

Nationwide Performance Study of In-Service Asphalt Concrete Overlays on Cracked and Seated Portland Cement Concrete Pavements

SHELLEY M. STOFFELS AND WALTER P. KILARESKI

One method used to rehabilitate portland cement concrete (PCC) pavements is to place an asphalt concrete overlay on the existing pavement. Although the overlay can improve the pavement's structural capacity and rideability, it can also create maintenance problems. These problems result from reflection cracking at the location of joints and cracks in the underlying slab. A method used to control the reflection cracking problem is to crack and seat the existing PCC pavement, thereby reducing the movement of the cracked slabs under the overlay. This paper discusses the results of a national study that investigated the performance of asphalt overlays of cracked and seated pavements. Pavements with up to 11 years of service life were evaluated with condition surveys, roughness measurements, and deflection measurements. Both cracked and seated pavements and control sections were evaluated. On the basis of the analysis, it was concluded that cracking and seating produced no significant loss of structural support but also did not appear to significantly improve overall pavement performance.

A common method used to rehabilitate portland cement concrete (PCC) pavements is to place an asphalt concrete (AC) overlay on the existing pavement. These overlays often deteriorate rapidly because of the problems associated with reflection cracking. Numerous techniques such as sawing and sealing of joints, crack-arresting interlayers, and fabrics have been used in an attempt to reduce the adverse effects of these cracks. The results have shown wide variations in performance. One method used to minimize reflection cracking is to crack and seat the PCC slab before overlay.

The concept of cracking and seating the PCC slab before overlaying is based on reducing the movement of the cracked slabs under the overlay. Horizontal movement caused by thermal effects and vertical movement with differential slab deflections caused by traffic loadings are both contributing factors to the reflection cracking problem. The intent of cracking the pavement is to create pieces small enough so that horizontal movement will be reduced but full aggregate interlock will be maintained. In this manner, reflection cracking will be reduced and the existing PCC pavement should maintain much of its original structural capacity.

The purpose of this study was to evaluate the performance of and verify or develop improved design and construction guidelines for cracked and seated PCC pavements. These

objectives were accomplished by evaluating the performance of cracked and seated pavements that have been in service for up to 11 years. Field condition surveys, roughness measurements, rut depths, deflection measurements, and traffic, environmental, and other data were obtained. These data elements were analyzed to document and evaluate the performance of the cracked and seated PCC pavements.

The research discussed in this paper was part of a major FHWA project on performance and rehabilitation of rigid pavements. Details of the complete crack-and-seat study can be found in the final report (1). The guidelines developed will become part of FHWA's *Pavement Rehabilitation Manual*, FHWA-ED-88-025.

STUDY SECTIONS

Five categories of data were used in the analysis and the development of improved design and construction procedures: original PCC pavement design factors, overlay design factors, measured field performance, traffic, and environmental data. These data were obtained from pavement condition surveys, state highway agency as-built plans and special provisions, and other agency records. In general, the procedures used were those specified in the *Distress Identification Manual for the Long-Term Pavement Performance Studies* compiled by the Strategic Highway Research Program (SHRP) (3).

An extensive literature search indicated that 24 states have had experience with crack-and-seat overlay projects. Only a few of these states either have an experimental plan or use the technique on a regular basis. From these states, the actual study sections were selected by using several criteria. The first criterion was to have study sections located in each of the four major environmental zones of the country. Figure 1 shows the distribution of states containing selected projects on an environmental basis.

The literature search showed that several important design features are associated with crack-and-seat overlays. Included are the overlay thickness, size of cracked pieces, and the type of existing pavement [jointed plain concrete pavement (JPCP) or jointed reinforced concrete pavement (JRCP)] that is cracked and seated. The study sections were selected on the basis of their ability to address as many of these design features as possible while staying within the resources of this study. The

<u>Wet/Freeze</u> Wisconsin	<u>Wet/Nonfreeze</u> California Florida
<u>Dry/Freeze</u> Minnesota	<u>Dry/Nonfreeze</u> California

FIGURE 1 Distribution of study sections by environmental zone.

8 projects selected for study contained 20 crack-and-seat sections and 9 control sections. Table 1 gives data on the 29 selected pavement sections.

Perhaps the most important design feature is the type of existing pavement (JPCP or JRCP) that is cracked and seated. The presence of reinforcement in the existing pavement is considered to have a significant impact on the performance of this rehabilitation technique. Only the Wisconsin sections were initially constructed with reinforced concrete pavement.

The Wisconsin sections are also the only study sections in the wet-freeze environmental zone.

The size of the cracked pieces ranged from a minimum of 6 in. by 10 in. to a maximum of 3.75 ft by 11 ft. Only the reinforced sections were cracked or broken into pieces smaller than 1 ft². Earlier studies have shown that an overlay range of 3 to 7 in. was commonly used on crack-and-seat projects. Consequently, study sections were selected that provided overlays within this range. Table 2 shows the interrelation between the overlay thicknesses and crack patterns. The ages of the selected overlays ranged from a minimum of 4 years to a maximum of 11 years.

FIELD DATA COLLECTION

A thorough condition survey was conducted on each pavement section. The Wisconsin sections were surveyed in early May 1988; the remainder of the sections were surveyed during July and August 1987. The SHRP Distress Identification Manual was used as a guide to identify the types, severities, and quantities of the various distresses (3). The roughness of each pavement section was determined using a Mays ride meter. In addition to the roughness measurements, the survey crew

TABLE 1 PAVEMENT SECTIONS SELECTED FOR INCLUSION IN THE STUDY

Project No.	Route	Location	Lane	Pavement Type
CA 9-1	SR 99	Bakersfield County, CA (control)	SB	JPCP
CA 9-2	SR 99	Bakersfield County, CA	SB	JPCP
CA 9-3	SR 99	Bakersfield County, CA (control)	SB	JPCP
CA 9-4	SR 99	Bakersfield County, CA	SB	JPCP
CA 9-5	SR 99	Bakersfield County, CA	SB	JPCP
CA 9-6	SR 99	Bakersfield County, CA	SB	JPCP
CA 9-7	SR 99	Bakersfield County, CA	SB	JPCP
CA 10-1	I-80	Davis County, CA	WB	JPCP
CA 10-2	I-80	Davis County, CA	WB	JPCP
CA 10-3	I-80	Davis County, CA	WB	JPCP
CA 11-1	I-80	Albany County, CA (control)	WB	JPCP
CA 11-2	I-80	Albany County, CA	WB	JPCP
CA 12	I-5	Yreka County, CA	NB	JPCP
FL 4-1	I-4	Hillsborough County, FL (control)	EB	JPCP
FL 4-2	I-4	Hillsborough County, FL	EB	JPCP
MN 7-1A	TH-71	Willmar, MN	NB	JPCP
MN 7-1B	TH-71	Willmar, MN	SB	JPCP
MN 7-2A	TH-71	Willmar, MN	NB	JPCP
MN 7-2B	TH-71	Willmar, MN	SB	JPCP
MN 7-3A	TH-71	Willmar, MN (control)	NB	JPCP
MN 7-3B	TH-71	Willmar, MN (control)	SB	JPCP
WI 1-1	I-94	Eau Claire, WI (control)	EB	JRCP
WI 1-2	I-94	Eau Claire, WI	EB	JRCP
WI 1-3	I-94	Eau Claire, WI	EB	JRCP
WI 1-4	I-94	Eau Claire, WI	EB	JRCP
WI 3-1A	SH 140	Rock County, WI	NB	JRCP
WI 3-1B	SH 140	Rock County, WI	SB	JRCP
WI 3-2A	SH 140	Rock County, WI (control)	NB	JRCP
WI 3-2B	SH 140	Rock County, WI (control)	SB	JRCP

drove over each of the pavement sections to give a subjective present serviceability rating (PSR).

Pavement deflections were measured on each cracked and sealed study section to determine the stiffness of the pavement layers and foundation. The deflections were measured using a falling-weight deflectometer (FWD) at three load levels, approximately 9,000, 13,000, and 17,000 lb. Deflection measurements were made in the wheel path at approximately 100-ft intervals. The Minnesota deflection data were collected by the Minnesota Department of Transportation. These data were collected at slightly lower load levels. The deflection measurements were normalized so that direct comparisons could be made.

