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RUT-RESISTANT COMPOSITE PAVEMENT DESIGN

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Final Report
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Prepared in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

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16. Abstract

The main objective of this study was to evaluate the ability of a new asphalt composite pavement design to economically reduce rutting on asphalt pavements. In addition, the longevity of the pavement was to be assessed by determining the durability and permeability of the seal, its resistance to moisture damage in the lower layers of the pavement, and the overall pavement performance.

Conclusions

The performance data does not support the use of the rut-resistant composite pavement design. Although there were only a few failures due to stripping, the extent of the failures were significant enough to warrant discontinuing the rut-resistant composite pavement design.

The failure mechanism in the RRCP was not due to rutting or cracking, but appears to be directly associated with stripping caused by hydrostatic pressure immediately below the PMSC layer. The conditions which are present when stripping occurs are heavy traffic, high temperatures, and the presence of moisture.

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Appendix K.....US 40, East of Hayden
Appendix L.....SH 172, South of Durango

I. INTRODUCTION

Historically, the design of asphalt pavements has been a balance between the needs of pavement stability and durability. Recently, many Colorado asphalt pavements have experienced an increase in rutting early in the life of the pavement. Rutting is caused by a number of factors. However, with the increase in truck loads and higher tire pressures rutting appears to be more prevalent. The magnitude of rutting has contributed to the premature loss of pavement service and has shifted design priorities to a more rut-resistant pavement.

In 1987, the Division of Highways revised its asphalt pavement design to help reduce rutting on Colorado's pavements. The essence of this design was a high stability asphaltic mix in the lower layers and a durable plant mixed seal coat (PMSC) for the top layer.

The stability in the lower layers was increased by reducing the asphalt content of the design mix. However, this reduction in the asphalt content was expected to reduce the durability of the resulting pavement. A plant mixed seal used for the top layer was expected to compensate for the reduced durability by preventing the intrusion of moisture and air into the lower layers. Together these layers formed an asphalt composite pavement that was intended to produce a high stability pavement with a highly durable wearing surface.

II. OBJECTIVE

The main objective of the Rut-Resistant Composite Pavement (RRCP) study was to evaluate the ability of the new design to economically reduce rutting on asphalt pavements. In addition, the longevity of the pavement was to be assessed by determining the durability and permeability of the seal coat, its resistance to moisture damage in the lower layers of the pavement, and the overall pavement performance.

III. SITE SELECTION

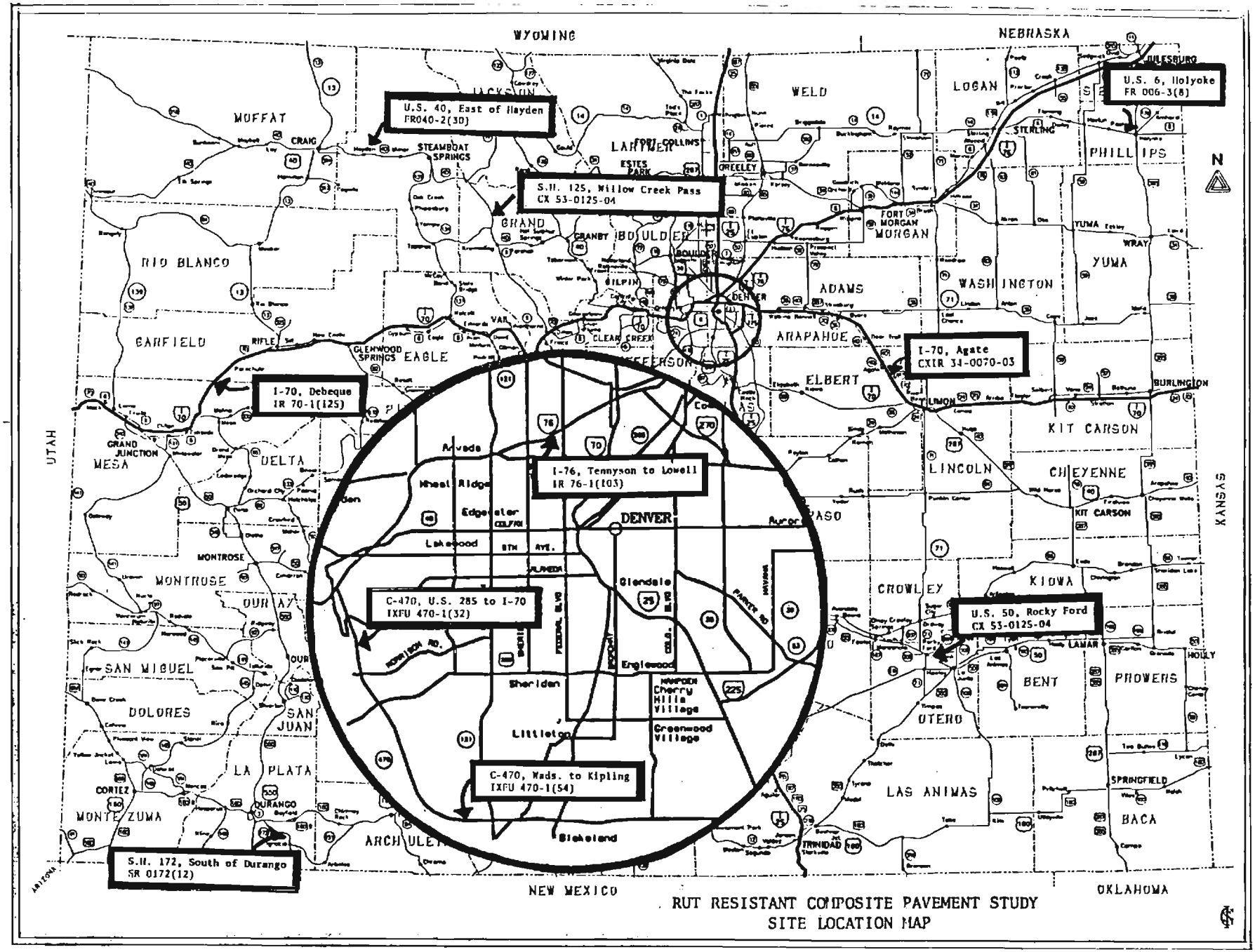
In 1987, the Colorado Division of Highways began incorporating this new asphalt pavement design into all new construction and rehabilitation projects when the item quantity for hot bituminous pavement (HBP) was greater than 1000 tons.

Of the 188 projects constructed with a PMSC between July 1987 and July 1989 a total of ten sites were selected for evaluation:

1. C470, between Kipling and Wadsworth,
2. I-76, between Tennyson and Lowell,
3. C470, between US 285 and I-70,
4. US 6, west of Holyoke,
5. SH 125, Willow Creek Pass,
6. I-70, east of Agate,
7. US 50, east of Rocky Ford,
8. I-70, east of Debeque,
9. US 40, east of Hayden, and
10. SH 172, south of Durango.

These sites were selected based on traffic volume and the different climatic regions in Colorado. Sites 1, 2 and 3 are located in Metro Denver. The location of the sites selected for evaluation are shown in Figure 1.

FIGURE 1



RUT RESISTANT COMPOSITE PAVEMENT STUDY
SITE LOCATION MAP

IV. PRE-CONSTRUCTION EVALUATION CRITERIA

For all the sites, excluding new construction and the site at Agate, pre-construction evaluations were performed prior to paving. These evaluations included deflection measurements (Dynaflect), rut depth measurements (six-foot straight edge), crack mapping and visual observations. The deflection measurements were taken every 50 feet in the right wheel path of the driving lane. At most locations, the rut depth measurements were taken every 50 feet in both the right and left wheel paths of the driving and passing lanes. On most sites, crack maps were drawn for the entire length of the test and control sections except on severely cracked sites. At the severely cracked sites crack maps were drawn only on the first 100 feet of the evaluation section. The evaluation sections were 500 to 600 feet long.

The deflection measurements taken during the pre-construction evaluations were used as a baseline and compared to subsequent evaluations.

During the pre-construction evaluation the location of the test and control sections were established. The test section contained the new high-stability design. The control section contained the design mix used prior to the incorporation of the new design with PMSC. Asphalt mix specification for the control and test sections which were used during the period from July 1987 through July 1989 are found in Appendix A.

Since paving with the RRCP design had begun prior to approval of this study, two evaluation sites constructed in the summer of 1987 did not contain control sections (C470, between Kipling and Wadsworth and I-76, between Tennyson and Lowell.)

V. CONSTRUCTION -- GENERAL

As part of the six-year study into the performance of the department's asphalt composite pavement design, the Research Branch developed two tests to evaluate the permeability of the plant mixed seal coat (PMSC). The two test methods are described in Appendix B.

During construction, permeability testing equipment was installed at four of the ten evaluation locations. Data acquisition equipment (Microloggers) was installed at some of the locations to continuously record moisture values. At the remaining locations permeability testing was only done during the yearly evaluations.

Conventional construction techniques were used in the placement of the rut-resistant composite pavement. Photos 1 through 3 illustrates an asphalt paving operation. A description of each project is found in Appendices C through L at the back of this report. Also included in each Appendix is a site map showing the location of the test and control section at each location. Table A contains the construction data for each individual evaluation sites.

PHOTO 1

A paving operation using windrow placement.

PHOTO 2

Steel-wheeled roller used for break down.

PHOTO 3

Pneumatic roller was used prior to finish roller.

TABLE A

Rut Resistant Pavement Construction Data

Site No.	District	Construction Dates	Permeablilty Test	TEST SECTION HBP Thickness	Design %AC	Actual %AC	Grade** or Type	CONTROL SECTION HBP Thickness	Design %AC	Actual %AC
1	6	Summer 1987	No	3" 1ST	5.50	5.69	Gr E	NO CONTROL SECTION FOR		
				3" 2nd	5.50	--	"	THIS PROJECT		
				2" 3rd	5.10	5.34	"			
				1-1/4" 4th	5.40	5.36	"			
				3/4" PMSC	7.20	7.26	Type A*			
2	6	Summer 1987	No	3" 1st	5.20	4.63	Gr E	NO CONTROL SECTION FOR		
				2" 2nd	5.20	4.51	"	THIS PROJECT		
				2" 3rd	5.20	--	"			
				1-1/2" 4th	5.20	--	"			
				3/4" PMSC	6.60	--	Type B*			
3	6	6/01/88	Yes							
		9/13/88		3-3/4" 1st	5.00	--	Gr E	3-3/4" 1st	5.00	--
				3" 2nd	5.00	--	"	3" 2nd	5.00	--
				2" 3rd	5.00	5.18	"	2" 3rd	5.20	4.98
				1-1/4" 4th	5.00	--	"	1-3/4" 4th	5.20	4.75
				3/4" PMSC	6.80	6.07	Type A*			
4	4	7/13/88	No	1-1/4"	5.80	6.14	Gr F	2"	5.70	6.07
				3/4" PMSC	6.50	--	Type A*			
5	3	7/25/88	Yes	1-3/4"	5.40	5.49	Gr E	2-1/4"	6.40	6.21
		10/22/88		3/4" PMSC	6.30	--	Type B*			

-- %AC values are unavailable

* Rubberized

** Grading specifications are in Appendix A

TABLE A (Cont.)

Rut Resistant Pavement Construction Data

Site No.	District	Construction Dates	Permeablilty Test	TEST SECTION				CONTROL SECTION			
				HBP Thickness	Design %AC	Actual %AC	Grade ** or Type	HBP Thickness	Design %AC	Actual %AC
6	1	Summer 1989	No	1-1/2"	5.50	--	Gr C*			
				3/4" PMSC	6.20	--	Type B*			
7	2	8/15/88	Yes	1-1/2"	6.00	6.22	Gr EX	2"	6.10	6.32
		10/15/88		3/4" PMSC	6.00	--	Type B*			
8	3	Spring 1989	No	1-3/4"	5.30	4.92	Gr E	2-1/2"	5.50	5.51
				3/4" PMSC			Type B*			
9	3	Summer 1989	Yes	1"	5.30	5.04	Gr E	1-3/4"	5.50	5.06
				3/4" PMSC	6.00	6.06	Type B*			
10	5	Summer 1989	No	1-1/4"	5.90	5.75	Gr E*	2-1/4" Northbound Lane	5.90	5.85
				3/4" PMSC	6.10	5.49	Type B*			
							Gr E	2-1/4" Southbound Lane	5.90	--

-- %AC values are unavailable

* Rubberized

** Gradation specifications are in Appendix A

VI. POST-CONSTRUCTION EVALUATION -- SUMMARIES

The first post-construction evaluation was made immediately following construction. This evaluation included deflection measurements, rut depth measurements, core sampling, permeability tests (when applicable), and visual observations.

After this initial evaluation, follow-up evaluations were made each spring and fall. Deflections, rutting, cracking, permeability tests and visual observations were made in the spring and the cores and additional rutting measurements were taken in the fall. Beginning in 1990, the fall evaluations were limited to only rutting and visual observations. The final evaluation was made in the spring 1991.

Deflections

Based on the analysis of the deflection data, there is no significant difference in the load carrying capacity of the high stability design test section as compared to the control section. Comparison of the deflection basin graphs for the test and control sections indicate little change in the maximum deflections or the load transfer properties from year to year.

Deflection basin graphs for each evaluation site can be found in the Appendix for each location.

Rutting

To date, there is no appreciable rutting in any of the original rut-resistant pavement design evaluation sections. There does not appear to be any difference in the rut measurements between the control and test section. All the rutting measurements have been in the low severity range (less than 0.25 of an inch).[1]

Individual rutting data is located in the Appendix for each site.

The Agate site is not one of the original evaluation sections. This site was unique from all the other sites being evaluated under this study. This site was added prior to the reconstruction of a RRCP paving project which failed nine months after construction. It failed due to severe stripping in the layer immediately below the PMSC. Since this site was not added to this study until after the RRCP showed signs of failure, rutting information found at this location was not included in the rutting evaluation. The reconstruction project was not a RRCP design and only a 1000 foot section of the reconstructed project contained a PMSC. The PMSC section was added for PMSC performance evaluation purposes only. In the fall of 1990, several months after resurfacing this project for a second time, the pavement began to show signs of stripping immediately below the PMSC and it was milled off. The evaluation at this location was discontinued when the PMSC was milled off.

Cracking

Cracking does not appear to be a significant problem at any of the evaluation sections. All of the projects containing both a test and control section indicated that the PMSC reduced surface cracking to some degree. Individual cracking data summaries are located in the Appendix for each evaluation site.

Cores

Cores were taken yearly in each evaluation section and visually inspected for stripping.

At most of the evaluation sites the cores showed signs of stripping progressing from year to year in the layer immediately below the PMSC, some sites more severe than others. A comparison of a core taken in 1990 at the Debeque location to a core taken in 1991 at the same location is shown in Photo 4. The core in Photo 5 was taken from C470 in 1990.

It should be noted that all RRCP projects which have failed due to stripping had Tensile Strength Ratios (TSR) values meeting or exceeding specifications. Lottman test values (TSR) as determined by the Department's procedures is not always a good predictor of stripping for lifts placed immediately below a PMSC. See Appendix A for Colorado's Lottman procedure.

Permeability Testing

During construction, wires and probes for permeability testing were placed in both the test and control sections on a number of selected projects. The wires were placed between each lift to record the difference in the moisture readings at each lift. It was hoped the readings would help determine if moisture was

present and if so where it was coming from. Cores taken at these permeability locations revealed that the PMSC was permeable and the pavement showed early signs of stripping in the lift immediately below the PMSC. The presence of moisture in the cores was in agreement with the data collected from the permeability equipment installed at the evaluation locations. Since it had been determined PMSCs were permeable, permeability testing was discontinued following a study panel meeting in January 1990.

Visual Observations

Post-construction evaluations also consisted of a visual observation of the entire project. The type of stripping failure which this design experienced was usually noticeable during this evaluation. Typically, the first visual sign of failure was the appearance of rich spots on the surface. This failure did not always show up on the surface of the study evaluation sections. When cores were drilled in or around these areas, stripping was found between the PMSC layer and the layer immediately below the PMSC. As the rich spots spread the magnitude of stripping increased resulting in severe distress on the roadway. If failures appeared anywhere within the project, it was a good indication that cores taken in the study areas would show the beginning of stripping.

Photos 6 through 10 show examples of the failures on the C470, between US 285 and I-70 and on the I-70, east of Agate locations. Photo 9 taken on I-70, east of Agate was taken before this site was added to this study. Photo 10 was taken after the rehabilitation of the RRCP. This pavement was not a high-stability (RRCP) design.

The final evaluation at the Debeque site showed no signs of failure on the surface, rutting was low and cracking was minimal. However, the cores showed signs of stripping in the layer immediately below the PMSC as shown in Photo 4.

Three variables which are common to the projects which failed during this study (and other projects which have failed around the state) are: the presence of moisture, high temperature and heavy traffic. All the failed projects have high rainfall (greater that 3 inches in a month). All the projects were in high temperature areas (above 85^{o}F average highs). The high temperature times usually corresponded with the high moisture times. It appeared that the volume of traffic controls the magnitude of stripping. As the traffic volume increases the time to failure decreases.

Moisture, temperature, traffic and pavement information for the projects showing failures included in this study are shown in Figures 2 through 4.

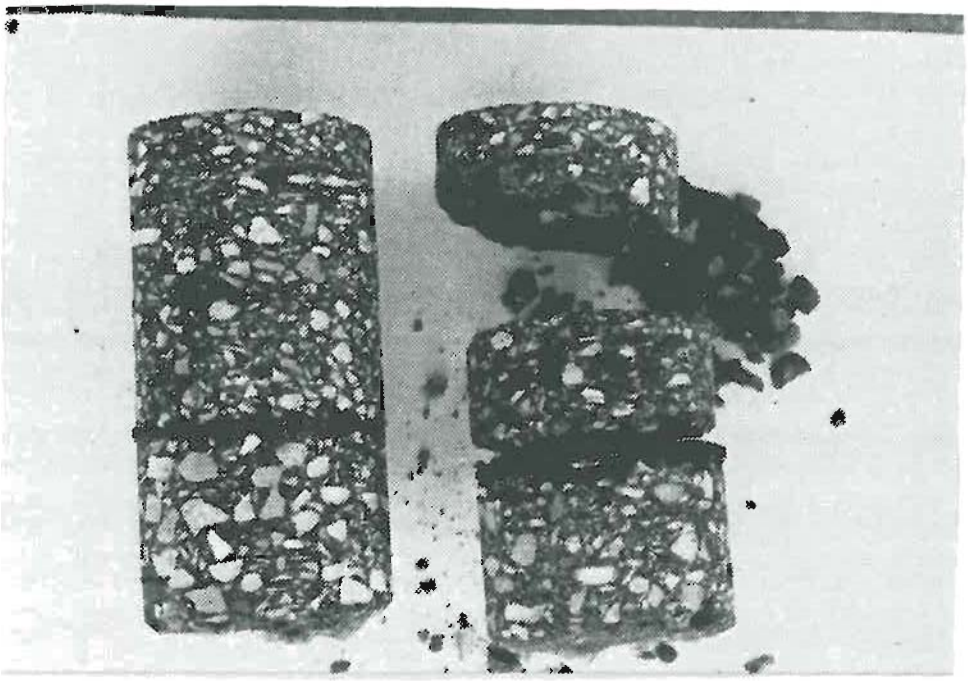


PHOTO 4

This photo shows how stripping progresses. The core on the left taken in 1990. The core on the right taken in 1991 at the Debeque evaluation site. Note that the top lift of PMSC is undisturbed.

PHOTO 5

This photo shows an extreme case of stripping below the PMSC. Both cores were taken out of C470 in 1990.

PHOTO 6

C470, US 285 to I-70
The first sign of the stripping failure is the appearance of rich spots on the surface. These rich areas are randomly spaced and typically found in the wheel paths.

PHOTO 7

C470, US 285 to I-70
This photo shows areas which have stripped under the PMSC. Evidence of raveling in the right wheel path is a result of extensive stripping in the RRCP layer below the PMSC.

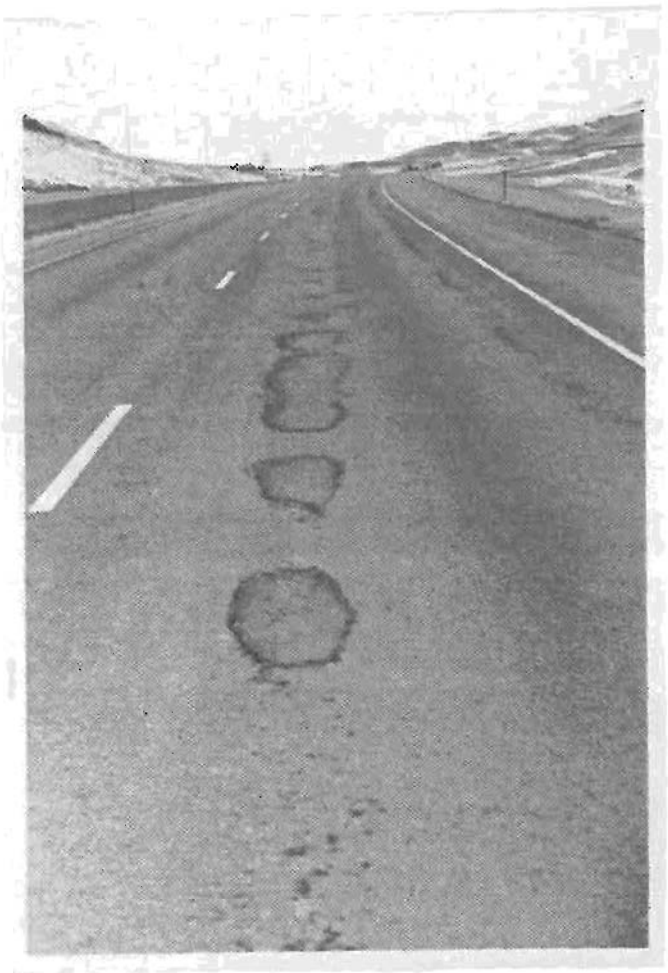


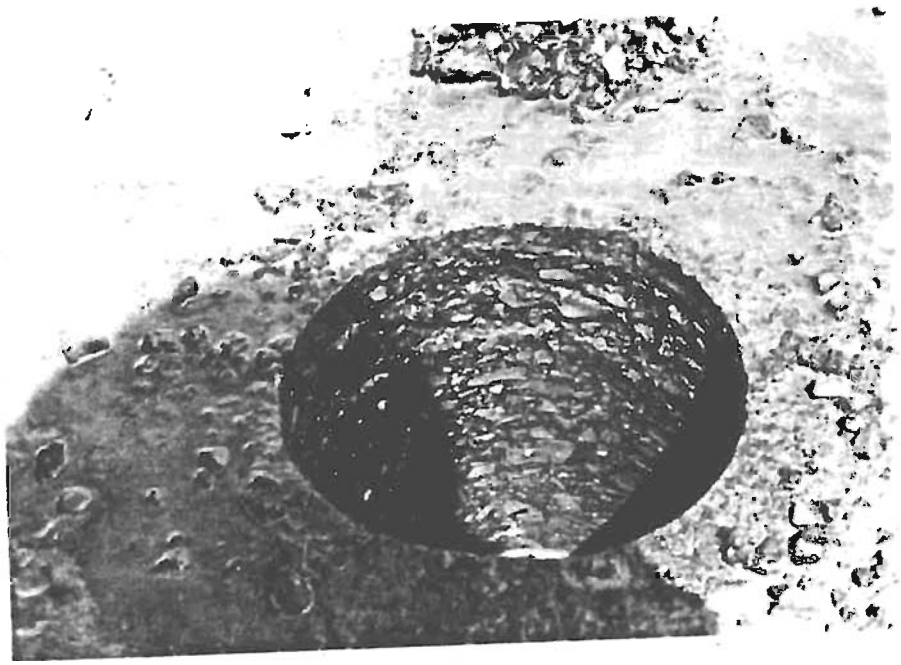
PHOTO 8

C470, US 285 to I-70
This type of distress was found throughout the project.

PHOTO 9

This photo was taken on I-70, east of Agate eight months after construction using the RRCP design. This type of distress was typical throughout the project.

PHOTO 10



This is not the high-stability (RRCP) design. This photo shows stripping occurring below the PMSC however. The portion stripping is a Grading C. This photo was taken at the test site on I70, east of Agate. The pavement had been down one year.

FIGURE 2

Project/Environmental Information
C470, Between Kipling and Wadsworth

District: 6
Project: IXFU 470-1(54)
Location: C470, Between Kipling and Wadsworth

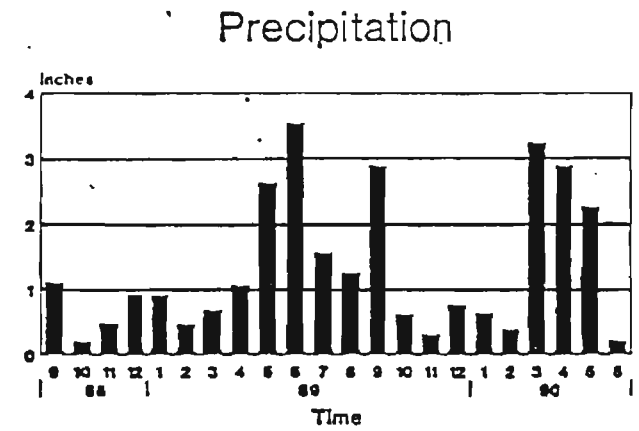
HBP Information
Grading: E
% AC: 5.1
* Lottmans: 104, 90, 102, 126, 108, 113, 100, 114, 126, 127, 117

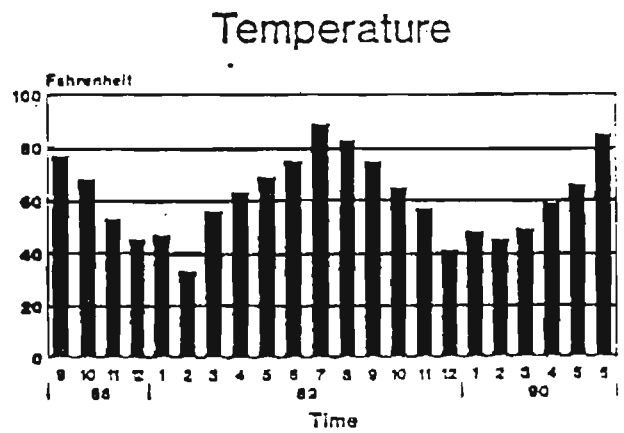
PMSC Information
Type: A

Design Traffic
10 year ESAL's: 1,565,000

* See Appendix A

Environmental Information





Project Status
High moisture, Low moisture susceptibility, moderate traffic

FIGURE 3

Project/Environmental Information
C470, US285 to I-70

District: 6
Project: IXFU 470-1(32)
Location: C470, US285 to I-70

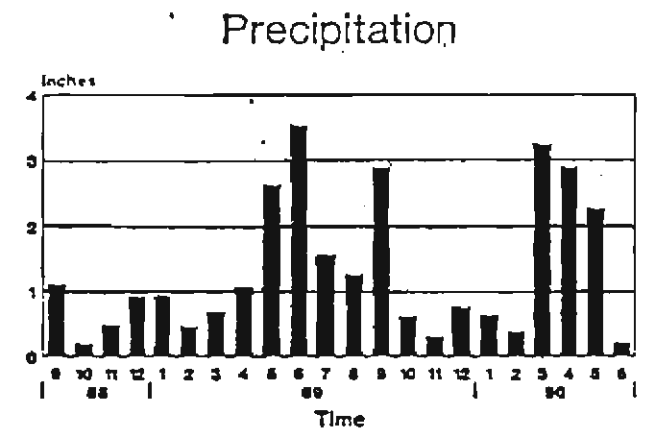
HBP Information
Grading: E
% AC: 5.2%
* Lottmans: 111, 101, 88, 77, 56, 81, 68, 77, 98, 96, 88, 42, 74, 56

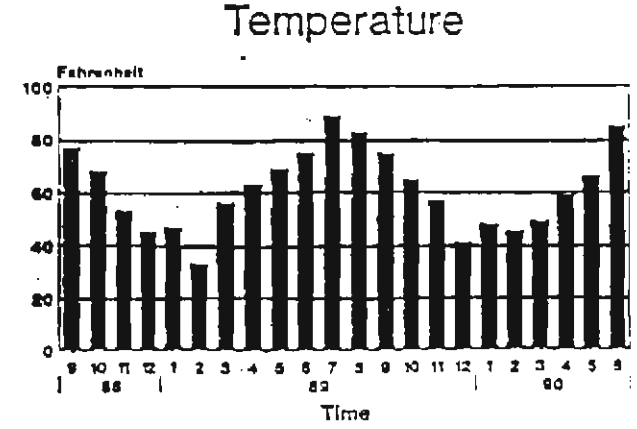
PMSC Information
Type: A

Design Traffic
10 year ESAL's: 1,565,000

* See Appendix A

Environmental Information





Project Status
High moisture, high moisture susceptibility, moderate traffic

Stripping noticed in mid 1989 and increased in 1990.

FIGURE 4

Project/Environmental Information
I-70, East of Agate

District: 1
Project: IR 70-4(118)
Location: I-70, East of Agate

HBP Information
Grading: C
% AC: 5.3%
* Lottmans: 102, 80, 92, 78, 64

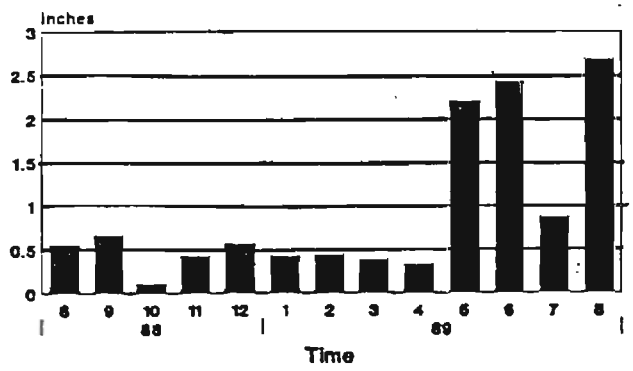
PMSC Information
Type: B

* See Appendix A

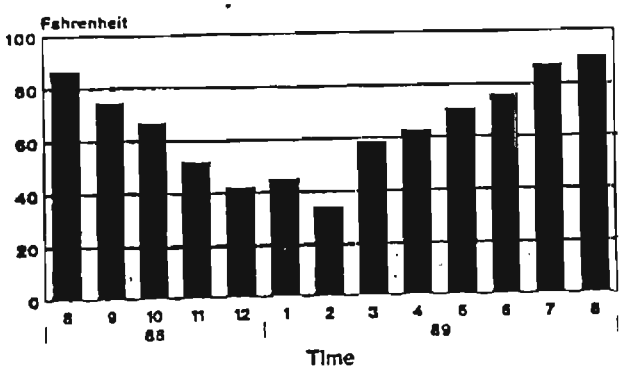
Design Traffic
10 year ESAL's: 3,500,000

Environmental Information

Precipitation



Temperature



Project Status
High moisture, moderate moisture susceptibility, high traffic

Failed in 7-89

VII. CONCLUSIONS

The rut-resistant design, in general, has performed well; however, because of several catastrophic failures the use of this design was suspended. Out of the 188 projects constructed with a plant mixed seal coat, four projects have completely failed within one year of construction. In addition, two projects are showing signs of failure.

Evaluations from data collected indicates the failure mechanism is not due to rutting or cracking, but appears to be directly associated with stripping caused by hydrostatic pressure immediately below the PMSC layer. Once the stripping process becomes visible on the surface the pavement fails rapidly. The pavement fails early in its design life before signs of rutting or cracking appear. As the stripping becomes more severe the pavement begins to rut and shove.

Since the rut-resistant composite pavement design was initiated in July 1987, approximately 824 center-line miles were paved with a plant mixed seal coat. However, not all of these projects contained the high-stability design in the lower lifts. Of the ten evaluation sites selected to evaluate the rut-resistant composite pavement design three have shown signs of stripping.

The remaining sites have not shown signs of distress and are performing as expected. These sites may never fail because the condition that triggers the stripping includes the combination of heavy traffic, high temperatures and the presence of moisture.

VIII. IMPLEMENTATION

Although there were only a few failures due to stripping, the extent of the failures were significant enough to warrant discontinuing the rut-resistant composite pavement design.

In those projects without premature failures performance data does not support the RRCP (rut-resistant composite pavement) design as being significantly superior to the design used in the control sections.

After continued performance evaluation of the existing PMSC projects the use of plant mixed seal coats on new pavements was suspended entirely during the 1990 paving season.

Numerous changes to the flexible pavement design criteria have been made since suspending the use of the rut-resistant composite pavement design which include:

1. designs are based on optimum AC content
2. VMA requirements for the various grades
3. minimum film thickness
4. minimum 1% hydrated lime added to aggregates
5. limited natural fines in mix to 20%

Even though the design used by Colorado did not produce the results hoped for, the use of Open Graded Friction Courses (OGFC) have been successful in other states.[3] The major difference between OGFCs and PMSCs is that the PMSCs have a higher percent fines which has a tendency to retain moisture in the pavement thus promoting stripping. The concept of OGFC has merit and several benefits such as a smoother ride, less tire noise, higher skid resistance and better appearance can be achieved.

This report finalizes the formal evaluation of the RRCP study. However, RRCP locations will be monitored informally on individual basis to determine if future research is needed with respect to rehabilitation, corrective action, etc.

REFERENCES

1. Roadway Design Manual, Colorado Department of Highways, 1990.

2. Acceptance of Materials, FHWA Technical Advisory T 5080.11, April 6, 1989.

3. Chip Seals, Friction Courses, and Asphalt Pavement Rutting 1990, No. 1259 Materials and Construction, Transportation Research board, National Research Council, Washington, D.C., 1990.

APPENDIX A
Mix Design Specifications

MIX DESIGN SPECIFICATIONS

Minimum Asphalt Content

	With Seal Coat	Without Seal Coat
1" maximum size (Grading "F")	5.5%	6.0%
3/4" maximum size (Grading "E" and "C")	5.2%	5.5%
1/2" maximum size (Grading "EX")	5.4%	5.8%

Air Void Criteria

The air void criteria for all lower layers and all gradings will be 4-8%. The air void criteria for the top layer, if a seal coat is not used, is 3-4%. For Grading "F" it should be 4-8%.

Moisture Damage Criteria

When aspahlt film thickness is reduced, durability is also reduced. This will affect the Lottman test results, so we are lowering the Lottman criteria from 70 to 60. Use the following table for moisture damage criteria.

TABLE I

1" maximum size (Grading "F" IRS = 70

3/4" and 1/2" maximum size
(Grading "E", "EX" & "C") Lottman = 60

If a seal coat is not used, the Lottman value for top layer of Grading "E", "EX" & "C" must be 70.

Type of Seal Coat

The top layer of pavement used with this design will normally be Plant Mixed Seal Coat. On low volume roads, a chip seal surface can be substituted for the PMSC. The thickness of the seal coat will normally be 3/4". Use the following table to select the proper type of PMSC.

Table II

20 Year 18K ESAL	PMSC Type
< 5,000,000	"A"
> 5,000,000	"B"

Gradation Criteria - PMSC

Sieve Size of Designation	Percentage by Weight Passing Square Mesh Sieves	
	Type A	**Type B**
1/2"	100	100
3/8"	90-100	90-100
#4	32-48	46-62
#8	8-20	27-39
#50	----	5-17
#200	3-7	3-7

Gradation Criteria - HBP

Sieve Size of Designation	Percentage by Weight Passing Square Mesh Sieves			
	Gr C	Gr E	Gr EX	Gr F
1"	----	----	----	100
3/4"	100	100	----	----
1/2"	70-95	----	100	----
3/8"	60-88	----	----	----
#4	44-72	44-72	50-78	----
#8	30-58	30-58	34-60	45-85
#50	7-27	----	----	----
#200	3-12	3-12	3-12	5-15

All mix design criteria for RRCP and standard HBP are the same except for % asphalt content. Gr F pavements did not utilize the low % AC mix design.

Colorado Procedure
L-5109

Method of Test for

EFFECT OF WATER-RELATED CONDITIONING ON INDIRECT TENSILE PROPERTIES OF COMPACTED BITUMINOUS MIXTURES (TSR)
(Lottman)

SCOPE

1.1 This method covers measurement of the change of diametral tensile strength resulting from the effects of saturation and accelerated water conditioning of compacted bituminous mixtures. Internal water pressures in the mixtures are produced by vacuum saturation followed by a freeze and warm water soaking cycle. Numerical indices of retained indirect tensile properties are obtained by comparing the retained indirect tensile properties of saturated and accelerated water conditioned laboratory specimens with the similar properties of dry (unconditioned) specimens.

APPARATUS

2.1 Water baths of sufficient size to permit total immersion of the specimens, automatically controlled, and capable of accurate and uniform control of immersion temperatures of $77^{o}\pm1.8$ F and $140^{o}\pm1.8$ F. Baths shall be lined with non-reactive material. Water used in baths may be tap water or potable water.

2.2 Freezer, automatically controlled, capable of maintaining temperature of $0^{o}\pm3.6$ F, and of sufficient size to permit total containment of specimens.

2.3 Vacuum pump with capacity to pull at least 26 inches of mercury, with accessories including vacuum jars at least 6 inches in diameter and 8 inches high; rubber gaskets, stiff metal plates greater than 6 inches by 6 inches in size, with hose fitting and suitable vacuum hose.

2.4 Testing machine capable of steady head speed of 0.2 inch per minute.

2.5 Balance having sufficient capacity, accurate to 0.1 gram, with suspension apparatus and container overflow device, similar to that specified in AASHTO T 166 for bulk specific gravity.

