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PERFORMANCE EVALUATION OF
CONCRETE PAVEMENT OVERLAYS
Final Report

MICHIGAN DEPARTMENT OF TRANSPORTATION

MATERIALS and TECHNOLOGY DIVISION

PERFORMANCE EVALUATION OF CONCRETE PAVEMENT OVERLAYS
Final Report

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Research Laboratory Section
Materials and Technology Division
Research Project 83 F-162
Research Report No. R-1303

Lansing, December 1989

OFFICE MEMORANDUM

DATE: July 26, 1990

TO: James D. Culp
Engineer of Materials & Technology

FROM: Jon W. Reincke
Engineer of Research

SUBJECT: Research Report No. R-1303 Clarification

This memo is prompted by a concern raised by Tom Coleman concerning the lack of mention of edge drains used on the projects evaluated in Research Report No. 1303.

Four-inch diameter edge drains with filter-sock were installed on both the US-23 at Dundee and the I-96 at Portland projects. Concrete overlay projects let under present specifications allow either the four-inch diameter or the PDS drains.

The addition of edge drains should have been included in the report since it is an important factor and is now a standard procedure.

MATERIALS & TECHNOLOGY DIVISION

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SUMMARY

Concrete overlays were a common method used by the Department from 1932 to 1954 to "rehabilitate" deteriorated roads. During that period the Department placed 21 overlays, ranging in thickness from 4 to 6 in. All of these overlays, except one, were of the unbonded type with a bituminous coat used as the separation medium. One overlay, still in service after 35 years, is on US 27 just west of Potterville, but most of them are no longer in existence. Now with the Interstate and many other routes needing rehabilitation or reconstruction, the concrete overlay has again emerged as an alternative to total reconstruction.

The newer versions of overlays are thicker (6 to 13 in.) and normally of the unbonded type. Two 7-in. reinforced, unbonded, and dowelled concrete overlays were constructed in 1984. One is located on US 23 at Dundee and one on I 96 at Portland. Both overlays are separated from the underlying pavement by a 3/4-in. sand-asphalt layer, and both have reinforced concrete shoulders. The original pavement on US 23 is a reinforced jointed pavement placed in 1959-61. It was in relatively poor condition when overlaid; that is, many of the joints and interior slab cracks were heavily patched with bituminous cold patch material. Portions of the I 96 pavement, placed in 1958, are continuously reinforced and were sawed into 100-ft slabs to reduce the movement at previously placed repairs. The conventionally reinforced portions of the pavement were in reasonably good condition prior to overlaying.

Observations, measurements, examination of cores, and load tests indicate that the overall performance of the 1984 overlays to date have been satisfactory. Substantial variation in joint movements indicate that the bituminous debonding layer does not allow total independent movement in the two concrete layers. Coring through cracks in the overlay, coupled with location measurements of cracks or joints in the two concrete layers, shows that the cracks in the overlay are likely to be located near or at cracks or joints in the original pavement beneath. Cores removed from joints in the overlay revealed no deterioration where the concrete is in contact with the impermeable bituminous layer. Load testing with a Falling Weight Deflectometer showed a 29 percent increase in load transfer efficiency at joints and a 25 percent decrease in mid-slab deflection in the overlays as compared to an adjacent 9-in. recycled pavement placed on a 4-in. open graded drainage base. It is estimated that using an overlay instead of recycling will result in at least a $35,000 savings per mile of two-lane pavement. Field and laboratory data indicate that overlays will have a favorable life cycle cost compared to recycled pavements.

Based on the performance to date of the two overlays, it is concluded that concrete overlays are a viable alternative to recycling when the existing facility can accommodate the extra overlay thickness. It is recommended that careful consideration be given during the design process

to the condition of the existing pavement and to the volume of commercial traffic the overlay will carry, to ensure that the overlay will be of sufficient thickness. It is also recommended that severely deteriorated and patched areas in the existing pavement be repaired to minimize failure in the overlay at these locations. No changes are recommended in the bituminous separation layer or in the location of joints in the overlay with respect to joints and cracks in the underlying pavement. It is recommended that consideration be given to improve the effectiveness of the debonding layer perhaps by the application of a coat of curing compound to the surface of the bituminous layer.

ACTION PLAN

1. District

   A. The District will request that a concrete pavement be programmed for rehabilitation. If a concrete overlay is indicated the following will be done.

2. Design Division

   A. The Design Division (Pavement Design Engineer) will review the data and recommendations to determine if the project is a reasonable candidate for a concrete overlay. If the project appears suitable, the Pavement Design Engineer will request that the Materials and Technology Division evaluate the project.

3. Materials and Technology Division

   A. The Materials and Technology Division (Materials Research Unit) will conduct a preliminary survey of the project to determine (based on the surface condition and the amount of pavement that requires removal to maintain clearance under structures) whether a concrete overlay is feasible. The project also will be checked for evidence of deficient base conditions.

   B. Survey results and recommendations will be provided to the Design Division.

4. Design Division

   A. The Design Division (Pavement Design Engineer) will determine the general design and pavement thickness required for the project.

   B. The Pavement Design Engineer will then prepare a life cycle cost estimate for the concrete overlay as well as the other possible methods of rehabilitation.

   C. The cost information and recommendations will be presented to the Engineering Operations Committee (EOC).

5. EOC

   A. The EOC will determine which of the rehabilitation methods will be utilized.

INTRODUCTION

With a large portion of the concrete highway system in need of major rehabilitation work, a renewed interest in concrete overlays has surfaced as a possible alternative to recycling the existing pavement. During 1984 the Department constructed two concrete overlays for the purpose of evaluating their performance as compared to recycled pavement and to compare the long-term cost effectiveness of the two rehabilitation systems. Also, the use of a thin sand-asphalt layer as a bond-breaker between the existing concrete surface and the new overlay would be evaluated with respect to controlling reflective cracking in the concrete overlay. MDOT Research Report R-1262, covering the construction operations, was issued in May 1985. Pertinent parts of that report are included in this report which deals with the performance of the overlays.

Project Locations

One overlay (Project FRR 58034, Job No. 20915A, Federal No. MAFR 23-1 (312), Federal Item FJ 432), is located on US 23 in Monroe County from Ida Center Rd northerly to one mile north of M 50 and consists of 7.8 miles of freeway (Fig. 1). The other overlay (Project IR 34044, Job No. 20730A, Federal No. IR 96-2 (112) 67, Federal Item NPO 241), is located on I 96 in Ionia County and consists of 2.86 miles of eastbound and 5.45 miles of westbound I 96, beginning just east of M 66 easterly to the Grand River (Fig. 2).

Original Pavement Design

The original US 23 pavement was constructed in 1959-61 and consists of a 9-in. thick reinforced concrete pavement with 99-ft joint spacing. The outside shoulder was sealcoated and the inside one was a Class A gravel shoulder. The joints were constructed with load transfer (1-1/4-in. diameter dowels, 18 in. long, on 12-in. centers) and the 1/2-in. wide by 2-in. deep formed joint grooves were originally sealed with a hot-poured sealant but were never resealed.

The original pavement on I 96 that was overlaid was built in 1958-59 and consists of 0.9 mile of 9-in. reinforced concrete and 2.0 miles of 8-in. continuously reinforced concrete on the eastbound raodway; with 3.4 miles of 9-in. reinforced concrete and 2.0 miles of 8-in. continuously reinforced concrete on the westbound roadway. The 9-in. pavement has dowelled joints (1-1/4-in. diameter dowels, 18 in. long, on 12-in. centers) with 1/2-in. wide by 2-in. deep formed joint grooves initially sealed with a hot-poured sealant but never resealed. The existing shoulders at the time of overlay consisted of a 2-1/2-in. bituminous mat over gravel.

Both the US 23 and I 96 pavements were constructed on a clay grade with a 10-in. sand subbase and a 4-in. densely graded aggregate base. The sand base extended to the ditch foreslopes to provide for 'daylight drainage.'

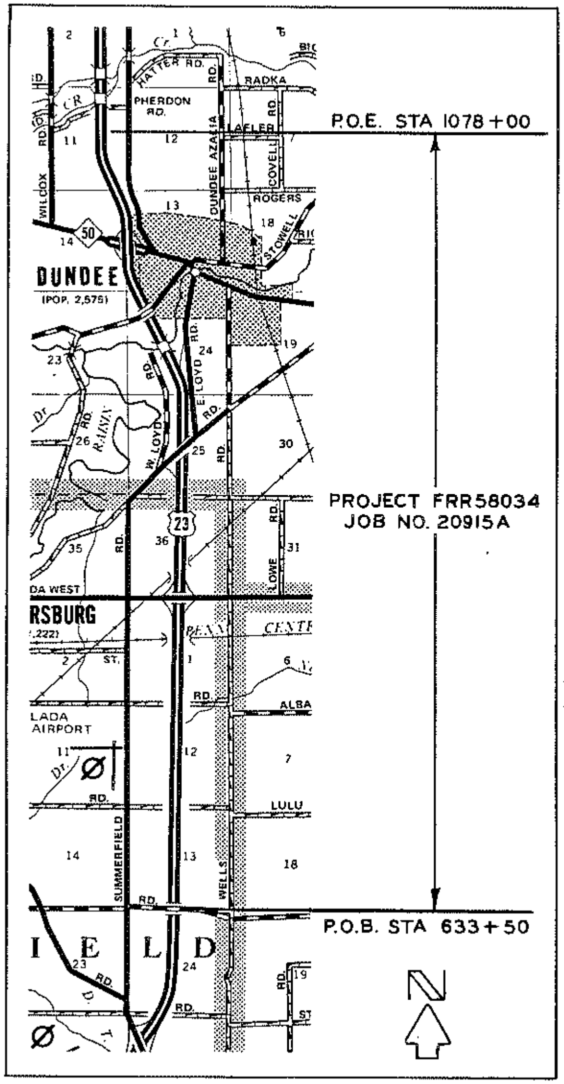
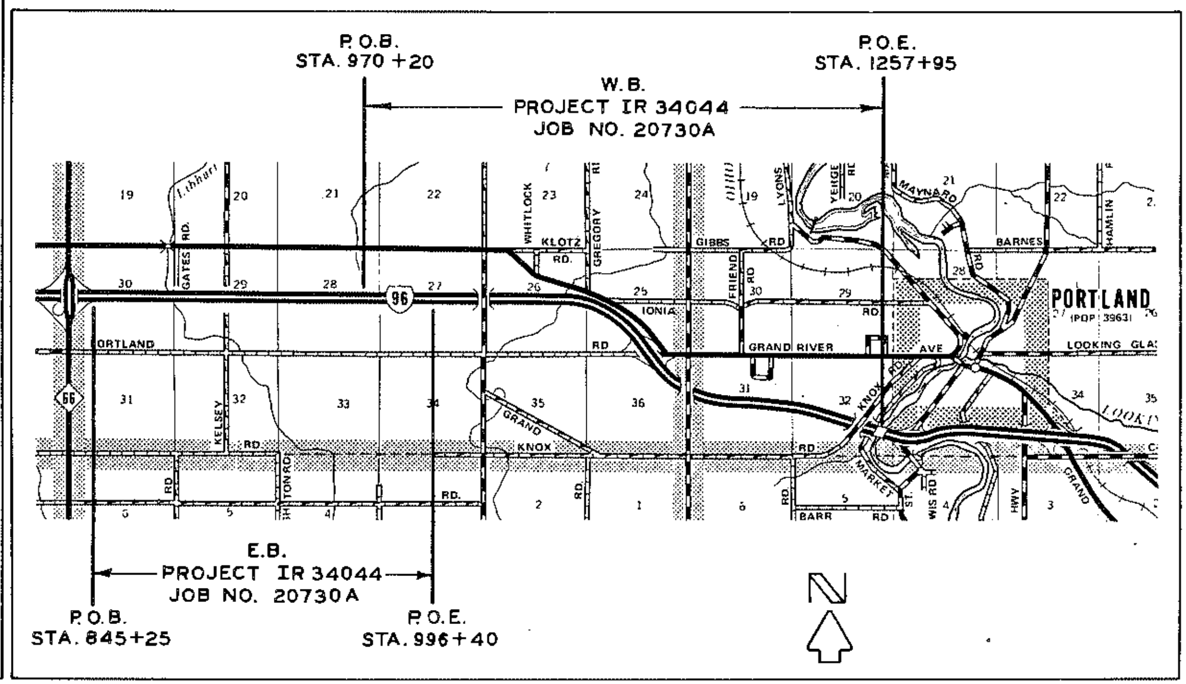


Figure 1. Location of US 23 concrete overlay.

