FINAL REPORT

LONG TERM MONITORING OF BROKEN AND SEATED PAVEMENTS

Submitted By

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and
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16. Abstract

This report presents details of a study conducted to evaluate the long term performance of asphalt overlays on broken and seated (B/S) concrete pavements, using field experiments. The primary purpose of this study is to evaluate the effectiveness of breaking and seating as a rehabilitation strategy for retarding reflection cracking in asphalt concrete (AC) overlays on jointed reinforced concrete pavements. Test sections were constructed by milling the original AC layer, breaking and seating the concrete slabs and constructing new AC overlays. Control sections were constructed adjacent to the B/S sections in the same way, but without breaking the underlying concrete slabs. The test sections carried a large volume of traffic. The original pavements selected in this study were fairly uniform with respect to their structural and surface conditions. Two types of pavement breakers were used in this study, namely guillotine and pile hammer. The extent of breaking was closely monitored. The performance of the test sections was monitored for a total period of nine years. The monitoring data included deflection measurements, crack mapping, a pavement condition surveys and roughness surveys on the original pavement and on the overlay. The results, in general, strongly indicate an improved performance of AC overlays on broken and seated concrete pavements. The B/S treatment has a significant effect on the structural response and behavior of the resulting pavement. Breaking the concrete slabs into smaller pieces resulted in a reduction in the flexural strength, an increase in the surface deflection (50% to 100%), and a decrease in AREA and Spreadability (20 to 30%). Breaking and seating has been extremely effective in delaying and minimizing reflection cracking. Hence, the breaking and seating procedure does indeed result in improved pavement performance. Ultimately, economics and serviceability will govern its use, based on the length of time future maintenance and rehabilitation is deferred.

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DISCLAIMER

EXECUTIVE SUMMARY

Long Term Monitoring of Broken and Seated Pavements

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Arudi Rajagopal & Issam Minkarah
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This report presents details of a study conducted by the University of Cincinnati (UC), in association with the Ohio Department of Transportation (ODOT), to evaluate the long term performance of asphalt overlays on broken and seated (B/S) concrete pavements, using field experiments. The primary purpose of this study is to evaluate the effectiveness of breaking and seating as a rehabilitation strategy for retarding reflective cracking in asphalt concrete (AC) overlays on jointed reinforced concrete pavements (JRCP). Several test sections were constructed by milling the original AC layer, breaking and seating the concrete slabs and constructing new AC overlays. Control sections were constructed adjacent to the B/S sections in the same way, but without breaking the underlying concrete slabs.

Two types of pavement breakers were used in this study, namely guillotine and pile hammer. The majority of the concrete slabs were broken into 0.46 m (18") segments. The extent of breaking was closely monitored. The performance of the test sections was monitored for a total period of nine years. The monitoring data included deflection measurements, crack mapping, pavement condition surveys (PCR) and roughness surveys on the original pavement and on the overlay. The results indicate that the B/S treatment has a significant effect on the structural response and behavior of the resulting pavement. Breaking the concrete slabs into smaller pieces resulted in a reduction in the flexural strength, an increase in the surface deflection (50% to 100%), and a decrease in AREA and Spreadability (20 to 30%). The Edward Ratio has been consistently high on B/S pavements (up to 30%) indicating a structural behavior closer to flexible pavements.

The reflection cracks on all the control sections appeared within two years after the AC overlay and within four years, more than 80% of the joints in all the control sections showed reflection cracks. The B/S sections were relatively free of cracks after nine years. In particular, the test sections where a pile hammer was used had less than 17% joint reflection cracks, while the control sections in the vicinity had 80% to 100% joint reflection cracks. This result clearly indicates that breaking and seating has been extremely effective in delaying and minimizing reflection cracking.

The primary difference in cost of control and B/S sections could be in the type, extent and timing of major rehabilitation. The mitigation of reflection cracking will cause the pavement PCR and serviceability to remain higher for a longer period of time than if the reflection cracks were allowed to come through. The lack of reflection cracking translates into a delay in future maintenance and rehabilitation which will more than make up or the extra cost of breaking the pavement. The difference in the cost will ofcourse depend on the type, extent and timing of major rehabilitation.

Based on the results of this study it is concluded that breaking and Seating is an effective technique for the rehabilitation of composite pavements (AC over JRCP) and it provides a cost-effective solution for the maintenance and rehabilitation of in-service composite pavements.

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ABOUT THIS REPORT

This report presents details of a study conducted by the University of Cincinnati (UC), in association with the Ohio Department of Transportation (ODOT), to evaluate the long term performance of asphalt overlays on broken and seated concrete pavements, using field experiments. The primary purpose of this study is to evaluate the effectiveness of breaking and seating as a rehabilitation strategy for retarding reflective cracking in asphalt concrete (AC) overlays on jointed reinforced concrete pavements. The study was performed in two phases. Phase I was performed between 1991 and 1994 and Phase II study between 1996 and 2001. Some of the tasks performed during Phase I include the following:

- planning the field experiment
- selection of test sections
- collection of relevant data on existing pavements
- laboratory testing of pavement materials
- construction of overlays
- documentation of construction procedures and construction costs, and
- performance monitoring for two years after overlay construction.

A final report of Phase I study [1] was submitted in 1995. The Phase II study was initiated to collect additional data to evaluate the long term performance of asphalt overlays. The present report synthesizes the efforts during the period 1996 through 2001. In order to make it easy for the reader, many important sections from the Phase I report are included here.

The primary issues considered in the present report include the following:

- What is the effect of breaking and seating on the structural integrity of the pavement?
- What are the consequences of breaking and seating: delay, minimize or eliminate reflection cracking?
- Is breaking and seating an effective technique for the rehabilitation of in-service composite pavements in Ohio?
- Are there any cost advantages in applying this technique?
- Is this a recommended procedure in Ohio?
- What changes are needed to the ODOT's current specifications?
- In general, what can this research do to benefit ODOT?

SUMMARY OF DATA PRESENTED IN THE STUDY

Table 1 shows a summary of the test sections in the study and the data presented. More details about the test sections, data collection procedures, analysis and results are presented in the following sections.

Table 1. Summary of Data Presented in the Study

Section	# of years monitored since last major rehabilitation	Data presented
I-71, Stn. 726 to 780	8	• deflection (statistical analysis of maximum deflection, Spreadabilily, AREA, and Edward Ratio); discussion on mechanistic behavior • reflection cracking (charts showing initiation and progression of cracking) • Pavement Condition Rating (PCR) • International Roughness Index (IRI) • maintenance (crack sealing data)
I-71, Stn. 35 to 88	8	
SR-4, Stn. 217 to 270	7	
SR-4, Stn. 105 to 160	7	
SR-4, Stn. 335 to 436	7	
I-70, Stn. 304 to 368	2	• reflection cracking (charts showing initiation and progression of cracking)

Note:

- Each section is approximately 1.6 km (1.0 mile) long
- Stn. means station point.
- Definition of Spreadability, AREA and Edward Ratio presented later in the report.
- The above mentioned monitoring data have been collected once, every year

BACKGROUND

Since 1989, ODOT has used the Break and Seat (B/S) technique as one of the methods for rehabilitating Jointed Reinforced Concrete Pavements (JRCP). Ten projects with a total length of 63 miles have been rehabilitated with AC overlays after breaking and seating the reinforced concrete pavements. Performance studies of these projects were not conclusive. As a result, there is some disagreement in Ohio, from district to district, on the effectiveness of this technique [2]. To address the above issue, ODOT initiated the following two research projects:

Special Project - 202

The first project was developed in 1991 as part of the Federal Highway Administration (FHWA) sponsored Special Project 202, Break and Seat of JRCP (SP-202) [3]. The objective of SP-202 was to determine the effectiveness of the break and seat rehabilitation strategy for JRCP.

The Ohio SP-202 test sections were constructed during May, 1991 as part of a larger, 7.98 mile (milepost 13.20 to 21.18), break and seat rehabilitation project on Interstate 70 east near Zanesville in Muskingum County. The site lies in an unglaciated area of Ohio along the western edge of the Allegheny Plateau approximately 60 miles east of Columbus (Figure 1). The topography consists of rolling hills. The sites were selected to lie entirely in either cut or fill. Bedrock, visible in the cuts, is sandstone, coal and limestone of Pennsylvanian age.

The existing pavement in this section is a jointed, 22.5 cm (9") thick, dowelled, wire mesh reinforced, portland cement concrete (PCC) on a 15 cm (6") dense graded aggregate subbase constructed in 1963. The joint spacing is 18.3 m (60 feet) and many slabs had third point cracks.

The core SP-202 sections are approximately 305 m (1000 feet) long. The SP-202 sections include a 17.5 cm (7") Hot Mix Asphaltic Concrete (HMAC) overlay of an existing PCC pavement including; an unbroken (control) section, and sections broken into 0.15 m (6"), 0.46 m (18"), and 0.76 m (30") patterns using a 6.0 ton guillotine hammer. More details about SP-202 can be seen in Reference 3.

Phase I University of Cincinnati Research

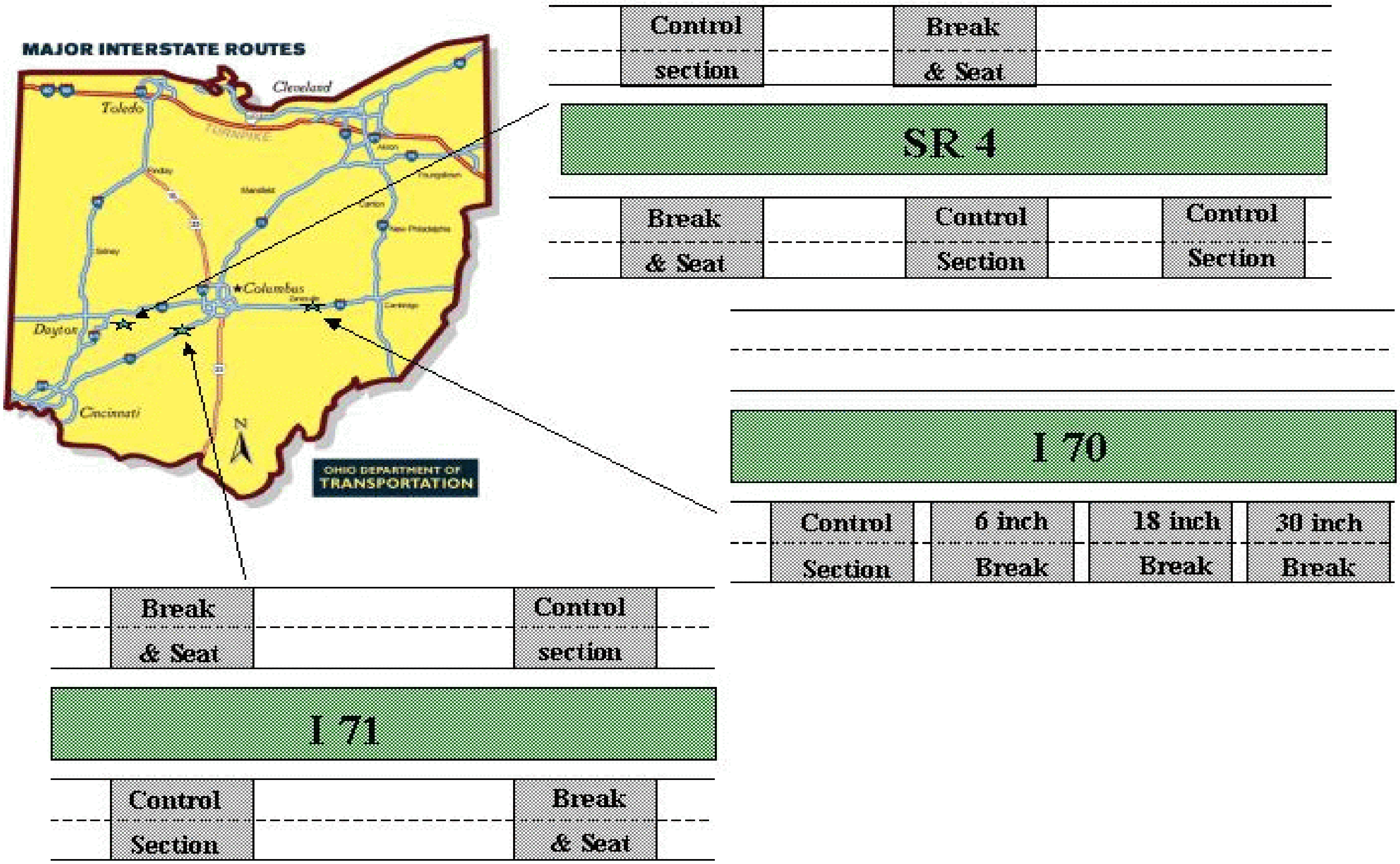
In an effort to include more test sections and additional variables like traffic and environmental characteristics in the evaluation of the break and seat technique, ODOT initiated another research in 1991 with UC. The UC research project included nine, approximately 1.6 km

(1.0 mile) long, sections of in-service composite pavements (AC over JRCP). Four of these sections are on I-71, South of Columbus, and five on SR-4 near Dayton. The location and layout of these test sections are shown in Figure 1.

Four sections were rehabilitated by milling the original AC layer, breaking and seating the concrete slabs and constructing new AC overlays. The remaining five sections were rehabilitated in the same way, but without breaking the underlying concrete slabs.

The concrete slabs on I-71 were broken with a 5440 kg ***guillotine*** hammer, while the sections on SR-4 were broken with a ***pile*** hammer. Seating the sections was accomplished with five passes of a 40,350 kg pneumatic roller.

Figure 1. Layout of Test Sections for Break and Seat Project



Performance Monitoring

Performance monitoring included periodical evaluation of structural characteristics using deflection measurements and a visual survey of surface characteristics. A photographic record of the condition of the joints and cracks was also kept. As a result, a large volume of photographs depicting the condition of joints and cracks prior to overlay and the new cracks formed in the AC overlay was obtained. These photographs were used to counter-check the location of joints and cracks and to ascertain the severity of the cracks.

Summary of Results of Phase I Study

Structural Response

The structural parameters investigated on the AC overlays are: (i) maximum deflection W_1 (ii) Spreadability and (iii) ratio of W_1/ W_5,. W_1 is the reading of the sensor closest to the Dynaflect load. W_5 is the reading of the sensor farthest from the load and is indicative of subgrade strength.

The deflections on the AC overlays were also used to backcalculate the moduli and to compare the mechanistic behavior of B/S to the control sections.

For all the test sections, the breaking and seating procedure resulted in an increase of surface deflection, a reduction in Spreadability, and an increase in the W_1/W_5 ratio. The W_1/W_5 ratio, also called Edward Ratio [4], is an empirical factor which suggests that if the ratio of the two deflections is greater than three, the pavement is acting as a flexible pavement and should be analyzed as such. The increased surface deflection is due to a loss of flexural strength. The lower Spreadability and higher W_1/W_5 of the B/S pavements indicate a behavior similar to flexible pavements. On the SR-4 sections where a pile hammer was used, the Spreadability values were considerably lower and W_1/W_5 values were higher than those on I-71 where a guillotine hammer was used. This is due to the higher degree of breakage in the SR-4 sections. The structural response of the test sections was fairly consistent during the study period.

Surface Characteristics

The I-71 sections survived the Winter of 1993 without developing any cracks. However, the Winter of 1993 was mild whereas the Winter of 1994 was very severe. The data collected from weather reports, indicated very low temperatures persisting over a long time during the winter of 1994. After the Winter of 1994, cracking was noticed in all control sections. Only two cracks were noticed in the two miles of B/S sections on I-71 and none in the SR-4 B/S sections. All these cracks were of low severity.

All the sections were revisited after the Winter of 1995. There were 3 to 33 new cracks in each of the control sections. Cracks also appeared in the two B/S sections on I-71 where the guillotine hammer was used. There were no cracks in the B/S sections on SR-4. These sections were broken with a pile hammer which proved to be more successful in delaying cracks than breaking with the guillotine hammer. This is obviously due to the higher degree of breakage achieved with the pile hammer. However, the total number of cracks in the B/S sections was still small in comparison to the number of cracks in the control sections.

Conclusions from Phase I study

The following conclusions were drawn from the results of the Phase I study of controlled break and seat research project:

1. Breaking and seating delayed reflection cracking in the AC overlay.
2. The break and seat sections exhibited significantly less reflection cracking than the control sections.

3. As observed from the FWD tests, breaking and seating resulted in loss of structural capacity of the pavement.
4. The type of breaking equipment and the extent of breaking have a significant effect on the performance of the AC overlays.

SHORT TERM EFFECTIVENESS VS. LONG TERM EFFECTIVENESS

Varied opinions exist among highway professionals within ODOT and across the country on the long term effectiveness of breaking and seating. Some professionals believe that, while broken and seated sections tend to perform better early on, they will develop cracks within a few years, and their overall condition would deteriorate until performance is equal to the control sections. The NAPA survey [5] reported observations on the field performance of several B/S projects in various States. The survey indicated a general reduction in the number of reflective cracks through the overlay during the first few years following construction of a B/S project. However, after 4 or 5 years, the B/S sections exhibited approximately the same number of reflective cracks as the control sections. California and Kentucky reported very good overall performance using this technique. California's experience is based on the cracking and seating of unreinforced JPCP with short slabs, while Kentucky's experience is with breaking and seating JRCP with long slabs, wire mesh reinforcing, and dowelled joints. Both states consider the use of the technique cost effective.

During a visit to the test sites in the Fall of 1995, the researchers also noticed additional cracks in the asphalt overlay on the broken and seated pavements. Pursuant to discussions with ODOT, it was decided to continue the study to collect and build data on the initiation and progression of cracks and provide more reliable information to establish the long-term effectiveness of breaking and seating as a rehabilitation technique. ODOT retained the UC researchers to continue monitoring the performance of the test sections for a period of five years from 1996 to 2001. The present report synthesizes the activities performed during the last five years and provides guidelines for the future application of the break and seat technique in the State of Ohio.

PRESENT STUDY: OBJECTIVES AND SCOPE

The objective of this investigation is to "monitor the asphalt overlays on the control and the broken and seated sections of I-71, SR-4 and I-70 (SP-202 Project) for five more years, to obtain relevant information on the long-term performance of the breaking and seating procedure".

The research was performed from 1996 to 2001 on the following test sections:

(i) I-71, Fayette County, Station 726+63 to 779+43, (south bound lanes broken and seated, north bound lanes control sites);

(ii) I-71, Fayette-Madison County, Station 35+00 to 88+00, (north bound lanes broken and seated, south bound lanes control sites);

(iii) SR-4, Montgomery County, Station 217+00 to 270+50, (north bound lanes broken and seated, south bound lanes control sites);

(iv) SR-4, Green County, Station 105+50 to 160+50, (south bound lanes broken and seated, north bound lanes control sites);

(v) SR-4, Montgomery County, Station 335+00 to 436+00, (north bound lanes only, control sites);

(vi) I-70, Muskingum County (SP-202 Project), Station 304+72 to 368+76, (east bound lanes).

Table 2 provides details of the pavement sections chosen for the study.

Table 2. Details of Test Sections

Section ID	Lanes/ Direction	ADT	Trucks %	Joint Spacing 'm'	# of Joints		Joints Patched		Slab Thickness 'cm'	Existing AC 'cm'	AC Overlay Thickness 'cm'	Remarks
					NB	SB	NB	SB				
I-71 (FAY) Stn. 726+63 to 779+43	2, each 3.6m	22,880	23	18.2 (60 ft.)	94	93	93	73	22.9 (9 in.)	7.6 (3 in.)	21.6(8.5 in.)	SB B/S NB Control
I-71 (FAY-MAD) Stn. 35+00 to 88+00	2, each 3.6m	22,880	23	18.2 (60 ft.)	93	86	90	78	22.9 (9 in.)	7.6 (3 in.)	21.6(8.5 in.)	NB B/S SB Control
SR-4 (MOT) Stn. 217+00 to 270+00	2, each 3.6m	31265	5	18.2 (60 ft.)	84	82	56	51	22.9 (9 in.)	7.6 (3 in.)	16.5(6.5 in.)	NB B/S SB Control
SR-4 (GRE) Stn. 105+50 to 160+50	2, each 3.6m	31265	5	18.2 (60 ft.)	93	93	69	93	22.9 (9 in.)	7.6 (3 in.)	16.5(6.5 in.)	SB B/S NB Control
SR-4 (MOT) Stn. 335+00 to 436+00	2, each 3.6m	31265	5	18.2 (60 ft.)	61		25		22.9 (9 in.)	7.6 (3 in.)	16.5(6.5 in.)	Control only
I-70 (MUS) 304+72 to 368+76	2, each 3.6m	38,330	30	18.2 (60 ft.)	East bound lanes only; no joint patching				22.9 (9 in.)	21.6 (8.5 in.)	17.5(7.0 in.)	Four sub-sections, each 1000 feet

The data required has been obtained by periodically monitoring structural and functional characteristics of the test sections. The monitoring program included the following:

- crack mapping, and
- deflection survey.

Also, the following data were collected from ODOT's pavement management database [6]:

- condition data (Pavement Condition Rating, PCR)
- surface profile (International Roughness Index, IRI)

CURRENT STATUS OF TEST SECTIONS

Table 3 shows the current status of the test sections, the year they were originally rehabilitated and when they were included in the study.

Table 3. Current Status of Test Sections

Section ID	Year of Rehabilitation	Year included in the study	Current Status
I-71 (FAY) Stn. 726+63 to 779+43	1992	1992	Sections rehabilitated in 2000
I-71 (FAY-MAD) Stn. 35+00 to 88+00	1992	1992	
SR-4 (MOT) Stn. 217+00 to 270+50	1993	1992	Sections proposed to be rehabilitated in 2003
SR-4 (GRE) Stn. 105+50 to 160+50	1993	1992	
SR-4 (MOT) Stn. 335+00 to 436+00	1993	1992	
I-70 (MUS) 304+72 to 368+76	1991	1996	Sections rehabilitated in 1999

The I-71 and SR-4 test sections were monitored systematically since 1992, resulting in a wealth of information on their behavior. The I-70 test section (constructed in 1991) was included in the present study only in 1996. This section was again rehabilitated in 1999. Hence most of the discussion in this report relates to the I-71 and SR-4 sections while a limited discussion is included for the I-70 section. The researchers held detailed discussions with the ODOT engineers on the criteria used by them for a decision to rehabilitate the I-71 sections in 2000 and the I-70 sections in 1999, and their proposal to rehabilitate SR-4 sections in 2003. A detailed report on this discussion is presented at the end of this report.

CONSTRUCTION

Construction involved the removal of the original 7.6 cm (3 in.) asphalt layer, breaking and seating the PCC slabs (only on the B/S sections), and placing an AC overlay. The I-71 sections were overlaid with a 21.6 cm (8.5 in.) thick AC overlay in three layers (item 301 14 cm (5.5 in.) + 446 Type II (4.45 cm (1.75 in.) + 446 3.175 cm (1.25 in.)). The SR-4 sections received a 16.5 cm (6.5 in.) thick AC overlay, in three layers (item 301 7.62 cm (3.0 in.) + 446 Type II (4.45 cm (1.75 in.) + 446 3.175 cm (1.25 in.)). The overlay thickness design was made by ODOT engineers using ODOT design procedures. In all sections, a 10.2 cm (4 in.) diameter longitudinal underdrain was installed along the shoulder at a depth of 0.9 m (3 ft.) below the top of the concrete pavement. Construction of the AC overlays on the I-71 sections was completed in September 1992 and the overlays on the SR-4 sections were completed in September 1993. The SP-202 sections were paved with a nominal 17.8 cm (7") AC. The overlay included a base, intermediate and wearing course.

Breaking and Seating

The ODOT specifications [7] for breaking and seating are as follows: 'The device to be used for breaking the exposed rigid pavement shall be approved by the Engineer and be capable of producing the desired pattern without significant displacement or spalling of the rigid pavement. The widest dimension of the guillotine hammer permitted is 1.8 m (6 ft.). A 40,350 kg (50 ton) pneumatic tire roller shall be used for seating the broken rigid pavement. The exposed rigid pavement shall be broken full depth to form concrete segments so that the largest dimension shall conform to the criteria as below:

1. The majority of the concrete segments shall be less than 0.45 m (18 in.);
2. No more than 20% of the segments shall be greater than 0.61 m (24 in.);
3. No concrete segments shall be greater than 0.76 m (30 in.).

The breaks shall be accomplished without any positive vertical displacement of the concrete greater than 7.6 cm (3 in.) and shall be visible to the Engineer without the aid of water. The breaking operation shall not form continuous longitudinal cracks'.