2.6 Plastic sheeting and heavy duty leak-proof plastic bags.

2.7 Cabinet, thermostatically controlled, capable of maintaining a temperature of $77^{o}\pm1.8$ F.

COMPACTION OF TEST SPECIMENS

3.1 Make at least four specimens for each test using the same

aggregate, the same asphalt source and grade (plus additive, if specified) at optimum AC Content that are anticipated to be used on a specific project in the field. Specimen size is 4 inches in diameter by 2.5 inches high. Mold the specimens according to CP L-5105.

PROCEDURE

4.1 Determine bulk specific gravity of specimens according to AASHTO T 166.

4.2 Select one pair of specimens to vacuum saturate, placing the other pair in the cabinet at 77° F.

4.3 Vacuum saturate the remaining specimens as follows: Place each specimen in a vacuum jar with flat surfaces vertical. Add 77° F water to the jar to approximately 1 inch above the upper surface of the specimen. Dampen gasket on vacuum cover and place on top of the jar. Attach hose to vacuum pump and fitting on vacuum cover. Apply a vacuum of 26 inches of mercury to the jar for a period of 30 minutes while occasionally agitating the jar gently. Remove vacuum and leave the specimen submerged in the jar for an additional 30 minutes.

4.4 Remove specimen from vacuum jar, and weigh submerged in room temperature water. After weighing, immediately wrap in plastic sheeting for freezing or resubmerge the specimen for later wrapping.

4.5 Calculate the bulk density and the permeable voids as follows:

Bulk density = A/B-C
Percent Permeable voids = 100 (B-A)/B-C

Where:
A = Weight of dry specimen in air
B = Weight of surface-dry (blotted) vacuum saturated specimen in air
C = Weight of vacuum saturated specimen in water

All weights are accurate to 0.1 grams.

ACCELERATED CONDITIONING PROCEDURE

5.1 Maintaining surface dampness and internal saturation, wrap the specimen tightly with two layers of plastic sheeting, using masking tape to secure the wrapping if necessary. Place wrapped specimen into a leak-proof plastic bag and seal the bag with a tie wire.

5.2 Place each individually wrapped and bagged specimen in a freezer for a period of 16 hours at $0^{\circ}\pm3.6$ F.

5.3 Remove specimen from freezer. Carefully remove bag and wrapping and immediately immerse the specimen in the water bath at $140^{\circ}\pm3.6$ F for 24 hours.

5.4 Carefully remove specimen from 140° F bath and immerse in water bath at $77^{\circ}\pm$F for two hours, minimum.

DIAMETRAL TENSILE STRENGTH PROCEDURE

6.1 Remove a specimen from the water bath, surface dry by blotting with a towel. Place the specimen, with the flat surfaces vertical (on edge without support blocks or loading strip) under the flat head of the compression testing machine. Test one specimen at a time. Proceed with testing as rapidly as possible because the test procedure will expose the specimen to ambient air temperature which may be different than the test temperature.

6.2 Load the specimen at a steady vertical deformation rate of 0.2 inch per minute. Record the maximum compressive load. Immediately decrease the load to zero, remove specimen, and measure specimen edge on a flattened side to the nearest 0.1 inch. Accomplish this by stroking the top flattened edge (side) with a piece of chalk held lengthwise and horizontally to delineate the flattened width. Measure and average the width of both flattened edges. Record this measurement.

6.3 Repeat the procedure using the dry (unconditioned) specimens.

CALCULATIONS

7.1 Calculate specimen diametral strength as follows:

$S_t + S_{10}P / 10,000L$

Where:

S_t = Diametral tensile strength, psi

S_{10} = Maximum tensile stress, psi, determined by calculating:

$S_{10} = 1658 - [(a + 0.7)a \times 150]$

Where:

a = flattened width, in inches, based on a 4 inch diameter specimen loaded at 10,000 lb. per inch of thickness.

P = Maximum compressive load on specimen, lbs.

10,000 = Load constant: 10,000 lb. per inch of thickness.

L = Thickness of specimen, inches.

7.2 Calculate the numerical indices of the effects of vacuum saturation and accelerated conditioning as the ratios of the mechanical properties of the conditioned specimen to the mechanical properties of the unconditioned specimen as follows:

$TSR = 100(S_tC/S_tD)$

Where:

TSR = Retained diametral tensile strength expressed as a percentage.

S_tC = Diametral tensile strength of specimen conditioned by freezing.

S_tD = Diametral tensile strength of unconditioned specimen.

7.3 Tensile Strength Rations may be interpreted as being related to long-term pavement performance (approximately eight years). Low ratios are associated with the inability of the compacted mixture to resist the effects of moisture.

APPENDIX B
Permeability Tests

As part of the six-year study into the performance of the department's asphalt composite pavement design, the Research Branch developed two methods of evaluating the permeability of the plant mixed seal coats (PMSC).

The first method consisted of a two-conductor 16 gauge wire. Approximately 1/2 inch of insulation was stripped off each conductor and the wire ends were spread to about 1/4 inch spacing. A sponge measuring 1/2" x 3/4" x 3/8" thick was placed on the bare wire ends. The purpose of the sponge was twofold: it prevented the two wire ends from touching each other and it distributed moisture evenly around the probe ends.

During construction a groove was cut into the lower lifts to facilitate the placement of the lead wires, as well as the probe's end. The sponge end was placed in the right wheel path of the driving lane under each lift. The wire was then extended to the edge of the pavement to be used later to measure resistance. The wire was tacked down to prevent it from being pulled up during paving.

The procedure for measuring permeability was to connect the probe wire to a volt-ohm-meter (VOM) which would measure the change of resistance due to presence of water. Water was placed on the pavement at the location of the sensor. Traffic was allowed to travel over the pavement to determine if water was forced into the pavement under traffic during periods when the pavement is wet.

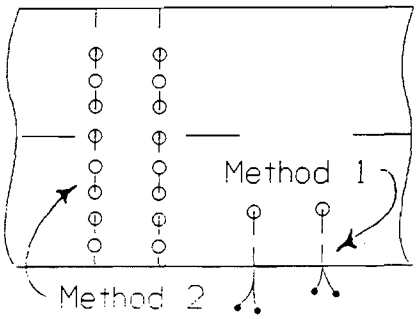
Data acquisition equipment (Microloggers) was used at some locations to record data over a period of time to determine if the pavement was permeable and, if so, how long the water stayed in the pavement.

The second method was a modification of a test that has previously been used to test for water proofing of bridge decks with membranes in Colorado.

In this method, individual 16-gauge galvanized bare wires were placed across the lanes beneath each lift. The wires were tacked down at both ends and every few feet with "U-shaped" staples to prevent damage or movement of the wire during the paving process. Approximately one foot of wire was left exposed at the edge of the pavement to facilitate conduction of test equipment. The exposed ends of the wires were buried to prevent disturbance of the installation but were easily accessible during the testing procedures.

To test this method, water was sprayed on the pavement over the wire in several location across the roadway. These locations are kept damp for approximately 20 minutes before testing. Soap is added to the water to break down the surface tension making the penetration of water faster. Testing was done using the bridge deck membrane testing equipment (direct measurement of resistance).

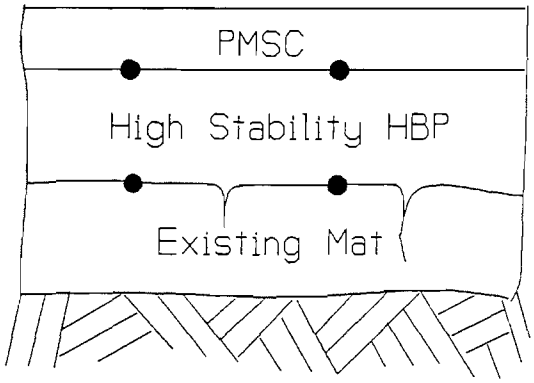
TYPICAL MOISTURE DETECTION INSTRUMENTATION LAYOUT



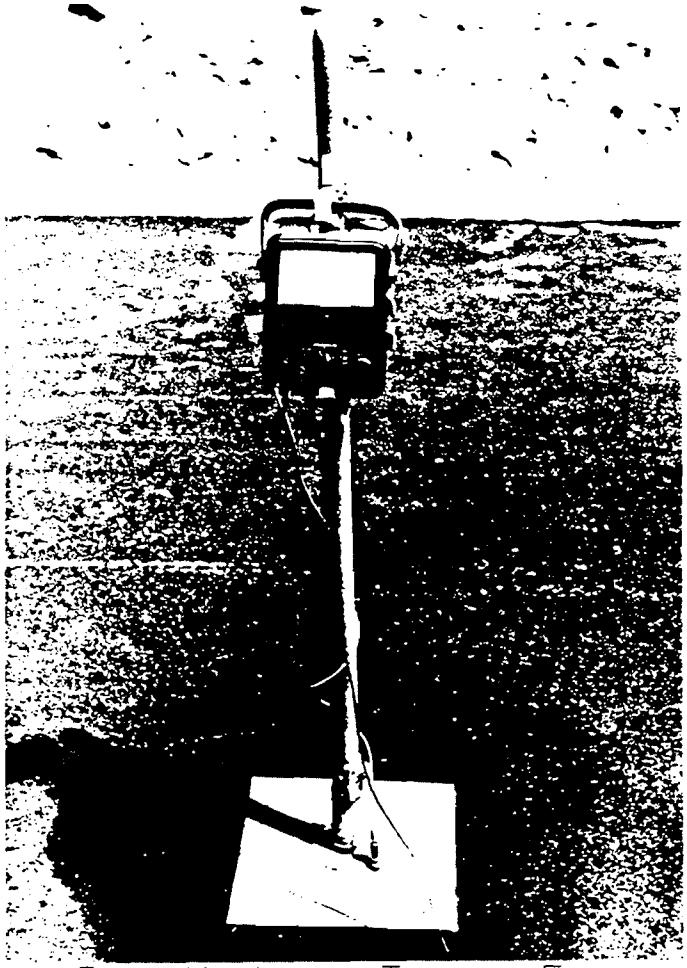
○ Water was sprayed at these locations to test the permeability.

Method 1: Probes extended into right wheel path of driving lane.

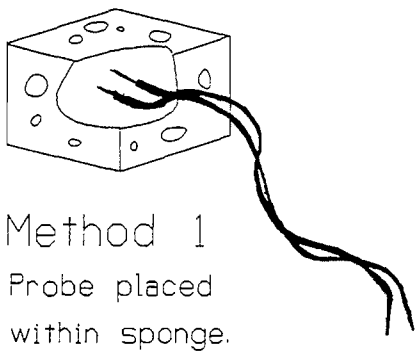
Method 2: Wires extended full width.



● General layout used in both methods.



Bridge Deck Membrane Testing Equipment
(Used for Test Method 2)



Method 1
Probe placed within sponge.

APPENDIX C
Project Information
C470, Between Kipling and Wadsworth

C470 -- Between Kipling and Wadsworth

Project No. IXFU 470-1(54), located between Wadsworth and Ken Caryl on C470 in the southwestern part of the city, was completed in the summer of 1987.

Since the paving process began before the study proposal was approved a control section containing the old mix design was not included on this project. However, a test section was established to evaluate the new pavement design. The test section was located between Wadsworth and Kipling in the eastbound driving lane.

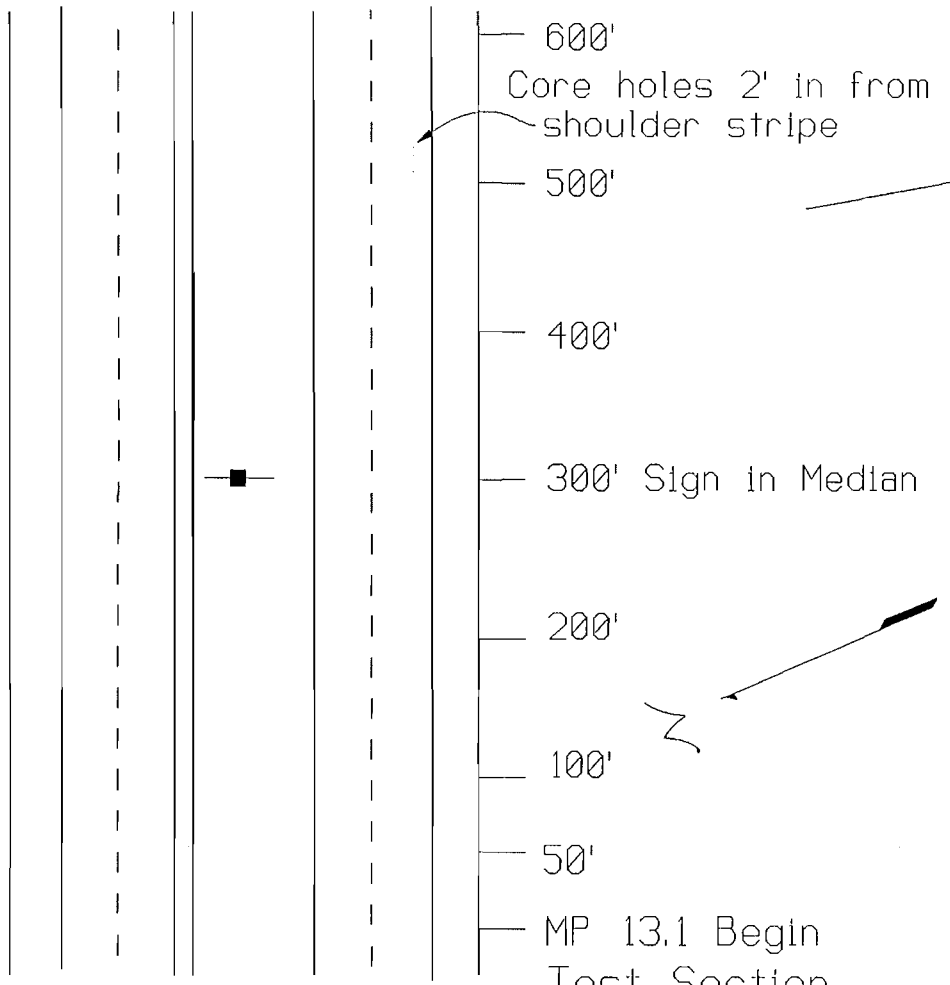
The original plans for this project required eight inches of lime treated subgrade throughout the project. However, on the portion between Kipling and Ken Caryl, the subgrade contained a large quantity of rock and the lime was deleted.

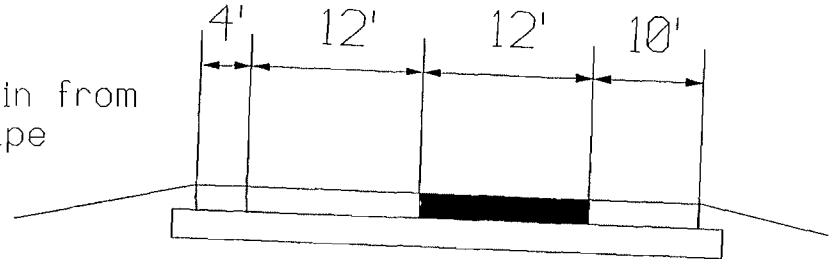
The typical section required the 9-1/2 inches of HBP to be placed in four lifts. A 3/4 inch lift rubberized PMSC Type A completed the paving process. The 500 foot test section which will be evaluated during the study period is located just east of the Kipling exit in the eastbound lane in this portion of the project.

During construction no significant placement problems were reported on this project.

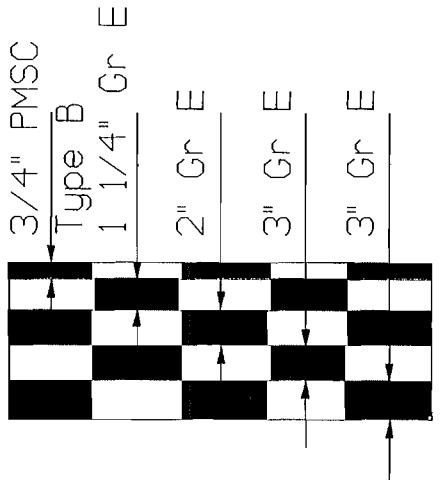
Rut Resistant Composite Pavement

C470 between Kipling and Wadsworth



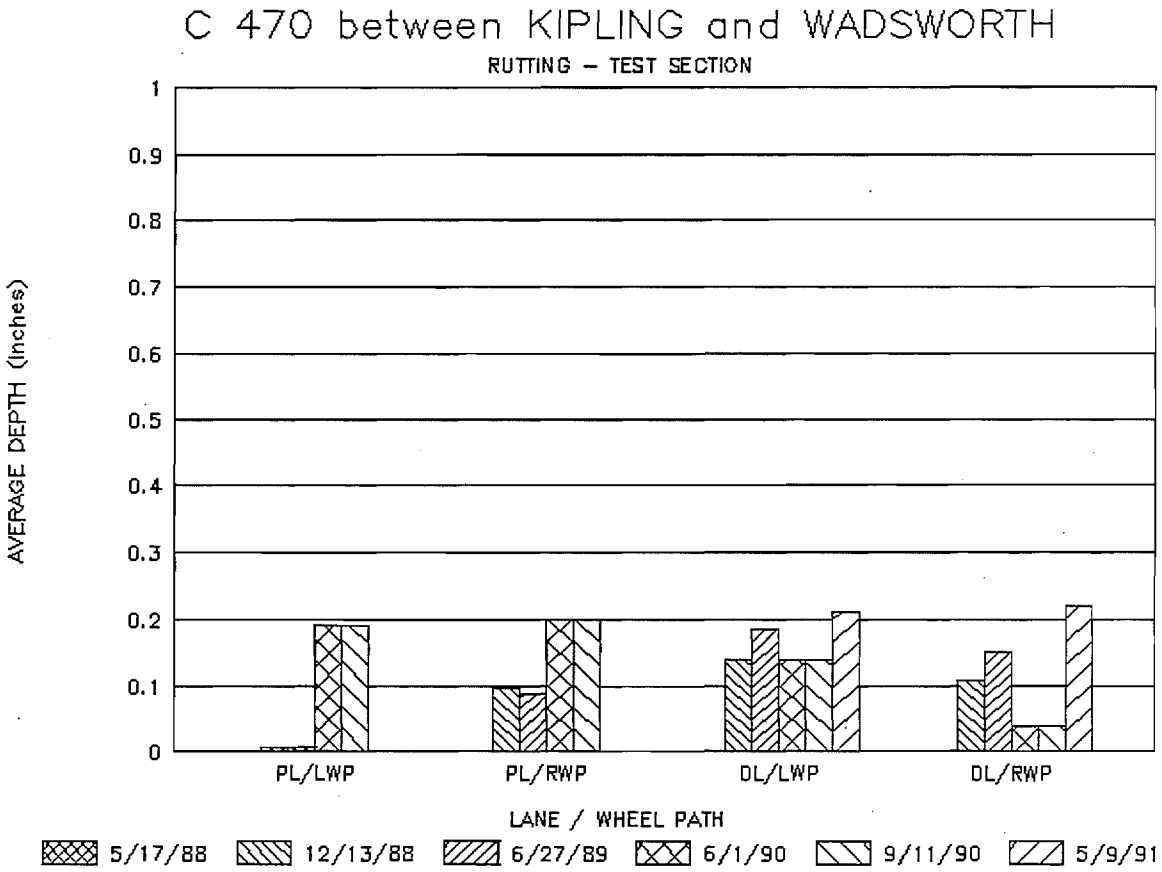


Evaluation Section



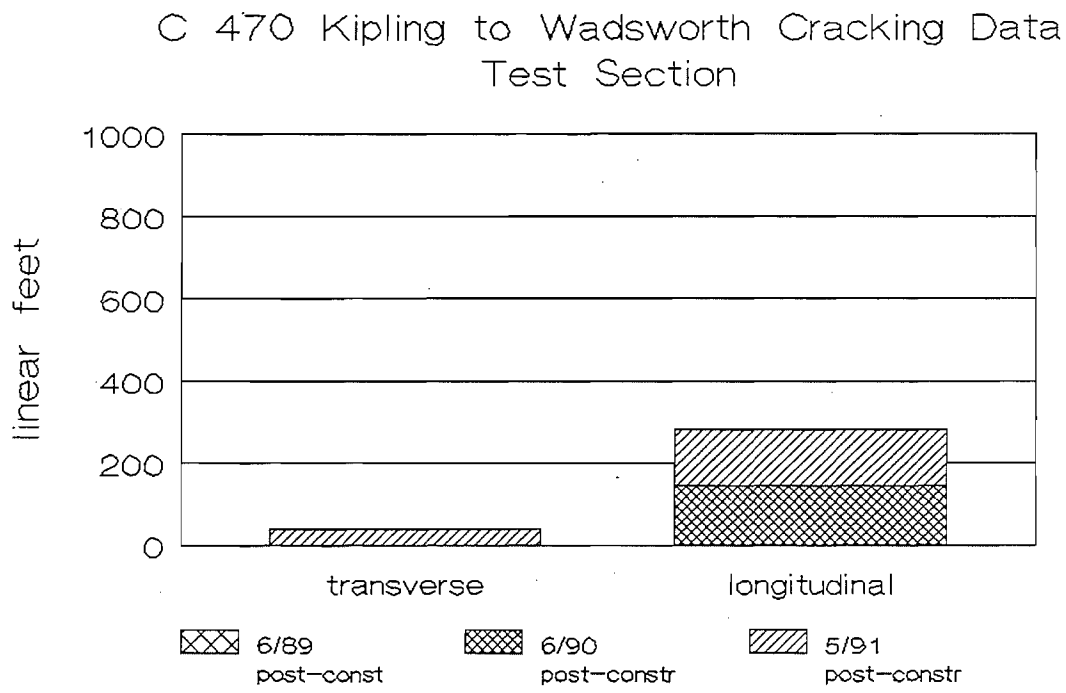
Project typical Test Section

All lifts AC-10F except PMSC



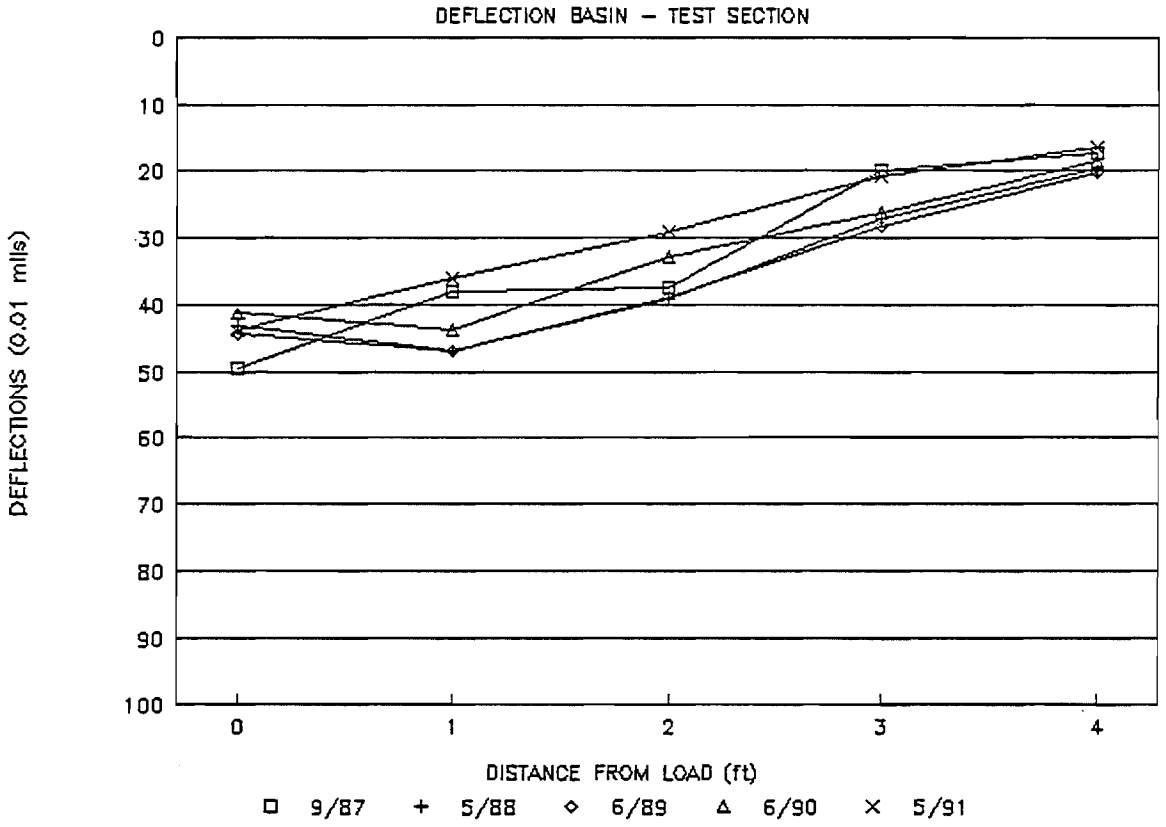
New Construction

5/17/88 -- first spring evaluation following construction



New Construction

C 470 BETWEEN KIPLING AND WADSWORTH



New Construction

9/87 -- evaluation immediately following construction

APPENDIX D
Project Information
I-76, Between Tennyson and Lowell

I-76, Between Tennyson and Lowell

Project No. IR76-1(103), located between Sheridan Blvd and Federal Blvd on I-76 in northwest Denver, was completed in the summer of 1987. The section which was chosen for evaluation was between Tennyson and Lowell in the eastbound lane.

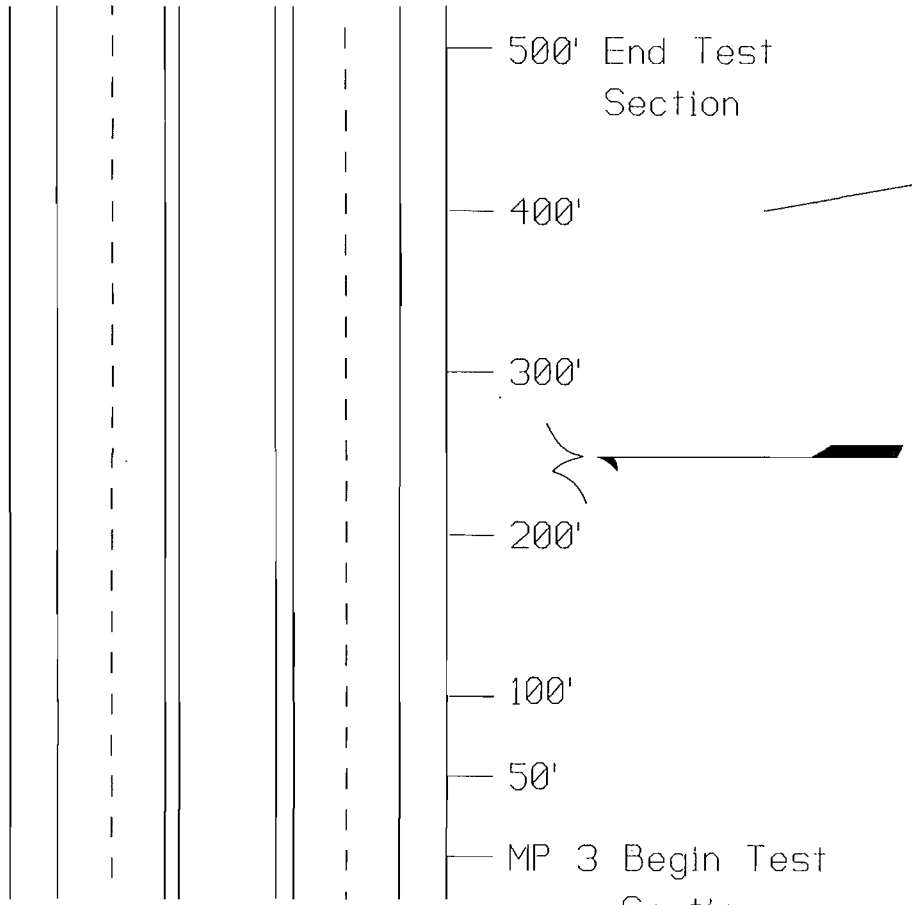
Since the paving process began before the study proposal was approved, a control section containing the old mix design could not be included in this project.

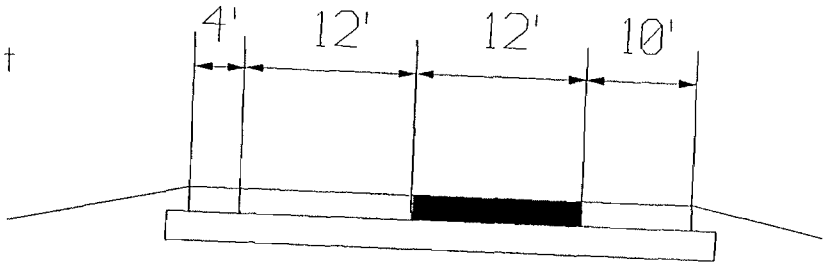
The plans for this project called for 8 inches of lime-treated subgrade, 8-1/2 inches of HBP and 3/4 inches of rubberized PMSC Type B. During construction difficulties arose when placing the PMSC. During the laydown of the 3/4 inch layer of PMSC the rubberized asphalt became very tacky as it cooled. This made raking the overlapping joints in tapered sections and on the ramps difficult. By changing the asphalt cement from AC-20R to AC-10 in the PMSC used in the tapered sections and on the ramp, the contractor was able to create smoother joints. On the mainline the laydown machine made a 24 foot wide pass. This wide pass in conjunction with the quick cooling of the material required additional attention in repairing tearing which was commonly found behind the laydown machine.

The original evaluation section was set up in a tapered section just west of the Federal Blvd exit. However, after construction it was moved further west as it was felt that a true rutting measurement could not be made in a tapered section. The 600 foot test section is located on the mainline in the eastbound lane between Tennyson and Lowell.

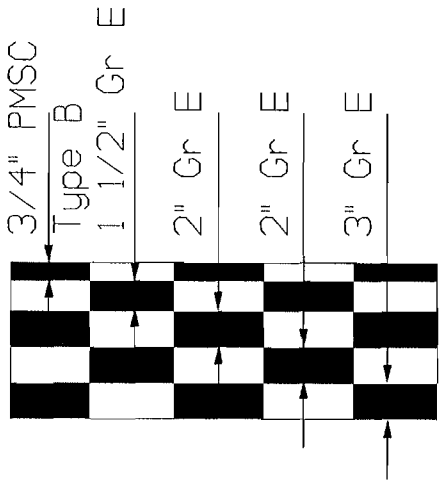
Rut Resistant Composite Pavement

I-76 between Tennyson and Lowell





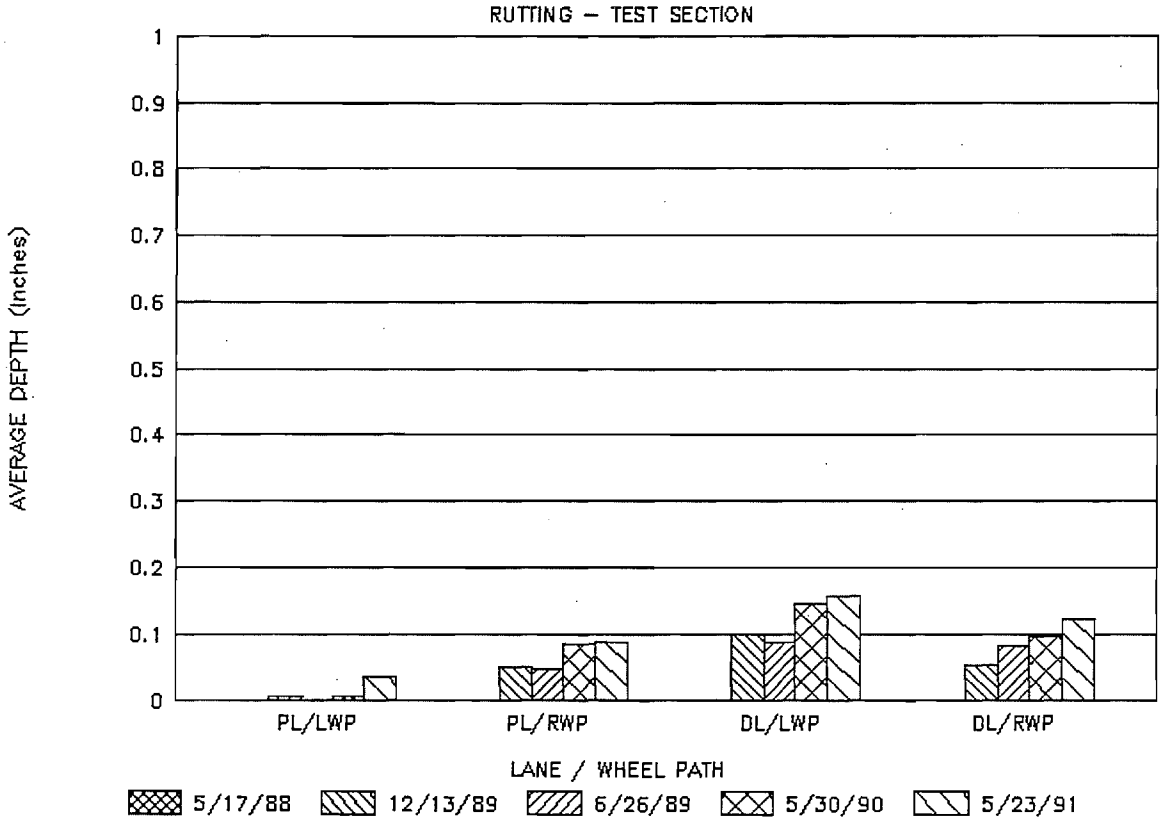
Evaluation Section



Project typical Test Section

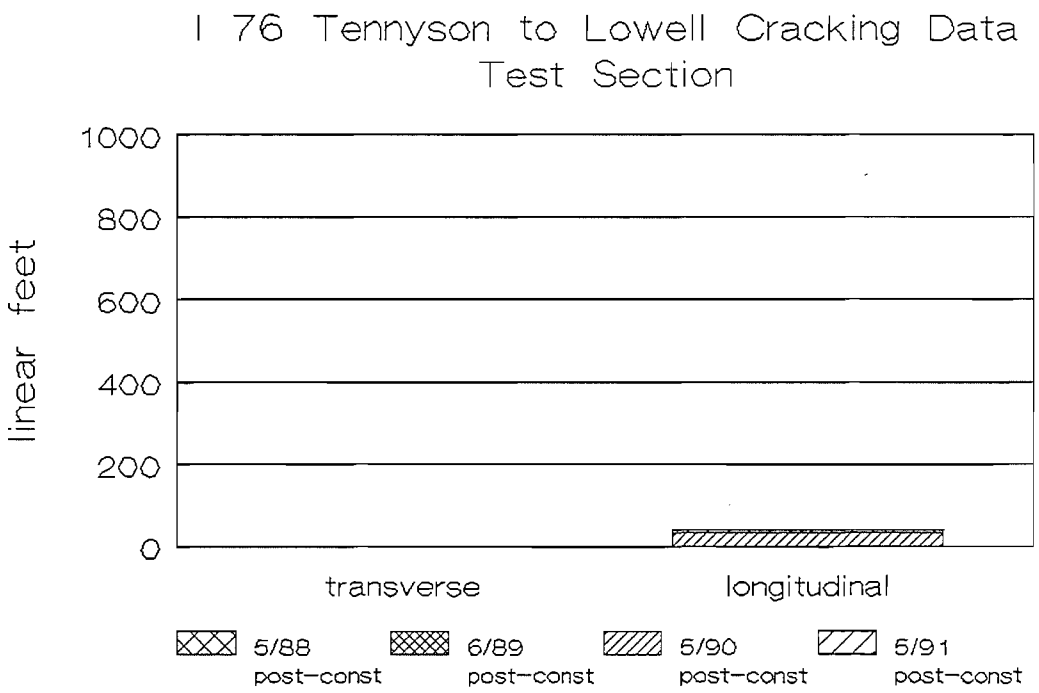
All lifts AC-10F except PMSC

I 76 between TENNYSON and LOWELL



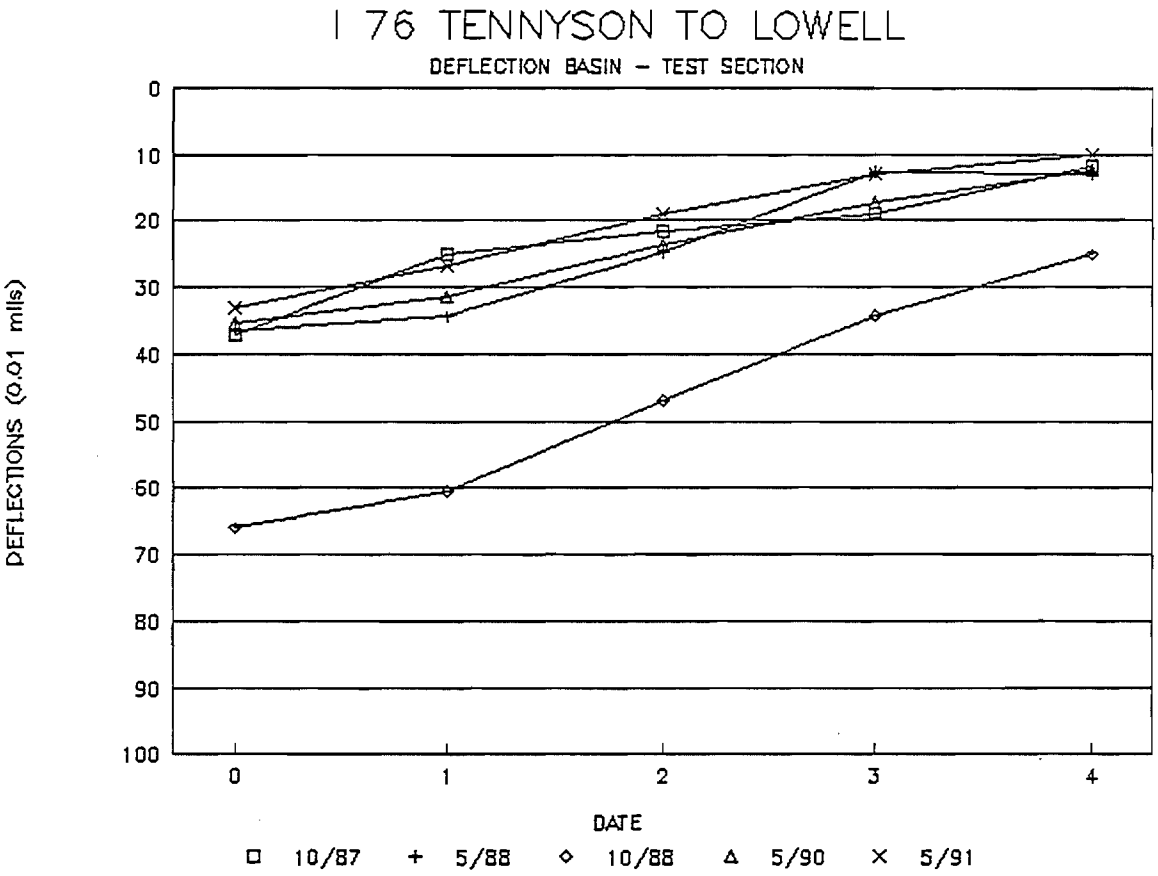
New Construction

5/17/88 -- first spring evaluation following construction



New Construction

5/88 -- first spring evaluation following construction



New Construction

10/87 -- evaluation immediately following construction

APPENDIX E
Project Information
C470, US 285 to I-70

C470, US 285 to I-70

Paving began on this phase of C470 (Project No. IXFU 470-1(32) on June 1, 1988. The length of this project was a little over 3 miles. The plans for this project called for 8 inches of lime treated subgrade, 10 inches of HBP and 3/4 inches of rubberized PMSC Type A for the entire project except for a 1500 foot section located between station 209+00 and 224+08 in the northbound lanes. This section is located just north of the Morrison interchange. This 1500 foot section consisted of 8 inches of lime treated subgrade and 10.5 inches of HBP. This control section did not include a PMSC and the design used for the HBP was not intended to be the new high-stability design mix.

