Structural Overlay Strategies for Jointed Concrete Pavements

Volume II, Cracking and Seating of Concrete Slabs Prior to AC Overlay

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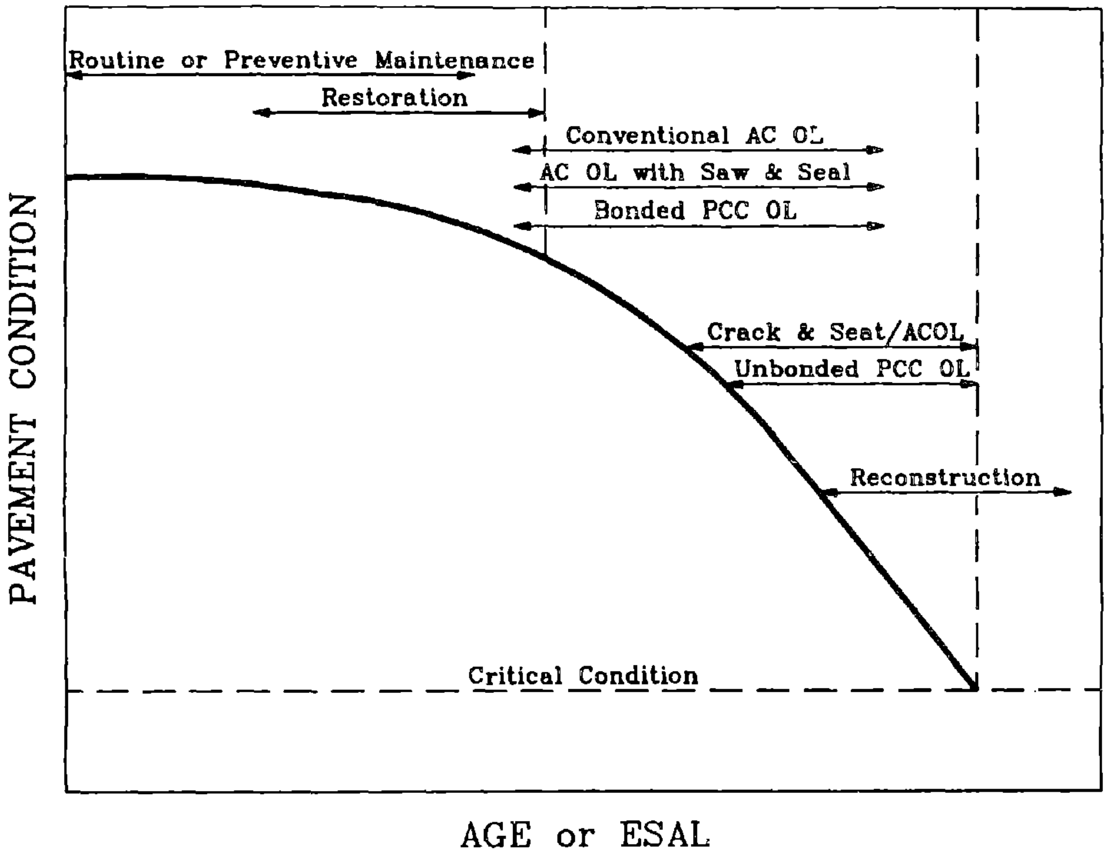

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Federal Highway Administration

Research, Development, and Technology
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FOREWORD

This report is one volume of a four volume set of interim reports documenting a major field study and evaluation of the effectiveness of three structural overlay types for jointed portland cement concrete pavements and guidelines for their use. The three overlay types are sawing and sealing joints in asphalt concrete (AC) overlays of PCC pavements, cracking and seating PCC pavements prior to AC overlay and constructing a thin bonded PCC overlay on top of the existing PCC pavement. Condition survey, deflection testing and roughness measurements were performed on a total of 60 sections. It should be noted that the small sample of projects and the unknown condition of the pavement prior to overlay limit the conclusions that can be drawn from the study. Volume V (Summary of Research Findings) and the technical summary will be given widespread distribution in the near future. These reports will be of interest to those involved in design, construction and rehabilitation of jointed concrete pavements.

Sufficient copies of this report are being distributed by FHWA memorandum to provide one copy to each FHWA Region and Division and two copies to each State highway agency. Direct distribution is being made to the division offices. Additional copies for the public are available from the National Technical Information Service (NTIS), U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161. A small charge will be imposed for each copy ordered from NTIS.

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16. Abstract

A major field study and evaluation has been conducted into the effectiveness of three structural overlay types for portland cement concrete (PCC) pavements. These include sawing and sealing asphalt concrete (AC) overlays of PCC pavements, cracking and seating PCC pavements prior to AC overlay, and constructing a thin bonded PCC overlay on top of the existing PCC pavement. Condition surveys, deflection testing, and roughness measurements were performed on a total of 55 sections. The performance of these sections was evaluated and the effectiveness of each overlay type analyzed. Based on the field data, guidelines were developed for the use of structural overlays. In addition, the results of this study were used to revise and enhance the EXPEAR rehabilitation advisory system.

This volume examines the rehabilitation technique of cracking and seating PCC pavement prior to overlay, which has been used to reduce reflection cracking. Cracking the slabs reduces slab movement due to temperature changes; seating the slabs stabilizes the pieces. The first part of this report examines the literature and evaluates the performance of inservice crack and seat overlays from several States; the second part incorporates these research findings into guidelines for crack and seat techniques and specifications.

This volume is second is a series. The other volumes are:

FHWA No.	Vol. No.	Short Title
FHWA-RD-89-142	I	Sawing and Sealing of Joints in AC Overlays of Concrete Pavements
FHWA-RD-89-144	III	Performance Evaluation and Analysis of Thin Bonded Concrete Overlays
FHWA-RD-89-145	IV	Guidelines for the Selection of Rehabilitation Alternatives
FHWA-RD-89-146	V	Summary of Research Findings
FHWA-RD-89-147	VI	Appendix A - Users Manual for the EXPEAR Computer Program

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

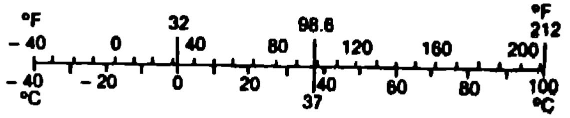
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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PART I

1. INTRODUCTION AND RESEARCH APPROACH

BACKGROUND

The highway system in the United States represents one of the Nation's most important public works investments. Highways such as the Interstate system, arterials, and collection roads account for approximately 25 percent of the highway mileage; however, these same highways carry approximately 85 percent of the traffic.[1] Interstate highways alone carry 21 percent of the Nation's traffic on only 1 percent of the total U.S. highway system.

Many of the miles of pavement on the Interstate and arterial network are composed of portland cement concrete (PCC). In most cases, these pavements have provided many years of service with relatively low maintenance costs. Many of these pavements are approaching the end of their design life, and consequently, they have reached their terminal serviceability level. The need to develop dependable and economic rehabilitation techniques for PCC pavements is becoming increasingly important.

Numerous techniques and treatments have been tried to prevent or minimize the reflection cracking problem that is inherent in asphalt concrete overlays of jointed concrete pavements. Some of the treatments include the use of fabrics, stress-relieving interlays, crack arresting interlayers, and sawing and sealing of joints in the asphalt concrete overlay. The success of these treatments varies considerably. It appears that it is almost impossible to stop reflection cracking, although the severity can be reduced.[2]

Because this is the case, some agencies have decided to control the problem rather than eliminate it. One method is to "crack" the existing slab into smaller pieces and then "seat" the pieces to keep them from rocking and moving. With a reduction in slab movement there should also be a reduction in reflection cracking of the asphaltic concrete surface. The purpose of this report is to document the effectiveness of the "crack and seat" method of reflective crack control.

PROBLEM STATEMENT AND RESEARCH OBJECTIVES

Cracking and seating of portland cement concrete pavements before placing an overlay has been used as a rehabilitation technique for over 30 years. It is believed that cracking and seating will control the occurrence and severity of reflective cracks; thus, it will prolong the life of the overlay. There has been limited evaluation or documentation of the field performance of crack and seat on a nationwide basis.[3,4] It was felt that an in-depth evaluation of crack and seat and overlay could provide information to determine expected performance life of the technique. This information can assist the highway engineer with the design of PCC pavement rehabilitation projects.

The research discussed in this report was part of a major Federal Highway Administration (FHWA) project titled "Performance/Rehabilitation of Rigid Pavements." The specific objectives of the entire study (Phases I and II) were to:

1. Evaluate the performance of different rigid pavement design features on in-place pavement sections under similar environmental and traffic loading conditions in each of eight different States. Relate the observed distress to the probable cause to allow valid analyses of the data.

2. Determine the adequacy of available models and design procedures to predict the performance of in-place pavement sections. Estimate the expected performance periods of recently constructed projects incorporating improved design features that provide drainage and reduced deflections. Determine the cost-effectiveness of these features.

3. Improve the analysis and design procedures and guidance for the design of rigid pavements to reflect the effects of sealing, drainage, and deflection on pavement performance.

4. Develop improved design and construction procedures for the following structural overlay techniques: thin bonded portland cement concrete (PCC) overlays, crack and seat and overlays, and sawing and sealing joints in asphalt concrete (AC) overlays over existing PCC joints.

5. Develop guidance on how to determine the most appropriate structural overlay technique(s) so the cost effectiveness can be compared with other strategies (e.g., concrete pavement restoration, unbonded overlays, or reconstruct/recycle).

The overall objective of the study was summarized as the improvement of initial design procedures and the improvement of overlay design procedures through consideration of existing analytical techniques and field performance observations.

The objective of Phase II of this study was to develop guidelines for the use of structural overlays of PCC pavements and to develop improved design and construction procedures for the three types of overlays. The specific objectives were to:

1. Develop guidelines and construction specifications for sawing and sealing of joints in AC overlays over existing PCC joints.
2. Verify and/or improve recommended design and construction procedures for crack and seat and overlay of rigid pavements.
3. Verify and/or improve design and construction procedures for thin bonded PCC overlays.
4. Develop practical guidelines to aid the design engineer in the selection of the most appropriate type of structural overlay for a rigid pavement.

A reported titled "Rigid Pavement Structural Overlay Summary Report" was prepared under Phase I.[5] The Summary Report provided the details that were used to develop a work plan for the crack and seat and overlay project. The research objective for Phase II, which included crack and seat, was listed above.

The specific objectives for the crack and seat and overlay task were to:

1. Evaluate the performance of inservice crack and seat and overlay projects.
2. Verify existing recommended design and construction procedures.
3. Evaluate the impact of drainage on the performance of crack and seat and overlay sections.
4. Develop improved design and construction procedures as appropriate.

SCOPE OF THE STUDY

As mentioned, several States have used crack and seat and overlay for many years. Consequently, several highway sections across the country have crack and seat treatments. Recognizing that the inclusion of an unlimited number of crack and seat overlays was beyond the resources of this project, the scope was limited to the evaluation of test sections that included a wide range of design variables. Furthermore, the test sections were restricted to overlays of jointed concrete pavement.

RESEARCH APPROACH

The research objectives were accomplished primarily by evaluating the performance of inservice crack and seat and overlay projects in several locations in the United States. In the course of this evaluation, an extensive database was developed that contained information regarding measured field performance, original pavement and rehabilitation design, traffic, and environmental data. The following procedures were used to obtain the above-mentioned data elements:

- The original pavement design and overlay designs were determined from as-built plans and specifications.
- Field condition surveys were conducted on each pavement section to determine the performance of the overlay.
- Historical traffic volumes and classifications were obtained from the State highway agencies for each project.
- Environmental data were taken from documentation of the monthly normals of temperature, precipitation, and heating and cooling degree days from the National Oceanic and Atmospheric Administration.

The data were assembled in a temporary database created by the SUPERCALC 5 Program for future inclusion into the main project database.[6] Engineering analysis of the data was done to determine the performance of the crack and seat and overlay projects.

2. THE REFLECTION CRACKING PROBLEM

The following background information and the information about failure mechanisms are paraphrased from chapter 2 of the FHWA report, "Improved Design and Construction Procedures for Sawing and Sealing Joints in AC Overlays Over Existing PCC Joints," since the reflection cracking problem is the same regardless of the overlay treatment.[2]

BACKGROUND OF REFLECTION CRACKING

Reflection cracking in an asphalt concrete overlay has always been a perplexing problem for highway engineers. This problem is becoming increasingly important because of the shift from new highway construction to rehabilitation of the existing highway system. The need for more pavement overlays increases the probability that more reflection cracking of pavements will occur around the country.

Perhaps Treybig et al. best defined this type of pavement distress:

> ...Fractures in an overlay or surface that are a result of, and reflect, the crack or joint pattern in the underlying layer, and may be either environmental or traffic-induced.[7]

Treybig et al. go on to state that:

> ...It is imperative that such cracking be prevented or controlled in order to provide a smooth riding surface, maintain the structural integrity of the overlay, and prevent the intrusion of water into the pavement system.[7]

Attempts to prevent the occurrence of these reflective cracks have been reported in the literature as far back as 1932.[8] Since that time, most advances in the state of the art for reflective crack prevention have come primarily from the experience gained from trial-and-error experiments on inservice pavements. Only in the last 10 to 15 years have theoretical studies of reflection cracking been conducted. While these studies have not succeeded in developing a method that successfully prevents reflection cracking, they have provided a better understanding of the mechanisms that cause an overlay to fail in this manner.

FAILURE MECHANISMS

An important step in developing a method to control reflection cracking is to develop an understanding of the mechanisms that cause such failures. Pavement researchers generally agree that the primary mechanisms leading to the development of reflection cracks in an asphalt concrete overlay are the horizontal and differential vertical movements at joints and cracks in the existing pavement with horizontal movements being considered more critical.[7,9-12] These damaging horizontal movements are caused by seasonal temperature changes and daily temperature cycles.[11]

Traffic loadings are considered to be responsible for differential vertical movements that occur at underlying joints with poor load transfer and at working cracks. Jayawickrama et al. have stated that three stress pulses occur as a moving wheel load travels across an underlying joint or crack as illustrated in figure 1.[13,14] According to Jayawickrama et al.:

> As the wheel load approaches the crack, the shear stress in the overlay above the crack will reach a maximum illustrated as point A.... When the wheel is directly above the crack, the maximum bending stress will occur as illustrated by point B.... As the wheel load crosses the crack, a second maximum shear stress in the reverse direction will occur as illustrated by point C....[13]

These stress pulses induce cracking in two distinct modes: opening (Mode I) and shearing (Mode II). These two stress modes are illustrated in figure 2.

Seasonal temperature changes and daily temperature cycles cause expansion, contraction, and curling in the existing slabs and overlay. The actual amount of movement is controlled by the temperature change, thermal coefficient of expansion of the pavement materials, the joint or crack spacing, and the amount of friction between the slab and base layer and also between the overlay and the PCC slab.[14]

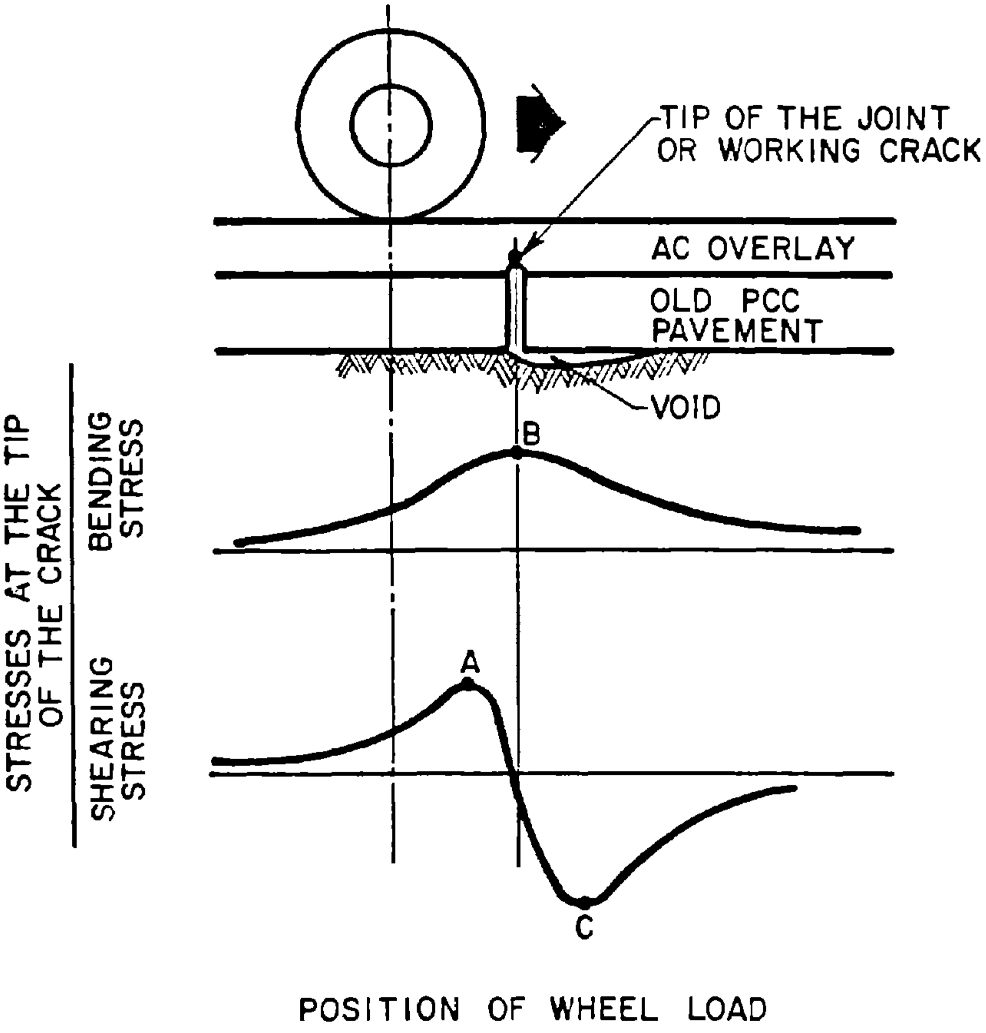
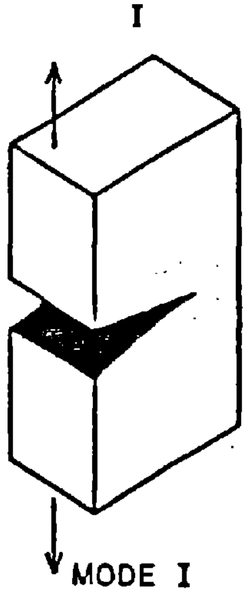
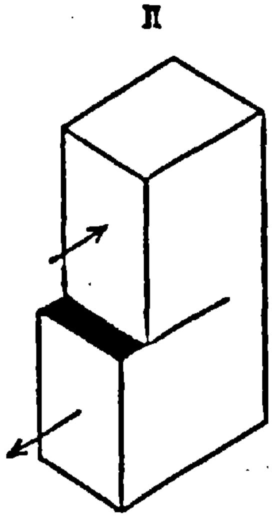


Figure 1. Shearing and bending stresses in an asphalt concrete overlay resulting from a moving traffic load.[13]



MODE I

OPENING MODE



MODE II

SHEARING MODE

Figure 2. Two distinct modes of crack propagation in an asphalt concrete overlay.[13]

The seasonal lowering of temperatures causes the existing PCC pavement to contract, which results in horizontal movements at the joints and cracks. As a result of this movement, the overlay is subjected to tensile stress concentrations in the opening mode as shown in figure 3. In addition, the overlay itself reacts to the lower temperatures, which results in additional tensile stress as shown in figure 4.

Daily temperature cycles also cause a tensile stress in the overlay. When a PCC pavement is subjected to a temperature gradient through its depth, it will tend to curl. If the top of the slab is warmer than the bottom, the curling will be concave downward. If, however, the top of the slab is cooler than the bottom, the corners and joints of the slab will tend to curl upward as shown in figure 5. This upward curling produces an opening at the joints, causing an increase in the tensile stress in the overlay.

REVIEW OF CRACK AND SEAT AND OVERLAY PROCEDURES

The concept of cracking and seating the portland cement concrete slab prior to overlaying is based on reducing the movement of the cracked slabs under the overlay. Horizontal movements caused by thermal effects and vertical movements 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 such that horizontal movement will be reduced but full aggregate interlock will still be maintained. In this manner, reflection cracking will be reduced and the existing PCC pavement should maintain much of its original structural capacity.

Cracking and seating of portland cement concrete pavements before placing an overlay has been used as a rehabilitation technique for almost 30 years. Historically, several different procedures and patterns of cracking have been used. The procedure of using a 50-ton pneumatic roller to break badly curled pavement slabs and seat them in the underlaying base was used in Minnesota.[15,16,17] Of five States using heavy rollers to break and seat PCC pavement in 1968, all had apparent success in retarding reflective cracks.[18]

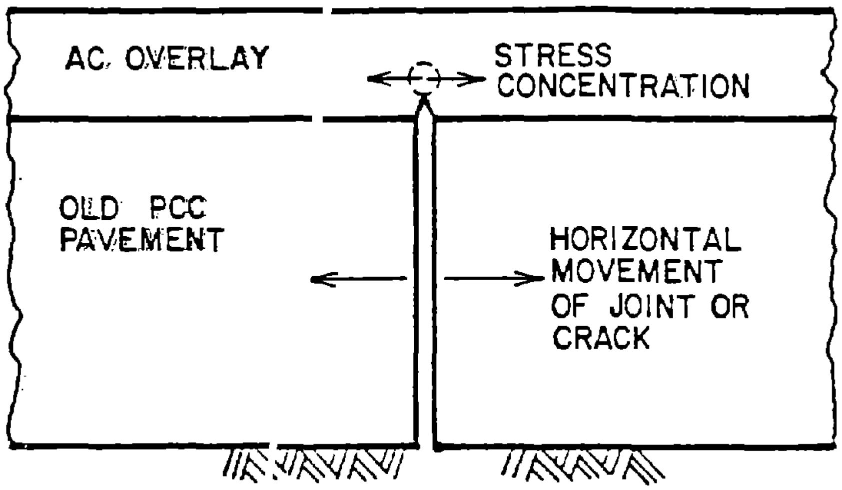


Figure 3. Stress concentrations in an AC overlay resulting from thermally induced movements of the PCC slab.[11]

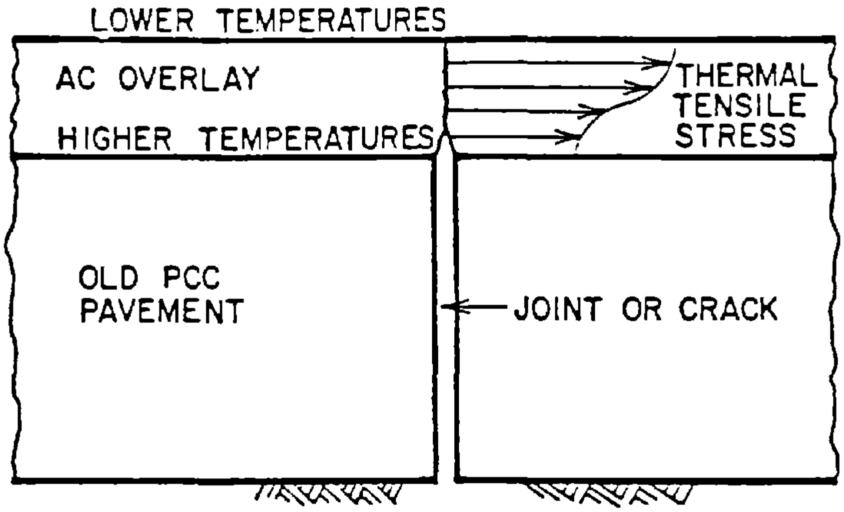


Figure 4. Thermal tensile stress in an AC overlay producing a crack above the joint or crack.[11]

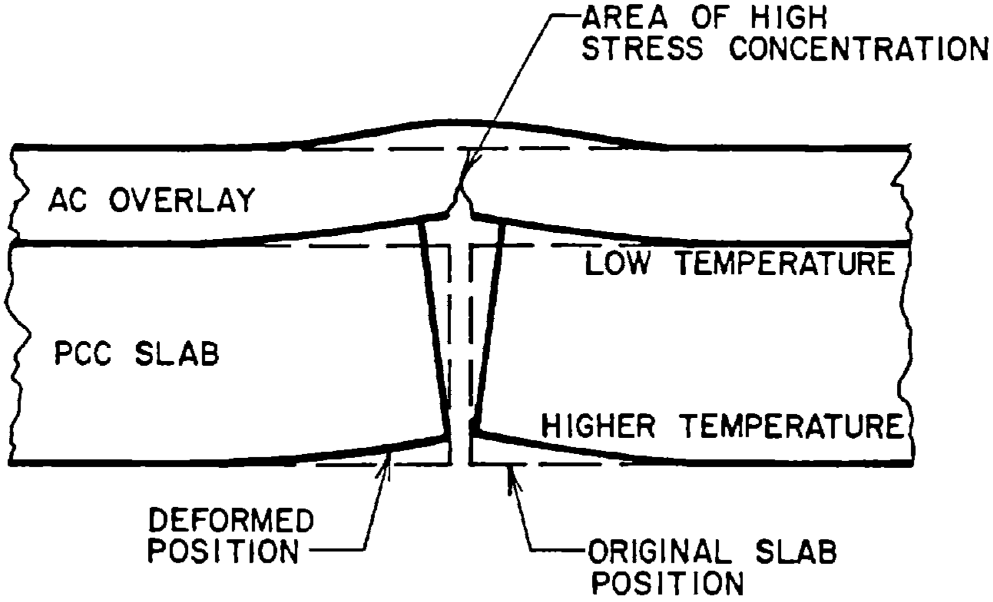


Figure 5. Stress concentrations in an AC overlay resulting from thermal curling of the pavement slab.

One of the earliest and most extensive reports on cracking and seating was written by Lyon in 1970.[19] He reported on a 10-year field study in Louisiana that determined the feasibility of using a 50-ton pneumatic-tire roller and an impact hammer to crack and seat the curled concrete pavement slabs on a wet subgrade. Lyon concluded that the best results were obtained when the hammer was used in conjunction with the roller.

It should be noted that most of the aforementioned research with rollers was carried out on PCC pavements on wet subgrades. According to Lyon, good results would not be expected on dryer, stronger subgrades. He recommended that this procedure only be used on projects where the subgrade moisture content was at optimum to 5 percent above the optimum value. This recommendation was confirmed when the use of a heavy roller failed to crack an 8-in concrete pavement in California. Because the slabs did not always break as planned when using a roller, this procedure never gained much popularity. Instead, the emphasis in recent years has shifted towards cracking the pavement with pavement breakers that have been modified to suit the pavement cracking process and then seating the pieces with a heavy pneumatic-tired roller.

Design Procedures for Cracked and Seated PCC

Since its inception, the crack and seat overlay procedure has remained a controversial rehabilitation technique. One of the reasons for this is the lack of an established pavement structural design method using the crack and seat and overlay technique. Most agencies using the crack and seat method rely on their past experience and engineering judgment when designing an overlay thickness. The new AASHTO Design Guide does, however, provide a procedure for the design of a "break and seat" overlay.

The AASHTO method offers two alternatives for designing overlays on cracked and seated pavements.[20] The equations for the two alternatives are given in table 1. The first approach assumes that a nominal slab fragment size of approximately 30 in will be obtained after cracking the pavement. With this particular crack spacing, the existing concrete slab is assumed to have an effective (in situ) structural number that represents 40 percent of its precracked structural number. This value along with the in situ layer properties for all pavement layers, other than the existing concrete, as determined by nondestructive testing (NDT), is then used to calculate the required thickness of the asphalt overlay.

The other approach is a postcracking design that uses NDT to determine the actual in situ properties of the cracked pavement. Depending on the particular design and construction sequence of each project, this approach will not always be feasible.

The equations shown in table 1 have two different forms: for a "normal" structural overlay and for a "break and seat" overlay. Regardless of which equation is selected, the form of the equation is the same. Essentially, the structural number of the overlay, SN_{OL}, is the total structural number, SN_{Y}, of a new design minus the effective structural capacity of the existing pavement system. As seen in table 1, the most significant difference in the equation is how the "effective" structural capacity is determined. The "normal" structural overlay uses NDT to determine in-situ layer properties, E, from backcalculation techniques. The remaining life factor, F_{RL}, is determined by the normal AASHTO procedure.

The AASHTO "break and seat" equations also use NDT as a postcracking evaluation to determine the structural capacity of the cracked slabs. In the first equation, a value of $F_{RL} = 0.7$ was selected since the cracking process transforms the pavement into a common "state of damage." The $SN_{xeff\text{-}rp}$ is the same for all equations. It represents the effective structural capacity of the sublayer, which can be the aggregate subbase or base layer.

After the design analysis begins, the engineer must assign "a structural layer coefficient (a)" to the crack and seat PCC layer. In the AASHTO Guide, it is noted in table 5.5 that "a" varies from 0.35 for a nominal crack spacing of approximately 2.0 ft to a value of 0.45 for a nominal crack spacing of 3.0 ft. Pennsylvania uses engineering judgment to assign an "a" of 0.2 to the cracked and seated PCC slab. The National Asphalt Paving Association (NAPA) suggests that "a" should be between 0.28 and 0.32.

Table 1. AASHTO overlay equations used in flexible overlays over existing rigid pavements. [20]

Major Overlay Condition	**Specific Method Used**	**SN_{ol} Equation**
Normal Structural Overlay	NDT Method 1	$SN_{ol} = SN_y - F_{RL}(0.8\, D_{xeff} + SN_{xeff\text{-}rp})$
	NDT Method 2	$SN_{ol} = SN_y - F_{RL} SN_{xeff}$
	Visual Condition Factor	$SN_{ol} = SN_y - F_{RL}(a_{2r} D_o + SN_{xeff\text{-}rp}$
Break-Seat Overlay	Estimating Nominal Crack Spacing	$SN_{ol} = SN_y - 0.7(0.4\, D_o + SN_{xeff\text{-}rp})^*$
	Post Cracking NDT	
	(a)NDT Method 1	$SN_{ol} = SN_y - 0.7(a_{bs}\, D_o + SN_{xeff\text{-}rp})$
	(b) NDT Method 2	$SN_{ol} = SN_y - 0.7\, SN_{xeff}$

Special Note: The coefficient of D_o (ie.,0.4) actually varies from 0.35 for a nominal crack spacing of approximately 2.0 ft. to a value of 0.45 for a nominal crack spacing of approximately 3.0 ft.

Other States such as Minnesota convert the crack and seat PCC slab to an equivalent asphaltic concrete thickness using a conversion factor of 0.7. This defines an "a" value of 0.28. Wisconsin assigns an "a" value of 0.20 to 0.25. Overall, the range of "a" values for crack and seat PCC slabs is from 0.2 to 0.45.

The minor exception to this is Kentucky, which assumes an "equivalent thickness" of crushed stone with an "a" equal to 0.13.[21]

Michigan does not have an overlay design procedure for crack and seat overlays. They have used a variety of reasons to select overlay thicknesses ranging from 2 to 8 in.[22]

California's current practice is to crack and seat PCC slabs in most instances where an AC overlay has been designated as the rehabilitation strategy.[23] In California's design, two alternative crack patterns are used.[24] The existing PCC slabs are cracked into nominal 4 ft by 4 ft subpanels if the pavement will be overlaid prior to opening to traffic. If the cracked pavement is to receive traffic before being overlaid, the existing PCC slabs are cracked into subpanels measuring 6 ft transversely by 4 ft longitudinally. This crack pattern avoids a longitudinal crack in the wheel path. California uses a standard thickness design of 1.2 in of leveling AC with 3.0 in of surface material. The overlay contains an interlayer of paving fabric (polypropylene, nonwoven polyester, or polypropylene/nylon materials). Slotted plastic edge drains are also installed to facilitate the removal of trapped water.

Cracked Slab Size

An important design consideration in crack and seat overlays is determining what size the cracked pieces should be. Few theoretical data are available for determining the optimum size of the cracked pieces. Engineering experience implies that the smaller the size of the cracked pieces, the better the chance that reflection cracking due to thermal movements will be reduced. However, cracking the concrete pavement into small pieces greatly reduces the effective slab structure of the existing concrete layer and causes it to behave much like a flexible or semi-rigid system. Consequently, there should be some optimum compromise in cracked slab size to maximize the structural support of the existing slab.

A typical PCC slab that is intact can be evaluated with various structural models including those as simple as Westergaard equations. Modulus values for the intact slab can be backcalculated with finite element programs such as ILLISLAB or with deflection basin calculations using "AREA" and deflection inputs.[25]

After the PCC slab has been cracked, the slab can have segment sizes ranging from small "shattered" pieces to a size of 30 to 40 in or even larger (up to 6 ft). It has been assumed that the broken slab does not have any moment carrying capacity. The broken pieces, however, do have shear transfer between the slab segments due to aggregate interlock. Also, as the slab size is reduced, the flexural stress in the slab will decrease. Because of this, the "modulus" of the cracked PCC slab can be much less than the original slab. Surface deflections and subgrade stress (fine-grained soil can be stress dependent) will increase. The resulting performance of the cracked slab is therefore a function of the size of the pieces.

In the past, a major problem during the breaking of JRCP slabs has been with rupturing the reinforcing steel. Several of the older devices that have been used to break the concrete did not shear the steel or break the bond with the concrete. Consequently, the fragmented pieces were still held together. This situation does not permit an effective seating of the broken fragments. Since the steel holds the fragmented pieces together, horizontal movements can be very similar to uncracked pavements. Cracking devices that will break the bond between the concrete and the steel are now available, and thus the problem can be reduced.

As an alternative to cracking JRCP slabs in order to reduce the joint movement caused by changes in temperature, Minnesota has attempted to reduce the existing concrete pavement panel size by sawing new skewed transverse joints.[26] The theory is that, with reduced panel size, the joint opening caused by thermal stresses will be smaller, resulting in a reduction of the stresses on the AC overlay at the joints. The saw cuts were skewed so that any reflective cracks that developed over these cuts would have a minimum impact on the rideability of the new surface. The 39.3-ft existing panels were saw cut into two sizes--13.1 ft and 6.5 ft. After the saw cuts were made, a 5 1/4-in AC overlay was placed. The study concluded that, of the four methods tried (saw cutting, full coverage fabrics, strip fabrics, and stress absorbing layers), the five saw cuts per panel (along with the stress absorbing layer) was the most effective procedure in terms of ability to reduce the amount of reflective cracking.

As in the case of any overlay design, most agencies rely on their past experience and engineering judgment when determining the optimum cracked piece size for a particular project.

Slab Cracking Equipment

The first step in the crack and seat and overlay construction process is to effectively crack the existing concrete slabs to the desired slab size. The typical range of slab size is approximately 18 in to 48 in. Today, some agencies "rubble" the slab into very small pieces (4 to 6 in), which is considered to be another option to the crack and seat technique.

Most pavement breakers in use today have been specially designed and modified to suit the cracking process. The variety of equipment includes:

- Pile drivers.
- Drop-type guillotine hammers.
- Impact hammers.
- Resonant breakers.

The equipment manufacturers have used very ingenious methods to develop equipment capable of breaking a concrete slab.[22]

Whip hammers are devices that have been developed as a direct result of the cracking and seating process. This versatile machine is mounted on the rear of a conventional truck. The whip hammer is a 6-ft-long leaf-spring arm that can be controlled in a horizontal as well as a vertical direction, which enables the machine to crack an entire lane width in one pass.

The guillotine machine utilizes a large steel-edged breaking head that is approximately 3 ft wide and weighs 5 to 7 tons. The amount of impact can be varied by changing the stroke height. This machine is ideal for making transverse cracks, which, according to current thinking, are the most important cracks in the process.

Another common type of pavement breaker is a pile driver with a modified shoe. The hammer is frequently mounted on a tractor-drawn trailer. The rate of impact is varied by changing the fuel input into the machine. These machines are capable of a very high rate of production, but are considered noisy and dirty.[27]

After a pavement breaker has cracked a lane of pavement, it has been found necessary, on most projects, to place water on the cracked pavement to reveal the crack pattern. On dry, properly prepared pavements, the crack pattern is difficult to see. Without spreading water to locate the crack pattern, it is difficult for inspection personnel to determine if the desired crack pattern has been achieved. It is critical that the slab be broken to the point where cracking can be seen.

Cracking of JRCP

As was mentioned above, reinforcing steel in JRCP can present a problem for the cracking process. To facilitate the cracking process, some States have sawed the pavement transversely to reduce slab size. Michigan has sawed slabs into 20-ft pieces, while West Virginia has used 15-ft spacings. Regardless of the type of equipment or whether slabs are presawed, the bond between the concrete and the steel must be broken or the steel must be ruptured.

