Transverse Cracking of Asphalt Pavements

Summary Report of a Cooperative Analysis by Teams from Iowa, Kansas, Nebraska North Dakota and Oklahoma

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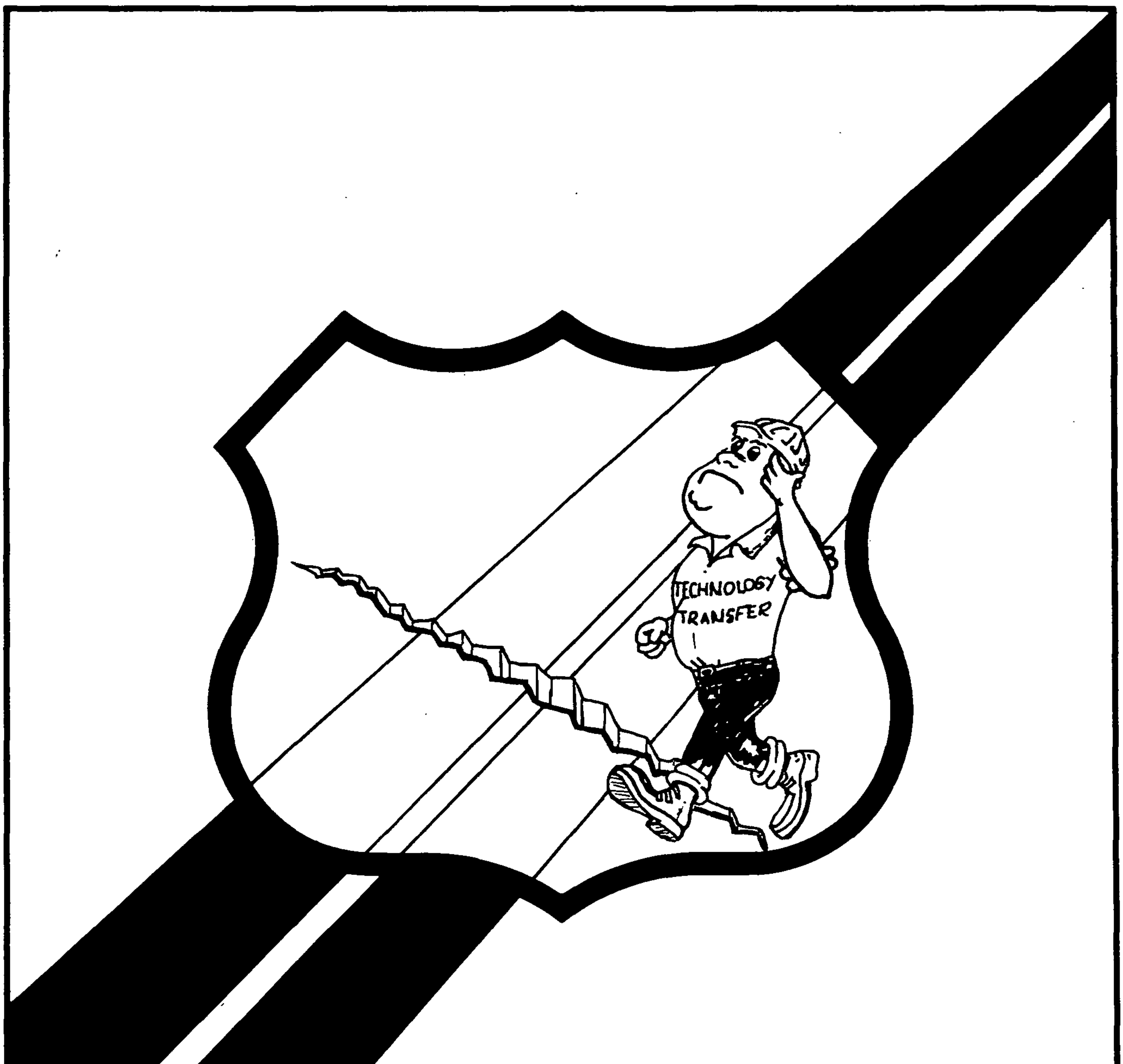

FOREWORD

This Tech Share summaries the analysis of tranverse cracking in asphalt pavements by a study team from the five States of Iowa, Kansas, Nebraska, North Dakota, and Oklahoma. The report should be of interest to pavement designers and maintenance engineers concerned with the performance of asphalt pavements.

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NOTICE

TRANSVERSE CRACKING OF ASPHALT PAVEMENTS

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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
Fahrenheit degree	5/9	Celsius degrees or Kelvins*
inches	2.54	centimeters
gallons per square yard	4.5272643	liters per square metre
ounces per square yard	33.90574972	grams per square metre
pounds per square yard	0.542492	kilograms per square metre
pounds per square inch	0.006894757	megapascals
dollars per square yard	1.19599005	dollars per square metre

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F-32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F-32) + 273.15$.

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SUMMARY

This report summarizes the analysis of transverse cracking in asphalt pavement by a five state study team from Iowa, Kansas, Nebraska, North Dakota, and Oklahoma. The study was initiated under the sponsorship of the Federal Highway Administration and four evaluation conferences were held during the course of the study.

