary to determine if the laboratory evidence can be transformed into field performance.

TREATMENT OF EXISTING PAVEMENTS

SEAL COATS AS A SURFACE APPLICATION ON AC PAVEMENT

Asphalt chip seal coats have been widely used as a maintenance treatment for AC pavement showing some distress in the form of cracking. This treatment has been successful in retarding the formation of additional cracking when the asphalt chip seal coats are applied at an early state of pavement deterioration. However, there is a high risk of chip loss involved in placing chip seals on heavily traveled truck routes, and little evidence in the literature that asphalt chip seal coats prevent or retard reflection cracking.

Slurry seal coats perform in a manner similar to asphalt chip seals in that their primary function is to retard surface abrasion and prevent surface water from entering the pavement. Cracks beneath a slurry seal will soon come to the surface but generally will be narrower. However, the effects of traffic and climate will eventually open the cracks to their original width.

Open-graded seal coats (AC friction courses) placed on the surface of a pavement appear to retard cracks from reflecting; or it may be that the rough texture tends to hide or minimize the crack for a period of time. As the asphalt hardens, cracks become visible and spalling of the open-graded mix occurs at the crack.

A primary surface seal coat application for retarding reflection cracking is the asphalt-rubber surface treatment known as the SAM (stress absorbing membrane). Developed in Arizona by McDonald (35, 36), and first reported in 1966, this treatment has been the subject of much research and many field trials.

Two types of asphalt rubber are being marketed for use in the SAM process. OVER-FLEX, the product of the Sahuaro Petroleum and Asphalt Company of Phoenix, Arizona, consists of vulcanized rubber (approximately No. 10 to No. 30 sieve—2.00 mm to 600 μm) in combination with asphalt (37). A solvent extender oil is added to aid the blending process and to improve spraying characteristics. The blend is made in the field, and the rubber and blending oil are added to asphalt at approximately 400° F (204° C) and sprayed on the roadbed using distributor trucks modified for this specific application.

The asphalt-rubber blend consists of 75 to 80 percent paving asphalt blended with 20 to 25 percent ground vulcanized rubber and 1 to 5 percent extender oil. The blend is generally spread on the pavement at a rate of 0.45 to 0.70 gal/yd² (2.0–3.2 L/m²) depending on aggregate size, roadway surface, etc.

For cover material, clean crushed rock or gravel conforming to either No. 7 or No. 8 gradation limits of AASHTO M 78-64 is generally preheated, and often precoated, and is applied in sufficient quantities to form an aggregate structure

to transmit loads to the underlying pavement (37). The thickness of the membrane system will range from 0.35 to 0.75 in. (9–19 mm).

ARM-R-SHIELD, the asphalt-rubber material marketed by the Arizona Refining Company of Phoenix, Arizona, is a blend of 40 percent powdered devulcanized rubber and 60 percent powdered vulcanized rubber high in natural rubber (30 percent minimum) (38). This material may be applied at the same general rate (0.45 to 0.70 gal/yd²) as described above. Aggregate can be spread at a rate between 30 and 50 lb/yd² (16 and 27 kg/m²) depending upon the applied film thickness or the amount determined by the method outlined by Vallerga and Bogley (39). It is recommended that aggregate be preheated not to exceed 300° F (149° C) and precoated with 0.25 to 0.75 percent asphalt (40).

A substantial amount of field and laboratory research has been conducted concerning the use, performance, and construction requirements of asphalt-rubber material (22, 23, 36, 38, and 41–47). The Arizona Minnetonka-East NEEP-10 project (22, 23) contained one test section with an asphalt-rubber precoated chip seal (SAM). In 1975 this section was ranked near the bottom in reflection cracking performance, but was ranked among the top five in 1978 after an additional seal coat (23).

The Arizona reports (22, 23) claim excellent success in the retardation of the reflection of fatigue cracking of AC pavements. Thermal cracks have reflected through the asphalt-rubber seal coat but are narrow and tend to heal during warm weather. The Arizona experience covers a variety of climates, ranging from desert to mountainous and from low rainfall to snow and icy conditions. An asphalt-rubber seal coat was also applied successfully at the Phoenix Sky Harbor Airport in 1971 (44).

Gonsalves (46) reported that the SAM process, when properly constructed, results in satisfactory skid resistance. Some roughness problems were reported, and some projects were covered with an asphalt finish course after approximately 4 yr., which altered the construction from a SAM to a SAMI (stress absorbing membrane interlayer) with improved ride qualities.

The SAM process appears to have potential for extending the life of an asphalt pavement. Projects are being placed in many states, cities, and counties, and reliable information on life expectancy of the SAM layers should be available for different climatic conditions within a few years. Costs of placing the asphalt-rubber SAM varies widely throughout the United States depending on the distance to the nearest sources of asphalt-rubber material. In 1979 the average cost for eight projects was \$1.121/yd² (\$1.34/m²) with a high of \$1.452 (\$1.74) and a low of \$0.830 (\$0.99) (23).

In 1974 and 1975 the Naval Civil Engineering Laboratory at Port Hueneme, California, placed a series of the asphalt-

rubber seal coat (SAM) test patches on AC runways and taxiways at the National Parachute Test Range at El Centro, California; the Naval Air Station at Miramar, California; and the Naval Air Station at Fallon, Nevada (48). The conclusions reached from these limited tests generally correlate well with those from the Arizona tests. It was found that after 2 yr, the asphalt-rubber seal was still functioning over fatigue cracking where the pavement had not yet begun to fail under load. This study found that shrinkage cracks reflect before fatigue cracks, and that wide shrinkage cracks (greater than 0.5 in.—13 mm) reflect almost completely within 1 yr after sealing. It was also reported that the SAM-type seal coat provided excellent skid resistance.

States with chip seal, asphalt-rubber projects include California, Colorado, Connecticut, Georgia, Mississippi, Rhode Island, Texas, Vermont, and Washington. The process has been used for maintenance in Flagstaff, Phoenix, and Prescott, Arizona; Hays, Kansas; Hingham, Montrose, and Springfield, Massachusetts; and other cities.

REJUVENATING AGENTS

Two direct-application products have been used for rejuvenating existing AC: Reclamite, from the Golden Bear Oil Company; and Petroset AT, from Phillips Petroleum (Petroset AT is no longer marketed). Reclamite is a petroleum resin-oil base emulsified with water. It is effective in penetrating pavement and tends to soften the surface by adding oily fractions to the asphalt, with a resultant lowering of viscosity. With the low viscosity, cracks tend to surface heal under traffic and temperature. In practice, the sealing effect tightens the surface, makes it more water-resistant, and retards or prevents surface raveling; it does not, however, eliminate cracks.

Petroset AT is also a penetrating emulsion to which rubber has been added; its purpose is to penetrate the mat through interconnecting voids and rubberize the AC. The amount of penetration depends on the density of the AC layer. Its effect on the road surface is similar to that of Reclamite.

A problem can occur with the use of either material on the final surface if the AC mix already contains sufficient asphalt and has proper compaction. Under these conditions, adding Reclamite or Petroset AT tends to over-asphalt the surface and can cause flushing, with a resulting low skid resistance. This is not true of old, dry pavements, where these additives have been used successfully to liven up the surface of the existing AC.

Several experiments have been conducted involving the application of Reclamite and Petroset AT under an AC overlay and on a new overlay to keep it more flexible. In Florida (20) no beneficial effect was found from either of the agents. Colorado (49) used both products on sections in its experimental I-70 NEEP-10 project; however, because of surface flushing, it was necessary to cover both with additional AC, which, coupled with a heavier than normal leveling course, made results difficult to evaluate. The North Dakota experiment (50) showed that applying Petroset to the surface of the overlay was beneficial with respect to reflection cracking; however, there was increased flushing and probably lower skid resistance.

HEATER-SCARIFIER PROCESS

Much rehabilitation work has been performed by means of the heater-scarifier process, which consists of heating and scarifying 0.75 to 1 in. (19 to 25 mm) of the existing pavement, adding a rejuvenating agent, and recompacting the material. In most cases, the remixed layer is covered by an AC overlay. Arizona (32, 51), Colorado, and Nevada have all done a significant amount of work in this area. The purpose of using the heater-scarifier process in the upper portion of the pavement is to eliminate the wide cracks caused by spalling and to provide a narrower crack beneath the overlay. Many of the cracks formed in AC are Y-shaped, with the crack at the surface of the pavement being spalled to a greater width than the crack in the middle and lower portion of the AC pavement. However, some cracks are the same width through the entire pavement.

An advantage of the heater-scarifier process is that when covered with an additional layer, the remixed layer serves as an increased thickness of overlay, which will slow the reflection cracking process of AC pavements.

In the Arizona Minnetonka-East NEEP-10 project, the heater scarification plus Reclamite test panel was ranked as the third best performer (32; appendix). From 1975 to 1979, 360 miles (580 km) of highways in Arizona were overlaid using the heater-scarifier process.

No data are available on the life expectancy of the heater-scarifier process covered with various thicknesses of AC.

CRACK FILLING—AC AND PCC

There is little reported experimentation on the effect of crack filling on reflection cracking. For almost every overlay process, whether it be the laying of an AC layer or the use of asphalt-rubber layers, fabric, or open-graded mixes, it is recommended that cracks greater than $\frac{1}{4}$ or $\frac{3}{8}$ in. (6 or 9 mm) wide be filled before overlaying. Experimental evidence of a beneficial effect was reported by Monismith and Coetzee (52) using two-dimensional finite-element analysis with and without crack filler.

Field tests provide conflicting information on the performance of filled cracks. Wyoming constructed an experimental AC overlay project in 1971 (53). Part of the experiment was to determine the effectiveness of a crack sealant consisting of 90 percent CRS-2 emulsion and 10 percent latex rubber. It was concluded that the crack sealer placed directly under an AC overlay did not significantly reduce reflection cracking. When the crack sealer was placed under a cushion course, the least amount of cracks occurred in the overlay.

In Texas (54) a sulfur compound was used as a crack filler on the auxiliary PCC runway at Kelly AFB. It was claimed that the sulfur compound acted as a load transfer at the cracking and minimized reflection cracking.

In January 1977 the Nova Scotia Department of Highways (55) reported on the results of field experiments in pressure filling cracks wider than $\frac{1}{8}$ in. (3 mm) with Colas Rubberized Crack Filler, a Flintkote product. The main purpose of the procedure, which was instituted in 1974, was to reduce reflection cracking on pavements covered with a chip seal coat. A noticeable reduction in reflection cracking was reported.

The purpose of filling cracks under an overlay is to restrict surface water from entering the supporting base and subgrade. A subgrade and base with reduced moisture provide greater load support, less surface deflection under load, and consequently less potential for reflection cracking.

STABILIZING PCC SLABS BY SUBSEALING

The need for stabilizing PCC slabs by subsealing before overlaying has been discussed previously (4). This process is necessary to minimize the differential slab movement at a crack or joint, because even slight differential movement can cause reflection cracks in an ACC overlay (4). Although the process of subsealing provides a more stable layer for an overlay, alternative procedures are sometimes used (i.e., slab breaking or increasing the thickness of the overlay to dampen differential vertical movement) because subsealing is slow, laborious, and costly.

In 1970, on a slab-jacking project in Louisiana, field trials of various slurry materials as well as laboratory tests were conducted (56). Trials were made using A-4 soil mixed with 4 bags / yd³ (376 lb / yd³ or 223 kg / m³) of portland cement and water. The addition of a wetting agent to the water appeared to aid travel of the slurry without loss of strength. The addition of emulsified asphalt in quantities up to 15 percent of the mixing water did not significantly increase the flow of slurry and resulted in some loss of strength.

In 1981 Del Val (57) recommended the use of one part portland cement and three parts pozzolanic material (fly ash) as a subsealing slurry. It was claimed that the fly ash particles and their predominantly spherical shape enable the slurry to be more easily pumped to fill voids than mixtures of portland cement and other mineral materials. Field trials are currently under way using this material. If the material proves success-

ful in filling voids under slab joints and cracks, it could aid in minimizing the amount and severity of reflection cracks in both AC and PCC overlays.

STABILIZING PCC SLABS BY BREAKING

There have been several experiments in which old concrete pavements were broken into smaller segments before overlaying. The procedure of using a 50-ton (45-Mg) pneumatic roller to break the pavement and put it in contact with the underlying base was reported by Kipp and Preus in Minnesota in 1950 (58), by Velz (59) in 1961, and by Korfhage (60) in 1970. A hydraulic or pneumatic hammer can also be used. Kanarowski (10) reported that of five states using heavy rollers to break and seat PCC pavement, all had apparent success in retarding reflection cracks with this method.

Lyon (61) reported in 1970 on a 10-yr study in Louisiana involving the breaking and seating of slabs with a pneumatic roller. He compared the results of the study with pavement broken by a pneumatic hammer and a hammer and roller. He concluded that the hammer and roller combination was the most effective (Figure 2). It should be noted that most of the early work using the rollers was on older PCC pavements and usually on wet or weak subgrades. According to Lyon, it is to be expected that the roller-breaking treatment would be less effective over strong subgrades. He recommended that the process be used only on subgrades with moisture content at or above optimum; this was confirmed in California when a 50-ton (45-Mg) roller failed to crack an existing 8-in. (200-mm) concrete pavement constructed over a 4-in. (100-mm) cement-treated base and a stable subgrade. Lyon also stated that one of the reasons for the reduction in reflection cracking was the reduction in Benkelman beam deflections (Figure 2).

