FINAL REPORT

EVALUATION OF RUTTING POTENTIAL OF OREGON SURFACE MIXES

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16. Abstract

The purpose of this study was to evaluate the rutting potential of selected asphalt concrete mixes used in Oregon. Dense- and open-graded, as well as large stone, mixes were considered. The experimental design included one asphalt cement, two aggregates, and nine different combinations of mix type and lift thickness. Specimens were fabricated in the lab by means of rolling wheel compaction and then evaluated by two methods: the LCPC (Laboratoire Central des Ponts et Chaussees) wheel tracking device and the simple shear device developed as part of the Strategic Highway Research Program (SHRP). With the wheel tracking device, rutting potential was characterized in terms of rut depth and rutting potential; with the simple shear device, rutting potential was characterized in terms of cumulative permanent shear strain. The wheel tracking and simple shear devices did discriminate among the various mix types. Based on these limited data, the relative ranking of mixes with respect to rutting potential is A > B > C > F (best to worst) in the simple shear device and B = C > A > F in the LCPC rut tester.

The limited laboratory testing of the F-mixes (open-graded) suggests that it might be prone to rutting which is contradictory to its observed performance in the field. Also, the layered F-mixes performed better than did the F-mix alone. Additional testing with increased confinement, in both the wheel tracking and shear devices, is clearly warranted. Finally, additional laboratory test data would permit the development of performance criteria for the Oregon mixes in terms of both test devices.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

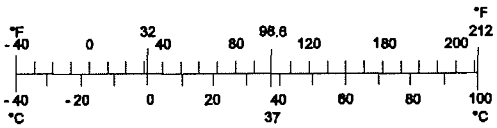
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	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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1.0 INTRODUCTION

1.1 Background

The Oregon Department of Transportation (ODOT), as well as other highway agencies, continues to experience rutting in asphalt concrete pavements. This is, in part, due to increasing axle loads and/or tire pressures. In an effort to improve the rutting resistance of the asphalt layer, new asphalt mixes are being employed. In Oregon, for example, both Class A (large stone) and Class F (open-graded) mixes are now being used. In addition, new performance-based asphalt (PBA) specifications are now being used by ODOT. Although these products have been implemented, in part, to reduce rutting, the performance of mixes containing PBA-graded asphalts has not been validated.

New techniques emerged from the Strategic Highway Research Program (SHRP) to evaluate mixes in terms of their resistance to permanent deformation. One of these techniques is the simple shear test which has been proposed for inclusion in Superpave (Monismith et al., 1993). The simple shear test can also be used to generate mix properties which are employed in prediction models to estimate the rutting in an asphalt pavement as a function of traffic and environment (Lytton et al., 1993). The performance of the shear test has been validated using a wheel tracking device such as that developed by Laboratoire Central des Ponts et Chausées (LCPC) in France (Brosseaud et al., 1993). The LCPC device was also used in studies at Oregon State University (OSU) in the validation efforts for water sensitivity which were a part of SHRP project A-003A (Terrel et al., 1993).

This study makes use of the LCPC rutting tester to evaluate the relative rutting characteristics of existing (B, C, and E) and new (A and F) asphalt mixes used in the state of Oregon. All of the mixes evaluated used PBA-5 asphalt. Similar rutting tests have been widely used in Europe to rank the relative performance of both conventional and modified asphalt mixes (Brosseaud et al., 1993).

1.2 Objectives

The objective of this study is to evaluate the rutting resistance of selected asphalt concrete mixes used in Oregon. In particular, it will evaluate the effect of mix type and lift thickness. Future studies should explore the effect of base support and asphalt type or modifiers.

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 the fall (1992) and winter (1993) and consisted of the evaluation of the test specimens in the wheel tracker and the simple shear device (at University of California, Berkeley (UCB)). 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. The results are presented in Chapter 6.

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

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

The study variables included mix types and lift thickness for two aggregate types.

2.1.1 Mix Types

The major mix types utilized in Oregon were selected for study. They included the following:

1) **Class A**, a large stone mix (1½ in. (38 mm) max. aggregate size) which is used primarily as a base layer;
2) **Class B**, the workhorse asphalt mix (¾ in. (19 mm) max.) which is normally used on high volume roads;
3) **Class C**, a commercial mix (½ in. (13 mm) max.) commonly used by cities and in private works;
4) **Class E**, an open-graded (12 to 17% voids) mix (½ in. max.) used as a thin (1 to 1½ in. (25 to 38 mm)) wearing surface on the A and B mixes; and
5) **Class F**, an open-graded (15 to 20% voids) mix (¾ in. max.) which is used as a thick (2 to 4 in. (50 to 100 mm)) wearing surface on B mixes.

2.1.2 Lift Thickness

To evaluate the effect of lift thickness in contributing to the amount of rutting, one or two levels of thickness were considered as shown below:

Mix Type	Lift Thickness in. (mm)
A	4 (100)
B	4 (100)
C	4 (100)
E	1 (25)
F	2,4 (50,100)

The total layer thickness was always held at 4 in. (100 mm). For example, 1 in. (25 mm) of E-mix would be placed on 3 in. (75 mm) of a base layer (A or B mix). Similarly, 2 in. (50 mm) of F-mix would be placed on 2 in. (50 mm) of B-mix. For all mix types, one asphalt type, a PBA-5, was used.

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

2.2 Materials

2.2.1 Asphalt Cement

For all test slabs, a Chevron PBA-5 was used. Three batches of binders were obtained from the Chevron Willbridge Refinery in Portland, Oregon. The first batch (30 gal. (114 L)) was obtained on June 23, 1992, the second batch (15 gal. (57 L)) in September 1992, and the third batch in June of 1993. The properties of each batch are summarized in Table 2.2.

Temperature-viscosity curves for each of the batches are summarized in Figure 2.1. These curves were used to establish the following mixing and compaction temperatures based on the Asphalt Institute criteria. (1986):

Mix Type	Mixing Temperature °F (°C)	Compaction Temperature °F (° C)
A	318 (159)	266 (130)
B	318 (159)	266 (130)
C	318 (159)	266 (130)
E	261 (127)	248 (120)
F	261 (127)	248 (120)

Table 2.1. Experiment Design for Rutting Study.

Combination	Surface Mix	Thickness in. (mm)	Base Mix	Thickness in. (mm)
1	A	4 (50)		
2*	B	4 (50)		
3	C	4 (50)		
4*	F	4 (50)		
5	E	1 (25)	B	3 (75)
6	E	1 (25)	A	3 (75)
7	F	2 (50)	B	2 (50)

*For the B and F mix only, two slabs were prepared so that the effect of test temperature (104 and 140 °F (40 and 60°C)) could be evaluated. (A total of 9 slabs/aggregate type.)