Each state conducted a crack inventory on their asphalt pavement. An effort was made to correlate this inventory with numerous factors that were considered to be pertinent to the cracking problem. One state did indicate that there was a correlation between transverse cracking severity and the subsurface geology. The other states were unable to identify any significant factors as being the primary contributors.

The analysis of the problem was divided into, (1) mix design, (2) maintenance, and (3) 3R rehabilitation. Many potential factors to be considered were identified under each of these three study divisions.

There were many conclusions as to good and bad practices. One major conclusion was that a more effective crack maintenance program with early sealing was essential. Some new practices were suggested as potentially more cost effective in design, construction and maintenance. The interchange of methods and procedures by individual states yielded benefits in that other states selected practices that would be an improvement to their program.

BACKGROUND

Transverse cracking of asphalt pavements has been a problem since asphalt was first used as a pavement material. The suggested causes for this phenomenon consist of, but are not limited to, ambient temperature changes, base or subbase, temperature susceptibility of the asphalt, grade of asphalt, mix stiffness, subgrade, etc. Crack filling and sealing efforts range from very extensive to none at all because of other work interferences such as snow storms, brush cutting, etc. Cracks which are not sealed at an appropriate time tend to deteriorate more rapidly and result in unsatisfactory riding quality. This, in turn, accelerates the rate of deterioration and more extensive repairs and resurfacing or rehabilitation are required.

Through the years, there has been much research and many reports have been written on the subject of eliminating or reducing the amount of transverse cracking in asphalt pavements. Most of these have indicated that transverse cracking can be reduced through mix design procedures and asphalt grade and quality controls. There do not seem to be any follow-up reports indicating significant success using these procedures.

At a pavement management study meeting in Omaha, Nebraska, September 12 and 13, 1979, the states of Iowa, Kansas and Nebraska agreed on the need for an in-depth engineering study of thermal cracking of bituminous pavement. Later, the states of Oklahoma and North Dakota agreed to participate in the study.

The scope of the study was to analyze all functions relating to thermal cracking to determine how different uses of preventative materials, mix design measures, maintenance repairs, and design of bituminous pavements and overlays might be contributing to the problem and to determine what improvements might be made in these procedures to reduce thermal cracking.

STUDY APPROACH

The cooperative study was conducted in cooperation with the highway agencies in the states of Iowa, Kansas, Nebraska, North Dakota and Oklahoma. The Federal Highway Administration sponsored and funded the study and the details and coordination were handled by a study coordinator working out of the Region 7 Office in Kansas City, Missouri. The study was carried out over a nine-month period in 1980. A value engineering approach was used for the study. Transverse cracking data from existing roadways was collected and studied. No new research was involved, but conclusions were drawn by reviewing the available data. This report was prepared upon completion of the study, based on the developments in the four-state meetings, and the final reports which were prepared by each of the participating states.

MIX DESIGN

Control of transverse cracking through mix design procedures is a subject which has been addressed in many studies and reports. Some of the studies have suggested the control of cracking through a mix stiffness analysis; some have suggested that cracking can be reduced through the use of softer asphalts while others have suggested that cracking can be controlled through the use of asphalt cements that are less susceptible to temperature changes.

Members of the workshop study group that were assigned to evaluate the mix design process as a means of controlling transverse cracking were aware of many of the studies. No one could relate to any experience in using study suggestions or recommendations which were totally successful in eliminating transverse cracking. The group was in general agreement that appropriate mix design procedures were the first step in the development of quality asphalt pavements. Most of the states have studied these reports in detail and have adopted some of the recommendations, particularly those which could be beneficial without significant increases in cost.

Fifteen factors were identified which should be considered in the design and placement of an asphalt pavement to assure that it will be economical, durable and more resistant to transverse cracking. They are as follows:

1) Distress Evaluation
2) Voids, Permeability, Compaction
3) Asphalt Content
4) Education of Personnel
5) Asphalt Quality
6) Traffic Volume
7) Antistripping Agents
8) Test Procedures and Methods
9) Aggregate Gradation
10) Cold Mix Design
11) Fillers
12) Aggregate Quality
13) Crack Relief Layers
14) Membranes, Fabrics
15) Asphalt Modifiers

A brief duscussion of how these factors are applied follows:

1. Distress Evaluation

Designing a new pavement is generally a straight forward process which utilizes such elements as soil types, traffic volumes and/or projections and structural coefficients to determine the pavement thickness and mix selection.

Designing an overlay for a deteriorated or structurally deficient pavement involves other factors which must be considered in assuring that an adequate structure with a durable surface is attained. Distress evaluation is the first step necessary to achieve this goal. Generally, distress evaluation consists of a visual analysis of the roadway surface condition, a review of the original design characteristics and subsequent rehabilitation or maintenance activities. From this data, a structural number (SN) can be estimated and an appropriate new surface thickness can be determined. The visual analysis can also be used to determine the extent of crack sealing and full depth patching needed to assure adequate surface preparation for the overlay. One state is using a "Road Rater" as an aid in determining how thick an overlay should be to obtain a desired structural number.