The concrete slabs on I-71 were broken with a 5440 kg, 1.8 m (6 feet) wide, guillotine hammer, dropped at 0.46 m (18") intervals. Two passes of the 1.8 m (6 ft.) wide hammer were required in each lane to cover the entire 3.6 m (12 ft.) width.

The sections on SR-4 were broken with a pile hammer on a 0.46 m (18") by 0.46 m (18") grid. Figures 2 and 3 show the pavement breakers in operation.

An attempt was made to get uniform breakage in each section; however, most of the pavements broken with the guillotine hammer had a problem where drops overlapped, usually in the middle of the lane. This area was cracked much more than other parts (see Figure 2). Breaking with

Figure 2. Pile Hammer in Operation on SR-4 Sections

Figure 3. Breaking Pattern with Guillotine Hammer

all types of hammers resulted in thorough slab cracking and no additional effort was made to break the reinforcement. Breaking was more extensive with the pile hammer.

About five lane miles of pavement could be broken in each working day with the guillotine hammer while, only about one lane mile was broken when using the pile hammer. Breaking caused some traffic disruption. However, no data was collected on traffic behavior through the work zone during the breaking operation. Seating the sections was accomplished with five passes of a 40,350 kg (50 ton) pneumatic roller.

MATERIAL SAMPLING AND ANALYSIS

Six core samples were taken from each mile of the original pavement on I-71 and SR-4 for laboratory testing. Two samples were taken at joints, two at cracks and two in the center of slabs showing no deterioration. The concrete core samples were tested in the lab for compressive strength. The concrete core thickness was measured and in each case, the thickness was found to be 22.5 cm (9 in.) Asphalt samples were not tested. Soil samples from Shelby tubes were tested for Atterberg's limits and sieve analysis, for the purpose of classification. In addition, soil samples were taken from the shoulder for density, CBR and resilient modulus determination. The lab test results on the concrete core samples and soil characteristics are shown in Table 4.

As can be seen, there is a large variation in the lab compressive strength of the concrete samples. The strength values ranged from 20685 kPa to 52400 kPa (3000 psi and 7600 psi). However, the compressive strength of most samples was between 34475 kPa to 48265 kPa (5000 psi and 7000 psi).

The liquid limit, plasticity index and sieve analysis test results were used to classify the subgrade soils using the AASHTO Soil Classification System [8]. The subgrade soils from the I-71 site were classified as type A-4 (silty soils). The soil samples from the SR-4 sections were classified as type A-6 (clayey soils), see table 5.

Table 4. Results of Laboratory Tests on Concrete Core Samples

Section ID		Lab Measured Compressive Strength, psi					
		at mid slab location		at cracks		at joints	
		sample 1	sample 2	sample 1	sample 2	sample 1	sample 2
I-71, (FAY) Stn. 726 to 779	NB	6282	5775	6089	-	3655	-
	SB	5574	4288	3786	-	2999	5973
I-71, (FAY-MAD) Stn. 35 to 88	NB	-	-	-	-	-	-
	SB	5366	5639	5135	6007	4854	6335
SR-4, (MOT) Stn. 217 to 270	NB	5178	6093	4666	2702	4774	7179
	SB	4212	-	5326	-	5839	-
SR-4, (GRE) Stn. 105 to 160	NB	6536	-	6041	6985	-	-
	SB	5793	-	7591	-	5575	-
SR-4, (MOT) Stn. 335to 436	NB	5885	4689	7237	6638	5245	7594

Note:

(i) 1 psi = .6.895 kPa

(ii) Blank spaces indicate specimens could not be tested in the lab. These specimens disintegrated when cored.

In addition, resilient modulus tests were carried out at Ohio University [9] for the samples from I-71 and SR-4 sections. A total of fifteen tests were performed on the soil samples recovered from the I-71 site and 18 tests on the soil samples from the SR-4 site. Efforts were made to conduct a set of three tests for each selected soil sample at the compaction moisture contents of 2% below optimum, optimum, and 2% above optimum. A typical test procedure employed in the study was the SHRP Protocol for Type 2 soil. For each resilient modulus test, a 15 cm (6 inch) diameter specimen was placed inside the triaxial chamber with all the sensors positioned properly and their initial readings reset to zero. Then, a desired level of confining pressure was applied, and the specimen was subjected to the predetermined loading sequence as shown below:

Load Sequence #	Confining Pressure (psi)	Deviator Stress (Psi)	Number of Load Applications
1	6	2	100
2	6	4	100
3	6	6	100
4	6	8	100
5	6	10	100
6	4	2	100
7	4	4	100
8	4	6	100
9	4	8	100
10	4	10	100
11	2	2	100
12	2	4	100
13	2	6	100
14	2	8	100
15	2	10	100

Average recovered deformation recorded by two miniature LVDTs were used in computing the resilient modulus. Each of the resilient modulus value was computed as the mean value from the last five of each 100 load cycles. Maximum, minimum, and average resilient modulus values for each test are summarized in Tables 6 and 7.

Table 5. Soil Characteristics

Section ID	Liquid Limit	Plastic Limit	Dry Density, pcf	OMC %	CBR %	AASHTO Classification
I-71, (FAY) Stn. 726 to 779	20 to 28	14 to 17	116.1 125.3	12 to 16	5.6	A-4
I-71, (FAY-MAD) Stn. 35 to 88	24 to 28	14 to 18	114.2 to 126.3	12 to 16	5.1	A-4
SR-4, (MOT) Stn. 217 to 270	21 to 35	14 to 27	108.1 to 117.0	13.7 to 19.5	3.6	A-6
SR-4, (GRE) Stn. 105 to 160	20 to 34	15 to 24	108.4 to 111.54	15.6 to 19.0	3.1	A-6
SR-4, (MOT) Stn. 335 to 436	23 to 37	13 to 20	116.3 to 118.5	13.o to 13.8	3.5	A-6

Table 6. Basic Summary of Resilient Modulus Test Results on I-71 Site Soils (Ref. 9)

Test No.	Sample Location		Moisture Content	Resilient Modulus - M_r (ksi)			
	General	Hole #		Max.	Min.	Ave.	Std. Dev.
1	N.B.	6	2.5% Below Optimum	11.00	7.688	9.141	1.108
2			0.9% Above Optimum	5.683	2.479	3.596	1.165
3			1.4% Above Optimum	7.150	2.215	3.438	1.633
4	N.B.	4	1.5% Below Optimum	12.59	8.060	9.384	1.591
5			0.6% Above Optimum	9.285	5.137	6.710	1.323
6			3.4% Above Optimum	8.582	2.831	4.642	1.914
7	S.B.	4	2.4% Below Optimum	13.70	7.024	9.213	2.097
8			0.4% Below Optimum	5.962	2.708	3.849	1.178
9			0.4% Above Optimum	5.481	2.297	3.331	1.004
10	S.B.	3	2.6% Below Optimum	13.34	3.778	6.239	3.117
11			1.1% Below Optimum	5.847	2.603	3.722	1.154
12			0.6% Above Optimum	5.280	2.072	3.083	0.998
13	S.B.	4	0.2% Above Optimum	4.672	1.797	2.536	0.925
14	S.B.	3	0.5% Below Optimum	5.767	2.042	3.018	1.122
15	S.B.	4	0.3% Below Optimum	5.697	2.451	3.439	1.045

Table 7. Basic Summary of Resilient Modulus Test Results on SR-4 Site Soils (Ref. 9)

Test	Sample Location		Moisture Content	Resilient Modulus - M_r (ksi)			
No.	County	Hole #		Max.	Min.	Ave.	Std. Dev.
16	Montgomery	N2	2.6% Below Optimum	12.48	8.51	10.30	1.294
17			1.0% Below Optimum	7.53	4.02	5.47	1.190
18			At Optimum	5.83	2.89	4.05	1.022
34			0.5% Above Optimum	6.31	2.76	4.26	1.212
35			1.9% Above Optimum	6.50	2.83	4.07	1.164
19		N4	2.3% Below Optimum	24.47	11.86	15.06	4.174
20			0.5% Below Optimum	10.56	6.70	8.22	1.289
21			0.3% Below Optimum	11.95	6.24	7.80	1.801
22			1.0% Above Optimum	9.30	4.15	6.47	1.790
23			1.9% Above Optimum	7.46	2.64	4.24	1.566
28	Greene	N2	2.6% Below Optimum	11.12	7.53	9.12	1.134
25			1.8% Below Optimum	8.46	4.90	6.45	1.110
26			0.6% Below Optimum	6.54	3.84	4.82	0.911
29			0.4% Below Optimum	6.09	3.56	4.49	0.813
30		S5	2.9% Below Optimum	8.60	5.07	6.70	1.195
31			0.7% Below Optimum	6.42	2.43	3.97	1.391
32			0.1% Above Optimum	5.53	1.81	3.03	1.264
33			1.1% Above Optimum	3.93	1.42	2.01	0.866

DEFLECTION

In this study, deflection data was collected using both Dynaflect and Falling Weight Deflectometer (FWD). This report presents the analysis of FWD deflections. In each section, 30 to 40 measurements were made periodically. The pavement surface temperature was recorded at the time of deflection measurements.

Structural Parameters Investigated

In the Phase I study, the structural investigation was perfomed using Dynaflect deflection data. However, in the present study (Phase II), FWD deflections were used for the structural investigation of the test sections.

The structural parameters investigated on the AC overlays are: (i) maximum deflection W_1 (ii) Spreadability and (iii) AREA, and (iv) Edward Ratio [4].

Spreadability is calculated by the equation:

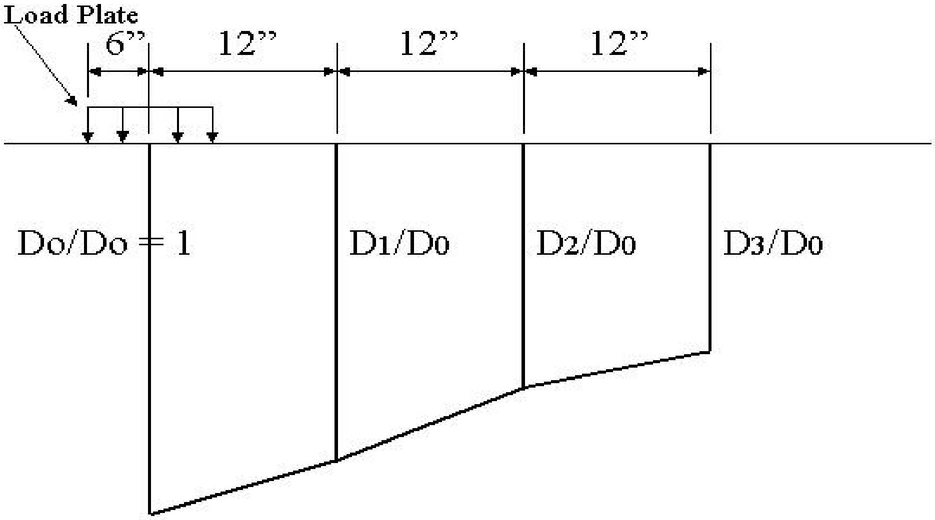
$$\text{Spreadability (\%)} = (W_1 + W_2 + W_3 + W_4 + W_5) \text{ x } 100 / 5\ W_1$$

AREA is computed by using the procedure shown in Figure 4 [10]. The term AREA refers to the general shape of and proportional variation along a line extending outwards from the load cell rather than the absolute cross-sectional area developed under loadings. For rigid pavements (slabs less than 11 inch thick), AREA values fall between 29.00 and 33.00.

Edward's Ratio was developed using Dynaflect data and defined as equal to W_1/W_5, where W_1 is the reading of the sensor closest to the load of Dynaflect; W_5 is the 5th sensor and is farthest from the load and is indicative of subgrade strength. However, the 6th sensor on the FWD is approximately at the same distance from the load as the 5th sensor on Dynaflect. Hence, the

Edward’s Ratio was modified as equal to W_1/W_6 while using FWD deflection data and the values were computed accordingly.

Figure 4. Calculation of Deflection Basin “AREA” [Ref. 10]



AREA (inch) = $6\,(1 + 2\,D_1/D_0 + 2\,D_2/D_0 + D_3/D_0)$

The FWD deflections on AC overlays were also used to investigate the mechanistic behavior of test the sections. Only a limited discussion of the mechanistic investigation is presented, since a detailed study is outside the scope of the present research.

The data collected at the cracks and joints were analyzed for load transfer and joint support ratio. However, this information was not useful to compare B/S and control sections. Hence this data is not presented in this report.

Comparing Structural Response of B/S and Control Sections

When comparing two measurements, it is desirable to know if the mean values for the two groups are different. If the mean values of the measurements are significantly different, the variable under question is said to have a pronounced effect on the measurement. In this study, the means of maximum deflections, AREA, Spreadability and W_1/ W_5 ratios for each B/S section were statistically compared with values on corresponding control sections. A two factor Analysis of Variance (ANOVA) was performed. The first factor is labeled as ‘treatment’, at two levels, representing control and B/S. The second factor is labeled as ‘year’, at seven or eight levels, representing the number of years when deflection data were collected on each test section. The null hypothesis (H_o) tested was, difference in means = 0, at a level of significance = 0.05.

Initially an attempt was made to normalize deflection values to a standard temperature using a model developed at the University of Toledo [11]. This model requires site-specific conditions such as solar-radiation, wind, air temperature, cloud cover and other values to calculate the temperature profile at a given time within an AC layer. Additionally, the model can work only for a three layer system. All the sections considered in the present study are four-layered (AC+PCC+Sub Base over Subgrade) and also the additional data required was not available. Hence the analysis was simplified by normalizing the deflections to a standard temperature of 21° C using the Asphalt Institute method [12].

Evaluation Based on Maximum Deflection

Figures 5, 6 7,8 and 9 show the variation in maximum deflection for all the test sections on I-71 and SR-4. As seen in these figures, the average maximum deflection values for B/S pavements are always higher than those of the control sections. Sections broken with the pile hammer have higher deflections as compared to those broken with the guillotine hammer. Table 8 presents a summary of the statistical analysis. The statistical analysis indicates a significant difference in average deflections between B/S and control sections. In this table, a value of ***P*** less than 0.05 indicates that the difference in the mean values of deflections between the control and B/S sections is significant. In other words, '1-***P***' value indicates the confidence in the statement that the estimated difference is significant.

Table 8. Results of Analysis of Variance for the Variable Maximum Deflection

Section ID	I-71		Section ID	SR-4	
	Based on 8 - Years Data			Based on 7 - Years Data	
	Est. Diff. between control and B/S	Significance (P value)		Est. Diff. between control and B/S	Significance (***P***-value)
Stn. 726 to 780	1.1840	Yes (<0.0001)	Stn. 217 to 270	1.7521	Yes (<0.0001)
Stn. 35 to 88	0.5516	Yes (<0.0001)	Stn. 105 to 160	3.4406	Yes (<0.0001)

Note: Deflections are in mils (1/1000 inch)

Figure 5. Variation in Maximum FWD Deflection on AC Overlay (mils)

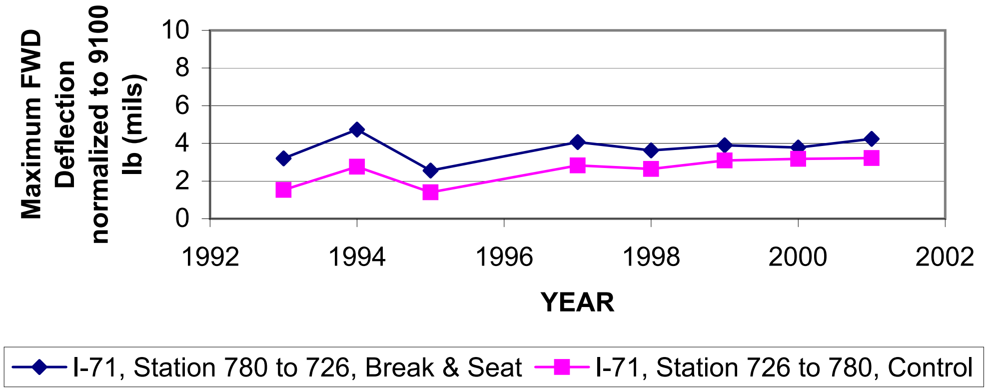


Figure 6. Variation in Maximum FWD Deflection on AC Overlay (mils)

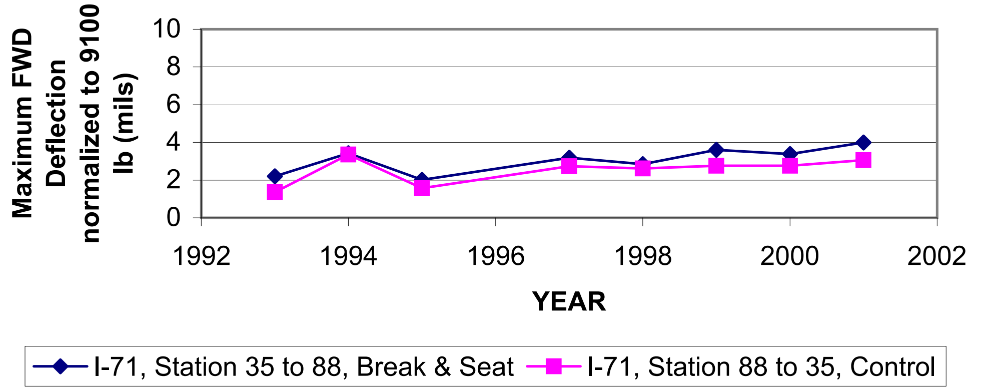


Figure 7. Variation in Maximum FWD Deflection on AC Overlay (mils)

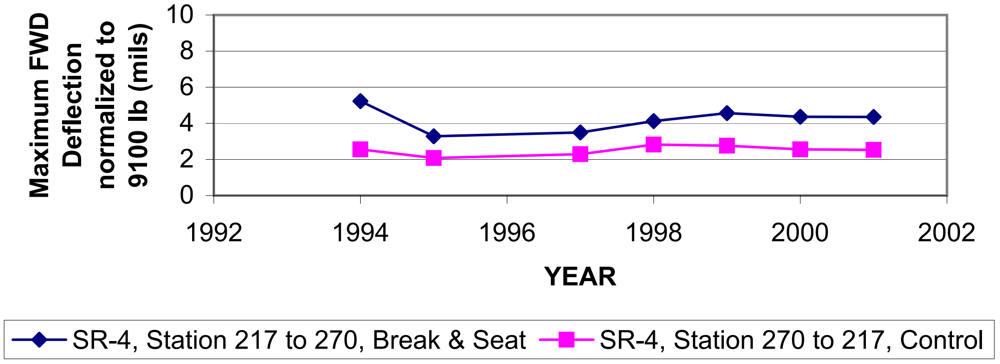


Figure 8. Variation in Maximum FWD Deflection on AC Overlay (mils)

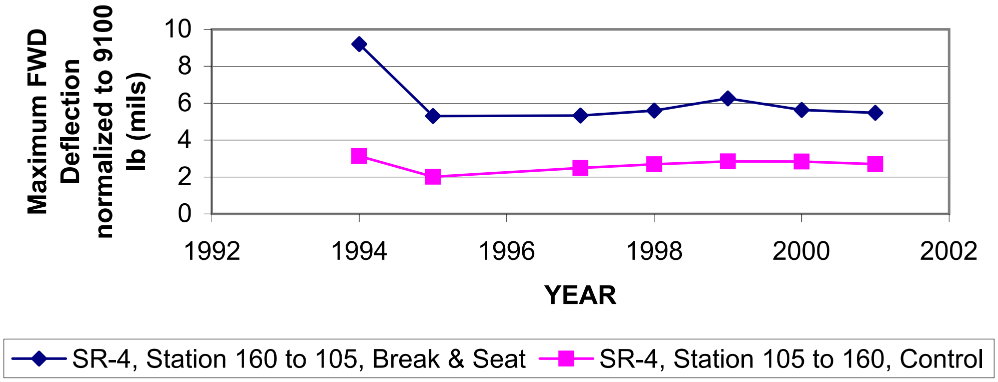
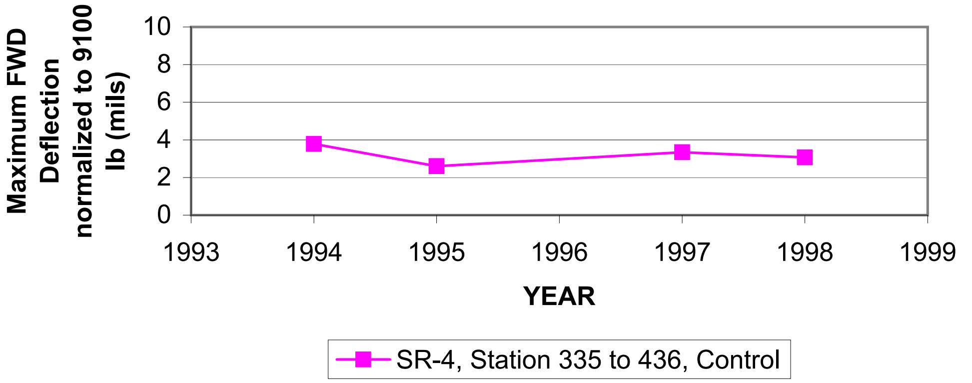


Figure 9. Variation in Maximum FWD Deflection on AC Overlay (mils)



Evaluation Based on Spreadability

Figures 10, 11, 12, 13 and 14 show the variation in Spreadability for all the test sections on I-71 and SR-4. The Spreadability values of the B/S sections were lower than the control sections. Concrete pavements, in general, exhibit higher Spreadability than flexible pavements. The lower Spreadability of the B/S sections indicates a behavior similar to flexible pavements. The Spreadability values of sections on SR-4, where a pile hammer was used, were considerably lower than those broken with a guillotine hammer. These sections resulted in a higher degree of breakage than sections broken with the guillotine hammer. Table 9 presents results of the statistical analysis. As seen in this table, the estimated difference in Spreadability is significant for SR-4 test sections while they are not significant for the I-71 test sections. The results reinforce the observation that the guillotine hammer is not an effective tool for breaking JRCP.

