Overlay Design for Unstable Asphalt Mixes

Final Report
SPR 5299

by

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16. Abstract

The first objective of this study was to evaluate the relative rutting characteristics of overlaid pavements, where the overlaid section (i.e., new "base") had previously exhibited rutting. A second study objective was to develop criteria for the design of overlays for unstable "bases." The mixtures were evaluated in an LCPC Wheel Tracker. Slabs of the dense graded "base" mixtures and a typical open graded overlay mixture were evaluated by themselves as well as in three alternative configurations of composite layered slabs to simulate an overlaid pavement. A Repeated Load Creep Test was also conducted on cylindrical specimens of the base and overlay mixtures.

The use of the wheel tracking device did not provide a satisfactory means of evaluating either the open-graded overlay mixture or the composite slabs. This was predominantly because of the need to confine the open-graded mixture in the test "mold." This could be achieved in the future by preparing the specimens in the molds, an option not available to the researchers for this study.

Tentative criteria for overlaying rutted pavements were developed. It is proposed that the Repeated Load Creep Test be conducted at 25°C for both base and overlay mixtures. After 2000 load repetitions, if the permanent strain for either mix exceeds 1 percent (10,000 microstrain), the overlay of this base should not be pursued. If the mixes pass the creep criterion, they should be tested at 60°C in a layered slab configuration in the Wheel Tracker and if the rutting is less than 10 mm after 50,000 passes, the field overlay project should proceed. If the rutting is more than 10 mm after 10,000 passes, the project should not proceed. If the rutting falls between these two limits, an overlay could proceed with an adjusted mix design or if the truck traffic for the project is light.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

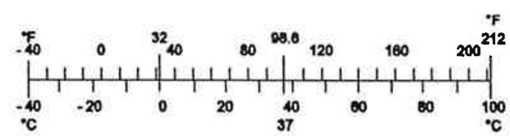
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared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

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

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

APPROXIMATE CONVERSIONS FROM SI UNITS

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



* SI is the symbol for the International System of Measurement

(4-7-94 jbp)

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DISCLAIMER

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1.0 INTRODUCTION

1.1 Background

The Oregon Department of Transportation (ODOT), as well as other highway agencies, continues to experience load related rutting in asphalt concrete mixtures. Rutted pavements require rehabilitation and this usually involves use of a thin overlay, e.g., 25 to 50 mm (1 to 2 in.) in combination with grind and inlay. Alternatives for overlays include both ODOT class "B" (conventional dense-graded) and ODOT class "F" (open-graded) mixes. At the present time ODOT uses a conservative empirically based approach to design overlays for this situation. The major intent of this research study was to see if an alternate approach, based on appropriate testing, could be developed.

This study made use of the LCPC rutting tester which was installed as a part of SHRP project A-003A at Oregon State University (OSU) in 1991. It was used to evaluate the relative rutting characteristics of overlaid and inlaid sections representative of newly rehabilitated rutted pavements in the state of Oregon. In addition, tentative criteria for overlaying rutted pavements were developed. The rutting tester has been widely used in Europe to rank the relative performance of both conventional and modified asphalt mixtures.

The LCPC device was also used in another project for ODOT titled, "Evaluation of Rutting Potential of Asphalt Concrete Mixtures," (Hicks et al., 1994). The project described in this report specifically addressed the problem of overlaying rutted pavements. However, there is some beneficial overlap between the two projects.

In addition to the evaluation of slabs of material using the LCPC device, small cylindrical specimens were tested in repeated loading to determine their resilient modulus and creep characteristics. These data were compared with the rutting data to see if these relatively simple tests could be used (perhaps with the LCPC data) to establish criteria for the design of overlays.

The information developed in this study allowed a comparison of the rutting resistance of overlaid sections. However, additional work is needed before any refinement of overlay design procedures can be made.

1.2 Objectives

The broad objectives of this study were to evaluate the effectiveness of overlays for rutted asphalt concrete pavements and to develop criteria for the design of these overlays. In particular, the study attempted to evaluate the effect of:

1) overlay lift thickness and
2) "stability" of pavement to be overlaid.

1.3 Study Approach

The study was accomplished in several tasks as follows:

1) **Task 1. Development of Laboratory Experiment Design.** This task consisted of selecting the materials to be studied and the various combinations to be evaluated. The results of this effort are presented in Chapter 2.
2) **Task 2a. Preparation of Test Specimens.** This task consisted of obtaining the necessary materials and preparing the test specimens. The results of this effort are given in Chapter 3.
3) **Task 2b. Testing of Asphalt Mixes.** This task took place in 1993 and winter and spring 1994, and consisted of the evaluation of the test specimens in the wheel tracker and the repeated load creep test. The results of these efforts are presented in Chapters 4 and 5.
4) **Task 3. Analysis of Results.** Data analysis produced a ranking of the relative rut resistance of the asphalt mixes tested. Preliminary analyses for each set of tests are

presented in Chapters 4 and 5. A comparison of LCPC and creep results are presented in Chapter 6.

5) **Task 4. Report.** This task documented the findings and recommendations resulting from the study.

During the project, the researchers attempted to implement a new computer program, PACE. This program is being developed by SWK Pavement Engineering for Shell Oil Company. It is a rigorous finite element based program to predict deformation and fatigue development in flexible pavements. The program utilizes data from tests, such as the repeated load creep test, to characterize the pavement layers. For this project, it was anticipated that creep data for the "unstable base" and new overlay material would be input and deformations for the life of the overlaid pavement output. It would then be a simple matter to evaluate whether the predicted performance of the overlaid pavement was acceptable.

Unfortunately, the development of PACE was delayed to the extent it could not be used in this project. However, the OSU researchers will continue to work with SWK and it is possible that PACE may be used for evaluating potential overlay projects in the future.

2.0 EXPERIMENTAL DESCRIPTION

This chapter describes the variables considered in the study, the experiment design, the materials used, and the job-mix formulas employed. The decisions on variables selected were based on numerous discussions between ODOT and OSU personnel.

2.1 Variables Considered

Since the primary purpose of the study was to evaluate the rutting characteristics of overlaid deformable bases, the following were selected as the study variables.

2.1.1 Mix Types

The major mix types utilized in Oregon for bases and overlays were selected for study. They were as follows:

1) **Class B**, a dense-graded asphalt mix (3/4 in. max.) which is normally used in high volume roads. It was attempted to select four levels of deformation susceptibility.

2) **Class F**, an open-graded mix (15 to 20% voids) (3/4 in. max.) which is used as a thick, typically 50 to 100 mm (2 to 4 in.), wearing surface on B mixes.

2.1.2 Lift Thickness

Each mixture was tested by itself using slabs 100 mm (4 in.) thick. These slabs also provided cylindrical specimens for the repeated load creep tests. In addition, to evaluate the effect of overlay thickness in contributing to the amount of rutting, three levels of overlay thickness were used in conjunction with mixtures with each level of base deformability. These were 40, 65, and 90 mm (1 1/2, 2 1/2, and 3 1/2 in.). The total thickness of these layered slabs varied, but the B-mix was always 50 mm (2 in.). For example, 40 mm (1 1/2 in.) of F-mix would be placed on 50 mm (2 in.) of a base layer (B-mix).

The experimental design for the study is summarized in Table 2.1. Each mix combination was fully replicated.

Table 2.1. Experiment Design

Combination	Surface Mix	Thickness (mm)	Base Mix	Thickness (mm)
1	F	40	B-1	50
2	F	65	B-1	50
3	F	90	B-1	50
4	F	40	B-2	50
5	F	65	B-2	50
6	F	90	B-2	50
7	F	40	B-3	50
8	F	65	B-3	50
9	F	90	B-3	50
10	F	40	B-4	50
11	F	65	B-4	50
12	F	90	B-4	50
13	F	100	—	—
14	B-1	100	—	—
15	B-2	100	—	—
16	B-3	100	—	—
17	B-4	100	—	—

Notes

1) The B-1 to B-4 base course materials used separate mix designs of varying instabilities. Where possible, these mix designs were based on projects known to have problems with premature rutting.
2) Combinations 13 through 17 were necessary to establish the individual rutting susceptibility of each base type, and, the surfacing.
3) Replicate slabs were tested in each case.

2.2 Materials

2.2.1 Asphalt Cement

For all overlay mixtures a Chevron PBA-6 was used, consistent with current ODOT practice. One batch of binder was obtained from the Chevron Willbridge Refinery in Portland, Oregon, to be representative of PBA-6 binder used in the 1992 and 1993 construction seasons.

For the four base mixtures, PBA-5 binder was used, representative of that used in four projects in the 1992 and 1993 seasons. Binder from two suppliers, Chevron and McCall, was used.

The specifications for Oregon PBA-5 and PBA-6 are shown in Table 2.2.

Temperature-viscosity curves for each of the binders were used to select mixing and compaction temperatures based on the Asphalt Institute criteria (1986).

2.2.2 Aggregates

The two aggregates used for this study were as follows:

1) **Hilroy Pit**, also referred to as Riverbend aggregate, is a gravel source with low fracture (within specification). This aggregate was obtained from Salem, Oregon. Selected properties of the aggregate, determined by ODOT, are given in Table 2.3. This aggregate was used for the base material for three of the four bases, and for all overlay mixtures.

2) **Reed Pit** is a crushed gravel from Salem, Oregon. Properties of this aggregate, determined by ODOT, are given in Table 2.4.

2.3 Job-Mix Formula

All mix designs were based on those used by ODOT for projects utilizing the binders and aggregates described above. All ODOT mix designs were developed following ODOT standard procedures (George and Dominick, 1993). ODOT mix design data sheets are given in Appendix A.

Table 2.2. Oregon Specifications for PBA-5 and PBA-6 Binders.

		Chevron PBA-5 June 23, 1992	PBA-5 Specifications	PBA-6 Specifications
Original Properties	• Absolute Viscosity @ 60°C (140°F)	2186	2000+	2000+
	• Kinematic Viscosity @ 135°C (275°F)	401	2000–	2000–
	• Flash (COC) °C (°F)	291 (555)	232+ (450+)	232+ (450+)
Aged (RTFO) Properties	• Absolute Viscosity @ 60°C (140°F)	6158	4000+	5000+
	• Kinematic Viscosity @ 135°C (275°F)	614	400+	275+
	• Pen @ 4°C (39.2°F)	20	15+	30+
	• Ductility @ 25°C (77°F)	130	50+	60+
	• Viscosity Ratio	2.82	4.0–	4.0–
	• Loss % Weight	0.641	—	—

Table 2.3. Properties of the Riverbend Aggregate

Property		Coarse	Fine
Sand Equivalent (TM 101)		NA*	82
Specific Gravity and Absorption (TM 203)	Bulk	2.64	2.62
	Apparent	2.76	2.77
	SSD	2.68	2.67
	Absorption (%)	1.66	2.15
Sodium Sulfate Soundness (TM 206)	Coarse	1.1	NA
	Fine	NA	2.0
LA Abrasion (TM 211)	Grading	B	NA
	% Wear	15	NA
Fracture (TM 213) (%)	3/4 in.	83	—
	1/2 in.	98	—
	3/8 in.	98	—
	1/4 in.	98	—
	#4	100	—
	Average	97	100

*Not available

Table 2.4. Properties of 1 1/2 to 3/4 Material from Reed Pit

Property		Coarse	Fine
Sand Equivalent (TM 101)		NA*	74
Specific Gravity and Absorption (TM 203)	Bulk	2.60	2.52
	Apparent	2.72	2.74
	SSD	2.64	2.60
	Absorption (%)	1.65	3.31
Sodium Sulfate Soundness (TM 206)	Coarse	3.1	3.2
LA Abrasion (TM 211)	Grading	B	NA
	% Wear	14.8	
Fracture (TM 213) (%)	1-1/2 in.	—	—
	1 in.	—	—
	3/4 in.	92	—
	1/2 in.	100	—
	3/8 in.	100	—
	1/4 in.	100	—
	Average	98	100

*Not available

Summaries of the job-mix formulas for both aggregates are given in Tables 2.5 and 2.6. This includes the following: aggregate gradation, asphalt content, and design Rice specific gravity.

Table 2.5. **Riverbend Mix Designs (Bases #1, #2, #4, and Overlay)**

Size	% Passing for each mix			
	Base #1	Base #2	Base #4*	F-Mix
1	100	100	100	100
3/4	97	96	98	91
1/2	84	84	87	67
3/8	73	72	76	42
1/4	57	57	58	24
10	28	29	35	14
40	11	11	17	6
200	4.9	4.5	4.7	3.5
AC % of total mix	5.6	5.4	6.5	6.0
Rice Specific Gravity	2.467	2.470	2.440	2.456
Air Voids (%)	6.0	5.0	3.5	11.5

*Base #4 mix design was based on those for #1 and #2 by adjusting the fine aggregate gradation and the binder content.

Table 2.6. **Reed Pit Mix Design (Base #3)**

Size	Base #3 (% Passing)
1	100
3/4	98
1/2	84
3/8	70
1/4	59
10	33
40	14
200	6.5
AC % of total mix	6.0
Rice Specific Gravity	2.425
Air Voids	4.5

3.0 SPECIMEN PREPARATION AND VOLUMETRIC ANALYSIS

This chapter describes the procedures used to prepare the specimens, and includes the results of the voids analyses on each layer of each slab.

3.1 Specimen Preparation

Specimen preparation for this research effort was accomplished by means of rolling wheel compaction. The procedure is outlined in detail in Appendix B. The procedure summarized in Table 3.1 was developed at OSU for the purpose of preparing specimens for previous studies. The method proved to be very effective and was retained for this ODOT study.

3.1.1 Mixing

The mixing process is shown schematically in Figure 3.1. The mixing device used consisted of a conventional concrete mixer modified to include infrared propane heaters (see Figure 3.2) to preheat the mixer prior to mixing as well as to minimize heat loss during the mixing process. The preheated and preweighed aggregate were added to the mixer followed by the asphalt. The mix for a single-mix slab was mixed in one batch, while a layered slab required two batches. After mixing, the dense-graded asphalt-aggregate mix was placed in a forced-draft oven set to 275°F (135°C) and "short-term aged" for 4 hrs in order to simulate the amount of aging which occurs in a batch or drum dryer plant (Bell et al., 1993). The mix was stirred once each hour to promote uniform aging. Attempts to cure an open-graded mix in the same manner in a previous study (Hicks et al., 1994) resulted in substantial asphalt run-off. This problem was alleviated by Hicks et al. by curing the open-graded mixes at 140°F (60°C) for 15 hrs. A similar procedure was used in this study.

3.1.2 Compaction

At the completion of the aging process, the mix was placed in an adjustable mold and compacted (Figure 3.3) to a predetermined density. The mold can accommodate several slab configurations: in this

Table 3.1. Summary of a Specimen Preparation Procedure

Step	Description
1	Calculate the quantity of materials (asphalt and aggregate) needed based on the volume of the mold, the theoretical maximum (Rice) specific gravity of the mix, and the desired percent air voids. Batch weights range between 30 kg (66 lbs) for a 25 mm (1 in.) lift and 90 kg (210 lb) for an entire single-mix slab.
2	Prepare the asphalt and aggregate for mixing.
3	Heat the materials to the mixing temperature, approximately 150 to 160°C (300 to 320°F) for the dense-graded mixes and 120 to 130°C (250 to 265°F) for the open-graded mixes.
4	Mix the asphalt and aggregate for 2 min. in a conventional concrete mixer fitted with infrared propane burners and preheated to the mixing temperature for the mix.
5	Age the dense-graded mix at 135°C (275°F) in a forced-draft oven for 4 hrs stirring the mix every hour. Age the open-graded mix for 15 hrs at 60°C (140°F). This "short-term aging" representing the amount of aging which occurs in the mixing plant.
6	Assemble and preheat the compaction mold using infrared heat lamps.
7	Place the mix in the compaction mold and level it using a rake while avoiding segregation of the mix.
8	Compact the mix when it reaches the compaction temperature using a rolling wheel compactor until the desired density is obtained. This is determined by the thickness of the specimen (the only volumetric dimension that can be varied during compaction for a set width and length of slab). Steel channels with depth equal to the thickness of the slab prevent overcompaction of the mix. Compaction temperature is approximately 120 to 130°C (250 to 265°F) for dense mixtures and 110 to 120°C (230 to 250°F) for open-graded mixtures.
9	Allow the compacted mix to cool to room temperature (about 24 hrs).
10	Disassemble the mold and remove the slab. Dry cut (saw) beams for the OSU wheel trackers. Dry cut cores for the repeated load creep test.

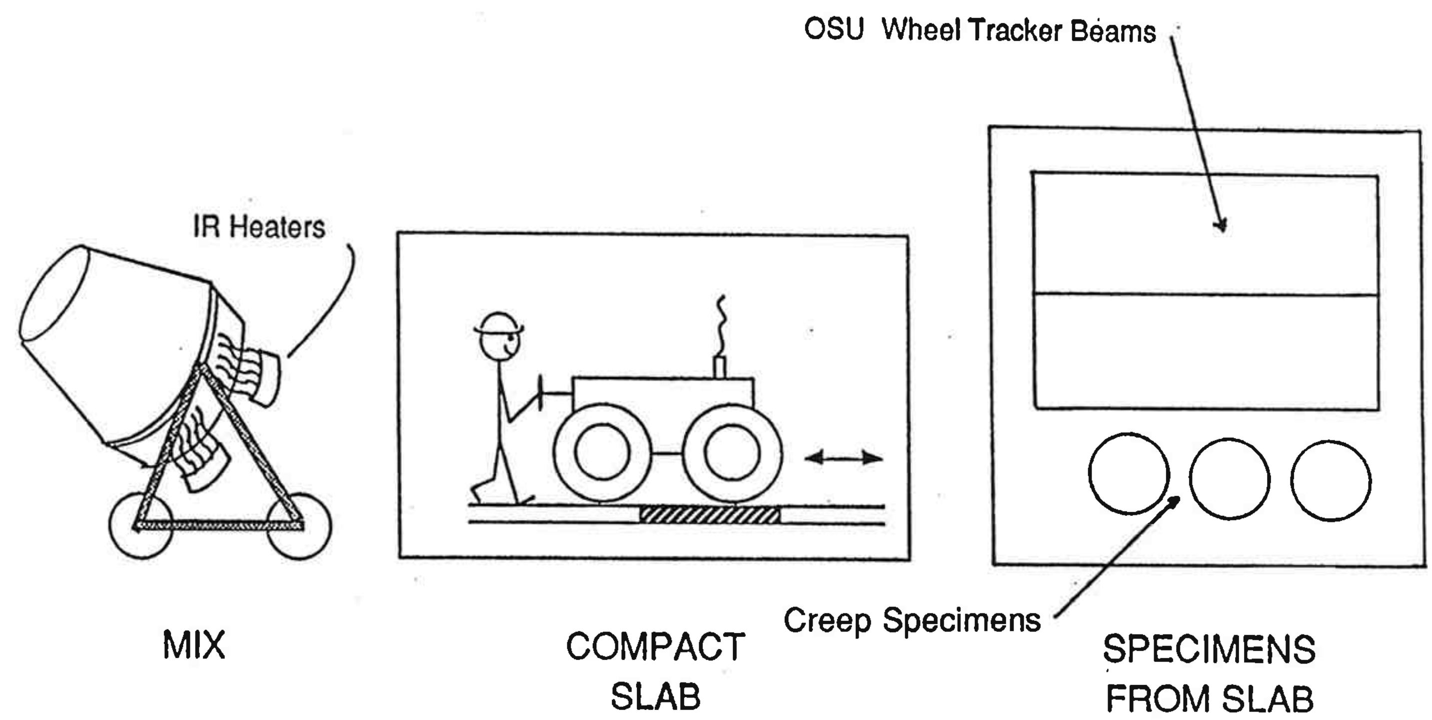


Figure 3.1. Mixing, Compaction and Sampling Process

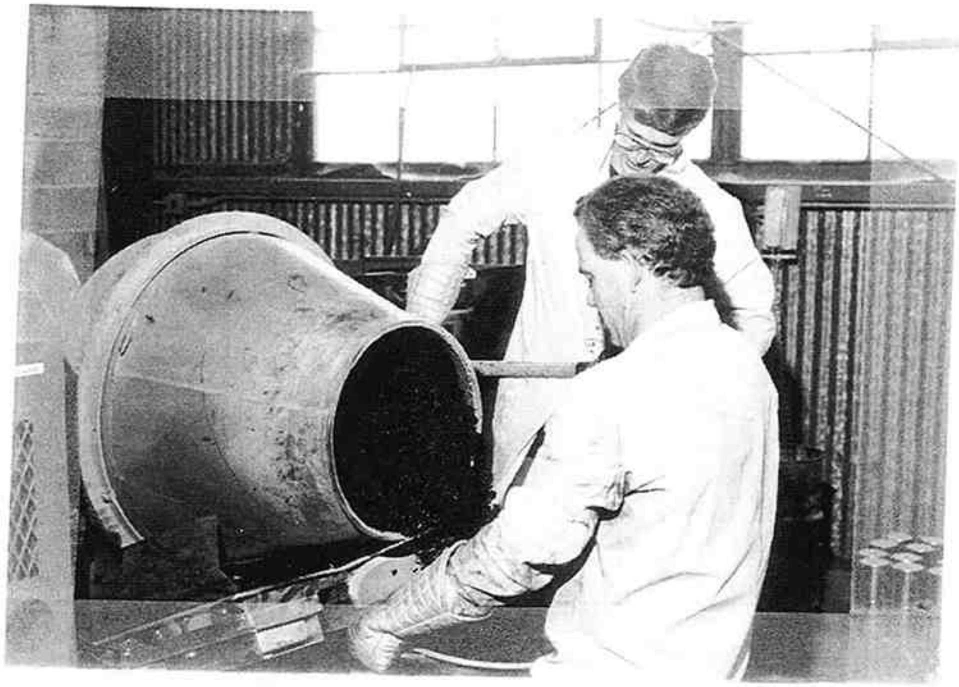


Figure 3.2. Photo of Mixer.

Figure 3.3. Photo of Compaction Process.

case, a 50 mm (2 in.) base and 40 mm (1½ in.) or 65 mm (2½ in.) or 90 mm (3½ in.) overlay, as well as a 100 mm (4 in.) single-mix slab. The compacted slab was allowed to cool overnight (about 24 hrs). To eliminate the effects of possible uneven compaction at the edge of the slab, approximately 25 mm (1 in.) of material was trimmed off before the rutting specimens were extracted. The 100 mm (4 in.) cores used for repeated load creep testing were also trimmed top and bottom to eliminate any edge effects.

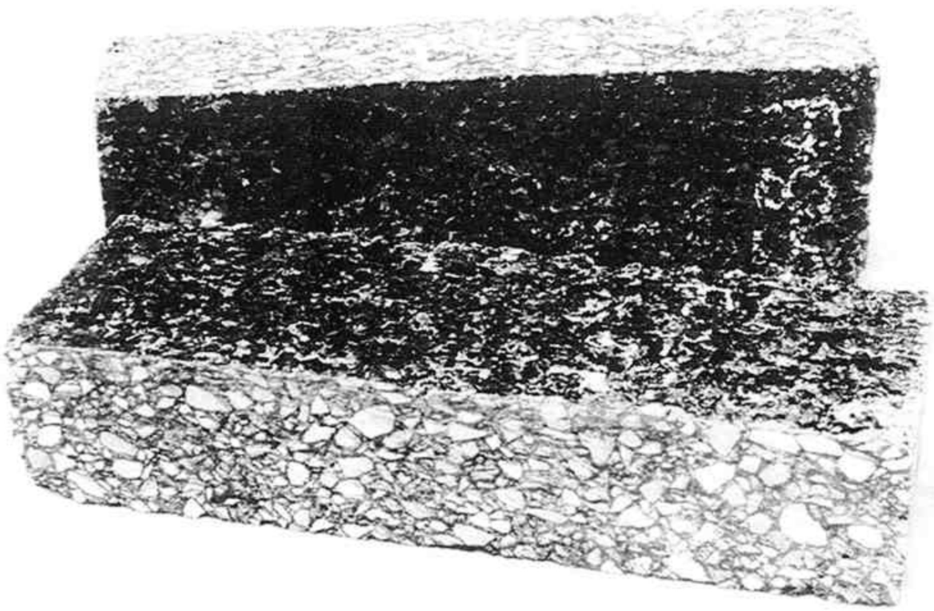
3.1.3 Cutting

After the slab had cooled it was pulled onto a pallet jack and taken outside where it was cut with a walk behind saw. Three beams 740 mm long × 170 mm wide (29¼ in. × 6⅝ in.) were cut from the slab. Two were used in the wheel tracking device; where necessary, cores were cut from the third for use in the repeated load creep tests (see Figure 3.4). Cores were not cut from the layered slabs.