2. Voids, Permeability, Compaction

The study group agreed that voids, permeability and compaction are not factors which, by themselves, exhibit significant relationship to transverse cracking of asphalt pavements. They are, however, very important factors of construction contributing to the durability and performance of these pavements (1).

Some of the research reports that were discussed in this study (2, 3, 4) have shown that (a) as the void content increases, the penetration of the recovered asphalt cement decreases significantly with time. (b) The optimum air void content appears to be a maximum of 7-8% in freshly placed dense graded mixes and they should be reduced to no lower than 3% after about three years of additional compaction by traffic.

Most of the states have specified some control of voids through their mix design process. Some have specified void limits for freshly placed mixes. The method of determining pavement density varies with some states using nuclear tests, some physical tests and others using only a rolling specification. States using a specific density specification generally require a minimum of either 92% of theoretical or 94% to 96% of laboratory density. At least one state applies a statistical formula based on an 80% compliance requirement with a price adjustment for failure to meet the test.

3. Asphalt Content

The asphalt content of any asphalt pavement mixture can have a critical effect on thermally induced stresses. A properly designed mix can produce high bond within the matrix with a resulting high internal resistance to thermal stress.

Most states in this study use either the Standard Hveem or Marshall Method in determining the optimum asphalt content for a particular mix. Some states have modified the standard procedures to better fit some of the problems they have with locally available aggregates. At least one state specifies minimum film thickness and a maximum fines-filler/Bitumen ratio. Another state has developed a bearing capacity test which is determined by use of the stability and flow of the Marshall specimen.

Control of the asphalt content in the production process is a problem reported by some states. This seems to come from contractors "shaving" the amount of bitumen added to save money. Some states acknowledge this had been a problem in the past but by resorting to payment for asphalt as a separate bid item the problem had diminished.

4. Education of Personnel

Educating and training both agency and contractor personnel in all areas of quality asphalt mix design criteria as well as in the art of producing and placing top quality pavements can do much to assure that the mix placed is in reasonably close conformance to the mix that was designed.

Most states have "in-house" training programs scheduled for their inspectors and most states also have association or contractor seminars for some of the owners, managers, and first line supervisors. One state reports that the State Asphalt Paving Association conducts a two-day seminar every year to bring together the lower level supervisors, operators and agency inspection personnel. Experts are brought in from local or adjoining State Highway Headquarters as well as from equipment and supply manufacturers and distributors to talk on such subjects as specifications, mix design, aggregate production and gradation control, plant calibration and operation, segregation, paver operation and compaction, as well as safety and other subjects which might benefit those intimately involved in the work. Attendance of owners and managers at this meeting is discouraged.

5. Asphalt Quality

There has been much work done with regard to pavement performance and asphalt quality. Dr. Norman McLeod (5, 6) suggests we can expect our asphalt pavements to crack at about +10°F (-12°C). He further suggests the use of softer asphalt cements with low temperature susceptibility can eliminate or reduce the amount of low temperature transverse cracking.

Other work (7) has shown that specimens made with absorptive aggregate and high penetration asphalt cement cracked more than specimens made with lower penetration asphalt cement when subjected to wet-dry cycles. Another report (8) suggests that resistance to thermal cracking can be expected if, after ten years, penetration of the extracted asphalt is no less than 25.

None of the states involved in this study had data to support alleged changes in the general quality or performance characteristics of asphalt cement since the 1974 oil embargo (9).

In selection of the asphalt used in specific projects, all states indicated they select on the basis of the grade best suited for their climate and/or traffic situation. Some states will, on occasion, specify ASTM or AASHTO Table 2 viscosity graded asphalts for special situations. None of the states indicated they have rejected a particular source because of temperature susceptibility. It was agreed that such a move, while perhaps desirable from a pavement cracking standpoint, would drastically limit sources and increase costs for asphalt cement.

6. Traffic Volumes

None of the states involved could site any correlation between traffic volumes and non-load associated transverse cracking. It was generally agreed that knowing the traffic volume and percent of trucks is of importance to the pavement designer as well as the mix designer in determining what type of mix, mix stability, asphalt content, and void percentage would be best suited for the particular situation.

7. Antistripping Agents

None of the states have used antistripping agents to any degree. Hydrated lime has been used in some states where specific aggregates are known to have a tendency to strip.

Since there was no knowledge of any reports which allude to the general use of antistripping agents, the group could not speculate on how the agents might benefit the transverse cracking problem. Two current NCHRP projects address the moisture-induced damage (NCHRP 4-8(3)) and the use of antistripping additives (NCHRP 10-17).

8. Test Procedures and Methods

Most of the states do use standard test procedures in mix design and mix quality control. Several states use modified test procedures to better fit local constraints which include, but are not limited to, climatological, geographical, available materials, facilities and budgets.

From the viewpoint of mix design, test procedures and methods appear to be in need of improvement. Conventional tests, or the interpretation of the results of these tests, have tended largely toward the measuring of compliance with certain contractual criteria. Research efforts often have utilized test methodology not readily available to conventionally equipped state highway laboratories. Other research has been entirely too restrictive in scope, failing to point out the non-universality of the specific problem being addressed or to propose a solution.

