EVALUATION OF ASPHALT ADDITIVES: LAVA BUTTE TO FREMONT HIGHWAY JUNCTION

The Dalles - California Highway
Deschutes County, Oregon

Final Report

FHWA Experimental Project No. 3

and

FHWA Experimental Features
OR84-02 to -04, and OR84-07 to -11

by Bo Miller, P.E.
Senior Research Specialist

and

L. G. Scholl, P.E.
Technical Studies Coordinator

Research Unit
Materials and Research Section
Highway Division
Oregon Department of Transportation

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16. Abstract

This report covers four year's performance of ten test sections using dense-graded hot mix asphalt concrete with these additives: Plus Ride mix containing granulated tire rubber, Arm-R-Shield modified asphalt containing ground and dissolved tire rubber, Fiber Pave polypropylene fibers, Boni Fibers polyester fibers, Pave Bond anti-stripping asphalt additive, lime as an anti-stripping aggregate treatment, and CA(P)-1 asphalt containing an EVA polymer. The control section used conventional AC-20 asphalt.

At the end of four years, none of the test sections performed better than the control. The only significant distresses were a slight loss of aggregate in the wheeltracks of the Plus Ride section and a comparatively large amount of wheeltrack and transverse cracking in the CA(P)-1 sections. None of this distress was severe enough to require repair.

The anti-stripping additives cannot be evaluated at this time, as no significant stripping has occurred on any section.

Distress measured on the roadway after four years was compared to the results of tests done on briquets made out of mix sampled from behind the paver. The best correlations were: rutting vs the 77°F and 115°F penetration, longitudinal wheeltrack cracking vs the unconditioned diametral resilient modulus, transverse cracking vs the 73°F fatigue test results, and ravelling and weathering vs the index of retained strength and the freeze-thaw/unconditioned diametral resilient modulus ratio.

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DISCLAIMER

The contents of this report reflect the view of the authors who are responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of either the Oregon State Highway Division or the Federal Highway Administration at the time of publication.

The brand names used in this report are essential to its content. This report does not constitute a standard, specification, or regulation.

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1.0 INTRODUCTION

1.1 Background

Many miles of Oregon highways need a stable and durable surface treatment to regain a good serviceability rating. To date, thick asphalt overlays have been the most effective rehabilitation method. To be successful, the overlay must resist all forms of distress. However, in central and eastern Oregon resistance to cracking caused by thermal stresses and asphalt stripping are of particular interest.

Today, several hot mix additives are sold that are supposed to improve the performance of hot mix overlays by reducing both cracking and stripping. As these additives increase project expenses, it is important to determine their cost-effectiveness.

1.2 Scope and Objectives

The purpose of this study was to evaluate the construction, short term performance, and cost-effectiveness of nine hot mix overlay test sections containing different additives.

Federal funding for this study came from two Federal Highway Administration (FHWA) programs created to promote the use of new products and technologies by transportation agencies: FHWA Experimental Project No. 3, "Asphalt Additives" and the Experimental Features program. The Experimental Features in this study are:

OR84-02	Arm-R-Shield
OR84-03	Plus-Ride
OR84-04	Fiber Pave 3010
OR84-07	Boni-Fibers B
OR84-08	Pavebond
OR84-09	Pavebond (With lime treated aggregate.)
OR84-10	Chevron CA(P)-1 (With lime treated aggregate.)
OR84-11	Chevron CA(P)-1

Prior reports have detailed the pre-construction condition, structural design, mix design, construction, unit costs, and inspection and laboratory test results for the first year of pavement life [1,2].

This is the final report for the FHWA funded studies. However, further reporting on these test sections is planned under Oregon Department of Transportation (ODOT) funding, as it is not yet possible to make firm conclusions about the cost-effectiveness of the various additives.

2.0 TEST SECTIONS

This chapter describes the test sections and the materials tested.

2.1 Location and Environment

The test sections are in a region where pavements often show distress such as transverse cracking after a few years. This area has cold winters, hot summers, large daily temperature swings, frequent freeze thaw cycles, rain, and snow. In addition, the pavements lie on a highly resilient subgrade material and are subject to heavy truck traffic.

The test sections are between milepoints 157.94 and 161.81 on The Dalles-California Highway (U.S. Route 97 or Oregon Highway 4). This is the main north-south highway across the Central Oregon Plateau (Figure 2.1).

The climate at the study site was determined from a nearby weather station. Temperatures vary from an average daily low of 21°F in January to an average daily high of 82°F in July. Daily temperature swings of 30°F to 40°F are the rule, with a 52°F swing noted in August 1986. In 1986, for example, there were freeze-thaw cycles on about 200 days out of the year. An average of 12 inches of rain and 39 inches of snow fall annually.

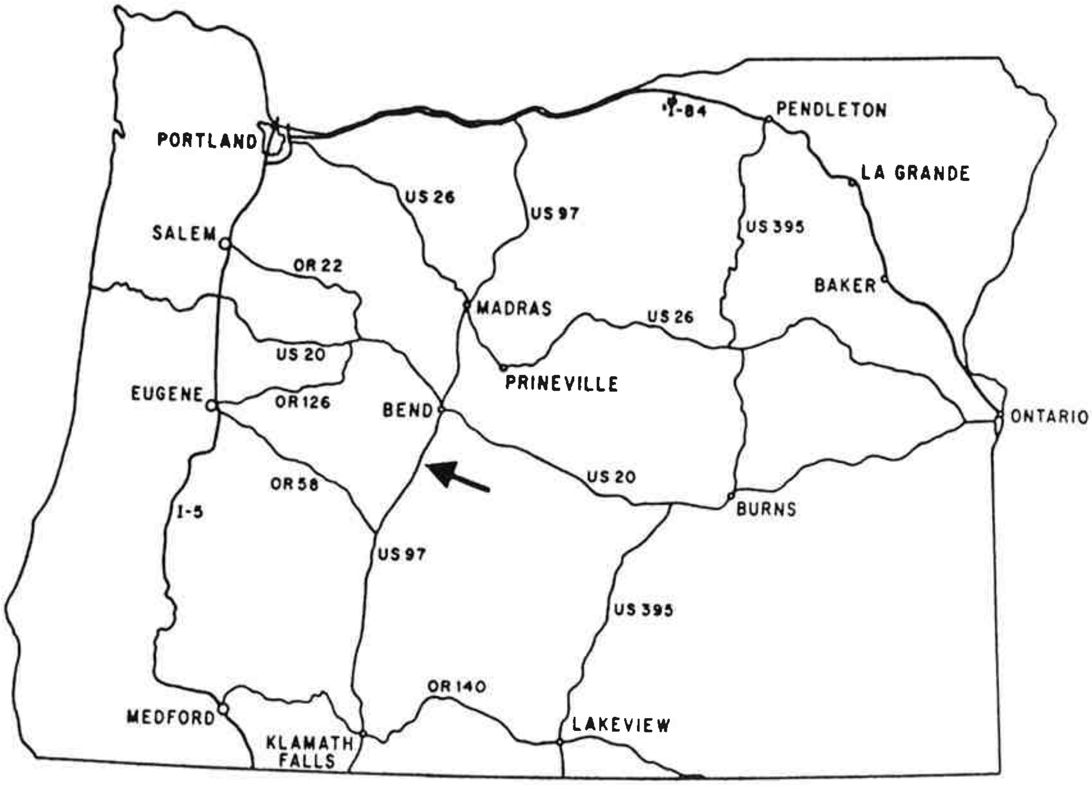
Although this section has a moderate traffic loading at present, use has been increasing. Historical data for 1985 through 1988, and projected traffic loadings for 1989, are shown in Table 2.1.

Table 2.1: Traffic Loading for 1985 through 1989

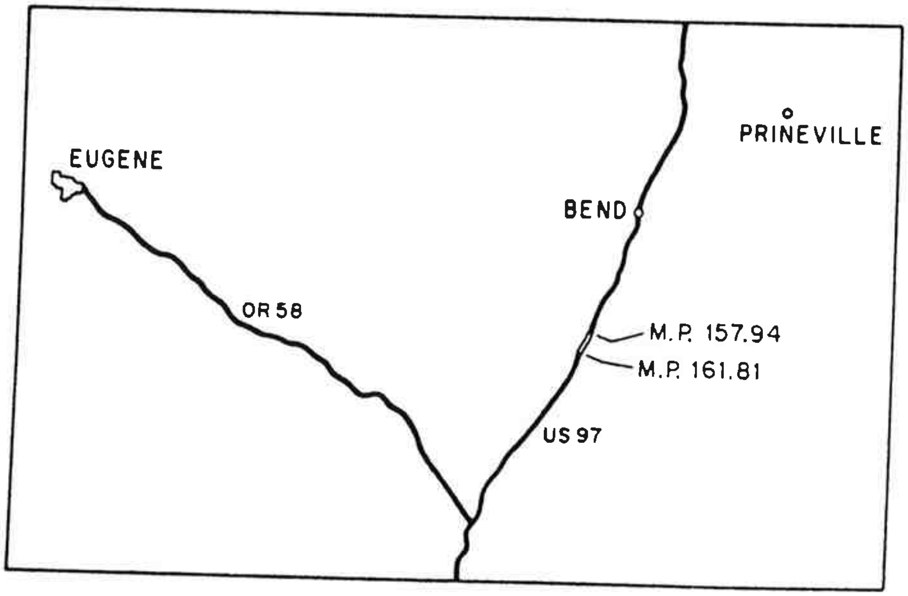
Year	Two Way Average Daily Traffic	Northbound 18 kip Equivalent Annual Axle Loads	Southbound 18 kip Equivalent Annual Axle Loads
1985	5,000	119,000	129,000
1986	5,000	126,000	136,000
1987	5,400	138,000	150,000
1988	5,700	151,000	163,000
1989	6,100	162,000	175,000

2.2 Layout and Cross-Section

The layout of the test sections is shown in Figure 2.2. The cross-section of the roadway was determined by analyzing both cores and plans from previous jobs (Figure 2.3).



(a) General Location



(b) Close Up of Project Site

Figure 2.1: Vicinity Map

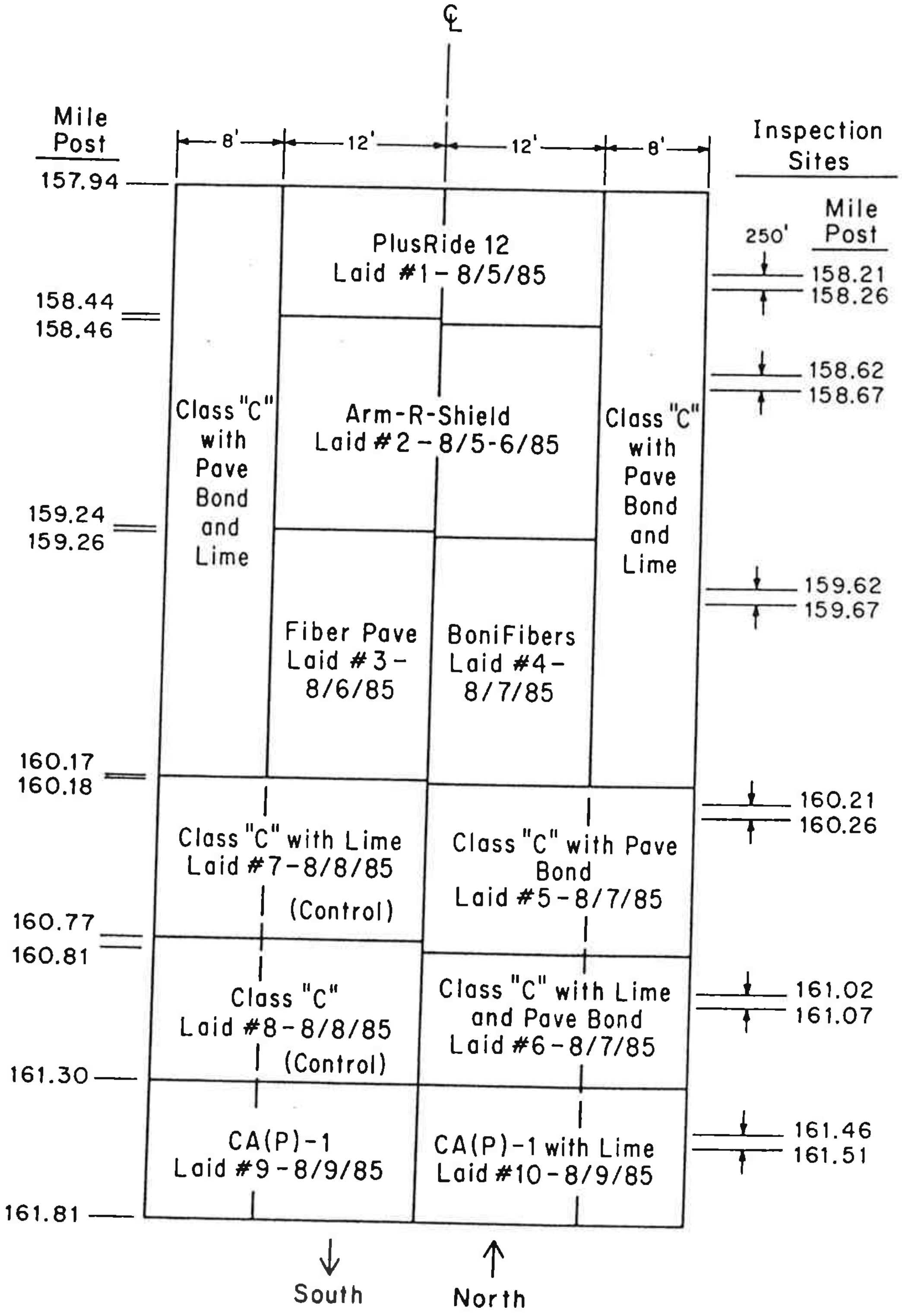
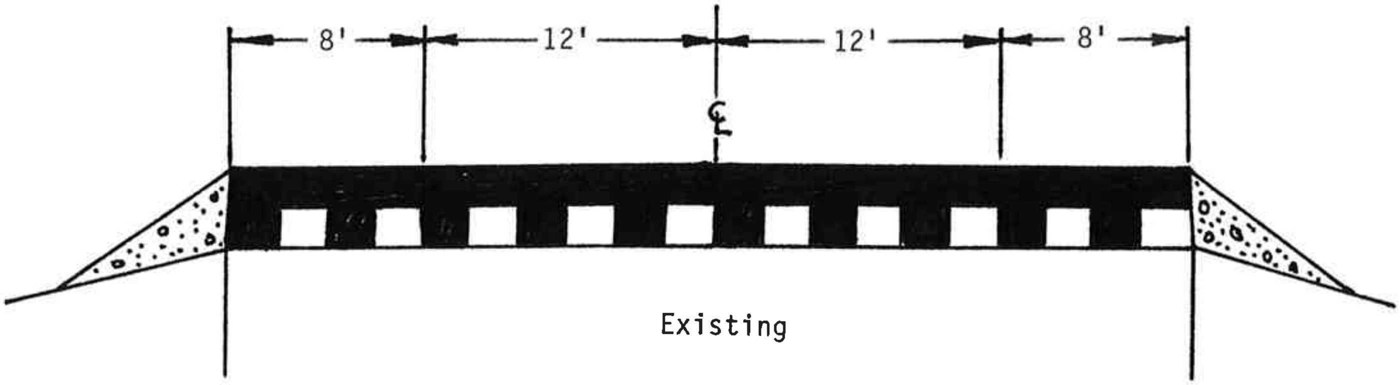


Figure 2.2: Test Section Layout



■ Class "C" Wearing Course

▚ Class "C" Base Course

▒ Aggregate Shoulder Material

Figure 2.3: Typical Roadway Cross-Section

Most of the wearing course placed during this project was a 1-1/2 to 2-inch thick layer of dense-graded asphalt concrete of ODOT Class "C" gradation using a 1/2-inch maximum stone size. The exception was the Plus Ride section, where the mix used a special gradation. Under the wearing course, the combined base and leveling course consisted of 2 to 4-1/2 inches of Class "C" mix using asphalt containing Pave Bond with lime treated aggregate.

The badly cracked existing surface consisted of two ODOT Class "B" dense-graded overlays. The first overlay was placed in 1955 and the second in 1970. The combined thickness of these overlays varied between 4-1/2 and 6-3/4 inches. Under the 1955 overlay there was an oil mat of approximately 1 to 2-1/2 inches thickness. Unlike the overlying layers which used crushed solid stone as an aggregate, the oil mat used volcanic cinders.

Cores drilled after the 1985 overlay show that both the 1955 and 1970 overlays were ravelled between the pavement layers. This distress was caused by stripped aggregate. It is not known if this stripping was caused by moisture sealed in the pavement by the 1985 overlay.

The subgrade consisted of powdered pumice interspersed with basalt boulders and volcanic cinders. Occasionally, the roadway cut through ledges of basalt.

2.3 Materials

The binders and antistripping treatments in the wearing course mix are described below. Product suppliers are listed in Table 2.2.

Plus Ride^{R} 12 with Pave Bond (Section 1) - This paving system used mineral aggregate of a special gradation, granulated tire rubber produced by the shearing technique, and Chevron AC-20 asphalt containing Pave Bond anti-stripping additive. The rubber content was 3% of the weight of the mix. The rubber, supplied by Rubber Granulators Inc., was added to the aggregate in the batch plant prior to mixing.

Plus Ride is a patented design. At the time of construction, All Seasons Surfacing Inc. held the patents and provided technical assistance to both the contractor and ODOT. The choice of materials sources was left to the contractor. At present, the patents are held by, and assistance is provided by, Pavetech Inc.

Arm-R-Shield^{R} (Section 2) - This binder consisted of 80% Chevron AR-4000W asphalt, 19% ground rubber, and 1% extender oil, by weight of mix. This binder was blended in a special truck on the jobsite by Arizona Refining, Inc.

Arizona Refining, the supplier the rubber and extender oils used in

Arm-R-Shield, merged with another refiner to form International Surfacing Inc. This company can supply binders similar to Arm-R-Shield.

Fiber Pave^R 3010 (Section 3) - This additive consisted of polypropylene fibers. It was added to mix containing Chevron AC-20 in the pugmill. A fiber content of .3% of the weight of the mix was used. In 1985, this additive was made and distributed by Hercules Inc. At present it is made by Hercules and distributed by Fiberized Products, Inc.

Boni Fibers^R B (Section 4) - This additive consisted of polyester fibers. It was added to mix containing Chevron AC-20 in the pugmill. A fiber content of .25% of the weight of the mix was used. This product was, and is, made and distributed by KAPEJO Inc.

Pave Bond^R Special (Sections 1, 5, and 6) - This complex polyamine anti-strip additive was added to the AC-20 asphalt by Chevron in their Willbridge, Oregon refinery. A concentration of .5% of the asphalt weight was used. In 1985, this product was produced by Morton-Thiokol Inc. Now it is made by Morton International Inc.

Testing performed in 1986 indicate that Pave Bond was not present in all of the test sections listed in the interim report. This product is found in Sections 1, 5 and 6 (Plus Ride with Pave Bond, Class "C" with Pave Bond, and Class "C" with Pave Bond and Lime).

Lime (Sections 6,7 and 10) - Hydrated lime supplied by Ash Grove Cement Inc. was used at a concentration of 1% of the aggregate weight. Aggregate was taken from a stockpile, mixed with powdered lime and water in the pugmill of a batch plant, and placed in a separate stockpile before the paving started.

Calcium ion testing on aggregate removed from cores showed that lime treated aggregate was used as intended in Sections 6,7,and 10 (Class "C" with Pave Bond and Lime, Class "C" with Lime, and CA(P)-1 with Lime). Testing also indicated the presence of lime in lesser quantities in Sections 3 and 8 (Fiber Pave and Class "C"). The source of this contamination is not known.

AC-20 (Section 8) - This binder was used in the control section and as a base stock in all sections except Section 2, 9, and 10 (Arm-R-Shield, CA(P)-1, and CA(P)-1 with Lime). This asphalt was refined in Chevron's Willbridge, Oregon refinery.

CA(P)-1 (Sections 9 and 10) - This binder contained Chevron asphalt modified with Elvax 150 ethylene-vinyl-acetate polymer from the Du Pont Company. The blending was done in Chevron's Willbridge, Oregon refinery. A polymer concentration of 5% of the asphalt weight was used. Although Chevron considers this specification obsolete, they can still supply the binder.

Table 2.2: Product Suppliers
August 1989

Product	Supplier
AC-20 and AR4000W Asphalt	**Chevron USA Inc.**, 5501 N.W. Front Avenue, Portland, Oregon, 97208. Contact: Carl Dunlap (503) 221-7818.
Arm-R-Shield	**International Surfacing Inc.**, 6751 West Galveston, Chandler, Arizona, 85226. Contact: R.L. (Dick) Messick (602) 268-0874.
Boni Fibers	**KAPEJO Inc.**, P.O. Box 649, New Castle, Delaware, 19720-0649. Contact: Boni Philip Martinez (302) 322-4222.
Elvax 150	**Du Pont Company**, 16165 S.E. 33rd Circle, Bellevue, Washington, 98008. Contact: Debbie Scott (206) 562-5009.
Fiber Pave	**Fiberized Products Inc.**, P.O. Box 217, Hilliard, Ohio, 43026. Contact: Auriel Damin (800) 822-9140.
Hydrated Lime	**Ash Grove Cement Inc.**, P.O. Box 83007, Portland, Oregon, 97283. Contact: Jeff Mendez: (503) 224-5747.
Pave Bond	**Morton International Inc.**, 2000 West Street, Cincinatti, Ohio, 45215. Contact: Mike Haskell (513) 733-2168.
Plus Ride	**Pavetech Inc.**, P.O. Box 48122, Seattle, Washington, 98122. Contact: Michael Harrington (206) 242-6792.
Tire Rubber in Plus Ride	**Rubber Granulators Inc.**, P.O. Box 692, Snohomish, Washington, 98290. Contact: Milton Chryst (206) 353-8040.

3.0 FIELD PERFORMANCE

This chapter describes the condition of the test sections.

3.1 Overall Field Performance Rating

The Overall Field Performance Rating is based on data collected during detailed inspections carried out in the Fall of 1988 and the Fall of 1989 (Table 3.1). Although the Fall 1989 data was collected one year beyond the end of the study period, it was included because there was a significant increase in pavement distress during this last year.

Most of the criteria used in the Overall Field Performance Rating were developed specifically for this study. This rating system was different than those used by ODOT's planning and design sections. Detailed inspection results and the rating criteria are shown in Appendix A.

3.2 Rutting

In 1989, after four years of use, there was no significant rutting (Table A-1). As the traffic on this road uses traction devices in the winter, the rut depths reflect the pavement's resistance to abrasion as well as compaction and displacement.

3.3 Cracking

All cracks were mapped during the annual field inspections (Figure 3.1 and Table A-2). It was assumed that the resistance of the pavement to spalling around the cracks was due to the same materials properties that were involved in preventing ravelling. Consequently, spalling and ravelling are rated together in a different section of this chapter.