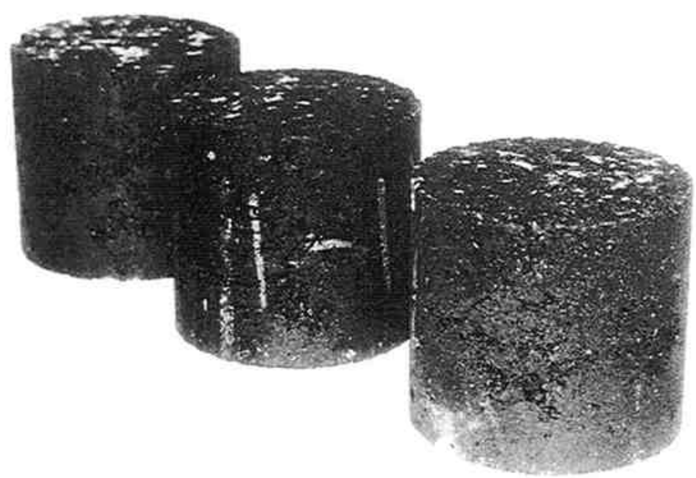
3.2 Volumetric Analyses

3.2.1 Procedure

The air voids were determined through a ratio of the bulk and maximum (Rice) specific gravities (calculated in accordance with ASTM D-3203). The bulk gravity is the density of the entire specimen, air voids included, and can be determined through the saturated-surface-dried (SSD) method or the parafilm wrapping method. The Rice gravity is the maximum specific gravity of the asphalt-coated aggregate. After the slabs were made, the void content of the rutting beams was determined using both the SSD and parafilm bulking methods. The two methods yield consistently different results. The voids calculated using parafilm bulking were typically two to three percentage points higher than those using the SSD method. A decision was made to use the results of the SSD bulk specific gravity for the void determination of the dense-graded specimens. The decision was based on the fact that the SSD method accounts for surface voids more accurately than does the parafilm method. The parafilm method was used for the open-graded mixes (F mixes) because the nature of the SSD makes it impossible to take



a) Wheel Tracker Beams



b) Repeated Creep Test Specimens

Figure 3.4. Photos of Typical Specimens Cut from Slabs

accurate measurements on an open-graded specimen. Table 3.2 gives a summary of the volumetric analyses.

3.2.2 Results

Summaries of the voids for all mixes are given in Table 3.2. There was not a specific target air voids for the dense-graded mixes. However, that for F-mix specimens was 17.5%. The voids achieved were related to the mix designs (Tables 2.5 and 2.6), but, because the method of compaction differed, they were not expected to be the same. As with field cores, the voids of roller compacted mixes (i.e., the slab specimens) were higher than the mix design specimens, compacted with the kneading compactor.

3.3 Storage and Labeling

The beams were stored at ambient temperature until the rutting tests were conducted. The open-graded and layered beams (since they all have an open-graded layer) were individually boxed because the open-graded mixes have a tendency to fall apart if not confined. The open-graded cores were wrapped in metal sheeting to prevent them from falling apart during storage.

All the specimens were labeled for identification. The unique five symbol code was designated for each specimen. This is explained in Table 3.3.

Table 3.2. Void Summary for All Slabs

Slab Description	Mix	I.D.	Avg. Rice/ # of Samples Averaged	Asphalt Content (%)	Bulk SSD	Bulk PF	Voids SSD	Voids PF
Overlay	F	UB00F4	2.450/1	6.0	—	2.096	—	14.4
Base #1	B	UB14F0	2.448/2	5.6	2.285	2.223	6.6	8.8
Base #1	B	UB12F1	2.467/2	5.6	—	2.210	—	10.4
+ 40 mm	F		2.447/1	6.0	—	2.103	—	14.0
Base #1	B	UB12F2	2.456/1	5.6	—	2.317	—	5.7
+ 65 mm	F		2.468/2	6.0	—	2.037	—	17.5
Base #1	B	UB12F3	2.430/1	5.6	—	2.265	—	6.8
+ 90 mm	F		2.457/2	6.0	—	2.090	—	14.9
Base #2	B	UB24F0	2.486/1	5.4	2.303	2.269	7.3	8.7
Base #2	B	UB22F1	2.468/2	5.4	—	2.265	—	8.2
+ 40 mm	F		2.458/2	6.0	—	2.134	—	13.2
Base #2	B	UB22F2	2.452/2	5.4	—	2.255	—	8.0
+ 65 mm	F		2.442/1	6.0	—	2.120	—	13.2
Base #2	B	UB22F3	2.434/1	5.4	2.250	2.166	7.6	11.0
+ 90 mm	F		2.455/2	6.0	—	2.033	—	17.2
Base #3	B	UB34F0	2.416/2	6.0	2.348	2.299	2.8	4.8
Base #3	B	UB32F1	2.416/1	6.0	—	2.305	—	4.6
+ 40 mm	F		2.439/2	6.0	—	2.114	—	13.3
Base #3	B	UB32F2	2.432/2	6.0	—	2.314	—	4.9
+ 65 mm	F		2.471/1	6.0	—	1.955	—	20.9
Base #3	B	UB32F3	2.416/2	6.0	—	2.333	—	3.4
+ 90 mm	F		2.443/1	6.0	—	2.079	—	14.9
Base #4	B	UB44F0	2.429/2	6.5	2.318	2.294	4.6	5.6
Base #4	B	UB42F1	2.419/2	6.5	2.327	2.292	3.8	5.3
+ 40 mm	F		2.453/2	6.0	—	2.037	—	17.0
Base #4	B	UB42F2	2.411/1	6.5	2.333	2.279	3.8	5.5
+ 65 mm	F		2.457/1	6.0	—	2.092	—	14.9
Base #4	B	UB42F3	2.414/2	6.5	2.296	2.240	4.9	7.2
+ 90 mm	F		2.456/1	6.0	—	2.151	—	12.4

Table 3.3. Coding Scheme for ODOT Unstable Mix Overlay Design Project

Project	Base Mix	Design	Thickness	Overlay Mix	Thickness	Specimen Type	Sequence Number
U (unstable mix overlay design)	B (class B)	0 (none)	0 (none)	F (class F)	0 (none)	R (rutting)	1-6
		1 (Riverbend)	2 (base)		1 (40 mm)	C (cores)	
		2 (Riverbend)	4 (full)		2 (65 mm)		
		3 (Reed Pit)			3 (90 mm)		
		4 (Riverbend)			4 (4 in.)		

Example: UB12F1R1 = 50 mm B-mix (Riverbend aggregate mix design) base with a 40 mm F-mix overlay, rutting specimen #1.

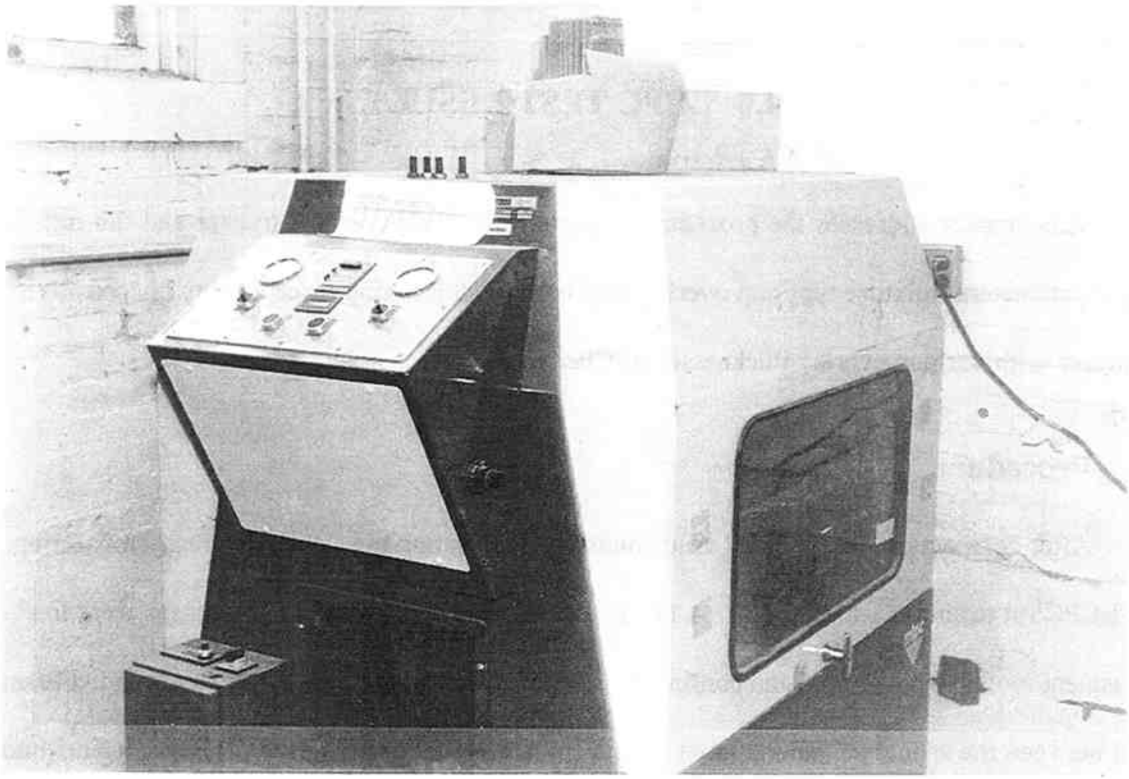
4.0 LCPC TEST RESULTS

This chapter addresses the procedural aspects of the LCPC wheel tracker and the influence of mixture parameters (mixture type and overlay thickness) on the rutting susceptibility of "sensitive" Class B mixtures with various overlay thicknesses of Class F-Mixture.

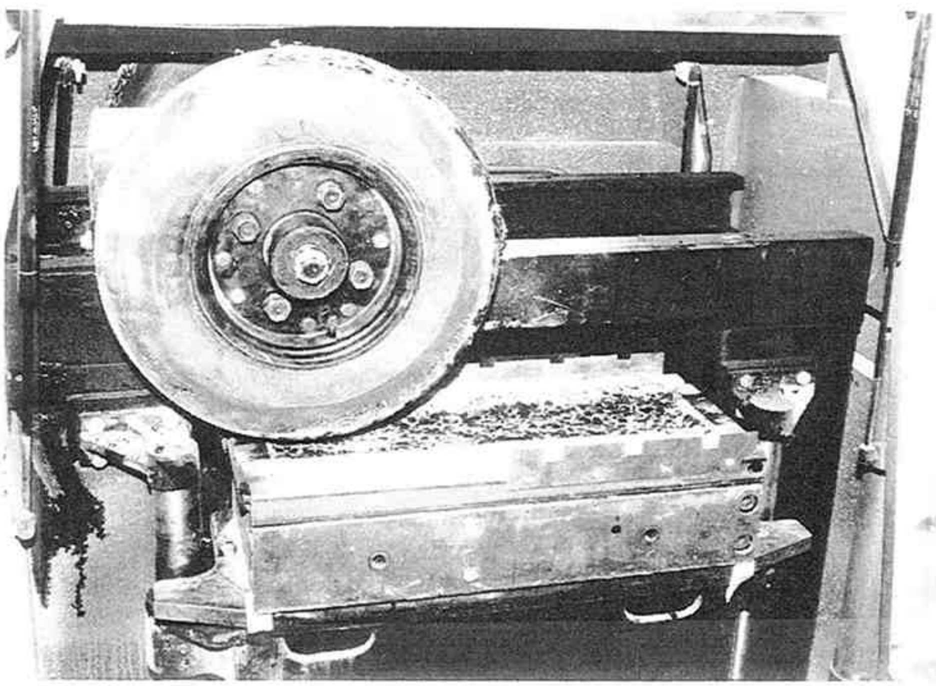
4.1 Procedure

After compaction, cutting, and void content determination the slabs were ready for testing in the OSU-LCPC rut testing machine (Figure 4.1). The day preceding testing, the specimens were loaded into confinement molds, used to hold and confine the specimen during testing. Sheets of expanded foam were placed between the specimen and the mold to prevent lateral movement of the prismatic beams under the reciprocating action of the rolling wheel. In addition, a sheet of butcher paper was placed between the bottom of the sample and the pneumatic platen, to provide a means of breaking the bond between the rutted slab and the platen when the test is completed. The mold-specimen assembly was then placed into the LCPC and bolted into place. The testing machine was then set to a test temperature of 60°C (140°F) for a minimum of 12 hours to ensure temperature equilibrium within the sample.

Prior to testing, a dusting of mineral fines (passing the #200 sieve) were spread over the top of the specimen to prevent binder and aggregate from sticking to the wheel. At this point 50 preconditioning wheel passes were applied to the specimen. The specimen was preconditioned to eliminate the high plastic primary deformation characteristics of asphalt-aggregate mixes at the onset of loading. After preconditioning, measurements were made on the specimen with the electronic displacement transducer, developed by OSU. The initial data was recorded and used as a bench mark for subsequent readings. Subsequent deformation measurements were made at 100, 200, 500, 1,000, 2,000, 5,000, 10,000, 20,000, 30,000, 40,000, and 50,000 wheel passes. After 50,000 passes the specimen was removed from the testing machine. A detailed test procedure is included in Appendix C.



a) Overview



b) Close Up of Specimen with 7.62 cm (3-in.) Riser

Figure 4.1. Photo of Test Equipment

Since this investigation involved testing specimens thicker than those tested in previous studies, the OSU Wheel Tracker molds needed to be modified to confine these specimens. The standard 101.6 mm (4 in.) specimen frame is shown in Figure 4.2a. Using this standard frame, a comparable frame 17.5 mm (11/16 in.) high was built and bolted to the existing frame structure for testing the 114.3 mm (4.5 in.) high samples. The profile view of this structure is shown in Figure 4.2b. For samples 139.7 mm (5.5 in.) high, a riser 38.1 mm (1.5 in.) high was built to bolt to the original confinement frame. This is shown in Figure 4.2c.

4.2 Test Results

All test results were reported using the format shown in Figure 4.3. Each of the three stages shown in Figure 4.3 are associated with the permanent deformation of a mixture (Carpenter, 1993). These three stages are:

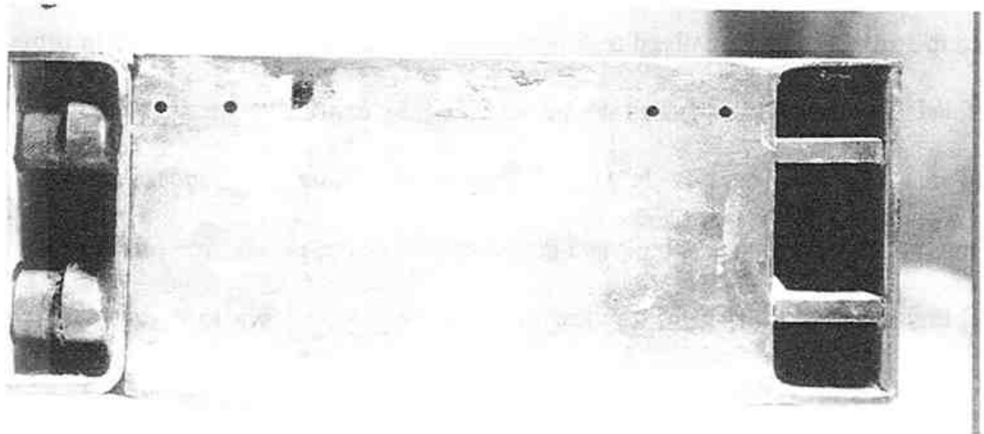
1) **Primary Stage.** This initial densification is due, in part, to the composition of the mixture tested.
2) **Secondary Stage.** This is associated with the stable shear period of a mixture.
3) **Tertiary Stage**. This third stage is associated with total failure of a mixture.

Test results are summarized in Figures 4.4 to 4.11. The results compare the average rutting of two mixtures, tested at the same time for different F-Mixture types and overlay thicknesses. The number of wheel passes is shown on a log scale, whereas the rutting depth is on a linear scale. All test data are given in Appendix E. A preliminary comparison of the results between replicate samples indicates that, for the Class F-Mixtures, the repeatability of the test is poor.

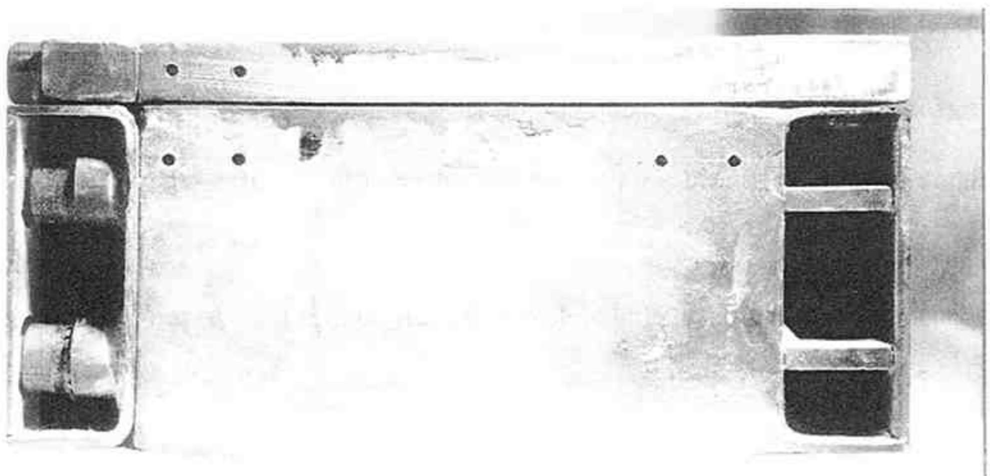
4.3 Discussion of Results

4.3.1 Effect of Mixture Type

The results indicate that mix type influences rut depth and rut potential. The figures clearly indicate that many mixtures were approaching tertiary failure. In addition, many mixtures experienced



a) Standard Specimen Frame (No Riser)



b) Specimen Frame with 1.75 cm (11/16-in) Riser

c) Specimen Frame with 3.81 cm (1.5-in.) Riser

Figure 4.2. End View of Specimen Frame

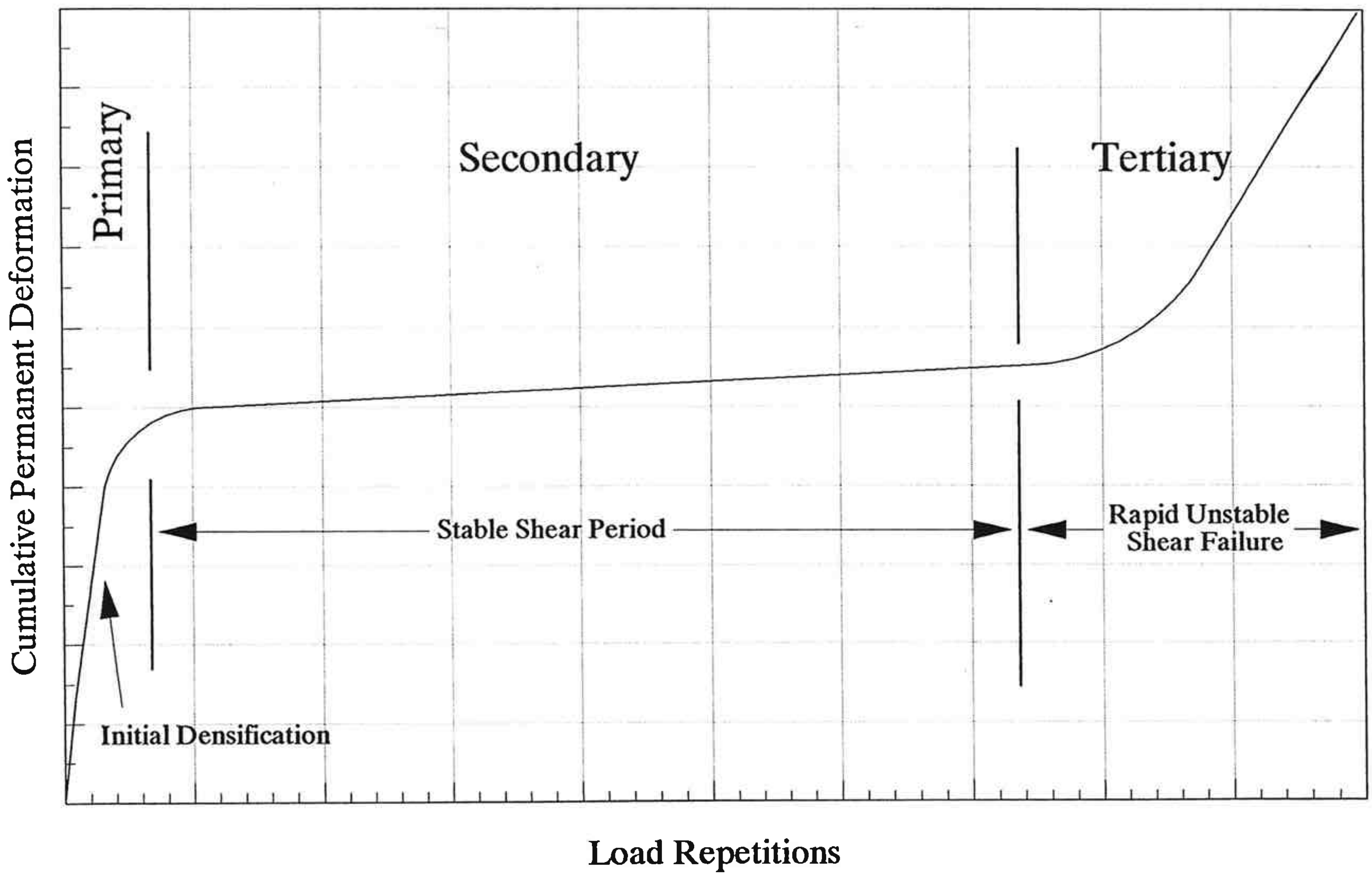


Figure 4.3. Three Stages of Permanent Deformation (Carpenter, 1993)