9. Combined Gradation

Properly combined aggregates are necessary if mix stability, voids, asphalt content and mix textural characteristics are to be maintained at appropriate levels.

All of the states attempt to develop high quality mixes for heavily traveled roads which, in some instances, requires importing a portion of the mix aggregate from a considerable distance. For lower traffic roads, the tendency is to design the best mix possible with locally available aggregates.

There was general agreement that better control of the aggregate combinations would do much to improve the mix characteristics but that in many instances the costs would be prohibitive.

10. Cold Mix Design

All of the states in the study have a considerable mileage of cold mix bases, most of which have been in service for ten years or more. None of the states are currently designing or building a significant amount of new cold mix pavements. Several states reported that the performance of cold mix bases ranges from very poor to very good with respect to transverse cracking. No one could suggest a reason for the variance other than the probability that the poor performers were deficient in asphalt and those which resisted cracking were probably over asphalted with significant rutting and flushing.

It was agreed that because of the current energy situation and the shift to emulsified asphalts, there is need for further research in cold mix design.

11. Fillers

Filler is generally defined as the material passing the No. 200 (0.075 mm) sieve. The gradation of the minus #200 fraction is seldom examined or seldom specified. Also, the stiffening of the asphalt cement due to the inclusion of these fines is often not considered.

Most states in the study do not require fillers to be added. One state indicated that some aggregate sources produce excessive minus #200 material and in order to control this, they have instituted a fines/bitumen ratio as an aid. One state uses fillers quite extensively. They report the use of limestone dust, fly ash, cement plant stack dust and soil filler. One state uses a sand equivalent requirement of 45 minimum to control their problem with kaolinite and other clays.

A report by the Asphalt Institute (10) suggests the advent of the bag house may be contributing to the problem of premature pavement cracking and asphalt aging. A National Cooperative Highway Research Program (NCHRP) has been undertaken to further investigate the subject of bag house fines.

It was the consensus that the subject of fillers and filler quality in asphalt pavements should be investigated further.

12. Aggregate Quality

Quality aggregates are those with good microtexture, high resistance to abrasion, low freeze-thaw loss and low absorption. Aggregates with all of these characteristics are capable of producing high quality mixes with maximum resistance to transverse cracking. All of the states indicated they have a wide variance in the quality of aggregates across their respective states, with a very limited supply of the high quality aggregates previously described. Because of the economic impact of requiring top quality aggregates in all asphalt mixes, all of the states have developed aggregate quality requirements and mix design parameters to utilize the best aggregates available for a particular area or project, even though some of the mixes can be expected to develop transverse cracks at an early age.

13. Crack Relief Layers

Crack relief layers are usually considered to consist of a 2½" (6.35 cm) to 3½" (8.89 cm) layer of 3" x 3/4" (7.62 cm x 1.91 cm) or 2" x 1/4" (5.08 cm x 0.64 cm) crushed aggregate with a thick asphalt film and are placed between an existing pavement and a new surface. This is known as the Arkansas Method.

None of the states in the study have any experience with this method of controlling transverse cracking, although one state has indicated it has an experimental project scheduled for 1981.

14. Membranes and Fabrics

Membranes and fabrics have been used on a limited or experimental basis by several of the states. None of the states reported any definite conclusions as to their success in eliminating transverse cracking. There was some indication that these treatments tend to reduce reflection cracking of fatigue type cracks in overlays but would not reduce reflection of cracks that react with temperature changes or movement due to traffic.

One state uses fabrics under seal coats and thin overlays. It was generally agreed that fabrics placed under less than 2 inches (5.08 cm) of surface were not effective in reducing or significantly retarding transverse crack reflection. Fabrics are equivalent in cost to about 1 inch (2.54 cm) of surface.

The use of fabrics in rehabilitation and maintenance is discussed elsewhere in this report.

15. Asphalt Modifiers or Substitutes

Asphalt modifiers or substitutes appear to have potential for reducing or retarding transverse cracking of asphalt pavements.

Several of the participating states have used some of the modifiers and substitutes currently available, however, no definite conclusions have been reached with regard to the total benefits of any of them. Among those currently being evaluated are:

1. Chem-Crete, a product marketed by the Chem-Crete Corporation, Menlo Park, California.

2. Asphadur or Additive 5990, a product marketed by the 3M Company.

3. Sulphlex, a product which is currently totally experimental.

4. Hydrated Lime, a readily available product to reduce stripping and early asphalt aging.

5. Sulphur, a product which may become more available by 1985 as an extender of asphalt.

6. Reclamite, a rejuvenating agent, used as a surface rejuvenator.

MAINTENANCE

After the initial meeting of the study group, each of the states conducted a survey of its flexible base bituminous roads to determine the magnitude of the cracking problem. There was also an attempt made to try to correlate the severity of the cracking problem to an identifiable factor such as base or sub-base type, asphalt mix, geographic location, climatological influence, type of asphalt, geological features, etc.