3.3.1 Transverse Cracking

For this study, transverse cracks that originated at the shoulder and extended into the travel lane were included in the count. Most of these cracks extended across the road from shoulder to shoulder (Figure 3.2a).

These transverse cracks may be caused by two sources; thermal cracking in the new overlay or reflective cracking from distress in the old roadway. Based on surveys of the original pavement, the frequency of transverse cracking was about 150 large cracks per mile, with much more numerous finer cracks. About half these cracks

Table 3.1: Overall Field Performance Rating

Fall 1988 and Fall 1989

Section	Name	1989 Rutting	1989 Transverse Cracking	1989 Wheeltrack Cracking	1989 Ravelling & Weathering	1988 Stripping	1988 Pavement Friction	1988 Roughness	1988 Deflections	Average Performance Rating
1	Plus Ride with Pave Bond	5	4	4	2	5	5	5	5	4.4
2	Arm-R-Shield	4	4	5	4	5	5	5	5	4.6
3	Fiber Pave	5	4	5	4	5	5	5	5	4.7
4	Boni Fibers	5	4	5	4	5	5	5	5	4.7
5	Class "C" with Pave Bond	5	4	5	4	5	5	5	5	4.7
6	Class "C" with Lime and Pave Bond	5	4	5	4	5	5	5	5	4.7
7	Class "C" with Lime	5	4	5	4	5	5	5	5	4.7
8	Class "C"	5	4	5	4	5	5	5	5	4.7
9	CA(P)-1	5	4	4	4	5	5	5	5	4.6
10	CA(P)-1 with Lime	5	3	4	4	5	5	5	5	4.5

Rating Criteria

5	Excellent
4	Good
3	Fair
2	Poor
1	Unsatisfactory

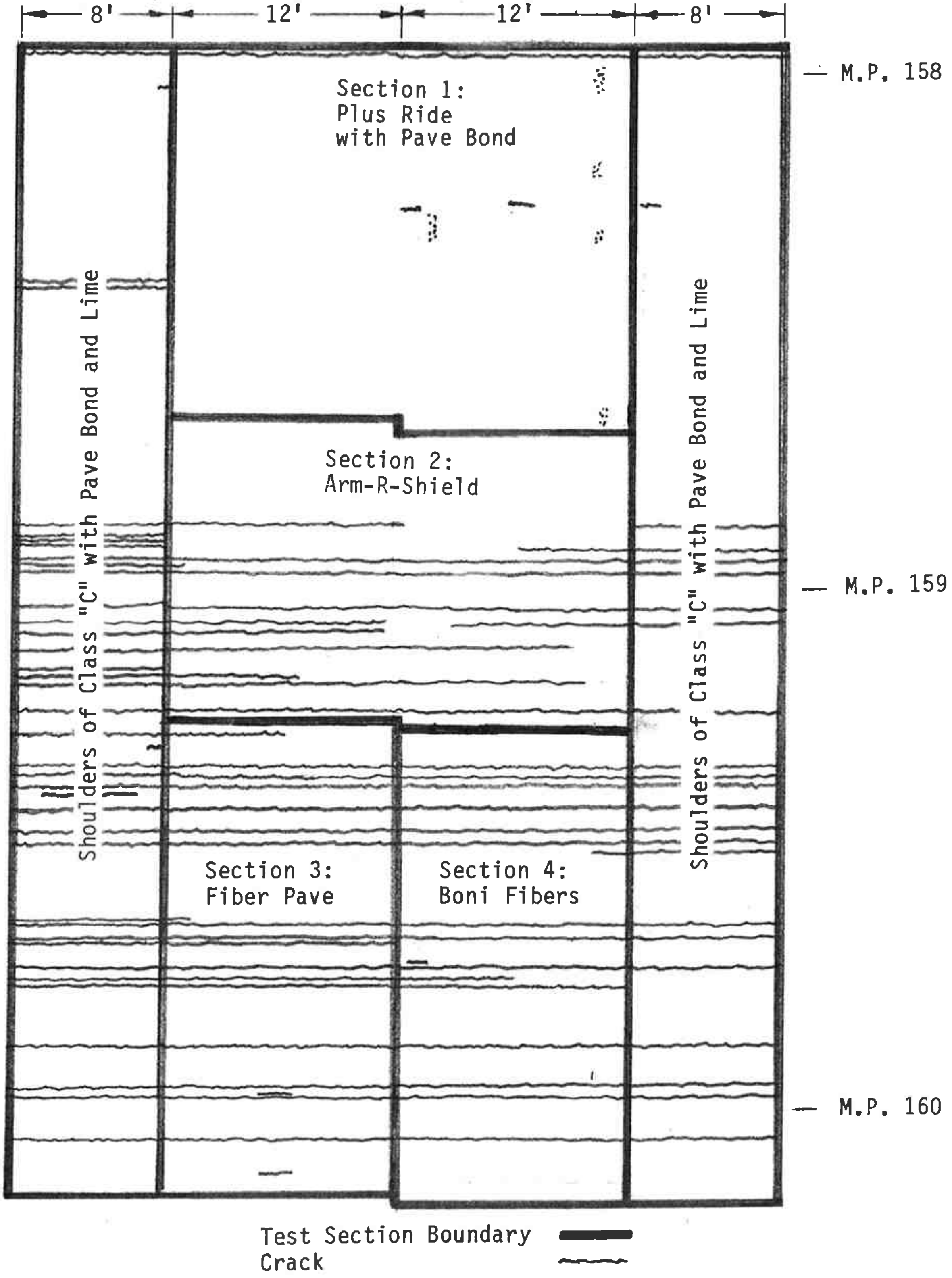


Figure 3.1a: Crack Map - October 1989

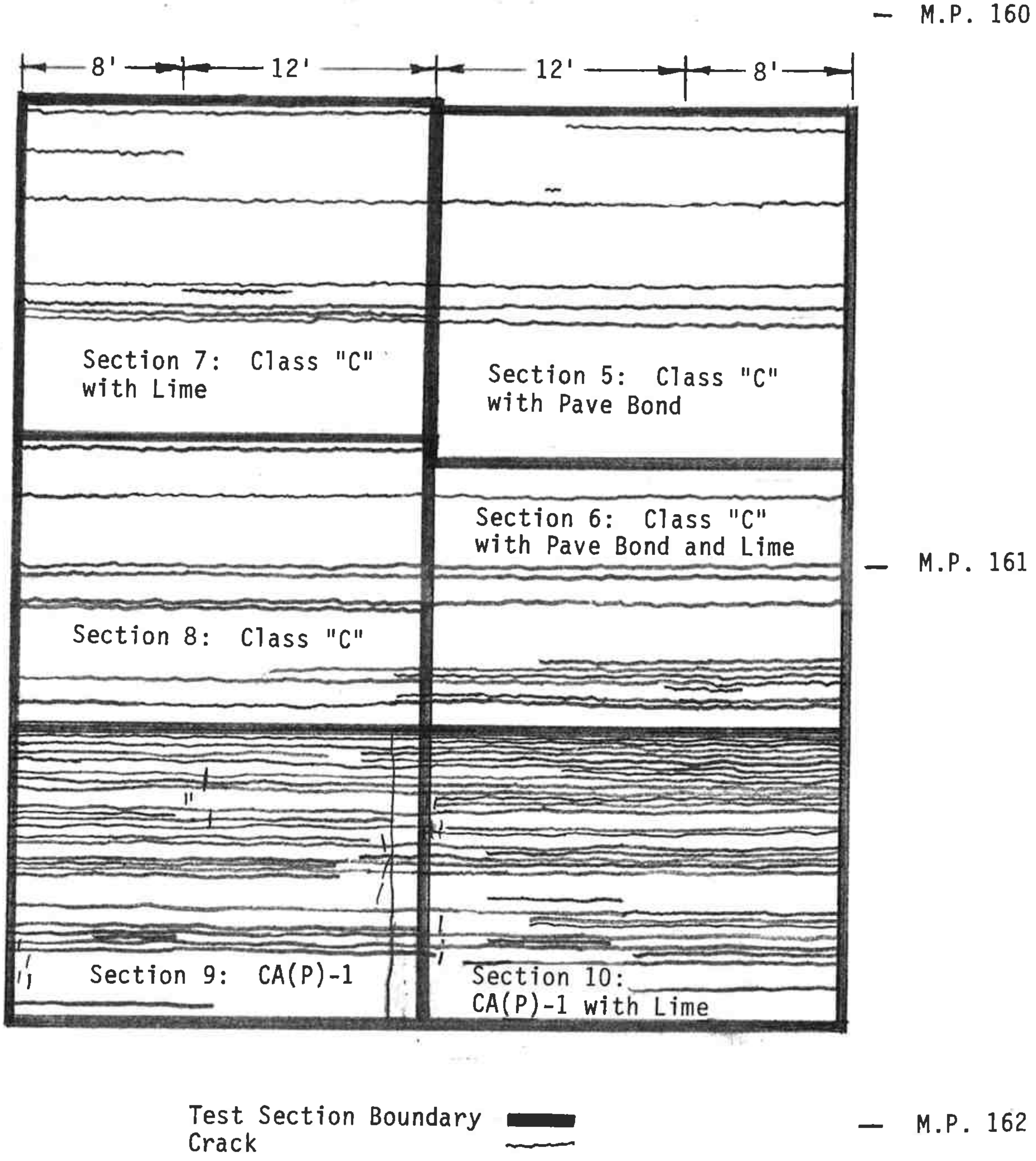
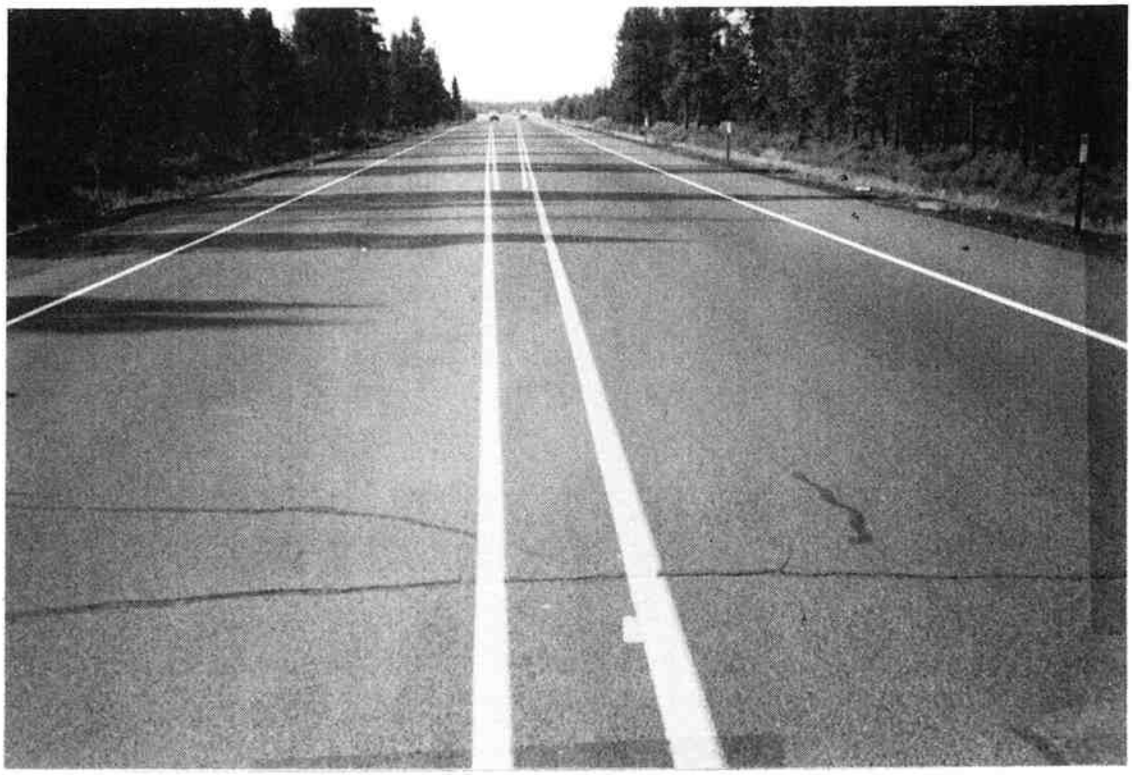


Figure 3.1b: Crack Map - October 1989



(a) Typical transverse crack in overlay during 1989. Crack has been covered with sealer.

(b) Typical transverse crack in pavement before construction.

Figure 3.2: Pavement Distress - Cracking

extended the full pavement width (Figure 3.2b). Although none of the sections had the crack severity or frequency of the original pavement, after four years there were major differences between the sections.

Section 1 (Plus Ride with Pave Bond) had been excellent at resisting transverse cracking. Unlike the other sections which had transverse cracking as early as the first winter, this section had none of this type of cracking for the first three years.

Throughout this project, there were many more cracks on the shoulder than in the travel lanes. On Sections 1,2,3,and 4 (Plus Ride with Pave Bond, Arm-R-Shield, Fiber Pave, and Boni Fibers) the shoulders were made using Class "C" mix with Lime and Pave Bond. On these sections many transverse cracks in the shoulders met, but did not enter, the travel lane. On the remaining six sections, the cracks that started on the shoulder progressed into the travel lane. It is suspected that the Class "C" mix on the shoulder was more susceptible to low temperature cracking than the rubber or fiber modified mixes in the travel lanes.

On Section 3 (Fiber Pave) and Section 4 (Boni Fibers) there were three and one, respectively, short one to two foot long transverse cracks in the center of the travel lane. Based on the location of these cracks, this distress may have been large transverse cracks in the old pavement reflecting through the overlay.

3.3.2 Wheeltrack Cracking

Longitudinal cracking in the wheeltracks was included in this rating. This cracking is often associated with pavement fatigue. The following forms of cracking, even if they were in the wheelpath, were not included in the rating: transverse thermal cracking, reflective cracking, shrinkage cracking, and longitudinal cracking over joints between pavement panels.

On Section 9 (CA(P)-1), in the Spring of 1988 there was one longitudinal crack extending the complete length of the inner wheelpath. In addition, there were several longitudinal cracks within and adjacent to the outer wheelpath. This distress was investigated in detail in 1988. Coring revealed that these cracks were not reflective and were limited to the wearing course. The cracks appeared to be load related distress due to uneven support provided by the cracked and ravelled pavement of the earlier overlays. In addition, cold temperature fatigue testing suggested that the comparatively brittle nature of the CA(P)-1 pavement may have contributed to the cracking, as discussed in Chapter 4 [3].

3.3.3 Other Cracking

Hairline transverse cracks approximately 1 to 2 feet long were noted in scattered sections near the centerline and in the inner wheelpaths of Sections 5,6,7,and 8. These were the Class"C" sections with and without Pave Bond and/or lime. These cracks may be due to pavement shrinkage or thermal fatigue.

Cracks along the seams where the panels joined were present, but not recorded, in this study. As pavements using different additives were adjacent to each other throughout the test sections, it was hard to attribute cracks at panel joints to properties of any particular products.

3.4 Ravelling and Weathering

Ravelling and weathering were rated by visual inspection (Table A-3). Ravelling was rated as both the loss of coarse aggregate from throughout the roadway surface and spalling around the edges of cracking. Weathering was the considered to be the loss of binder and fine aggregate.

On Section 1 (Plus Ride with Pave Bond), there was very slight ravelling throughout the wheeltracks with a sporadic loss of coarse aggregate (Figure 3.3a). About 6% of the total wheeltrack length was moderately ravelled, with the north and south ends of the outer northbound wheeltrack having the most distress. In these moderately ravelled areas the surface erosion was 1/2 to 3/4 inches deep due to the loss of aggregate and fines. The exposed surface was cracked (Figure 3.3b). This ravelling was getting worse year-by-year.

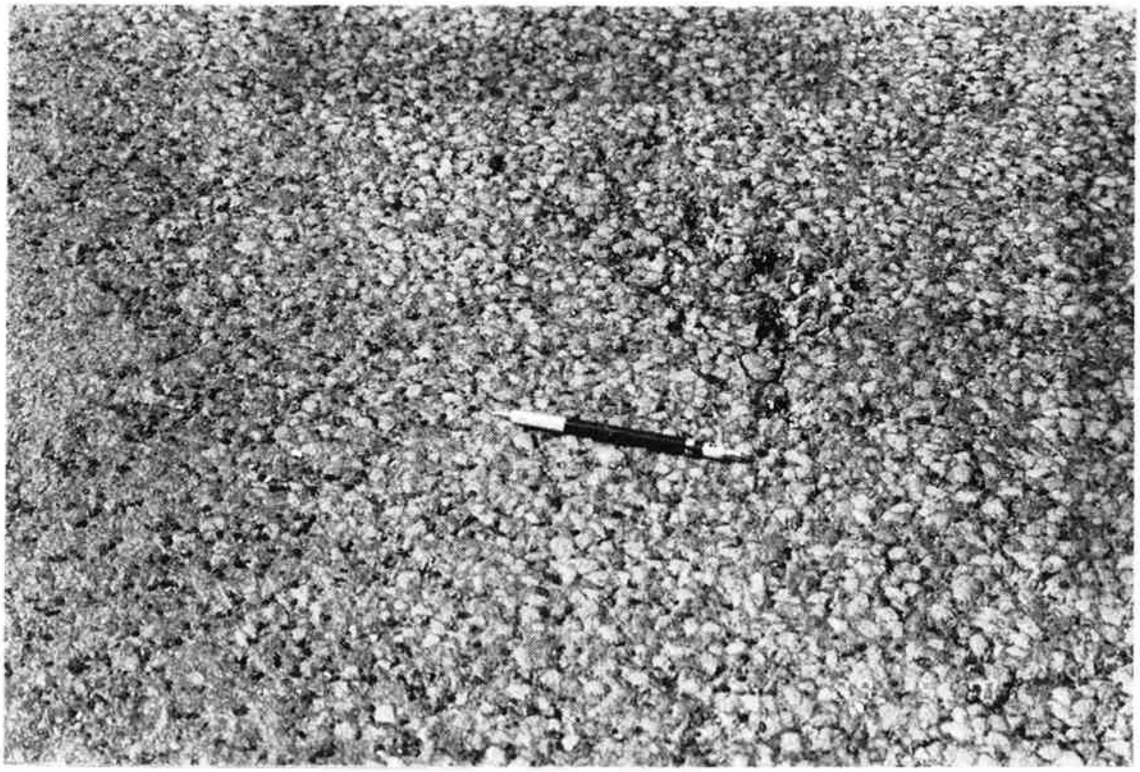
Over the entire surface there was weathering to a depth of 1/4 the coarse aggregate size. Within these small pits there were exposed pieces of rubber. Most of this weathering occurred during the first year.

All other sections had no ravelling and little weathering.

3.5 Stripping

Stripping was determined by examining cores broken during the 1988 fatigue test (Table A-4). The percentage of the aggregate surface not covered by asphalt was estimated through visual inspection.

The only core that had any exposed aggregate was from Section 8 (Class "C").



(a) Typical wheeltrack distress in 1989. Rubber particles appear as small dark spots. Ravelling is near pencil.

(b) Cracking and ravelling typical of 6% of wheeltrack length. Pits and cracks have retained moisture and appear as dark areas.

Figure 3.3: Pavement distress - Plus Ride with Pave Bond Section

3.6 Pavement Friction

All friction testing was done at speeds near 40 mph in the left wheel path (Table A-5) using a K. J. Law trailer. The data from these tests were converted to standard 40 mph friction numbers (FN_{40}) using correlation equations. The test methods, calibration techniques, and equipment conformed to AASHTO T 242-84. According to the FHWA, minimum friction numbers of 50 and 37 are needed for curves and tangents, respectively, on this 55 mph road [4].

Throughout the duration of this study, there was little difference in skid resistance among the sections. In addition, all of the test pavements had values higher than the FHWA's recommended minimums as well as the original pavement's average FN_{40} of 51. At two years of pavement life, all sections had their highest friction numbers.

Although not directly related to pavement friction, Section 1 (Plus Ride with Pave Bond) did shed ice better than the other sections. This may have given this section a comparatively high frictional resistance in icy weather. During snowplowing, packed snow and ice tended to separate from this pavement more readily than in the other sections. On this particular test section, this advantage did not reduce plowing costs significantly, as the reduction in ice was not complete enough to reduce the number of passes needed to clear the road. In addition, this area has many light and dry snowfalls. Unlike an area with heavy snows, the problem of breaking large amounts of wet snow and ice off of the road by a pass of a snowplow seldom occurs.

3.7 Pavement Roughness

The roughness, or ride, of the pavement was measured with a Mays ride meter mounted in a trailer.

During the study period, the Mays meter was not calibrated to the International Roughness Index (IRI). Consequently, the inches per mile roughness figures in Table A-6 are not be converted to commonly used IRI values. However, all measurements were made using the same machine with speed corrected to 50 mph and temperature corrected to 70°F using the same equations. As a result, the ride data in this report is useful for comparing both the relative roughness and changes in roughness of the test sections.

All sections were "smooth" based on the ODOT paving award criteria. In addition, when the roughness measurements were compared, there was little change in any of the test section's ride during the study period. As a result, all sections were "Excellent" in the Overall Field Performance Rating.

3.8 Deflections

Deflections were measured with a Dynaflect pavement deflection measuring system in the Fall of each year of the study (Figure 3.4).

Changes in deflection were considered an indicator of increases in pavement distress. As none of the section's deflections had increased significantly since construction, all pavements were "Excellent" in the Overall Field Performance Rating.

The deflections for Section 7 (Class "C" with Lime), and Section 9 (CA(P)-1) were higher than the rest of the project. This indicates that these sections are supported by a relatively weak base and may fail earlier due to lack of support.