Table 9. Results of Analysis of Variance for the Variable Spreadability

Section ID	I-71		Section ID	SR-4	
	Based on 8 - Years Data			Based on 7 - Years Data	
	Est. Diff. between control and B/S	Significance (P value)		Est. Diff. between control and B/S	Significance (***P***-value)
Stn. 726 to 780	-0.5321	No (<0.1262)	Stn. 217 to 270	-4.8474	Yes (<0.0001)
Stn. 35 to 88	0.5718	No (<0.1615)	Stn. 105 to 160	-4.3803	Yes (<0.0001)

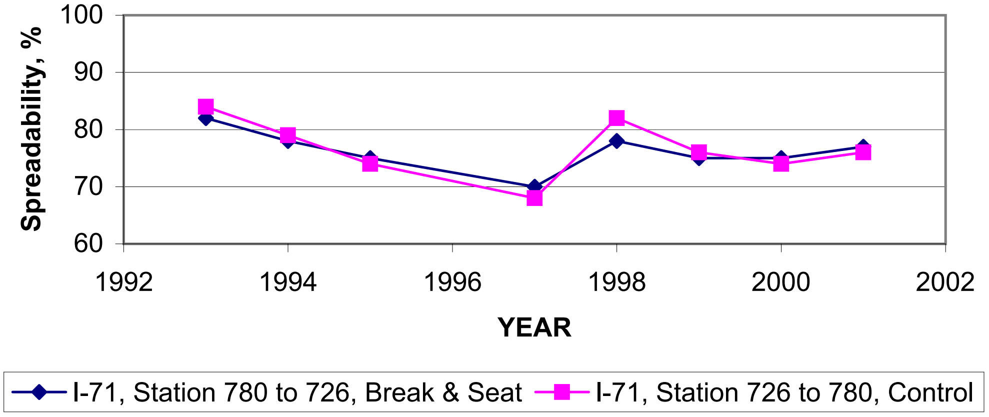


Figure 10. Variation in Spreadability on AC Overlay

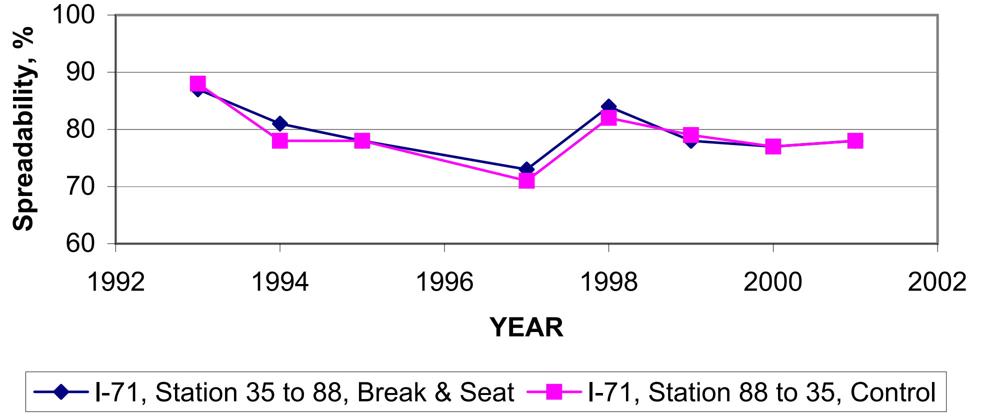


Figure 11. Variation in Spreadability on AC Overlay

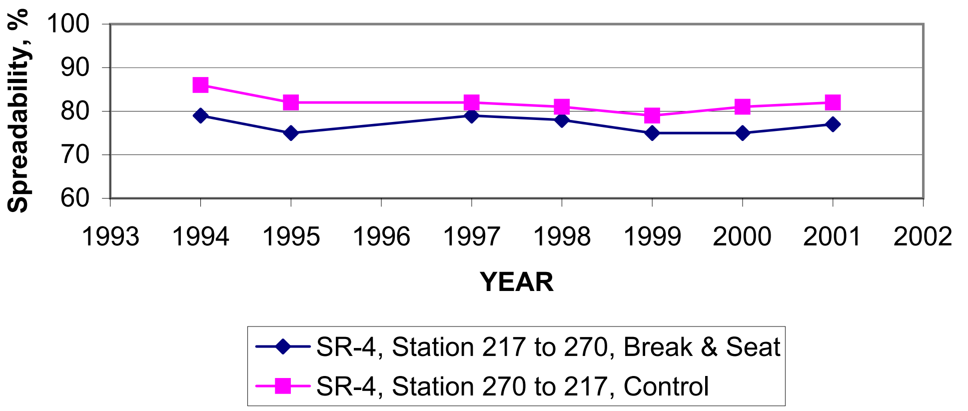


Figure 12. Variation in Spreadability on AC Overlay

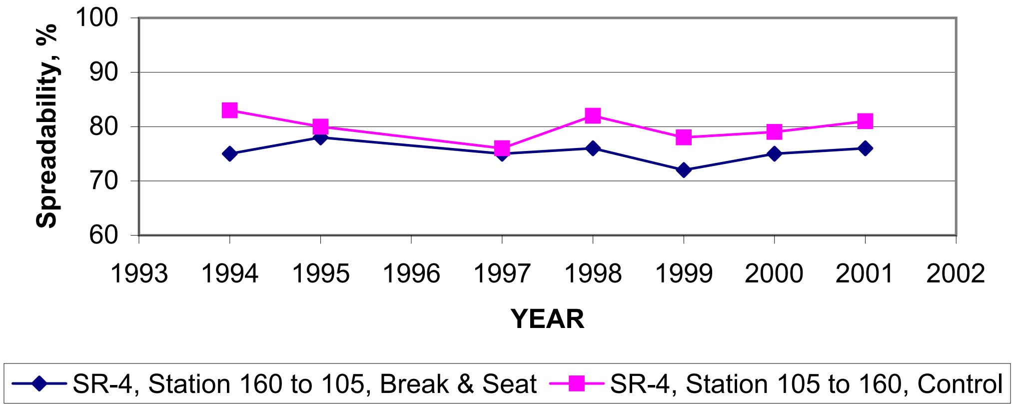


Figure 13. Variation in Spreadability on AC Overlay

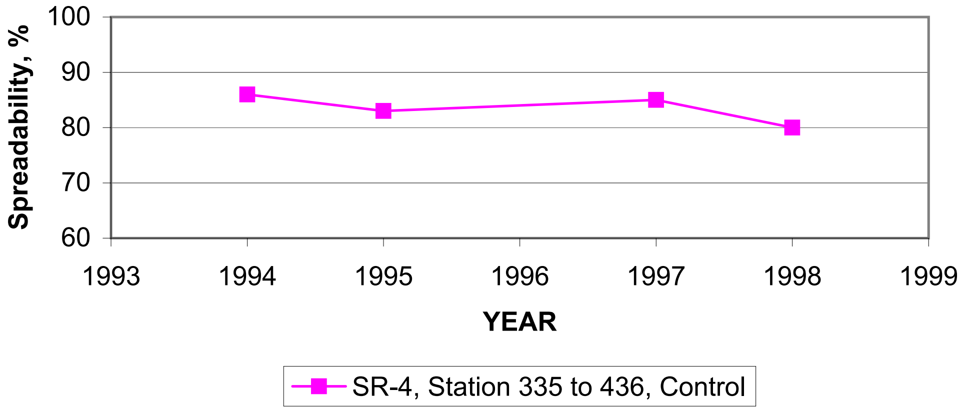


Figure 14. Variation in Spreadabilityon AC Overlay

Evaluation Based on AREA

Figures 15, 16, 17, 18 and 19 show the variation in AREA for all the test sections on I-71 and SR-4. Similar to Spreadability, the AREA values for the B/S sections were lower than those for the control sections. The AREA values for sections on SR-4, where a pile hammer was used, were considerably lower than those broken with a guillotine hammer. These sections resulted in a higher degree of breakage than sections broken with the guillotine hammer. Table 10 presents results of the statistical analysis. The results of the statistical analysis are very similar to those that obtained for Spreadability. As seen in this table, the estimated difference in AREA values is significant for SR-4 test sections while it is not significant for the I-71 test sections. The results further reinforce the observation that the guillotine hammer is not an effective tool for breaking JRCP.

Table 10. Results of Analysis of Variance for the Variable AREA

Section ID	I-71		Section ID	SR-4	
	Based on 8 - Years Data			Based on 7 - Years Data	
	Est. Diff. between control and B/S	Significance (P value)		Est. Diff. between control and B/S	Significance (***P***- value)
Stn. 726 to 780	-0.1410	No (<0.3858)	Stn. 217 to 270	-2.0861	Yes (<0.0001)
Stn. 35 to 88	0.3047	No (<0.1068)	Stn. 105 to 160	-1.8199	Yes (<0.0001)

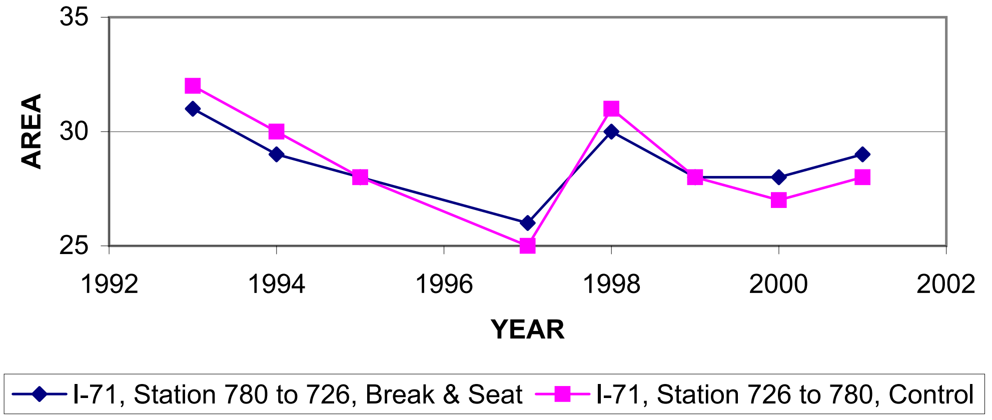


Figure 15. Variation in AREA on AC Overlay

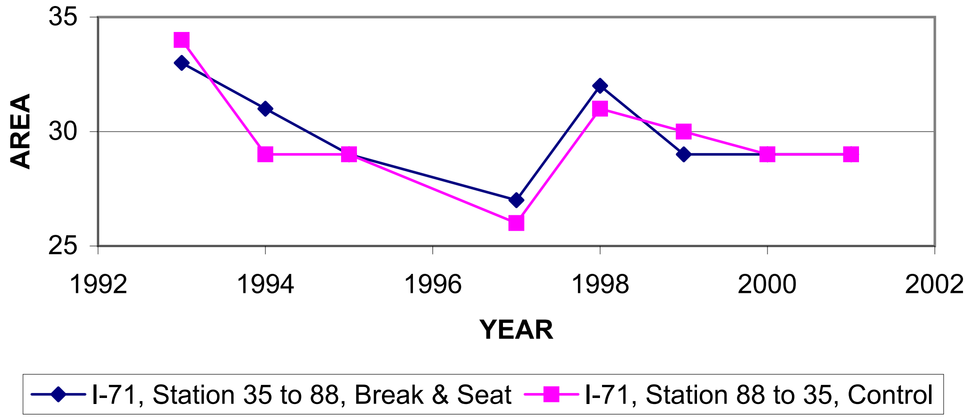


Figure 16. Variation in AREA on AC Overlay

Figure 17. Variation in AREA on AC Overlay

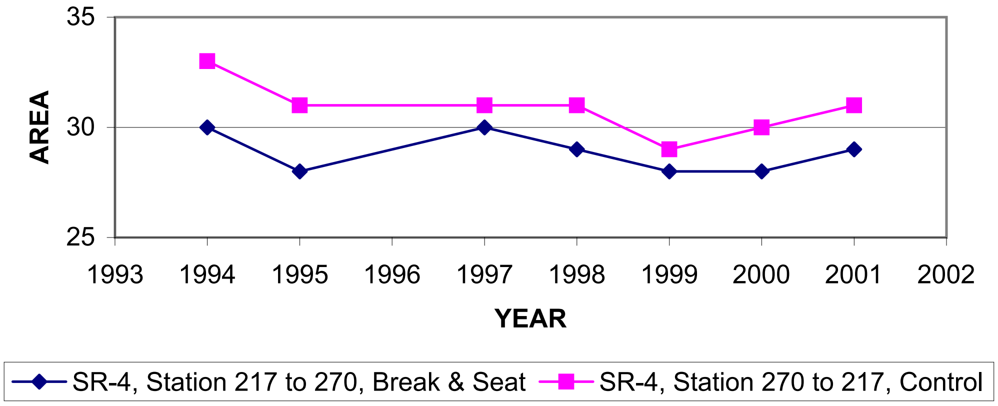


Figure 18. Variation in AREA on AC Overlay

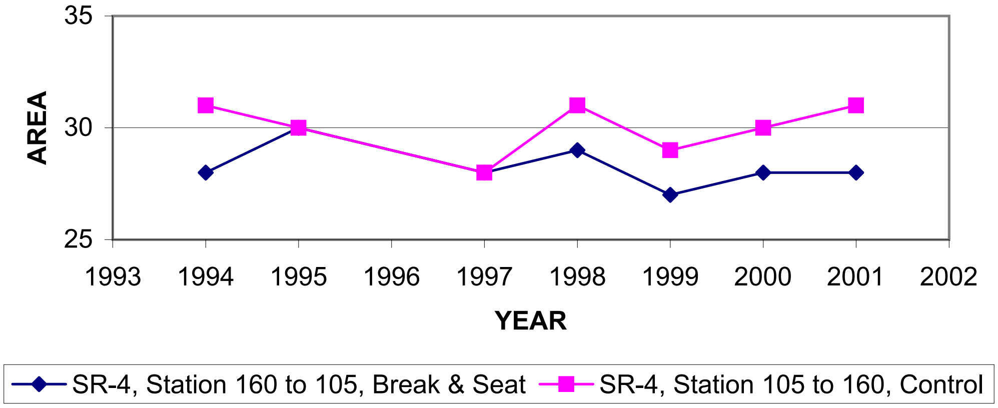
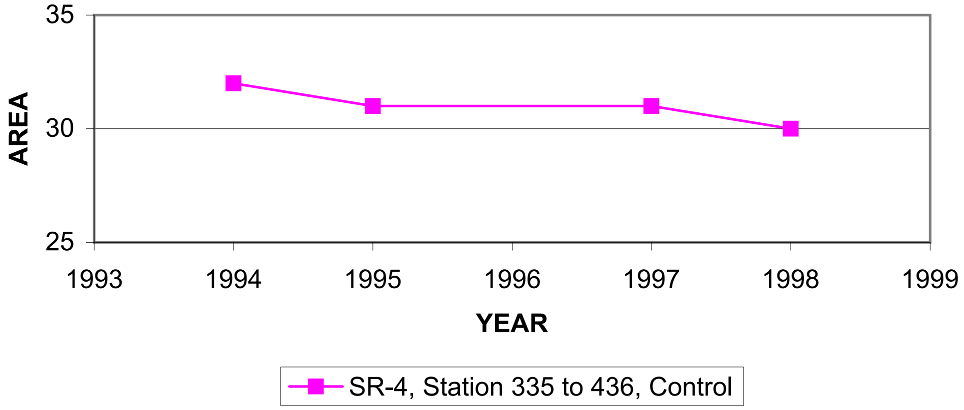


Figure 19. Variation in AREA on AC Overlay



Evaluation Based on W_1/W_6

Figure 20 shows the stress distribution in a typical pavement structure subjected to a load [13]. The stress due to the load gets distributed over a wide area through the upper layers of the pavement before reaching the subgrade level. The deflection values measured at or beyond a_{3e} are indicative of subgrade characteristics. The measured surface deflection at this radial offset value must logically be influenced by the subgrade layer. It is generally believed the deflection value W_6 indicates subgrade soil properties. A ratio of W_1 to W_6 which can be a good indicator of the load spreading characteristics of pavement layers, is a function of pavement type. If two pavements have nearly equal W_6 measurements, the values of the maximum deflections (W_1) would indicate the relative strength of the two pavements, with the weaker pavement exhibiting a higher maximum deflection. The ratio of W_1/W_6 for the weaker pavement would be higher. This means, the higher the W_1/W_6 ratio, the lower the load spreading ability of the pavement. Using this rationale, rigid and composite pavements would exhibit a lower W_1/W_6 value as compared to flexible pavements.

Figures 21, 22, 23, 24 and 25 show a comparison of W_1/W_6 for the test sections. As seen in these figures, most break and seat sections resulted in higher W_1/W_6 values than the control sections (except for I-71 between stations 35 and 88). The statistical analysis (Table 11) shows a significant difference between the two means. However, the results also indicate the estimated difference in W_1/W_6 for I-71 section between stations 35 and 88 is not significant. Also, SR-4 sections have very high W_1/W_6 ratios. This is obvious because these sections, broken with a pile hammer, were almost rubblized.

Table 11. Results of Analysis of Variable for the Variable W_1/W_6

Section ID	I-71		Section ID	SR-4	
	based on 8 - Years Data			Based on 7 - Years Data	
	Est. Diff. between control and B/S	Significance (P value)		Est. Diff. between control and B/S	Significance (*P*-value)
Stn. 726 to 780	0.0868	Yes (<0.0001	Stn. 217 to 270	0.3002	Yes (<0.0001)
Stn. 35 to 88	0.0134	No (0.4610)	Stn. 105 to 160	0.3338	Yes (<0.0001)

Figure 20. Schematic of Stress Zone Within Pavement Structure [13]

Note:

'r' is radial distance

'a3e' is the radial distance at which the stress zone intersects the interface of the subbase and subgrade layers

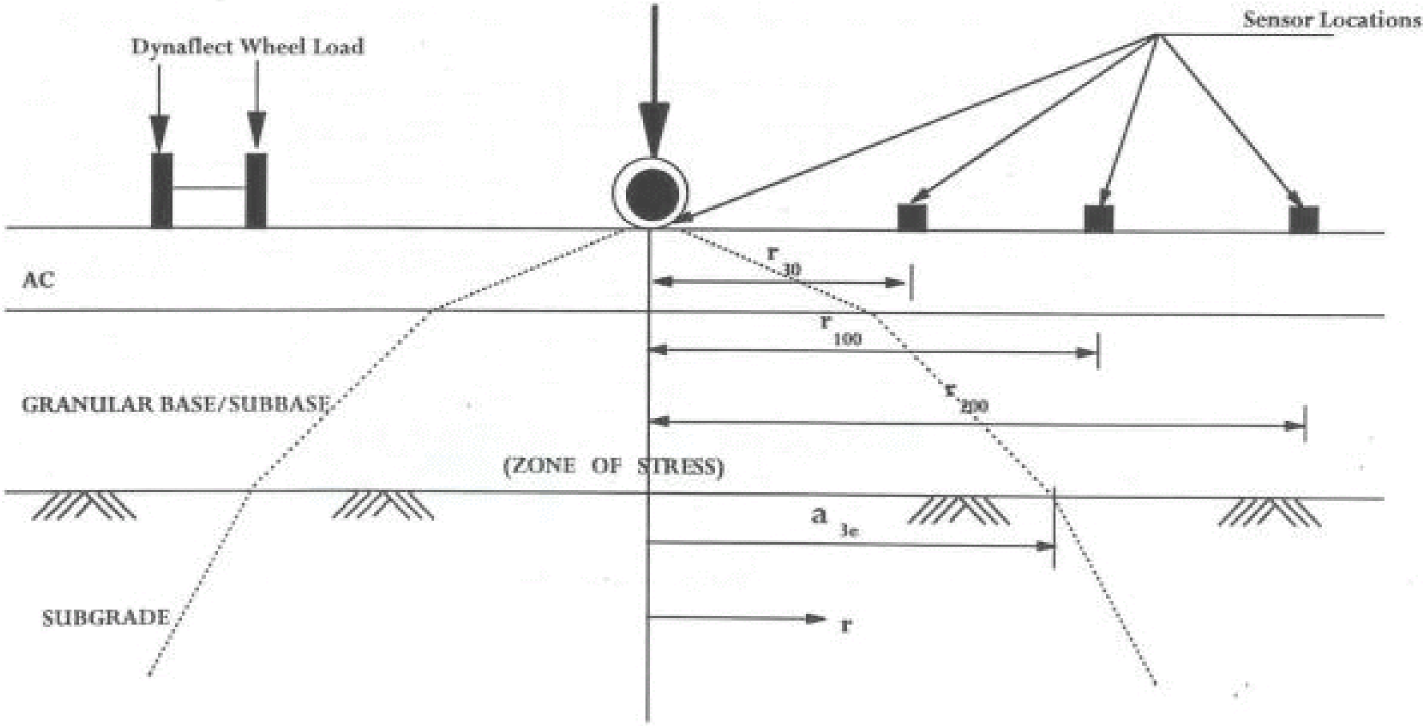


Figure 21. Variation in W1/W6 on AC Overlay

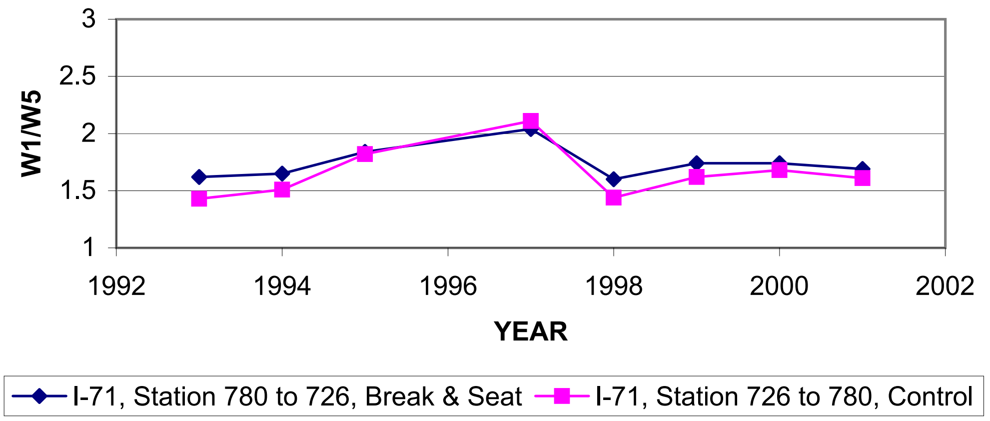


Figure 22. Variation in W1/W6 on AC Overlay

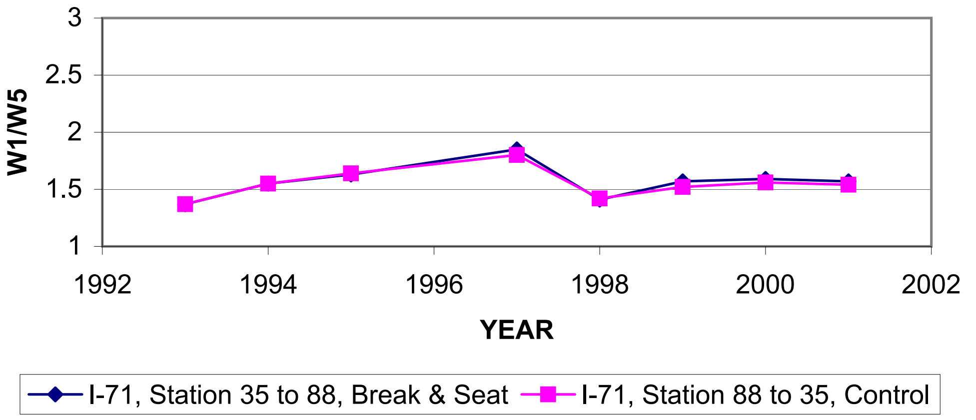


Figure 23. Variation in W1/W6 on AC Overlay

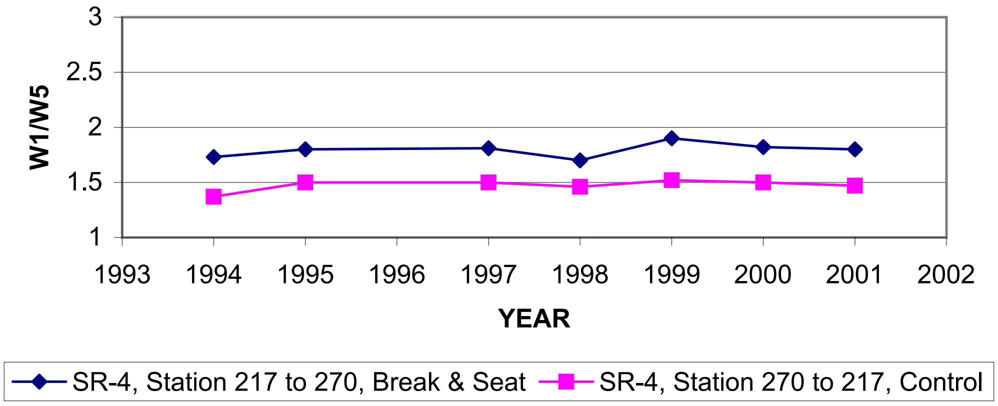


Figure 24. Variation in W1/W6 on AC Overlay

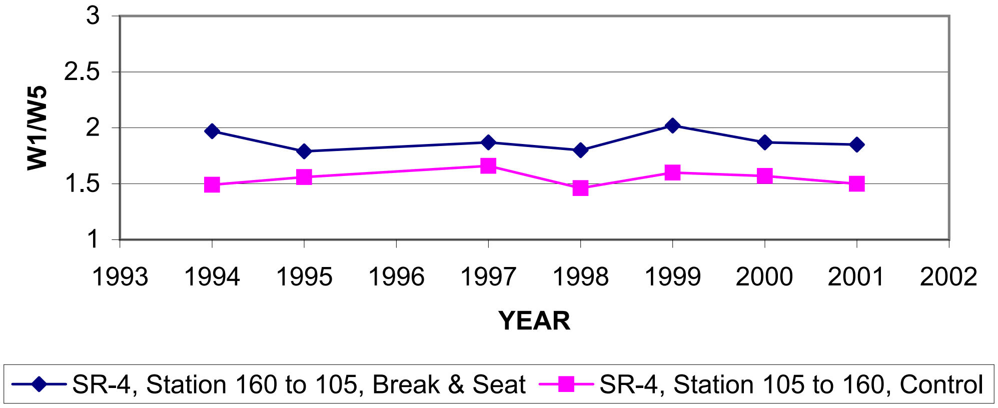
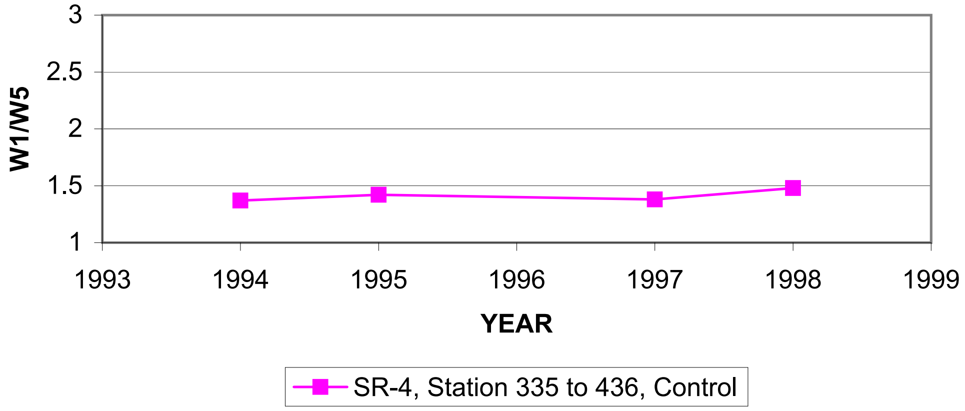


Figure 25. Variation in W1/W6 on AC Overlay



Statistical Significance vs. Practical Significance

In most cases, the statistical analysis indicates a difference between the two means. However, some of the sections on I-71 exhibit no statistically significant difference. This could be because, some of these areas were not broken to the desired extent resulting in patches of continuous concrete pavement. The results of a hypothesis test in terms of a ***P***-value is very useful, because it conveys more information than just the simple statement "reject H_0" or "fail to reject H_0". That is, rejection of H_0 at the 0.05 level of significance is much more meaningful if the value of the test statistic is well into the critical region, greatly exceeding the 5% critical value, rather than if it barely exceeds that value [14]. Even a very small ***P***-value can be difficult to interpret from a practical viewpoint when we are making decisions; although a small ***P***-value indicates **statistical significance** in the sense that H_0 should be rejected in favor of H_1, the actual departure from H_0 that has been detected may have little (if any) **practical significance** or engineering significance. This is particularly true when the sample size is large. Statistical significance means that the observed mean differences are not likely due to sampling error. Practical significance looks at whether the difference is large enough to be of value in a practical sense.