One state did indicate that there was a correlation between transverse cracking severity and the subsurface geology. The other states were unable to identify any significant factors as being the primary contributors, although most states concluded that climatological influence did contribute to the frequency of crack spacing. The need for more research in this direction is indicated. These factors should be recognized in pavement management systems and should also be recognized in pavement design.

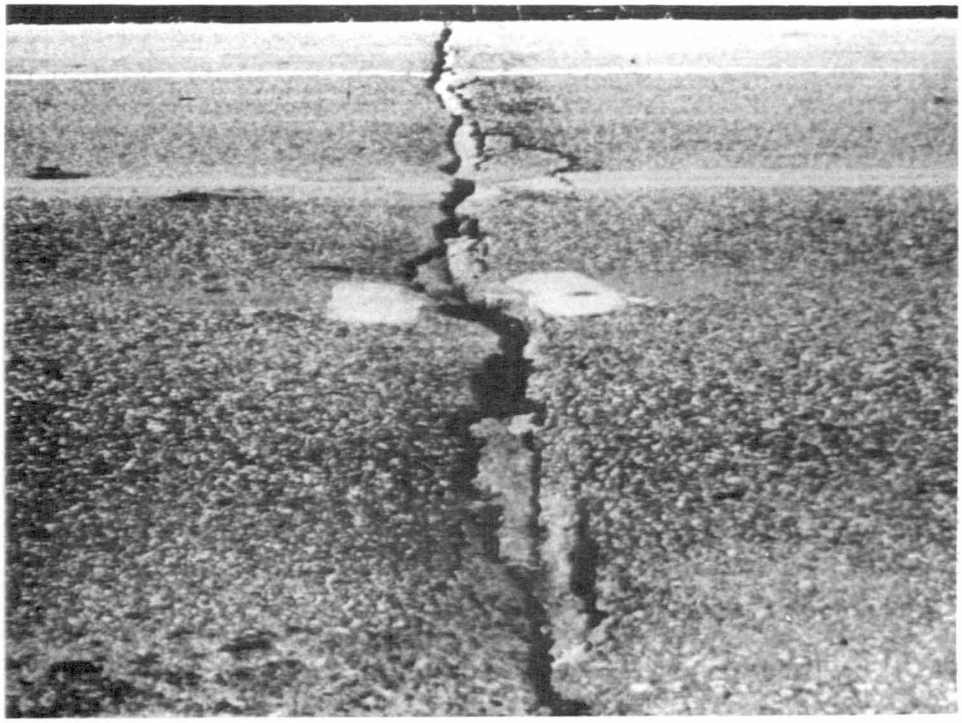
Maintenance of Transverse Cracks

Fog Seal:

Four of the five states in this study use fog seals (usually with dilute emulsion) as the first preventive maintenance procedure. Fog seals are applied as soon as the first hairline cracks appear or raveling of the surface is apparent. One state's policy is to apply a fog seal within one month after placement of a new mat and it is reapplied annually. The other three states begin fog seals as soon as initial or hairline cracks appear. One state uses MC-70 or MC-250 applied at 0.05 to 0.08 gal. per sq. yd. (o.23 to 0.36 liters per sq. meter) for fog seals. The other states use dilute emulsions. Dilution rates vary slightly but are in the range of one part emulsion to 5 to 10 parts water. Recommended application rates are from 0.10 to 0.20 gals. per sq. yd. (0.45 to 0.91 liters per sq. meter) of dilute emulsion. These light applications do not normally require application of sand cover. All of the states that include fog seals as a part of their routine maintenance procedure believe that this is cost effective and retards development of cracks or surface deterioration that will require more costly maintenance procedures.

Crack Filling:

All states in the study recommend that larger transverse cracks (figure 1) be filled with some type of bituminous crack filler.



(Figure 1)
Badly deteriorated transverse crack.

One state starts filling cracks when they become 1/8 inch (0.32 cm) wide, the other states begin filling cracks when they reach the 1/4 inch (0.64 cm) to 3/8 inch (0.95 cm) range. The recommended method of cleaning cracks is either air blast or high pressure water to clean the crack before it is filled. Crack filling materials included cut backs, emulsions, emulsion slurry, asphalt cements, and rubberized asphalts. Three states reported excellent results in sealing cracks with rubberized asphalt blended in the field in standard maintenance distributors.

It was agreed that asphalt cements, cut backs and emulsions do not seal the wider cracks but do provide a filler and thus reduce the amount of water that can infiltrate the base and weaken the road structure. Crack filling equipment (figures 2 and 3) used was, in general, the same for all the states involved in the study; i.e., crack cleaning equipment, an asphalt distributor and hand pouring pots or a hand hose applicator of some kind.

(Figure 2)
Crack sealing equipment.