Figure 2. Location of I 96 concrete overlay.



The average daily traffic volume (ADT) on each roadway on US 23 is 11,750 with 16 percent commercial; and on I 96 the ADT volume is 8,850 with 22 percent commercial on each roadway.

Overlay Description

The overlays are of the unbonded type. The bond-breaker consists of a sand-asphalt mix (MDOT Bituminous Mixture No. 1100T, 35A). The placement rate varied from 80 lb/sq yd at the outer edges to 150 lb/sq yd at the pavement centerline to change from a parabolic crown in the old pavement to a straight line crown in the overlay.

Both overlays consist of two 12-ft lanes of 7-in. reinforced concrete with reinforced concrete shoulders. The shoulder thickness tapers from 7 in. at the pavement edge to 6 in. at the outside shoulder edge. The width of the right-hand concrete shoulder is 8 ft on the I 96 project and 9 ft on the US 23 project; the left-hand shoulder widths are 3 ft and 5 ft on the I 96 and US 23 projects, respectively.

A grade 35P concrete with an anticipated 28-day compressive strength of 3,500 psi and flexure strength of 650 psi was used for the roadway lanes and a Grade 30P concrete was used for the shoulders. The I 96 overlay used a 6A gravel and the US 23 project used a 6A crushed limestone. Fly ash was used in the US 23, 35P concrete mixtures at the rate of 72 lb/cu yd with 5.1 sacks of cement and a water reducer. The reinforcement for both the roadway and shoulders consisted of wire mesh weighing 6.3 lb/sq yd. The transverse joints in the roadway slab contain load transfer assemblies consisting of 1-1/4-in. diameter epoxy coated dowels 18 in. long and spaced on 12-in. centers. The shoulder joints were not dowelled. The longitudinal roadway centerline joint and the roadway-shoulder joints were tied with 24-in. No. 5 epoxy coated deformed bars. The tie bar spacing in the centerline joint was 2 ft 6-3/4 in. and 4 ft 6-2/3 in. in the roadway-shoulder joints.

The transverse joints were required to be located at least 3 ft away from a joint or crack in the existing pavement slab. A maximum joint spacing of 41 ft was specified with reduced spacing permitted to conform to the location requirement with respect to cracks and joints in the underlying concrete slab. The shoulder slab lengths were adjusted to coincide with the pavement slab lengths. Rumble strips were formed in the center of every other shoulder slab.

Both transverse and longitudinal joints were constructed by sawing. The transverse joints in both mainline pavement and shoulders were sealed with a preformed neoprene seal. The seal extended across both the pavement and shoulder and down the edge groove of the shoulders (nominal groove size 9/16 in. wide by 2-1/8 in. deep). The longitudinal centerline and the pavement-shoulder joints were sealed with a hot-poured sealant (nominal groove size 1/4 in. wide by 1 in. deep).

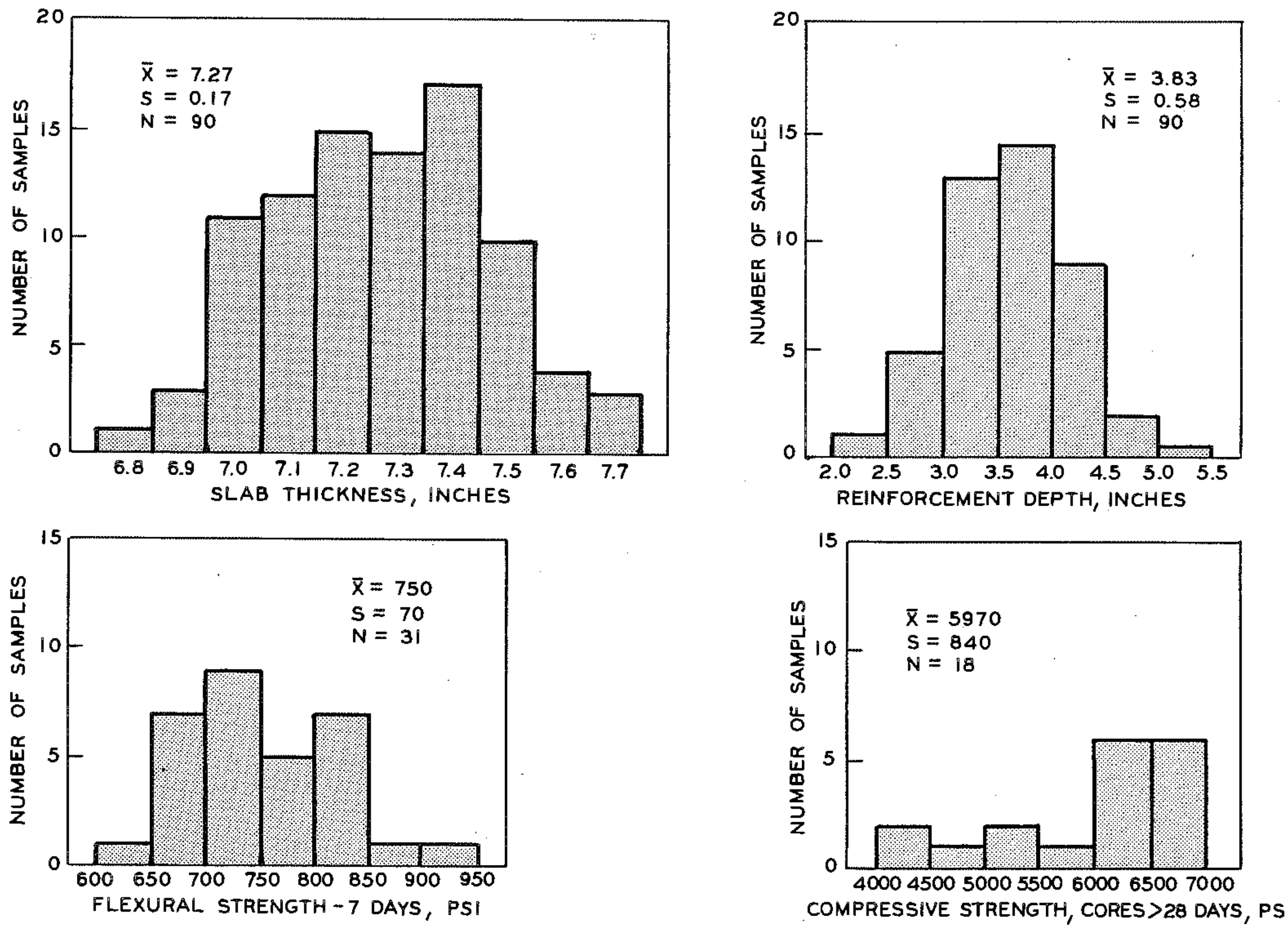


Figure 3. Distribution of slab thickness (top left), reinforcement depth (top right), concrete flexure strength (bottom left), and concrete compressive strength (bottom right) on I 96 concrete overlay.

At structures, a 224-ft length of the existing concrete slab was removed so the overlay could be transitioned down to meet the elevation of the existing bridge deck surface. A 235-ft long bituminous taper was used to meet the elevation of the existing slab at the project limits or at ramp pavements. On both projects sufficient clearance was available under overpasses to allow construction of the overlay without removing the original pavement.

Concrete Properties

The Department's specifications concerning concrete pavement give requirements for slab thickness, reinforcement depth, concrete flexure strength, and concrete compressive strength. The flexure strength is determined by casting test beams from the pavement concrete and then breaking them after seven days cure in moist sand. Slab thickness, steel depth, and compressive strength are determined from cores taken through the slab after 28 days or more of curing time.

The distribution of these data along with the mean, standard deviation, and number of samples taken are shown in Figures 3 and 4 for I 96 and US 23, respectively. As can be seen the average flexural strength on the I 96 project was 110 psi higher than the strength measured on the US 23 project. The average compressive strength was also slightly (150 psi) higher on the I 96 job. The anticipated flextural strength of 550 psi at seven days was met on I 96 and also on US 23 except for six beams which ranged in strength from 500 to 550 psi and two beams with a strength range of 450 to 500 psi. The minimum compressive strengths on both projects were well above the anticipated 3,500 psi 28-day strength.

The average slab thickness measured was 7.27 in. on both projects but the standard deviation was somewhat greater on US 23, 0.39 compared to 0.17 on I 96. The average steel depth and standard deviation were, respectively, 3.83 and 0.58 on I 96, 3.45 and 0.52 on US 23. Slab thickness and steel depth on both projects met the specification requirements based on the prescribed sampling procedure.

PERFORMANCE EVALUATION

A total of eight test sections, each 2,000 ft long were established prior to beginning the construction of the two overlay projects. Two test sections representing the range in condition of the existing concrete pavement were set up on each roadway of both the US 23 and the I 96 overlays. On the I 96 project one test section on each roadway was selected in the CRC portion of the existing pavement. (The CRC pavement was sawed into slab lengths of 100 ft maximum to reduce movement at previously placed repairs and steel fractures.)