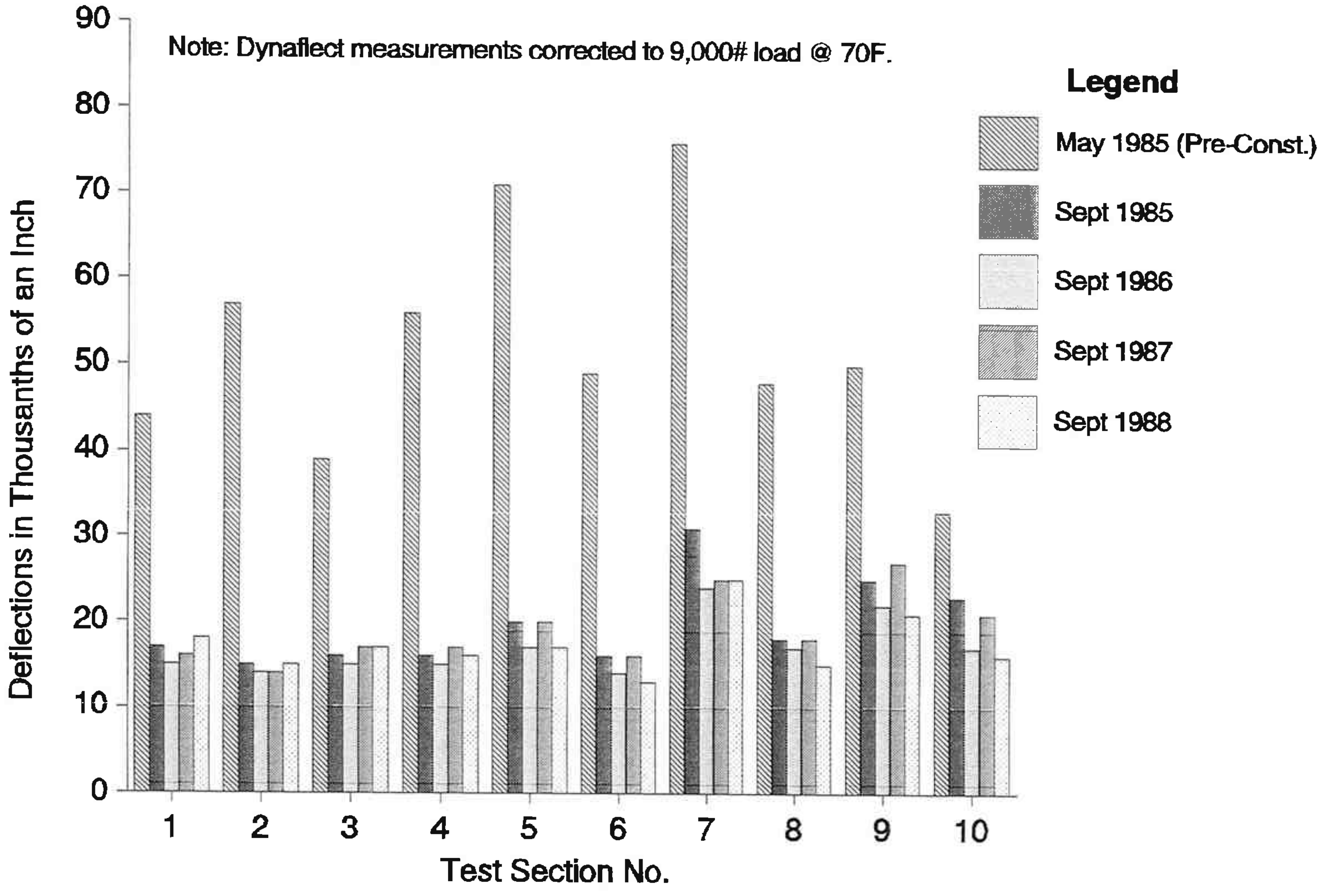
One of the goals of this project's pavement design was to reduce the deflections after construction to less than .010 inches. These low deflections were needed to assure that the overlay would last through the 20 year design life. After construction, the average pavement deflection was near .020 in. These higher deflections may have been due to the relatively resilient pumice subgrade common to this region. Consequently, this overlay may not last for the intended design life.

3.9 Summary

During the four year study period, all of the test and control sections have resisted rutting, stripping, loss of pavement friction, deterioration of ride, and increases in deflection. However, among the test sections there have been differences in resistance to cracking and ravelling.

The Plus Ride with Pave Bond section has been superior to all other sections in resisting the transverse cracking that usually occurs on dense graded pavements in this part of Oregon. In contrast, the CA(P)-1 pavements have been comparatively poor at resisting this type of distress. In addition, one of the CA(P)-1 pavements was the only section with significant longitudinal cracking in the wheelpath. All of the other sections have performed similar to the control section.

The Plus Ride with Pave Bond section has been the only section with ravelling. While this distress has not affected the section's ride during the study period, this aggregate loss has been worsening year by year.



Note: Dynaflect measurements corrected to 9,000# load @ 70F.

Figure 3.4: Pavement Deflections in Outer Wheeltrack

4.0 MATERIALS PROPERTIES

This chapter discusses the laboratory test methods and the results of the tests performed on materials used in the wearing course.

The ODOT obtained samples of loose hot mix from behind the paver. One portion of this mix supplied material for ODOT binder tests (Table B-1). A second portion of this mix was tested by Chevron for binder and mix properties (Table B-2). A third portion of this mix was made into five 4-inch diameter laboratory fabricated briquets. The first briquet was tested by ODOT for both void contents and Hveem stabilities at first and second compaction (Tables B-3 and B-9). The second briquet was tested was tested by ODOT for resilient modulus (Table B-4). The third and fourth briquets were tested by ODOT for the Index of Retained Strength (Table B-6). The fifth briquet was tested by Oregon State University (OSU) for resilient modulus and fatigue (Tables B-7 and B-8).

The ODOT removed four 4-inch diameter and two 6-inch diameter cores from the outer wheeltracks of the travel lane just after construction and at annual intervals. The 4-inch cores were tested directly. The first core was tested by ODOT for void contents, both in-place and recompacted (Table B-3). The second core was tested by ODOT for resilient modulus (Table B-5). The third and fourth cores were tested by OSU for resilient modulus and fatigue (Tables B-7 and B-8).

The 6-inch cores were heated and the cut aggregate and the binder attached to this aggregate was removed. The remaining aggregate and binder was mixed together and then divided into three parts. The first part supplied material for the ODOT binder tests (Table B-1). The second part provided material for ODOT gradation and binder content tests (not shown). The third part was fabricated into two 4-inch briquets. The first briquet was tested by ODOT for both voids and Hveem stabilities at first and second compaction (Tables B-3 and B-9). The second briquet was tested by ODOT for resilient modulus (Table B-4).

4.1 Binders

The binder properties discussed are: viscosity, temperature susceptibility, and age hardening.

In this report, "binder" generally refers to all materials within the pavement matrix except mineral aggregate. This could include asphalt cement, rubber particles - both coarse and fine, fibers, anti-strip additives, any lime or lime components dissolved or suspended in the binder, polymers, etc. However, when the binder contained rubber particles, fibers, or particulate lime, the filtering in the recovery process removed this undissolved material (Table 4.1). As a result, the behavior of the recovered binder used

Table 4.1: Binder Materials Removed During Recoveries

Section	Name	Binder Material Removed During Recovery	Material in Recovered Binder
1	Plus Ride with Pave Bond	Granulated rubber.	Asphalt. Any rubber dissolved in the asphalt. Pave Bond.
2	Arm-R-Shield	Ground rubber.	Asphalt. Rubber dissolved in the asphalt. Extender oils.
3	Fiber Pave	Fibers.	Asphalt.
4	Boni Fibers	Fibers.	Asphalt.
5	Class "C" with Pave Bond	None.	Asphalt. Pave Bond.
6	Class "C" with Lime and Pave Bond	Particulate lime.	Asphalt. Any lime components dissolved in the asphalt. Pave Bond
7	Class "C" with Lime	Particulate lime.	Asphalt. Any lime components dissolved in the asphalt.
8	Class "C"	None.	Asphalt.
9	CA(P)-1	None.	Asphalt. Polymer.
10	CA(P)-1 with Lime	Particulate lime.	Asphalt. Polymer. Any lime components dissolved in the asphalt.

in these tests may not be representative of how the binder would behave in place.

The binder was obtained by the Abson method of vacuum recovery using trichloroethylene (OSHD TM 314) [6]. This procedure was a modified version of AASHTO T 164-D and T 170.

The 100 gram penetration test used a 50 gram weight on a 50 gram spindle for a 5 second duration at 77°F (AASHTO T 49). The absolute viscosity test used 30 cm Hg of vacuum at 140°F (AASHTO T 202). The kinematic viscosity test was run at 275°F (AASHTO T 201).

4.1.1 Viscosity

The consistency of the recovered binder was examined using conventional penetration and viscosity tests. The following binder characteristics are observed:

1) The binders with rubber and polymer additives were softer than the conventional AC-20 between 77°F and 140°F (Figure 4.1 a, b, h, and i). This temperature range covers the daily high temperatures that occur on this road in the summer. The greatest overall softening occurred with the Plus Ride binder.

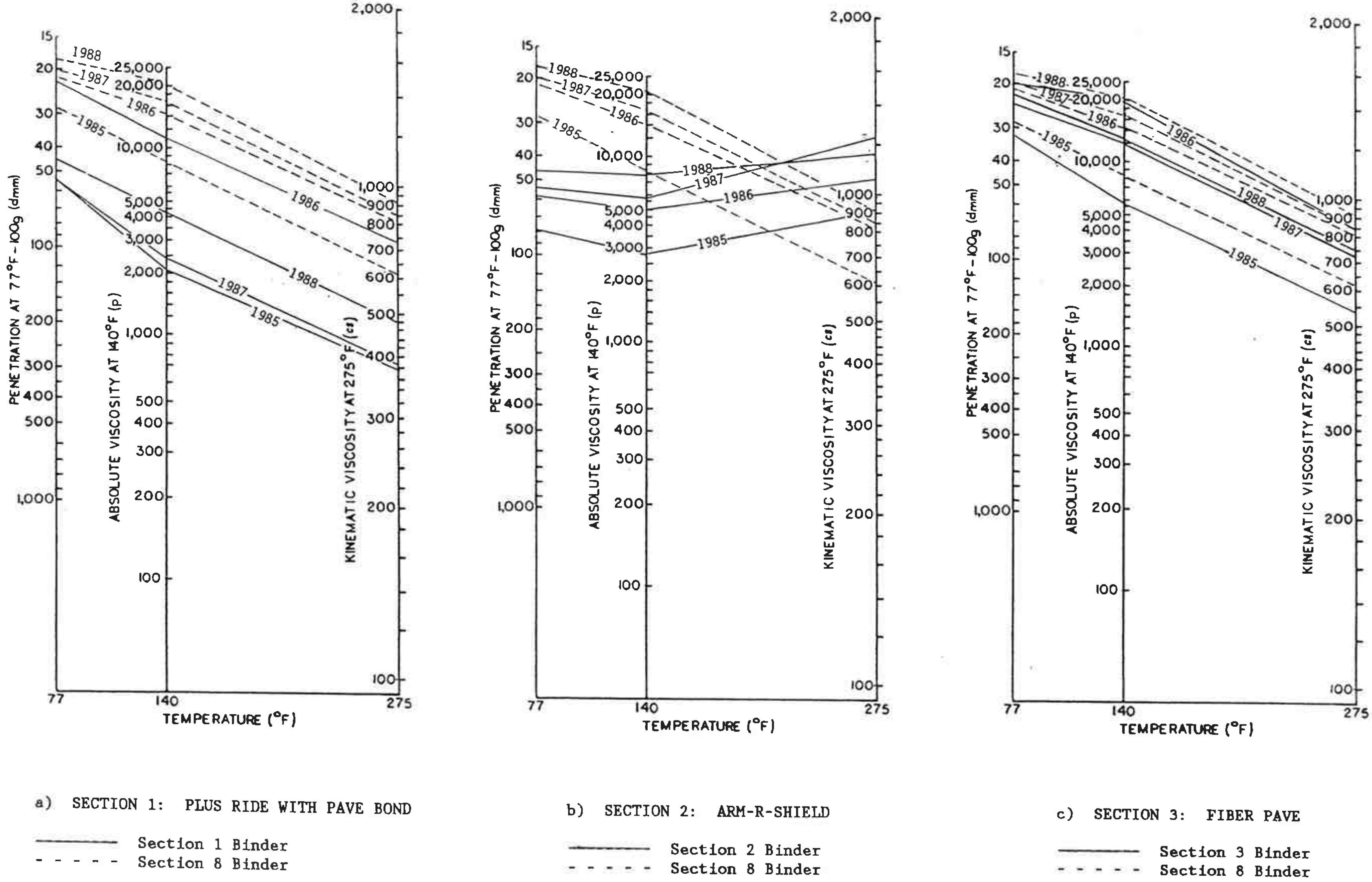
2) The addition of the anti-strip additives Pave Bond, lime, and Pave Bond and lime together appeared to lower the viscosity of the AC-20 base asphalt (Figures 4.1 e, f, and g).

4.1.2 Temperature Susceptibility

The temperature susceptibility of each binder is shown by the slope of the temperature-viscosity curves in Figure 4.1. On the temperature-viscosity graphs used in this study, conventional asphalt cements usually have straight and downward sloping curves. The following binder characteristics are noted:

1) The Arm-R-Shield and the two CA(P)-1 binders did not soften as much at elevated temperatures as the conventional AC-20 (Figures 4.1 b, h, and i). This behavior is commonly seen in binders containing rubbers or other polymers in solution.

2) The addition of the Plus Ride rubber, Fiber Pave and Boni Fiber fibers, Pave Bond, lime, or Pave Bond and lime together, had little effect on the slopes of the temperature-viscosity curves (Figures 4.1 a, c, d, e, f, and g).



a) SECTION 1: PLUS RIDE WITH PAVE BOND

——— Section 1 Binder
- - - - - Section 8 Binder

b) SECTION 2: ARM-R-SHIELD

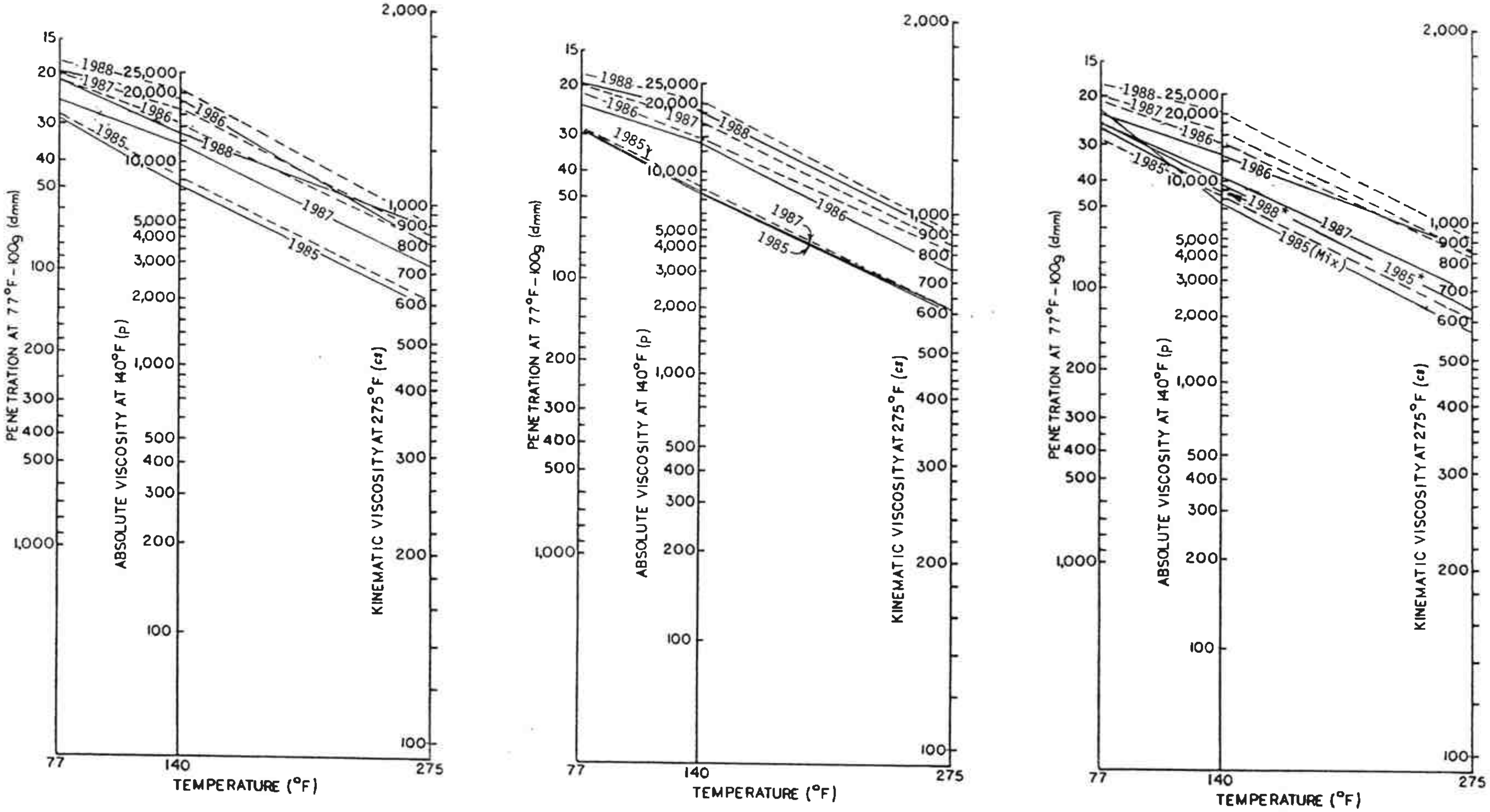
——— Section 2 Binder
- - - - - Section 8 Binder

c) SECTION 3: FIBER PAVE

——— Section 3 Binder
- - - - - Section 8 Binder

All binder recovered from cores.

Figure 4.1: Temperature - Viscosity Relationships



d) SECTION 4: BONI FIBERS

—— Section 4 Binder
- - - - - Section 8 Binder

e) SECTION 5: CLASS "C" WITH WITH PAVE BOND

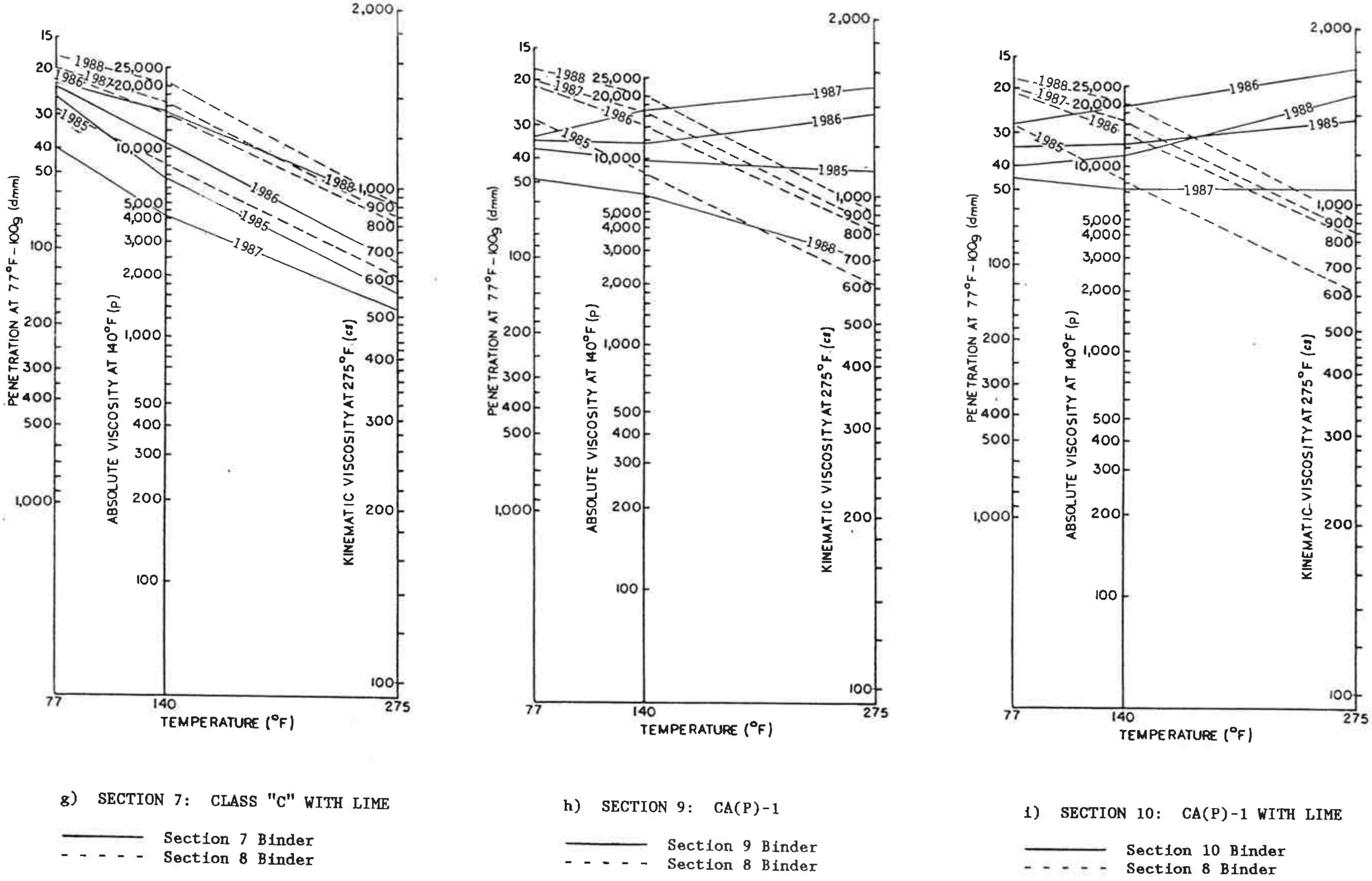
—— Section 5 Binder
- - - - - Section 8 Binder

f) SECTION 6: CLASS "C" WITH PAVE BOND AND LIME

—— Section 6 Binder
- - - - - Section 8 Binder

All binder recovered from cores.

Figure 4.1: Temperature - Viscosity Relationships



g) SECTION 7: CLASS "C" WITH LIME

Section 7 Binder
Section 8 Binder

h) SECTION 9: CA(P)-1

Section 9 Binder
Section 8 Binder

i) SECTION 10: CA(P)-1 WITH LIME

Section 10 Binder
Section 8 Binder

All binder recovered from cores.

Figure 4.1: Temperature - Viscosity Relationships

4.1.3 Age Hardening

The following was noted (Figures 4.1 and 4.8):

1) In most cases, a binder hardens each year as it ages. This behavior was seen in the binders on Sections 2 and 8 (Arm-R-Shield and Class "C"). On the other sections, the rate of aging was uneven. On some sections, the binder softened as time passed. To determine if this erratic aging was due to either random errors in sampling and testing or an actual change in material properties, the ODOT 77°F penetration data was compared to the OSU 73°F fatigue test results (Figure 4.8).

   For eight of the ten sections, there appeared to be a relationship between the penetration and fatigue test results. When the penetration increased or decreased over time, the fatigue life did likewise. In most cases when the binder temporarily softened between the Fall of 1986 and the Fall of 1988, the fatigue life temporarily increased (Figure 4.8 a,b,c,d,e,f, and j).

   The relationships between the results of these different tests, performed in different laboratories, and on different groups of samples, suggests that some process occurred that caused many of the binders to have inconsistent hardening rates over the study period. It is unlikely that this behavior is due entirely to errors in testing and/or sampling.

2) The CA(P)-1 binder may have been excessively aged in the mix plant. Lloyd Coyne, a consultant, offered the explanation summarized below [5].

   > The CA(P)-1 asphalt concrete was mixed at 340°F., while the conventional Class"C" material was mixed around 300°F. These elevated mix temperatures may have excessively aged the CA(P)-1. The hardening resulting from this aging is shown by the recovered binder penetration and viscosity test results (Table 4.2). Note that the binders recovered from the mix had aged much more than the rolling thin film oven (RTFC) residues of the original binders. These excessively aged and hard binders could have made the two CA(P)-1 sections susceptible to cracking.

   Chevron representatives have stated that when this project was built, they requested that these high mix temperatures be used to assure both a good bond between the binder and the aggregate and adequate workability of the polymerized mix during placement. Chevron no longer feels that these higher mix temperatures are needed. Since this project was constructed they have been mixing CA(P)-1 pavement at the same temperature as conventional asphalt concrete with no ill effects.