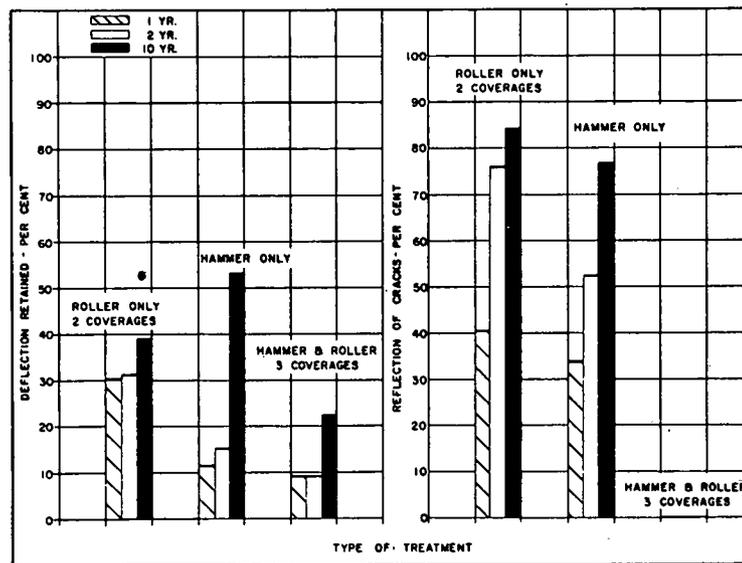


FIGURE 2 Changes in deflections and reflection cracking for 1, 2, and 10 yr of exposure to traffic compared with original conditions for various treatments (Louisiana) (61).

In 1980 Noonan and McCullagh (62) reported that the procedure of breaking rigid pavement plus sawing joints in the AC overlay on old rigid pavement joints was generally successful in reducing reflection cracking.

PAVEMENT RECYCLING

The pavement-recycling process involves the milling of a layer or layers of a pavement, adding asphalt, rejuvenating agent, or aggregate as required, and then remixing, relaying, and recompacting. When the entire pavement is recycled, the possibility of reflection cracking from the recycled materials is eliminated (63). If an additional surface layer is placed on the recycled pavement, the resultant heavier structural section should outperform the original pavement.

One advantage of this method is that the vertical grade line is raised a minimum amount. In the case of multilane highways where the inner lanes and shoulder areas are in satisfactory condition and only the outer lanes require rehabilitation,

considerable savings in overlay materials can be realized. A minimum thickness of overlay can be placed over the entire pavement. In cities or urban counties where it is desirable to maintain curb lines and drainage, the recycling process is advantageous because it reduces the reflection cracking potential without using a thick overlay.

Projects involving the recycling of AC and PCC pavements are described in *NCHRP Synthesis 54* (63) and will not be reviewed here. It is sufficient to conclude that the recycling process eliminates existing cracks and, therefore, their reflection through a covering layer. Evidence of the benefit was provided in a 5-yr test in Ontario, Canada (64), which compared using a 4-in. (100-mm) overlay on AC pavement to using granular interlayers or pulverizing the old surface as a base with and without the addition of asphalt. The most viable alternative, from the standpoint of minimum reflection cracking and economic analysis, was found to be pulverization of the existing surface for use as a base. The 4-yr performance of the enriched pulverized AC was equally as effective for reducing reflection cracking but less economical.

CHAPTER FOUR

STRESS-RELIEVING INTERLAYERS

During the 1970's, stress-relieving interlayers were widely used in experiments designed to reduce or prevent reflection cracking. The experiments involved overlays on both AC and PCC. For AC, attempts were made to prevent or slow the reflection of alligator fatigue cracking or transverse and longitudinal cracks. For PCC, the aim was to prevent or slow the reflection of transverse joint cracks as well as structural cracks developed under traffic.

The principal objective of the interlayer experimentation was to minimize the thickness of overlay needed to rehabilitate a road surface by retarding or eliminating reflection cracking for the design life of the project. This is economically important for all roads, but has particular significance for multilane highways where although inner lanes may have adequate structural and ride ratings, outer lanes with concentrated heavy wheel load traffic may require rehabilitation. Overlays must cover all lanes and, in many cases, additional materials are required for the shoulders. Therefore the thinnest overlay that will provide the required design life for the truck lanes will generally be the most economical design.

Although laboratory experimentation and theoretical analysis have determined that interlayers can reduce the high stresses developed at a crack (see Chapter 6), as yet a proven design method to utilize stress-relieving interlayers to the fullest advantage has not been developed.

In various projects, seven interlayer methods have been

tested to determine their effectiveness in retarding reflection cracking:

- Asphalt-rubber layer under an AC overlay.
- Prefabricated fabric membrane strip.
- Fabric layer under AC.
- Low-viscosity asphalt in an AC layer placed under a layer using a normal paving-grade asphalt.
- Open-graded AC base layer.
- Open-graded AC layer 1.5 in. (38 mm) or less in thickness.
- Gravel or crushed rock layer.

ASPHALT-RUBBER INTERLAYERS

The Arizona Department of Transportation has conducted extensive field research on the use of asphalt rubber both as a seal coat (the construction process referred to as SAM) and as an interlayer (the construction process referred to as SAMI) under an AC wearing course. The chemical and physical properties, testing methods, construction techniques, and performance of the asphalt-rubber layer over both AC and PCC have been described in several reports (22, 23, 26, 36, 38, 41-44). Most test applications have been on AC pavements.

The two types of asphalt rubber described in the discus-

sion on seal coats in Chapter 3 have been used to provide interlayers under an AC surface course. Arizona has been a leader in the study and use of SAMI construction for reducing reflection cracking. The purpose of the SAMI process and the importance of proper construction practice are described as follows (47):

The procedure in placing the SAMI is similar to that used in placing the SAM. However, in the design of SAMI system, it is important to keep in mind that the SAMI must provide for strain attenuation in the horizontal direction and must be capable of transferring vertical loads so that excessive deflections do not occur in the overlay. Embedding aggregate into the hot cast-in-place asphalt-rubber membrane also has a primary function of protecting the membrane from damage by construction traffic. In general, the aggregate may be any suitable single size material ranging from chips to pea gravel or coarse sand.

The quantity of asphalt-rubber sprayed is generally within the range of 0.6-0.8 gsy [gal/yd²]. The rate of spread of the aggregate is kept to a minimum (15-25 psy) [16/yd²] with just enough aggregate to give a working surface. This is to ensure that the resulting SAMI will exhibit primarily the desired properties of the asphalt-rubber material with least interference from the aggregate particles. The SAMI so constructed will have a thickness of 0.35 to 0.50 inches (9 to 13 mm).

The NEEP-10 experimental project in Arizona (22, 23; appendix) consisted of 18 sections; 2 sections were constructed in 1972 using a SAMI covered with a 0.5-in. (13-mm) AC finish course. The SAMI construction was rated as one of five treatments that significantly reduced reflection cracking over old AC pavements (22) and also was reported the top-rated treatment (23).

A second type of asphalt rubber made from a mixture of powdered reclaimed rubber and ground scrap high in natural rubber content has been used in SAMI construction projects reported as showing promising performance (38).

In March 1981 Mascunara (65) reported on an Illinois reflection-crack study of AC overlays on both AC and PCC pavements. The study included a test of an asphalt-rubber interlayer. Based on the test results, asphalt rubber was recommended for use over flexible bases and for longitudinal joints, such as center-line or other lane joints, and widening joints over a rigid base.

Gonsalves (46) reported the successful use of SAMI construction over both PCC and AC in 29 Arizona projects. Other states reported to be experimenting with SAMI construction are California, Connecticut, Montana, New Hampshire, New Mexico, Oklahoma, Texas, Utah, Vermont, and Washington (47). Brown (66) reported that the FHWA Demonstration Projects Division had participated in the construction and evaluation of 23 asphalt-rubber interlayer projects in 20 states.

PREFABRICATED FABRIC MEMBRANE STRIPS

The I-85 Gwinnette County reflection-crack study in Georgia included testing the effectiveness of placing 18-in. (450-mm) wide strips of Bituthene, a prefabricated membrane, over the transverse and longitudinal center-line and shoulder joints of PCC pavement. The strips were covered

with 2 in. (50 mm), 4 in. (100 mm), and 6 in. (150 mm) AC resurfacing (18; appendix). (Previously Bituthene had been used as a membrane for bridge decks under an AC overlay.) Traffic was permitted to travel on the strips for 1 day before a leveling course and the required thickness of AC were placed.

The performance and use of the prefabricated membrane in Georgia was described as follows (18):

The use of heavy duty waterproofing strips over concrete pavement joints and cracks prior to an asphalt concrete overlay has prevented cracks from occurring in a 2-in. (51-mm) thick asphalt concrete overlay after 15 months of service. The corresponding control section without the waterproofing strips has 88 percent of the concrete joints reflected through the overlay. . . .

The excellent results obtained to-date with the waterproofing membrane has resulted in the use of this material on other major Interstate overlay projects on I-24, I-85 and I-285 for a total of approximately 760,000 lineal feet (232 000 m) of waterproofing material. The width of strips used on the experimental project was 18 in. (457 mm), but this was reduced to 12 in. (305 mm) for the contract projects. The in-place cost of the waterproofing strips on the three projects average \$0.50 per lineal foot (\$1.64/m). The decision to recommend the waterproofing strips was based upon its early excellent performance and lower cost as compared to the engineering fabrics.

Data on the performance of Bituthene in Georgia after 4 yr indicate that the material is still performing well, particularly under the 4- and 6-in. (100- and 150-mm) overlays (19; appendix). When concluded, the test project in Georgia should provide excellent data on the performance of AC overlays of variable thickness used both alone and over engineering fabrics and prefabricated membranes as well as data on the Arkansas open-graded base design. In addition, the project also includes edge drained sections and a series of PCC overlays.

FABRIC INTERLAYERS

Starting in the late 1960's and continuing through the 1970's, there has been an increasing use of synthetic fabrics under AC overlays (Figure 3). The fabrics are manufactured from polypropylene, glass, nylon, polyester, or combinations of these and other fibers (67). The principal fabrics currently in use in the United States for pavement rehabilitation are polypropylene and polyester. These fabrics are manufactured by several processes, including needle-punched, spunbonded, woven, and various combinations of these processes (67).

Fabric layers are used to retard or prevent reflection cracking and to waterproof the pavement structure to prevent surface water from entering an AC overlay. Field experimentation to verify the effectiveness of fabric layers was given impetus in May 1970 when the FHWA initiated the National Experimental and Evaluation Program Project No. 10 (NEEP-10). Most of the projects constructed under NEEP-10 included test sections utilizing fabrics, with as many as three different synthetic materials being tested in some projects.

The fabrics tested in the NEEP-10 projects are listed below (67):

FABRIC NAME	FABRIC TYPE	MANUFACTURER
Cerex	Spunbonded nylon	Monsanto
Petromat	Nonwoven polypropylene	Phillips Petroleum
Structofors	Open-weave polyester	American Enka
Fiber glass	Matting	PPG Industries
Glass fabric	Woven	Burlington
Mirafi 140	Spunbonded polypropylene/nylon	Celanese

The number of tests conducted for each of the above fabrics as part of the NEEP-10 project varied.

Proper preparation of the surface to be covered is critical to the performance of fabric interlayers. All potholes and large cracks in AC should be filled by acceptable practices. If necessary, a leveling course should be applied. For the fabric to be an effective water retardant, an asphalt tack coat must be used to fill the voids in the fabric. If wide, unfilled cracks are allowed under the fabric, there will not be sufficient asphalt to penetrate the fabric and the fabric may not

TABLE 1
FABRIC INTERLAYERS TESTED IN VARIOUS STATES

State	Pvmt. Type	Fabric Tested	Reference
Arizona	AC	Petromat, fiber-glass matting	<u>23, 32</u>
California	AC PCC	Cerex, Petromat Petromat	<u>21</u> <u>21</u>
Colorado	AC	Cerex, Petromat	<u>49</u>
Florida	AC	Petromat, Structofors	<u>20</u>
Georgia	PCC	Petromat, Mirafi	<u>18</u>
Iowa	PCC	Cerex, Petromat, Structofors	<u>68</u>
Kansas	AC	Petromat	<u>17</u>
Louisiana	PCC	Petromat	<u>69</u>
Missouri	AC	Petromat	<u>17</u>
Nevada	AC	Petromat	<u>17</u>
New Mexico	PCC	Petromat, Mirafi	<u>17</u>
North Carolina	PCC	Fiber glass, Structofors, Mirafi, Petromat	<u>16</u>
North Dakota	AC	Structofors, Petromat	<u>50</u>
Oklahoma	AC	Mirafi, Petromat	<u>17</u>
Pennsylvania	AC	Petromat	<u>17</u>
South Dakota	AC	Petromat	<u>70</u>
Texas	AC	Petromat, Mirafi	<u>71 - 77</u>
Virginia	PCC	Petromat, Cerex	<u>4, 78, 79</u>
Wyoming	AC	Petromat	<u>17</u>

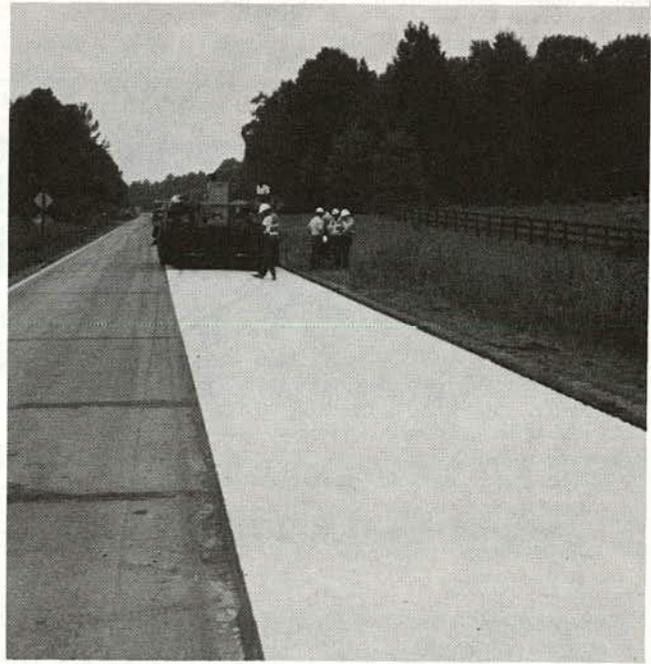


FIGURE 3 Fabric interlayer is tacked to old PCC before overlaying.

prevent water from entering the crack. In the case of PCC, not only should cracks be filled but, to obtain the best results, slabs must also be stabilized so that differential vertical movement at the slabs is minimized (4).

The tests of fabric interlayers conducted by various states as part of the NEEP-10 project are listed in Table 1. Some of the tests, representative of multiple designs and differences in climates and locations, are presented in more detail in the appendix.