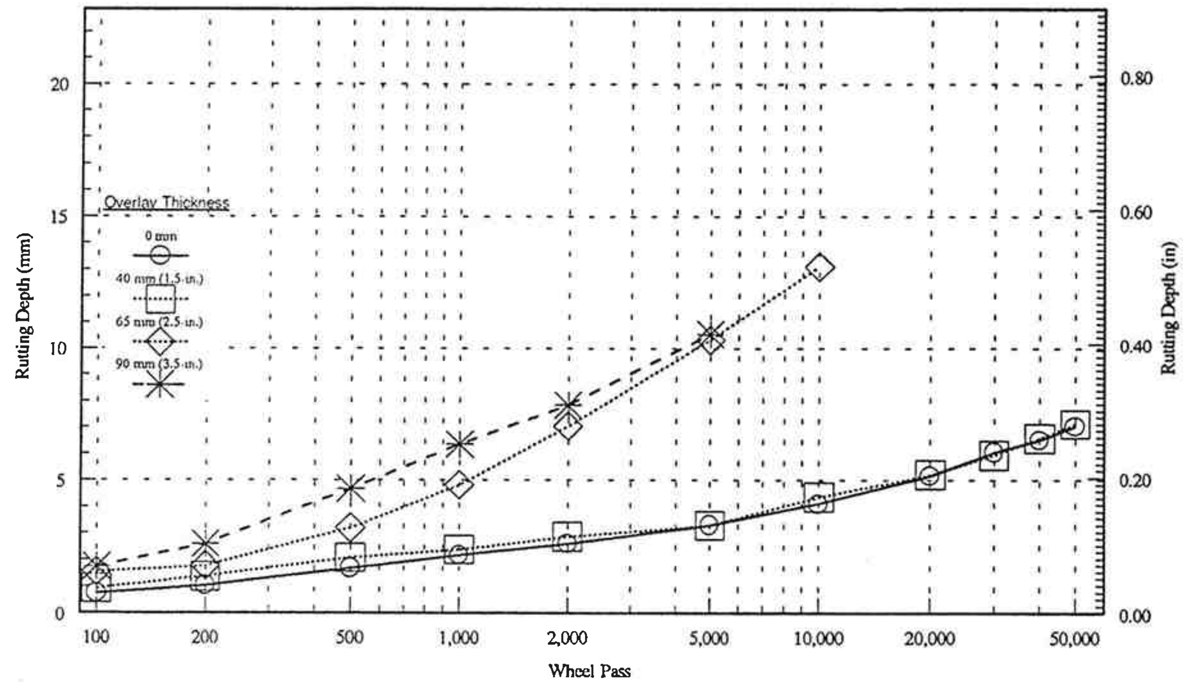


Figure 4.4. Base #1 (Riverbend) Average Rutting Results

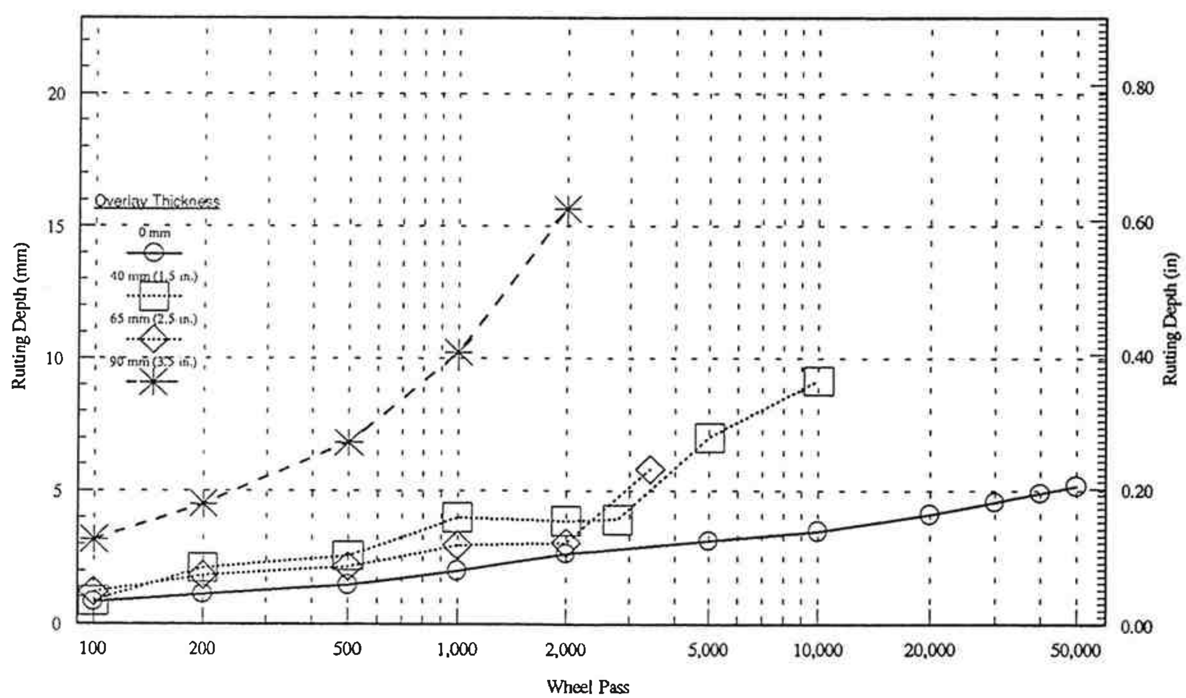


Figure 4.5. Base #2 (Riverbend) Average Rutting Results

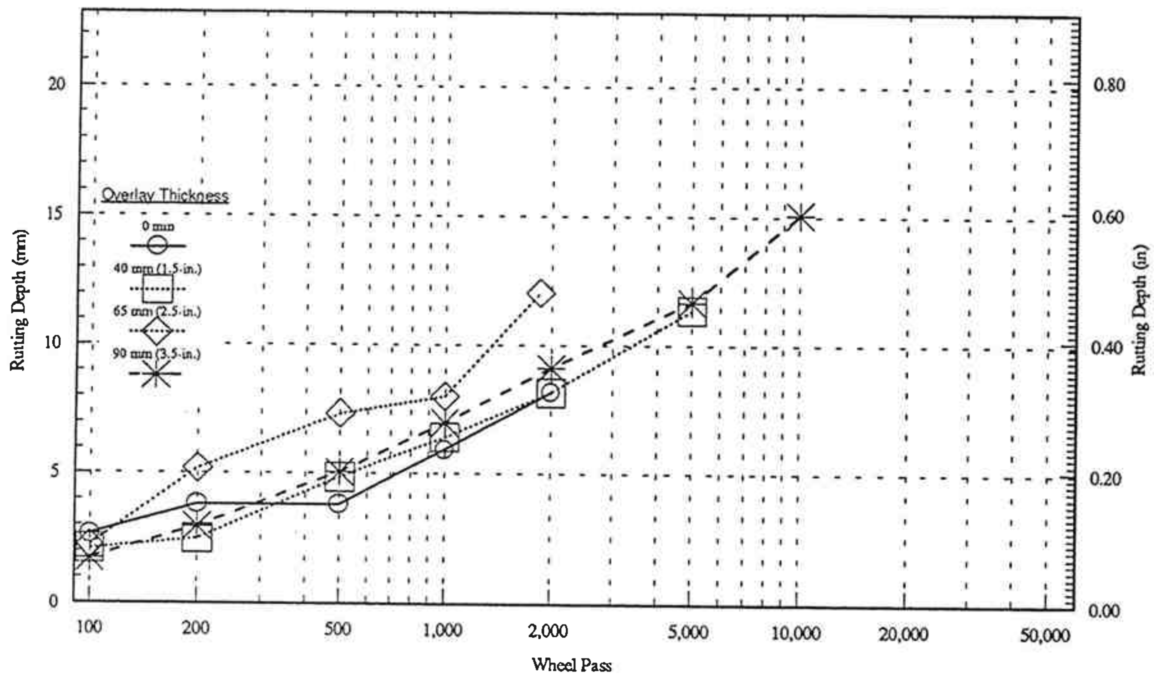


Figure 4.6. Base #3 (Reed Pit) Average Rutting Results

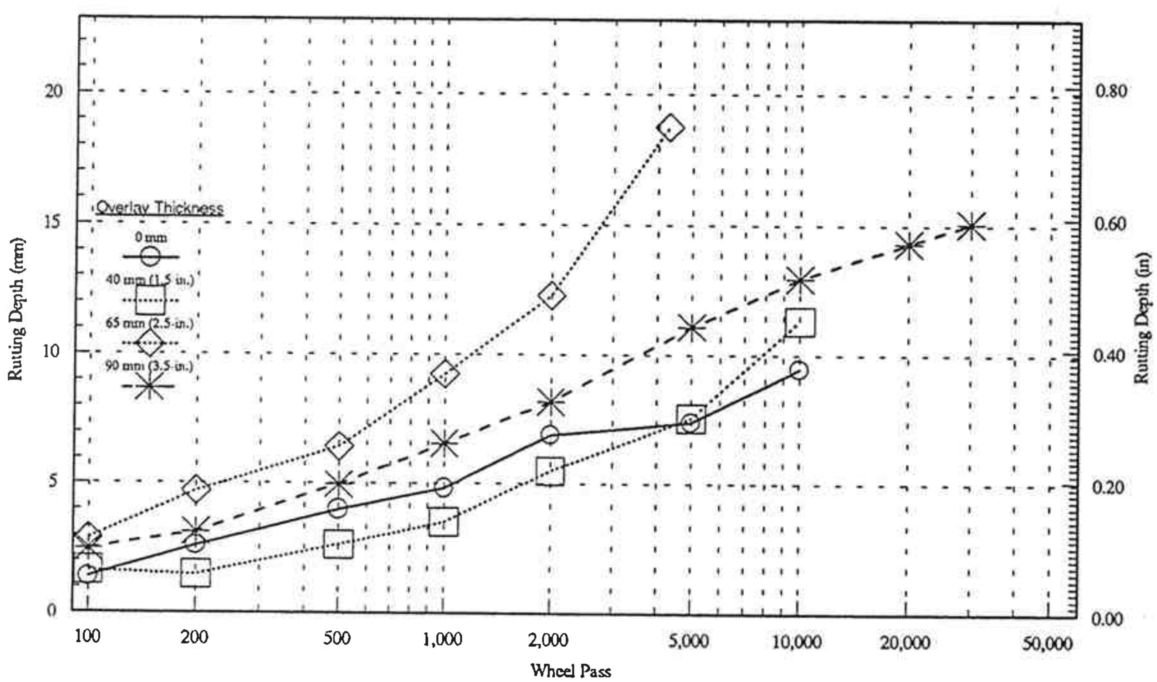


Figure 4.7. Base #4 (Riverbend) Average Rutting Results

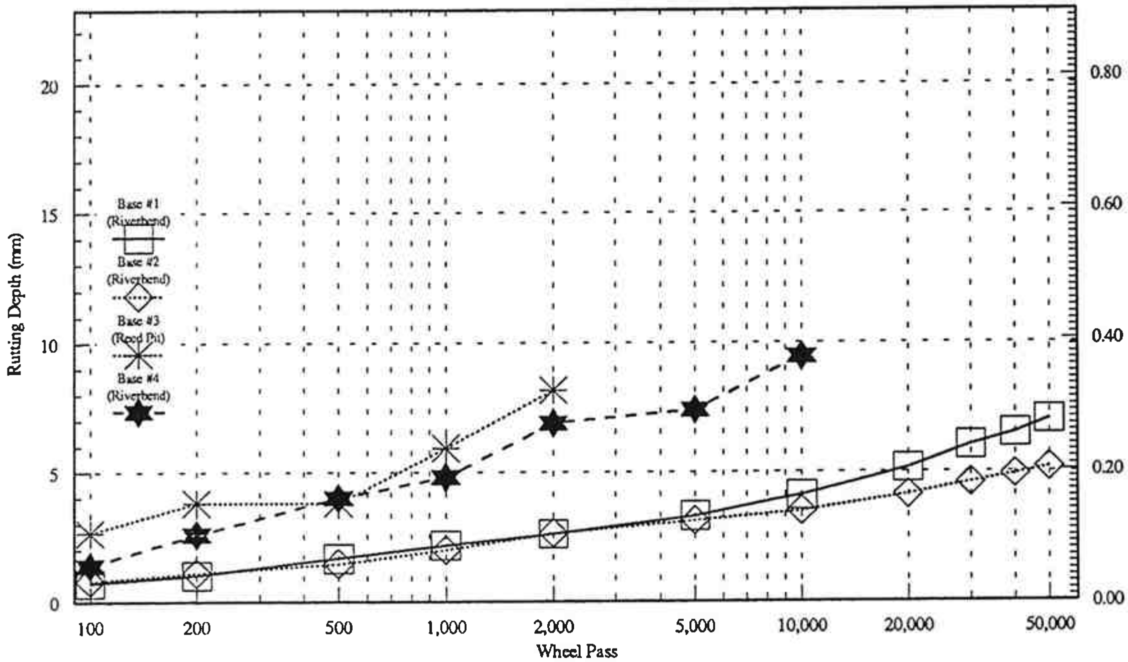


Figure 4.8. Average Overlay Rutting Results (No Overlay)

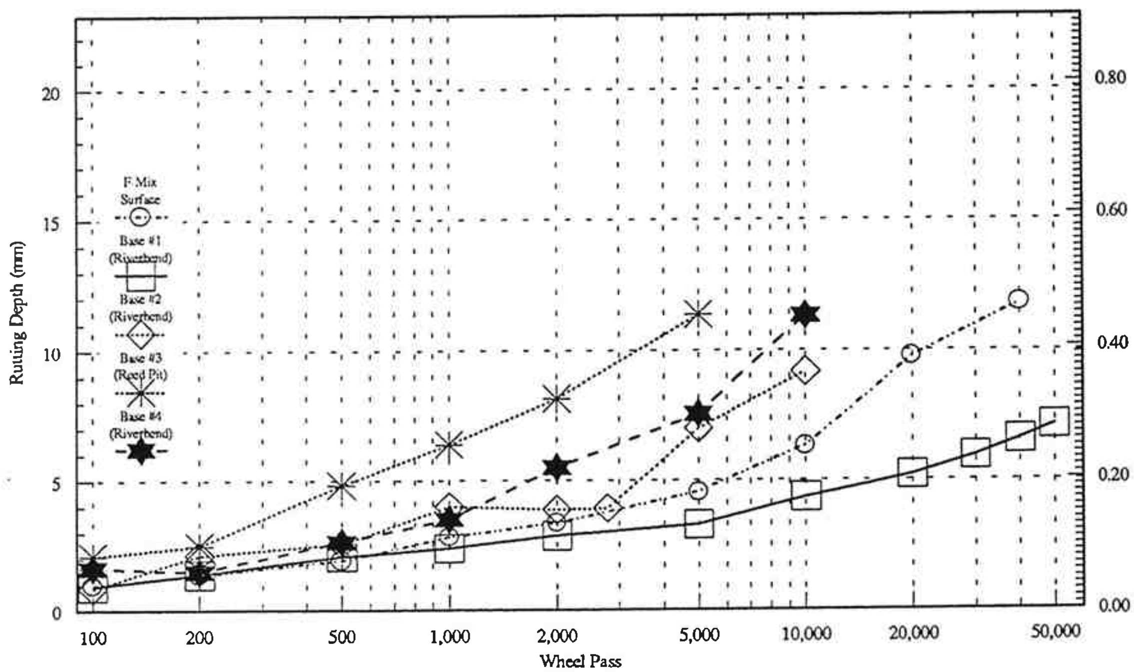


Figure 4.9. Average 40 mm (1.5 in.) Overlay Rutting Results

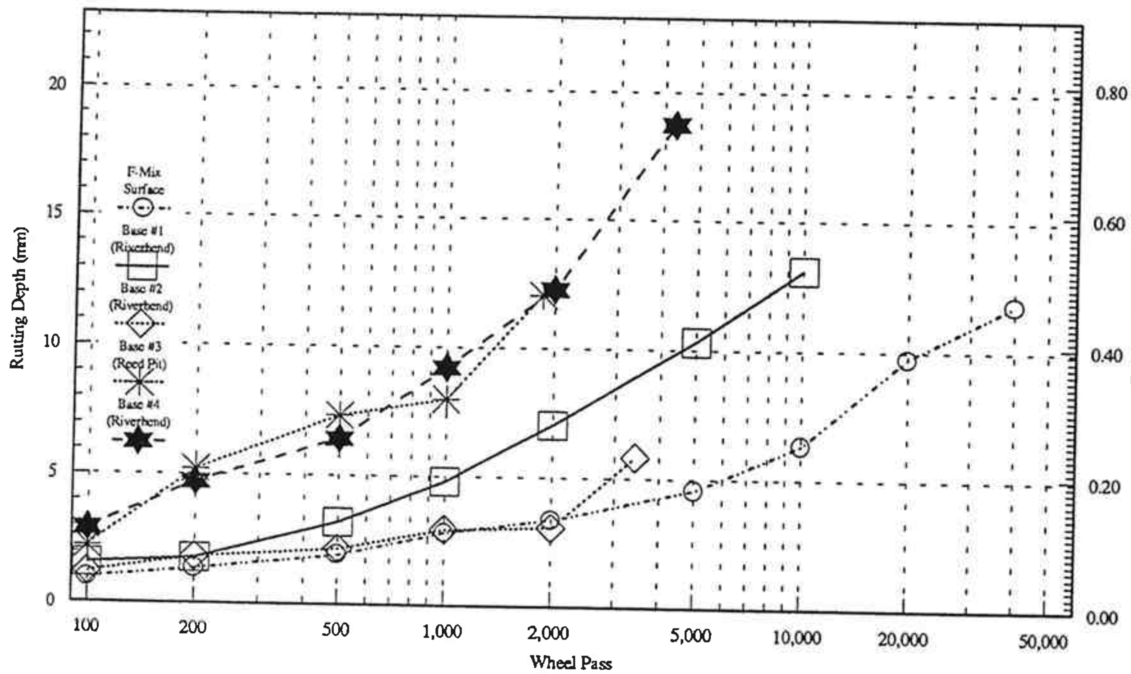


Figure 4.10. Average 65 mm (2.5 in.) Overlay Rutting Results

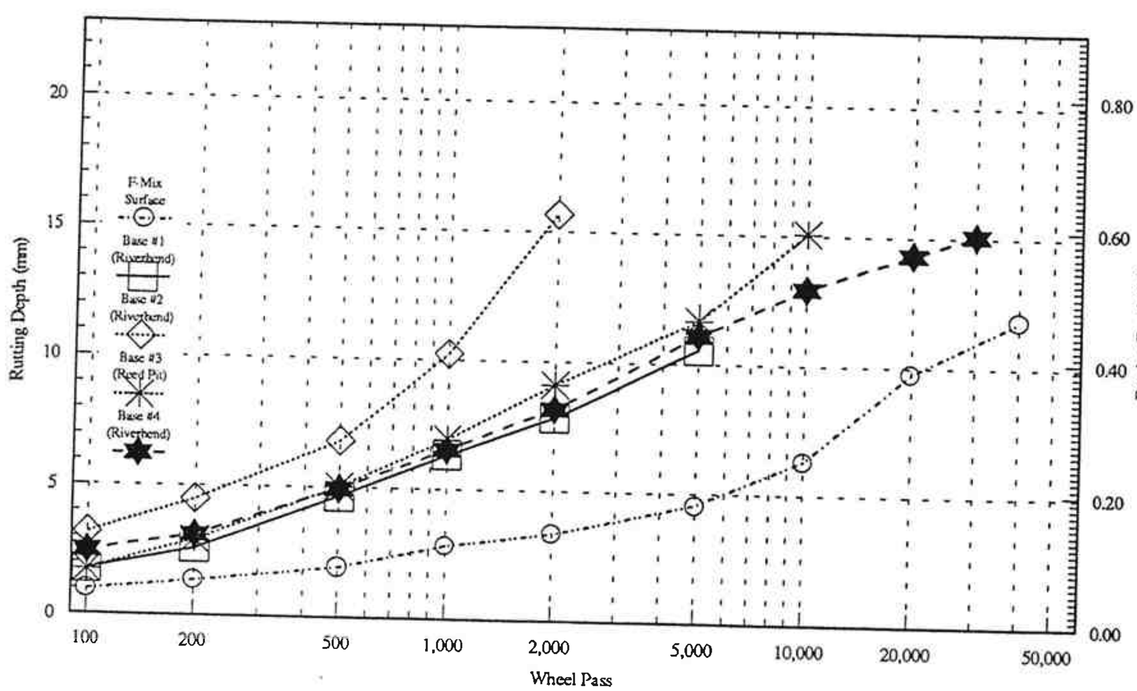


Figure 4.11. Average 90 mm (3.5 in.) Overlay Rutting Results

large amounts of shoving. This made measurement of total rutting (height of shove plus the depth of rut) very difficult because the aggregate would debond from the test slab during rutting. Therefore, for this study it was decided to define rutting depth as the decrease in slab thickness in the wheel path. From Figures 4.4 through 4.11 it can be seen that the amount of rutting in the wheel path is still not a smooth relationship. This could be due to the aggregate debonding under the wheel path, causing irregularities in rutting depth. Between these two sets of data, rutting depth in the wheel path proved to be the most consistent source of information.

Table 4.1 shows, through multiple regression analysis, how each mixture ranks as far as rutting potential. In the regression analysis, indicator variables were used to define the mixture tested and depth of overlay thickness. From this, a ranking of mixtures is determined from the coefficient's magnitude (associated with the indicator variable). This coefficient is shown in Table 4.1--Between Mixtures. The beneficial aspect of using these coefficients is that it not only ranks the mixtures but also provides an indication of the magnitude of rutting between mixtures. Table 4.1 also shows how each mixture ranked, from 1 as the least susceptible to rutting, to 4, the most susceptible to rutting. Two of the mixtures were statistically similar in rutting potential at a 95% confidence interval and share the same mixture ranking. For comparison between layered mixtures, the F-Mixture is included in Table 4.1. It can be observed that the F-Mixture resisted rutting less than the Base #1 and Base #2 mixtures. However, Base #3 and Base #4 showed greater rutting than the Class F-Mixture.

A comparison of the results of this study with those from the study by Hicks et al. (1994) is appropriate. Hicks et al. conducted wheel tracking tests on typical B-mixes at 40°C and 60°C and on F-mixes at 40°C. The B-mixes were designed for normal use, i.e., not to be unstable as in the present study. The degree of rutting observed for the Hicks et al. B-mixes at 60°C was similar to that observed for bases 1 and 2 shown in Figure 4.8. The degree of rutting observed for the Hicks et al. F-mixes at 40°C was more than double that for their B-mixes at 40°C. This is similar to that observed in this study

Table 4.1 Statistical Summary of LCPC Test Results

Mixture	F-Mix Overlay Thickness mm (in.)	Average Rutting Potential			
		Within Mixtures		Between Mixtures	
		Coefficient	Ranking	Coefficient	Ranking**
F-Mixture	100 (4.0)	NA‡	NA	0.14	2
Base #1* (Riverbend)	0	0	1	0	1†
	40 (1.5)	0.05	1†		
	65 (2.5)	0.40	2		
	90 (3.5)	0.46	3		
Base #2 (Riverbend)	0	0	1	0	1†
	40 (1.5)	0.26	3		
	65 (2.5)	0.18	2		
	90 (3.5)	0.73	4		
Base #3 (Reed Pit)	0	0	1	0.16	3
	40 (1.5)	0.13	1†		
	65 (2.5)	0.28	2		
	90 (3.5)	0.29	1†		
Base #4 (Riverbend)	0	0	1	0.20	4
	40 (1.5)	-.08	1†		
	65 (2.5)	0.29	2		
	90 (3.5)	0.08	1†		

*Note: Aggregate used shown in parentheses.
**A ranking of 1 indicates the best resistance to deformation; a ranking of 4, the worst.
†Note: Mixtures were statistically similar at a 95% confidence interval.
‡Note: Not Applicable

where the F-mix rutted about twice as much at 60°C as the two more stable B-mixes (those that behaved similarly to the B-mixes tested by Hicks et al.).

4.3.2 Effect of Layer Thickness

The addition of a layer of F-Mixture over the Class B-Mixtures influences the rutting potential of the combined mixtures. Figures 4.4 and 4.5 show that the 90 mm (3.5-in.) overlays had the highest degree of rutting with bases #1 and #2. However, Figures 4.6 and 4.7 show that the 65 mm (2.5-in.) overlay had the highest degree of rutting with bases #3 and #4. In general, Figures 4.4 through 4.7 show that as the thickness of overlay increases, the degree of rutting tends to increase. These observations are consistent with the ranking reported in Table 4.1 and with Hicks et al. (1994).

For each mixture tested in this study a comparison was made to determine the rutting potential of the mixtures (Table 4.1) with various overlay thicknesses. Again, indicator variables were used to differentiate the overlay thicknesses. The higher the indicator variable, the higher the degree of rutting for the mixtures. From these results, a ranking within mixtures is made and shown in Table 4.1. The regression model used was not perfect (adjusted $R^2 = 61\%$). However, many of the assumptions made with regression were adequately satisfied with the transformed regression model (i.e. linearity, constant variance, normality, and independence). With this in mind, the results provided relative insight into the ranking of each mixture. These statistical results can be verified through visual comparisons of Figures 4.4 through 4.11.

Figures 4.4 thorough 4.7 show the average OSU Wheel Tracker results for each mixture. Each figure shows the increased Rutting Depth for the Class B-Mixtures with 0 through 90 mm (3.5-in.) of F-Mixture overlays. Figures 4.8 through 4.11 show the same results grouped by overlay thickness. Each figure shows the increased Rutting Depth for each mixture type with the same Class F-Mixture overlay thickness. Figures 4.9 through 4.11 also include the average Rutting Depth for the Class F-Mixture, with no Class B-Mixture used as a base material. This is shown for a relative effect comparison of mixture thicknesses.

As noted in the previous section, the F-mixes tested by Hicks et al. rutted twice as much as the B-mixes, similar to what was observed in this study for the better mixes. They also noted an increase in rut depth for a layered slab of F-mix plus B-mix compared to a similar thickness of B-mix. It is logical that adding an F-mix layer to a slab of good B-mix will increase the total amount of rutting, if the total thickness remains constant. If the total thickness increases, it is possible that the total amount of rutting will decrease because of a decrease in the stresses and strains in the slab. However, because rutting is the result of permanent strain multiplied by depth, unless the strain decreases by an amount greater than the increase in depth, rutting will increase. This is the case for all the combinations of F- and B-mixtures used in this study. However, the increase tends to be less for bases 3 and 4 (the least stable) than for bases 1 and 2 (the most stable).