Table 2.2. Properties of Chevron PBA-5.*

	Chevron PBA-5 June 23, 1992	Chevron PBA-5 September 4, 1992	Chevron PBA-5 June 4, 1993	Specifications
Original Properties	• Absolute Viscosity (140°F) = 2186 P • Kinematic Viscosity (275°F) = 401 cSt • Flash (COC) °F = 555	• Absolute Viscosity (140°F) = 2141 P • Kinematic Viscosity (275°F) = 405 cSt • Flash (COC) °F = 520	• Absolute Viscosity (140°F) = 2050 P • Kinematic Viscosity (275°F) = 424 cSt • Flash (COC) °F = 545	2000+ 2000- 450+
Aged (RTFO) Properties	• Absolute Viscosity (140°F) = 6158 P • Kinematic Viscosity (275°F) = 614 cSt • Pen @ 39.2°F = 20 dmm • Ductility @ 77°F = 130 cm • Viscosity Ratio = 2.82 • Loss % Weight = .641	• Absolute Viscosity (140°F) = 7304 P • Kinematic Viscosity (275°F) = 675 cSt • Pen @ 39.2°F = 22 dmm • Ductility @ 77°F = 150 cm • Viscosity Ratio = 3.41 • Loss % Weight = .940	• Absolute Viscosity (140°F) = 5982 P • Kinematic Viscosity (275°F) = 710 cSt • Pen @ 39.2°F = 18 dmm • Ductility @ 77°F = 114 cm • Viscosity Ratio = 3.0 • Loss % Weight = .28	4000+ 400+ 15+ 50+ 4.0- -

*Data provided by Chevron USA.

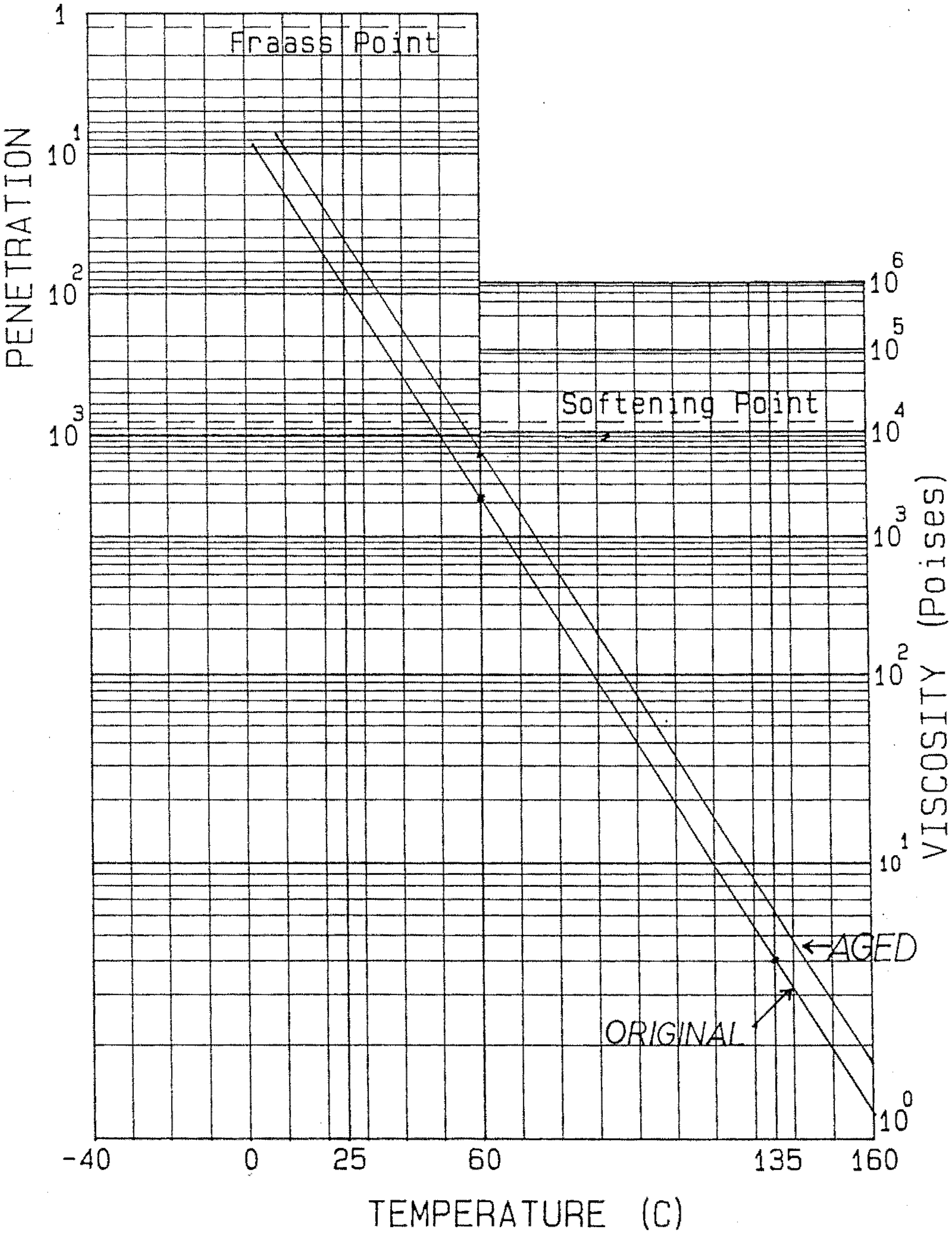


Figure 2.1. Temperature Viscosity Curves for PBA-5.

2.2.2 Aggregates

Two aggregates were used for this study as follows:

1) **Riverbend**, a gravel source with low fracture (within specification), this aggregate was obtained from Salem, Oregon. Properties of the aggregate are given in Table 2.3. To make the A-mix, 1½ - ¾ in. (38 - 17 mm) material was obtained from a nearby source (Reed pit). Properties of this material are given in Table 2.4.

2) **Cake-Pit** is a 100% crushed quarry stone from near Bend, Oregon. Properties of this aggregate are given in Table 2.5.

2.3 Job-Mix Formula

All mix designs were obtained from the ODOT Materials Laboratory in Salem, Oregon. Mix designs were developed following ODOT standard procedures (Quinn et al., 1987).

Summaries of the job-mix formulas for both aggregates are given in Tables 2.6 and 2.7. This includes the following: aggregate gradation, asphalt content, and design Rice specific gravity.

Table 2.3. Properties of the River Bend Aggregate.