Seating of the Slabs

In many cases, old concrete pavements have warped panels or voids in the subgrade caused by pumping. After the pavement has been cracked, it is essential that the pavement be rolled thoroughly to ensure that all of the cracked pieces are firmly seated on the existing sublayer. Without proper seating, the cracked pieces might rock and cause reflection cracking in the asphalt concrete overlay.[28]

In general, in the past, a 50-ton pneumatic tire roller has given the best results in seating cracked pavements. Two passes with this roller have proven successful on some projects. It has been reported that too many passes of the roller have resulted in loosening the cracked pieces instead of seating them.[27]

Indiana has conducted some recent research in an attempt to determine if the seating of cracked pieces is actually beneficial. During the rehabilitation of a 12.4-mi section of I-74 in 1984, deflection measurements were made after cracking the slabs and after application of a variable number of passes by a 50-ton pneumatic-tired roller to determine the degree of seating.[29] Dynaflect measurements were taken after three passes on most sections and after a variable number of passes for seven additional subsections. The deflection measurements obtained in this study before rolling and after a given number of passes of the roller are plotted in figure 6. The slope of each line represents the average increase in deflection per pass for each section tested. The combined average increases in deflections were 2.3×10^{-5} in/pass for the No. 1 sensor and 0.8×120^{-5} in/pass for the No. 5 sensor.

As can be seen in figure 6, the deflection of both the No. 1 and No. 5 sensors increased with each pass of the roller. Thus, the concrete slab and the subbase lost strength with each pass of the 50-ton roller. The researchers conducting this study concluded that rolling with a 50-ton roller should not be used since it unseats the pieces rather than seats them as was intended.

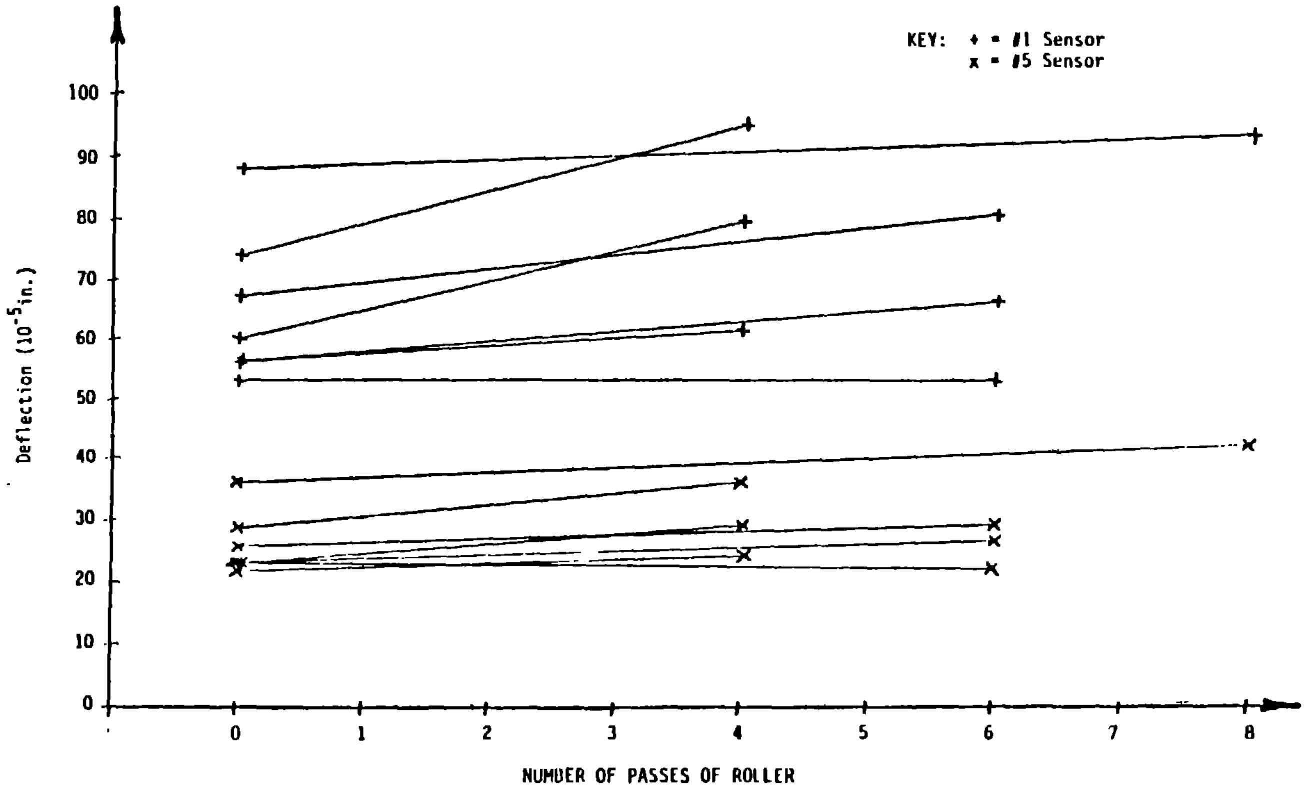


Figure 6. Effect of rolling cracked pavement on deflection measurements.[29]

California has also conducted research into the benefits of seating the cracked pavement.[30,31] On a 1,500-ft test section of pavement near Davis, a vibratory sheepsfoot roller with a rolling load of 44,000 lb was used to seat the pavement after cracking. The machine was set to produce 1,700 vibrations per minute with a rolling speed of 5 mph. Deflection measurements made after seating showed that deflections after seating operations were actually greater at 23 of the 42 measuring locations. In addition, 8 locations indicated additional reduction in deflection, while 11 exhibited no change. Thus, at approximately 80 percent of the measuring locations, the seating operating had either a negative effect or no effect at all on differential vertical movements at joints and cracks.[30]

A second study was conducted on US-99 in Bakersfield, California, to determine the benefits of seating the cracked pavement.[31] A 13-ton vibratory sheepsfoot roller was used to roll the typical rolling sections, while a single section was seated using a 13-ton rubber-tired roller. Deflection measurements were made before cracking and seating, after cracking, and after seating. The results of the deflection testing are summarized in table 2.[31]

The study concluded that "seating broken PCC slabs using a vibratory sheepsfoot or a pneumatic rubber-tired roller had little effect on differential vertical measurements. There was no detectable difference between these two methods of seating slab segments."

Just as there is debate concerning the size of the cracked slab, there is no consensus as to the proper seating technique. It should be kept in mind that the objective of slab seating is to ensure that the cracked segments are in contact with the sublayer. Experience has shown that some rolling must take place, but it is easy to over-roll the slab. It appears that five passes by a 35-ton pneumatic-tired roller are best; three passes of a 50-ton pneumatic-tired roller are also acceptable.[30] Steel drum rollers tend to bridge the slabs, and their use has not been successful.

Table 2. Deflection testing results.

After Breaking/Before Seating		
Change in Deflection	Number of Joints	Amounts
Reduced	36 of 39 (92%)	Average = 0.006 in
Increased	1 of 39 (3%)	Average = 0.001 in
Unchanged	2 of 39 (5%)	------
After Seating		
Change in Deflection	Number of Joints	Amounts
Reduced	9 of 35 (26%)	Average = 0.001 in
Increased	14 of 35 (40%)	Average = 0.001 in
Unchanged	12 of 35 (34%)	------

Other Considerations with Crack and Seat Treatment

Several State agencies have added edge drains on their crack and seat overlay projects. The benefits of the edge drains have not been documented. There has been some concern that fines are created during the cracking process and that these fines will migrate and clog the drainage system. The detrimental effects have not been confirmed.

With respect to the asphalt concrete overlay, conventional construction practice has been used without any problems. The only suggestion has been to avoid traffic on thin asphalt concrete lifts. California suggests that the "full overlay thickness" should be placed to avoid cracking of a thin lift if traffic is allowed on the overlay during construction.

3. DATA COLLECTION PROCEDURES

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 specified in the "Distress Identification Manual for the LTPP Studies" were used.[32] This chapter describes the pavement sections selected for the study, the procedures used in collecting data, and the types of data obtained.

SELECTION OF STUDY SECTIONS

Pavement sections suitable for study were identified by several methods. An extensive literature search identified experimental projects, research projects, and other pavement sections for which performance data had been reported in published studies. A computer search of the Transportation Research Information Services (TRIS) on-line computer files was conducted by the FHWA; in addition, a manual search of the card catalogues and HRIS abstracts of the library of the contractor was conducted. Publications from major transportation organizations such as the Transportation Research Board, FHWA, and the National Cooperative Highway Research Program were reviewed.

The 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 using several criteria. The first criterion was to have study sections located in each of the four major environmental zones of the country. Figure 7 shows the distribution of States containing selected projects on an environmental basis.

Wet/Freeze	Wet/Nonfreeze
Wisconsin	California* Florida*
Dry/Freeze	Dry/Nonfreeze
Minnesota*	California*

*Phase I States

Figure 7. States selected for crack and seat overlay study.

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 (JPCP or JRCP) that is cracked and seated. The study sections were selected based on their ability to address as many of these design features as possible while staying within the resources of this study. They were also selected to be in Phase I States. The 8 projects selected for study contained 20 crack and seat sections and 9 control sections. Table 3 lists 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. Figure 8 shows the distribution of pavement type (plain or reinforced) by environmental zone for crack and seat overlay sections. 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.

Table 3. 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

Table 3. Pavement sections selected for inclusion in the study (continued).

Project No.	Route	Location	Lane	Pavement Type
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

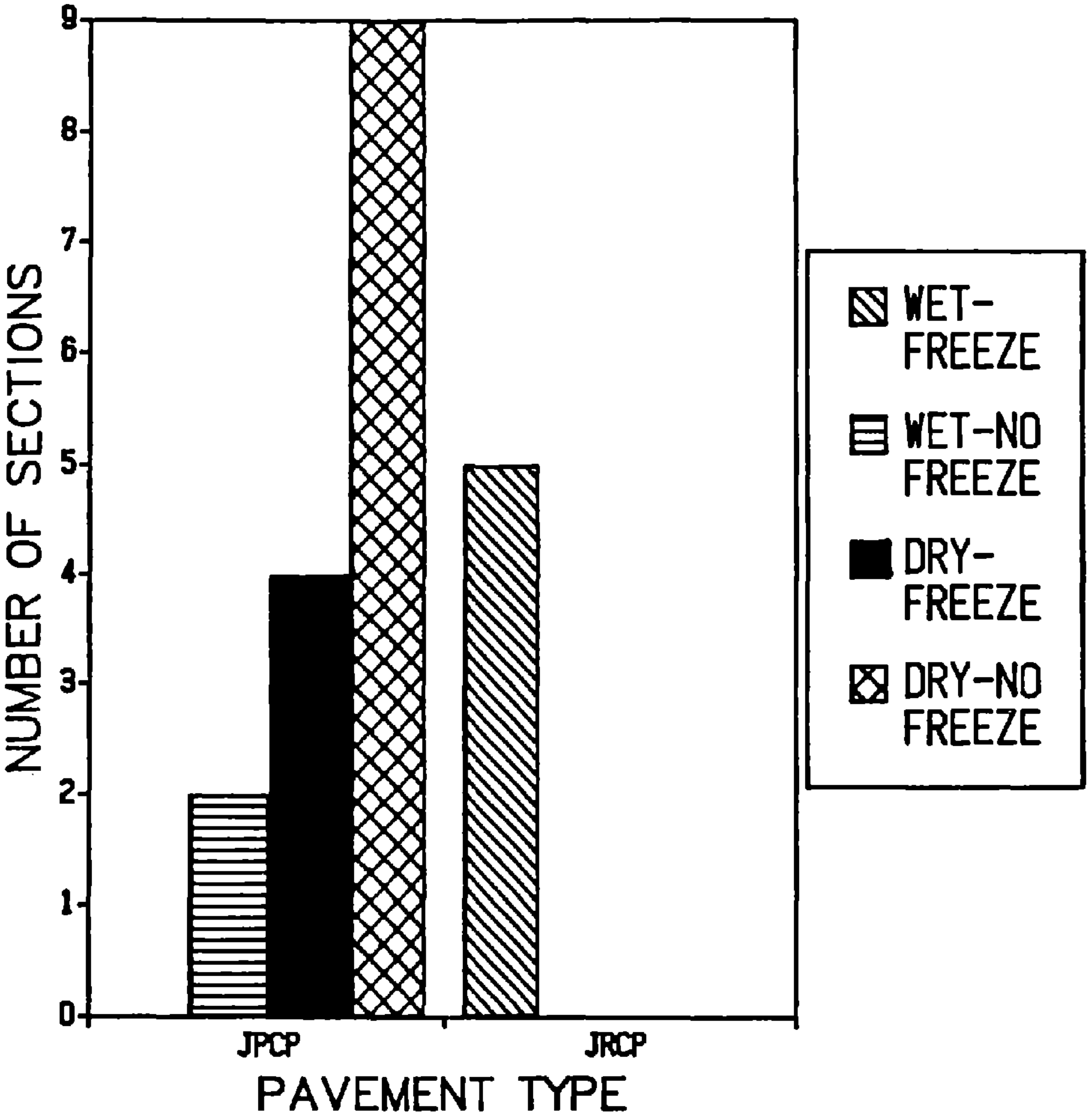


Figure 8. Distribution of pavement type by environmental zone for crack and seat and overlay sections.

Cracked piece size ranged from a minimum of 6 in by 10 in to a maximum of 3.75 ft by 11 ft. The distribution of the cracked piece size area by pavement type is shown in figure 9. Only the reinforced sections were cracked/broken into small pieces; all of the reinforced sections were broken into pieces smaller than 1 ft^2. 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. The distribution of overlay thicknesss is shown in figure 10. As can be seen from this figure, overlay thicknesses are, for the most part, evenly distributed throughout the 3 1/2- to 7 1/2-in range with the 3 1/2- to 5-in overlay being the most heavily represented. In addition, figure 11 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. The age distribution is shown in figure 12.

The original PCC pavement and rehabilitation designs were determined from as-built plans, specifications, and special provisions, which were obtained from the appropriate State agency for each study section. The original PCC pavement and rehabilitation design variables obtained (when available) during the study are summarized in tables 4 and 5, respectively.

FIELD DATA COLLECTION

Three categories of field data were collected: pavement distress, roughness, and deflections. These data collection efforts are described in the following sections.

Pavement Distress

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 "Distress Identification Manual for the LTPP Studies" was used as a guide to identify the types, severities, and quantities of the various distress.[32] Table 6

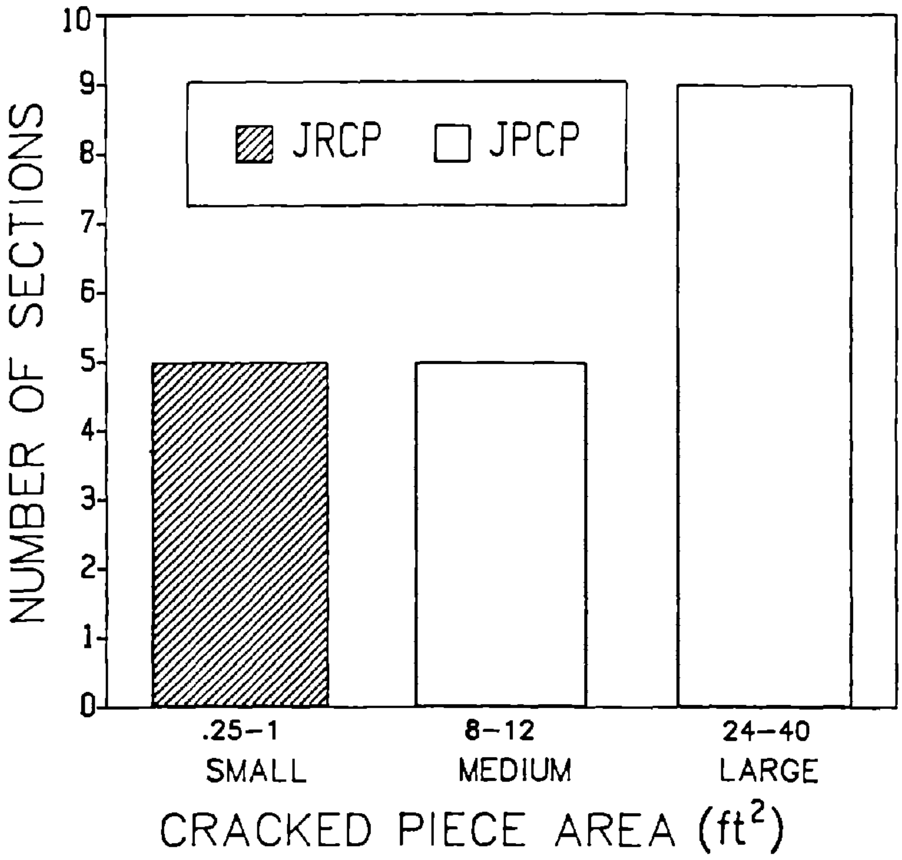


Figure 9. Distribution of cracked piece size area by pavement type for crack and seat study sections.

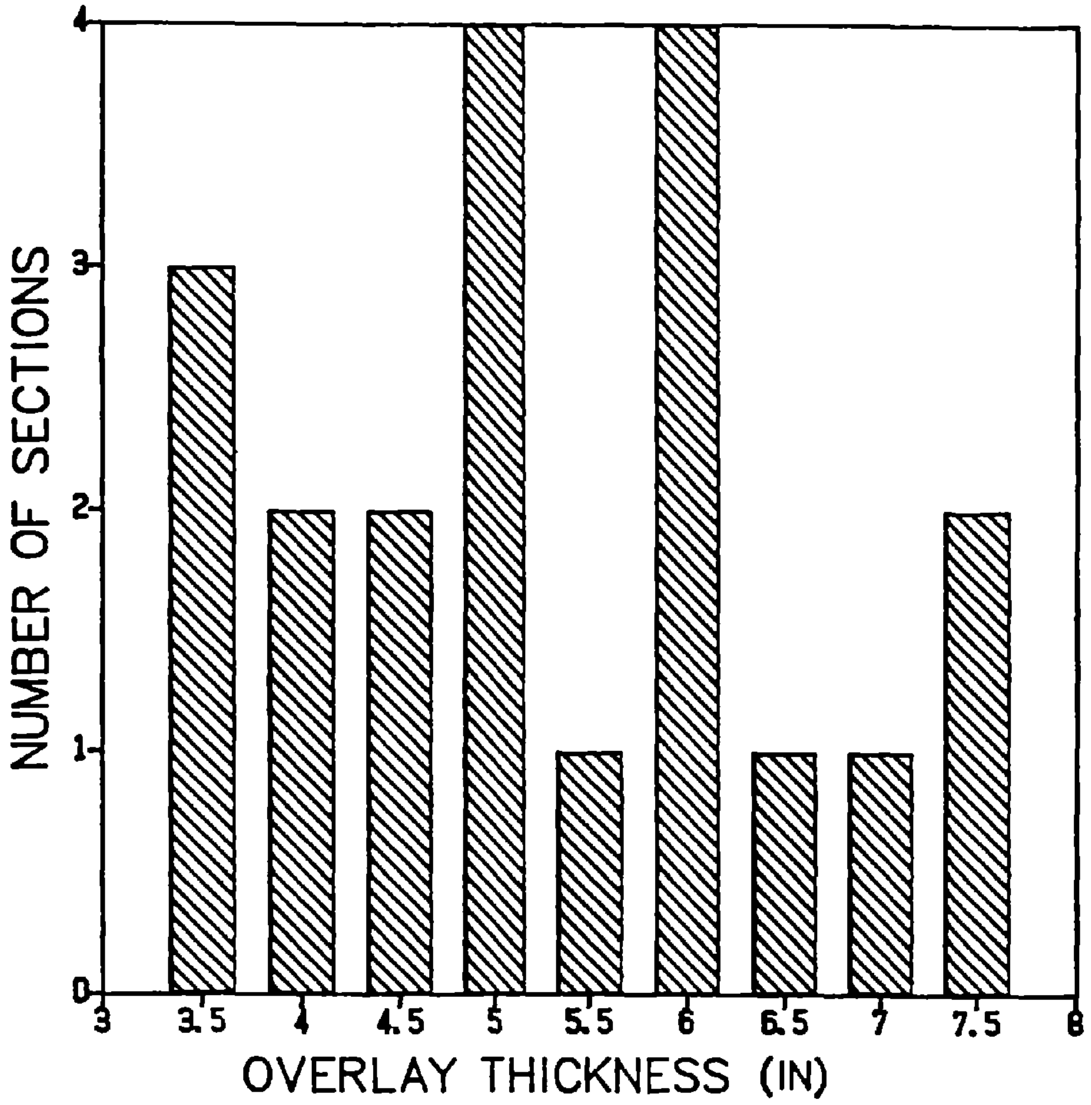


Figure 10. Distribution of overlay thickness of crack and seat and overlay sections.

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

Figure 11. Experimental matrix for crack and seat overlay thickness and crack patterns.

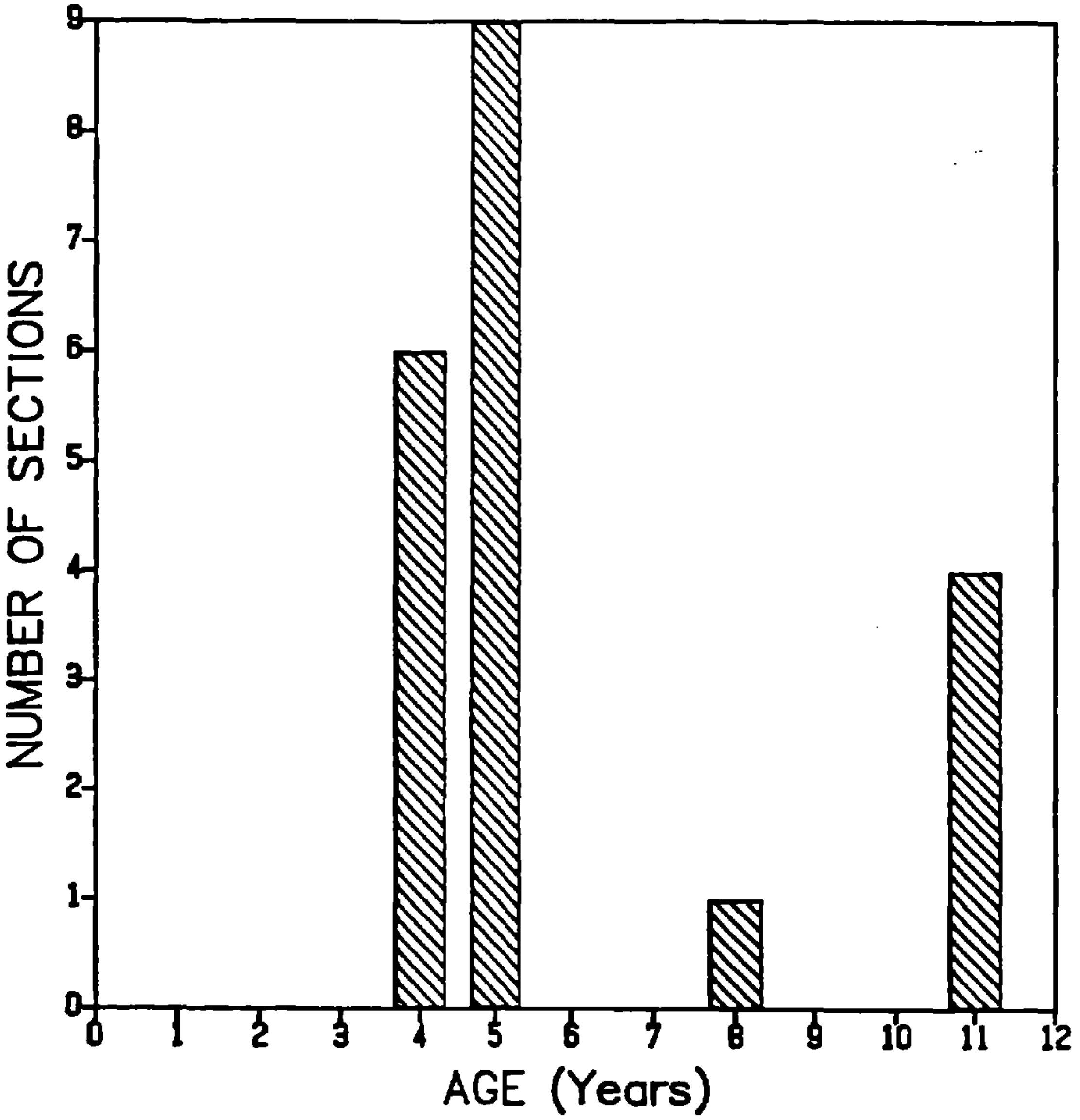


Figure 12. Age distribution of crack and seat and overlay study sections.

Table 4. Original PCC pavement design variables.

Identification and Location Data
Project ID
Date of data collection
Highway number
Direction of survey
Test section location (beginning and ending mile markers or stations)
Date constructed
Geometric and Shoulder Data
Number of through lanes (one direction)
Lane width
Lanes included in study section
Outside shoulder width
Inside shoulder width
Shoulder surface type
Shoulder base type
Shoulder surface thickness
Shoulder base thickness
PCC Pavement Joint Data
Average construction joint spacing
Skewness of transverse joints

Table 5. Rehabilitation design variables.

Variables
Date of construction of AC overlay
Thickness of AC overlay
Presence of fabric in overlay
Size of cracked pieces
Type of cracking equipment
Type and weight of rolling equipment
Broken pavement exposure to traffic
Preoverlay repair information

contains a summary of the types of distress data collected during the field surveys.

Table 6. Pavement distress data collected during the field surveys.

General
Date of distress survey
Lane number
Number of transverse joints in the study section
AC Overlay Distress
Alligator cracking
Bleeding
Block cracking
Crack between lane and shoulder
Longitudinal cracking
Longitudinal joint reflection cracking
Mean lane shoulder dropoff
Mean rut depth inner wheel path
Mean rut depth outer wheel path
Patch deterioration
Potholes
Pumping and water bleeding
Raveling/weathering
Transverse cracking
Transverse joint reflection cracking
Transverse reflection cracking at patch

Roughness

The roughness of each pavement section was determined using a May's Ride Meter--an electromechanical device that continuously logs the pavement surface by recording the magnitude, direction, and summation of rear axle to body excursions of its patent automobile together with synchronized distance increments.[33] This is accomplished by a photocell sensing system that drives a stepping motor for pen and chart movements on a paper tape recorder. By measuring the amount of chart movement per unit of road length traveled, a roughness index, in inches per mile, was computed for each study section.

The same automobile was used for all measurements to provide compatibility of results. In addition, standard pavement sections were rated before and after each distress collection trip to maintain calibration.

In addition to the roughness measurements, the survey crew rode each of the pavement sections to give a subjective present serviceability rating (PSR).

Deflections

Pavement deflections were measured on each cracked and seated study section to determine the stiffness of the pavement layers and foundation. The deflections were measured using a Falling Weight Deflectometer (FWD) at three approximate load levels: 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 was collected by the Minnesota Department of Transportation. This data was collected at slightly lower load levels. These deflection measurements were normalized so that direct comparisons could be made.

TRAFFIC DATA

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 survey. However, in some instances traffic counts were unavailable for each year the overlay experienced traffic and thus traffic data quite often had to be interpolated and extrapolated.

ENVIRONMENTAL DATA

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.[34] Table 7 summarizes the environmental data elements that were collected.

DATABASE DESCRIPTION

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 database that resides on a hard storage disk of an IBM personal computer. SUPERCALC 5 was used to manage the database; this software enabled researchers to efficiently enter, retrieve, and manage data. The data elements can be easily exported in several forms. The completed database has also been incorporated into the overall UNIFY database developed to compile all phases of this research effort.

DATABASE SUMMARY

The data elements that were collected from the crack and seat sections are presented in tables 8 through 14. Many of the data fields represent the raw data; however, several of the fields are the results of data analysis. For example, the 18-kip ESALs were calculated based upon ADT, growth rates, and truck factors. Data elements that were not available are listed as N/A.

Table 7. Environmental data elements collected in the study.

Temperature
Average monthly temperature
Average maximum daily temperature by month
Average minimum daily temperature by month
Freezing index
Elevation above sea level
Precipitation
Average monthly precipitation
Average annual number of days of precipitation
Thornthwaite Moisture Index
General
General type of environment (zone)
Visual indicators of poor drainage
Cross-Section
Longitudinal slope
Transverse slope
Cut or fill depth
Depth of ditch line
Lane/shoulder joint integrity
Type of subsurface drainage present

Table 8. General and crack and seat method data.

PROJECT LOCATION	PROJECT SECTION ID	YEAR OVERLAY PLACED	STARTING MILE MARKER	ENDING MILE MARKER	DIRECTION	NUMBER OF LANES IN ONE DIRECTION	LENGTH FT.	OVERLAY THICKNESS IN	CRACK AND SEAT?	CONTROL?	PCC BREAKAGE WIDTH IN	PCC BREAKAGE LENGTH IN	PAVEMENT BREAKER TYPE	TYPE OF PROOF ROLLER USED	WEIGHT OF ROLLER TONS	BROKEN PAVEMENT EXPOSURE TO TRAFFIC
SR 99, BAKERFIELD COUNTY, CA	CA 9-1	1983	10.44	10.33	SB	3	605	4.6	N	Y						
SR 99, BAKERFIELD COUNTY, CA	CA 9-2	1983	10.33	10.22	SB	3	600	3.7	Y	N	72	48	GUILLOTINE DROP HAMMER	PNEUMATIC	13	>7 DAYS
SR 99, BAKERFIELD COUNTY, CA	CA 9-3	1983	10.22	10.11	SB	3	602	4.0	N	Y						
SR 99, BAKERFIELD COUNTY, CA	CA 9-4	1983	10.11	10	SB	3	603	4.1	Y	N	72	48	GUILLOTINE DROP HAMMER	VIBRATORY SHEEPSFOOT	13	>7 DAYS
SR 99, BAKERFIELD COUNTY, CA	CA 9-5	1983	10	9.89	SB	3	602	4.8	Y	N	72	48	GUILLOTINE DROP HAMMER	VIBRATORY SHEEPSFOOT	13	>7 DAYS
SR 99, BAKERFIELD COUNTY, CA	CA 9-6	1983	9.89	9.78	SB	3	604	4.6	Y	N	72	48	GUILLOTINE DROP HAMMER	NONE		
SR 99, BAKERFIELD COUNTY, CA	CA 9-7	1983	9.78	9.66	SB	3	609	3.7	Y	N	72	48	GUILLOTINE DROP HAMMER	VIBRATORY SHEEPSFOOT	13	>7 DAYS
I-80, DAVIS COUNTY, CA	CA 10-1	1982	1.86	1.77	WB	3	480	6.2	Y	N	24-48	24-48	HYDRAULIC RAM	VIBRATORY SHEEPSFOOT	22	N/A
I-80, DAVIS COUNTY, CA	CA 10-2	1982	1.95	1.86	WB	3	480	6.5	Y	N	24-48	24-48	HYDRAULIC RAM	VIBRATORY SHEEPSFOOT	22	N/A
I-80, DAVIS COUNTY, CA	CA 10-3	1982	1.77	1.68	WB	3	480	6.0	Y	N	24-48	24-48	HYDRAULIC RAM	VIBRATORY SHEEPSFOOT	22	N/A
I-80, ALBANY COUNTY, CA	CA 11-1	1982	7.62	7.58	WB	3	232	3.5	N	Y						
I-80, ALBANY COUNTY, CA	CA 11-2	1982	7.58	7.52	WB	3	311	3.7	Y	N	36	48	HYDRAULIC RAM	VIBRATORY SHEEPSFOOT	15	N/A
I-5, YREKA COUNTY, CA	CA 12	1983	41.8	42	NB	2	1056	4.6	Y	N	N/A	N/A	N/A	N/A	N/A	N/A
I-4, HILLSBOROUGH COUNTY, FL	FL 4-1	1979	11.6	11.8	EB	2	1056	3.5	N	Y						
I-4, HILLSBOROUGH COUNTY, FL	FL 4-2	1979	12	12.2	EB	2	1056	4.8	Y	N	36.0	36	GUILLOTINE DROP HAMMER	VIBRATORY STEEL WHEELED	15.0	N/A
TH-71, WILLMAR, MN	MN 7-1A	1976	115	114.8	NB	1	1056	7.5	Y	N	132.0	45	GUILLOTINE DROP HAMMER	PNEUMATIC	>35	>7 DAYS
TH-71, WILLMAR, MN	MN 7-1B	1976	115	114.8	SB	1	1056	7.5	Y	N	132.0	45	GUILLOTINE DROP HAMMER	PNEUMATIC	>35	>7 DAYS
TH-71, WILLMAR, MN	MN 7-2A	1976	113.86	113.77	NB	1	500	6	Y	N	132.0	45	GUILLOTINE DROP HAMMER	PNEUMATIC	>35	>7 DAYS
TH-71, WILLMAR, MN	MN 7-2B	1976	113.86	113.77	SB	1	500	6	Y	N	132.0	45	GUILLOTINE DROP HAMMER	PNEUMATIC	>35	>7 DAYS
TH-71, WILLMAR, MN	MN 7-3A	1976	113.77	113.68	NB	1	510	7.5	N	Y						
TH-71, WILLMAR, MN	MN 7-3B	1976	113.77	113.68	SB	1	510	7.5	N	Y						
I-94, EAU CLAIR, WI	WI 1-1	1982	77.3	77.5	EB	2	1056	4	N	Y						
I-94, EAU CLAIR, WI	WI 1-2	1982	77.6	77.8	EB	2	1056	5.5	Y	N	12.0	12	PILE DRIVER HAMMER	VIBRATORY STEEL WHEELED	50.0	NONE
I-94, EAU CLAIR, WI	WI 1-3	1982	78	78.2	EB	2	1056	7	Y	N	12.0	12	PILE DRIVER HAMMER	VIBRATORY STEEL WHEELED	50.0	NONE
I-94, EAU CLAIR, WI	WI 1-4	1982	78.44	78.64	EB	2	1056	4	Y	N	12.0	12	PILE DRIVER HAMMER	VIBRATORY STEEL WHEELED	50.0	NONE
SH 140, ROCK COUNTY, WI	WI 3-1A	1982	2.7	N/A	SB	1	1056	4.875	Y	N	6-10	6-10	PILE DRIVER HAMMER	VIBRATORY STEEL WHEELED		>7 DAYS
SH 140, ROCK COUNTY, WI	WI 3-1B	1982	2.7	N/A	SB	1	1056	4.875	Y	N	6-10	6-10	PILE DRIVER HAMMER	VIBRATORY STEEL WHEELED		>7 DAYS
SH 140, ROCK COUNTY, WI	WI 3-2A	1982	5.3	N/A	SB	1	1056	2.75	N	Y						
SH 140, ROCK COUNTY, WI	WI 3-2B	1982	5.3	N/A	SB	1	1056	2.78	N	Y						

Table 9. Environmental data.

PROJECT LOCATION	PROJECT SECTION ID	ENVIRONMENTAL ZONE	THORNTHWAITE MOISTURE INDEX	CORPS OF ENGINEERS FREEZING INDEX	HIGHEST AVERAGE DAILY MAXIMUM TEMP, F	LOWEST AVERAGE DAILY MINIMUM TEMP, F	DESIGN TEMP CHANGE DEGREES F	ANNUAL AVERAGE PRECIP., IN	LATITUDE DEGREES NORTH	LONGITUDE DEGREES WEST
SR 99, BAKERFIELD COUNTY, CA	CA 9-1	DRY-NO FREEZE	0	0	99	38.7	60.3	5.72	3525	11903
SR 99, BAKERFIELD COUNTY, CA	CA 9-2	DRY-NO FREEZE	0	0	99	38.7	60.3	5.72	3525	11903
SR 99, BAKERFIELD COUNTY, CA	CA 9-3	DRY-NO FREEZE	0	0	99	38.7	60.3	5.72	3525	11903
SR 99, BAKERFIELD COUNTY, CA	CA 9-4	DRY-NO FREEZE	0	0	99	38.7	60.3	5.72	3525	11903
SR 99, BAKERFIELD COUNTY, CA	CA 9-5	DRY-NO FREEZE	0	0	99	38.7	60.3	5.72	3525	11903
SR 99, BAKERFIELD COUNTY, CA	CA 9-6	DRY-NO FREEZE	0	0	99	38.7	60.3	5.72	3525	11903
SR 99, BAKERFIELD COUNTY, CA	CA 9-7	DRY-NO FREEZE	0	0	99	38.7	60.3	5.72	3525	11903
I-80, DAVIS COUNTY, CA	CA 10-1	DRY-NO FREEZE	-10	0	93.2	37.2	56	17.14	3832	12146
I-80, DAVIS COUNTY, CA	CA 10-2	DRY-NO FREEZE	-10	0	93.2	37.2	56	17.14	3832	12146
I-80, DAVIS COUNTY, CA	CA 10-3	DRY-NO FREEZE	-10	0	93.2	37.2	56	17.14	3832	12146
I-80, ALBANY COUNTY, CA	CA 11-1	DRY-NO FREEZE	0	0	71.7	43.2	28.5	23.24	3752	12215
I-80, ALBANY COUNTY, CA	CA 11-2	DRY-NO FREEZE	0	0	71.7	43.2	28.5	23.24	3752	12215
I-5, YREKA COUNTY, CA	CA 12	WET-NO FREEZE	20	0	90.7	24.6	66.1	19.2	4143	12230
I-4, HILLSBOROUGH COUNTY, FL	FL 4-1	WET-NO FREEZE	20	0	91	51	40	46.73	2758	8232
I-4, HILLSBOROUGH COUNTY, FL	FL 4-2	WET-NO FREEZE	20	0	91	51	40	46.73	2758	8232
TH-71, WILLMAR, MN	MN 7-1A	DRY/WET-FREEZE	0	2000	83	-0.4	83.4	27.71	4508	9501
TH-71, WILLMAR, MN	MN 7-1B	DRY/WET-FREEZE	0	2000	83	-0.4	83.4	27.71	4508	9501
TH-71, WILLMAR, MN	MN 7-2A	DRY/WET-FREEZE	0	2000	83	-0.4	83.4	27.71	4508	9501
TH-71, WILLMAR, MN	MN 7-2B	DRY/WET-FREEZE	0	2000	83	-0.4	83.4	27.71	4508	9501
TH-71, WILLMAR, MN	MN 7-3A	DRY/WET-FREEZE	0	2000	83	-0.4	83.4	27.71	4508	9501
TH-71, WILLMAR, MN	MN 7-3B	DRY/WET-FREEZE	0	2000	83	-0.4	83.4	27.71	4508	9501
I-94, EAU CLAIR, WI	WI 1-1	WET-FREEZE	40	1500	86	6	80	30.31	4455	9130
I-94, EAU CLAIR, WI	WI 1-2	WET-FREEZE	40	1500	86	6	80	30.31	4455	9130
I-94, EAU CLAIR, WI	WI 1-3	WET-FREEZE	40	1500	86	6	80	30.31	4455	9130
I-94, EAU CLAIR, WI	WI 1-4	WET-FREEZE	40	1500	86	6	80	30.31	4455	9130
SH 140, ROCK COUNTY, WI	WI 3-1A	WET-FREEZE	30	875	84.9	11.1	73.8	32	4230	8902
SH 140, ROCK COUNTY, WI	WI 3-1B	WET-FREEZE	30	875	84.9	11.1	73.8	32	4230	8902
SH 140, ROCK COUNTY, WI	WI 3-2A	WET-FREEZE	30	875	84.9	11.1	73.8	32	4230	8902
SH 140, ROCK COUNTY, WI	WI 3-2B	WET-FREEZE	30	875	84.9	11.1	73.8	32	4230	8902

Table 10. Pavement layer data.

