Field Performance of Crack and Seat Projects

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Crack and seat rehabilitation on concrete pavements is the process whereby the existing concrete pavement is cracked to destroy the integrity of the slab. This cracking reduces the slab length, which reduces the thermal effect on joint movement. The seating operation is required to ensure that the pieces of slab are firmly seated into the underlying foundation material to eliminate vertical movement. Both of these are contributing factors in the development of reflection cracking. Reduction in the amount and severity of reflection cracking in an asphalt concrete overlay is the sole design requirement of the crack and seat procedure on a rigid pavement. This paper presents the results of an analysis of seventy crack and seat projects from twelve states throughout the United States. These data were collected as part of a study funded by the Federal Highway Administration (FHWA) of rehabilitation techniques to evaluate the parameters that affect their performance. By regression analysis of the database, models were developed that demonstrate general tendencies evident from the data concerning the performance of the crack and seat sections. This evaluation will provide the information to develop guidelines and recommendations for construction to improve their performance.

To date there has been one nationwide documentation of the performance of the crack and seat technique (*1*). However, a uniformly recognized standard for construction procedures has not been developed for this overlay technique. General guidelines have been proposed by several agencies, relying on their local experience, but they have not been verified with a comprehensive field survey of performance. The National Asphalt Pavement Association has published two reports on the performance of crack and seat projects in the Midwest (*2, 3*). Recently the Federal Highway Administration (FHWA) released the results of their survey of crack and seat projects in the United States, which provides some indications of performance variables but with no specific recommendations concerning design procedures (*1*). In 1984 the FHWA initiated the study "Rehabilitation Techniques for Rigid Pavements" to establish performance and design recommendations for several rehabilitation techniques.

DATA COLLECTION

To obtain specific indications regarding design of crack and seat rehabilitation projects, the development of an extensive database containing information on the original pavement design, asphalt concrete overlay design, traffic, environmental conditions, and performance of existing overlays was developed. The projects surveyed for inclusion in the database represent a cross section of the crack and seat projects in the United States. These pavements were surveyed between June 1985 and July 1986.

There are five basic data types necessary for the development of life prediction models and for analysis to develop and improve design and construction procedures.

1. Field condition data;
2. Original pavement structural design, in situ conditions, and historical improvement data;
3. Rehabilitation design factors;
4. Historical traffic values, classifications, and accumulated 18-kip equivalent single-axle loadings; and
5. Environmental data.

The database contains as many projects as were available or that could be included, given available resources, to provide a valid range of design parameters. Figure 1 shows the general location of the crack and seat and asphalt concrete overlay projects.

Variables

Figures 2 and 3 show the distribution of age and thickness for the crack and seat projects in the database. These parameters are broken out based on whether the original concrete pavement was plain or reinforced. The presence of reinforcing steel has long been felt to be a major factor influencing the performance of crack and seat rehabilitation. It is seen from the figures that the reinforced pavements have received thicker overlays and are generally not much older than the plain pavements.

There are no "overlay design" variables for crack and seat as there is no design procedure for this rehabilitation strategy outside of assuming a structural layer coefficient for the cracked concrete slab and designing the overlay based on this coefficient. Variables that are felt to be significant to the performance of a crack and seat project are listed in Table 1.

The severity levels employed in describing distresses are those defined in the FHWA distress manual (*4*). For example, low-severity cracking describes hairline cracking, medium-severity describes working cracks, and high-severity describes a badly spalled and faulted crack needing immediate repair.

Distress Present

Data on the condition of the existing pavements prior to the crack and seat rehabilitation were not available. Therefore,

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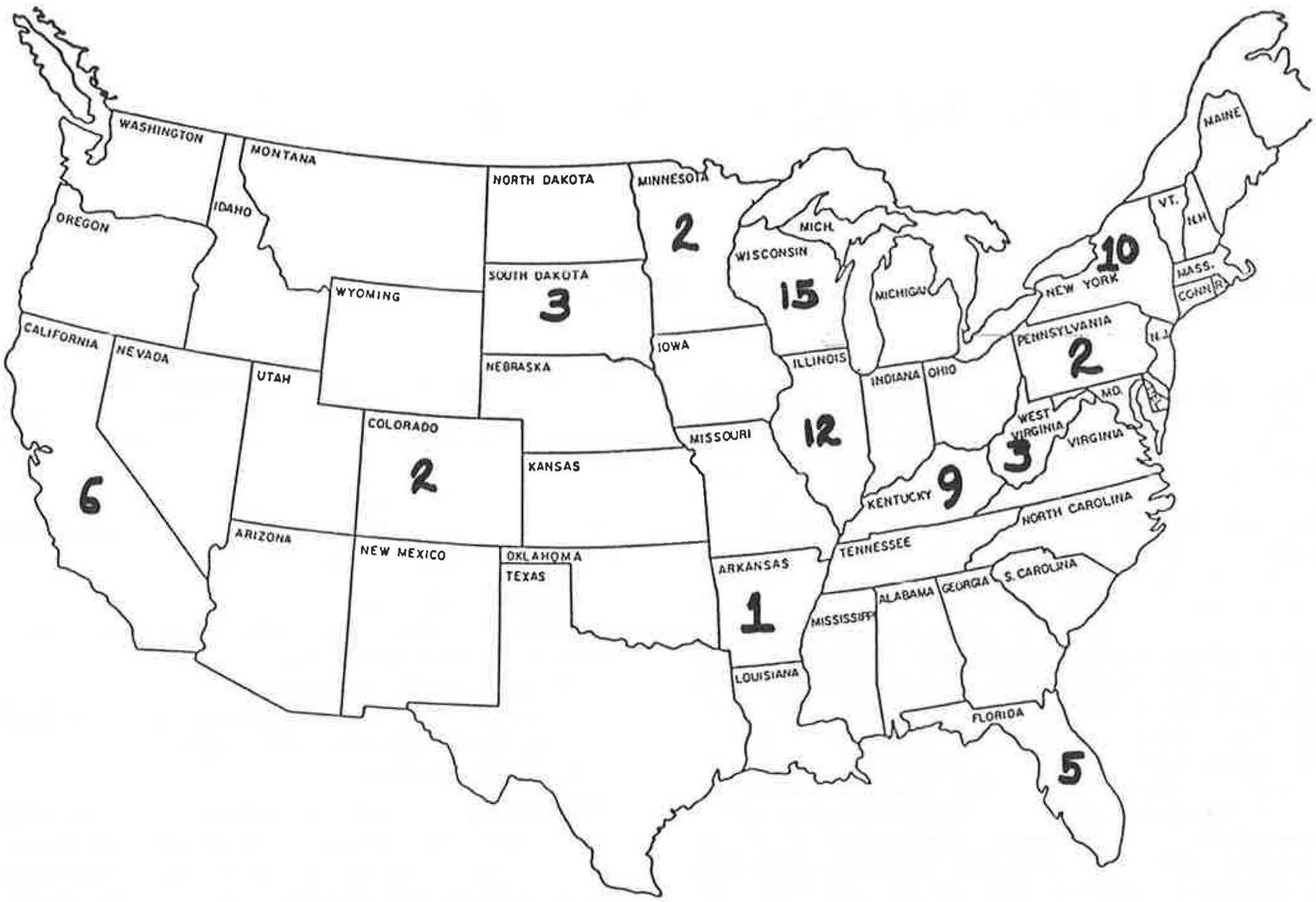

FIGURE 1 Distribution of crack and seat projects in the United States.

