MINIMIZING REFLECTIVE CRACKS IN SOIL-CEMENT PAVEMENTS: A STATUS REPORT OF LABORATORY STUDIES AND FIELD PRACTICES

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Shrinkage is a natural characteristic of soil-cement. The cracks that develop are not the result of structural failure and from an engineering standpoint have not been a significant problem except in some very localized instances. This paper summarizes results of laboratory research performed by several investigators to determine why and how soil-cement cracks. Also discussed is experience with the conventional types of bituminous surfaces commonly used satisfactorily for various traffic conditions, as well as other surfacing practices used, particularly to reduce or retard reflective cracking. Laboratory research, field studies, and a drive-over inspection of several thousand miles of soil-cement show that the following procedures will minimize shrinkage of the base and reflective cracking: Use a granular soil with minimum clay content; during construction compact the mixture close to standard optimum moisture; use the highest penetration asphalt commensurate with adequate stability; and delay placement of the bituminous surface as long as practical. Other special treatments of the surfacing that have been helpful in further minimizing or delaying reflective cracks are the use of a bituminous surface treatment between the soil-cement base and the asphaltic concrete surface, upside-down design, and asphalt-ground rubber treatments.

•SOON after construction, shrinkage cracks occur in a soil-cement[1] base. This is a natural characteristic of soil-cement and is evidence that the cement is producing a hardened base course with significant flexural and tensile strength. The crack face is irregular, and field experience shows that there is an effective load transfer when the pavement thickness is adequate for traffic and subgrade conditions. The many thousands of miles of soil-cement in all areas of North America attest to its successful application as an economical, high-load-carrying base that can be made from a wide variety of soil materials.

A bituminous wearing surface is placed on the soil-cement base. The surface type and thickness depend on traffic volume, availability of materials, cost, climatic conditions, and local practices. A common type of wearing surface for lightly traveled pavements is a double bituminous surface treatment about ¾ in. thick. As traffic volumes increase, thicker asphaltic concrete surfacings are warranted.

Later, some of the cracks in the base reflect through the bituminous surface. Only the wider reflective cracks require sealing. The bituminous wearing surface is re-

Publication of this paper sponsored by Committee on Soil-Portland Cement Stabilization.

[1]The widespread use of mixtures of soil and cement and the many materials used have resulted in several names for a soil-cement mixture: soil-cement, cement-treated base, cement-stabilized soil, cement-stabilized soil aggregate, cement-stabilized crushed aggregate. In this paper, all mixtures of cement with aggregate, soil-aggregate, or soil used for a base with a bituminous surface are generally referred to as soil-cement.

sealed or overlaid periodically, as is common practice for all bituminous surface pavements.

As shown in Figure 1a, cracks reflected from a soil-cement highway base are transverse, with a fairly regular pattern and some longitudinal cracking near the centerline. Occasional longitudinal cracking may occur at about the quarter points but usually not in the wheelpaths. Wheelpath "alligator" cracking as shown in Figure 1b would be an indication of inadequate design and structural failure.

To evaluate the condition of soil-cement pavements having various base and surfacing designs, the author made "drive-over" inspections, with special emphasis on reflective cracking, of several thousand miles of soil-cement pavements in the United States and Canada. This paper summarizes the results of this inspection and other pertinent reports. In general, soil-cement is giving good service, and the reflective cracks that appear soon after construction have had no major effect on the service life of pavements. Minimum maintenance is required.

REFLECTIVE CRACKS

To properly orient one's philosophy regarding reflective cracks in soil-cement pavements, it should be kept in mind that cracks occur in the bituminous surface of all types of flexible and stabilized pavements. The amount of cracking varies with the properties of the bituminous surface and base, age, climatic conditions, and traffic.

The regular network of transverse and longitudinal cracks in bituminous surfaces on flexible bases was recognized a number of years ago as a problem for study. The complexity of the problem was recognized by Anderson, Shields, and Dacyszyn in a report (1) published in 1966.

Low-temperature cracking of bituminous surfaces on flexible pavements is a costly problem over much of northern North America (2). This type of cracking is caused primarily by low temperature and temperature changes that induce tensile forces in the surface.

"Tenting" or raising up of the pavement in the area of the cracks has occurred on all types of bituminous surface pavements in Canada and some northern states. Tenting has occurred on soil-cement pavements in some localized areas. Considerable effort is being devoted to determining the causes and prevention of tenting of asphalt surface pavements.