4.3.3 Estimation of Rutting Potential

Another analysis was performed to estimate the mixture rutting potential and further evaluate the type of rutting experienced by each sample. Using a ratio of cumulative deformation to layer thickness for the non layered slabs, the amount of strain incurred at 1,000 wheel passes is used to predict the amount of deformation in the layered slabs. This prediction was compared to the actual amount of deformation at 1,000 wheel passes. In all cases, this prediction estimate under-estimated the amount of rutting by amounts of 2% to 66%. This inconsistency within and between each mixture would suggest that there was a lack of uniform deformation in the underlying layers. This is further illustrated by the photographs shown in Figures 4.12 through 4.15. Figure 4.12 shows the OSU Wheel Tracker results for the Base #1 mixture. Note the small amount of rutting when compared to the other three figures. Figures 4.13 through 4.15 show rutted cross sections of Base #1 (Riverbend) with three Class F overlay thicknesses. These figures only show one of the base mixtures but are representative of the results of all the mixtures. A scale is shown for relative comparison in each figure. The long divisions of the scale represents 25 mm (1-in.). In Figures 4.13 through 4.15, the Class B-Mixture occupies the bottom 50 mm (2-in.) of each sample. Following the fine line of aggregate at the 50 mm (2-in.) mark, it can be

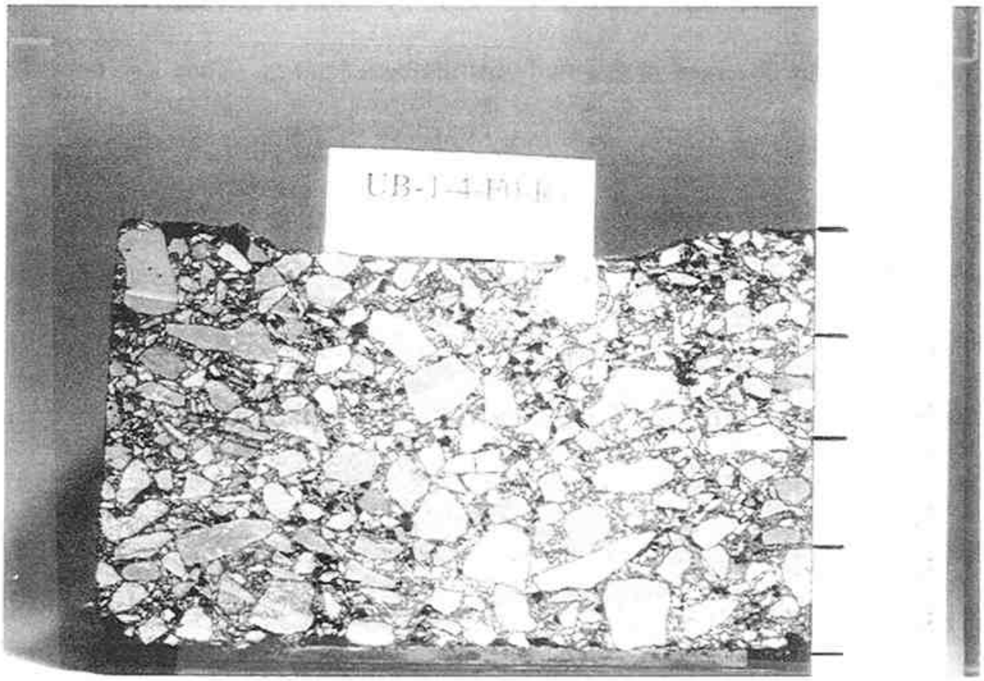


Figure 4.12. Base #1 Mixture After 50,000 Wheel Passes

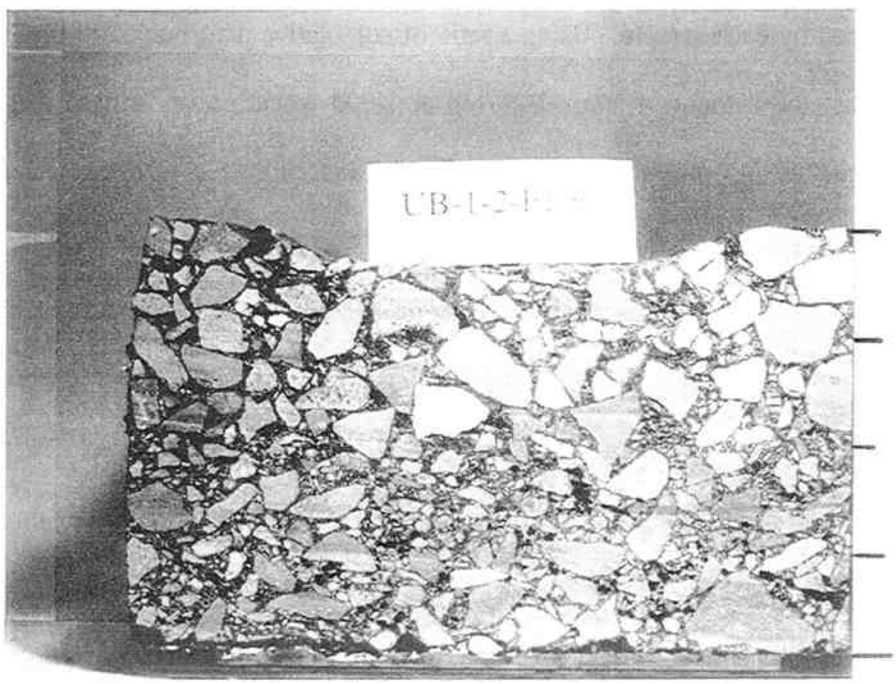


Figure 4.13. 40 mm (1.5 in.) Class F over Base #1 (Riverbend) After 50,000 Wheel Passes

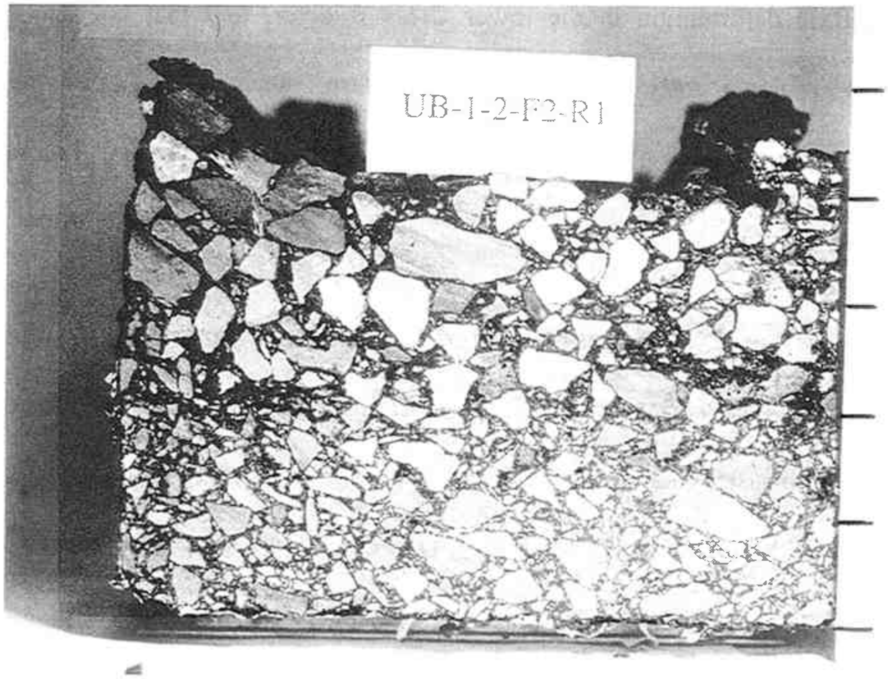


Figure 4.14. 65 mm (2.5 in.) Class F over Base #1 (Riverbend) After 10,000 Wheel Passes

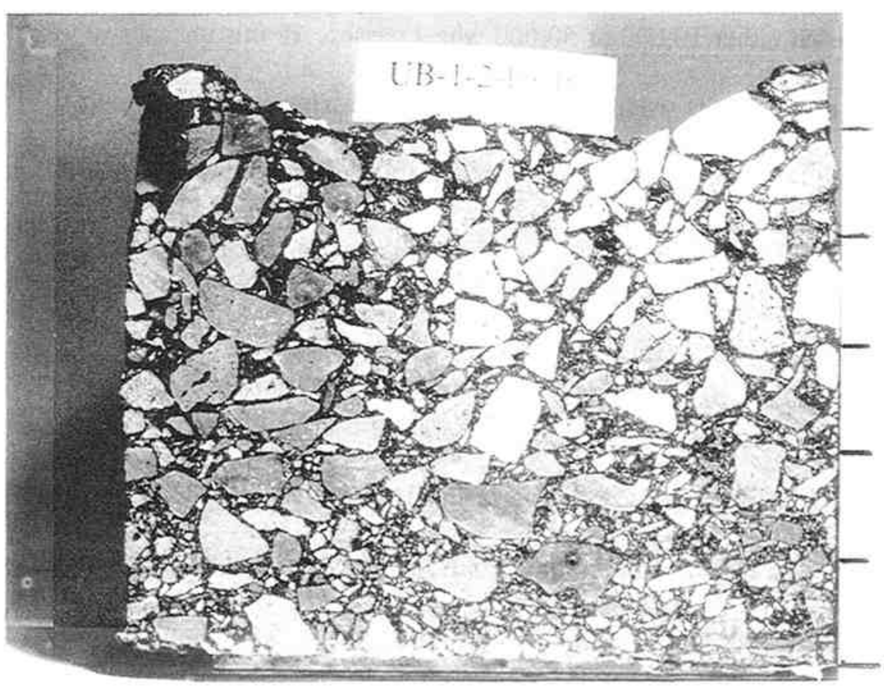


Figure 4.15. 90 mm (3.5 in.) Class F over Base #1 (Riverbend) After 10,000 Wheel Passes

observed that there is little deformation in the lower Class B layer, and that the majority of the deformation occurred in the upper portion of the Class F-Mixture. Once again this demonstrates the problems incurred with rutting evaluations of the Class F-Mixtures in the OSU Wheel Tracker.

4.3.4 Tentative Failure Criteria

To develop tentative failure criteria for the mixtures, through visual interpretation of the mixture results in Figures 4.4 through 4.11, two points of failure are defined. Rutting is regarded as severe when rut depth exceed 10 mm (0.40-in.). This can be defined at 50,000 passes (where the OSU Wheel Tracker test is terminated), as in the previous study by Hicks et al. (1994). However, because the mixtures tested in this study were more sensitive to rutting, it was also necessary to consider 10,000 passes to define failure. Table 4.2 shows the results of both of these criteria. A mixture is defined as failing the criteria when rut depth exceeds 10 mm (0.40-in.) at 50,000 passes or at 10,000 passes if the test does not continue to 50,000 passes. It may be noted when comparing Table 4.2 to Figures 4.4 through 4.11 that many mixtures did not reach either 10,000 or 50,000 wheel passes. In this instance, a visual projection was made to determine if the results would indeed produce a passing or failing result for the mixture. When this is done, it may be seen that only bases 1 and 2 (by themselves) and base 1 overlaid with 40 mm (1.5 in.) of F-mix meet the criteria.

4.3.5 Other Considerations

As noted above, the results of this study, and indeed the results of the study by Hicks et al. (1994), do not seem to adequately reflect the performance of open-graded mixtures. This may be attributed to the lack of confinement in the testing molds. Hicks et al. showed that attention to packing of the specimens in the molds did improve the quality of the rutting data obtained. This technique was also used in this project. However, it does not satisfactorily solve the problem of achieving adequate confinement.

Table 4.2. Mixture Summary Using Two Failure Criteria

Mixture	F-Mix Overlay Thickness mm (in.)	10 mm (0.40-in.) Average Rutting Depth — Wheel Passes 10,000	50,000
F-Mixture	100 (4.0)	Passed	Failed
Base #1* (Riverbend)	0	Passed	Passed
	40 (1.5)	Passed	Passed
	65 (2.5)	Failed	Failed
	90 (3.5)	Failed	Failed
Base #2 (Riverbend)	0	Passed	Failed
	40 (1.5)	Passed	Failed
	65 (2.5)	Passed	Passed
	90 (3.5)	Failed	Failed
Base #3 (Reed Pit)	0	Failed	Failed
	40 (1.5)	Failed	Failed
	65 (2.5)	Failed	Failed
	90 (3.5)	Failed	Failed
Base #4 (Riverbend)	0	Passed	Failed
	40 (1.5)	Failed	Failed
	65 (2.5)	Failed	Failed
	90 (3.5)	Failed	Failed

*Note: Aggregate used shown in parentheses.

Earlier studies reporting use of the Wheel Tracker, such as Nievelt and Thamfald (1988), indicate that slabs were compacted in the test molds. Such an approach would undoubtedly improve the confinement of the specimens and should be investigated in future OSU studies. This approach was not used in this or previous OSU studies because of lack of appropriate equipment, particularly that needed to compact a large slab in its mold.

5.0 REPEATED LOAD CREEP TEST RESULTS

This chapter addresses the procedures of the Repeated Load Creep Test and evaluates the test results based on mix type and test temperatures.

5.1 Procedures

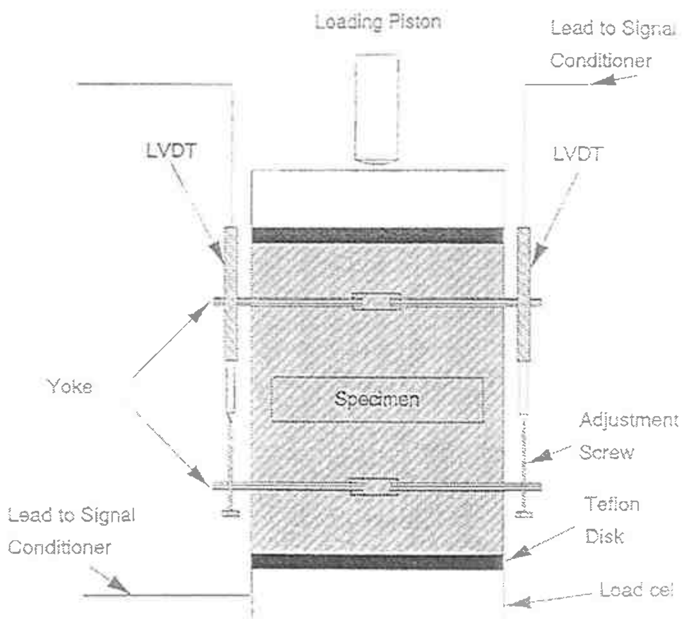
The Repeated Load Creep Test consists of repeated load creep and creep recovery phases. The Repeated Load Creep Test was performed by applying a repeated sinusoidal axial load to cylindrical specimens under three different temperatures (25, 40, 60 or 50°C) with no confining pressure. The load frequency was 0.5 Hz, and 2000 cycles of repeated loading were applied. The recovery phase followed the creep loading for a period equivalent to 2000 cycles. This test procedure is based on one used in Europe (BSi, 1993).

The load and vertical cumulative deformation were monitored during the test. Load was measured by a load cell at the bottom of the specimen. Vertical deformation was measured by two linear voltage differential transducers (LVDTs) attached to the side of the specimen with a set of yokes, as shown in Figure 5.1.

5.1.1 Specimen Preparation

Specimens for the Repeated Load Creep Test were cored from an asphalt concrete slab compacted at Oregon State University. Core specimens measured 102 mm (4in.) diameter by 102 mm (4 inch) high cylinders. The air voids content for each specimen was determined prior to the test. The yokes were separated by four 51 mm (2 in.) spacers before they were glued to the specimen with cyanoacrylate adhesive (Figure 5.1). The glue was allowed to set for 15 min. at room temperature (25°C). Each specimen was placed in an environmental cabinet set at designated temperatures for approximately 8 hrs before testing. Two LVDTs were placed on the yoke of each specimen to measure the deformation of the specimen during the entire experiment. The Repeated Loading Creep Test was then conducted.

a) Photo of Prepared Specimen



b) Schematic Drawing of Prepared Specimen

Figure 5.1. Specimen Preparation (Yunus Ab-Wahab, 1993)

5.1.2 Test Procedure

The test duration was 4000 cycles (approximately 2 hrs, 30 min.) and consisted of the creep measurement (2000 cycles) and the creep recovery measurement (2000 cycles). Both dead load and pulse load were applied for the creep experiments. The main purpose for the application of dead load was to hold the specimen and prevent impact loading. In order to reduce the effects of dead load for the creep experiments, a small amount of dead load was applied, e.g., the dead load was 4535 g (10 lb) at 25°C, 2268 g (5 lb) at 40°C, 1134 g (2.5 lb) at 60°C. Instant deformation of each specimen occurred as the loads were applied, so that it was necessary to begin data collection immediately before each dead load was applied.

The pulse load was set at 100 micro strain immediately after each dead load was applied. The strain was not constant during testing because the material characteristics of each specimen changed according to the number of repeated loadings. Stress, however, was constant during the entire creep experiment. The 100 micro strain setting selection was selected in order to prevent excessive specimen deformation at 60°C, and to stay within the linear viscoelastic measurement so that the data could be analyzed using linear viscoelastic theory. Unfortunately, the pulse load for some specimens at 40°C and all specimens at 50°C had to be set at approximately 200 microstrain or 300 microstrain due to mechanical problems with the testing setup. These problems caused difficulty maintaining relatively low loads and higher loads had to be used.

Repeated Load Creep Tests were conducted at three different testing temperatures (25, 40 and 50 or 60°C), each of which was replicated three times. The cumulative strain raw data was automatically collected at the prescribed cycles.

Two testing systems, hydraulic and pneumatic, were used. The hydraulic system was used first. When approximately half of the creep testing was completed, the testing was switched to the pneumatic testing system (due to mechanical problems in the pulse loading of the hydraulic system). The pneumatic system consists of a load frame, a double-acting pneumatic cylinder, a servo-valve, a servo-valve control amplifier, a signal conditioner, and a computer with a data acquisition card (Figure 5.2). The hydraulic testing system, made by the MTS System Corporation, consists of the MTS load frame, a hydraulic cylinder, and system controller. A high-speed 486 computer was used to control both testing systems and to collect data from the load cell and pair of LVDTs on each specimen.

The test procedures are summarized in order below:

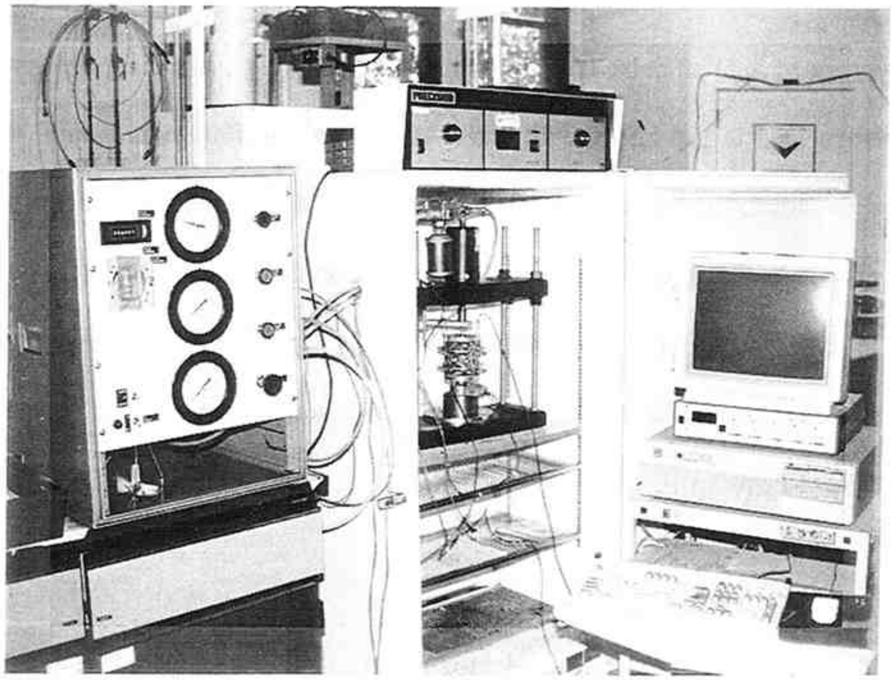
1) The specimen was placed on the MTS plate.
2) Two LVDTs were attached to the yoke.
3) Data collection started immediately before dead load was applied.
4) Dead load was applied according to designated temperatures.
5) Pulse load was applied.
6) Pulse load was removed at 4000 seconds of test time.
7) Dead load was removed at 4600 seconds of test time.
8) Data collection continued up to 8000 seconds of test time.

5.2 Data Analysis

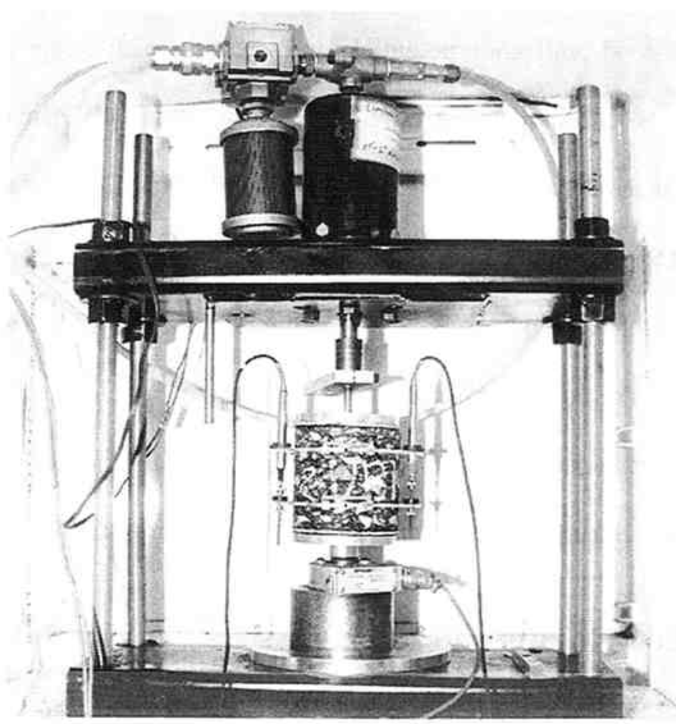
Data analysis was based on raw data as well as on normalized data. The average value of the raw data and normalized data versus testing time was plotted at three different temperatures. Evaluations were based on residual strain at the end of each experiment (e.g., less residual strain at the end of the experiment indicate less susceptibility to rutting potential). Statistical analysis was conducted in addition to the qualitative analysis of the tabular and graphic data.

A failure criterion for mixes was developed based on visual examination of Figure 5.4 to Figure 5.6. One percent strain was selected for the failure criteria (e.g., if the residual strain at end of testing is less than one percent strain, the mixture passes).

The raw data collected directly from the Repeated Load Creep Test were obtained for a constant strain condition. However, creep data are more appropriately evaluated at similar levels of stress. The raw data was therefore normalized by applying to it adjusting factors obtained by dividing the applied



a) Overview



b) View of Specimen

Figure 5.2. Photo of Test Equipment

pulse load by the average of applied pulse load at each temperature (e.g., if the applied load is 113 kg (250 lb) and the average load is 136 kg (300 lb) and the raw strain is 5000 microstrain, the adjusting factor is 136/113 and the normalized strain is 5000 × 136/113). This normalizing process assumes that permanent strain is proportional to applied stress. The average applied pulse loads were determined to be 136 kg (300 lb) at 25°C, 45 kg (100 lb) at 40°C, and 16 kg (35 lb) at 50°C and 60°C. Since the pavement condition, in theory, is assumed to be under a constant stress condition, the analysis was focused on the normalized data.