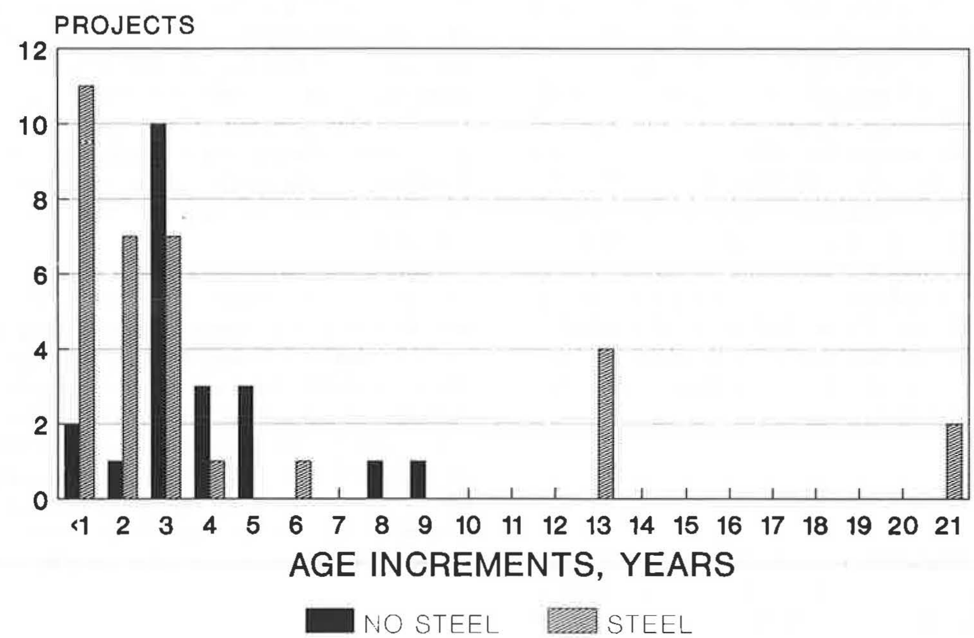

FIGURE 2 Age comparisons for the crack and seat projects in the database.

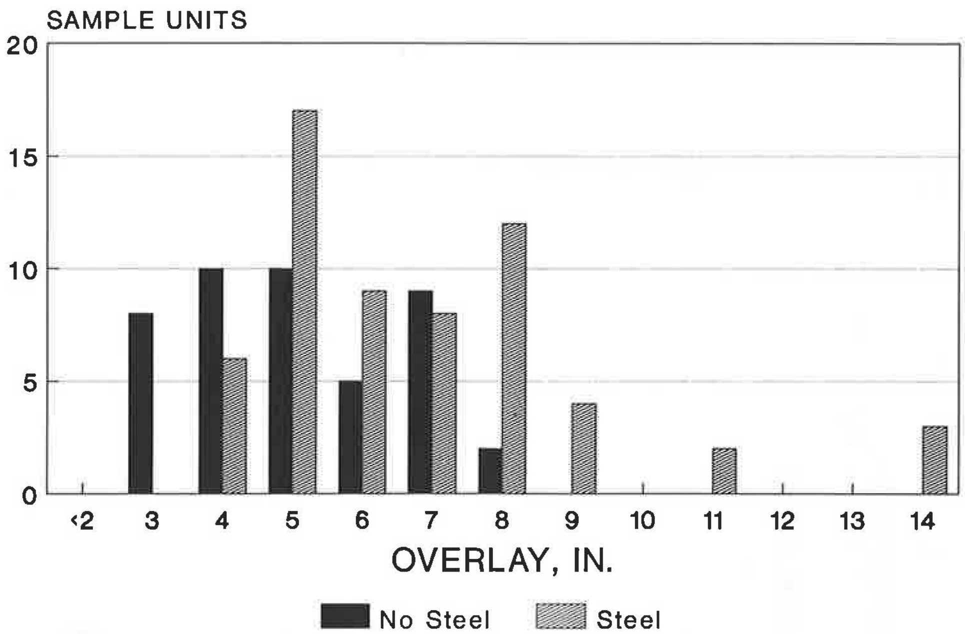

FIGURE 3 Thickness comparisons for crack and seat projects in the database.

TABLE 1 CRACK AND SEAT OVERLAY DESIGN VARIABLES

Project Identification Number
Sample Unit
Presence of "D"Cracking on Existing Pavement
Original Slab Repair
Pavement Breaker Type
Average PCC Breakage Size -- Width
Average PCC Breakage Size -- Length
Wire Mesh Cut or Broken
Seating Roller Type
Seating Roller Weight
Broken Pavement Exposure to Traffic
Sample Unit
Sample Unit Length
Present Serviceability Rating
Foundation of Sample Unit
Condition of Drainage Ditches
Subsurface Drainage Functional
DISTRESS DATA
Outer Lane, Inner Lane
Centerline Longitudinal Cracking
Transverse Cracking
Joint Reflective Cracking
Longitudinal Cracking
Lane Edge Cracking
Pumping
Alligator Cracking
Block Cracking
Raveling/Weathering
Bleeding
Rutting, Inner Wheelpath
Rutting, Outer Wheelpath

a mapping process to illustrate the time development of reflection cracking on each project could not be conducted, and the distress data represent one time-sequence data point. Reflection cracking is the major distress in an asphalt concrete overlay of a concrete pavement. Because the crack and seat process produces a more "flexible" base layer compared with a concrete slab, the development of fatigue cracking may be a distress that develops that would not develop in an asphalt concrete overlay of an uncracked concrete slab.

The percentage of projects containing lengths of cracking (ft/1,000 ft) of low, medium, and high severity are shown in Figures 4 and 5. These figures indicate, for example, that 100 percent of the projects exhibited no high-severity cracking for the plain pavements, and 96 percent of the reinforced pavements had no high-severity cracking. These figures are separated to demonstrate any differences caused by the presence of reinforcing steel in the concrete slab, as this is felt to be a significant variable in the performance of crack and seat rehabilitation.

Figures 4 and 5 show that the reinforced pavements develop more high- and medium-severity cracking than the plain pavements. The plain pavements exhibit much more low-severity cracking, as demonstrated by the greater length of cracking found on the plain sections, which may be a function of shorter joint spacings not allowing the reflection crack to deteriorate.