Property		Coarse	Fine
Sand Equivalent (ODOT TM 101)		NA*	82
Specific Gravity and Absorption (ODOT 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 (ODOT TM 206)	Coarse	1.1	NA
	Fine	NA	2.0
LA Abrasion (ODOT TM 211)	Grading	B	NA
	% Wear	15	NA
Average Fracture (ODOT TM 213) (%)		97**	100

*Not available

**Detailed fracture data:

Sieve Size	% Fracture
¾ in.	85
½ in.	98
⅜ in.	98
¼ in.	98
#4	100

Table 2.4. Properties of 1½ to ¾ Material from Reed Pit.

Property		Coarse
Sand Equivalent (ODOT TM 101)		NA*
Specific Gravity and Absorption (ODOT TM 203)	Bulk	2.61
	Apparent	2.73
	SSD	2.65
	Absorption (%)	1.59
Sodium Sulfate Soundness (ODOT TM 206)	Coarse	2.3
LA Abrasion (ODOT TM 211)	Grading	A
	% Wear	15.6
Fracture (ODOT TM 213) (%)		79**

*Not available

**Detailed fracture data:

Sieve Size	% Fracture
1½ in.	73
1 in.	60
¾ in.	84
½ in.	95
⅜ in.	100
¼ in.	100

Table 2.5. Properties of Cake-Pit Aggregate.

Property		Coarse	Fine
Sand Equivalent (ODOT TM 101)		NA*	81
Specific Gravity and Absorption (ODOT TM 203)	Bulk	2.69	2.56
	Apparent	2.83	2.83
	SSD	2.74	2.65
	Absorption (%)	1.81	3.71
Sodium Sulfate Soundness (ODOT TM 206)	Coarse	1.2	NA
	Fine	NA	2.6
LA Abrasion (ODOT TM 211)	Grading	B	NA
	% Wear	12.6	NA
Fracture (ODOT TM 213) (%)		100	100

*Not available

Table 2.6. Riverbend Mix Designs.

Size	% Passing for each mix						
	A	B-Single Mix	B-Layered	C	E-Layered	F-Single Mix	F-Layered
1½	100						
1¼	97.9						
1	87.0	100	100			100	100
¾	79.1	97.0	97.0	100	100	91.5	90.4
½	64.5	85.3	85.4	98.2	95.2	69.9	67.7
⅜	56.0	75.1	74.9	80.1	69.6	41.8	42.3
¼	47.4	61.7	61.9	61.4	38.8	24.6	24.1
10	25.0	28.3	29.0	30.8	9.4	13.6	13.9
40	11.5	12.2	12.2	13.3	4.5	6.3	6.6
200	5.0	5.1	5.4	5.2	2.1	3.6	3.9
AC % of total mix	5.8	5.5		5.8	6.5	6.0	
Rice Specific Gravity	2.463	2.467		2.455	2.429	2.456	

Table 2.7. Cake-Pit Mix Designs.

Size	% Passing for each mix							
	A	B-Single Mix	B-Layered*	C	E-Layered	F-Single Mix	F-Layered	B-BEQ
1½	100							
1¼	98.2							
1	90.1	100	100			100	100	100
¾	79.1	94.7	97.4	100	100	91.3	92.8	97.0
½	68.0	80.4	81.4	97.9	96.6	66.8	67.7	81.5
⅜	61.9	68.0	69.0	80.9	67.9	43.4	44.1	68.2
¼	51.6	56.8	57.1	58.4	36.4	26.0	26.3	56.2
10	31.1	27.3	28.2	31.7	18.2	11.6	12.2	27.2
40	10.4	12.1	12.0	12.5	7.5	5.8	6.5	11.2
200	4.4	5.3	5.4	4.5	3.2	3.4	4.0	4.4
AC % of total mix	6.2	5.8		6.5	7.0	6.5		5.8
Rice Specific Gravity	2.493	2.505		2.481	**	2.455		2.505

*This gradation used for the BFQ (B-mix base, F-mix lift, quarry rock aggregate) base only. It replaced the gradation used for the base of the BEQ (B-mix base, E-mix lift, quarry rock aggregate) slab.

**No Rice was specified by ODOT for this mix.

3.0 SPECIMEN PREPARATION

This chapter describes the procedures used to prepare the specimens, as well as selected properties (gravities, voids) of the test samples.

3.1 Procedure

Specimen preparation for this research effort was accomplished by means of rolling wheel compaction. The procedure is outlined in detail in Appendix A. The procedure was developed at OSU for the purpose of preparing specimens for a previous study (see Table 3.1). The method proved to be very effective and was retained for the 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. An attempt to cure an open-graded mix in the same manner resulted in substantial asphalt run-off. This problem was alleviated by curing the open-graded mixes at 140°F (60°C) for 15 hrs.

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: a 2 in. (50 mm) base and 2 in. (50 mm) lift or a 3 in. (75 mm) base with a 1 in. (25 mm) lift as well as a 4 in. (100 mm) single-mix slab. The compacted slab was then allowed to cool overnight (about 24 hrs).

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 ranged between 60 lb (.3 kN) for a 1 in. lift and 210 lb (.9 kN) for a 4 in. (100 mm) slab.
2	Prepare the asphalt and aggregate for mixing.
3	Heat the materials to the mixing temperature, 318°F (159°C) for the dense-graded mixes and 261°F (127°C) 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 275°F (135°C) in a forced-draft oven for 4 hrs stirring the mix every hour. Age the open-graded mix for 15 hrs at 140°F (60°C). 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 was 266°F (130°C) for the dense-graded mixes, and 248°F (120°C) for the open-graded mixes.
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 UCB shear study.