LOCATION	Project Section ID	Pvmt Type	AC OVERLAY				PCC SURFACE								BASE			Composite E of Base and Subgrade from FWD KSI
			THICKNESS, IN		E, KSI from FWD	OVERLAY DATE	ORIGINAL CONST. DATE	THICKNESS, IN		Joint Spacing, FT	E, KSI from FWD	E, KSI from core	Mr, PSI	Ft, PSI (From cores)	Type	THICKNESS,		
			Design	Core/As Built				Design	Core							Plans	Field	
SR 99, BAKERFIELD COUNTY, CA	CA 9-1	JPCP	3.6	4.6	1000	1983	1968	9	9	15	7000-10000	6306	762.8	542	CTB	4.2	0	18
SR 99, BAKERFIELD COUNTY, CA	CA 9-2	JPCP	3.6	3.7	925-1000	1983	1968	9	9.2	15	2750-7000	N/A	N/A	N/A	CTB	4.2	0	22
SR 99, BAKERFIELD COUNTY, CA	CA 9-3	JPCP	3.6	4	500-1000	1983	1968	9	9	15	7000-10000	8768	869.9	642	CTB	4.2	0	18
SR 99, BAKERFIELD COUNTY, CA	CA 9-4	JPCP	3.6	4.1	400-1000	1983	1968	9	9.2	15	6000-8500	6752	782.2	561	CTB	4.2	0	18
SR 99, BAKERFIELD COUNTY, CA	CA 9-5	JPCP	3.6	4.8	350	1983	1968	9	8.5	15	5000-7000	4478	603.3	464	CTB	4.2	0	18
SR 99, BAKERFIELD COUNTY, CA	CA 9-6	JPCP	3.6	4.6	230-425	1983	1968	9	9.5	15	5000-7000	4876	700.6	481	CTB	4.2	0	18
SR 99, BAKERFIELD COUNTY, CA	CA 9-7	JPCP	3.6	3.7	350-600	1983	1968	9	9.2	15	6000-7000	N/A	N/A	N/A	CTB	4.2	0	19
I-80, DAVIS COUNTY, CA	CA 10-1	JPCP	6	6.2	350	1982	1942	9	7.2	15	2500	8207	845.5	623	Large Rock	5	6	13
I-80, DAVIS COUNTY, CA	CA 10-2	JPCP	6	6.5	350	1982	1942	9	7	15	2500-3500	7713	824	602	Large Rock/clay	5	3	17
I-80, DAVIS COUNTY, CA	CA 10-3	JPCP	6	6	350	1982	1942	9	N/A	15	2000-3000	N/A	N/A	N/A	N/A	5	N/A	17
I-80, ALBANY COUNTY, CA	CA 11-1	JPCP	3	3.5	300-500	1982	1955	8	N/A	15	2000-8000	N/A	N/A	N/A	N/A	4.8	N/A	16
I-80, ALBANY COUNTY, CA	CA 11-2	JPCP	3	3.7	300-500	1982	1955	8	12.5	15	150-1500	11021	967.9	743	Stones/black clay	4.8	4	15-30
I-5, YREKA COUNTY, CA	CA 12	JPCP	5.4	4.6	N/A	1983	N/A	8.4	8.5	15	N/A	2860	612.9	395	Lean PCC	4.8	3	N/A
I-4, HILLSBOROUGH COUNTY, FL	FL 4-1	JPCP	3.5	3-4	500	1979	1957	9	9-10	20	3500	867/3329	562/633	310/415	Cement Stab.	12	N/A	25
I-4, HILLSBOROUGH COUNTY, FL	FL 4-2	JPCP	3.5	4.8	500	1979	1957	9	9	20	2500	2274	507.4	370	Cement Stab.	12	N/A	25
TH-71, WILLMAR, MN	MN 7-1A	JPCP	7.5	7.5	200-1000	1976	1946	9-7-9	N/A	15	2500-4000	3446	639.4	420	SAND	6	N/A	8
TH-71, WILLMAR, MN	MN 7-1B	JPCP	7.5	7.5	200-1000	1976	1946	9-7-9	N/A	15		N/A	N/A	N/A	SAND	6	N/A	8
TH-71, WILLMAR, MN	MN 7-2A	JPCP	6	6	200-1000	1976	1946	9-7-9	N/A	15	1500-6000	4547	686.3	467	SAND	6	N/A	8
TH-71, WILLMAR, MN	MN 7-2B	JPCP	6	6	200-1000	1976	1946	9-7-9	N/A	15		N/A	N/A	N/A	SAND	6	N/A	8
TH-71, WILLMAR, MN	MN 7-3A	JPCP	7.5	7.5	350-900	1976	1946	9-7-9	N/A	15	3000-7000	N/A	N/A	N/A	SAND	6	N/A	8
TH-71, WILLMAR, MN	MN 7-3B	JPCP	7.5	7.5	700-950	1976	1946	9-7-9	N/A	15		N/A	N/A	N/A	SAND	6	N/A	8
I-94, EAU CLAIR, WI	WI 1-1	JRCP	4	N/A	300-475	1982	1967	9	N/A	80	4500-7000	N/A	N/A	N/A	CEM-AGG MIX.	4.5	N/A	22
I-94, EAU CLAIR, WI	WI 1-2	JRCP	5.5	N/A	200-450	1982	1967	9	N/A	80	5500-7000	N/A	N/A	N/A	CEM-AGG MIX.	4.5	N/A	22
I-94, EAU CLAIR, WI	WI 1-3	JRCP	7	N/A	225	1982	1967	9	N/A	80	3000-4000	N/A	N/A	N/A	CEM-AGG MIX.	4.5	N/A	22
I-94, EAU CLAIR, WI	WI 1-4	JRCP	4	N/A	200-1000	1982	1967	9	N/A	80	3000-4725	N/A	N/A	N/A	CEM-AGG MIX.	4.5	N/A	22
SH 140, ROCK COUNTY, WI	WI 3-1	JRCP	4	4.875	N/A	1982	1931	9-6.5-9	10.5	20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SH 140, ROCK COUNTY, WI	WI 3-2	JRCP	4	2.75	N/A	1982	1931	9-6.5-9	N/A	20	N/A	N/A	N/A	N/A	Gravel/Crushed Stone**	9	8.5	N/A

** Between AC and PCC

Table 11. Drainage and shoulder information.

PROJECT LOCATION	PROJECT SECTION ID	SUB-DRAINAGE Y/N	DEPTH OF DITCH, FT	AVERAGE TRANS. SLOPE, %	AVERAGE LONGIT. SLOPE, %	OUTER SHOULDER		INNER SHOULDER		SHOULDER JOINT SEAL DAMAGE N/L/M/H	OVERALL DRAINAGE EVALUATION
						SURFACE TYPE	WIDTH, FT	SURFACE TYPE	WIDTH, FT		
SR 99, BAKERFIELD COUNTY, CA	CA 9-1	N	1	1.04	0	AC	11	AC	3	N	GOOD
SR 99, BAKERFIELD COUNTY, CA	CA 9-2	N	2	1.04	0	AC	9.5	AC	3	N	GOOD
SR 99, BAKERFIELD COUNTY, CA	CA 9-3	N	3	1.04	0	AC	9.5	AC	3	N	GOOD
SR 99, BAKERFIELD COUNTY, CA	CA 9-4	N	6-8	1.04	0	AC	11	AC	3	N	GOOD
SR 99, BAKERFIELD COUNTY, CA	CA 9-5	N	10	1.04	0	AC	11	AC	3	N	GOOD
SR 99, BAKERFIELD COUNTY, CA	CA 9-6	N	6	1.04	0	AC	9.5	AC	3	N	GOOD
SR 99, BAKERFIELD COUNTY, CA	CA 9-7	N	6	1.04	0	AC	11	AC	3	N	GOOD
I-80, DAVIS COUNTY, CA	CA 10-1	N	5	0	0	AC	10	AC	N/A	N	GOOD
I-80, DAVIS COUNTY, CA	CA 10-2	N	5	0.52	0	AC	10	AC	N/A	N	GOOD
I-80, DAVIS COUNTY, CA	CA 10-3	N	5	0	0	AC	10	AC	N/A	N	GOOD
I-80, ALBANY COUNTY, CA	CA 11-1	N	3	3.64	0.68	AC	7	AC	N/A	N	GOOD
I-80, ALBANY COUNTY, CA	CA 11-2	N	3.5	6.25	0.52	AC	7	AC	N/A	N	GOOD
I-5, YREKA COUNTY, CA	CA 12	N	5	2.08	2.08	AC	10	AC	N/A	N	GOOD
I-4, HILLSBOROUGH COUNTY, FL	FL 4-1	N	4	2.08	1.04	AC	7.5	AC	2	M	GOOD
I-4, HILLSBOROUGH COUNTY, FL	FL 4-2	N	5	2.08	1.04	AC	7.5	AC	2	L	POOR
TH-71, WILLMAR, MN	MN 7-1A	N	7	1.04	0	AC	10	N/A	N/A	N	GOOD
TH-71, WILLMAR, MN	MN 7-1B	N	7	1.04	0	AC	10	N/A	N/A	N	GOOD
TH-71, WILLMAR, MN	MN 7-2A	N	6	1.04	1.04	AC	10	N/A	N/A	N	GOOD
TH-71, WILLMAR, MN	MN 7-2B	N	6	1.04	1.04	AC	10	N/A	N/A	N	GOOD
TH-71, WILLMAR, MN	MN 7-3A	N	6	1.04	1.04	AC	10	N/A	N/A	N	GOOD
TH-71, WILLMAR, MN	MN 7-3B	N	6	1.04	1.04	AC	10	N/A	N/A	N	GOOD
I-94, EAU CLAIR, WI	WI 1-1	N	5	1.04	0	AC	9	AC	4	N	GOOD
I-94, EAU CLAIR, WI	WI 1-2	N	14	1.04	0	AC	9	AC	4	N	GOOD
I-94, EAU CLAIR, WI	WI 1-3	N	12	1.04	0	AC	8.5	AC	4.5	N	GOOD
I-94, EAU CLAIR, WI	WI 1-4	N	4-10	1.04	0.52	AC	8.5	AC	4	N	GOOD
SH 140, ROCK COUNTY, WI	WI 3-1A	N	3	1.56	1.04	GRANULAR	7	GRANULAR	7	N	GOOD
SH 140, ROCK COUNTY, WI	WI 3-1B	N	3	1.56	1.04	GRANULAR	7	GRANULAR	7	N	GOOD
SH 140, ROCK COUNTY, WI	WI 3-2A	N	2	2.56	1.04	GRANULAR	7	GRANULAR	7	N	GOOD
SH 140, ROCK COUNTY, WI	WI 3-2B	N	2	2.56	1.04	GRANULAR	7	GRANULAR	7	N	GOOD

Table 12. Performance data.

LOCATION	PROJECT SECTION ID	LANE NUMBER	AVG PSR	MAY'S ROUGH IN/MI	AVG RUT DEPTH IN	TRANSVERSE CRACKING LIN FT/MI	LONG. CENTER-LINE CRACKS	LONGITUDINAL CRACKING LIN FT/MI	CRACK BETWEEN LANE AND SHOULDER LIN FT/MI	ALLIGATOR CRACKING SQ FT/MI	BLEEDING SQ FT/MI	PATCHES SQ FT/MI	WEATHERING AND RAVELING SQ FT/MI
SR 99, BAKERFIELD COUNTY, CA	CA 9-1	1	4.4	51	0.03	4189	0	3665	0	0	0	0	0
SR 99, BAKERFIELD COUNTY, CA	CA 9-2	1	4.4	50	0.12	97	0	1153	0	88	0	0	3740
SR 99, BAKERFIELD COUNTY, CA	CA 9-3	1	4.4	46	0.10	2786	0	3824	0	0	0	0	53
SR 99, BAKERFIELD COUNTY, CA	CA 9-4	1	4.4	45	0.08	254	0	3765	0	0	0	0	0
SR 99, BAKERFIELD COUNTY, CA	CA 9-5	1	4.4	42	0.15	0	0	1298	0	0	0	0	0
SR 99, BAKERFIELD COUNTY, CA	CA 9-6	1	4.4	37	0.12	26	0	1923	0	227	0	0	175
SR 99, BAKERFIELD COUNTY, CA	CA 9-7	1	4.4	39	0.08	61	0	1465	0	0	0	0	0
I-80, DAVIS COUNTY, CA	CA 10-1	1	4.4	43	0.30	0	0	264	0	0	0	0	0
I-80, DAVIS COUNTY, CA	CA 10-2	1	4.4	47	0.27	0	0	0	0	0	0	0	0
I-80, DAVIS COUNTY, CA	CA 10-3	1	4.4	47	0.24	0	0	0	0	66	143	0	0
I-80, ALBANY COUNTY, CA	CA 11-1	1	3.4	82	0.10	2458	0	865	0	0	0	91	46
I-80, ALBANY COUNTY, CA	CA 11-2	1	4.1	99	0.12	0	0	0	0	0	0	85	85
I-5, YREKA COUNTY, CA	CA 12	1	4	69	0.24	0	0	0	0	0	10580	0	0
		2	4.4	40	N/A	0	0	0	0	0	10580	0	0
I-4, HILLSBOROUGH COUNTY, FL	FL 4-1	1	3.7	58	0.19	1357	0	594	2487	0	0	0	1169
		2	4.2	33	0.11	1300	0	580	2400	0	0	0	1130
I-4, HILLSBOROUGH COUNTY, FL	FL 4-2	1	4.4	24	0.17	770	0	3800	0	0	0	0	0
		2	4.3	35	0.14	787	0	3823	0	0	0	0	0
TH-71, WILLMAR, MN	MN 7-1A	1	3.4	60	0.08	4135	4150	4590	0	0	0	50	0
TH-71, WILLMAR, MN	MN 7-1B	1	3.1	56	0.13	4910	1950	3875	0	0	0	50	0
TH-71, WILLMAR, MN	MN 7-2A	1	3.3	70	0.03	5111	1690	1056	0	3062	0	3062	0
TH-71, WILLMAR, MN	MN 7-2B	1	3.0	99	0.15	5227	0	1056	0	4541	0	7206	0
TH-71, WILLMAR, MN	MN 7-3A	1	3.3	77	0.10	5694	311	207	0	3779	0	1760	0
TH-71, WILLMAR, MN	MN 7-3B	1	3.3	113	0.15	5352	0	207	0	445	0	52	0
I-94, EAU CLAIR, WI	WI 1-1	1	3.8	62	0.24	1400	0	220	600	12	0	0	0
		2	3.9	44	0.09	1400	0	215	585	13	0	0	0
I-94, EAU CLAIR, WI	WI 1-2	1	3.6	50	0.39	870	0	90	910	0	0	0	0
		2	3.9	42	0.10	870	0	85	915	0	0	0	0
I-94, EAU CLAIR, WI	WI 1-3	1	3.6	57	0.45	630	0	125	250	40	0	0	0
		2	3.9	43	0.13	625	0	125	250	35	0	0	0
I-94, EAU CLAIR, WI	WI 1-4	1	3.6	56	0.32	2000	2200	230	550	300	0	0	0
		2	3.8	51	0.11	1950	2200	220	525	250	0	0	0
SH 140, ROCK COUNTY, WI	WI 3-1A	1	3.7	61	0.20	1140	0	125	0	625	0	0	0
SH 140, ROCK COUNTY, WI	WI 3-1B	1	3.7	73	0.23	950	0	375	0	50	0	0	0
SH 140, ROCK COUNTY, WI	WI 3-2A	1	3.5	86	0.21	2520	0	4750	0	2475	0	0	800
SH 140, ROCK COUNTY, WI	WI 3-2B	1	3.6	80	0.27	2265	0	550	0	600	0	0	0

Table 13. Deflection data at 9,000 lb from wheelpath of outer lane.

Location	Project Number	Deflection (mils)		
		High	Low	Avg.
SR 99, BAKERFIELD COUNTY, CA	CA 9-1	4.80	3.20	3.80
SR 99, BAKERFIELD COUNTY, CA	CA 9-2	4.70	3.00	3.65
SR 99, BAKERFIELD COUNTY, CA	CA 9-3	4.30	3.30	3.72
SR 99, BAKERFIELD COUNTY, CA	CA 9-4	4.70	2.50	3.75
SR 99, BAKERFIELD COUNTY, CA	CA 9-5	4.60	4.00	4.35
SR 99, BAKERFIELD COUNTY, CA	CA 9-6	5.00	4.20	4.52
SR 99, BAKERFIELD COUNTY, CA	CA 9-7	4.50	3.60	3.90
I-80, DAVIS COUNTY, CA	CA 10-1	10.70	4.80	6.20
I-80, DAVIS COUNTY, CA	CA 10-2	6.00	4.40	5.11
I-80, DAVIS COUNTY, CA	CA 10-3	5.90	4.10	5.01
I-80, ALBANY COUNTY, CA	CA 11-1	12.80	3.90	6.64
I-80, ALBANY COUNTY, CA	CA 11-2	9.10	3.80	6.13
I-5, YREKA COUNTY, CA	CA 12	11.00	4.20	6.52
I-4, HILLSBOROUGH COUNTY, FL	FL 4-1	25.50	3.00	6.40
I-4, HILLSBOROUGH COUNTY, FL	FL 4-2	4.80	3.10	3.99
TH-71, WILLMAR, MN	MN 7-1	9.60	4.80	6.79
TH-71, WILLMAR, MN	MN 7-2	9.00	4.70	6.47
TH-71, WILLMAR, MN	MN 7-3	11.30	4.00	6.93
I-94, EAU CLAIR, WI	WI 1-1	4.80	2.80	3.47
I-94, EAU CLAIR, WI	WI 1-2	4.80	3.30	4.06
I-94, EAU CLAIR, WI	WI 1-3	6.90	3.40	5.19
I-94, EAU CLAIR, WI	WI 1-4	6.20	3.60	4.61
SH 140, ROCK COUNTY, WI	WI 3-1	26.20	14.10	20.87
SH 140, ROCK COUNTY, WI	WI 3-2	36.20	19.70	26.88

Table 14. Traffic data.[35]

PROJECT	TWO-WAY ADT 1987	PERCENT TRUCKS 1967	OUTER LANE ESALS 1987	CUMULATIVE ESALS SINCE OVERLAY OUTER LANE
CA-9	20900	25	600744	3514665
CA-10	58000	9.2	736208	4216900
CA-11	141000	8.5	857407	5077384
CA-12	11000	30	573342	2802847
FL-4	71316	15	1398024	9490912
MN-7	3053	11.3	74286	824652
WI-1	16000	15*	438438	2604659
WI-3	2000	10*	57196	303571

*ESTIMATED

4. FIELD PERFORMANCE AND EVALUATION

OVERVIEW OF PERFORMANCE

Pavement performance can be evaluated using criteria from several categories. These categories include functional and structural characteristics, safety, and appearance.[34] In this study, it was decided to evaluate the field performance of the pavement sections based on functional and structural characteristics.

Functional performance can be described as the ability of a pavement to provide a serviceable surface in terms of the quality of the ride experienced by the roadway user.[34] This serviceability can be evaluated subjectively or by using physical measurements correlated with subjective evaluations. Research has shown that the primary factor affecting the serviceability, and hence the functional performance of a pavement, is its surface roughness.[36] In this study, the functional performance of the study sections was determined using longitudinal roughness measurements, in particular, roughness measured with a Mays Meter. The results of this testing are presented in "Pavement Roughness," found later in this chapter.

Structural performance refers to the ability of a pavement to maintain its structural integrity without experiencing distress.[36] In this study, the structural performance of the study sections was determined using the nondestructive deflection testing methods described in chapter 3. These test results and the occurrences of distress, observed in the field, are summarized in "Overlay Distress" and "Deflection Measurements," found later in this chapter.

The evaluation of safety primarily involves the measurement of skid resistance, but can be expanded to include other factors such as hydroplaning, icing potential, and severe surface distortion, such as rutting.[37] While such considerations are certainly of paramount importance when evaluating a pavement, the inclusion of such factors (with the exception of surface distortion) was considered beyond the scope of this study.

The evaluation of a pavement's appearance is rather self-explanatory and is not as important a consideration as the first three factors. It was not considered when evaluating the performance of the study sections.

Only five projects had control sections with overlay thicknesses approximately equal to that 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 asphalt concrete 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 as listed in table 15 were utilized.

Table 15. Projects with crack and seat and control sections of comparable cross-section.

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

PAVEMENT ROUGHNESS

Pavement roughness is a phenomenon that manifests itself at the surface of the pavement structure. It has been defined as "... the longitudinal deviations of a pavement surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, and dynamic pavement loads."[38] The three main components of pavement roughness are: longitudinal variations, transverse variations, and horizontal variations of the pavement alignment.[37] Longitudinal variations have been shown to be the major cause of undesirable vehicle forces.[39] Transverse variations, or the roll component transmitted to the vehicle, are the second major cause of roughness. The least offensive is the horizontal curvature of a roadway, which, if poorly designed, can impart undesirable yaw forces to a vehicle.

The longitudinal roughness of each pavement section was measured with a Mays Meter as described earlier. The roughness measurements obtained on each of the 29 study sections are listed in table 16. 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, FL. 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.

The present serviceability rating of each section is also listed in table 16.

Five projects had control sections with overlay thicknesses approximately equal to that of at least some of the corresponding crack and seat sections. The roughness measurements taken on the 17 sections in five projects from table 15 are depicted in figure 13. On four of the five projects, the crack and seat and overlay sections exhibited 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, CA, in 1982. The crack and seat sections have significantly less roughness (approximately 14.5 in/mi less).

Table 16. Mays Meter roughness measurements.

Section ID	Outer Lane Roughness	Outer Lane 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

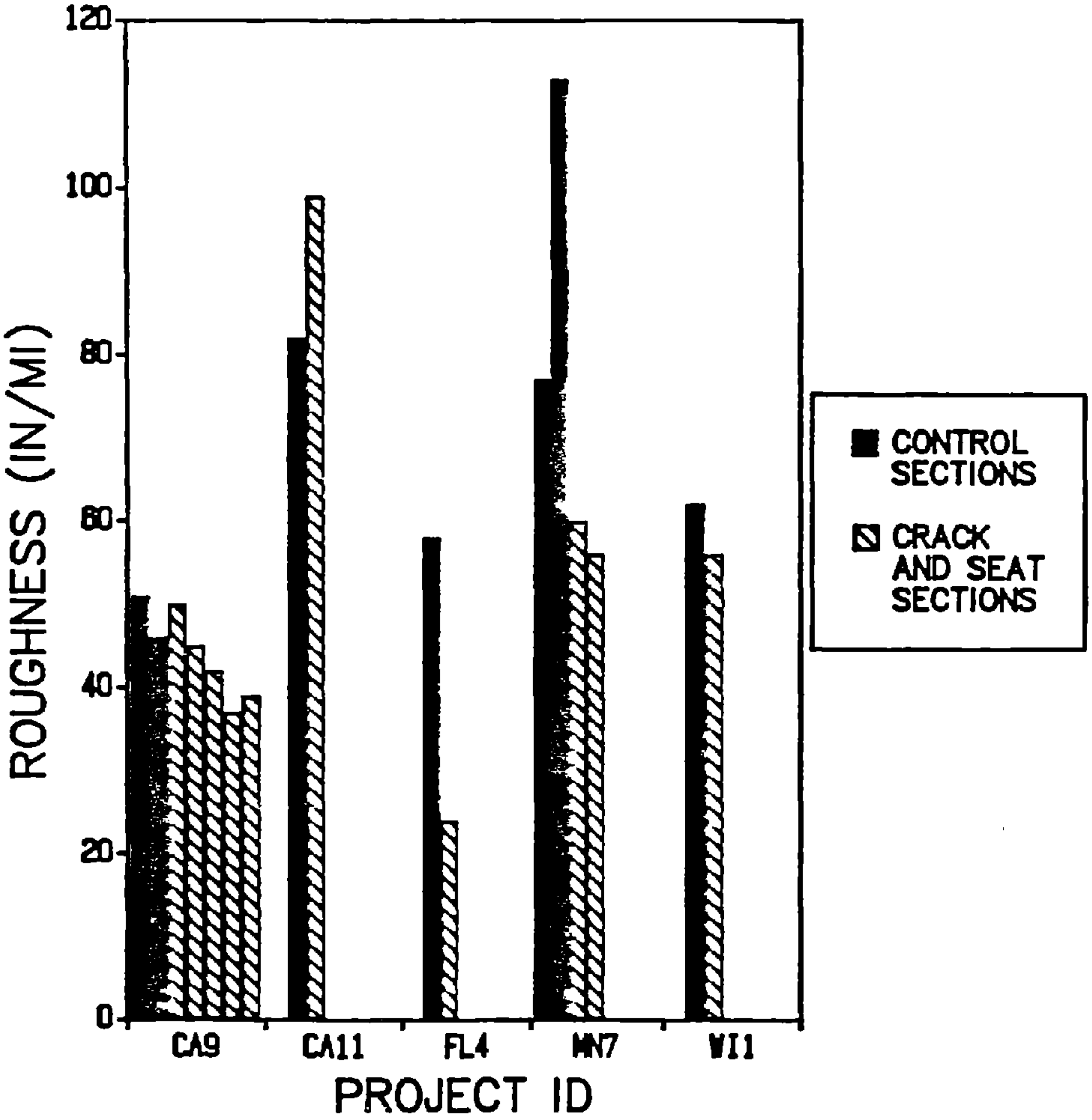


Figure 13. Comparison of roughness measurements taken on crack and seat and overlay sections with control sections.

The PSR on the five control projects was also 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. The graph is shown in figure 14. As can be seen in the figure, there is an increase in roughness with an increase in overlay thickness for the control sections. This trend does not follow engineering experience where an increase in thickness usually reduces roughness. Viewing figure 15, it is seen that the control sections with the lower amount of traffic also experienced more roughness. One would expect, however, that the thicker overlay will be rougher if there is more traffic on the section. This data shows the opposite. However, both of 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. The remaining control sections follow the expected pattern.

Observing the figure with respect to the crack and seat sections (figure 14) shows that the thickness of the overlay does not influence pavement roughness.

Figure 15, however, indicates that both the crack and seat and control sections with higher traffic volumes experienced less roughness. Again, the trend does not seem logical since 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 16. 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 JRCP and might be expected to perform

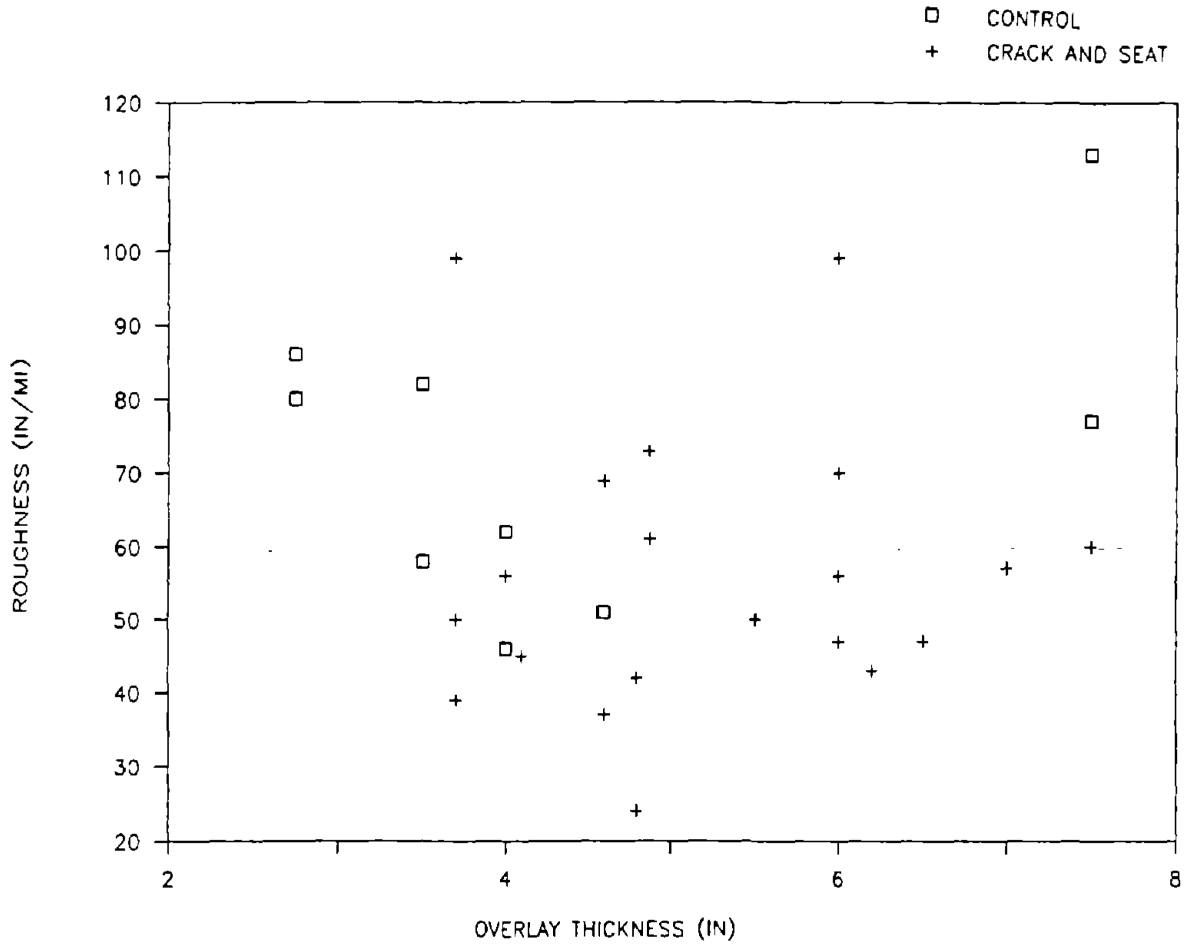


Figure 14. Pavement roughness versus overlay thickness.

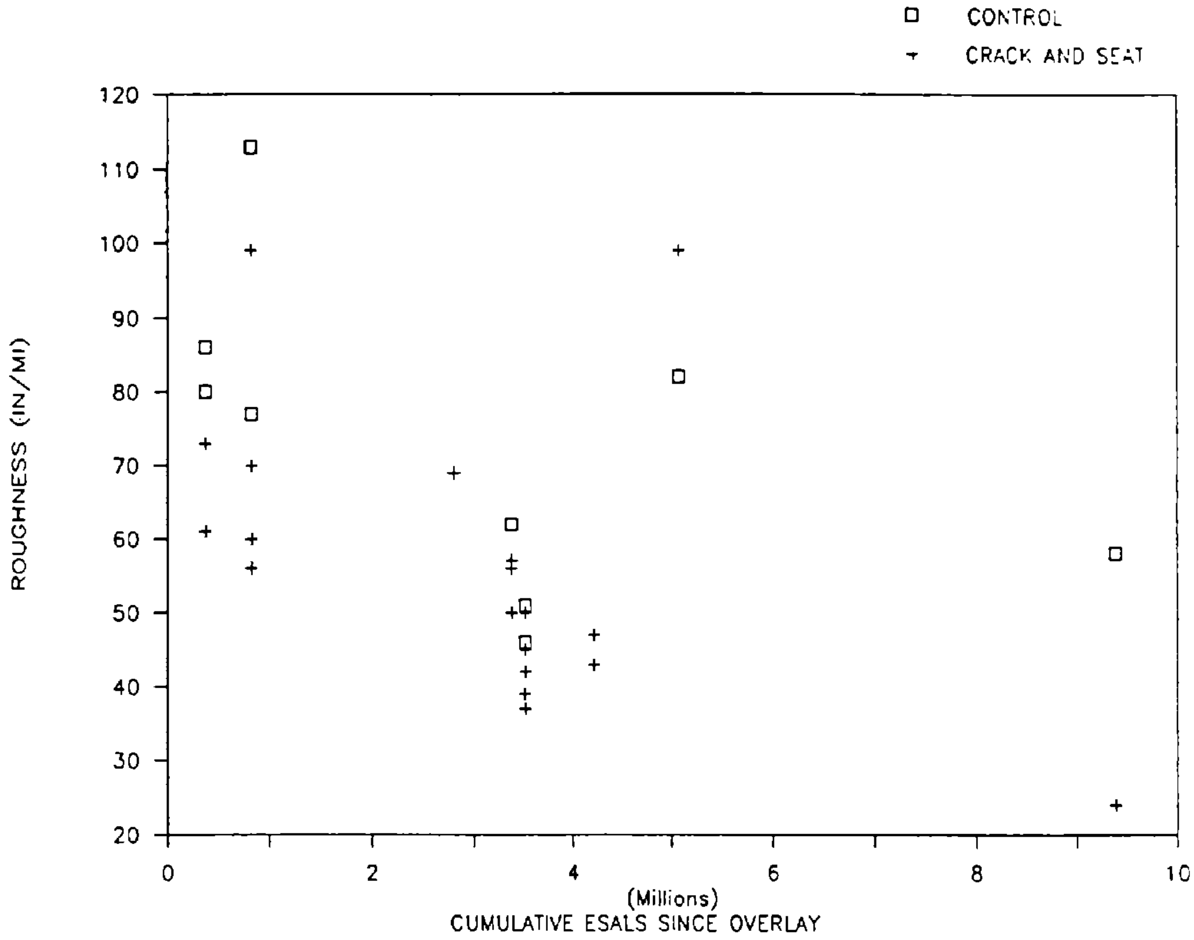


Figure 15. Pavement roughness versus traffic since overlay.