The 10 inches of HBP was placed in four lifts: 3-3/4 inches, 3 inches, 2 inches and 1-1/4 inches, respectively. The 10-1/2 inches of HBP was also placed in four lifts: 3-3/4 inches, 3 inches, 2 inches and 1-3/4 inches respectively.

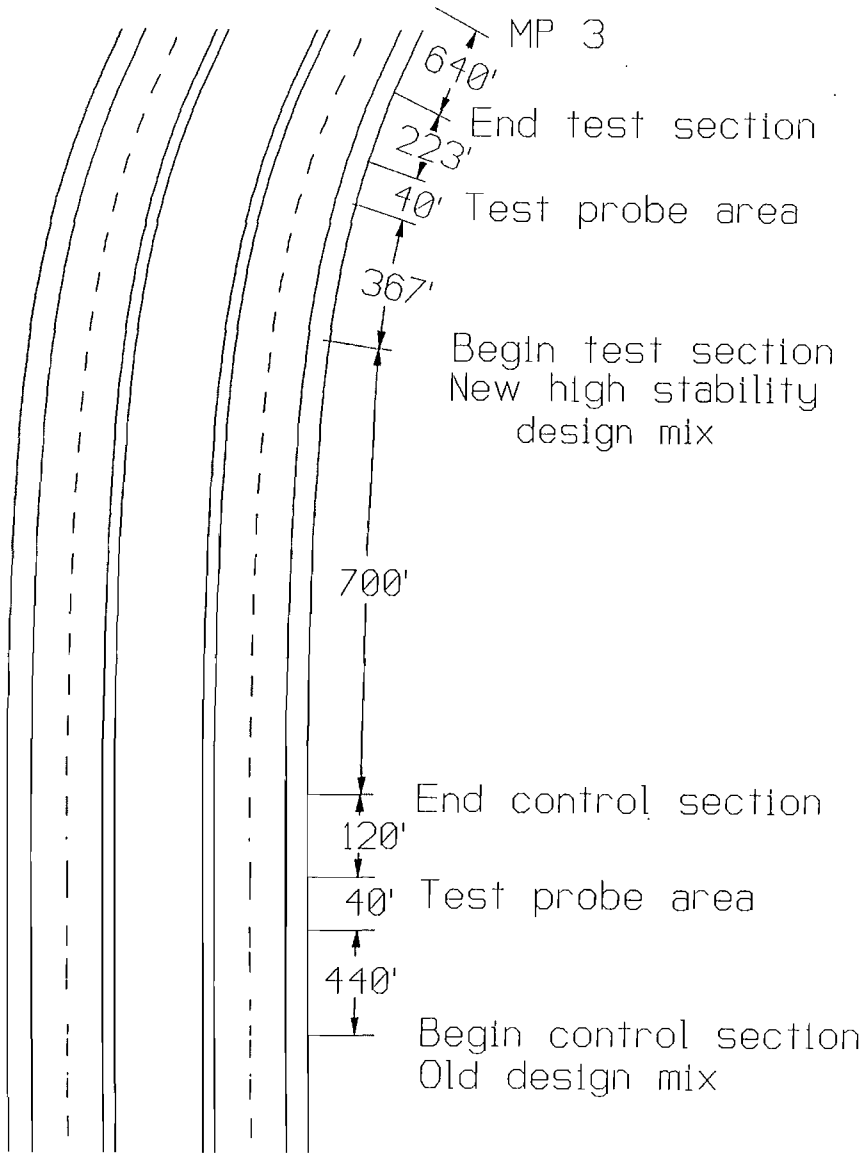
Originally, the plans called for two different AC contents in the test and control designs. The AC content in the control section was to be 5.2$\pm$0.3% and the remainder of the project was to be 5.0$\pm$0.3%. However, the district waived these requirements and allowed the contractor to keep the AC content in the lower lifts the same throughout the project and only increase the AC content in the final lift on the control section. Two lifts were placed before the research branch was notified of the changes. At the request of the Research Branch the AC content in the control section was returned to the higher AC content. However, samples taken during construction of the third lift indicated that the AC in the driving lane of the control section was 4.98%. The AC

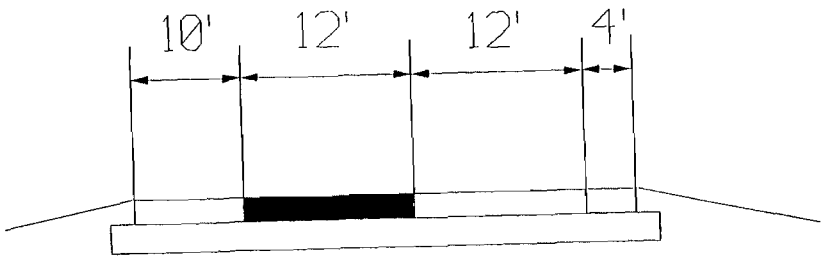
content in the third lift of the driving lane in the test section was 5.18%. It was the intent of this study to have the higher AC content in the control section.

Paving was completed on September 25, 1988. This section of C470 was opened in November 1988.

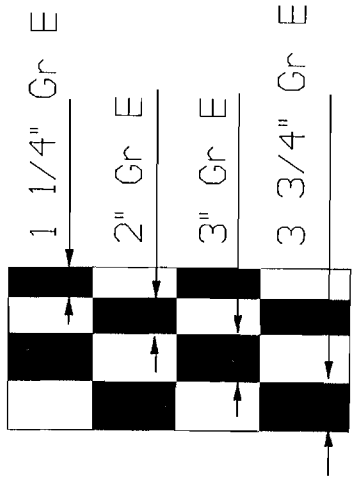
Since construction, portions of this project have failed due to stripping in the layer immediately below the PMSC.

Rut Resistant Composite Pavement
C470 between US 285 to I-70

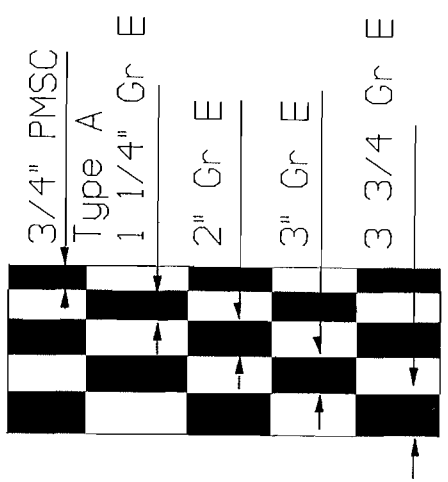




Evaluation Section

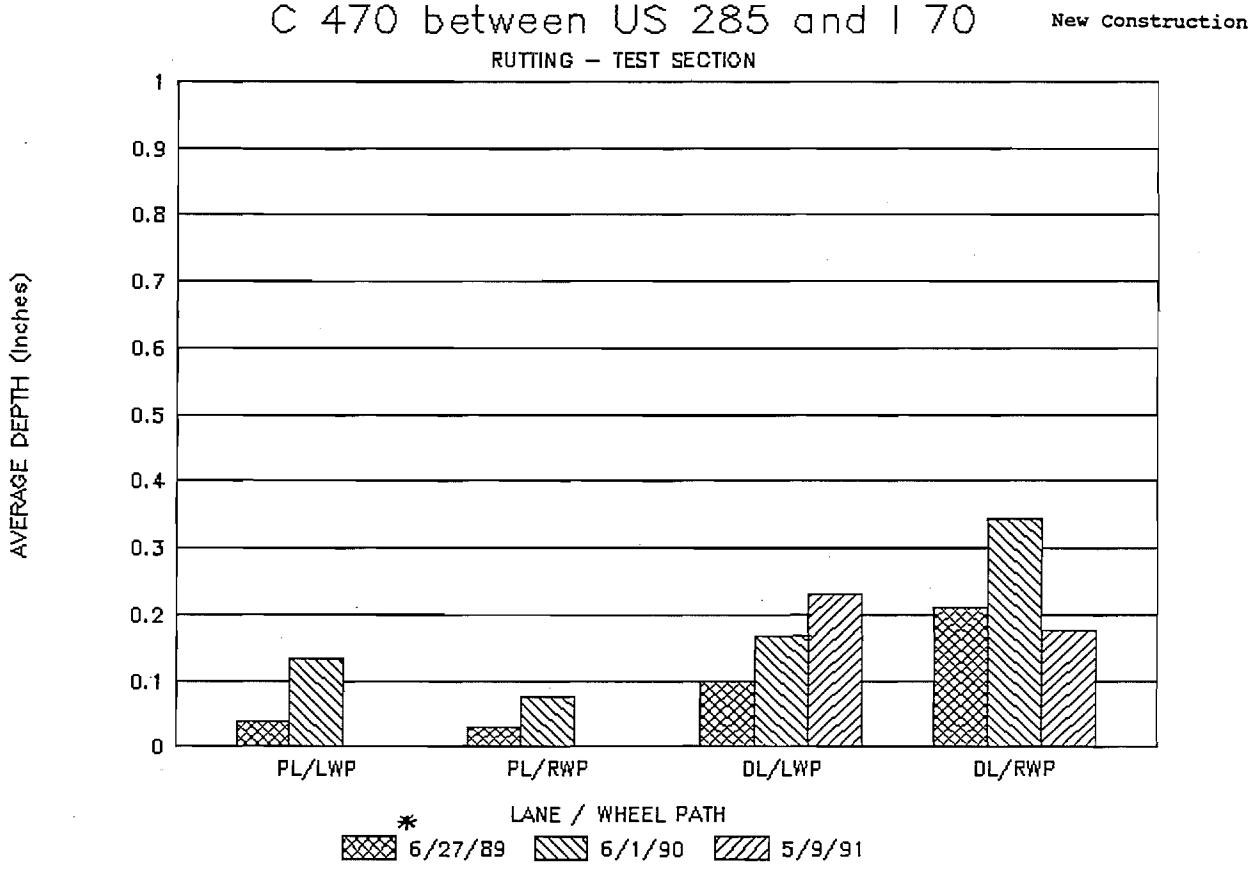


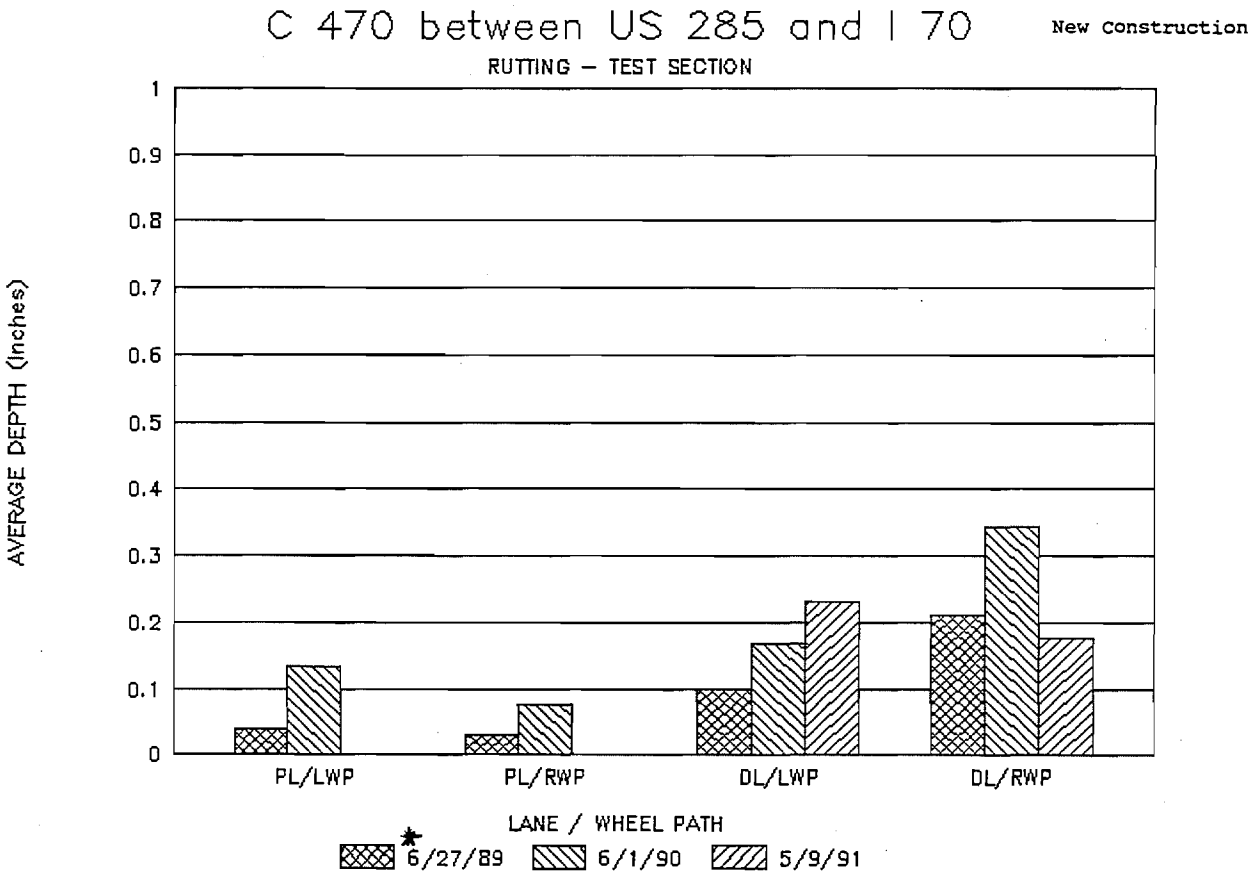
Control section



Project typical
Test section

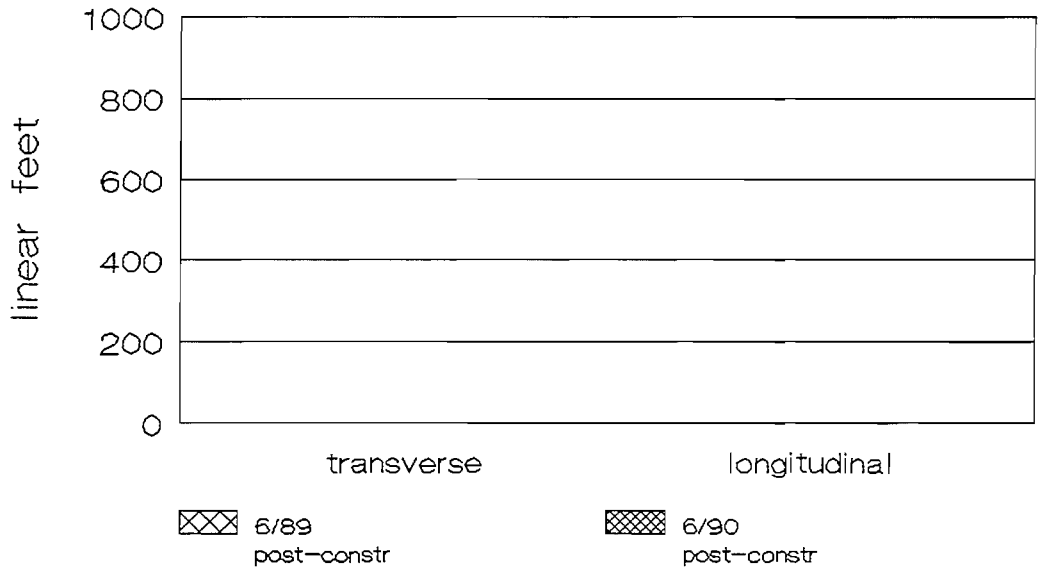
All lifts AC-10F except PMSC





* 6/27/89 -- first spring evaluation following construction

C470 Between US285 & I70 Cracking Data
Test Section – Westbound Lanes

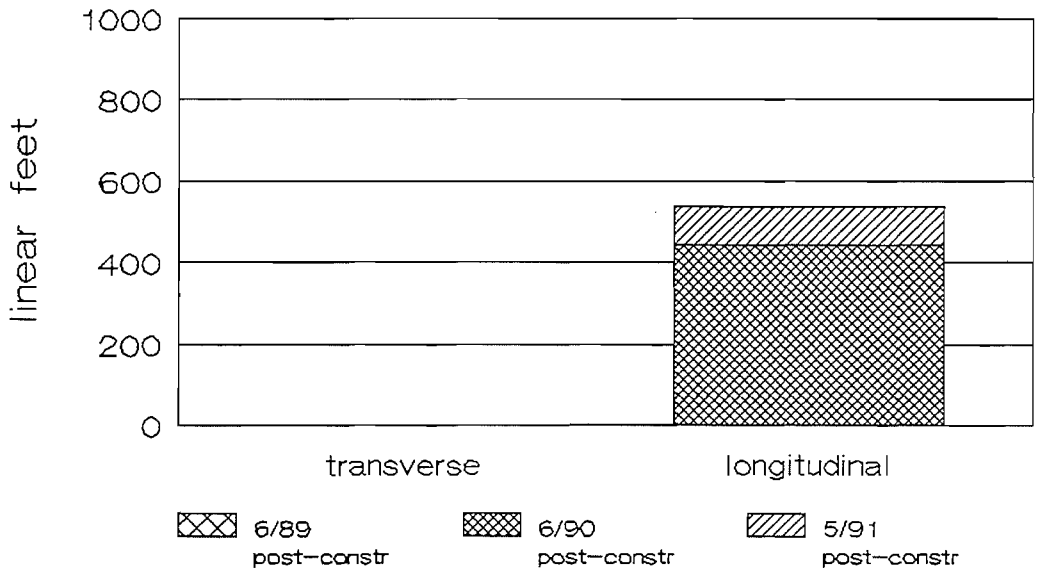


New Construction

6/89 -- first spring evaluation following construction

No cracking to date in test section

C470 Between US285 & I70 Cracking Data
Control Section – Westbound Lanes



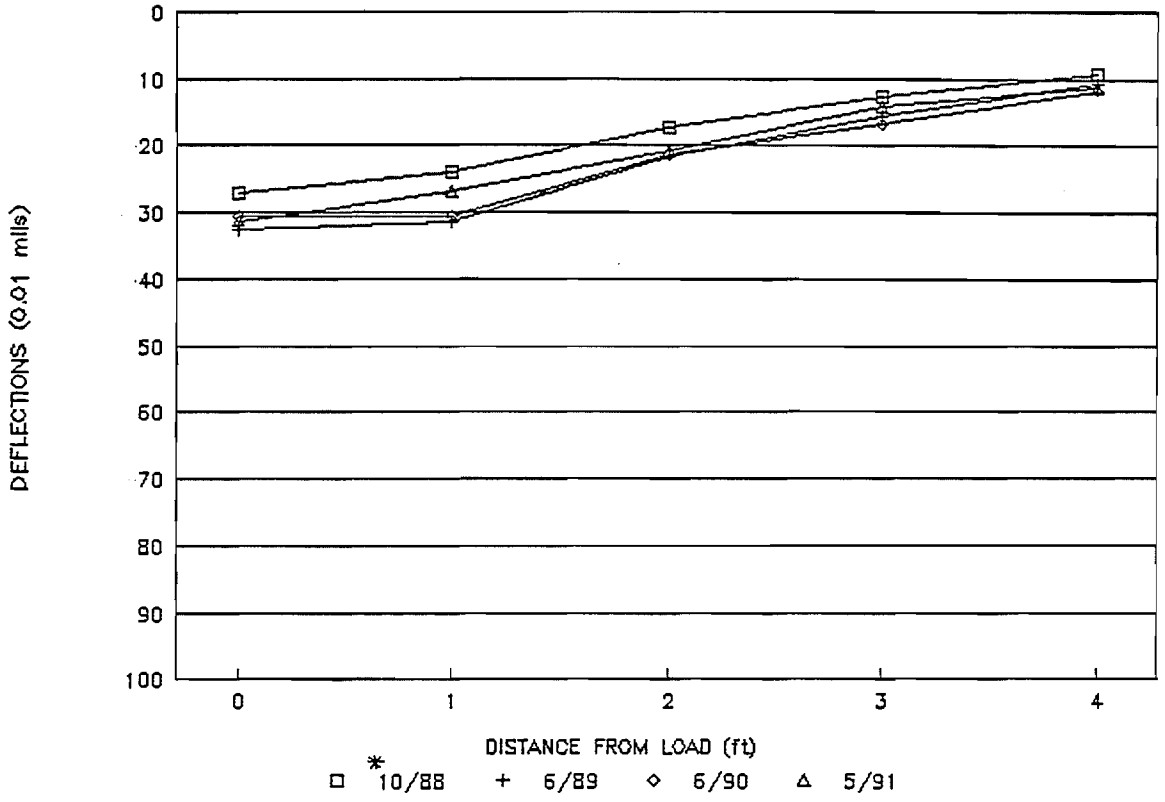
New Construction

6/89 -- first spring evaluation following construction

C 470 BETWEEN US 285 AND I 70

New Construction

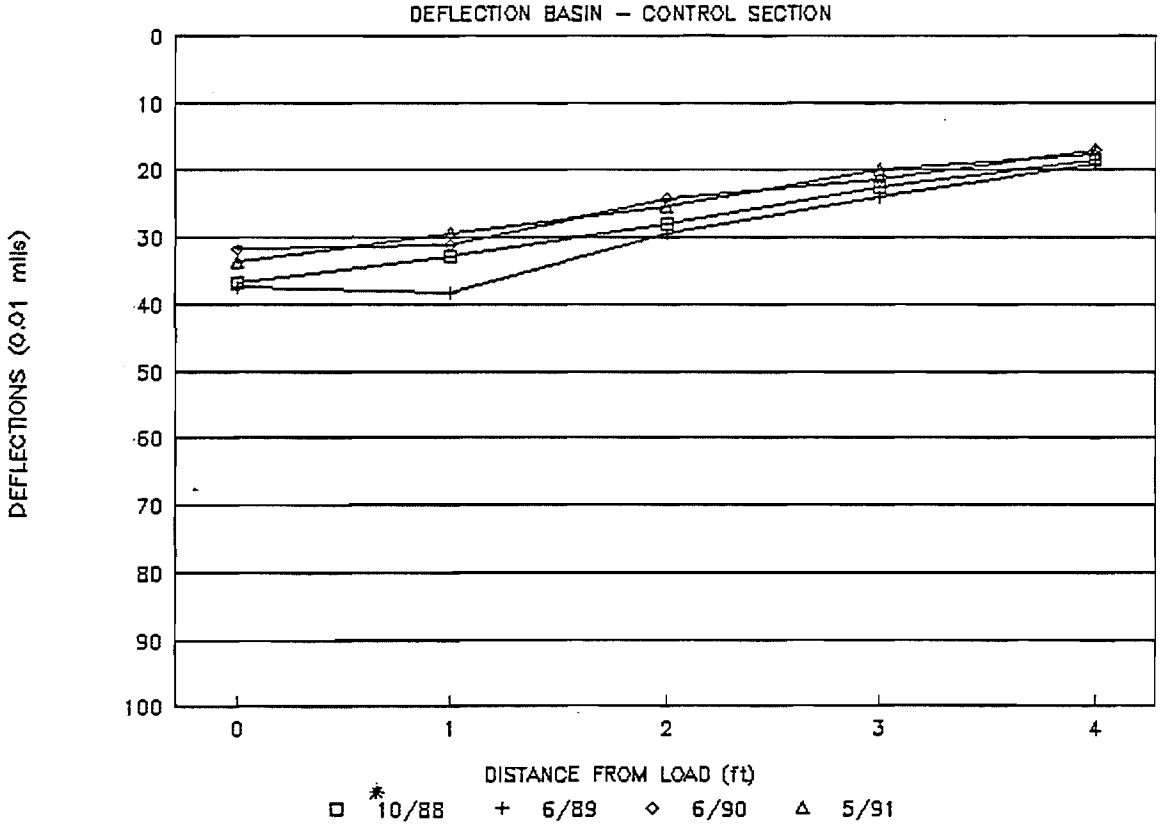
DEFLECTION BASIN – TEST SECTION



C 470 BETWEEN US 285 AND I 70

New Construction

DEFLECTION BASIN – CONTROL SECTION



*10/88 -- evaluation immediately following construction

APPENDIX F
Project Information
US 6, West of Holyoke

US 6, West of Holyoke

Paving on Project No. FR 006-3(80) began on July 19, 1988. This project is located on SH 6 in Phillips County. Work started on the east end of the project by paving west in the westbound lanes. The project was nine miles long and ran between Paoli and Holyoke. The project plans called for 1/2 inch leveling course, 1-1/4 inches HBP and 3/4 inches rubberized PMSC Type A throughout the project except for the 750 foot control section which did not include the PMSC. On this section the HBP was increased by 3/4 inch to compensate for not having a PMSC.

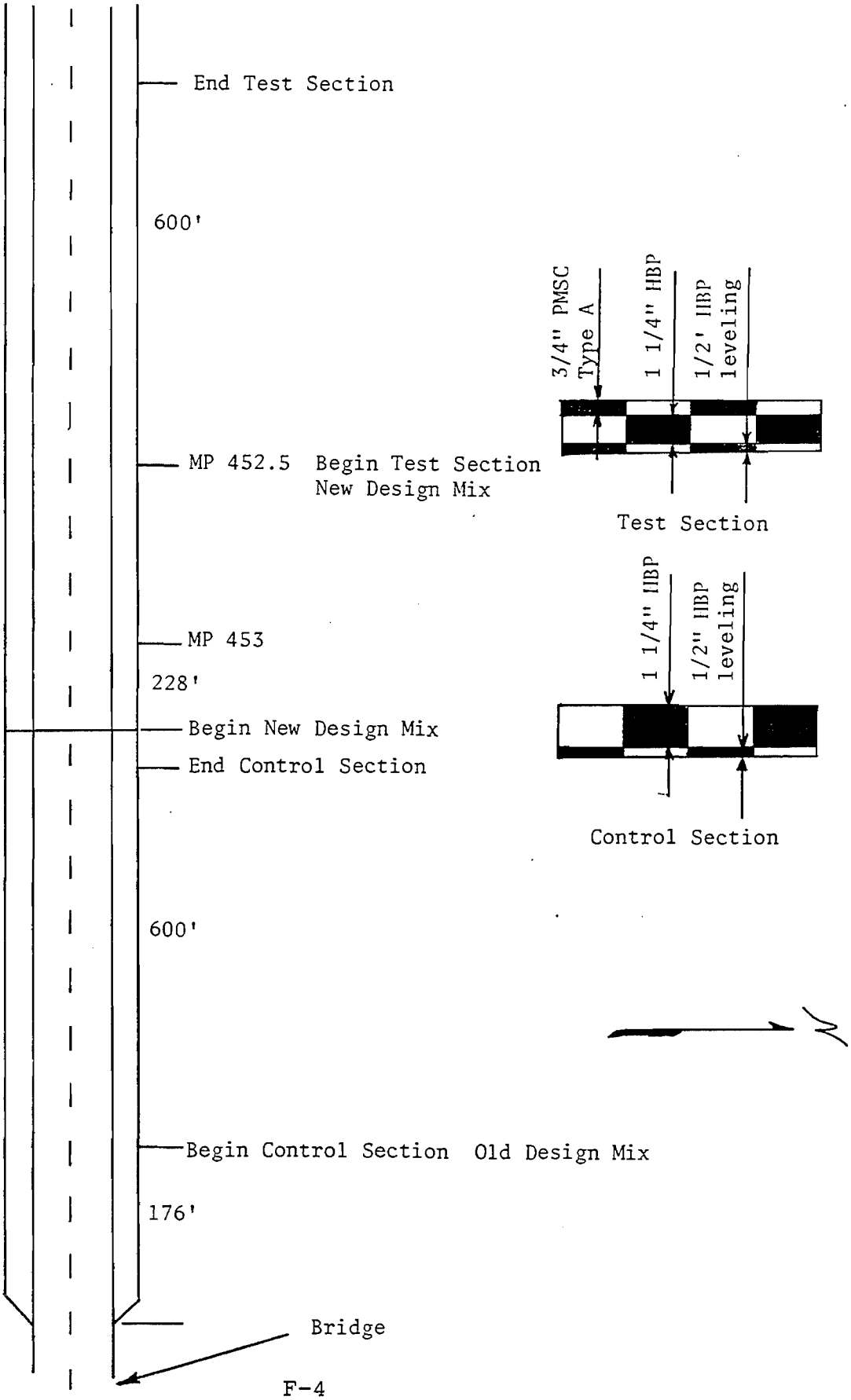
Since the theory behind the high stability design was to increase the stability in the lower lift, the AC content in the lower lifts was reduced. Typically the old mix design would have had a higher AC content than the new high stability design. In the design stage the AC content for the control section was 5.9$\pm$0.3%, the AC content for the test section was 5.8$\pm$0.3%. However the 5.9% was adjusted to 5.7% after applying an environmental factor. This factor was based on traffic, altitude, and the time of year the paving is taking place. The AC content was reduced to prevent bleeding during paving. This factor is not applied in the new high stability design. Even though this project did not meet the typical design criteria for this study it is still representative of the old design mix and the new high stability design mix.

The existing rutting on this project before paving was very high. Rutting in the right wheel path averaged over 1/2 inch, and in some places it was over an inch. The leveling course was placed which removed the majority of the ruts before the paving began.

The rolling pattern for this project began with the steel roller. The steel roller made two to three passes, and was followed by one pass with the rubber tire roller and one pass with the finishing roller.

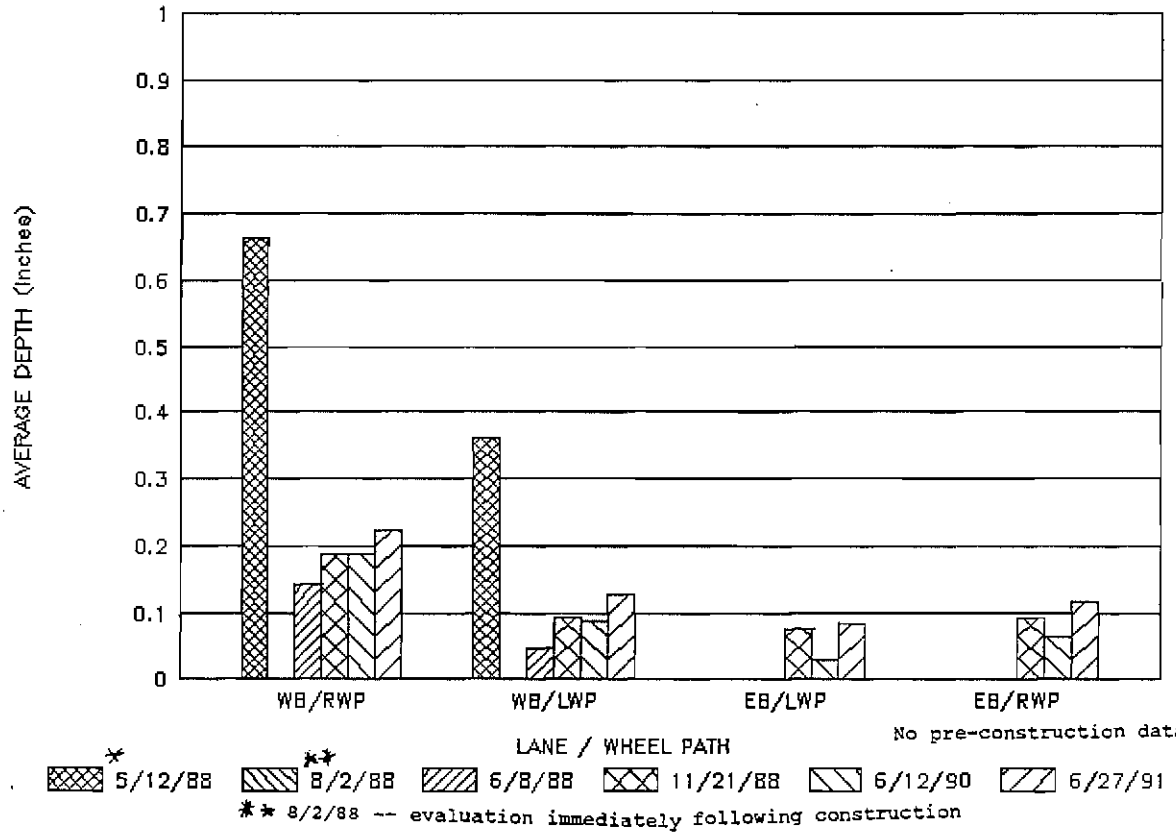
There was no significant construction problems noted during construction.