There is not a great amount of high-severity reflection cracking in any of the sections, even though some of these projects are quite old. The development of medium- to high-severity reflection cracking on the crack and seat projects should be compared to that in conventional overlay projects

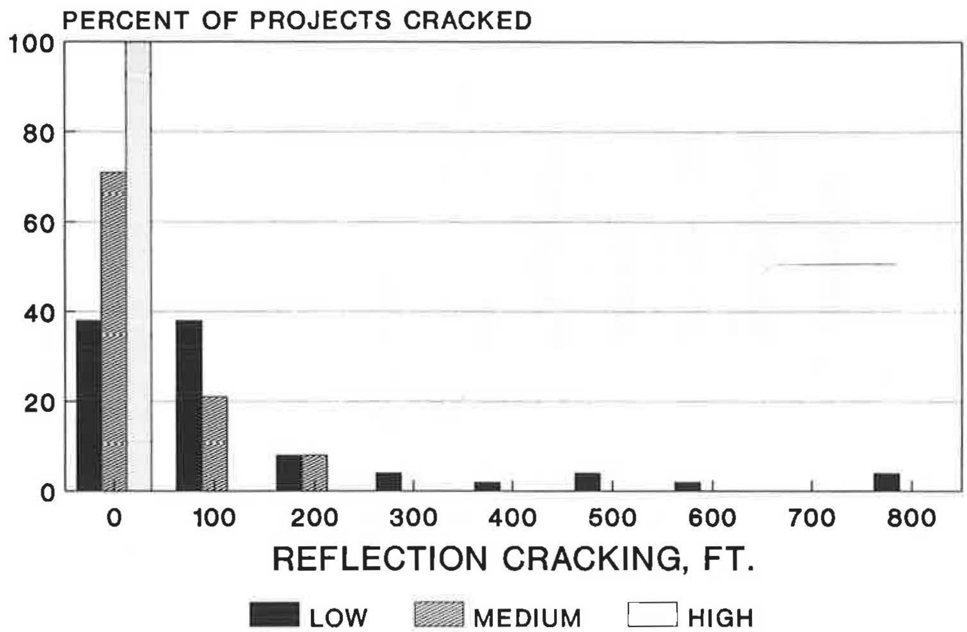

FIGURE 4 Amount and severity of reflection cracking present on crack and seat projects with no reinforcing steel.

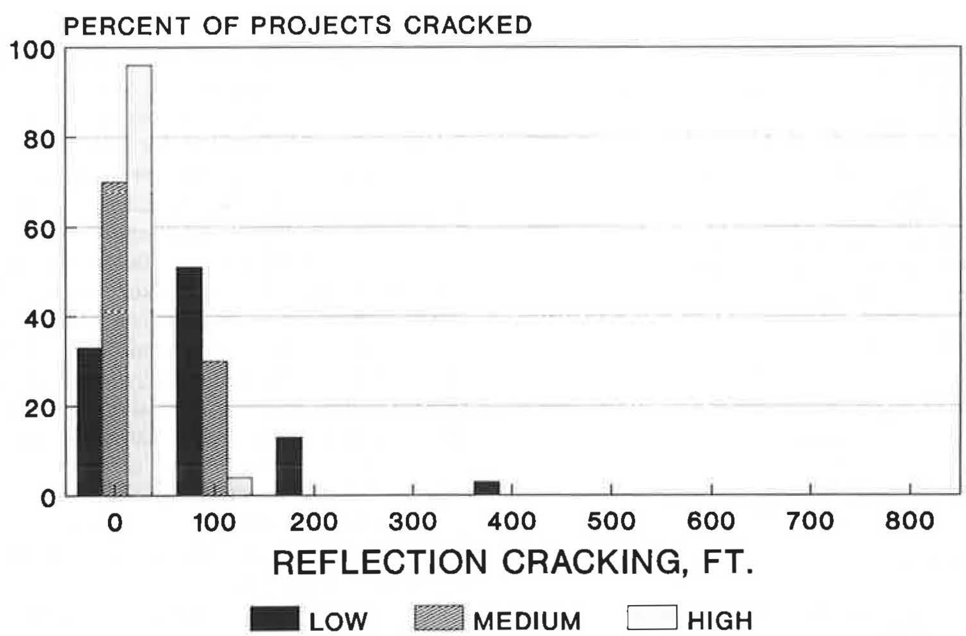

FIGURE 5 Amount and severity of reflection cracking present on crack and seat projects with reinforcing steel.

to determine if the rehabilitation reduces the severity, if not the amount, of the reflection cracking. The small occurrence of the high- and medium-severity cracking was primarily on the reinforced pavements. This may indicate that on plain concrete pavements the severity is being reduced, although the age and traffic may be other factors that must be included in the comparison.

PAVEMENT PROJECT CHARACTERISTICS

Overlay Thickness

The thickness of the overlay has a critical role in the development of reflection cracking, particularly when the overlay is below approximately 6 in. thick. Figure 3 shows the distribution of overlay thicknesses broken out by pavement type. The average overlay thickness for the plain pavements was 4.25 in., while the average overlay thickness for the reinforced pavements was 6.25 in. Thicker overlays retard the appearance of reflection cracking and should produce a lower-severity crack, significantly reducing the development of high-severity cracking. The thicker overlays are indicating a higher potential for medium-severity reflection cracking, which may indicate that the presence of reinforcing steel, joint spacing, and other factors may be significant in the performance of the overlay on a crack and seat project.

Age and Traffic

The average age of the reinforced pavements was 4.7 years, while the age for the plain pavement sections was 4.0 years. The thicker overlays have been in place longer, and they have been subjected to more traffic. The accumulated 18-kip equivalent single-axle loads (ESALs) since overlay for the plain pavements is 1.3 million ESALs while for the reinforced pavements it is 1.9 million ESALs. The percentage of trucks in the traffic stream was also higher for the reinforced pavements (24 percent) compared with the plain pavements (18 percent). The actual values of ESALs varied from approximately 0.08 to 8.3 million ESALs for all projects.

Serviceability

Present Serviceability Rating (PSR) information was available from a small cross section of the crack and seat projects (twenty-seven projects). The PSR curve for the crack and seat sections is shown in Figure 6. There is no tendency for the better performing pavements to have thicker overlays. The best performing projects were in the milder climates (California and Florida, with relatively thin overlays and mixed traffic levels).

This serviceability loss, which begins around 3 million ESALs, can be attributed to cracking, rutting, and possibly roughness induced by slab motion under traffic. The average rut depth for these projects was 0.15 in., with the maximum rut depth measured at 0.42 in., which may contribute to roughness on a few of the sections. In general, the higher rutting did not occur on the projects with lower PSR values, indicating that some design variable in the crack and seat procedure may be contributing to the development of the roughness. Similar correlations with the various forms of cracking also showed no direct relationship between the severity or amount of cracking and the roughness, further lending credence to the feeling that a design variable in the crack and seat process may be responsible.