Traffic volumes, including percentage of truck traffic, were collected from the appropriate state highway agency for each study section. Requests were made to the state agencies for traffic volumes from the time the pavement was opened to traffic to the date of the survey. However, in some instances traffic counts were unavailable for each year that the overlay experienced traffic, and thus traffic data had to be interpolated and extrapolated.

Environmental data were taken from documentation of monthly temperatures and precipitation published by the National Oceanic and Atmospheric Administration. The nearest weather station was assumed to be representative of the environmental conditions at each study section. In addition, the U.S. Army Corps of Engineers freezing index contour map was used to determine the mean freezing indices of the study sections.

The raw data obtained from the aforementioned sources were in several formats, such as field distress forms, construction plans, and research reports. After reduction, these data elements were entered into a microcomputer data base. SUPERCALC 5 was used to manage the data base; this software enabled researchers to efficiently enter, retrieve, export, and manage data.

OVERVIEW OF PERFORMANCE

Pavement performance can be evaluated using criteria from several categories, including functional and structural characteristics, safety, and appearance (4). In this study, the field performance of the pavement sections was evaluated on the basis of functional and structural characteristics.

Only five projects had control sections with overlay thicknesses approximately equal to those of at least some of the corresponding crack-and-seat sections. These five projects are the only basis for true comparisons of performance between the crack-and-seat sections and a standard AC overlay. Therefore, although general conclusions and comparisons were made considering all of the study sections, when a statistical comparison was desirable between the crack-and-seat and control sections, only these five projects, listed in Table 3, were utilized.

Pavement Roughness

The longitudinal roughness of each pavement section was measured with a Mays meter as described earlier. The rough-

ness measurements obtained on each of the 29 study sections are given in Table 4. It can be seen that there was a wide variation in the amount of surface roughness, from a low of 24 in./mi to a high of 113 in./mi. The study section with the least amount of roughness, 24 in./mi, was the crack-and-seat and overlay section on I-4 near Tampa, Florida. The study section found to have the most roughness, 113 in./mi, was one of the control sections on TH-71 near Willmar, Minnesota. The average roughness for the crack-and-seat and control sections was found to be 56 and 73 in./mi, respectively.

Five projects had control sections with overlay thicknesses approximately equal to those of at least some of the corresponding crack-and-seat sections. The roughness measurements taken on the 17 sections in five projects from Table 3 are shown in Figure 2. On four of the five projects, the crack-and-seat and overlay sections exhibited a roughness range from equivalent roughness to 59 percent less roughness than the control sections. The one crack-and-seat and overlay section with significantly more roughness than its control section was the overlay built on I-80 in Albany County, California, in 1982. A pooled regression analysis indicated that the crack-and-seat sections have significantly less roughness (approximately 14.5 in./mi less).

The present serviceability rating of each section is also given in Table 4. The PSR on the five control projects was evaluated. Although the PSR on the crack-and-seat sections is slightly higher than on the control sections, the magnitude of the difference is statistically insignificant.

The roughness of each study section was plotted against overlay thickness to determine the effects of this variable on performance (Figure 3). The graph shows no significant correlation between overlay thickness and roughness. Figure 4 indicates that the control sections with the lower amount of traffic apparently experienced more roughness. Regression analyses supported this conclusion, but with a low correlation ($R^2 = 25$). One would expect, however, that the thicker overlay would be rougher if there is more traffic on the section. These data show the opposite. However, both the 7.5-in. sections with high roughness are located in project MN7 (the oldest project) and therefore really represent only a single observation. These Minnesota sections did not, however, exhibit high levels of rutting as a possible cause of the roughness.

Observing Figure 3 with respect to the crack-and-seat sections shows no correlation between the thickness of the overlay and pavement roughness. Figure 4, however, indicates that the sections with higher traffic volumes experienced less roughness. However, one would expect an increase in roughness on high-traffic routes. Consequently, other factors must have an overriding effect on roughness.

One important parameter is the size of the cracked pieces. It has been assumed that it is better to have smaller segments rather than large pieces, thereby reducing the thermal movements to a lower level. The roughness of the sections was plotted with respect to segment size as shown in Figure 5. Observing the figure, it can be seen that there is no distinct difference in performance for the large, medium, or small pieces. The sections with small pieces were all constructed of JRPC and might be expected to perform differently. However, there is no statistically significant difference between the performance of the medium and large pieces on the JPCP sections.

The type and quantity of seating has been considered a possible factor in the performance of cracked and seated sections. Three types of rollers were used to seat the cracked pavement on the study sections: vibratory sheepsfoot, vibratory steel-wheeled, and pneumatic. One section, CA 9-6, was not seated. The roughness was plotted as a function of the type of roller used to seat the slabs. The plot (Figure 6) did not show any significant difference in roughness between the different types of rollers used to seat the slabs.

Reviewing the roughness data, there is a statistically significant difference in average roughness between the control sections and the crack-and-seat sections. There was no difference, however, with regard to the roller type or the size of the pieces.

Reflection Cracking

For purposes of the study, all cracking observed in the overlay was considered to be reflective. It is possible that some of the observed cracking can be due to temperature differentials or other AC materials problems. However, it is difficult to dis-

tinguish the exact cause when only a condition survey was conducted. The severity of the cracking was classified as low, medium, or high, whereas the amount of cracking was combined as total linear feet per mile.

The transverse cracking for the outside lane is shown in Figure 7. It can be seen that the Minnesota section (the oldest section) had the highest amount of cracking, with the majority of the cracking being of medium severity. In all cases except Minnesota and Wisconsin, the control sections had more transverse cracking than the crack-and-seat section.

A plot of longitudinal cracking in the outside lane was also prepared (Figure 8). It includes centerline cracking but not lane-shoulder joint cracking. As seen in the figure, Minnesota had the highest amount of longitudinal cracking. The control sections had an average cracking of 1688 ft/mi, whereas the crack-and-seat had 1759 ft/mi, or a difference of only 4 percent.

The five control projects were again examined on the basis of total linear cracking and medium-high linear cracking. The crack-and-seat sections had less total cracking (67 percent

TABLE 2 EXPERIMENTAL MATRIX FOR CRACK-AND-SEAT OVERLAY THICKNESS AND CRACK PATTERNS

Maximum Cracked Piece Area	Approximate Asphalt Concrete Overlay Thickness (in)				
	3.5 - 4.0	4.1 - 5.0	5.1 - 6.0	6.1 - 7.0	7.1 - 7.5
SMALL 0.25 ft ² to 1 ft ²	WI 1-4	WI 3-1	WI 1-2	WI 1-3	
MEDIUM 8 ft ² to 12 ft ²	CA 11-2	FL 4-2	CA 10-3	CA 10-1 CA 10-2	
LARGE 24 ft ² to 40 ft ²	CA 9-2 CA 9-7	CA 9-4 CA 9-5 CA 9-6	MN 7-2		MN 7-1

TABLE 3 PROJECTS WITH CRACK-AND-SEAT AND CONTROL SECTIONS OF COMPARABLE CROSS SECTION

Project	Control Sections	Comparable Crack and Seat Sections	Pavement Type
CA 9	CA 9-1 CA 9-3	CA 9-2 CA 9-4 CA 9-5 CA 9-6 CA 9-7	JPCP JPCP JPCP JPCP JPCP
CA 11	CA 11-1	CA 11-2	JPCP
FL 4	FL 4-1	FL 4-2	JPCP
MN 7	MN 7-3A MN 7-3B	MN 7-1A MN 7-1B	JPCP JPCP
WI 1	WI 1-1	WI 1-4	JRCP

confidence) and more medium-high cracking (84 percent confidence). The magnitude of these differences was small, especially as compared with the differences between projects.

When the total cracking is plotted against the age of the overlay, a different view of the comparative performance of the crack-and-seat sections is presented. Observing Figure 9, it is seen that during the early life of the overlays (less than 6 years), the control sections had more reflection cracking than the crack-and-seat sections. With additional age (more than 6 years), the crack-and-seat sections apparently had more cracking than the control sections.