Studies of all types of Oklahoma pavements made at the University of Oklahoma (3) show that after a short initial period the subgrade moisture content for expansive soils increases to an equilibrium of 1.1 to 1.3 times the subgrade plastic limit, particularly where the subgrade has been compacted on the dry side of AASHO T99 optimum moisture. This produces some vertical swelling but, of more significance, produces lateral subgrade expansion causing longitudinal cracking of all types of pavements. It is important that proper subgrade compaction controls be used with expansive clay subgrades on all pavement types.

The overall objectives of the NCHRP Project, "Minimizing Premature Cracking of Asphaltic Concrete Pavements," and the FHWA NEEP Program Project, "Reducing Reflective Cracking in Bituminous Overlays," are to determine suitable methods for designing and constructing asphaltic concrete surfaces that will have minimum premature cracking. Although soil-cement is not mentioned in the project statements, the results should be helpful in the design of surfacings for soil-cement as well as other bituminous-surfaced pavements.

Thus, reflective cracks are not unique to soil-cement. In spite of soil-cement's property of shrinking and cracking soon after construction, reflective cracks rarely cause failure, apparently because of the base's slab-like character and resistance to water. This is particularly the case where the appearance of the bituminous surface due to reflective cracking is not related to the structural adequacy of the pavement.

Before discussing reflective cracking in surfaces on soil-cement, it is appropriate to review some of the laboratory research to determine factors that affect the volume changes in a soil-cement base.

LABORATORY STUDIES AND TEST SECTIONS

One of the early laboratory studies on shrinkage properties of soil-cement was reported by Nakayama and Handy in 1965 (4). Effects of varying the cement content, initial water content, and curing methods can be summarized by two very basic factors: Minimization of shrinkage requires a reduction of the initial compaction water content and a reduction in the amount of clay in the soil.

More recently, George (5, 6, 7, 8) has reported considerable research on shrinkage of soil-cement, including methods for estimating crack spacing and crack widths. In a 1968 paper (5) he stressed that molding moisture content has the most influence on shrinkage. He also concluded that shrinkage is a function of the amount and kind of clay. He asserted that montmorillonite contributes more than other clays and discussed the effect of cement hydration and loss of moisture on the total shrinkage. George stated also that shrinkage of soil-cement can be reduced by compacting to higher densities. It is assumed that this would be related to the compaction moisture content (higher maximum densities are associated with lower optimum moisture contents).

If the soil-cement base is allowed to complete most of its initial shrinkage before the bituminous surface is placed, later movements in the base are considerably less because of smaller and slower changes in moisture content and temperature. Unpublished data by the Portland Cement Association (Fig. 2) show that the volume change due to later moisture changes will only be about 33 to 45 percent of the initial shrinkage due to drying. Data were obtained by compacting a granular and a silty soil-cement mixture at optimum moisture content, curing the specimens at 100 percent humidity for 14 days, allowing them to reach equilibrium at humidities down to 10 percent, and rewetting at 100 percent. The maximum shrinkage values shown are for 75 percent relative humidity where 80 to 90 percent of the shrinkage occurred.

Another 1968 paper by George (6) reported on methods of minimizing cracking and presented simplified calculations for crack spacing and crack width.

In 1969 and 1971 papers, George (7, 8) reported on studies to delineate the primary causes of cracking. Expressions for shrinkage stresses were derived by the linear viscoelastic theory. The results indicated that creep strain produced from the restraint in the slab partly compensates for the shrinkage, thereby reducing crack width. When shrinkage occurs slowly, the strain capacity of the soil-cement is greater than when rapid shrinkage takes place. This points up the importance of immediate, proper curing.

Pretorius and Monismith (9) reported on methods of approximating crack spacing and crack widths and showed the possibility of predicting the propagation of fatigue cracking by a 3-dimensional finite element approach.

Fossberg, Mitchell, and Monismith (10) have applied repeated loads at a load crack and at the edge and interior of 8½-in. thick, 20-ft square panels. The panels were tested unsurfaced and after being surfaced with 1, 3, and 5 in. of asphaltic concrete (AC). Cracking of a panel under loading caused only a slight increase (about 20 percent) in vertical deflection but increased the vertical stresses in the subgrade about 50 percent near the crack when the load was placed directly over the crack. However, the deflection and vertical stress values were still very low and well within safe limits. The investigation on edge loading showed that, for the slab tested, loading at least 2 ft from the slab edge can be analyzed as "central loading." Loading close to the edge is more severe in terms of stresses and deformations. Since the outer wheels of vehicles generally travel about 2 ft from the outside edge of a 12-ft lane (11), most wheel loads can be considered as central loading.