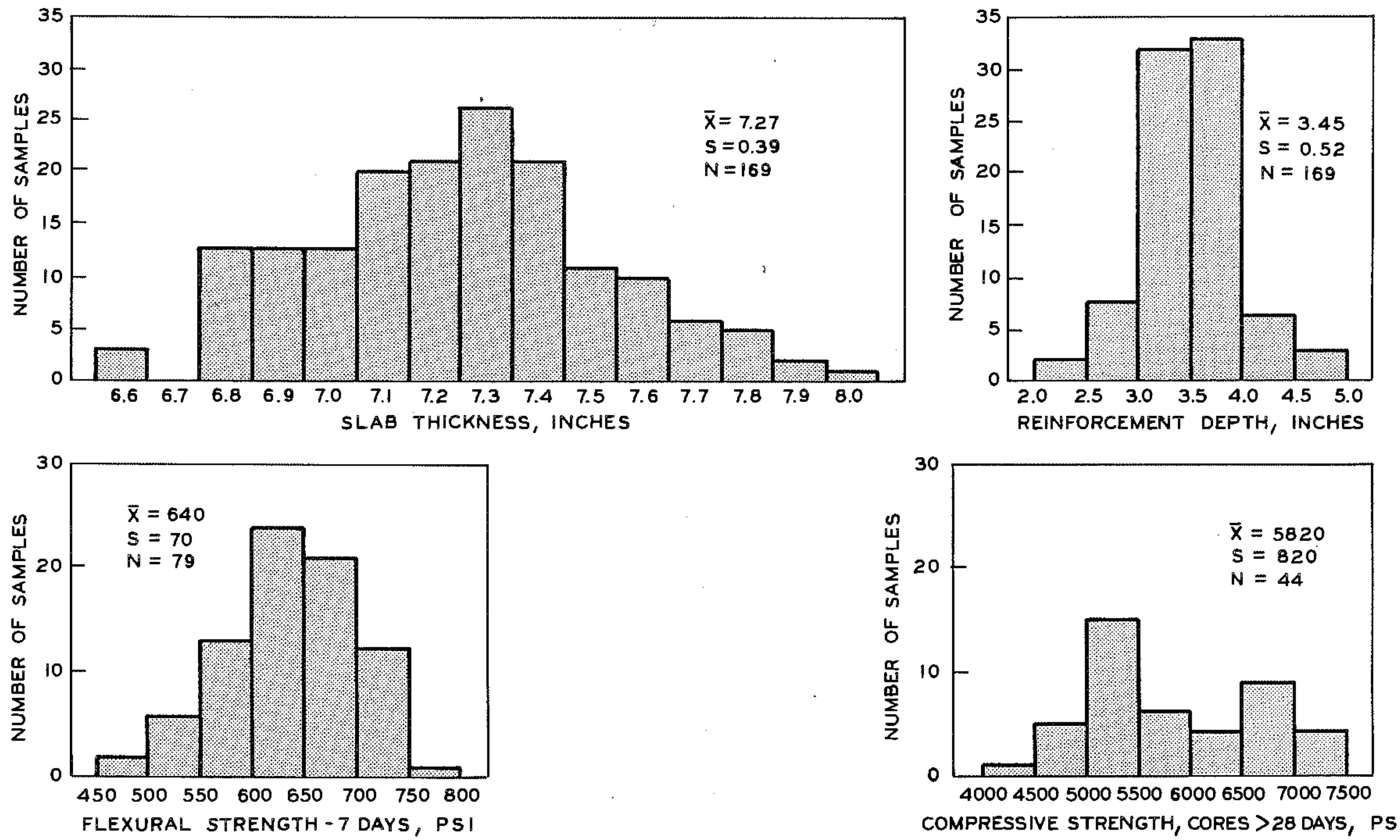


Figure 4. Distribution of slab thickness (top left), reinforcement depth (top right), concrete flexure strength (bottom left), and concrete compressive strength (bottom right) on US 23 concrete overlay.

The locations of the test sections are:

Route	Roadway	Test Section Number	Sta. to Sta.
US 23	Southbound	A	975+00 - 955+00
US 23	Southbound	B	775+00 - 755+00
US 23	Northbound	C*	774+97 - 792+97
US 23	Northbound	D	957+31 - 977+29
I 96	Westbound	A	1238+90 - 1218+90
I 96	Westbound	B**	1018+00 - 998+00
I 96	Eastbound	C**	867+84 - 887+84
I 96	Eastbound	D	957+00 - 977+00

* Section C only 1800 ft long
**Existing CRC Pavement

Since the length of slab segments, the location of points of movement, and the deteriorated condition of the existing pavement may affect the performance of the overlay and the bond-breaker layer, information on these factors was obtained prior to beginning the construction operations. First, a reference line was established at the beginning of each test section and each joint and crack with fractured steel reinforcement (cracks acting as joints) were located with respect to the reference line. From these measurements the lengths of slab segments contributing to movement at cracks and joints in the existing pavement were obtained. A distribution of the slab segment lengths in the traffic lane for the US 23 project is shown in Figure 5 and for I 96 in Figure 6. As can be seen in Figure 5, Sections A and D on US 23 contain mostly slab segments in the 10 to 20 and 20 to 30-ft length group, whereas the segment lengths in Sections B and C are more distributed. Slab segment lengths in Sections A and D on I 96 (Fig. 6) are also fairly well distributed. The slab lengths in Sections B and C in the CRC pavement are generally longer than those in the jointed pavement. As shown in Figure 6, more than 50 percent of the slab segments in these sections are over 60 ft long.

The deteriorated condition of joints and cracks was rated using the procedure and definitions given in the Department's concrete pavement survey manual. Figures 7 and 8 give the descriptions and severity levels for joint and crack conditions, respectively. Severity Level 5 for cracks is not included in the survey manual but has been added here so information on the total number of transverse cracks would be available. The photographs shown in Figures 7 and 8 are from the US 23 project.

In addition to locating joints and cracks in the test sections, previous repairs and pressure relief joints were also located. Since the joints at repairs and the relief joints were basically free of deterioration they were not rated with respect to current condition. A typical repair condition is shown in Figure 9. The deteriorated condition of joints and cracks for

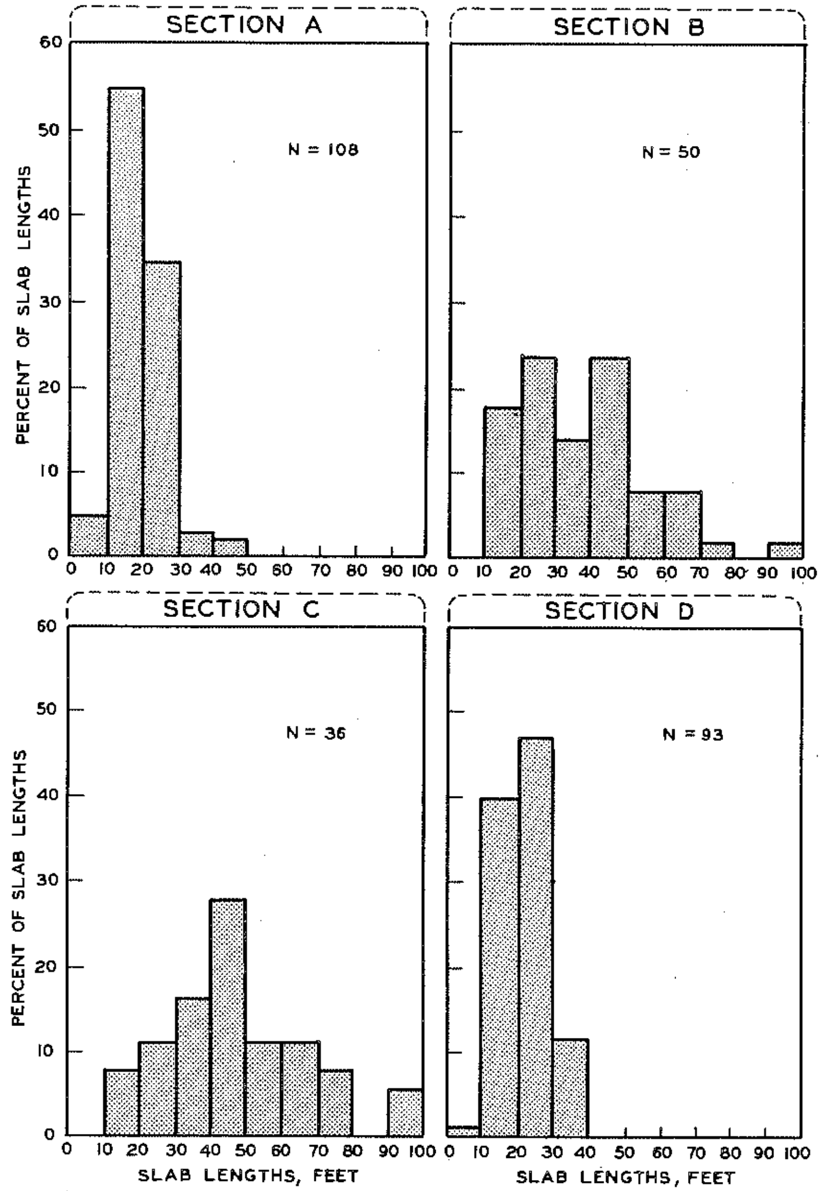


Figure 5. Distribution of slab lengths in the traffic lane contributing to movement at cracks and joints in the overlaid standard concrete pavement on US 23.

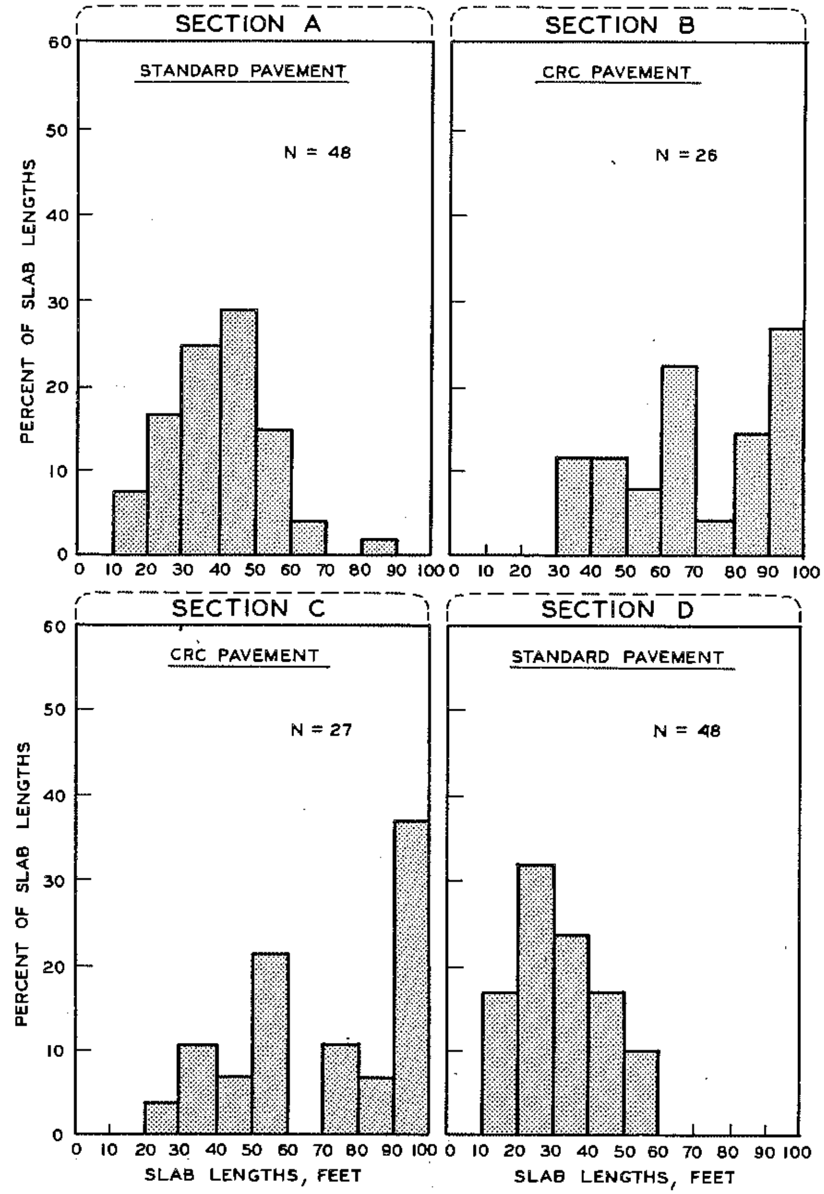
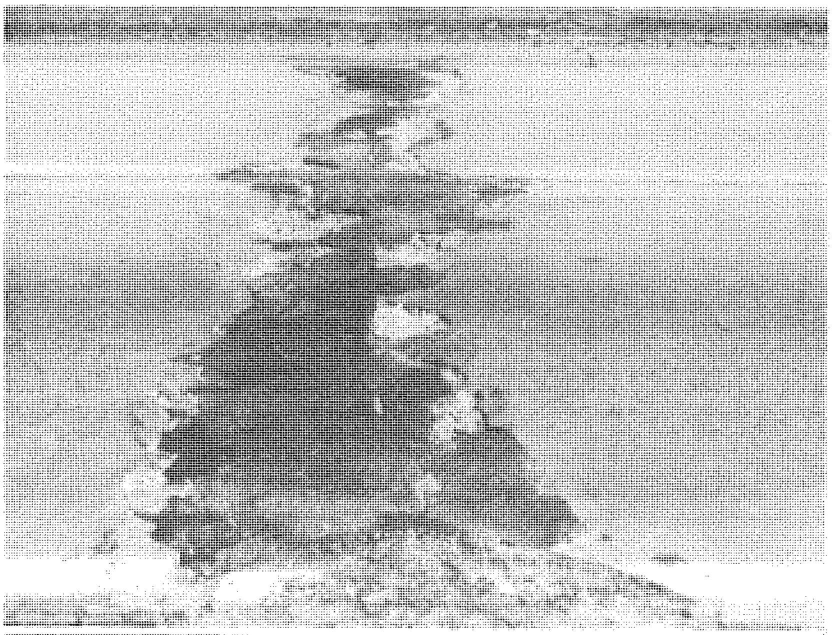
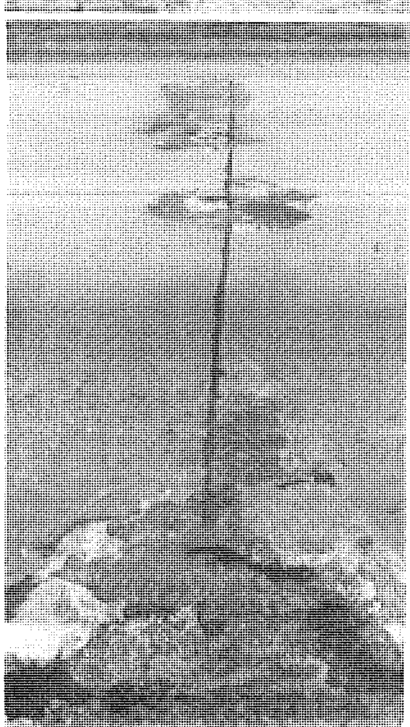