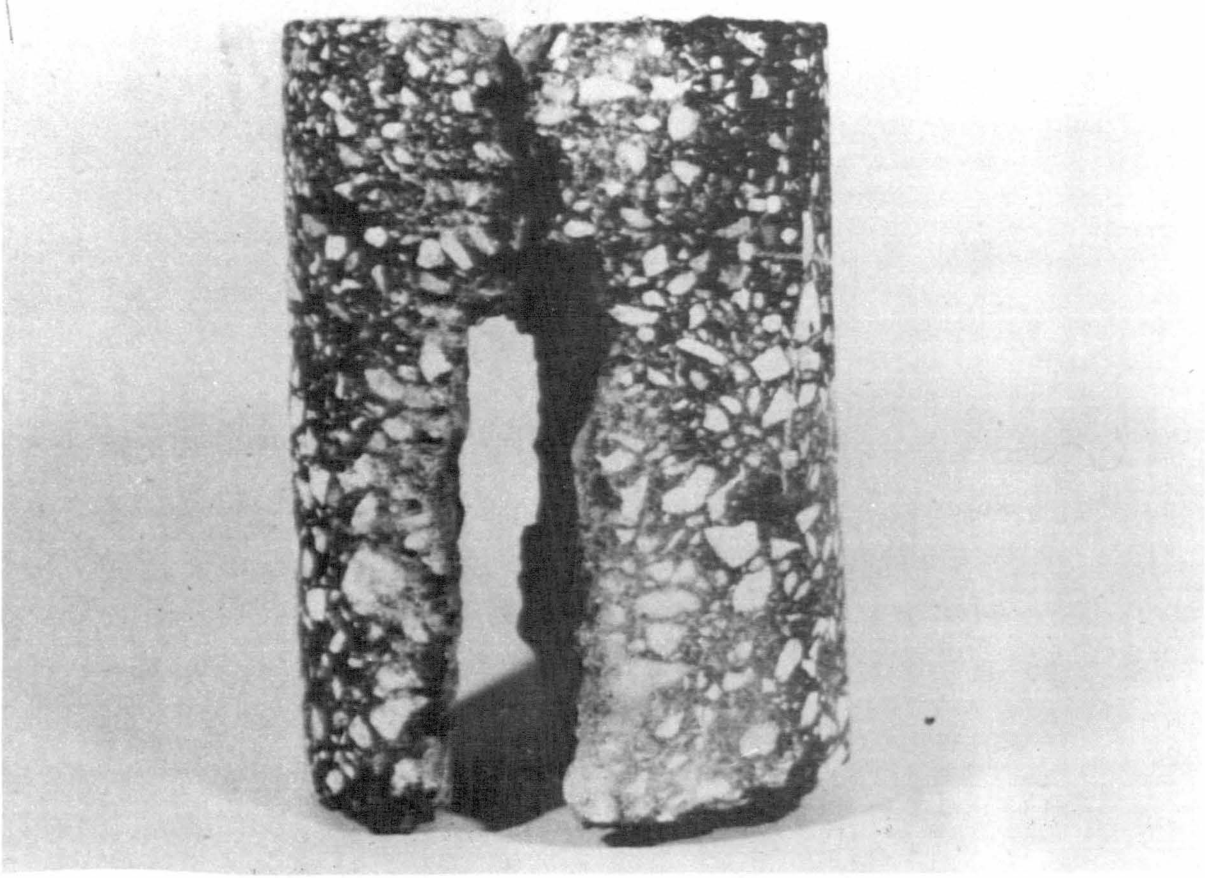
There was no disagreement on the necessity of crack filling and preferably crack sealing for the preservation of bituminous pavements. It was also recognized that transverse crack maintenance is costly, time consuming, and very labor intensive.

Rubberized asphalts, though somewhat higher in material cost, appear to be the most cost effective if placed in a properly prepared crack. The crack faces must be clean if proper adhesion to the sides of the crack is to be achieved. Wider (3/8 inch to 1/2 inch or more)(0.95 cm to 1.27 cm or more) cracks should be "choked" or partially filled with a compressible material prior to the application of the rubberized asphalt.

(Figure 3)
Sealing of a crack.

Crack Repair:

Procedure for restoring the riding quality of the road surface after depressions develop adjacent to transverse cracks was essentially the same in all states. Narrow cracks are filled with liquid bitumen and wider cracks are filled with slurry or bituminous mix after which the depression is leveled using cold mix or slurry. One state has developed a procedure and equipment for pressure injecting slurry into the cavity (figure 4) that is almost always present at the bottom of cracks that exhibit a depression on the surface. Although it is intended that this slurry injection will effectively fill the void and deter further distortion at the crack, the method is too new to make any factual claims.



(Figure 4)
Large void under a transverse crack.

Patching:

Repair of cracked areas, whether surface failure or base failure, are handled essentially the same by all the states involved in the study. Localized surface failures evidenced by cracking or raveling are given what amounts to an inverted penetration seal. Base failures require removal of the unstable material and restoring the area with stable material. Drainage of the base in the area will be included with the repair, if warranted.

3R REHABILITATION OF TRANSVERSE CRACKS

Transverse crack reflection through asphalt overlays has historically been a serious problem. Infiltration of moisture into the subgrade through these cracks may cause heaving, and pavement deterioration at the cracks resulting in loss of riding comfort and pavement structure.