Wang, Moultrop, and Nacci reported on field test pavement studies in Rhode Island (12). Several designs of soil-cement base and cement-treated subbase were compared with penetrated rock base. The test sections were evaluated over a 4-year period with Benkelman beam, plate bearing, and roughometer tests, crack surveys, and frost studies. The soil-cement, made of an A-4 soil, had much smaller deflections than the penetrated rock base. The number of cracks in the soil-cement that have reflected through the 3-in. AC surface increased with age. However, there was no evidence that the cracks would reduce pavement stiffness or increase deflection of the soil-cement beyond safe limits.

Data on size and distribution of cracks in a soil-cement base are limited. Highway Research Board Bulletin No. 292 (13) summarizes data obtained on 3 airfields in Australia (14). The sandy soils treated with 10 percent cement contained 10 to 25 percent 0.002-mm clay and had a PI ranging from nonplastic to 7. The bases were cured 7 days under Sisalkraft paper, and crack measurements at the surface of the base were observed 32 to 77 days after construction. Linear shrinkages determined by measurement of cracks at the surface were 0.15, 0.3, and 0.4 percent for the 3 airfields. As shown in Figure 3, 40 to 80 percent of the cracks at 5 test sections were less than $^1/_{48}$ in. wide and about 3 percent were $^1/_8$ in.

Additives to Reduce Shrinkage

Research on the use of additives to reduce shrinkage of soil-cement has been done by George (6, 8), Barksdale and Vergnolle (15), Anday (16), and Wang and Kremmydas (17).

A few of the additives are beneficial only at an optimum amount. Other levels of concentration, especially those above optimum, may impair effectiveness. For some additives the amount of reduced shrinkage depends considerably on soil type and relative humidity. Others reduce compressive strength. All of these critical reactions and variations in results show that more study is needed before any of the additives can be considered a practical field solution to shrinkage.

Summary of Laboratory Studies and Test Sections

Laboratory research shows that the following practical factors affect the amount of base shrinkage:

1. Initial shrinkage is caused mainly by loss of water due to drying of the base and to cement hydration.
2. The soil type is an important variable. Low-clay-content granular soil-cement shrinks less than soil-cement made of a fine-grained soil.
3. A mixture compacted above optimum moisture will shrink much more than the same mixture compacted at optimum moisture content (ASTM D558).
4. Changes in cement content, density, and temperature have only a minor effect on the amount of shrinkage compared to the effect of initial compaction moisture content.
5. The spacing and width of the cracks depend on the tensile strength of the soil-cement, shrinkage properties (soil type), and friction between the base and subgrade or subbase.

FIELD PRACTICES

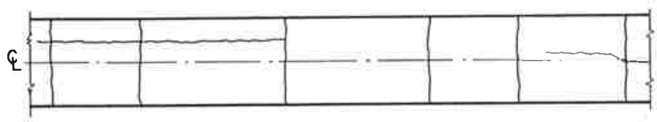
Experience and present practice with conventional bituminous surfaces and other surfacing practices to reduce or retard reflective cracking are summarized in the following sections to help in preparation of designs for soil-cement.

Bituminous Surface Treatment

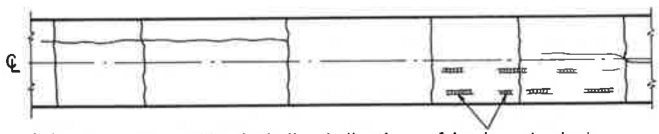
Experience shows that fewer shrinkage cracks reflect through a bituminous surface treatment than through an AC surface. Those that do reflect through are narrow and difficult to see because of the texture of the surface treatment. Many miles of soil-cement pavement having a double bituminous surface treatment (DBST) or a triple bituminous surface treatment (TBST) have served adequately for traffic and exposure conditions suitable for this type of surface.

North Carolina built about 900 miles of soil-cement on low-to-moderate traffic roads in the central and western part of the state after World War II. A surface called a "prime, mat, and seal" was used. A cutback asphalt was used in the prime, which was then sanded with 18 lb of sand per square yard. The mat called for 0.4 gal of hot asphalt and 40 lb of chips per sq yd, and then cutback asphalt was used in the seal. Half the cutback asphalt was placed, followed by 30 lb of seal chips per sq yd, and finally the remainder of the asphalt was applied. The final surface was broom-dragged

Figure 1. Typical transverse and longitudinal reflective cracks and cracking indicative of inadequate design.



(a) Typical reflective cracking



(b) Reflective cracking including indications of inadequate design

Figure 2. Initial shrinkage of a fine-grained and a granular soil-cement mixture after 14 days' moist curing, drying to 75 percent relative humidity, where 80 to 90 percent of the shrinkage occurred, and rewetting to 100 percent.