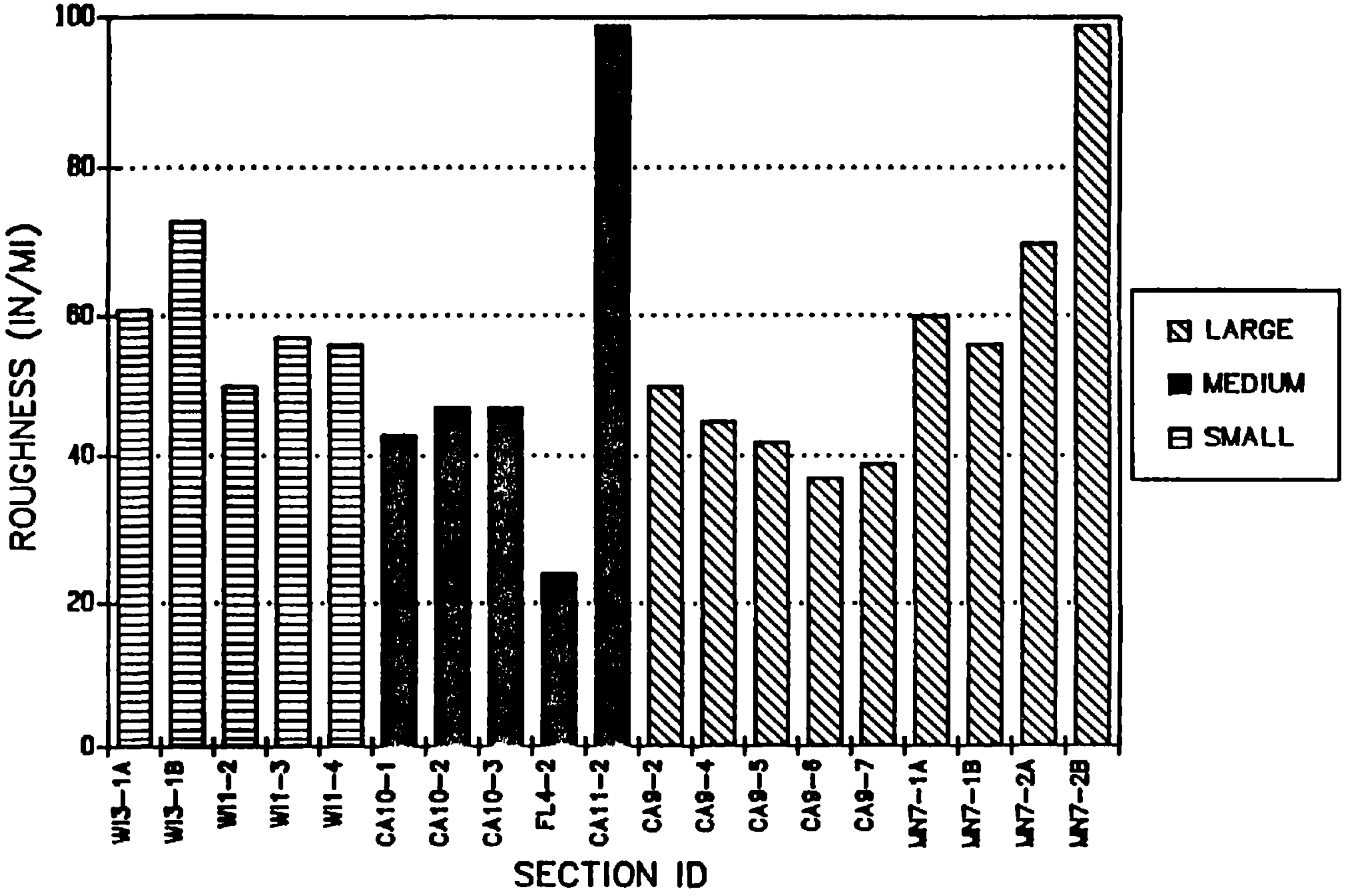


Figure 16. Pavement roughness with respect to cracked piece size.

differently. However, there is no statistically significant difference between the performance of the medium and large pieces on the JPCP sections.

The roughness was also plotted as a function of the type of roller that was used to seat the slabs. The plot (figure 17) 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 in roughness with the roller type or the size of the pieces.

OVERLAY DISTRESS

The primary goal when designing a pavement is to design and construct a structure able to support the estimated axle loads expected during its design life and to withstand the adverse effects of the environment. These traffic loadings and environmental effects cause stresses, strains, and deflections in the pavement system. It is the accumulation of these permanent strains and the repeated application of stress that can cause the limiting strains of the material involved to be exceeded, and causes pavement distress in the form of fracture or permanent deformation. Failure of the pavement structure occurs only when the accumulation of distress results in a lowering of the pavement's serviceability below a minimum acceptable level.

Hudson et al. have identified the most important distresses that affect the performance of an AC-overlaid PCC pavement.[40] Two of the more important distresses were found to be reflection cracking and rutting. The occurrences of these distresses observed during the field surveys are discussed in the following sections. Fatigue cracking of the overlays is also discussed.

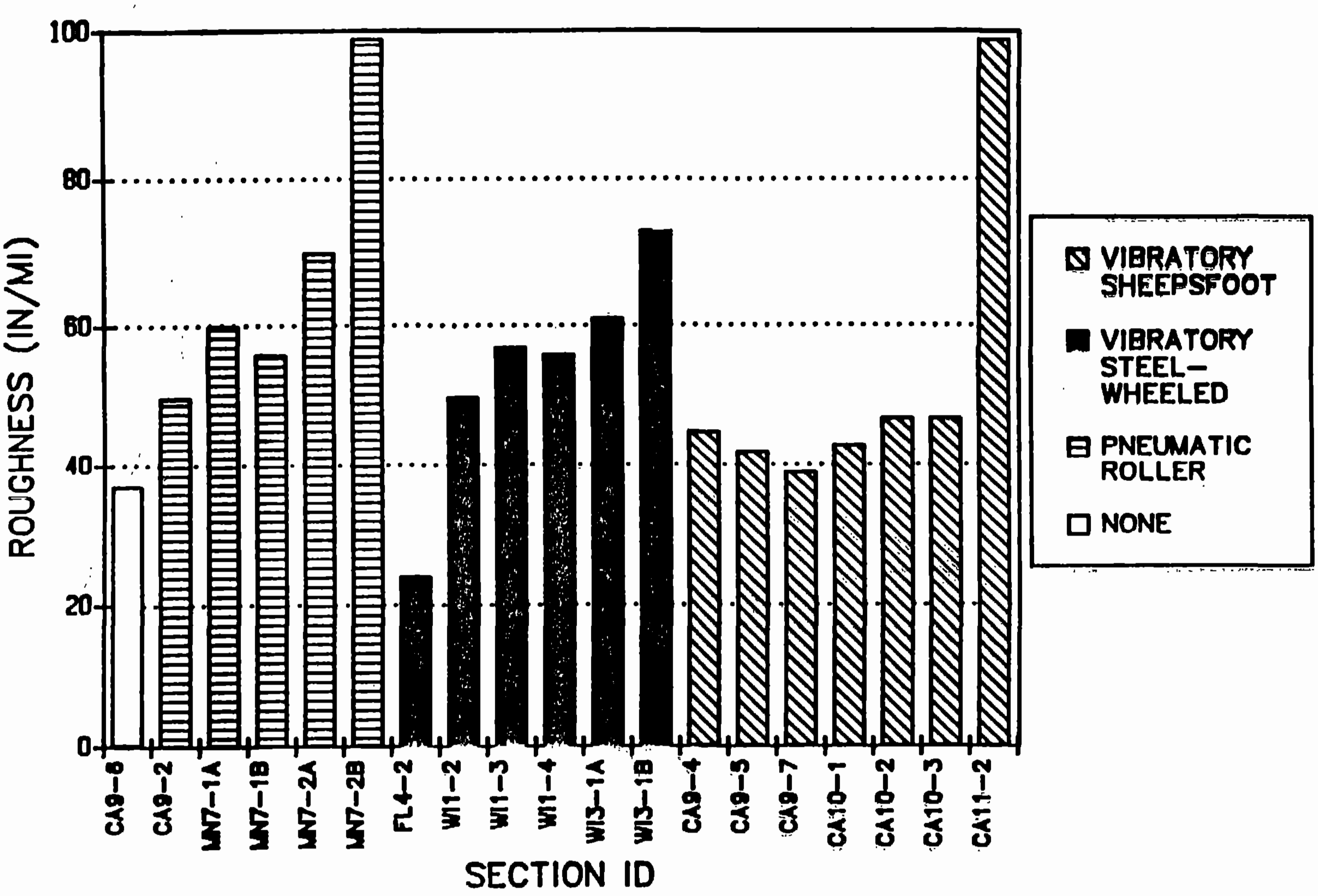


Figure 17. Pavement roughness with respect to type of seating equipment.

Reflection Cracking

Reflection cracks are a common distress manifestation of AC overlays of PCC, the causes of which were discussed in chapter 2. After these cracks develop, traffic loading and environmental effects tend to spall and deteriorate these cracks. The deteriorated cracks create serious maintenance problems as well as allow moisture to enter the pavement system. The cracking and seating of the PCC slab is supposed to effectively reduce the amount of reflection cracking.

For purposes of the study, all cracking was considered to be reflective. It is possible that some of the observed cracking can be due to temperature differentials or other AC material problems; however, it is difficult to distinguish the exact cause when only a condition survey was conducted.

The severity of the cracking was classified as low, medium, or high, while the amount of cracking was combined as total linear feet per mile.

The transverse cracking for the outside lane is shown in figure 18. It can be seen that the Minnesota section (the oldest section) had the highest amount of cracking with the majority of the cracking being medium severity. In all cases except Minnesota and Wisconsin, the control sections had more transverse cracking than the crack and seat section.

A plot (figure 19) of longitudinal cracking in the outside lane was also prepared. 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 1,688 ft/mi, while the crack and seat had 1,759 ft/mi, or a difference of only 4 percent.

The total cracking, including centerline cracking, is presented in figure 20. The figure also shows that Minnesota had the highest amount of cracking with a large amount of centerline cracking. Wisconsin experienced the same. Observing figure 20, it can be seen that several of the control sections had more cracking than the crack and seat sections. The average

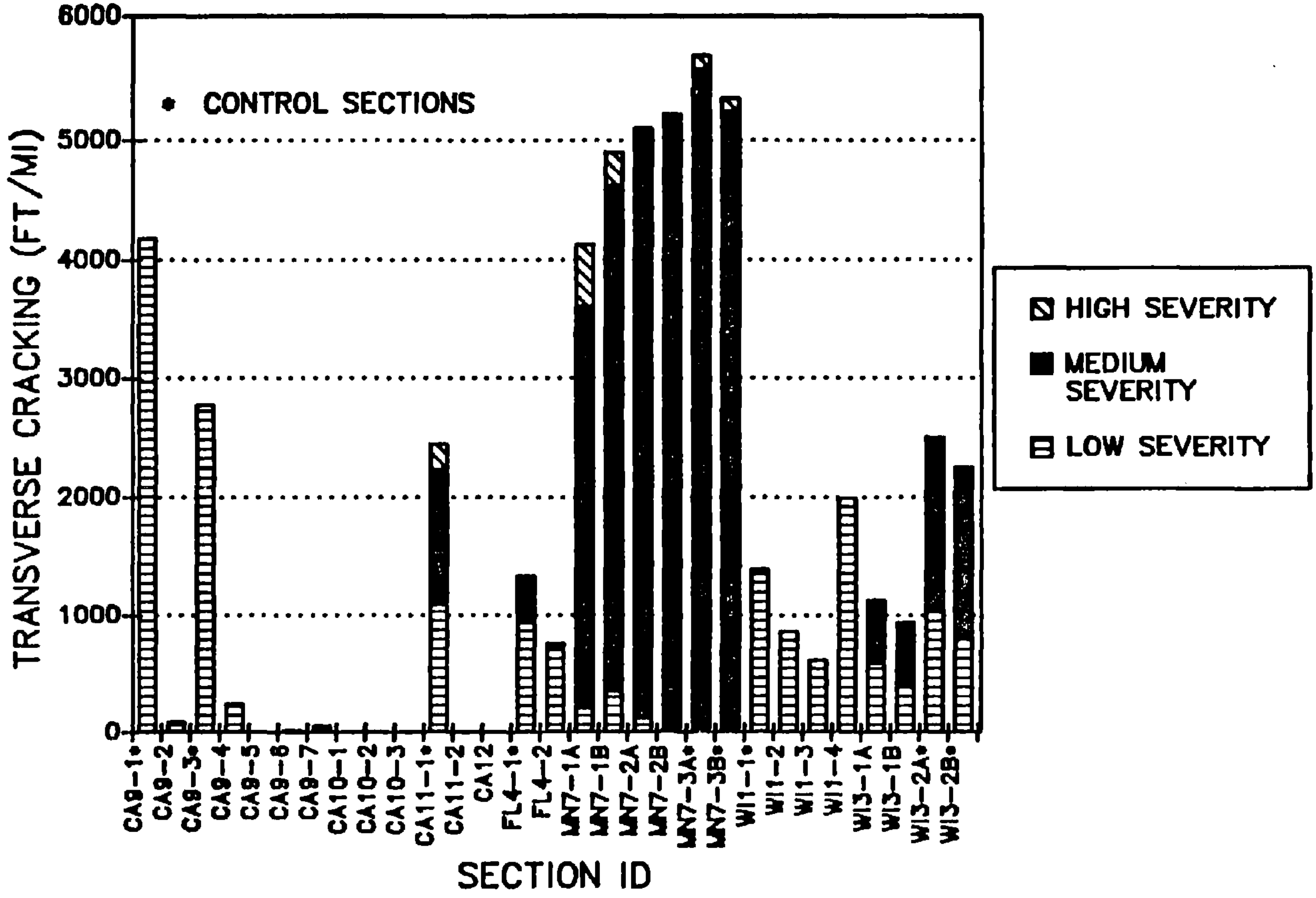


Figure 18. Quantity and severity of transverse cracking in the outside lane.

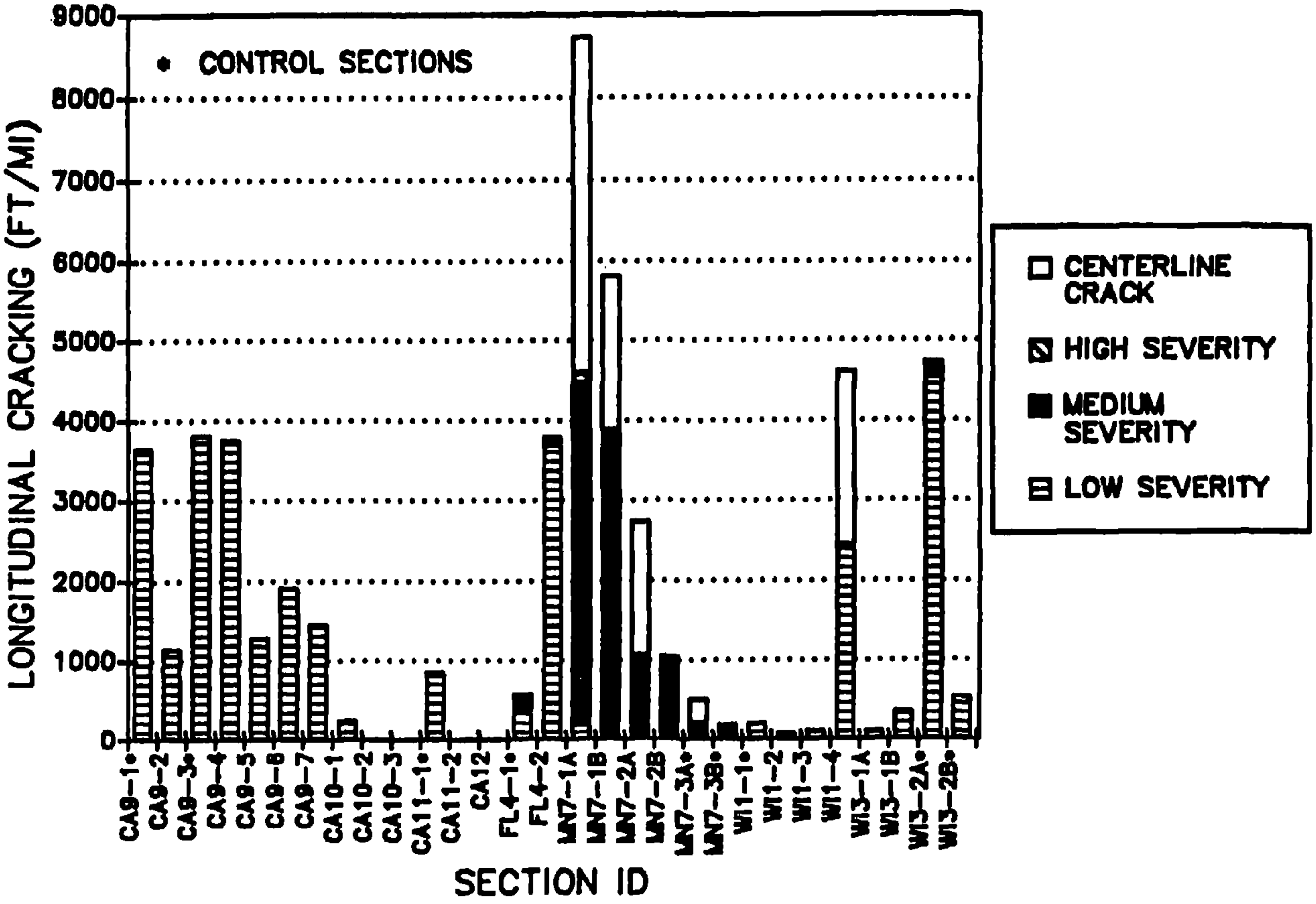


Figure 19. Quantity and severity of longitudinal cracking in the outside lane.

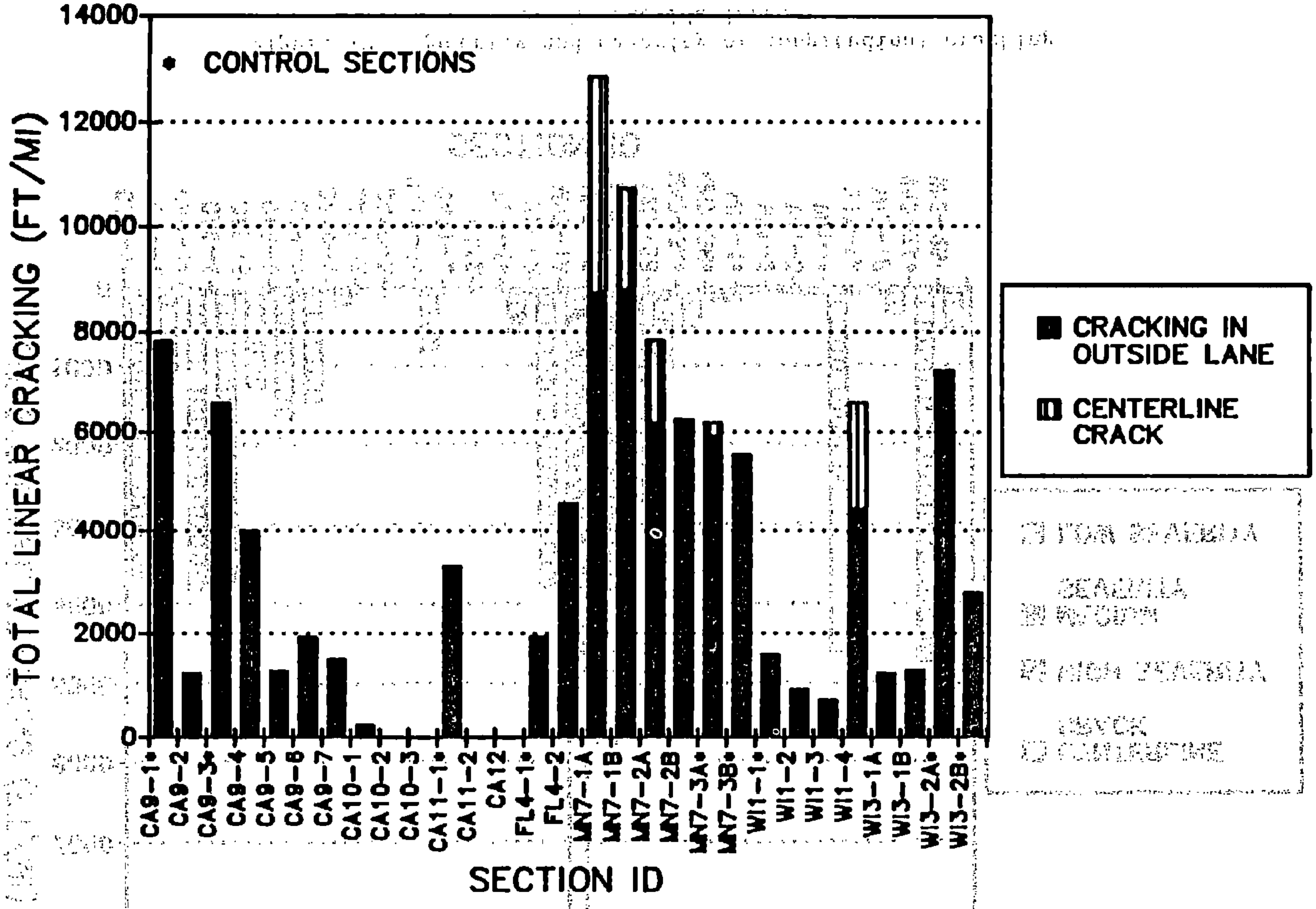


Figure 20. Total linear cracking.

amount of cracking for all of the control sections was 4,800 ft/mi, while the average amount for all of the crack and seat sections was 3,068 ft/mi. This represents a 36 percent reduction in total cracking.

The five control projects were examined on the basis of both total linear cracking and medium/high linear cracking. The crack and seat sections had less total cracking (only 67-percent confidence), but more medium/high cracking (84-percent confidence).

Reflection Cracking and Overlay Age

When the total cracking is plotted against the year of the overlay, a different view of the comparative performance of the crack and seat sections is presented. Observing figure 21, 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.

Reflection Cracking and Overlay Thickness

Figure 22 shows that the overlay thickness for most of the control sections was in the range of 2.75 to 4.75 in, while the crack and seat overlay thickness was from 3.75 to 7.75 in (two control sections had 7.75 in). Since the crack and seat sections generally had thicker overlays, one would expect that it would take longer for the reflection cracking to occur; however, this could not be shown statistically from the available data. Although figure 22 may appear to indicate that a thicker overlay produced more linear cracking, this is again a result of the oldest sections having the thickest overlays.

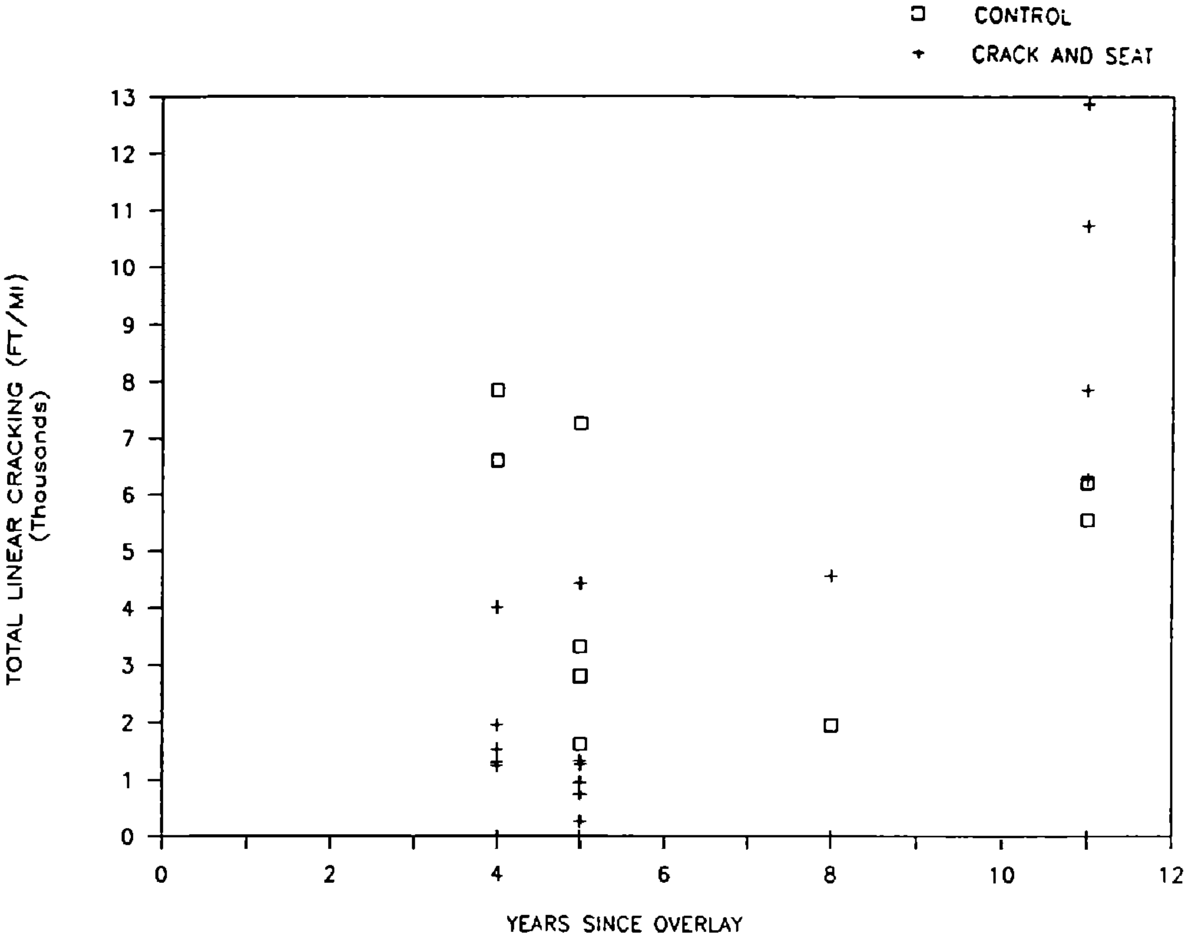


Figure 21. Total linear cracking versus years since overlay.

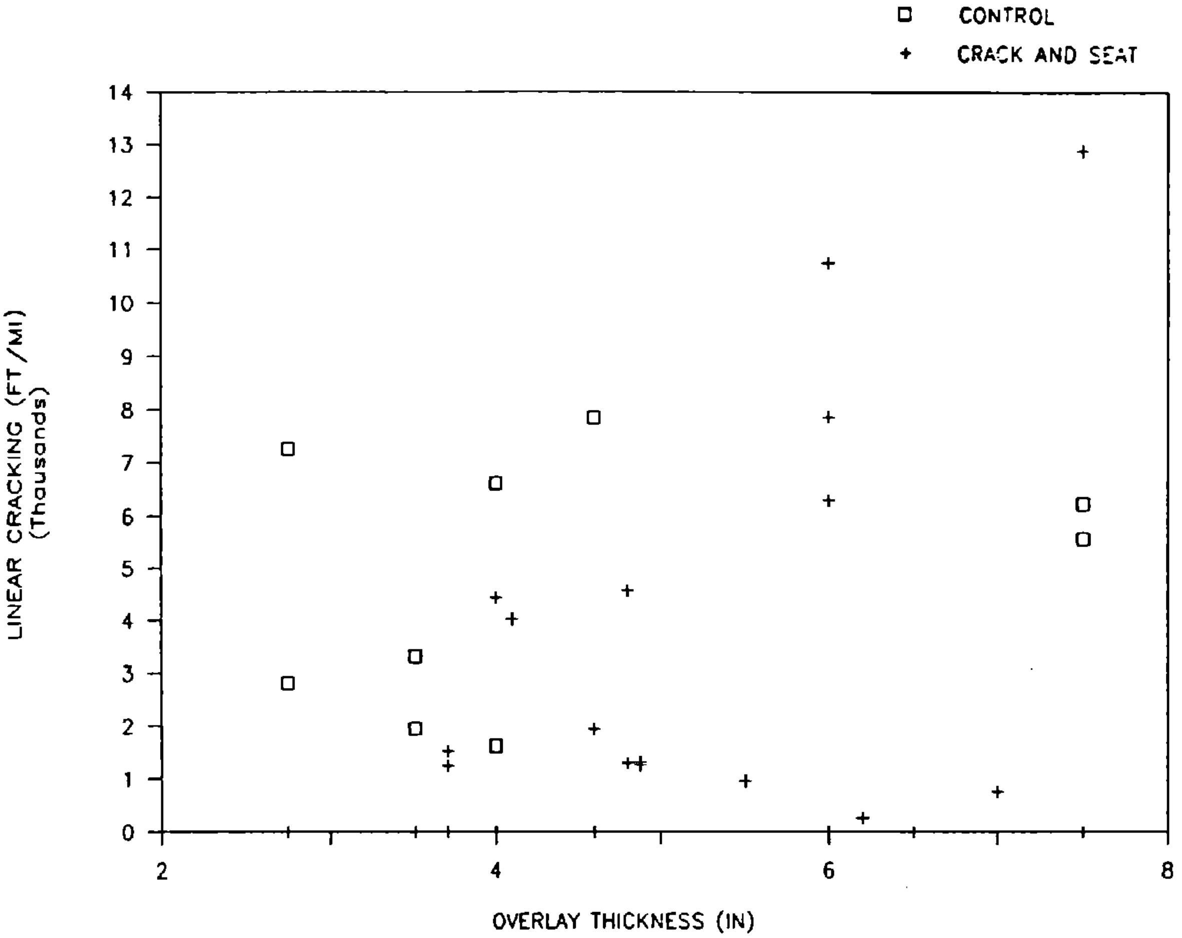


Figure 22. Total linear cracking versus overlay thickness.

Reflection Cracking and Segment Size

The size of the broken pieces should influence the amount of reflection cracking. Figure 23 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.

Reflection Cracking and Type of Roller

The amount of reflection cracking with respect to type of roller was also evaluated. The results are shown in figure 24. 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 sheepsfoot 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.

Alligator Cracking

The typical type of reflection cracking in an AC overlay on PCC pavements is usually transverse or longitudinal cracking. The condition survey also revealed some interconnected cracking with the appearance of fatigue, or alligator, cracking. A plot of this cracking is shown in figure 25.

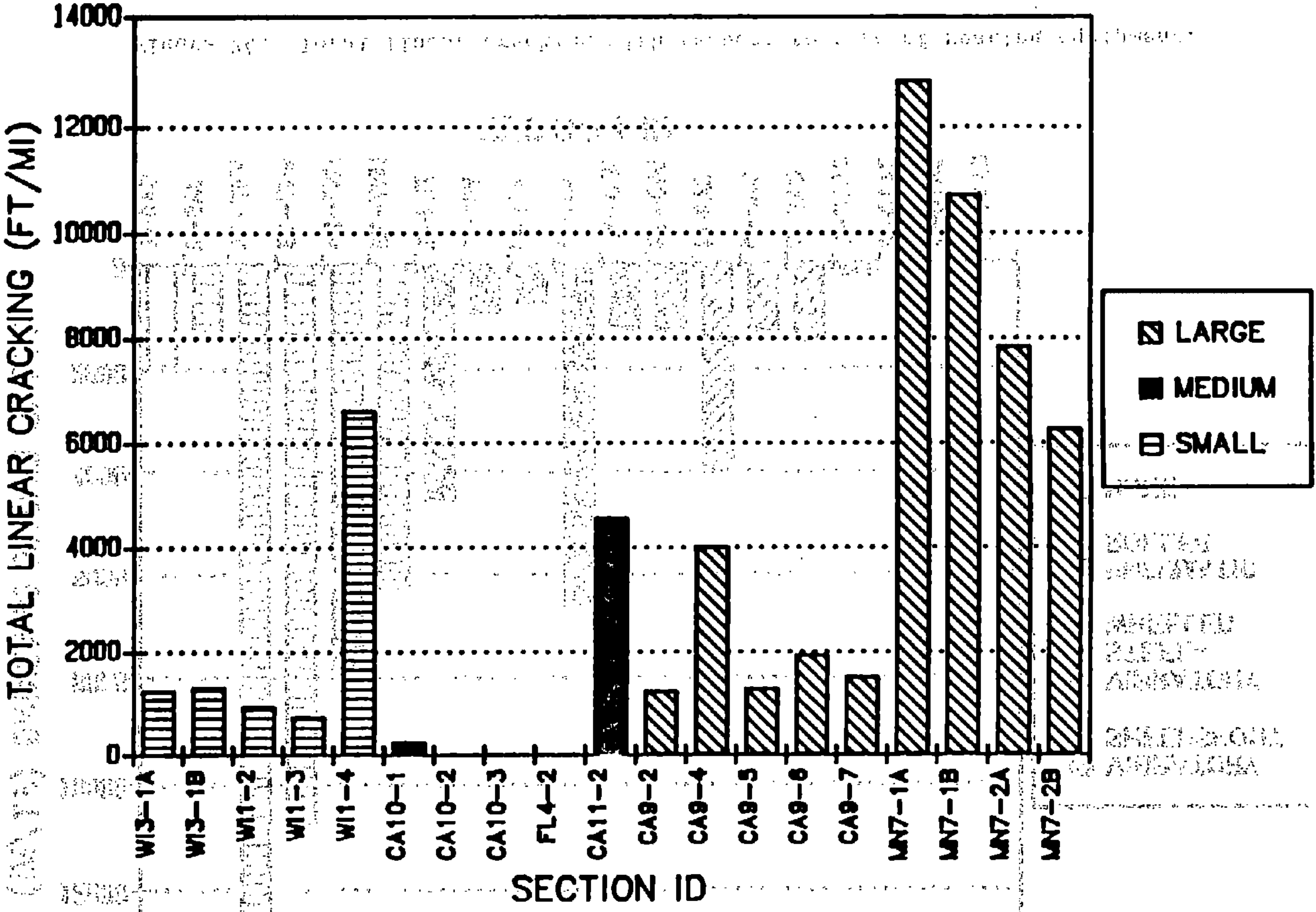


Figure 23. Total linear cracking with respect to cracked piece size.

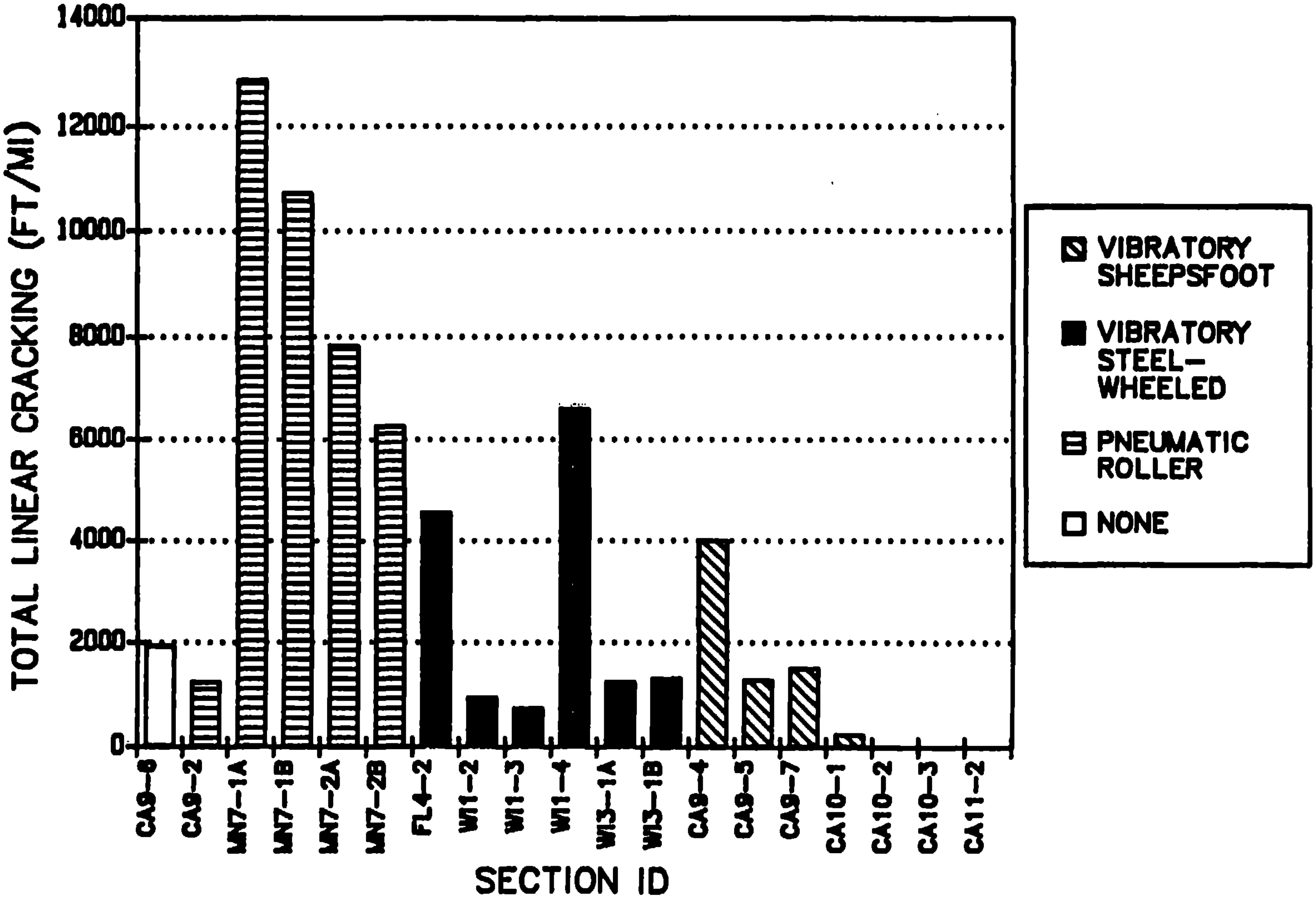


Figure 24. Total linear cracking with respect to type of seating equipment.