These differences indicate that the performance of plain and reinforced pavements cannot be made on a direct comparison of visual survey data taken from a distress survey

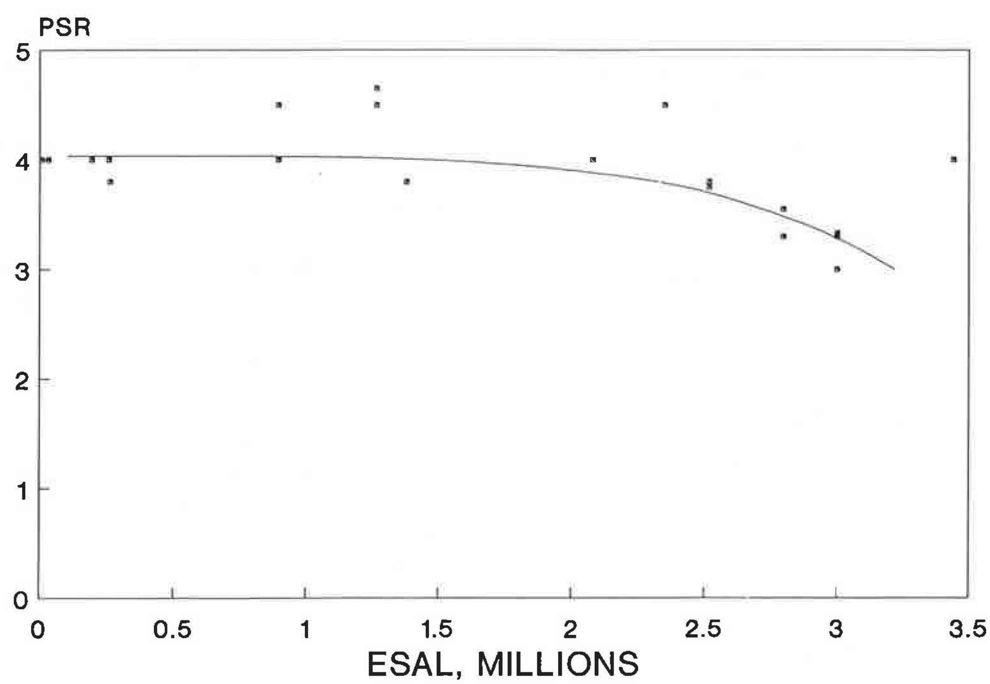

FIGURE 6 Serviceability rating (PSR) for the crack and seat projects.

without knowing the causative factors that may produce different levels of cracking on the surface. In this case, similar performance has developed on projects with very different design considerations of thickness, age, and traffic, which indicates that one set of overlays, those over crack and seated reinforced pavements, are not performing as well as those over plain pavements.

PERFORMANCE MODELS

Model Development

Predictive models were developed for significant distress variables using the regression techniques as included in the Shazam statistical package (*5*). Models for rutting and reflective cracking were developed from the database (*6*), but only the reflection cracking models are discussed here.

As a first step in analyzing the data, all independent variables that were considered to have meaningful and significant influence on the performance of the crack and seat overlays were identified. These variables were then considered in the development of the models with linear regression. Separate models were developed for each severity level (low, medium, and high) of reflection cracking. This was done to illustrate the different factors that are important in the development of cracking and the progression of cracking from low to medium and high. The individual models are not used to predict overall performance primarily because of the lack of sample units in certain distress categories. Because only 4 sample units out of the 107 surveyed contained any high-severity distress, fewer inferences could be drawn from the inadequate models developed. The models for low-severity and for a combined medium- and high-severity are presented here.

Medium- and High-Severity Combination

There were 44 sample units of the 107 surveyed that exhibited some medium-severity reflection cracking. The model developed using data from all 107 sample units was

$$\begin{aligned} RFLCMH = {} & 14.0523 + 2.928(AGE) + 0.04158(FI) \\ & - 10.677(TPCC) - 0.5853(SWR) \\ & - 13.583(WDT) - 6.555(LT) \\ & + 3.236(AREA) + 2.1345(ANNPREC) \\ & - 0.003928[0.14263(ANNAVGT) \\ & - 0.12123(ANNPREC) \\ & + 0.1955(ANNRNG) - 5.9531](ESAL) \end{aligned}$$

R^2, correlation coefficient = 0.61;
SEE, standard error of estimate = 32.7; and
N, number of sample units = 107.

where

RFLCMH = high-severity reflection cracking (ft/1,000 ft);
AGE = age of overlay in years;
TPCC = thickness of original slab (in.);
FI = Freezing Index;
SWR = seating weight of roller in tons;
WDT = width of crack pattern (ft);
LT = length of crack pattern (ft);
AREA = area of the cracked slab pattern (sq ft);
ANNPREC = annual precipitation (in.);
ANNAVGT = average annual temperature (°F);
AVGRNG = average monthly temperature range; and
ESAL = total 18-kip equivalent single-axle loads since overlay (in millions).

Low Severity

There were 71 sample units of the 107 analyzed that exhibited some amount of low-severity reflection cracking. The model developed for low-severity distress with the data from all 107 sample units is

$$\begin{aligned} RFLCL = {} & 87.396 - 1.7074(JTS) + 3.3215(SWR) \\ & + 33.596(LT) - 1.5298(AREA) \\ & - 47.438(SOIL) - 4.6739(ANNPREC) \\ & + 2.5865(ESAL) \times [0.14263(ANNAVGT) \\ & - 0.12123(ANNPREC) \\ & + 0.1955(AVGRNG) \\ & - 5.9531] \end{aligned}$$

R^2 = 0.41,
SEE, standard error of estimate = 111.2, and
N = 107

where the variables are as previously defined with the addition of SOIL = subgrade soil type, 1—coarse, 0—fine grained; and JTS = joint spacing (ft).

Model Discussion

These models provide insight into potential areas where performance of crack and seat rehabilitation projects can be improved through control of variables. The development of medium-severity cracking is affected by age and environment, variables that are slightly less influential in the development of low-severity cracking. The original pavement variables and construction procedures are more significant in the development of low-severity cracking and not as significant in the development of medium- or high-severity, with the exception of the cracking pattern and thickness of the original pavement slab.

The analysis of these individual equations tends to indicate that low-severity cracking will occur regardless of environment and traffic, and that construction variables influence the amount of low-severity reflection cracking and its progression. The progression of low-severity cracking into medium- and high-severity cracking is more dependent on the environment in which the project is constructed and the traffic levels on the project.

Application Limits

The use of data outside those present in the database has the potential to produce predicted amounts of reflection cracking that are not typical of a pavement with the variables chosen. Further, there are certain combinations of variables that should be noted and not used because they were not present in the database, and may or may not be present in another pavement not included in this analysis. The range of variables should be determined (*6*) before using these models on pavements that could be unique. As an example, climatic parameters must be selected in a combination representative of the actual values common to an area. A check is to use the following equation:

$$\text{ZONE} = [0.14263(\text{AVGTMP}) - 0.12123(\text{ANNPREC}) + 0.1955(\text{ANNRNG}) - 5.9531]$$

The result *must* be between 0.5 and 9.5, preferably between 1 and 9, numbers that correspond to the nine environmental zones for FHWA classifications (*7*). When this equation is calculated outside the limits, the combination is not representative of a naturally occurring climatic area of the country, and the input variables should be examined.

Model Performance

The models clearly show that several variables are missing that many have intuitively felt should be influential on the performance of crack and seat and overlay rehabilitation. These variables were either determined to be statistically insignificant in characterizing the noted performance of the overlays or were not present with sufficient variability in the database to allow a true indication of their actual effect. Future refinement of the models as the database is expanded should address the proper inclusion of the following:

1. Thickness of the overlay,
2. Pre-crack and seat and overlay repair techniques employed,
3. Reinforced versus plain concrete,
4. Mechanistic data, such as elastic moduli from FWD deflection testing, that indicate cracking efficiency, and
5. Overlay asphalt mixture properties.