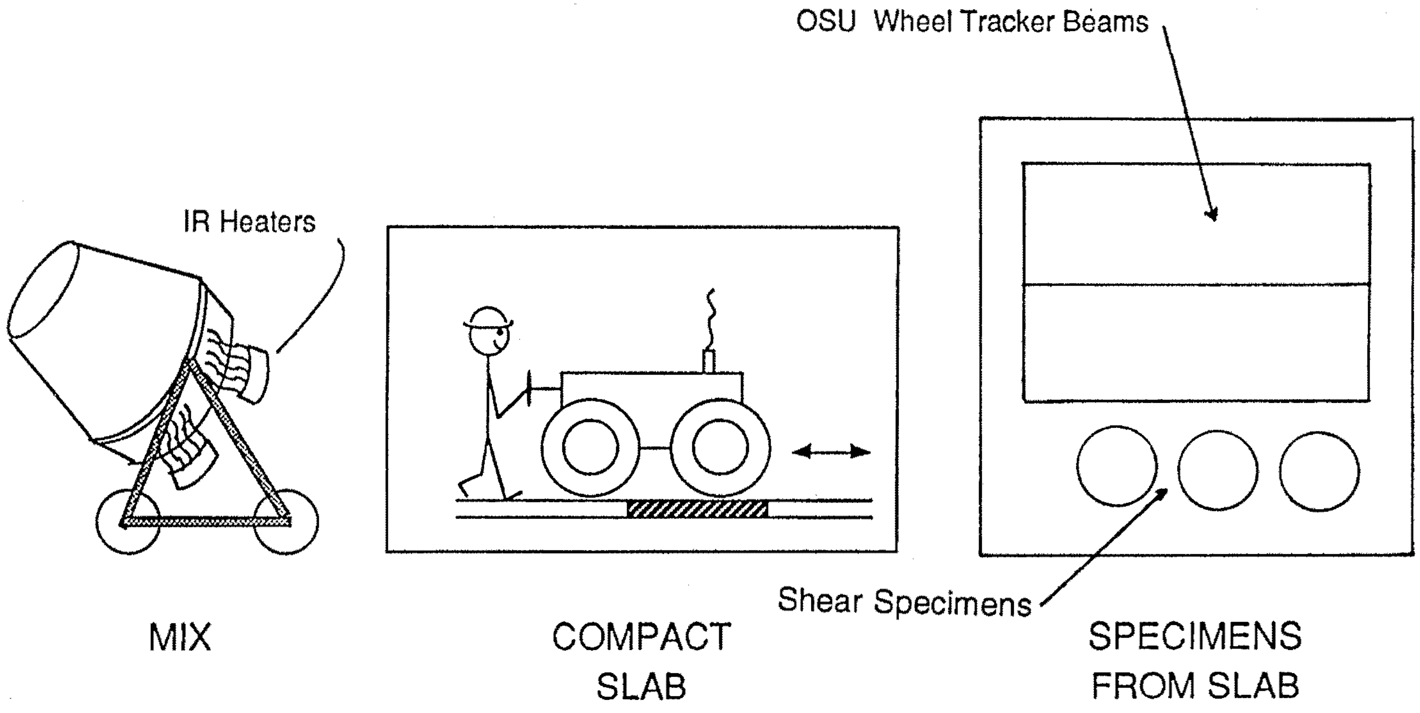


Figure 3.1. Mixing, Compaction and Sampling Process.

Figure 3.2. Photo of Mixer.

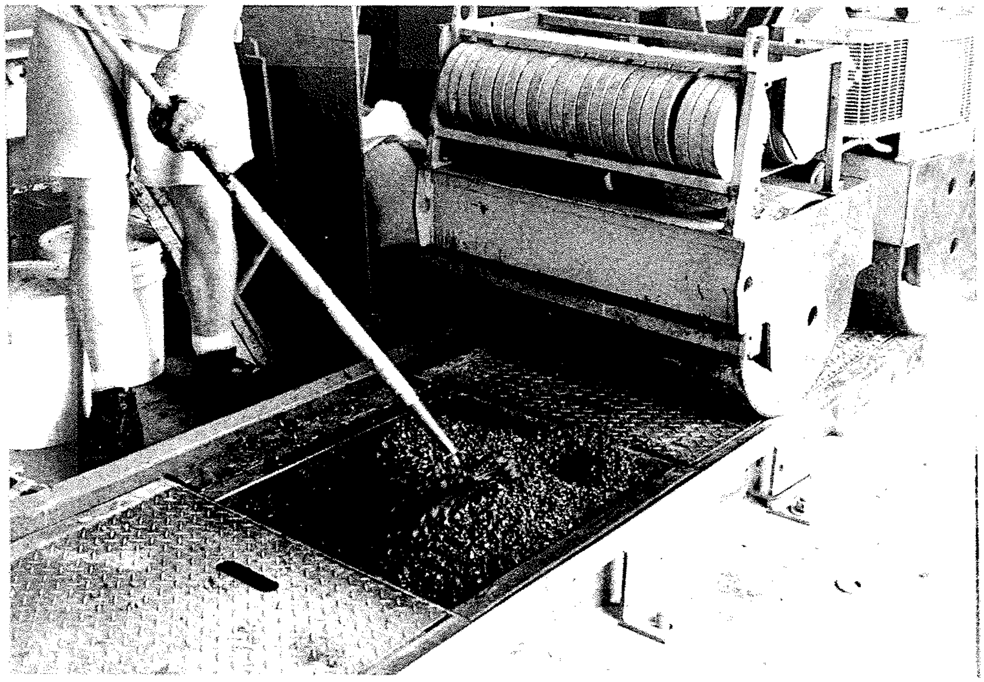


Figure 3.3. Photo of Compaction Process.

To eliminate the effects of possible uneven compaction at the edge of the slab, approximately 1 in. (25 mm) of material was trimmed off before the rutting specimens were extracted.

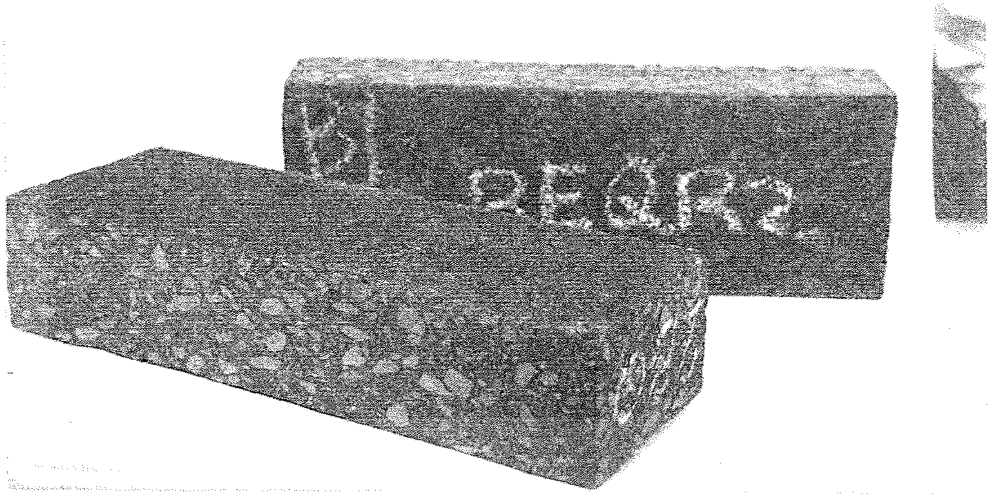
3.1.3 Cutting

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, 29¼ in. × 6⅝ in. × 4 in. (743 mm × 168 mm × 100 mm) were cut from the slab. Two were used in the wheel tracking device; cores were extracted from the third for use in the shear device (see Figure 3.4). The 6 in. (150 mm) cores were also trimmed top and bottom to eliminate any edge effects.

3.2 Void Determination

3.2.1 Procedure

The air voids were determined through a ratio of the bulk and Rice 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 initial slabs were made, the void content of the rutting beams was determined using both the SSD and parafilm bulking methods. The two methods yielded markedly 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 accurate measurements on an open-graded specimen. Unless otherwise noted in the Tables 3.2 to 3.4, the Rice gravity was determined by averaging the values from replicate specimens.



a) Wheel Tracker Beams

b) Simple Shear Cylinders

Figure 3.4. Photos of Resulting Samples.