Fabric Interlayers Over PCC Pavement

Bituminous overlays placed on PCC pavement are subject to both vertical and horizontal stresses. The horizontal stresses are caused by thermal movement of slabs at cracks or joints. The amount of differential vertical movement depends on the load-transfer ability at the crack. This, in turn, depends on slab temperature, the support beneath the slab, efficiency of dowels, traffic, curling of the slabs, and the moisture present in the underlying support layers. Unfortunately, few differential slab measurements were performed in tests under the NEEP-10 project, and thus it is difficult to discern whether reflection cracks were caused by horizontal or vertical movements. In most cases, the cause of reflection cracking is probably a combination of both horizontal and vertical movements.

The effect of the use of fabric on crack reflection where there is differential vertical movement at cracks was reported in Virginia (4, 79). The results of a project on Route 460 in Virginia after 8 months of service are presented in Table 2. The pavement on Route 460 was PCC with 30-ft (9-m) joint spacing. In 1972 3-ft (0.9-m) wide strips of Petromat were placed over 99 joints and covered with 1.25 in. (32 mm) AC.

TABLE 2
CRACKING AND DIFFERENTIAL DEFLECTION AFTER 8 MONTHS OF SERVICE
(ROUTE 460, VIRGINIA)

Differential Deflection d (in.)	Joints Cracked		Joints Uncracked		Joints Cracked (%)	
	Fabric	Control	Fabric	Control	Fabric	Control
0	0	4	20	5	0	44
0.002	7	20	17	17	29	54
0.004	23	35	3	12	88	74
0.005	14	11	2	0	88	100
0.008	12	20	0	0	100	100

1 in. = 25.4 mm

In a second project on I-95 near the Pentagon in Virginia, both Petromat and Cerex fabric strips were placed over joints of PCC. The results were similar to those of the Route 460 project. The following conclusions were based on the results of the two projects in Virginia (4):

1. Neither sand as a bond breaker nor high strength fabrics as stress relieving layers are effective in reducing reflection cracking where vertical joint movement (differential deflection) is a significant factor.

2. When differential deflections are greater than about 0.002 in. (0.05 mm) reflection cracks form early. Such cracking is delayed for lower differential deflection but may occur as the magnitude and frequency of wheel loadings increase.

3. Both an asphalt impregnated polypropylene fabric and an unwoven, spun-bonded nylon fabric, when placed to span joints in portland cement concrete base and covered with an asphaltic concrete overlay, are able to sustain the formation of reflection cracking in the overlaying layer without undergoing damage.

4. An asphalt impregnated polypropylene fabric spanning the joints in portland cement concrete pavements, and placed between the pavement and an asphaltic overlay, may be effective in reducing the infiltration of surface water to pavement sub-layers. There is some evidence that pavement pumping may be reduced by this method.

5. Both an asphalt impregnated polypropylene fabric and an unwoven, spun-bonded nylon fabric can delay the formation of reflection cracking. There is strong evidence, however, that such cracking is fatigue in nature and will eventually develop under the application of repetitive wheel loadings.

Other states reporting experiments with fabric placed on PCC are Iowa, Louisiana, Georgia, and North Carolina. During a 5-yr period, Iowa tested three fabrics under a 3-in. (75-mm) AC overlay on an existing 20-ft (6-m) PCC widened to 24 ft (7.3 m) (68). It was reported that in comparison to the control the use of fabrics reduced reflection cracking, and that reflection cracking over the pavement-widening crack was nearly eliminated. It was also noted there was a disparity between reflection cracking on the rural sections of the road and that on the urban sections. For example, transverse cracking over Petromat in the rural section was 16 percent after 5 yr compared to 50 percent in the control. In the urban section there was about 40 percent reflection cracking compared to 60 percent in the control.

In tests in Louisiana the use of two fabrics on PCC failed to eliminate or reduce cracking in comparison to the control sections (69).

In Georgia a test involving the use of Mirafi and Petromat over PCC (18, 19; appendix) showed the benefit of thicker overlays over fabric in comparison to the control sections. Overlays in thicknesses of 2, 4, and 6 in. (50, 100, and 150 mm) were applied to both control and fabric test sections. The cracking data are given in Table 3. There appears to be a definite retardation of total cracking with the use of fabrics.

The test in North Carolina (16) utilized a uniform 2-in. (50-mm) overlay thickness at six locations selected statistically (see the appendix for a more detailed description of the

TABLE 3
CRACKING IN OVERLAY (SOUTHBOUND LANE, I-85, GWINNETT COUNTY, GEORGIA) (19)

Treatment Before Overlay ^a	Asphalt Concrete Overlay					
	5.1 cm		10.2 cm		15.2 cm	
	Reflection Cracking (%)	Severity of Cracking ^b (%)	Reflection Cracking (%)	Severity of Cracking (%)	Reflection Cracking (%)	Severity of Cracking (%)
Bituthene	87	44	57	17	0	0
Mirafi	100	80	60	24	4	1
Petromat	98	71	57	22	18	4
Edge drain	100	93	98	78	66	29
Control	100	98	95	62	24	7

Note: 1 cm = 0.39 in.

^aArkansas Base (16 percent and 6 percent) was also used.

^bLength of transverse cracking reflected through overlay as percentage of total length of transverse joints.

project). The test showed little benefit from four types of fabrics, but did demonstrate the importance of location. It was concluded: "Joint cracking seems to vary much more with location along the highway than with different overlay treatments." The results of this experiment, as well as those of other experiments, indicate the need for multiple tests or identical conditions when comparing the performance of new materials with existing or known performances. A single test can be misleading. The North Carolina test also demonstrated the need for prior physical tests to determine if the test sections are indeed comparable.

The test in North Dakota (50) consisted of seven test sections covering 13.79 miles (22.2 km) on I-94 (see the appendix for a more detailed description of the project). Five major test sections varied from 2.4 to 2.8 miles (3.9–4.5 km) in length. A 2-in (50-mm) overlay was placed on the entire pavement width of the existing road consisting of a 5-in. (125-mm) overlay reinforced with welded wire fabric over a thickened-edge PCC pavement. Both Petromat and Structofors were tested, the former in a 2.76-mile (4.4-km) section and the latter in a 0.18-mile (0.3-km) section. The reflection cracks in this experiment were primarily transverse cracks reflected through from the PCC pavement. The graph in the appendix shows that the control section performed as well as the other test sections and better than most. Variations in performance were averaged out in the long test sections.

The use of fabric as an interlayer over PCC pavement would not appear to be advantageous under thin [2-in. (60-mm) or less] overlays. The Georgia experiment should provide additional data on the effect of fabric interlayers under thicker bituminous overlays.

Fabric Interlayers Over AC Pavement

The use of fabric interlayers over AC pavement has been tested in many states, counties, and cities. The results of many of the tests have not been reported, and the results of the reported tests are varied. The most favorable results have been reported from California (21), Colorado (49), Florida (20), and Texas (77). Tests with unfavorable results were reported from Arizona (23), California (80), Colorado (81, 82), Maine (83), Vermont (84), and Wyoming (17).

The test in Colorado (49; appendix) was conducted on I-70 in the west central part of the state. Ten pairs of 1000-ft (300-m) test sections were installed; Petromat was used in two pairs of the test sections. The test was made on pavements with both transverse and longitudinal cracking as well as alligator cracks. After 5 yr of exposure to traffic, the Petromat sections showed the best results with less than 5 percent reflection cracks compared to 70 percent in the controls.

Both Petromat and Structofors were tested in Florida (20; appendix). The Petromat section performed best, with 31 percent less cracking than in the original pavement. The control and Structofors sections showed increases in cracking of 33 percent and 76 percent, respectively. However, the control and Petromat sections were among the least cracked sections at the start of the test, which may have influenced the performance of these sections. The increased cracking in

other test sections raises the question of the structural adequacy of the roadbed even with the addition of the overlay. The second best performing section was the extra-thickness section [3 in. (75 mm) as compared to 2 in. (50 mm) used on other sections], but even this section developed only 15 percent less cracking than the original pavement. However, the extra thickness was placed on the most cracked section of the original pavement.

The Arizona Minnetonka-East test included one section with fiber-glass matting and one section with Petromat. At the end of the 1975 test period, they were ranked 3rd and 6th in performance among the 18 test sections (see the appendix).

In California Petromat has been used in several test projects (21). The most successful tests involved placing Petromat over alligator cracking. On two AC projects, one on I-15 near Riverside (13,500 ADT with 10 percent truck traffic) and one on Route 78 near Vista (40,000 ADT with 10 percent truck traffic), the life of the 1-in. (25-mm) overlays with Petromat was estimated to be 3 to 4 yr greater than without Petromat. On the I-15 project, test panels using overlays of 0.35 ft (4.2 in.—107 mm) as a control and similar overlays on Petromat showed no reflection cracking throughout the 5-yr life of the project.

On a project on Route 395 in northern California (3500 ADT, 16 percent truck traffic) with thermal cracking, a section with a 2 1/2-in. (64-mm) overlay performed better than a 1-in. (25-mm) overlay on Petromat. However, after 6 yr the fabric section outperformed the controls and was still functioning after three of five control sections were resurfaced with a seal coat. An interesting sidelight from this experiment was reported on the section utilizing Cerex (no longer marketed). When a windrow of hot AC was placed on the Cerex, it wrinkled so much that the experiment was abandoned. However, the 0.30 gal/ yd² (1.4 L/m²) tack coat was left on the pavement and the section performed slightly better than the Petromat section: 13 percent reflection cracking compared to 18 percent for the Petromat and 2 percent for the extra-thickness section.

Wyoming reported that Petromat placed on a thermal-cracked test section failed to produce any benefit, with cracking in the control and Petromat sections about equal (17).

Texas (77) has tested Fibertex and Petromat, reporting construction problems with wrinkling of the Fibertex; data on performance have not yet been reported. Petromat, the primary fabric tested, has been used as an underseal and covered with a chip seal coat on bituminous roads. This process appears to be most effective on low-volume roads or as a maintenance operation to prevent potholes on severely alligator-cracked roadway. Petromat has also been tested under AC and under open-graded friction courses (71, 72). On I-40 near the Potter County line, use of fabric underseal caused a reduction in number and size of cracks compared to the control section (71).

On a project on I-20 west of Pecos, Texas (72), the sections listed below were constructed and compared. Based strictly on performance, the control section was judged the best after 2 yr. Costs of the four types of sections were:

1. Petromat underseal, one-course surface treatment, and 0.75-in. (19-mm) open-graded friction course: \$1.51/yd² (\$1.81/m²).

2. One-course surface treatment underseal and 0.75-in. (19-mm) open-graded friction course: \$0.70/ yd² (\$0.84/ m²).
3. Two-in. (50-mm) Type C HMA, fabric underseal, one-course surface treatment, and 1.25 in. (32 mm) Type D HMA: \$3.65/ yd² (\$4.37/ m²).
4. One-course surface treatment, 2 in. (50 mm) Type C HMA, and 1.25 in. (32 mm) Type D HMA: \$2.84 / yd² (\$3.40/ m²).

Use of Fabric Interlayers to Retard Water Penetration

Further evaluation is necessary before the use of fabrics can be included in design concepts. The benefits of asphalt-saturated fabrics in retarding penetration of water have been recognized by some agencies, but the benefits have not been quantified. For overlays on PCC, the elimination or reduction of surface water available under the slab should reduce pumping and faulting. For AC pavement, a reduction of the surface water available to base and subgrade materials should result in lower deflections in the spring and in thinner structural overlay requirements, especially in areas where frozen base and subgrade do not cause problems. It should be noted that placing a water barrier between the overlay and original cracked pavement can cause problems where subsurface water is available from outside the pavement area. The use of a fabric or any other layer to retard penetration of water will not substitute for a good drainage design.

LOW-VISCOSITY AC INTERLAYERS OVER AC PAVEMENT

As early as 1962, Nevada was using stress-relief courses over distressed AC pavements (J. C. Hodge, *internal memorandum*, Nevada Department of Highways, Oct. 1975). MC-3000 or SC-3000 asphalts were used as binders for a leveling course of 1 to 1.5 in. (25 to 38 mm) in thickness. The SC-3000 required a longer period of time for volatiles to leave the mixture before it was covered with the surface course; otherwise, volatiles tended to soften the surface course, particularly when the leveling course was mixed in a dryer-drum plant at low temperatures. AR-1000 asphalt has been used successfully in the leveling course, but it is not always available.

Nevada has used AC made with 85-100 penetration or AR-4000 asphalt as a surface course over the stress-relief course. These harder asphalts in the surface course provide a stiffer mixture with greater resistance to chain or studded-tire wear as well as to rutting under heavy truck traffic.

On several projects in Nevada, performance of overlays with and without the soft interlayer was studied; it was concluded that the interlayer provides an extended overlay life (J. C. Hodge, *internal memorandum*, Nevada Department of Highways, Oct. 1975). Approximately 250 miles (400 km) of roadway have been constructed using the interlayer system. An 8- to 9-yr life expectancy with some minor reflection cracking (mostly transverse) is anticipated. The performance of the interlayer, which utilizes a relatively low-viscosity bitumen, parallels that of the 200-300 penetration AC overlay

section in the Arizona Minnetonka NEEP-10 project, which was judged one of the best in performance. Thus the experience in Nevada confirms the conclusion reported by Arizona that bitumen viscosity is a significant factor in retarding reflection cracking.

In 1971 the Wyoming Highway Department constructed an experimental project [on I-80 between Cheyenne and Laramie at an elevation of 8600 ft (2600 m)] to evaluate the benefits of crack sealing and the use of a soft asphalt interlayer (53). A 2-in. (50-mm) soft asphalt interlayer (cushion) (AC-2.5F) plant-mix was used. Cracks 1/8-in. (3-mm) or more in width were sealed with two applications of CRS-2 emulsion containing 10 percent latex rubber. The conclusions reported in 1975 (53) state that the crack sealer by itself did not significantly reduce the reflection cracking. The combination of the 2-in. (50-mm) interlayer (cushion layer) and crack sealer produced the fewest cracks and was the most effective for reducing reflection cracks compared to both the standard (control) and the 1-in. (25-mm) leveling plant-mix section using AC-5F. The 1-in. (25-mm) leveling section was only fairly effective in reducing reflection cracking. The data indicate that the reflection cracking was from transverse thermal cracks. No reflection cracking from alligator cracking was noted.