Figure 6. Distribution of slab lengths in the traffic lane contributing to movement at cracks and joints in the overlaid standard and CRC pavement on I 96.

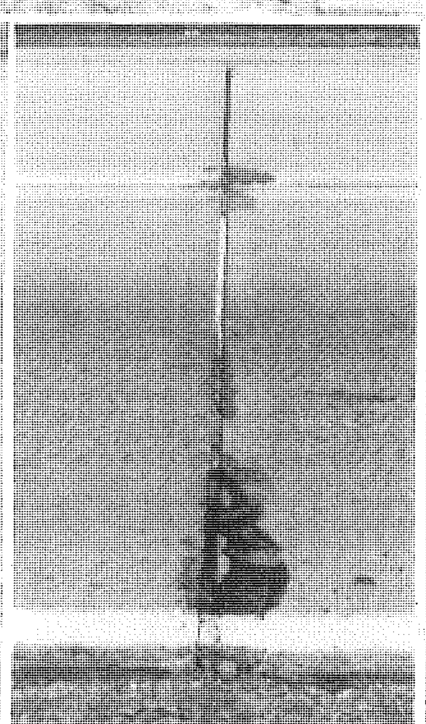
Description: Failure of the transverse joints is the spalling, breaking, or buckling of the concrete along one or both edges of the joint groove for a total width of 4 in. or more. Failures normally occur gradually and are maintained by temporary bituminous patching.



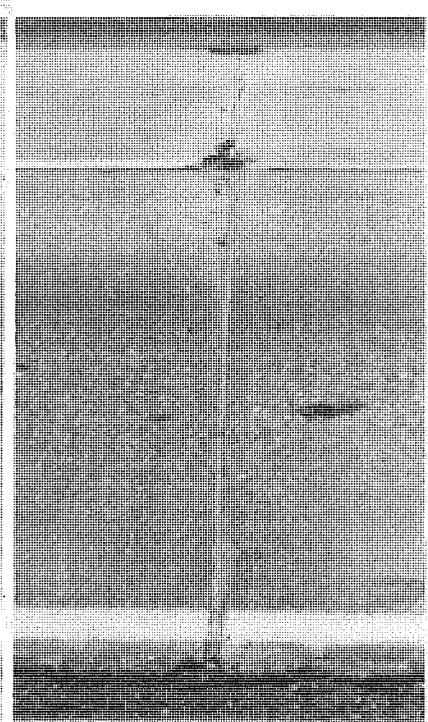
Severity Level 1-From 6 to 12 ft of spall or bituminous patching.



Severity Level 2-From 3 to 6 ft of spall or bituminous patching.



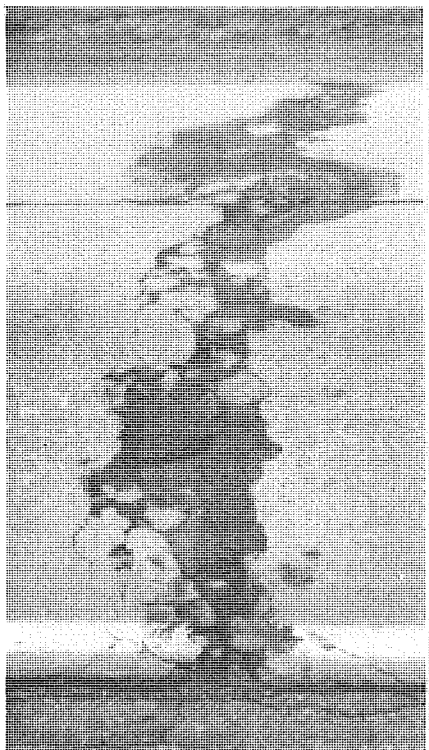
Severity Level 3-From 1 to 3 ft of spall or bituminous patching.



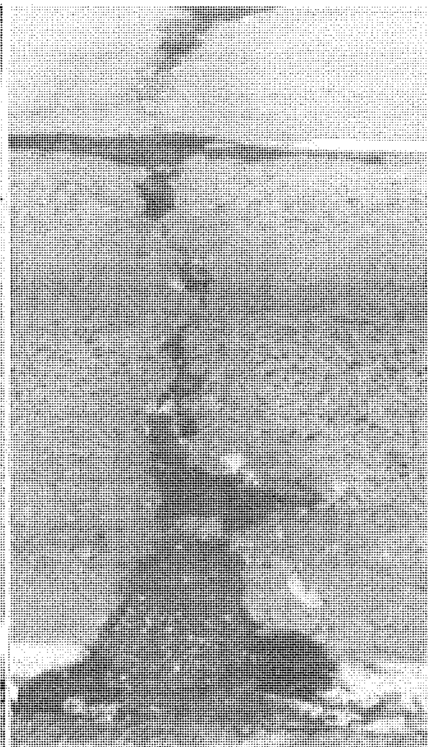
Severity Level 4-From 0 to 1 ft of spall or bituminous patching.

Figure 7. Description of transverse joint failure and severity levels.

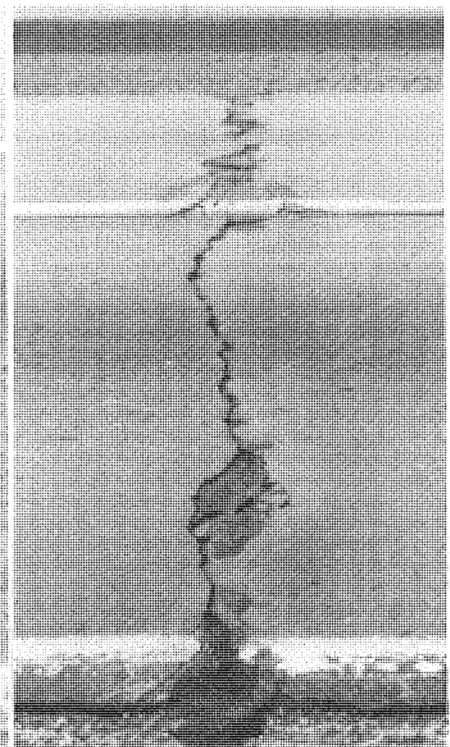
Description: An open transverse crack is a small gap in the pavement slab between joints. The reinforcement has fractured and the crack acts as a joint. Normally the width of the crack must be 1/4 in. or more to be considered open. Spalling, bituminous patching, and faulting may have occurred.



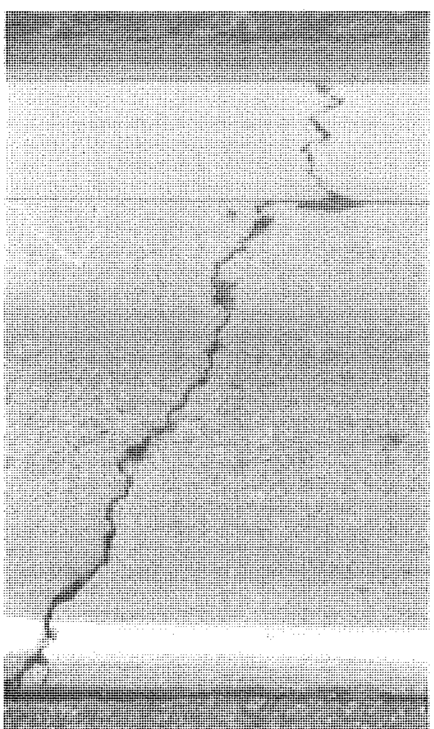
Severity Level 1-From 6 to 12 ft of spall or bituminous patching. Faulting may have occurred.



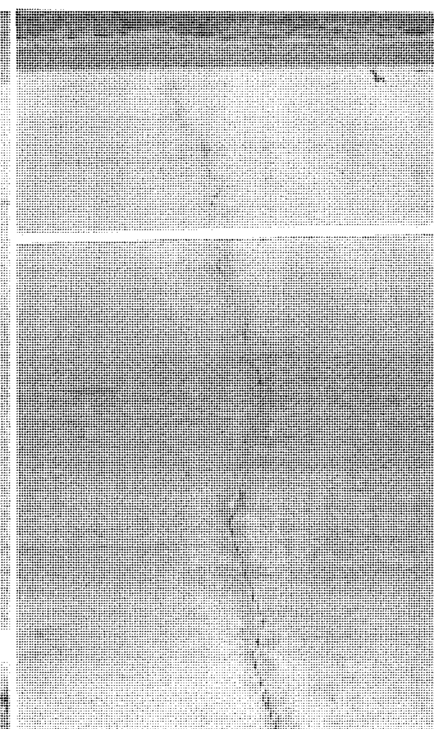
Severity Level 2-From 3 to 6 ft of spall or bituminous patching. Faulting may have occurred.



Severity Level 3-From 1 to 3 ft of spall or bituminous patching. Faulting may have occurred.



Severity Level 4-From 0 to 1 ft of spall or bituminous patching. Faulting may have occurred.



Severity Level 5-Transverse cracks with only minor spalls and reinforcement still intact.

Figure 8. Description of transverse crack deterioration and severity levels.