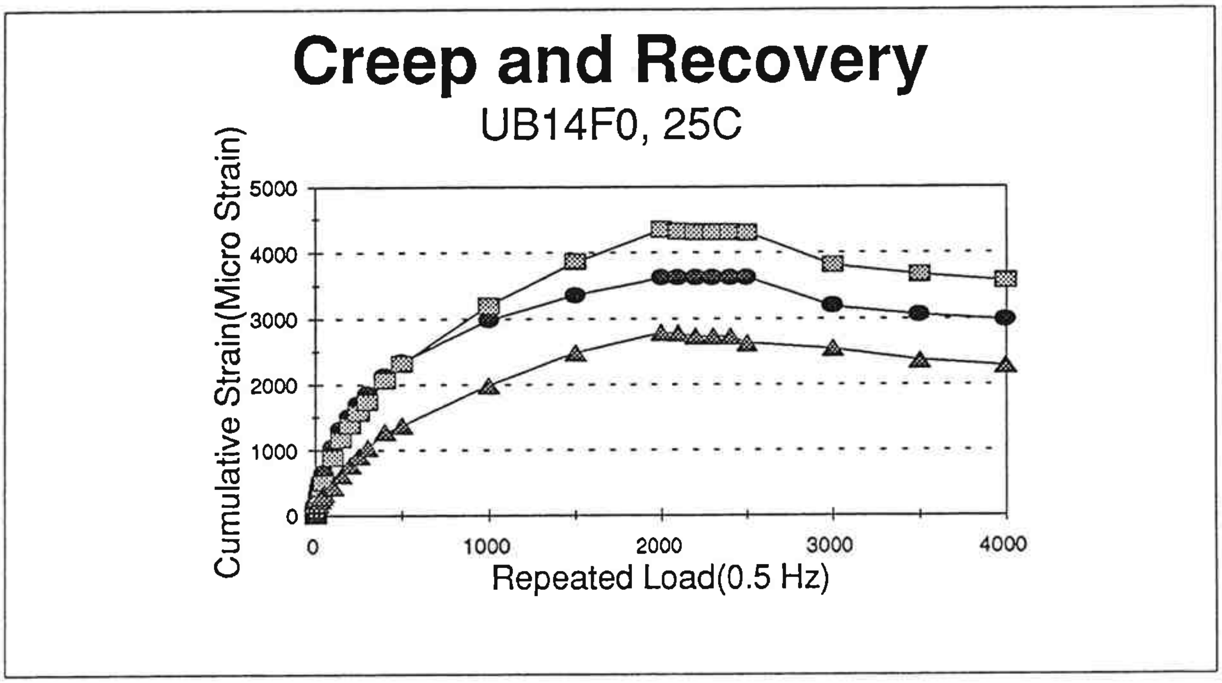
5.3 Test Results

The Repeated Load Creep Tests were conducted at three different temperatures for the four base mixes (B-mix) and the open-graded overlay mix (F-mix). The test results for the raw data and the normalized data for three replicates of one of the base mixtures (Base #1) at 25°C are shown in Figure 5.3. These results indicate good replication potential for Repeated Load Creep Tests, although one of the three tests is significantly different to the other two. Raw data and normalized data from tests conducted at 25°C are summarized in Figure 5.4. Raw data and normalized data from tests conducted at 40°C and tests conducted at 50 and 60°C are summarized in Figures 5.5 and 5.6. Table 5.1 summarizes both the raw data and the normalized data at the end of testing for each of the mix types at three different temperatures. The complete summary of results is given in Appendix F. Table 5.2 shows ranking of rutting potential at each temperature based on the normalized residual strains. Table 5.3 shows an evaluation of mixtures summary using the one percent failure criterion.

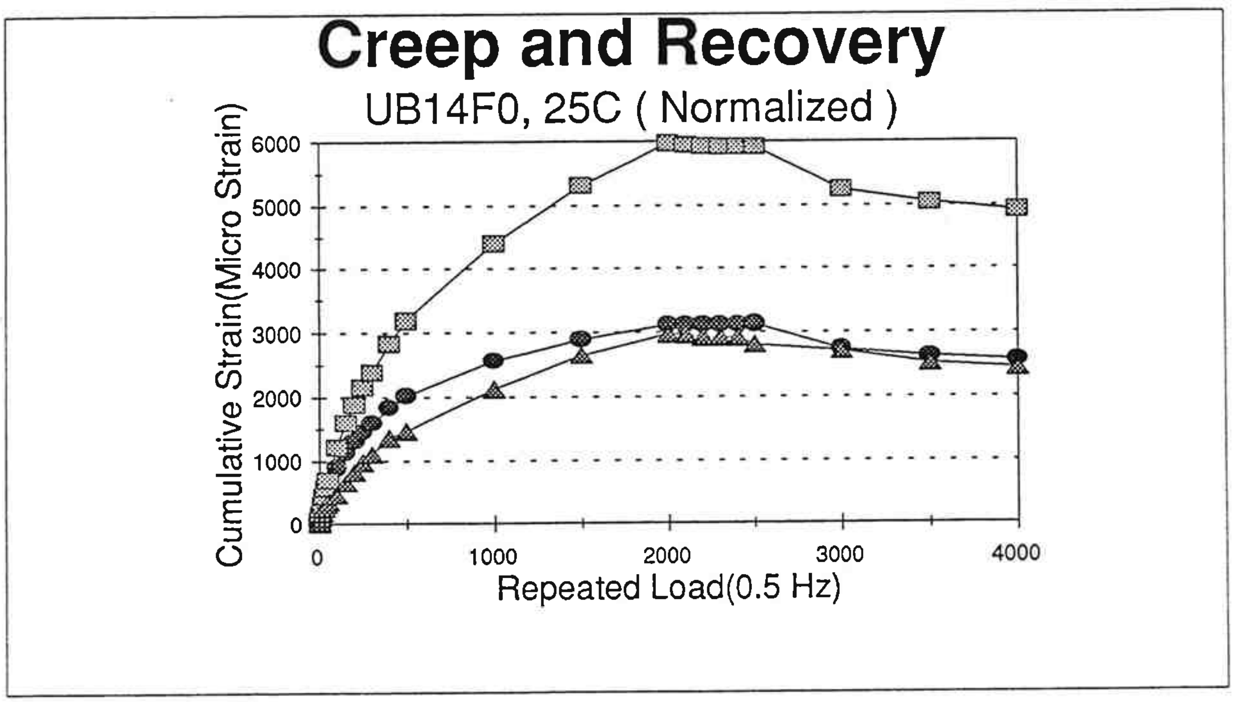
5.4 Discussion of Test Results

The results from the Repeated Load Creep Test are summarized below:

1) **Effect of Mix Type.** The normalized data collected from tests at 25°C and 40°C (Figures 5.4 and 5.5) indicate that the dense-graded mixes are less susceptible to rutting potential than the open-graded mix. However, the

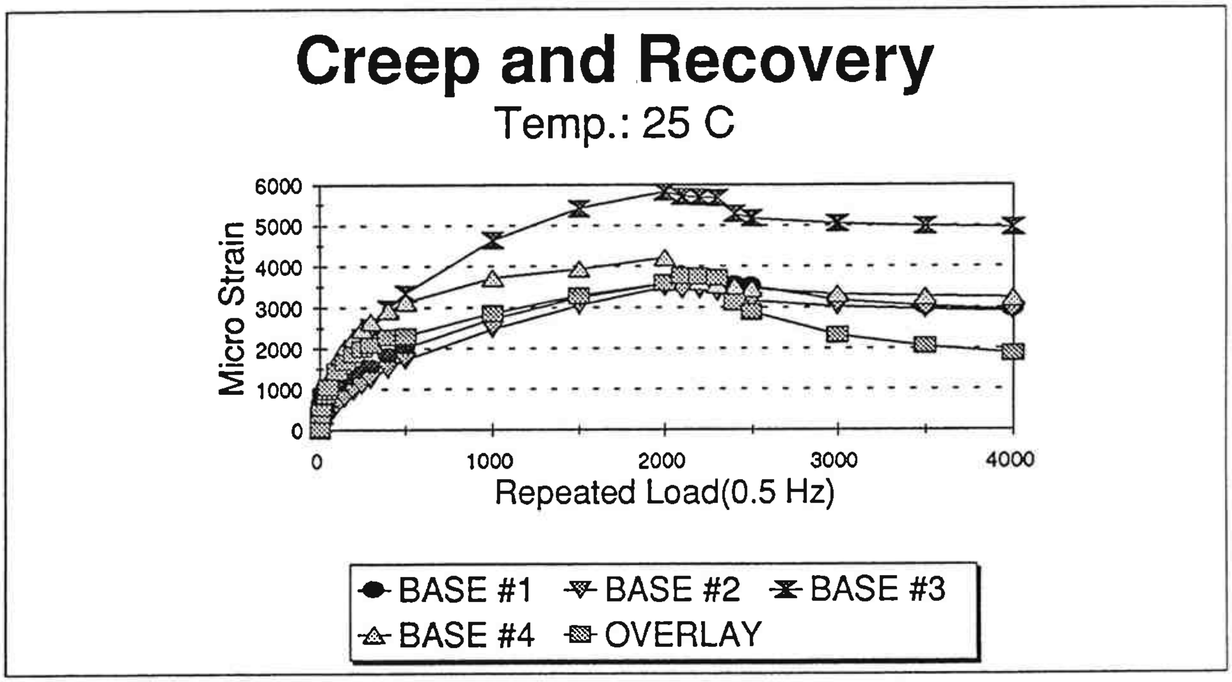


a) Raw Data

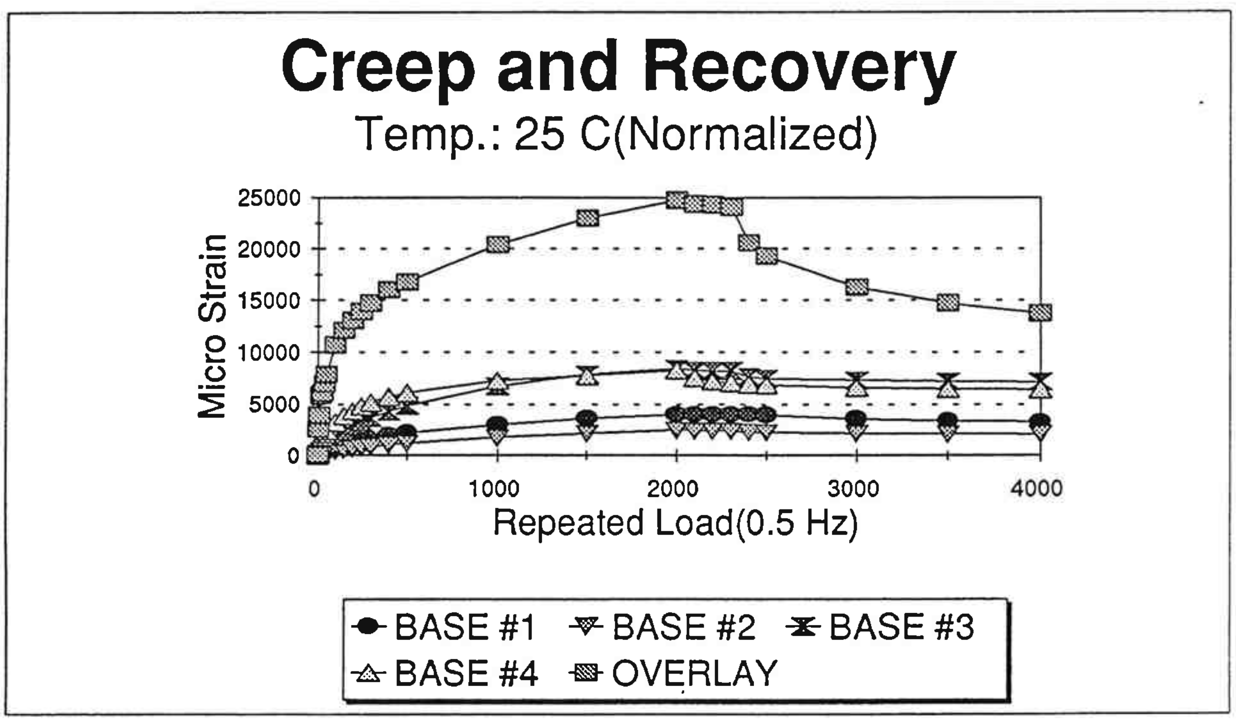


b) Normalized Data

Figure 5.3. Creep and Recovery vs. Number of Repetitions for Base #1 (Repeatability)

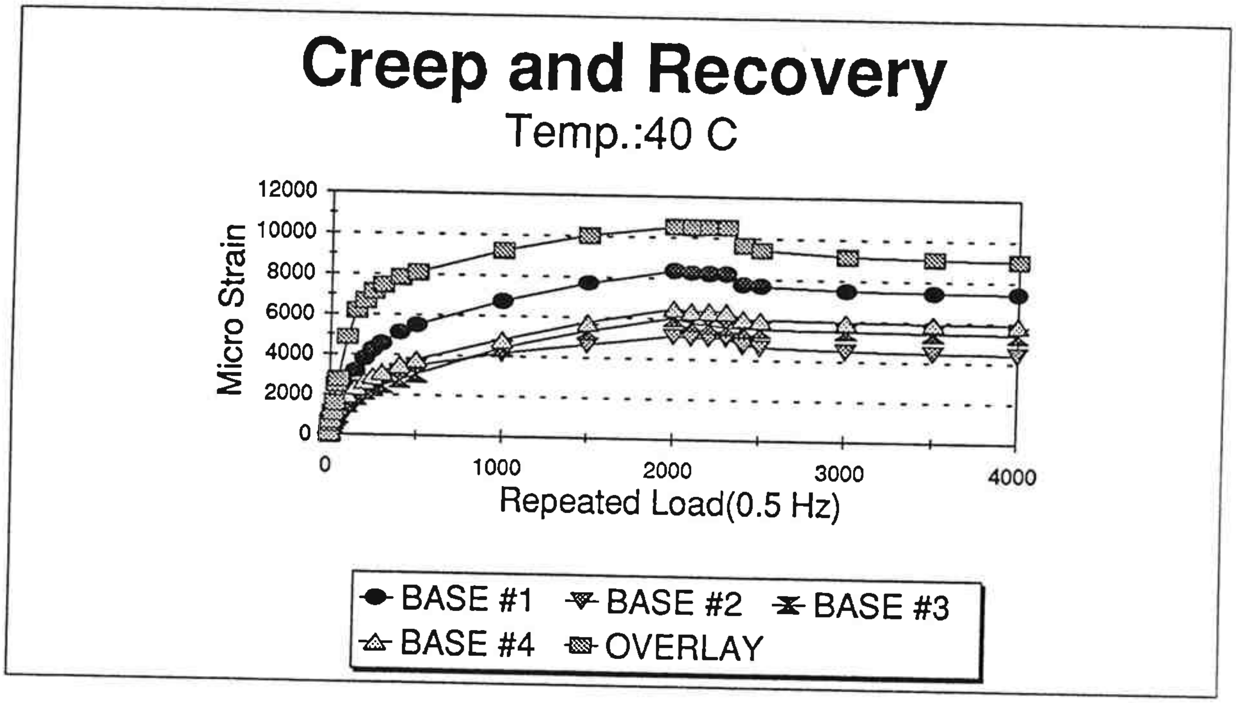


a) Raw Data

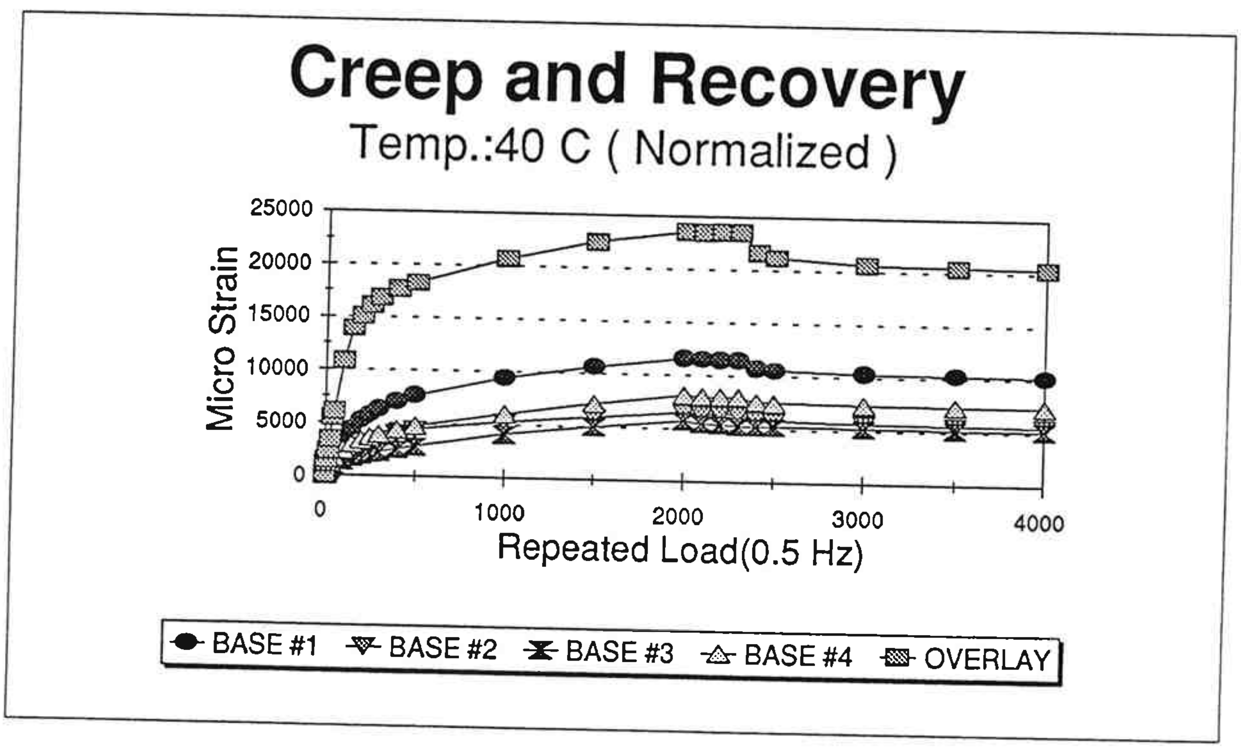


b) Normalized Data

Figure 5.4. Creep and Recovery vs. Number of Repetitions at 25°C

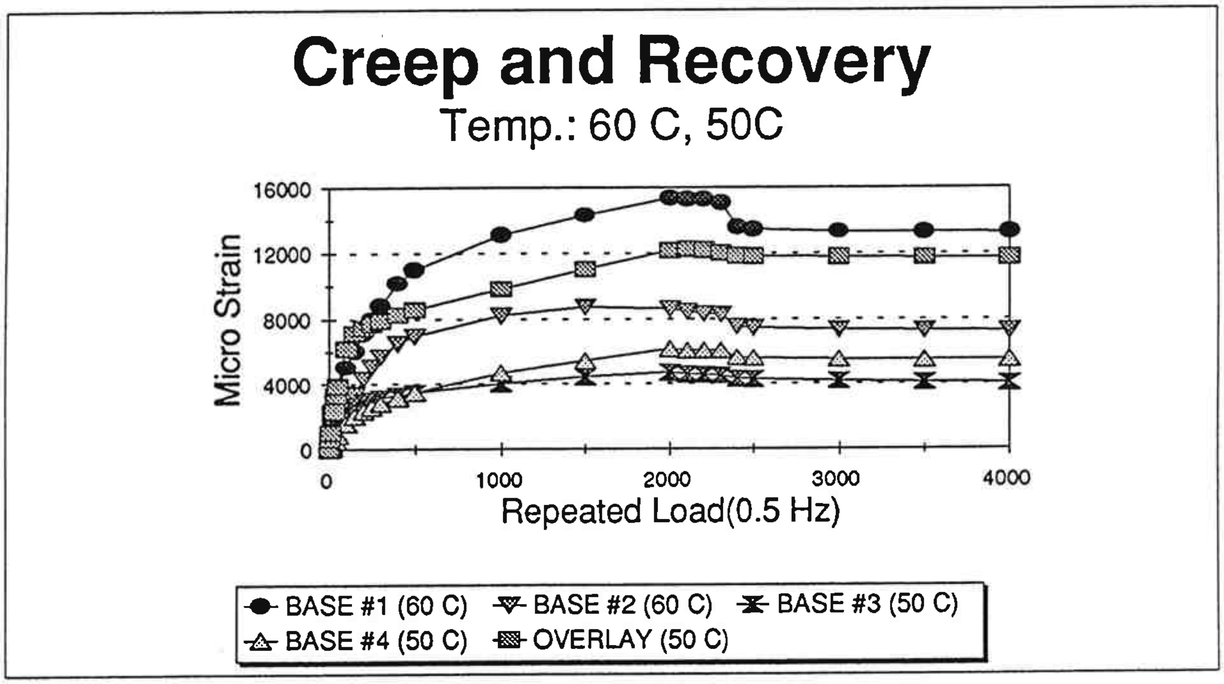


a) Raw Data

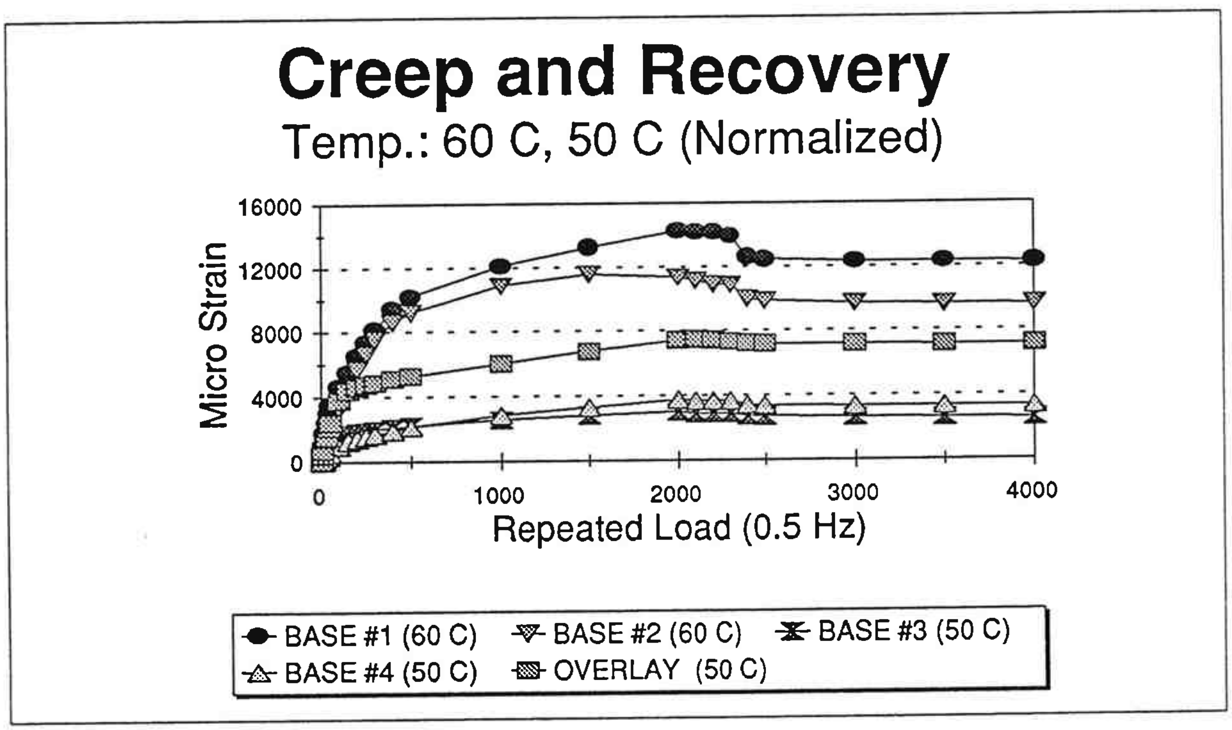


b) Normalized Data

Figure 5.5. Creep and Recovery vs. Number of Repetitions at 40°C



a) Raw Data



b) Normalized Data

Figure 5.6. Creep and Recovery vs. Number of Repetitions at 60°C

Table 5.1. Summary of Repeated Load Creep Tests

Mixture	Temp °C	Residual Strain @ End of Testing		Avg. Pulse Load kg (lb)	Initial Micro Strain (Pulse Load Set On)
		Raw Data (Micro)	Norm. Data (Micro)		
Base #1	25	2930	3190	128 (283)	100
	40	7412	10197	36 (80)	100
	60	13389	12283	18 (39)	100
Base #2	25	2445	1634	192 (424)	100
	40	4424	5540	37 (81)	100
	60	7239	9589	12 (27)	100
Base #3	25	4952	7168	93 (204)	100
	40	5421	5175	51 (113)	100
	50	4023	2991	25 (55)	200
Base #4	25	3250	6459	73 (160)	100
	40	5917	5740	36 (80)	100
	50	5477	3326	26 (58)	250
Overlay	25	1870	13607	29 (63)	100
	40	9032	18218	23 (50)	300
	50	11706	7150	26 (58)	600

Table 5.2. **Ranking of Rutting Potential at Three Different Temperatures (Normalized Data)**

	25°C			40°C			50°C	60°C		
	Residual Strain	Ranking	Homog. Groups*	Residual Strain	Ranking	Homog. Groups*	Residual Strain	Residual Strain	Ranking	Homog. Groups*
Base #1	3190	2	A	10197	4	A	—	12283	5	C
Base #2	1634	1	A	5540	2	A	—	9589	3	B,C
Base #3	7168	4	A	5175	1	A	2991	—	1	A
Base #4	6459	3	A	5740	3	A	3326	—	2	A
Overlay	13607	5	B	18218	5	B	7150	—	4	B

*Results from Duncan's Multiple Range Test

Table 5.3. Mixture Evaluation Using the One Percent Failure Criterion

	25°C		40°C		50°C	60°C	
	Residual Strain		Residual Strain		Residual Strain	Residual Strain	
Base #1	3190	Passed	10197	Failed	—	12283	Failed
Base #2	1634	Passed	5540	Passed	—	9589	Passed
Base #3	7168	Passed	5175	Passed	2991	—	Passed
Base #4	6459	Passed	5740	Passed	3326	—	Passed
Overlay	13607	Failed	18218	Failed	7150	—	Passed

normalized data collected from tests conducted at 60°C (Figure 5.6) indicate that the cumulative strain of one of the dense-graded mixes (base #1) is much larger than that of the open-graded mix tested at 50°C. Because the temperatures are different, direct comparison of these data cannot be made. Nevertheless, the data imply that the open-graded mix is less susceptible to rutting potential at high temperature than at least one dense-graded mix (base #1). However, the other base mixtures appear to be less susceptible to higher temperature deformation.