Rut Resistant Composite Pavement
US 6 west of Holyoke



US 6 west of HOLYOKE

RUTTING – TEST SECTION

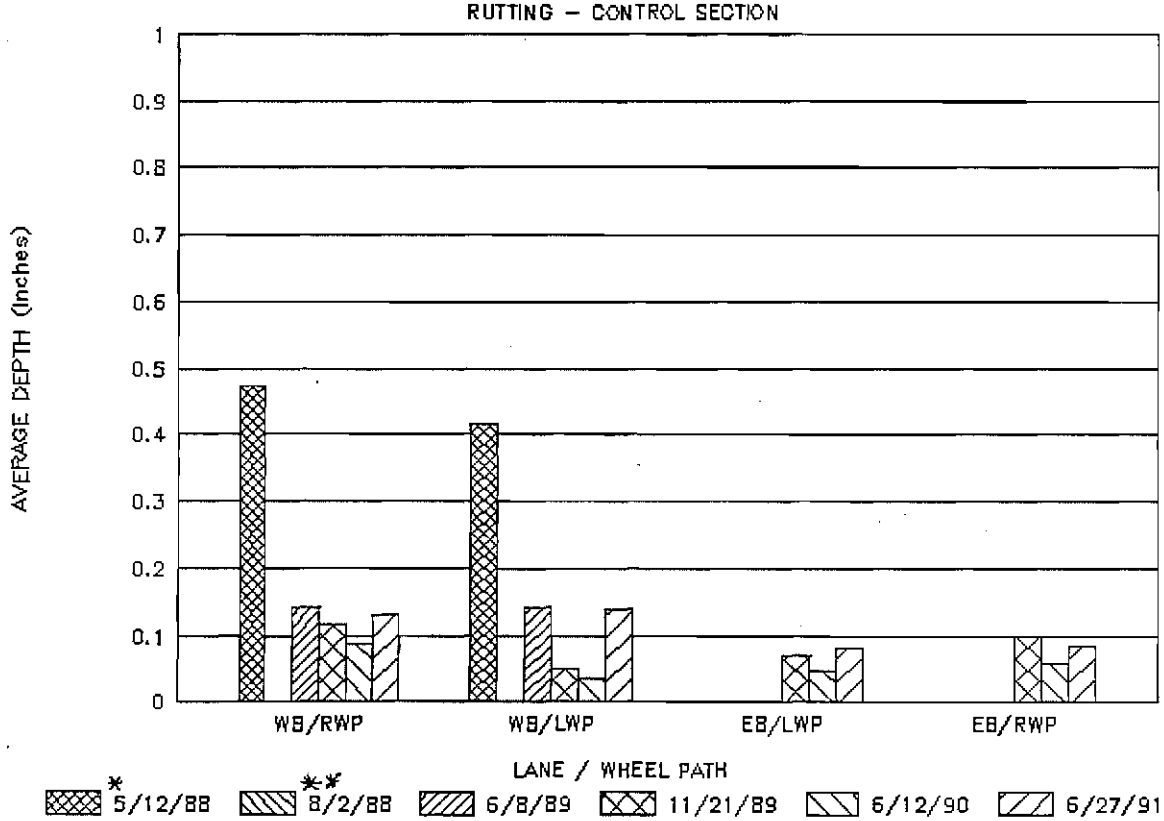


No pre-construction data available for eastbound direction

** 8/2/88 -- evaluation immediately following construction

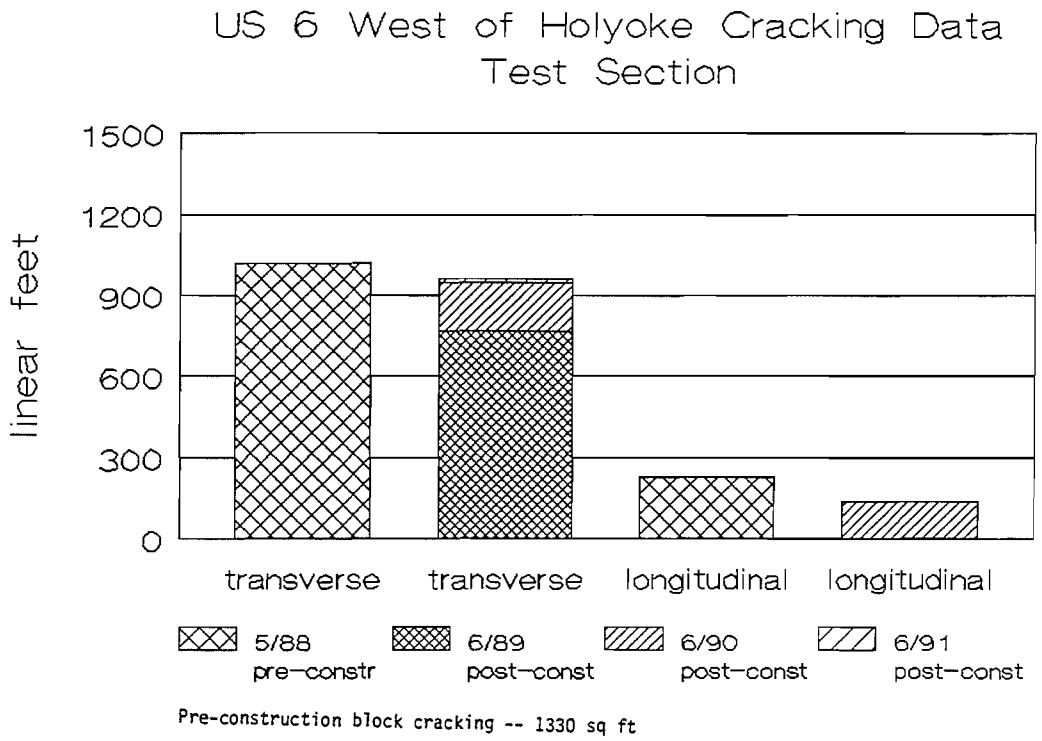
US 6 west of HOLYOKE

RUTTING – CONTROL SECTION

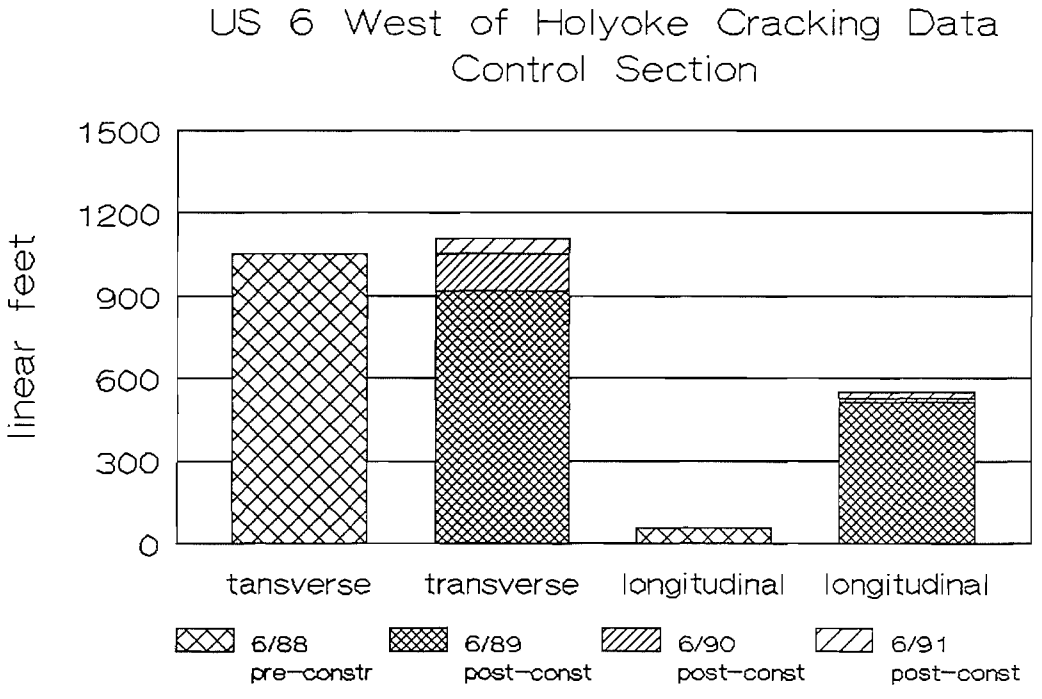


No pre-construction data available for eastbound direction

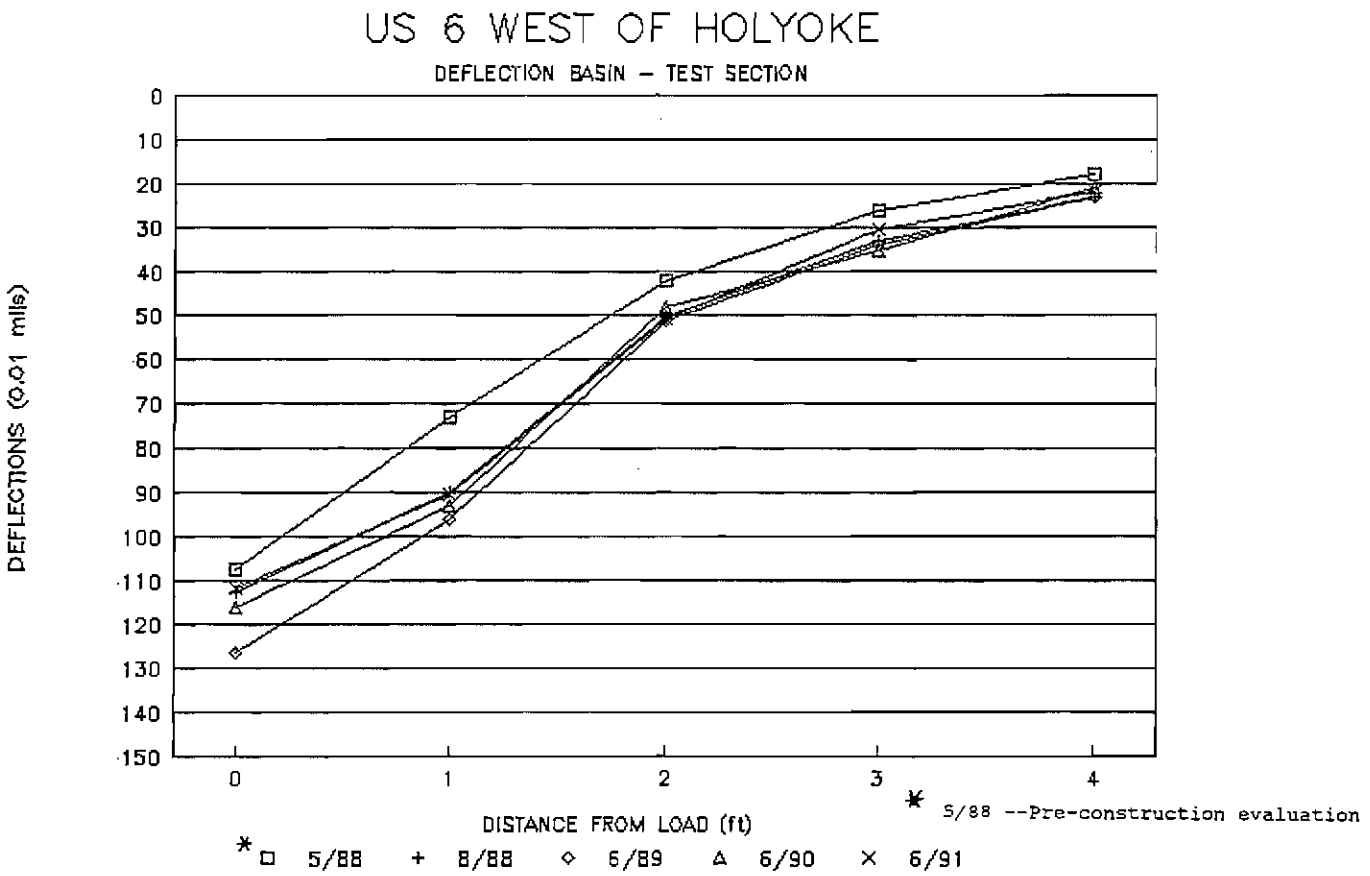
* 5/12/88 -- Pre-construction evaluation

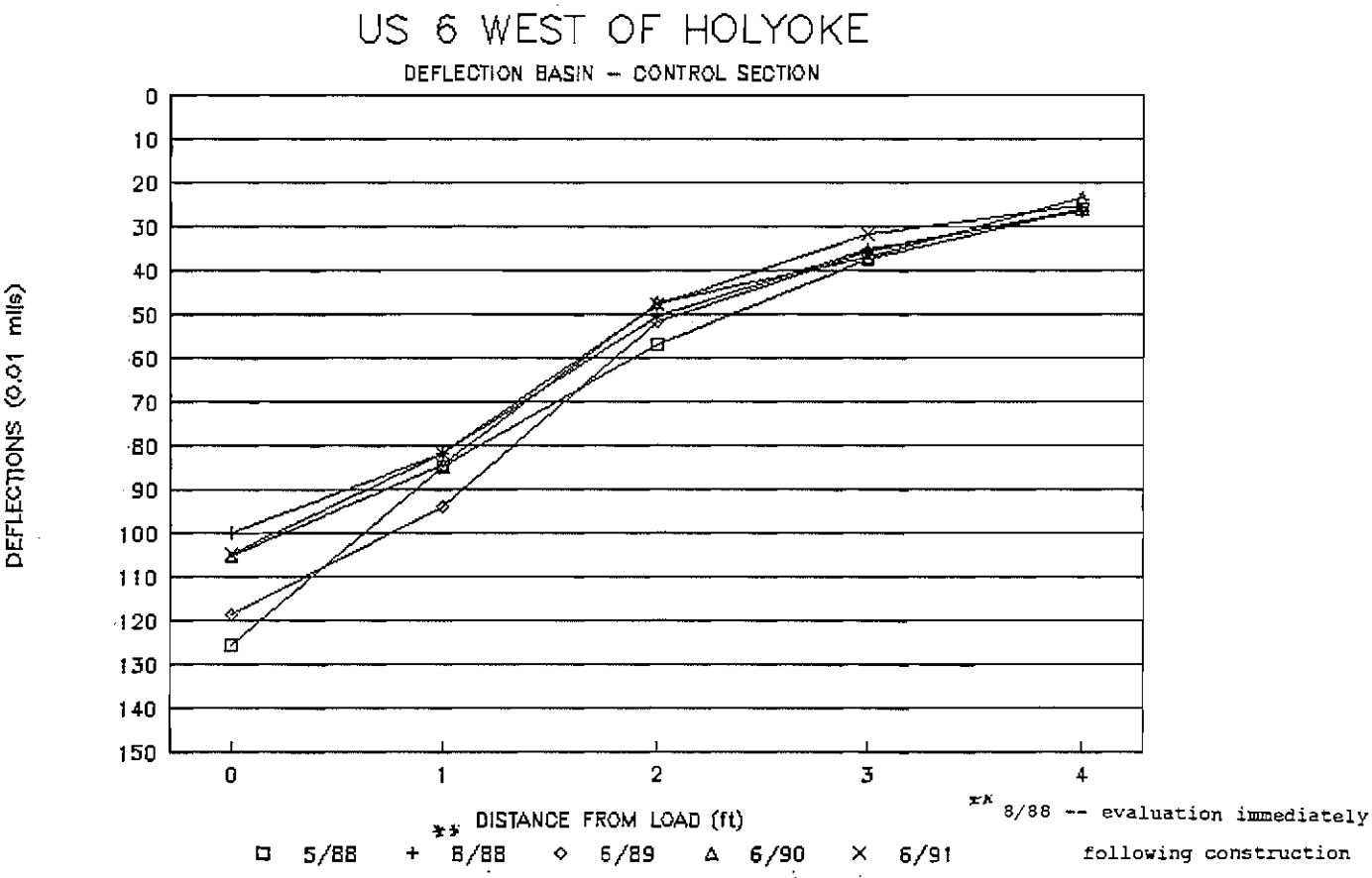


Pre-construction block cracking -- 1330 sq ft



Pre-construction block cracking -- 4677 sq ft


US 6 WEST OF HOLYOKE
DEFLECTION BASIN – TEST SECTION
DEFLECTIONS (0.01 mils)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0
1
2
3
4
DISTANCE FROM LOAD (ft)
* 5/88 --Pre-construction evaluation
* □ 5/88 + 8/88 ◇ 6/89 △ 6/90 × 6/91


US 6 WEST OF HOLYOKE
DEFLECTION BASIN – CONTROL SECTION
DEFLECTIONS (0.01 mils)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0
1
2
3
4
DISTANCE FROM LOAD (ft)
** 8/88 -- evaluation immediately following construction
** □ 5/88 + 8/88 ◇ 6/89 △ 6/90 × 6/91

APPENDIX G
Project Information
SH 125, Near Willow Creek Pass

SH 125, Near Willow Creek Pass

Paving on Project No. CX53-0125-04 began on July 25, 1988. The project originally began at M.P. 0.00 at the junction of US 40 and SH 125 and continued on SH 125 to M.P. 21.5. Before construction began the project was extended to M.P. 33.5.

The control section was located between M.P. 0.00 and M.P. 0.25 in both the northbound and southbound directions. This section consisted of 2-1/4 inches of HBP with no PMSC. The design mix AC content in this section was 6.4±0.3%. The sample that was tested in this section had a 6.21% AC content. During construction a 600 foot section was established on this section in the southbound lane to be used for further evaluations. This section began approximately 300 feet north of M.P. 0.00.

On the remainder of the project 1-3/4 inches of HBP was placed, covered by 3/4 inches of rubberized PMSC Type B. The design AC content for this HBP portion of the project was 5.4±0.3%. The sample taken during construction had a AC content of 5.49%. A 600 foot test section was set up in the southbound lane for evaluation purposes. This section is located approximately 1200 feet south of M.P. 1.00.

The plant was located just south of Rand. It was approximately 32 miles north of M.P. 0.00. The plant produced an average of 2500 tons per day. Sixteen trucks were in operation during the paving of the test sections. The mix left the plant at a temperature of 285°F and was placed on the site at temperature of 260°F.

The rolling process began with one pass by the vibratory roller, followed by three passes with the rubber tire roller and finished with one pass with the steel-wheeled roller.

Except for the weather no delays were encountered.

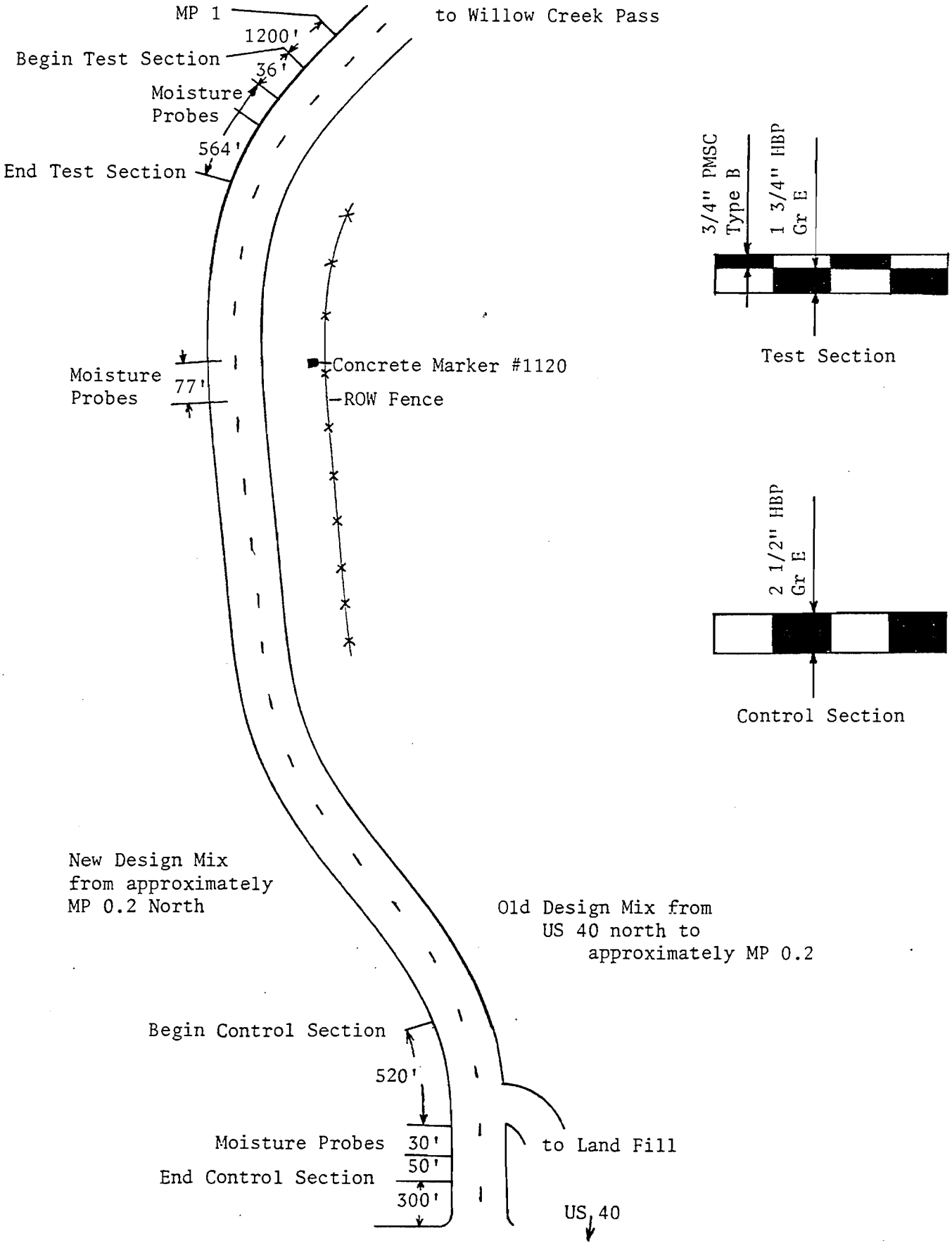
During the post-construction evaluation it was noticed that the texture of the PMSC changed as the distance from the plant increased. The surface texture was not as uniform and the there was more segregation in the PMSC furthest from the plant. The longer haul and because the PMSC was placed late in the season allowing the mix time to cool the paver was unable to mix the PMSC as thoroughly as it should have been.

Typically the difference in the AC content between the control and test sections on each selected project has been only a couple tenths of a percent; however, this project had a difference of 1% between the control and test sections.

Paving on this project was completed on October 22, 1988.

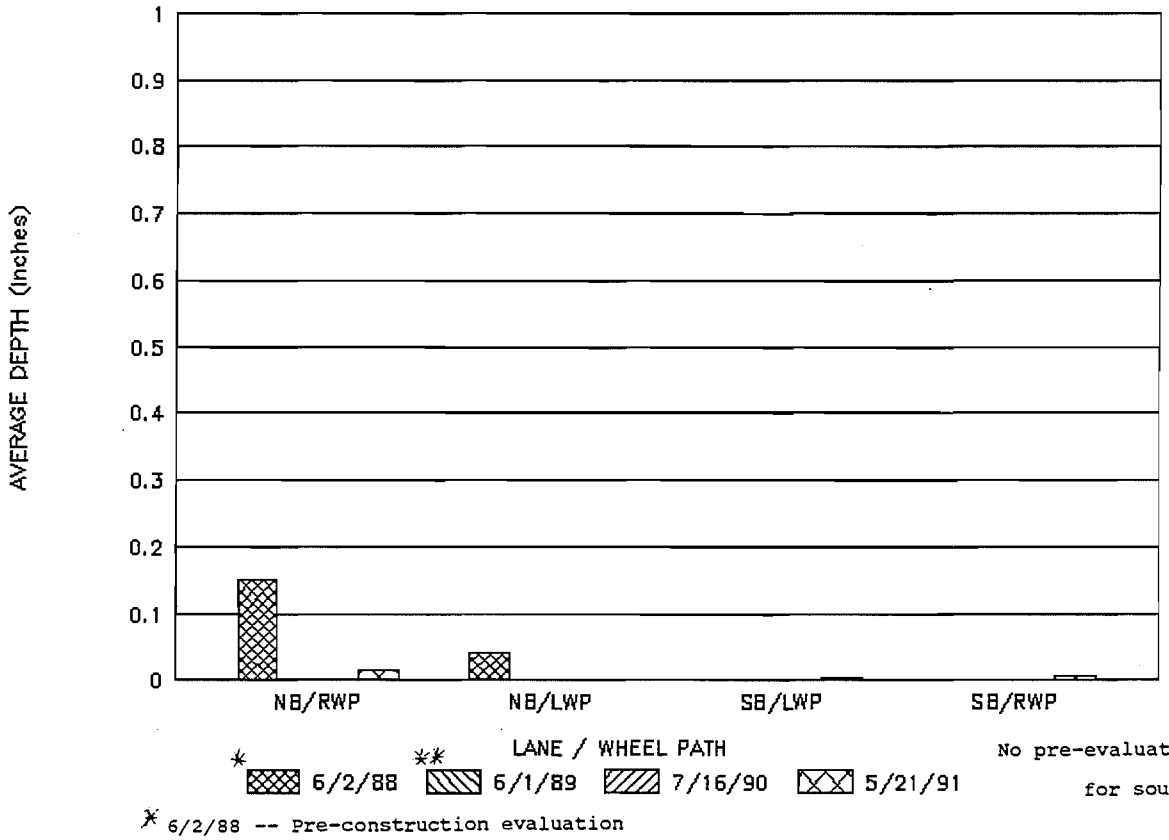
Because of the distinct difference in the AC content between the control and test mix designs this project is considered a good choice for evaluating the two different pavement designs.

Rut Resistant Composite Pavement
SH 125 Willow Creek Pass



SH 125 WILLOW CREEK PASS

RUTTING – TEST SECTION

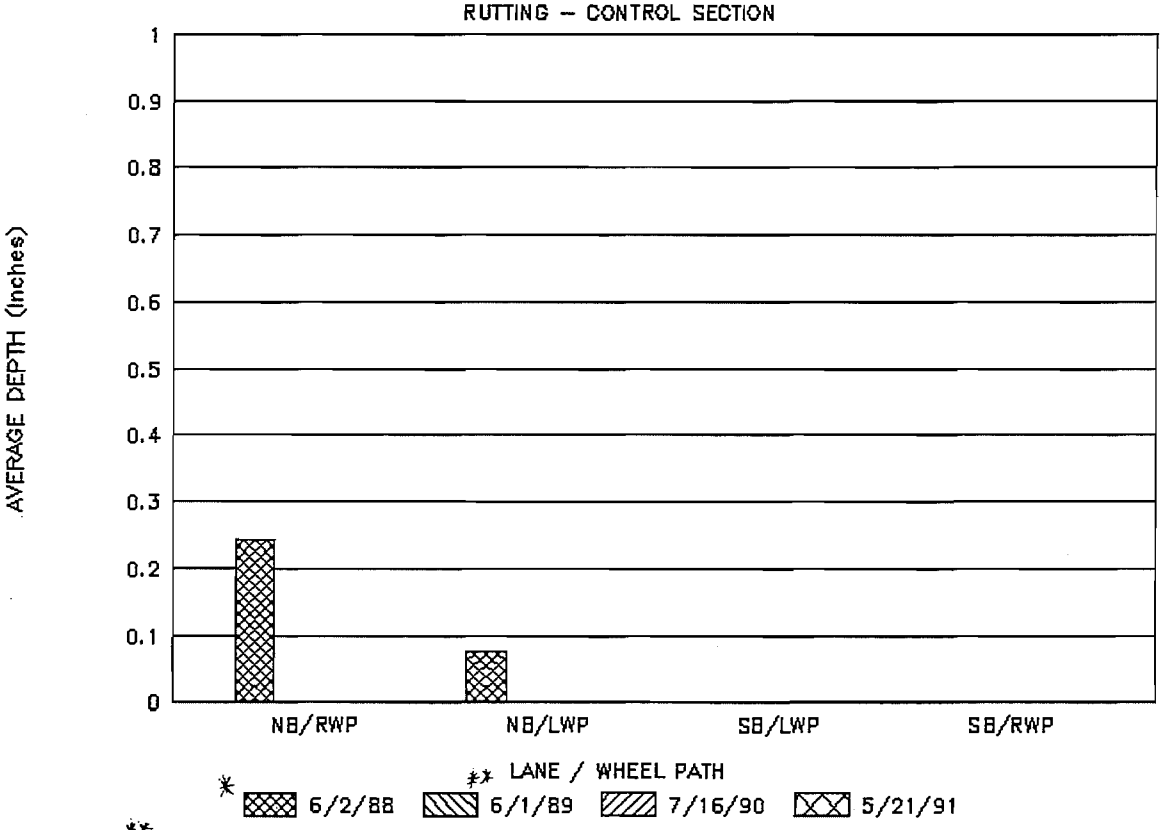


No pre-evaluation data available for southbound direction

* 6/2/88 -- Pre-construction evaluation

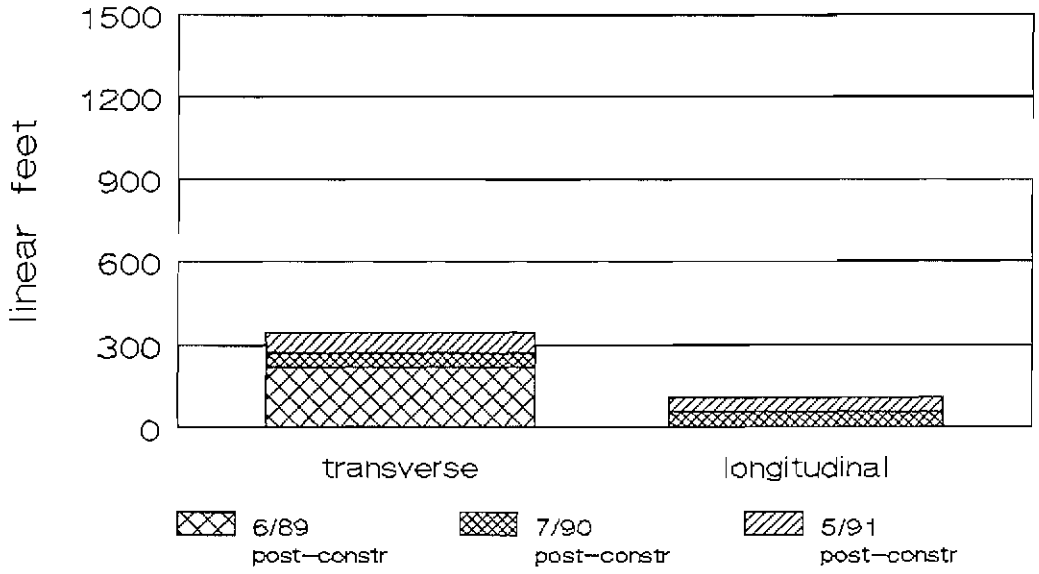
SH 125 WILLOW CREEK PASS

RUTTING – CONTROL SECTION



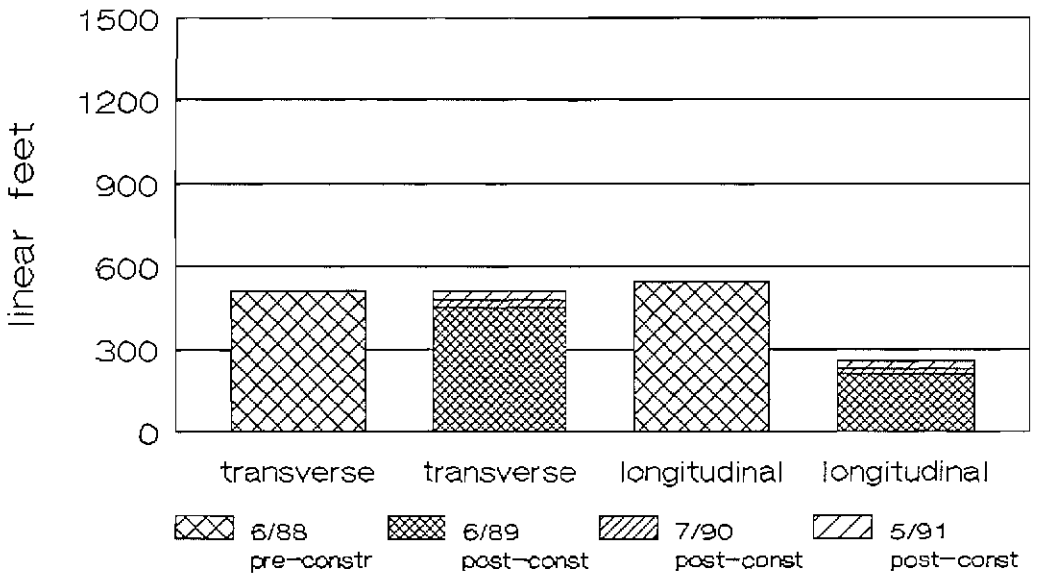
** 6/1/89 -- First evaluation following construction

SH 125 near Willow Creek Pass Crack Data
Test Section



No pre-construction data available for test section

SH 125 near Willow Creek Pass Crack Data
Control Section

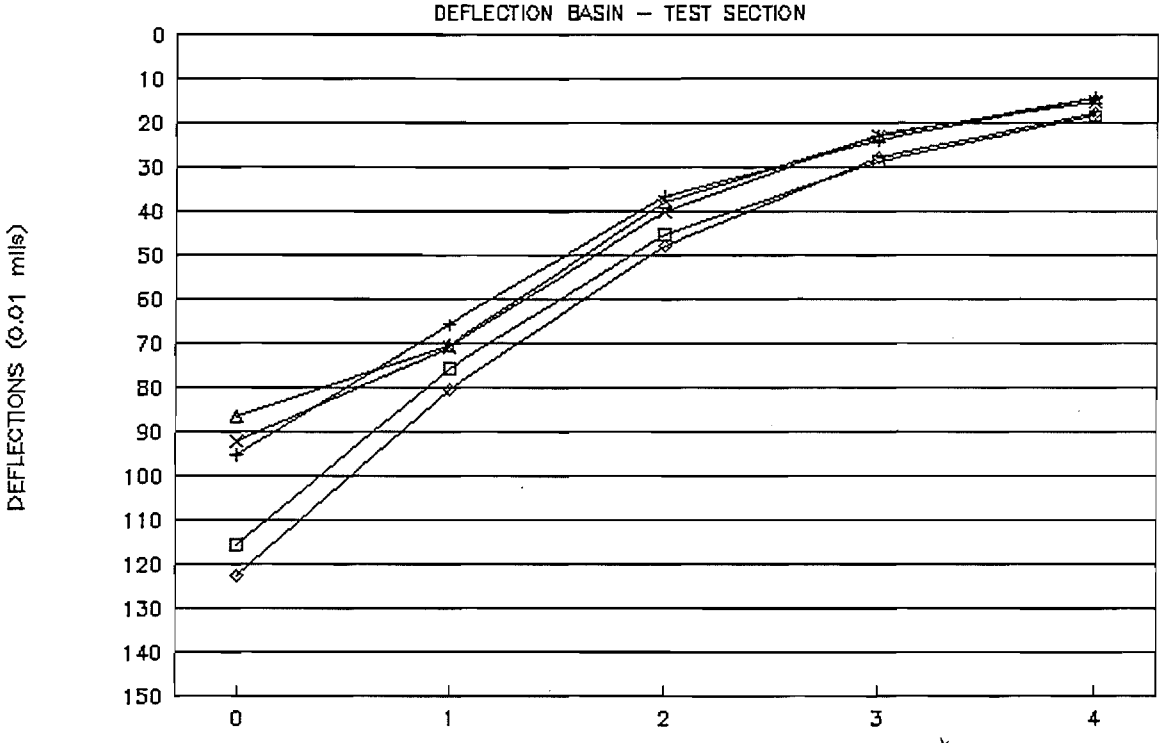


Pre-construction block cracking -- 60 sq ft

Pre-construction patching -- 142 sq ft

SH 125 – WILLOW CREEK PASS

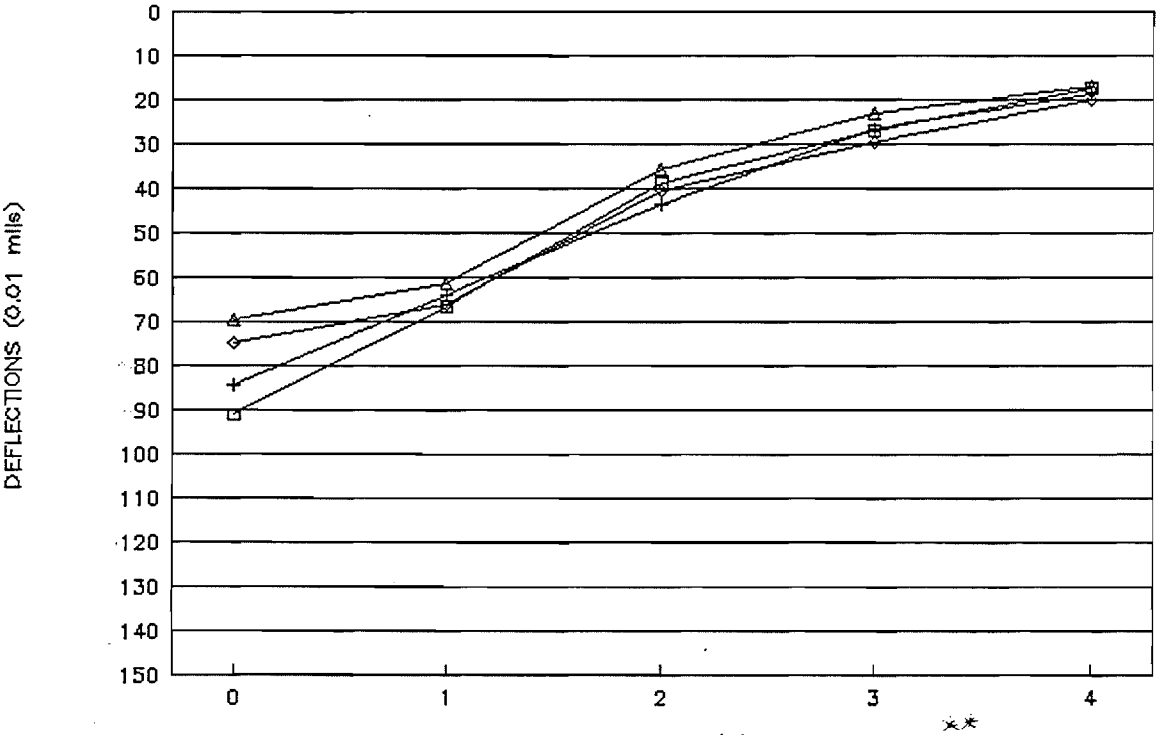
DEFLECTION BASIN – TEST SECTION



* 6/88 -- Pre-construction evaluation

SH 125 – WILLOW CREEK PASS

DEFLECTION BASIN – CONTROL SECTION



** 11/88 -- evaluation immediately following construction

No pre-evaluation dynaflect data available for the control section

APPENDIX H
Project Information
I-70, East of Agate

I-70, East of Agate

A site on I-70 between Agate and Cedar Point was added to the rut-resistant composite pavement study in August 1989. This site is located in the eastbound driving lanes and extends for 5.38 miles, between M.P. 343.26 to M.P. 348.64.

This site is unique from all the other evaluation sites in that this project (CXIR 34-0070-03) is a rehabilitation of the previously reconstructed rut-resistant composite pavement project (IR 70-4(118)) which was completed in the summer of 1988.

Project No. IR70-4(118) consisted of covering the existing concrete pavement with one to three feet of R 70 material before placing full depth asphalt. The contractor used locally available material (sugar sand) for the borrow source. The full depth paving consisted of four lifts (3/4 inches rubberized PMSC Type B wearing surface, over 1-1/2 inches, 1-1/2 inches, and 2-3/4 inches HBP Grading C.) The design criteria for the AC in the PMSC was 6.0% and for the HBP Grading C it was 5.3±0.3%. The paving was completed on July 7, 1988.

The gradation criteria for a Grading C is as follows:

Sieve Designation	Percent by Weight Passing Square Mesh Sieves
3/4"	100
1/2"	70-95
3/8"	60-88
#4	44-72
#8	30-58
#50	7-27
#200	3-12

Within eight months of the completion date the pavement began showing signs of failure. The driving lane began to rut and shove severely requiring emergency action.