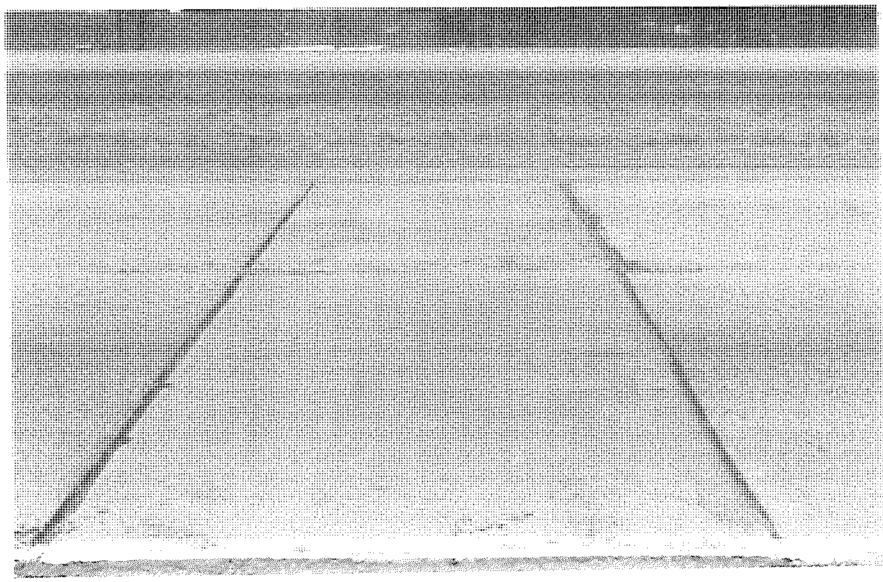
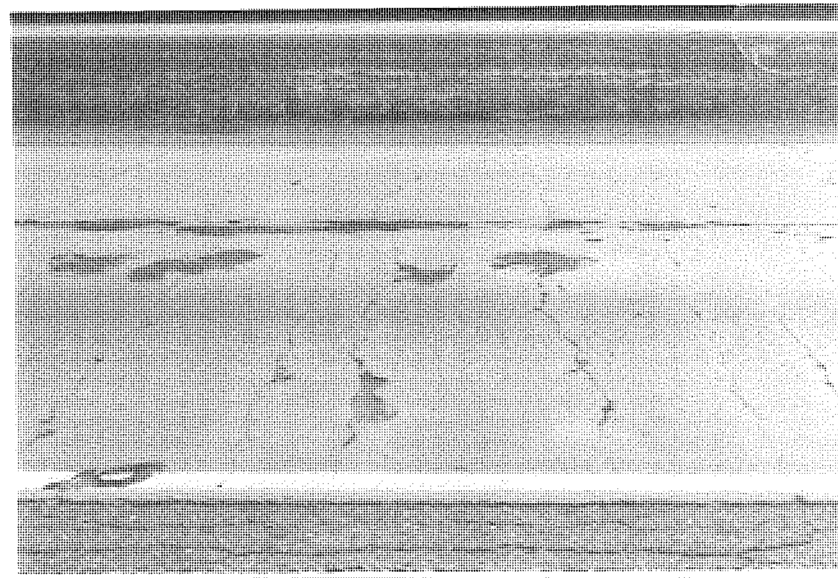


Figure 9. Typical condition of undowelled repairs located within the test section limits.



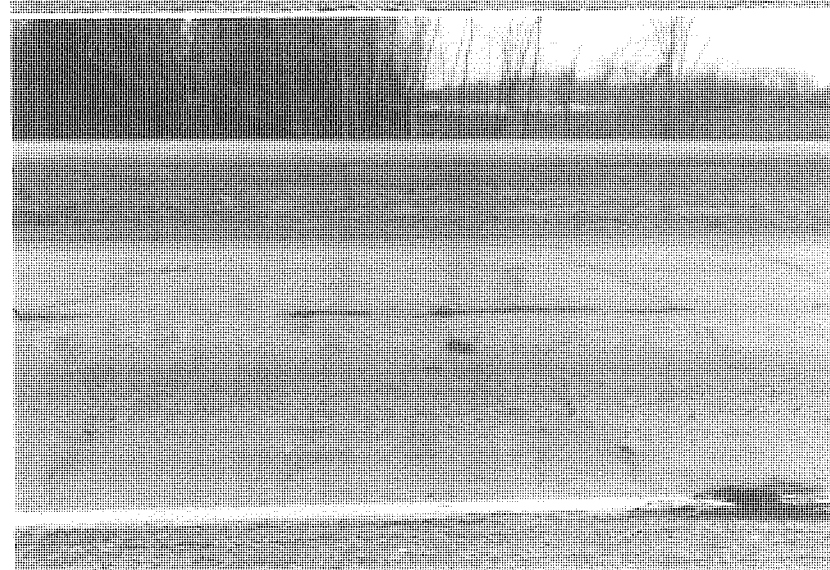


Figure 10. The condition of the I 96 CRC pavement ranged from medium (top) to minor spalling and patching of the transverse cracks (bottom).

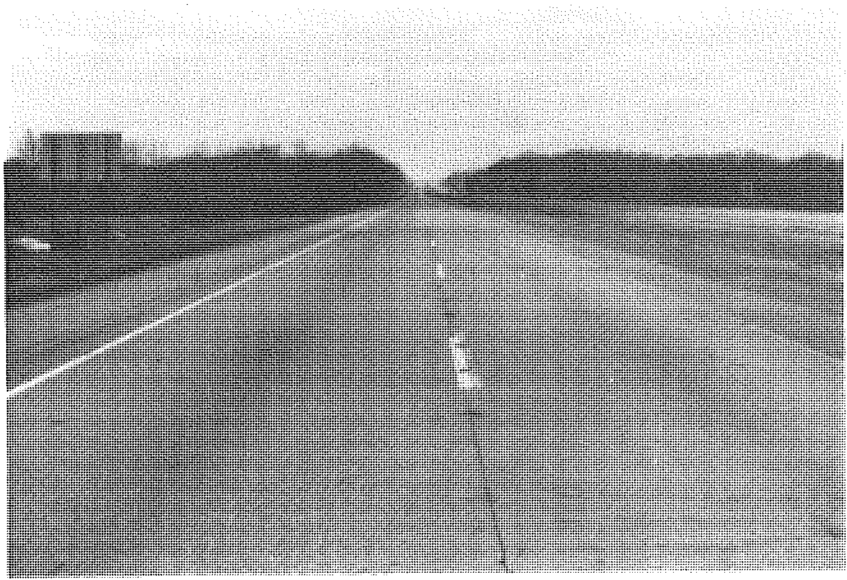


Figure 11. The longitudinal joint in the CRCP test sections exhibited only minor to moderate spalling and patching and only occasional areas where the joint had separated.

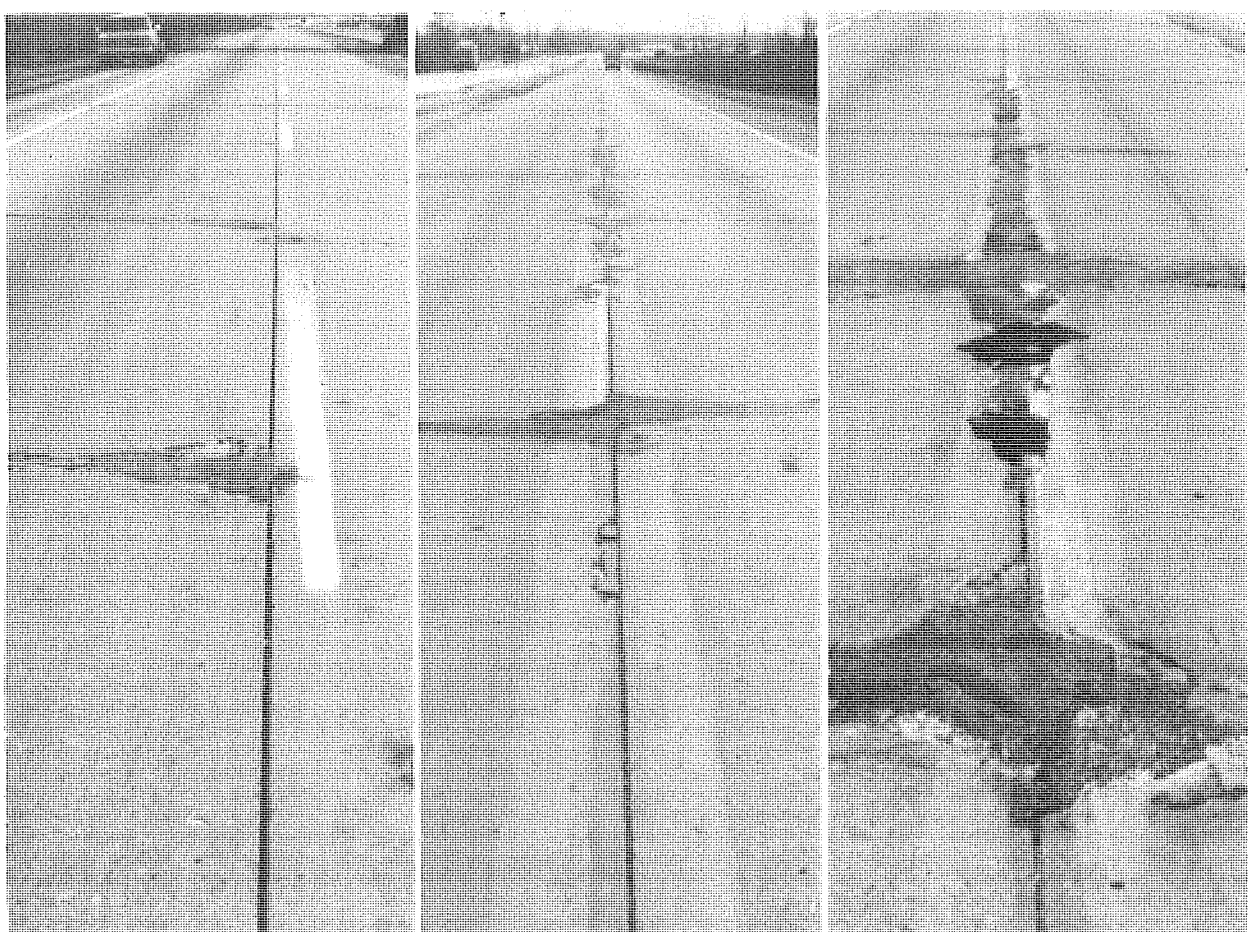


Figure 12. Condition of the longitudinal joint varied from basically no spalling (left) to medium spalling and patching (center) to heavy spalling and patching (right). Throughout most of the test sections' lengths separation of the joint had occurred indicating that the tie bars had fractured.

Table 1
Number of Joints and Cracks in the Traffic and Passing Lane in Each Severity Distress Level

Route	Test Section No.	Severity Levels																
		Traffic Lane									Passing Lane							
		Joints				Cracks					Joints				Cracks			
		1	2	3	4	1	2	3	4	5	1	2	3	4	1	2	3	4	5
US 23	A	18	0	1	0	64	14	3	1	15	18	0	1	0	49	10	4	7	9
US 23	B	14	4	3	0	14	8	6	0	30	18	2	1	0	7	5	5	1	7
US 23	C	7	4	7	1	14	4	5	0	26	18	1	0	0	8	2	1	1	9
US 23	D	18	0	0	1	36	20	10	3	29	14	5	1	0	26	10	10	4	17
I 96	A	10	6	1	2	7	3	7	10	44	5	10	4	0	7	9	6	9	27
I 96	D	6	1	4	0	7	14	7	2	39	4	3	5	0	9	8	12	2	27

Note: The condition of the I 96 CRC pavement test sections is not included in the table but is discussed in the text.
Sections A and D on I 96 contain 2 and 23 repairs, respectively. Section A on US 23 contains 2 pressure relief joints and 4 repairs. Sections B, C and D on US 23 contain 3, 2 and 2 pressure relief joints, respectively.

test sections in the jointed pavement is summarized in Table 1. As can be seen, the US 23 test sections show more deterioration than the I 96 sections. However, it should be noted that Section D on I 96 previously had been extensively repaired, which would reduce the severity of the rated surface defects.