2) **Effect of Temperature.** Because of the difficulty in comparing the high temperature data at 50°C and 60°C, a deformation temperature susceptibility (DTS) was estimated using another set of normalized data. The 25°C and 40°C raw strain data were all normalized using the same deviator load of 91 kg (200 lb), i.e., to the same stress level. The 40°C, 50°C and 60°C data were also normalized using a deviator load of 23 kg (50 lb). The DTS was then determined as follows:

$$DTS = \frac{\mathrm{Log}_{10}\ (\text{Residual strain at } T_2\ °C) - \mathrm{Log}_{10}\ (\text{Residual strain at } T_1\ °C)}{T_2 - T_1}$$

Table 5.4 shows a summary of normalized data for 25°C and 40°C, including the DTS values. The ranking of mixtures based on residual strain and on DTS is also shown. Table 5.5 shows similar data for 40°C, 50°C and 60°C. In summary, the DTS data confirm what was discussed above, that the open-graded mix tends to be less susceptible to changes of deformation with temperature than the dense mixes, particularly at high temperature.

3) **Ranking of Rutting Potential.** Tables 5.4 and 5.5 show that the rankings of mixtures change with temperature and with the basis of ranking, i.e., whether based on residual strain or DTS. In particular, the open-graded mixture is

Table 5.4. Summary of Normalized Data and DTS Estimates, 25°C and 40°C

Mixture	Temp. °C	Residual Strain at End of Testing		Deformation Temperature Susceptibility (DTS)	Avg. Pulse Load kg (lb)	Nor. Dev. Load kg (lb)	Initial Microstrain (Pulse Load Set on)	Rank* Based on	
		Raw Data (Micro)	Nor. Data (Micro)					Resid. Strain	DTS
Base #1	25	2930	2127	0.065	128 (283)	91 (200)	100	2	4
	40	7412	20394		36 (80)	91 (200)	100	4	
Base #2	25	2445	1090	0.067	192 (424)	91 (200)	100	1	5
	40	4424	11082		37 (81)	91 (200)	100	2	
Base #3	25	4952	4779	0.031	93 (204)	91 (200)	100	4	2
	40	5421	13757		51 (113)	91 (200)	100	1	
Base #4	25	3250	4305	0.028	73 (160)	91 (200)	100	3	1
	40	5917	11481		36 (80)	91 (200)	100	3	
Overlay	25	1870	9071	0.040	29 (63)	91 (200)	100	5	3
	40	9032	36436		23 (50)	91 (200)	300	5	

*1 exhibits the least deformation or lowest DTS

Table 5.5. Summary of Normalized Data and DTS Estimates, 40°C, 50°C and 60°C

Mixture	Temp. °C	Residual Strain at End of Testing		Deformation Temperature Susceptibility (DTS)	Avg. Pulse Load kg (lb)	Nor. Dev. Load kg (lb)	Initial Microstrain (Pulse Load Set on)	Rank* Based on	
		Raw Data (Micro)	Nor. Data (Micro)					Resid. Strain	DTS
Base #1	40	7412	5508	0.025	36 (80)	23 (50)	100	4	4
	60	13389	17546		18 (39)	23 (50)	100	5	
Base #2	40	4424	2770	0.035	37 (81)	23 (50)	100	2	5
	60	7239	13698		12 (27)	23 (50)	100	3	
Base #3	40	5421	3328	0.011	51 (113)	23 (50)	100	1	2
	50	4023	4274		25 (55)	23 (50)	200	1	
Base #4	40	5917	2871	0.022	36 (80)	23 (50)	100	3	3
	50	5477	4752		26 (58)	23 (50)	250	2	
Overlay	40	9032	9104	0.007	23 (50)	23 (50)	300	5	1
	50	11706	10693		26 (58)	23 (50)	600	4	

*1 exhibits the least deformation or lowest DTS ranked best based on DTS for the higher temperature range but worst based on residual strain at 40°C. The DTS rankings compare better with field observations with regard to open-graded and dense-graded mixtures and are, therefore, probably more valid.

4) **Failure Criteria.** Only the overlay mixture (tested at 25°C and 40°C) and base #1 (tested at 60°C) failed the arbitrarily selected criterion of one percent (10,000 microstrain) at the end of the test.

The results of these tests indicate that the Repeated Load Creep Test procedure is sensitive to mix type and testing temperature. Also, the Repeated Load Creep Test results indicate high probability that the open-graded mix can be effective in field performance, particularly at high temperature. However, it may be best to include some confinement for such mixtures.

6.0 COMPARISON OF TEST RESULTS

This chapter presents discussion on the comparison of results from the OSU Wheel Tracker and the Repeated Load Creep Test. It should be noted that the two previous chapters contain discussion on each set of results. Correlation between the OSU Wheel Tracker and the Repeated Load Creep Test results was performed to determine if Repeated Load Creep Test results could be used to indicate whether a mixture is suitable for overlaying. It is tentatively proposed that a mixture could undergo a prescreening creep test and if it displays resistance to rutting under this test (under a predetermined failure criterion), then the mixture could then be evaluated with an overlay in a wheel tracking test. If the performance is satisfactory with the wheel tracking test, then the overlay project is likely to be satisfactory. Such an approach could not be implemented at present because of the problems with testing open graded mixtures in the wheel tracker. However, if these problems could be overcome, the approach merits further investigation.

6.1 Mixture Ranking

In Chapters 4.0 and 5.0, each mixture was ranked according to it's sensitivity to permanent deformations, with respect to each test procedure. Table 6.1 compares the rankings made herein, between the testing procedures. These comparisons were performed for 60°C (140°F) for the OSU Wheel Tracker and for all temperatures for the Repeated Load Creep Test. Although the ranking shown in Table 6.1 defines each mixture in terms of least sensitive (1) to most sensitive (5) for permanent deformation, it should be noted that through multiple range analysis many of the mixtures performed statistically similar. For the OSU Wheel Tracker, all the ranges overlapped for each of the mixtures showing each mixture was not independent of the others. The poor repeatability of the results from the wheel tracker contributes to this overlap.

Duncan's Multiple Range Analysis was used to determine the ranking of the mixtures with the Repeated Load Creep Test results. As with the Wheel Tracker results, there was overlap between rankings.

Table 6.1. Mixture Ranking†

Mixture	Wheel Tracker (60°C)	Repeated Load Creep Test†			DTS	
		Strain @ 25°C	Strain @ 40°C	Strain @ 60°C or 50°C	25-40	40-50 or 40-60
Base #1 (Riverbend)	2	2	4	5	4	4
Base #2 (Riverbend)	1	1	2	3	5	5
Base #3 (Reed Pit)	5	4	1	1	2	2
Base #4 (Riverbend)	4	3	3	2	1	3
Class F Overlay Mixture	3	5	5	4	3	1

†(1) represents least sensitive, (5) represents most sensitive

It is interesting to note that the rankings based on residual strain from 25°C creep tests are very similar to those from the Wheel Tracker tests at 60°C. Rankings based on residual strains from creep tests at 40, 50 and 60°C are considerably different from the Wheel Tracker rankings. Similarly, the rankings based on deformation temperature susceptibility (DTS) are considerably different than the Wheel Tracker rankings. In view of these differences, it may be pragmatic to consider the 25°C repeated load creep test as a means of screening mixtures before proceeding with a Wheel Tracking test as a more thorough evaluation.

6.2 Mixture Criteria

Using the pass or fail criteria for mixtures outlined in Chapter 4.0 and 5.0, Table 6.2 shows the results comparing mixtures between the Repeated Load Creep Test at 25°C and the OSU Wheel Tracker at 60°C. A change in the pass or failure criteria is noted in Table 6.2. Only one mixture (Base #3) shows a difference. Possibly a lower value of strain, such as 0.5% would be more appropriate as a criterion.

Although the data discussed in this section is not encouraging, it is proposed that there be two stages in testing of sensitive mixtures. Stage 1 consists of testing the individual mixtures (Base or Surface courses) in the Repeated Load Creep Test at 25°C. If the mixtures pass the creep failure criteria (less than one percent strain at the end of the test), then the mixtures should be tested together in the OSU Wheel Tracker at 60°C. Table 6.3 sumarizes the criteria.

6.3 Discussion of Comparison

Inconsistencies in the results with the OSU Wheel Tracker and the Repeated Loading Creep Test provided wide variances in results, however these can be explained and in some cases are expected. The base mixtures tested were manufactured so that they would be more sensitive to permanent deformation than conventional mixtures. Other inconsistencies can be traced to the testing procedures used, as outlined below.

Table 6.2 Pass or Fail of Mixtures

Mixture	OSU Wheel Tracker (10,000 Wheel Passes)	Repeated Load Creep Test, 25°C (Test Termination)	Change
Base #1 (Riverbend)	Passed	Passed	No
Base #2 (Riverbend)	Passed	Passed	No
Base #3 (Reed Pit)	Failed*	Passed	Yes
Base #4 (Riverbend)	Passed**	Passed	No
F-Mixture	Passed	Passed	No

*Data from Figure 4.8 was extrapolated.
** Base #4 would fail if 50,000 was used as the criterion.

Table 6.3 Two Stages to Evaluate Mixtures

Test Procedure	Failure Criteria	Action
Repeated Load Creep Test @ 25°C	Is strain at 2000 repetitions < 1%	Produce specimens to test in the OSU wheel tracker
	Is strain at 2000 repetitions > 1%	Reject the mixture
OSU Wheel Tracker @ 60°C	Is rutting after 50,000 passes < 10 mm (0.40-in.)	Proceed with overlay in the field
	Is rutting after 10,000 passes > 10 mm (0.40-in.)	Do not build overlay in the field
	Is rutting after 10,000 passes < 10 mm (0.40-in) but after 50,000 passes > 10 mm (0.40-in.)	Consider alternate mix or overlay design, or proceed only if truck traffic is light

The Repeated Load Creep Test can be improved to better predict asphalt concrete performance. To reduce the amount of data variance from specimen preparation, testing setup, and testing procedures the following should be considered, respectively:

- The top and bottom of the specimen should be parallel and the sides of the specimen should be perpendicular to the top and bottom.
- The yoke for LVDTs should be modified to improve their stability, such that secure fixing of LVDTs is guaranteed.
- Automatic loading control and resetting for the LVDTs during testing should be developed.

The sensitivity of the mixtures tested in the OSU Wheel Tracker provided large variances in results. Usually results from the OSU Wheel Tracker are more consistent and would only require two test specimens for adequate mixture evaluation. However, the base mixtures tested for the project reported herein were manufactured to be more sensitive to permanent deformations than the usual mixtures. Hicks et al. (1994) showed OSU Wheel Tracking results for the Class B-Mixtures to be around 7.5 mm to 10 mm (0.3-in. to 0.4-in.) at 50,000 wheel passes. Two of the base mixtures tested for the project herein rutted a similar amount after 50,000 passes and two exceeded this amount. Hence, the rutting for these "unstable" mixtures tended to be more severe than "stable" Class B-Mixtures tested previously in the OSU Wheel Tracker. This mixture sensitivity to rutting contributed to the difficulty of obtaining consistent results. The F-mixes tested for the project reported herein showed similar sensitivity to rutting to those tested previously by Hicks et al. (1994), i.e., about twice that of a stable B-mix. This greater sensitivity of the F-mix, together with the variation of thickness in the base and overlay layers of composite slabs, compounds the variability in the results.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The following conclusions may be drawn from the results of this study.

1) As with the previous study conducted by Hicks et al. (1994), this study showed that open-graded mixtures performed poorly in both laboratory tests. This is associated with lack of confinement of the test specimens. Clearly, there is a need for improved protocols for preparing and testing open-graded mixtures.

2) Because of the difficulty in achieving expected performance from the open-graded mixtures in the wheeltracker, the objectives of this study could not be achieved satisfactorily. The open-graded mixture was more susceptible to deformation than two of the base mixtures in the wheeltracker and less susceptible than the other two. When composite slabs of each base and various thicknesses of overlay were tested, the general finding was that the thicker the overlay the greater the rutting. This is as would be expected with deformation susceptible materials. However, the results of tests on the composite slabs indicate that when the overlay is less susceptible than the base, there is less difference in the deformation of the base alone and the overlaid section. This suggests that if the problems testing open-graded mixtures can be overcome, the wheeltracker could be reevaluated for overlay testing.

3) The wheeltracking tests showed that the four base mixtures tested had a range of susceptibilities to rutting as intended in the study objectives. When these mixtures and the open-graded mixture were tested by themselves in the wheeltracker, only one base mix failed an arbitrary criterion of 10 mm rutting at 10,000 passes. However, all mixtures failed a criterion of 10 mm rutting at

50,000 passes. By comparison, "stable" base mixtures tested by Hicks et al. (1994) passed both these criteria. The open-graded mixes tested by Hicks et al. failed both criteria.

4) The repeated load creep test also showed that the mixtures had a range of susceptibility to deformation. A ranking of susceptibility based on residual strain results from this test conducted at 25°C compared quite well to the wheeltracker (at 60°C). Rankings based on results from creep tests at higher temperatures did not compare as well. If a failure criterion of 1 percent permanent strain (i.e., 10,000 microstrain at the end of the test) is applied, no mixtures fail if data from tests at 25°C are considered.

5) It is possible that the creep and wheeltracking tests may be used in a two-stage processs to evaluate the suitability of base mixes for overlay and of the proposed overlay. The relatively simple creep test could be used to prescreen mixtures before proceeding with the more complex wheeltracking test. However, as recommended below, more work needs to be done before such an approach could be used with confidence.

7.2 Recommendation for Implementation

1) The results of this study do not suggest any immediately implementable methods of evaluating base mixtures for overlaying. However, the two-stage procedure suggested is promising, particularly if it can be supplemented with analyses using the PACE program.

7.3 Recommendations for Further Work

1) The LCPC wheeltracking device as used in this study for evaluating a slab of open-graded overlay mixture (or a slab of dense-graded mixture overlaid by open-graded mixture) does not reflect the field performance of such mixtures. It is recommended that future studies utilize a method of specimen preparation that improves their confinement in the test. This could be done by compacting the specimens in the frame used to mount the specimens in the testing device. This change should result in performance of open-graded mixtures similar to that in the field.

2) The protocol for conducting the repeated load creep test needs to be examined closely. In particular, the use of the same stress levels at each temperature may be desirable to enable more thorough evaluation of deformation susceptibility.

3) The visco-elastic computer program PACE should be evaluated in future projects. It was not possible to adequately test the program in this research effort, as it was not fully developed.

8.0 REFERENCES

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APPENDICES

APPENDIX A

Mix Designs

Note: The mix designs for Base #1 and Base #2 using Hilroy Pit aggregate are based on the first two mix design sheets following, i.e., 91-15290 and 92-05149, respectively. The mix design used for Base #4 (also using Hilroy Pit aggregate) was developed at OSU by adjusting the design of Base #1 to cause a more deformation susceptible mix. The design for Base #3 was based on the third mix design sheet in this appendix, i.e., 93-09462, but with an adjustment to the asphalt content to cause a more deformation susceptible mix. Finally, the mix design for the F-mix overlay was based on the fourth mix design sheet (93-02278) with minor adjustments.

PRELIMINARY BITUMINOUS MIXTURE DESIGN

MATERIALS SECTION

LAB NO. 15290

PROJECT: WILLAMETTE RIVER - BALDOCK SRA (Safety Rest Area)		EA/SUB JOB/ACTIVITY: C11120	DATA SHEET NO.: *AB 52748-50TR
PRIME CONTRACTOR: WILDISH STANDARD PAVING		FED. AID NO.: MAIR-5-5(123)281	
PAVING CONTRACTOR	MIX TYPE CLASS: "B" a/c	DATE RECEIVED: 12/06/91	DATE REPORTED: 12-12-91
REGION ENGINEER: KEN STONEMAN	PROJECT MANAGER: RON CLAY 8014	TEST NO.: 301A / 319	VAR.: X / LAB CHARGES: $150 / $ 92

AGGREGATE GRADATION: Source— Hiroy #24-002-2 Type— Gravel

Aggregate Size	3/4-1/4	1/4-10	10-0				Combined Dry Sieve	Agg. Grad. Extracted
% Comb.	38	32	30					
1"	100 100						100	100
¾	91 91						97	96
½	58 59						84	84
⅜	29 30	100 100					73	74
¼	6 7	77 78	100 100				57	57
10	2 3	12 14	73 73				27	28
40	1 2	4 5	29 30				10	11
200 (Dry)	0.7	2.1	8.6				3.5	4.9
200 (Wet)	1.3	3.2	10.6					
No. Ave.	8	22	24					
Lime Treat (%)							P200/AC - 0.9	

JOB MIX FORMULA TEST DATA:

Percent Asphalt (total mix)	4.5	5.0	5.5	6.0	6.5
Asphalt Film	D-Suf	Suff	Suff	Suff	Thick
Sp. Gr. @ 1st Comp. ~~(T-246)~~ (T-166)	2.33	2.30	2.32	2.32	2.40
Percent Voids @ 1st Comp.	7.1	7.3	6.1	5.2	1.9
Stability @ 1st Comp. ~~(T-247)~~ (T-246)	36	34	38	35	32
Sp. Gr. @ 2nd Comp.	2.37	2.39	2.40	2.41	2.44
Percent Voids @ 2nd Comp.	5.5	3.6	2.9	1.6	0.2
Stability @ 2nd Comp.	45	43	45	41	10
Max. Sp. Gr. (T-209)	2.508	2.480	2.472	2.448	2.446
Index Ret. Str. (T-165)	65		81		88
Index Ret. Mr. (TM315)	54		83		109

JOB MIX FORMULA:

CALCULATED JOB MIX FORMULA PROPERTIES

Aggregate Sieve Size	JMF Gradation	Paving Course	Asphalt Content % By Wt. of Total Mixture	Sp Gr. @ 1st Comp	Sp Gr. @ 2nd Comp	Max Sp Gr T-209	Design Voids 1st Comp	Design Voids 2nd Comp
1"	100	Wearing	5.6	2.32	2.40	2.467	6.0	2.7
¾	97	Base	5.6	2.32	2.40	2.467	6.0	2.7
½	84							
⅜	73	Shoulder						
¼	57	Asphalt Lab No.	91-15273					VMA=15.0%
10	28	Brand—	Chevron	Mix Placement Temp.—			290 °F—	298 °F
40	11	Grade—	PBA-5	Mixing Temp.—			308 °F—	318 °F
200	4.9	Additive—	-----					

AGGREGATE TEST DATA:

90-5173 CA: LAR=16.7%; Na2So4=0.7%; Deg=0.5",13.4%; Friable=0.5%

90-5174 & 75 FA: Na2SO4=1.1%; Deg=0.9",17.0%; Friable=0.1%; SE=78

Const.
FHWA
Reg. Engr.
Res. Engr.
Dist. Engr.
Region Geo.
Files

COMMENTS:

W. J. [signature]
Engineer of Materials

734-1887 (5-89)

PRELIMINARY BITUMINOUS MIXTURE DESIGN

MATERIALS SECTION

LAB NO.	9205149
PROJECT	BEAR CREEK - KEITH ROAD
EA/SUB JOB/ACTIVITY	C11137
DATA SHEET NO.	AB67543-45
PRIME CONTRACTOR	NORTH SANTIAM PAVING
FED. AID NO.	F-74(18)
PAVING CONTRACTOR	
MIX TYPE CLASS	"B" a/c
DATE RECEIVED	5-5-92
DATE REPORTED	
REGION ENGINEER	ART LOUIE
PROJECT MANAGER	EARL MERSHON 8009
TEST NO.	301A
VAR.	
LAB CHARGES	$150.00

AGGREGATE GRADATION: Source— Hilroy Pit #24-2-2 Type— Gravel

Aggregate Size	3/4 - 1/4	1/4 - 10	10 - 0				Combined ~~Dry Sieve~~ Wet sieve	Agg. Grad. Extracted
% Comb.	39	26	35					
1"	100						100	
¾	90						96	
½	60						84	
⅜	29	100					72	
¼	8	73					57	
10	3	9	100				29	
40	1	4	28				11	
200 (Dry)	--	--	--				--	
200 (Wet)	1.0	2.7	10.4				4.5	
No. Ave.	35	14	16					
Lime Treat (%)							P200/AC = 0.8	

JOB MIX FORMULA TEST DATA:

Percent Asphalt (total mix)	4.0	4.5	5.0	5.5	6.0
Asphalt Film	dry	dry-suf	thick	suff-thk	thick+
Sp. Gr. @ 1st Comp. ~~(T-246)~~ T-166	2.290	2.317	2.318	2.353	2.348
Percent Voids @ 1st Comp.	9.1	7.1	6.5	4.7	4.2
Stability @ 1st Comp. ~~(T-247)~~ T-246	36	34	30	32	31
Sp. Gr. @ 2nd Comp.	2.341	2.370	2.385	2.414	2.409
Percent Voids @ 2nd Comp.	7.1	5.0	3.8	2.2	1.8
Stability @ 2nd Comp.	48	45	44	46	43
Max. Sp. Gr. (T-209)	2.520	2.495	2.480	2.468	2.452
Index Ret. Str. (T-165)	61		86		100
Index Ret. Mr. (TM315)	60		87		120
					VMA = 13.9%

JOB MIX FORMULA:

Aggregate Sieve Size	JMF Gradation	Paving Course	Asphalt Content % By Wt. of Total Mixture	Sp Gr. @ 1st Comp	Sp Gr. @ 2nd Comp	Max Sp Gr T-209	Design Voids 1st Comp	Design Voids 2nd Comp
1"	100	Wearing	5.4	2.346	2.408	2.470	5.0	2.5
¾	96	Base	5.4	2.346	2.408	2.470	5.0	2.5
½	84							
⅜	72	Shoulder						
¼	57	Asphalt Lab No. 92-0601						
10	29	Brand— Chevron		Mix Placement Temp.—		287 °F— 296 °F		
40	11	Grade— PBA-5		Mixing Temp.—		306 °F— 315 °F		
200	4.5	Additive—						

(CALCULATED JOB MIX FORMULA PROPERTIES)

AGGREGATE TEST DATA:

92-0852 CA: LAR = 12.1%; Na2SO4 = 2.6%; Degrade = 0.6", 15.7%; Friables = 0.2%; Dust = 0.16%
92-0853 FA: " = ---- ; " = 4.4%; " = 0.5", 12.9%; " = 0.2%; SE = 77
92-0854 FA: " = ---- ; " = 4.4%; " = 0.5", 12.9%; " = 0.9%; SE = 77

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Reg. Engr.
Res. Engr.
Dist. Engr.
Region Geo.
Files

COMMENTS: NUKE DATA:
Calibration Number: 5149
Mix ID: 11137
Number of Samples: 4
Count Time per Sample: 16
Fit Coeff= 8.999
Calibration Date: 5/28/92
Background Count: 2473
Weight: 6725
Calibration Constants:
A1: -2.335656
A2: 1.[illegible]

" "B PBA-5

9-23-93 F73M-61

The Oregon Department of Transportation
Highway Division

SUBMITTED BITUMINOUS MIXTURE DESIGN

LABORATORY NO. 93–09462

PROJECT: BATTLE CREEK – N. JEFFERSON INTG.		EA / SUB JOB / ACTIVITY: C11365	DATA SHEET NO.: NONE
PRIME CONTRACTOR:	COUNTY:	FED AID NO.: IM–S001(6)	
PAVING CONTRACTOR: MORSE BROTHERS INC.	MIX TYPE CLASS: "B" (HD)+LIME	DATE RECIEVED: 9–7–93	DATE REPORTED: 9-16-93
REGION ENGINEER: KEN STONEMAN	PROJECT MANAGER: RON CLAY	TEST NO.: 309A/B 301S / VAR.: V	LAB CHARGES: $161.00 $229.00

AGGREGATE GRADATION:

SOURCE : 24–023–2 REED PIT — TYPE: QUARRY

AGGREGATE SIZE						AGG. GRAD EXTRACTED		
% COMB.							MIX ID	
1"						100	NUMBER OF SAMPLES	
3/4						98	COUNT TIME PER SAMPLE	
1/2						84	FIT COEFF=	
3/8						70	CALIBRATION DATE	
1/4						59	BACKGROUND COUNT:	
4						53	BASE WEIGHT:	
10						33	CALIBRATION CONSTANTS– A1:	
40						14	A2:	
200						6.5	A3:	
NO. AVE.				ASPHALT CONTENT =		5.5	P200/AC =	1.2

CALIBRATION NUMBER

JOB MIX FORMULA TEST DATA:

PERCENT ASPHALT (TOTAL MIX)	5.5					
ASPHALT FILM	THICK					
SPECIFIC GRAVITY @ 1ST COMP. (T–166)	2.379					
PERCENT VOIDS @ 1ST COMP.	2.3					
STABILITY @ 1ST COMP. (T–246)	38					
SPECIFIC GRAVITY @ 2ND COMP.	–––					
PERCENT VOIDS @ 2ND COMP.	–––					
STABILITY @ 2ND COMP	–––					
MAXIMUM SPECIFIC GRAVITY (T–209)	2.434					
INDEX RET. STR. (T–165)	102%					
INDEX RET. Mr. (TM315)	–––					

JOB MIX FORMULA: 93–08171

CALCULATED JOB MIX FORMULA PROPERTIES

AGGREGATE SIEVE SIZE	JMF GRADATION	PAVING COARSE	ASPHALT CONTENT % BY Wt. OF TOTAL MIXTURE	RAP	Sp. Gr. @ 1ST COMP.	Sp. Gr. @ 2ND COMP.	MAX Sp. Gr. I – 209	DESIGN VOIDS 1ST COMP.	DESIGN VOIDS 2ND COMP.
1"	100	WEARING							
3/4	93	BASE	5.0		2.30	–––	2.443	5.7	–––
1/2	77								
3/8	67	SHOULDER							
1/4	56	Asphalt LAB NO.	93–06703						
4		BRAND–	McCALL		MIXING TEMP.– 290 °– 298 ° F				
10	27	GRADE–	PBA–5		PLACEMENT TEMP.– 274 °– 281 ° F				
40	12	ADDITIVE–	1.0% LIME TREATMENT OF THE AGGREGATE IS REQUIRED						
200	5.0								

DISTRIBUTION:
2X FILES
X OPERATIONS
X FHWA
X RON CLAY
X RAS 2
X MORSE BROS., INC.