From the evaluations performed on the distressed pavement it was determined moisture was getting into the HBP layer directly below the PMSC and caused stripping. Once the AC was stripped from the aggregate the pavement began to rut. The PMSC appeared to be sealing the moisture in and the action of traffic worked the water into the lower lifts.

Due to the short notice for including this project in the RRCP study a pre-evaluation was not performed in the two sections in the eastbound direction.

The evaluation section in the westbound direction had already been established under a large aggregate study. The pre-evaluation was performed on this section on May 19, 1989. This pre-evaluation included crack mapping, rut depth measurements, deflection measurements and visual observations. Cracking was minimal. There was 308 linear feet of transverse cracking and only 38 linear feet of longitudinal cracking in the 600 foot evaluation section. Rutting in this section averaged 0.3 inches in the right wheel path and 0.2 inches in the left wheel path of the driving lane. The highest measurement being 7.5 tenths of an inch and located 400 feet into the evaluation section in the right wheel path of the driving lane.

The test section (with PMSC) in the eastbound direction is located between M.P. 347.30 and M.P. 347.41 (600 feet). The control section (without PMSC) in the

eastbound direction is located between M.P. 347.50 and M.P. 347.61 (600 feet). The test section in the westbound direction is located between M.P. 347.75 and M.P. 347.64 (600 feet).

Construction Eastbound Lanes

To repair the damaged roadway the pavement was milled 26 feet wide to an average depth between 2-1/2 inches and 2-3/4 inches the entire length of the project. The 26 foot width of milling consisted of the two 12 foot driving lanes and two feet into the outside shoulder.

The milled section was inlaid with Grading C rubberized. A 1-1/2 inch Grading C rubberized lift was placed on the top of the entire roadway. The design AC content for the Grading C was established at 5.5%±0.3%.

During construction two 600 foot sections were established for evaluation. One section was set-up with PMSC. The other section was established in the Grading C section just east of the PMSC section. In addition to these sections a third 600 foot section was established in the westbound driving lane. The eastbound driving lanes were rehabilitated under a contract modification order established for the westbound project.

The milling began on Friday, August 4, 1989. On this day 1900 tons of material were removed. On Monday, August 7, 1989, the contractor began using two milling machines in tandem and doubled his production. The milling took approximately three days.

The milled material from the driving lane was placed in a windrow on the outside shoulder. This material was later used to shoulder up. The material from the passing lane was salvaged by state maintenance forces and stockpiled at the east end of the job.

Due to difficulty in visually inspecting the roadway during the milling operation some sections were not milled deep enough to remove all the loose material.

Following the milling operations two brooms (one rotary and one pick-up) were used in conjunction with a small loader to clean the surface.

Each day the milled section was inlaid with Grading C rubberized mix in order to open the roadway to traffic by the end of the day. Once the inlay was completed the entire project was covered with 1-1/2 inches of rubberized Grading C. A 1000 foot section on the east end of the job was covered with a 3/4 inch rubberized PMSC Type B in addition to the milling and the 1-1/2 inch lift. The design AC criteria for the rubberized PMSC Type B was established at 6.2%.

The top mat was paved in three passes beginning with the inside shoulder and passing lane (16 foot), driving lane (12 foot), and the outside shoulder (10 foot).

The drum-dryer plant was used and located at Cedar Point which was at the easterly end of the project.

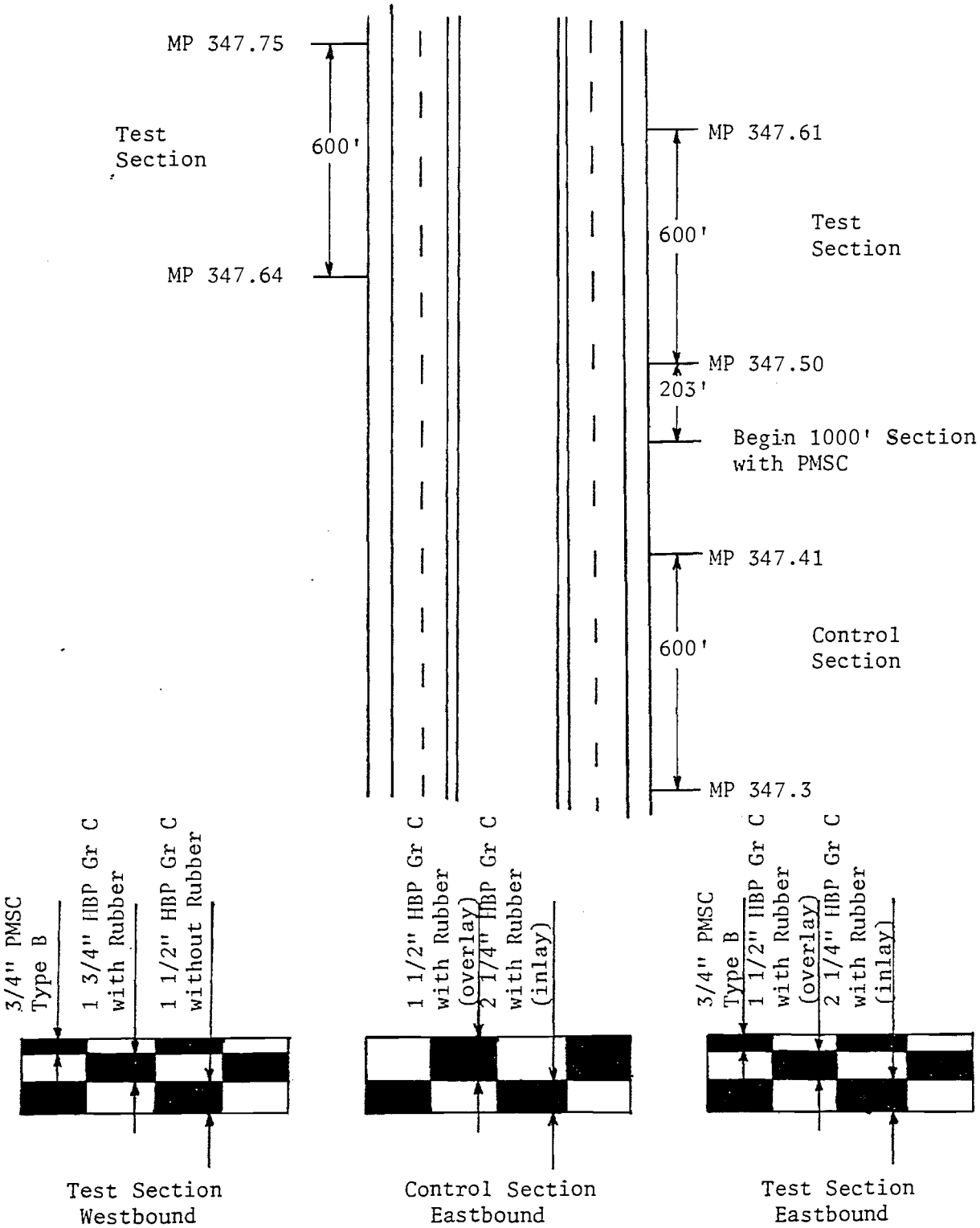
During paving there were no problems obtaining density.

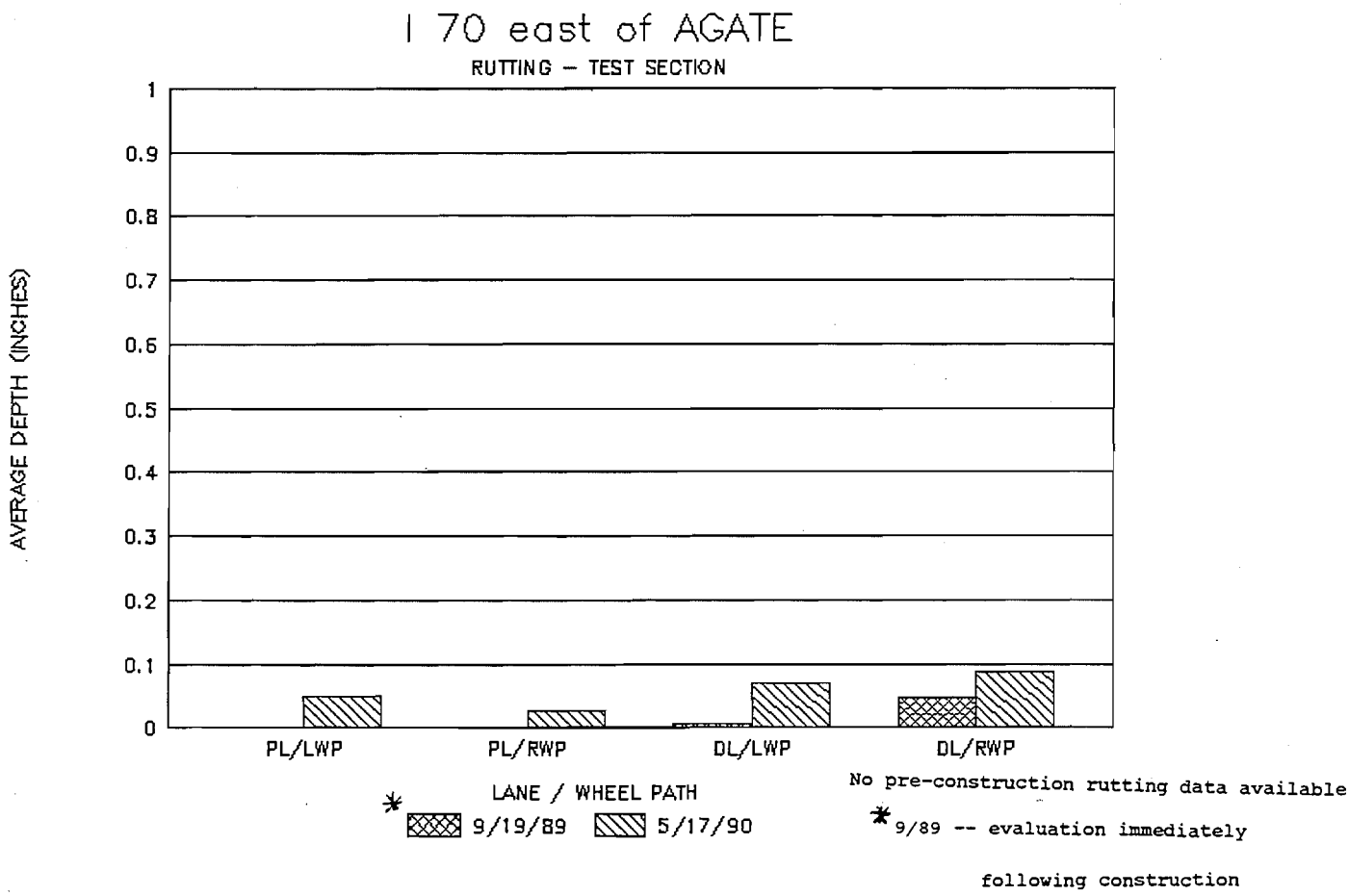
Construction Westbound Lanes

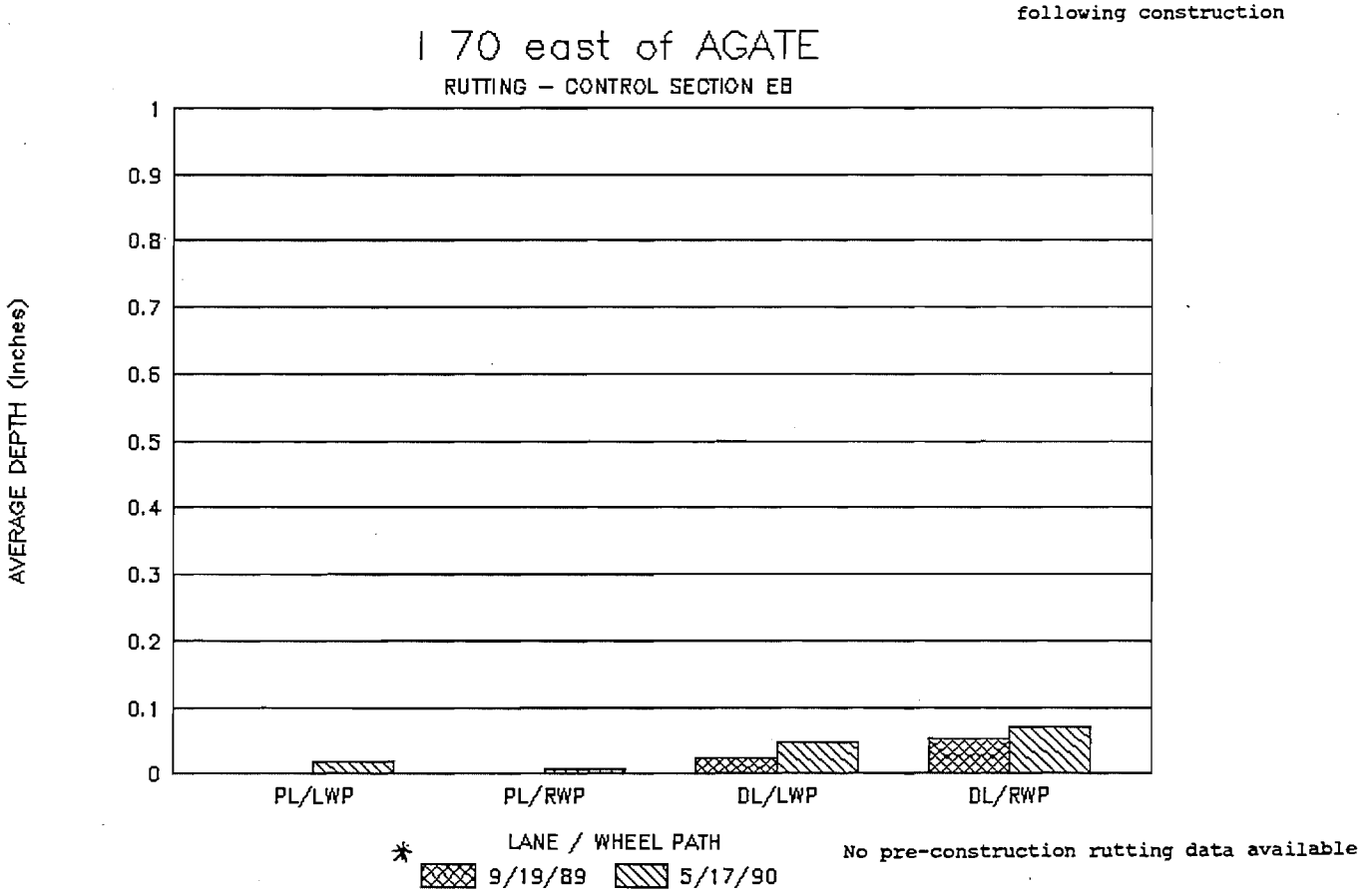
The plan typical section for the westbound lanes consisted of 1-1/2 inches HBP Grading C without rubber in the bottom lift. The middle lift contained 1-3/4 inches HBP Grading C with rubber. The top layer consisted of 3/4 inches rubberized PMSC Type B. The mix design criteria for the westbound lanes was the same as in the eastbound lanes. A evaluation section was established for this study in the driving lane as shown on the site map.

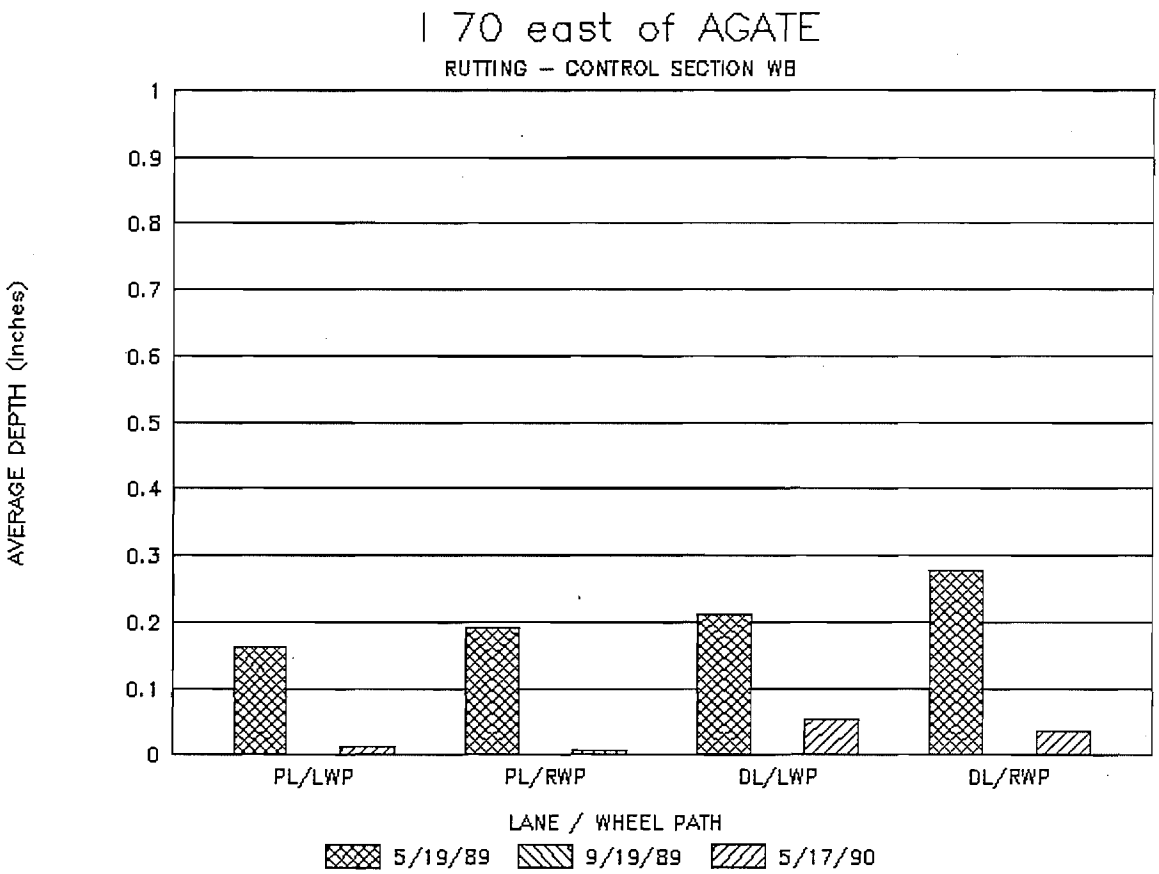
The PMSC sections in both the east and westbound lanes were milled and replaced with Grading C in the fall 1990 because they were beginning to show signs of failure. The evaluation at this location was discontinued.

Rut Resistant Composite Pavement
I-70 east of Agate



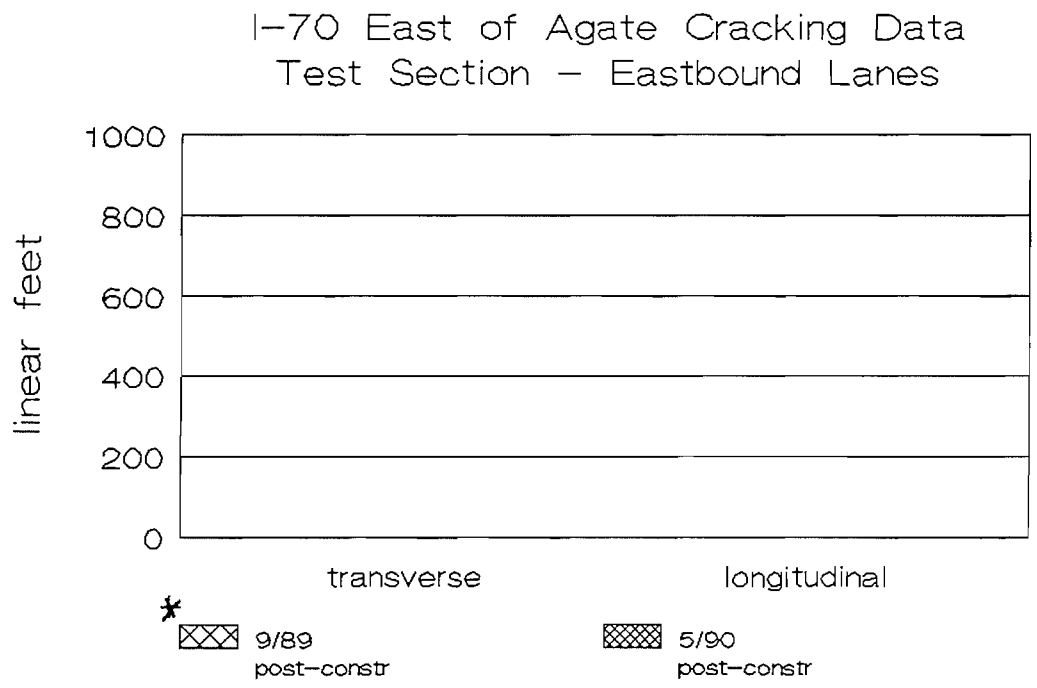

I 70 east of AGATE
RUTTING – TEST SECTION
AVERAGE DEPTH (INCHES)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
PL/LWP
PL/RWP
DL/LWP
DL/RWP
LANE / WHEEL PATH
9/19/89
5/17/90
No pre-construction rutting data available
*9/89 -- evaluation immediately following construction


I 70 east of AGATE
RUTTING – CONTROL SECTION EB
AVERAGE DEPTH (Inches)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
PL/LWP
PL/RWP
DL/LWP
DL/RWP
LANE / WHEEL PATH
9/19/89
5/17/90
No pre-construction rutting data available



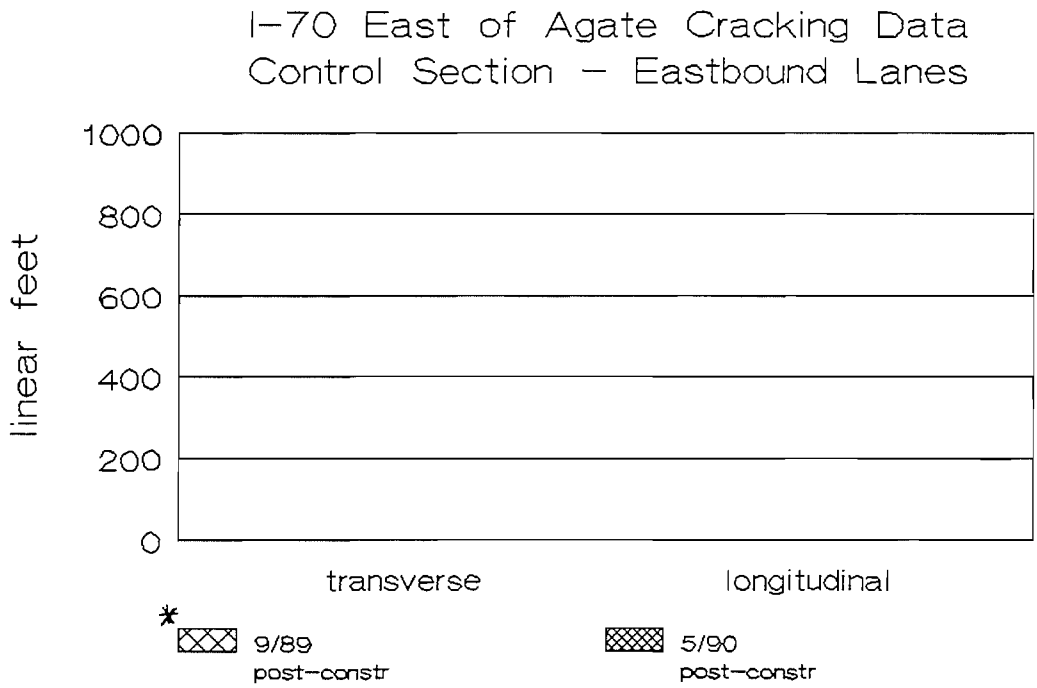
5/19/89 -- Pre-construction evaluation

9/19/89 -- first evaluation following construction

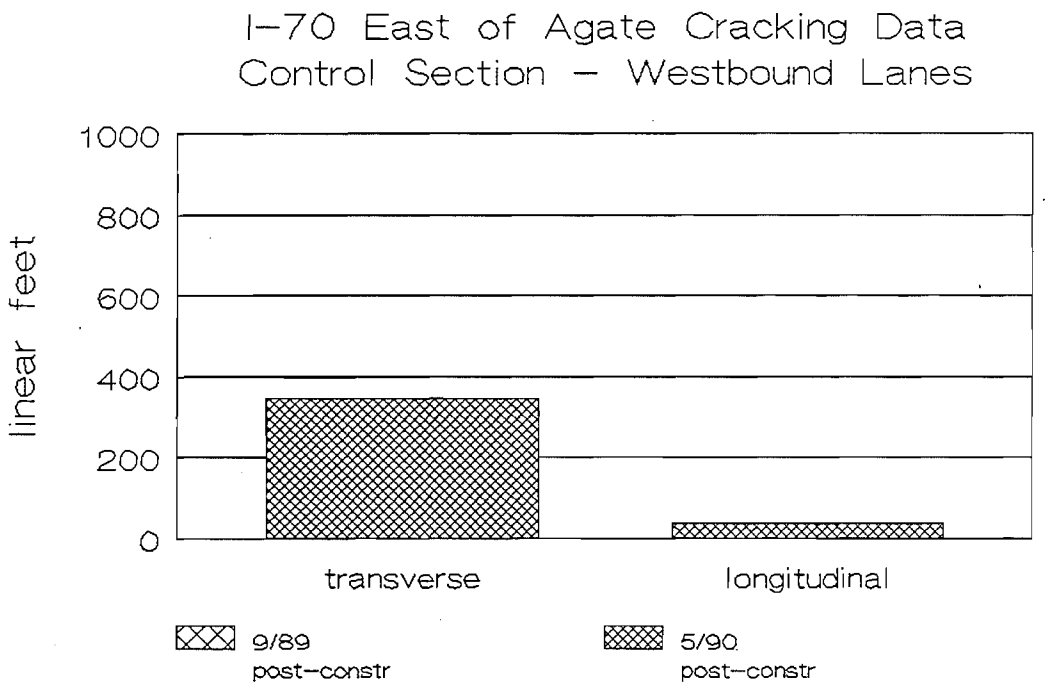


* 9/89 -- evaluation immediately following construction

No pre-construction cracking data available

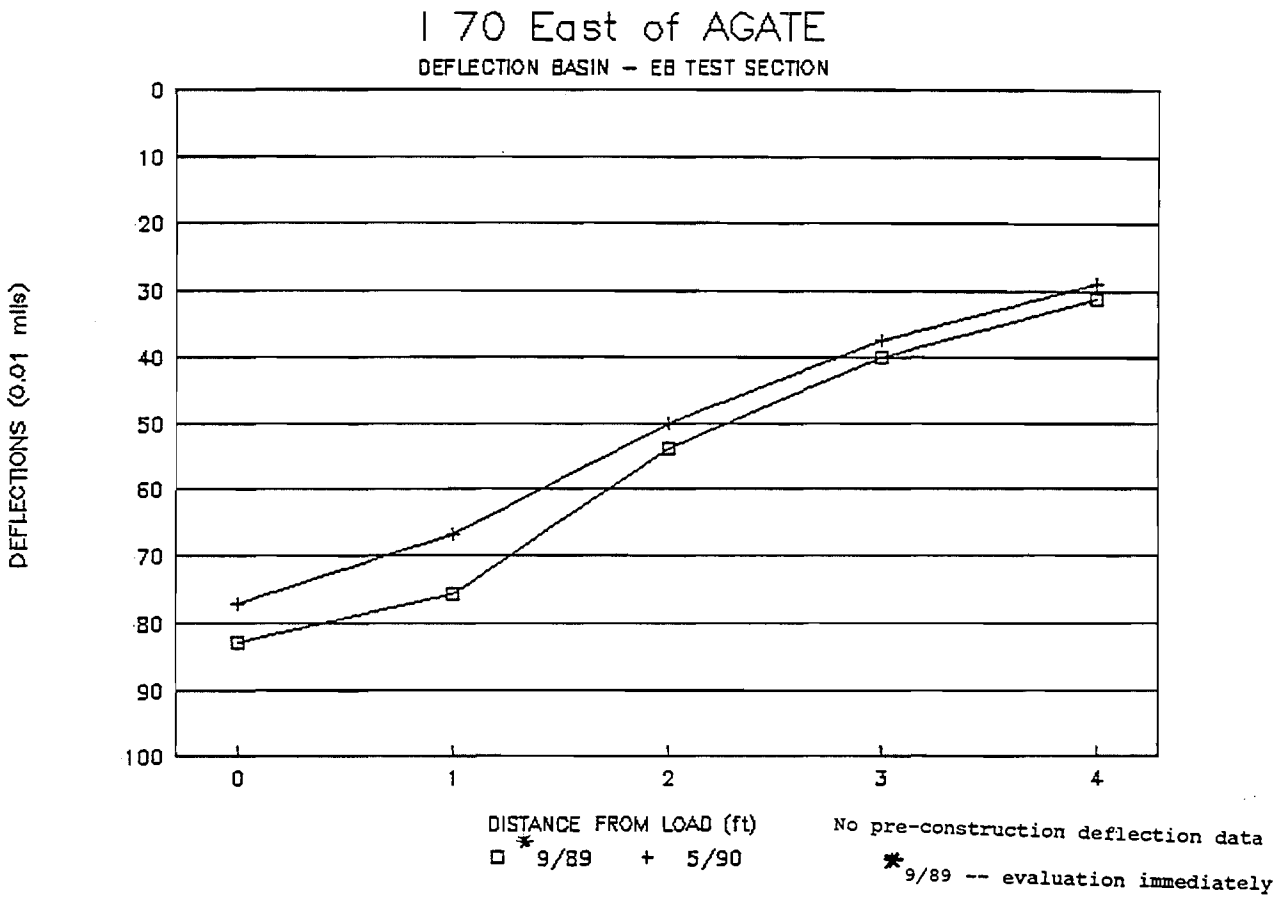


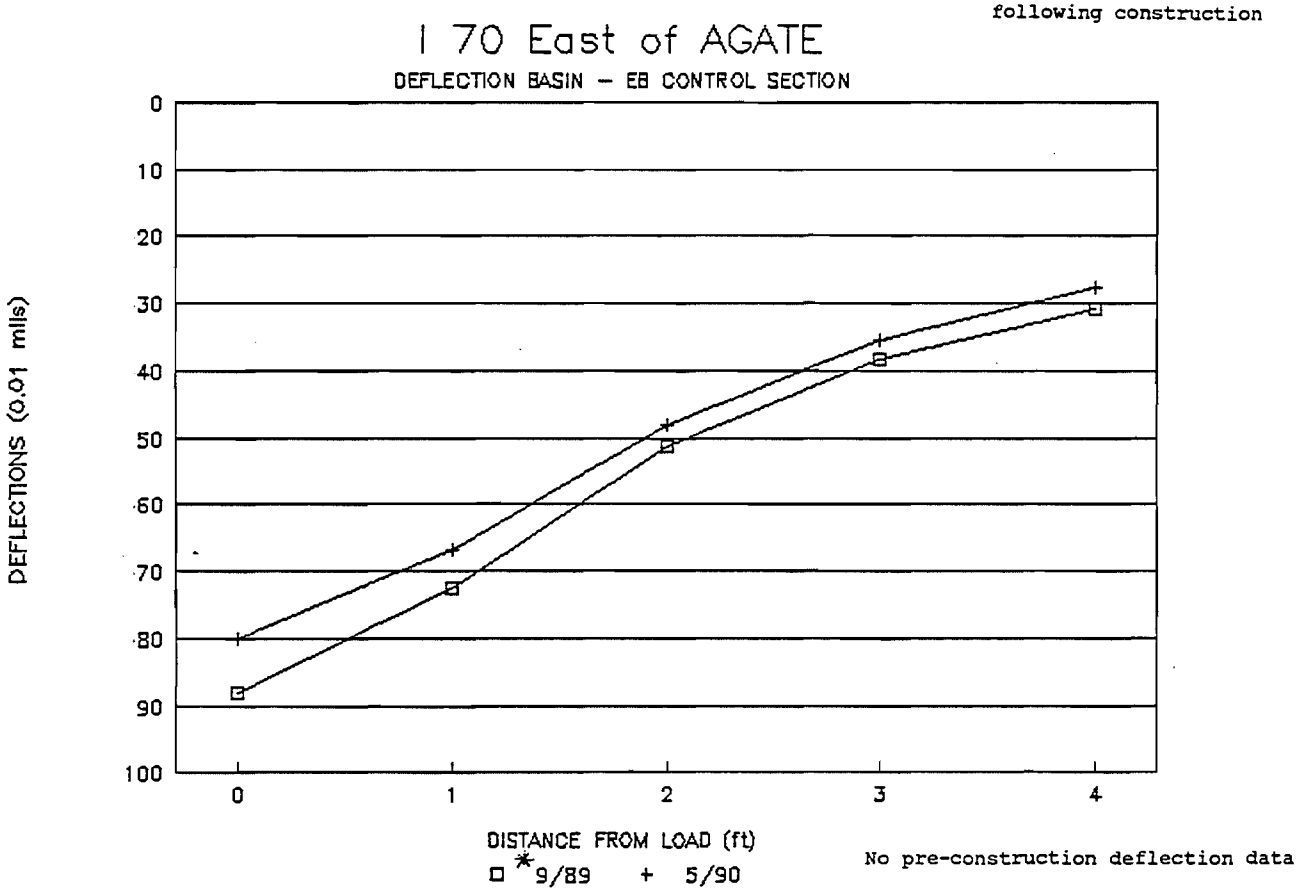
No pre-construction cracking data available

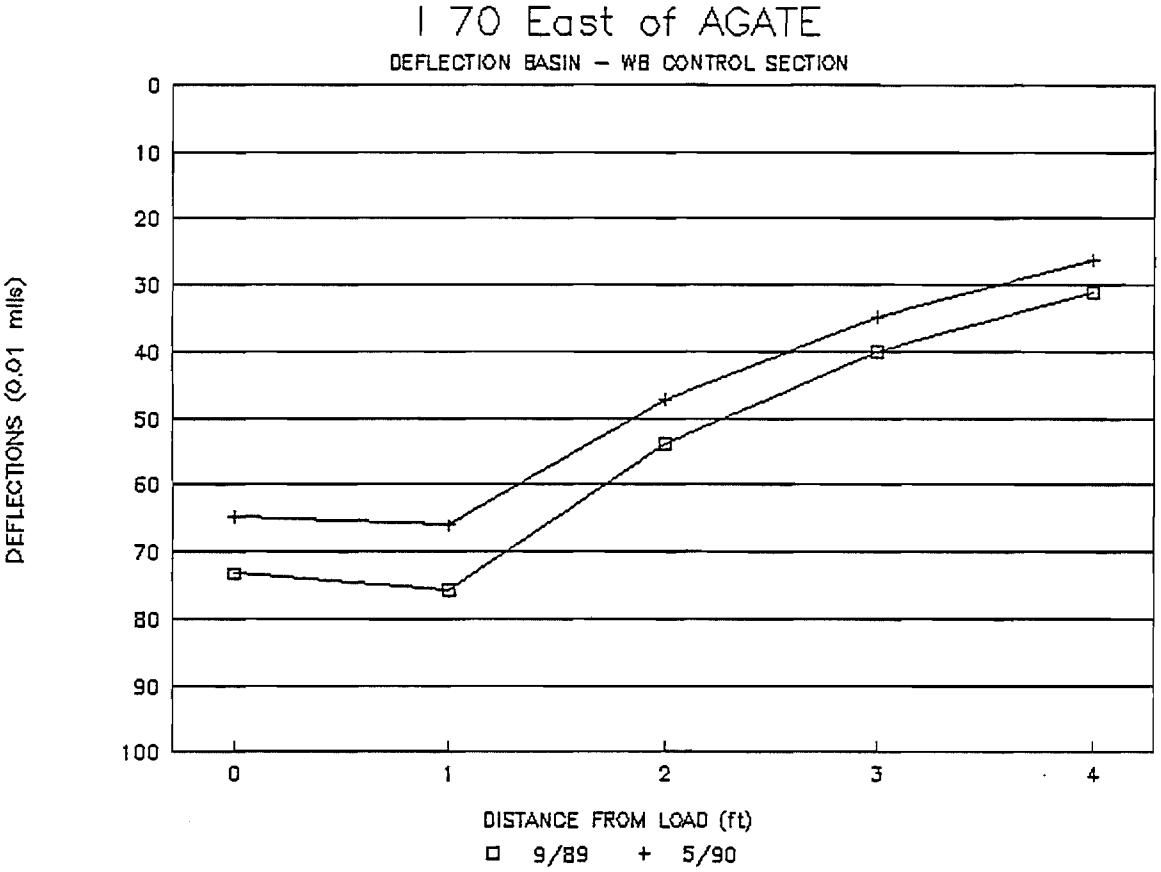


No pre-construction cracking data available for the Agate location.

9/89 -- evaluation immediately following construction


I 70 East of AGATE
DEFLECTION BASIN – EB TEST SECTION
DEFLECTIONS (0.01 mils)
0
10
20
30
40
50
60
70
80
90
100
0
1
2
3
4
DISTANCE FROM LOAD (ft)
□ *9/89 + 5/90
No pre-construction deflection data
*9/89 -- evaluation immediately following construction


I 70 East of AGATE
DEFLECTION BASIN – EB CONTROL SECTION
DEFLECTIONS (0.01 mils)
0
10
20
30
40
50
60
70
80
90
100
0
1
2
3
4
DISTANCE FROM LOAD (ft)
□ *9/89 + 5/90
No pre-construction deflection data



No pre-construction dynaflect data available

9/89 -- evaluation immediately following construction

APPENDIX I
Project Information
US 50, East of Rocky Ford

US 50, East of Rocky Ford

Construction on US 50 Project No. CX(5) 09-0050-12 just east of Rocky Ford began on August 15, 1988. This project began by heater-scarifying the top 3/4" to 1" of the existing pavement on the driving and passing lanes in both directions throughout the entire project.