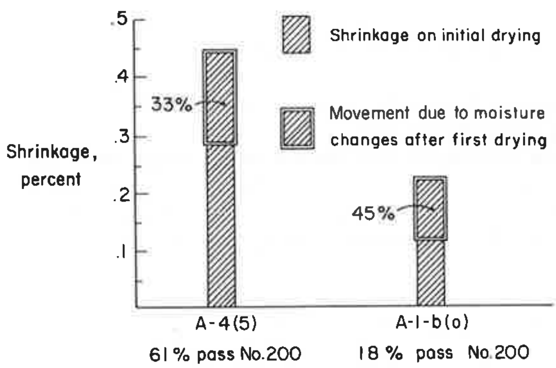
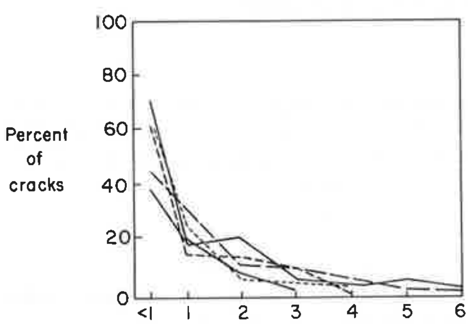


Figure 3. Frequency distribution of various width cracks on three Australian soil-cement airports.



and rolled. This surface treatment tends to seal any cracks that come up from the base. An inspection of many miles of these roads when they were up to 8 years old showed very few visible reflective cracks. Because most of these projects are now 20 to 25 years old, nearly all of them have had resurfacings.

A TBST is being used on some secondary state and parish roads in Louisiana. Asphalt cement is used with a wide range of aggregate types. Quantities of materials per square yard consist of 0.40 gal of asphalt and 0.0200 cu yd of 1½-in. maximum size aggregate for the first application, 0.30 gal and 0.0111 cu yd of ¾-in. maximum size aggregate for the second application, and 0.20 gal of asphalt and 0.0075 cu yd of ½-in. maximum size aggregate for the third application. A November 1971 inspection of a number of miles in Vermillion Parish showed very little visible reflective cracking in these surfaces. Some soil-cement projects in the same area have 1-in. hot-mix AC surfaces, and reflective cracks are very evident. By the end of 1973 Vermillion Parish will have 400 miles of soil-cement parish and state roads. Soil-cement pavements are particularly advantageous in this area because of the high water table.

The Nova Scotia Highway Department has developed an armor coat for soil-cement on its secondary system that is believed to minimize reflective cracks. When placed over a sanded curing seal the armor coat consists of the following applications per square yard from the bottom up: 65 lb ¾-in. stone, 0.40 gal RS-2K emulsion, 35 lb ½-in. stone, 0.40 gal RS-2K emulsion, and 20 lb of minus No. 4 sand. The soil-cement pavements will require additional service life to determine the benefit of this surface in minimizing reflective cracks.

New Brunswick uses soil-cement with a triple bituminous surface treatment on its secondary road system. One popular method is to place 2 layers the year of construction and the third layer the following year.

It must be recognized that surface treatments are only suitable in the light-to-moderate traffic range and that in northern areas they may be damaged by snowplows.

Hot-Mix Asphaltic Concrete Surfaces

As traffic volumes increase, thicker AC surfaces are commonly used. Designs include several variations.

California, one of the leading users of granular soil-cement (CTB), reported in 1969 the results of a survey of 175 projects built between 1950 and 1962 (18). California uses 120-150 penetration asphalt in the mountainous areas and 85-100 penetration in valley and desert areas. The surface contains the highest asphalt content (4.5 to 6.0 percent residual) consistent with other specification requirements such as stability. On projects where a comparison between AC surface thickness and longitudinal and transverse cracking was made, 80 percent had surface thicknesses of 2 to 3 in. The remaining 20 percent were thicker. The California report considers an average granular soil-cement pavement to have narrow transverse cracks at a spacing of about 20 ft, with a small amount of intermittent longitudinal cracking. Of the projects, 64 percent were rated as giving excellent service, 17 percent were rated good, 8 percent fair, and 11 percent required extensive maintenance early in their design lives due to several inadequate design and construction factors.

Transverse and longitudinal cracking was not significantly affected by an increase in compressive strength of the base, type of terrain, amount of commercial traffic, season of the year constructed, or type of cement (I or II). However, reflective cracking was affected by thickness of bituminous surface, use of one- or two-layer construction for an 8-in. thick base, mixing method, and geographic location.