Table 4.2: CA(P)-1 Binder Properties:
Original, RTFC, and Recovered from Mix Samples

(Sections 9 and 10)

Test Property	Binder Recovered From Mix Samples Chevron	ODOT	Binder Before Mixing (Chevron) Original	RTFO
Pen. @ 39.2°F.	12-13	--	47	25
Pen. @ 77°F.	37-38	36-40	116	51
Visc. @ 140°F.	9739-9842	8010-10100	1852	5241
Visc. @ 275°F.	1149-1355	1040-1137	664	1098

4.2 Asphalt-Aggregate Mixture

The mixture properties discussed in this section include: void content, modulus, stripping resistance, fatigue resistance, and Hveem stability.

4.2.1. Void Contents

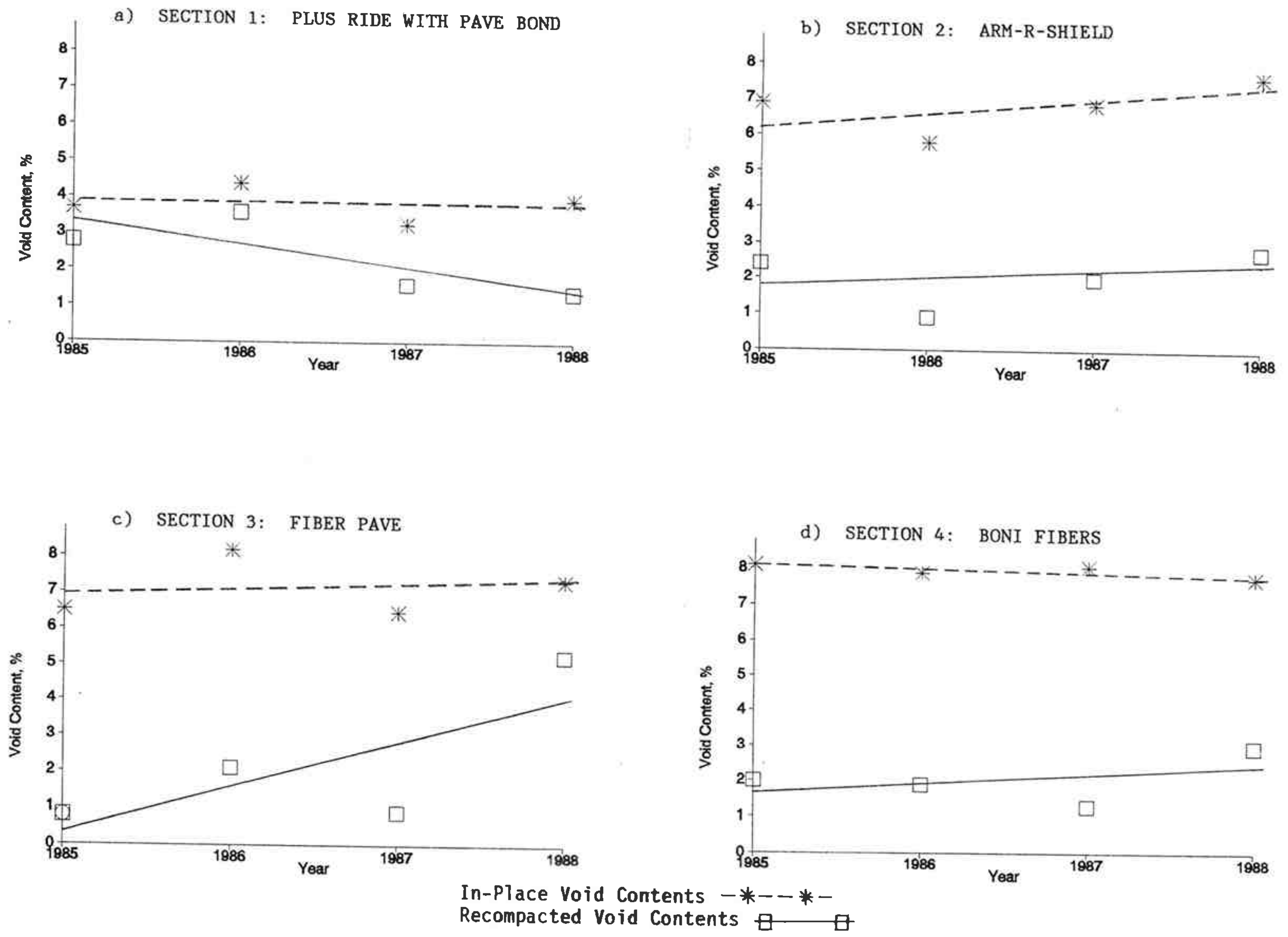
Void contents of wheeltrack cores were measured at the in-place compaction level and after recompaction using OSHD TM 310 [6]. Linear regressions were plotted through the data points (Figure 4.2). The following trends were observed:

1) All sections resisted consolidation throughout the three year study period, as shown by their level, or nearly level, in-place void content curves.

2) The pavement in the wheeltracks of Sections 5, 6, 9, and 10 (Class "C" with Pave Bond, Class "C" with Pave Bond and Lime, CA(P)-1, and CA(P)-1 with Lime) may consolidate in the future under prolonged traffic. This is shown by the recompacted void content curves (Figures 4.2 e, f, i, and j). The recompaction load was intended to simulate the consolidating effects of prolonged traffic [7]. Pavement consolidation and subsequent rutting and bleeding usually occur when the recompacted void contents are 1% or lower, based on the ODOT's experience.

4.2.2. Modulus

The stiffness of the asphalt concrete can be represented by its resistance to elastic and/or plastic deformation under slow and/or instantaneous loading. In this study, the diametral resilient modulus test was used (ASTM D-4123). This test indicates the pavement's resistance to elastic deformation under a cyclic loading. The higher the resilient modulus, the stiffer the pavement.



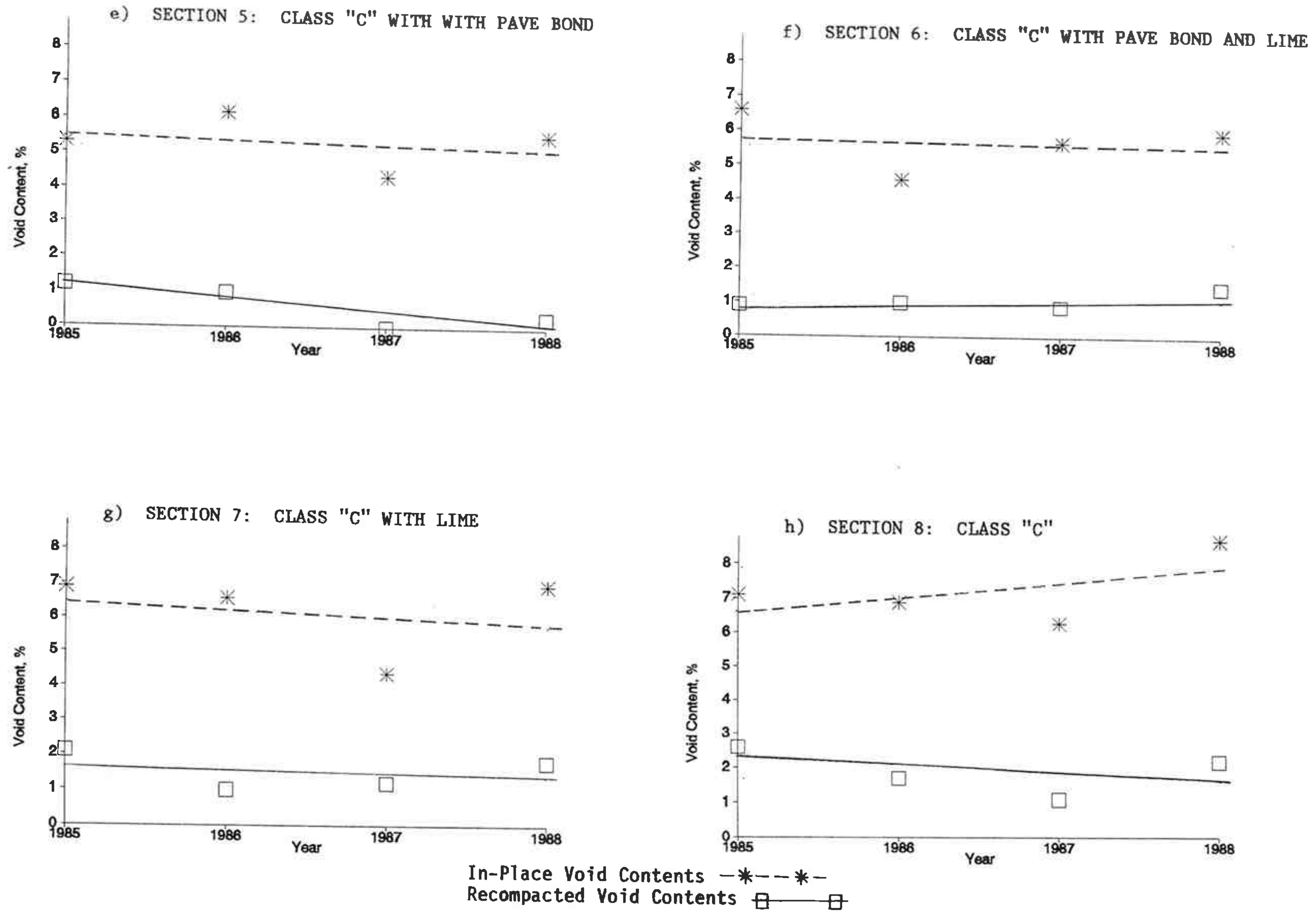
a) SECTION 1: PLUS RIDE WITH PAVE BOND

b) SECTION 2: ARM-R-SHIELD

c) SECTION 3: FIBER PAVE

d) SECTION 4: BONI FIBERS

Figure 4.2: Void Contents - Cores



e) SECTION 5: CLASS "C" WITH WITH PAVE BOND

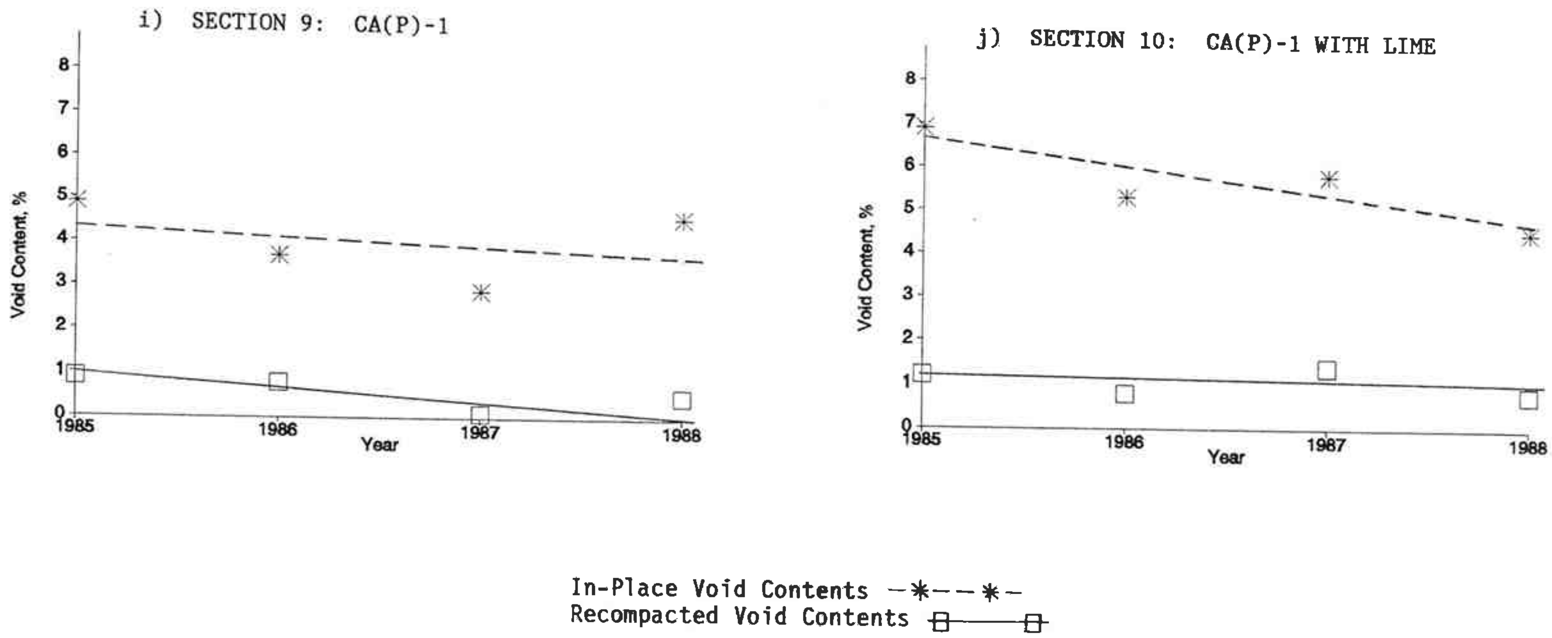
f) SECTION 6: CLASS "C" WITH PAVE BOND AND LIME

g) SECTION 7: CLASS "C" WITH LIME

h) SECTION 8: CLASS "C"

In-Place Void Contents —✳– – ✳–
Recompacted Void Contents ⊟——⊟

Figure 4.2: Void Contents - Cores


i) SECTION 9: CA(P)-1

j) SECTION 10: CA(P)-1 WITH LIME

Figure 4.2: Void Contents - Cores

Unconditioned resilient modulus tests were run by ODOT at 77°F and OSU at 73°F. The ODOT also tested the samples after conditioning using OSHD TM 315 [8]. The OSU performed resilient modulus tests using different test equipment and a slightly different method [9].

The following trends were noted (Figure 4.3):

1) The asphalt mixtures in all sections were maintaining or gaining strength over the study period, as shown by their level or rising resilient modulus curves.

2) The briquets manufactured in the laboratory out of mix from pavement cores had moduli that were much higher than the core moduli for the Class"C" sections with and without fibers (Sections 3,4,5,6,7,and 8). The briquet and core moduli were much closer when the pavements contained rubber or polymers (Sections 1,2,9,and 10).

   The higher densities of the briquets, as compared to the cores, may account for the differences in resilient moduli. For the Class"C" sections with and without fibers, the briquets were compacted to 3.2% higher void contents than the cores, on the average. For three of the other four sections, the briquets were compacted to 1.0% higher void contents than the cores. The one exception was CA(P)-1 with Lime. This had similar core and briquet moduli, and the briquets were compacted to 3% higher void contents than the cores, on the average.

3) The relatively low moduli of mixes containing some of these additives may need to be considered during the structural design of the roadway.

   As an example, the resilient modulus is used in the AASHTO structural design method for the prediction of pavement strength, and consequently in selecting pavement layer thicknesses or materials [10]. Usually, the higher the resilient modulus, the thinner the required layer thickness.

   The rubber modified pavement in Section 2 (Arm-R-Shield) had much lower resilient moduli on the average, than the other sections. Using the AASHTO method and the unconditioned resilient moduli from the ODOT test, a pavement using the Arm-R-Shield binder would require a 50% increase in pavement layer thickness in order to have the same structural strength as a conventional Class "C" pavement. The calculations are presented in Appendix C.

4.2.3. Stripping Resistance

Two tests were used in this study to predict the stripping of a

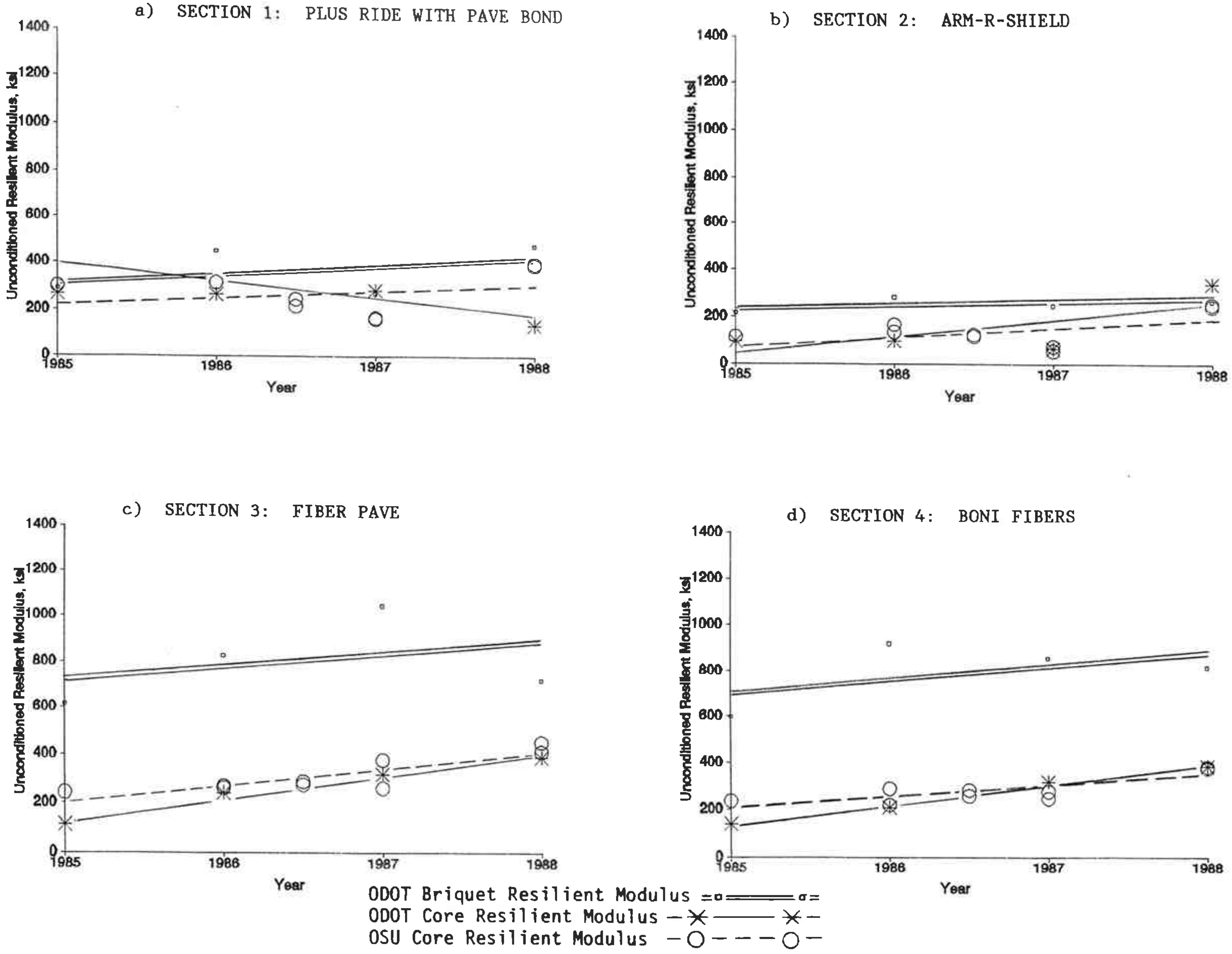
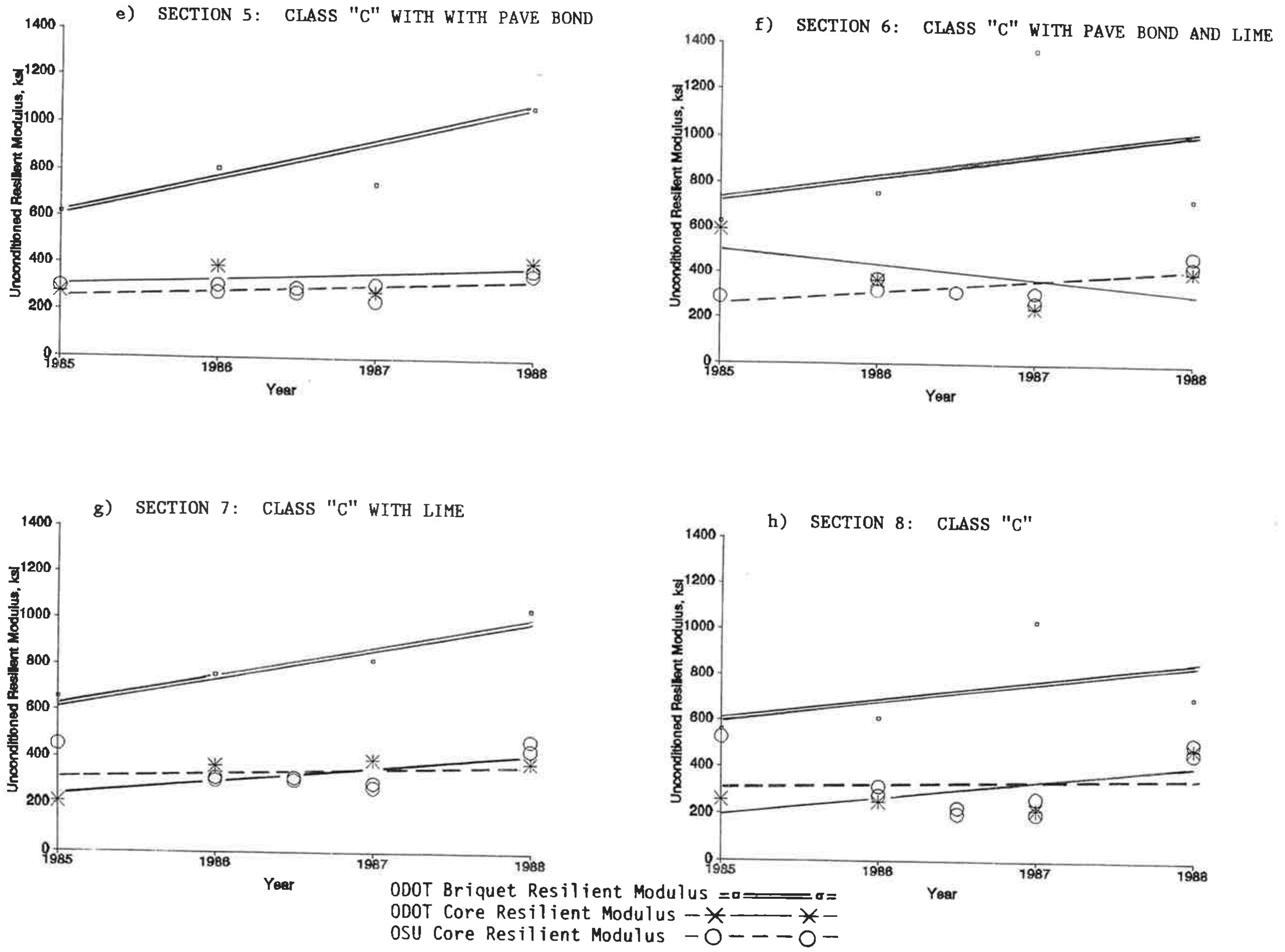