For all the crack-and-seat sections, total linear cracking was regressed as a function of age. A clear relationship existed: total linear cracking increases with age. However, when the same function was regressed for the control sections, no relationship could be determined for the control sections. Therefore, it is not possible to extract significant comparisons of performance with age from the available data.

The size of the broken pieces should influence the amount of reflection cracking. Figure 10 is a plot of amount of cracking as a function of piece size. It can be seen that the sections in Minnesota that had large pieces experienced the highest amount

of cracking. However, these are also the oldest sections. In Wisconsin, one section with small pieces had a significant amount of cracking. The remaining sections had less cracking. The Wisconsin sections, however, are JRCP. The one section with significant cracking had the thinnest overlay placed over a crack-and-seat JRCP section. No real conclusions can be drawn regarding the influence of piece size due to the confounding factors of pavement type, age, and overlay thickness.

The amount of reflection cracking with respect to type of roller was also evaluated. The Minnesota sections had the highest amount of cracking, and these sections were seated with a pneumatic tire roller. CA 9-2 was also seated using a pneumatic roller; however, that section did not exhibit a greater quantity of cracking than the other CA 9 sections. CA 9-6, which was not seated, also did not fall outside of the range of cracking exhibited by the remaining sections. The other study sections were seated either with a vibrating sheepfoot or steel-wheeled roller. These sections had less reflection cracking than the Minnesota sections. It should be noted, however, that the Minnesota sections had the largest-size cracked pieces. Consequently, there probably is an interaction between roller type and size of pieces, which makes it difficult to draw conclusions about the effects of roller type. In addition, the Minnesota sections were the oldest sections, further confounding the analysis.

TABLE 4 OUTER-LANE ROUGHNESS MEASUREMENTS

Section ID	Mays Meter Roughness	PSR
CA 9-1*	51	4.4
CA 9-2	50	4.4
CA 9-3*	46	4.4
CA 9-4	45	4.4
CA 9-5	42	4.4
CA 9-6	37	4.4
CA 9-7	39	4.4
CA 10-1	43	4.4
CA 10-2	47	4.4
CA 10-3	47	4.4
CA 11-1*	82	3.4
CA 11-2	99	4.1
CA 12	69	4.0
FL 4-1*	58	3.7
FL 4-2	24	4.4
MN 7-1A	60	3.4
MN 7-1B	56	3.1
MN 7-2A	70	3.3
MN 7-2B	99	3.0
MN 7-3A*	77	3.3
MN 7-3B*	113	3.3
WI 1-1*	62	3.8
WI 1-2	50	3.6
WI 1-3	57	3.6
WI 1-4	56	3.6
WI 3-1A	61	3.7
WI 3-1B	73	3.7
WI 3-2A*	86	3.5
WI 3-2B*	80	3.6

*Control sections

Rutting

The average rut depths varied from a low of 0.02 in. on Minnesota section 7-2A to a high of 0.48 in. on Wisconsin section 1-3. The rut depths measured on the cracked and seated overlays were compared with the amount measured on their control sections. The average rutting on the cracked and seated overlays was 0.19 in. while on the control overlays the average was 0.14 in. Average rut depth was analyzed for the five control projects. The crack-and-seat sections exhibited greater rutting by 0.02 in. (87 percent confidence), which is an insignificant difference.

A plot of rut depth is shown in Figure 11. It can be seen that in many cases, the crack-and-seat sections had more rutting than the control sections. In particular, the crack-and-seat sections in Wisconsin and California had significantly more rutting. Rutting on the control sections decreased with increased overlay thickness, while rutting on the crack-and-seat sections did not show any trend.

The higher rutting on the crack-and-seat sections is probably due to secondary movement of the cracked slabs under traffic loading. The slabs in the control section still provide a rigid base, whereas the cracked slabs can now move. Observing the figure, it is seen that Wisconsin had the highest rutting; Wisconsin also had the smallest cracked pieces. The smaller pieces will have secondary movement before the large pieces, thus explaining increased rutting.

Deflection Measurements

Nondestructive testing of all 29 study sections was conducted using a falling-weight deflectometer as described previously.

There was a wide variation in the measured wheelpath deflections, from a low of 2.50 mils to a high of 25.5 mils. The range of deflections for each section is shown in Figure 12. The roughness of each study section was evaluated against average deflection. As would be expected, sections with higher deflections tend to exhibit greater roughness.

Three deflection basins for each section were analyzed using the BISDEF elastic-layer analysis program (5). Points were selected to indicate the variations of values along the sections. The results generally did not indicate as great a reduction in modulus as might be expected. Only two sections had low values for the cracked and seated concrete of less than 2 million psi. Only the Yreka County, California, section had any backcalculated modulus values of less than 1 million.

The results of the backcalculations indicated a broad range of values for many of the sections. Two factors contributed to these ranges. First, there was a wide variation in the results obtained. Second, many of the deflection basins could not be matched within an acceptable tolerance. Therefore, the results had to be considered within a wide margin of error.

If the analysis of the crack-and-seat sections is considered carefully, the cause of both of the above factors is revealed. A cracked and seated layer may not behave as an elastic layer and therefore not be easily modeled as such. The location of

an underlying crack with respect to the load may influence the shape of the resulting deflection basins. The same load applied at different distances from an underlying crack results in different deflection basins. These different basins will result in the calculation of varying moduli for the cracked and seated layer. In addition, a deflection basin resulting from an applied load near an underlying crack may have an erratic shape that cannot be fitted by a smooth curve. Such basins are difficult to match with confidence using an elastic-layer program. Therefore, answers could not be obtained for some of the analyzed deflection basins. The analysis was further complicated by the presence of cement-stabilized or lean PCC bases in some of the sections.

Because the evaluation of layer properties was somewhat unsuccessful, a simplified approach to evaluating the structural effects of cracking and seating was undertaken. For each section, the average deflection at each sensor position was analyzed. In addition, the cross-sectional areas of these average deflection basins were calculated.

These values were then compared for the five control projects. The differences between the measured maximum deflections and calculated basin areas for the crack-and-seat and control sections were not statistically significant at the 95 percent confidence level. On the basis of the available data, no

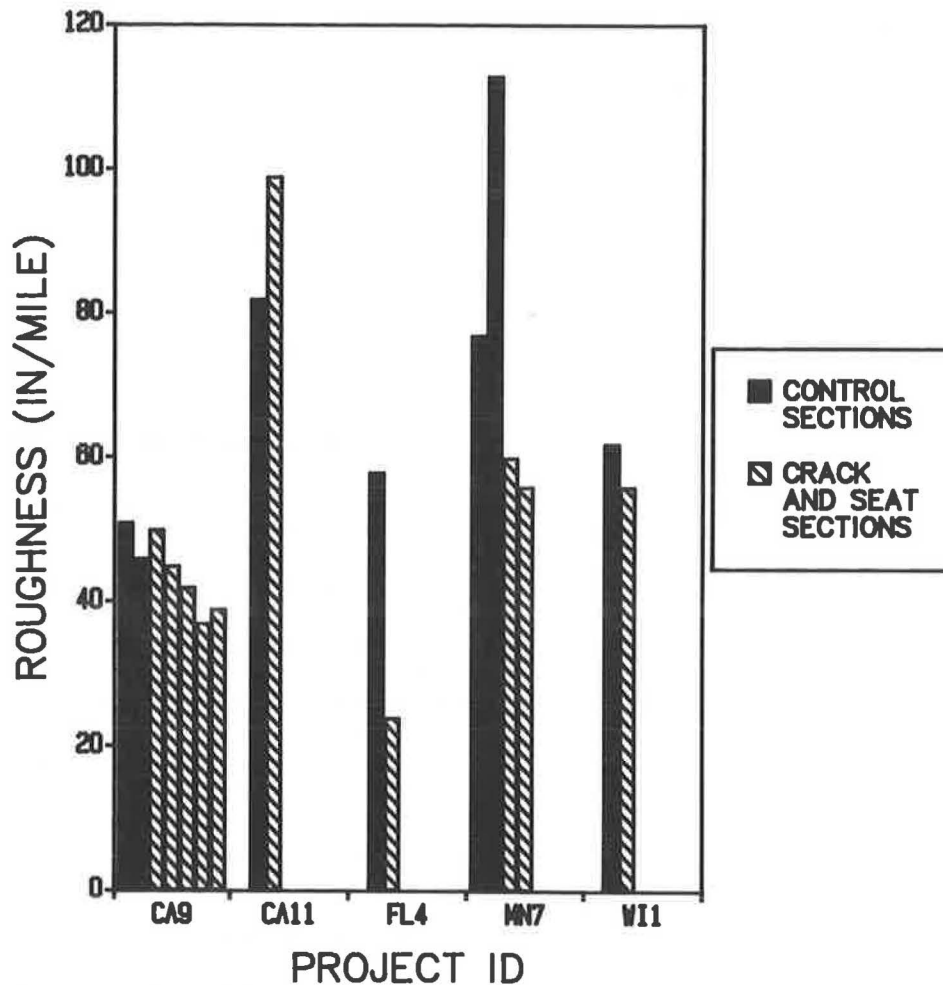


FIGURE 2 Comparison of roughness measurements taken on crack-and-seat and overlay sections with control sections.