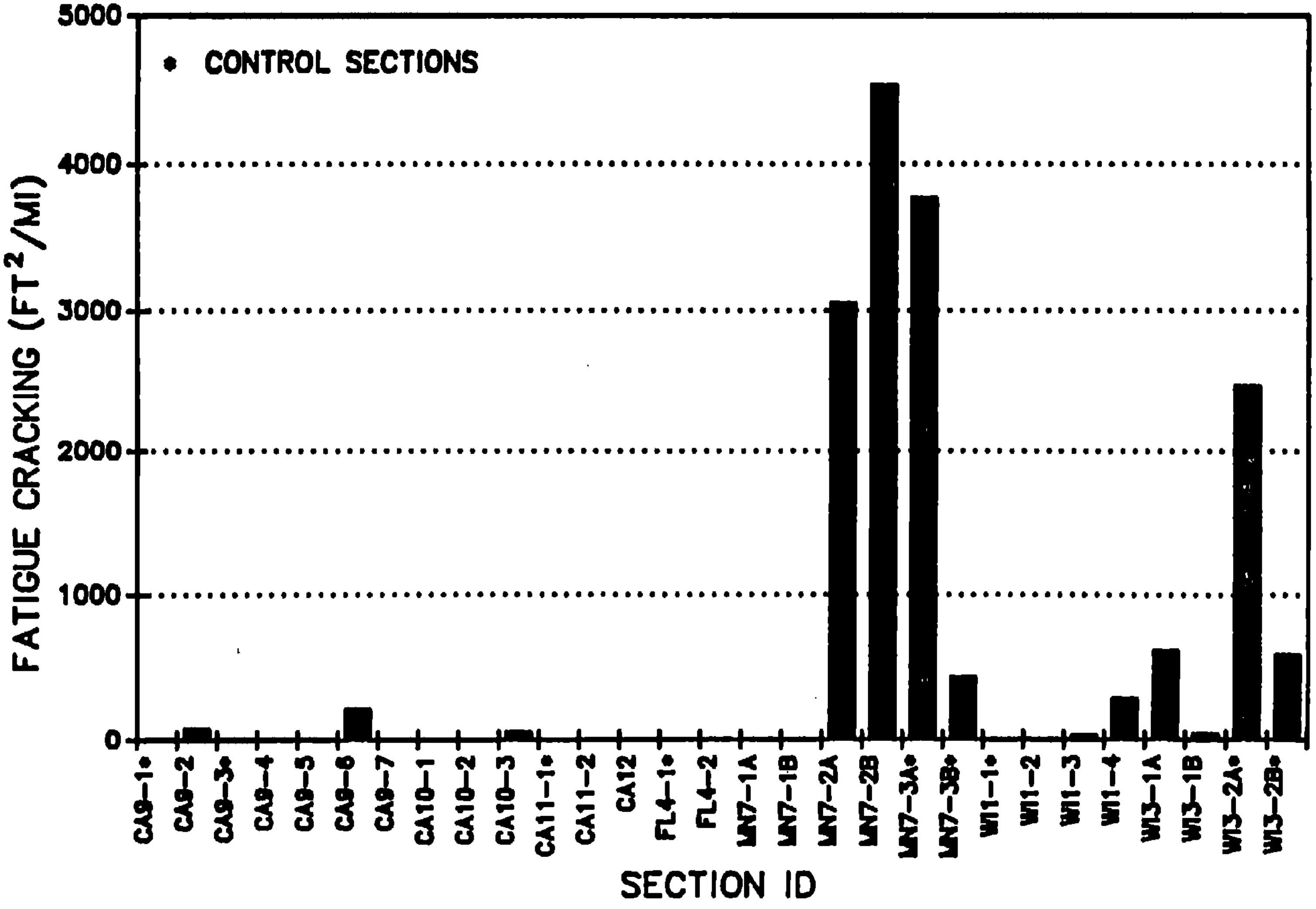


Figure 25. Alligator cracking quantities.

Minnesota sections experienced the most alligator cracking, while Wisconsin also had some. Both the control and the crack and seat sections experienced alligator cracking. Three of the California crack and seat sections also had minor amounts of alligator cracking. The alligator cracking indicates base failure, which is difficult to justify when the base in composed of PCC pieces. However, the cracking is generally interconnected with linear cracking. Therefore, the alligator cracking may be due to the further breakdown of the pavement in the areas where traffic loading interacts with existing cracks.

Rutting

Rutting is the longitudinal depression of a pavement's surface in the wheelpaths. Rutting stems from a permanent deformation in one or more of the pavement layers or subgrade, which can be caused by lateral movement or consolidation of the materials due to traffic loadings. In an AC overlay of PCC, this movement or consolidation takes place entirely in the hot mix AC, due to the PCC being much stiffer than the AC. Inadequate compaction of the AC overlay during construction can also lead to rutting.

During the field surveys, rut depths were measured at 200-ft intervals in both wheelpaths in the outer (travel) lane for each of the study sections. Where traffic conditions permitted, measurements were made in additional lanes. Rut depths were measured as the maximum distance from the bottom of a 6-ft straightedge placed across one half of the traffic lane to the bottom of the rut. The average measurements are given in table 17.

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.

Table 17. Average rut depth (in).

Section ID	Overlay Thickness (in)	Outside Lane	
		Inner Wheel Patch	Outer Wheel Patch
CA 9-1*	4.6	0.03	0.03
CA 9-2	3.7	0.13	0.11
CA 9-3*	4.0	0.13	0.06
CA 9-4	4.1	0.12	0.04
CA 9-5	4.8	0.20	0.09
CA 9-6	4.6	0.20	0.06
CA 9-7	3.7	0.11	0.05
CA 10-1	6.2	0.30	0.30
CA 10-2	6.5	0.28	0.25
CA 10-3	6.0	0.26	0.26
CA 11-1*	3.5	0.09	0.09
CA 11-2	3.7	0.15	0.13
CA 12	4.6	0.29	0.20
FL 4-1*	3.5	0.21	0.18
FL 4-2	4.8	0.22	0.14
MN 7-1A	7.5	0.05	0.13
MN 7-1B	7.5	0.13	0.10
MN 7-2A	6.0	0.00	0.02
MN 7-2B	6.0	0.15	0.15
MN 7-3A*	7.5	0.07	0.07
MN 7-3B*	7.5	0.10	0.11
WI 1-1*	4.0	0.26	0.23
WI 1-2	5.5	0.38	0.40
WI 1-3	7.0	0.48	0.43
WI 1-4	4.0	0.30	0.30
WI 3-1A	4.9	0.17	0.25
WI 3-1B	4.9	0.22	0.23
WI 3-2A*	2.8	0.11	0.25
WI 3-2B*	2.8	0.35	0.19

*Control sections

A plot of rut depth is shown in figure 26. It can be seen that in many cases, the crack and seat section had more rutting than the control sections. In particular, the crack and seat sections in Wisconsin and California had significantly more rutting. A plot of rut depth versus overlay thickness is shown in figure 27. The figure shows that the rutting on the control sections decreased with 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, while 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.

Drainage

The surface and visual drainage evaluation as described in chapter 3 indicated drainage problems only for section FL4-2. FL4-2 is a crack and seat section with the overlay placed in 1979; the 1987 PSR rating was 4.4. Therefore, no basis for evaluating surface drainage characteristics is provided.

The 1986 AASHTO Design Procedure added several elements to the Interim Guide for the design of pavements.[20] One significant addition was the inclusion of drainage coefficients. Volume V of Phase 1, "Appendix B - Data Collection and Analysis Procedures," describes a rational procedure to determine a combined "whole pavement" drainage coefficient that represents the impact of drainage on the potential life of the pavement being analyzed.[41] This procedure was used to evaluate each of the pavement sections. The resulting AASHTO drainage coefficients are plotted versus total linear cracking in figure 28 and versus roughness in figure 29.

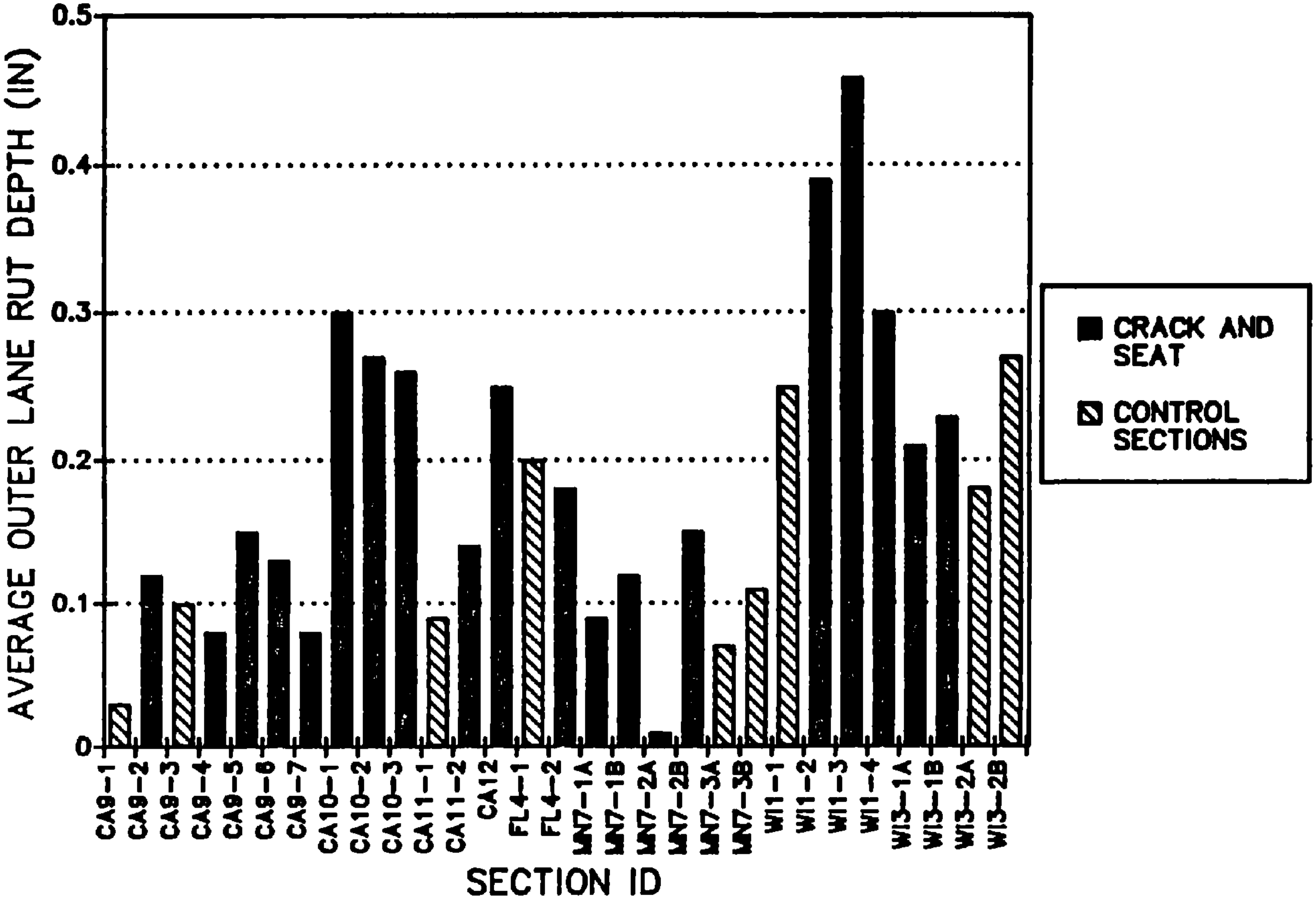


Figure 26. Average outer lane rut depths.

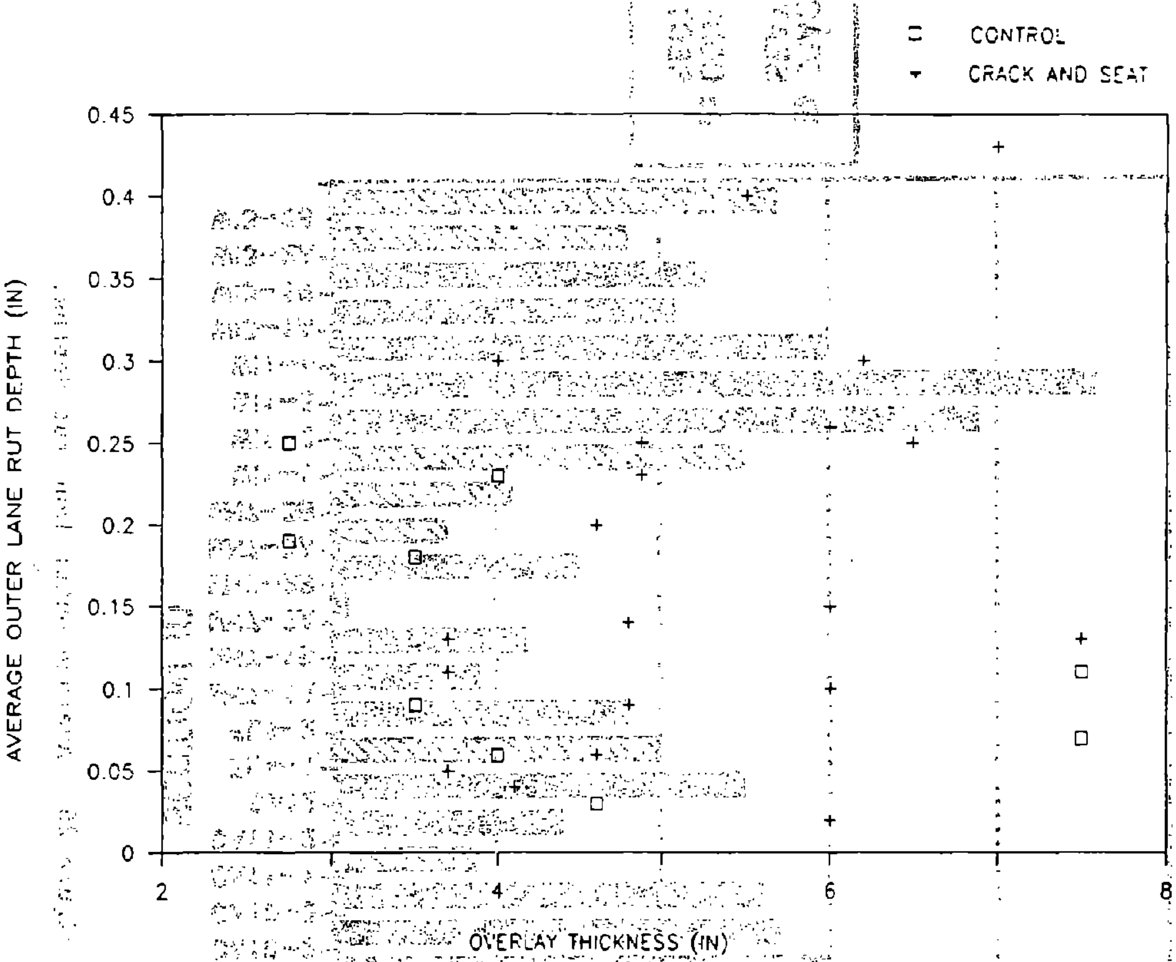


Figure 27. Rut depth versus overlay thickness.

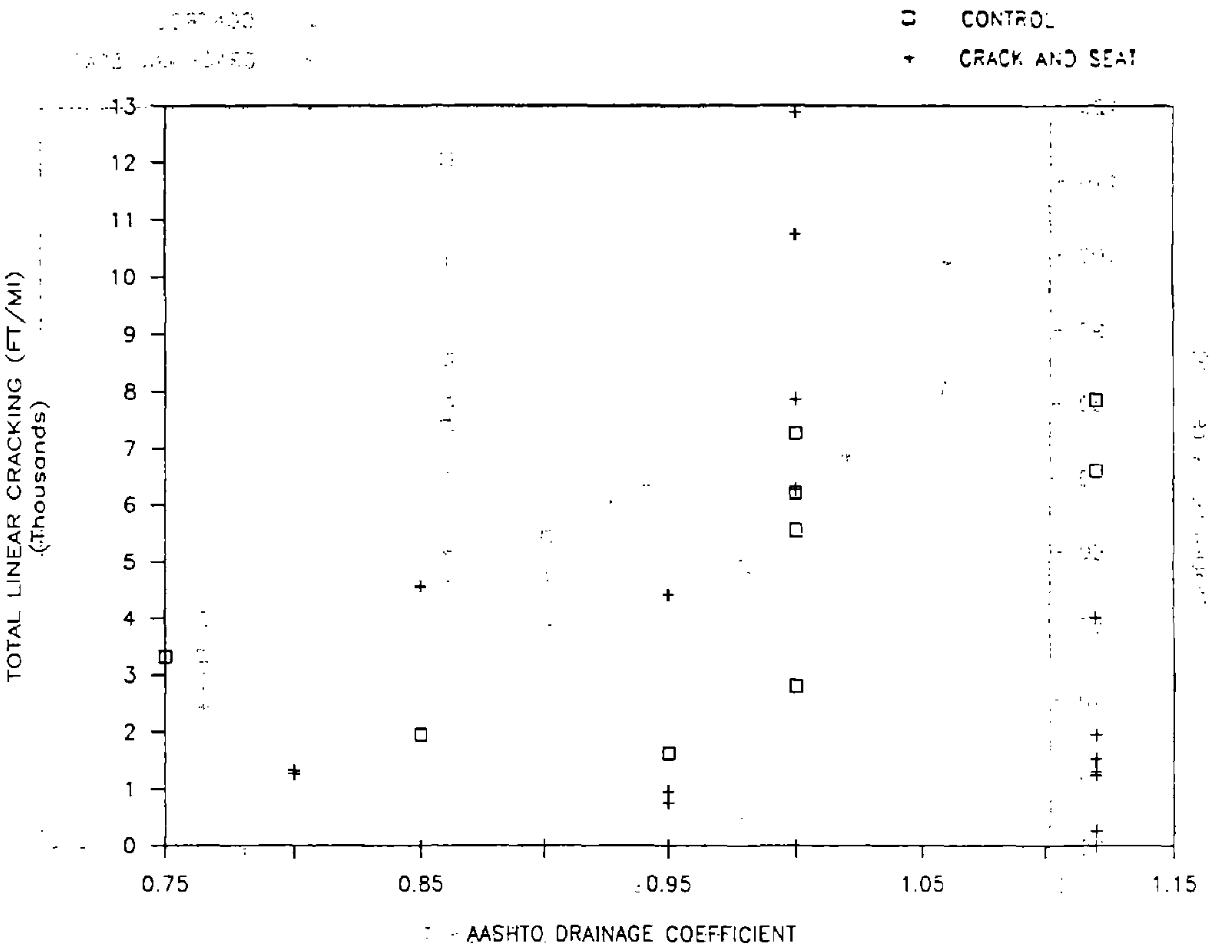


Figure 28. AASHTO drainage coefficients versus total linear cracking.

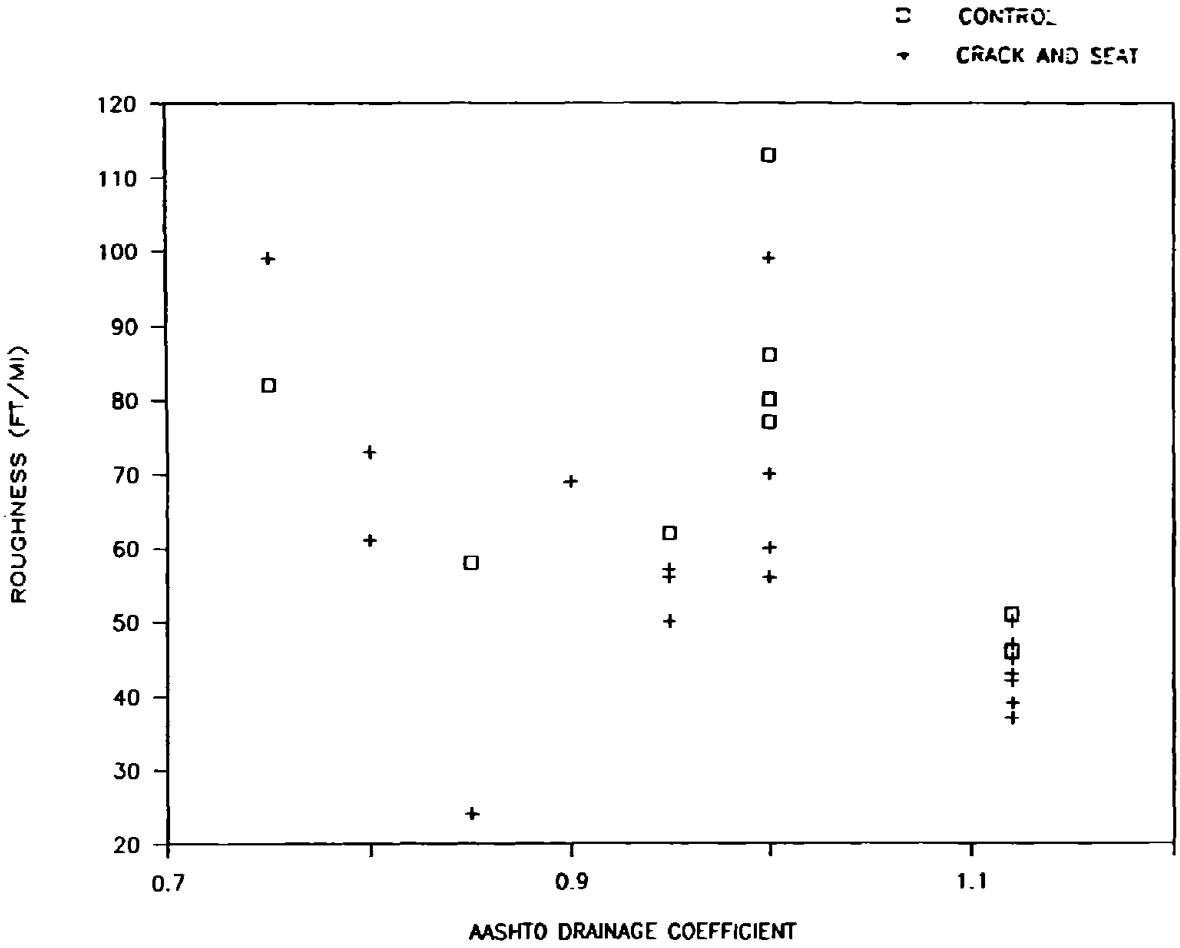


Figure 29. AASHTO drainage coefficients versus roughness.

Fabric Interlayers

In California, the standard AC overlay used with the crack and seat treatment is 0.35 ft thick and contains an interlayer of paving fabric (nonwoven polyester, polypropylene, or polypropylene/nylon materials).[23] Table 18 presents the California sections (of those studied on this project) that contained a fabric interlayer.

Table 18. California sections with fabric interlayer.

Controls	Crack and Seat
CA 9-3	CA 9-2 CA 9-7
	CA 10-2 CA 10-3
CA 11-1	CA 11-2

On project CA 9, the two crack and seat sections with a fabric interlayer had less average linear cracking (1,388 ft) than the three corresponding crack and seat sections without fabric (2,422 ft). The control section with fabric, CA 9-3, also exhibited less linear cracking (6,610 ft) than the control section without fabric, CA 9-1 (7,854 ft). On CA 10, neither of the sections with fabric exhibited any linear cracking, while the section without fabric contained a small amount of linear cracking (264 ft).

DEFLECTION MEASUREMENTS

Nondestructive testing of all 29 study sections was conducted using a falling weight deflectometer (FWD) as described previously. The deflection measurements obtained were summarized in table 13. It can be seen that there was a wide variation in the measured wheel path deflections; from a low of 2.50 mils to a high of 25.5 mils. The range of deflections for each section is illustrated in figure 30. The roughness of each study section was plotted against average deflection as shown in figure 31. As would be expected,

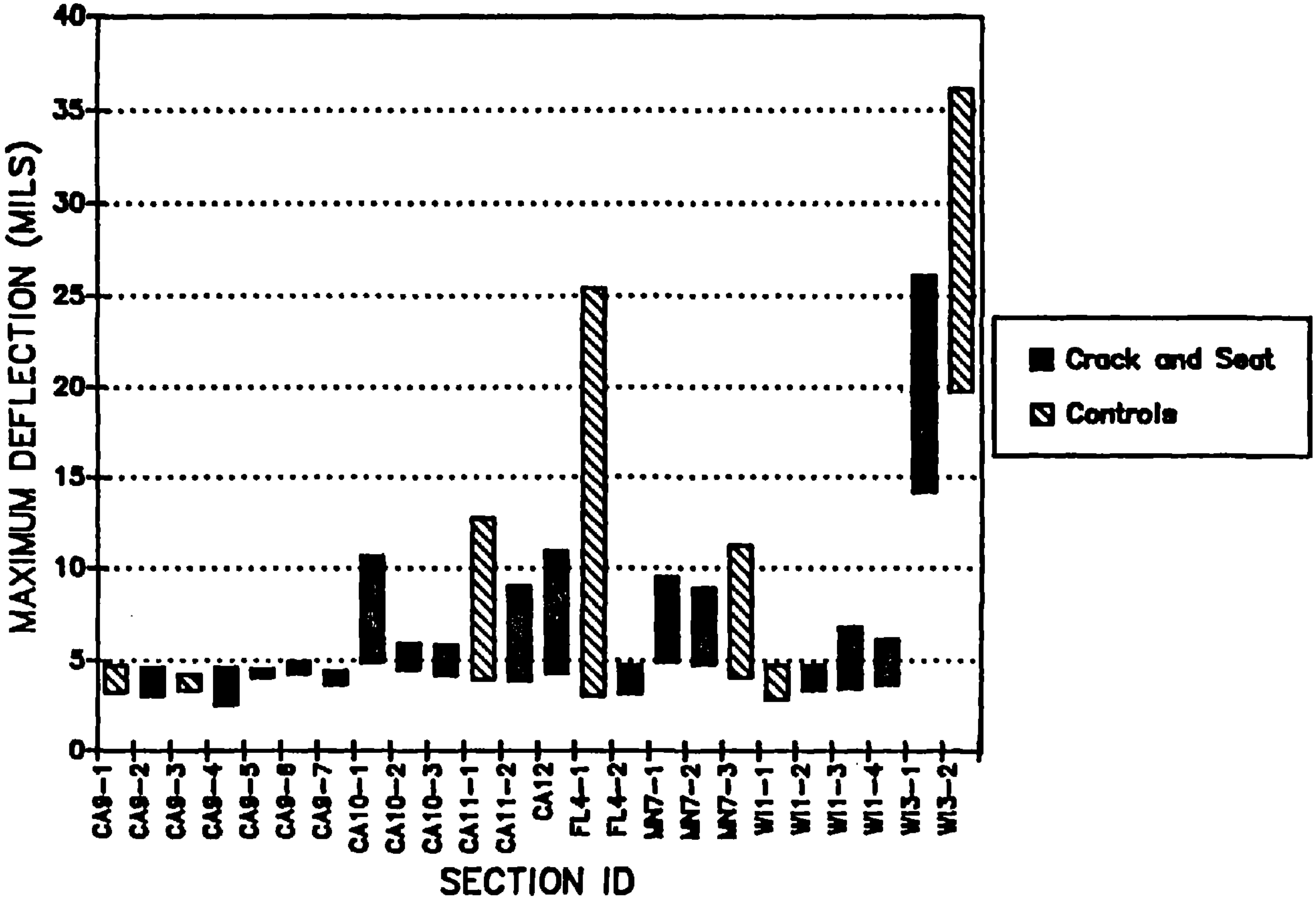


Figure 30. Range of maximum deflections for each study section.

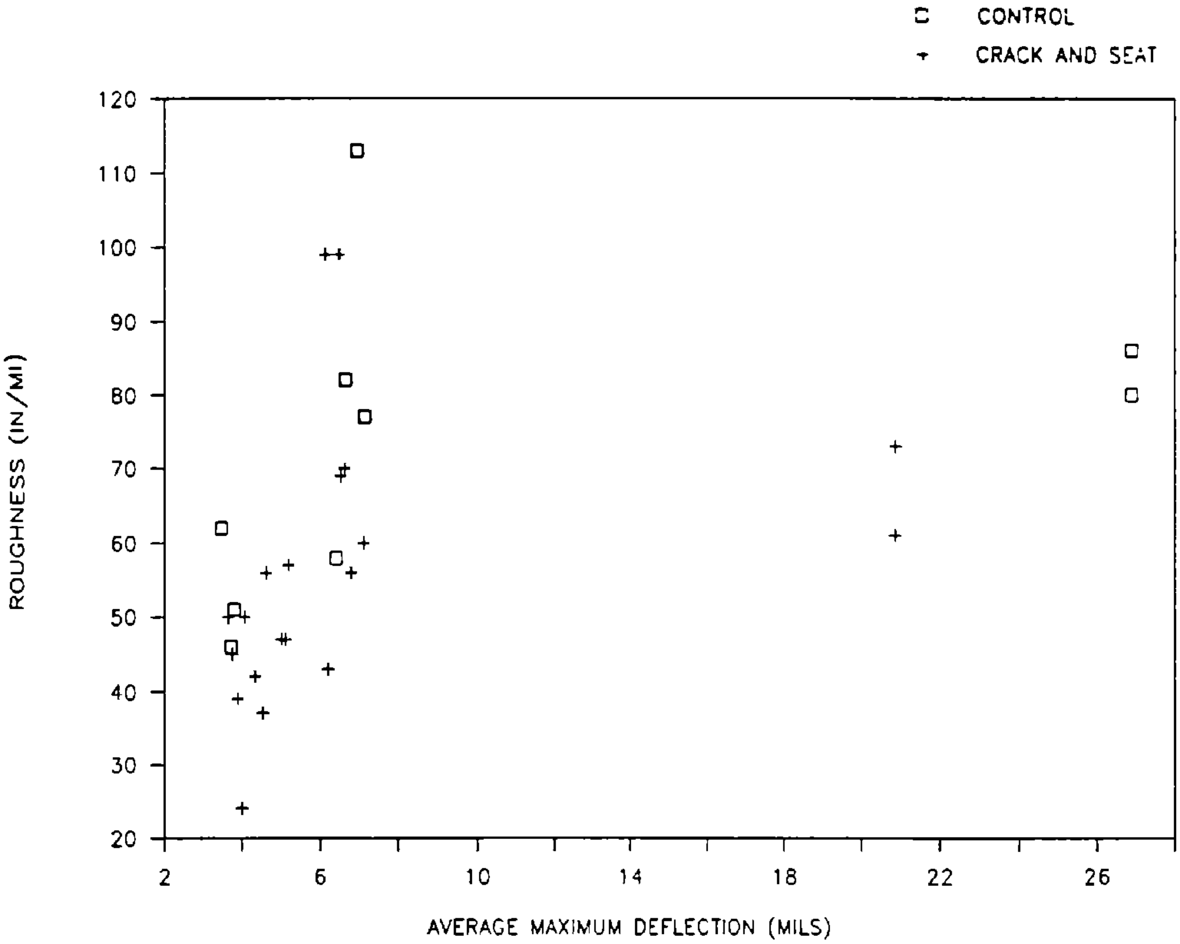


Figure 31. Roughness versus average maximum deflection.

sections with higher deflections tend to exhibit greater roughness. Average deflection was also plotted against overlay thickness as shown in figure 32. No clear pattern is apparent. Although a thicker overlay may contribute to the overall structural capacity, the asphalt concrete will deform more than the underlying PCC.

The maximum deflections for each wheel path testing point were plotted along the length of each section. These are presented in the appendix. Three deflection basins from each section were analyzed using the BISDEF elastic layer analysis program.[42] Points were selected to indicate the variations of values along the sections. The results, which were included in the design data summary table, 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 in the design data summary table indicate 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 with 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 is not an elastic layer and is not easily modeled as such. The location of an underlying crack with respect to the load influences 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.

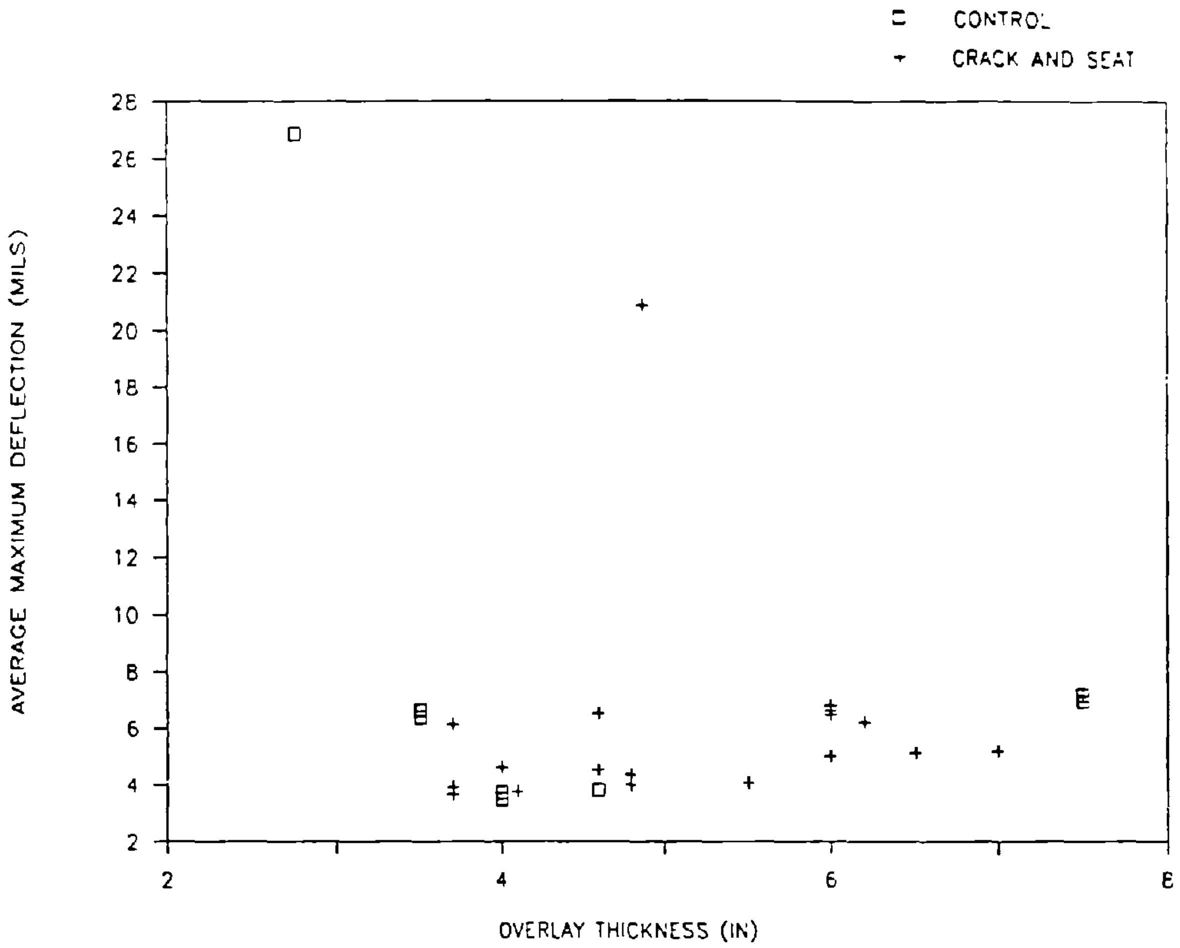


Figure 32. Average maximum deflection versus overlay thickness.

Since the evaluation of layer properties was largely unsuccessful, an alternative approach to evaluating the structural effects of cracking and seating was undertaken. For each section, the average deflection at each sensor position was analyzed. These average deflections were presented in table 13. In addition, the cross-sectional areas of these average deflection basins were calculated. Finally, a volumetric k (applied load/displaced volume) was determined for each pavement structure. These results were also provided in table 13.

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. However, the average volumetric k's calculated for the crack and seat sections were slightly greater than those for the corresponding control sections. So, on the basis of the available data, no reduced layer structural properties can be predicted as a result of crack and seat procedures.

5. SUMMARY DISCUSSION AND CONCLUSIONS

SUMMARY DISCUSSION

A common method used to rehabilitate PCC pavements is the placement of an AC overlay. These overlays often deteriorate rapidly due to the problems associated with reflection cracking. Numerous techniques such as sawing and sealing of joints, cracking and seating of the concrete slabs, 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. The crack and seat method (not rubblizing) produces slab pieces much shorter than the original slab length, thus reducing movement due to temperature changes. The seating of the slab is designed to prevent rocking and other slab movements. Since the PCC slabs are not cracked into very small pieces, some structural capacity still remains in the existing pavement system.

The purpose of this study was to evaluate the performance of and verify and/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 12 years. Field condition surveys, roughness measurements, rut depths, deflection measurements, traffic, environmental, and other data were obtained and analyzed to document and evaluate the performance of the cracked and seated PCC pavements. Design construction guidelines and guide specifications were developed using information from past research studies, existing design procedures, and field performance results from this study.

It should be noted that the conclusions presented herein on the effectiveness of the crack and seat and overlay procedure are based on a limited number of sections. A total of 29 sections were evaluated, and of those there were only 5 true control sections which allowed direct performance comparisons between the crack and seat and AC overlay technique and the conventional AC overlay procedure. Further limitations to the analysis include the relatively few JRCP sections included in the study, the unequal distribution of crack and seat sections across climatic regions, the lack of JPCP crack and seat sections with small cracked pieces, and the lack of JRCP crack and seat sections with medium to large cracked pieces.

Although the conclusions presented herein are based on a limited number of sections, the conclusions are consistent with the previous findings of the Federal Highway Administration. An FHWA Review Report "Crack and Seat Performance" states:[44]

> "Of the 22 projects reviewed, only four projects showed appreciably less reflective cracking in the crack and seat (C&S) sections than in the control sections. To quantify the benefits of C&S, a measure of the difference in the percent of transverse joints which had reflected through the overlay was employed. Observations made during this review coupled with previous State condition surveys, where available, indicated a reduction in the percent transverse joints reflecting through the overlay during the first few years when C&S is applied. However, after 4 to 5 years the C&S sections generally have approximately the same cracking as the control sections. Therefore, it can be concluded that overall, C&S appears to provide benefits under some conditions by delaying, not eliminating, reflective cracking."