The plans called for an application of 0.10 gallon per square yard of an asphalt rejuvenator to be applied to the heater scarified material. This amount was varied throughout the job after the pavement showed signs of flushing under traffic.

Following the heater scarifying process the pavement was rolled with both the rubber tire and steel-wheeled roller. Within a couple of hours after rolling traffic was permitted on the pavement.

Paving began in the eastbound lanes on August 25, 1988. It was done in three passes, a 16 foot, a 12 foot and 10 foot pass, respectively, beginning with the inside shoulder and passing lane.

The heater scarifying process continued in the westbound lane when the paving began in the eastbound lane.

The batch plant which was located at the Valco Pit approximately five miles from the west end of the project produced 2000 tons a day and approximately 200 tons were placed per hour. On the first day of paving six trucks were in operation and little time was spent waiting on mix. Paving began at 7:30 AM on the first day and at noon the air temperature was in the low 90's.

The mix left the plant at 300°F and was placed at an average temperature of 270°F.

This project was extended 0.6 of a mile on the west end and 0.7 of a mile on the east end. The 0.7 of a mile on the east end was heater scarified and a 3/4" rubberized PMSC Type B was placed to complete this section.

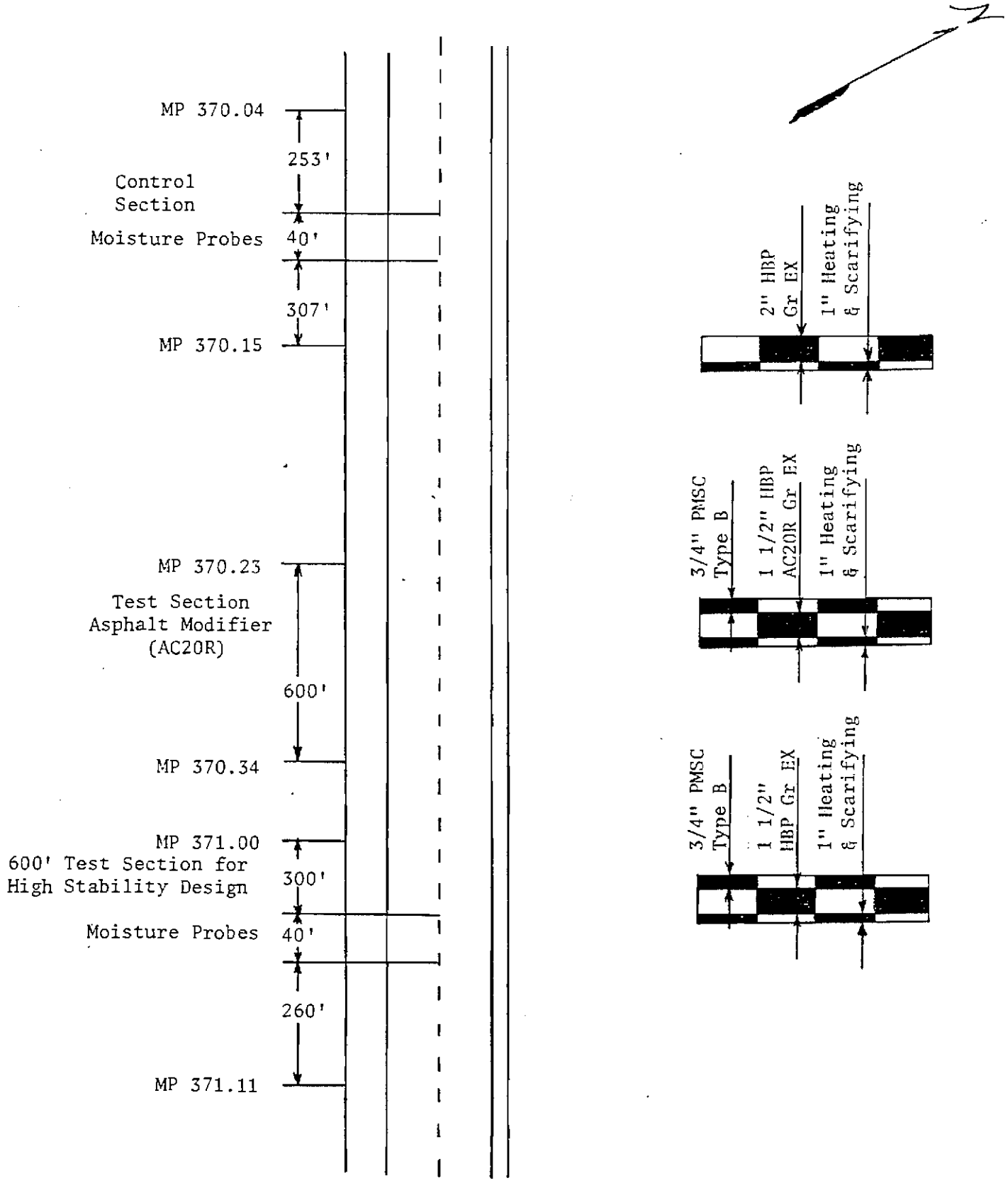
The depth of the lifts varied in different sections of the project. The HBP (Gr EX) extension at the west end was placed at a depth of 1.5" with a 3/4" rubberized PMSC Type B. Beginning at M.P. 370.00 to M.P. 370.19 approximately 1000 feet was designated as the control section for this project. During the post-evaluation a 600 foot section was established in this section to be used for the remainder of the evaluations. This section was overlaid with 2.0 inches of HBP and was not covered with a PMSC. The oil content in this section was to be 6.1±0.3%. Samples were taken and were sent to the lab to determine the exact AC content. The test section used for comparison on this project was located between M.P. 371.00 and M.P. 371.19 in the eastbound lanes. This section was covered with a 1.5 inch HBP (Gr EX) and a 3/4 inch rubberized PMSC Type B. The design oil content in this section was 6.0±0.3%.

The rolling pattern throughout the project was different than the method usually used. A rubber tire roller followed immediately behind the paver. It made six to eight passes on each section of the pavement. The steel-wheeled roller made two passes up and back with the vibratory and one pass with the static roller after the rubber tire completed its passes.

The job was delayed several days during the placement of the PMSC due to the weather. The paving portion of the job was completed on October 15, 1988.

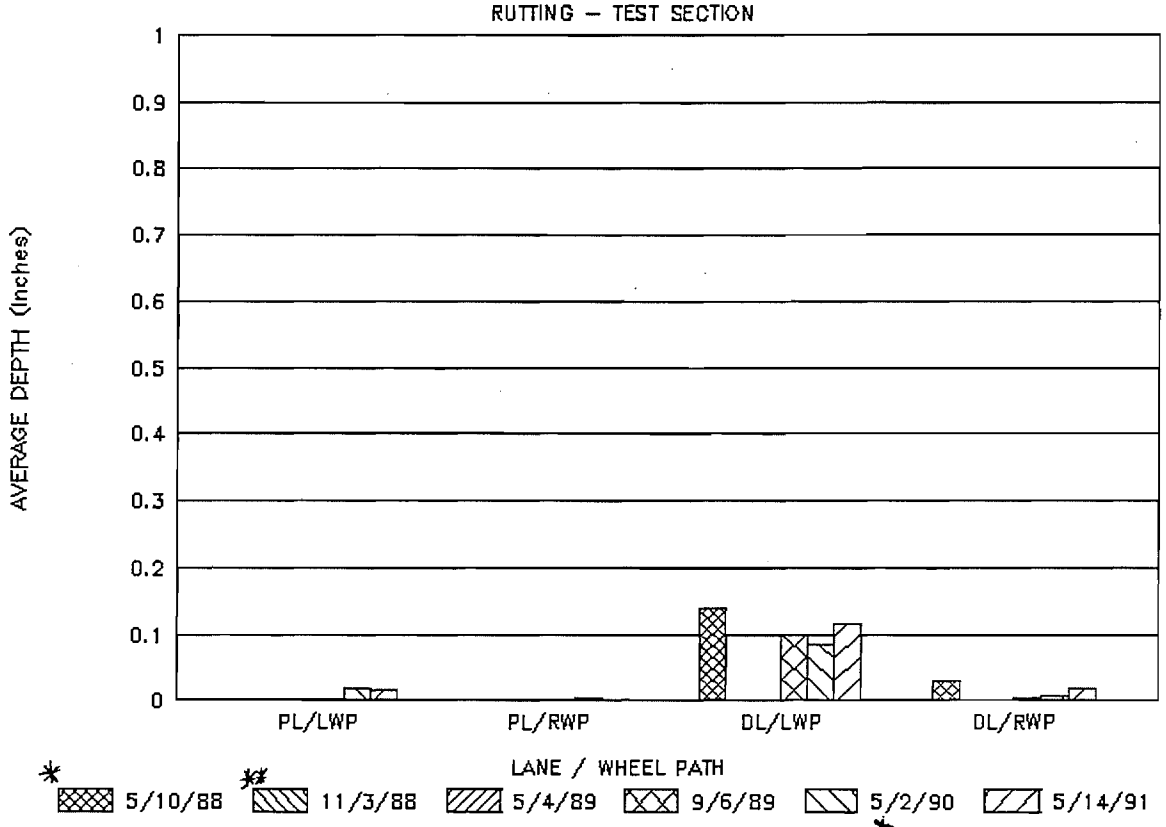
This site is also a site for the polymerized (rubberized) pavement study (file number 13.04). The section used for this study substituted AC-20R for AC-20 in the lower lift. A common section is used both as a control for the polymer study and a test section for the RRCP study.

Rut Resistant Composite Pavement
US 50 east of Rocky Ford



US 50 east of ROCKY FORD

RUTTING – TEST SECTION

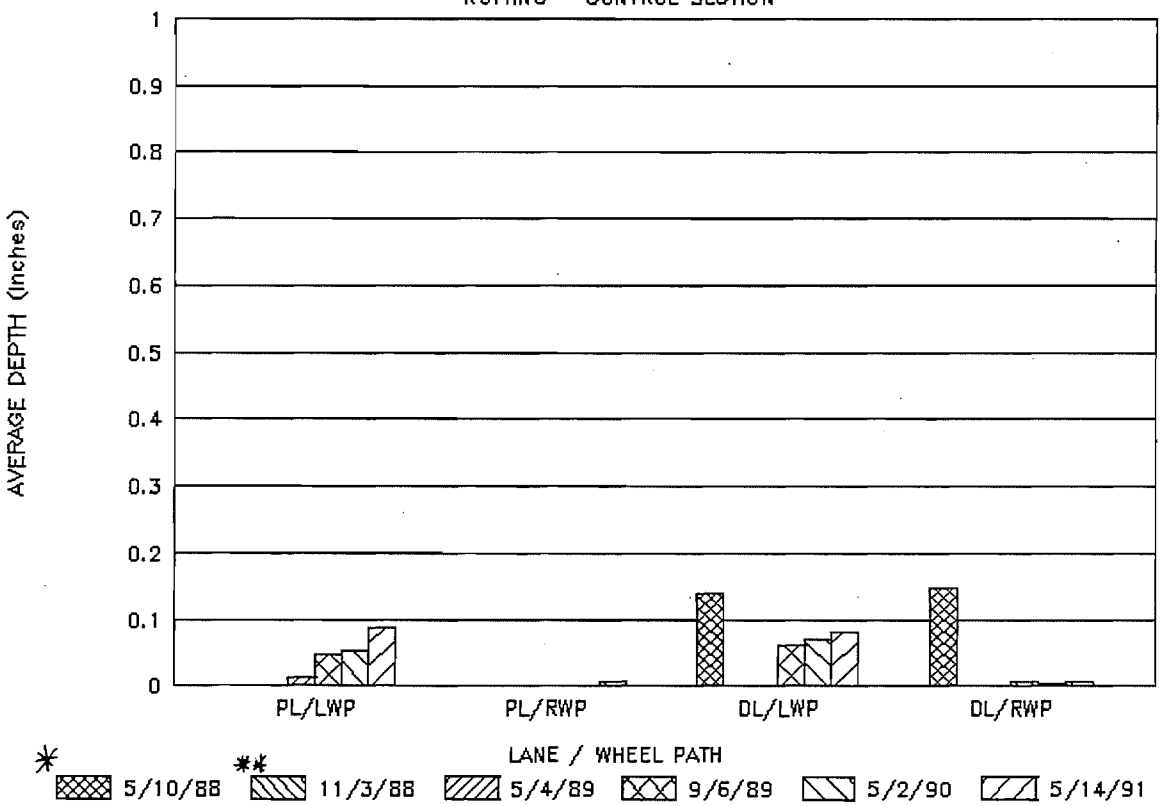


* 5/10/88 -- Pre-construction evaluation

No pre-construction data available for passing lane

US 50 east of ROCKY FORD

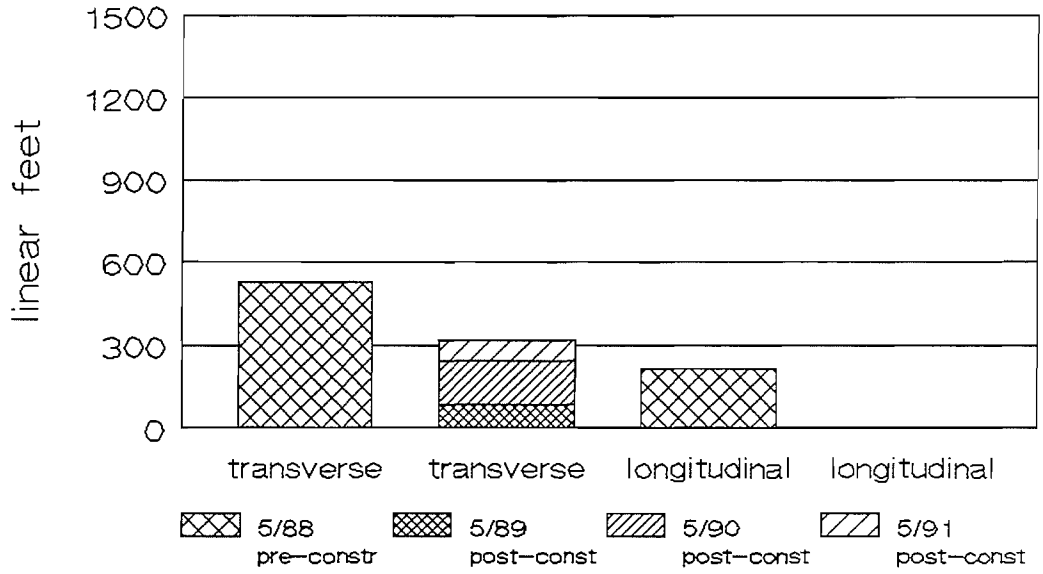
RUTTING – CONTROL SECTION



No pre-construction data available for passing lane

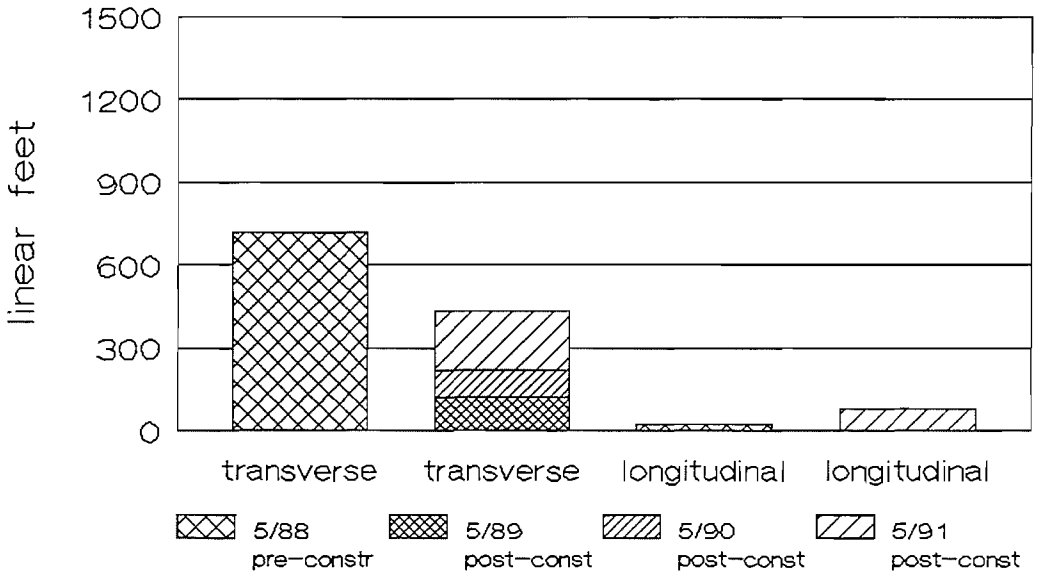
** 11/3/88 -- evaluation immediately following construction

US 50 East of Rocky Ford Cracking Data
Test Section



Pre-construction block cracking -- 67 sq ft

US 50 East of Rocky Ford Cracking Data
Control Section

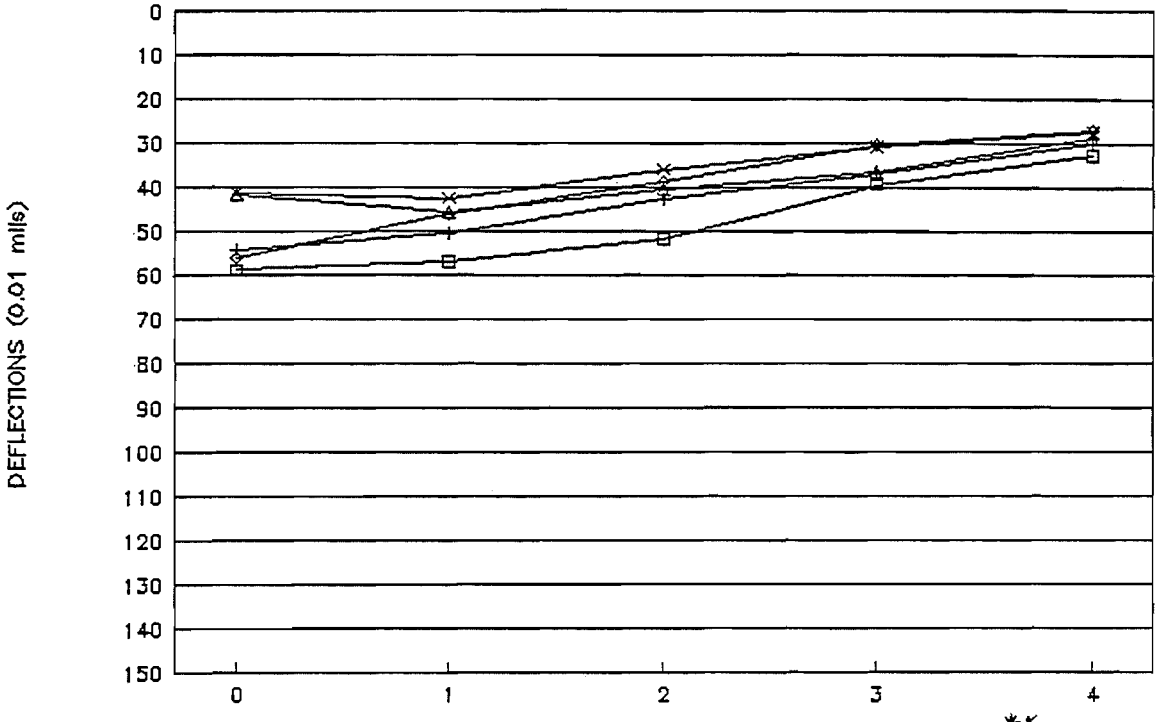


Pre-construction block cracking -- 2400 sq ft

Pre-construction patching -- 3600 sq ft

US 50 EAST OF ROCKY FORD

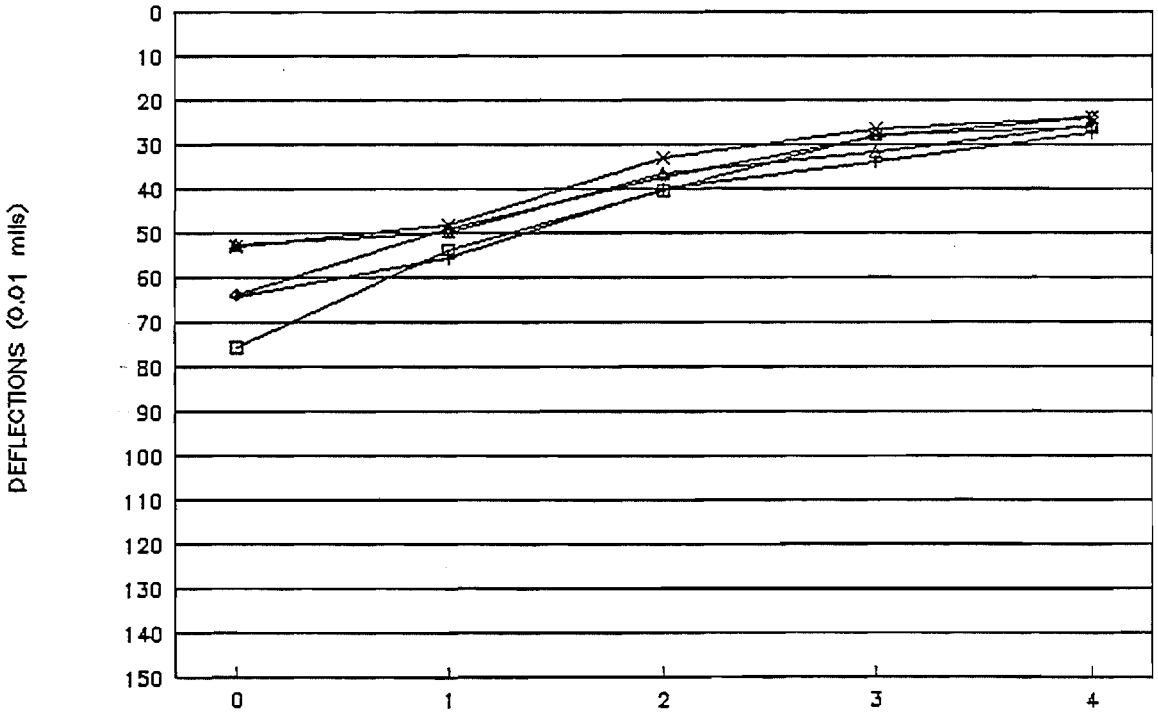
DEFLECTION BASIN – TEST SECTION



* 11/88 -- evaluation immediately following construction

US 50 EAST OF ROCKY FORD

DEFLECTION BASIN – CONTROL SECTION



* 5/88 -- Pre-construction evaluation

APPENDIX J
Project Information
I-70, East of Debeque

I-70, East of Debeque

Paving on Project No. IR 70-1(125) began on April 3, 1989. This project is located on Interstate 70 around the Debeque interchange on the western slope. It begins at M.P. 56.8 and extends for approximately 10.5 miles to M.P. 67.3. Originally paving was scheduled to begin in the summer of 1988, however the paving was postponed until the spring of 1989.

The plans called for 1-3/4 inches HBP Grading E in the eastbound lanes with a 3/4 inch rubberized PMSC Type B place on the top. The control section which was located between Sta 950+00 in the eastbound direction, called for 2-1/2 inches HBP Grading E to be placed in one lift. This control section which was set up by the district is located a couple 100 feet east of where the Research Branch did the pre-construction evaluation of the existing pavement. The values obtained during the pre-construction evaluation are considered to be representative of the existing pavement for the control section set up by the district. The remainder of the evaluation will be on the control section set up by the district.

The minimum AC content for the test section was 5.3%, with 4-6% voids. the minimum AC content for the control was 5.5%, with 3-6% voids.

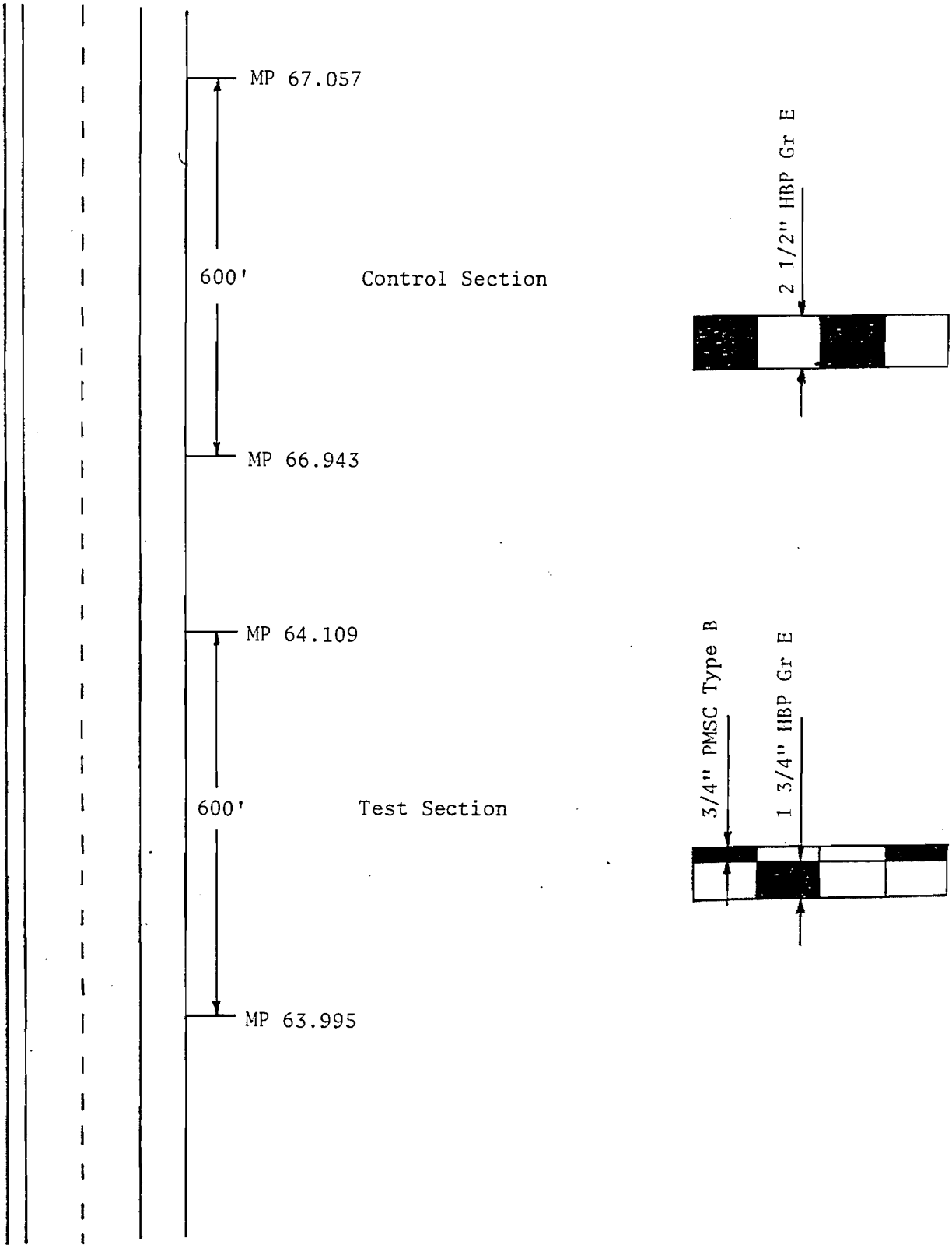
The 38 foot roadway was paved in two passes (outside 21 feet, inside 17 feet). The contractor arranged his daily paving operations so that there was no exposed longitudinal joints between the driving and passing lanes at the end of the day.

The drum dryer plant was located off the frontage road on the project. It operated from 8:00 A.M. to 4:00 P.M. five days a week and it produced between 2000 to 3000 tons a day. The mix was placed at 250°F.

The rolling pattern consisted of a vibratory steel roller which made two passes over each section. The rubber tire roller followed with two to three passes over each section. The finishing roller completed the mat with one vibrating pass and one static pass over each section. There were no problems obtaining densities.

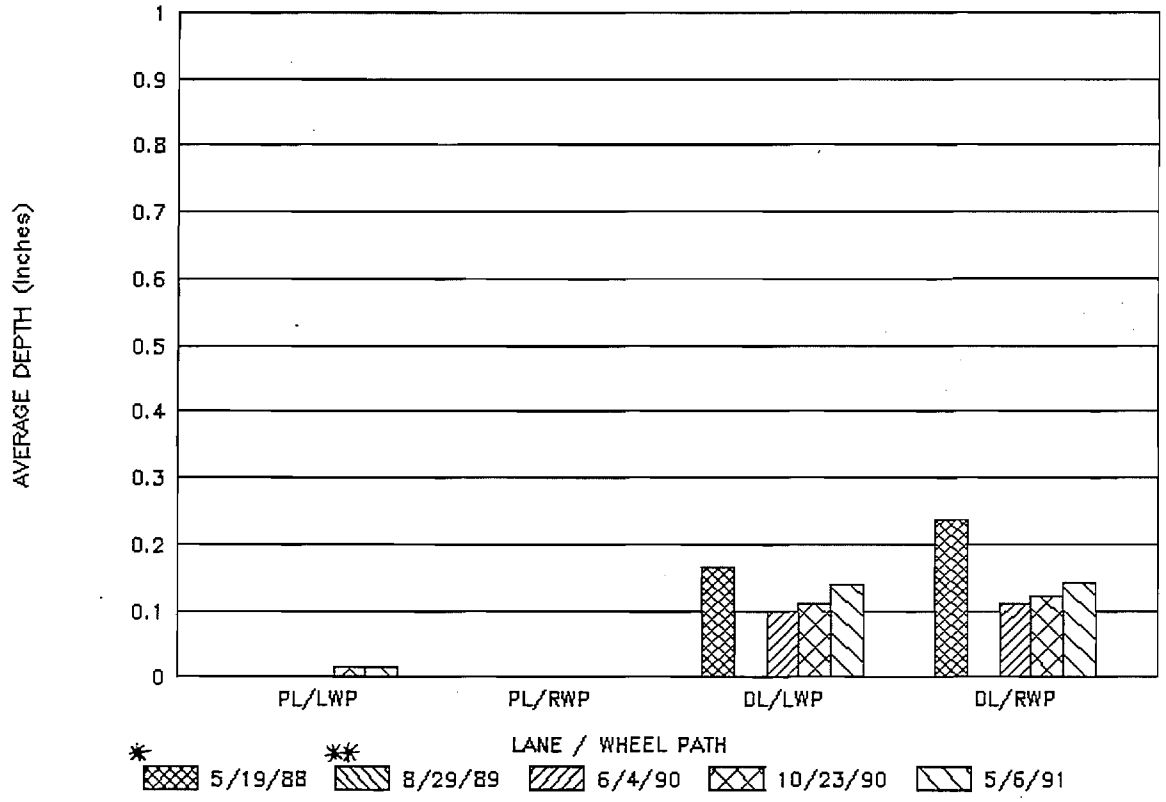
Due to a scheduling change in the paving, permeability equipment was not able to be installed on this project.

Rut Resistant Composite Pavement
I-70 east of DeBeque



I 70 east of DEBEQUE

RUTTING – TEST SECTION

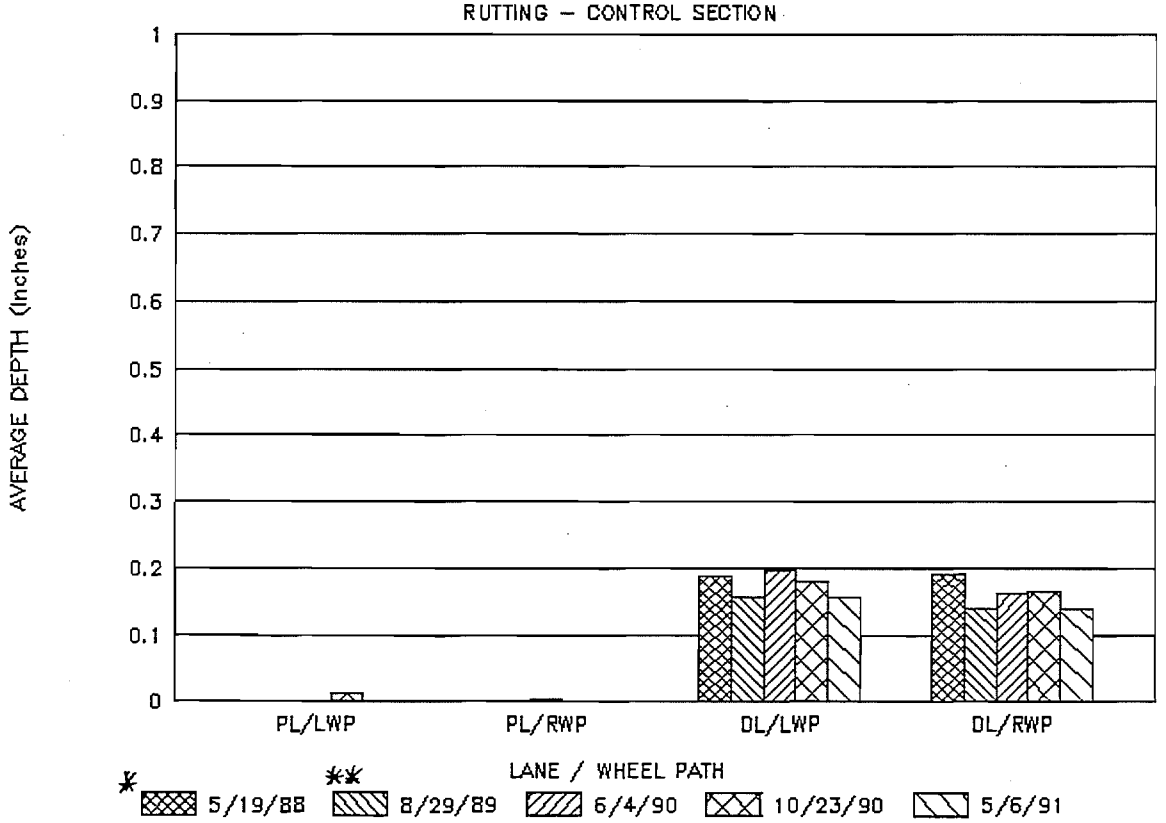


No pre-construction data available for passing lane

* 5/19/88 -- Pre-construction evaluation

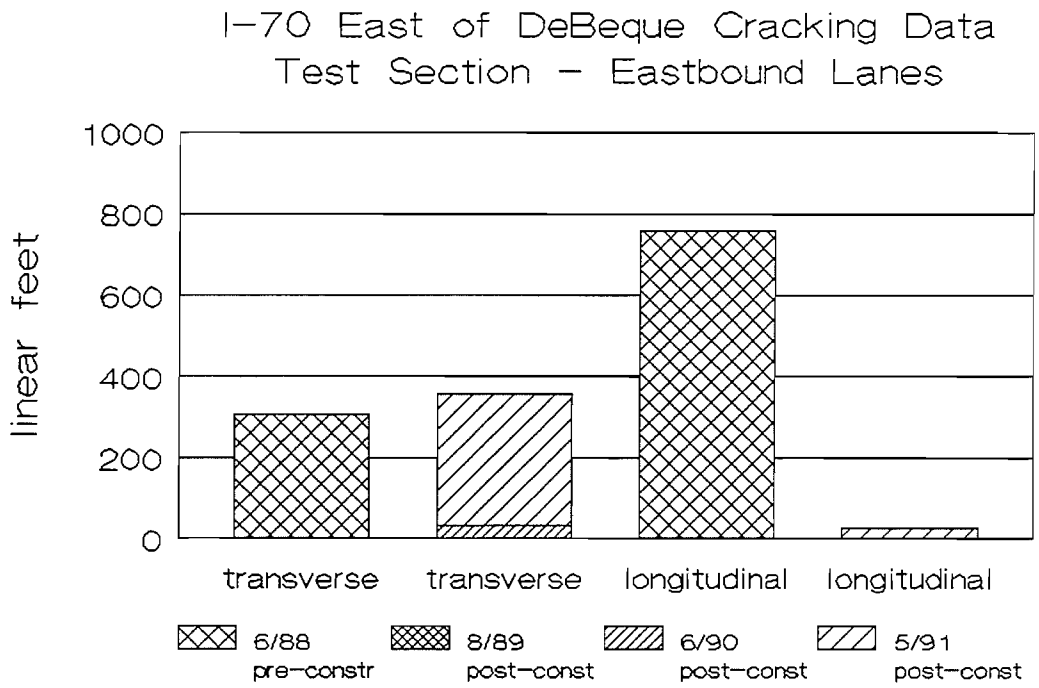
I 70 east of DEBEQUE

RUTTING – CONTROL SECTION

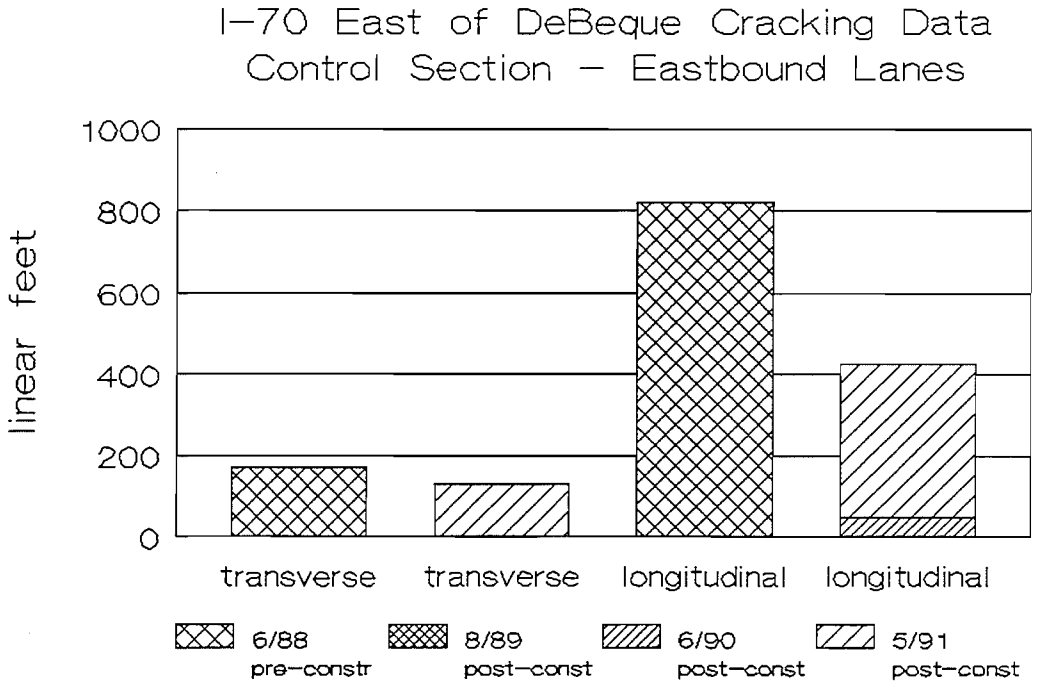


No pre-construction data available for passing lane

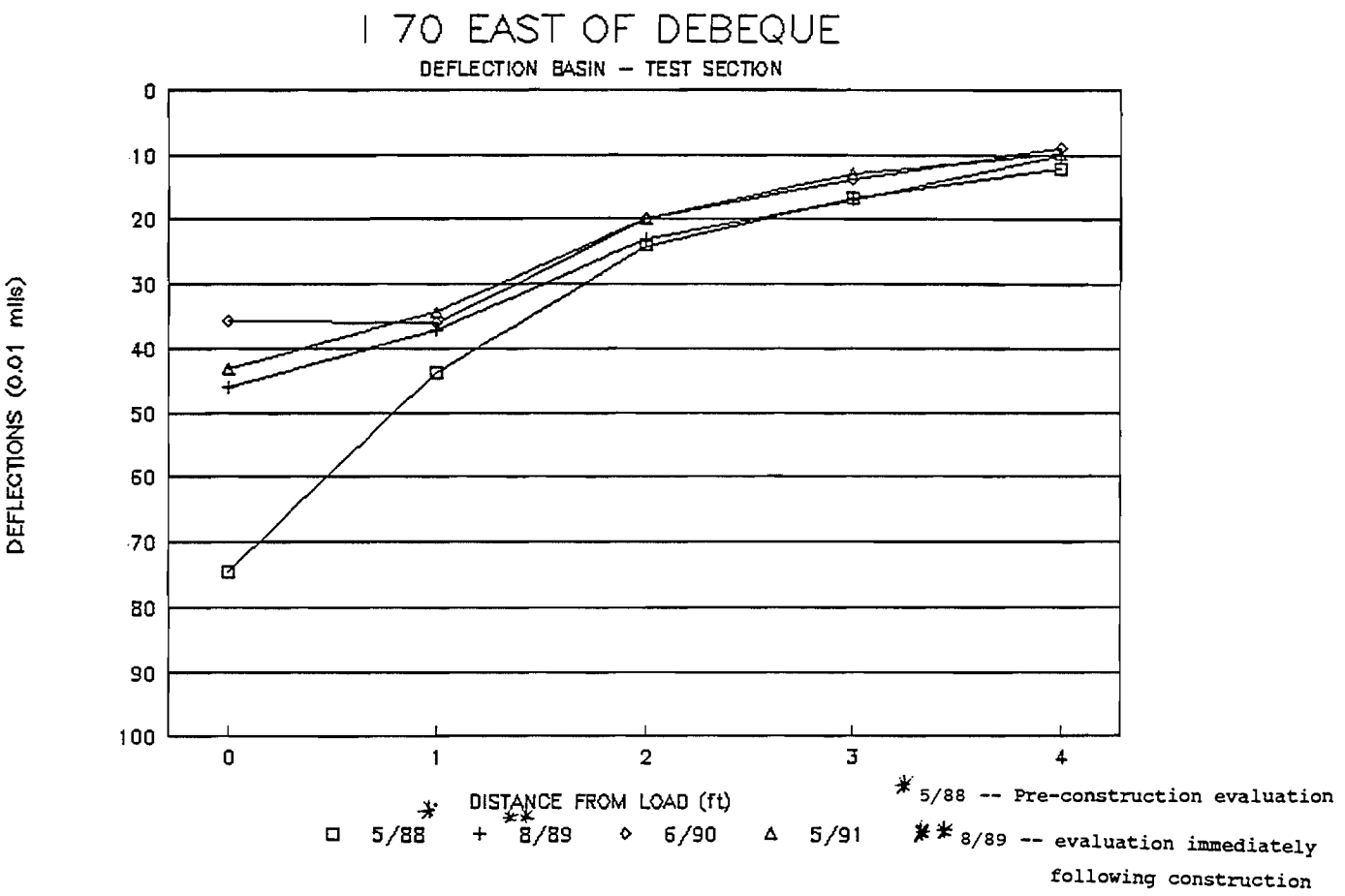
** 8/29/89 -- evaluation immediately following construction