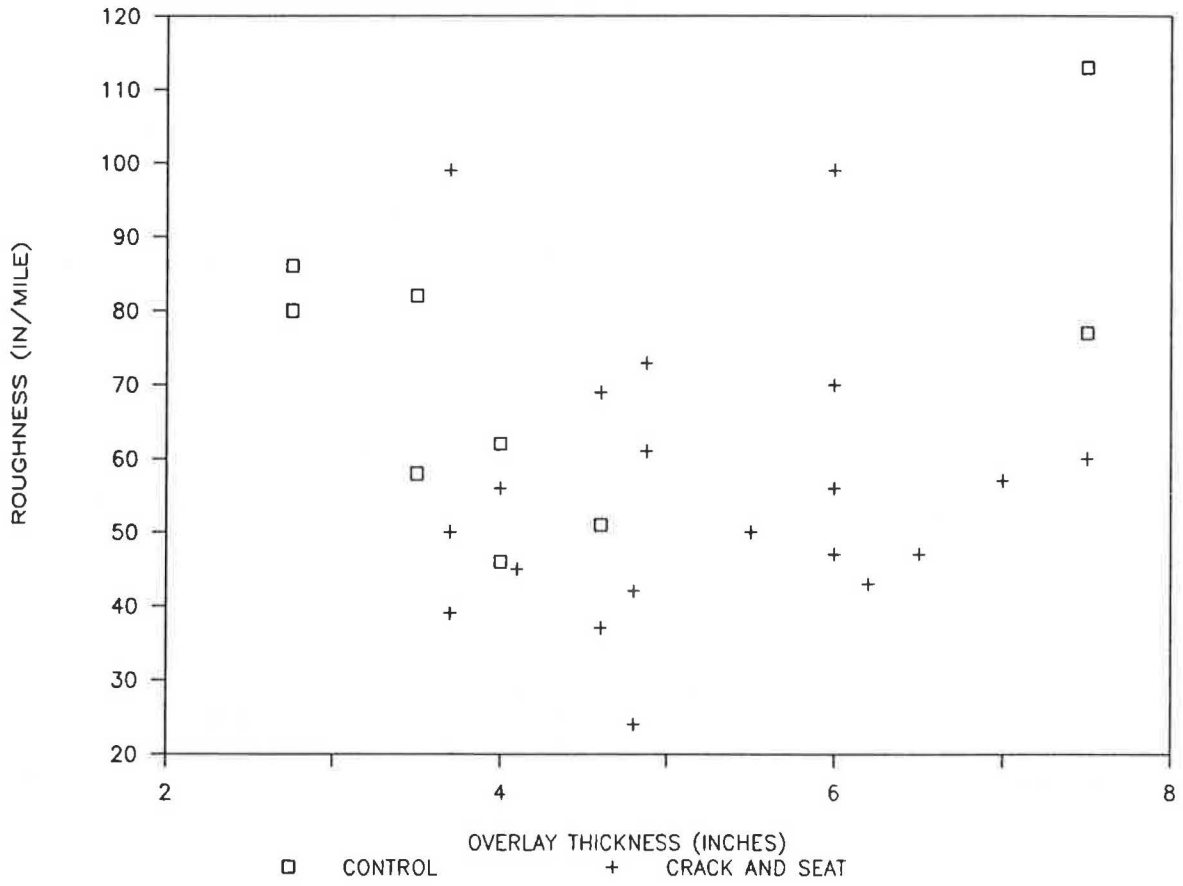


FIGURE 3 Pavement roughness versus overlay thickness.

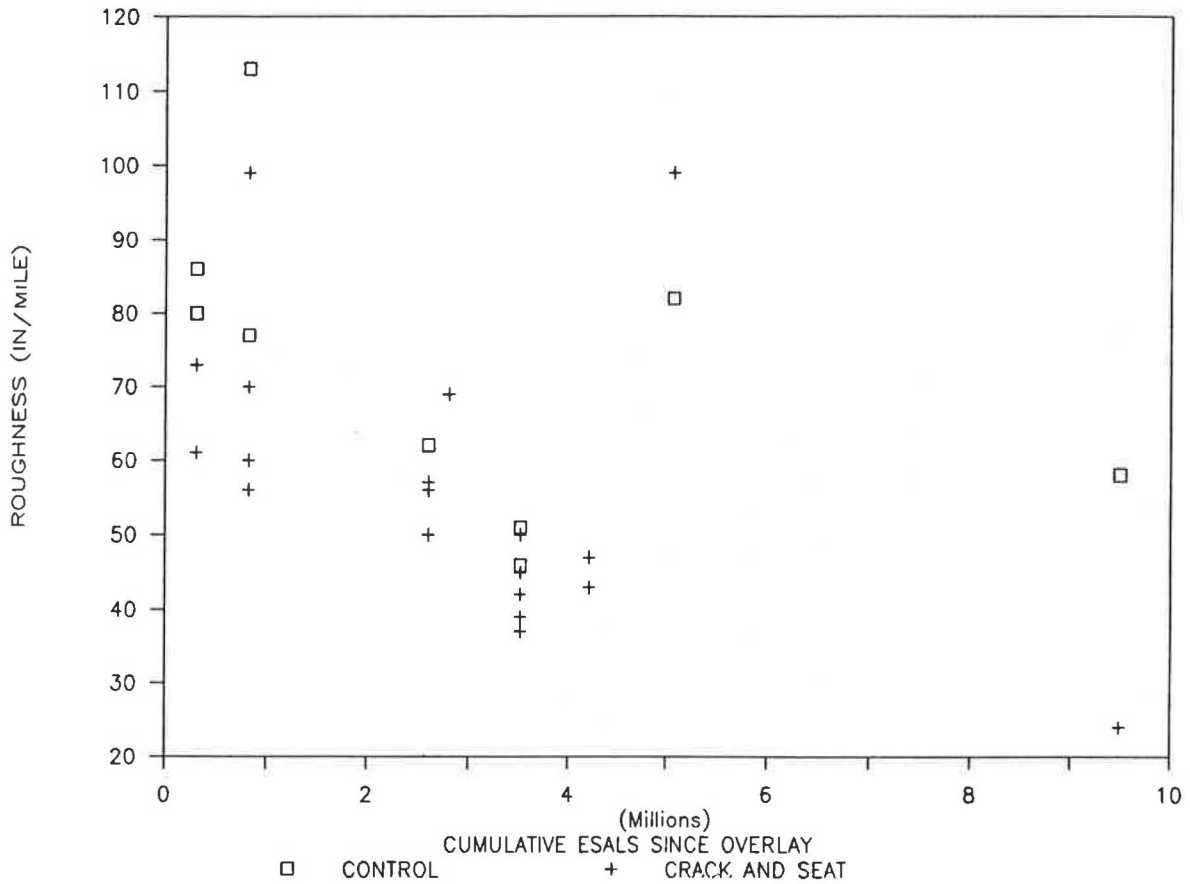


FIGURE 4 Pavement roughness versus traffic since overlay.

reduced layer structural properties can be predicted as a result of crack-and-seat procedures. The intent of cracking the pavement is to create pieces small enough so that horizontal movement is reduced, whereas much of the original structural integrity is maintained. Structural integrity appears to have been retained on the crack-and-seat study sections in this project.