The analysis conducted for this study did, however, show that the crack and seat procedure did not significantly reduce the structural capacity (modulus of elasticity) of the pavement. This differs from the FHWA review which states:[44]

> "Since the structural capacity of the existing pavement is reduced by cracking, more overlay thickness is required to maintain the same structural number as the non-cracked pavement. Using an overlay analysis such as AASHTO would typically result in the need for up to 3 inches to maintain equivalent structural capacity.
>
> The additional cost of: 1) the additional overlay thickness; 2) the cracking and seating; and 3) other required work such as shoulder and guardrail raising, must be evaluated to determine if these costs are justified.
>
> Based on this review and the limited field performance data available to date, it appears these extra costs may not be justified since the condition of the C&S and control sections seemed to be the same after some period of time on most of the projects reviewed."

The purpose of crack and seat is to significantly reduce reflection cracking, particularly the deterioration of cracks (medium and high severity). The data analysis did not show that the crack and seat and AC overlay technique significantly reduced medium and high severity reflection cracking except in California. In addition, reflection cracking for the crack and seat projects increased significantly with age.

CONCLUSIONS

It should be noted that the number of field evaluations under this research contract was limited by available funding and by the more comprehensive work (which is now underway) that was anticipated under the

Strategic Highway Research Program. Also, additional evaluations of the performance of the crack and seat and AC overlay technique are being conducted by the FHWA (under Demonstration Project SP-202). States using this technique are encouraged to establish control sections (same AC overlay thickness but without cracking and seating) to verify that their specified procedures result in the benefits desired or expected from the use of this rehabilitation technique. Other procedures used elsewhere or subsequently developed may result in different pavement performance.

Based on work conducted during this study and reported herein, the following conclusions were drawn (the conclusions are presented in no particular order):

- Over the past 30 years, 24 States throughout the United States have experimented with the crack and seat and overlay of jointed portland cement concrete pavements. States that have documented their experiments with cracking and seating have reported experiences that range from poor to excellent.
- The crack and seat sections in California exhibited significantly less reflection cracking than the control sections. In addition, the use of a fabric interlayer further reduced the quantity of reflection cracking.
- The crack and seat sections with adjacent control sections studied in this project exhibited significantly less roughness than their corresponding control sections. The initial roughness of the sections, however, was unknown.
- Based on the analysis of the falling weight deflectometer (FWD), there was no significant loss of structural support (decrease of the modulus of elasticity) on the crack and seat sections.
- The crack and seat sections exhibited significant increases in cracking with age.
- The crack and seat sections with adjacent control sections exhibited more medium and high severity cracking than the corresponding control sections, but less total cracking than the control sections.

PART II. CRACKING, SEATING, AND OVERLAY OF PORTLAND CEMENT CONCRETE PAVEMENTS

A. DESIGN AND CONSTRUCTION GUIDELINES

INTRODUCTION

These guidelines provide information for engineers, technicians, and contractors involved with the design and construction of asphalt concrete (AC) overlays on portland cement concrete pavements. In particular, the guidelines discuss the cracking and seating and asphaltic concrete overlay of an existing jointed PCC pavement.

NEED FOR CRACKING AND SEATING

An accepted rehabilitation strategy for jointed portland cement concrete pavements is to overlay the pavement with an asphalt concrete material. The overlay should provide a new, smooth riding surface with good skid resistant characteristics. Thicker overlays will also increase the structural capacity of the pavement. Highway engineers often select an AC overlay because the work can be completed in a reasonable amount of time and initial capital costs are usually less than portland cement concrete overlays and concrete pavement restoration (CPR).

There is a perplexing problem, however, with AC overlays on PCC pavements--the phenomenon of reflection cracking. Reflection cracking is the propagation of cracks and joints in the existing PCC pavement through the new overlay. Movement of the existing pavement causes reflective cracks in the overlay. Movement can be caused by temperature change, moisture content change, traffic loadings, and a combination of these conditions. The movements are usually classified as horizontal or vertical: traffic loading and poor load transfer efficiency cause vertical movements; temperature changes create horizontal movements. Movement of the PCC slab causes stress to concentrate above the existing joint or crack, and when the stress exceeds the limiting strength of the material, a crack will propagate.

The major concern with reflection cracking is the possibility that it will lead to rapid deterioration of the overlay. Reflection cracking allows moisture into the pavement system and causes a loss of support from the subgrade and base layers. The crack can also deteriorate and spall, creating a maintenance problem. Excessive spalling can lead to potholes or peeling of the AC surface.

The reflection cracking problem has been the focus of a significant amount of research. Many highway engineers are looking for a solution because of the large number of miles of pavement overlaid each year. Typically, these overlays will fail because of reflection cracking or other types of deterioration caused by cracking. Each load passing over the pavement or each change in temperature creates additional damage.

Currently, there are two basic approaches to the solution of the reflection cracking problem. The first approach is to let the crack occur, but control it. This approach assumes that reflection cracking is inevitable; however, with proper construction techniques, the severity of cracking is minimal and good performance can be achieved. Sawing and sealing joints in asphalt concrete overlays on PCC pavements is the only treatment that effectively reduces the severity of reflection cracking. Other approaches, such as very thick overlays, will defer the cracking; however, a trade-off exists with increased overlay costs versus delay of cracking.

The sawing and sealing of joints in asphalt overlays eliminates or reduces the severity of spalling at the reflective crack. Without the sawing and sealing, the reflective crack usually spalls and deteriorates to the point where a rough ride results from rapid breakdown of the pavement.

The second approach is to mitigate the propagation of cracks in the AC overlay. Some of the treatments include:

- Fabrics.
- Stress-relieving interlayers.
- Crack-arresting interlayers.

- Preoverlay repair.
- Crack and seat.

In one way or another, all of these treatments are designed to stop or reduce the rate of crack propagation. For example, fabrics act as a reinforcement layer in the AC overlay. The fabric physically restrains the opening of cracks. However, excessive movement will still cause reflection cracking.

Stress-relieving interlayers dissipate the stresses from joint movement within the interlayer. Rubberized asphalt chip seals are an example of a stress-relieving interlayer. Crack-arresting interlayers are comprised of aggregate graded to create large voids designed to stop crack propagation.

The crack and seat procedure involves cracking the PCC slab into small segments, seating the segments into the sublayer, and then overlaying the PCC slab with an asphalt concrete. The purpose is to create small pieces of concrete so slab movement by thermal or other causes is minimal. The segments, however, are still large enough to have some structural integrity due to aggregate interlock. The slab seating is intended to ensure that the segments are in contact with the sublayer in order to eliminate any voids.

Since the PCC slabs will be cracked, the condition of the existing PCC slabs can be less than desirable; some types of distress can be present without affecting the overlay performance. In fact, crack and seat is a technique that can be used when conditions are beyond a level of acceptability for other treatments. Some of the distresses that are addressed by crack and seat are:

- Faulted joints and cracks.
- Rocking slabs due to voids.
- Longitudinal cracking.
- Patch deterioration.
- Lane separation.
- Joint deterioration due to D-cracking.
- Deterioration due to reactive aggregate.

- Uneven slab settlement.
- Corner breaks.
- Spalling.

The limits of distress severity are usually established by engineering judgment. The engineer should take into account the type and severity of cracking, load transfer ability, void size, pumping, etc., before making a decision about any treatment.

California is one of the few States that have established criteria for cracking and seating. Their policy is:

> When a pavement has developed an unacceptable ride and there are extensive structural problems indicated by multiple cracking of over 10% of the slabs in the individual truck lanes, the strategy is to crack and seat in the deteriorated lanes, install edge drains, and overlay with 0.35 ft. of AC including a pavement reinforcement fabric interlayer.[43]

The California Department of Transportation (CALTRANS) uses the following criteria to determine the extent of the cracking and seating:

A. Use in all lanes expected to carry an appreciable amount of truck traffic. On facilities with six or more lanes, this would generally include the outer two lanes. On four-lane facilities, it would often include all lanes, especially in urban areas.

B. Use in lanes expected to carry primarily auto traffic if there is 1/8 in or more average faulting with or without slab breakage. Where there is less than 1/8 in average faulting and no slab breakage, cracking and seating is not recommended.

Other States use crack and seat on an experimental basis or use engineering judgment to determine when and where to use this procedure.

EFFECTIVENESS

The crack and seat and overlay technique has been used for over 30 years by 24 State highway agencies. The results of its effectiveness have ranged from poor to very good depending upon the agency.

The results of a national study, "Performance/Rehabilitation of Rigid Pavements," highlighted these mixed results. In the study, the crack and seat test sections had slightly less roughness than the control sections. With respect to reflection cracking, the control sections initially had more cracking, but after 6 years the crack and seat sections had more reflective cracking. The crack and seat sections had slightly more rutting than the control sections. Consequently, it was concluded that the cracking and seating did not significantly improve the performance of the AC overlay.

WORK PRIOR TO OVERLAY

The nature of cracking and seating implies that the pavement will be broken and, consequently, that the condition of the existing pavement is irrelevant. This is only true in a limited sense. Cracking and seating should not be thought of as a panacea for rigid pavements with severe problems. For example, extensive fatigue damage may be an indication that slabs are poorly supported and the foundation is inadequate. Therefore, the base will not provide sufficient support for the cracked and seated segments.

Distress conditions such as severe joint spalling require full or partial depth repairs prior to the cracking and seating process. Joints and cracks should also be sealed prior to the cracking and seating construction. It should be remembered that the objective of the cracking process is to leave PCC segments that are large enough to provide structural capacity. If the pavement is broken into very small pieces, such as a rubbled condition, then the structural integrity of the slab is lost.

Drainage problems should also be considered and corrected when a crack and seat treatment is used. Adequate drainage is important regardless of the rehabilitation scheme. No extra benefit from crack and seat eliminates the need to provide adequate drainage for the pavement.

DESIGN AND CONSTRUCTION

The design of a crack and seat project requires a complete engineering evaluation of the entire project. A condition survey, nondestructive testing, a pavement design evaluation, and an economic analysis should be conducted to determine if cracking and seating is the most effective rehabilitation scheme. Like any other pavement project, each crack and seat job must be evaluated and designed on an individual basis. No two projects are ever alike. In general, however, a crack and seat project can be appropriate for most jointed PCC pavements. Both plain and reinforced slabs have been successfully cracked, seated, and overlayed. The pavement should be in fair condition, and the sublayer should be capable of supporting the expected traffic loads.

Structural Design

Many State agencies use engineering judgment to determine the required thickness of AC overlay. The AC overlay thickness is a function of the effective structural capacity of the existing PCC slab. The design of the thickness varies considerably across the United States.

California, for example, overlays with a standard AC thickness of 0.35 ft with a fabric interlayer. In Minnesota, the cracked PCC pavement is considered to be an asphalt concrete base that is 70 percent of the original slab thickness. Pennsylvania assigns a structural coefficient of 0.20 to all cracked and seated pavements. Kentucky assumes the cracked and seated pavement is equivalent to a dense graded aggregate.

The only documented crack and seat design procedure is found in the 1986 AASHTO Pavement Design Guide.[20] The AASHTO procedure is based upon a structural deficiency concept. Essentially, the AC overlay thickness is the difference between a "new" pavement structure and the "effective" thickness of the existing slab. The design procedure follows the same method as the flexible overlay over existing rigid pavement analysis. Since it is assumed that the cracking will create a common state of "damage," the F_{RL} factor is held constant at 0.7. The effective thickness of the existing PCC slab is assumed to be 40 percent of the original thickness with a slab fragment size of approximately 30 in. If a postcracking NDT evaluation is done, then the a_{bs} value is a function of the backcalculated modulus value with an a_{bs} range of values equal to 0.14-0.44. The effective thickness of the existing subbase is also added to the cracked PCC slabs.

Using the AASHTO design procedure with the selection of a structural coefficient does not guarantee the elimination of reflection cracking. Other types of AC overlay cracking can occur. For example, if the AC overlay is too thin, then fatigue cracking can occur. Overlay thickness has been in the range of 3 to 7 in.

In the national study, the deflection data indicated a broad range of data. Many of the deflection basins could not be matched to theoretical basins. Based upon volumetric k and maximum deflection, there was no statistically significant difference (95-percent confidence) between the control sections and the crack and seat sections. On the basis of the available data, no reduced layer structural properties could be predicted as a result of the cracking and seating procedure.

Crack Pattern and Segment Size

The size requirement for cracked PCC slabs is subject to question. Crack sizes (longitudinal direction) have varied from 18 in to 6 ft. For design purposes, the question of slab size necessitates a compromise. The smaller the slab size, the less chance of movement due to temperature change. The larger the slab size, the more structural support from the existing slab. These two requirements are in competition during design. The trend has been to develop a smaller cracking pattern, which should reduce the reflection cracking. In the national study, no real conclusion could be drawn regarding the influence of piece size.

The length to width ratio of the segments should be kept at 1:1 with a segment area of 4 to 6 ft^2.

It is important that the cracking of the slab extends through the entire depth of slab. More important, however, is rupturing the steel reinforcement (if used) or breaking the bond between the steel and concrete. If the steel and concrete bond remains intact, then the cracked slabs will still act as if they were not broken. Slab movements due to temperature changes will be much larger than if the segments are short.

A large variety of cracking equipment is available to contractors for the cracking process. In fact, the equipment is constantly being modified. The most common type of equipment is a pile driver with a modified shoe. Another similar piece of equipment is the guillotine hammer. The impact force can be controlled by changing the drop height. Another type of device is the whip hammer, which consists of a hammer attached to a leaf-spring arm. The fourth type of device is the resonant breaker. There have been problems, however, with this device since controlling the crack pattern is difficult.

Keep in mind that the purpose of the cracking process is to crack the pavement--not destroy it. If the cracking device shatters the concrete into very small pieces, then the process is "rubbling," not cracking and seating. Care must be exercised so the device does not severely spall existing cracks or joints. It is good practice to keep the cracking device at least 10 in from an existing crack or joint.

Seating of the PCC Segments

After the PCC slabs have been cracked, the pieces must be firmly seated into the sublayer. The purpose of the seating operation is to ensure that all PCC segments are in contact with the support layer, which eliminates the rocking or movement of the slab. If the slabs are not properly seated, then excessive movement will take place and reflection cracking can occur.

Slabs have been seated using very heavy rollers in the load range of 35 to 50 tons. Steel wheel, pneumatic tire, sheepsfoot, and vibratory rollers have all been used. The most effective rollers found in the national study were the vibratory sheepsfoot drum rollers. The steel drum rollers (without vibrations) tend to bridge the slab segments; consequently, the roller does not seat the segment. Pneumatic tire rollers are also considered effective by many agencies.

In the past, a variety of rolling speeds, passes, and weights has been used. Experience has shown that the cracked pavement can be "over-rolled," which tends to weaken the subgrade. The strength of many fine-grained subgrade soils is stress dependent, and the over-rolling process reduces the modulus of the soil. It has been shown that deflections continue to increase with continued rolling.

California suggests that not less than five passes of a 15-ton oscillating pneumatic-tired roller or a vibrating sheepsfoot roller that exerts a dynamic centrifugal force of 20,000 lb be used. The consensus implies that 2 to 3 passes of a 50-ton pneumatic tire or 4 to 5 passes of a 35-ton pneumatic tire are adequate to seat the slabs. Additional rolling will not be beneficial to pavement performance.

MAINTENANCE OF TRAFFIC

There is a wide range of opinions concerning the maintenance of traffic and time to overlay. Some States, such as Kentucky and Tennessee, require that the overlay be placed within 24 hours of the crack and seat process. Other States, such as California and New York, allow up to 14 or 15 days of traffic before the overlay is placed.

Obviously, if the subgrade is weak, it is possible that traffic will disturb the seated pieces. Also, the longer a section remains uncovered, the greater the possibility of water infiltration due to rainfall.

Once again, the decision to open the section to traffic must be made on an individual basis as determined by the individual agency or the project engineer.

UTILITIES AND CULVERTS

Cracking and seating should not be done over any subsurface utilities or culverts; the process can damage utility structures. The cracking process should be performed more than 5 ft from the utility/culvert locations.

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B. GUIDE SPECIFICATIONS

GENERAL

The following guide specifications are recommended for use only after revision to reflect local agency policy and standards.

DESCRIPTION OF WORK

The work shall consist of cracking, seating, and overlaying portland cement concrete pavements.

STANDARD SPECIFICATIONS

The standard specifications applicable to the work on this project are as published in the current edition of (Local, State, Federal, Military) "Standard Specifications."

SUBMITTALS

Asphalt cement, aggregates, fabrics, and other materials associated with the construction shall be inspected and approved by the agency or engineer prior to their incorporation into the work. All asphaltic concrete mix designs shall be submitted for approval prior to the start of work. The contractor shall provide advance notice to the agency to permit testing and approval of materials before placing orders. All samples and the collection of samples will be forwarded without charge to the agency.

Unless otherwise designated, all tests will be done in accordance with the most recently cited standard methods of ASTM or AASHTO--those current on the date of advertisement for bids--or with other testing methods approved by the agency and/or engineer. All materials are subject to inspection, testing, or rejection at any time. Any work done with unacceptable materials used without approval will not be paid for. The unacceptable materials will be removed and replaced with acceptable materials at the contractor's expense.

Equipment

A list of equipment to be used shall be submitted to the agency and/or engineer for approval prior to use on the project.

Manufacturer's Recommendations

Copies of the manufacturer's installation procedures that are applicable to the material and equipment shall be submitted to the agency and/or engineer at the time the materials are submitted for approval.

CONSTRUCTION REQUIREMENTS

Breaking the PCC Pavement

Prior to the cracking of the pavement, any existing asphalt patching or overlay shall be removed to the satisfaction of the engineer.

Breaking of the PCC pavement shall be accomplished with equipment that has positive controls for the magnitude and location of the breaking force. Unguided free-falling weights such as "wrecking balls" shall not be permitted to crack the pavement. The equipment for cracking the concrete shall be approved by the engineer and shall be capable of producing the desired cracking without excessive displacement (no more than 1/2 in) or spalling of the concrete.

Before the cracking operation takes place, the engineer shall designate a test section area where the contractor can test the cracking procedure and equipment. The contractor shall crack the pavement with various load magnitudes and spacing until a satisfactory crack pattern is established.

The PCC pavement shall be cracked such that the majority of the pavement shall be in 18- to 24-in pieces with occasionally up to 30-in pieces. Acceptance of the cracked slab size shall be at the discretion of the engineer. The contractor shall apply a minimum amount of water to the pavement surface to help determine the extent of the cracking.

The contractor shall be required to crack the PCC slab for the full depth of the pavement section. If the slab contains reinforcement steel, the bond between the steel and the concrete shall be broken by the cracking process.

The contractor shall not crack the pavement within 5 ft of subsurface utilities or culverts. Also, the contractor shall make provisions to protect passing traffic from any flying debris.

Seating the PCC Pavement Segments

After the pavement has been cracked, the contractor shall seat the cracked pieces into the existing sublayer. The pavement shall be seated with a pneumatic tire roller weighing a minimum of 35 tons or a vibratory sheepsfoot roller. The number of passes of the roller shall be determined by the engineer during the cracking and seating of the test section. A minimum number of roller passes shall be used to minimize softening of the subgrade.

Overlaying the Cracked and Seated Pavement

Traffic can be maintained on the cracked and seated pavement at the discretion of the engineer; however, the pavement shall be cleaned of all loose debris prior to overlay. The overlay shall be placed according to the standard operating procedures of the agency.

MEASUREMENT AND PAYMENT

Method of Measurement

Cracked and seated concrete pavement will be measured by the square yard.

Basis of Payment

The unit bid price shall include the cost of furnishing all labor, materials, and equipment necessary to complete the crack and seat and overlay work.

APPENDIX

Figures 33 through 56 are plots of the maximum deflections measured in the wheel path of the outer lane during the FWD testing.

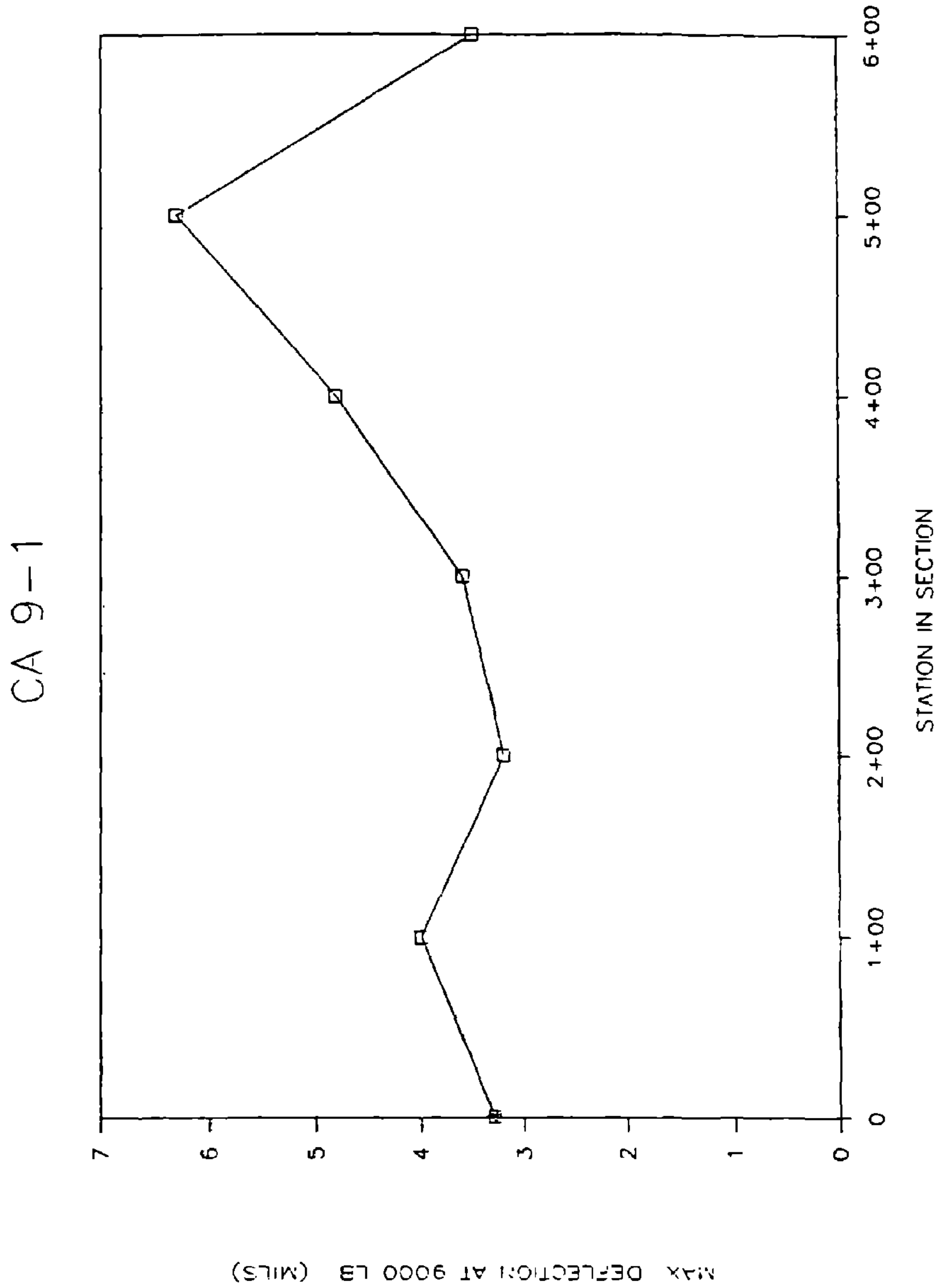

Figure 33. Deflection profile for CA 9-1.

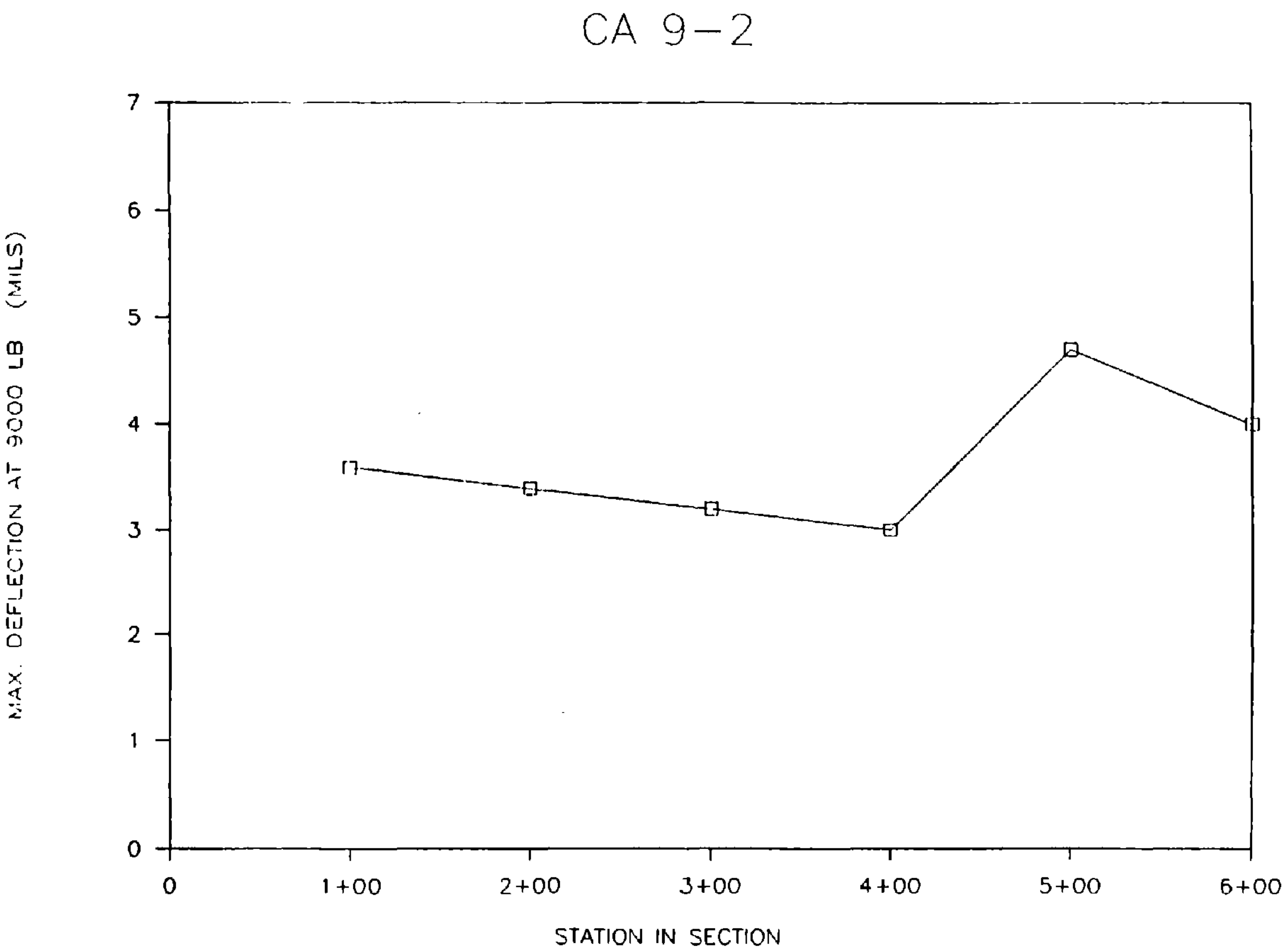

Figure 34. Deflection profile for CA 9-2.

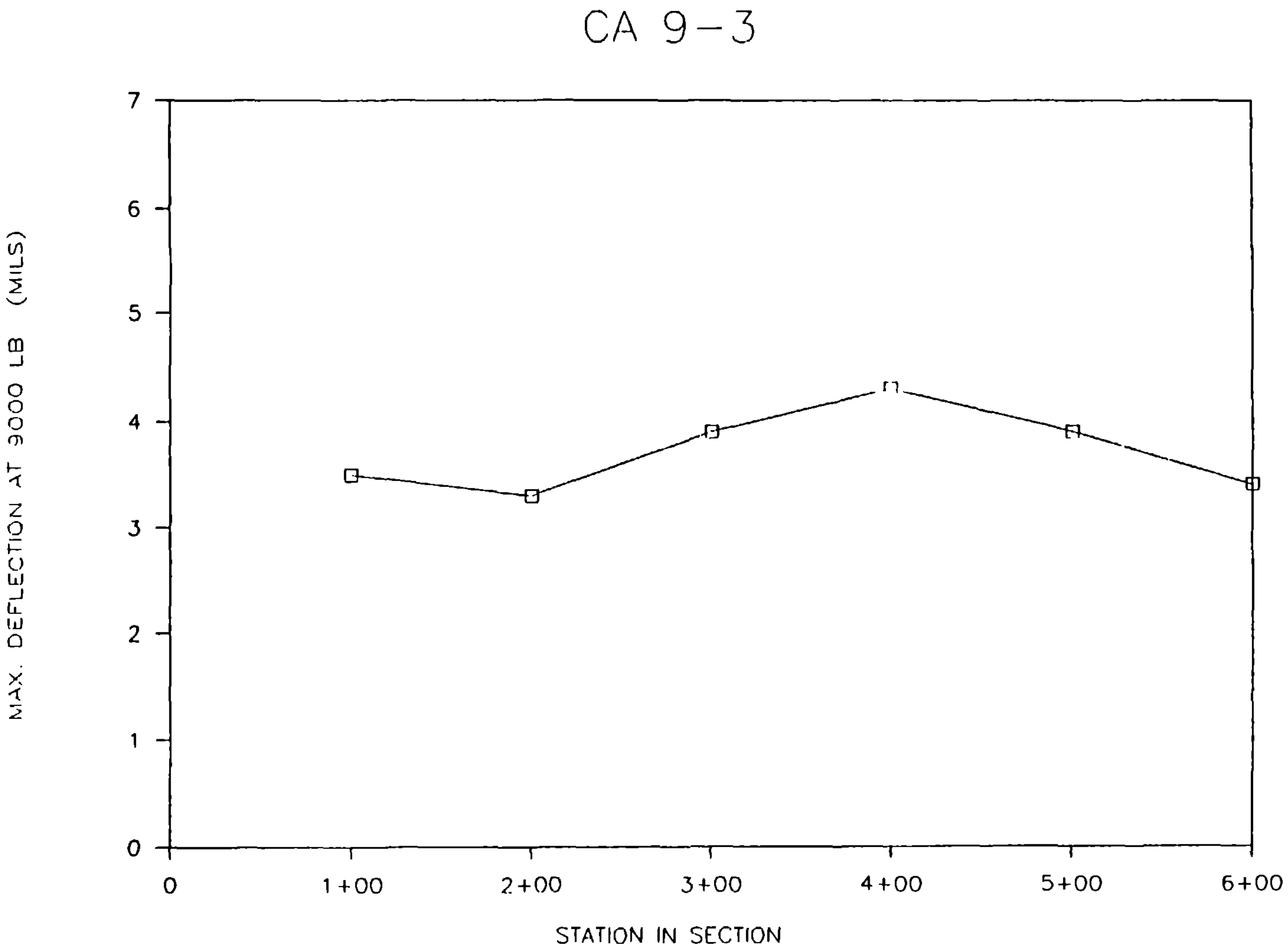

Figure 35. Deflection profile for CA 9-3.

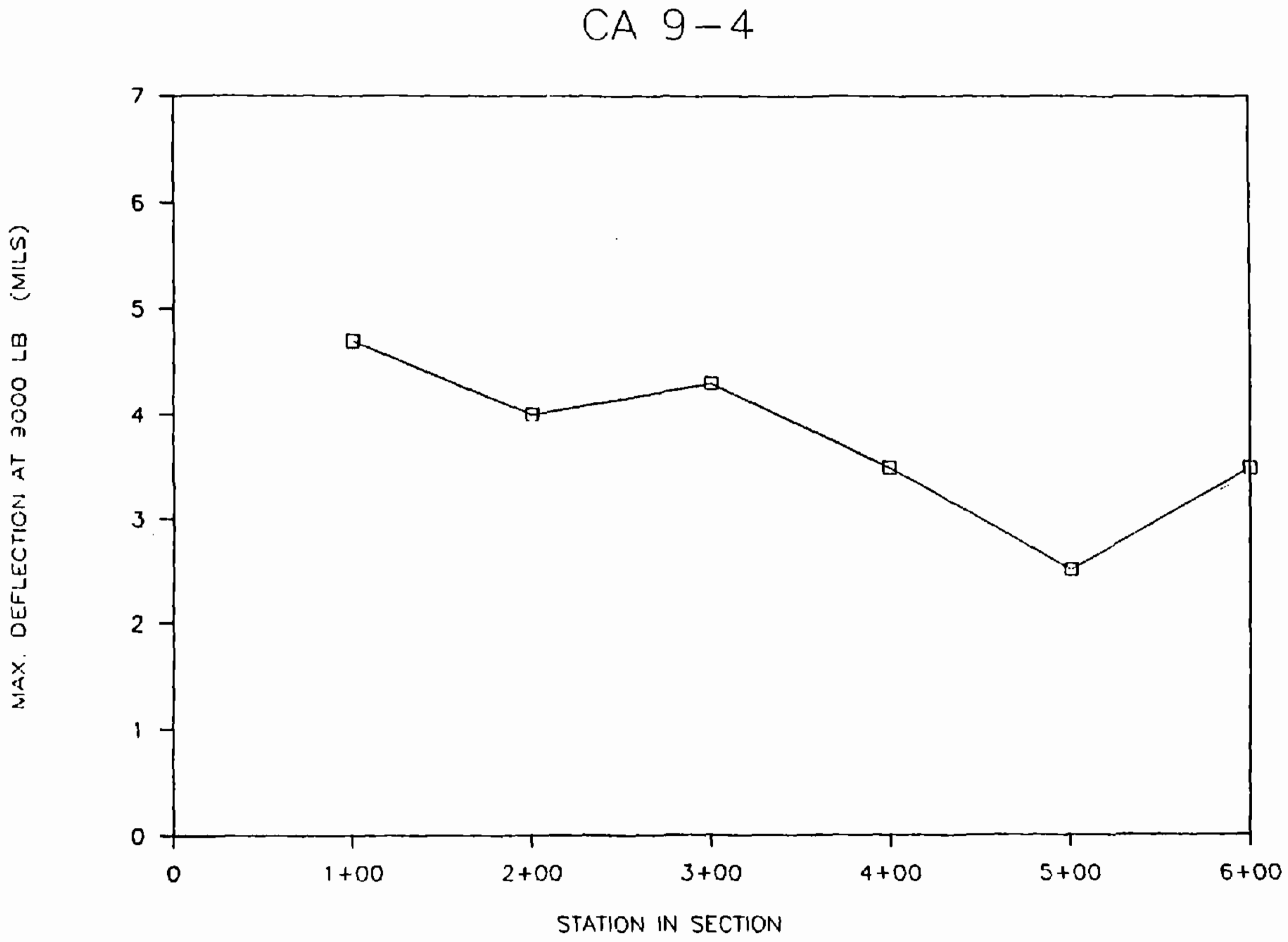

Figure 36. Deflection profile for CA 9-4.

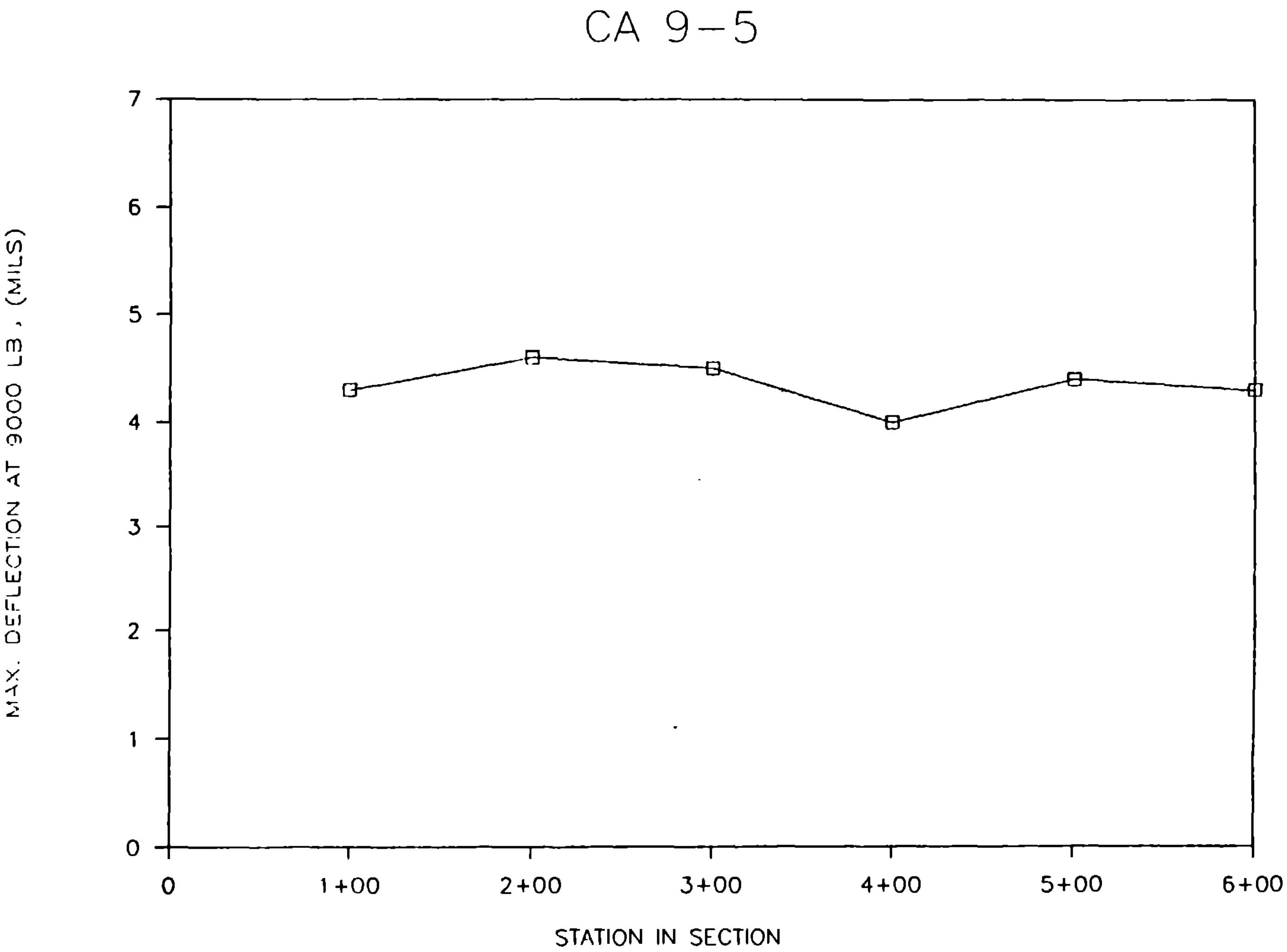

Figure 37. Deflection profile for CA 9-5.