Many techniques have been used in an attempt to eliminate or minimize crack reflection through the new overlay. For the purpose of this study, these techniques are broken down into:

1. Membrane and Fabrics

Various membranes and fabrics have been used experimentally over the last 10 years as a stress relieving interface material and waterproofing membrane. Their use has been mainly over cracks and distressed areas in both strip and full lane width. Strip treatments have been both heavy and light fabrics with either self-adhesive or prime. When used as full lane coverage, the material has been a lighter (approximately 4 ounces per square yard)(approximately 136 grams per square meter) weight polyester or polypropylene fabric applied over a 0.20 - 0.30 gal/sq. yd. (0.91 to 1.36 liters/sq. meter) A.C. tack.

Critical to the performance of these products is the base preparation. All cracks wider than 1/2" (1.27 cm) must be cleaned and sealed, or filled with asphaltic concrete mixture. A leveling lift should be placed over faulted or depressed joints prior to placement of fabric.

Mechanical methods of application are available which result in a minimal amount of hand labor. Placement full width, or in strip form is normally done just ahead of the paver without adverse effect on the asphalt paving operation.

The cost of full fabric coverage including tack coat is approximately equal to one additional inch of asphaltic concrete overlay. As contractors become more experienced in the application of fabrics, lower application costs should result.

Based on limited experience and evaluation period, the participating states reported that reflection of from 1/3 to 1/2 of the transverse cracks can be retarded for up to 5 years with fabrics. Full width fabrics have proven to be an effective deterrent to reflective cracking for alligator or block type cracking on bituminous pavements. One state reported the reflective crack along longitudinal joints was nearly eliminated where reinforcing fabric was used prior to overlay. Another state reported good success with use of a lighter weight fabric over fatigue cracking prior to chip sealing.

2. Asphalt Rubber

Another membrane treatment being used to retard crack reflection through asphalt overlays is by the use of an asphalt-rubber mixture. This technique involves application of a thin layer (0.55 to 0.70 gallons per square yard) (2.49 to 3.17 liters per square meter) of hot asphalt-rubber mixture on the existing surface followed by application of a cover aggregate at 30 to 40 lbs./sq. yd. (16.2 to 21.7 kilograms/sq. meter). An asphalt overlay of 1" (2.54 cm) to 3" (7.62 cm) would be placed over this layer. This usage has become known as a stress absorbing membrane interlayer, or SAMI. When used as a surface application, this treatment has been referred to as SAM.

Experimental work with this technique was first done in Arizona and Colorado. The rubber used in the projects was from discarded tires which were ground and added to make up approximately one-fourth of the asphalt-rubber mixture. As with other membranes, critical to the success of the treatment is crack filling and preparation of the base.

Only one of the participating states reported any experience with SAMI. Some reduction in the amount of reflective transverse cracking was evident after two years, but it was too early to draw any firm conclusions. Several western states consider both systems to be effective in control of fatigue cracking, and the interlayer system with thick overlay is effective in the control of all types of reflective cracking. The higher cost of these systems may prevent them from being cost effective.

3. <u>Heater Scarification</u>

Heater scarification is a means of surface recycling existing asphalt pavements. The process consists of heating the bituminous surface with one or two commercial heater units to temperatures not in excess of 475°F (246°C), and scarifying to depths of up to 1" (2.54 cm). Admixtures may be added to alleviate surface oxidation, and rejuvenate the scarified material. The surface is then leveled with augers and screed, or special drag assembly. Normally, this process is followed by placement of a thin asphalt overlay (1" or less) (2.54 cm or less).

Advantages attributed to heater scarification include: correction of surface distortion and rutting, elimination of minor surface cracking related to oxidation, reduction in the overlay depth thereby saving material and retaining drainage capacity along existing curb and gutter sections, a good bond between treatment and the overlay, and temporarily sealing off the surface to moisture.

This treatment has been used on a more limited scale with 2" to 3" (5.08 cm to 7.62 cm) overlays for some of the same reasons stated above. It is no substitute for proper preparation of transverse thermal cracks open 3/8" (0.95 cm) or more, and should not be used to correct structural problems. One state considers heater-scarification with 1" (2.54 cm) overlay to be cost effective if it lasts 3 years with only minor maintenance.

This is another technique available for use on 3R repair projects and should be used selectively. It appears to be a temporary, but economical solution to the problem of PCC pavement joints reflecting - costs $.50 to $.60/sq. yd. ($0.60 to $0.72/sq. meter).

4. <u>Cold Milling</u>

Cold milling is a term applied to the removal of asphalt or portland cement concrete pavements by a milling or planing machine. This process has been used in correcting surface irregularities or for the removal of the pavement for recycling purposes. New equipment on the market allows milling to close tolerances at high production rates.

The cold milling technique has been used to improve the riding quality of bituminous pavements with badly dipped transverse cracks. This involved trimming 3/4 to 1 inch (1.91 to 2.54 cm) of material over the entire surface of the roadway. This technique improves the serviceability (riding quality) but does not eliminate the transverse cracking. Sealing of wider cracks is recommended followed by fog seal or thin overlay. Milling full width is relatively inexpensive.

Badly depressed transverse cracks have also been treated individually by milling over the crack and constructing a partial depth patch. This treatment is more expensive. Cracks may still reflect, but the objectionable depression is eliminated.