Figure 4.3: Unconditioned Resilient Moduli


e) SECTION 5: CLASS "C" WITH WITH PAVE BOND

f) SECTION 6: CLASS "C" WITH PAVE BOND AND LIME

g) SECTION 7: CLASS "C" WITH LIME

h) SECTION 8: CLASS "C"

Figure 4.3: Unconditioned Resilient Moduli

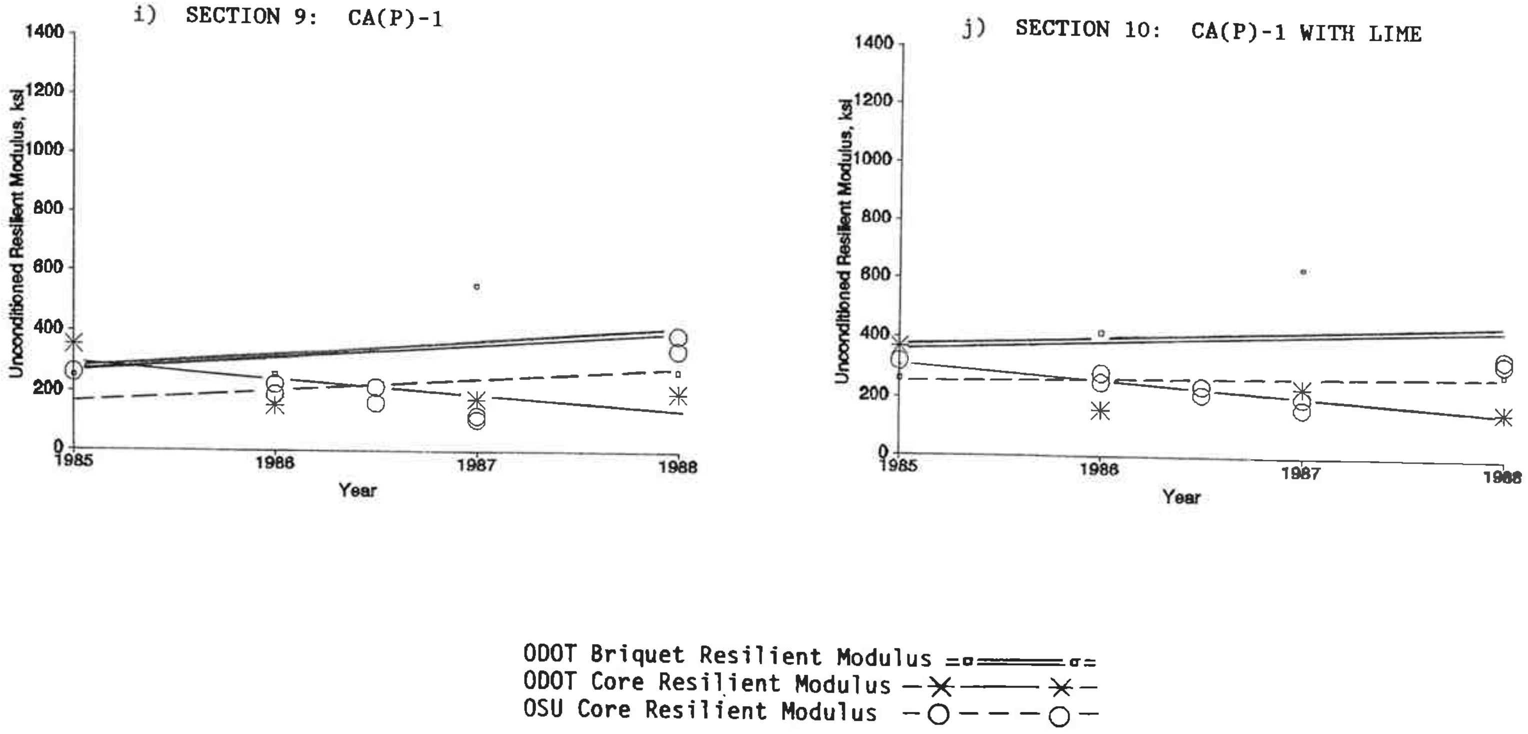


Figure 4.3: Unconditioned Resilient Moduli

binder from a pavement by water. One test was used to find the Index of Retained Strength (AASHTO T 165). The other test was a modified version of the Lottman test (OSHD TM 315) used to find the Vacuum Saturated/ Unconditioned and Freeze-Thaw/Unconditioned Resilient Modulus Ratios [8].

The Index of Retained Strength (IRS) is a measure of the effect of water on the cohesion and adhesion of compacted asphalt concrete mix samples (Figure 4.4). This test provides the ratio, in percent, of the compressive strength of a conditioned sample to the strength of an unconditioned sample. The higher the IRS, the better the pavement's resistance to stripping. The ODOT requires an IRS of 75% or higher for the wearing course job mix formula at design asphalt content [11].

In Oregon the modified Lottman test is usually performed during the mix design stage. In this test, the resilient modulus (M_r) of the same sample is measured three times. The first test, made on a sample without prior conditioning, provides the unconditioned M_r. The second test, made after the sample is saturated with water, provides the vacuum-saturated M_r. The third test, made on the sample after it is frozen and thawed, provides the freeze-thaw M_r. The ODOT requires that samples made from the job mix formula have both M_r ratios greater than or equal to .70 [11].

The ratio of the vacuum saturated to unconditioned M_r is used to estimate the susceptibility of the sample to stripping during the first four years of pavement life [12]. The ratio of the freeze-thaw to unconditioned M_r values is used to estimate the susceptibility of the sample to stripping over a longer term [12]. In both cases the higher the ratio, the better the resistance to stripping.

Based on testing of briquets made from mix sampled from behind the paver, the following trends were noted (Figure 4.4):

1) None of the briquets had an IRS lower than the ODOT required 75%. Only one of the M_r ratios was less than the ODOT required .70. This was the freeze-thaw ratio for Section 1 (Plus Ride with Pave Bond). Based on the results of this test, this section may exhibit stripping damage in the long term.

2) The Pave Bond anti-stripping agent did not significantly raise the IRS or consistently raise the M_r ratios, as shown by the data for Sections 5 and 8 (Class "C" with and without Pave Bond).

3) In general, the sections with lime had higher IRS and M_r ratios than their counterparts without lime, as shown by comparing the data for Sections 7 and 10 (Class "C" with Lime and CA(P)-1 with Lime) to Sections 8 and 9 (Class "C" and CA(P)-1).

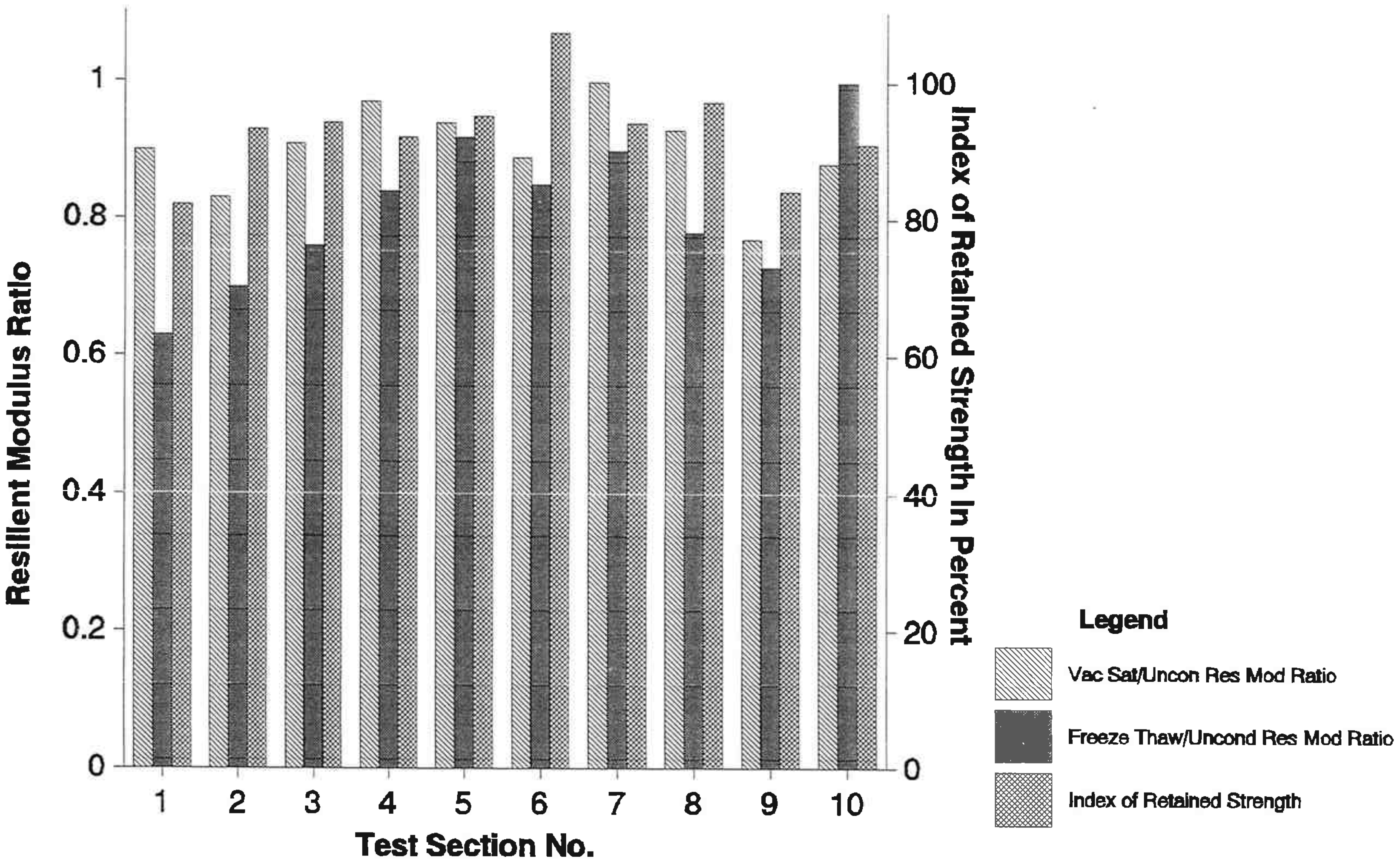


Figure 4.4: Moisture Damage Susceptibility Tests on Mix Sampled From Behind Paver

Based on the testing of briquets made from mix taken from cores throughout the study period, the following was noted (Figures 4.5 and 4.6):

1) Based on the M_r testing during the study period, no firm conclusions can be made on the susceptibility of these mixes to moisture damage. A full five years of data may be needed to determine the overall trends in stripping resistance. As noted in both this study and work by Lottman, a pavement's M_r ratios can rise and fall erratically as time passes. From examination of the curves in Lottman's study [12], a full five year study period was needed to determine overall trends in stripping resistance.

2) Many sections showed an overall increase in M_r ratios. Although this trend may be due to sampling and testing errors, the increase is similar to trends observed by Lottman, and may be temporary "field conditioning or stiffening effects" due to changes in binder properties such as aging and stiffening [12].

4.2.4 Fatigue Resistance

A diametral fatigue test developed by Oregon State University (OSU) was used to determine the pavement's resistance to fatigue [13].

In all tests the load pulse was a 1 Hertz square wave and the load duration was .1 seconds. However, there were variations in both the initial strain level and test temperature. In the summer and fall of 1985 many tests were made at 73°F and 100 microstrain. These tests gave data that could be compared to the results of prior studies on other pavements. However, at this low strain level it took an excessive number of repetitions to fail some samples. In addition, theoretical analyses of pavement structures suggested that this strain level was too low to represent the actual strain at the underside of pavement layers under truck wheel loads. As a result, the initial strain level was increased to 200 microstrain for the duration of the study.

After fatigue related distress was noted during the winter of 1988 on a test section that had good 73°F fatigue test results, the test temperature was lowered to 32°F for a series of tests in Spring 1988.

Particular care was taken over the years to assure that the same testing equipment, procedures, and calculation methods were used. However, one technician ran the 1985 tests, another did the 1986, 1987, and Spring 1988 tests, and a third did the Fall 1988 testing.

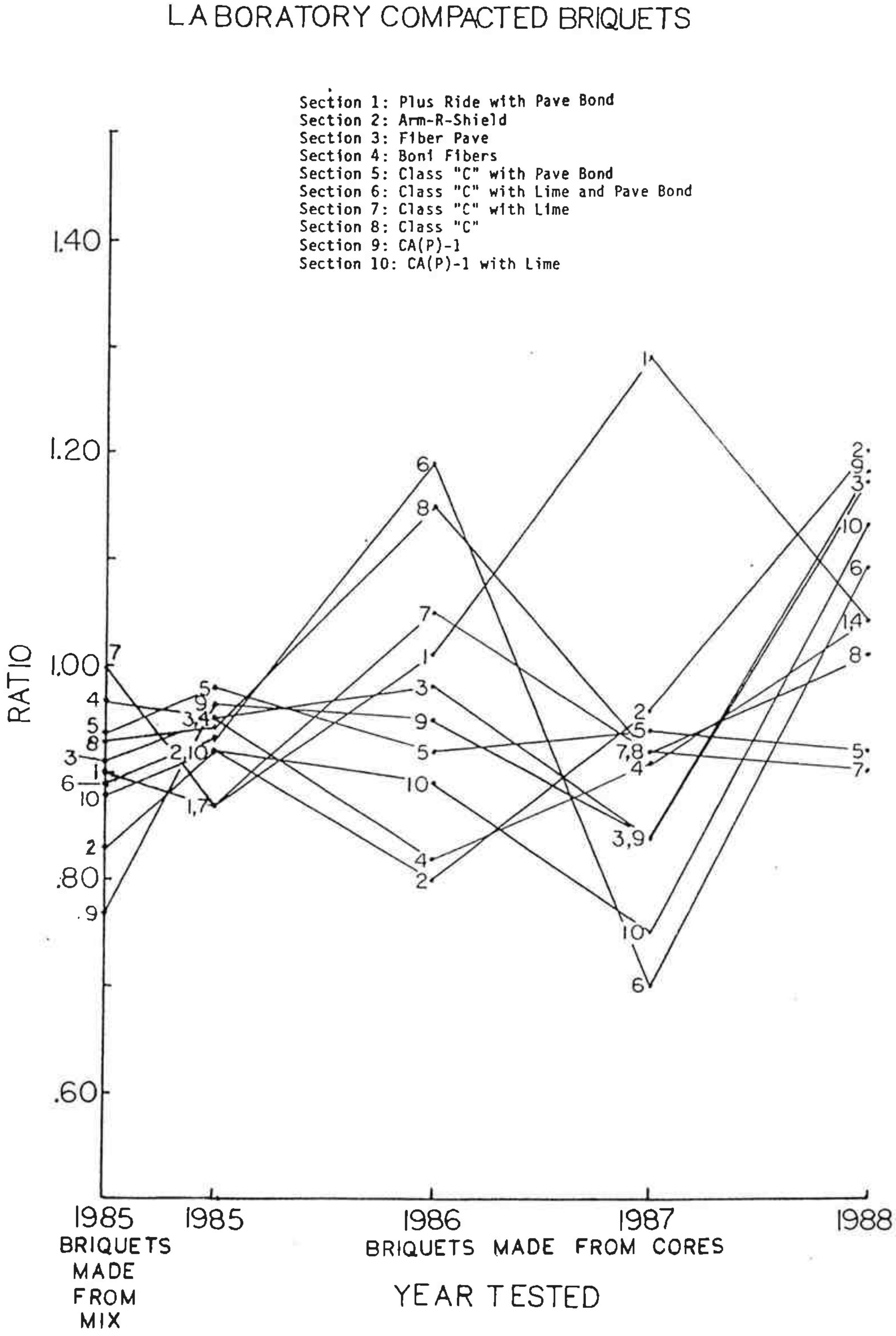


Figure 4.5: Resilient Modulus Ratios - Vacuum Saturated/Unconditioned

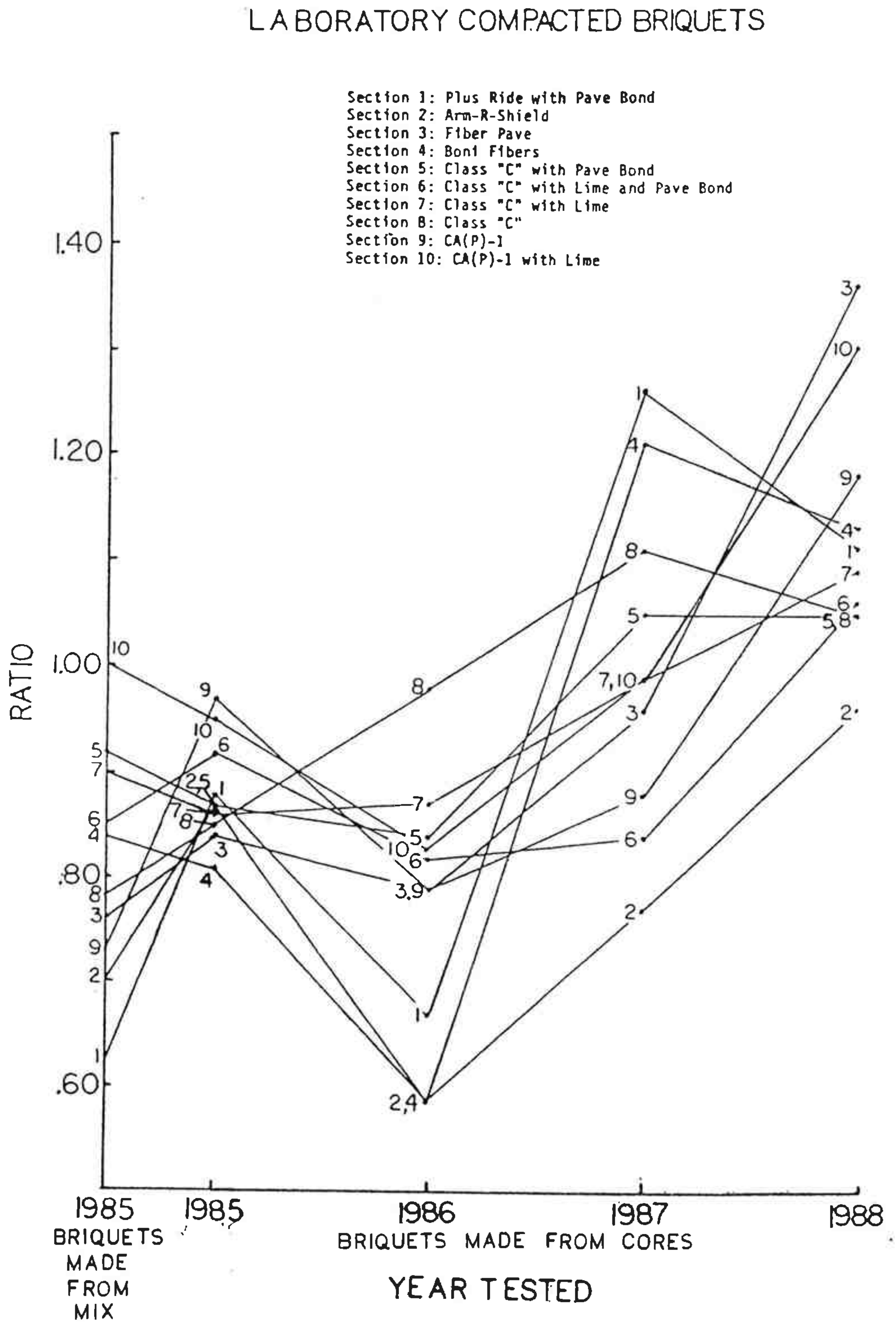


Figure 4.6: Resilient Modulus Ratios - Freeze-Thaw/Unconditioned

As a test for indicating pavements susceptible to fatigue, the following was noted:

1) The fatigue test at 73°F was a poor predictor and indicator of load related cracking. Section 9 (CA(P)-1), at 36,600 repetitions, had the second highest fatigue test results among the mix briquets that were tested (Figure 4.7). However, this pavement had the only extensive wheeltrack cracking. In addition, throughout the study the CA(P)-1 sections usually had the highest core fatigue test results (Figure 4.8). However, these sections had the highest amounts of both transverse and wheeltrack cracking.

2) The increase in fatigue life of most sections during the Fall of 1987 may be due to temporary binder softening (Figure 4.8). The fatigue test results may be related to changes in the binder viscosity, as detailed in Section 4.1.3 of this chapter. In most cases, when the binders softened, the fatigue life increased.

3) The addition of fibers did not significantly improve fatigue test results, as seen by comparing the curves of Sections 3 and 4 (Fiber Pave and Boni Fibers) with the other sections (Figure 4.8).

4) The cold temperature fatigue test at 32°F on cores was a poor indicator of pavements susceptible to fatigue distress. Although Section 9 (CA(P)-1) had poor cold temperature fatigue results and excessive wheeltrack cracking, Section 6 (Class "C" with Pave Bond and Lime) had low cold temperature test results and no wheeltrack cracking (Figure 4.9).

5) On this project the cold temperature fatigue test on cores had poor repeatability. There was more scatter among the results of the two tests on each section than there was between the individual sections (Figure 4.9). For the individual sections, each of the two tests varied an average of 4,500 repetitions from the mean value for the test section. For the eight sections that were tested, the mean value of each test section varied an average of 3,300 repetitions from the mean value of all of the test sections.

4.2.5 Hveem Stability

Hveem stabilities are used in ODOT mix designs. The first and second compaction Hveem stabilities are intended to predict pavement characteristics after initial compaction and after years of traffic loading, respectively [11].