CONCLUSIONS

Based upon work conducted during this study and reported herein, the following conclusions were drawn:

- Over the past 30 years, 24 states throughout the United States have experimented with the crack-and-seat and overlay of jointed PCC pavements. States that have documented their experiments with cracking and seating have reported experiences that range from poor to very good.
- The crack-and-seat sections with adjacent control sections studied in this project exhibited significantly less roughness than their corresponding control sections.
- Based on analysis of the falling-weight deflectometer data, there was no significant loss of structural support on the crack-and-seat sections.
- The crack-and-seat sections exhibited significant increases in cracking with age.

- The crack-and-seat sections exhibited more medium- and high-severity cracking than the corresponding control sections. The crack-and-seat sections displayed less total cracking than the control sections.

- Based on the data analyzed in this study, the crack-and-seat and overlay process does not appear to have consistently and significantly improved overall pavement performance.

Limitations of this study include the limited number of sections, the relatively few JRCP sections, the unequal distribution of sections across climatic regions, the lack of JPCP with small cracked pieces, and the lack of JRCP with medium to large cracked pieces. States using this technique are encouraged to establish control sections to verify that their specified procedures result in the benefits desired or expected from the use of this rehabilitation technique.

ACKNOWLEDGMENTS

This paper describes a portion of a major national field and analytical study that investigated the effects of various design features on the performance of jointed concrete pavements. The study was sponsored by the Federal Highway Administration with Roger M. Larson serving as the Contract Manager (COTR). ERES Consultants, Inc. was the prime research contractor. The assistance of Michael I. Darter and Kurt Smith is greatly appreciated.

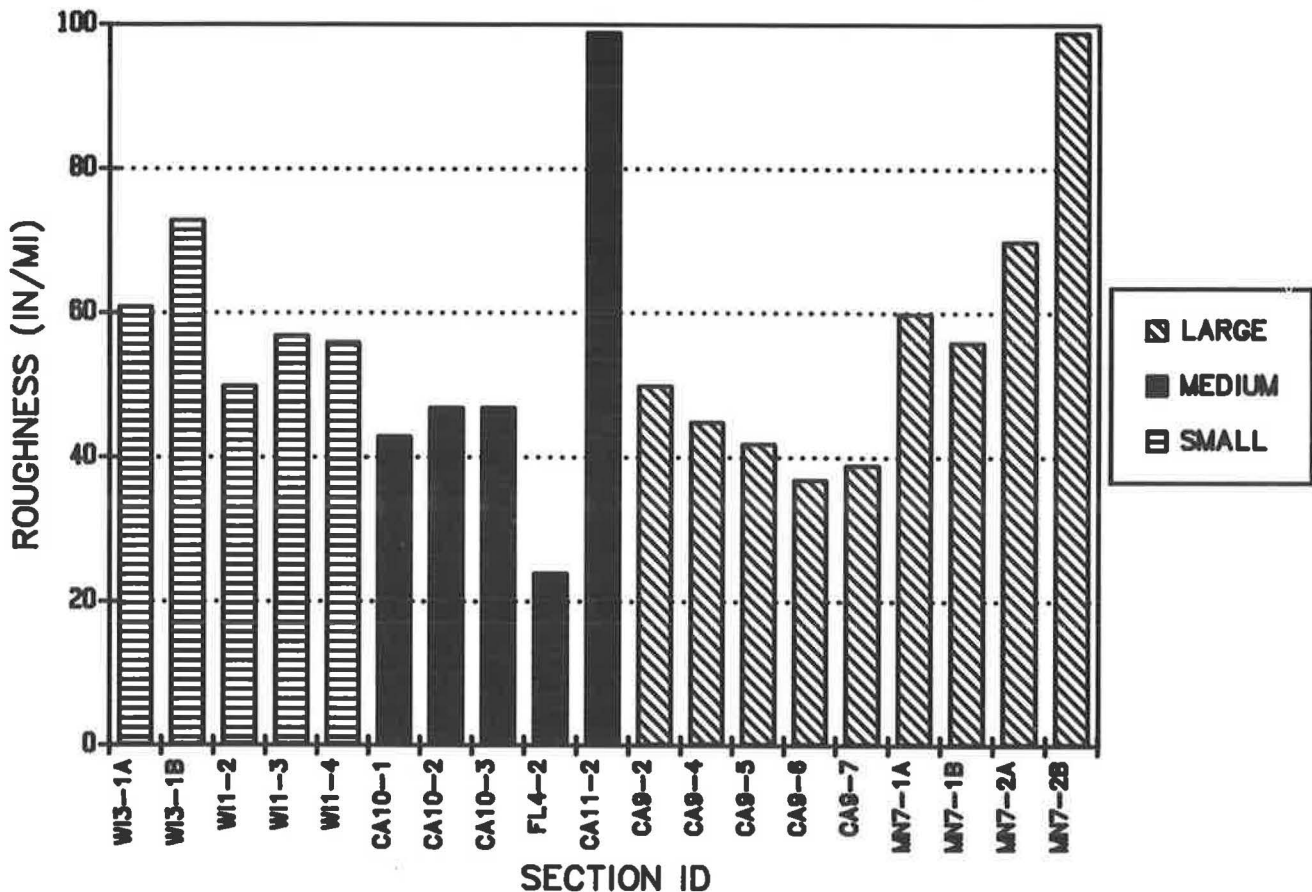


FIGURE 5 Pavement roughness with respect to cracked piece size.

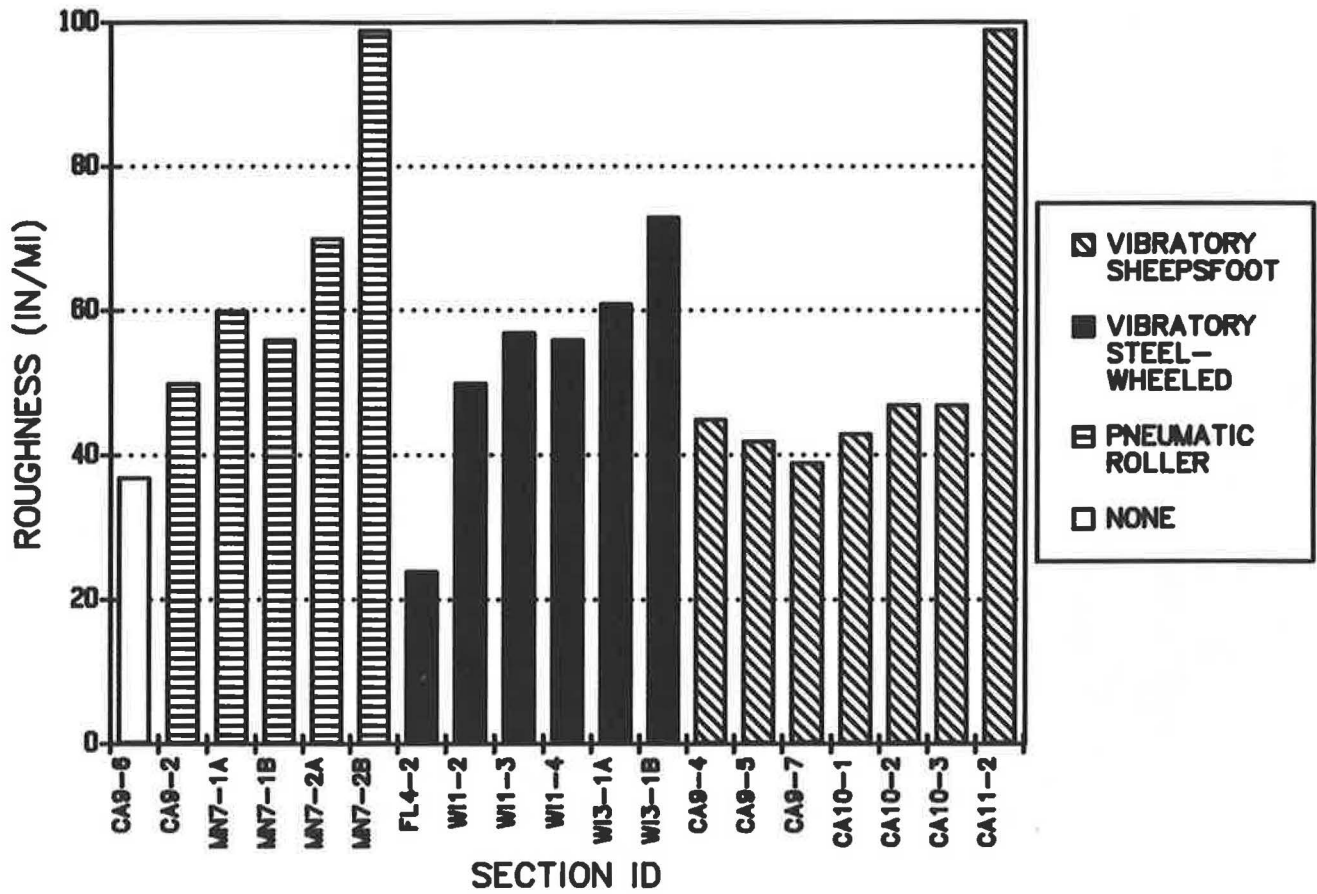


FIGURE 6 Pavement roughness with respect to type of seating equipment.