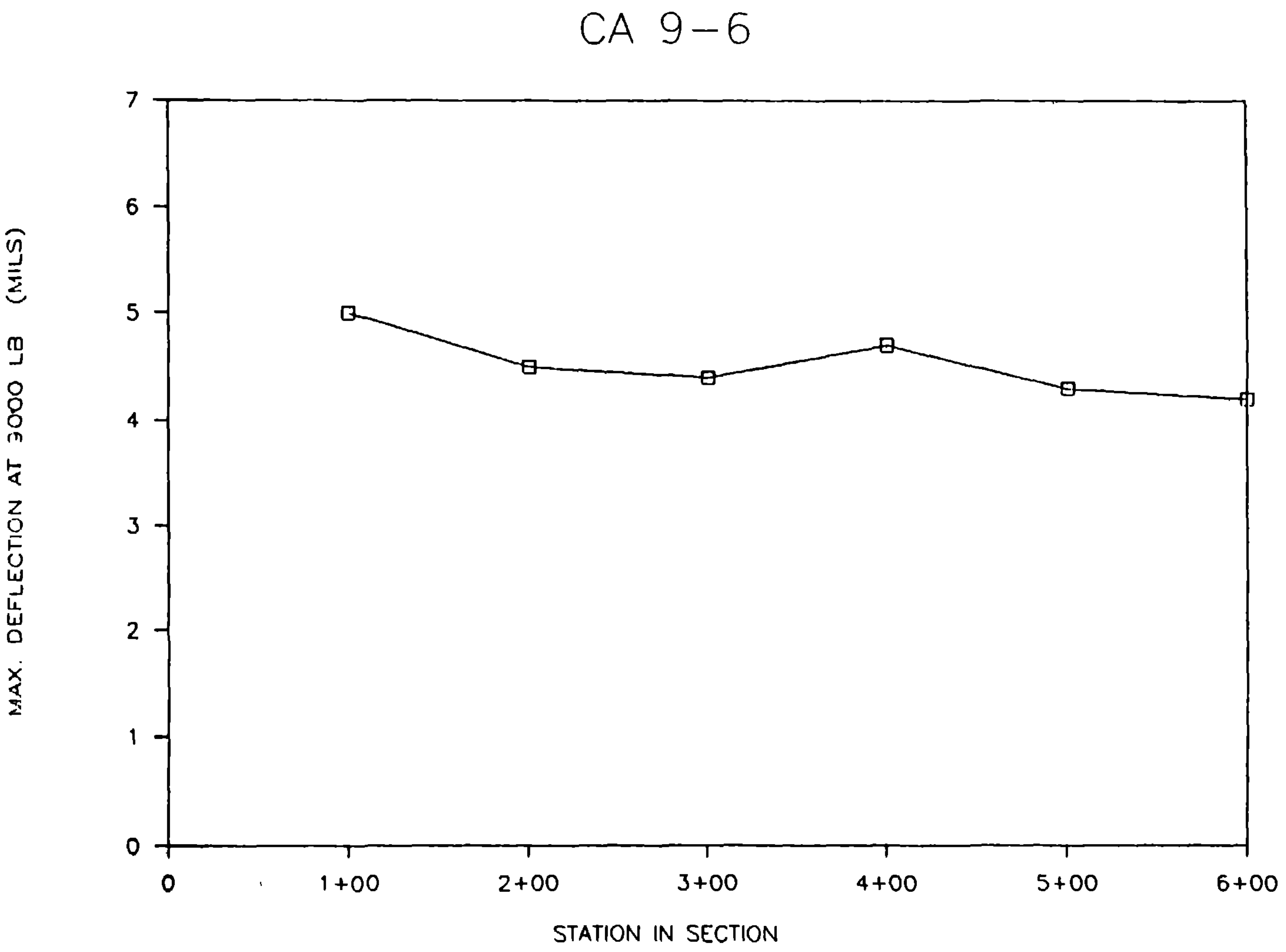

Figure 38. Deflection profile for CA 9-6.

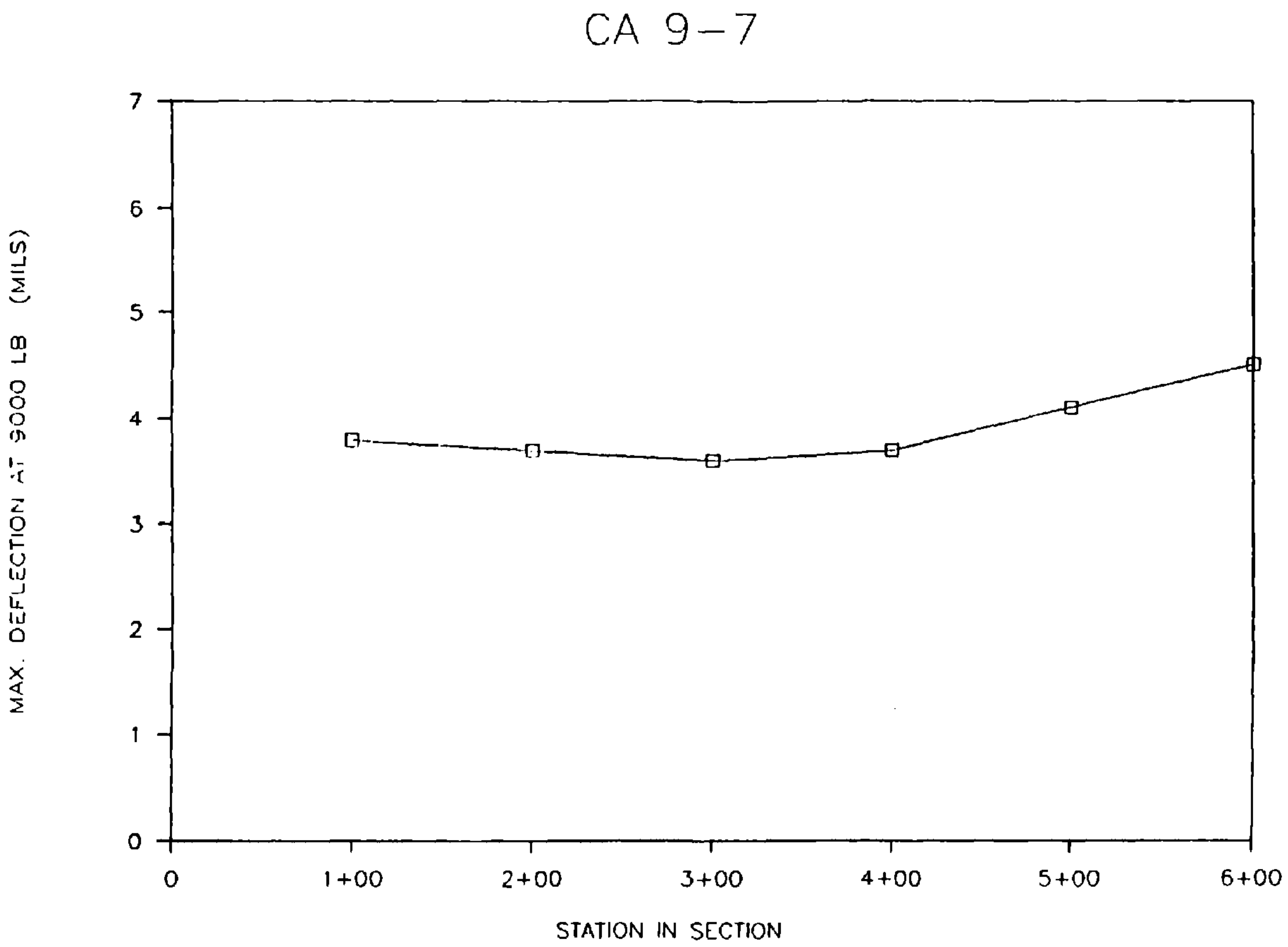

Figure 39. Deflection profile for CA 9-7.

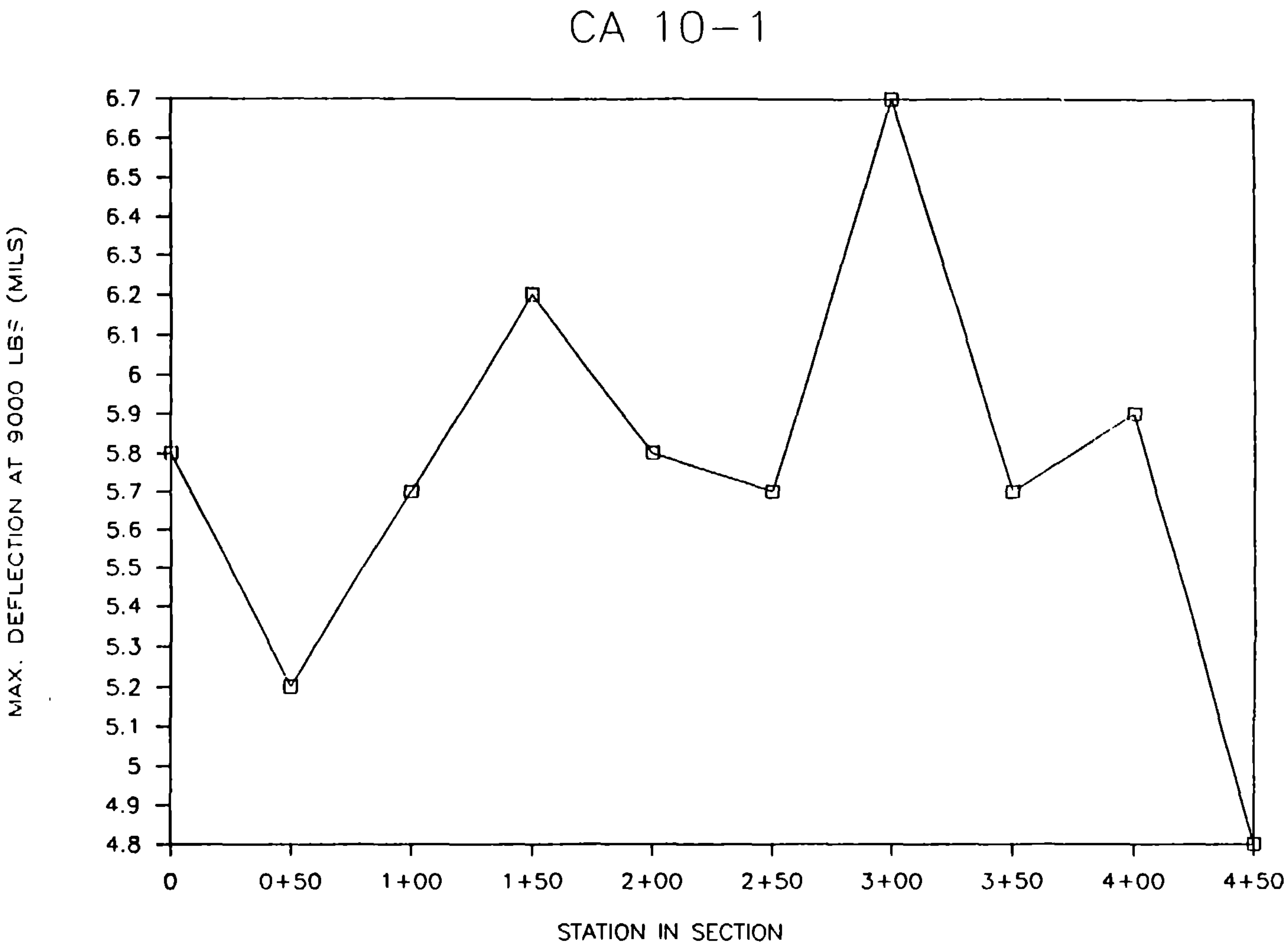

Figure 40. Deflection profile for CA 10-1.

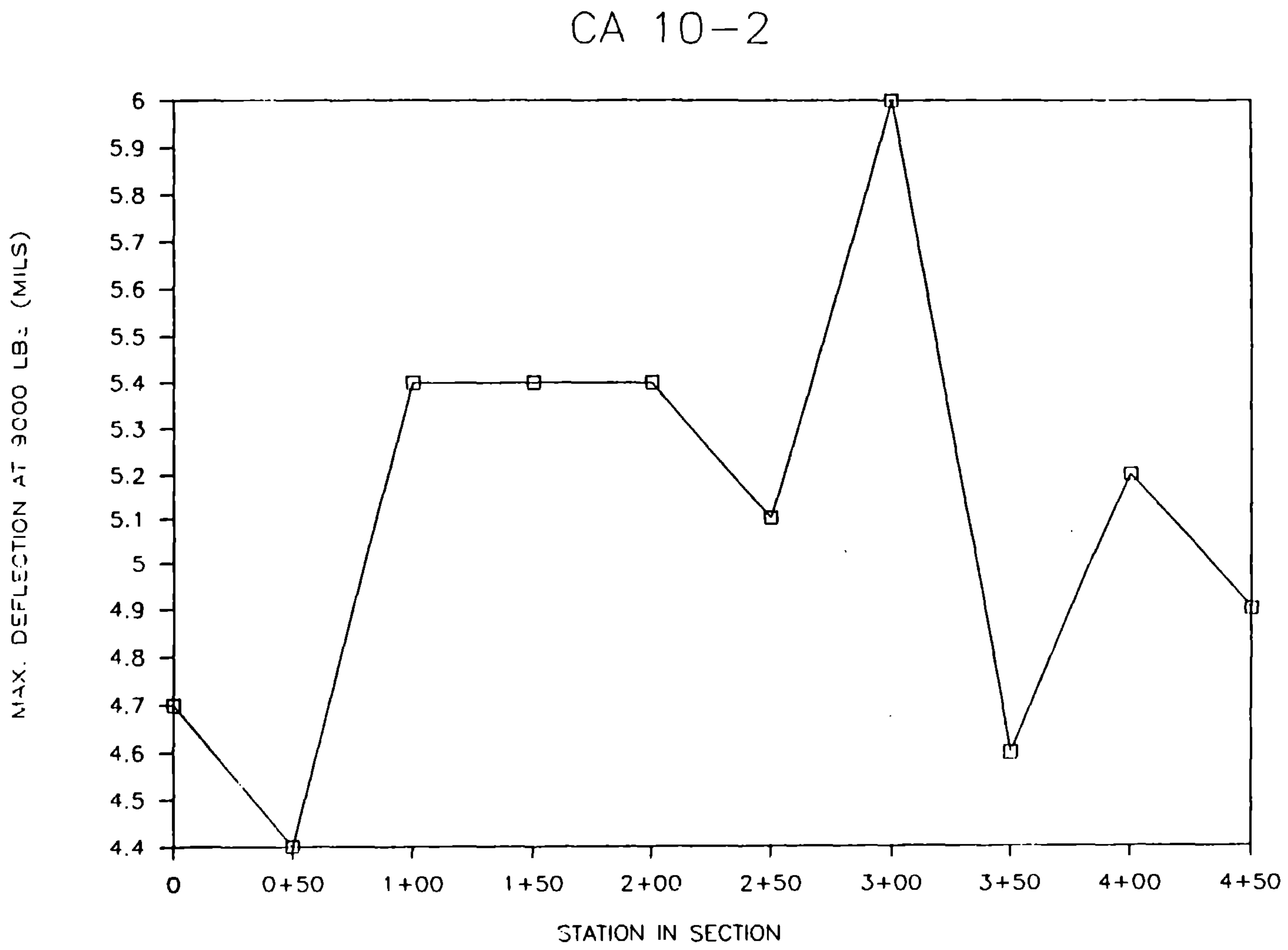

Figure 41. Deflection profile for CA 10-2.

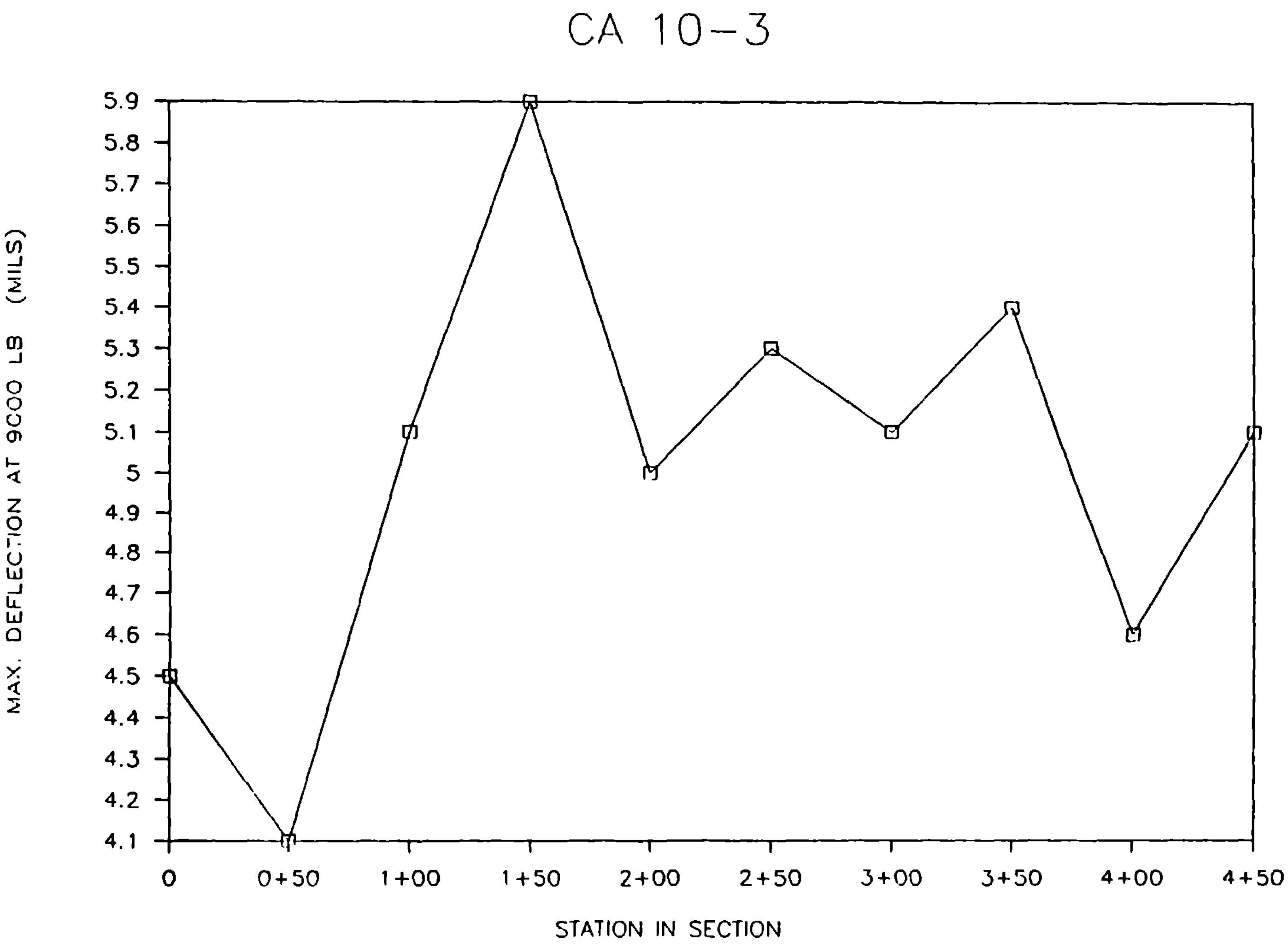

Figure 42. Deflection profile for CA 10-3.

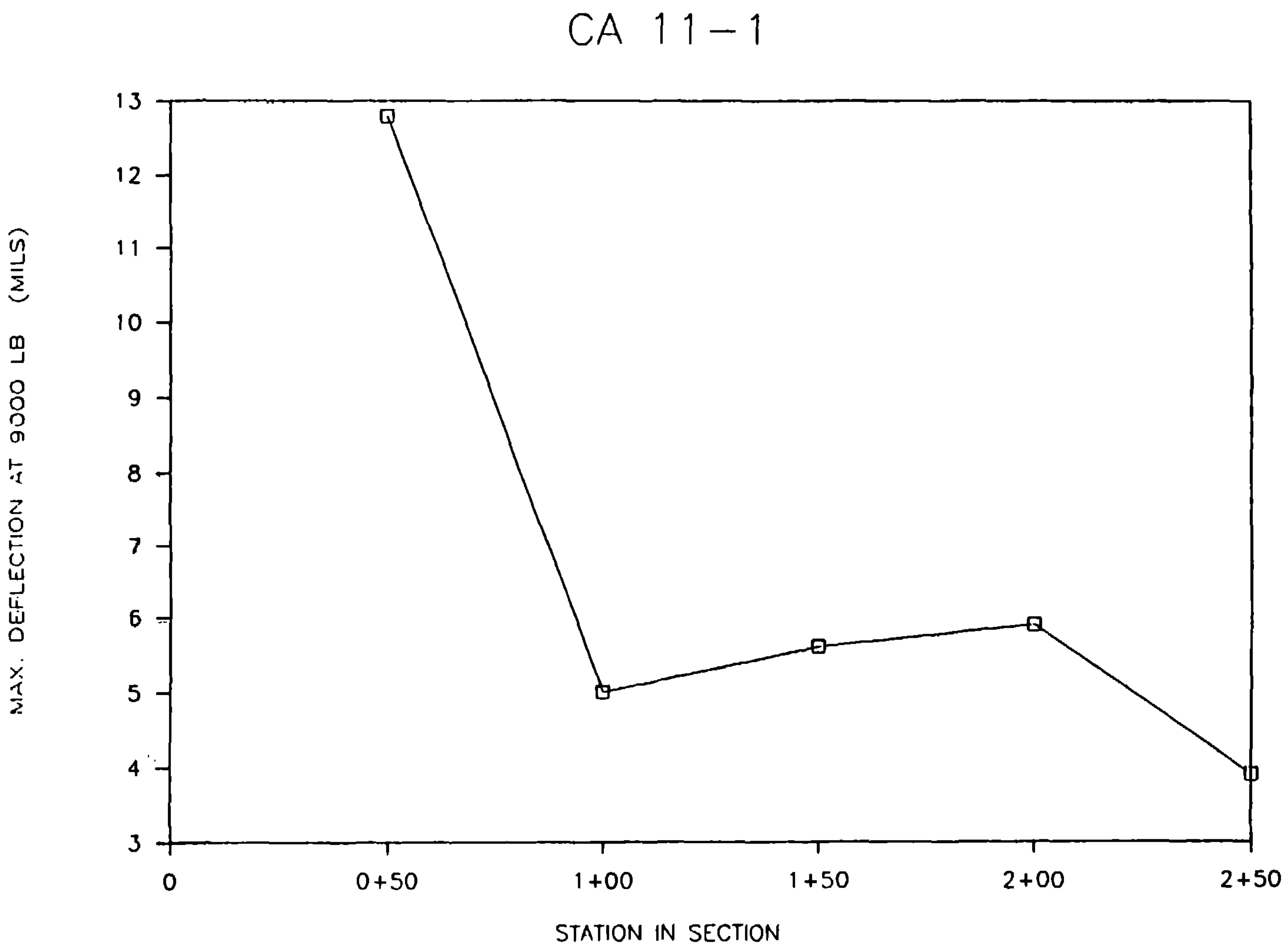

Figure 43. Deflection profile for CA 11-1.

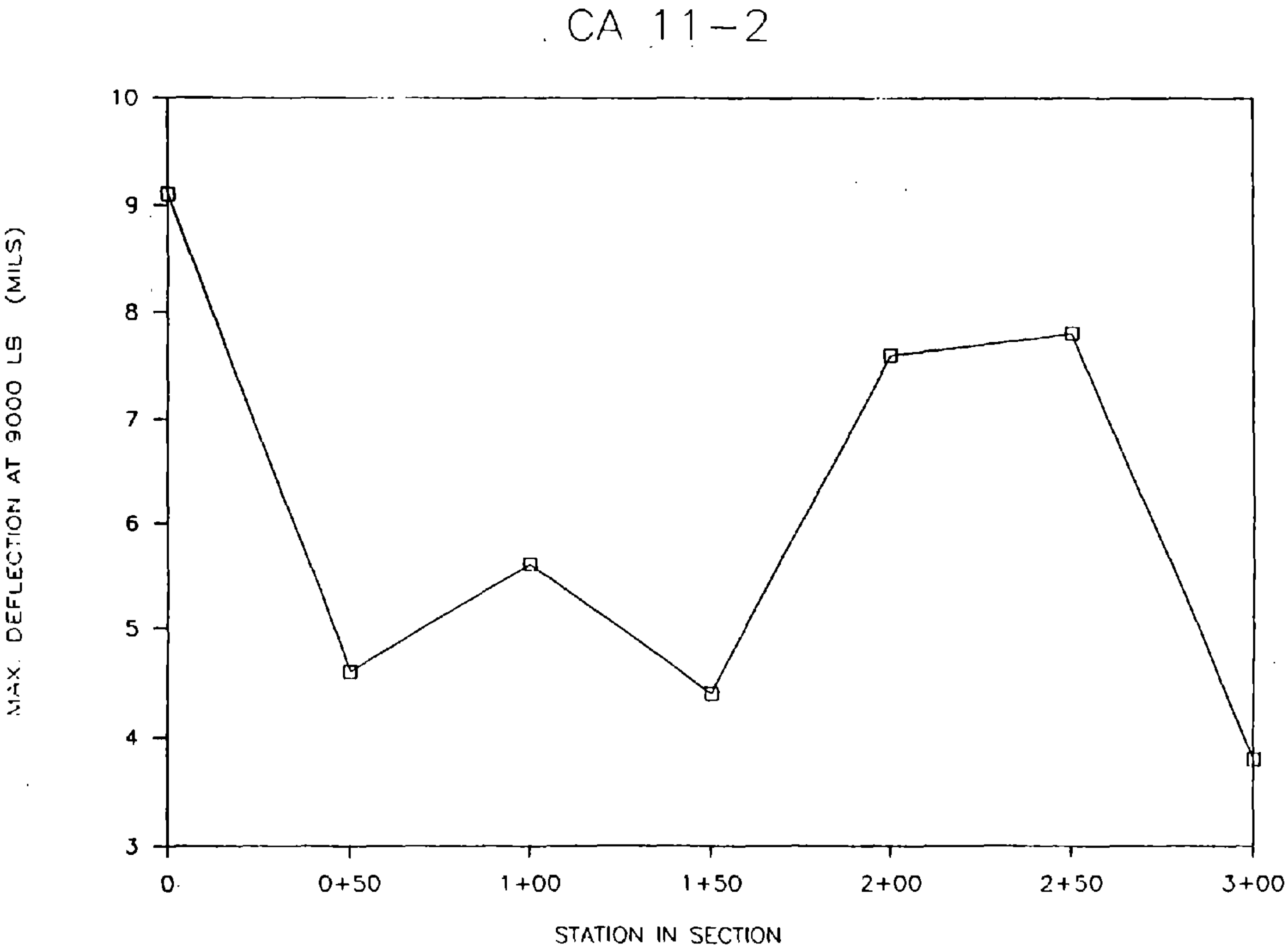

Figure 44. Deflection profile for CA 11-2.

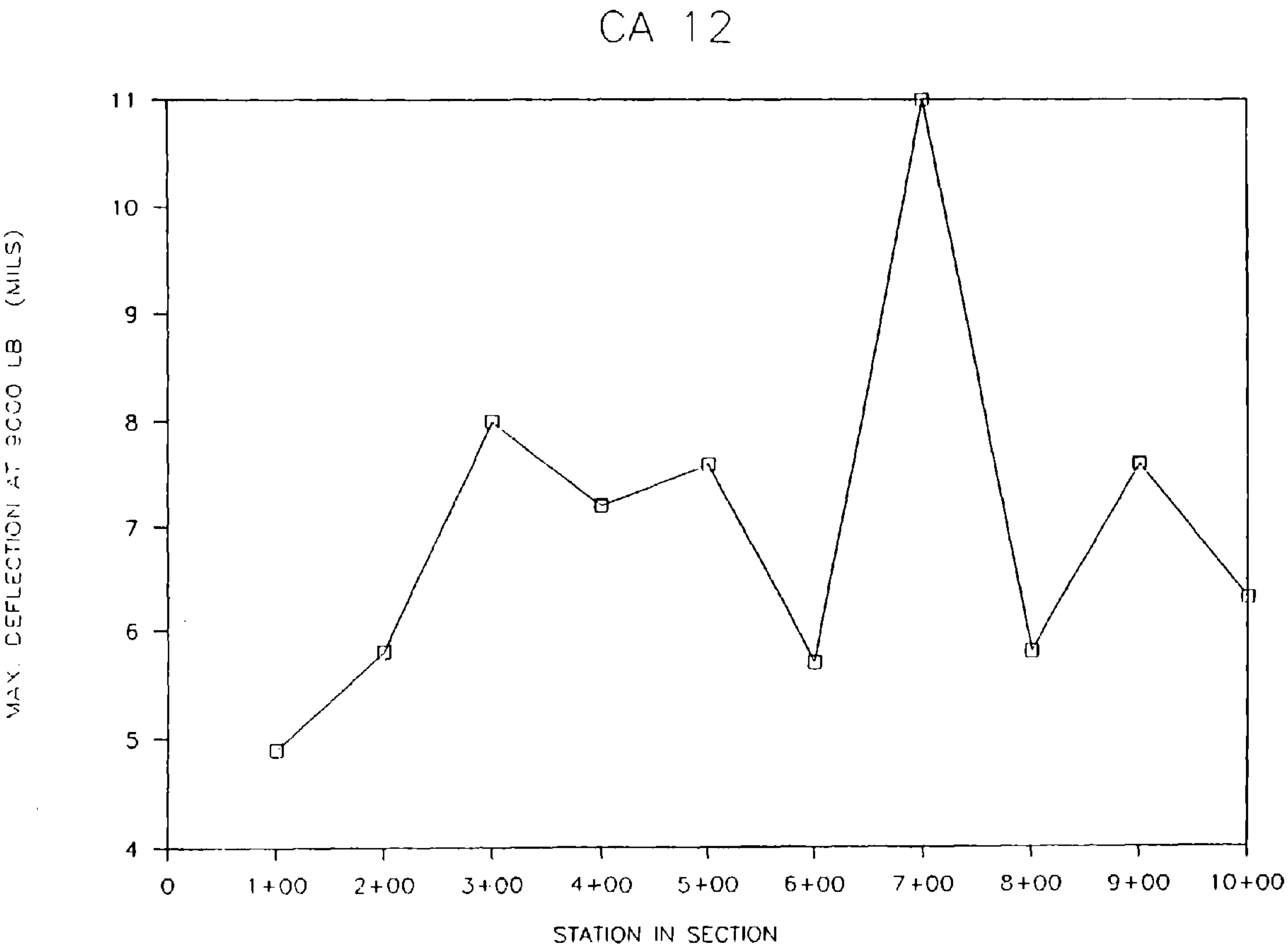

Figure 45. Deflection profile for CA 12.

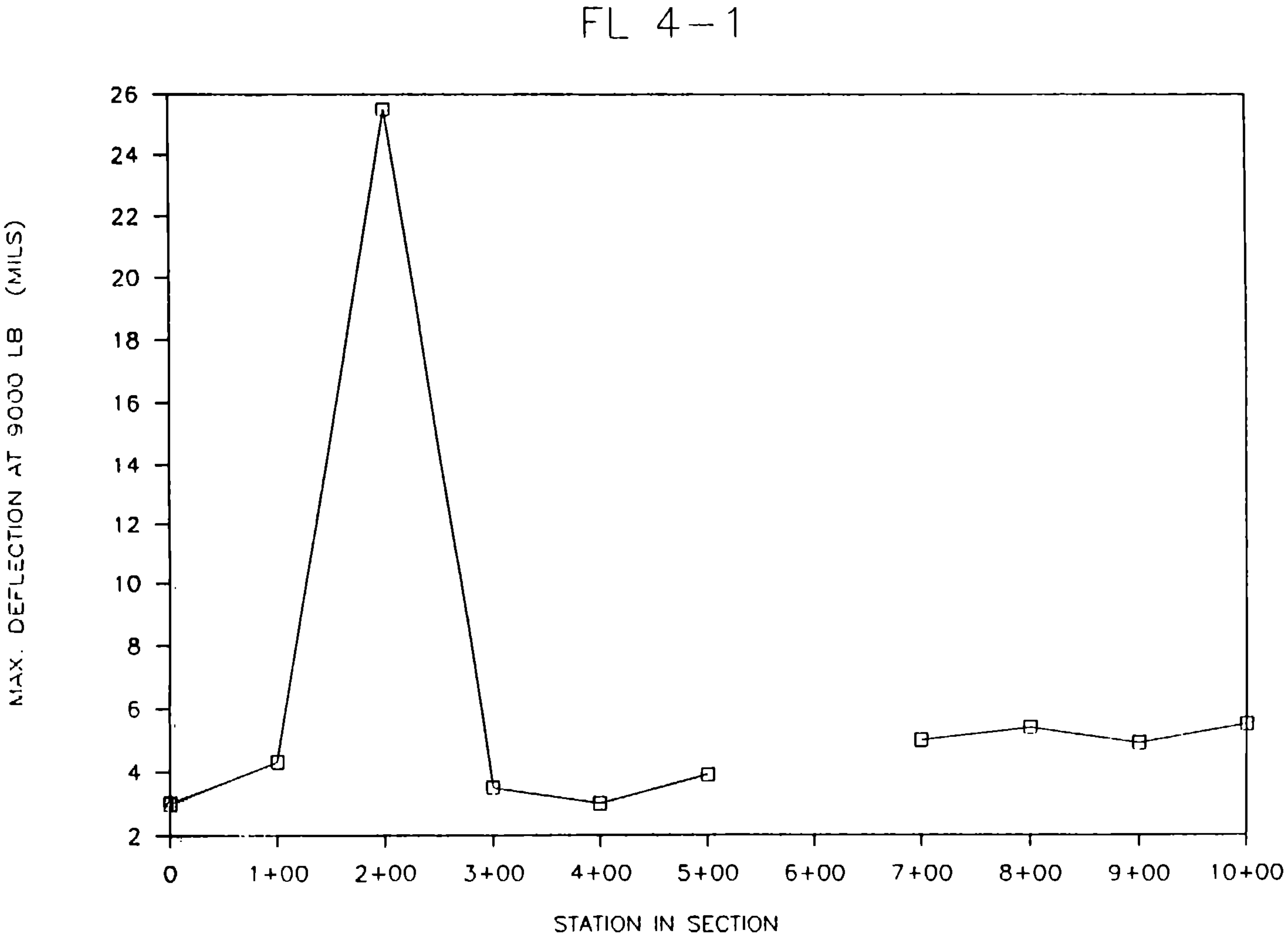

Figure 46. Deflection profile for FL 4-1.