From the practical or engineering standpoint, it is important to find out if the process of breaking and seating transformed the composite pavements into flexible pavements. In other words, should the broken and seated pavements be categorized as composite pavements or flexible pavements? The statistical analysis leads us to conclude that pavements that are broken with a pile hammer can be categorized as flexible pavements while those broken with a guillotine hammer tend to perform more like composite pavements. More importantly, this result suggests that the most important factor to be considered in applying the B/S technique is ***'extent of breaking'***. This finding coincides with the visual observations of the test sections made by the researchers throughout the period of the study.

Mechanistic Behavior of Broken and Seated Pavements

The main causes of stress in AC overlays on concrete pavements are:

- Thermal stresses due to change in temperature, and
- Stresses due to traffic wheel loads.

Changes in temperature cause expansion or contraction of PCC slabs. The total amount of horizontal movement is given by the expression (TL) where is the coefficient of thermal expansion, T is the change in temperature, and L is the length or width of the slab. In addition, there may be a difference in temperature between the top and bottom surfaces, which causes curling. This, again, is dependent on the length of slab. Thus, the smaller the length of slab, the smaller the movement. The asphalt overlay is bonded to the PCC slab. Hence, the movement of the PCC slabs translates directly into stresses in the asphalt layer.

When a PCC slab is broken, the size of slab fragments seem to have two types of effects. First, by the their response to temperature movements, and secondly, through the achieved load distribution. A larger slab size (as is the case in an intact slab) essentially distributes the entire load to the base over a large area. When a crack is introduced by breaking the slab, the load distribution changes at the crack. A good interface shear transfer capability leads only to a small increase in the slope of the load spread. However, a low or negligible interface shear transfer leads to a direct transfer of load to the subgrade.

The width of the crack influences the interface shear transfer capability. A larger width leads to low shear transfer whereas a smaller width yields a high shear transfer. A broken slab with a thinner width observed at the surface may, however, retain continuity at the bottom which defeats the purpose of breaking. Likewise, unbroken (and bonded) reinforcement at the interface, essentially transfers temperature movements across the cracks. Thus the interface shear transfer capability also varies with season and temperature.

A preliminary three dimensional finite element analysis was performed by employing linear elastic analysis. The scope of this analysis was to evaluate the effect of wheel loads on AC overlays on B/S pavements using field data. The main purpose of this investigation was to generate information regarding the effects of various parameters like, extent of breaking (as in pile and guillotine hammer), size of broken slab fragments, and subgrade stiffness. The joints between slab fragments were modeled and the interface between segments was simulated by the use of 3D-springs. A Winkler foundation was employed for the subgrade. Material properties were derived using the backcalculation procedure. The model was calibrated using field data.

After ensuring that the finite element model is capable of simulating B/S and control pavements, a parametric study was undertaken. The various parameters considered were:

- effect of interface joint stiffness
- effect of segment size
- effect of subgrade stiffness, and
- effect of concrete modulus

Each of these effects were considered for both one-way and two-way broken slabs to simulate guillotine and pile hammer operation respectively.

In summary, the results indicated that, two-way breaking (pile hammer) causes the deflections to be more susceptible to interface shear effects than one-way breaking (guillotine hammer). Thus the deflections on AC layers overlying pavements broken with pile hammer are always higher than those broken with a guillotine hammer. For a given interface shear transfer capability, different fragment sizes do not appreciably affect the deflection characteristics in case of one-way breaking. In case of two-way breaking, however, there is a pronounced effect of fragment size on the deflections.

More detailed investigation is underway. However, this preliminary analysis reinforces the observation made by using other structural parameters presented earlier.

Idealized Behavior

An intact PCC slab normally exhibits low surface deflections, shallow and broad deflection bowls, high Spreadability and AREA values, high flexural stresses and low subgrade stresses. Breaking would result in larger maximum deflections, deeper but not broader deflection basins, reduced areas, reduced flexural stresses and increased subgrade stresses. The behavior will be more like flexible pavements [15]. The structural behavior of all the sections in this study conforms to this idealized model.

CRACK MAPPING

The intensity of transverse cracks in each section was visually observed and recorded in conformity with ODOT's Pavement Condition Rating Manual [16]. The location of the cracks was measured with reference to established bench marks. Crack mapping was done on the original AC surface, on the exposed concrete surface after milling, and several times after the AC overlay. When the concrete pavement was exposed, the location of the joints and permanent patches were also recorded. Several bench marks were established to locate the exact position of cracks, joints and permanent patches. In the AC overlays, the date when a crack was first noticed was noted along with its location. Also a photographic record of the condition of the joints and cracks was kept. A large volume of photographs depicting the condition of joints and cracks prior to overlay and the new cracks in the AC overlay was obtained. These photographs were used to counter check the location of joints and cracks and to ascertain the severity of the cracks.

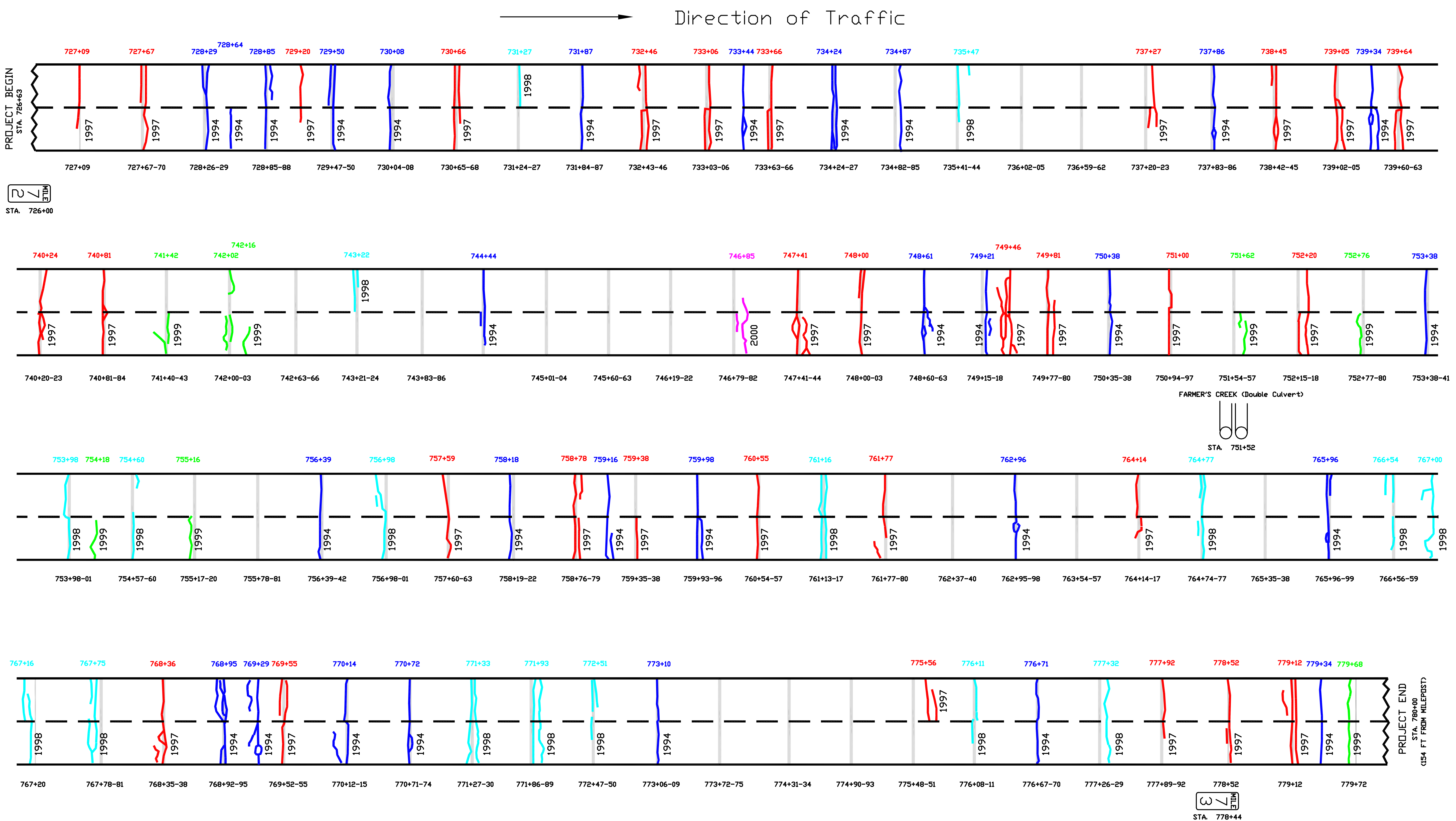
After milling the original AC layer and exposing the concrete surface, the exact location of the cracks and joints with respect to the bench marks were recorded. More than 80% of the slabs had 1 to 3 cracks. Very rarely there were slabs with 4 or more cracks. The average spacing of cracks varied from 3 to 9 m (10 to 30 feet). This survey also assisted in establishing how many of the cracks in the original AC layer were reflected from the joints and how many from the cracks. The results of crack mapping are presented in Figures 26 through 34. A time history of reflection cracking for each test section is graphically presented in Figures 35 through 42.

For about a length of 300 meters (1000 ft.), the concrete slabs on one section of I-71 were broken with a 2.4 m (8 ft.) wide, 5440 kg (6 ton) guillotine hammer. This section was the passing lane on the north bound lanes between Stations 35 and 88. The 2.4 m (8 ft.) wide hammer was dropped at the center of the lane which is 3.6 m(12 ft.) wide. Since the width of the hammer was smaller than that of the lane, the desired result was not achieved. Hence the use of the 2.4 m (8 ft.) wide hammer was discontinued and further breaking was achieved by using a 1.8 m(6 ft.) wide hammer. Two passes of the 1.8 m (6 ft.) wide hammer were required in each lane to cover the entire 3.6 m (12 ft.) width. This resulted in the development of irregular cracks on the B/S section on I-71 between Stn. 35 and 88. As a result, the survey could not establish the number of reflection cracks as in other test sections. Hence, the reflection cracking data fo this section is not presented. Also, it should be realized that for the I-70 test section, a table showing time history of reflection cracks is not presented because the section was rehabilitated only two years back. Table 12 shows a summary of the most recent survey of reflection cracks in the test sections.

Table 12. Summary of Reflection Cracking

Section ID	Number of Joints/Patches Reflected as of 2001		Overlay Construction
	Break & Seat Section	Control Section	
I-71 (FAY) Stn. 726+00 to 780+00	(37/89) = **42%** (Guillotine Hammer, 18" spacing)	(86/89) = **97%**	1992
I-71 (FAY-MAD) Stn. 35+00 to 88+00	Cracks of irregular pattern	(93/95) = **98%**	1992
SR-4 (MOT) Stn. 217+00 to 270+00	(15/86) = **17%** (Pile Hammer, 18" spacing)	(88/88) = **100%**	1993
SR-4 (GRE) Stn. 105+00 to 160+00	(7/94) = **7%** (Pile Hammer, 18" spacing)	(74/94) = **79%**	1993
SR-4 (MOT) Stn. 335+00 to 436+00	No section	(54/61) = **89%**	1993
I-70 (MUS), Control		(17/17) = **100%**	1999
I-70 (MUS), 6" break (Guillotine Hammer)	(11/17) = **65%**		1999
I-70 (MUS), 18" break (Guillotine Hammer)	(13/17) = **76%**		1999
I-70 (MUS), 30" break (Guillotine Hammer)	(11/17) = **65%**		1999

Figure 26. Reflection cracking on I-71, Station 726 to 780 (Control Section)



Location of Transverse Cracking

SECTION ID: I-71 (FAY) Station: 726+63 to 779+43

TOTAL LENGTH: 1.63 km (1.01 miles)

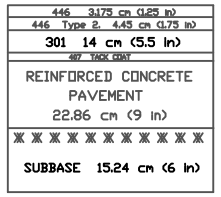
CONTROL SITE

Overlay Construction: 1992

ADT (1992): 22,880

ADT (2010): 34,330

% Truck: 23

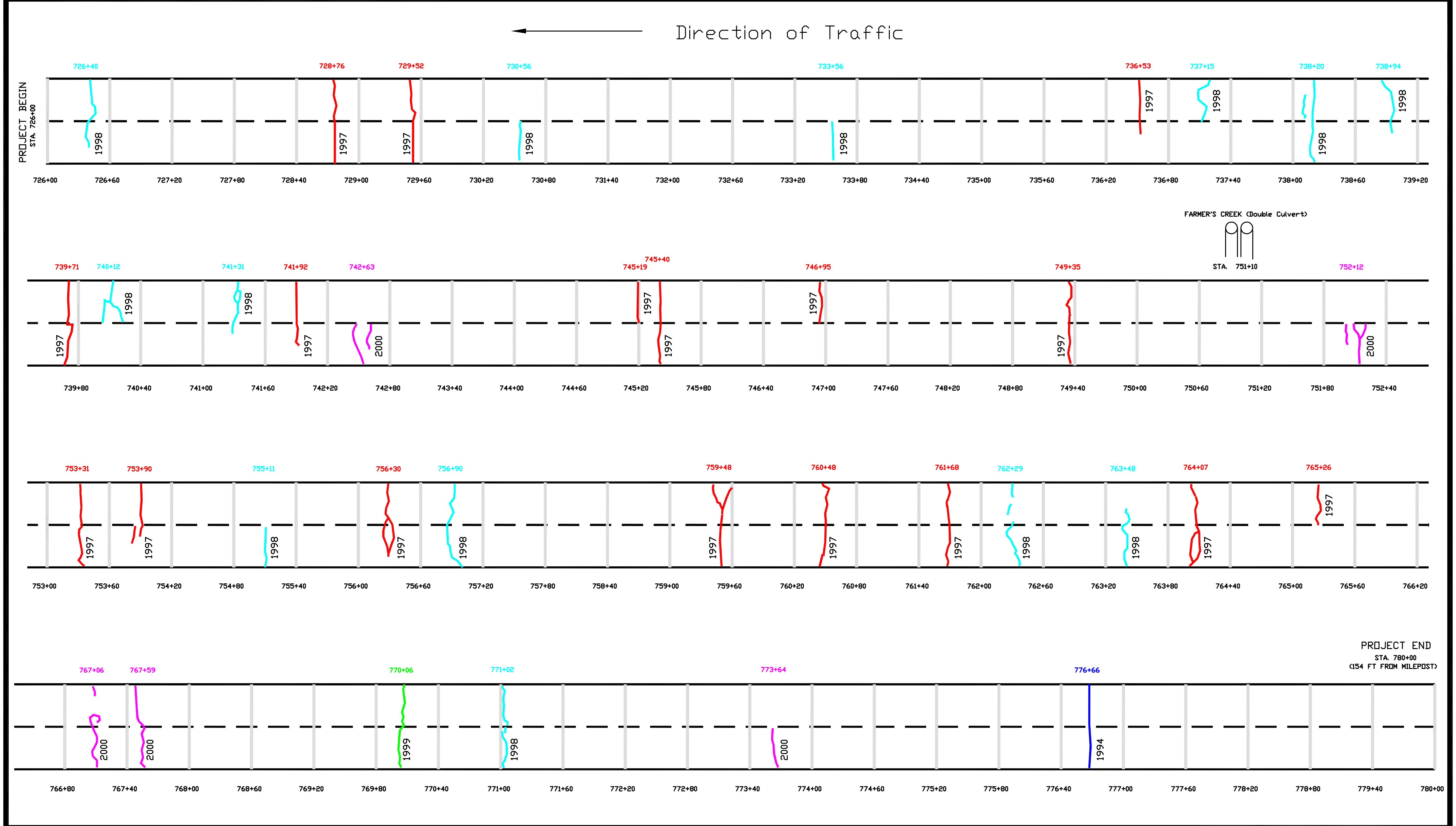


North

LEGEND

— 1994 No. of Cracks: 29 (Total: 29)
— 1997 No. of Cracks: 31 (Total: 60)
— 1998 No. of Cracks: 17 (Total: 77)
— 1999 No. of Cracks: 8 (Total: 85)
— 2000 No. of Cracks: 1 (Total: 86)
— 2001 No. of Cracks: NA (Total: 86)

Figure 27. Reflection Cracking on I-71, Station 780 to 726 (Break and Seat section)



Location of Transverse Cracking

SECTION ID: I-71 (FAY) Station: 726+00 to 780+00

TOTAL LENGTH: 1.65 km (1.02 miles)

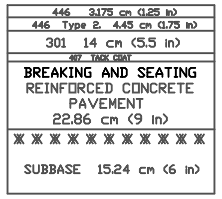
BREAK AND SEAT SECTION

Overlay Construction: 1992

ADT (1992): 22,880

ADT (2010): 34,330

% Truck: 23

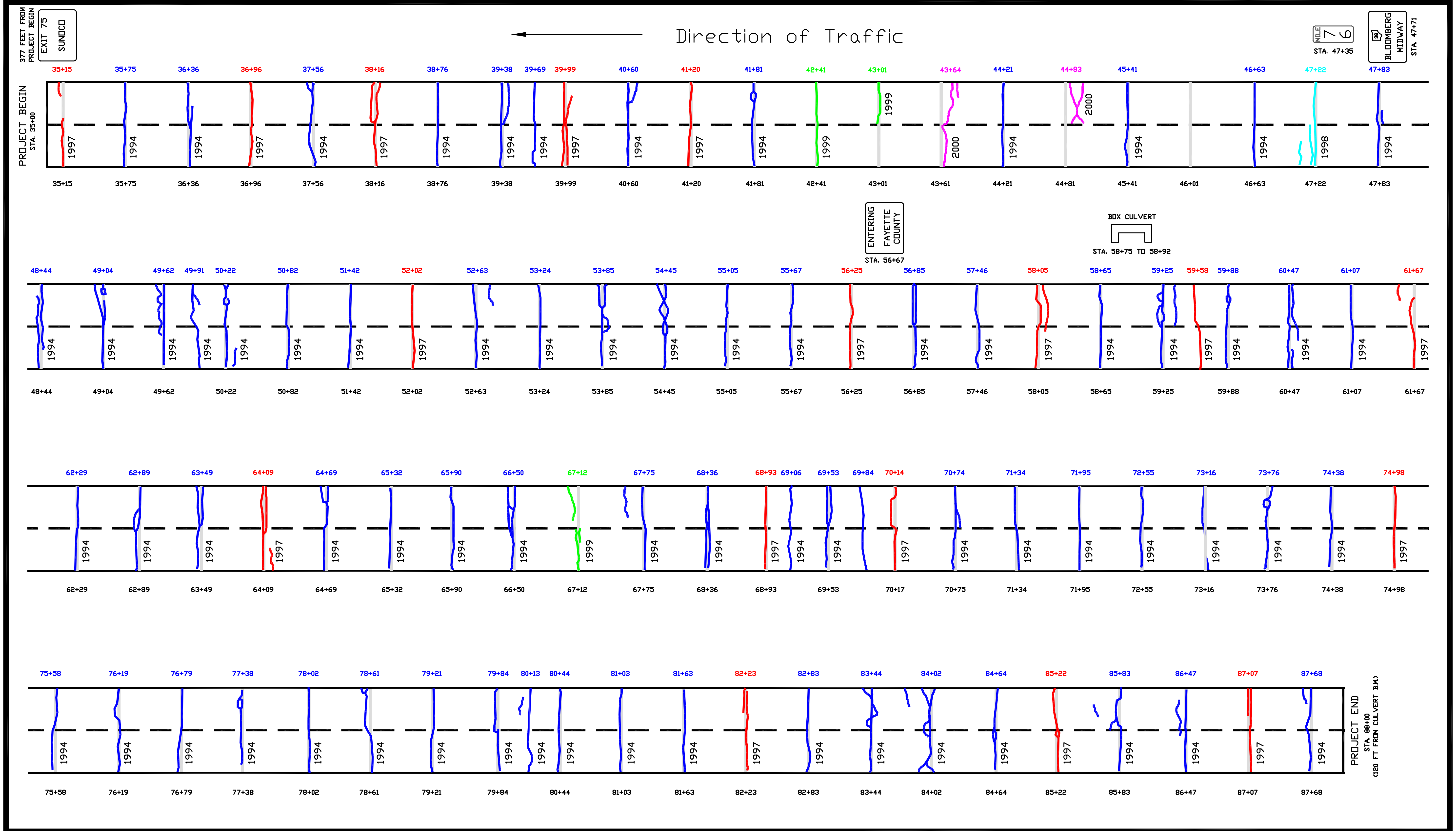


North

LEGEND

🟦	1994 No. of Cracks: 1 (Total: 1)	🟩	1999 No. of Cracks: 1 (Total: 32)
🟥	1997 No. of Cracks: 17 (Total: 18)	🟪	2000 No. of Cracks: 5 (Total: 37)
🟦	1998 No. of Cracks: 13 (Total: 31)	🟨	2001 No. of Cracks: NA (Total: 37)

Figure 28. Reflection Crackin on I-71, Station 35 to 88 (control section)



Location of Transverse Cracking

SECTION ID: I-71 (FAY) Station: 35+00 to 88+00

TOTAL LENGTH: 1.6 km (1.0 mile)

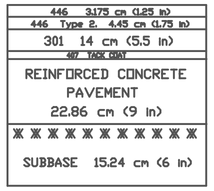
CONTROL SECTION

Overlay Construction: 1992

ADT (1992): 22,880

ADT (2010): 34,330

% Truck: 23



North →

LEGEND

🟦 1994 No. of Cracks: 70 (Total: 70)

🟥 1997 No. of Cracks: 17 (Total: 87)