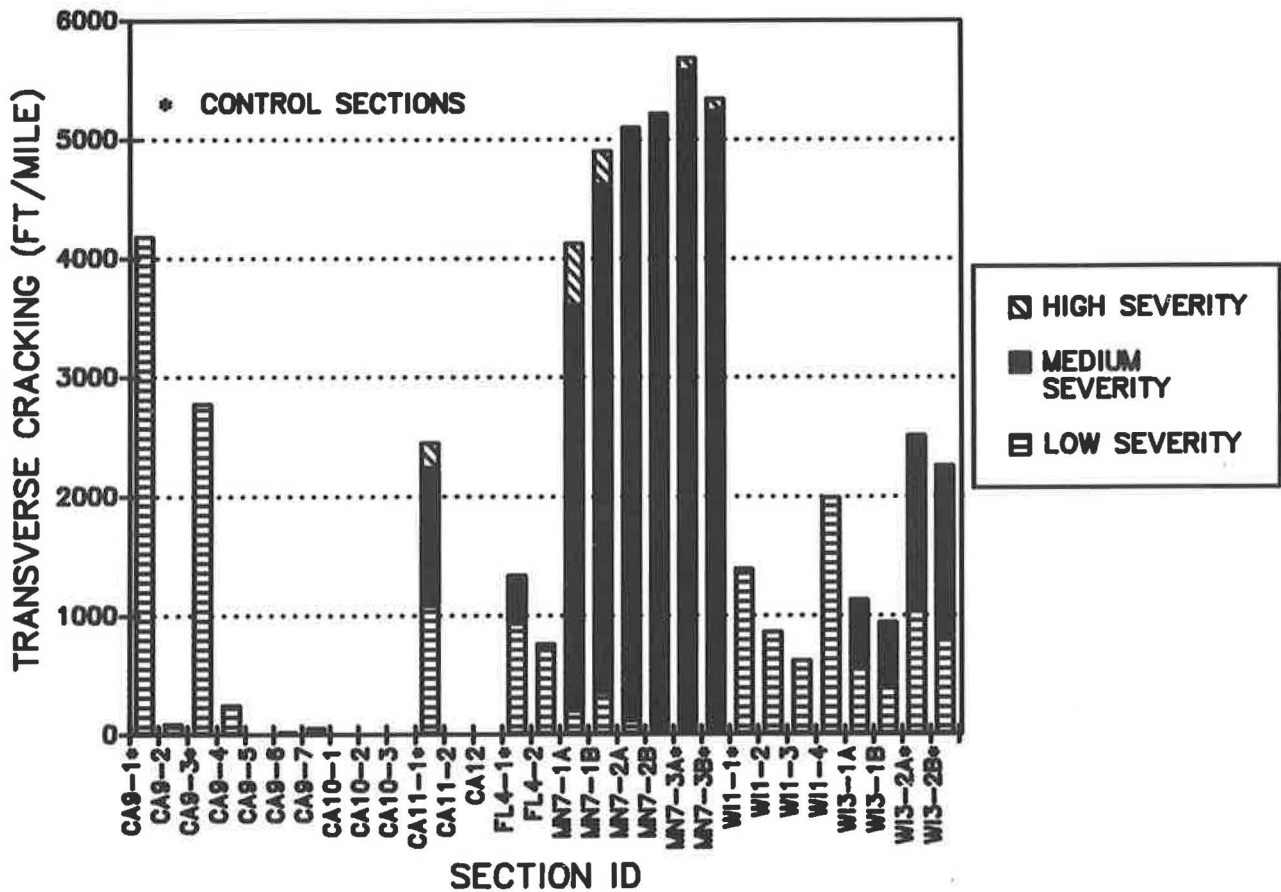


FIGURE 7 Quantity and severity of transverse cracking in the outside lane.

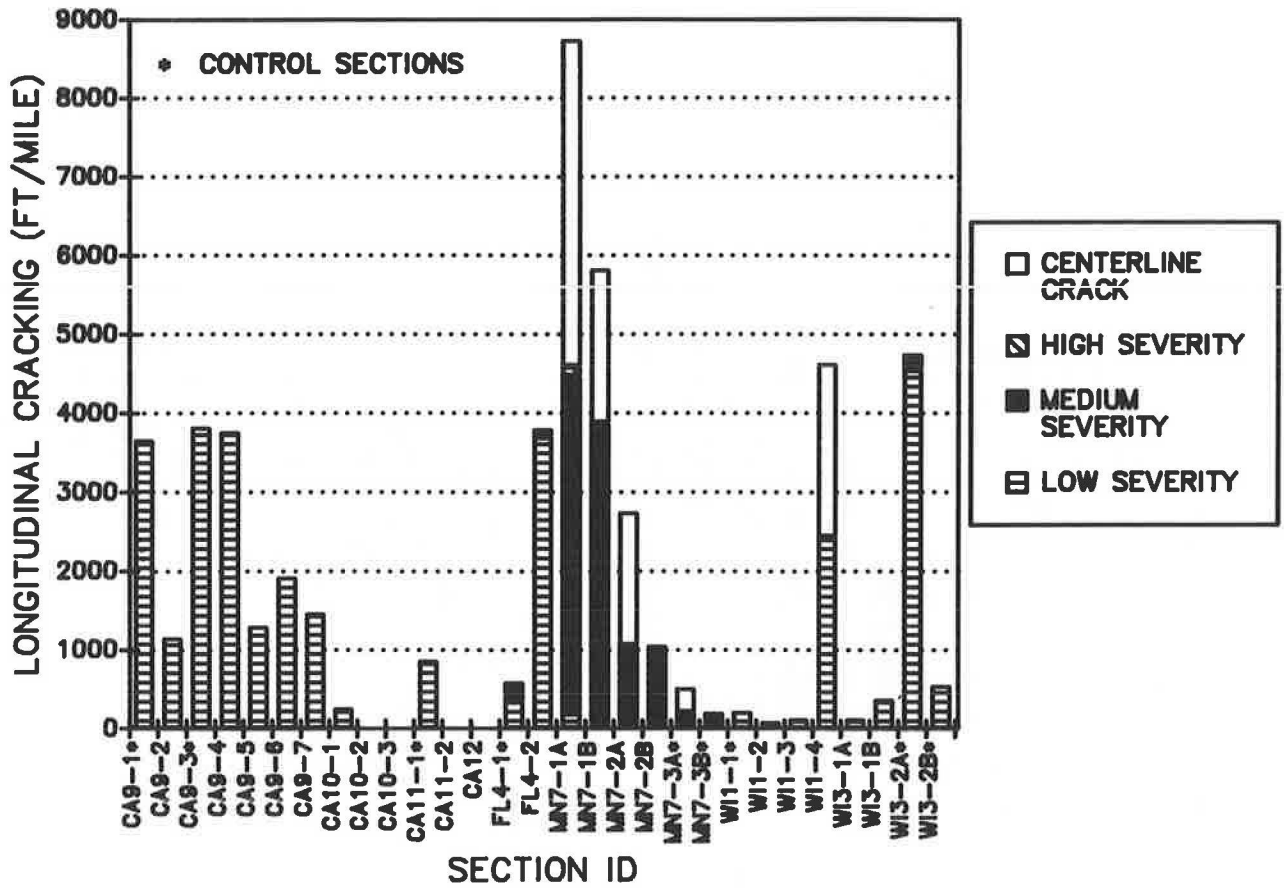


FIGURE 8 Quantity and severity of longitudinal cracking in the outside lane.