Table 3.2. Void Summary for Riverbend Slabs.

Mix	I.D.	Avg. Rice/ # of Samples Averaged	Asphalt Content (%)	Bulk Gravities		Voids	
				SSD	PF	SSD	PF
A	1AGR1	2.456/3	5.8	2.309	2.255	6.0	8.2
	1AGR2	2.456/3	5.8	2.299	2.233	6.4	9.1
B	2BGR1	2.459*	5.5	2.273	2.220	7.6	9.7
	2BGR2	2.459*	5.5	2.260	2.206	8.1	10.3
	2BGR3	2.459*	5.5	2.255	2.200	8.3	10.5
	2BGR3	2.459*	5.5	2.257	2.189	8.2	11.0
	2BGR5	2.459/3	5.5	2.248	2.173	8.6	11.6
	2BGR6	2.459/3	5.5	2.261	2.173	8.1	11.6
C	3CGR1	2.449/2	5.8	2.224	2.154	9.2	12.0
	3CGR2	2.449/2	5.8	2.224	2.154	9.2	12.3
F	4FGR1	2.453/2	6.0	--	2.000	--	18.5
	4FGR2	2.453/2	6.0	--	2.065	--	15.8
	4FGR3	2.453*	6.0	--	1.998	--	18.5
	4FGR4	2.453*	6.0	--	1.982	--	19.2

*Based on one sample.

Table 3.3. Void Summary for Cake-Pit Slabs.

Mix	I.D.	Rice Gravity*	Asphalt Content (%)	Bulk Gravities		Voids	
				SSD	PF	SSD	PF
A	1AQR1	2.485	6.2	2.273	2.207	8.5	11.2
	1AQR2	2.485	6.2	2.275	2.214	8.4	10.9
B	2BQR1	2.522	5.8	2.277	2.227	9.7	11.7
	2BQR2	2.522	5.8	2.282	2.231	9.5	11.5
	2BQR3	2.522	5.8	2.340	2.301	7.2	8.8
	2BQR3	2.522	5.8	2.328	2.283	7.7	9.5
	2BQR5	2.522	5.8	2.315	2.268	8.2	10.1
	2BQR6	2.522	5.8	2.309	2.251	8.4	10.8
C	3CQR1	2.483	6.5	2.290	2.228	7.8	10.3
	3CQR2	2.483	6.5	2.291	2.247	7.7	9.5
F	4FQR1	2.505	6.5	--	1.982	--	20.8
	4FQR2	2.505	6.5	--	1.979	--	21.0
	4FQR3	2.505	6.5	--	2.061	--	17.7
	4FQR4	2.505	6.5	--	2.070	--	17.4

*Based on one sample.

Table 3.4. Void Summary for Layered Slabs.

Mix (Base/Lift)	I.D.[a]	Avg. Rice (Base/Lift)	No. of Rices Averaged (Base/Lift)	Bulk Gravities		Voids		A.C. Base/Lift
				Base (SSD)	Lift[b] (Parafilm)	Base	Lift	
A/E	6AEGR3	2.467/2.438	2/2	2.297	2.053	6.9	15.8	5.8/6.5
	6AEGR4	2.467/2.438	2/2	2.308	--	6.4	--	5.8/6.5
	6AEQR1	2.455/2.480	1/1	2.272	2.000	7.5	19.4	6.2/7.0
	6AEQR2	2.455/2.480	1/1	2.269	--	7.6	--	6.2/7.0
B/E	5BEGR1	2.430/2.373	2/2	2.235	2.019	8.0	14.9	5.5/6.5
	5BEGR2	2.430/2.373	2/2	2.347	1.992	7.5	16.1	5.5/6.5
	5BEQR1	2.443/2.440	1/1	2.276	2.033	6.8	16.7	5.8/7.0
	5BEQR2	2.443/2.440	1/1	[c]	--	--	--	5.8/7.0
B/F	7BFGR1	2.404/2.425	2/2	2.277	1.976	5.3	18.5	5.5/6.0
	7BFGR2	2.404/2.425	2/2	2.271	1.997	5.5	17.6	5.5/6.0
	7BFQR1	2.463/2.525	1/2	2.323	1.995	5.7	21.0	5.8/6.5
	7BFQR2	2.463/2.525	1/2	2.318	--	5.9	--	5.8/6.5

[a] Bulk gravity and void calculations were not made for the actual rutting beams whose ID numbers appear. To calculate voids for those specimens, a larger slab was made so extra beams could be extracted specifically for void determination. The beams used for void content determination were sawed apart so that bulk gravity could be conducted on the bases and lifts individually.

[b] On a 1 or 2 in. thick specimen (the thickness of the lifts), surface voids can greatly increase the apparent air voids as calculated with the parafilm bulking method. For this reason, some specimens with excessive surface voids were not tested. As a result, for some beam types (e.g. the 6AEGR beams), there is only one value for lift void content rather than two.

[c] Only one extra beam was made for this slab for void determination.

3.2.2 Results

Summaries of the voids for all mixes are given in Tables 3.2 to 3.4. Target air voids were 8% for all dense-graded specimens, 15% for all E-mix specimens, and 17.5% for all F-mix specimens. A few slabs were redone due to low air voids. The air voids of accepted specimens ranged from 6.0% to 9.2% for all dense-graded single-mix specimens. Those on the dense-graded bases of layered specimens ranged from 5.3% to 8.0%. E-mix voids ranged from 14.9% to 19.4% and F-mix voids ranged from 18.5% to 21.0%.

3.3 Storage and Labeling

The beams were then 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 and layered cores are wrapped in metal sheeting to prevent them from falling apart during storage.

All the specimens were then labeled for identification. A unique five or six symbol code was designated for each specimen. The first two or three symbols indicate the mix type. The next digit denotes the type of aggregate used. The next digit designates if the specimen was for rutting or simple shear. The last digit represents a sequence number for the specimens. For example the label, 1AQR1, designates a class A mix made from the quarry rock for the rutting test and was the first specimen made.