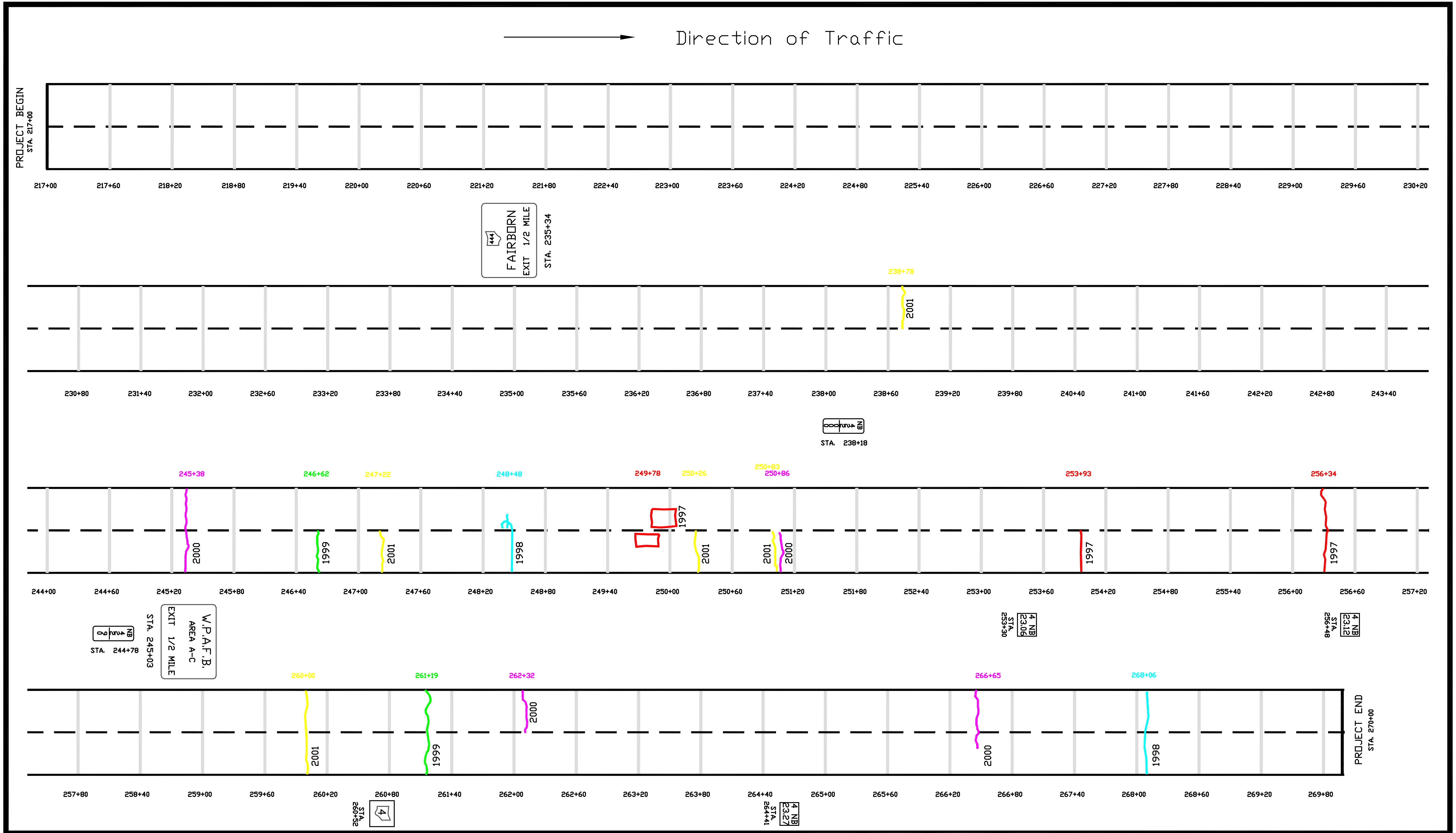
🟦 1998 No. of Cracks: 1 (Total: 88)

🟩 1999 No. of Cracks: 3 (Total: 91)

🟪 2000 No. of Cracks: 2 (Total: 93)

🟨 2001 No. of Cracks: NA (Total: 93)

Figure 29. Reflection Cracking on SR-4, Station 217 to 270, (break and seat section)



Location of Transverse Cracking

SECTION ID: SR-4 (MOT) Station: 217+00 to 270+00

TOTAL LENGTH: 1.61 km (1.00 miles)

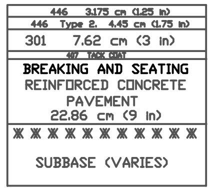
BREAK AND SEAT SITE

Overlay Construction: 1992

ADT (1991): 31,265

ADT (2008): 40,645

% Truck: 5

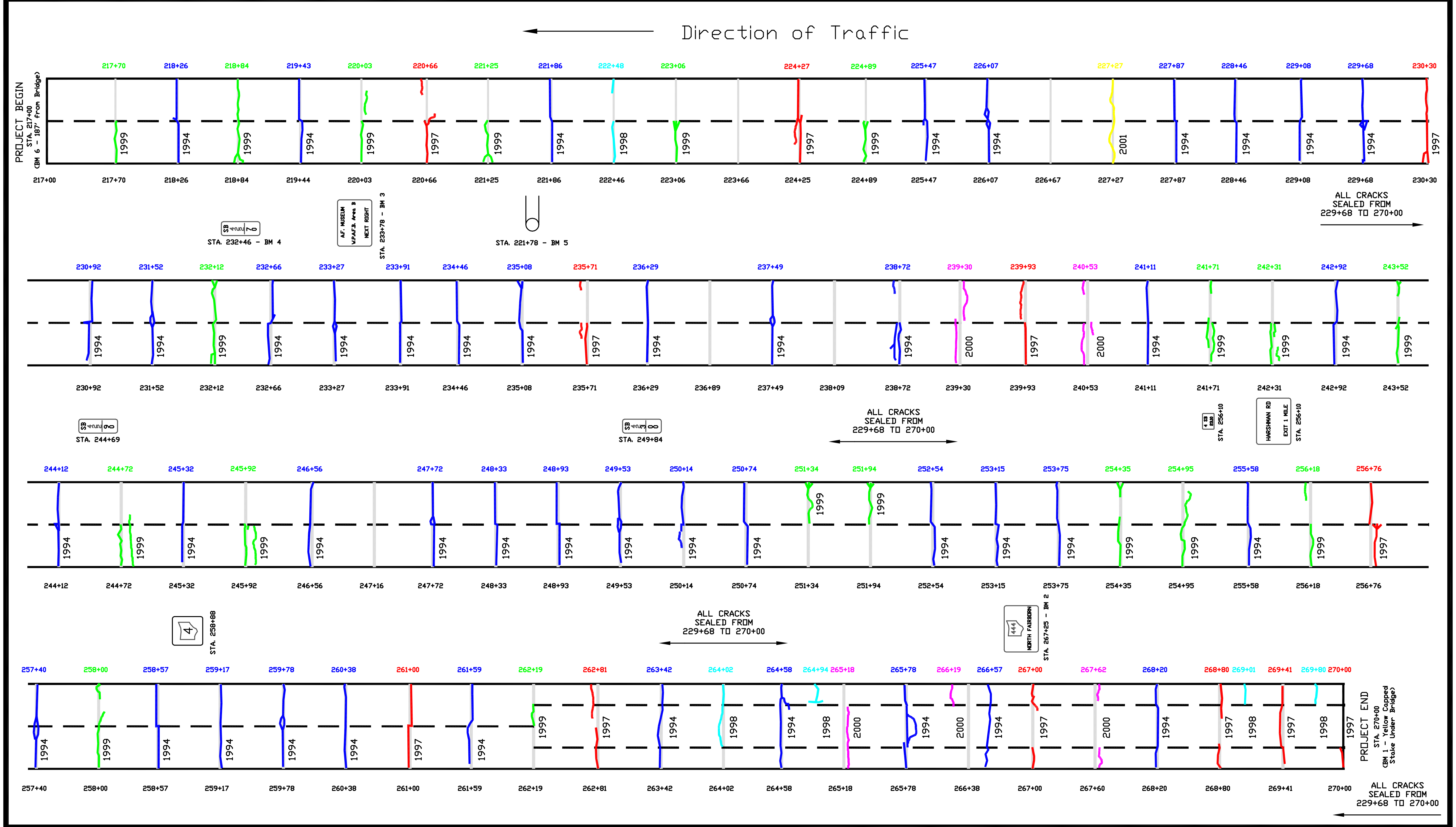


North

LEGEND

1994 No. of Cracks: 00 (Total: 00)	1999 No. of Cracks: 2 (Total: 6)
1997 No. of Cracks: 2 (Total: 2)	2000 No. of Cracks: 4 (Total: 10)
1998 No. of Cracks: 4 (Total: 4)	2001 No. of Cracks: 5 (Total: 15)

Figure 30. Reflection Crackin on SR-4, Station 270 to 217, (control section)



Location of Transverse Cracking

SECTION ID: SR 4 (MOT) Station: 217+00 to 270+00

TOTAL LENGTH: 1.6 km (1.0 mile)

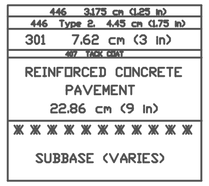
CONTROL SECTION

Overlay Construction: 1992

ADT (1991): 31,265

ADT (2008): 40,645

% Truck: 5

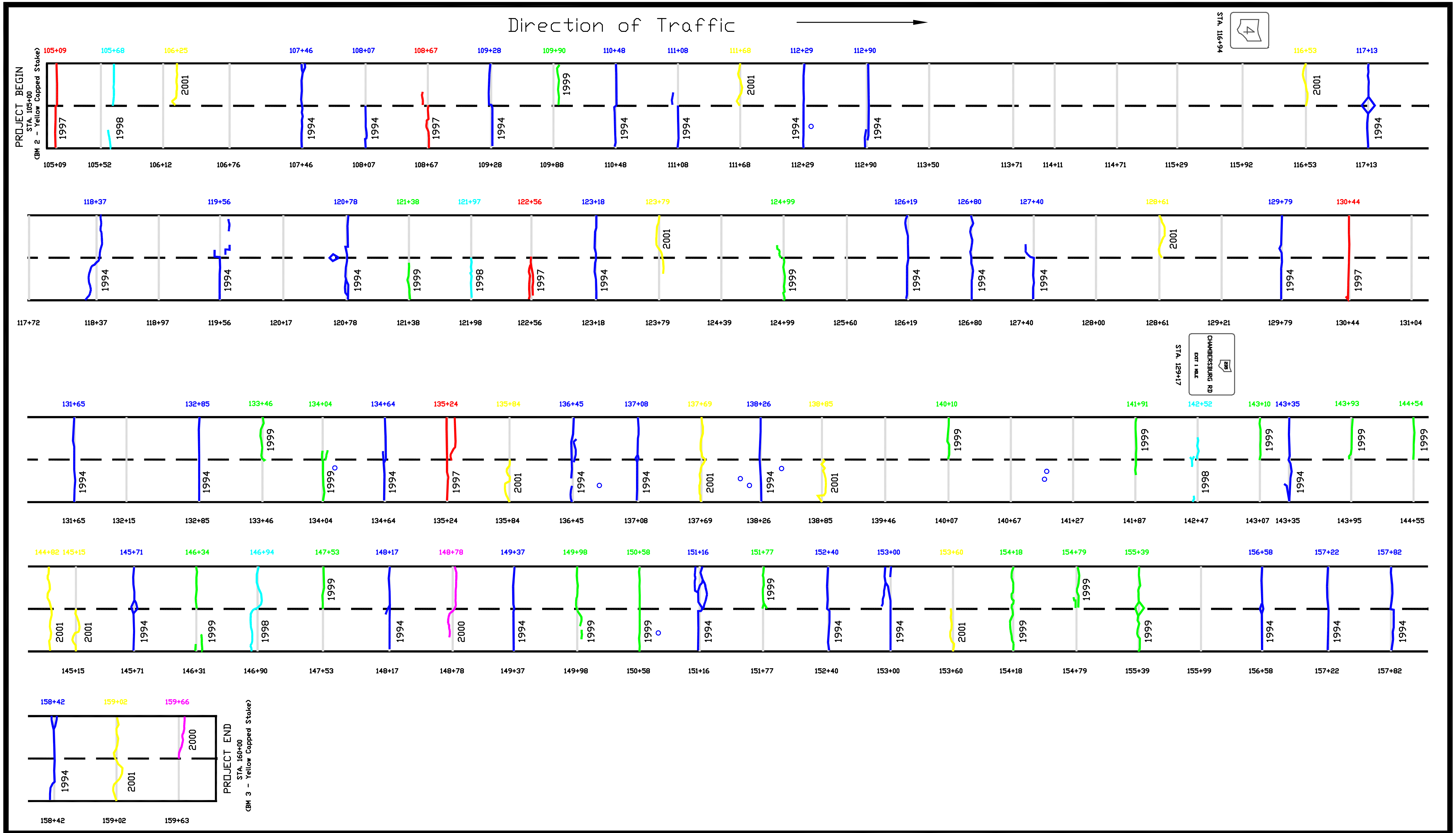


North

LEGEND

🟦 1994 No. of Cracks: 46 (Total: 46)	🟩 1999 No. of Cracks: 19 (Total: 82)
🟥 1997 No. of Cracks: 12 (Total: 58)	🟪 2000 No. of Cracks: 5 (Total: 87)
🟦 1998 No. of Cracks: 5 (Total: 63)	🟨 2001 No. of Cracks: 1 (Total: 88)

Figure 31. reflection Crackin on SR-4, Station 105 to 160, (control section)



Location of Transverse Cracking

SECTION ID: SR 4 (GRE) Station: 105+00 to 160+00

TOTAL LENGTH: 1.67 km (1.04 miles)

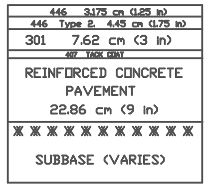
CONTROL SECTION

Overlay Construction: 1992

ADT (1991): 31,265

ADT (2008): 40,645

% Truck: 5



North →

LEGEND

—	1994 No. of Cracks: 33 (Total: 33)	—	1999 No. of Cracks: 18 (Total: 60)
—	1997 No. of Cracks: 5 (Total: 38)	—	2000 No. of Cracks: 2 (Total: 62)
—	1998 No. of Cracks: 4 (Total: 42)	—	2001 No. of Cracks: 12 (Total: 74)

Figure 32. Reflection Crackin on SR-4, Station 160 to 105, (break and seat section)

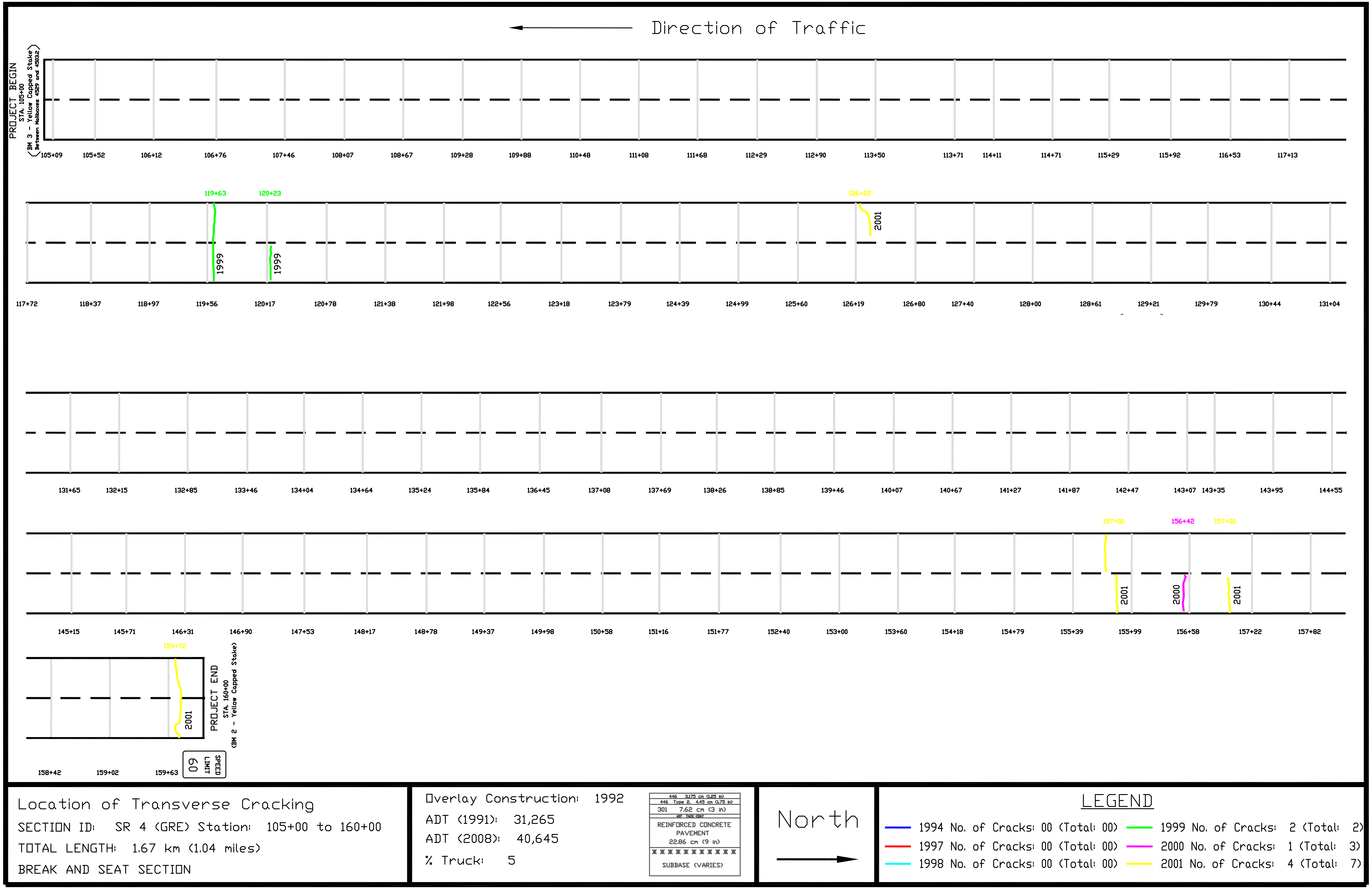
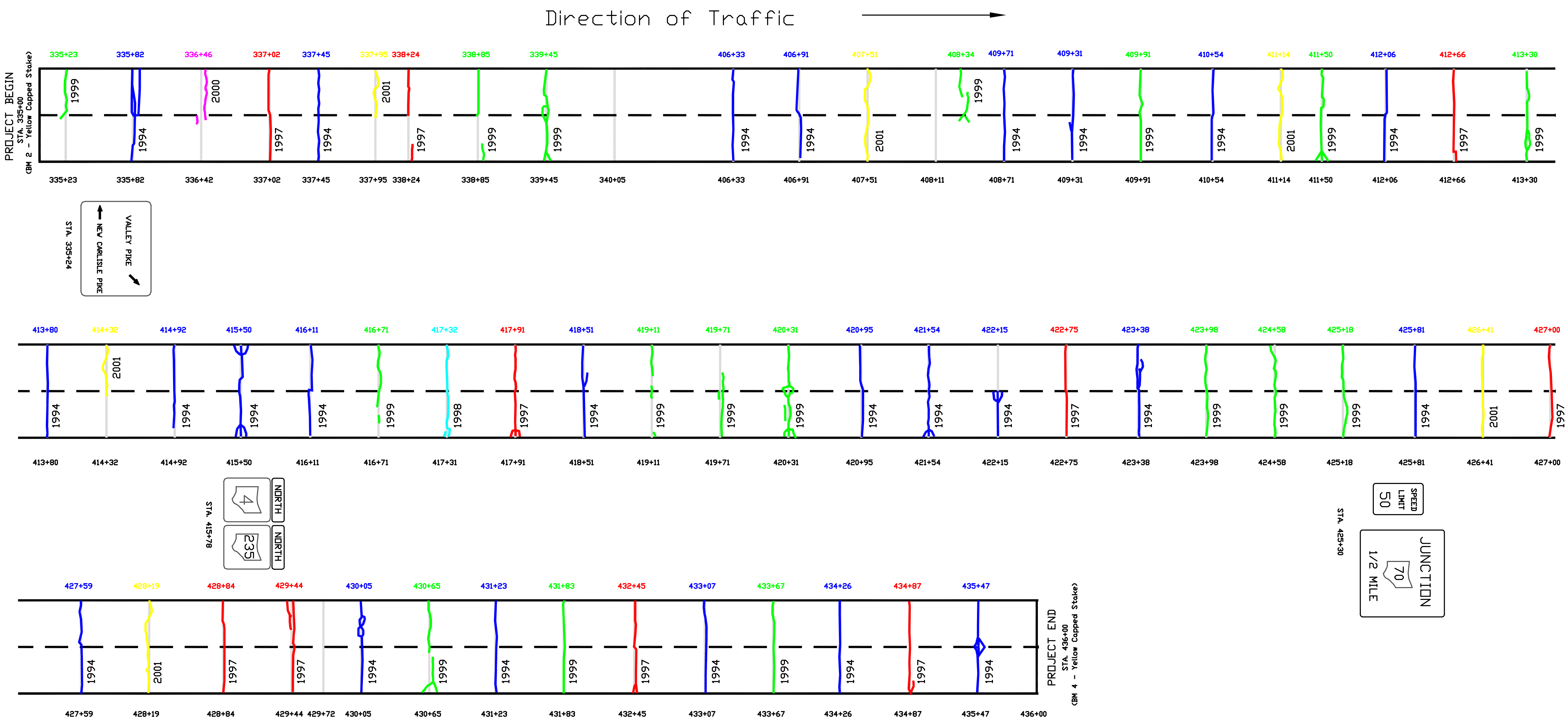


Figure 33. Reflection Crackin on SR-4, Station 335 to 436, (control section)



Location of Transverse Cracking

SECTION ID: SR 4 (MOT) Station: 335+00 to 436+00

TOTAL LENGTH: 1.0 km (0.66 miles)

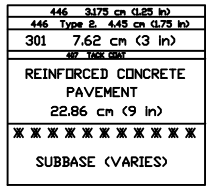
CONTROL SECTION

Overlay Construction: 1992

ADT (1991): 31,265

ADT (2008): 40,645

% Truck: 5



North →

LEGEND

— 1994 No. of Cracks: 24 (Total: 24)

— 1997 No. of Cracks: 10 (Total: 34)

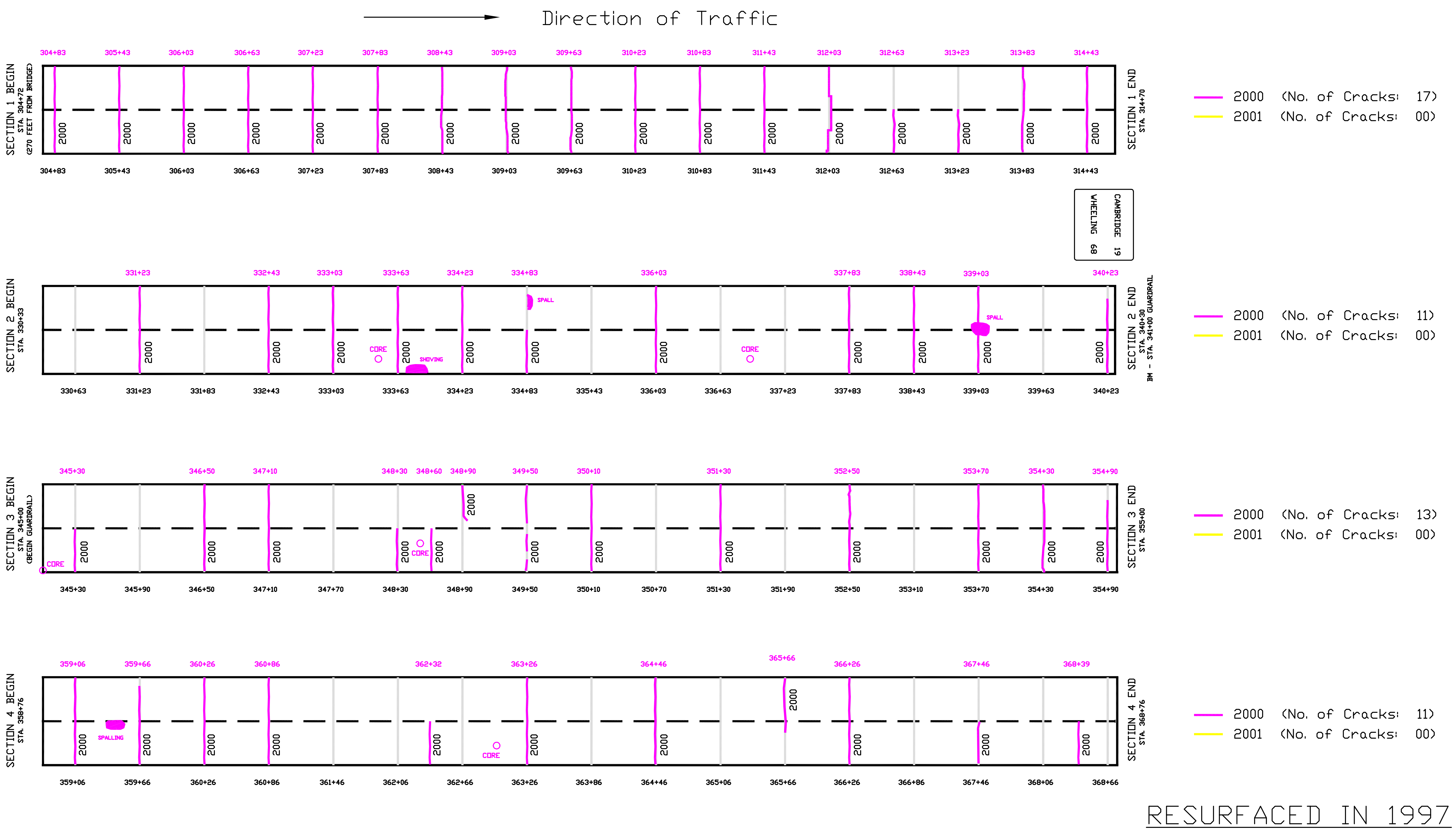
— 1998 No. of Cracks: 1 (Total: 35)