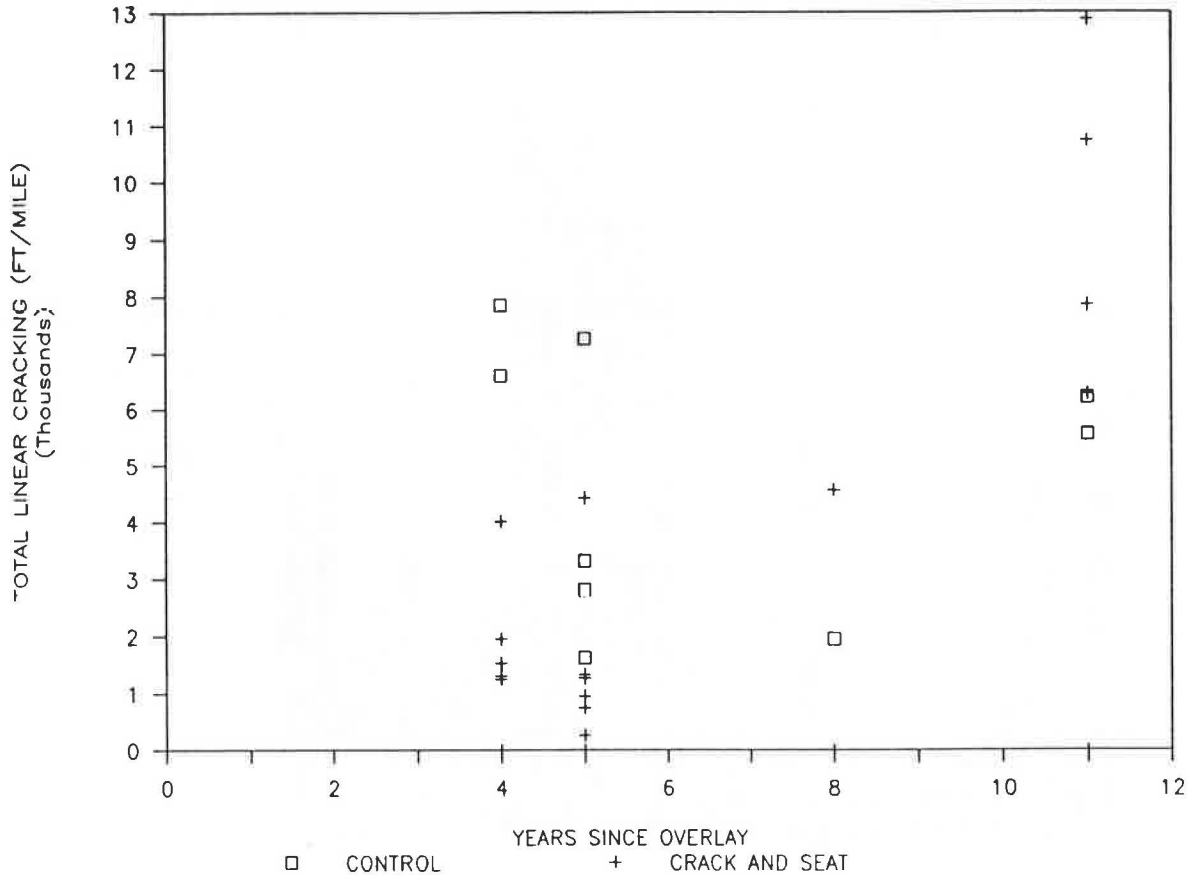


FIGURE 9 Total linear cracking versus years since overlay.

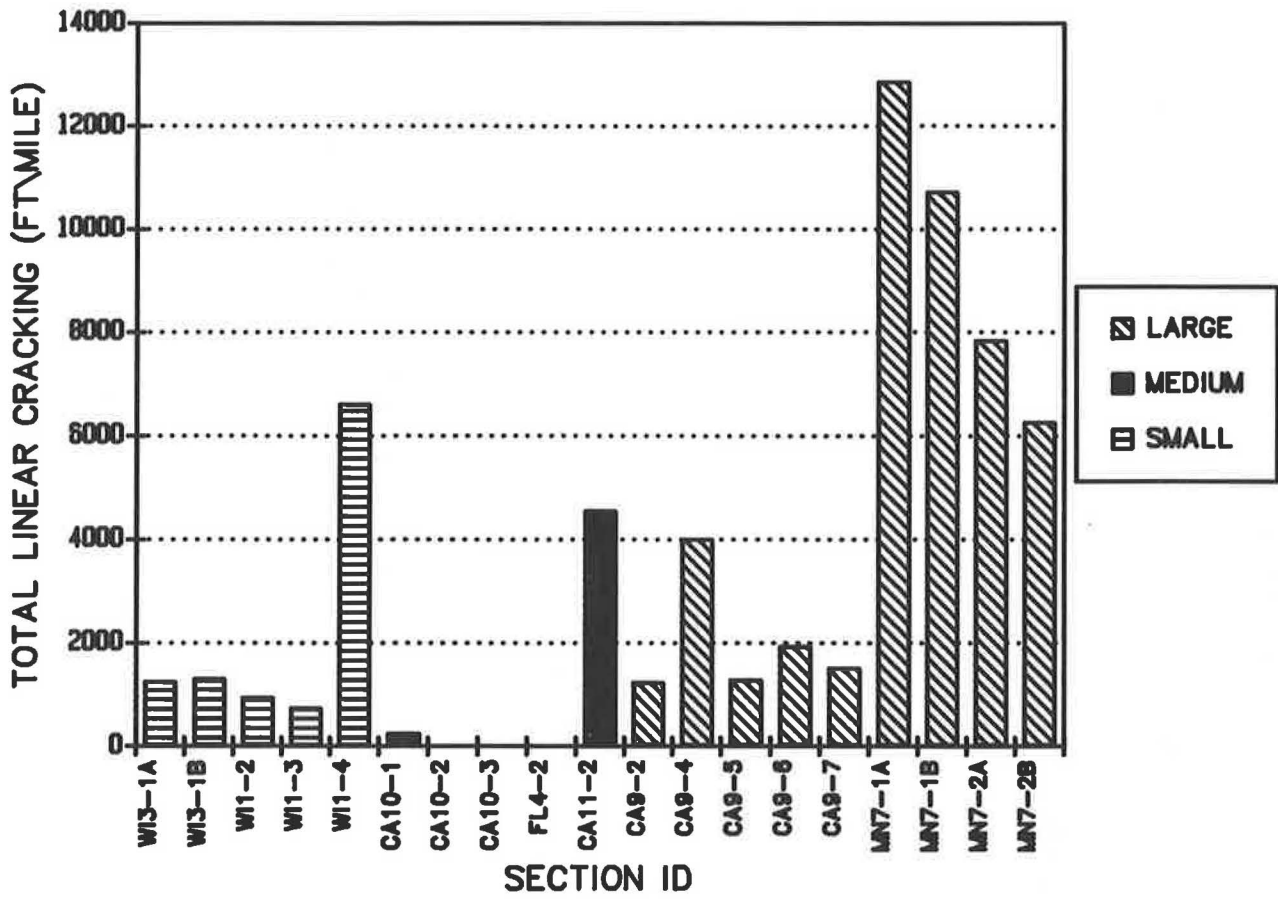


FIGURE 10 Total linear cracking with respect to cracked piece size.