OPEN-GRADED AC BASE LAYERS

At the annual meeting of the Highway Research Board in 1932, Gray and Martin (6) reported the successful use of 3 in. (75 mm) of penetration macadam as a resurfacing over PCC in New York. In 1969, after reviewing this type of construction in Tennessee, Arkansas experimented with the use of 2- and 3-in. (50- and 75-mm) top-sized aggregate as a base in two- and three-layer systems.

The first use of the open-graded layer was over an old oxidized and cracked AC pavement. Since 1969 both PCC, plain and continuously reinforced, and AC pavements have been overlaid. With all of the overlays placed on Interstate highways, an underdrain system was installed as part of the preparation of the existing surface.

Arkansas uses three aggregate gradings in bases: "A," 3 in. (75 mm); "B," 2.5 in. (63 mm); and "C," 2 in. (50 mm). The selection of aggregate size is described as follows (85):

The selection of an open-graded mix should be based on the expansion-contraction characteristics of the pcc pavement to be overlaid. Highly expansive pavements would require the larger voids mix such as grading "A." Grading "A" with the larger aggregates and voids offers the most protection against reflection cracking from both horizontal strain and vertical strain mode. Continuity of deflections is important across the joint or crack to ensure the asphalt concrete an adequate fatigue life. The large aggregates, such as the "A" grading, interlock to provide load transfer across these joints. This type grading should be selected when the coarse aggregate of the pcc is highly expansive such as silica gravels or when the slabs are excessively long where contraction movements are expected to be quite large. The differential deflections of the longer slabs are also much greater, that is, the ratio of deflections at the joints to the middle slab point is larger.

The "C" grading should be selected when short slabs are involved or on crcp where the horizontal movements are uniformly distributed. Grading "C" should be quite adequate for all old asphalt concrete, soil cements, and uniformly cracked

crep. Prior to the selection of the open-graded mix, the load transfer capabilities of the cracked areas should be checked by deflection ratios. The selection of grading "C" assumes the requirement for load transfer to be quite low.

Over a 3.5-in. (90-mm) open-graded base, Arkansas places a minimum of 2 in. (50 mm) binder and a minimum of 1 in. (25 mm) surface course, making the overlay thickness a minimum of 6.5 in. (165 mm). The following information on performance was reported (85):

Crack-relief mixes have performed satisfactorily in Tennessee for 25 years and in Arkansas for 10 years. On one project in Arkansas where the open-graded mix was not daylighted, the joints puffed. The puffing of these joints are more pronounced following a rain. As the moisture dissipates, the puffing also dissipates. Although the project has a drainage system, these puffs at the joints indicate the presence of moisture vapor, and the drainage system is only designed for free moisture and is of no value in this situation. To date, the puffing has not marred the rideability of the project.

The State of Arkansas has over 200 two-lane miles of this type overlay on the Interstate and primary system. The experience with this method indicates it is a viable method for overlaying both old pcc and flexible pavements to reduce the inherent failures such as cracking. To reduce this cracking with such a system, it will provide longer lasting overlays with reduced maintenance cost, improved rideability, and reduced environmental effects through the sealing of the surface course. Once the existing pavement has been soundly repaired and properly overlaid, surface recycling as required should be a viable means of maintaining the facility.

In an experimental project in Georgia (18, 19) using the Arkansas open-graded system, the overlay was placed on a plain, jointed, and undoweled PCC pavement with joint spacings of 20 to 30 ft (6–9 m). The experimental 1320-ft (400-m) long section was placed in July 1976; in February 1978 it was reported to have performed without cracking, whereas the 4-in. (100-m) overlay control showed 3.6 percent reflection cracks (18). In 1981 it was reported that 16 percent of the joints reflected through the Arkansas base and 6 percent of the total length of transverse cracking reflected through (19). In the same 4-yr period, 24 percent of the joints reflected through the 6-in. (150-mm) AC overlay and 7 percent of the total length of transverse cracking reflected through (see the appendix).

OPEN-GRADED AC LAYERS

1.5 IN. (38 MM) OR LESS IN THICKNESS

Open-graded AC friction courses (plant-mixed seals) have been used as a surface course to cover up cracks, with the expectation that the cracks would not reflect through the thin layer. However, this procedure has proven not to be entirely satisfactory as cracks do reflect through and many times spall to an even wider crack. Thin, layered open-graded friction courses have also been tested as strain-relieving layers beneath an AC overlay.

The NEEP-10 project in Colorado (49) included two 1000-ft (300-m) sections in which a $\frac{5}{8}$ -in. (16-mm) thick plant-mixed seal coat (similar to the friction surface course except that the asphalt content was reduced from 7 percent to 4 percent) was placed on the old AC surface and covered with a 2-in. (50-mm) mat. The comparative results are given in the appendix. The plant-mixed seal performed well for the first

year but deteriorated rapidly after that time. Because of the variable amounts of leveling course used on the project, Colorado adjusted the ranking of the nine test sections. The plant-mixed seal sections were ranked eighth in a series of nine tests, with a better performance than the standard overlay section.

In North Dakota in September 1971 seven test sections totaling 13.79 miles (22.2 km) in length were placed on Interstate 94 near Casselton (50). The purpose of the project was to compare several methods of reducing crack reflection of an existing 5-in. (125-mm) thick AC overlay that covered a 6.5 to 8-in. (165 to 200-mm) thickened-edge PCC pavement. The strain-relieving interlayers are listed in the appendix. After 5 yr of exposure to traffic, the performance of the plant-mixed seal section was reported to be equal to the control section and the asphalt-treated sand, but better than the other treatments.

One of the test sections of the Trout Creek experimental road in Ontario, Canada (25, 64) consisted of 1.5 in. (38 mm) open-graded AC on a cracked AC pavement covered with 1.25 in. (32 mm) AC binder and 1.25 in. AC surfacing. After 4 yr of exposure to traffic, this section was reported to be one of the poorest performers of eight test sections: there were 149 transverse and 34 longitudinal cracks per km (39 and 21 per mile) compared to 183 transverse and 42 longitudinal cracks per km (114 and 26 per mile) in the control section, which was covered with 2.75 in. (70 mm) binder course and 1.25 in. AC surface course.

The NEEP-10 project in Florida (20; appendix) included a test section of open-graded mix under a 2-in. (50-mm) bituminous concrete overlay placed on an existing bituminous concrete pavement. The performance of the open-graded mix section was ranked as third best among the test sections (see the appendix); however, the benefit was small and further experimentation was recommended. The Florida test also included a mineral seal coat interlayer, which did not show good performance and was ranked fifth among the eight test sections.

The NEEP-10 project in North Carolina (16; appendix), constructed over PCC pavement, included six sections of open-graded seal coat covered with 2 in. (50 mm) AC. It was concluded that the open-graded mixture performed better than the other nonfabric test sections.

GRAVEL OR CRUSHED ROCK INTERLAYERS

Several agencies have used a layer of aggregate base material over PCC to reduce reflection cracking (20). The results have been variable, ranging from poor to very good or excellent. The method requires the placement of several inches of base rock and sufficient thickness of AC to carry the design traffic. The aggregate layer insulates the old PCC and reduces the horizontal strains in the new overlay as well as the stresses developed by vertical movements of the underlying slabs. Although this method has been successful in many instances on rural roadways, the amount of grade elevation can total 12 in. (300 mm) or more, which would probably be intolerable on most urban highways.

Forsyth and Munday (86) reported in 1966 in a study of

cushion-course projects in California that 4-in. (100-mm) cushion courses developed some reflection cracking, whereas courses 6 in. (150 mm) or greater did not. To perform successfully, the base course interlayer must be drained well because free water in the interlayer on grades can create pressures against the overlay leading to early failure. Also, the cushion course does not eliminate thermal cracks in the overlay that may be caused by climatic conditions and mixture characteristics.

The reflection cracking experiment in Ontario, Canada (25, 64) included sections with 3-in. (75-mm) and 6-in. (150-mm) granular layers placed over an AC pavement and

covered with 5 in. (125 mm) bituminous mixtures. After 4 yr of exposure to traffic, the 3-in. granular layer section showed 66 transverse cracks per km (41/mile) and the 6-in. granular layer showed 47 per km (29/mile). On the control section 183 cracks per km (114/mile) were recorded. Both granular layers showed 2 longitudinal cracks per km (1.2/mile), whereas the control showed 42 per km (26/mile). These results would indicate a definite benefit from this type of construction. However, it was concluded that pulverizing the old surface and using it as a base [7 transverse and 2 longitudinal cracks per km (4.4 and 1.2/mile) after 4 yr] was a more economical procedure.

CHAPTER FIVE

PORTLAND CEMENT CONCRETE OVERLAYS

Some designs for concrete resurfacing over old concrete pavements are effective in controlling reflection cracking. Three designs for concrete overlays are based on the bonding interaction between old and new concrete: bonded, partially bonded, and unbonded. Bonded overlays are usually quite thin and generally unreinforced. Unbonded and partially bonded sections are thicker and designed to perform more independently of the base pavement.

Where new concrete is bonded to the old pavement, control of reflection cracks from the base pavement is not expected to be achieved. With this design the thin new concrete layer becomes a monolithic part of the pavement on which it is placed. Any cracks in the base slab that have not been immobilized (by filling with epoxy, etc.) will appear in the surface layer. If bond remains effective, the cracks are usually narrow and can be easily maintained. Joints in bonded overlays must be located directly over joints in the base pavement, and also matched according to joint type.

With partially bonded (also called direct) resurfacing, the new overlay is designed with a greater thickness, and no attempt is made either to promote or to inhibit bond. Where there are cracks in the base slab, a joint placed above the crack will frequently control crack formation. A strip of fabric or membrane placed over the area of the crack in the old slab helps to break bond over the crack, and makes it more likely that the crack in the new overlay will form immediately below the joint that has been formed in its surface. Joints in partially bonded overlays should be located to match as closely as possible the joints in the base pavement.

A more effective means of eliminating reflection cracking

is the unbonded (also called separated) overlay design. The new and old slabs are separated by a bond-breaking interlayer. The overlay thickness is designed to be completely independent of the base pavement. The bond-breaker also permits the use of a jointing design and spacing different from the configuration used in the base slab. There is no need to match joints, and cracks do not reflect through the resurfacing layer.

Partially bonded and unbonded overlays are thicker and perform more like independent slabs; therefore they can be designed like normal full-depth concrete pavements. The overlays can be (a) plain concrete, with or without doweled joints; (b) conventionally reinforced, with mesh and doweled joints; (c) continuously reinforced concrete (CRC); (d) prestressed concrete; or (e) fiber-reinforced concrete. Minimum thickness is normally 5 in. (125 mm) for plain and mesh-dowel designs and 6 in. (150 mm) for CRC. Most of the major prestressed and fiber-reinforced overlay projects in this country have been on airport runways and taxiways.

Condition surveys of projects in service, made in 1975 for CRC overlays (87) and in 1977 for plain and mesh-dowel resurfacing projects (88), have been published by the Portland Cement Association. Additional information on concrete resurfacing designs and the conditions under which each design should be used can be found in a 1981 publication of the Portland Cement Association (89). (Also information on concrete resurfacing will be presented in a forthcoming NCHRP Synthesis of Highway Practice, entitled "Resurfacing with Portland Cement Concrete" and scheduled for publication in late 1982.)

THEORETICAL APPROACHES

Several researchers have studied reflection cracking using fracture mechanics principles, including crack-growth considerations (90-93). Majidzadeh and Suckarieh (94) developed a design methodology based on the assumption that cracking of AC overlays over PCC pavement starts at the surface of an overlay and works downward. This assumption is based on horizontal movements and curling of the PCC slabs caused by temperature changes occurring after placement of the overlay. A two-dimensional finite-element analysis was used to estimate the stresses resulting from horizontal joint movements, and nomographs were developed to determine the tensile stresses in the overlay. The Westergaard solutions for temperature differentials between top and bottom of the slab was used to determine the various angles of slab curl. A nomograph was prepared to determine the maximum stress in the overlay, taking into account pavement thickness, slab length, overlay characteristics, and joint width.

Treybig et al. (1) developed an analytical procedure for the determination of reflection cracking of AC overlays on PCC without applying fracture mechanics. Cracking that is caused by the horizontal movement of the existing PCC pavement due to temperature changes is considered as well as cracking caused by differential deflections resulting from a load passing over a crack in the PCC pavement. Horizontal movements are determined by field measurements to define joint spacing and crack or joint movement associated with a specific temperature change. From these data, the frictional

force between the PCC and underlying materials is determined. The force-displacement relationship is modified when an overlay is added. Provision is also made to incorporate the effects of a bond-breaker at the crack. The horizontal tensile strain can be computed for various temperatures and compared to an allowable tensile strain to determine if reflection cracks will occur.

The effects of differential vertical movement at cracks are determined from measurement of deflections at each side of the crack resulting from a load on one side. From this information, the shear strain in the overlay can be determined and compared to a limiting value. A flow chart of the overall procedure is shown in Figure 4.

Treybig et al. (1) reported on verification of the design concepts (Volume 1), and design procedures for flexible and rigid overlays of rigid pavements as well as a reflection cracking analysis procedure for flexible overlays (Volume 2).