The condition of the CRC pavement in test sections B and C is shown in Figures 10 and 11. As shown in Figure 10, the transverse cracks exhibited medium to heavy spalling and patching in some areas and only minor spalling and patching at other locations. Six failed areas were previously repaired with undowelled joints in Section B and seven areas in Section C. The condition of the centerline joint, Figure 11, in the CRC sections was generally good with only minor patching. The condition of the centerline joint on the sections in the jointed pavement (Fig. 12) varied from minor to medium to heavy patching and fracture of the tie bars was evident because of separation of the slabs.

Following placement of the overlay the reference line at the beginning of each test section was re-established and the locations of the joints in the overlay were determined. Knowing the overlay joint locations and the locations of the existing joints, cracks, and deteriorated condition of the underlying pavement, it was possible to relate the cause of cracks in the overlay to slab segment length or deteriorated condition of the old concrete pavement. Twenty joints in each test section were instrumented with stainless steel gage plugs for measuring horizontal and vertical movement at the joints. The horizontal measurements were taken summer and winter and the vertical taken in the summertime only. A crack survey was conducted each winter.

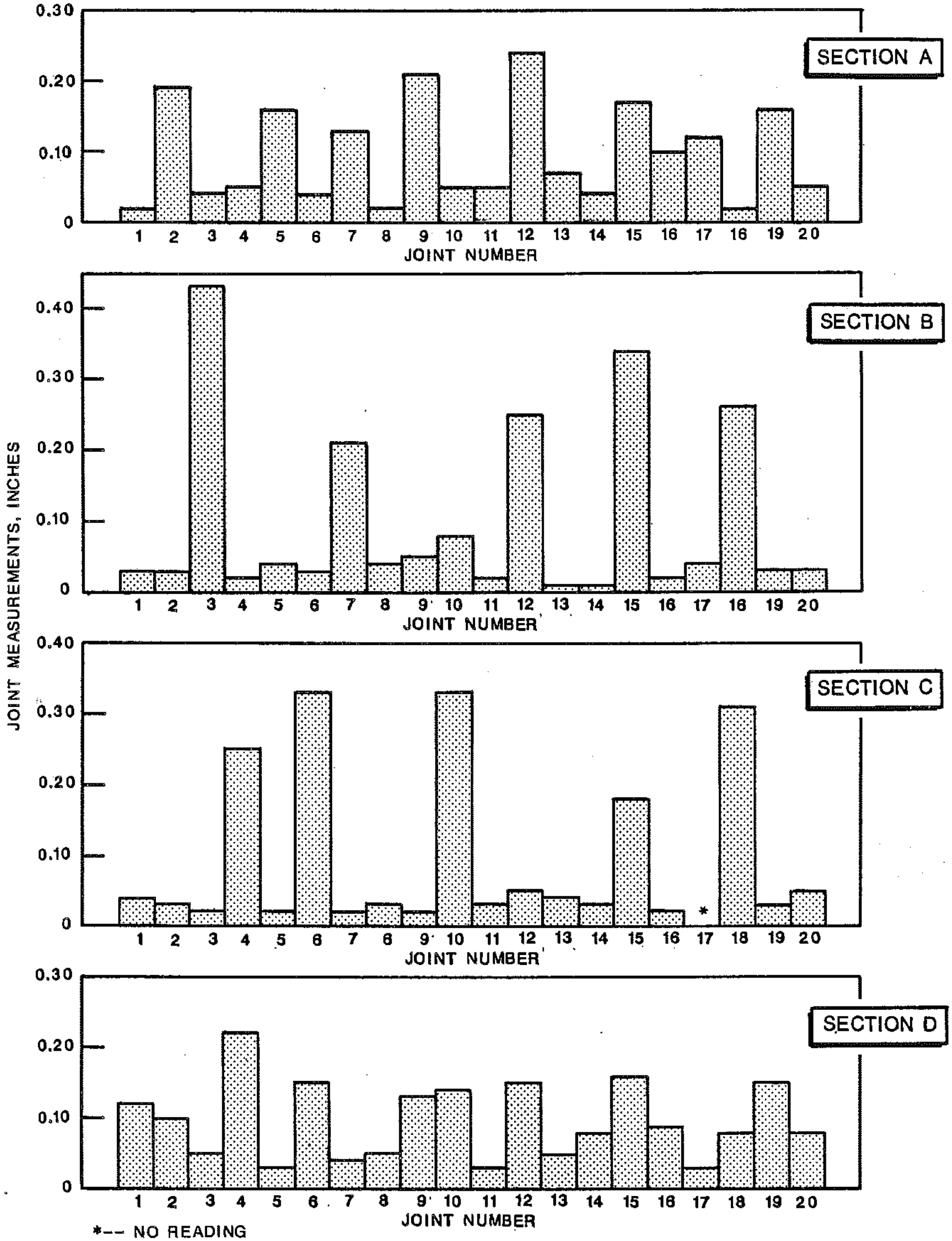


Figure 13. Joint width changes on the I 96 test sections caused by a 56 F temperature change.

Overlay Joint Performance

Measurements of the joint openings in the instrumented sections have been made on a summer-winter schedule. These measurements indicate non-uniformity in the movements of the 20 consecutive joints. This variation is shown graphically in Figure 13 for the four test sections on I 96 and in Figure 14 for the US 23 sections. The joint width changes (openings) shown are the difference between the 1988 summer measurements and the 1989 winter readings.

It will be seen that the largest variations have occurred on Sections B and C on I 96 where the overlay was placed on the CRC pavement which was sawed into 100-ft slab lengths. To determine the cause of these variations, the saw cuts or repairs (free floating) were plotted with respect to location and then the overlay joint locations were superimposed on the layout (Fig. 15). The joint movements shown for Section B on Figure 13 have been written next to joints 1 through 20. In all cases the large movement always occurred where the overlay joint was close (3 ft minimum) to a free-moving joint or saw cut in the underlying pavement.

The reason for the large movements is shown in Figure 16. As can be seen the movement (contraction) of the bottom and top slabs complement each other when the joints are near each other, whereas when the joints in the two slabs are far apart they oppose one another.

The very small movements recorded at some of the overlay joints indicate that the bituminous bond-breaker does not function as intended when the underlying pavement consists of slabs of about 100 ft in length. For shorter slab segments such as those in Sections A and D on I 96 and all four sections on US 23 (Figs. 5 and 6), the variations in movement of the joints are less pronounced, but again the bond-breaker does not provide totally independent movement of the two slabs. It should be noted that the stress pattern created in the overlay slabs as a result of the non-independent movements has not as yet caused any noticeable distress in the overlay or in the joints.

Vertical movement measurements at the instrumented joints show that the dowels are effective in maintaining the smoothness of the joints. A limited number of load transfer efficiency tests conducted with a Falling Weight Deflectometer (FWD) show that the joints in the overlay are 80 percent efficient. This compares very favorably with an efficiency of 62 percent measured at joints in an adjacent 9-in. reinforced recycled concrete pavement placed on an open graded base. FWD mid-slab tests with a 9000-lb load show a 2.4-mil deflection in the 7-in. overlay and 3.4 mil in the 9-in. recycled concrete which indicates superior base support under the overlay.

Since the bituminous bond-breaker layer and underlying concrete slab provide an impermeable base there was concern that moisture--rainwater and salt water from ice and snow removal--would be trapped in the joints

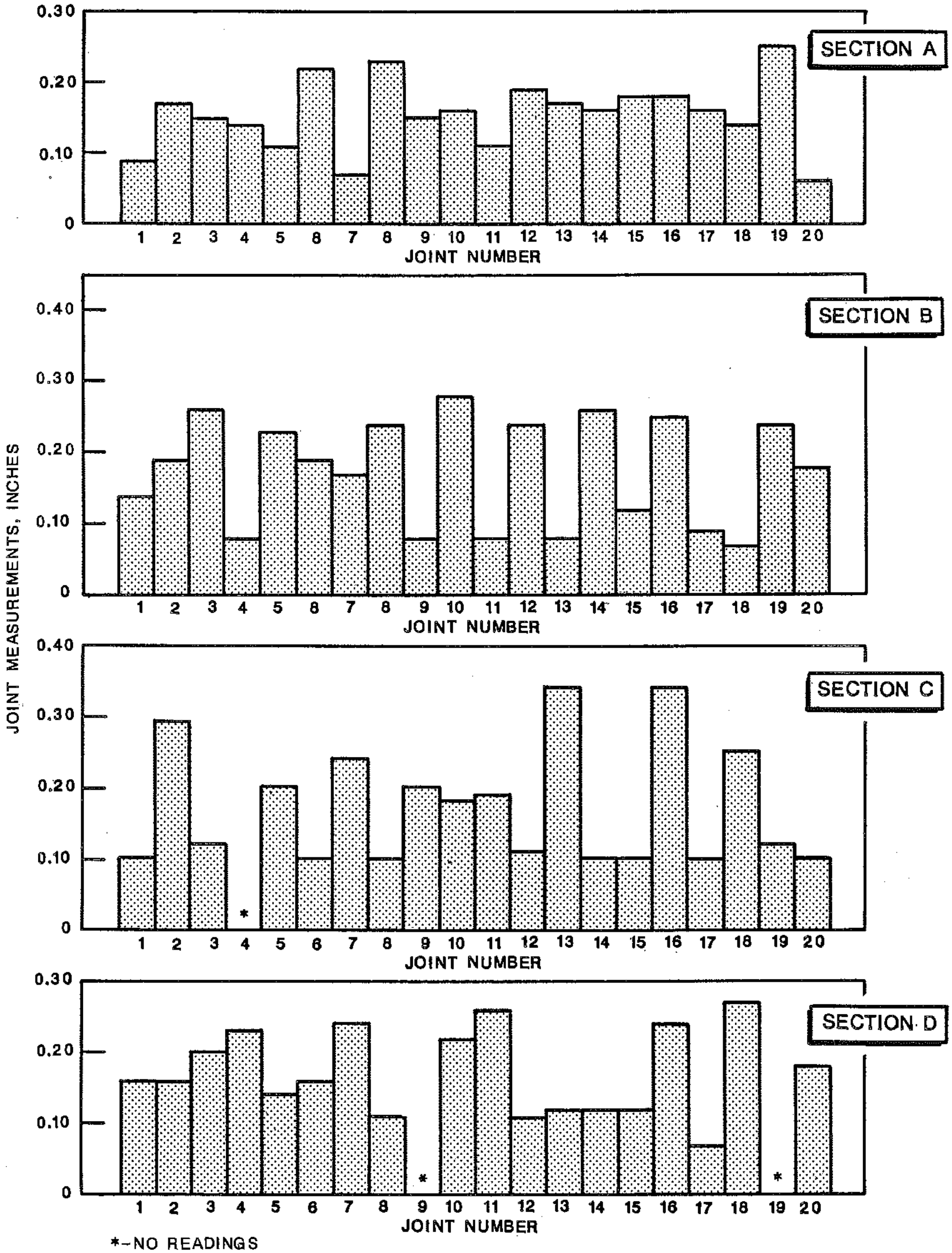


Figure 14. Joint width changes on the US 23 test sections caused by a 75 F temperature change.