Sensitivity comparisons developed from the models are given in Figures 7 through 13. The separate straight-line portions with different slopes on each graph show the separate influence of low- and medium-high-severity cracking that makes up the total reflection cracking. The following discussions can be drawn from these figures.

Area

Analysis of the area of the cracked sections shows that large areas should be avoided. The area shown on Figure 7 is calculated from length and width. The length-to-width ratio of the cracking pattern also influences the development of reflection cracking. The pattern should be kept nearly square as elongated pieces crack more readily.

Freezing Index

More total reflection cracking can be expected in areas with higher Freezing Index (FI) values up to a certain age, as shown in Figure 8. The FI value relates directly to the amount of thermal activity that produces movement in the joint, propagating the reflection crack.

Thickness

The thickness of the original Portland cement concrete (PCC) slab affects medium- and high-severity cracking but does not alter the development of low-severity cracking, as shown in Figure 9.

Roller Weight

Heavier rollers to seat the cracked sections will produce more low-severity reflection cracking while it reduces the development of medium- and high-severity cracking, as shown in Figure 10. The use of heavy rollers may alter the cracking effectiveness and change the development of low-severity cracking. The effectiveness of the cracking is a critical element in the performance of crack and seat; it cannot be evaluated from distress surveys and thus cannot be included in this analysis. The use of the heavier roller to seat the cracked sections delays the progression from low- to medium- or high-severity and may thus be beneficial.

Joint Spacing

Longer joint spacings produce less total length of cracking in the overlay than do short joint spacings, as shown in Figure 11. This is due partly to the fact that there are fewer joints in a long jointed pavement. An examination of cracking as a percent of joints may be warranted as a better indicator of the performance of the procedure.

Subgrade

The presence of a coarse-grained subgrade soil greatly reduces the amount of low-severity cracking but has no effect on the development of medium- or high-severity cracking, as shown in Figure 12. Better subgrade support allows slightly larger cracked pieces to be produced in the cracking operation, although no correlation is available to relate an optimum size to a subgrade support factor. Poor subgrades generally indicate the need for drainage prior to the crack and seat operation. A thorough evaluation should be performed.

Age and Axle Loadings

The interaction of age and ESALs is unique. Low-severity cracking increases with increasing axle loadings, with no direct relation to age of the overlay. This implies that the same amount of cracking can develop in different time periods, as long as the number of axle loadings is the same. The age of the overlay appears as a factor in the development of medium- and high-severity cracking, in addition to the effect of the axle loadings that accumulate during the year.

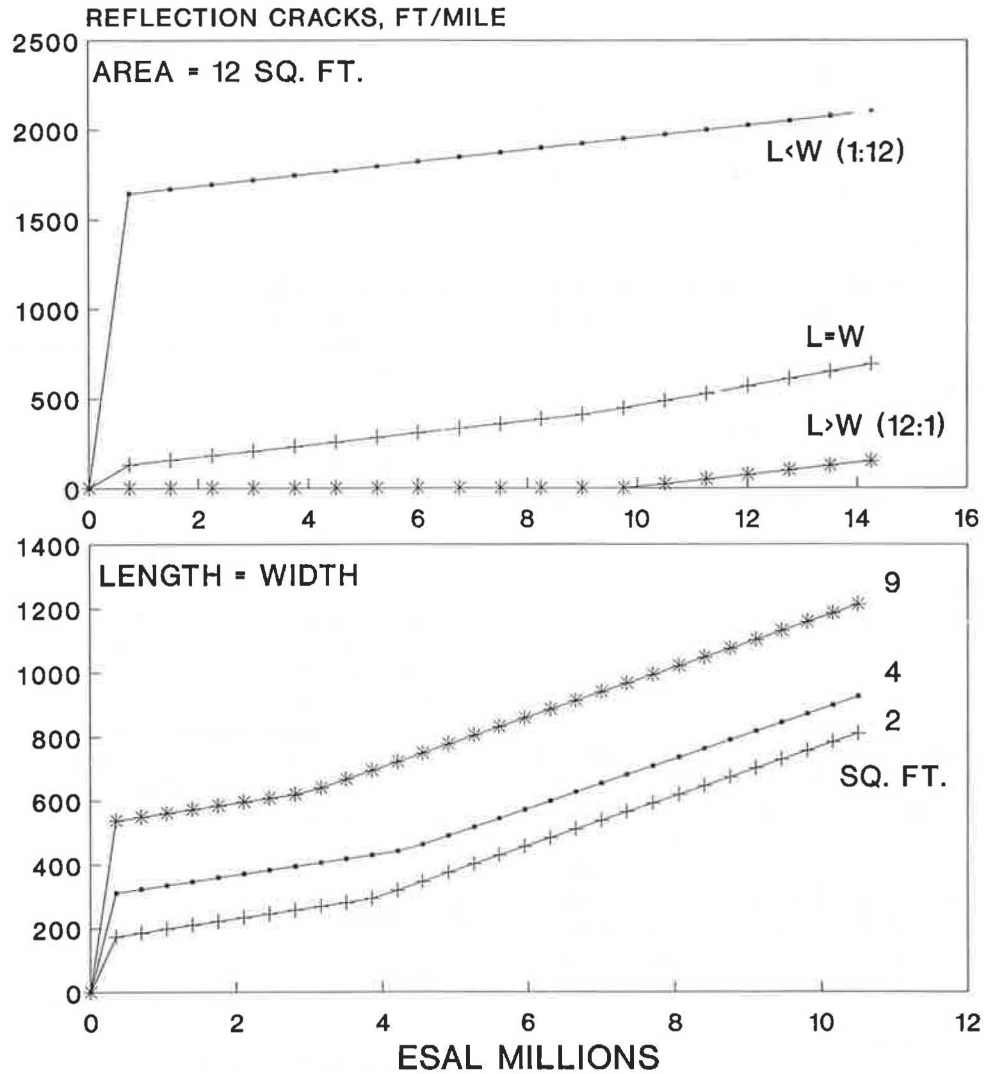

FIGURE 7 Influence of cracking pattern on reflection cracking.

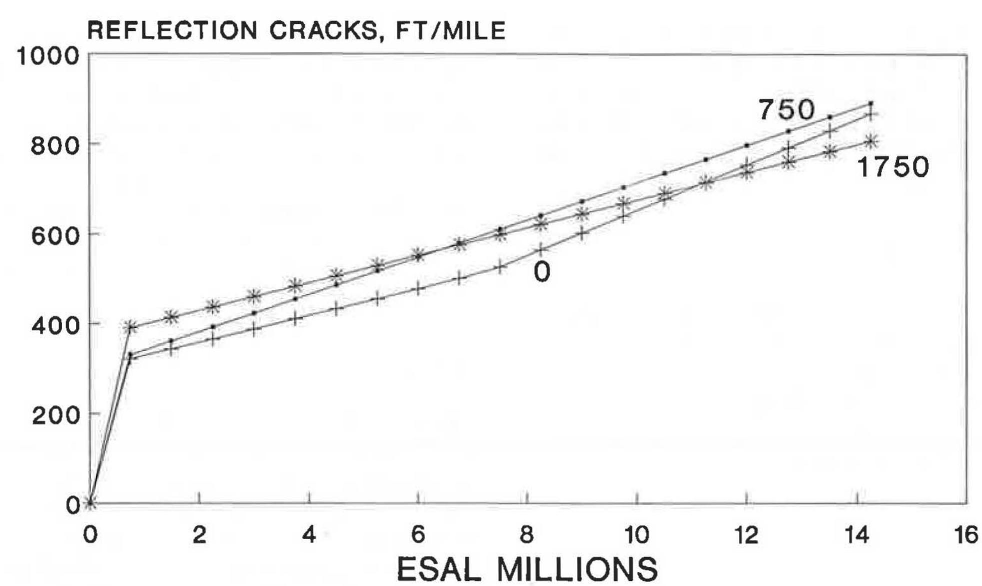

FIGURE 8 Influence of Freezing Index on reflection cracking.