Monismith and Coetzee (52) utilized a two-dimensional finite-element procedure to examine the distribution of stresses in the vicinity of a crack with and without an asphalt-rubber interlayer (SAMI). A series of full-scale pavement models of AC overlays were made on a cracked PCC slab resting on a Winkler spring foundation with and without SAMI construction at the AC-PCC interface. The results generally substantiated the analytical study. The results of the laboratory analysis are shown in Figure 5. The large reduction in stress resulting from the use of the interlayer is evident as well as a reduction in stress with increased

TABLE 4
RESULTS OF TESTS ON FABRICS (93)

Test Number	" Crack Opening (Inches)	Number of Samples Tested	Samples (Inches)	N _f Cycles to Failure (Average)	Gradation and Aggregate Type	Asphalt Type and Content (By Wt. of Agg.)	Fabric Type
1	0.055	5	3 × 3 × 15	2,155	Dense Graded Based On ASTM D-1663 -5A Standard Using River Gravel	AC - 10 3.8%	1
	0.065	5		975			
	0.075	5		500			
2	0.065	4		765			2
3	0.055	4	1,241	3			
4	0.055	5	750	No Fabric			
	0.065	3	115				
	0.075	4	42				

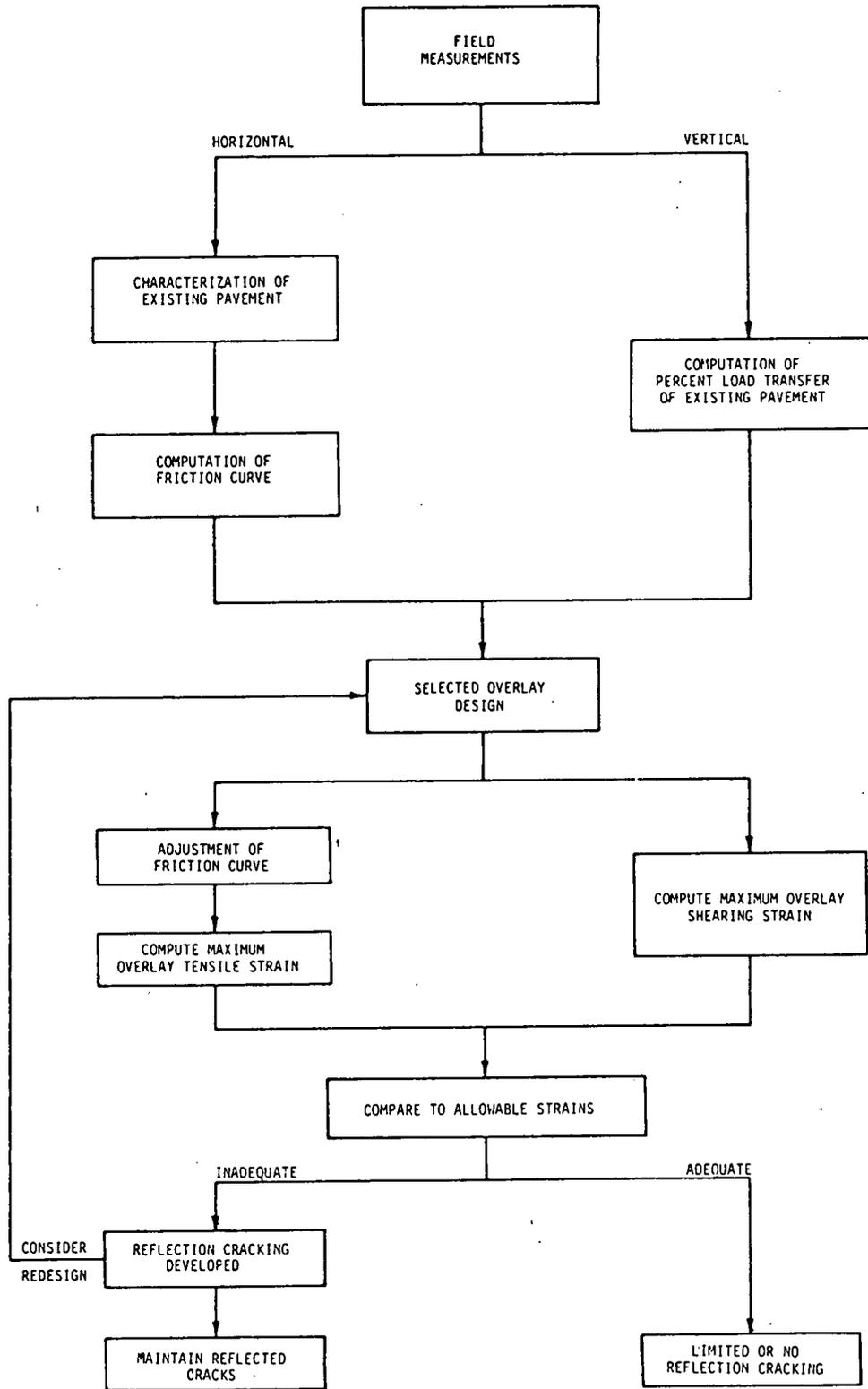


FIGURE 4 Procedure for determining if a given overlay design will eliminate reflection cracks resulting from extreme environmental conditions (1).

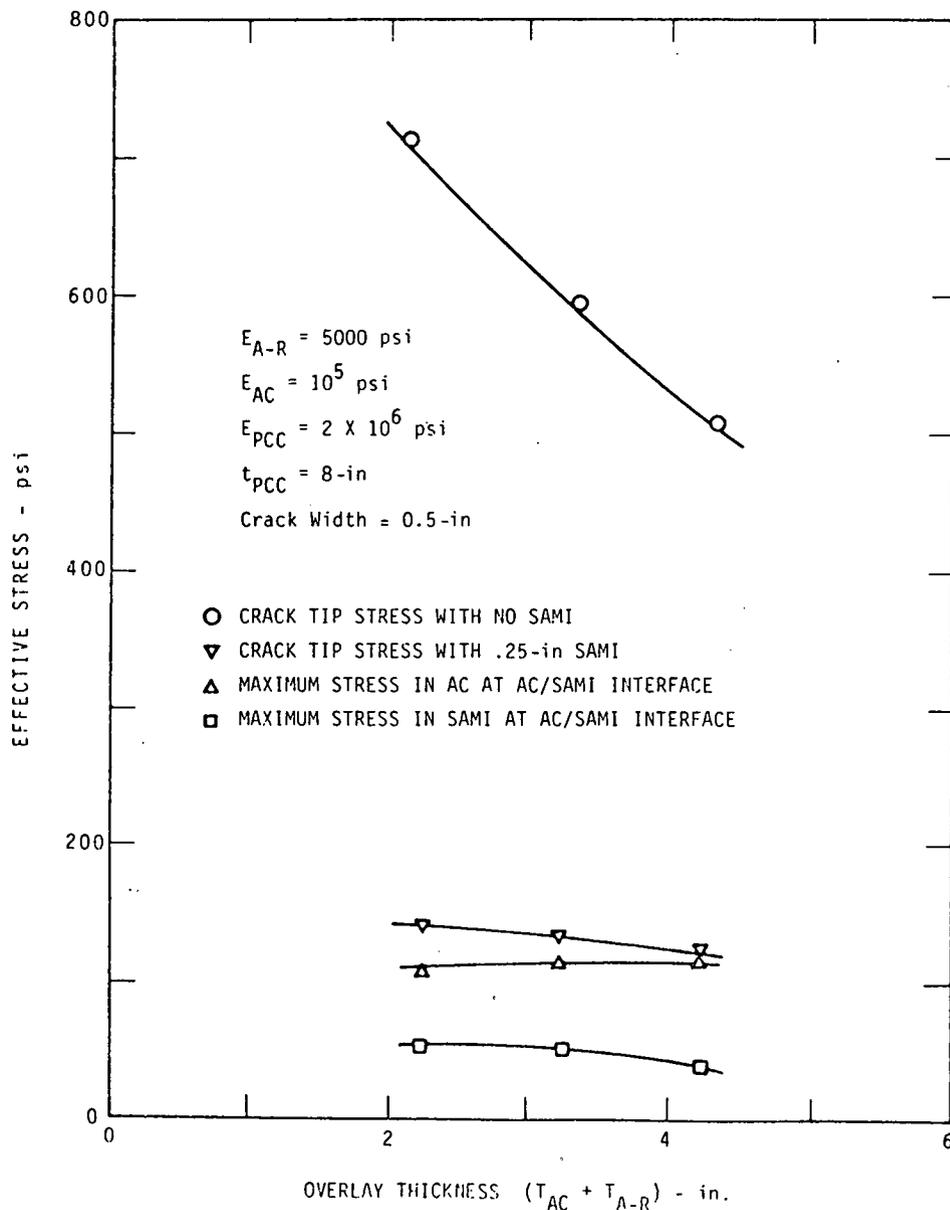


FIGURE 5 Effect of thickness of AC overlay on effective stress at crack tip with and without asphalt-rubber SAMI located at AC/PCC interface, and on maximum stress in AC and SAMI (52).

thickness without the interlayer, which accounts for the delayed reflection cracking occurring with the use of thicker overlays.

Germann and Lytton (93) reported on laboratory test results using a device called the TTI Overlay Tester. Various types of overlay samples were tested, including fabrics and

different grades of asphalt. The results obtained with the use of fabric are given in Table 4, and the results from using various grades of asphalt and types of mixtures are given in Table 5. These results parallel some of the data from NEEP-10 project tests. The TTI Overlay Tester provides a method for an initial evaluation of new products without the expense of a field test.

TABLE 5
RESULTS OF TESTS ON VARIOUS TYPES OF ASPHALT MIXTURES (93)

Test Number	u Crack Opening (Inches)	Number of Samples Tested	Size of Samples (Inches)	N _f Cycles to Failure (Average)	Gradation and Aggregate Type	Asphalt Type and Content (By Wt. of Agg.)	Experimental Values		Shapery's Theory		E(t) - psi Back Calculated From Finite Elen. Program (Average)	t (Sec)	
							A	n	A	n			
5	0.030	2	1 x 3 x 15	5	DENSE GRADED BASED ON ASTM D-1663 -5A STANDARD USING LIMESTONE AGGREGATE	AC - 10 LOW - 3.5%	0.122	0.193	2.88×10^{-7}	4.86	2863.	7×10^{-4}	
6	0.030	2	2 x 3 x 15	285			1.49×10^{-6}	2.82	6.42×10^{-8}	4.86			
7	0.030	2	3 x 3 x 15	425			1.20×10^{-6}	2.35	6.42×10^{-8}	4.86			
8	0.030	2	1 x 3 x 15	10		AC - 10 HIGH - 5.5%	0.0291	0.424	1.07×10^{-7}		1889.	1.4×10^{-3}	
9	0.030	2	2 x 3 x 15	2,100			2.78×10^{-8}	4.08	5.01×10^{-9}	4.86			
10	0.030	2	3 x 3 x 15	VERY HIGH			1.40×10^{-8}	4.29	5.01×10^{-9}	4.86			
11	0.045	2	3 x 3 x 15	840		HOT SAND MIX CONCRETE 65% - SAND 30% - FIELD SAND 5% - FILLER	AC - 20 MED - 4.5%	1.53×10^{-8}	3.84	7.57×10^{-12}	5.75	3056.	2×10^{-3}
12	0.045	2	3 x 3 x 15	1,330			AC - 5 MED - 4.5%	2.14×10^{-8}	4.63	2.31×10^{-8}	4.99	1509.	1×10^{-3}
13	0.045	2	3 x 3 x 15	235			AC - 20 MED - 5%	8.46×10^{-6}	2.11	2.68×10^{-10}	5.75	3613.	1.3×10^{-3}
14	0.045	2	3 x 3 x 15	700			AC - 5 MED - 3.5%	2.73×10^{-6}	4.32	3.63×10^{-6}	4.99	832.	2.7×10^{-3}
15	0.045	2	3 x 3 x 15	75	OPEN GRADED LIMESTONE 90% - 3/4" AND 1/2" AGGREGATE 10% - #30 SIEVE SIZE	AC - 20 LOW - 2%	---	--	---	--	---	---	
16	0.045	2	3 x 3 x 15	.852		AC - 20 HIGH - 4%	---	--	---	--	---	---	
17	0.045	2	3 x 3 x 15	230		AC - 5 LOW - 2%	---	--	---	--	---	---	
18	0.045	2	3 x 3 x 15	1,275		AC - 5 HIGH - 3%	---	--	---	--	---	---	

CONCLUSIONS AND RECOMMENDATIONS

Despite the great amount of field testing that has been conducted since 1932, progress has been slow in developing AC overlay systems to minimize reflection cracking.

Systems with a demonstrated capability to retard reflection cracking of AC overlays on old AC pavements in specific circumstances include:

- Low-viscosity asphalt (200-300 penetration) used in AC as an overlay or as an interlayer.
- Heater-scarifier remix of the old surface covered with a new bituminous layer.
- Asphalt-rubber interlayer (SAMI construction process).
- Certain fabric interlayers that retard reflection cracks other than those thermally induced.
- Thick overlays, which are less likely than overlays with a thickness of 2 in. (25 mm) or less to reflect cracks over a period of time.

Systems with a demonstrated capability to retard reflection cracking of AC overlays on old PCC pavements in specific circumstances include:

- Thick AC overlays (6 in.—150 mm), which are more effective than thin (2 or 4 in.—50 or 100 mm) AC overlays where vertical movement is not excessive.
- Prefabricated fabric membrane strips.
- 3.5-in. (90-mm) layers of open-graded AC base mixture.

PCC overlays over either AC or PCC pavement, which are normally constructed to strengthen the highway, can also control reflection cracking. To reduce cracking to a minimum, the following practices are recommended:

- For bonded or partially bonded PCC overlays, new joints should be placed directly over old joints.
- Matching joints are not required for unbonded overlays.

Theoretical approaches to the design of systems for retarding reflection cracking have been developed; however, additional research and field testing are necessary to transform or verify these approaches as practical design systems.

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APPENDIX

SUMMARY OF EXPERIMENTAL OVERLAY PROJECTS
IN SELECTED STATES

ARIZONA

In 1972 Arizona constructed a NEEP-10 project on a 9-mile (14-km) section of highway (Minnetonka-East) located near Winslow on Interstate 40 (22, 23, 32). The area has an elevation of 6000 ft (1500 m), an annual rainfall of less than 8 in. (200 mm), and a temperature range from 0° F (-18° C) to 100° F (38° C). The roadway had moderate to heavy traffic with an average daily traffic (ADT) of 10,000. In 1975 the ADT was 10,600; there were 159,213 18-kip (80-kN) loads. The AC roadway had a history of severe cracking problems.