— 1999 No. of Cracks: 17 (Total: 52)

— 2000 No. of Cracks: 1 (Total: 53)

— 2001 No. of Cracks: 1 (Total: 54)

Figure 34a. Reflection Cracking on I-70 after major rehabilitation in 1997



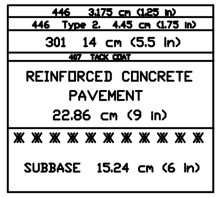
Location of Transverse Cracking

SECTION ID: I-70 Station: 304+72 to 368+76

TOTAL LENGTH: 1.2 km (0.757 mile)

CONTROL/BREAK & SEAT SITE

SECTION 1: CONTROL
SECTION 2: 6" PATTERN
SECTION 3: 18" PATTERN
SECTION 4: 30" PATTERN

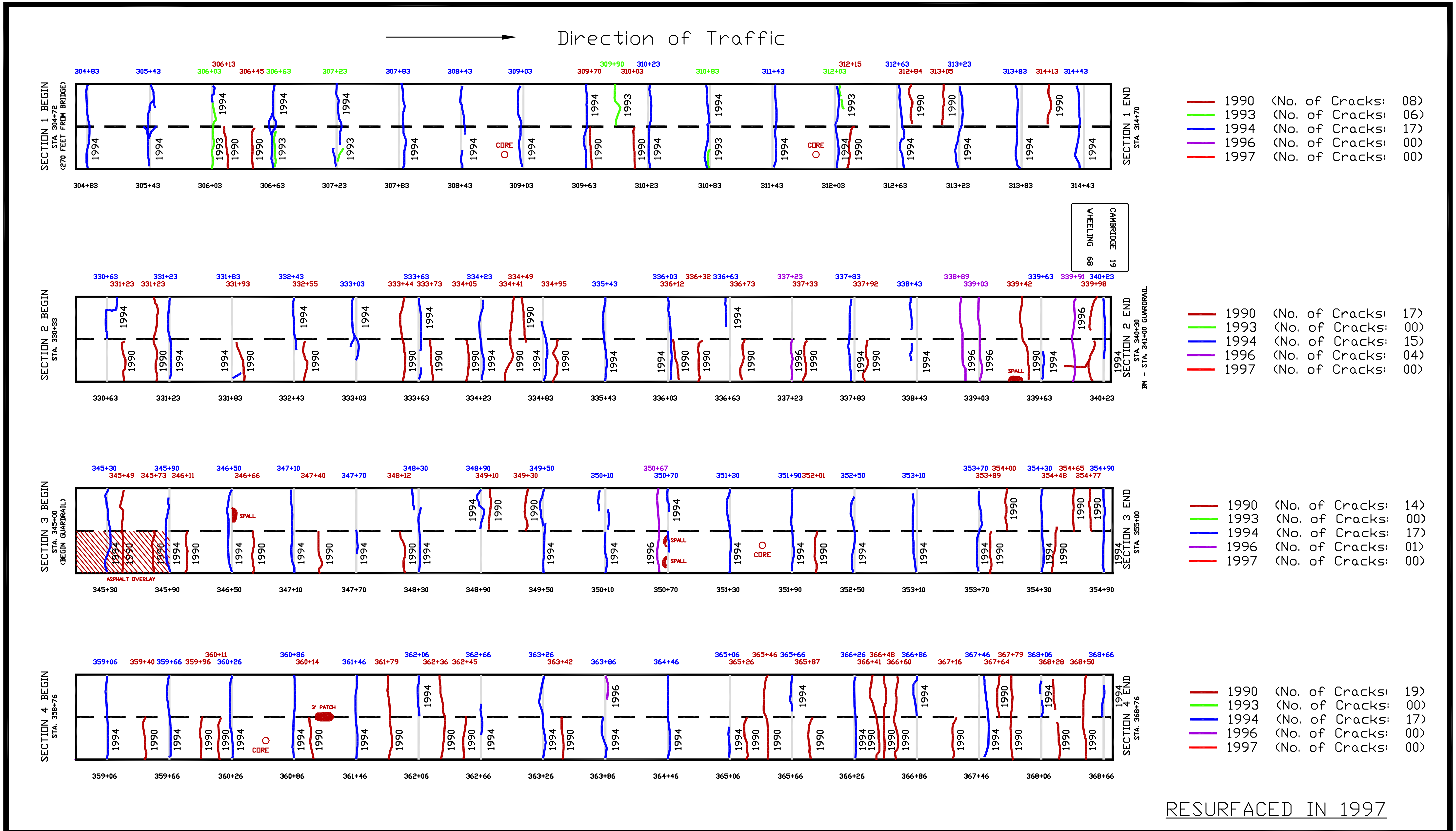


North

LEGEND

1997 No. of Cracks: 00 (Total: 00)	2000 No. of Cracks: 52 (Total: 52)
1998 No. of Cracks: 00 (Total: 00)	2001 No. of Cracks: 00 (Total: 00)
1999 No. of Cracks: 00 (Total: 00)	

Figure 34b. Reflection Crackin on I-70 prior to major rehabilitation in 1997



Location of Transverse Cracking

SECTION ID: I-70 Station: 304+72 to 368+76

TOTAL LENGTH: 1.2 km (0.757 mile)

CONTROL/BREAK & SEAT SITE

SECTION 1: CONTROL

SECTION 2: 6" PATTERN

SECTION 3: 18" PATTERN

SECTION 4: 30" PATTERN

446 3.175 cm (1.25 in)

446 Type 2. 4.45 cm (1.75 in)

301 14 cm (5.5 in)

407 TACK COAT

REINFORCED CONCRETE PAVEMENT 22.86 cm (9 in)

SUBBASE 15.24 cm (6 in)

North

LEGEND

1990 No. of Cracks: 00 (Total: 58)

1993 No. of Cracks: 00 (Total: 06)

1994 No. of Cracks: 00 (Total: 66)

1996 No. of Cracks: 00 (Total: 05)

1997 No. of Cracks: 00 (Total: 00)

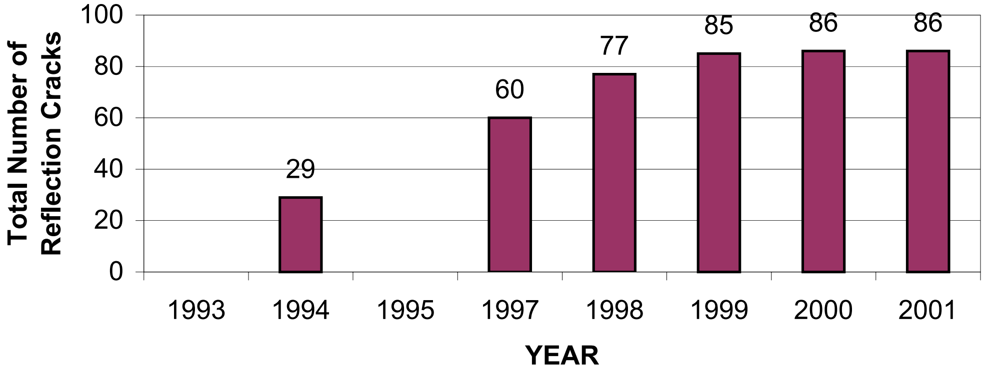


Figure 35. Progression of Reflection Cracking on I-71, Station 726 to 780 Control Section

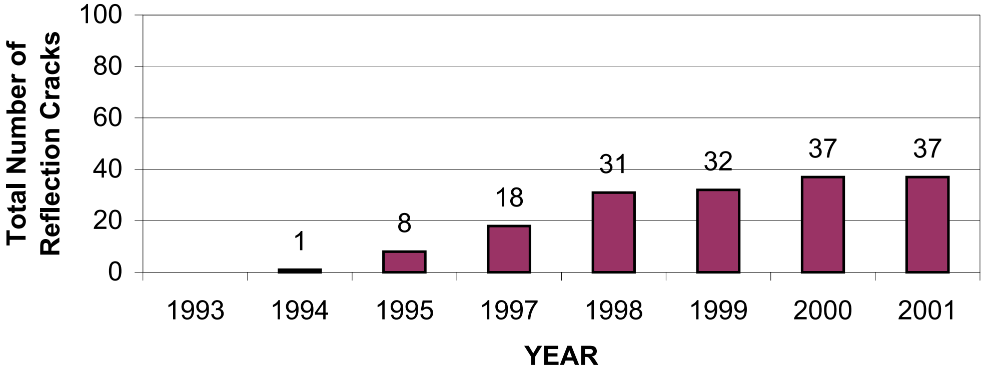


Figure 36. Progression of Reflection Cracking on I-71, Station 780 to 726 B/S Section

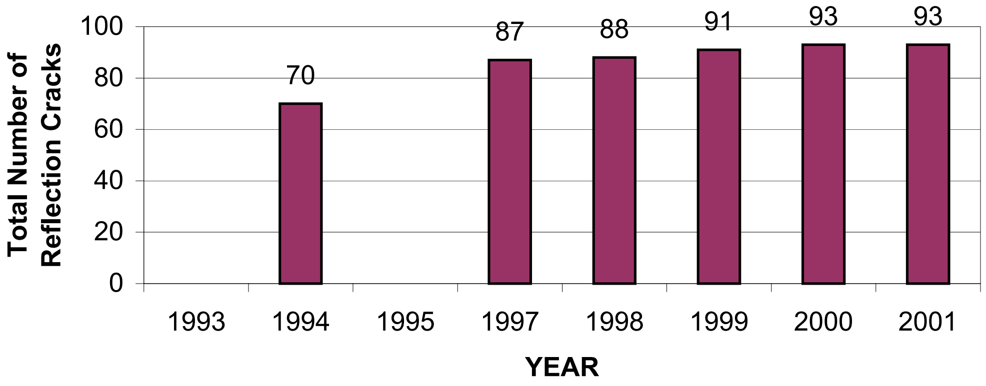


Figure 37. Progression of Reflection Cracking on I-71, Station 88 to 35, Control Section

Figure 38. Progression of Reflection Cracking on SR-4, Station 270 to 217, Control section

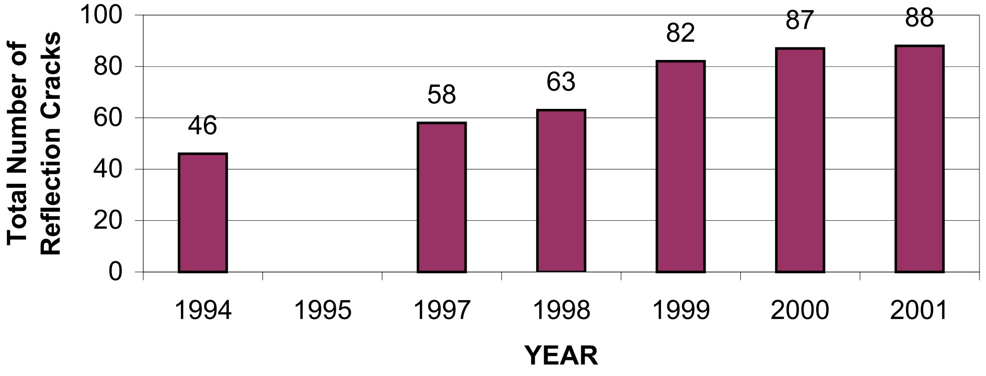
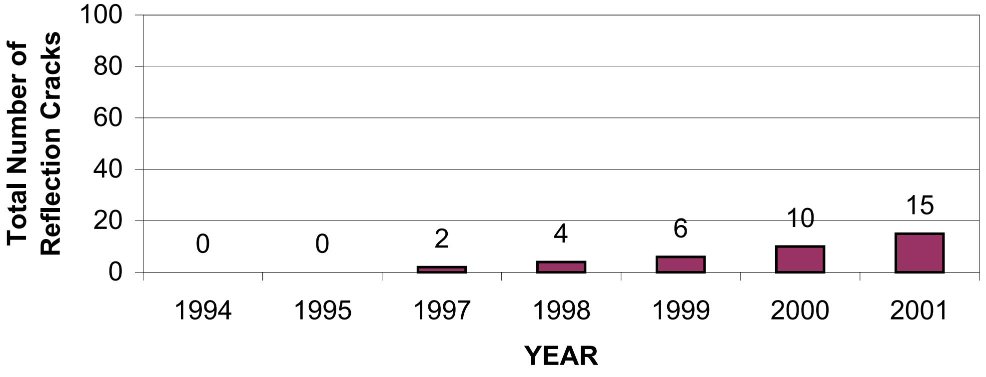


Figure 39. Progression of Reflection Cracking on SR-4, Station 217 to 270, B/S Section



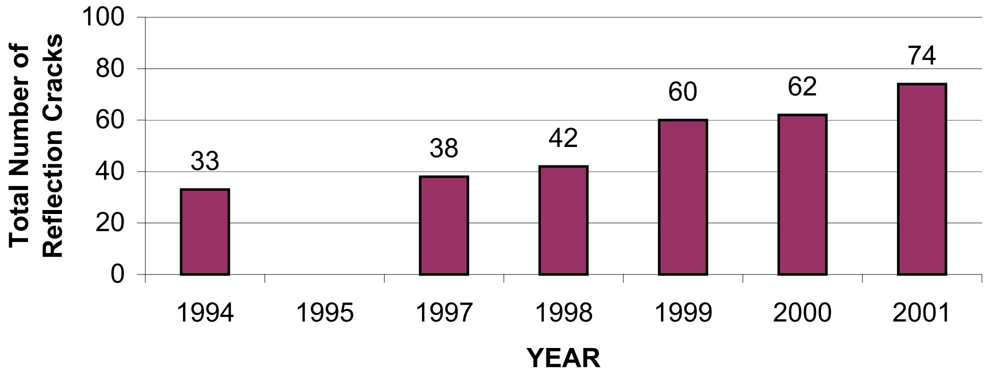


Figure 40. Progression of Reflection Cracking on SR-4, Station 105 to 160, Control Section

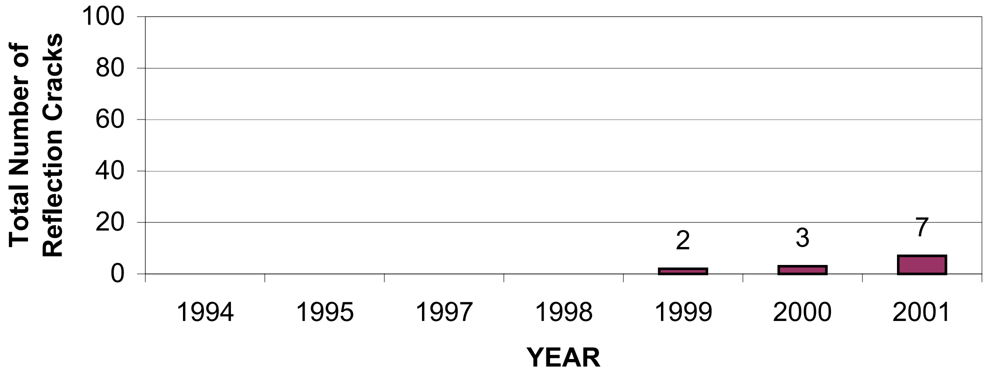
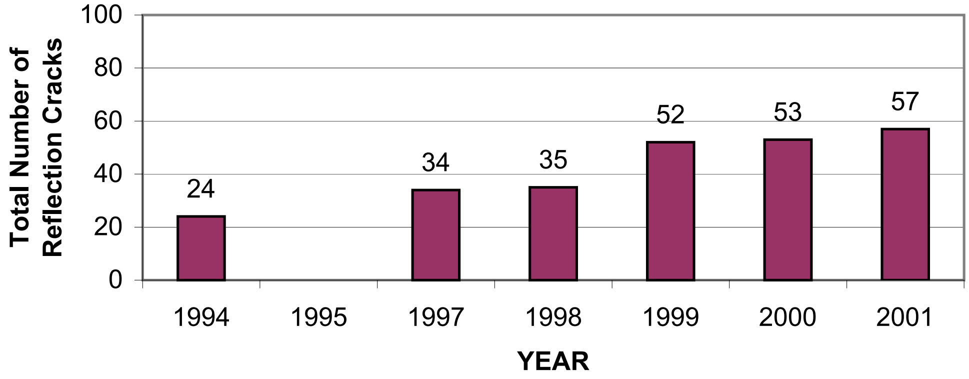


Figure 41. Progression of Reflection Cracking on SR-4, Station 160 to 105, B/S Section

Figure 42. Progression of Reflection Cracking on SR-4, Station 335 to 436, Control section



From the results above, it is evident that the number of reflection cracks reflected in broken and seated pavements is significantly lower than in the control sections. A careful review of the figures 26 through 42 leads to the conclusion that breaking and seating has not only succeeded in delaying cracks but has also considerably minimized the number of cracks at any given time. The effect is even more pronounced in the SR-4 sections where the use of a pile hammer has resulted in extensive breaking of the concrete slabs, which is more close to the basic definition of breaking. The primary reason for the occurrence of reflection cracking in composite pavements is due to the excessive tensile strain at the bottom of the AC layer as a result of excessive horizontal thermal movements of the concrete slabs. Breaking and seating has resulted in reducing the effective slab length and thus considerably reduced or sometimes even eliminated horizontal movements of the concrete slabs which in turn led to negligible tensile strains at the bottom of the AC layer.

It is thus seen, breaking and seating concrete pavements can delay and/or minimize reflection cracking. However, this statement is more true for the sections broken with the pile hammer.

COMPARISON OF PERFORMANCE BASED ON PAVEMENT CONDITION RATING (PCR)

The ODOT's Office of Pavement Engineering collected PCR data every year on the test sections. The PCR is a composite index of various types of distresses as defined in the pavement condition rating manual [16]. Figures 43 to 50 show the variations in the PCR with time.

On the I-71 sections, the differences in the PCR at any time is minimal for both the B/S and control sections. This is because both sections, according to ODOT's distress rating procedure, have extensive cracks. However, the B/S sections on SR-4 have considerably higher PCR. It should also be recognized that all control sections received crack seal treatment by the counties in 1997. Thus, the PCR survey also indicates that the B/S sections on SR-4 are performing better than other sections after nine years of service.

COMPARISON OF PERFORMANCE BASED ON RIDE NUMBER

Figures 51 through 58 present a comparison of Ride Number (RN) with time. Ride number data were collected by ODOT. Ride number represents driving comfort experienced by the traveling public and captures surface irregularities. A higher value of RN represents a smooth pavement offering a high quality ride. On the I-71 sections, it can be seen that the RN has been steady over the years but increased in year 2001. This is because the I-71 sections were rehabilitated in 2001 and the data presented was for the condition soon after rehabilitation. It is difficult to develop an appropriate conclusion based on RN. However, it is interesting to see that the RN value on one B/S site on SR-4, station 217 to 270 is considerably lower in 2001 (Figure 55). Although this section was relatively free of reflection cracks, during the field survey, the researchers noticed bumps at the joints. This surface irregularity has been captured in the RN. Further monitoring can establish the consequences of such bumps on the overall performance of this test section.

COMPARISON OF PERFORMANCE BASED ON IRI

Figures 59 through 66 illustrate the change in IRI with time for all the test sections. IRI data was collected by ODOT. Unlike RN, a small value of IRI represents excellent ride quality. The IRI data is plotted in units of meter/kilo meter. The data suggests that all pavements fall under the 'excellent' category, meaning they offer an excellent ride quality [17]. The variation in IRI follows a trend similar to RN and hence the same argument can be made.

Figure 43. Change in Pavement Condition Rating with Time on I-71, Station 726 to 780, Control Section

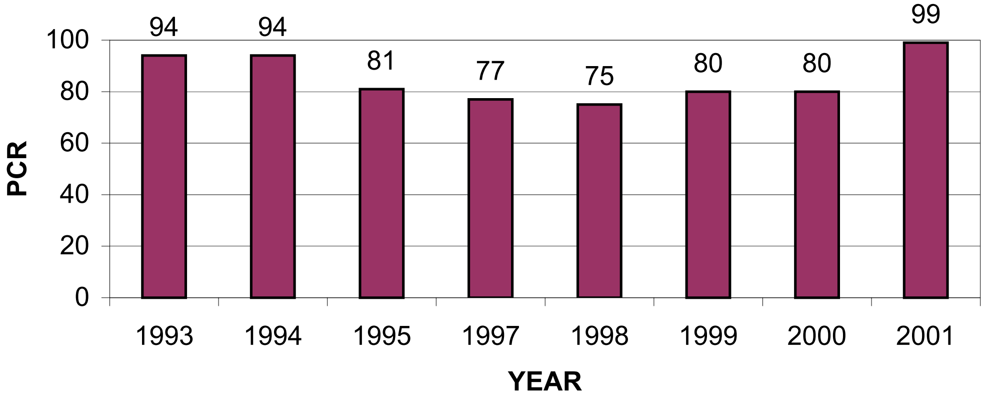


Figure 44. Change in Pavement Condition Rating with Time on I-71, Station 780 to 726, B/S Section

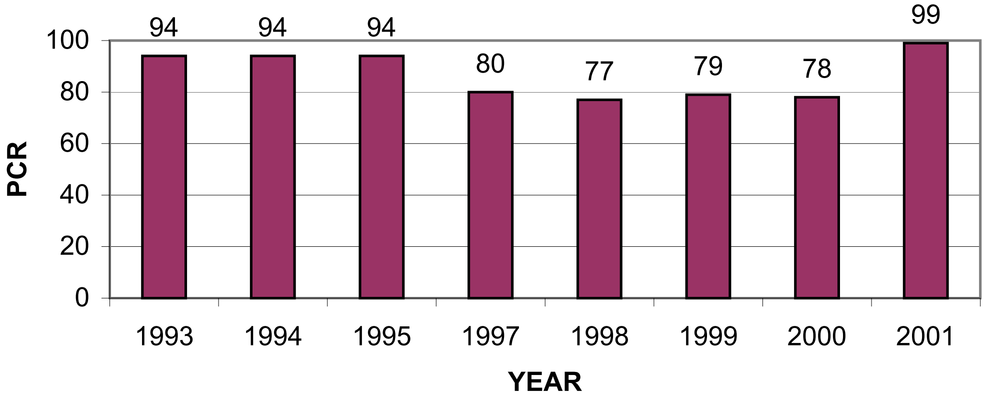


Figure 45. Change in Pavement Condition Rating with Time on I-71, Station 88 to 35, Control Section

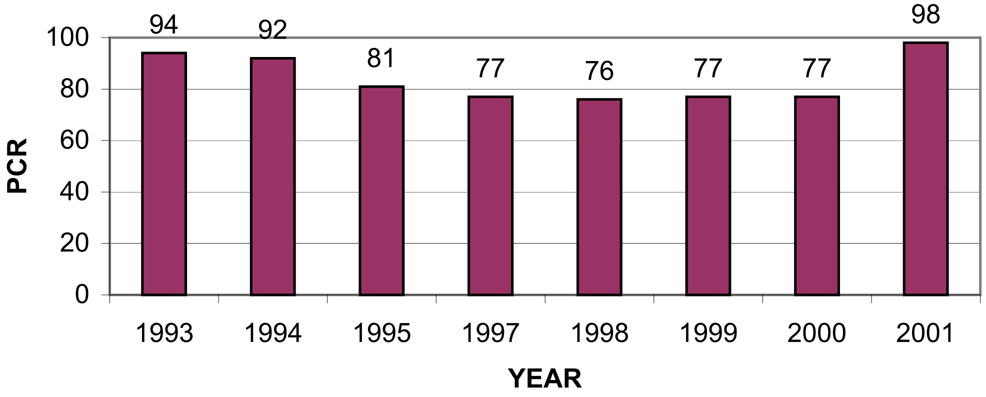


Figure 46. Change in Pavement Condition Rating with Time on SR-4, Station 270 to 217, Control Section