Of the briquets made from mix sampled from behind the paver, only the Plus Ride sample had a first compaction stability lower than the

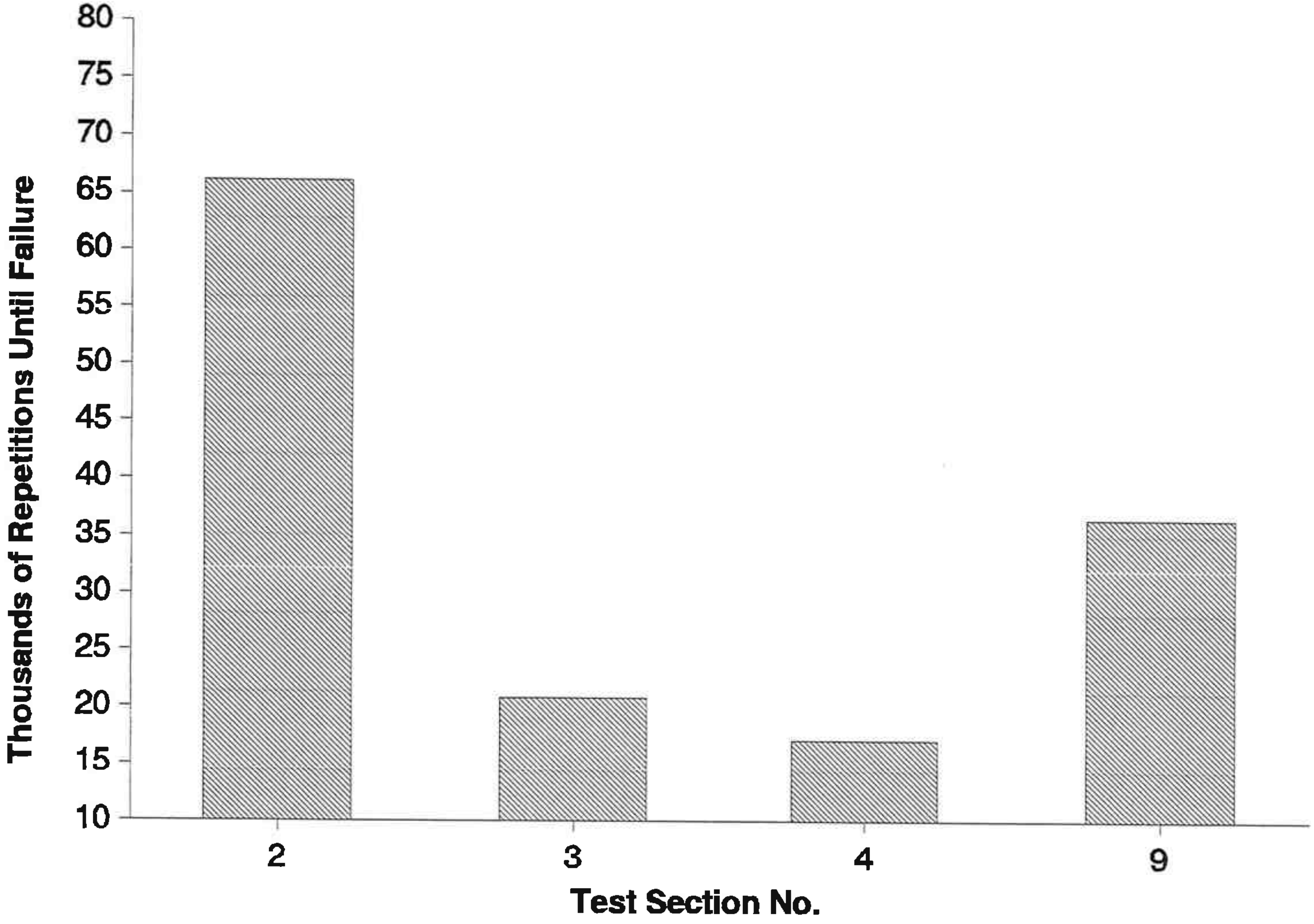
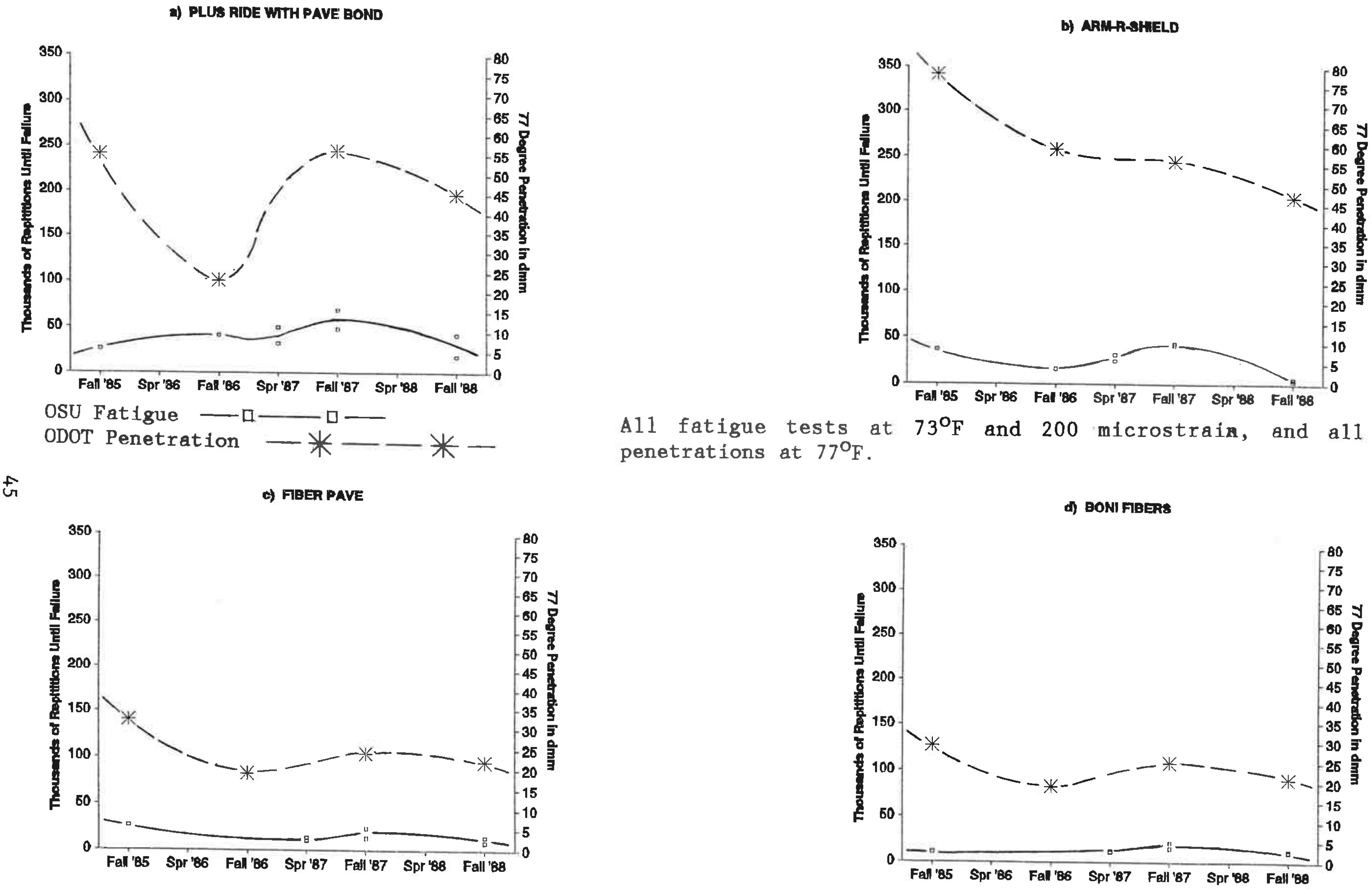
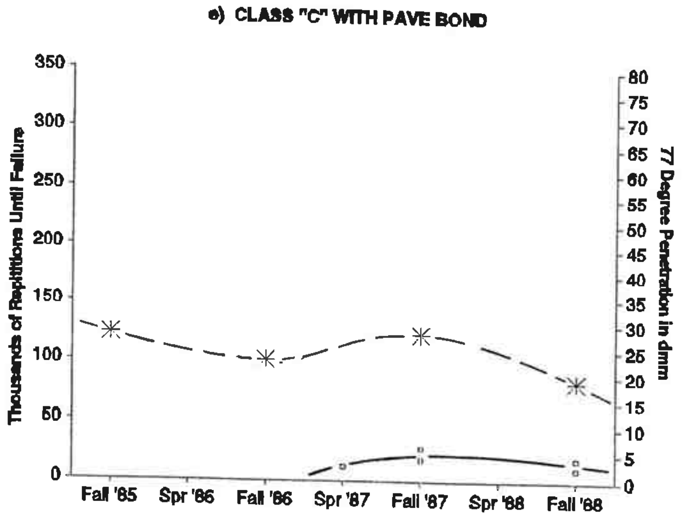


Figure 4.7: OSU Fatigue Tests Made on Briquets Made Out of Mix Sampled from Behind Paver

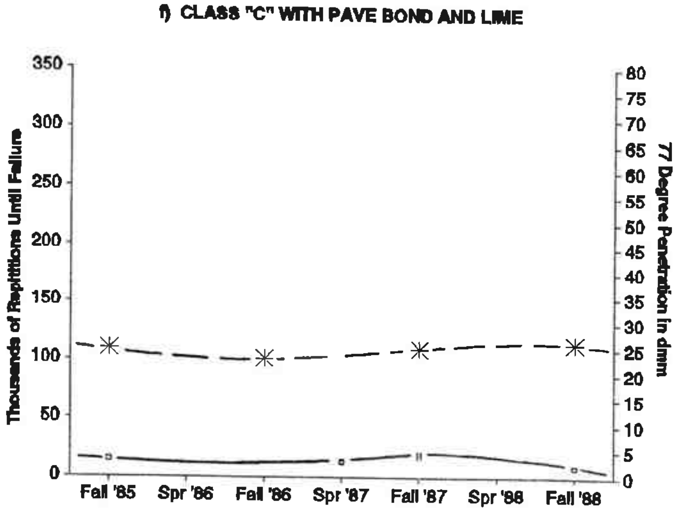


All fatigue tests at 73^{o}F and 200 microstrain, and all penetrations at 77^{o}F.

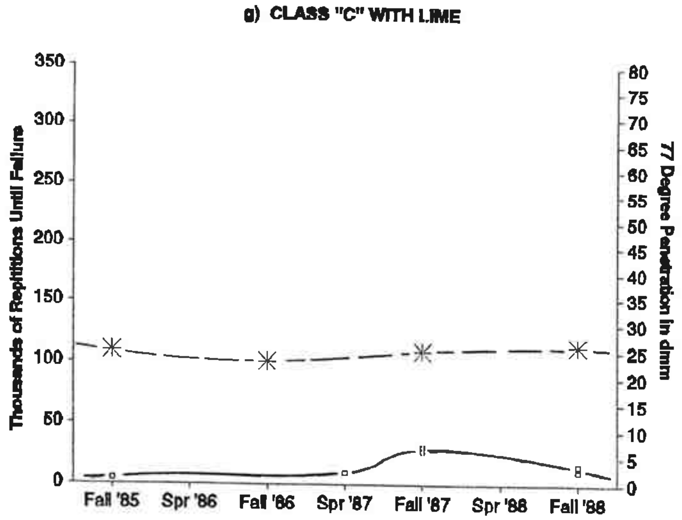
Figure 4.8: OSU Fatigue Tests on Cores and ODOT Penetration Tests


e) CLASS "C" WITH PAVE BOND

OSU Fatigue —□——□—
ODOT Penetration —✳— — —✳—


f) CLASS "C" WITH PAVE BOND AND LIME

All fatigue tests at 73°F and 200 microstrain, and all penetrations at 77°F.


g) CLASS "C" WITH LIME

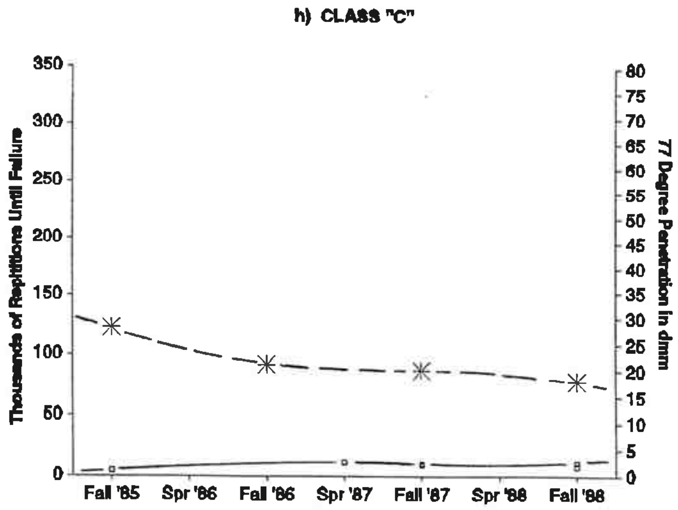
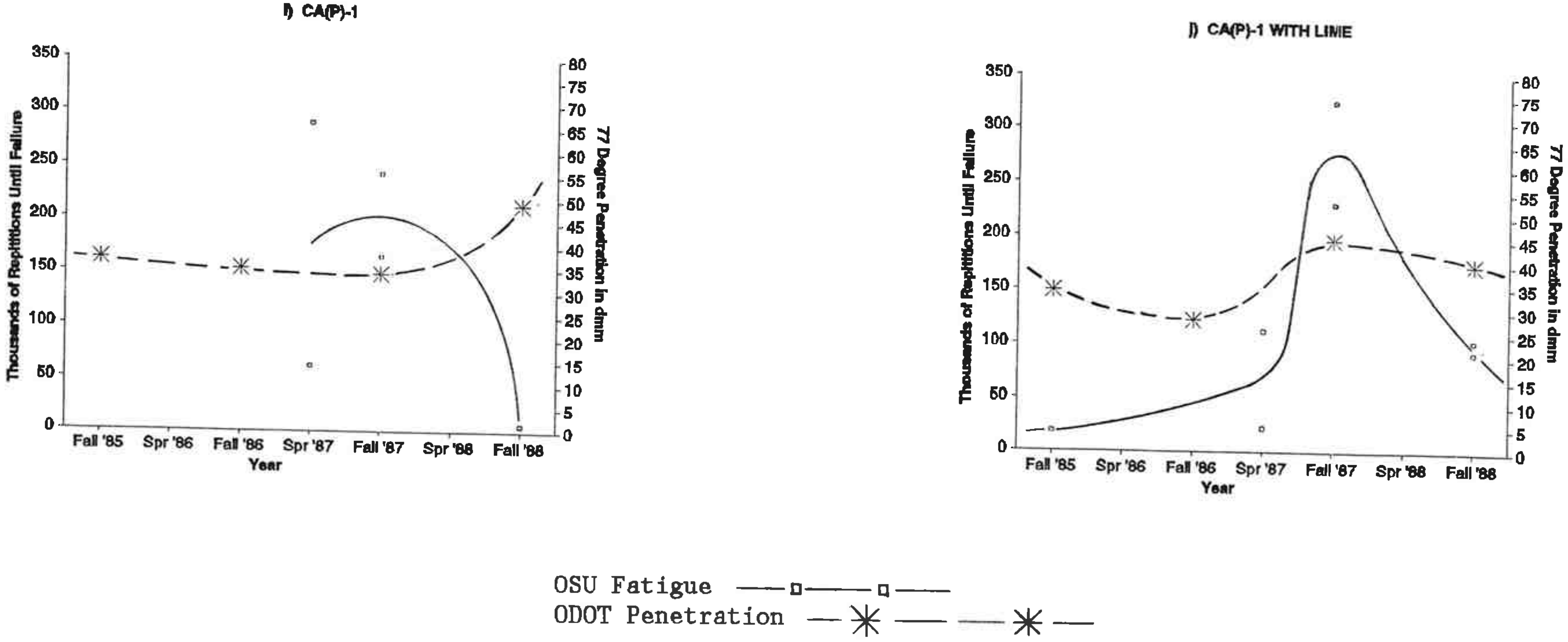

h) CLASS "C"

Figure 4.8: OSU Fatigue Tests on Cores and ODOT Penetration Tests



All fatigue tests at 73°F and 200 microstrain, and all penetrations at 77°F.

Figure 4.8: OSU Fatigue Tests on Cores and ODOT Penetration Tests

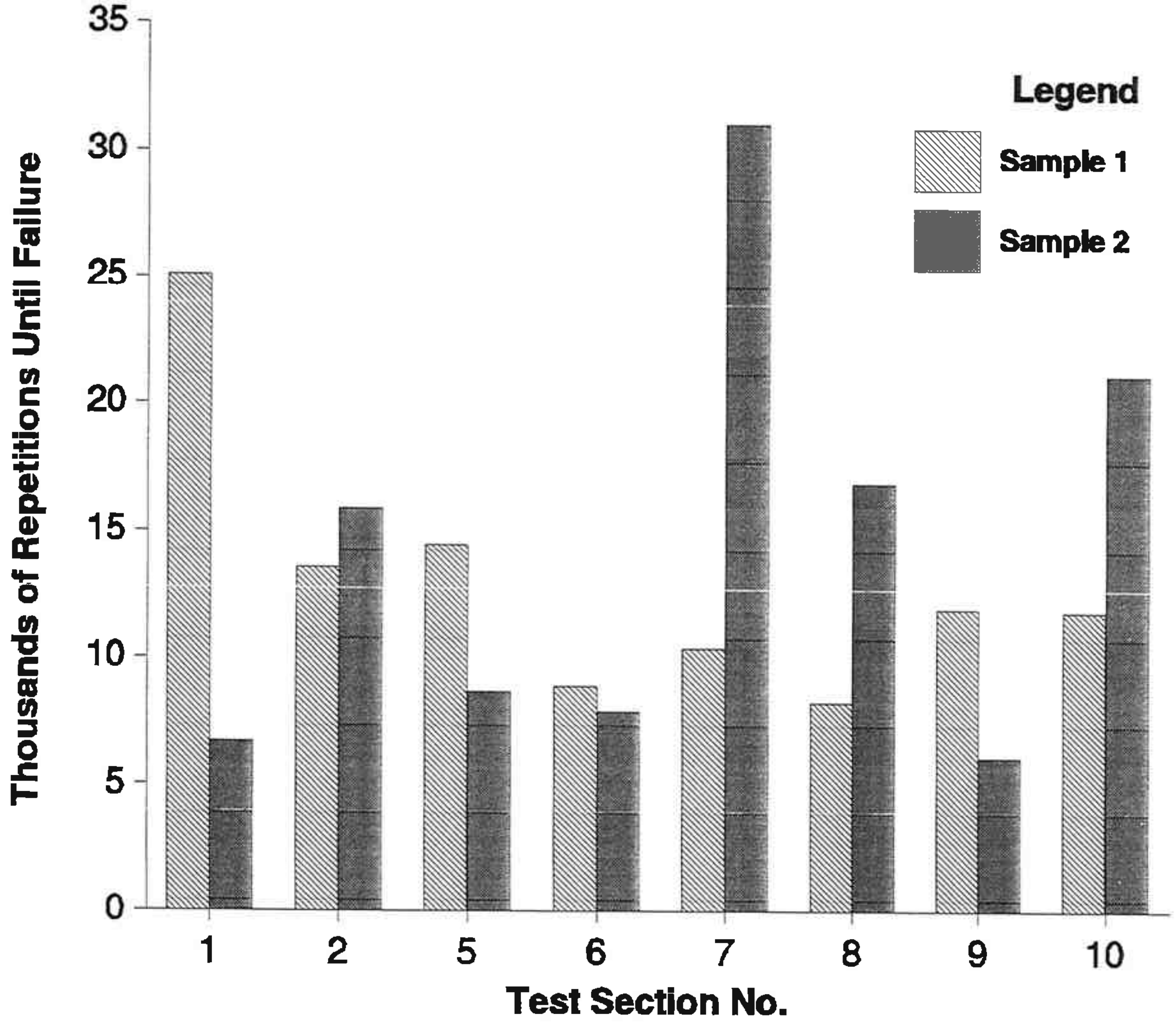


Figure 4.9: OSU Cold Temperature Fatigue Tests on Cores

minimum of 30 required in ODOT mix designs (Figure 4.10). This low stability may be due to the resilience imparted to the mix by the rubber particles, rather than an indicator of potential distress, as the pavement has shown no signs of instability such as rutting or bleeding during the study period.

No analyses were made of changes in pavement stability through the study period, as there was only two year's data on the stabilities of briquets made out of mix taken from cores.

4.3 Summary

Binder Tests –

Conventional tests such as penetration and viscosity on recovered binders do not test samples representative of the binders in the pavement. Additives such as rubber particles and fibers are removed from the binder during the recovery process.

Binders from sections using anti-strip additives usually had higher penetrations and lower viscosities than conventional unmodified asphalt.

Binders containing either dissolved rubber or polymers had less hardening at low temperatures and less thinning at high temperatures than the other binders.

Few of the binders hardened year after year during the study period. Most binders softened during the first year, hardened during the second year, and softened during the third year.

The CA(P)-1 binder may have been excessively aged due to high mixing temperatures in the batch plant. This aging may have contributed to the excessive cracking seen on the CA(P)-1 test sections.

Void Contents –

All sections resisted consolidation in the wheeltracks during the three year study period. However, four of the ten mixes may consolidate under prolonged traffic. Rutting and bleeding within the wheeltracks may occur when these pavements consolidate.

Moduli –

All pavements maintained or gained strength during the study period.

Some pavements containing additives had much lower moduli than pavements with no additives or only anti-stripping additives. This reduction in rigidity should be considered during the structural design of the pavement.

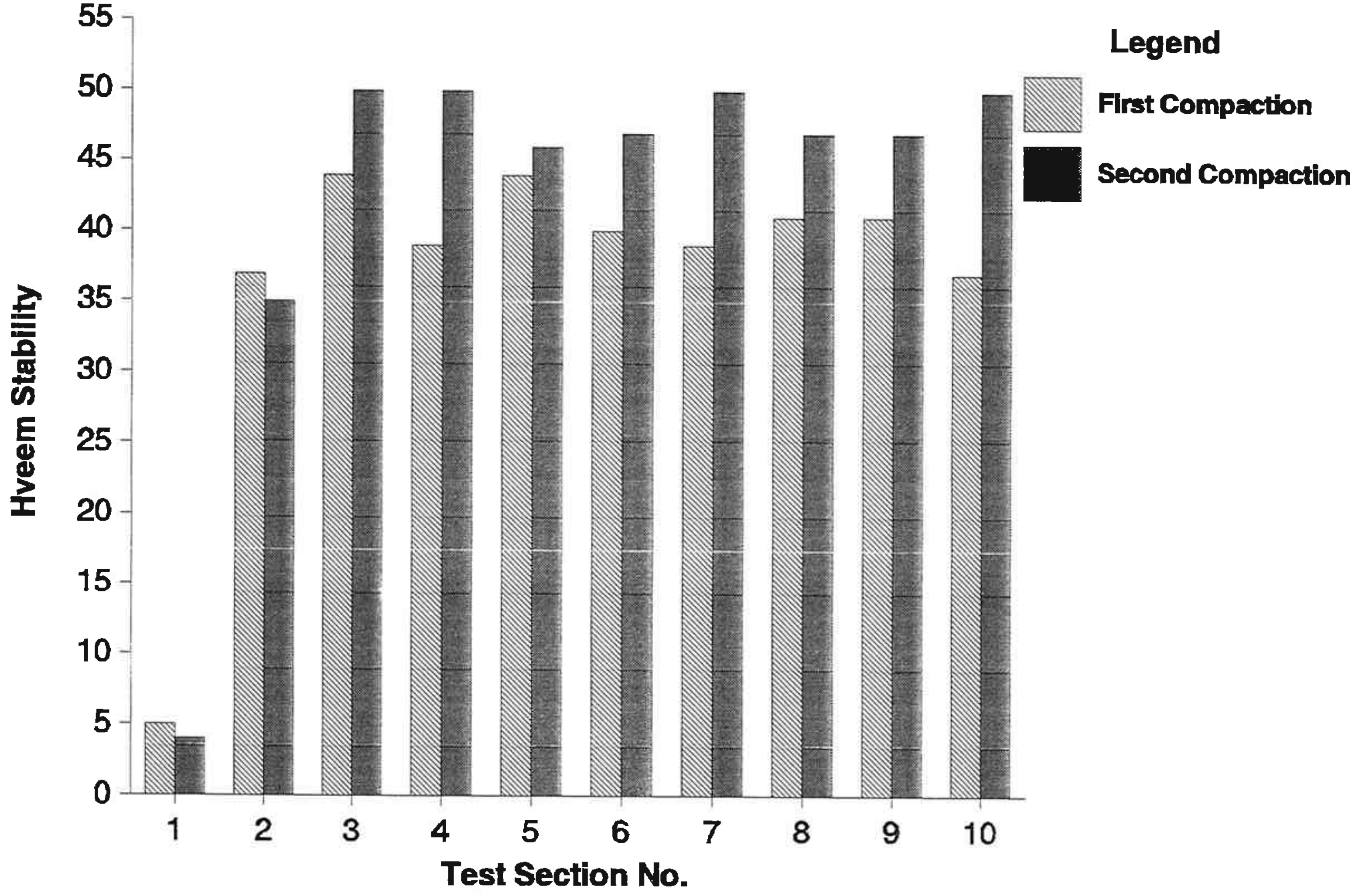


Figure 4.10: Hveem Stability Tests on Mix Sampled from Behind Paver

Stripping Resistance -

None of the briquets made from mix sampled from behind the paver failed either the ODOT Index of Retained Strength or Vacuum Saturated/Unconditioned Resilient Modulus Ratio requirements. Only the Plus Ride with Pave Bond mix briquet failed the ODOT Freeze-Thaw/Unconditioned requirement. Based on experience with this test, this pavement may start to strip several years after construction. However, no stripping was seen on cores removed after three years.