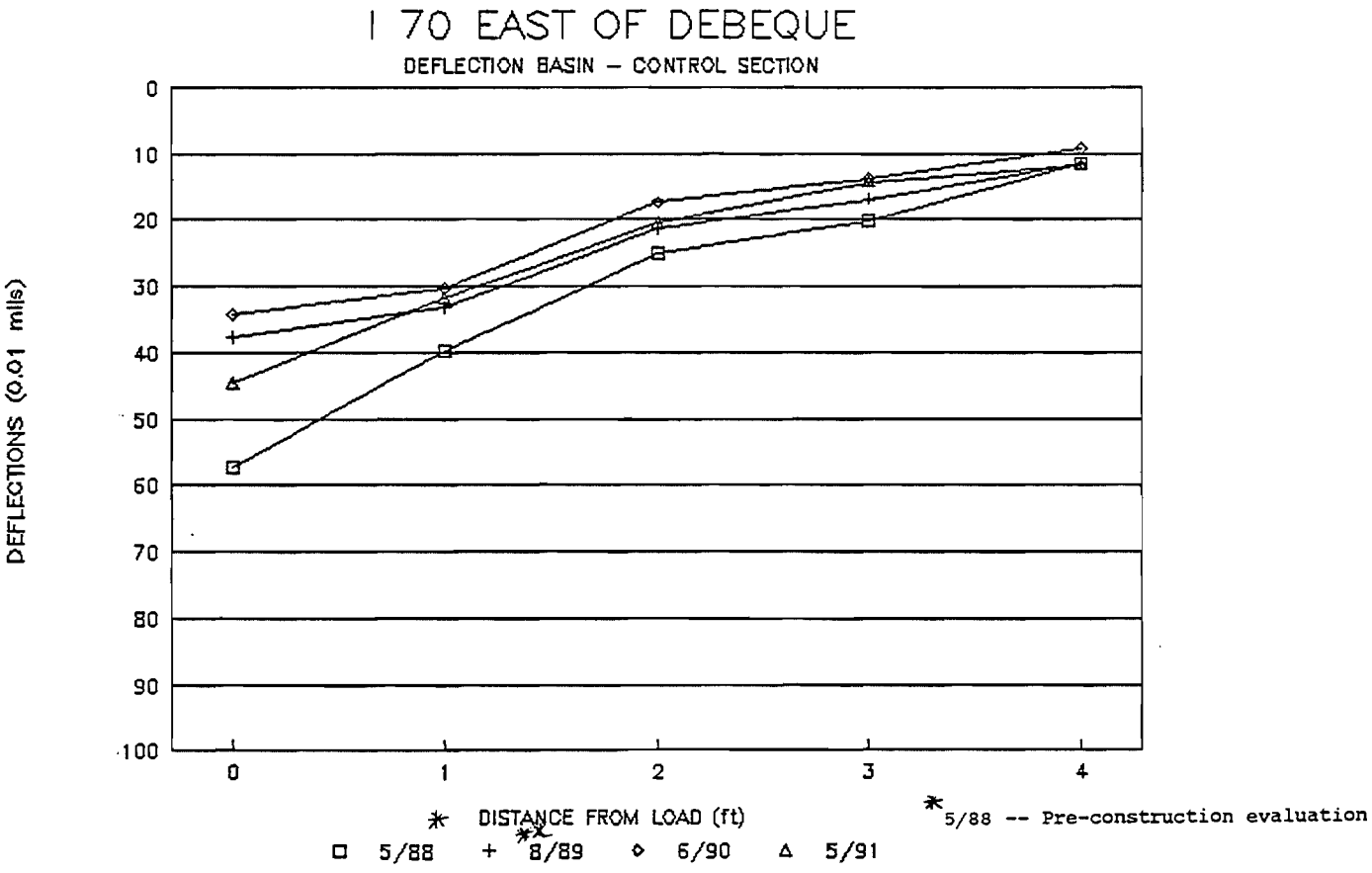


Pre-construction block cracking -- 774 sq ft



Pre-construction block cracking -- 220 sq ft


I 70 EAST OF DEBEQUE
DEFLECTION BASIN – TEST SECTION
DEFLECTIONS (0.01 mils)
0
10
20
30
40
50
60
70
80
90
100
0
1
2
3
4
DISTANCE FROM LOAD (ft)
5/88
8/89
6/90
5/91
5/88 -- Pre-construction evaluation
8/89 -- evaluation immediately following construction


I 70 EAST OF DEBEQUE
DEFLECTION BASIN – CONTROL SECTION
DEFLECTIONS (0.01 mils)
0
10
20
30
40
50
60
70
80
90
100
0
1
2
3
4
DISTANCE FROM LOAD (ft)
5/88
8/89
6/90
5/91
5/88 -- Pre-construction evaluation

APPENDIX K
Project Information
US 40, East of Hayden

US 40, East of Hayden

Paving on Project No. FR 040-2(30) began on July 6, 1989. This project is located on US 40 just east of Hayden. It begins at M.P. 108.1 and extends in the easterly direction approximately 8 miles to M.P. 116.3.

Construction consisted of widening the 11 foot driving lanes to 12 feet and adding 6 foot shoulders. This involved placing 4 inches of ABC (Cl 6) covered with 1-1/2 inches of HBP on the shoulders to bring them up to the existing roadway surface. A leveling course was placed with a laydown machine throughout the project except between Sta 0+00 to Sta 14+57. In this area the overlay was placed directly on top of the old mat. A 1-3/4 inch lift of HBP was placed in the section containing the design mix used prior to July 1987. This included approximately the first 2400 feet of the project. In the high stability pavement section, 1 inch of HBP (Grading E) was placed with a 3/4 inch rubberized PMSC Type B.

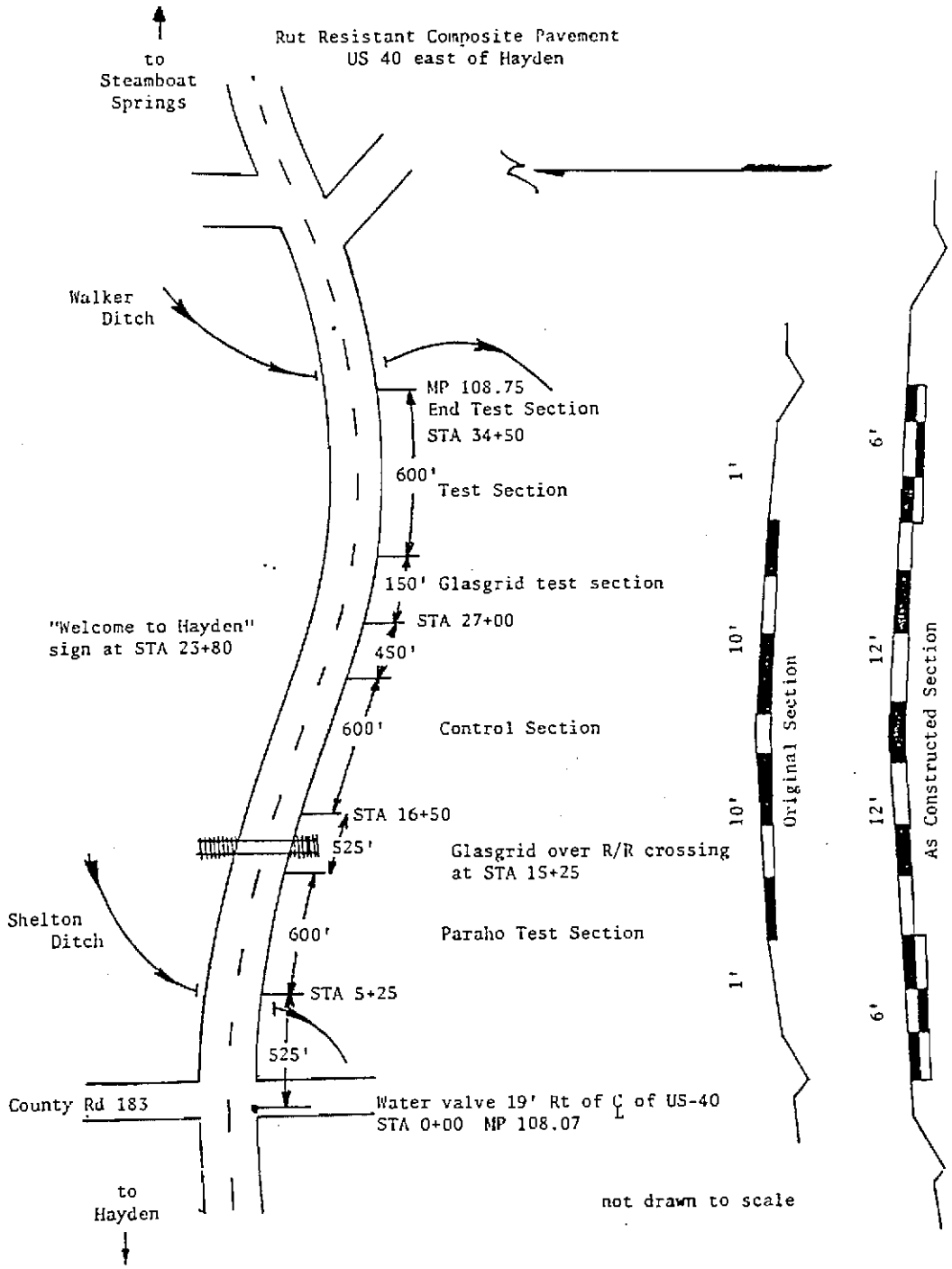
The 36 foot roadway was paved in two passes (17-1/2 foot pass eastbound lane, 18-1/2 foot pass westbound lane). The contractor tried to arrange his daily operation so that there were no exposed longitudinal joints between the east and westbound lanes at the end of the day. They were able to pave one-lane mile in each direction per day.

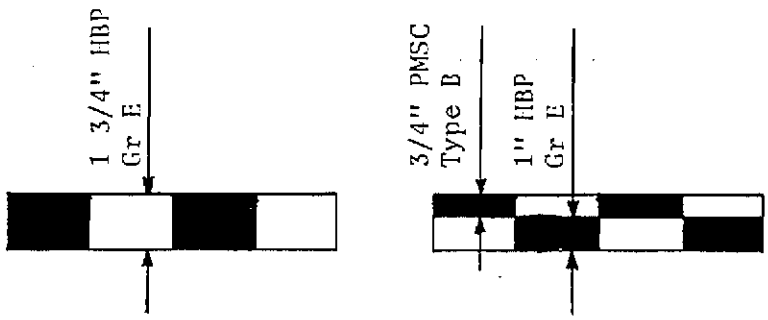
The drum-dryer plant was located approximately seven miles from the beginning of the job. The day these test sections were paved the plant was started around 7:00 A.M. and paving continued until 6:00 P.M.. Eight dump trucks were used for hauling the asphalt. The placement temperature ranged from 235^{o}F to 270^{o}F.

The rolling pattern consisted of one pass with the roller in the vibratory mode and the second pass in the static position. The rolling was done as soon as possible behind the paver. A rubber tire roller followed with six to eight passes. On the HBP lift a finishing roller was not used.

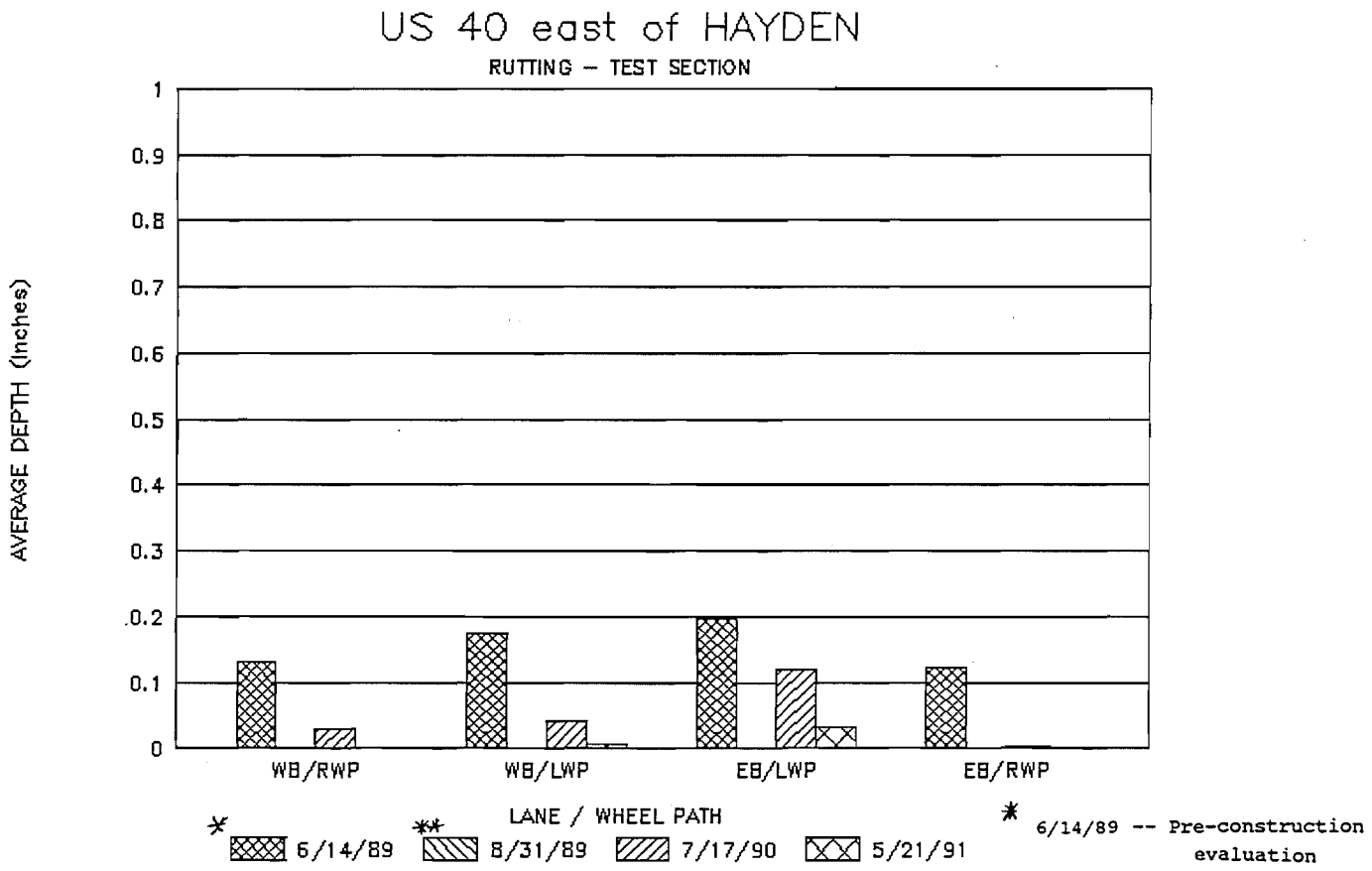
The minimum design AC content for the control was 5.5%, with 3-6% voids. The minimum design AC content for the test section (high stability design) was 5.3% with 4-6% voids. During construction samples were taken in both test sections and the control section.

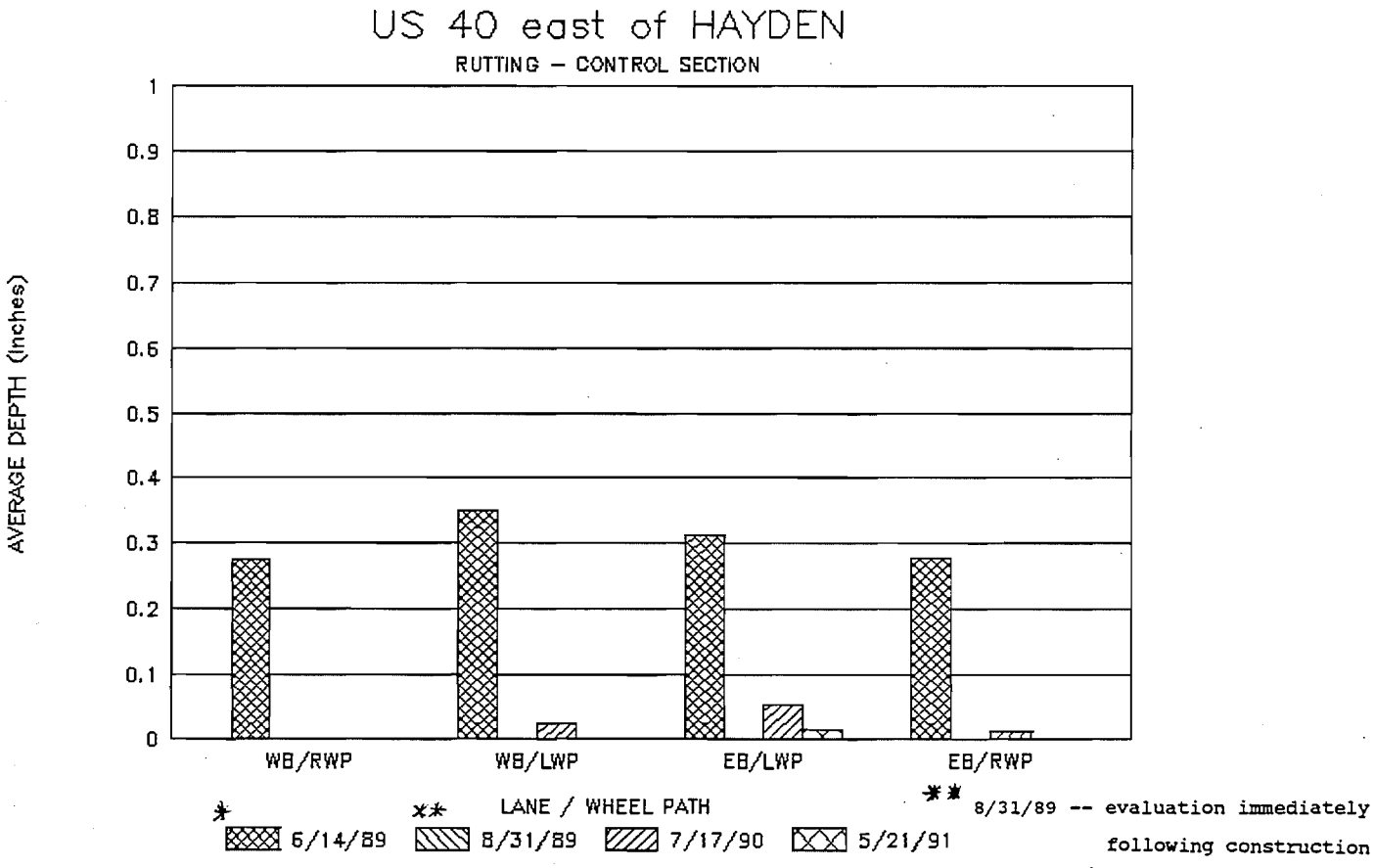
A 3/4 inch rubberized PMSC Type B was placed over the entire project except for the first 2400 feet. PMSC paving began on July 19, 1989. The average placement temperature was 295^{o}F. The mix design called for 6.0$\pm$0.3% AC in the mix.

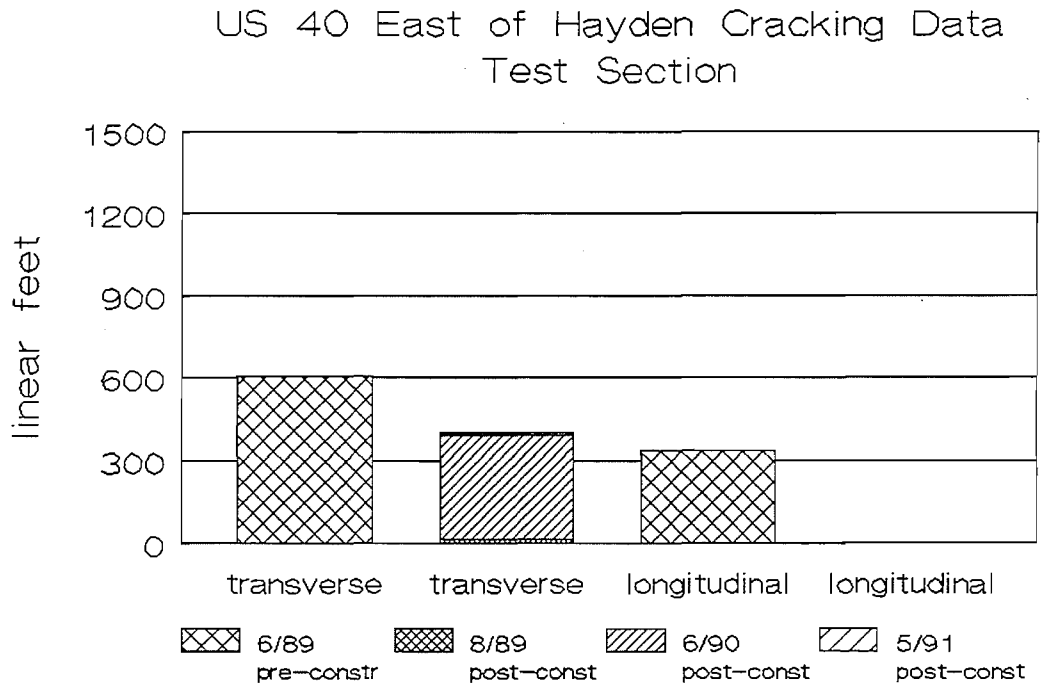




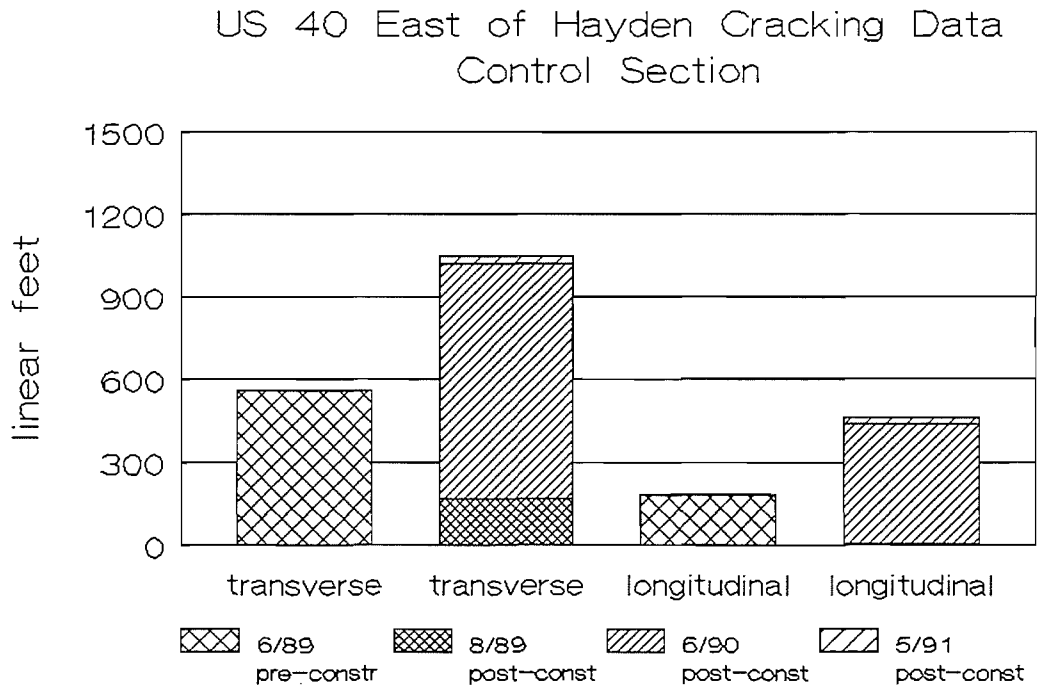
Paraho and Control Sections Test Section


US 40 east of HAYDEN
RUTTING – TEST SECTION
AVERAGE DEPTH (Inches)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
WB/RWP
WB/LWP
EB/LWP
EB/RWP
LANE / WHEEL PATH
* 6/14/89
** 8/31/89
7/17/90
5/21/91
* 6/14/89 -- Pre-construction evaluation

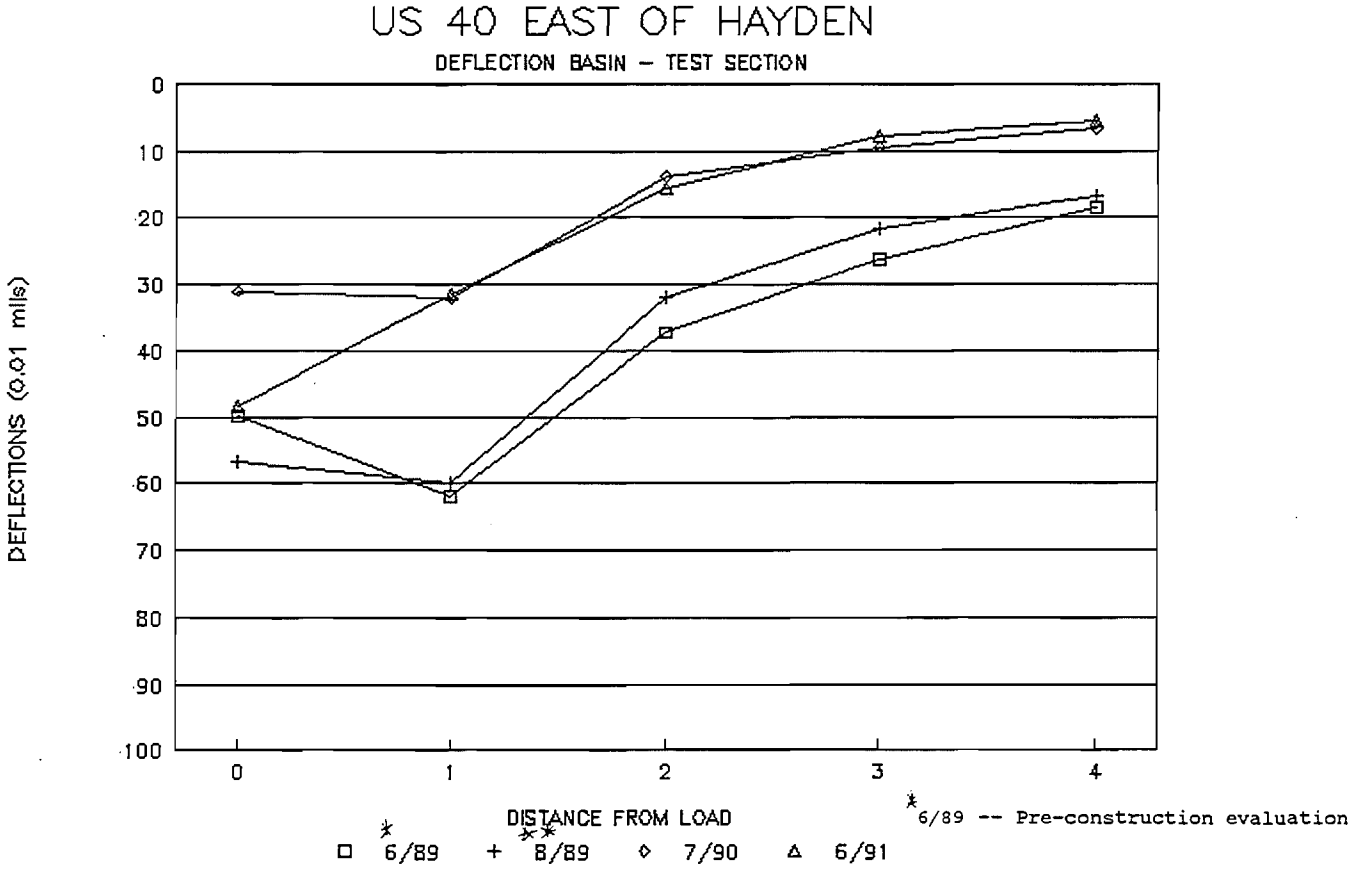

US 40 east of HAYDEN
RUTTING – CONTROL SECTION
AVERAGE DEPTH (Inches)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
WB/RWP
WB/LWP
EB/LWP
EB/RWP
LANE / WHEEL PATH
* 6/14/89
** 8/31/89
7/17/90
5/21/91
** 8/31/89 -- evaluation immediately following construction

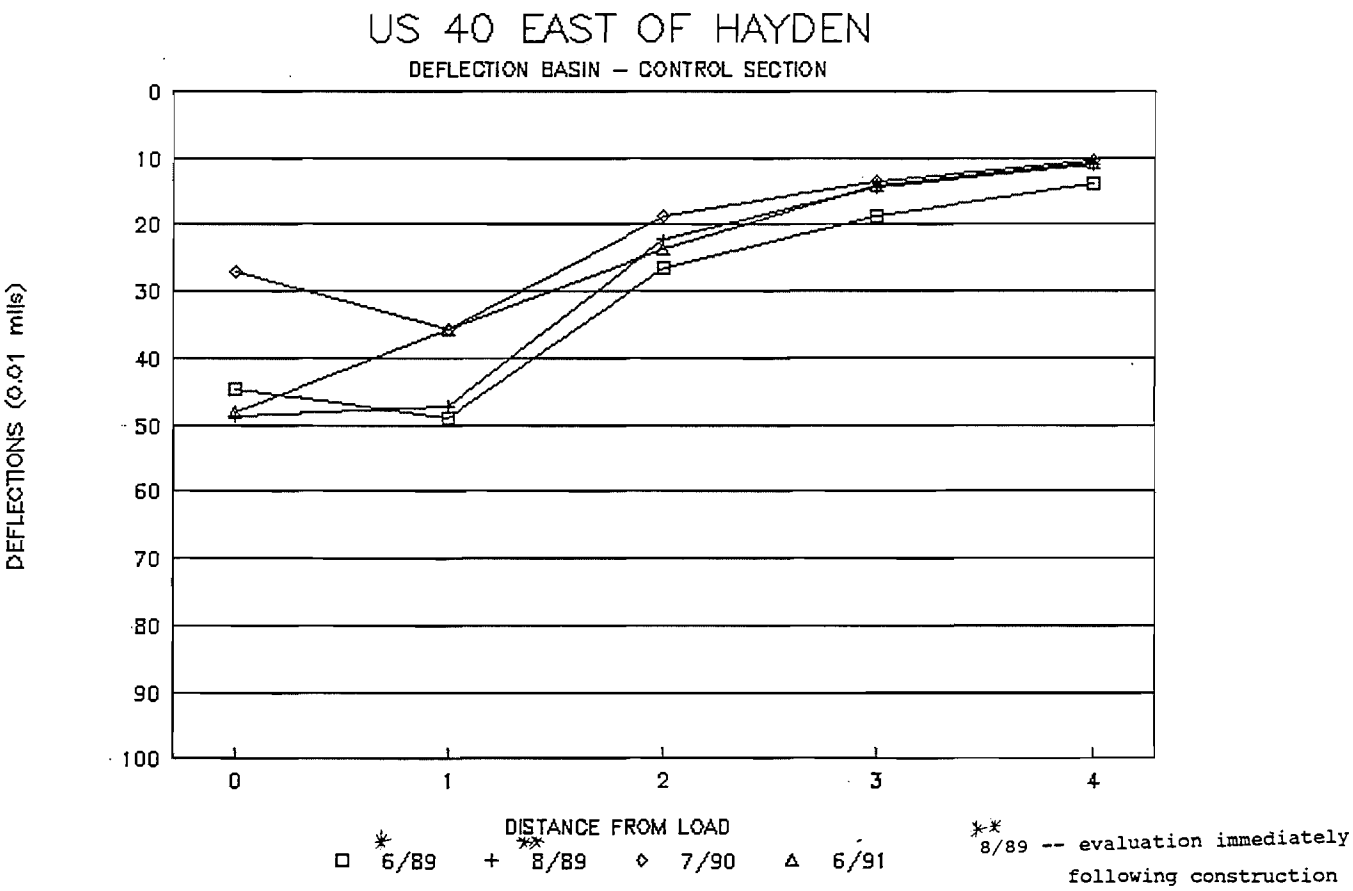


Pre-construction block cracking -- 2200 sq ft



Pre-construction block cracking -- 3874 sq ft


US 40 EAST OF HAYDEN
DEFLECTION BASIN – TEST SECTION
DEFLECTIONS (0.01 mils)
0
10
20
30
40
50
60
70
80
90
100
0
1
2
3
4
DISTANCE FROM LOAD
6/89
8/89
7/90
6/91
6/89 -- Pre-construction evaluation


US 40 EAST OF HAYDEN
DEFLECTION BASIN – CONTROL SECTION
DEFLECTIONS (0.01 mils)
0
10
20
30
40
50
60
70
80
90
100
0
1
2
3
4
DISTANCE FROM LOAD
6/89
8/89
7/90
6/91
8/89 -- evaluation immediately following construction

APPENDIX L
Project Information
SH 172, South of Durango

SH 172, South of Durango

Paving on project No. SR 0172(12) began on July 17, 1989. This project begins at M.P. 24.5 and extends to the south to M.P. 19.7. The original plans called for 1-1/4 inches of HBP Grading E with a 3/4 inch Type B PMSC for a cover. The project included widening at various locations. However, the test and control sections established for this study did not include widening. The pavement in the evaluation area consisted of two twelve foot driving lanes with eight foot shoulders.