4.0 LCPC TEST RESULTS

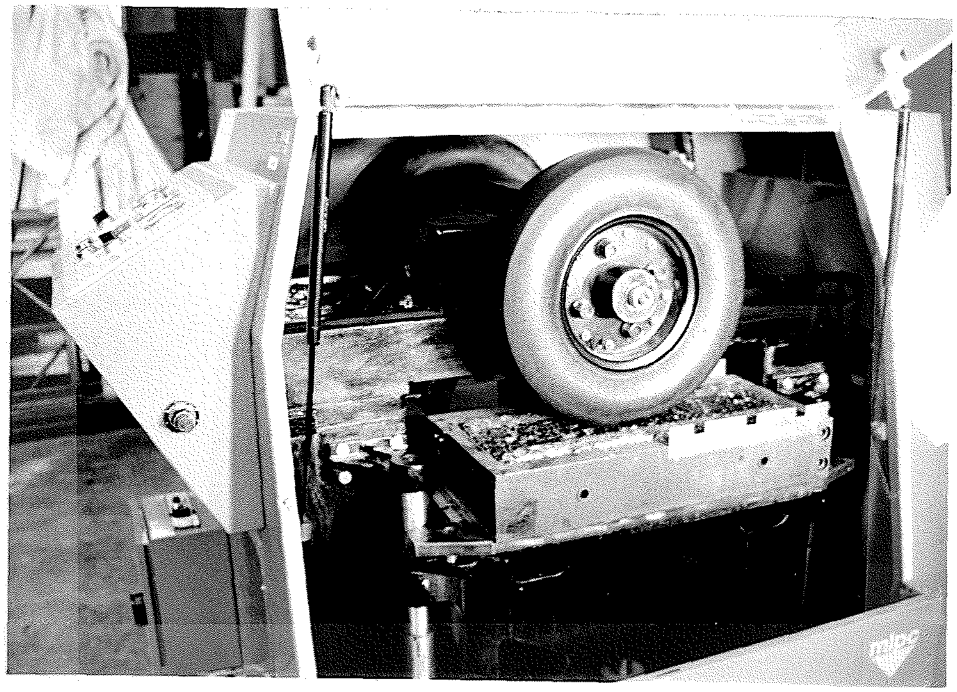
This chapter addresses procedural aspects of the LCPC wheel track testing and the influence of mix test conditions (temperature, confinement) and mix parameters (mix type, aggregate type) on the test results. Furthermore, an evaluation of the ODOT mixes is made with respect to the LCPC rutting criteria.

4.1 Procedure

After compaction, cutting, and void content determination, the slabs were ready for testing in the OSU-LCPC rutting testing machine (Figure 4.1). The day before the test was performed, the test specimen was loaded into the molds used to hold the specimen during the test. Thin sheets of expanded foam were placed between the specimen and the mold to prevent movement of the beam specimen under the action of the rolling wheel. Similarly, a ⅛-in. (3 mm) thick piece of teflon sheeting, the same size as the specimen, was placed between the specimen and the wheel tracker platen to provide a frictionless surface. The mold-specimen assembly was then placed into the machine and bolted down. The testing machine was then set to the test temperature for a minimum of 12 hours to ensure temperature equilibrium.

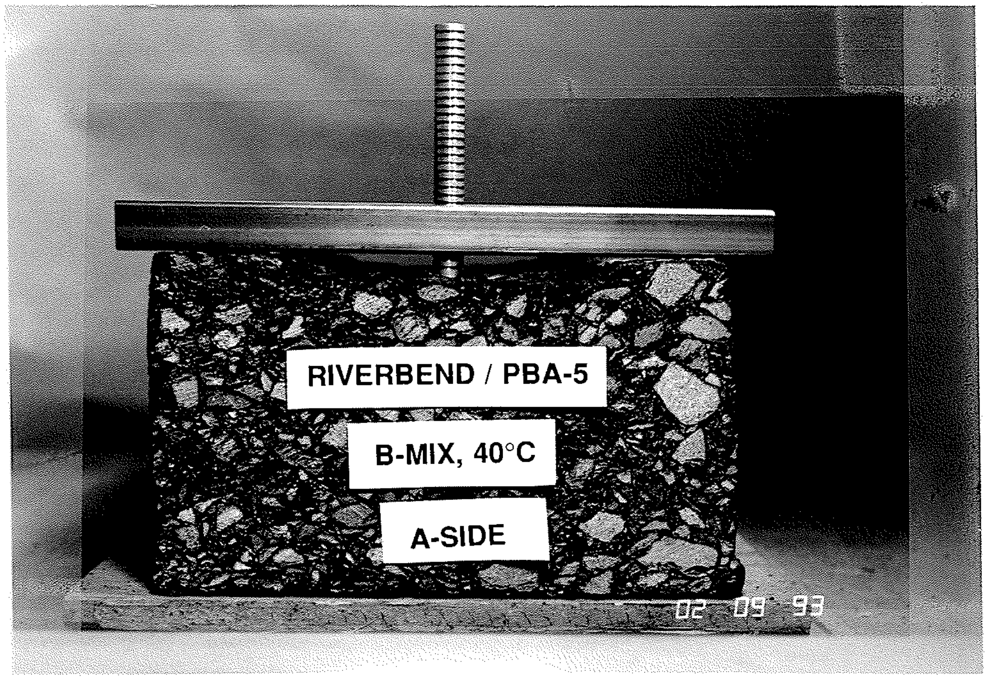
Prior to testing, talcum powder was spread over the top of the specimen to prevent particles from the top of the specimen from sticking to the wheel. At this point, 50 preconditioning wheel passes were applied to the specimen. The specimen was preconditioned to eliminate the high plastic deformation characteristics of asphalt-aggregate mixes at the onset of loading. After the preconditioning wheel passes, measurements were made on the specimen with the electronic displacement transducer developed at OSU. These initial data were recorded by a personal computer and used as a zero determination for the subsequent readings. Subsequent deformation measurements were made at 100, 200, 500, 1000, 2000, 5000, 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 as Appendix B. Shown in Figure 4.2 are typical specimens after testing.