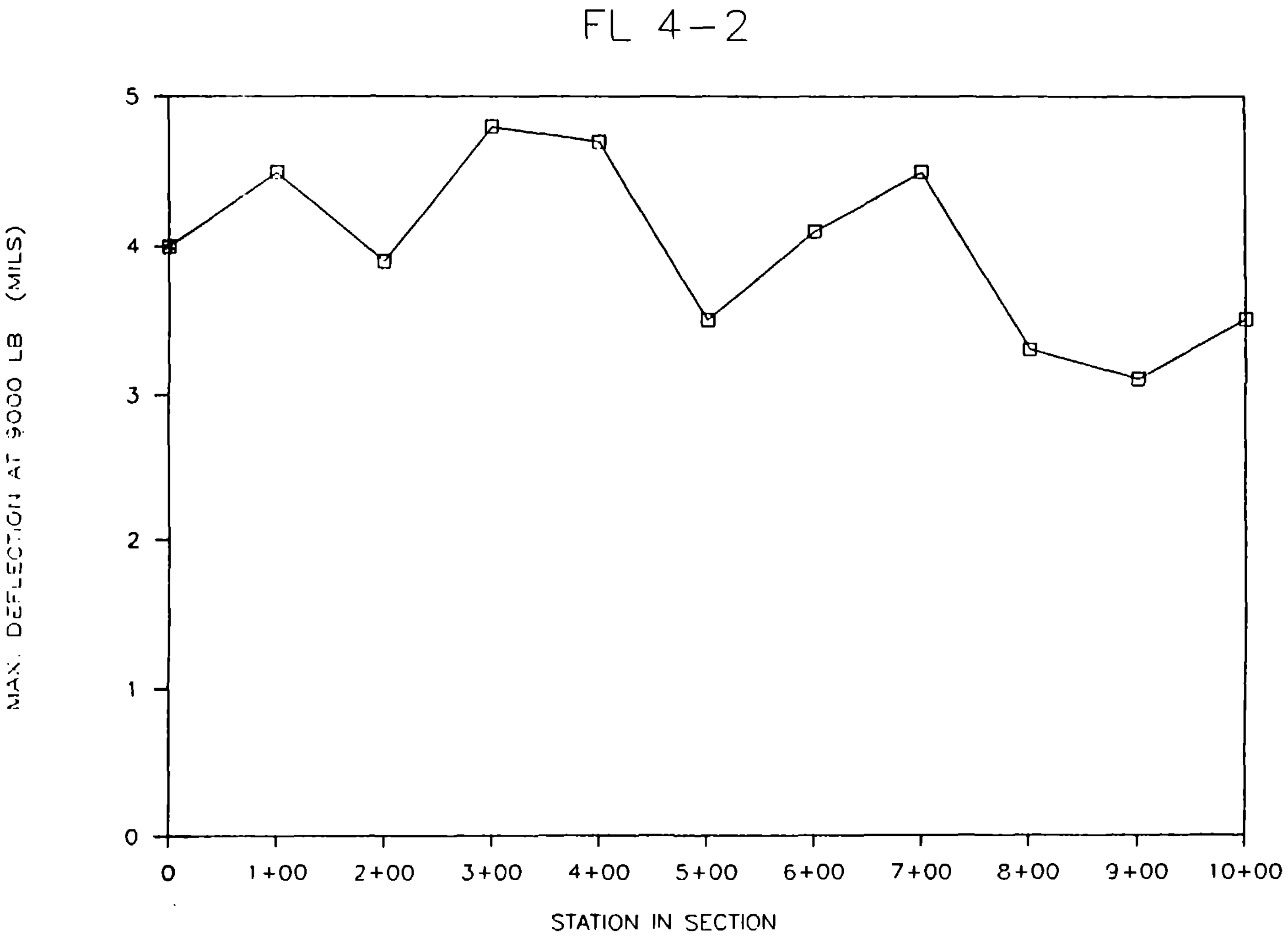

Figure 47. Deflection profile for FL 4-2.

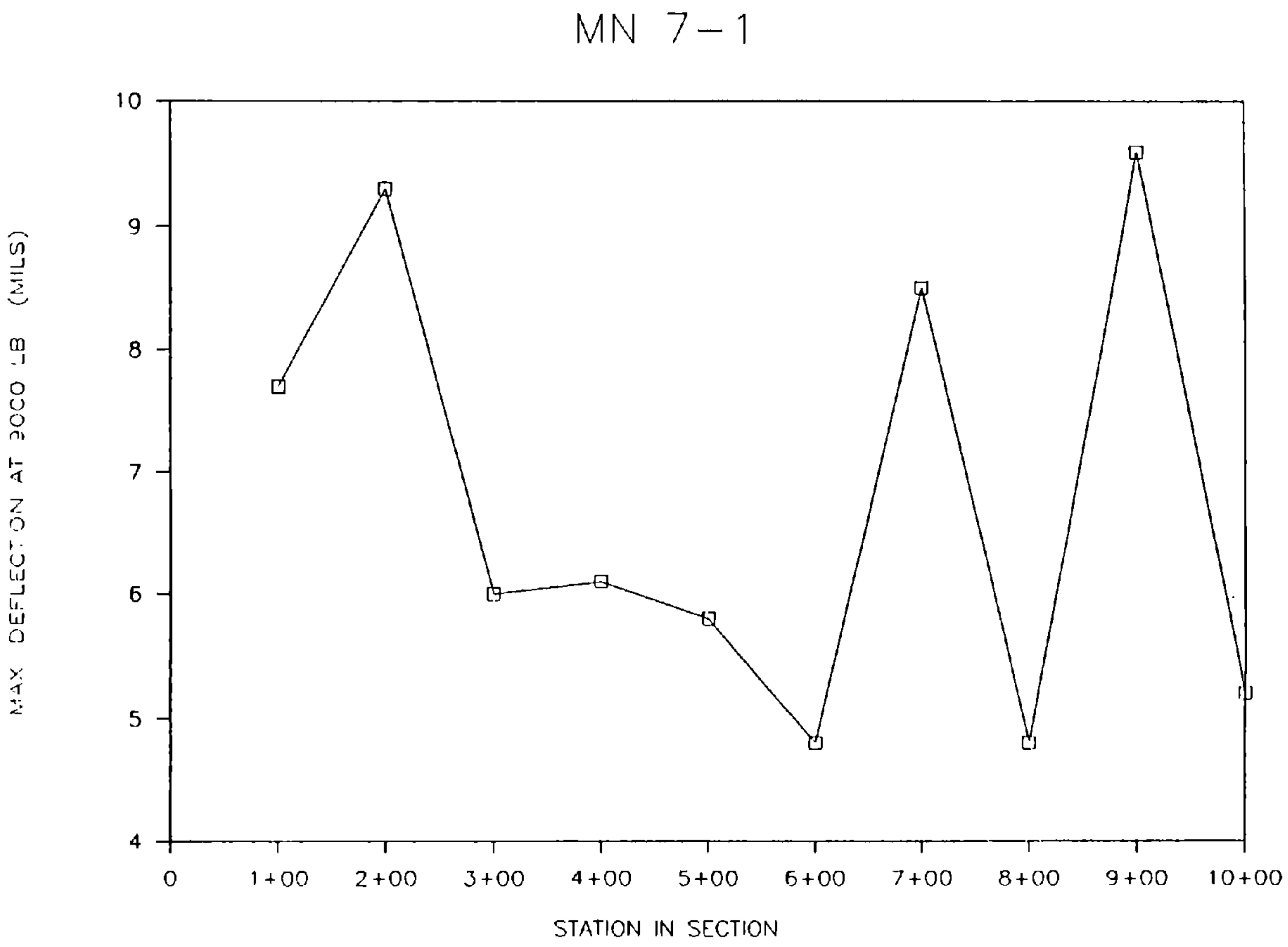

Figure 48. Deflection profile for MN 7-1.

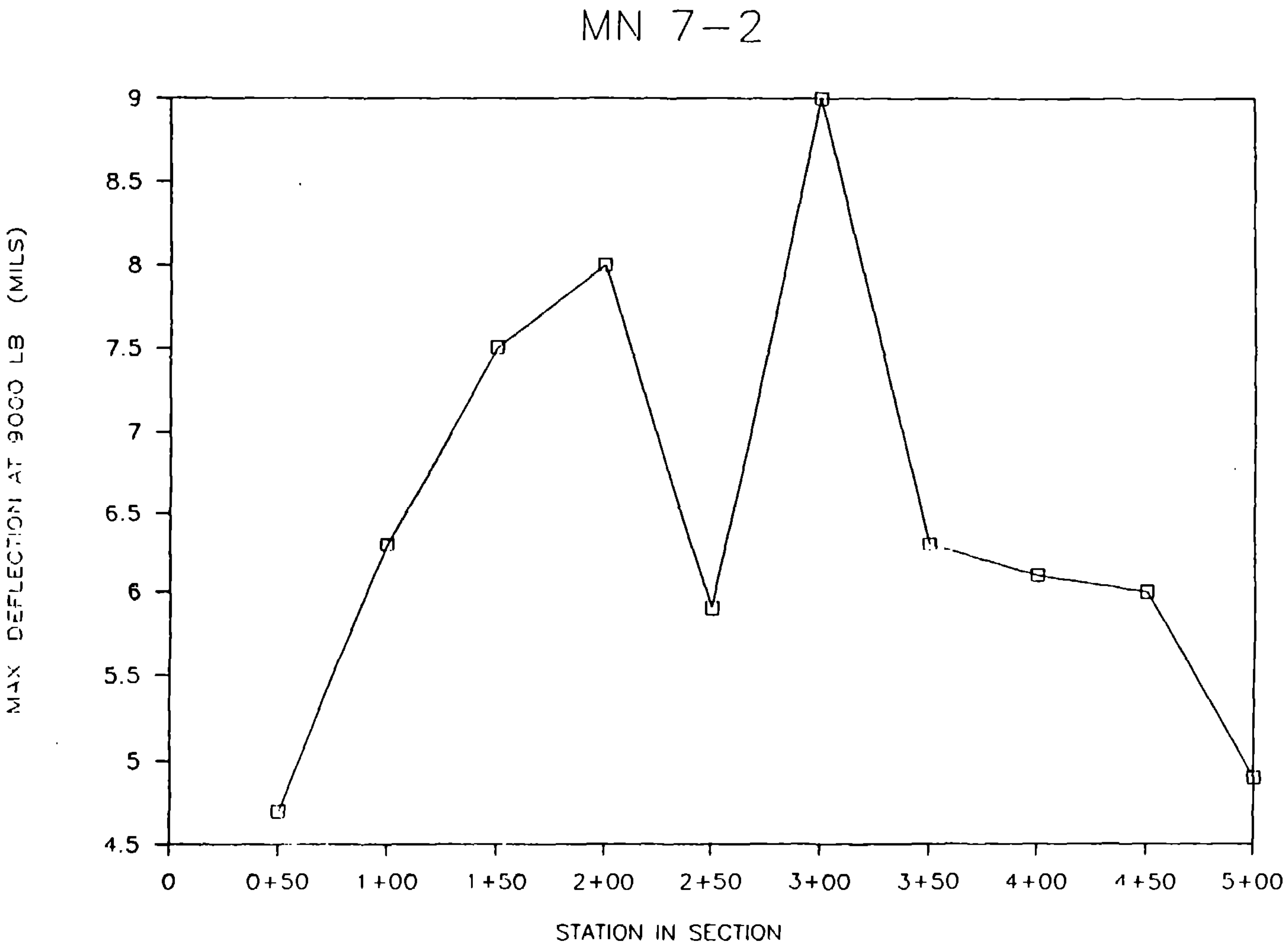

Figure 49. Deflection profile for MN 7-2.

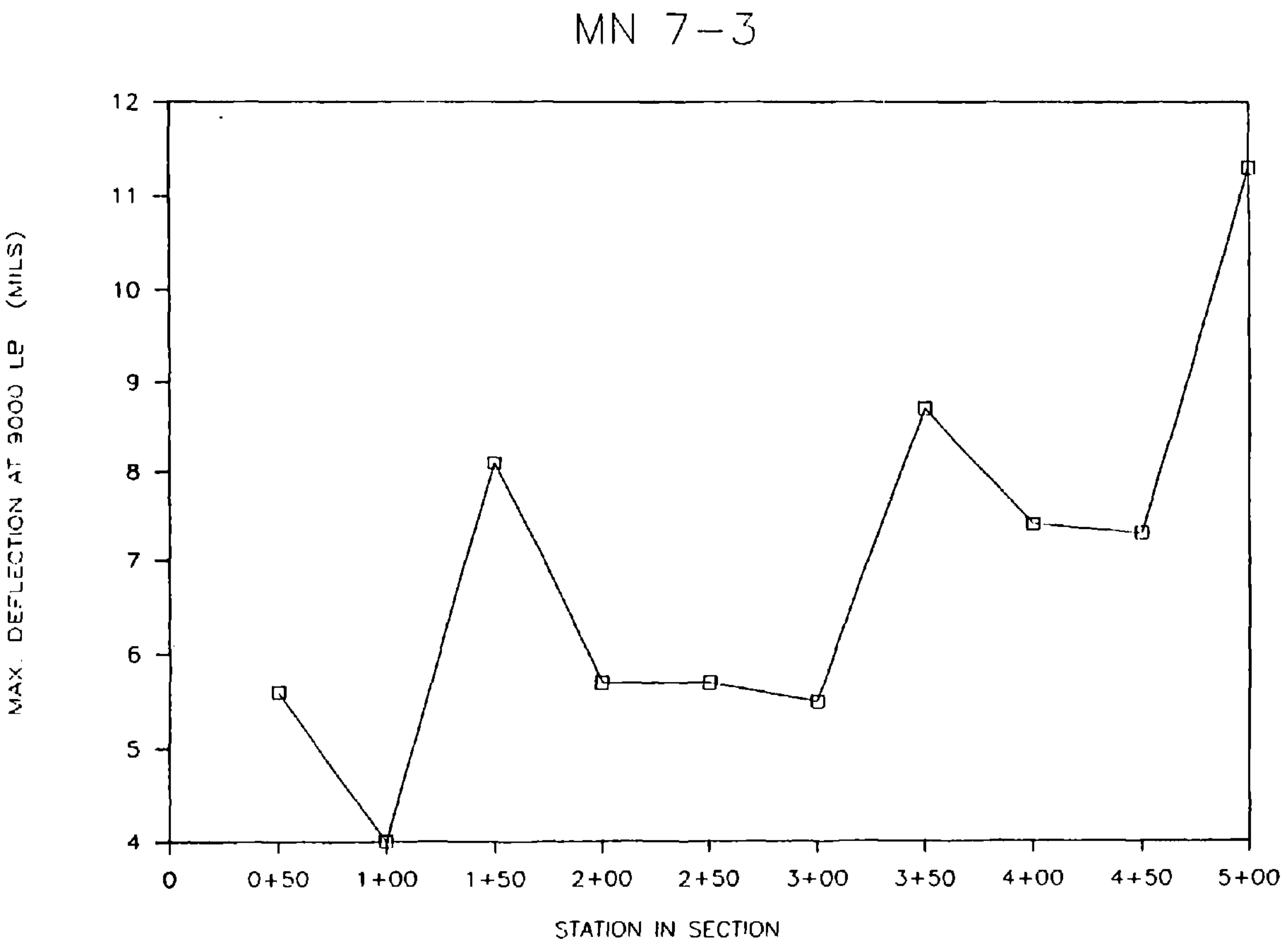

Figure 50. Deflection profile for MN 7-3.

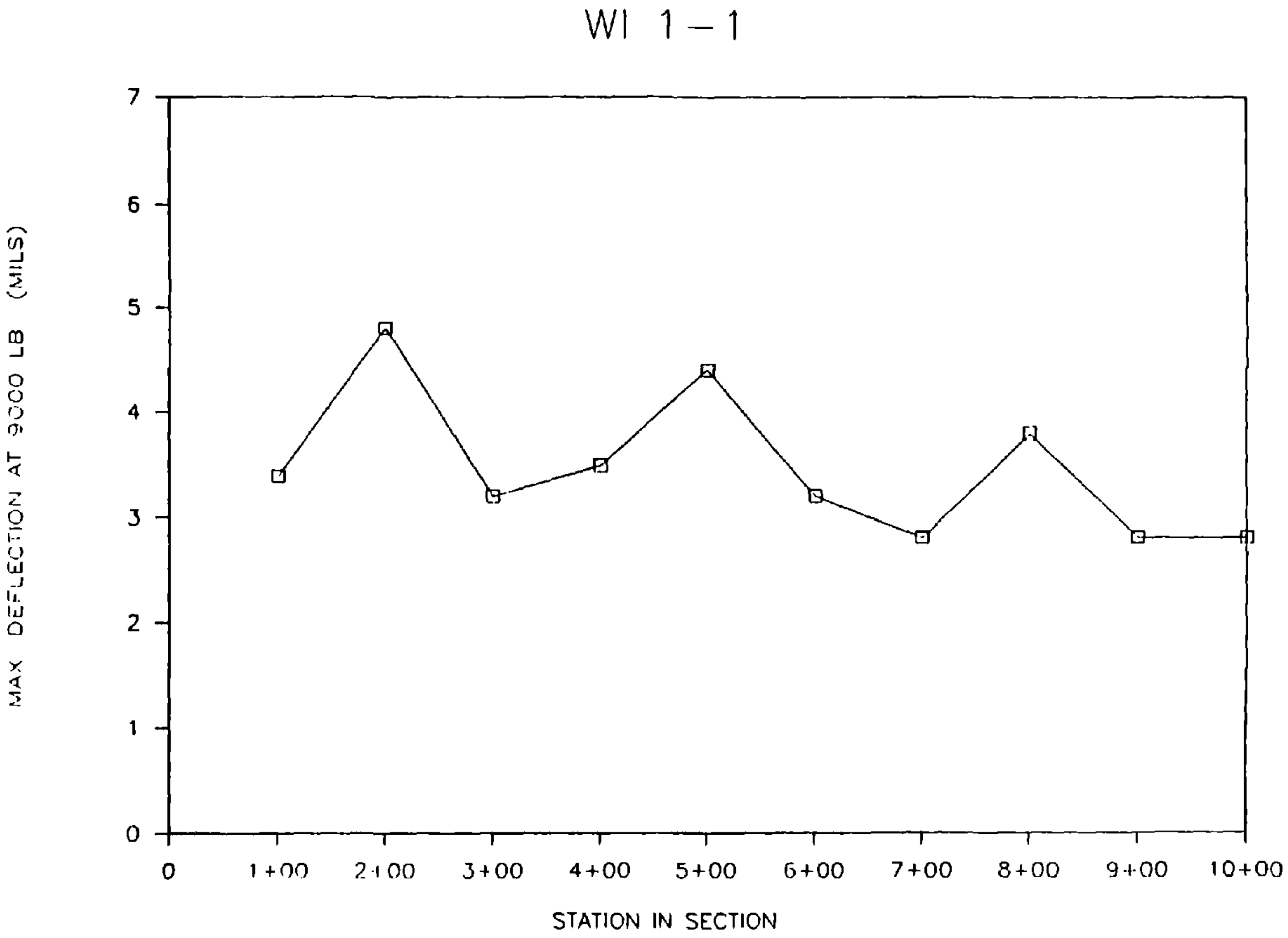

Figure 51. Deflection profile for WI 1-1.

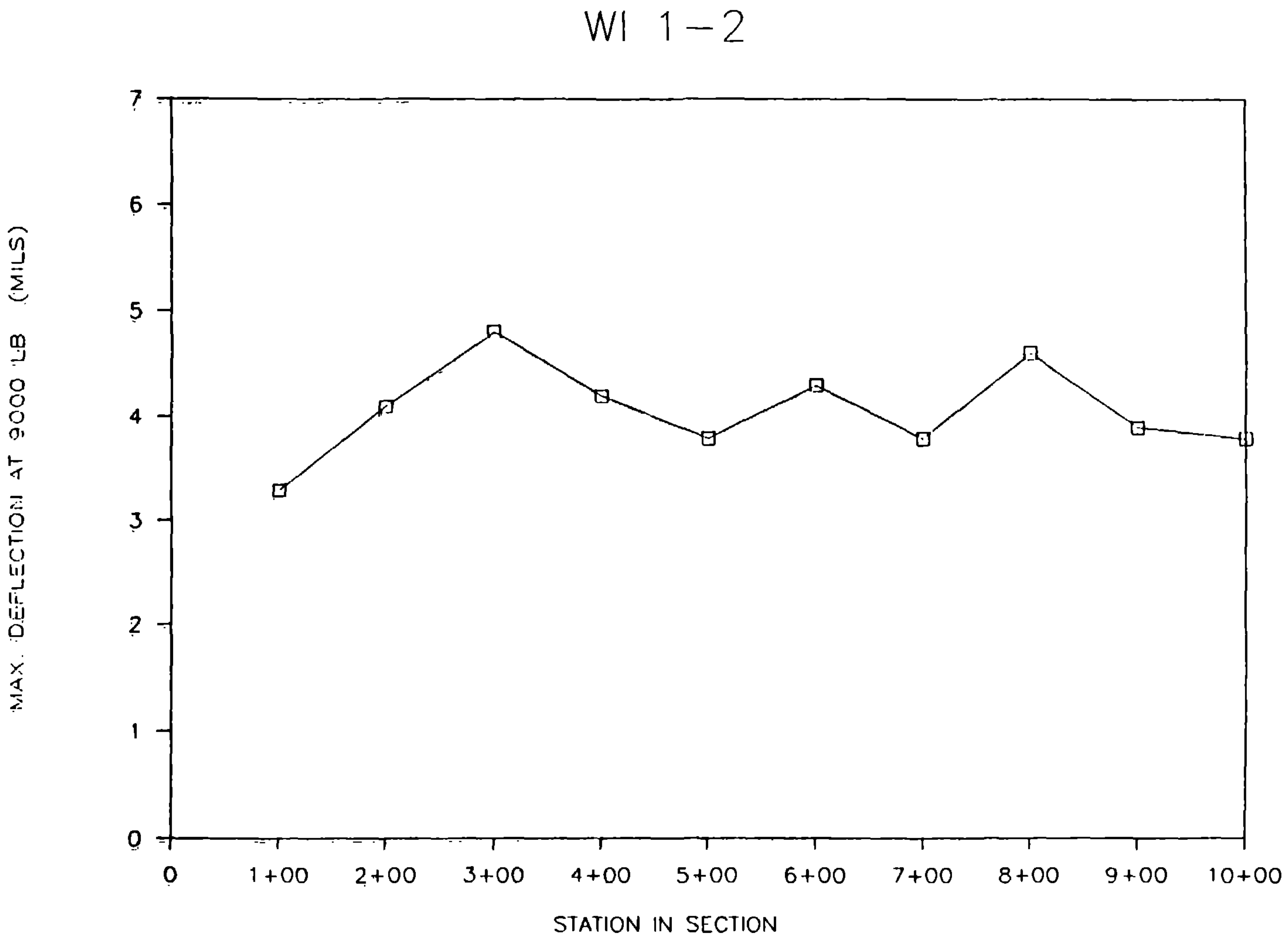

Figure 52. Deflection profile for WI 1-2.

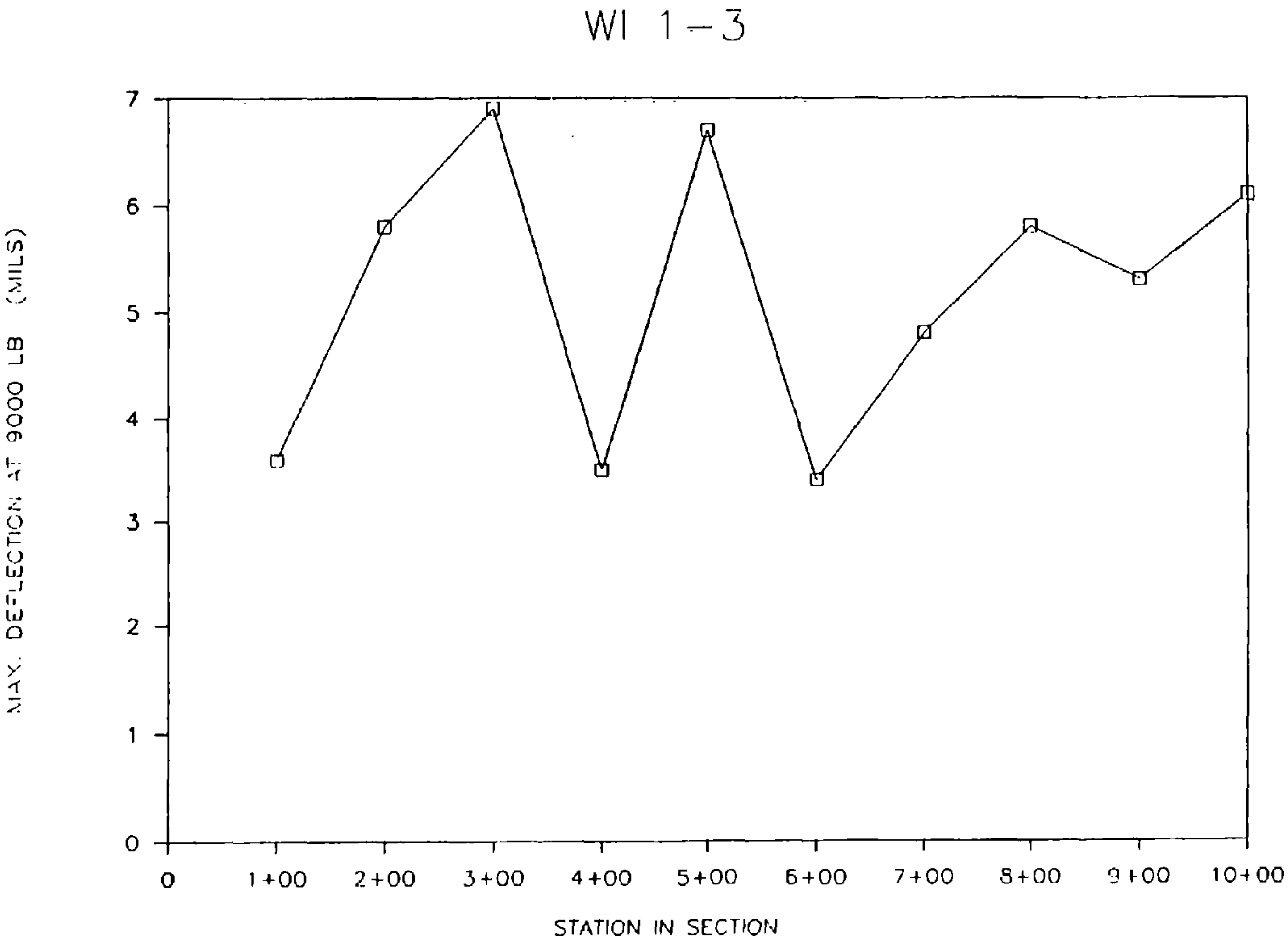

Figure 53. Deflection profile for WI 1-3.

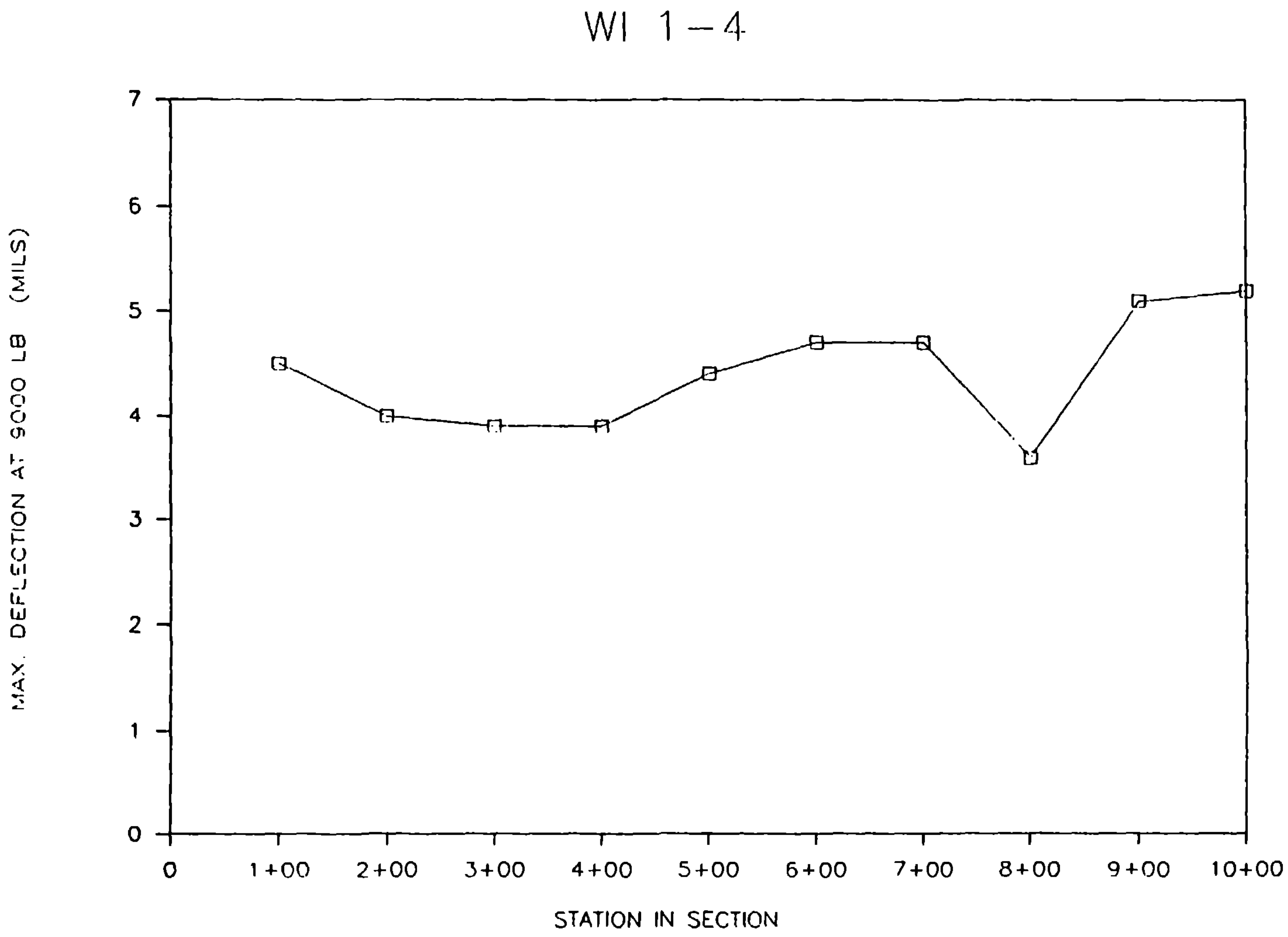

Figure 54. Deflection profile for WI 1-4.

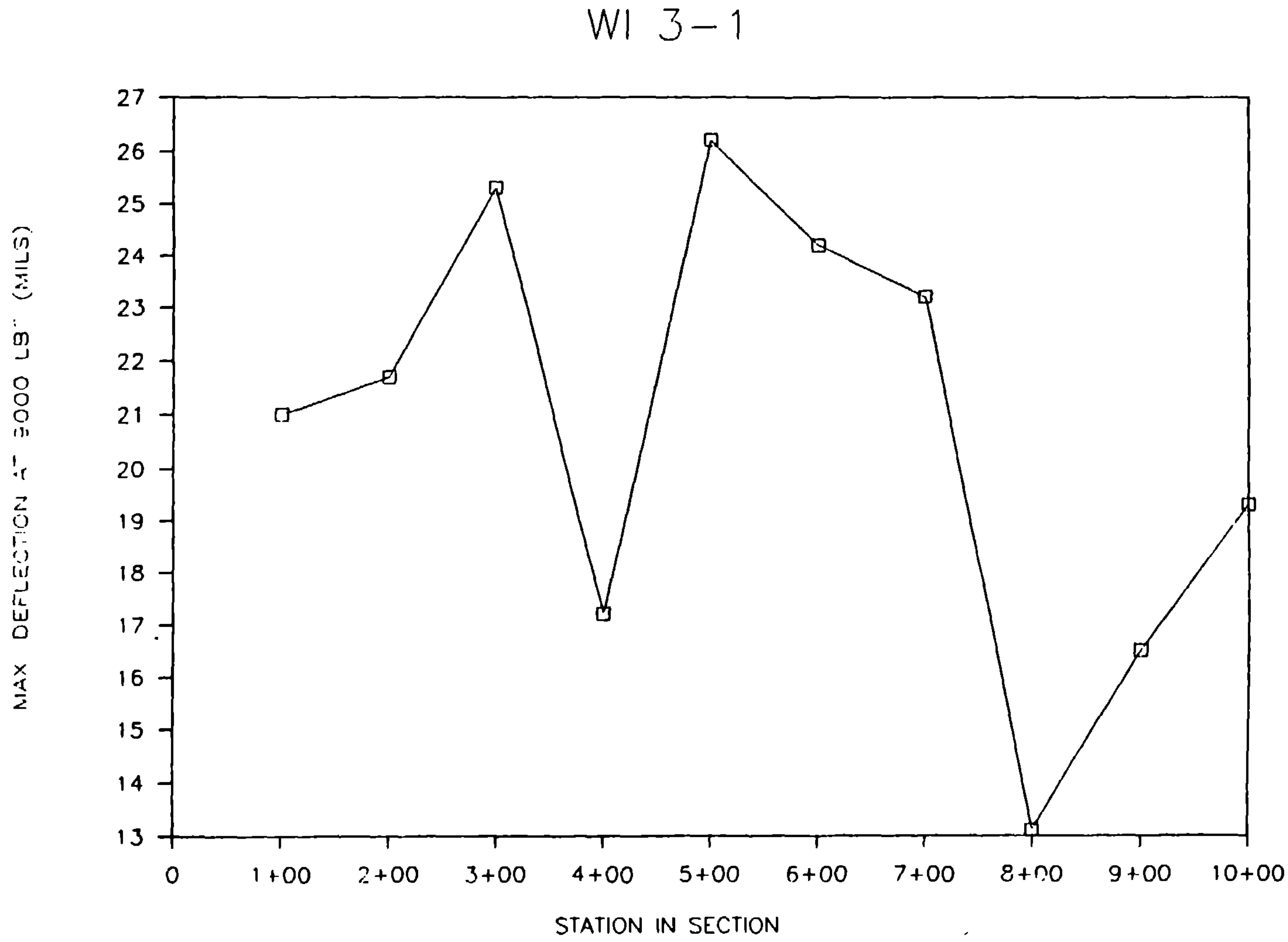

Figure 55. Deflection profile for WI 3-1.

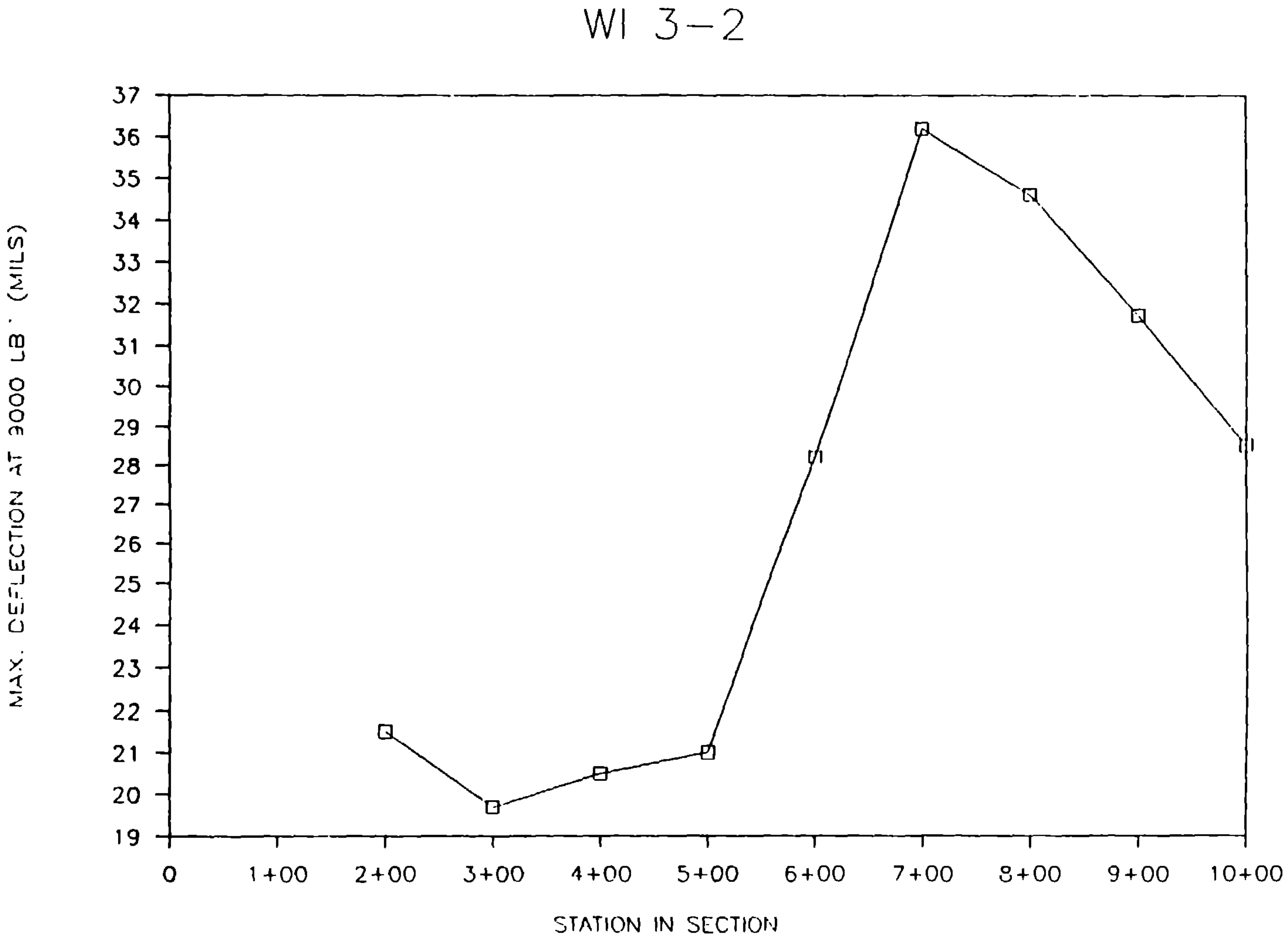

Figure 56. Deflection profile for WI 3-2.

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