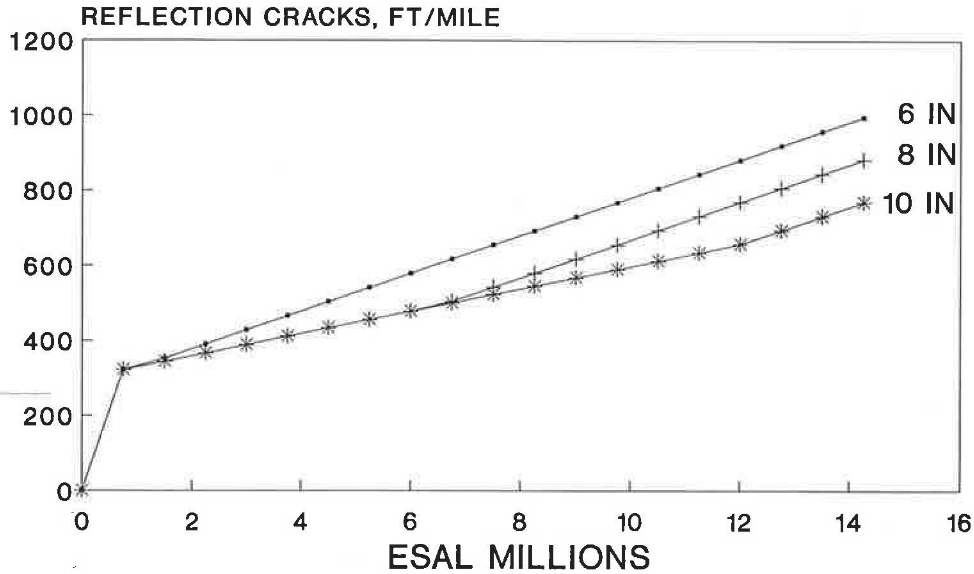

FIGURE 9 Influence of original concrete pavement thickness on reflection cracking.

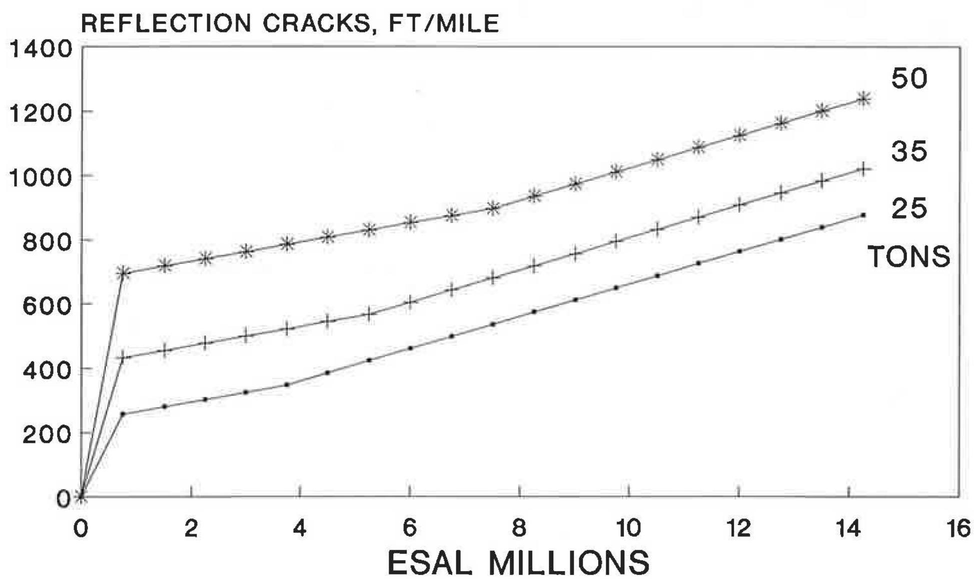

FIGURE 10 Influence of seating roller weight on reflection cracking.

Climate

The climatic variables illustrate the impact of environment on reflection cracking performance. Areas with larger annual rainfall showed lower amounts of low-severity cracking, while the development of medium- and high-severity cracking is greater in these same areas, as shown in Figure 13. Medium- and high-severity cracking develops over time, and higher annual rainfall may produce a lower support in the subgrade that accelerates breakdown of existing cracks. The higher amount of low-severity cracking in areas having low rainfall may be due to greater temperature variations. The combined effects of the climatic factors cannot be totally separated and investigated independently. The annual average temperature and monthly average temperature range combine with the annual precipitation to describe the general climate in the area. Generally, the areas with warmer annual temperatures and a smaller temperature range performed better.

CONSTRUCTION GUIDELINES

The placement of an asphalt concrete overlay over a jointed PCC pavement typically is done to restore smoothness and/ or structural adequacy to the overall pavement structure. There are design procedures to select the thickness of asphalt con-

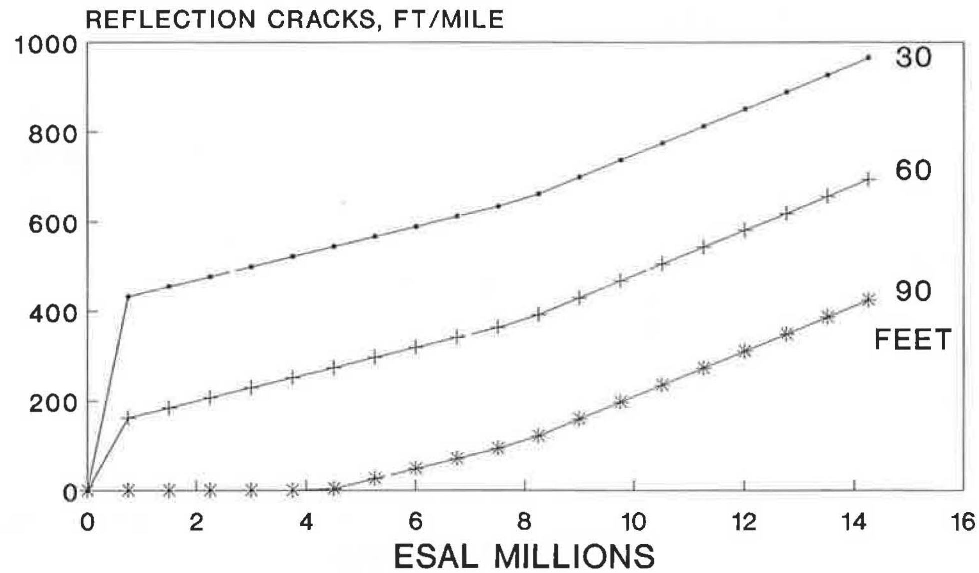

FIGURE 11 Influence of joint spacing on reflection cracking.