The project consisted of 18 test sections (Table A-1). The

standard, or control, sections consisted of 32 mm (1.25 in.) AC and 13 mm (0.5 in.) asphalt concrete friction course (ACFC). Except as noted, this was also the overlay used in the test sections.

The performance of the test sections was evaluated in 1975 (22). Those sections remaining unpatched in 1975 were given an asphalt-rubber seal coat in 1975. A re-evaluation of the performance of the test sections was made in 1978 (23, 32). Table A-2 gives the percentage cracking in 1975 and 1978 and the cracking and patching ratio in 1978. The 1977 construction cost index and the performance index of the various sections are given in Table A-3.

TABLE A-1
TEST AND CONTROL SECTIONS (ARIZONA MINNETONKA-
EAST) (23)

Test Section No.	Description
1	Asphalt-Rubber Plus Pre-coated Chips
2	Heater Scarification Plus Petroset
3	Asphalt-Rubber Membrane Interlayer -- Placed Over AC and Under ACFC
4	Asphalt-Rubber Membrane Interlayer -- Placed Over AC and Under ACFC
5	Asbestos Fortified AC Mix
6	Two Inches AC, No ACFC
7	Los Angeles Basin 120/150 Penetration Asphalt
8	Los Angeles Basin 40/50 Penetration Asphalt
9	Four Corners 120/150 Penetration Asphalt
10	Los Angeles Basin 200/300 Penetration Asphalt
11	Emulsion Treated Base in Place of AC
12	Petromat Placed Under Overlay
13	Fiberglas Placed Under Overlay
14	Petroset Flush of Overlay Before ACFC Placed
15	Petroset Placed in Cracks
16	Reclamite Placed in Cracks
17	Reclamite Flush of Old AC
18A, B, C	Heater Scarification of Old AC Plus Reclamite Flush, with Varying AC Overlay Thickness
18A	32 mm (1.25 inch) AC Overlay
18B	76 mm (3.00 inch) AC Overlay
18C	38 mm (1.50 inch) AC Overlay
Control Sections	Conventional (Standard) Overlay

TABLE A-2
CRACKING AND PATCHING DATA (ARIZONA MINNETONKA-EAST) (32)

Test Sections and Numbers	1 Percent Cracking Before Overlay	2 Percent Reflective Cracking 1975	3 Percent Reflective Cracking 1978	4 Cracking Plus Patching 1978	5 Dynalect Deflection June 1971
Heater Scarification & Petroset (2)	9.5	3		52.2	1.72
Asphalt Rubber Under ACFC (3 & 4)	23.4	4	2.1	25.0	1.71
Fiberglass (13)	25.5	5		76.9	1.76
Heater Scarification & Reclamite (13A)	10.0	6	7.4	73.1	.98
200/300 Pen LA (10)	18.7	8	16.1	18.6	1.49
Petromat (12)	38.4	12		50.8	1.95
Petroset in Cracks (15)	36.5	12		81.4	1.89
Asbestos (5)	18.4	13	5.9	74.7	.99
120/150 Pen LA (7)	33.4	14		104.5	1.73
Emulsion Treated AC (11)	33.6	14		90.5	1.60
Reclamite Flush (17)	18.9	15		97.7	1.24
Petroset Flush (14)	29.2	16		100.0	1.93
Control Sections	29.7	17	27.0		1.51
120/150 Pen AC (9)	10.5	18		118.3	1.84
Reclamite in Cracks (16)	26.1	20		198.7	1.40
40/50 Pen LA (8)	46.1	20		469.4	1.91
Asphalt Rubber Seal Coat (1)	18.7	19	12.8	21.4	1.07
2" AC no ACFC (6)	15.2	64		1260.8	1.36

Columns 1 through 5 were obtained from two reports.

Report #1—"Prevention of Reflective Cracking In Arizona Minnetonka-East (a case study)" May 1976.

Report #2—"Prevention of Reflective Cracking Minnetonka-East (1979 addendum report)." August 1979

Description of Columns 1 Through 5

Column 1—Average Percent Cracking Just Before Overlay Obtained From Table 8 in Report #1

Column 2—Test Section Ranking By Average Percent Reflective Cracking Table 9 Report #1

Column 3—Test Section Ranking By Average Percent Reflective Cracking Table 2 Report #2

Column 4—Test Section Ranking By Ratio of Percent Reflective Cracking Plus Patching of Test Section Compared to Adjacent Control Section Table 3A Report #2

Column 5—Average Dynalect Deflection of First Geophone in Mills of an Inch (1.00 = .001 inch) For Each Test Section; Taken in June 1971 Just before overlay work began. Data from Table 7A, Report #2.

As a result of the test program, researchers in Arizona concluded that the following treatments significantly reduced reflection cracking from an old AC pavement:

- Asphalt-rubber membrane seal coat placed on top of a 1.25-in (32-mm) AC overlay and covered with 0.5 in. (13 mm) AC finish course (SAMI).
- 3 percent asbestos and 3 percent additional asphalt added to a 1.25-in (32-mm) AC overlay and covered with 0.5 in (13 mm) AC finish course.
- Heater-scarification to a depth of 0.75 in. (19 mm), application of 0.10 gal/yd² (0.5 L/m²) rejuvenating agents, rolling, and overlaying with 1.25 in. (32 mm) AC and 0.5 in. (13 mm) AC finish course.
- 1.25-in. (32-mm) AC overlay flushed with 1 gal/yd² (5 L/m²) asphalt rubber and coated with chips (SAMI).
- 200-300 penetration asphalt from the Los Angeles Basin used in a 1.25-in. (32-mm) AC overlay and covered with 0.5 in. (13 mm) AC finish course.

TABLE A-3
COST PERFORMANCE INDEX^a (ARIZONA MINNETONKA-EAST) (23)

TEST SECTION	MAINTENANCE			COST PERFORMANCE INDEX		
	1977 CONSTRUCTION	ROUTINE	SEAL COAT	CRACKING	RIDE	PSI
#10 LA BASIN 200/300	1.56	.05	.71	1.55	.63	1.16
#3 & 4 ASPHALT RUBBER BETWEEN A.C. ACFC	2.72	.02	.71	1.73	2.55	3.33
#5 ASBESTOS	2.33	.04	.71	1.85	1.11	1.96
#18C HEATER SCARIFICATION 3" AC, 1/2" ACFC	3.34	.07	.65	2.32	.98	1.70
#7 LA BASIN 120/150	1.56	.22	.71	2.77	1.25	1.54
#1 ASPHALT RUBBER CHIP SEAL ON AC	2.00	.12	.71	3.14	1.29	3.18
#18A & B PLUS RECLAMITE HEATER SCARIFICATION	2.20	.27	.71	3.19	1.89	3.25
CONTROL 1 1/2" AC, 1/2" ACFC	1.60	.36	.71	3.87	1.79	2.94
HEATER SCARIFICATION #2 PLUS PETROSET	2.12	.29	.71	4.50	2.05	3.07
RECLAMITE AND #15, 16, 17 PETROSET FLUSH	1.69	.54	.71	4.90	2.47	3.45
#18B LAST 20' ROAD STRIPPING AC	2.29	.47	.71	5.33	2.17	3.94
#14 PETROSET FLUSH ON NEW AC	1.70	.87	.71	5.47	3.57	4.56
#6 2" AC NO ACFC	1.40	.74	.71	5.70	1.44	2.88
#13 FIBERGLASS	2.71	.30	.71	6.20	2.74	4.00
#11 EMULSION TREATED BASE	1.94	.76	.71	6.82	2.80	4.43
#12 PETROMAT	2.55	.43	.71	7.58	2.43	3.64
#9 FOUR COUPERS 120/150 PEN	1.56	.90	.71	7.93	2.30	3.69
#8 LA BASIN 40/50 PEN	1.56	.79	.71	8.50	2.91	4.25

^aCost per yd² divided by performance.

COLORADO

In 1971, as part of the NEEP-10 project, 10 pairs of 1000-ft (300-m) test sections were placed on I-70 between Clifton and Carneo in west central Colorado (49). The original pavement was constructed on A4 and A6 subgrades covered with 6 to 16 in. (150–430 mm) untreated subbase, 4 in. (100 mm) base course, and 3 in. (75 mm) hot bituminous pavement. Both longitudinal and transverse cracking were present in the AC surfacing. Many of the primary cracks had developed adjacent secondary cracks. Alligator cracking was also present.

The overlay project included a 2-in. (25-mm) overlay and a leveling course that was variable in thickness, affecting the performance of some sections and resulting in the elimination of two sections (16 and 17) from the final analysis. The adjusted performance of the test panels after 5 yr of exposure to traffic is shown in Figure A-1. Costs of the various treatments for the project are shown in Figure A-2.

The conclusions from the report on this project indicate that there was some difficulty in interpreting the results of this test because of the variability of the leveling course (49):

Results from this project indicate that the effects of a leveling course are very influential on reflection cracking. Preventive measures used on this project were less effective in areas where a large amount of leveling course was present. When the leveling course reached a depth of 5 inches (12.7 cm) the influence of the various treatments on reflection cracking was eliminated. Therefore, most all of these treatments could be expected to be replaced by a 5-inch (12.7 cm) overlay; however, costs of this excessive material makes this approach unreasonable.

The cracks reflected through the overlay on this project were exclusively linear. The variation in this type of cracking was very evenly distributed between longitudinal and transverse on most sections. There was no alligator cracking reflected through on any of the sections indicating no base or pavement structural failures. This was verified in the pavement deflection and profile measurements. . . .

The percentage of reflection cracking for each treatment, as it appears in the field, is shown in [Figure A-3]. This data shows the trends of performance from the time of laydown to 1976. (Sections 16 and 17 were eliminated from this data because of the excessive amount of leveling course.)

The following is the order in which the treatments fall when ranked at the time of the 1976 observations [best to worst].

- Petromat (Sections 10 and 12)
- Petroset (Sections 3 and 5)
- Slurry Seal (Sections 6 and 7)
- Rubberized Asphalt (Section 18)
- Plant Mixed Seal (Sections 13 and 14)
- Standard (Sections 1 and 2)
- Hand Poured (Sections 5 and 11)
- Squeegee Seal (Sections 1 and 2)
- Reclamite (Section 9)
- Heater-Scarifier (Sections 4 and 8)

The Plant Mixed Seal and Reclamite Sections did perform very well for the first year; however, they deteriorated rapidly after that time. Both the Squeegee Seal and the Standard overlay treatments deteriorated rapidly from the beginning of the project. The Petromat sections performed well throughout the evaluation.

The curves plotted on [Figure A-1] illustrate the trends of reflection cracking after the influence of the leveling course was removed. . . . The following is a list of treatments and section numbers by order in which the treatments performed best based on the average amount of reflection cracking:

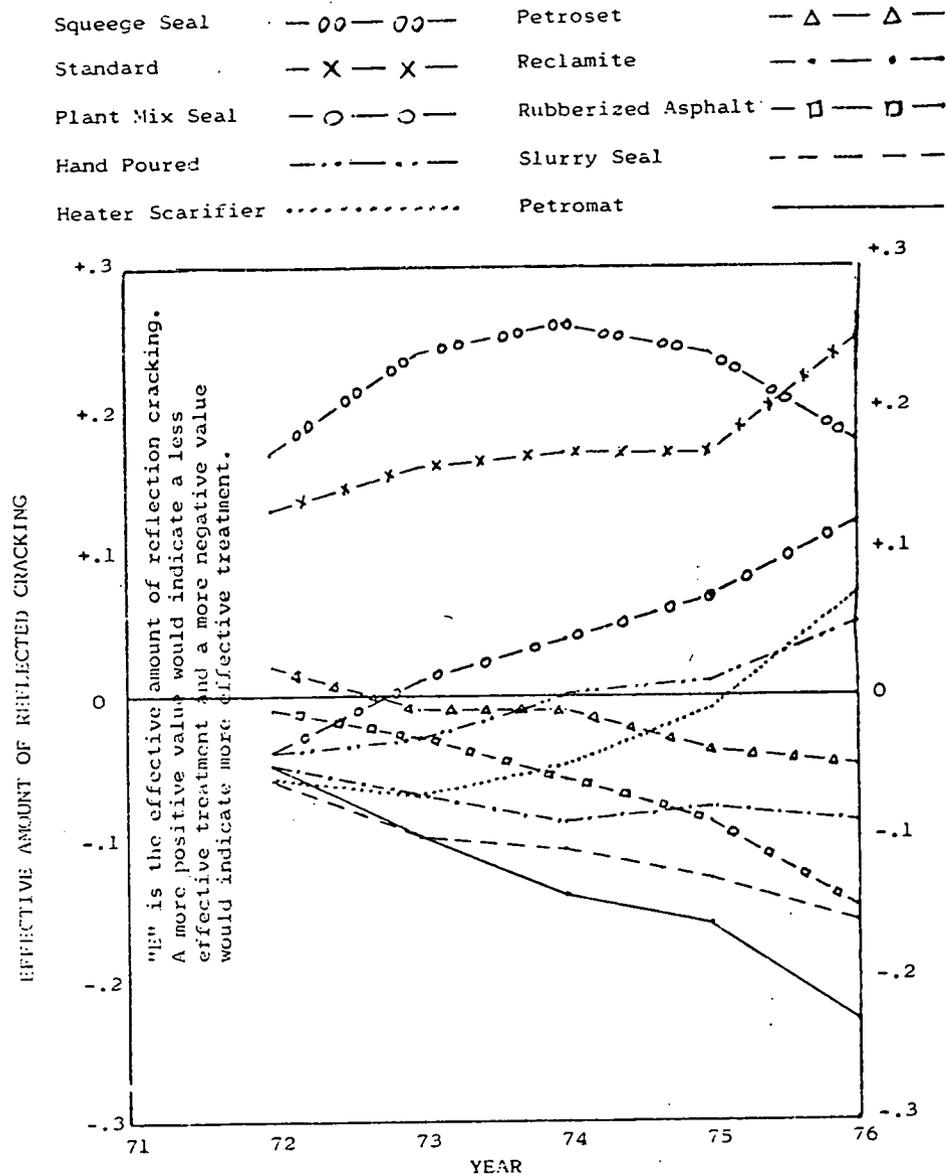


FIGURE A-1 Reflection cracking after the influence of the leveling course was removed (Colorado) (49).