5. Crack Filling Materials

The crack filling or sealing procedures and materials are essentially the same as those described in the "Maintenance" section. The participating states generally agreed that effective filling or sealing of cracks with a high quality material prior to an asphalt overlay would extend the life of the resurfacing. Filling of cracks prior to an overlay will provide additional protection to the critically weakened cross-sections. Penetration grade asphalt, cutback, emulsion, and asphalt-rubber are the main fillers being considered. The trend has been toward the use of emulsions due to energy considerations with an additional benefit being that it has less tendency to bleed and track. Several states are changing to the use of asphalt-rubber for wider cracks. Most participating states are continuing to evaluate asphalt-rubber fillers.

A high-quality, cost-effective filler material that will readily adhere to the face of an older crack is still needed.

6. Drainage

Drainage of the pavement structure should be reviewed prior to any 3R project. Means for removal of both surface and subsurface water should be provided. Shoulders and ditches should be properly graded to prevent standing water.

Subsurface water may cause subgrade and pavement deterioration and failure. Longitudinal subdrains at the edge of pavement at a sufficient depth to drain the subgrade may be necessary in rehabilitation to insure longevity of the overlay.

7. Crack Repair

Due to the wide variety of conditions encountered, it is difficult if not impossible to establish a set of criteria to determine the necessary repair. Many times the deterioration is unique and the repair must be adapted to the particular pavement. Again, the methods of crack repair prior to an overlay will be very similar to those used for maintenance purposes.

Cleaning or routing of joints prior to sealing or filling will result in better performance of the crack repair which will in turn result in better performance of the overlay. One new method which has potential for more effective crack cleaning is a high pressure (2000 psi)(13.79 mPa) industrial washer. Waterblast cleaning appears substantially superior to air jet cleaning.

Even though it was generally accepted that all unsound or unstable material should be removed prior to resurfacing, full depth patching has disadvantages. It is relatively expensive at approximately $62 per square yard ($74.15 per square meter). Often the full depth patch eliminates one deteriorated crack and results in two other cracks at each edge of the patch which may deteriorate.

CONCLUSIONS

1. Pavement management systems may eventually create a much better data base relative to costs and effectiveness of the various pavement maintenance strategies.

2. There are no treatments currently available which will effectively reduce transverse crack reflection, particularly if the crack is temperature or flexure related.

3. Variability of asphalt from source to source indicates a need for improved design and construction to insure the best possible performance.

4. Factors contributing to transverse cracking of asphalt pavements vary from one geographic area to another. Any recommendations should acknowledge this fact and be tempered accordingly.

5. Fog seals can do much to reduce the aging of asphalt surfaces.

6. Proper timing for placement of fog seals, chip seals, thin overlays with or without fabrics or for milling to restore rideability or improve surface texture can do much to preserve an existing pavement.

7. Transverse cracking is more severe when the mat or surface is placed on subbases or bases containing portland cement or lime.

8. Most of the deterioration and stripping at transverse cracks occurs in the base course indicating a need for more concern in the design of asphalt treated bases.

9. Cracks that have been effectively sealed are not as badly deteriorated as those which have not been sealed.

10. Treating or sealing cracks as they occur can effectively reduce the amount of deterioration which usually develops because of water infiltration.

11. A better quality, cost effective crack filling or sealing material is needed.

12. Asphalt-rubber is an effective and durable crack sealing material. Routing may be beneficial.

13. Full depth patching is a costly repair technique and the results are not always desirable.

14. Improved surface preparation techniques are needed in the sealing and patching of surfaces prior to placing overlays.

15. Heater scarification can economically correct minor surface distortions and shallow surface cracks.

16. Cold milling is an effective treatment of an asphaltic surface prior to the use of fabric and as a leveling operation prior to overlay.

17. Better under-slab drainage systems may reduce the amount of transverse cracking and rate of deterioration. Drainage should be reviewed prior to 3R projects and better pavement drainage provided if deemed necessary.

18. Fabrics or asphalt rubber membranes should be included as one method for prevention or retardation of reflective cracking through overlays and to retard moisture infiltration.

19. Thick overlays are a means of retarding early reflection of transverse cracks.

RECOMMENDATIONS

1. Continued research at the national level to look further into the transverse cracking problem with emphasis on environment, soils and their effect on cracking, admixtures, fabrics, membranes, crack relief layers, etc.

2. Further investigation into the temperature susceptibility and hardening rates of asphalt cements and the actual performance of the asphalt on a source-by-source basis.

3. Continued regional meetings of technical people for an exchange of information, possibly on an annual basis.

4. Promote research to develop new test procedures and methods which will require less sophisticated and less costly equipment.

5. Develop positive procedures to require timely sealing of cracks.

6. Strengthen specifications and/or requirements for preparing pavement surfaces for overlays.

7. Recommend field compaction requirements that will yield density and void levels to assure maximum durability.

8. More restrictions should be placed on the use of absorptive aggregates.

9. Develop more and better instruction and programs for training agency and contractor personnel in areas of asphalt pavement construction and quality control.

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