COMMENTS: Mix sample had excess P#10 and excess asphalt.

Second compaction testing and IRMR were deleted to expedite testing. Mix sample had acceptable test results with the exception of low void content. This is due to a fine gradation and high asphalt content. This mix may be prone to rutting.

[signature]
ENGINEER OF MATERIALS

The Oregon Department of Transportation
Highway Division

PRELIMINARY BITUMINOUS MIXTURE DESIGN
MATERIAL SECTION

LABORATORY NO. 02278

PROJECT: PORT ROAD – PACIFIC HIGHWAY		EA / SUB JOB / ACTIVITY: C11228		DATA SHEET NO.: AB 67658 & 60
CONTRACTOR: COMPTON		FED AID NO.: NH – 23(16)		
PAVING CONTRACTOR:	MIX TYPE CLASS: "F"	DATE RECEIVED: 8/13/92		DATE REPORTED: 4-8-93
REGION ENGINEER: KEN STONEMAN	PROJECT MANAGER: RON CLAY	TEST NO.: 308A 319	VAR.: V	LAB CHARGES: $350.00 $40.00

AGGREGATE GRADATION: SOURCE– 24 – 002 – 2 HILROY PIT TYPE: GRAVEL

AGGREGATE SIZE	3/4–1/4	10 – 0			COMBINED WET SIEVE	AGG. GRAD. EXTRACTED
% COMB.	83%	17%			100%	
1"	100				100	
3/4	91				92	
1/2	59				66	
3/8	29				41	
1/4	11	100			26	
4	------	------			------	
10	4	71			16	
40	3	9			7	
200(WET)	1.4	10.3			2.9	
NO. AVE.	22	15				
LIME TREAT % =	NONE				P200/AC = 0.5	VMA = 21.8

CALIBRATION NUMBER	2278
MIX ID	11228
NUMBER OF SAMPLES	4
COUNT TIME PER SAMPLE	16
FIT COEFF =	0.997
CALIBRATION DATE	4-5-93
BACKGROUND COUNT:	2473
BASE WEIGHT:	6500
CALIBRATION CONSTANTS– A1:	–26.338074
A2:	14.233910
A3:	–14.722926

JOB MIX FORMULA TEST DATA:

PERCENT ASPHALT (TOTAL MIX)	4.5	5.0	5.5	6.0	6.5
ASPHALT FILM	SUFF – THK	THICK	THICK	THICK +	THICK +
SPECIFIC GRAVITY @ 1ST COMP. (T–166)	2.12		2.15		2.17
PERCENT VOIDS @ 1ST COMP.			10.9		
STABILITY @ 1ST COMP. (T–246)					
SPECIFIC GRAVITY @ 2ND COMP.					
PERCENT VOIDS @ 2ND COMP.					
STABILITY @ 2ND COMP					
MAXIMUM SPECIFIC GRAVITY (T–209)			2.414		
INDEX RET. STR. (T–165)			60		
INDEX RET. STR. (T–165) WITH 0.5% PAVEBOND			74		
PERCENT DRAIN DOWN	35	40	80	90	95

JOB MIX FORMULA:

CALCULATED JOB MIX FORMULA PROPERTIES

AGGREGATE SIEVE SIZE	JMF GRADATION	PAVING COURSE	ASPHALT CONTENT % BY Wt. OF TOTAL MIXTURE	Sp. Gr. @ 1ST COMP.	Sp. Gr. @ 2ND COMP.	MAX Sp. Gr.	DESIGN VOIDS 1ST COMP.	DESIGN VOIDS 2ND COMP.
1"	100	WEARING	5.5	2.15	------	2.414	10.9	------
3/4	92	BASE						
1/2	66							
3/8	41	SHOULDER						
1/4	26	Asphalt LAB NO.	93 – 01908					
10	16	BRAND–	ALBINA		MIXING TEMP.– 247 ° – 255 ° F			
40	7	GRADE–	PBA – 5		PLACEMENT TEMP.– 231 ° – 239 ° F			
200	3.0	ADDITIVE–	0.5% PAVEBOND SPECIAL OR EQUIVALENT REQUIRED.					

AGGREGATE TEST DATA:

CA: 92 –09584; SP GRAV = 2.62; Na2SO4 = 2.0%; DEG = 0.5",12.8%; LAR = 14.3%, FRIAB = 0.2%; DUST = .08%

FA: 92 – 09586; SP GRAV = 2.50; Na2SO4 = 5.1%; DEG = 0.9",13.3%; FRIAB = 0.6%; SE = 70

Files
CONST.
FHWA
Engr.
Engr.
Dist. Engr.
Region Geo.
Contractor

COMMENTS:

Wayne H. Obie
ENGINEER OF MATERIALS

APPENDIX B

Mixing and Compaction Protocol

Draft 11/23/92

PROTOCOL FOR SAMPLE PREPARATION BY MEANS OF ROLLING WHEEL COMPACTION

Oregon Dept. of Transportation

OSU-TM-91-2

by

Todd Scholz
Research Engineer

Dan Sosnovske
Research Engineer

Karl Frick
Undergraduate Research Assistant

Oregon State University
Department of Civil Engineering
Corvallis, OR 97331

December 1992

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INTRODUCTION

This protocol describes the materials preparation procedures as well as the mixing and compaction procedures necessary to produce large single-mix or layered slabs (≈30 x 30 x 4 in.) of asphalt concrete. Also described are procedures for cutting and coring test specimens from the slab.

RELATED DOCUMENTS

OSU-TM-91-1	Protocol for Material Processing and Sample Preparation, Task D, June 1991.
ASTM C117-90	Materials finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing.
ASTM C136-84a	Sieve Analysis of Fine and Coarse Aggregates.
ASTM D-2041-78	Test Method for Theoretical Maximum Specific Gravity Of Bituminous Paving Mixtures.

MATERIALS PREPARATION

Prior to mixing and compacting asphalts and aggregates it is first necessary to prepare the materials. This section describes the necessary procedures for preparing asphalts and aggregates.

Preparation of Aggregates

The necessary preparations to be performed on the aggregates include the determination of a batch gradation, calculation of batch quantities, and the batching of the aggregate sizes according to the batch gradation. A brief description of these preparations is provided in the following paragraphs.

Determination of Batch Gradations. The steps necessary for the determination of the batch gradation if a particular aggregate as follows:

1) Dry the bulk aggregate (i.e., aggregate as received from the quarry) to constant weight at 110°C (230°F).

2) Following the ASTM C136 test method, sieve the bulk aggregate to divide it into uniform ranges of sizes (e.g., 3/4 x 1/2-in, 1/2 x 3/8-in., 3/8 x 1/4-in., etc.). It is desirable to divide the bulk aggregate into the same sizes as specified by the target gradation.

3) Using the target gradation as the batch gradation, batch a 2500 g (total mass) sample of the aggregate.

4) Following the ASTM C117 test method, perform a wet sieve analysis on the aggregate sample. Retain the washed aggregate and perform a dry sieve analysis (ASTM C136) on the sample.

5) Compare the target gradation on the aggregate to the actual gradation as determined by the wet and dry sieve analyses. If the actual and target gradations do not match to within ± 0.5% on all sizes, make necessary adjustments to the batch gradation and repeat steps 4 and 5 until the actual gradation matches the target gradation to within ± 0.5% on all sizes.

Calculation of Batch Quantities. After determining the batch gradation for the aggregate as described above, calculation of the batch quantities for a particular aggregate is accomplished as follows:

1) Calculate the volume of the mold (which equals the volume of the slab).

2) Estimate the theoretical maximum (Rice) specific gravity of the asphalt-aggregate mixture. It is preferable to use actual data for this estimation. For example, it is recommended that a sample of asphalt and aggregate be mixed for the specific

purpose of determining the theoretical maximum specific gravity of the mixture via ASTM D2041-78.

3) Using the estimated theoretical maximum specific gravity and the target air void content, calculate the target bulk specific gravity for the compacted slab:

$$G_{mb} = G_{mm}\left[1 - \frac{\%AV}{100}\right]$$

where:

G_{mb} = target bulk specific gravity of the compacted slab

G_{mm} = estimated theoretical maximum specific gravity of the mixture

%AV = target air void content of the compacted slab

4) Calculate the unit weight of the compacted slab:

$$\gamma = G_{mb}\gamma_w$$

where:

γ = unit weight of the compacted slab, lb/ft^3

γ_w = unit weight of water (= 62.4 lb/ft^3)

G_{mb} = target bulk specific gravity of the compacted slab

5) calculate the weight of the compacted slab:

$$W = \gamma V$$

where:

W = weight of the compacted slab

γ = unit weight of the compacted slab

V = volume of the mold, ft^3

6) Calculate the weight of aggregate:

a) Asphalt content based on dry aggregate:

$$W_{aggr} = \left[\frac{W}{1 + \left[\frac{\%AC}{100} \right]} \right]$$

where:

W_{aggr} = total weight of aggregate, lb

W = total weight of compacted slab, lb

%AC = asphalt content of the mixture, %

b) Asphalt content based on total weight of mix:

$$W_{aggr} = \left[1 - \frac{\%AC}{100} \right] W$$

where:

W_{aggr} = total weight of aggregate, lb

W = total weight of the compacted slab, lb

%AC = asphalt content of the mixture, %

7) Calculate the batch quantities for each size fraction and the cumulative batch quantities based on the weight of the aggregate (W_{aggr}) as shown in the following example:

Size	Batch Gradation (%)	Batch Quantity (lb)	Cumulative Batch Quantity (lb)
1" x 1/4"	23	32.2	32.2
1/4" x #10	47	65.8	98.0
#10 -	30	42.0	140.0

Notes:
1) W_{aggr} = 140 lb
2) Batch Quantity = (Batch Gradation Percentage) X W_{aggr}
3) Cumulative Batch Quantity = Σ(Batch Quantities)

Aggregate Batching. Once a batch gradation has been determined, the aggregate can be batched as follows:

1) Obtain the following:

- A balance with a capacity of at least 100 lb and a resolution of 0.1 lb.
- The aggregate to be batched.
- Several large pans (e.g., 2 x 3 x 0.5 ft.).

2) Place a pan on the balance and tare the pan.

3) Beginning with the largest size fraction of aggregate place some aggregate in the pan. Continue adding aggregate until the correct batch quantity is obtained.

4) Repeat step 3 for all size fractions of aggregate. Note: When placing the aggregate in the pan, position the size fractions in separate and distinctive piles so that aggregate of a particular size can be removed in case too much of the particular size is added.

5) Check to ensure the total aggregate weight matches that of the cumulative batch weight.

Preparation of Asphalts

The necessary preparations to be performed on the asphalts include subdividing the large quantities (5 gal.) into smaller quantities (e.g., 1 qt.) and calculation of the required quantity to be used while mixing the asphalt with the aggregate. A brief description of these preparations are provided in the following paragraphs.

Subdividing Asphalts. The asphalts arrive in 5 gallon epoxy-lined containers and need to be subdivided into smaller cans (e.g., quart or liter containers). The following procedure describes how to subdivide the asphalts:

1) Obtain the following:

- The asphalt to be subdivided.
- An oven (preferably forced draft) sufficiently large to contain the number of 5 gal. containers being subdivided.
- Enough quart or liter cans (with lids) to contain the asphalt being subdivided (approx. 20 quart cans per 5 gal. container).
- Self adhesive paper labels and a permanent marker.
- Paper such as freezer wrap or news print with 2 to 3 ft. width.
- A large stir rod (e.g., 3/4 in diameter, 3 ft. long).
- A spatula and bunsen burner (with gas source).

2) Place the 5 gal. container(s) in the oven set at 135°C (275°F). The lid of each container should remain loosely in place.

3) After ≈ 1½ hours, the sample should be removed from the oven and an attempt made to stir the asphalt with the stir rod to prevent or minimize local overheating. This should be repeated every hour thereafter until the asphalt is fluid enough to pour. After stirring the asphalt, clean the stir rod by heating it with the bunsen burner and scraping the asphalt from it using the spatula. This must be done if dividing asphalts of different grades or from different refineries so that the asphalt from one container is not introduced into another container having a different asphalt. Note: Paper (e.g., freezer wrap or news print) should be placed under the bunsen burner prior to cleaning the stir rod so that the asphalt drips onto the paper and not the counter or the floor.

4) While waiting for the asphalt to heat, cover 75-100 sq. ft. of the floor near the oven with paper. Also, label approximately 20 qt. or liter cans per 5 gal. container with the

asphalt type and date of subdivision using the self adhesive labels and the permanent marker. Arrange the quart or liter cans on the paper covering the floor in a sequence convenient for pouring.

5) When the asphalt is fluid enough to pour easily, stir the asphalt for approximately one minute to obtain uniformity and fill the quart or liter cans to ≈95% capacity (do not fill the cans completely). Also, care should be taken to avoid any spilling onto the container label.

6) After filling, close all quart or liter cans tightly and allow them to cool to room temperature. Closing the containers while they are still hot will produce a partial vacuum seal.

7) While waiting for the cans to cool, clean all items used in the process as well as the area in which the work was performed.

8) When the containers reach room temperature, transfer the cans to the storage area set to a temperature of 10°C (50°F).

Calculation of the Amount of Asphalt. Calculation of the quantity (weight) of asphalt to be mixed with aggregate is accomplished as follows:

1) For an asphalt content based on dry weight of aggregate:

$$W_{AC} = \left[\frac{\%AC}{100} \right] W_{aggr}$$

where:

W_{AC} = weight of asphalt, lb

W_{aggr} = total weight of the aggregate, lb

%AC = asphalt content of the mixture, %

2) For an asphalt content bases on total weight of mix:

$$W_{AC} = \left[\frac{\%AC}{100} \right] W$$

where:

W_{AC} = weight of asphalt, lb

W = weight of compacted slab, lb

%AC = asphalt content of the mixture, %

MIXING ASPHALTS AND AGGREGATES

Once aggregates have been batched to the gradation specified by the mix design, the next step in the sample preparation procedure is to mix the aggregate with asphalt.

Preparation for Mixing Slab Materials

The necessary preparations that must be accomplished prior to mixing include:

1. Set the oven in the Asphalt Rutting Lab (Aero Engineering Lab) to the 170±20 cS (mixing) temperature of the asphalt to be used at least six (6) hours prior to mixing. A mixing temperature of 160°C (320°F) was used for the PBA-5 asphalt in the dense graded mixtures. The temperature was lowered to 127°C (261°F) for the open-graded mixtures to keep the asphalt from draining off the aggregate.
2. Place the aggregate in the oven at least four (4) hours prior to mixing.
3. Place the asphalt in the oven approximately two (2) hours prior to mixing. The lids to the cans should remain loosely in place. The asphalt must be periodically stirred throughout the heating process to ensure uniform heating as well as to prevent burning. Also, asphalt that has been at its mixing temperature for 3.5 hours or more or asphalt that has been burned should not be used and must be discarded.

4. Ignite the propane burner elements on the asphalt mixer approximately 1 hour before mixing is to begin, in order to heat the mixer bowl.

IMPORTANT: **Although the above preparations are presumably sufficient to preheat the tools, equipment, aggregate, and asphalt, it is necessary to ensure that this is in fact true prior to actual mixing. In short, monitor the temperature of everything to ensure the appropriate mixing temperature has been achieved.**

Once the above preparations have been accomplished and the necessary time for preheating has elapsed, the asphalt and aggregate is ready to be mixed.

Mixing Slab Materials

When the equipment, aggregate, and asphalt are at the appropriate mixing temperature (the 170±20 cS temperature of the asphalt), mixing can proceed as follows:

1. Weigh a pot, then tare it and add the appropriate amount of asphalt and a given amount extra (80 g for dense-graded mixes and 120 g for open-graded mixes). The extra amount is what will stick to the pot when the asphalt is poured into the mixer (more will stick when mixing open-graded mixtures due to the lower mixing temperature).
2. Position the mixing bowl in an up-right position, or at an angle which allows easy dumping of the aggregate without spillage.
3. Remove the pans of aggregate from the oven one at a time and carefully place them in the mixer taking care not to waste material.
4. Carefully add the appropriate amount of asphalt within ±5 grams (see Table 2 for asphalt contents) taking special care not to overshoot the target amount. When the asphalt stops pouring and starts dripping, reweigh the pot and make sure the proper amount of asphalt has been added. At the same time make every effort to minimize the time required to add the asphalt.

5. Mix the asphalt and aggregate for two to three (2-3) minutes. Record the time of mixing.
6. Stop the mixer. Measure and record the temperature of the mix.
7. Start the mixer and dump the mixture into pans. Label the mix accordingly.
8. Set the oven to 135°C and place the mixture in the oven when the oven reaches 135°C.

Table 1. Asphalt Contents for the Riverbend and Cake Pit Aggregates by mix.

Aggregate Type	Mix Type	% Asphalt by Weight of Mix
Riverbend	A	5.8
	B	5.5
	C	5.8
	E	6.5
	F	6.0
Cake Pit	A	6.2
	B	5.8
	C	6.5
	E	7.0
	F	6.5

COMPACTION OF THE MIX

Once the mix has been batched (or blended), mixed, and allowed to cure for 4 hours at 135°C, the next step in the sample preparation procedure is to compact the mix. However, as with mixing, several preliminary preparations need to be accomplished before compaction can be preformed as described below.

Preparation for Compaction of Slabs

The preparation that must precede compaction of slabs is as follows:

1. Assemble the mold as follows:

   - Place the 4 ft x 4 ft particle board (with holes) on the floor. On top of this place the 4 ft x 4 ft mold base (steel plate with studs and handles).
   - Place the channels on the mold base such that the slotted angles face outward and fit over the studs.
   - Place the stud collars over the studs at each corner such that they fit inside the slotted angles and contact the mold base.
   - Slide one of the channels inward ensuring proper alignment (i.e., the outer radius of the slots in the angles should be butted up against and in full contact with the stud collars).
   - Place a washer and nut over the middle stud and tighten the nut. Remove the stud collars, place washers and nuts on the outside studs, and tighten the nuts.
   - Repeat the last two steps for the other channel.
   - Place a 31 x 48 x 1/2 inch particle board between the channels, and overlay it with metal sheeting (aluminum sheeting that has been used as printing plates has worked) to keep the slab from sticking to the particle board.
   - Place the particle board shims (large boards) at each end of the mold such that the top of the shims are level with the particle board between the channels.
   - Place the appropriate size ramp and platform (two, three or four inches depending on desired base thickness) inside the channels and adjust the distance between them such that this distance is equal to the slab length.

- Align the pin holes in the ramp and platform with the pin holes in the channels and check the distance between the ramp and platform to ensure it is correct.
- Place the two channels with angled ends between the ramp and platform ensuring the web of each channel faces inward and that the angled channels butt against the mold channels.
- If setting up to compact a lift, just put on the appropriate (one or two inch) lift attachment by fitting the pins on the attachment into the holes in the base ramp and platform.

2. Check the fuel and oil levels of the compactor and fill if necessary.
3. Start compactor to ensure proper functioning and allow it to warm up.

Once the above preparations have been accomplished and the prescribed time for curing the mix has elapsed, the mix is ready to compact.

Compaction of Slabs

Compaction of slabs is accomplished as follows:

1. Remove a pan of mix from the oven and dump it in the center of the mold. Level the mix using a shovel or rake while at the same making every attempt to avoid segregation of the mix.
2. Repeat Step 1 for the remaining pans of mix ensuring the mix is as level as possible.
3. Allow the mix to cool to the compaction temperature (130°C (266°F) for the dense-graded mixtures and 120°C (248°F) for the open-graded mixtures).
4. Compact the mix until the rollers bear down on the compaction stops (steel channels with depths equal to the slab thickness inserted in the mold).

5. Record the time required to compact the mix.

6. Allow the compacted mix to cool to room temperature.

7. Clean all tools, the compactor, and the area surrounding the mold.

REMOVAL OF SLAB FROM MOLD

After the specimens have cooled to room temperature the final step in the sample preparation procedure is the removal of the specimen from the compaction mold.

The removal of the slab from the mold is accomplished as follows:

- Remove the ramp and platform from the mold
- Remove the two mold channels
- Remove the two angled channels from the sides of the sample
- Slide the board and slab onto the pallet jack

CUTTING/CORING TEST SPECIMENS FROM THE SLAB

A slab will be cut into three beams (two 6 5/8 x 19 1/4 x 4 in. beams and one 6 1/2 x 19 x 4 in. coring beam), three 6 in. diameter cores will be drilled from the coring beam. The layered slabs are made four inches wider so extra specimens can be extracted and cut between layers so that air voids can be determined for both layers of the slab.

Cutting Beams from the Slab

Cutting of the slab into specimens suitable for testing in the LCPC rutting tester is accomplished as follows:

1. Transfer the slab outside using the pallet jack. NOTE: Leave the slab on the particle board to prevent damage to the slab (e.g., bending and cracking).
2. Place the cutting platform adjacent to the slab.
3. Mark the slab with a chalk line to establish cut lines.
4. Check the fuel and oil levels of the walk-behind saw and fill if necessary.

5. Check the blade for proper installation and damage. NOTE: Do not use the saw if the blade is damaged or improperly installed.
6. Position the saw on the cutting platform ensuring proper alignment with the chalk line on the slab.
7. Start the saw at half throttle and allow it to warm up for at least three (3) minutes. **NOTE**: Use protective clothing (gloves, boots, eye protection, etc.) when using the saw.
8. Adjust the saw to full throttle and position the blade over the chalk line about halfway along the line.
9. Begin cutting by lowering and locking the blade at a depth of 2 inches. Push the saw forward such that the blade cuts along the chalk line.
10. When the blade is just beyond the end of the slab, raise and lock the blade such that the blade is above the slab. Pull the saw backward until the point of initial cutting is reached. Lower the blade to full depth (4 inches) and cut through the slab using the first cut as a guide.
11. Raise the blade above the slab and stop the saw.
12. Repeat the above procedure to make all required cuts.
13. Transfer the test specimens inside, peel of the aluminum sheeting, and vacuum them using a shop vacuum to remove the dust from cutting.
14. Transfer the remaining portion of the slab to the core drill area.

Cutting Cores from the Slab

1. Place a piece of particle board (with plan area greater than the plan area of the portion of the slab to be cored) beneath the core barrel.
2. Place the portion of the slab to be cored on the particle board and align it for the first cut.