Initially, this project was designed requiring the use of the high stability asphaltic mix in the lower layer with a plant mixed seal coat for the top layer. However, since that time, the design criteria for the asphalt pavement was revised and the revisions were incorporated into this project. These changes included raising the asphalt content in the HBP layers to 5.9±0.3% and using rubberized asphalt cement in the layer immediately below the PMSC pavement. The thirty-seven Hveem stability value was retained, and the design voids were established at 3-4%.

Paving at the evaluation sections began on July 19, 1989. The plant was started up around 7:00 A.M. and paving continued until 9:00 P.M.. The plant was located approximately 5 miles west of the project. Hourly production was 300 tons per hour but because of production problems only 2600 tons were placed on July 17, 1989. On July 19, nine belly dump trucks were in operation and made one round trip per hour.

The original control section for this project was established using an AC-10 at an asphalt content of 5.9±0.3%. The remainder of the project was to contain the

high stability mix with an AC content of 5.5±0.3%. Because of the revisions, the 5.5% AC mix was deleted and 5.9% AC mix was used throughout the entire project. The majority of the HBP in the southbound lanes contained AC-10, but because of the design revisions, the northbound lane was constructed using AC-20R.

During construction the control section in the northbound lane was reduced from 1000 feet to 600 feet (Sta 350+00 to Sta 356+00). This section contains 2-1/4 inches of HBP GR E AC-20R without PMSC. The test section in the northbound lane was relocated during construction. It is now located between Sta 357+00 and Sta 363+00. This test section consisted of 1-1/2 inches HBP GR E AC-20R with 3/4 inches rubberized PMSC.

Since the mix design in the southbound and northbound lanes were different, a second 600 foot control section (2-1/4 inches HBP GR E AC-10 without PMSC) was established in the southbound lane opposite the control section in the northbound lane.

Because of construction related problems effecting performance evaluations, this site was dropped from this study following construction.

Rut Resistant Composite Pavement
SH 172 South of Durango

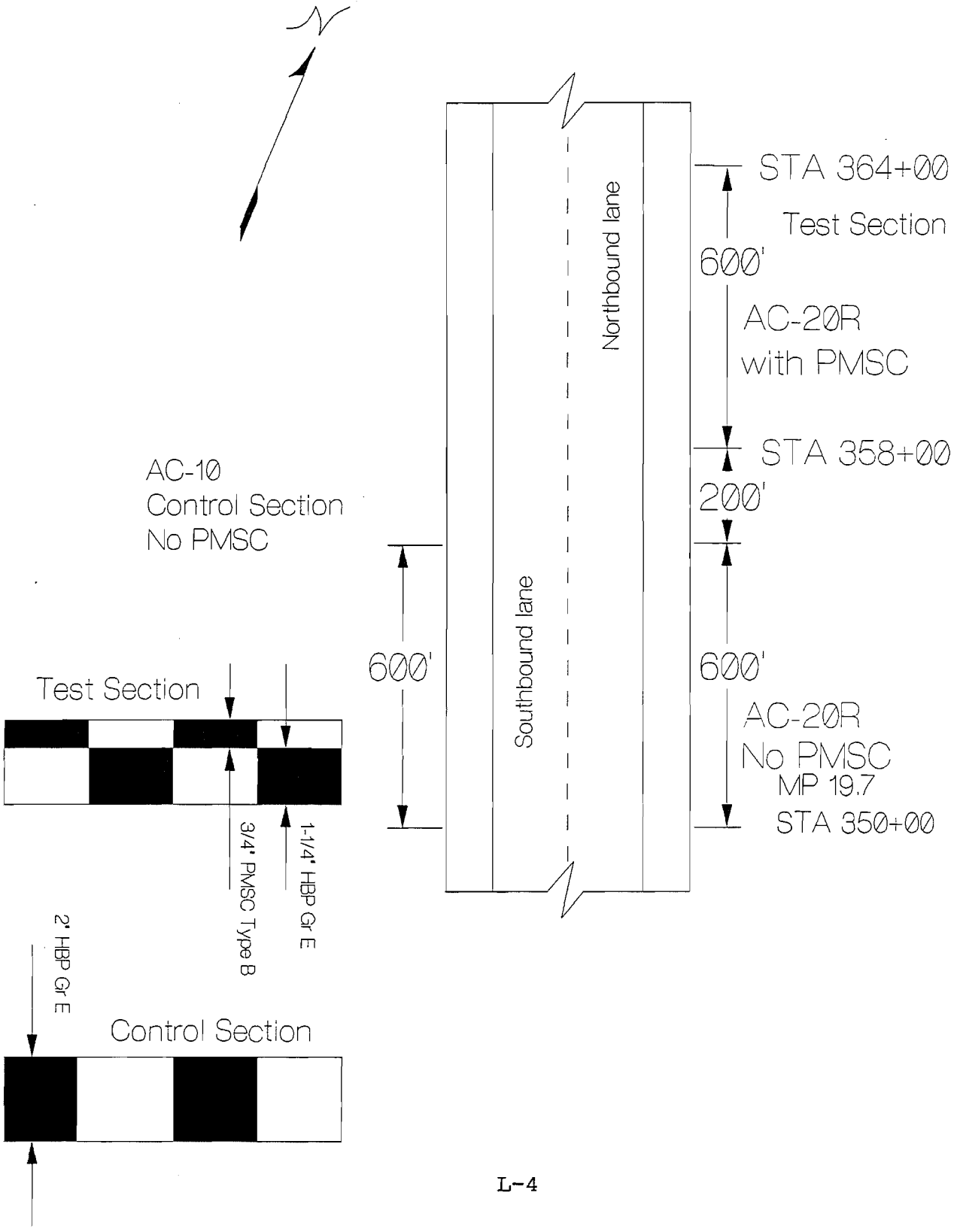
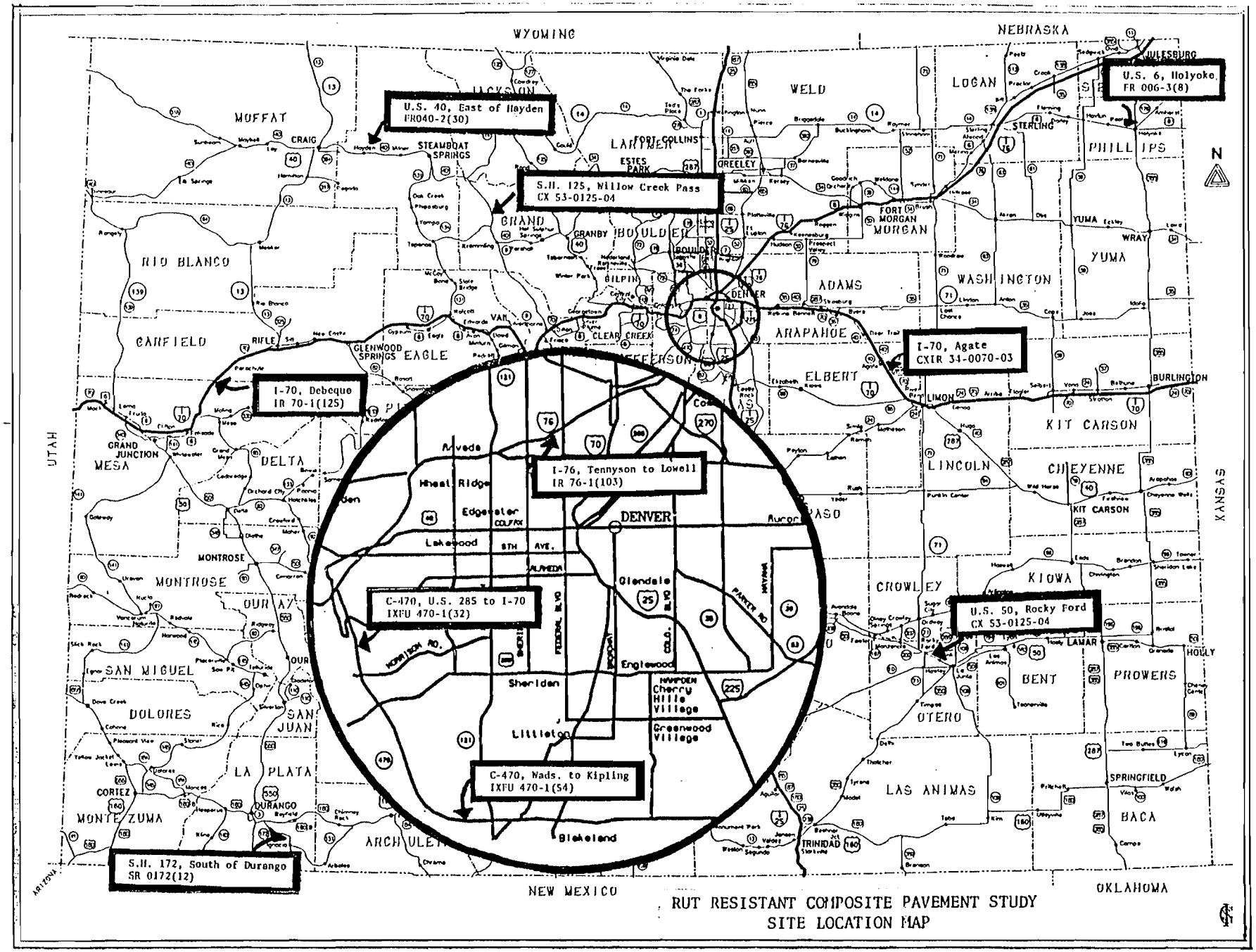


FIGURE 1


U.S. 40, East of Hayden
FR040-2(30)
S.H. 125, Willow Creek Pass
CX 53-0125-04
U.S. 6, Holyoke
FR 006-3(8)
I-70, Debeque
IR 70-1(125)
I-70, Agate
CXIR 34-0070-03
I-76, Tennyson to Lowell
IR 76-1(103)
C-470, U.S. 285 to I-70
IXFU 470-1(32)
C-470, Wads. to Kipling
IXFU 470-1(54)
U.S. 50, Rocky Ford
CX 53-0125-04
S.H. 172, South of Durango
SR 0172(12)
WYOMING
NEBRASKA
UTAH
NEW MEXICO
OKLAHOMA
KANSAS
ARIZONA
DENVER
N
RUT RESISTANT COMPOSITE PAVEMENT STUDY
SITE LOCATION MAP

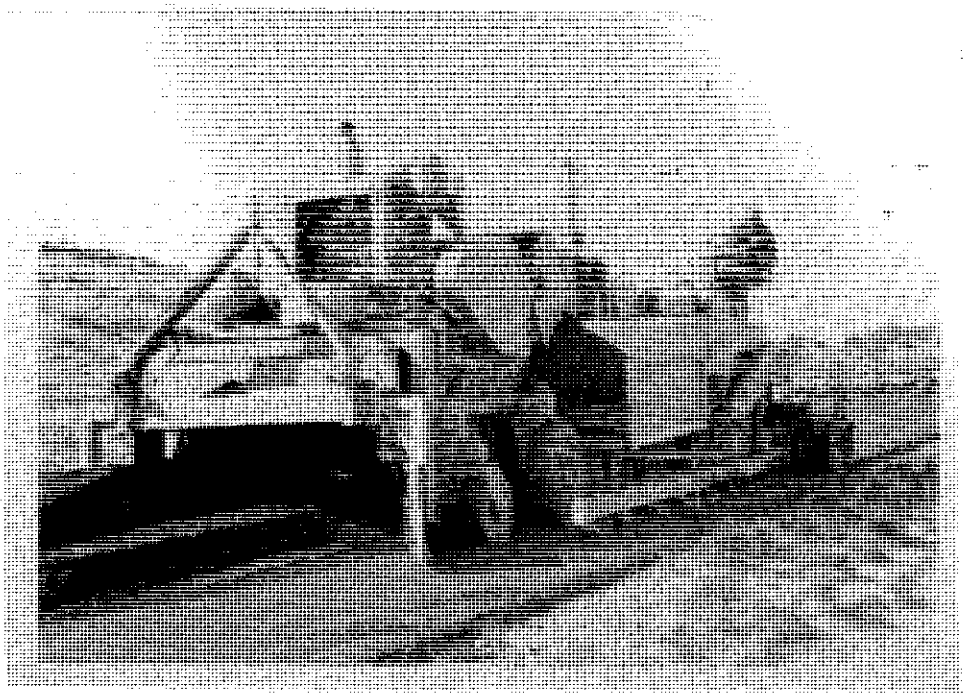


PHOTO 1

A paving operation using windrow placement.

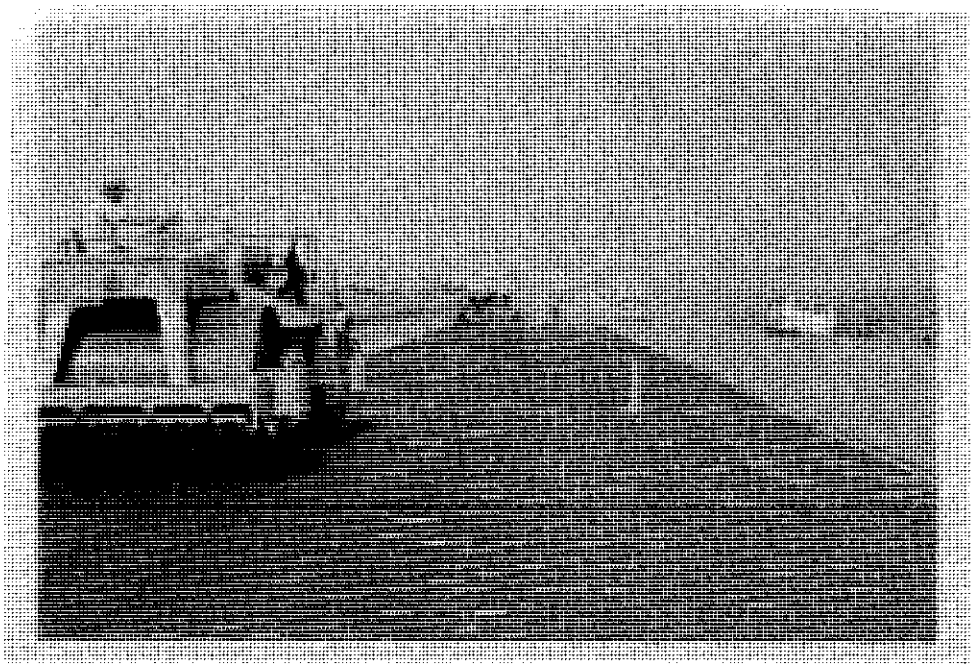


PHOTO 2

Steel-wheeled roller used for break down.

PHOTO 3

Pneumatic roller was used prior to finish roller.

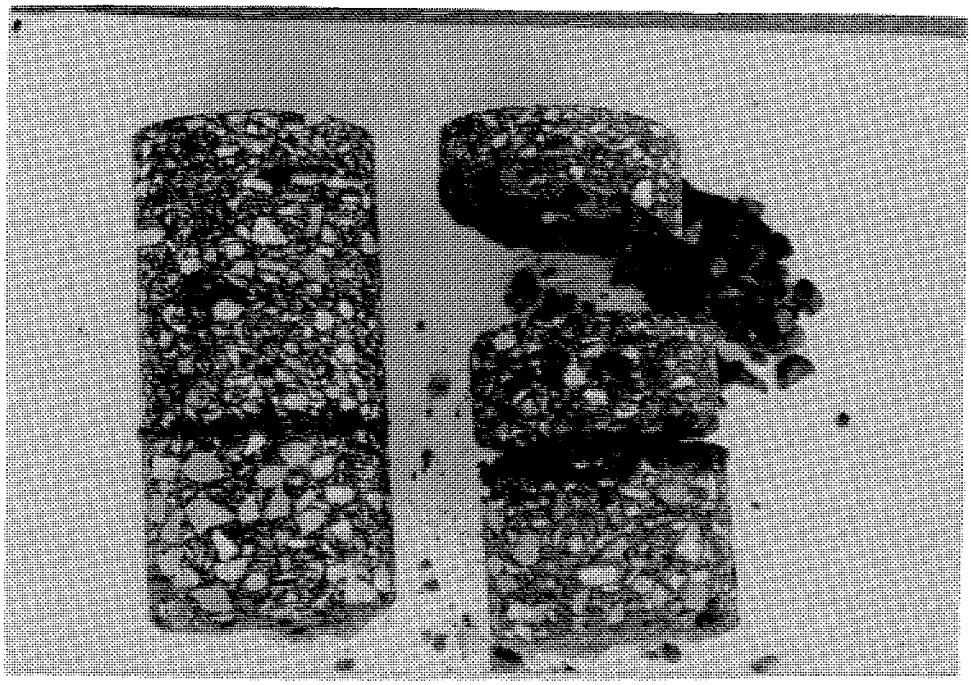


PHOTO 4

This photo shows how stripping progresses. The core on the left taken in 1990. The core on the right taken in 1991 at the Debeque evaluation site. Note that the top lift of PMSC is undisturbed.

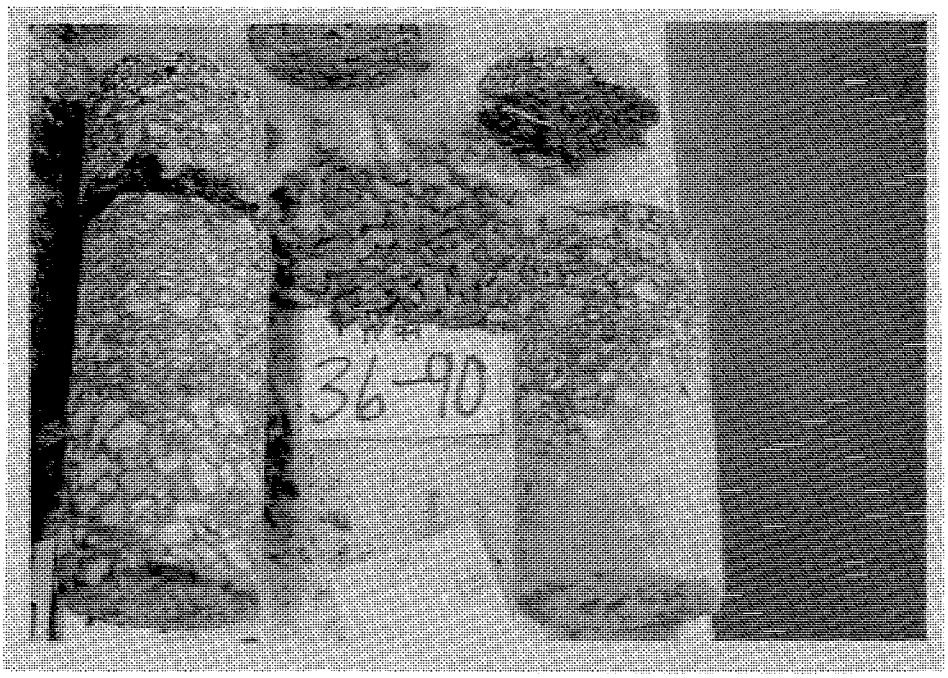


PHOTO 5

This photo shows an extreme case of stripping below the PMSC. Both cores were taken out of C470 in 1990.

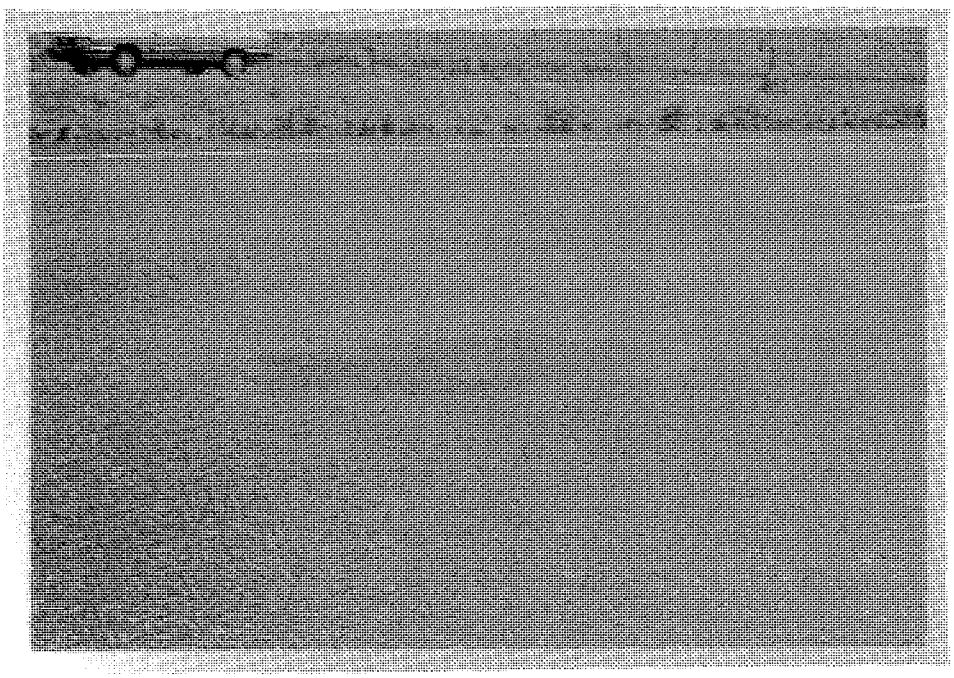


PHOTO 6

C470, US 285 to I-70
The first sign of the stripping failure is the appearance of rich spots on the surface. These rich areas are randomly spaced and typically found in the wheel paths.

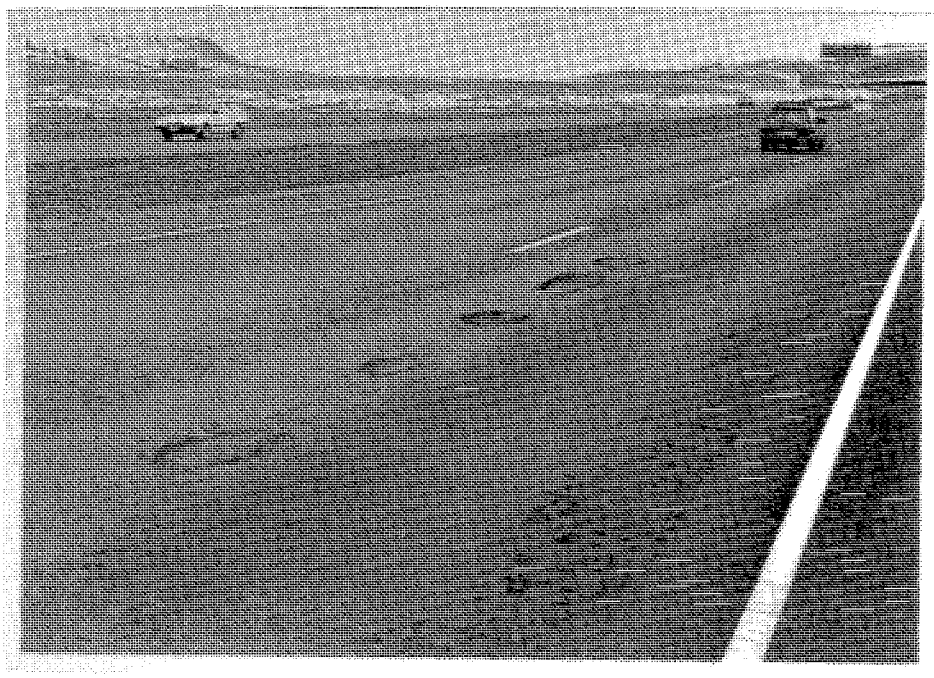


PHOTO 7

C470, US 285 to I-70
This photo shows areas which have stripped under the PMSC. Evidence of raveling in the right wheel path is a result of extensive stripping in the RRCP layer below the PMSC.

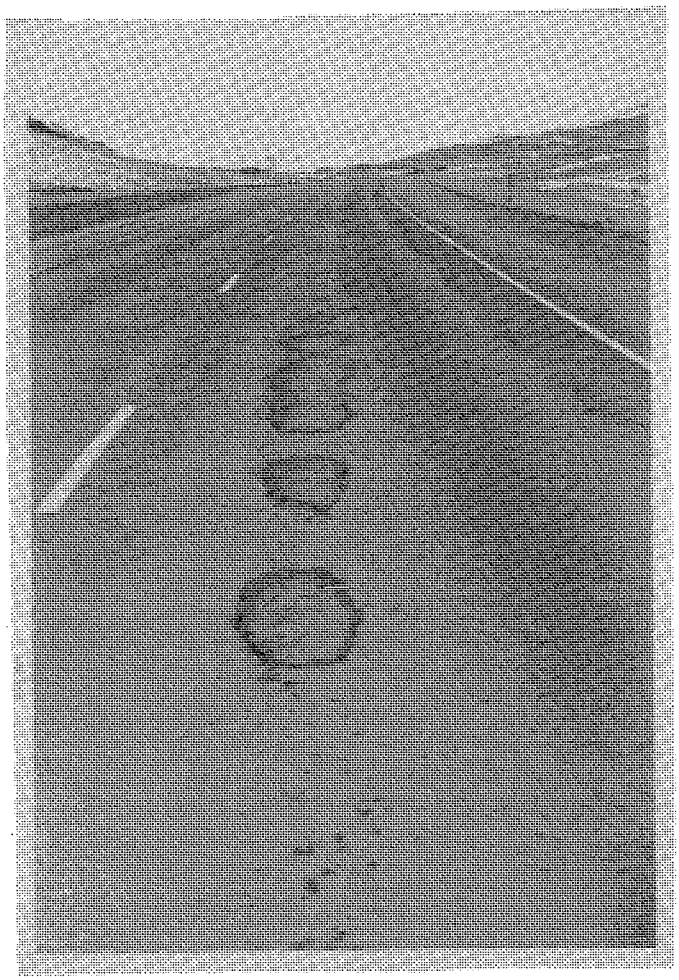


PHOTO 8

C470, US 285 to I-70
This type of distress was found throughout the project.

PHOTO 9

This photo was taken on I-70, east of Agate eight months after construction using the RRCP design. This type of distress was typical throughout the project.

PHOTO 10

This is not the high-stability (RRCP) design. This photo shows stripping occurring below the PMSC however. The portion stripping is a Grading C. This photo was taken at the test site on I70, east of Agate. The pavement had been down one year.

FIGURE 2

Project/Environmental Information
C470, Between Kipling and Wadsworth

District: 6
Project: IXFU 470-1(54)
Location: C470, Between Kipling and Wadsworth

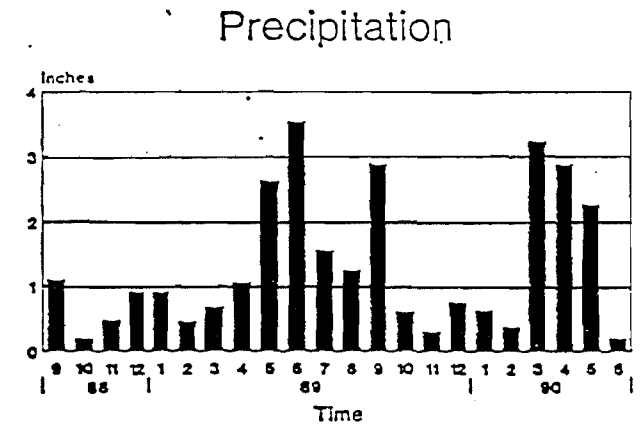
HBP Information
Grading: E
% AC: 5.1
* Lottmans: 104, 90, 102, 126, 108, 113, 100, 114, 126, 127, 117

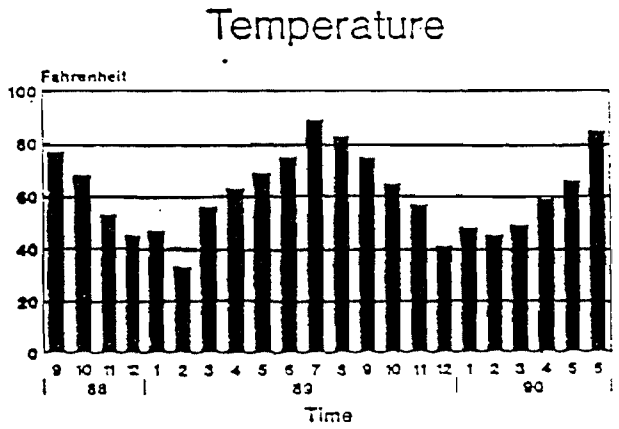
PMSC Information
Type: A

Design Traffic
10 year ESAL's: 1,565,000

* See Appendix A

Environmental Information





Project Status
High moisture, Low moisture susceptibility, moderate traffic

FIGURE 3

Project/Environmental Information
C470, US285 to I-70

District: 6
Project: IXFU 470-1(32)
Location: C470, US285 to I-70

HBP Information
Grading: E
% AC: 5.2%
* Lottmans: 111, 101, 88, 77, 56, 81, 68, 77, 98, 96, 88, 42, 74, 56

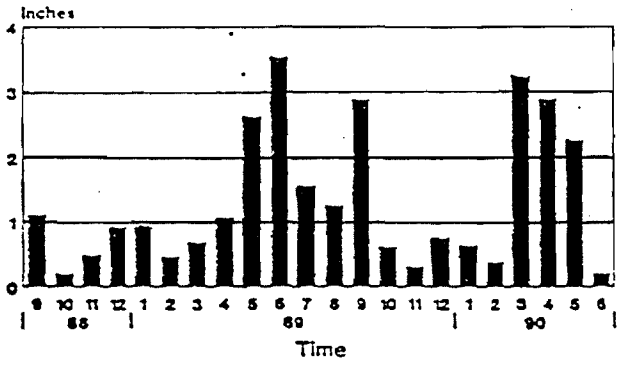
PMSC Information
Type: A

Design Traffic
10 year ESAL's: 1,565,000

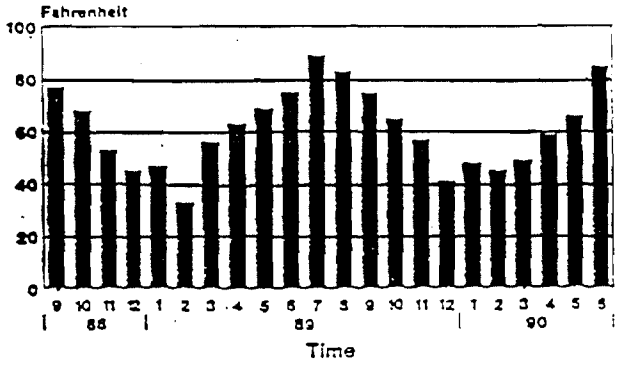
* See Appendix A

Environmental Information

Precipitation



Temperature



Project Status
High moisture, high moisture susceptibility, moderate traffic

Stripping noticed in mid 1989 and increased in 1990.

FIGURE 4

Project/Environmental Information
I-70, East of Agate

District: 1
Project: IR 70-4(118)
Location: I-70, East of Agate

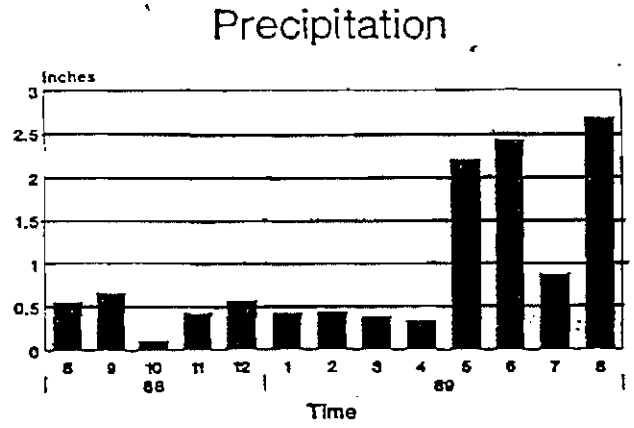
HBP Information
Grading: C
% AC: 5.3%
* Lottmans: 102, 80, 92, 78, 64

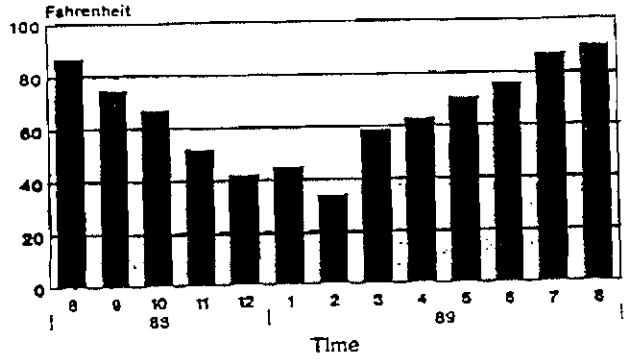
PMSC Information
Type: B

* See Appendix A

Design Traffic
10 year ESAL's: 3,500,000

Environmental Information

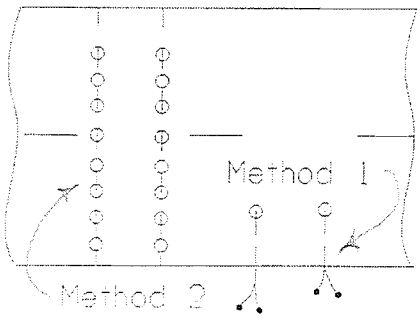




Project Status
High moisture, moderate moisture susceptibility, high traffic

Failed in 7-89

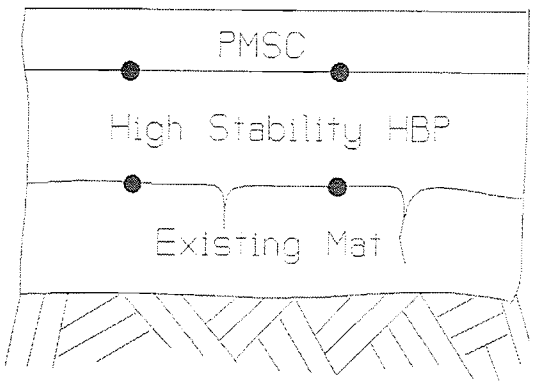
TYPICAL MOISTURE DETECTION INSTRUMENTATION LAYOUT



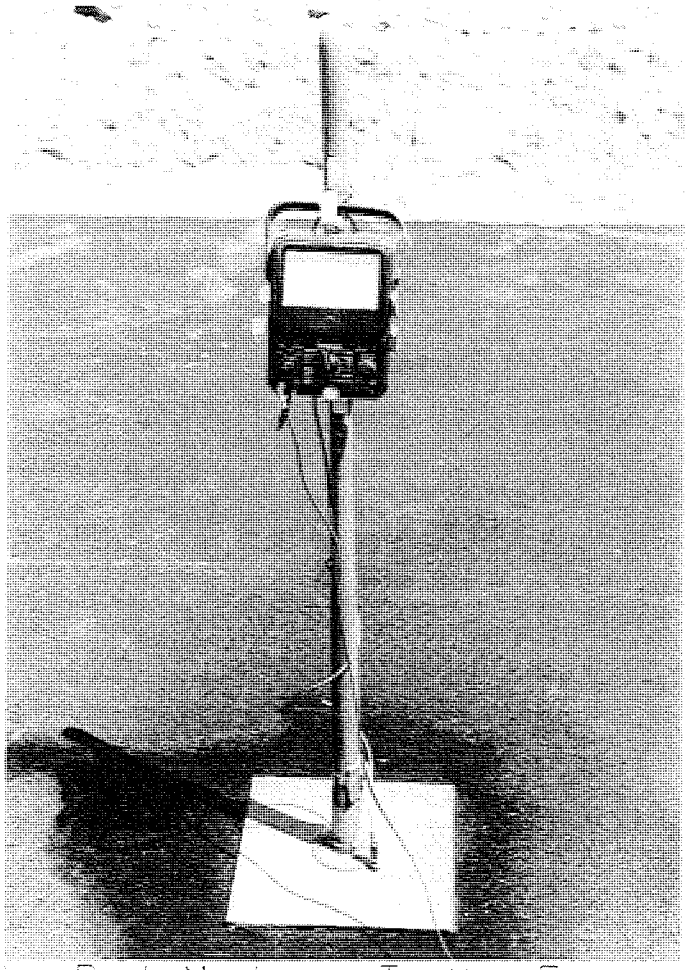
○ Water was sprayed at these locations to test the permeability.

Method 1: Probes extended into right wheel path of driving lane.

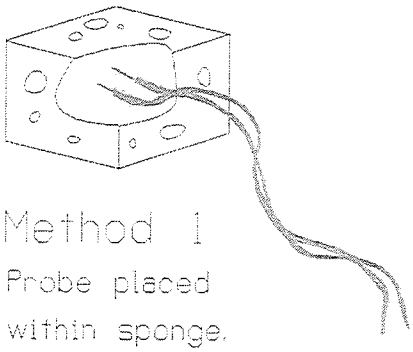
Method 2: Wires extended full width.



● General layout used in both methods.



Bridge Deck Membrane Testing Equipment
(Used for Test Method 2)



Method 1
Probe placed within sponge.