California now uses a minimum surface thickness of 3 in., and reflective cracks are minimal.

The state of Washington normally has used a 3-in. AC surface with 85-100 penetration asphalt directly on a 6-in. soil-cement base. Highway I-5 in western Washington, built in 1954-1955, carries high traffic (35,400-44,200 ADT with 1,400 single-unit and 1,300 combination trucks in 1966). In general, the sections on I-5 have been overlaid, in some areas twice. Other projects built between 1959 and 1965 in the Tacoma-Bremerton Area (carrying 4,000-11,000 vpd) are in good condition, with less-than-average amounts of cracking. This may be partially due to the small temperature variations and high moisture conditions in that area. This effect of geographic location is in agreement with the results of the California study. Reports indicate that Interstate projects built in eastern Washington in the late 1950's and early 1960's have a more pronounced crack pattern, with a spacing of 20 to 30 ft, but did not require overlaying in the first 10 years. Now that these projects are approaching 15 years, they appear to require resurfacing. This is in contrast to I-5, which carried much more traffic and required overlaying in the first 10 years.

The Oregon State Highway Department uses a 2-layer AC design on granular soil-cement bases and reports no reflective cracking. A significant factor in this design is that the first 2-in. layer of Class B AC contains about 6½ percent asphalt and a void ratio of 2 percent. Either a 60-70 or 85-100 penetration asphalt is used with an open-graded coarse mix. The second 1½-in. layer has about the same gradation as the first lift except that the asphalt content is reduced to about 5 percent, with a void ratio of 5 percent.

Prince Edward Island, Canada, has over 800 miles of soil-cement pavement. The 3-in. AC surface (150-200 penetration asphalt) is placed within 5 days and commonly the same day as construction of the base. Reflective cracks appear at regular intervals. To minimize reflective cracks, a softer SC-6 asphalt will be tried on future projects. It has been suggested that delaying placement of the AC surface will also be helpful.

Delayed Surface Placement

Delaying placement of the bituminous surface provides time for much of the total shrinkage of the base to occur before the surface is placed. This should result in less shrinkage of the base after the surface is placed and less reflective cracking through either AC surfaces or surface treatments.

Edmonton, Alberta, which has about 15 million sq yd of soil-cement, is an exception to this rule. This city generally places a 2-in. AC surface containing 200 penetration asphalt within 48 hours. The actual reflective cracking varies from only 1 or 2 cracks in many blocks to a normal 15- to 20-ft spacing in others. Sufficient project data are not available to determine the reason for the variation. Edmonton soil-cement has had no significant maintenance in the 12-year period since the first projects were built.

Higher Penetration Asphalt

When a softer or higher penetration asphalt is used, the AC surface is less brittle and the cracks tend to heal under traffic during warm weather. The highest penetration asphalt commensurate with adequate stability for the traffic and climatic conditions should be used.

Canada's Sainte Anne Test Road (19) showed that the viscosity of the asphalt is also a significant variable affecting reflective cracking. A surface incorporating both properties of high viscosity and soft grade asphalt (SC-3000) showed the greatest resistance to cracking.

At the Sainte Anne Test Road, asphalt content and aggregate gradation were not significant variables in reflective cracking of flexible base pavements.

Delayed Multiple Layers

Delayed multiple layers is another version of AC surface construction. About 99 percent of the subdivision residential streets in the rapidly growing urban area of Dekalb County, Georgia, are soil-cement. A one-week waiting period is required between placement of a 1-in. binder course and a 1-in. surface course. A minimum of reflective cracking occurs.

The Alberta Highway Department has built about 1,200 miles of soil-cement. A 2-in. road mix using 4 percent MC 250 asphalt is placed the year of construction; 1 to 3 years later a 2- or 4-in. AC surface (6 to 6½ percent, 250 minimum penetration asphalt) is applied, followed during the next 1 to 3 years with a seal coat consisting of 0.25 gal per square yard of cationic emulsion and 30 lb of ½-in.-maximum chips.

On a project north of Edmonton the soil-cement base and asphalt surfaces extend through the shoulder, and the seal coat covers the traffic lanes only. Reflective cracks are evident in the shoulder at about a 20- to 25-ft spacing. They are much less evident in the traffic lanes that have the seal coat. There is some longitudinal cracking in this wider pavement, with a predominant crack about 3 ft in from the outside shoulder edge that could be caused by subgrade movement.