- Petromat (Sections 10 and 12)
- Slurry Seal (Sections 6 and 7)
- Rubberized Asphalt (Sections 17 and 18)
- Reclamite (Sections 9 and 16)
- Petroset (Sections 3 and 5)
- Hand Poured (Sections 5 and 11)
- Heater-Scarifier (Sections 4 and 8)
- Plant Mixed Seal (Sections 13 and 14)
- Squeegee Seal (Sections 1 and 2)
- Standard (Sections 1 and 2)

Sections 16 and 17 were included in this list since the effort of their leveling course was eliminated mathematically.

Results of this analysis should be used as a final determination of performance of the reflection cracking treatments on this project.

The data indicate that the trends of treatment generally perform in the same rank throughout the evaluation period.

Some variation did take place such as the Heater-Scarifier treatment which performed very well; however, after 1973 rapid deterioration took place. Throughout the evaluation period the Standard and Squeegee Seal treatments performed much worse than the other treatments. After 1973 the Petromat treatments displayed the best performance with the Slurry Seal and Rubberized Asphalt treatments showing relatively good performance.

There have been no post-construction costs on this project. Consequently, a comprehensive cost benefit analysis cannot be computed. However, some trends may be made using initial cost and section performance. The high cost of the Petromat fabric makes this material somewhat less desirable for marginal cracking problems and low traffic roadways. This treatment is recommended for use in high traffic areas and on severely cracked roadways. The slurry seal and rubberized asphalt treatments displayed the best benefits when considering their moderate cost and good performance.

Hand Poured Crack Filling		
■	\$0.02	(from bid price on this experimental project)
■	0.005	(based on maintenance costs for a similar road)
Asphalt Rejuvenating Agent (Reclamite)		
■	\$0.09	
■	0.075	
Rubberized Asphalt Cement (Neoprene)		
■	\$0.42	
■	0.42	
Squeegee Seal		
■	\$0.45	
■	0.27	
Plant Mixed Seal		
■	\$0.52	
■	0.57	
Heater Blade Scarifier		
■	\$0.74	
■	0.18	
Emulsified Asphalt Binder (Petroset)		
■	\$1.00	
■	0.40	
Polypropylene Fabric (Petromat)		
■	\$1.40	
■	0.75	
Asphalt Emulsion Slurry Seal		
■	\$2.32	
■	0.23	

FIGURE A-2 Treatment costs (\$/yd²) in Colorado (49).

Conclusions made from this project generally follow those reported in Arizona by Way [23]. The best treatment (Heater-Scarifier) found in the Arizona tests varied from the Colorado findings in that Arizona used 0.05 gal/yd² less undiluted Petroset as a rejuvenation agent on the scarified material. Colorado's best treatment (Petromat) included hand poured crack sealing and 0.07 gal/yd² more emulsion than was used in Arizona. However, the significance of the variation in these treatments is not known. The greatest influence on performance is believed to be the structural support properties. Arizona's project was located in a high desert region containing terrance sand and gravel deposits, whereas the Colorado project had very unstable Mancos Shales for the subgrade material.

FLORIDA

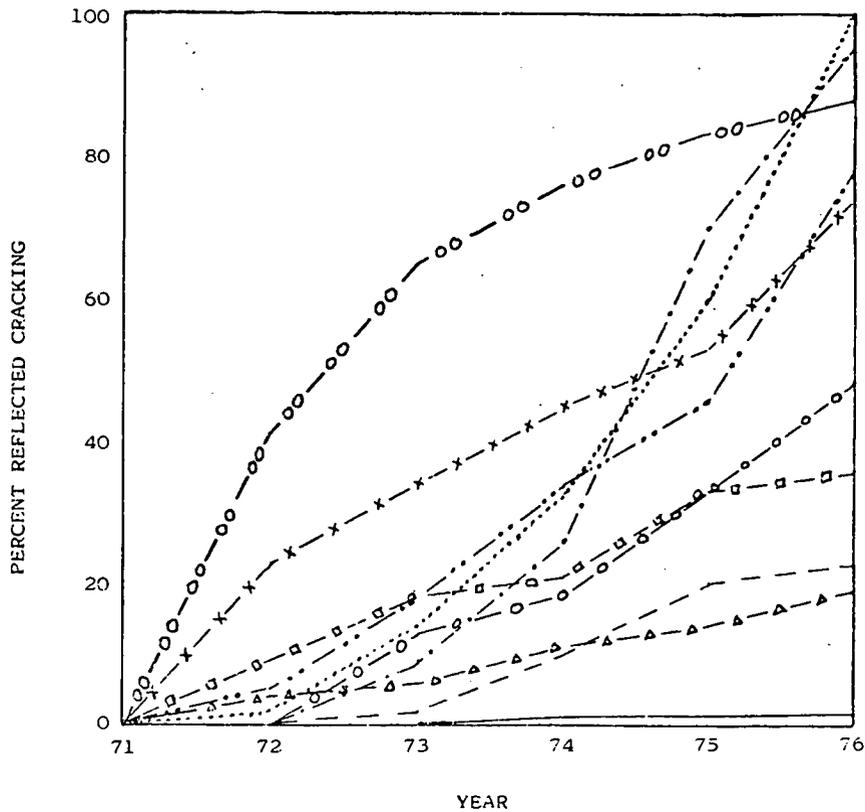
In 1971 the Florida DOT placed a 2-in. (50-mm) bituminous concrete overlay on an existing flexible pavement on a portion of Interstate 75 in Alachua County. As part of the NEEP-10 Project, eight 1,000-ft (300-m) test sections were included in the project for the purpose of evaluating various ways of reducing or eliminating reflection cracking (20):

1. Control section—standard construction.
2. Structofors—polyester fiber-reinforcement material.
3. Reclamite—asphalt rejuvenating agent.
4. Petromat—nonwoven polypropylene material.
5. Petroset—asphalt rubberizing agent.
6. Mineral seal and overlay.
7. Open-graded mix between leveling and surface courses.
8. Extra thickness.

A profile of the experimental test sections is shown in Figure A-4. During the test, traffic counts indicated that 16,206,565 vehicles used the roadway and that 1,685,482 18-kip (80-kN) equivalent wheel loads traveled over the experimental sections.

Before the overlay experiment, the existing roadway had a majority of transverse cracks along with some longitudinal cracks. Cores were taken at random locations directly over cracks that appeared in the overlay surface. Cracks that stopped short of the old pavement were considered to be nonreflective, and cracks that appeared in the surface and continued through the old pavement were considered to be reflective.

Squeegee Seal	—○—○—	Petroset	—△—△—
Standard	—x—x—	Reclamite	—·—·—
Plant Mix Seal	—○—○—	Rubberized Asphalt	—□—□—
Hand Poured	—·—·—	Slurry Seal	—- - - - -
Heater Scarifier	Petromat	—————



Note: Sections 16 and 17 were not included because of the excessive amount of leveling course.

FIGURE A-3 Percentage of reflection cracking as observed in the field (Colorado) (49).

The results of this experiment are presented in Table A-4. The conclusions of the study are as follows (20):

It should be noted from the initial crack survey that the Control and Petromat Sections, which were among the least cracked sections, both performed well. This may be an indication that early maintenance of the pavement before extensive cracking occurs could be a key factor in the prevention of reflection cracking.

A general review of the study indicates the use of Petromat for reducing reflection cracking appears to have some merit. However, a cost-benefit ratio study should be made and compared to the other methods that appear to be effective; namely, the Extra Thickness Section, the Open-Graded Section, and the Control Section.

Petroset and Reclamite do not appear to be suited for this type of application.

While the Structofors and Mineral Seal Sections performed better than some of the other sections, additional field studies should be made before specifying them for use.

GEORGIA

In 1976 an experimental project was constructed in Georgia to determine if an overlay system for PCC could be designed to minimize or prevent reflection cracking (18, 19). The project is located on Interstate 85 in Gwinnett County, approximately 30 miles (50 km) north of Atlanta. In 1977, the ADT was approximately 20,000, with 34 percent truck traffic.

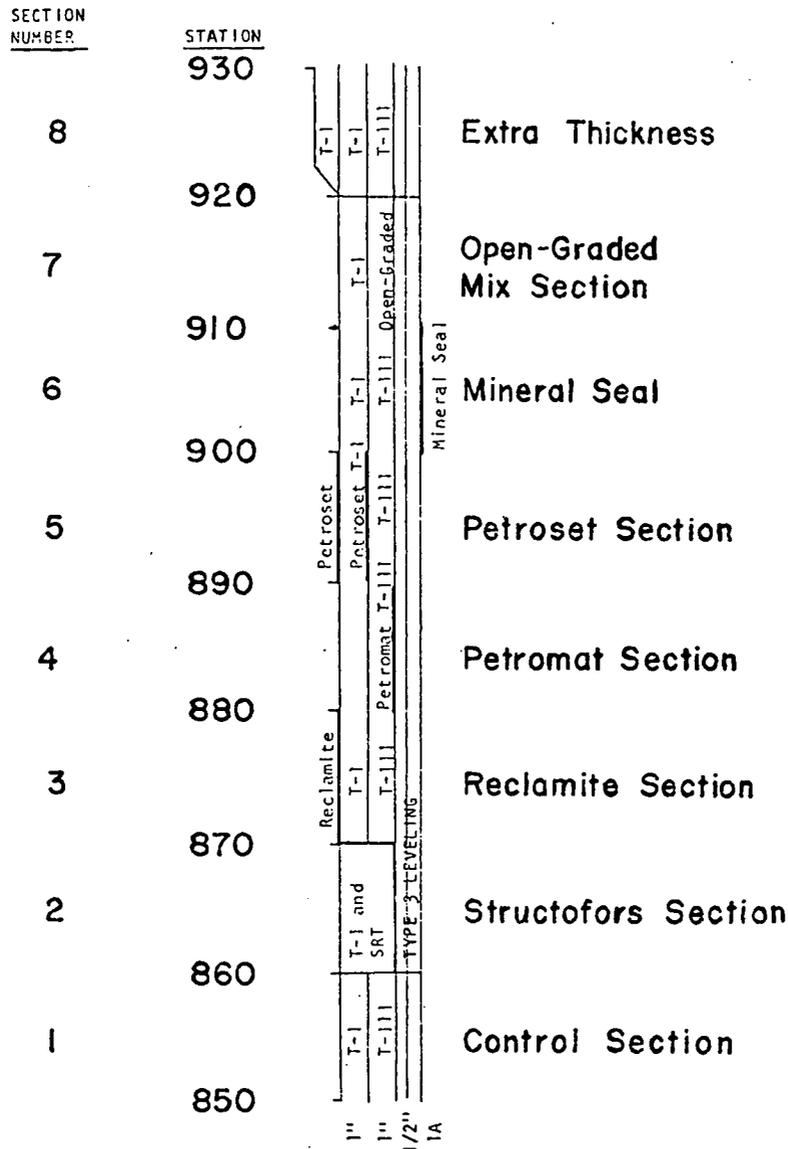


FIGURE A-4 Test section profile (Florida) (20).

The AC overlay portion of this test consisted of test sections with and without edge drains plus one section to test the effectiveness of the Arkansas base design. The control and Bituthene sections were placed directly on the PCC pavement. The Mirafi and Petromat and the Arkansas base were placed on a 70 lb/yd² (38 kg/m²) AC leveling course. Test sections included:

- Petromat fabric covered with 2, 4, and 6 in. (50, 100, and 150 mm) AC.
- Mirafi fabric covered with 2, 4, and 6 in. AC.
- Bituthene waterproofing membrane covered with 2, 4, and 6 in. AC.
- Arkansas base consisting of 3.5 in. (90 mm) base covered with 2.5 in. (64 mm) AC binder course and 1 in. (25 mm) surface course.
- Controls of 2, 4, and 6 in. AC.

The project is still under test. Preliminary information (18) was released in 1978 after a 15-month period of exposure to traffic. Additional information (19) on the progress of the reflection cracking after 4 yr is presented in Table 3 in Chapter 4, which indicates the effectiveness of the various treatments under the three thicknesses of overlays. The greatest reduction in reflection cracking was obtained with the 5-in. (150-mm) AC covering layer, but some benefits were recorded with the 4-in. (100-mm) cover.

Because of the test results obtained at an earlier date (18), the Georgia DOT has made extensive use of heavy-duty waterproofing strips (Bituthene) on all AC overlays placed on jointed PCC pavement on the Interstate system.

It is recommended that engineers concerned with reducing the effects of reflection cracking follow the progress of this well-planned experiment through the next few years to learn more about the effects of thicknesses, fabrics, and waterproofing membranes.

TABLE A-4
CRACK SURVEYS (ft²) (INTERSTATE 75, FLORIDA) (20)

Test Section	Original 8/27/70 (1)	3/73 (2)	9/74	6/75	12/75	1/77	Percent Deviation (3)	Ranking By % Deviation	Ranking By Existing Condition
Control	934	C1	100	306	710	1,246	+ 33	4	2
Structofors	1,876	C1 & 2	803	1,064	2,668	3,298	+ 76	6	6
Reclamite	1,168	C1	244	2,537	5,469	4,117	+ 252	8	7
Petromat	1,590	C1 & 2	98	295	852	1,102	- 31	1	1
Petroset	1,606	C2	4,344	4,009	5,679	4,979	+ 210	7	8
Mineral Seal	1,116	0	974	1,280	1,736	1,850	+ 66	5	5
Open Graded	1,788	C1	995	374	1,988	1,771	- 1	3	3
Extra Thickness	2,150	C1	1,680	1,006	1,357	1,838	- 15	2	4

(1) Original survey taken before overlay.

(2) Only minor cracking noted; no attempt was made to measure it.

(3) Percent deviation is the percentage of increase or decrease in cracking that occurred between the crack survey before overlaying and the final crack survey.