a) Overview

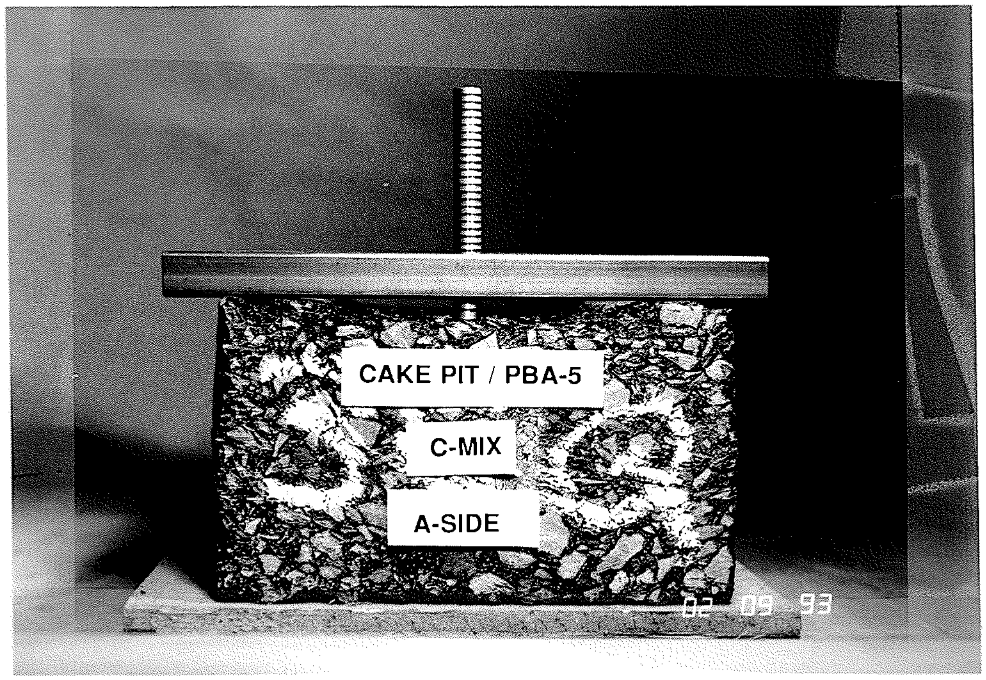


b) Close Up of Specimen

Figure 4.1. Photo of Test Equipment

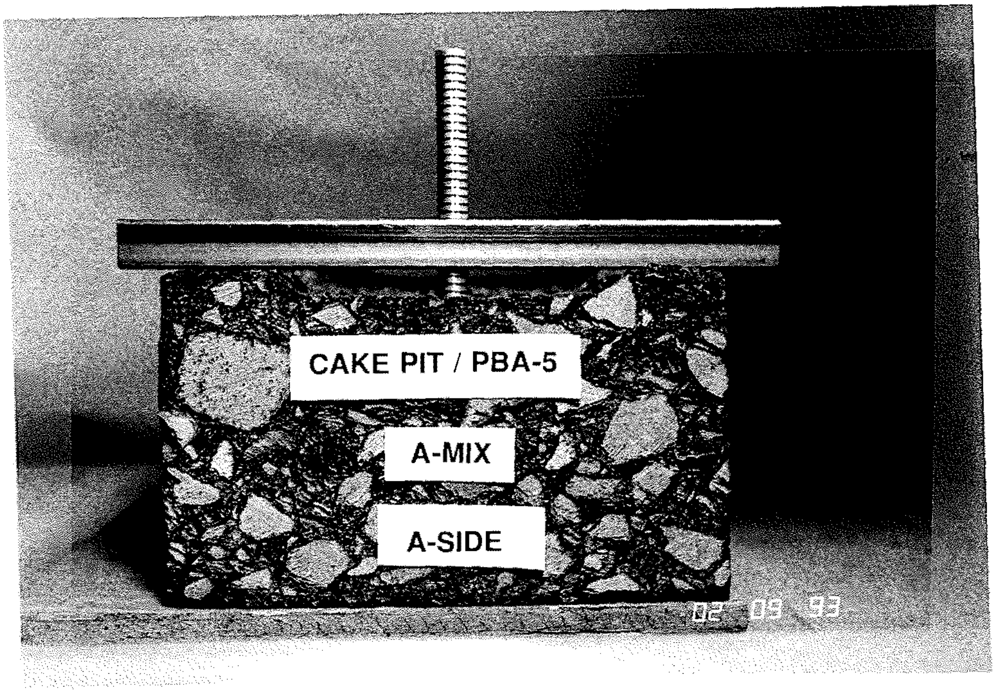


a) B-Mix

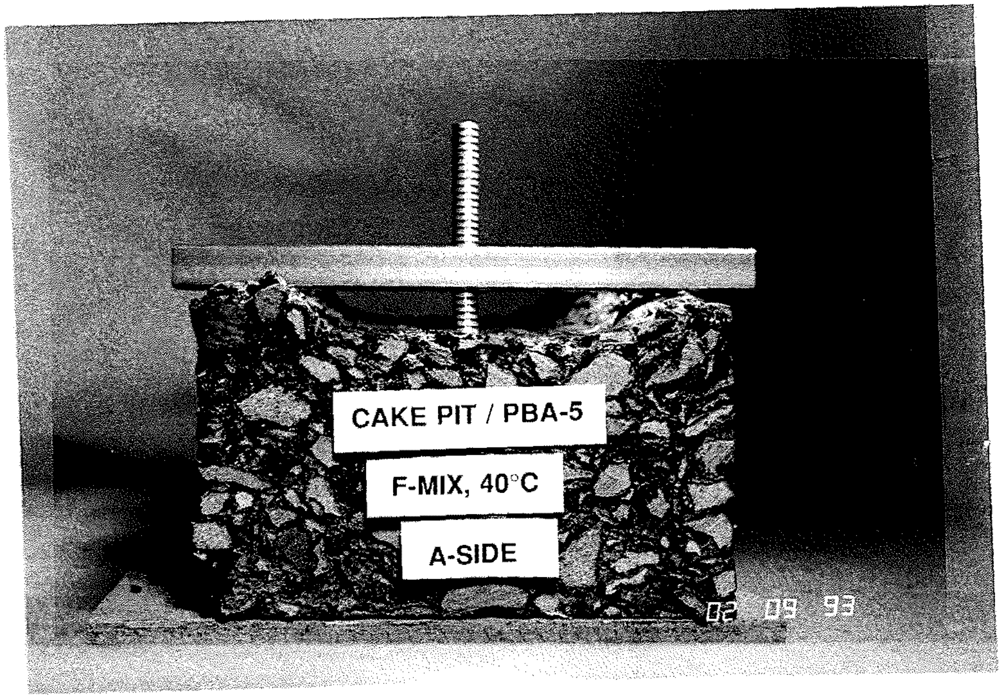


b) C-Mix

Figure 4.2. Typical Specimens after Testing.



c) A-Mix



d) F-Mix

Figure 4.2. Typical Specimens after Testing (continued).

4.2 Test Results

All test results were reported using the format shown in Figure 4.3. The total rut depth consists of three components:

1) **Initial consolidation.** This is due in part to composition of the slab.
2) **Second stage deformation.** This is defined in terms of a rutting potential (rut depth per 1000 wheel passes).
3) **Third stage deformation.** This is associated with the failure of the mix.

A comparison of the results for the replicate samples indicates that the repeatability of the test is very good. The largest difference between rut depth at 50,000 wheel passes for duplicate specimens was 0.05 inches (1.3 mm); the average difference in rut depth between duplicate specimens was only 0.026 inches (0.7 mm). Table 4.1 summarizes the average rut depth and rut potential for each of the mix types.

Test results are summarized in Figures 4.4 to 4.11. Two samples were tested for each mix type and for each type of aggregate. All test data are given in Appendix C.