The effectiveness of either lime or Pave Bond as an anti-stripping additive was not proven by laboratory testing on this project. Based on moisture susceptibility tests on briquets made from mix sampled from behind the paver, the mixes containing lime had better results than other samples. However, when briquets made from mixes taken from cores were tested, neither lime or any other anti-stripping additive consistently improved test results.

Fatigue Resistance -

The fatigue test, regardless of testing temperature, was a poor predictor or indicator of fatigue susceptible pavements. The 73°F test did not indicate fatigue related problems in the CA(P)-1 pavement, although this was the only section with fatigue related distress. The 32°F test indicated that there may be fatigue problems with both the CA(P)-1 and Class "C" with Lime and Pave Bond sections, yet the Class "C" section showed no fatigue distress.

The 73°F fatigue results of the cores correlated well with 77°F penetration. When the binders were softer, the fatigue lives were greater.

The addition of fibers did not significantly improve fatigue test results.

The cold temperature fatigue test used on this project had little repeatability. There was wider scatter among the results of the two tests on each section than there was between the sections.

Hveem Stabilities -

All sections except Plus Ride with Pave Bond had first compaction stabilities above the ODOT minimum of 30. The lack of rutting or bleeding on the Plus Ride section indicates that this material's low stability may be a characteristic of the rubber modified mix and not an indicator of an unstable mix.

5.0 MATERIALS PROPERTIES vs FIELD PERFORMANCE

In this section, the results of the Fall 1989 inspections are compared to the results of tests performed on both recovered binder and briquets made from loose mix sampled from behind the paver (Appendices A and B).

Selected linear correlations were made between the materials test results and the field distress measurements. In these comparisons, the correlation coefficient "R" was determined, as listed in Table 5.1. A positive correlation coefficient shows that the field inspection measurements are proportional to the test results. A negative coefficient indicates the opposite: the field inspection measurements are inversely proportional to the test results.

In the author's experience a correlation coefficient between -1 and -.500, or 1 and +.500, shows a good linear relationship between field data and test results. These correlations are rarely found on projects such as this one, where many different products are evaluated.

The various forms of measured pavement distress were best <u>predicted</u> by the following tests on mix sampled from behind the paver:

1) **Rut depth** by both the **115°F penetration** test by Chevron and the **77°F penetration** test by ODOT, with .606 and .716 correlations, respectively. In general, the deeper the rut depth, the softer the binder.

2) **Transverse cracking** count by the **73°F fatigue test** by OSU, with a -.533 correlation. This correlation, however, includes test results from only five of the ten sections.

   The fatigue test is normally associated with longitudinal cracking in the wheeltracks caused by load related fatigue. However, on this project, there may be a relationship between the results of this test and transverse cracking caused by temperature related fatigue. This fatigue is caused by the expansion and contraction of pavement due to daily temperature swings. On this project, the 73°F fatigue test results had about twice as good a correlation with the transverse crack count (-.533) as they did with wheeltrack cracking rating (.289). In general, the higher the transverse crack count or the lower the wheeltrack cracking rating, the lower the fatigue test result.

3) **Wheeltrack cracking** rating by both the **unconditioned resilient modulus** test at **77°F** by ODOT, with a .649 correlation; and the **unconditioned resilient modulus** at **73°F** by OSU, with a .556 correlation. In general, the lower the wheeltrack cracking rating, the lower the resilient modulus.

4) **Ravelling and weathering** vs the **index of retained strength** by ODOT and the **freeze-thaw/unconditioned resilient modulus** ratios by ODOT, with .557 and .567 correlations, respectively. In general, the lower the index of retained strength or freeze-thaw/unconditioned modulus ratio, the lower the ravelling and weathering rating.

Table 5.1: Correlations of Field Inspection Measurements vs Laboratory Test Results

1985 Tests on Binder Extracted from Mix Placed by Paver	1989 Rut Depths (Inches)	1989 Transverse Cracking (Cracks/ Mile)	1989 Rating: Wheeltrack Cracking	1989 Rating: Ravelling and Weathering
Pen. @ 39.2°F. by Chevron (dmm)		-.042	-.057	
Pen. @ 77°F. by ODOT (dmm)	.716	-.043	-.250	
Pen. @ 115°F. by Chevron (dmm)	.606			
Abs. Visc. @ 140°F. by ODOT (poise)	-.451			
Duct. @ 39.2°F. by Chevron (cm)		.397	-.388	.128
1985 Tests on Briquets Made From Mix Placed by Paver				
Unc. Res. Mod. @ 39.2°F. by Chevron (ksi)		.193	-.256	-.171
Unc. Res. Mod. @ 77°F. by ODOT (ksi)		-.164	.649	.430
Index of Ret. Str. by ODOT (%)				.557
Res. Mod. Ratio 1: Vac. Sat./Uncond. by ODOT				.011
Res. Mod. Ratio 2: Freeze Thaw/Uncond. by ODOT				.567

Table 5.1, contd.: Correlations of Inspection Measurements vs Laboratory Test Results

1985 Tests on Binder Extracted from Mix Placed by Paver	1989 Rut Depths (Inches)	1989 Transverse Cracking (Cracks/ Mile)	1989 Rating: Wheeltrack Cracking	1989 Rating: Ravelling and Weathering
1st Comp. Voids by ODOT (%)	-.253			
2nd Comp. Voids by ODOT (%)	.097			
Hveem Stability @ 1st Comp. by ODOT	-.226			
Hveem Stability @ 2nd Comp. by ODOT	-.321			
Surface Abrasion Loss by Chevron (grams)				-.218
Unc. Res. Mod. @ 73°F. by OSU (ksi)*		.039	.556	.133
Fatigue Test by OSU @ 73°F. (Repetitions)#		-.533	.289	

*This correlation involved test results from only six sections. All other correlations used data from all ten sections.

#This correlation involved test results from only five sections.

6.0 PRODUCT PERFORMANCE AND RECOMMENDATIONS

Four years after construction, all test sections were in satisfactory condition. Although some distress was noted, as reported below, it is too early to make firm conclusions about the additive's cost-effectiveness or long-term performance.

6.1 Product Performance and Recommendations

General:

It is recommended that none of the rubber asphalt products, fibers, or polymers be widely used until further experience shows their cost-effectiveness. However, the anti-stripping properties of Pave Bond and lime are well established through other studies. Therefore, the use of these two products should continue without change.

Plus Ride:

Product Performance - This section has been superior to all other sections in resisting cracking. However, the loss of large aggregate from the wheeltracks casts doubts on the long-term durability of this pavement.

The Plus Ride pavement was slightly superior in shedding ice during snowplowing. However, this property could not be fully evaluated on these test sections, as this project was not in a heavy snow zone.

As the Plus Ride pavement system contains granulated tires, it recycles a waste product. It is estimated that this 1-3/4-inch deep by 24-foot wide by 1/2-mile long test section used 3,000 tires.

Recommendations - Continue to use Plus Ride on an experimental basis. Fog sealing or sand sealing just after construction, or using a polymerized binder may reduce or eliminate the loss of surface aggregate.

Arm-R-Shield, Fiber Pave, and Boni Fibers:

Product Performance - These sections have performed no better than the Class "C" sections.

The Arm-R-Shield Pavement contains ground tires. As with the Plus Ride system, this pavement allows the recycling of a waste product.

Recommendations - At present, the added cost of these additives are not justified by improved performance. These added costs were significant on this project, as the fiber reinforced mixes cost almost twice as much per ton as the conventional asphalt concrete, and the Arm-R-Shield mix costs almost four times as much.

Pave Bond and Lime:

Product Performance - None of the test sections had significant stripping. As a result, this study cannot evaluate the anti-stripping properties of these products at this time. Tests show a slight softening of binders.

Recommendations - None resulting from this study. Continue current policy.

CA(P)-1:

Product Performance - The test sections with this polymer were poor at resisting both transverse and wheeltrack cracking.

The performance of these sections may not be representative of CA(P)-1 or other EVA modified asphalts in general use, as the binder may have been overly aged by high mixing temperatures.

Recommendations - The decision on the use of EVA should be based on the performance of other projects in Oregon where lower mixing temperatures were used.

6.2 Test Methods

The following was concluded about the materials test's ability to predict pavement performance:

1) The conventional **consistency tests** may not be adequate for modified binders, as the extraction process removes many components that may affect binder properties such as rubber particles and fibers.

2) The **115°F** and **77°F penetration tests** were the best predictors of **rutting.**

3) **Resilient modulus** testing revealed different stiffness characteristics among the various mixes. When pavements are made using some of these mixes, their comparatively low stiffness may need to be considered in the structural design.

4) The **unconditioned resilient modulus tests** were the best predictors of **load related wheeltrack cracking.**

5) The **fatigue test**, both at 32°F and 73°F, was a poor predictor of **load related wheeltrack cracking.** The 73°F test failed to predict the cracking in the CA(P)-1 section, and the 32°F test predicted cracking in the CA(P)-1 section and one of the Class "C" sections that had no transverse cracking. In addition, the cold temperature fatigue test had little repeatability.

6) Although the fatigue test was intended to predict load related cracking, the **73°F fatigue test** was a good predictor of

temperature related transverse cracking.

7) The **Hveem stability test** indicated a low stability for the Plus Ride section. However, this section had shown no distress related to low stability.

5) The **index of retained strength test** and the **freeze-thaw/unconditioned resilient modulus ratios** were the best predictors of **ravelling and weathering.** Neither Pave Bond or lime consistently improved any of the water damage susceptibility test results.

7.0 REFERENCES

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12. R.P. Lottman, Field Evaluation and Correlation of Laboratory Test Method for Predicting Moisture Induced Damage to Asphalt Concrete, Paper prepared for the Annual Meeting of the Transportation Research Board's Committee A2D01 Sponsored Papers Session, January 1982.

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APPENDIX A: FIELD INSPECTION RESULTS

Table A-1: Rut Depths

Fall 1989 Inspection

Section	Name	Average Rut Depth in Inches	Rating
1	Plus Ride with Pave Bond	1/16	5 (Excellent)
2	Arm-R-Shield	3/16	4 (Good)
3	Fiber Pave	1/16	5 (Excellent)
4	Boni Fibers	1/8	5 (Excellent)
5	Class "C" with Pave Bond	1/16	5 (Excellent)
6	Class "C" with Lime and Pave Bond	1/16	5 (Excellent)
7	Class "C" with Lime	1/16	5 (Excellent)
8	Class "C"	None	5 (Excellent)
9	CA(P)-1	1/16	5 (Excellent)
10	CA(P)-1 with Lime	1/16	5 (Excellent)

Rating Criteria

5 (Excellent) - 1/8 inch or less rut depth.
4 (Good) - 1/4 inch or less rut depth.
3 (Fair) - 1/2 inch or less rut depth.
2 (Poor) - 1 inch or less rut depth.
1 (Unsatisfactory) - more than 1 inch rut depth.

Table A-2: Cracking
Fall 1989 Inspection

Section	Name	Transverse Cracking- Cracks per Lane Mile	Rating	Wheeltrack Cracking- Rating	Transverse Shrinkage Cracking
1	Plus Ride with Pave Bond	3	4 (Good)	4 (Good)	No
2	Arm-R-Shield	12	4 (Good)	5 (Excellent)	No
3	Fiber Pave	23	4 (Good)	5 (Excellent)	No
4	Boni Fibers	20	4 (Good)	5 (Excellent)	No
5	Class "C" with Pave Bond	8	4 (Good)	5 (Excellent)	Yes
6	Class "C" with Lime and Pave Bond	22	4 (Good)	5 (Excellent)	Yes
7	Class "C" with Lime	12	4 (Good)	5 (Excellent)	Yes
8	Class "C"	22	4 (Good)	5 (Excellent)	Yes
9	CA(P)-1	45	4 (Good)	4 (Good)	No
10	CA(P)-1 with Lime	53	3 (Fair)	4 (Good)	No

Rating Criteria: Transverse Cracking

5 (Excellent) - No transverse cracks.
4 (Good) - Less than 50 transverse cracks per lane mile.
3 (Fair) - Less than 100 transverse cracks per lane mile.
2 (Poor) - Less than 200 transverse cracks per lane mile.
1 (Unsatisfactory) - More than 200 transverse cracks per lane mile.

Rating Criteria: Wheeltrack Cracking

5 (Excellent) - No longitudinal cracking in the wheelpaths.
4 (Good) - Some longitudinal cracking in the wheelpaths. Cracks do not connect to form alligator or map cracking.
3 (Fair) - Alligator and/or map cracking on less than 10% of the lane length.
2 (Poor) - Alligator and/or map cracking on less than 50% of the lane length.
1 (Unsatisfactory) - Alligator and/or map cracking on more than 50% of the lane length.

Table A-3: Ravelling and Weathering

Fall 1989 Inspection

Section	Name	Rating
1	Plus Ride with Pave Bond	2 (Poor)
2	Arm-R-Shield	4 (Good)
3	Fiber Pave	4 (Good)
4	Boni Fibers	4 (Good)
5	Class "C" with Pave Bond	4 (Good)
6	Class "C" with Lime and Pave Bond	4 (Good)
7	Class "C" with Lime	4 (Good)
8	Class "C"	4 (Good)
9	CA(P)-1	4 (Good)
10	CA(P)-1 with Lime	4 (Good)

Rating Criteria

5 (Excellent) - No ravelling or weathering.
4 (Good) - No ravelling, and weathering to a depth of 1/8 the coarse aggregate size.
3 (Fair) - Less than 1/8 of the wheeltrack and/or crack length ravelled, and/or weathering to a depth of 1/4 the coarse aggregate size.
2 (Poor) - Less than 1/4 of the wheeltrack and/or crack length ravelled, and/or weathering to a depth of 1/2 the coarse aggregate size.
1 (Unsatisfactory) - More than 1/4 of the wheeltrack and/or crack length ravelled and/or weathering to a depth greater than 1/2 the coarse aggregate size.

Table A-4: Stripping

Fall 1988 Cores

Section	Name	Percent of Aggregate Surface Exposed	Rating
1	Plus Ride with Pave Bond	0	5 (Excellent)
2	Arm-R-Shield	0	5 (Excellent)
3	Fiber Pave	0	5 (Excellent)
4	Boni Fibers	0	5 (Excellent)
5	Class "C" with Pave Bond	0	5 (Excellent)
6	Class "C" with Lime and Pave Bond	0	5 (Excellent)
7	Class "C" with Lime	0	5 (Excellent)
8	Class "C"	1	5 (Excellent)
9	CA(P)-1	0	5 (Excellent)
10	CA(P)-1 with Lime	0	5 (Excellent)

Rating Criteria

5 (Excellent) - 5% or less of the aggregate surface exposed.
4 (Good) - 10% or less of the aggregate surface exposed.
3 (Fair) - 25% or less of the aggregate surface exposed.
2 (Poor) - 50% or less of the aggregate surface exposed.
1 (Unsatisfactory) - more than 50% of the aggregate surface exposed.

Table A-5: Pavement Friction

Fall 1988

Section	Name	Average Friction Number FN_{40} 8/84	3/87	11/87	6/88	8/88	10/88	Rating
All	Before Construction	51						5 (Excellent)
1	Plus Ride with Pave Bond		55	65	61	59	62	5 (Excellent)
2	Arm-R-Shield		55	59	56	55	56	5 (Excellent)
3	Fiber Pave		57	63	57	58	60	5 (Excellent)
4	Boni Fibers		57	65	60	60	62	5 (Excellent)
5	Class "C" with Pave Bond		56	68	64	58	61	5 (Excellent)
6	Class "C" with Lime and Pave Bond		57	67	60	60	62	5 (Excellent)
7	Class "C" with Lime		57	66	61	60	62	5 (Excellent)
8	Class "C"		58	67	62	60	62	5 (Excellent)
9	CA(P)-1		57	67	56	56	61	5 (Excellent)
10	CA(P)-1 with Lime		53	67	61	58	62	5 (Excellent)

Rating Criteria

5 (Excellent) - FN_{40} is 50 or higher.
3 (Fair) - FN_{40} is 37 or higher.
1 (Unsatisfactory) - FN_{40} is less than 37.

Table A-6: Pavement Roughness (Ride)

Section	Name	Average Pavement Roughness (Mays inches/mile) 1985	1987	1989	Increase in Average Pavement Roughness 1985 to 1989 (Mays inches/mile)	Rating
1	Plus Ride with Pave Bond	33	32	28	0	5 (Excellent)
2	Arm-R-Shield	35	40	35	0	5 (Excellent)
3	Fiber Pave	36	34	43	7	5 (Excellent)
4	Boni Fibers	30	29	27	0	5 (Excellent)
5	Class "C" with Pave Bond	31	26	31	0	5 (Excellent)
6	Class "C" with Lime and Pave Bond	21	22	17	0	5 (Excellent)
7	Class "C" with Lime	30	26	28	0	5 (Excellent)
8	Class "C"	34	25	27	0	5 (Excellent)
9	CA(P)-1	26	31	26	0	5 (Excellent)
10	CA(P)-1 with Lime	40	39	39	0	5 (Excellent)

Rating Criteria

ODOT's Paving Award Criteria

Description	Mays inches/mile	Rating
Smooth	0 - 74	5 (Excellent)
Average	75 - 99	4 (Good)
Slightly Rough	100 - 149	3 (Fair)
Rough	150 - 199	2 (Poor)
Very Rough	200 +	1 (Unsatisfactory)

APPENDIX B: LABORATORY TEST RESULTS

Table B-1: ODOT Binder Test Results

All tests performed on binder extracted from either loose mix placed by paver or cores.

Section	Binder	Year	Penetration @ 77°F, 100g, 5 sec. (dmm)	Absolute Viscosity @ 140°F (poise)	Kinematic Viscosity @ 275°F (centistokes)
1	AC-20 with Plus Ride and Pave Bond	1985(mix)	42	4,480	514
		1985	55	2,070	374
		1986	23	10,600	726
		1987	56	2,390	384
		1988	45	3,690	474
2	AR-4000W with Arm-R-Shield	1985(mix)	75	3,300	849
		1985	78	2,730	929
		1986	59	4,940	1,050
		1987	56	5,780	1,230
		1988	47	7,690	1,160
3	AC-20 with Fiber Pave	1985(mix)	27	8,060	597
		1985	32	5,740	539
		1986	19	19,000	842
		1987	24	12,100	719
		1988	22	12,400	749
4	AC-20 with Boni Fibers	1985(mix)	22	9,130	591
		1985	29	7,230	599
		1986	19	19,200	811
		1987	25	11,700	719
		1988	21	12,700	898
5	AC-20 with Pave Bond	1985(mix)	23	8,120	624
		1985	28	7,670	599
		1986	23	13,900	750
		1987	28	7,880	619
		1988	19	18,700	887
6	AC-20 with Lime & Pave Bond	1985(mix)	22	7,640	572
		1985	25	2,570	635
		1986	23	12,600	863
		1987	25	10,600	695
		1988	26	8,810	1,200
7	AC-20 with Lime	1985(mix)	25	5,650	534
		1985	26	6,540	560
		1986	24	10,600	661
		1987	40	4,040	511
		1988	23	15,300	901

Table B-1 contd.: ODOT Binder Test Results

All tests performed on binder extracted from either loose mix placed by paver or cores.

Section	Binder	Year	Penetration @ 77°F, 100g, 5 sec. (dmm)	Absolute Viscosity @ 140°F (poise)	Kinematic Viscosity @ 275°F (centistokes)
8	AC-20	1985(mix)	21	6,560	568
		1985	28	8,430	609
		1986	21	14,600	813
		1987	20	17,200	842
		1988	18	20,200	908
9	CA(P)-1	1985(mix)	40	8,010	1,040
		1985	37	9,960	1,090
		1986	35	11,600	1,360
		1987	34	17,100	1,510
		1988	49	6,120	695
10	CA(P)-1 with Lime	1985(mix)	36	10,100	1,140
		1985	34	12,500	1,370
		1986	28	19,500	1,690
		1987	45	7,190	1,070
		1988	40	11,100	1,520

Table B-2: Chevron Test Results

All tests were made on loose mix sampled from behind paver.

Section No.	1	2	3	4	5	6	7	8	9	10
Recovered Asphalt Properties:										
Pen @ 39.2°F.	12	26	10	8	9	11	9	9	12	13
Pen @ 77°F.	41	69	34	27	28	35	28	28	38	37
Pen @ 115°F.	222	250+	200	168	182	208	182	177	169	164
Visc @ 140°F. p	4144	3420	5301	7522	6793	4992	6023	6478	9739	9842
Visc @ 275°F. cs	505	973	545	549	540	511	539	546	1149	1355
Duct. @ 39.2°F.	6	20	5	4	4	5	5	4	15	13
PVN (77-140)	-0.67	-0.07	-0.7	-0.69	-0.74	-0.71	-0.84	-0.78	0.02	-0.01
Mix Properties:										
S-Value	--	28	32	31	32	35	27	31	31	32
C-Value	--	61	110	83	83	187	63	122	121	172
Density, pcf	125.1	135.1	140.9	137.6	141.3	141.9	143.0	141.3	142.4	144.9
Air Voids	14.6	13.1	9.2	11.7	--	8.25	7.1	8.6	7.5	5.7
MR @ 39.2°F.	1680000	1020000	719000	2440000	1080000	2040000	841000	1130000	1660000	1510000
MR @ 77°F.	224000	104000	376000	325000	376000	591000	582500	665500	221500	258500
MR @ 100°F.	37300	22100	62600	88800	76300	61400	74900	90600	40200	55400
MR Vac Sat	356000	128000	520000	470000	509000	675000	772000	927000	324500	410000
MR F-T	270000	326000	349000	376000	520000	451000	559500	607500	193000	290000
% Moist VS	1.6	3.4	2.6	2.8	1.9	2.4	2.2	2.1	2.0	1.7
% Moist F-T	2.5	3.8	2.7	2.9	2.0	2.5	2.3	2.4	2.2	1.7
Stress Split T.	96.12	48.24	139.37	148.66	177.92	158.57	148.09	133.18	114.83	166.49
Strain Split T.	0.0191	0.0191	0.0204	0.0175	0.0133	0.0141	0.0169	0.0131	0.0181	0.0141
Mod. (init.)	10210	4477	14642	22924	27886	20487	17265	22736	14258	22418
Work	2.116	1.0259	1.9513	1.8772	1.6762	1.5374	1.7387	1.235	1.472	1.6439
Vac Sat Ratio	158.9	123.1	138.3	144.6	135.4	114.9	126.4	132.7	131.2	143.3
F-T Ratio	120.5	313.5	92.8	115.7	138.3	68.0	92.2	85.3	87.0	111.8
Surf. Abrasion loss, gms.*	11.8	3.9	12.5	15.3	10.7	9.0	6.7	8.8	11.5	7.5

* Single sample only

Table B-3: ODOT Void Content Test Results

All tests performed on cores, briquets made from loose mix placed by paver, or briquets made out of material removed from cores.