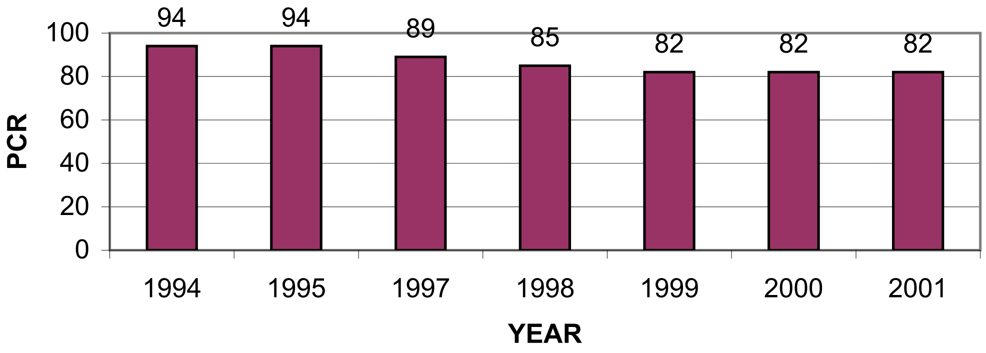


Figure 47. Change in Pavement Condition Rating with Time on SR-4, Station 217 to 270, B/S Section

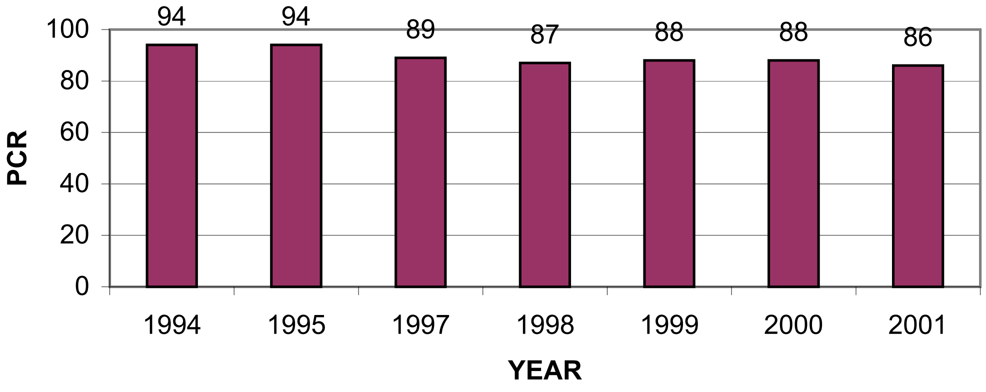


Figure 48. Change in Pavement Condition Rating with Time on SR-4, Station 105 to 160, Control Section

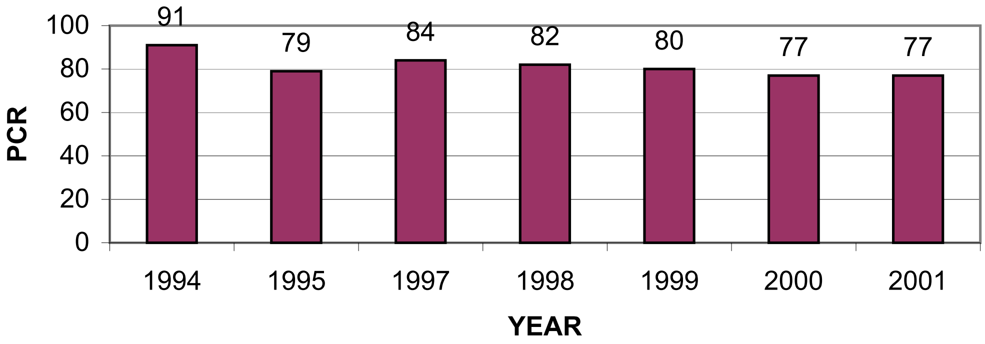


Figure 49. Change in Pavement Condition Rating with Time on SR-4, Station 160 to 105, B/S Section

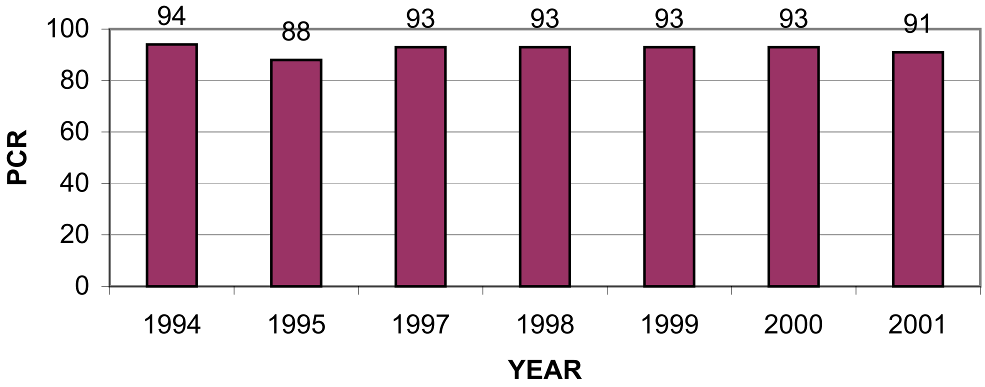


Figure 50. Change in Pavement Condition Rating with Time on SR-4, Station 335 to 436, Control Section

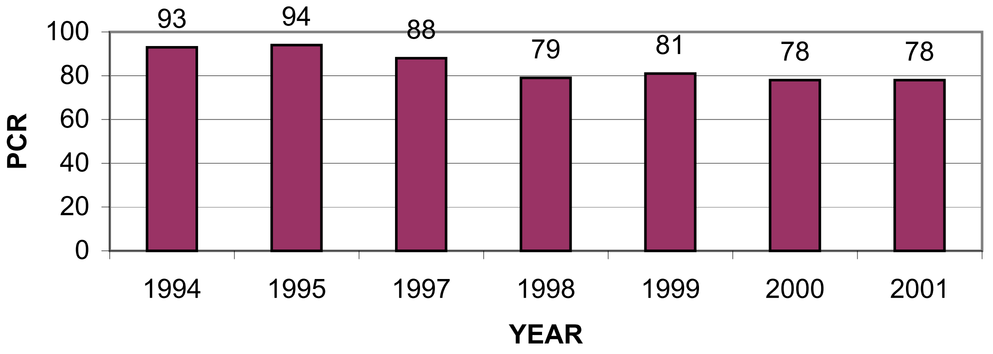


Figure 51. Change in Ride Number with Time on I-71, Station 726 to 780, Control Section

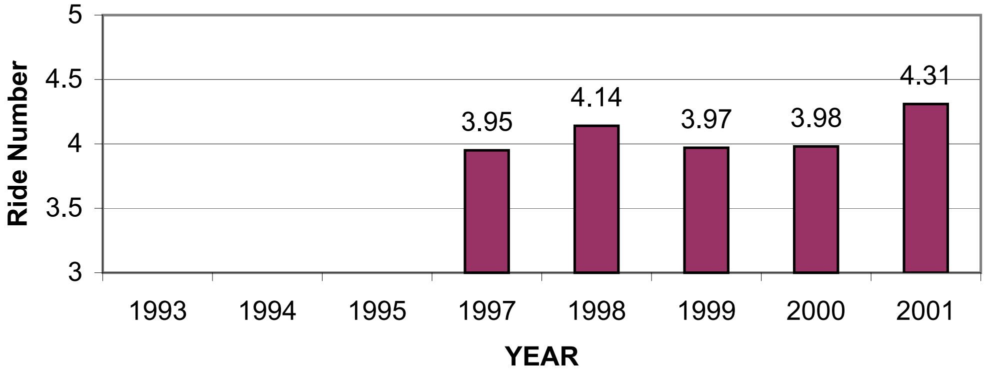


Figure 52. Change in Ride Number with Time on I-71, Station 780 to 726, B/S Section

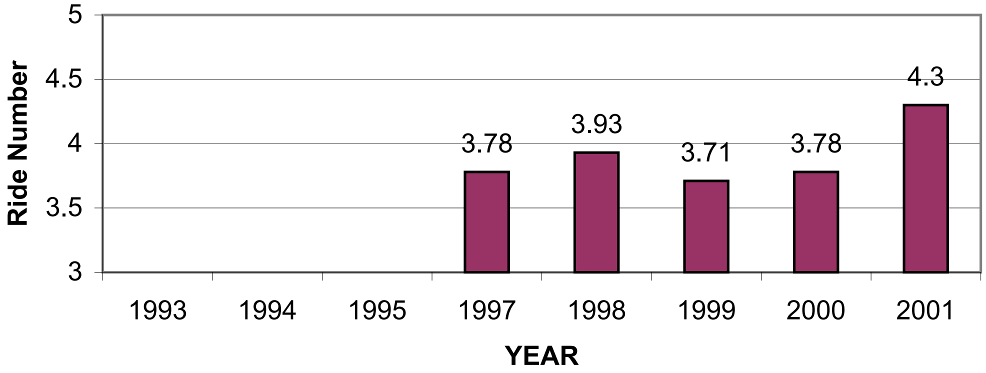


Figure 53. Change in Ride Number with Time on I-71, Station 88 to 35, Control Section

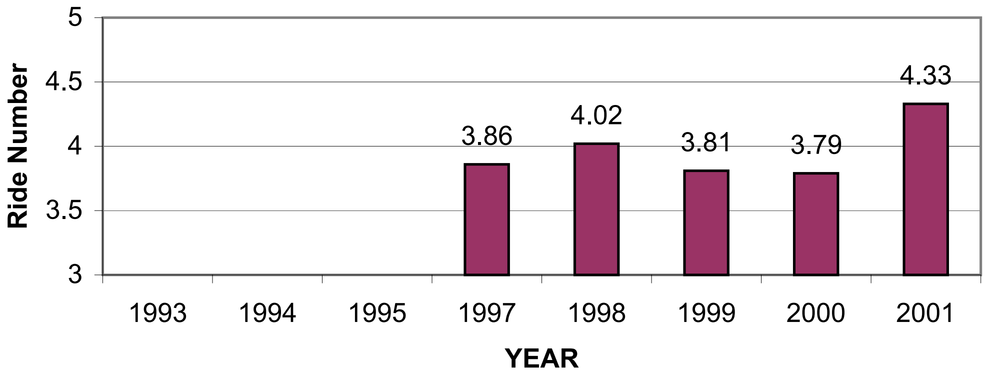


Figure 54. Change in Ride Number with Time on SR-4, Station 260 to 217, Control Section

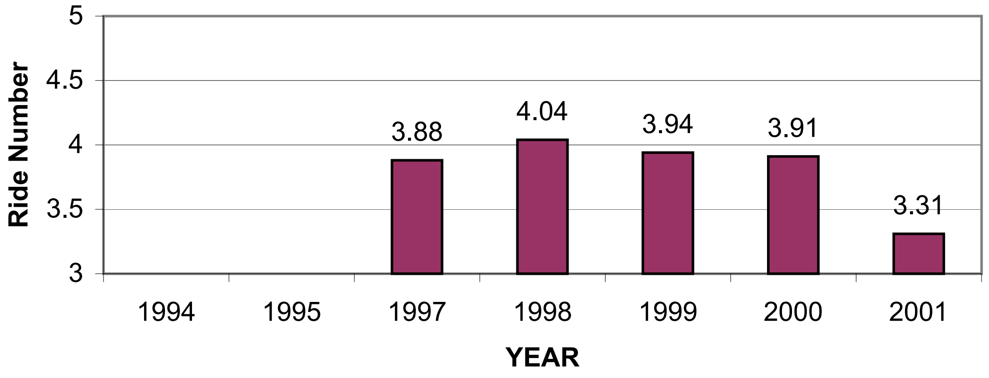


Figure 55. Change in Ride Number with Time on SR-4, Station 217 to 260, B/S Section

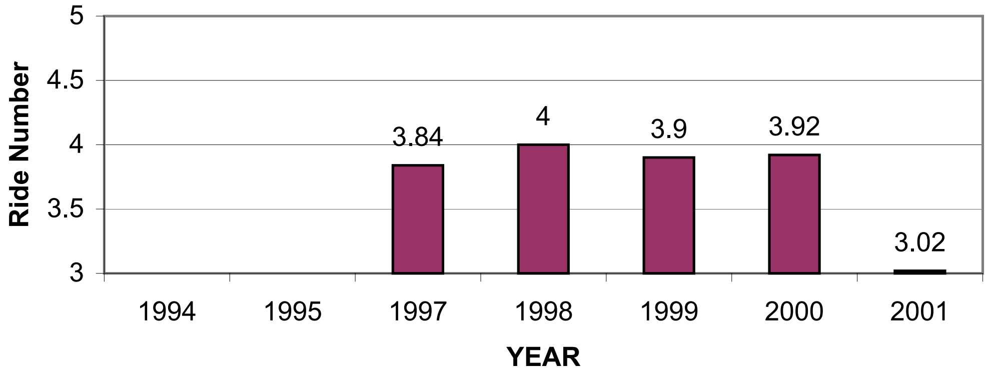


Figure 56. Change in Ride Number with Time on SR-4, Station 335 to 436, Control Section

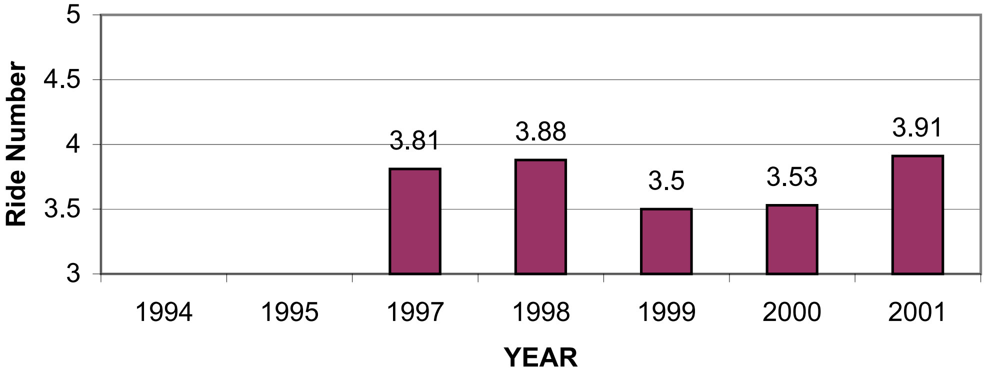


Figure 57. Change in Ride Number with Time on SR-4, Station 105 to 160, Control Section

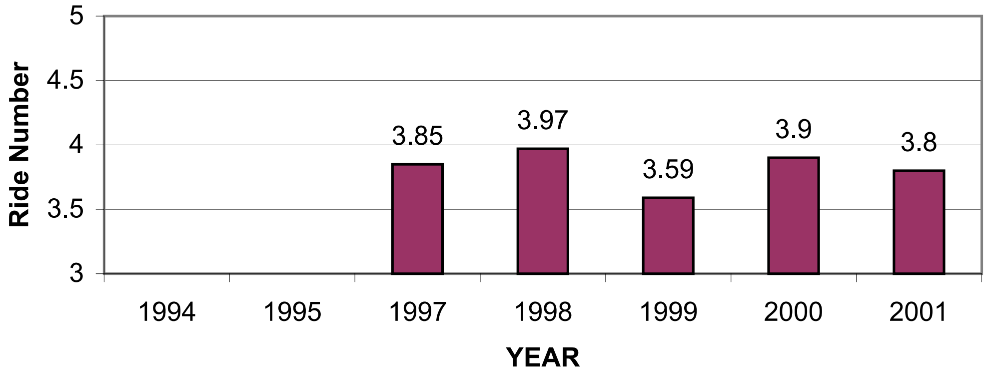


Figure 58. Change in Ride Number with Time on SR-4, Station 160 to 105, B/S Section

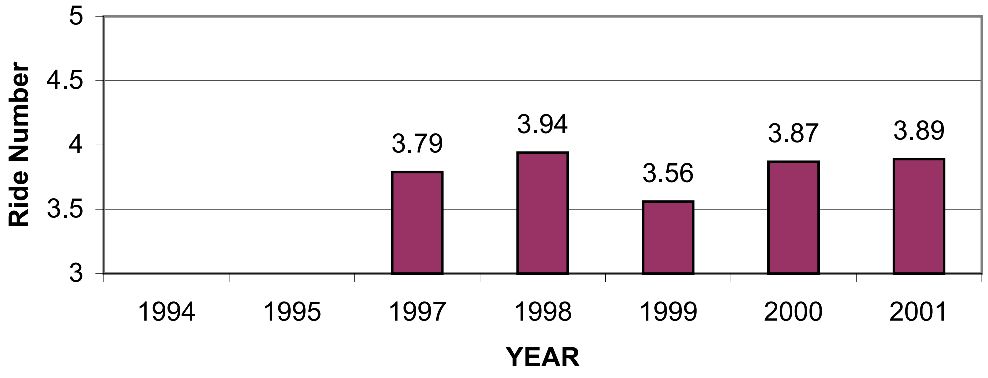


Figure 59. Change in IRI with Time on I-71, Station 726 to 780, Control Section

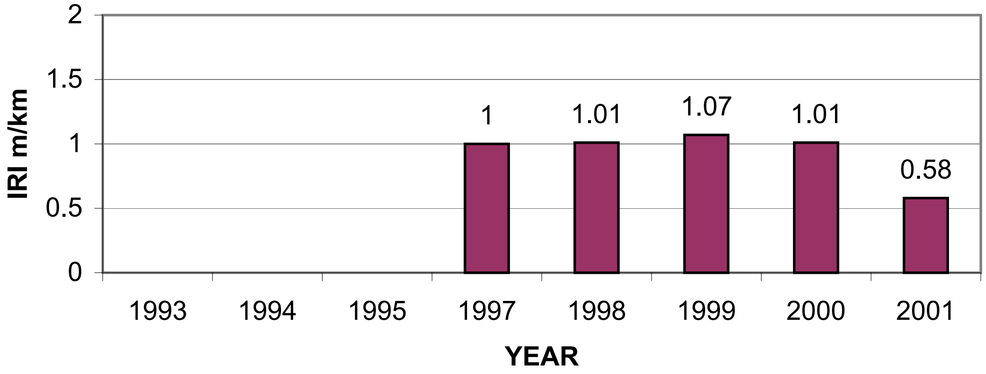
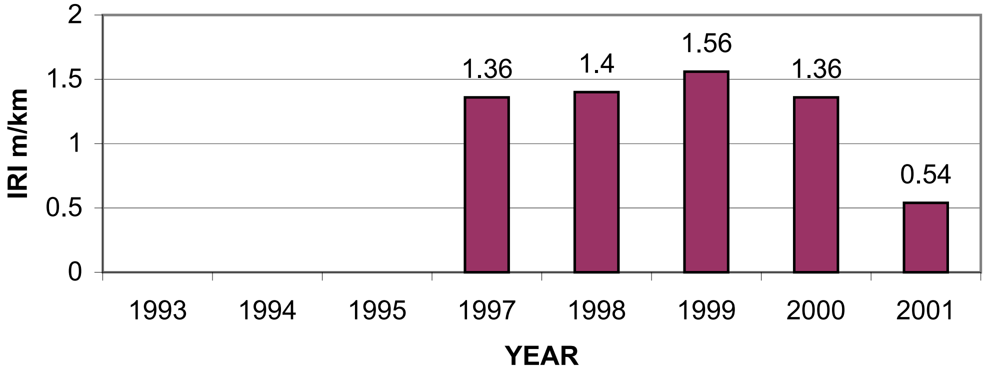


Figure 60. Change in IRI with Time on I-71, Station 780 to 726, B/S Section



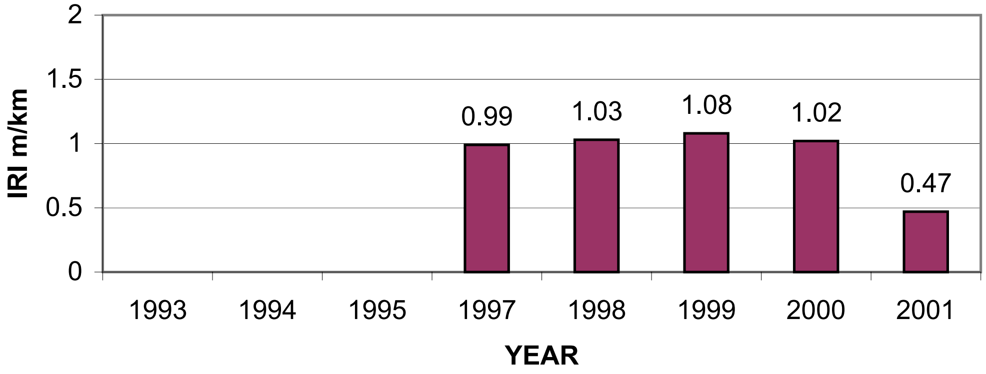


Figure 61. Change in IRI with Time on I-71, Station 88 to 35, Control Section

Figure 62. Change in IRI with Time on SR-4, Station 270 to 217, Control Section

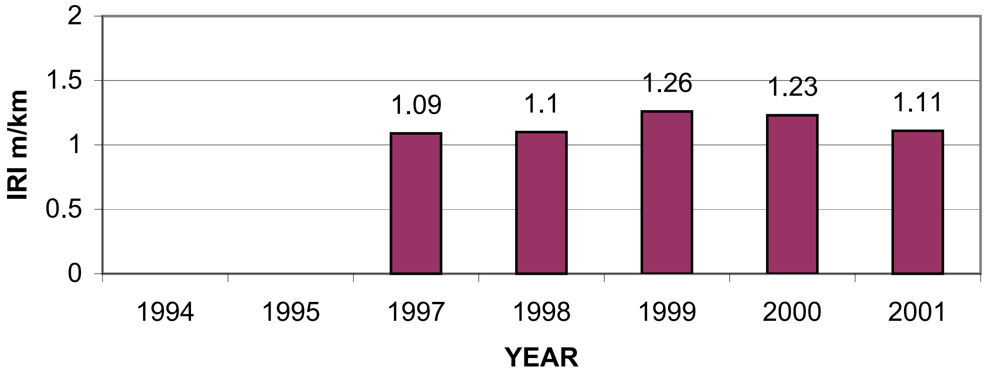
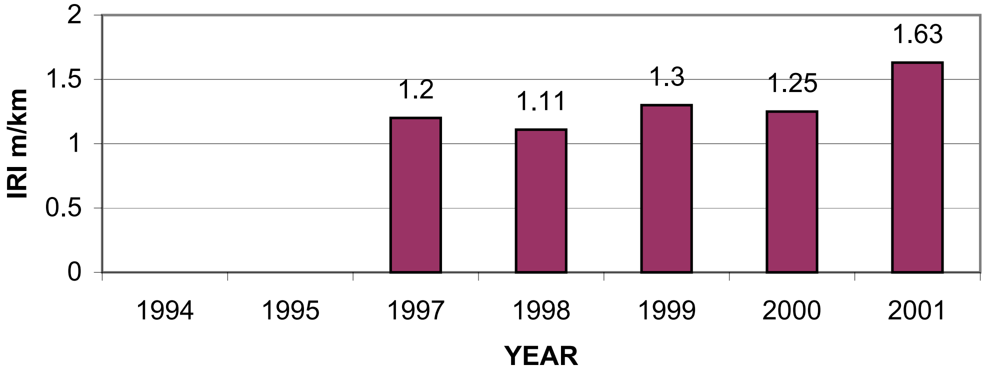


Figure 63. Change in IRI with Time on SR-4, Station 217 to 270, B/S Section



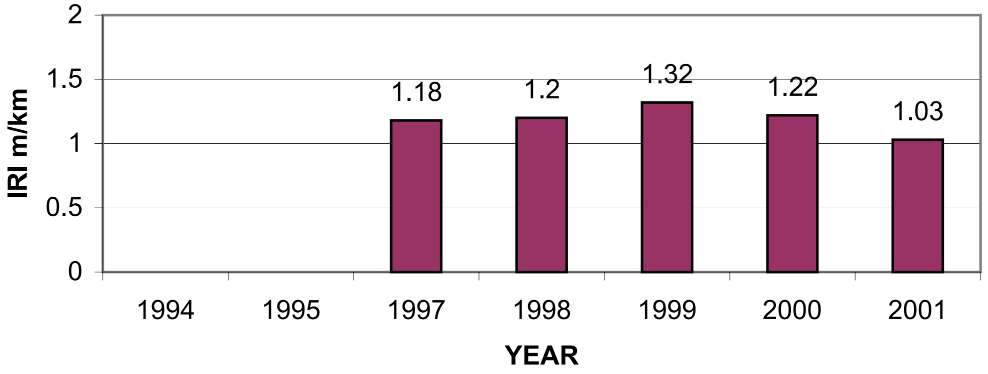


Figure 64. Change in IRI with Time on Station SR-4, 105 to 160, Control Section

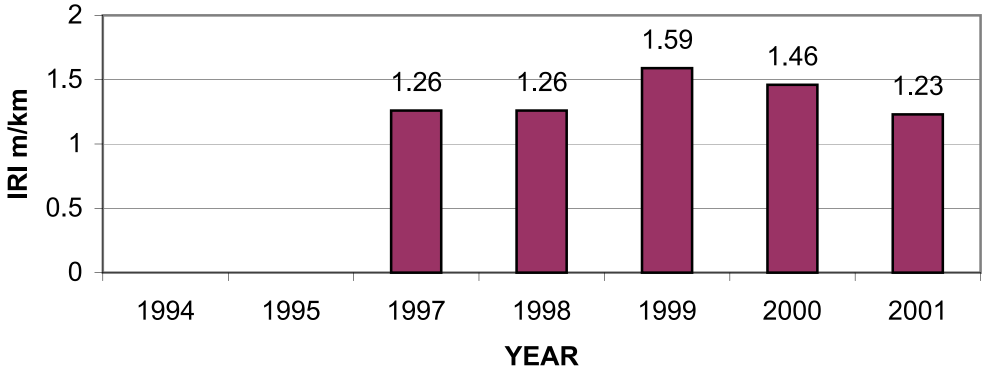
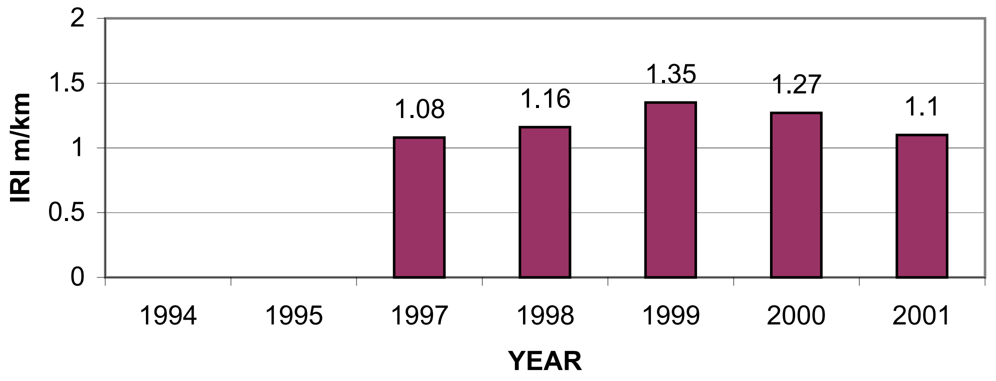


Figure 65. Change in IRI with Time on Station SR-4, 160 to 105, B/S Section

Figure 66. Change in IRI with Time on SR-4, Station 335 to 436, Control Section



EFFECT OF CLIMATIC FACTORS

Ohio's climate changes considerably throughout the state. Mean annual temperatures range from 49^0 F in the northeast to 57^0 F in the extreme south [19]. Normal annual precipitation ranges from a low of less than 75 cm (30 inch) to a high of more than 110 cm (44 inch). Ohio's climate is continental with a wide range of temperatures, higher precipitation in the spring and summer, and lower precipitation in the fall and winter. The average length of freeze-free periods ranges from a high of 200 days along the Lake Erie shore to a low of 140 days in east central Ohio.