NORTH CAROLINA

In 1978 the North Carolina DOT, in cooperation with North Carolina State University, completed a 5-yr NEEP-10 experiment on US-70 Bypass in Orange County (16). The

project included testing a 2-in. (50-mm) AC layer over four fabrics covering a full lane, and four strip fabric treatments covering only the crack. In addition, three nonfabric treatments and a normal 2-in. (50-mm) AC overlay were tested, all on a two-lane jointed, unreinforced PCC pavement (Table A-5).

TABLE A-5
OVERLAY TREATMENT TYPE AND SYMBOL (16)

Treatment Type	Treatment Symbol
Mat course of AP-0 and #5 stone followed by a layer of I-2 mix.	A
Open-graded bituminous seal coat followed by a layer of I-2 plant mix.	B
Control section - 2" of I-2 plant mix.	C
Plant mixed mat coat followed by a layer of I-2 plant mix.	D
Mirafi reinforced overlay; fabric continuous over one lane.	F ₁
Structofors reinforced overlay; fabric continuous over one lane.	F ₂
Petromat reinforced overlay; fabric continuous over one lane.	F ₃
Fiberglass reinforced overlay; fabric continuous over one lane.	F ₄
Mirafi strip reinforced overlay; fabric strip over transverse joints and cracks only.	S ₁
Structofors strip reinforced overlay; fabric strip over transverse joints and cracks only.	S ₂
Petromat strip reinforced overlay; fabric strip over transverse joints and cracks only.	S ₃
Fiberglass strip reinforced overlay; fabric strip over transverse joints and cracks only.	S ₄

The PCC pavement was constructed in 1942 with 11-ft (3.3-m) lanes and transverse contraction joints at 40-ft (3.3-m) intervals and expansion joints at 120-ft (37-m) intervals. The condition of the existing pavement was described as follows (16):

The general condition of the test site was very good, particularly in view of the age and traffic history of the pavement. Many of the 11 ft. wide and 30 ft. long panels had few, if any, interior cracks. The transverse contraction joints and expansion joints were considered to be 'cracks' while the longitudinal joint at the pavement centerline was excluded from the study.

The annual average daily traffic in 1976 was 4,100, including 947 commercial vehicles of which 123 were semi-tractor trailer vehicles.

The 3.5 miles (5.6 km) of test pavement was divided into six experimental blocks two lanes wide containing 12 experimental units in each block. Each of the 12 treatments was repeated in each block.

The relative performance of the various test sections with respect to reflection cracks at the joints is shown in Figure A-5. Also shown are the position and number of replications of each treatment. Additional data as well as an explanation of the statistical treatment are presented in the report on the experiment by Mullen and Hader (16). The general conclusions are as follows (16):

Joint Crack Reflection

- (1) Joint cracking seems to vary much more with location along the highway than with the different overlay treatments used in this experiment.

- (2) The performance of the fabric treatments as a group is not significantly different from the performance of the non-fabric treatments as a group.

- (3) Within the group of non-fabrics, treatment D is significantly (statistically) better than the others (including the control, C).

- (4) Within the group of fabrics, treatments 2 and 3 are significantly (statistically) better than treatments 1 and 4.

- (5) The performance of the best fabric treatment is not appreciably different from the best non-fabric treatment nor significantly different from the control.

- (6) The continuous and strip versions of the fabric treatments are not significantly different.

- (7) None of the foregoing conclusions have changed appreciably for data collected approximately every six months over the last two years.

Interior Crack Reflection

With respect to proportion of original cracking reflected through the overlay, there are no apparent differences between treatments. In particular, the non-fabric treatments seem to do as well as the fabric treatments.

NORTH DAKOTA

In 1972 North Dakota constructed a NEEP-10 experimental overlay in the westbound roadway on I-94 between Buffalo and Casselton. The original road, built in 1948, consisted of a 22-ft (6.6-m) wide thickened-edge plain PCC pavement. Widened and overlaid with 5 in. (125 mm) AC in 1963, the section contained a 3 by 6 in. (75 by 150 mm) welded

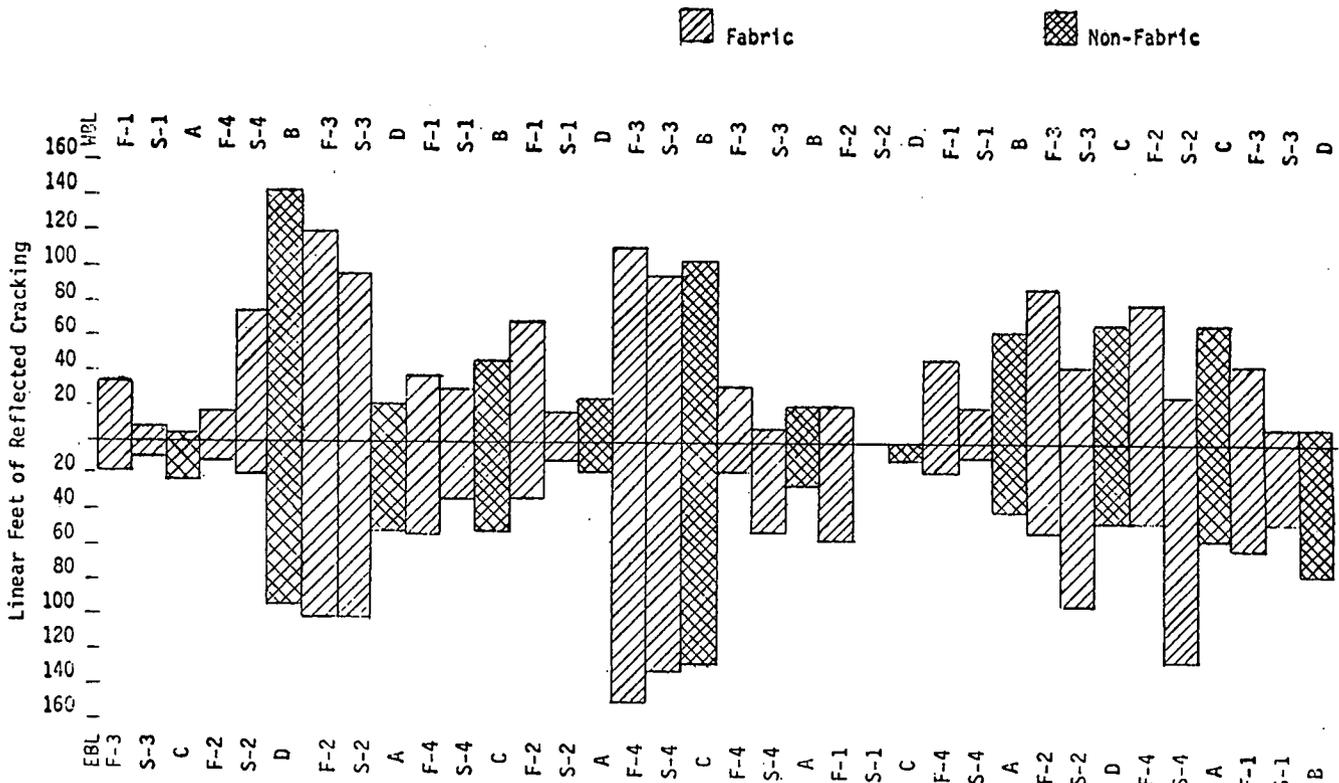


FIGURE A-5 Reflection cracking at joints for successive experimental units (July 1978, North Carolina) (16).

wire fabric reinforcing. By 1970 the entire section had deteriorated as described below (50):

Nearly every joint and crack from underlying concrete had reflected through the asphalt. In addition, there were longitudinal cracks at or near the location of the longitudinal joints in the mesh reinforcing placed in 1963. The entire roadway exhibited severe map cracking. The transverse reflective cracks were spalling badly and "chuckholes" existed where the asphalt had been eroded. These cracks, spalls and chuckholes had been repeatedly sealed and patched but with little success.

The 1972 overlay consisted of a 2-in. (50-mm) thick, full-width (37 ft—11.3 m) leveling course and a 1.5-in. (38-mm) thick, 24-ft (7.3-m) wide wearing course. Seven different experimental sandwich sections were constructed (Table A-6). Section 1 consisted of a layer of AC-treated sand placed on

TABLE A-6
EXPERIMENTAL TREATMENTS BEFORE OVERLAYING
(NORTH DAKOTA)

Section	Treatment	Length	
		miles	km
1	0.25 in. (6 mm) of AC treated sand	2.77	4.46
2	Control section	2.80	4.51
3	Structofors fabric	0.18	0.29
4	Petromat fabric	2.76	4.44
5	0.25 in. (13 mm) of plant-mixed seal	2.69	4.33
6	Emulsion slurry seal	2.40	3.86
6A	Rubberized emulsion slurry seal	0.19	0.31

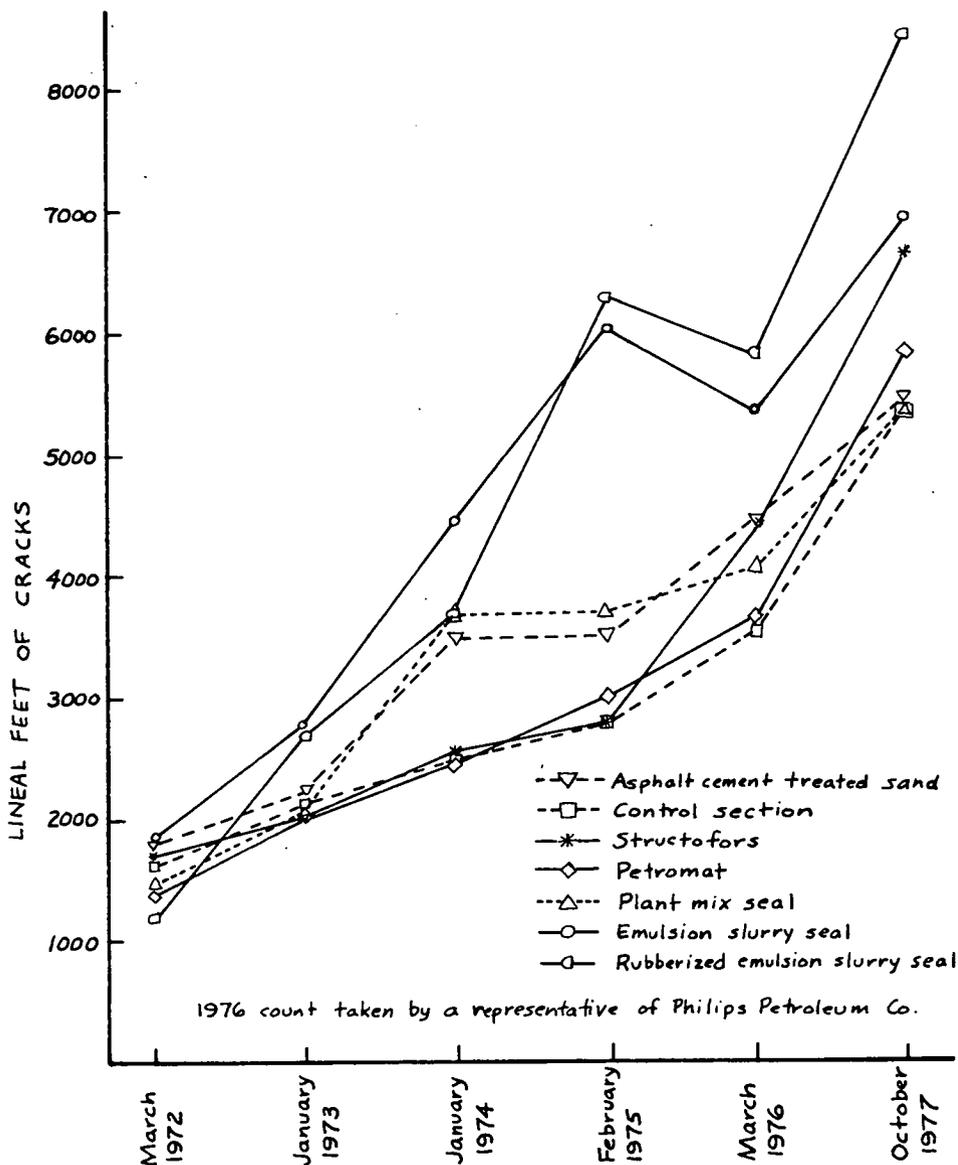


FIGURE A-6 Crack count on North Dakota experimental project (50).

the existing AC surface before application of the overlay to fill spalled cracks and small surface irregularities. Sections 2-6 were treated with a thin layer of asphalt-treated sand to fill spalled cracks and small surface irregularities before completing the treatment. Section 2 was the control section without any treatment other than the crack filling.

In Section 3, the Structofors fabric was laid on the surface before overlaying. In Section 4, a nonwoven synthetic fabric, Petromat, was placed on the pavement before applying the overlay. In Section 5, a 0.5-in. (13-mm) thick layer of plant-mixed seal was placed before overlaying. In Section 6, an emulsion slurry seal was placed on the section before overlaying. In Section 6A, a rubberized emulsion slurry seal was applied as a strain-relieving interlayer on the emulsion slurry seal before overlaying.

The conclusions from this extensive project are as follows (50):

The District personnel made a final crack count in November, 1977. At that time the longitudinal cracking

throughout the project was negligible other than the center line, which is expected on asphalt laydowns of this type.

The crack spacing had reduced from an average of some 70 feet between cracks during the first year to a point where it would appear that the reflection cracking follows the concrete pattern plus a crack between each panel for a distance of about 10 feet between the cracks. This pattern seems to run true for all sections and it can be noted that section 2, the control section, has as large a spacing between the cracks as any other section.

The matter of reflection cracks or the elimination of them appears to still be with us. It is doubtful that the present spacing between cracks could be considered an acceptable level.

There are several applications which can be made relative to the data by statistical methods, such as the rate of cracking developing between years, as it appears there was a period where it was quite stable between 1974 and 1975; however, it has accelerated as of this last count. It would appear from all data that the control section is serving as satisfactorily as any of the test sections. The 1976 plotting is not representative as it was counted by a different group.

Attached is a graph of the crack count for each year [Figure A-6]. It appears that none of the products used to reduce reflective cracking worked.

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