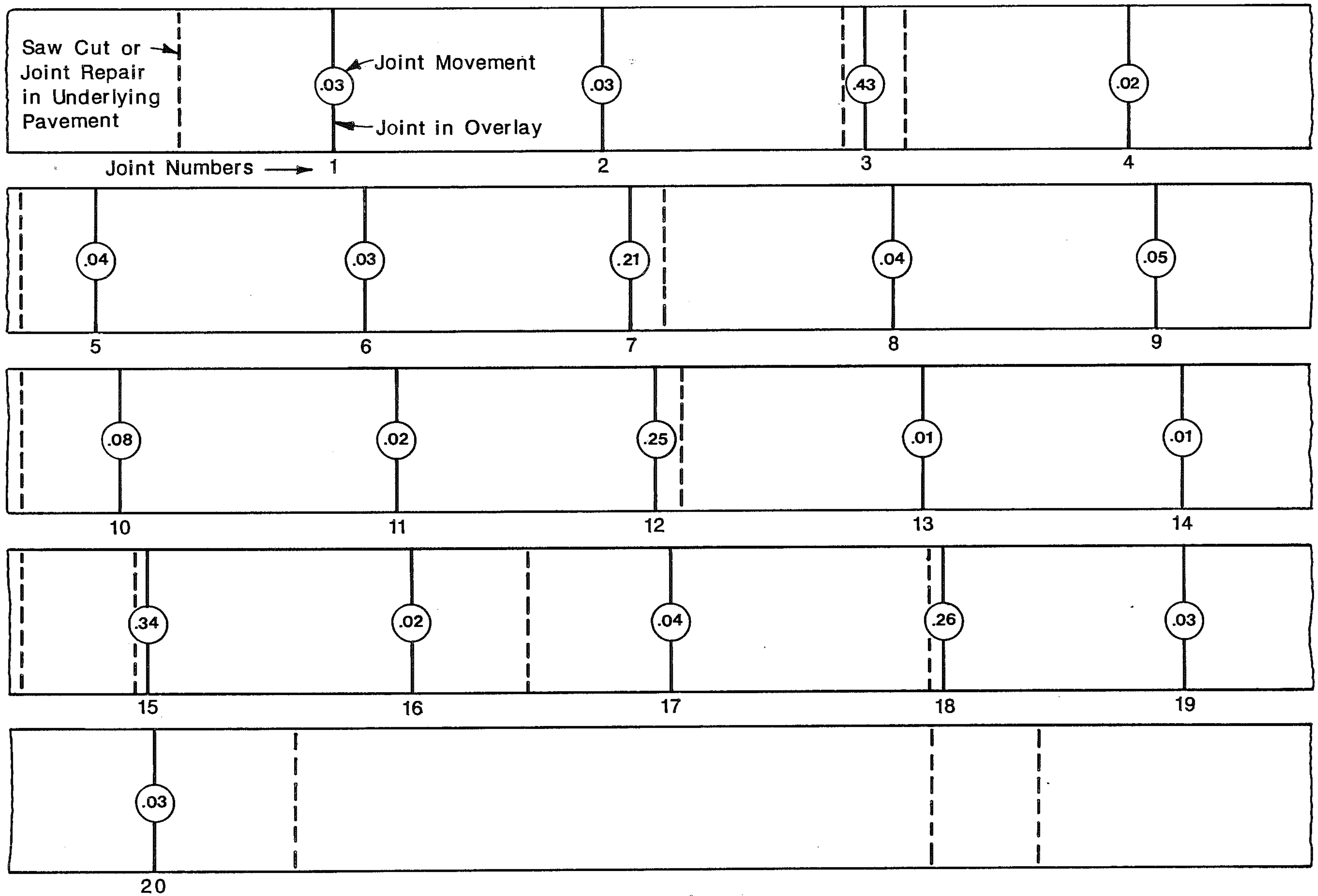


Figure 15. Relation of joint movement to location of joint in the overlay with respect to the joints (saw cuts) in the underlying pavement (Section B, I 96).

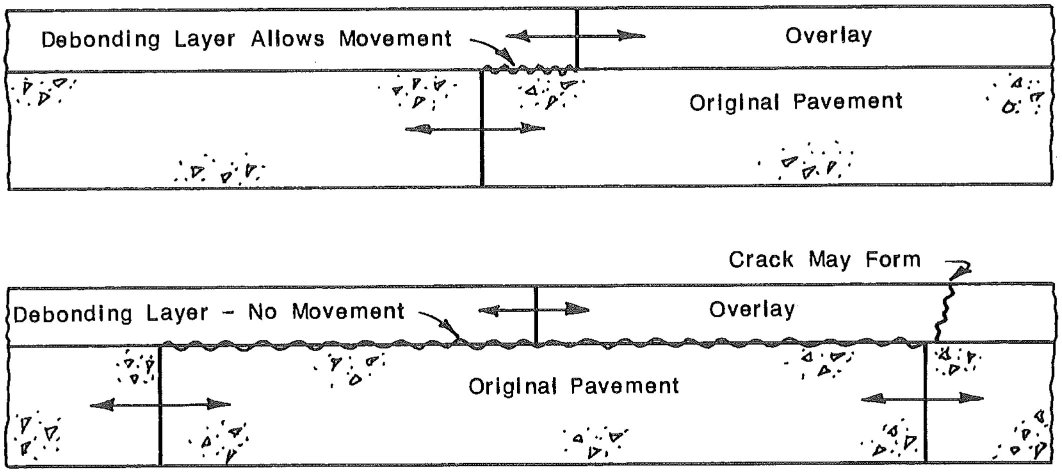


Figure 16. Sketch showing complementary (top) and opposing (bottom) movements in the two concrete slabs.

and promote deterioration at the bottom of the concrete overlay. Because of this concern, cores were taken through six joints on I 96 and four on US 23. As shown in Figure 17, there was no evidence of any concrete deterioration on any of the cores at an age of approximately five years. In general, the joints were very clean, indicating that the neoprene seals had been effective in preventing contamination of the joints.

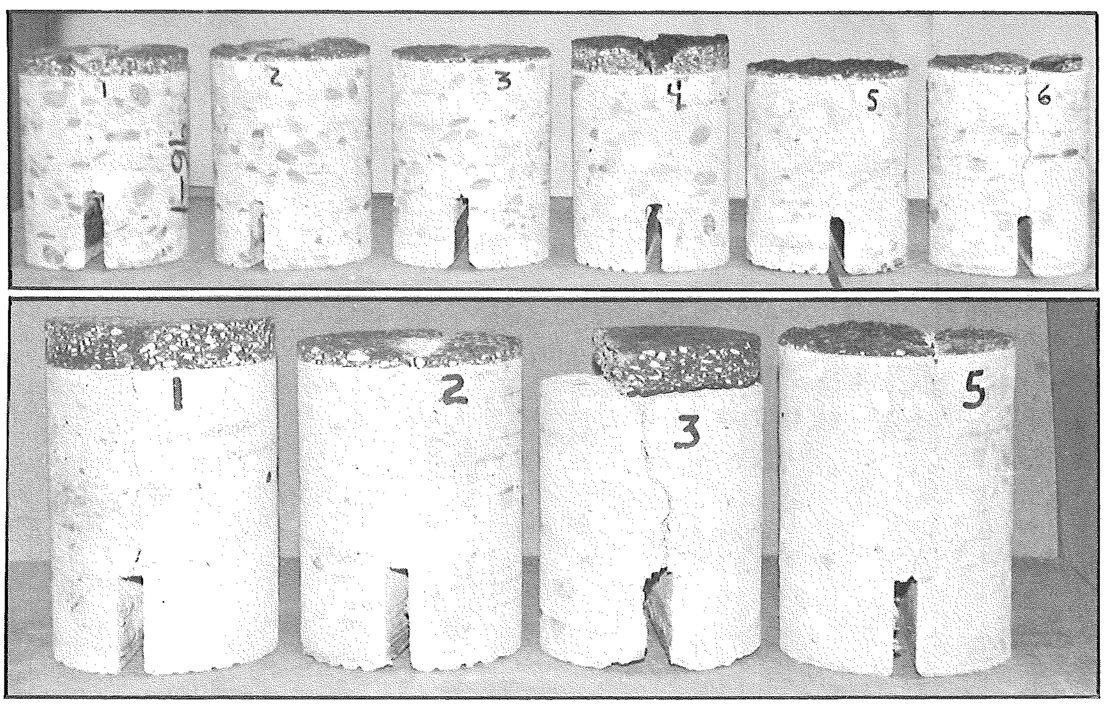


Figure 17. Condition of 5 year old cores (shown upside down) from I 96 (top) and from US 23 (bottom).

Slab Performance

Yearly crack surveys were conducted on the test sections as well as of the entire pavement. The number of slabs with cracks in the traffic lane in each test section after five years service is as follows:

Route	Direction	Section	No. of Cracks
I 96	Westbound	A	1
I 96	Westbound	B	0
I 96	Eastbound	C	3
I 96	Eastbound	D	4
US 23	Southbound	A	0
US 23	Southbound	B	1
US 23	Northbound	C	5
US 23	Northbound	D	23

Only Section D on Northbound US 23 shows any significant amount of cracking. Since the location and distress severity level of joints and cracks (acting as joints) in the original pavement was accurately determined prior to overlaying it is possible to relate the formation of cracks in the overlay to the location and condition of the overlaid pavement. This information is shown in Table 2.

From the table and Figure 18, the cracks in the overlay, with the exception of one, always occurred in the mid-third of the 41 ft slabs.

It appears that the cracks or joints in the original pavement promote reflection cracks in the overlay especially when the point of movement in the original pavement is near the mid-point of the slab in the overlay. The bituminous debonding layer apparently fails to let the two concrete layers move independently which then results in additional tensile stress in the overlay in areas where the stress is already at or near its maximum during decreasing temperature.

The last two columns in Table 2 give the distress severity levels of the cracks or joints in the overlaid pavement that may have promoted the crack in the overlay. The percentage of the cracks or joints with severity levels 1, 2, 3, and 4 (Figs. 7 and 8), were 53, 17, 17, and 13, respectively. This indicates that the more severely deteriorated the cracks or joints are in the old pavements, the more likely the formation of cracks in the overlay.

Other factors promoting cracks in concrete slabs are low base support values and large volumes of heavy trucks. It is speculated that the northbound roadway carries heavier truck loads than the southbound roadway which may explain why cracking in the overlay is absent in Section A on southbound US 23 although the underlying pavement was cracked and deteriorated more than that in Section D (Fig. 5 and Table 1).

TABLE 2
CRACK FORMATION IN OVERLAY IN RELATION TO CRACKS AND JOINTS IN THE ORIGINAL PAVEMENT
(Section D, US-23)

Slab No.	Distance of Crack (ft)		Distress Severity Level*	
	From Overlay Joint	From Joint or Crack in Original Pavement	Traffic Lane	Passing Lane
2	22.0	0.5	1	1
3	25.5	5.6	1	1
5	21.6	0.9	1	1
6	20.2	0.1	1	1
7	19.5	1.1	3	3
12	24.9	2.4	1	1
13	22.2	2.6	1	1
21	24.8	4.6	1	3
22	17.0	5.8	3	1
23	22.0	9.3	1	2
24	5.0	0.5	1	1
25	17.9	3.8	1	2
26	22.5	0.8	1	1
27	18.0	4.8	2	4
33	26.8	3.8	1	1
34	25.6	3.1	4	4
38	16.5	0.1	2	1
39	18.5	7.5	3	3
40	21.0	2.2	3	3
42	18.5	9.1	2	2
47	25.5	6.5	1	4
48	24.0	1.2	4	4
50	15.0	2.3	2	2

*Distress Severity Level of Joints and cracks in Underlying pavement

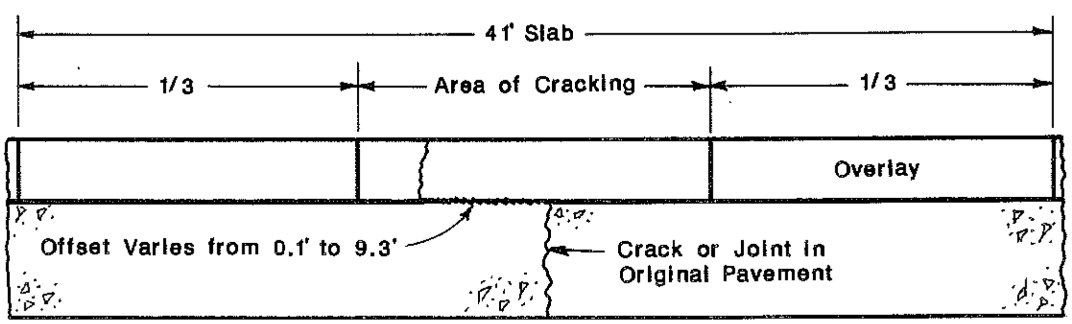


Figure 18. Sketch showing location where cracks most likely will occur.