Two-Stage Construction

Wyoming has several hundred miles of granular soil-cement built using 2-stage construction of the AC surface. Many of the projects inspected in 1971 have only the first stage of 2-in. AC surfacing, which was placed in the late 1950's or early 1960's. Generally, reflective cracks in the first-stage surfacing occurred during the first 2 years. On some projects an attempt has been made to seal the cracks, at first with asphalt cements, more recently with liquid asphalts and emulsions. Only a limited amount of crack sealing had been done until 1970. The transverse reflective cracks are 15 to 25 ft apart, with closer-spaced block cracking occurring on some projects. The cracks in the outer lane tend to seal together due to traffic, which produces a slight indentation or "necking-down" of the asphalt on some of the projects. However, joint noise was evident only on a few jobs. The transverse cracks in the inner lane are not sealed shut by traffic; they have some breaking down of the asphalt, but the lane rides well. Most second-stage construction includes sealing of existing cracks with emulsion or liquid asphalts prior to paving. After placement of the second-stage surfacing (2-in. AC or 1½-in. AC plus a ¾-in. plant-mix seal), often 10 or more years after initial construction, transverse cracks reflect through the new surface at 60- to 100-ft spacings in 1 or 2 years. An experimental second-stage project was constructed using plain AC on the lanes on one side of a 4-lane divided highway and a latex additive on the other side. After nearly 3 years, much less reflective cracking has occurred on the lanes containing the latex additive.

The Wyoming granular soil-cement projects are serving satisfactorily. Many sections have reached or surpassed design life expectancy for first-stage construction based on current AASHO design standards and have had no significant engineering or maintenance problems, even though reflective cracks have been in evidence since shortly after the projects were built. A very few areas show some structural failure in the wheelpaths that may be due to inadequate cement content and subgrade support.

New Mexico has a number of CTB projects built with 2-stage surfacing construction. Five projects built between 1957 and 1961 on I-40 west of Albuquerque were inspected. They consist of a 3- to 4-in. AC surface, 4- to 6-in. granular CTB, and variable subbase. As part of stage construction, a 2-in. AC surface or 1-in. AC plus ½-in. plant-mix seal coat was placed after 4 to 7 years. In the 6 to 7 years since overlaying, transverse cracks slightly over ⅛ in. have appeared at 40- to 55-ft intervals on 4 of the projects. One project has very narrow cracks spaced at 20 ft.

Of 4 other conventional CTB projects on US 70 northwest of Lordsburg, built between 1961 and 1964, 2 projects have typical transverse reflective cracks ⅛ in. or less in width at 30- to 50-ft spacing and 2 projects have very few cracks.

Most of the conventional New Mexico projects have typical crack patterns. The projects are satisfactory, and cracking is causing no excessive maintenance problems.

Special Treatments

The various versions of conventional bituminous surfaces discussed have generally provided surfaces that have not had excessive detrimental reflective cracking. With a properly designed asphalt mix and an adequate soil-cement base design, the cracks that occurred have not caused engineering problems in most situations. In some areas additional means for further reducing reflective cracks may be justified. Based on present knowledge, the designs discussed in the following sections should be helpful in further minimizing and delaying reflective cracking. They will not produce a permanently crack-free surface on soil-cement or on any type of base course. When the cracks do appear over a period of time they should be narrower than the cracks that would normally occur.

Bituminous Surface Treatment Between Soil-Cement Base and Asphaltic Concrete Surface

The use of a DBST or SBST followed in 30 days or more by an AC surface delays occurrence of reflective cracks. When cracks do appear, the width is somewhat narrower than the width of those that occur where no surface treatment is used. Although not now a standard design except for some Michigan county work, projects have been built in Georgia, Iowa, Tennessee, and Michigan.

In Huron and Genesee Counties, Michigan, a single surface treatment of AE-3 emulsion and stone chips is placed within 3 days after base construction. This is followed in 30 to 90 days with an AC surface. Severe climatic conditions and de-icing procedures on the county projects in Michigan are not having any adverse effect on the reflection cracks that do occur.

Upside-Down Design

The upside-down design has been used extensively in New Mexico, Arizona, and British Columbia.

New Mexico, where the upside-down design originated, has many miles of CTB in service. This design adds an untreated granular layer between the cement-treated base and the bituminous surface to minimize and delay reflective cracking. The typical design, from the bottom up, consists of 0 to 6 in. of granular subbase, depending on the subgrade soil; 6 in. of CTB with 3 to 5 percent cement; 4 to 6 in. of untreated granular material; a 3½- to 4-in. AC surface; and a ½- to ⅝-in. plant-mix seal coat placed at time of construction or a few years later. The material treated with cement meets specification requirements of granular base material.