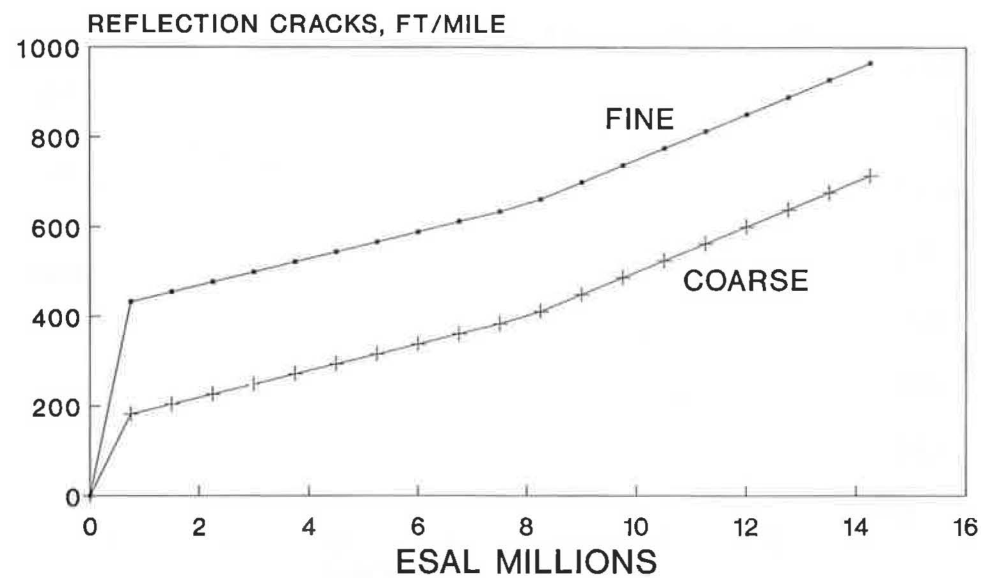

FIGURE 12 Influence of subgrade type on reflection cracking.

crete to carry the predicted traffic (*8*). The design procedures for crack and seat overlays are currently in the formative stages (*9*), and the field data represented by the models developed here provide an excellent initial indication of construction procedures that should be followed.

Selection

This rehabilitation scheme is cost-effective for pavements that do not require extensive slab replacement. A large number of severely deteriorated slabs that normally require replacement may indicate very poor foundation support, and this pavement could not be considered a prime candidate for crack and seat. The crack and seat process does not lend any extra structure to the pavement and actually produces a layer with less structural adequacy than the original concrete slab (*10, 11*). Severely deteriorated and spalled joints and cracks may require repair to the same extent as would be required for a standard asphalt concrete overlay to minimize deterioration once the overlay cracks. The cracking process must not worsen the crack; the crack must be tight and closed for good performance. Slabs exhibiting excessive fatigue damage may indicate that there is a foundation problem that may hinder the provision of sufficient support to the crack and seat section. Further, a fatigued concrete slab may produce a very different crack pattern than a sound slab, and damage to the fatigued slab may be easier, therefore requiring closer control of the cracking equipment and monitoring of the crack pattern to achieve the best performance.

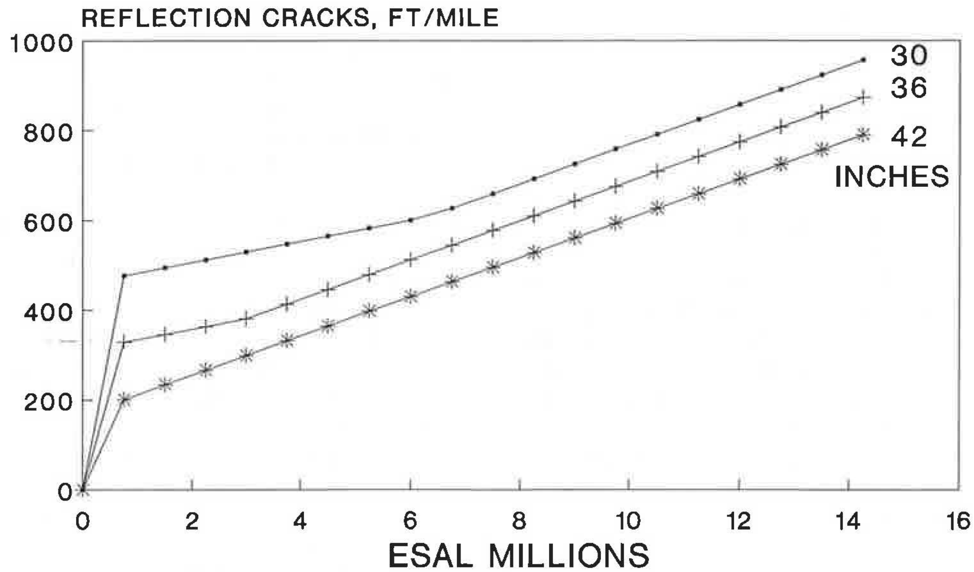

FIGURE 13 Influence of annual precipitation in inches on reflection cracking.

Drainage Considerations

When there is a drainage problem and moisture-susceptible materials are in the pavement structure, drainage should be considered and installed prior to the crack and seat operation. This requires careful evaluation of the pavement to ensure that drainage will improve the performance of the materials.

Subgrade Quality

Subgrade support is influential on performance of the crack and seat overlay. Better subgrade support will provide better support for the seated pieces and better resistance to movements. Pavements with poor subgrades are not the best candidates for crack and seat rehabilitation; when poor support is expected, the seating operation should not use the heaviest roller since this definitely causes nonuniform or excessive movement in the pieces.

Cracked Pattern

It is good practice to specify the cracking pattern desired. To ensure that the specified cracking is obtained, it is recommended that test sections be constructed prior to production. This allows the contractor to investigate various combinations of equipment and striking patterns that will guarantee the desired result. Spalling along the cracks and shattering of the pieces during the cracking operation should be avoided. The cracking pattern should be validated and recorded for comparison during the progress of the crack and seat operation.

Cracking Equipment

If the steel is not ruptured, the integrity of the slab is not broken and the slab will continue to move as an integral unit, propagating reflection cracks. Conversely, the breakdown of the concrete when overcracked may be so extreme that aggregate interlock is lost between the shattered pieces, producing pieces that are capable of moving independently under traffic, accelerating the development of reflection cracks.

Devices that demonstrate the ability to produce the desired cracking pattern should be allowed on the job with the exception of free-fall devices, such as headache balls. Pile drivers and guillotine hammers are the most common devices, generally used with modified striking plates shaped to produce the desired cracking pattern. Sharp striking plates or small striking areas should be avoided as these will tend to spall or penetrate the surface. It is recommended that the cracking not be done any closer than 10 in. to a joint or crack in the original slab.

The whiphammer and the resonant breaker are two newer pieces of equipment that have been investigated for use on crack and seat operations. Further work with these devices is needed to define their operating characteristics (*1*).