3. Attach the shop vacuum hose to the core barrel shroud.
4. Power on the air compressor.
5. When the air compressor reaches 125 psi and switches off, power on the vacuum.
6. Connect the air compressor hose to the core drill.
7. Power on the core drill and begin cutting. NOTE: When cutting cores the load on the core drill should be maintained at approximately 15 amps.
8. Continue cutting at constant load until the core bit cuts completely through the asphalt concrete.
9. Withdraw core bit and switch off the core drill.
10. Detach the air compressor hose and switch off the vacuum.
11. Remove and label the core.
12. Reposition the asphalt concrete for the next cut.
13. Repeat steps 5-12 for the two remaining cuts.

APPENDIX C

LCPC Protocol

Standard Method of Test for

Asphalt Pavement Rutting Test with the OSU Wheel Tracker

AASHTO DESIGNATION: T ###-YY
(ASTM DESIGNATION: D ####-YY)

This document is the draft of a test method being developed by researchers at Oregon State University for the Strategic Highway Research Program (SHRP). The information contained herein is considered interim in nature and future revisions are expected. It is also recognized that this document may lack details with respect to the test equipment (schematics, dimensions, etc.); more details will be provided after the test procedure is finalized. This version represents the state of the test procedure as of ***March 1, 1993****.*

The test method is in a format similar to the test methods contained in the American Association of State Highway and Transportation Officials' (AASHTO) standard specifications. At the conclusion of SHRP, selected test methods will be submitted to AASHTO for adoption into its standard specifications.

1. SCOPE

1.1 This method determines the rutting susceptibility of water and temperature conditioned asphalt concrete beam specimens. The amount of rutting is used a measure of the performance of the mixture in terms of water sensitivity.

2. APPLICABLE DOCUMENTS

2.1 *AASHTO Test Methods:*

T ### Practice for Preparation of Asphalt Concrete Specimens by Means of the Rolling Wheel Compactor

2.2 *ASTM Test Methods:*

D 8 Standard Definitions of Terms Relating to Materials for Roads and Pavements

D 3549 Method for Thickness or Height of Compacted Bituminous Paving Mixture Specimens

3. SUMMARY OF PRACTICE

3.1 Compacted asphalt concrete test specimens are subjected a water and temperature conditioning process. The water sensitivity characteristics of the compacted mixtures are determined based upon measurements of percent stripping, binder migration and the amount of rutting.

4. APPARATUS

4.1 *LCPC Rutting Tester* - Also known as the OSU Wheel Tracker, described in Table E.1.

4.2 *Specimen Conditioning System* - A system capable of pulling a vacuum of 25 in. Hg (635 mm) through the beam specimen.

4.3 *Hot Water Bath* - A hot water bath capable of holding two 20 x 7.5 x 4 in. (508 x 190.5 x 101.6 mm) specimen containers. The bath will be capable of maintaining a temperature of 140°F ± 9°F (60°C ± 5°C).

4.4 *Temperature Controlled Cabinet* - A hot water bath capable of holding two 20 x 7.5 x 4 in. (508 x 190.5 x 101.6 mm) specimen containers. The cabinet will be capable of maintaining a temperature of -0.4°F ± 9°F (-18°C ± 5°C).

4.5 *Miscellaneous Apparatus:*

4.5.1 Specimens Holders
4.5.2 Compressed Air Source
4.5.3 Vacuum Source

5. MATERIALS

5.1 The following materials are required:

5.1.1 Clear silicone sealant
5.1.2 Latex rubber sheeting

6. SPECIMEN PREPARATION

6.1 Prepare two asphalt concrete mixture specimens in accordance with T ### "Standard Practice for Preparation of Test Specimens of Bituminous Mixtures by Means of Rolling Wheel Compactor."

6.2 Determine the air void content of the specimens in accordance with Section 6 of T ###.

6.3 Place an 1 in. band of latex rubber sheeting around the circumference of each beam specimen at mid-height, using silicon rubber sealant. Allow to cure overnight (24 hours).

6.4 *Vacuum Conditioning*

6.4.1 Verify the dry weight of specimen and air void content of the specimen were determined in accordance with T ####.

6.4.2 Place the beam specimen on the bottom platen of the vacuum conditioning apparatus.

6.4.3 Place the top platen of the vacuum conditioning system on the specimen.

6.4.4 Fit the latex rubber membrane of the vacuum conditioning up over the specimen and top platen. Secure with appropriate clamping ring.

6.4.5 Set vacuum level to 23 in. Hg (584 mm). Allow specimen to draw water for 30 minutes.

6.4.6 Remove the specimen from the vacuum apparatus.

6.4.7 Weight the specimen and determine the degree of saturation.

6.4.8 If the saturation level is less than 60 percent, repeat steps 6.4.2 through 6.4.7 until the saturation level exceeds 60 percent, but not more than three additional times. The total conditioning time is not to exceed two hours.

6.4.9 Repeat steps 6.4.1 through 6.4.8 with companion specimen.

6.4.10 Place each specimen in a specimen holder and fill the holder with distilled water to cover the specimen.

6.4.11 Place the specimens in their holders in the hot water bath set at 60°C (140°F). Allow the specimens to condition for six hours.

6.4.12 Remove the specimens from the hot water bath and allow the specimens to cool to 25°C (140°F) for ten hours. Refill the specimen holder with distilled water as necessary.

6.4.13 Place the specimens into the 60°C (140°F) hot water bath again. Allow the specimens to condition for six hours.

6.4.14 Remove the specimens from the hot water bath and place in the cold cabinet. Allow the specimens to cool to -20°C (-4°F) for eight hours.

6.4.15 Remove the specimens from the cold cabinet and place in the 60° C (140° F) hot water bath. Allow the specimen to condition for ten hours.

6.4.16 Remove the specimen from the hot water bath and allow the specimen to cool to 25° C (140° F) for ten hours.

6.4.17 Wrap the specimen in plastic wrap to avoid moisture loss. The specimen are now ready to test in the OSU wheel tracker. The testing should take place immediately.

7. TEST PROCEDURE

7.1 Lubricate the platens of the OSU wheel tracker with a spray lubricant such as Pam.

7.2 Place 19 x 6-1/2 in. (482.6 x 165.1 mm) teflon sheet on the platen.

7.3 Place the asphalt concrete beam in the rutting tester, on the teflon sheet. Do not rip the plastic wrap.

7.4 Place the rutting tester mold over the specimen and teflon sheet. Do not rip the plastic wrap.

7.5 Place thin expanded foam sheets between the specimen and the walls of the mold on all four sides of the specimen. The foam sheets will be cut to the side dimensions of the beam specimen.

7.6 Bolt the mold to the platen of the OSU wheel tracker.

7.7 Repeat steps 7.1 through 7.6 to place the other beam on the opposite side of the OSU wheel tracker.

7.8 Close the doors of the OSU wheel tracker.

7.9 Connect the OSU wheel tracker to power and compressed air.

7.10 Power on the fan/temperature controller and adjust the setpoint temperature to 104°F (40°C). Allow the actual temperature to reach the setpoint temperature before proceeding further.

7.11 Remove the plastic wrap from the top of the specimen. Using a 15/64-in. bit, drill a hole 2-in deep each beam in the outer front corner. Insert the temperature probe in the hole. Manually move the carriage to ensure the tire does not make contact with the temperature probe.

7.12 When the actual temperature reaches the setpoint temperature check the pressure in each tire. Ensure that each tire is pressured to 100 psi.

7.13 Spread the top of the specimen with chalk dust to prevent sticking between the tire and specimen surface.

7.14 *Precondition the test specimens as follows:*

7.14.1 With the pressure switches in the off (arret) position, set each piston pressure to 50 psi.

7.14.2 Set the counter to 25. The counter value is the number of cycles the carriage will travel: one cycle equals two wheel passes; thus, a counter value of 25 cycles equals 50 wheel passes.

7.14.3 Set the pressure switches in the on (marche) position and ensure the pressure for each piston reads 50 psi. If not, adjust the pressure to 50 psi.

Note 1: When adjusting the pressure, always bring the pressure up to the setpoint pressure, never reduce the pressure to the setpoint pressure.

7.14.4 Start the carriage in motion by pressing the on (marche) push button.

7.14.5 Immediately after 50 wheel passes have been applied to the test specimens (when the carriage stops), release the pressure of each piston by turning the pressure switches to the off (arret) position.

7.15 Take measurements of the test specimen using the finger apparatus and software.

7.16 With the pressure switches still in the off (arret) position, adjust the pressure for each piston to 90 psi. Set the counter to apply the number of wheel passes for the next data set, as shown by the software. Wait for the actual temperature to reach the setpoint temperature before proceeding further.

7.17 When the actual temperature reaches the setpoint temperature, load the test specimens by turning the pressure switches to the on (marche) position. Ensure each piston pressure is 90 psi. If not, adjust the pressure to 90 psi.

Note 2: When adjusting the pressure, always bring the pressure up to the setpoint pressure; never reduce the pressure to the setpoint pressure.

7.18 Start the carriage in motion by pressing the on (marche) push button.

7.19 Immediately after the wheel passes have been applied (when the carriage stops) release the pressure to each piston by turning the pressure switch to the off (arret) position.

7.20 Take measurements of the test specimen using the finger apparatus and software.

7.21 Repeat Steps 7.16 though 7.20 for all data sets given in the software package.

7.22 At the completion of the test, leave the doors to the rutting tester open and allow the test specimens to cool to room temperature. Once cooled, remove the test specimens and store them for photographing and coring.

7.23 Take a photographic record of the specimen.

7.24 Dry core three cores from the specimen into three cores. The cores will be laterally centered in the wheel path, and one core will be taken from the direct center of the length of the wheel path. No cores should be taken from the end of the wheel path where the OSU wheel tracker tire changes direction.

8. DATA ANALYSIS

Analysis of the data obtained from the rutting tester should consist of the following as a minimum:

8.1 *Calculation of the average rut depth versus number of wheel passes* - This accomplished by taking the average of the finger reading after a certain number of wheel passes, *i*, minus the average reading of data set *0*. That is,

$$\text{rut depth} = \frac{P12_i + P13_i + P14_i + P22_i + P23_i + P24_i + P32_i + P33_i + P34_i}{9}$$

$$- \frac{P12_0 + P13_0 + P14_0 + P22_0 + P23_0 + P24_0 + P32_0 + P33_0 + P34_0}{9}$$

where:

PXY = gage reading at position XY.

8.2 *Calculate the average shove (on each side of the rut) versus number of wheel passes* - This is accomplished by taking the average of the finger readings after certain number of wheel passes, *i*, minus the average of the finger readings for zero wheel passes. That is,

$$\text{shove}_{left} = \frac{P11_i + P21_i + P31_i}{3} - \frac{P11_0 + P21_0 + P31_0}{3}$$

and

$$\text{shove}_{right} = \frac{P15_i + P25_i + P35_i}{3} - \frac{P15_o + P25_o + P35_o}{3}$$

where:

PXY = gage reading at position XY.

8.3 *Plot the average rut depth and the average shove (both sides) versus number of wheel passes.*

Table E.1. Specifications of the LCPC rutting tester

Applied Load	0 to 500 N (0 to ≈ 1120 lb)[a]
Carriage Velocity (maximum)	1.6 m/s (≈ 5.25 ft/s)
Carriage Acceleration (maximum)	10 m/s^2 (≈ 32.8 ft/s^2)
Carriage Travel	360, 410, 450, or 500 mm (≈ 14, 16, 18, or 20 in.)
Travel Frequency	1 Hz (carriage cycle is forward and back in 1 s)
Number of Tires	2[b]
Tire Pressure	7 kg/cm^2 (≈ 100 psi)
Tire Yaw	0 to 10°
Temperature Range	35 to 60° C (39 to 140° F) (can run at ambient temperature without temperature regulation)
Test Criterion	Rut depth at a predetermined number of cycles (1 cycle equals 2 wheel passes). The number of cycles is controlled by a mechanical counter. It is possible to monitor the propagation of rut depth by making intermediate measurements (this requires temporarily stopping the test).

[a] The OSU wheel tracker can attain loads of up to 1700 lb
[b] Tire size: 8.0 in. (203 mm) inside diameter (ID)
16.0 in. (406 mm) outside diameter (OD) (at 100 psi [689 kPa], no load)
4.0 in. (102 mm) width (3.25 in. [82.5 mm] tread width)

APPENDIX D

Repeated Load Creep Test Procedures

Repeated Load Creep Test Procedures

Sample Preparation

1) Set an environmental cabinet at designated temperature.

2) Assemble the LVDT yokes to include the four spacers with wing nuts snugly in place but without the LVDts.

3) Clamp the yokes around the specimen such that the yokes are centered at mid-height of the specimen. The holes for the LVDTs should be in the top ring of the yoke.

4) Use small rubber bands to hold the yoke securely around the specimen. Check to ensure that the portion of the yoke rings which grip the specimen make full contact with the specimen and adjust if necessary.

5) Place a small drop of cyanoacrylate ("superglue") at the yoke-specimen interface to help secure the yoke rings to the specimen.

6) Allow the glue to cure for 15 minutes at 25°C before placing the specimen in the environmental cabinet.

7) Place the specimen in the environmental cabinet for 8 hours.

Repeated Load Creep Test Procedures

1) Turn on the air flow to the servo-valve.

2) Turn on the power to the computer, the printer, the signal conditioner, and the servo-valve amplifier.

3) Type "MT" to run the repeated load creep test program.

4) Select Run Test from the main menu.

5) Type the file name to save the data. The file name should have less than 5 characters.

6) Place a teflon disk on the bottom platen. Place the specimen on the teflon disk. Mount both LVDTs in the holes and take out all the spacers before loading the specimen.

7) Place a teflon disk on top of the specimen.

8) Place the top platen on top of the teflon disk.

9) Press [C] to start data collection immediately before a static load is applied.

   Press [I] to interrupt the data collection.

10) Apply static load.

11) Set the pulse load at 100 micro strain.

12) Remove the pulse load at 4000 seconds of test time.

13) Remove the dead load at 4600 seconds of test time.

14) Continue data collection up to 8000 seconds of test time.

APPENDIX E

LCPC Data

OSU Wheel Tracker Results

Specimen ID	Aggregate Source	Class B-Mix Air Voids Parafilm (%)	Class B-Mix Air Voids SSD (%)	Class F-Mix Overlay Thickness (in)	Class F-Mix Overlay Air Voids Parafilm (%)	WHEEL PASS RUTDEPTH 0 (in)	100 (in)	200 (in)	500 (in)	1,000 (in)	2,000 (in)	5,000 (in)	10,000 (in)	20,000 (in)	30,000 (in)	40,000 (in)	50,000 (in)
UB-0-0-F0-R1				4.0	14.4	0	0.0430	0.0579	0.0845	0.1268	0.1508	0.2259	0.3362	0.4989	0.3999	0.4812	0.3623
UB-0-0-F0-R2	Surface			4.0	13.6	0	0.0340	0.0488	0.0673	0.0959	0.1141	0.1339	0.1621	0.2690	0.3544	0.4479	0.3837
Average					14.0	0	0.0385	0.0533	0.0759	0.1114	0.1325	0.1799	0.2492	0.3840	0.3771	0.4646	0.3730
Standard Deviation					0.6	0	0.0063	0.0065	0.0122	0.0218	0.0260	0.0650	0.1231	0.1626	0.0322	0.0235	0.0151
UB-1-4-F0-R1		9.2	6.7	0.0		0	0.0172	0.0296	0.0517	0.0665	0.0818	0.1027	0.1354	0.1649	0.2005	0.2194	0.2440
UB-1-4-F0-R2		8.5	6.5	0.0		0	0.0394	0.0493	0.0794	0.1045	0.1231	0.1571	0.1879	0.2408	0.2753	0.2933	0.3089
Average		8.9	6.6			0	0.0283	0.0395	0.0655	0.0855	0.1024	0.1299	0.1617	0.2029	0.2379	0.2564	0.2764
Standard Deviation		0.5	0.1			0	0.0156	0.0139	0.0196	0.0268	0.0293	0.0384	0.0371	0.0537	0.0529	0.0522	0.0459
UB-1-2-F1-R1		10.4		1.5	14.0	0	0.0345	0.0542	0.0832	0.0950	0.1135	0.1253	0.1556	0.1837	0.2077	0.2282	0.2456
UB-1-2-F1-R2		10.4		1.5	14.0	0	0.0381	0.0538	0.0797	0.0931	0.1131	0.1348	0.1885	0.2262	0.2603	0.2900	0.3156
Average		10.4			14.0	0	0.0363	0.0540	0.0815	0.0940	0.1133	0.1301	0.1720	0.2050	0.2340	0.2591	0.2806
Standard Deviation	Base #1					0	0.0026	0.0002	0.0024	0.0013	0.0003	0.0067	0.0233	0.0300	0.0372	0.0437	0.0495
UB-1-2-F2-R1	Riverbend	5.7		2.5	17.5	0	0.0680	0.0787	0.1519	0.2317	0.2854	0.4161	0.5602				
UB-1-2-F2-R2		5.7		2.5	17.5	0	0.0536	0.0608	0.0997	0.1475	0.2691	0.3965	0.4710				
Average		5.7			17.5	0	0.0608	0.0697	0.1258	0.1896	0.2772	0.4063	0.5156				
Standard Deviation						0	0.0102	0.0127	0.0369	0.0595	0.0115	0.0138	0.0630				
UB-1-2-F3-R1		6.8		3.5	14.9	0	0.0630	0.0978	0.1861	0.2512	0.3057	0.5006					
UB-1-2-F3-R2		6.8		3.5	14.9	0	0.0745	0.1063	0.1814	0.2489	0.3119	0.3292	0.3169				
Average		6.8			14.9	0	0.0688	0.1021	0.1837	0.2501	0.3088	0.4149	0.3169				
Standard Deviation						0	0.0082	0.0060	0.0033	0.0016	0.0044	0.1212					
UB-2-4-F0-R1		8.6	7.4	0.0		0	0.0328	0.0418	0.0515	0.0722	0.0949	0.1114	0.1294	0.1541	0.1651	0.1810	0.1849
UB-2-4-F0-R2		8.8	7.3	0.0		0	0.0301	0.0454	0.0634	0.0846	0.1129	0.1340	0.1456	0.1699	0.1953	0.2055	0.2226
Average		8.7				0	0.0314	0.0436	0.0575	0.0784	0.1039	0.1227	0.1375	0.1620	0.1802	0.1933	0.2038
Standard Deviation						0	0.0019	0.0026	0.0084	0.0088	0.0127	0.0160	0.0114	0.0112	0.0214	0.0174	0.0267
UB-2-2-F1-R1		8.2		1.5	13.2	0	0.0366	0.1145	0.1399	*0.1981	0.1775	0.2761	0.3611				
UB-2-2-F1-R2		8.2		1.5	13.2	0	0.0305	0.0516	0.0624	*0.1173	0.1280						
Average		8.2			13.2	0	0.0335	0.0830	0.1011	0.1577	0.1527	0.2761	0.3611				
Standard Deviation	Base #2					0	0.0043	0.0445	0.0548	0.0572	0.0350						
UB-2-2-F2-R1	Riverbend	8.0		2.5	13.2	0	0.0705	0.0927	0.1020	0.1357	0.1287						
UB-2-2-F2-R2		8.0		2.5	13.2	0	0.0243	0.0505	0.0687	0.0974	0.1123						
Average		8.0			13.2	0	0.0474	0.0716	0.0853	0.1165	0.1205						
Standard Deviation						0	0.0327	0.0299	0.0236	0.0271	0.0116						
UB-2-2-F3-R1		11.0		3.5	17.2	0	0.1028	0.1502	0.2607	0.4578	0.7825						
UB-2-2-F3-R2		11.0		3.5	17.2	0	0.1479	0.2051	0.2762	0.3478	0.4503						
Average		11.0			17.2	0	0.1253	0.1777	0.2685	0.4028	0.6164						
Standard Deviation						0	0.0319	0.0388	0.0110	0.0778	0.2349						
UB-3-4-F0-R1		5.0	3.4	0.0		0	0.0914	0.1489	0.1721	0.2453	0.3220						
UB-3-4-F0-R2		4.6	2.2	0.0		0	0.1170	0.1508	0.1281	0.2218							
Average		4.8	2.8			0	0.1042	0.1499	0.1501	0.2335	0.3220						
Standard Deviation		0.3	0.8			0	0.0181	0.0013	0.0311	0.0166							
UB-3-2-F1-R1		4.6		1.5	13.3	0	0.0938	0.1062	0.2245	0.2855	0.3414	0.4285					
UB-3-2-F1-R2		4.6		1.5	13.3	0	0.0712	0.0892	0.1577	0.2186	0.3016	0.4667					
Average		4.6			13.3	0	0.0825	0.0977	0.1911	0.2520	0.3215	0.4476					
Standard Deviation	Base #3					0	0.0160	0.0120	0.0473	0.0473	0.0281	0.0270					

OSU Wheel Tracker Results

Specimen ID	Aggregate Source	Class B-Mix Air Voids	Class B-Mix Air Voids	Class F-Mix Overlay Thickness	Class F-Mix Overlay Air Voids	WHEEL PASS RUTDEPTH 0	100	200	500	1,000	2,000	5,000	10,000	20,000	30,000	40,000	50,000
		Parafilm (%)	SSD (%)	(in)	Parafilm (%)	(in)	(in)	(in)	(in)	(in)	(in)	(in)	(in)	(in)	(in)	(in)	(in)
UB-3-2-F2-R1	Reed Pit	4.9		2.5	20.9	0	0.0883	0.1610	0.2481	0.3152							
UB-3-2-F2-R2		4.9		2.5	20.9	0	0.0857	0.2480	0.3286								
Average		4.9			20.9	0	0.0870	0.2045	0.2884	0.3152							
Standard Deviation						0	0.0019	0.0615	0.0570								
UB-3-2-F3-R1		3.4		3.5	14.9	0	0.0621	0.1225	0.2098	0.3025	0.4075	0.5435	0.7444				
UB-3-2-F3-R2		3.4		3.5	14.9	0	0.0731	0.1094	0.1876	0.2461	0.3109	0.3755	0.4437				
Average		3.4			14.9	0	0.0676	0.1159	0.1987	0.2743	0.3592	0.4595	0.5940				
Standard Deviation						0	0.0078	0.0093	0.0157	0.0399	0.0683	0.1188	0.2126				
UB-4-4-F0-R1	Base #4 Riverbend	5.7	4.4	0.0		0	0.0491	0.0940	0.1317	0.1438	0.1987	0.2916	0.3726				
UB-4-4-F0-R2		5.5	4.8	0.0		0	0.0589	0.1103	0.1829	0.2360	0.3446						
Average		5.6	4.6			0	0.0540	0.1021	0.1573	0.1899	0.2717	0.2916	0.3726				
Standard Deviation		0.1	0.3			0	0.0069	0.0115	0.0362	0.0651	0.1032						
UB-4-2-F1-R1		5.3		1.5	17.0	0	0.0608	0.0263	0.0942	0.1183	0.1961	0.2731	0.4862				
UB-4-2-F1-R2		5.3		1.5	17.0	0	0.0678	0.0905	0.1135	0.1593	0.2374	0.3227	0.4055				
Average		5.3			17.0	0	0.0643	0.0584	0.1038	0.1388	0.2167	0.2979	0.4458				
Standard Deviation						0	0.0050	0.0454	0.0136	0.0290	0.0292	0.0351	0.0571				
UB-4-2-F2-R1		5.5		2.5	14.9	0	0.1326	0.2057	0.2701	0.3960	0.5215						
UB-4-2-F2-R2		5.5		2.5	14.9	0	0.0948	0.1651	0.2363	0.3311	0.4454						
Average		5.5			14.9	0	0.1137	0.1854	0.2532	0.3636	0.4834						
Standard Deviation						0	0.0268	0.0287	0.0239	0.0459	0.0539						
UB-4-2-F3-R1		7.2		3.5	12.4	0	0.0938	0.1339	0.2172	0.2987	0.3773	0.5346	0.6568	0.7371	0.7884		
UB-4-2-F3-R2		7.2		3.5	12.4	0	0.1010	0.1127	0.1735	0.2178	0.2666	0.3385	0.3622	0.3904	0.3982	0.4089	0.4371
Average		7.2			12.4	0	0.0974	0.1233	0.1953	0.2582	0.3220	0.4365	0.5095	0.5637	0.5933	0.4089	0.4371
Standard Deviation						0	0.0051	0.0150	0.0309	0.0572	0.0783	0.1386	0.2083	0.2452	0.2759		

APPENDIX F

Repeated Load Creep Test Data