Section	Name	Year	Core In-Place Void Content (%)	Core Recompacted Void Content (%)	Briquet 1st Comp. Void Content (%)	Briquet 2nd Comp. Void Content (%)
1	Plus Ride with Pave Bond	1985(mix)			4.2	2.0
		1985	3.7	2.8		
		1986	4.4	3.6		
		1987	3.3	1.6	5.0	2.8
		1988	4.0	1.4	2.8	1.1
2	Arm-R-Shield	1985(mix)			3.6	0.7
		1985	6.9	2.4		
		1986	5.8	0.9		
		1987	6.9	2.0	5.3	2.8
		1988	7.7	2.8	5.4	1.3
3	Fiber Pave	1985(mix)			3.5	1.5
		1985	6.5	0.8		
		1986	8.2	2.1		
		1987	6.5	0.9	3.1	0.2
		1988	7.4	5.3	2.2	0.2
4	Boni-Fibers	1985(mix)			5.7	4.1
		1985	8.1	2.0		
		1986	7.9	1.9		
		1987	8.1	1.3	4.1	0.0
		1988	7.8	3.0	4.0	0.7
5	Class "C" with Pave Bond	1985(mix)			4.7	1.5
		1985	5.3	1.2		
		1986	6.2	1.0		
		1987	4.4	0.0	2.7	0.2
		1988	5.6	0.3	3.6	0.0
6	Class "C" with Lime and Pave Bond	1985(mix)			4.8	1.6
		1985	6.6	0.9		
		1986	4.6	1.0		
		1987	5.7	0.9	3.5	0.7
		1988	6.0	1.5	3.3	0.0
7	Class "C" with Lime	1985(mix)			3.9	1.1
		1985	6.9	2.1		
		1986	6.6	1.0		
		1987	4.4	1.2	3.0	0.2
		1988	7.0	1.8	3.5	0.2

Table B-3 contd.: ODOT Void Content Test Results

All tests performed on cores, briquets made from loose mix placed by paver, or briquets made out of material removed from cores.

Section	Name	Year	Core In-Place Void Content (%)	Core Recompacted Void Content (%)	Briquet 1st Comp. Void Content (%)	Briquet 2nd Comp. Void Content (%)
8	Class "C"	1985(mix)			6.0	2.3
		1985	7.1	2.6		
		1986	6.9	1.7		
		1987	6.3	1.1	3.8	0.6
		1988	8.7	2.2	3.7	0.1
9	CA(P)-1	1985(mix)			3.1	0.3
		1985	4.9	0.9		
		1986	3.7	0.8		
		1987	2.9	0.1	3.1	0.3
		1988	4.6	0.5	2.0	0.0
10	CA(P)-1 with Lime	1985(mix)			4.1	1.2
		1985	6.9	1.2		
		1986	5.3	0.8		
		1987	5.8	1.4	3.1	0.2
		1988	4.5	0.8	2.1	0.0

Table B-4: ODOT Resilient Modulus Test Results - Laboratory Compacted Briquets

All tests performed at 77°F on briquets made from either loose mix placed by paver or material removed from cores.

Section	Name	Year	**No. 1:** Res. Mod. Uncon. (ksi)	**No. 2:** Res. Mod. Vac. Sat. (ksi)	**No. 3:** Res. Mod. Freeze/ Thaw (ksi)	Ratio **No. 2/ No. 1**	Ratio **No. 3/ No. 1**
1	Plus Ride	1985(mix)	258	232	162	.90	.63
	with Pave	1985	289	252	255	.87	.88
	Bond	1986	451	455	302	1.01	.67
		1987	269	347	338	1.29	1.26
		1988	479	497	531	1.04	1.11
2	Arm-R-Shield	1985(mix)	263	219	185	.83	.70
		1985	213	197	185	.92	.87
		1986	280	224	164	.80	.59
		1987	245	235	188	.96	.77
		1988	263	316	252	1.20	.96
3	Fiber Pave	1985(mix)	574	525	437	.91	.76
		1985	614	585	514	.95	.84
		1986	829	809	657	.98	.79
		1987	1050	885	1010	.84	.96
		1988	727	849	985	1.17	1.36
4	Boni Fibers	1985(mix)	421	410	352	.97	.84
		1985	594	564	483	.95	.81
		1986	920	755	542	.82	.59
		1987	860	782	1040	.91	1.21
		1988	823	858	926	1.04	1.13
5	Class "C"	1985(mix)	483	456	444	.94	.92
	with Pave	1985	616	607	537	.98	.87
	Bond	1986	815	747	687	.92	.84
		1987	756	709	795	.94	1.05
		1988	1090	1000	1140	.92	1.05
6	Class "C"	1985(mix)	473	421	399	.89	.85
	with Lime	1985	626	583	573	.93	.92
	and Pave	1986	757	898	623	1.19	.82
	Bond	1987	1380	974	1160	.70	.84
		1988	739	803	785	1.09	1.06

Table B-4, contd.: ODOT Resilient Modulus Test Results – Laboratory Compacted Briquets

All tests performed at 77°F on briquets made from either loose mix placed by paver or material removed from cores.

Section	Name	Year	**No. 1:** Res. Mod. Uncon. (ksi)	**No. 2:** Res. Mod. Vac. Sat. (ksi)	**No. 3:** Res. Mod. Freeze/ Thaw (ksi)	Ratio **No. 2/ No. 1**	Ratio **No. 3/ No. 1**
7	Class "C" with Lime	1985(mix)	397	396	358	1.00	.90
		1985	658	574	567	.87	.86
		1986	760	800	661	1.05	.87
		1987	828	764	822	.92	.99
		1988	1050	945	1150	.90	1.09
8	Class "C"	1985(mix)	446	414	348	.93	.78
		1985	560	526	476	.94	.85
		1986	612	701	601	1.15	.98
		1987	1040	959	1160	.92	1.11
		1988	712	722	752	1.01	1.05
9	CA(P)-1	1985(mix)	364	281	265	.77	.73
		1985	251	240	244	.96	.97
		1986	256	244	203	.95	.79
		1987	554	464	498	.84	.88
		1988	269	318	317	1.18	1.18
10	CA(P)-1 with Lime	1985(mix)	245	216	246	.88	1.00
		1985	261	241	248	.92	.95
		1986	418	374	345	.89	.83
		1987	640	481	634	.75	.99
		1988	290	330	378	1.13	1.30

Table B-5: ODOT Resilient Modulus Test Results - Cores

All tests performed at 77°F.

Section	Name	Year	No. 1: Res. Mod. Uncon. (ksi)	No. 2: Res. Mod. Vac. Sat. (ksi)	No. 3: Res. Mod. Freeze/ Thaw (ksi)	Ratio No. 2/ No. 1	Ratio No. 3/ No. 1
1	Plus Ride with Pave Bond	1985	264				
		1986	264	226	289	.85	1.09
		1987	284	286	215	1.00	.76
		1988	136	221	23	1.60	.20
2	Arm-R-Shield	1985	93				
		1986	94	80	73	.85	.77
		1987	63	52	32	.82	.50
		1988	339	391	371	1.20	1.10
3	Fiber Pave	1985	111				
		1986	240	207	220	.86	.92
		1987	319	310	233	.97	.89
		1988	393	459	377	1.17	.96
4	Boni Fibers	1985	137				
		1986	208	258	214	.86	.92
		1987	319	310	233	.97	.73
		1988	388	317	370	.82	.95
5	Class "C" with Pave Bond	1985	275				
		1986	390	309	448	.79	1.15
		1987	285	287	268	1.00	.94
		1988	420	501	370	1.20	.88
6	Class "C" with Lime and Pave Bond	1985	590				
		1986	367	345	400	.94	1.09
		1987	244	256	236	1.05	.97
		1988	411	546	536	1.33	1.30
7	Class "C" with Lime	1985	209				
		1986	366	384	387	1.05	1.06
		1987	393	392	339	1.00	.86
		1988	383	448	436	1.17	1.14
8	Class "C"	1985	256				
		1986	249	229	177	.92	.71
		1987	218	251	99	1.15	.45
		1988	484	457	449	.94	.93

Table B-5 contd.: ODOT Resilient Modulus Test Results - Cores

All tests performed at 77°F.

Section	Name	Year	**No. 1:** Res. Mod. Uncon. (ksi)	**No. 2:** Res. Mod. Vac. Sat. (ksi)	**No. 3:** Res. Mod. Freeze/ Thaw (ksi)	Ratio **No. 2/ No. 1**	Ratio **No. 3/ No. 1**
9	CA(P)-1	1985	352				
		1986	152	125	121	.82	.79
		1987	175	154	148	.88	.85
		1988	197	222	244	1.13	1.24
10	CA(P)-1 with Lime	1985	366				
		1986	158	149	113	.94	.71
		1987	238	251	174	1.05	.73
		1988	162	212	184	1.30	1.13

Table B-6: ODOT Index of Retained Strength Test Results

All tests were performed on briquets made with loose mix sampled from behind paver.

Section	Name	Year	Unconfined Compressive Strength-Wet (psi)	Unconfined Compressive Strength-Dry (psi)	Index of Retained Strength (%)
1	Plus Ride with Pave Bond	1985	279	341	82
2	Arm-R-Shield	1985	454	489	93
3	Fiber Pave	1985	692	740	94
4	Boni Fibers	1985	836	907	92
5	Class "C" with Pave Bond	1985	678	716	95
6	Class "C" with Lime and Pave Bond	1985	837	783	107
7	Class "C" with Lime	1985	645	683	94
8	Class "C"	1985	719	740	97
9	CA(P)-1	1985	583	697	84
10	CA(P)-1 with Lime	1985	859	947	91

Table B-7: OSU Resilient Modulus Test Results

All tests were performed at 73°F, using 200 microstrain, on cores, except as noted. "Mix" tests were done on briquets made from loose mix sampled from behind the paver.

Section	Name	Year	Sample No. 1 Uncond. Res. Mod. (ksi)	Sample No. 2 Uncond. Res. Mod. (ksi)
1	Plus Ride	Summer 1985	364 (mix, 100 ms)	
	with Pave	Fall 1985	533 (100 ms)	555 (100 ms)
	Bond	Fall 1985	298	
		Fall 1986	316	
		Spring 1987	216	245
		Fall 1987	161	167
		Spring 1988	1332 (32°F, 52 ms)	1417(32°F, 52ms)
		Spring 1988	666 (50°F, 52 ms)	769(50°F, 52ms)
		Spring 1988	152 (77°F, 52 ms)	179(77°F, 52ms)
		Fall 1988	394	401
2	Arm-R-Shield	Summer 1985	351 (mix, 100 ms)	
		Fall 1985	391 (100 ms)	384 (100 ms)
		Fall 1985	112	
		Fall 1986	133	164
		Spring 1987	113	121
		Fall 1987	54	72
		Spring 1988	613 (32°F, 52 ms)	764(32°F, 52ms)
		Spring 1988	305 (50°F, 52 ms)	339(50°F, 52ms)
		Spring 1988	77 (77°F, 52 ms)	105(77°F, 52ms)
		Fall 1988	250	241
3	Fiber Pave	Summer 1985	1061 (mix, 100 ms)	
		Fall 1985	811 (100 ms)	791 (100 ms)
		Fall 1985	241	
		Fall 1986	260	269
		Spring 1987	274	287
		Fall 1987	379	261
		Fall 1988	416	456
4	Boni Fibers	Summer 1985	819 (mix, 100 ms)	
		Fall 1985	780 (100 ms)	766 (100 ms)
		Fall 1985	234	
		Fall 1986	218	288
		Spring 1987	282	257
		Fall 1987	277	247
		Fall 1988	378	385

Table B-7, contd.: OSU Resilient Modulus Test Results

All tests were performed at 73°F, using 200 microstrain, on cores, except as noted. "Mix" tests were done on briquets made from loose mix sampled from behind the paver.

Section	Name	Year	Sample No. 1 Uncond. Res. Mod. (ksi)	Sample No. 2 Uncond. Res. Mod. (ksi)
5	Class "C" with Pave Bond	Fall 1985	983 (100 ms)	914 (100 ms)
		Fall 1985	297	
		Fall 1986	309	278
		Spring 1987	279	300
		Fall 1987	317	246
		Spring 1988	1988 (32°F, 52 ms)	2001(32°F, 52ms)
		Spring 1988	989 (50°F, 52 ms)	1028(50°F, 52ms)
		Spring 1988	1071 (77°F, 52 ms)	1022(77°F, 52ms)
		Fall 1988	366	386
6	Class "C" with Lime and Pave Bond	Fall 1985	1046 (100 ms)	998 (100 ms)
		Fall 1985	288	
		Fall 1986	373	319
		Spring 1987	315	316
		Fall 1987	313	268
		Spring 1988	1959 (32°F, 52 ms)	2044(32°F, 52ms)
		Spring 1988	1071 (50°F, 52 ms)	1022(50°F, 52ms)
		Spring 1988	271 (77°F, 52 ms)	249(77°F, 52ms)
		Fall 1988	481	434
7	Class "C" with Lime	Fall 1985	860 (100 ms)	967 (100 ms)
		Fall 1985	453	
		Fall 1986	314	303
		Spring 1987	315	305
		Fall 1987	274	293
		Spring 1988	1725 (32°F, 52 ms)	1416(32°F, 52ms)
		Spring 1988	869 (50°F, 52 ms)	782(50°F, 52ms)
		Spring 1988	251 (77°F, 52 ms)	218(77°F, 52ms)
		Fall 1988	439	480
8	Class "C"	Fall 1985	1050 (100 ms)	973 (100 ms)
		Fall 1985	525	
		Fall 1986	314	276
		Spring 1987	226	201
		Fall 1987	202	267
		Spring 1988	1755 (32°F, 52 ms)	1573(32°F, 52ms)
		Spring 1988	931 (50°F, 52 ms)	821(50°F, 52ms)
		Spring 1988	251 (77°F, 52 ms)	218(77°F, 52ms)
		Fall 1988	464	510

Table B-7: OSU Resilient Modulus Test Results

All tests were performed at 73°F, using 200 microstrain, on cores, except as noted. "Mix" tests were done on briquets made from loose mix sampled from behind the paver.

Section	Name	Year	Sample No. 1 Uncond. Res. Mod. (ksi)	Sample No. 2 Uncond. Res. Mod. (ksi)
9	CA(P)-1	Summer 1985	562 (mix, 100 ms)	
		Fall 1985	599 (100 ms)	591 (100 ms)
		Fall 1985	260	
		Fall 1986	224	190
		Spring 1987	162	215
		Fall 1987	120	107
		Spring 1988	1316 (32°F, 52 ms)	1355(32°F, 52ms)
		Spring 1988	570 (50°F, 52 ms)	588(50°F, 52ms)
		Spring 1988	173 (77°F, 52 ms)	164(77°F, 52ms)
		Fall 1988	390	340
10	CA(P)-1 with Lime	Summer 1985	436 (mix, 100 ms)	
		Fall 1985	576 (100 ms)	558 (100 ms)
		Fall 1985	317	
		Fall 1986	251	282
		Spring 1987	212	240
		Fall 1987	202	166
		Spring 1988	1761 (32°F, 52 ms)	1825(32°F, 52ms)
		Spring 1988	757 (50°F, 52 ms)	828(50°F, 52ms)
		Spring 1988	183 (77°F, 52 ms)	215(77°F, 52ms)
		Fall 1988	342	326

Table B-8: OSU Fatigue Test Results

All tests were performed at 73°F, using 200 microstrain, on cores, except as noted. "Cold" tests were made at 32°F. "Mix" tests were done on briquets made from loose mix sampled from behind the paver.

Section	Name	Year	Sample No. 1 (Repetitions x 10^3)	Sample No. 2 (Repetitions x 10^3)
1	Plus Ride with Pave Bond	Fall 1985	19.4 (100 ms)	12.4 (100 ms)
		Fall 1985	26.0	
		Fall 1986	40.4	
		Spring 1987	49.4	31.8
		Fall 1987	47.7	68.4
		Spring 1988	25.1 (cold)	6.7 (cold)
		Fall 1988	41.1	17.8
2	Arm-R-Shield	Summer 1985	66.2 (mix, 100 ms)	
		Fall 1985	4.2 (100 ms)	4.1 (100 ms)
		Fall 1985	36.5	
		Fall 1986	15.9	
		Spring 1987	24.3	31.1
		Fall 1987	41.5	42.9
		Spring 1988	13.6 (cold)	15.9 (cold)
		Fall 1988	5.7	3.5
3	Fiber Pave	Summer 1985	20.8 (mix, 100 ms)	
		Fall 1985	6.1 (100 ms)	7.4 (100 ms)
		Fall 1985	26.5	
		Spring 1987	13.6	10.0
		Fall 1987	13.2	23.6
		Fall 1988	14.1	8.5
4	Boni Fibers	Summer 1985	17.1 (mix, 100 ms)	
		Fall 1985	3.4 (100 ms)	5.6 (100 ms)
		Fall 1985	10.6	
		Spring 1987	10.7	11.8
		Fall 1987	15.3	21.7
		Fall 1988	11.1	11.8
5	Class "C" with Pave Bond	Fall 1985	5.7 (100 ms)	5.0 (100 ms)
		Spring 1987	11.5	11.5
		Fall 1987	17.3	26.9
		Spring 1988	14.5 (cold)	8.7 (cold)
		Fall 1988	18.5	10.3
6	Class "C" with Lime and Pave Bond	Fall 1985	4.9 (100 ms)	7.2 (100 ms)
		Fall 1985	14.6	
		Spring 1987	12.5	13.7
		Fall 1987	19.7	17.3
		Spring 1988	8.9 (cold)	7.9 (cold)
		Fall 1988	8.7	

Table B-8, contd.: OSU Fatigue Test Results

All tests were performed at 73°F, using 200 microstrain, on cores, except as noted. "Cold" tests were made at 32°F. "Mix" tests were done on briquets made from loose mix sampled from behind the paver.

Section	Name	Year	Sample No. 1 (Repetitions x 10^3)	Sample No. 2 (Repetitions x 10^3)
7	Class "C" with Lime	Fall 1985	4.1 (100 ms)	5.8 (100 ms)
		Fall 1985	4.4	
		Spring 1987	9.4	9.5
		Fall 1987	30.5	27.5
		Spring 1988	10.4 (cold)	31.1 (cold)
		Fall 1988	16.0	10.8
8	Class "C"	Fall 1985	6.7 (100 ms)	7.5 (100 ms)
		Fall 1985	4.5	
		Spring 1987	11.2	11.5
		Fall 1987	10.2	8.6
		Spring 1988	8.3 (cold)	16.9 (cold)
		Fall 1988	7.8	11.1
9	CA(P)-1	Summer 1985	36.6 (mix, 100 ms)	
		Fall 1985	20.5 (100 ms)	21.9 (100 ms)
		Spring 1987	289.7	62.0
		Fall 1987	165.4	243.2
		Spring 1988	12.0 (cold)	6.1 (cold)
		Fall 1988	6.5	6.6
10	CA(P)-1 with Lime	Summer 1985	8.9 (mix, 100 ms)	
		Fall 1985	32.7 (100 ms)	42.0 (100 ms)
		Fall 1985	19.0	
		Spring 1987	112.6	22.7
		Fall 1987	230.5	325.2
		Spring 1988	11.9 (cold)	21.2 (cold)
		Fall 1988	92.9	104.1

Table B-9: ODOT Hveem Stability Test Results

All tests were performed on briquets made from either loose mix sampled from behind paver or material removed from cores.

Section	Name	Year	First Compaction Hveem Stability	Second Compaction Hveem Stability
1	Plus Ride with Pave Bond	1985(mix)	5	4
		1987	3	5
		1988	4	4
2	Arm-R-Shield	1985(mix)	37	35
		1987	38	49
		1988	40	37
3	Fiber Pave	1985(mix)	44	50
		1987	47	19
		1988	34	12
4	Boni Fibers	1985(mix)	39	50
		1987	38	2
		1988	44	42
5	Class "C" with Pave Bond	1985(mix)	44	46
		1987	44	12
		1988	39	40
6	Class "C" with Lime and Pave Bond	1985(mix)	40	47
		1987	43	16
		1988	39	32
7	Class "C" with Lime	1985(mix)	39	50
		1987	43	25
		1988	40	25
8	Class "C"	1985(mix)	41	47
		1987	42	23
		1988	38	37
9	CA(P)-1	1985(mix)	41	47
		1987	49	24
		1988	32	9
10	CA(P)-1 with Lime	1985(mix)	37	50
		1987	37	9
		1988	28	5

APPENDIX C: PAVEMENT LAYER STRENGTH CALCULATIONS

Pavement Layer Thickness Calculations

This method is shown in the 1986 AASTHO Guide for Design of Pavement Structures [10]. In this example, the resilient modulus of pavement material "C" is 302,000 psi. This corresponds to the average unconditioned modulus of a core from the Class "C" section during the study period. The modulus of material "A" is 147,000 psi. This corresponds to the average unconditioned modulus of cores from the Arm-R-Shield section, a pavement with a binder containing an additive.

Problem: If a 1-1/2 inch thick layer of material "C" is required, how thick of a layer of material "A" is needed to have the same structural strength?

> M_r"C"= 302,000 psi. M_r"A" = 147,000 psi. From figure 2.5 in the AASHTO manual, the structural layer coefficients are: a"C" = .365, and a"A" = .245. D"C" = 1.5, and D"A" is unknown.
>
> SN (structural number) = a x D
> SN"C" = a"C" x D"C" = .365 x 1.5 = .55 = SN"A"
> D"A" = SN"A" / a"A" = .55 / .245 = 2.24in

Answer: A 2 1/4-inch thick layer of the weaker material is needed. This is a 50 percent increase.

The ODOT resilient modulus test results are similar to, but not exactly equivalent to the values used in developing Figure 2.5 in the AASHTO manual, as the ODOT used a different test temperature and test method. However, this example is of sufficient accuracy to illustrate the effects of pavement modulus on pavement thickness.