Climatic factors are a function of the average condition of the weather at a location, usually over a period of time, as exhibited by temperature, wind velocity and precipitation. Climatic factors influence the performance of a pavement and illustrate the impact of environment on initiation and progression of reflection cracking. Previous studies [20] indicate that areas with larger annual rainfall have a lower level of low-severity cracking and a higher level of medium to high-severity cracking. The higher level of low-severity cracking in areas with low rainfall may be due to greater temperature variations. The combined effects of the climatic factors cannot be totally separated and investigated independently. The annual average temperature and monthly average temperature ranges combine with the annual precipitation to describe the general climate in the area. Generally, the areas with warmer annual temperatures and a smaller temperature range performed better.

The basic mechanisms leading to the development of reflection cracking are horizontal and differential vertical movements between the original pavement and the overlay. Studies attempting to establish the influence of climatic data on the occurrence of reflection cracks are available in the literature. However, there are no current criteria that have been validated adequately with an extensive number of test sections. In the present study, the I-71, SR-4 and I-70 test sections are all located in areas with little variation in climatic factors among them. Hence, the present study did not provide adequate data to quantify the effect of climatic factors on the performance of broken and seated pavements, and control sections in Ohio. However, the present study has indicated that breaking concrete slabs into smaller segments using a pile hammer has been very effective in delaying and reducing reflection cracking. This is because, by breaking the concrete pavement, the effective length of the slabs is considerably reduced to the extent that the horizontal and vertical movements at the joints are no longer large enough to induce excessive strains in the asphalt overlay. It is hence concluded that this study is applicable to the whole state irrespective of the differences in climatic factors between the North and South ends of Ohio.

WHAT DID WE LEARN FROM THIS STUDY?

This report presents the details of a systematic investigation of the long-term effectiveness of the breaking and seating technique on the performance of AC overlays, using a controlled field experiments. Performance has been monitored using the following performance indicators:

- Deflection
- Visual survey of reflection cracking
- Pavement Condition Rating
- Ride Number, and
- International Roughness Index

The results, in general, strongly indicate an improved performance of AC overlays on broken and seated concrete pavements. Hence, the breaking and seating procedure does indeed result in improved pavement performance that may justify its use. Ultimately, the economics will govern based on the length of time future maintenance and rehabilitation is deferred. The discussion presented below is an effort to provide ODOT with specific information to develop an implementation plan.

What is the effect of breaking and seating on the structural integrity of the resulting pavement?

The B/S treatment has a significant effect on the structural response and behavior of the resulting pavement. Breaking the PCC slabs into smaller pieces resulted in a reduction in the flexural strength, an increase in the surface deflection (50% to 100%), and a decrease in AREA and Spreadability (20 to 30%). The Edward Ratio has been consistently high on B/S pavements (up to 30%) indicating a behavior closer to flexible pavements.

The extent of breaking plays a key role in the application of the B/S technique. A majority of the studies reported in the past in Ohio as well as other states utilized a guillotine hammer for breaking PCC slabs. In the present study, two types of breakers (guillotine and pile) were employed allowing for a comparison of their effectiveness. All the results reported in this study lead to the conclusion that the pile hammer is very effective in breaking the PCC slabs by inducing through slab cracks in all directions. The primary result of such an operation is a reduction in the effective slab size. In doing so, the horizontal and vertical movements of the slabs with changes in temperature are considerably reduced and so is the tensile strain exerted at the bottom of the AC overlay. However, there is a significant loss in shear transfer. Wheel load transfer is achieved by means of aggregate interlock resulting in an increase in the maximum surface deflection and deeper deflection bowls.

In summary, the use of a pile hammer for breaking PCC slabs changes the behavior of the rigid or composite pavements into flexible pavements. In such a case, subgrade conditions become increasingly important while designing AC overlays.

Most of the discussion presented above relates to slabs broken into 0.45 m x 0. 45 m (18 inch x 18 inch). The field experiment in this study could not be used to establish the optimum size of the broken slab fragments to retain structural integrity and at the same time minimize thermal movements. A preliminary mechanistic analysis illustrated that different fragment sizes do not appreciably affect the deflection characteristics when a guillotine hammer is used. However, when a pile hammer is used, there is a pronounced effect of fragment size on deflections. A detailed study is necessary to establish the optimum slab size of slab fragments.

What are the consequences of breaking and seating - delay or minimize or eliminate reflection cracking?

Crack initiation in composite pavements is caused by the vertical and horizontal movements of the PCC slabs. When PCC slabs undergo horizontal movements, they exert a tensile strain at the bottom of AC layer, at the interface of AC-PCC. If the tensile strain thus exerted exceeds the limiting value, a crack develops at the bottom of the AC layer. With time and passage of traffic, the crack works upwards.

Studies show that horizontal movements of PCC slabs are directly proportional to the length of the slab. Thus, the shorter the slab length, the better the chance of reducing the tensile strain at the bottom of AC overlay. The primary objective of breaking and seating is to reduce the effective slab size. The pile hammer has been successfully used to break the PCC slabs into the desired fragment size thus reducing the effective slab length. The guillotine hammer, on the other hand, has been partially successful. The results are evident in terms of reflection cracks appearing on the AC overlays of the test sections.

The reflection cracks on all the control sections appeared within two years after the AC overlay. Within four years, more than 90% of the joints showed reflection cracks. On I-71 the B/S test section where a guillotine hammer was used, one crack was noticed two years after the AC overlay. After being in service for nine years, 42% of the joints have reflection cracks. The SR-4 B/S sections, where a pile hammer was used, are relatively free of cracks after eight years. The two sections have 7% and 17% joint reflection cracks, while the control sections in the vicinity have 80% to 100% joint reflection cracks.

This result clearly indicates that breaking and seating has been extremely effective in ***delaying and minimizing*** reflection cracking.

<u>Is breaking and seating an effective technique for the rehabilitation of in-service composite pavements in Ohio?</u>

This study has clearly demonstrated that the B/S technique can be effectively applied for the rehabilitation of composite pavements in Ohio. This conclusion has been reached based on a systematic investigation of the long-term performance of B/S and control pavements in the vicinity. This conclusion is supported by a large quantity of field data on several test sections over a 9-year monitoring period.

Caution has to be exercised in applying this technique. It is observed that the extent of breaking is the key factor in the application of the B/S technique. A pile hammer can be used effectively to obtain the desired result.

In this study, the pile hammer was found to be slow in its operation and was able to break only one lane mile per day. Of late, a modified version of the pile hammer, known as Multiple Head Breaker, is available, which can improve the productivity by as much as five times.

Are there cost advantages in using B/S technique?

The additional cost of breaking and seating is generally \$0.50 to \$0.70 per square yard depending on the type of pavement breaker used. This will translate to approximately \$3,500 to \$5,000 per lane mile. Compared to the cost of rehabilitation that involves thick AC overlays, the cost of construction of B/S sections is only marginally higher than the control sections.

Breaking causes disruption to the traffic moving in adjacent lanes. No data was recorded on traffic flow during the breaking and seating operation. However, an attempt was made to compute the additional road user costs during breaking and seating using a model developed by the researchers [21]. The key inputs required to run this model was either obtained from the field or assumed appropriately. The additional road user cost per lane mile was found to be approximately \$300 on I-71 sections (guillotine hammer) and \$1,400 on SR-4 sections (pile hammer).

Crack sealing was performed on all the control sections in 1997. None of the B/S sections have been treated so far. Crack sealing was performed by the county forces using their own crew and equipment. The cost of crack sealing varied from \$0.50 to \$0.75 per square yard, depending on the sealant material used, method of application, equipment used, and density of cracks. This preventive maintenance treatment resulted in an expenditure of \$3,500 to \$5,300 per lane mile.

The primary benefit of using the B/S technique is to defer the need for major rehabilitation. The data presented by the UC researchers show clearly that, for the SR 4 project reflective cracking was drastically reduced in the B/S sections. The mitigation of reflection cracking will cause the pavement PCR and serviceability to remain higher for a longer period of time than if the reflection cracks are allowed to come through. The lack of reflection cracking translates into a delay in future maintenance and rehabilitation. The I-70 sections (control and B/S sections) were rehabilitated in 1997; the I-71 sections (both control and B/S sections) were rehabilitated in 2001. All the sections received similar rehabilitation at the same time. The SR-4 sections (control and B/S sections) are proposed to be rehabilitated in 2003. A field tour of the test sections was arranged in 2001. This tour was attended by representatives from ODOT Districts, central office, FHWA, and the Flexible Pavement Association. During this tour, a discussion was held to verify the criteria used by ODOT districts to rehabilitate pavement sections.

During the discussion, it was evident that, although other issues like longitudinal joint cracking could have triggered rehabilitation, had the unbroken and broken portions of the pavement not been contiguous, the type and timing of the rehabilitations would indeed have been different. The close proximity of the broken and unbroken sections, perhaps, led to the decision to consider them for similar rehabilitation at the same time.

Is this a recommended procedure in Ohio?

In order to develop and establish appropriate criteria for the use of broken and seated pavements in Ohio, the researchers suggest a survey of district and county engineers which can be used in conjunction with the results of this study. The survey would include questions relating to experience with the breaking and seating technique, performance of pavements and triggers used for maintenance and rehabilitation. A sample questionnaire is presented below. A study[2] was conducted in 1992 and 1993 by FHWA to assess the pavement rehabilitation program in Ohio. This study included a survey of district engineers on their experience with the break and seat technique.

The questionnaire presented below may help ODOT to update the knowledge base and to develop criteria based on the most current information.

Sample Questionnaire

Name of the person completing the form: ________________

District/County: _________________

Person's phone number and e-mail address: _________________________________

1. Pavement section(s) in your district or county where breaking and seating has been used:

   ____

2. Type of pavement breaker used: ______________________

3. Number of years since last major rehabilitation using breaking and seating: _________

4. Did you observe a noticeable difference in the condition of the break and seat sections and unbroken (control) sections in the vicinity? Yes No

   Not Sure

   Comments: ____

5. Would you conclude that there are fewer reflection cracks in the break and seat sections compared to the control sections: Yes No Not Sure

   Comments: ____

6. How do the PCR values of broken and seated pavements and unbroken pavements compare?

   ____

7. What in your opinion will trigger rehabilitation of these pavements?

   PCR Reflection Cracking Longitudinal Cracks

   Other factors: ____

8. Would you be willing to use the break and seat technique again in your district/county?

Yes No Not Sure

Comments: ____

9. Additional comments: ____

What changes are needed to ODOT's current specifications?

According to ODOT's Pavement Design and Rehabilitation Manual [18], break and seat is not to be used in Ohio as a major rehabilitation strategy per the pavement design and selection process. Crack and seat for plain concrete and rubblization for all concrete pavements are recommended. The structural coefficient for rubblized concrete pavements is 0.14. An appropriate structural coefficient for B/S pavements will need to be assigned. This can be done based on the past experience of ODOT engineers or a review of published literature or another study to develop a structural layer coefficient.

In general, what can this research do to benefit ODOT?

This research has helped ODOT generate physical evidence on the long term performance of AC overlays on B/S pavements. ODOT is responsible for the maintenance and rehabilitation of 4682 miles of composite pavements which is always a challenging task. Maintenance is performed by the counties by crack sealing the reflection cracks. Rehabilitation is performed usually on a 8 to 10 year cycle. Rehabilitation involves removal of existing AC, joint repairs and construction of a new AC layer. Joint repair is often made using what is termed a 'flexible patch'. This consists of removal of a 0.45 m (1.5 feet) wide PCC layer on either side of the joint and replacing it with an asphalt material of the same thickness. In doing so, it is often seen that, two cracks that are 0.9 m (3 feet) apart reflect to the top in a 2 to 3 year period. B/S has resulted in minimizing and delaying reflection cracks significantly. The results of the present study have demonstrated that breaking and seating provides an alternate solution for a cost effective method for maintenance and rehabilitation of composite pavements in Ohio.

SUMMARY, CONCLUSIONS AND GUIDELINES FOR IMPLEMENTATION

This study provided an opportunity to objectively assess the long term performance of AC overlays constructed with and without breaking the underlying concrete pavements. Four sections, each about a mile long, were broken and seated prior to constructing the AC surface layer. Two of these sections were on I-71 near Columbus, Ohio and two were on SR-4, near Dayton, Ohio. Four control sections were constructed, adjacent to the B/S sections. One additional control section was constructed on SR-4. The test sections were all Jointed Reinforced Concrete Pavements and carried a large volume of traffic. The original pavements selected in this study were fairly uniform with respect to their structural and surface conditions. The thickness of the concrete layer was the same (22.5 cm or 9 in.) throughout and the subbase and subgrade exhibited very little variation. The AC overlay on SR-4 was 16.5 cm (6.5 in.) and 21.6 cm (8.5 in.) on I-71.

The SP-202 sections on I-70 are approximately 305 m (1000 feet) long. The SP-202 sections have a 17.5 cm (7") Hot Mix Asphaltic Concrete (HMAC) overlay on an existing PCC pavement. They include an unbroken (control) section, and sections broken into 0.15 m (6"), 0.46 m (18"), and 0.76 m (30") patterns using a 6.0 ton guillotine hammer. This section was first included in the study in 1996. Later the entire pavement section was rehabilitated in 1999.

Two types of pavement breakers were used in this study, namely guillotine and pile hammer. The goal was to break the slabs into segments of 0.45 m x 0.45 m (18 in. x 18 in). The extent of breaking was closely monitored. Several visits to the site were made during construction and the relevant data were collected.

The performance of the test sections was monitored for a total period of nine years. The monitoring data included deflection measurements, crack mapping, a pavement condition survey and a roughness survey on the original pavements and on the overlay at several times.

The structural behavior of the broken and seated pavements was analyzed and compared to the control sections. Crack surveys were made by visually recording the location of the cracks in the AC overlay with respect to the joints and cracks in the underlying concrete layer. Pavement condition and roughness data in terms of IRI were collected by ODOT personnel.

The following sections present a summary of results, the conclusions derived from the study and recommendations with respect to the objectives of this research.

Performance Effectiveness

The primary variables introduced in this study are (i) type of equipment for breaking, (ii) extent of breaking, and (iii) size of fragments. The other variables present are traffic volume and AC overlay thickness.

Breaking was more extensive in sections broken with the pile hammer compared to sections broken with the guillotine hammer. The pile hammer produced more uniform transverse and longitudinal cracks while pavements broken with the guillotine hammer exhibited severe breaking, where drops overlapped, usually in the middle of the lane. The 1.8 m (6 ft.) guillotine and the pile hammer produced slab fragments of the desired size. Breaking with all types of hammers resulted in through slab cracking but the reinforcement was more damaged when using the pile hammer.

Breaking and seating concrete pavements prior to AC overlay resulted in an increase of surface deflection, reduction in AREA and Spreadability, loss of flexural strength and increased subgrade stresses. The difference in the mean values of the structural parameters investigated for the broken and seated sections and the control sections were found to be statistically significant. The maximum deflections on sections broken with the pile hammer were higher as compared to those broken with the guillotine hammer. The AREA and Spreadability values of broken and seated pavements were lower than the values for the control sections. Concrete pavements in general exhibit higher AREA and Spreadability than flexible pavements. The lower AREA and Spreadability values for the B/S sections indicate a behavior similar to flexible pavements. The AREA and Spreadability values of sections on SR-4, where a pile hammer was used, were considerably lower than those on I-71 where a guillotine hammer was used. This is due to the higher degree of breakage in these sections. Breaking and seating resulted in higher W_1/W_5 values as compared to the control sections. The statistical analysis shows a significant difference between the two means. Also, SR-4 sections had higher W_1/W_5 ratios. This is to be expected since these sections, broken with the pile hammer, were almost rubblized.

Because of limited data, the details of the structural characteristics for the pavement sections on I-70 are not presented. This also limited the discussion of the effect of slab fragments on the structural characteristics of these sections.

Reflection cracking was observed in all control sections monitored in this study. In the I-71 and I-70 sections, the first set of cracks was noticed about 15 months after construction of the AC overlay. In the SR-4 sections, cracks were observed within 7 months of construction of the AC overlay. The cracking in both sections occurred after the severe Winter of 1993. No cracking was noticed on any of the broken and seated sections. The cracking of the control sections may be due to the size of the underlying concrete slabs. The control sections have reinforced concrete slabs, 18.2 m (60 ft.) long whereas the broken and seated sections have slab fragments 0.45 m by 0.45 m (18 in. by 18 in.).

The construction of I-71 sections was completed in the Fall of 1992 while the SR-4 sections were completed in the Fall of 1993. Reflection cracks in the SR-4 sections appeared after the first winter whereas, cracks in the I-71 sections did not appear until the second winter. The winter of 1992 was normal whereas the 1993 winter was very severe. The early appearance of reflection cracks on SR-4 is, therefore, attributed to the severity of the winter of 1993 rather than to the age or thickness of the overlay.

In the I-71 control sections, reflection cracks appeared over more than 90% of the joints within four years. However, in the I-71 B/S test section where a guillotine hammer was used, only one crack appeared two years after the AC overlay. After being in service for nine years, reflection cracks appeared over 42% of the joints. The SR-4 B/S sections, where a pile hammer was used, have been relatively free of cracks after eight years. The two sections have 7% and 17% of joint reflection cracks, while the control sections in the vicinity have 80% to 100% joint reflection cracks.

In the I-70 test sections, the control section exhibits 100% joint reflection cracks. The condition of the B/S sections is similar irrespective of the size of slab segments.

The IRI values on control and B/S sections were nearly identical. Thus, breaking and seating did not have a pronounced effect on the ride quality of the test pavements. The PCR values, on the other hand, are higher in the SR-4 B/S sections indicating that the overall condition of these sections is much better than the control sections as well as the B/S sections in the I-71 and I-70 pavements.

These results clearly indicate that while breaking and seating can be effective in ***delaying and minimizing*** reflection cracking, the type of breaking equipment and extent of breaking are extremely important factors that govern the behavior of the AC overlays on the B/S pavements.

Cost Effectiveness

Table 13 compares costs for the control and B/S sections during the 9-year monitoring period.

Table 13. Comparing Cost of Control and B/S Sections

Additional cost per lane mile due to:	Control Sections	B/S Sections
Breaking and Seating	None	\$3,500 to \$5,000
User delay during construction and preventive maintenance	\$100 to \$400	\$400 to \$1,800
Preventive Maintenance	\$3,500 to \$5,300	None
TOTAL ADDITIONAL COST PER LANE MILE	\$3,600 to \$5,700	\$3,900 to \$6,800

As has been stated earlier, the control and B/S sections were constructed similarly with the only difference being breaking of concrete pavements on B/S sections prior to the AC overlay. Thus the above table compares additional costs between the control and B/S sections, since the remaining costs are the same.

The cost of breaking has been calculated using information from bid documents. All the control sections in this study received crack seal treatment in 1997. This was in accordance with the maintenance policy of the counties. Because the breaking and seating operation has been successful in delaying and minimizing reflection cracking, the B/S sections have not received maintenance treatment so far. Based on the performance of pavements as observed in this study, it can be concluded that, the difference in cost of constructing and maintaining control and B/S sections is insignificant.

The primary difference in cost of control and B/S sections could be in the type, extent and timing of major rehabilitation. The I-70 and I-71 sections were rehabilitated in 1999 and 2000 respectively. The control and B/S pavements were rehabilitated at the same time since they followed each other. The SR-4 sections are proposed to be rehabilitated in 2003. Although it can be argued that the differences in the condition of control and B/S pavements of I-70 and I-71 sections were practically not significant, the differences in the SR-4 sections are significant. The control sections may indicate a need for rehabilitation. However, the present condition of the B/S pavement on SR-4 does not warrant rehabilitation in the year 2003. ODOT may benefit by deferring the rehabilitation of the B/S sections in SR-4 till such a time when the pavement condition warrants such an action.

Conclusions

The following conclusions are made based on the results of this study:

1. Breaking and Seating can be successfully used to delay and minimize the occurrence of joint reflection cracking.
2. The extent of breaking is a critical factor in the successful application of the B/S technique.
3. The optimum size of broken slab fragments needs to be established.
4. The pile hammer is more effective in breaking jointed reinforced concrete pavements than the guillotine hammer. The pile hammer produces uniform breaking and causes more damage to the reinforcement.

5. The difference in cost of constructing and maintaining the control and B/S sections is insignificant. However, the type and extent of future maintenance and rehabilitation can help establish the cost effectiveness of B/S pavements.

Guidelines for the Implementation of Research Findings

1. **Use break and seat technique as a major rehabilitation strategy**: All of the results presented in this study indicate that the break and seat technique can be used effectively to delay and minimize the appearance of reflection cracking in jointed reinforced concrete pavements. The primary benefit of using the break and seat technique is to increase the service life of composite pavements and defer the need for major rehabilitation. Hence it is strongly recommended that the break and seat technique be used as a major rehabilitation strategy in the pavement design and selection process.
2. **Select an appropriate pavement breaker**: A pile hammer should be used to break the exposed jointed reinforced concrete pavement. It is strongly recommended to explore the applicability of multiple head breaker for this purpose.
3. **Develop an appropriate layer coefficient for use in the design**: Develop an appropriate layer coefficient value for the broken and seated layers based on a review of literature supported by an analytical investigation of broken and seated pavements.
4. **Develop quality control measures**: The most significant factor that affects the outcome of the break and seat process is 'extent of breaking'. Hence, it is necessary to develop necessary quality control specification to verify the extent of breakage achieved.
5. **Defer the rehabilitation of SR-4 test sections**: At present, neither the structural condition nor the surface condition of the break and seat test sections on SR-4 warrant rehabilitation.

Hence it is strongly recommended that the rehabilitation of these sections be deferred till their condition meet the rehabilitation criteria generally used by the ODOT. This will also give an excellent opportunity to better establish the increase in service life achieved due to breaking and seating.

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