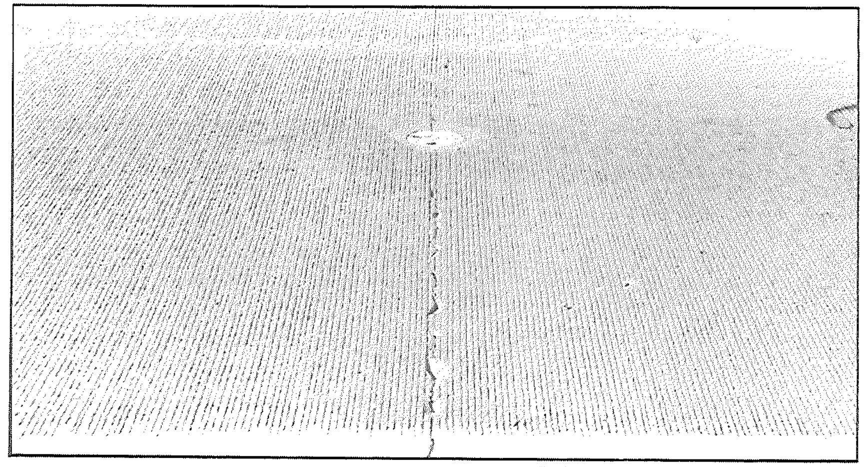
Table 3 summarizes the cracking of slabs since the overlays were constructucted in 1984. It is of interest to note that the I 96 overlay has significantly less cracks than the US 23 overlay and that the northbound roadway of US 23 has significantly more cracks than the southbound roadway. As previously mentioned, a plausible explanation for the difference in cracking on the US 23 project is that the northbound roadway carries larger volumes of heavy truck loads.

TABLE 3
SUMMARY OF CRACK FORMATION
(Traffic Lanes)

Roadway	Year	No. of Slabs with Noted No. of Cracks		
		0	1	2
I 96 Westbound	1986	711	3	1
	1987	711	3	1
	1988	710	4	1
	1989	693	21	1
I 96 Eastbound	1986	376	5	1
	1987	375	6	1
	1988	373	7	2
	1989	363	17	2
US 23 Southbound	1986	983	11	0
	1987	973	21	0
	1988	973	21	0
	1989	895	98	1
US 23 Northbound	1986	914	54	8
	1987	861	107	8
	1988	794	160	22
	1989	686	248	42

Two cores were taken through cracks on northbound US 23 to examine the condition of the reinforcement. One core (No. 4, Sta. 959+56) was taken through a narrow crack which is representative of the majority of the cracks in the overlay. The other core (No. 6, Sta. 972+16) was taken through a wider crack representing only a few of the overlay cracks. Both cracks had formed nearly directly over a crack or joint in the old pavement. Figures 19 and 20 illustrate the surface condition of the crack, the core as removed from the overlay, and the condition of the reinforcement at core locations 4 and 6, respectively.

It is evident that at narrow cracks, such as the one at core location 4, the penetration of moisture or salt water from ice and snow removal is still very minimal and there is no significant corrosion of the reinforcement. It should also be noted that although the overlay crack had formed



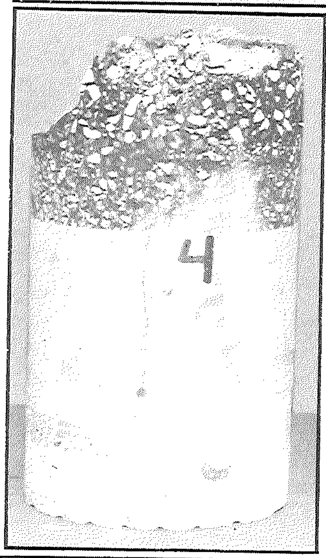


Figure 19. Surface condition of crack (above). Core with attached debonding layer and cold patch material (left), and condition of reinforcement (below).

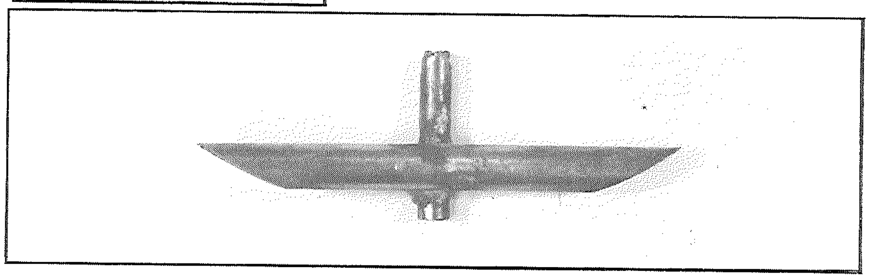
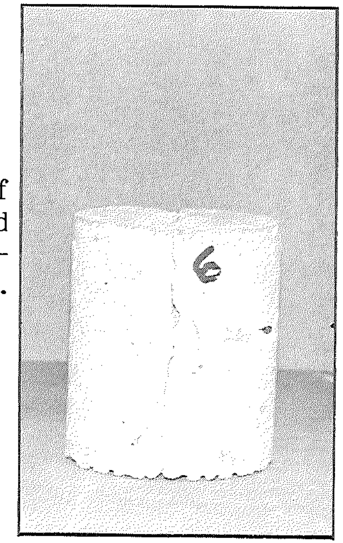
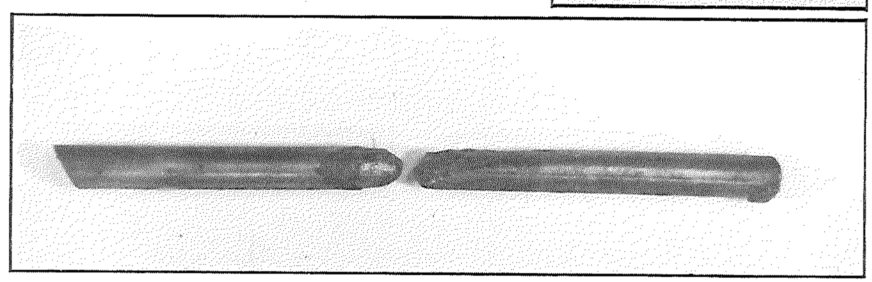


Figure 20. Surface condition of work (above). Core as removed from overlay (right), and fractured reinforcement (below).





over a crack or joint in the old pavement the surface condition of the overlay crack indicates adequate base support. At core location 6, it is obvious from the surface condition of the crack that the distress in the old pavement resulted in inadequate base support. Thus, load and temperature stresses plus easy access of moisture and salt water through the wide crack resulted in the premature failure of the reinforcement at this location.

COST COMPARISON

An alternative to using a concrete overlay is the reconstruction of the roadway using recycled concrete. One of the factors entering into the decision whether to recycle or overlay is the life cycle cost of each construction method. Since the overlays and most of the recycled projects are only a few years old, life cycle costs cannot be calculated as yet with any accuracy.

A comparison of the initial construction costs using the contractor's bid prices shows that the average costs per sq yd per in. of thickness were $1.25 and $1.50 for the recycled concrete and the overlay concrete, respectively. Thus, a 10-in. recycled concrete pavement would cost $12.50/sq yd and a 7-in. overlay $10.50/sq yd which would amount to a $28,160 saving per mile of a 24-ft wide overlay. The 3/4-in. bituminous debonding layer was $7,600 less per mile of two-lane roadway compared to the 4-in. open graded drainage course used under the recycled concrete. Based on these prices, a saving in initial cost of approximately $35,000 per mile of two-lane roadway is possible, by using an overlay instead of recycling.

In addition to the saving in initial cost, the overlay offers other advantages over recycled pavement. The overlay contains virgin aggregate which if properly selected should have better freeze-thaw durability and better abrasive resistance than recycled aggregate. The compressive and flexural strength of the overlay concrete is higher than that of recycled concrete. These better qualities of the overlay concrete plus the initial saving in cost favor the overlay with respect to life cycle costs. The major disadvantage of a concrete overlay is that it may not be cost competitive in areas where structures are closely spaced because of the cost of solving clearance problems.

CONCLUSIONS

Based on data collected on the performance of the two 7-in. unbonded concrete overlays, it is concluded that their overall performance has been satisfactory. In relation to the specific objectives of the study—performance of the bituminous debonding layer and the life cycle cost of the overlay—the following has been concluded:

1) The bituminous separation layer does not allow fully independent movements of the overlay and the underlying concrete pavement. This results in large variation in movements of the joints, especially when

the underlying pavement has long slab lengths and when the movement point in the overlaid pavement is near the joint in the overlay. It should be noted that this unequal movement of the joints has only had a marginal effect on the overlay's performance so far.

2) A savings in original cost of approximately $35,000 per mile of a two-lane, 7-in. overlay is possible, compared to a 10-in. recycled pavement. Field evaluation and laboratory data indicate a favorable life cycle cost for the overlay compared to recycled pavement, based on the first five years of life.

Additional conclusions are:

3) Load transfer efficiency of joints in the overlay is 29 percent greater than that for joints in a 9-in. recycled pavement.

4) Mid-slab deflections are 25 percent less in the overlay compared to a 9-in. recycled pavement.

5) Coring and measurements indicate that cracks or joints in the original pavement promote cracks in the overlay at points where the stresses in the overlay are accentuated by the underlying pavement.

6) Steel fractures are likely to occur over severely distressed joints or cracks in the underlying pavement, apparently because of high tensile stress during slab contraction and reduced base support by the heavily patched joint or crack.

7) Cores through joints showed no deterioration of the concrete at the interface with the impermeable bituminous layer.

RECOMMENDATIONS

It is recommended that concrete overlays be considered for use as an alternative to reconstruction in areas where the existing facility can economically accommodate the extra layer of concrete. The performance of the 7-in. overlay on US 23 indicates it may be underdesigned for the truck loadings it carries; therefore, it is recommended that future overlays be carefully designed to reflect both truck volumes and the condition of the pavement to be overlaid. It is also suggested that the most severely deteriorated joints and cracks be repaired full-depth to minimize premature steel fracture in the overlay at such locations. Although the bituminous debonding layer did not provide completely independent movement in the two concrete layers, its performance to date has not had any substantial detrimental effect; however, it is suggested that consideration be given to improve the effectiveness of the debonding layer, perhaps by applying a coat of curing compound to the bituminous surface. The requirement that joints in the overlay be at least 3 ft away from a joint or crack in the underlying pavements must be adhered to on future overlays.