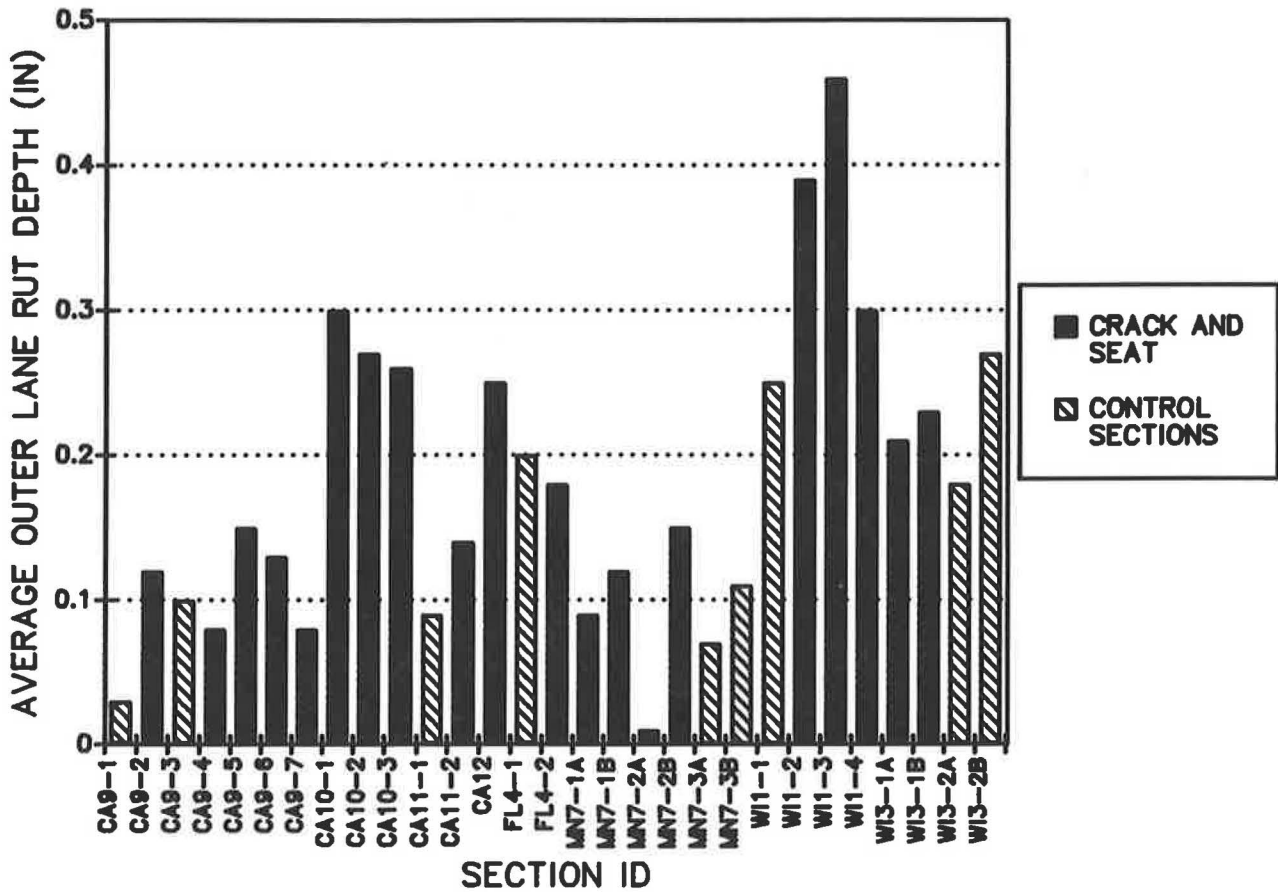


FIGURE 11 Average outer-lane rut depths.

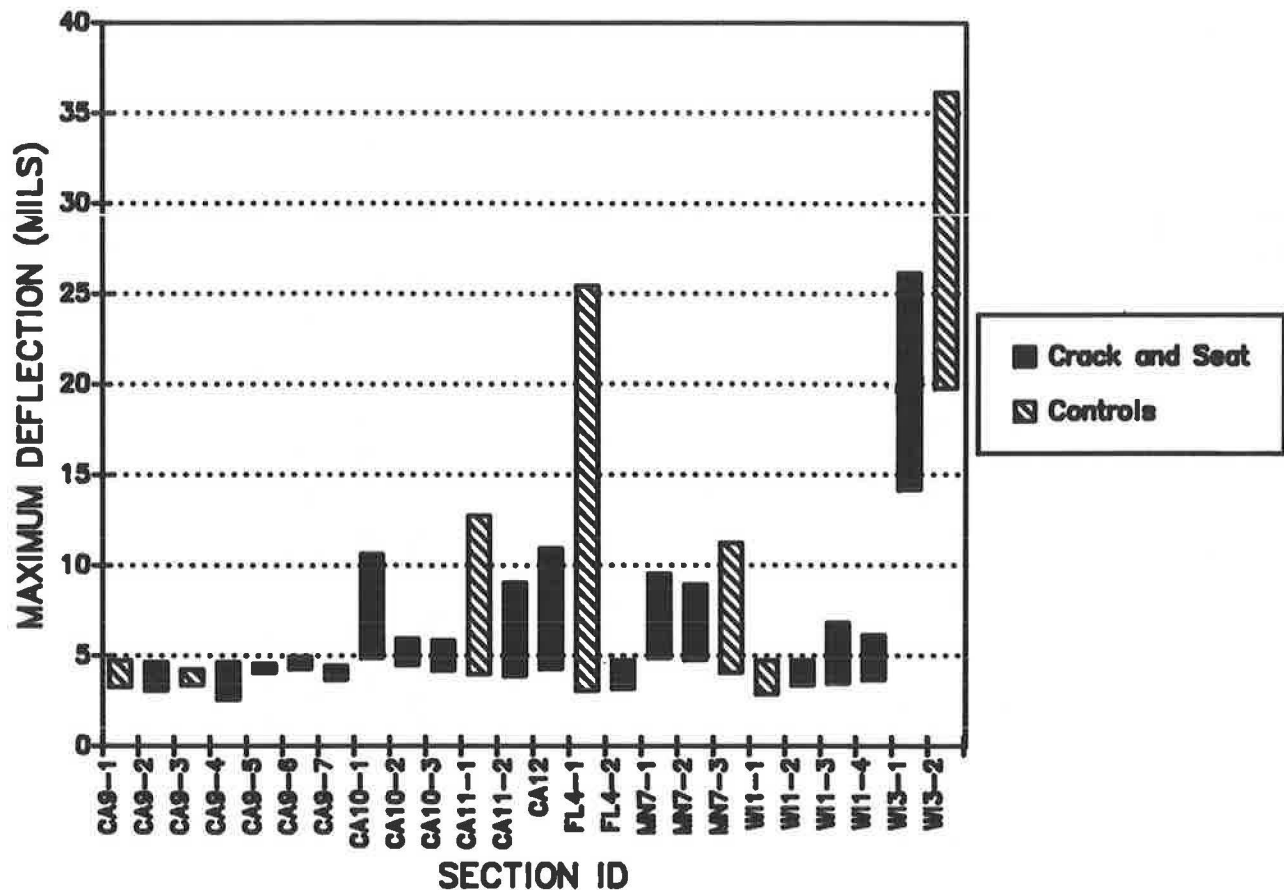


FIGURE 12 Range of maximum deflections for each study section.

REFERENCES

1. W. P. Kilareski and S. M. Stoffels. *Crack and Seat and AC Overlay of Rigid Pavements*. Final Report FHWA-RD-89-127. FHWA, U.S. Department of Transportation, 1989.
2. *Pavement Rehabilitation Manual*, Report FHWA-ED-88-025. FHWA, U.S. Department of Transportation, 1988.
3. K. Smith, M. I. Darter, J. B. Raubut, and K. T. Hall. *Distress Identification Manual for the Long-Term Pavement Performance Studies*. Strategic Highway Research Program, National Research Council, Washington, D.C., March 1987.
4. C. L. Monismith and F. N. Finn. *NCHRP Synthesis of Highway Practice 116: Asphalt Overlay Design Procedures*. TRB, National Research Council, Washington, D.C., Dec. 1984.
5. A. J. Bush III. *Nondestructive Testing for Light Aircraft Pavements, Phase II: Development of the Nondestructive Evaluation Methodology*. Report FAA-RD-80-9-II. FAA, U.S. Department of Transportation, Nov. 1980.

Publication of this paper sponsored by Committee on Pavement Rehabilitation.