Seating

Recent studies indicate that excessively heavy rollers may do more damage than good. A report from Indiana (*12*) indicates that a 50-ton pneumatic roller increased deflections in the cracked pieces after each pass of the roller. These increased deflections indicate less strength in the pavement section, producing a reduced load-carrying capacity. Two projects in California (*13*) with a 13-ton roller gave results indicating that the cracking procedure reduced deflections at 92 percent of the joints, while subsequent rolling increased the deflection at 40 percent of the joints. These studies indicate that rolling may not be beneficial from a structural adequacy standpoint. It is done to seat the pieces to reduce their potential to move under traffic and propagate another crack.

It is recommended that a means of measuring deflections in the broken pieces be implemented to determine the most efficient roller weight and the optimum number of roller passes before the pieces start to unseat. This can be a simple procedure using a Benkelman beam and a loaded dump truck that is run over the project periodically.

Maintenance of Traffic

Several states allow traffic to use the cracked and seated pavement prior to overlay. It is recommended that traffic not be allowed unlimited access to a project where subgrade support may be low, since the potential for unseating the pieces is higher for this pavement. Where foundation support is good and the base is strong, traffic can be allowed for a limited time. It is good practice to begin placing the overlay within 2 to 3 days following cracking and seating to prevent breakdown of the aggregate interlock and unseating of the pieces. If an excessive delay is encountered, it may be advisable to reseat the pieces immediately prior to overlay.

Utilities, Culverts, Curbs, and Gutters

Cracking operations directly over utilities, culverts, curbs, and gutters should be avoided. This will require accurate marking of the locations of these appurtenances. The Direct Federal Division of FHWA has a specification that does not permit cracking and seating operations within 5 ft of subsurface utilities and structures. The contractor should be required to repair all damage to these installations, which might require a survey prior to crack and seat to determine the preconstruction condition.

Reflection Cracking Treatments

There are many reflection crack treatments (*14*). At present it is not felt that reflection crack treatments such as fabrics should routinely be used in conjunction with crack and seat. The reason for this is principally the cost involved and the inability to predict the effectiveness of fabric installations in general. There are no data to indicate the performance of fabrics in a crack and seat job. If a state has good experience with fabrics for reflection crack reduction, they may be used, and the projects should be studied to determine whether the fabric provides an advantage.

Cracking of a Composite-Asphalt Overlaid Pavement

Cracking can be done through an asphalt overlay. The problem with the operation is that the extent of the cracking cannot accurately be verified without removing the asphalt concrete for visual inspection. It is recommended that the existing asphalt be removed by an appropriate means, and considered for recycling, before the cracking operation.

CONCLUSIONS AND RECOMMENDATIONS

Crack and seat rehabilitation with overlay has been done since the mid-1940s and has recently received increased attention with the increased need for rehabilitation of concrete pavements to reduce reflection cracking in the overlay. The crack and seat operation has as its primary goal the reduction of reflection cracking in the overlay.

A total of seventy projects were surveyed in twelve states for inclusion in the database. Where the projects were long enough, two sample units were surveyed. This resulted in 107 sample units in the final database. These projects represent a cross section of projects constructed in the United States in recent years.

Previous surveys have indicated that crack and seat overlays can reduce reflection cracking, particularly in the early years of the overlay's life. There is some evidence that after a specific number of years, the effectiveness of the crack and seat operation may diminish.

The projects surveyed in this study exhibited good performance in general, with only one section exhibiting high-severity reflection cracking and approximately one-third exhibiting medium-severity reflection cracking of limited extent.

The design and construction of crack and seat overlays require special considerations to reduce the effective slab length to minimize cracking and to seat the cracked sections so they will not move under traffic. Overall conclusions and recommendations from this research study are as follows:

1. The presence of reinforcing steel has a significant influence on the effectiveness of the crack and seat operation. If the cracking operation does not rupture the steel, the slab length will not be reduced. The major difference is in the extra precautions that must be taken in the cracking operation on reinforced pavements. The database analysis did not show a difference in the performance with or without steel, primarily because of other interactions.
2. Without deflection testing of the completed project, there is no way to evaluate the effectiveness of the cracking operation beyond a recognition of the size of the cracked pieces. At present there is no acceptable procedure for evaluating the cracking effectiveness on the concrete slab prior to overlay.
3. The crack and seat overlays develop low-severity reflection cracking relatively quickly, and this development appears to be influenced more by the variables in the crack and seat operation than the original pavement design or environment. The progression of low-severity cracking to medium- and high-severity cracking is more a function of environment, age, original pavement design, and traffic and less a function of the crack and seat construction variables.
4. The seating roller weight has a dual action on reflection cracking. Heavier rollers cause more low-severity cracking to develop initially, while reducing the rate at which the low-severity cracks progress to medium- and high-severity cracking. The impact of heavier rollers is related to foundation quality, and heavy rollers should not be used on weak foundations. The use of a heavy roller does not guarantee improved performance.
5. Cracking pattern is more complicated then merely investigating the area of the cracked pieces. The area should be minimized to the range of 4 to 6 sq ft, and the ratio of length to width should also be controlled. When the length of the cracked piece (length is measured along the longitudinal direction of the pavement) is less than the width (width is measured transversely across the pavement), more cracking will result

than if the length and width are equal or the length is greater than the width. For construction it is recommended that the dimensions be kept equal, and if variation should occur, attempts should be made to control this toward producing a pattern with a slightly greater length than width.

6. Overlay thickness did not show an influence on reflection cracking, which may be due to an interaction effect with the reinforcing steel. The reinforced pavements generally had a thicker overlay, had been in place longer, and had higher traffic levels than the plain concrete sections. The performance of the reinforced and plain sections was so similar that the effect of steel and thickness did not enter the predictive relationships. In general, thicker overlays will perform better for a longer period than thinner overlays placed over the same crack and seat sections.

7. The quality of the asphalt concrete mixture has a significant impact on the performance of an overlay in resisting reflection cracking. The data in the database contained no indication of the mix quality in the individual projects. The rutting performance of these sections was typical of conventional overlays, which indicates the mix quality could be considered typical. Any comparisons of the performance of individual sections should be made with the realization that variability in mix quality can alter reflection cracking.

8. The environment showed an effect on the progression of cracking to the medium- and high-severity levels. In general the milder climates showed the best performance. High monthly temperature extremes and low monthly average temperatures produce more medium- and high-severity cracking. This interaction is shown in the decreased cracking with lower Freezing Index and the decreased cracking with higher precipitation. Higher precipitation generally occurs in areas with a more moderate climate without extreme swings in temperature.

9. Regression models were developed for low-severity and a combination of medium- and high-severity reflection cracking. The ability to model medium- and high-severity cracking is essential to planning rehabilitation, as these levels generally trigger the decision to overlay again. While these initial equations are not refined enough at present to use in designing rehabilitation projects, they provide a means of investigating the variables in a pavement rehabilitation project that have an impact on the development of reflection cracking. These relationships can assist the design and construction engineer in planning a crack and seat operation to provide the highest degree of reliability possible. As crack and seat projects are applied in more states with differing climates and designs, these initial models can be revised to include more variables and wider ranges of applicability to overcome some of the limitations of the database mentioned earlier.

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