Inspection of 13 projects, most of them 4 to 6 years old, on 3 Interstate routes indicates that reflective cracks in upside-down CTB pavements under New Mexico conditions do not appear for 3 to 5 years; when they do appear, they are narrow and spaced farther apart than normal. Plant-mix seal coats applied as stage construction temporarily seal reflective cracks. As is the case with all bituminous-surfaced pavements inspected regardless of base type, additional cracks appear with time. It has not been determined what percentage of the cracks have reflected from the granular CTB or originate in the AC surface.

The upside-down projects inspected in New Mexico are serving satisfactorily. No maintenance problems are evident at this time, although a 10-year-old experimental section requires overlaying.

British Columbia has used the upside-down design extensively since 1961. The untreated granular layer between the granular soil-cement base and the AC surface is commonly 3 in. thick, has a maximum minus No. 200 content of 9 percent, a maximum PI of 5, and is usually of higher quality than the material used for the granular soil-cement base.

The AC surfacings used in the mountainous areas of British Columbia have a 120-150 penetration asphalt, whereas 85-100 penetration asphalt material is used in the lower interior and Vancouver areas.

Inspections of some of the British Columbia upside-down projects in October 1971 did not permit an estimate of the time required for the cracks to reflect through the AC surface (3 to 5 years was determined in New Mexico). Several projects built in the early 1960's in areas of low elevation, small temperature range, and high precipitation have very few if any cracks. A classic example is the 16-mile 4-lane divided freeway built in 1961-64 on Route 401 between the Port Mann bridge and Springbrook Road near Vancouver. The project has a 3-in. AC surface over 4-in. untreated granular layer on 6 in. of granular soil-cement containing 5 percent cement by weight. The project carries about 24,000 vpd with 3 percent trucks. Maximum and minimum mean daily temperatures range from 72 to 29 deg. Mean yearly precipitation is 60 in., and the elevation is 500 ft. The project is in excellent condition, and only two reflective cracks were noted in the 16 miles.

Projects built between 1966 and 1969 at higher elevations with larger temperature ranges and lower precipitation have typical reflective cracking but have good riding qualities. These projects at higher elevations were inspected in the British Columbia Design Engineering Department by viewing strip photographs obtained on the projects with their photographic inventory device.

The conventional granular soil-cement pavements in the Vancouver area have somewhat more cracking than upside-down projects in the same location. The conventional soil-cement projects are giving good service, however.

The untreated layer in the upside-down design must be designed so that it does not collect water.

Asphalt-Ground Rubber Treatments

Gallaway and LaGrone (20) have suggested that a strain-relieving interlayer utilizing ground-vulcanized-rubber aggregate, mineral filler, and anionic asphalt emulsion can be used as a crack arrestor between a base course and bituminous surface. It has been reported that the allowable foundation movement before cracks reflect through the surface course would be 300 percent greater using a ⅛-in. strain-relieving interlayer and 440 percent greater for a ¼-in. layer. Strain-relieving interlayers of more than ½ in. are not recommended because of possible stability problems.

A test section using a strain-relieving interlayer as part of an overlay project was built in College Station, Texas (21). In spite of some unanticipated problems, a practical construction method was worked out.

C. H. McDonald of Phoenix has done considerable field work on fatigue cracking of bituminous surfaces to prevent further distress of various types of pavement (22, 23). This patching or overlaying work originally involved the use of various types of elastomers. For economic reasons, however, ground rubber from old tires was subsequently used. From 20 to 35 percent rubber and from 65 to 80 percent 120-150 penetration grade asphalt by weight is normally used, depending on traffic and climatic conditions. Test panels employing 33 percent rubber have been tested on cracked flexible pavements under severe winter conditions in the West at elevations up to 7,000 ft without developing reflection cracking.

In 1966 three small asphalt-rubber test sections were placed in Phoenix on soil-cement pavements that had reflective cracking (23). The material covered the cracks and has prevented further reflective cracking.

This discussion of ground rubber-asphalt mixtures has dealt mostly with its use in maintaining bituminous-surfaced pavements that have already cracked. In areas where reflective cracks in soil-cement pavements are a concern, it is suggested that the rubber-asphalt mixture be tried at time of original construction by using it as a seal coat on the AC surface or as a double bituminous surface treatment or thin plant-mix surface placed directly on the cured soil-cement base where traffic will permit this type of surface.

Maintenance of Reflective Cracks

From a performance standpoint, experience has shown that it is not necessary to seal fine shrinkage cracks that reflect through the bituminous surface. Sealing these cracks is not effective and usually detracts from the appearance of the pavement. In many cases, periodic resealing of the asphalt surface will cover the fine cracks.

Cracks ⅛ in. and wider may require sealing, depending on local climatic conditions. The cracks should be cleaned thoroughly and all spalled pieces of the surface removed. Liquid asphalt or asphalt emulsion slurry can be used to fill the cracks. The asphalt kettle and hand-pouring pot are commonly used. Special nozzles or attachments are helpful in controlling the flow of material into the crack. Emulsion slurry or liquid asphalt (SS-1, SS-1h, SM-k) mixed with sand can be used in the widest cracks. This mixture should be broomed into the opening and the surface of the cracks sealed with liquid asphalt. An application of sand over the bitumen will prevent pickup by traffic.

An interesting method of sealing cracks in the bituminous surface has been developed in District No. 4 of the Colorado Department of Highways. An average rate of 0.15 gal of MC-70 is applied followed by about 6 lb of blow sand per square yard. Motor patrols with rubber cutting edges then squeegee the materials across the roadway to the center, then back to the shoulder, where all excess material is wasted. This squeezes the batter-like mixture into the cracks. The final step is to apply a blotter of any clean sand or crusher waste over the surface. Cost for materials and labor is estimated at 3 to 4 cents per square yard. Soon after the sealing operation, the cracks on a soil-cement project appeared to be very well sealed. On a flexible-base project 1 year old the cracks were starting to become visible but were still sealed. Long-term performance has not been determined.

The New Mexico State Highway Department has experimented with several crack-sealing materials. One that looks particularly promising is a mixture of 90 percent AE-5 emulsion and 10 percent latex, which requires no heating. A few test strips near Santa Fe looked good.

As discussed earlier, Phoenix is using asphalt-ground tire rubber treatments to maintain cracked flexible pavements. In the chip seal process the asphalt is heated to a temperature between 350 and 400 F; 25 percent ground tire rubber, No. 16 to 25 mesh size, is added, followed by 5.5 to 7.5 percent kerosene to reduce the viscosity for spraying. After application, ⅜-in. chips are applied. A similar ½-in.-thick plant-mix surface using ¼-in. aggregate is also being used.

Slurry seals are particularly popular in the Southwest and West (24). Proponents cite their good crack-filling properties and low cost. It is reported that Waco, Texas, has placed slurry seal directly on soil-cement bases. A number of articles report on the use of slurry seals to fill cracks in any type of pavement.

The NCHRP and FHWA experimental projects referred to earlier will provide helpful information on maintenance of reflective cracks in all types of bituminous-surfaced pavements.

SUMMARY AND CONCLUSIONS

Shrinkage of soil-cement and the resulting cracking should be recognized as a natural characteristic of soil-cement. The cracks are not the result of structural failure.

Laboratory research and field experiments have provided valuable information on the factors that affect shrinkage properties of soil-cement and on ways to minimize the number of cracks that reflect from the base through the bituminous surface. Extensive research is under way on the properties of bituminous materials to provide surfaces with less cracking potential for all types of pavements. A survey of several thousand miles of soil-cement pavements covering a wide range of environmental conditions and other reports of field studies show that properly designed and constructed soil-cement pavements are generally serving satisfactorily and, except for a few localized areas, reflective cracks have had a minimum effect on field performance.

The testing and construction procedures given in the following list should be considered to minimize shrinkage of the soil-cement base and the amount of reflective cracking through the bituminous surface; the recommendations apply to fully hardened soil-cement tested by the standard soil-cement tests and PCA weight-loss criteria or material of equivalent quality:

1. If a choice of soil type is economically feasible, use a granular soil material or at least one with minimum clay content, which produces less shrinkage.
2. During construction, compact the soil-cement as close to optimum moisture (AASHO T134 or ASTM D558) as possible—not too wet. Cure the soil-cement quickly to prevent early rapid evaporation of moisture.
3. After delaying as long as practical to allow the soil-cement base to shrink, place the bituminous surface. Fewer cracks reflect through a surface treatment, commonly used on lightly traveled pavements, than reflect through an AC surface used for higher traffic volumes. When hot-mix AC surfaces are used and placed in two layers, a delay period of at least 1 week between layers is beneficial. Use of a high asphalt content in the first layer with a lower content in the top layer is also helpful. Except in very-high-temperature areas use high-penetration, high-viscosity asphalts.
4. In some areas other special treatments have been used for further reducing reflective cracks. These include (a) a surface treatment between the soil-cement base and AC surface, (b) the upside-down design, and (c) asphalt-ground rubber treatments.

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