4.3 Discussion of Results

- **Effect of mix type.** The results clearly indicate that mix type influences rut depth and rut potential. The B and C mixes performed the best as measured by both average rut depth at 50,000 wheel passes and average rut potential. The large stone A-mix also performed well, with slightly larger values for rut depth and rut potential. This is likely due to the low amount of ¾ in. (17 mm) maximum material in the mix. The open-graded F-mix did not perform well despite its success in the field. When this project was started, a target void level of 17 to 20% was the target for the F-mix slabs. It was later discovered that actual field voids for an F-mix section were more on the order of 12 to 15%. Due to the fact that the F-mix voids in the lab specimens were not representative of the field voids of a typical F-mix, the results obtained in the LCPC and the simple shear test do not match the field performance of the in situ sections. It is shown in

41

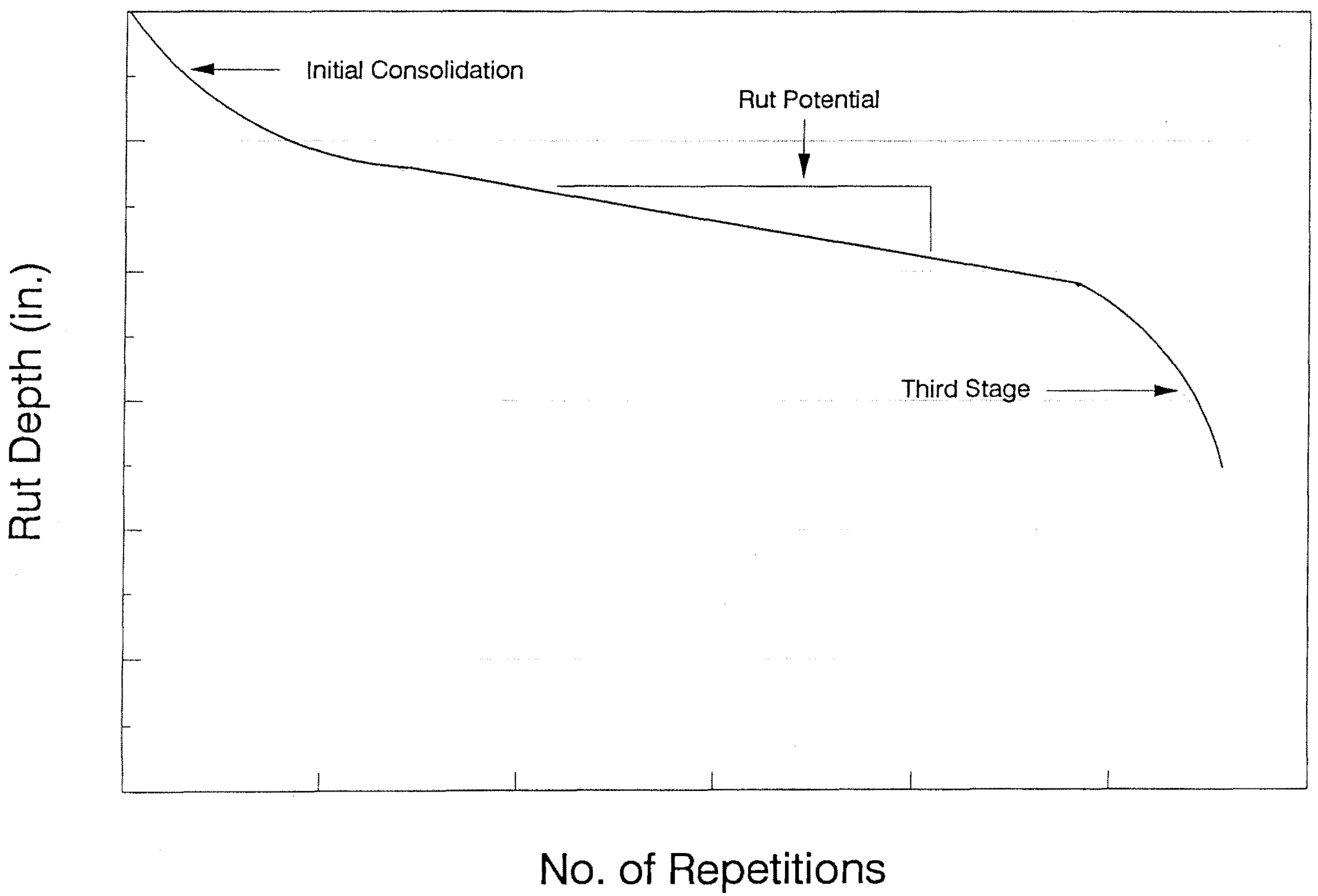


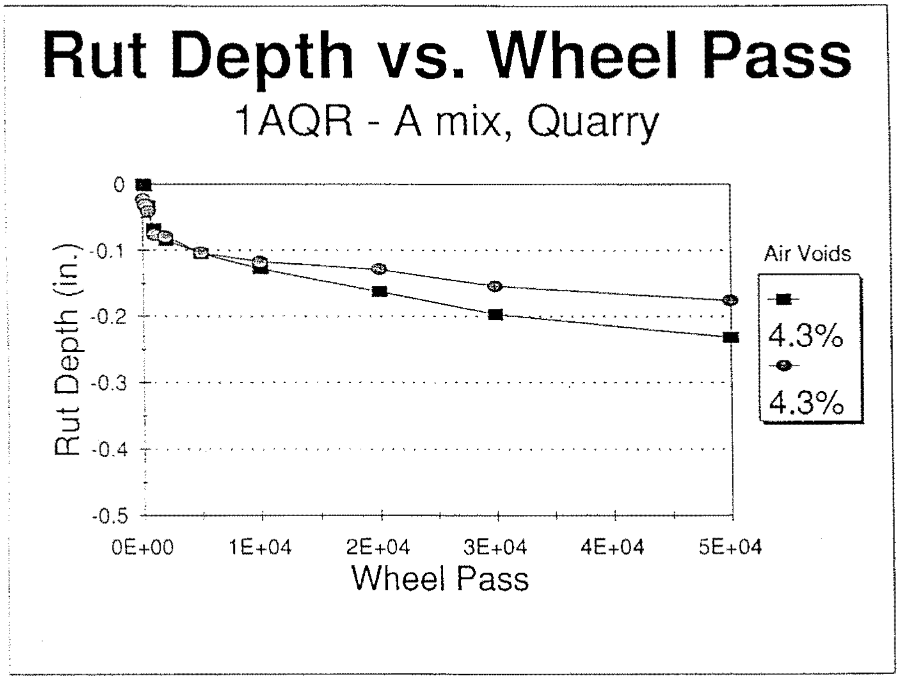
Figure 4.3. Reporting Format for Wheel Tracking Data.

Table 4.1. Summary of LCPC Test Results.

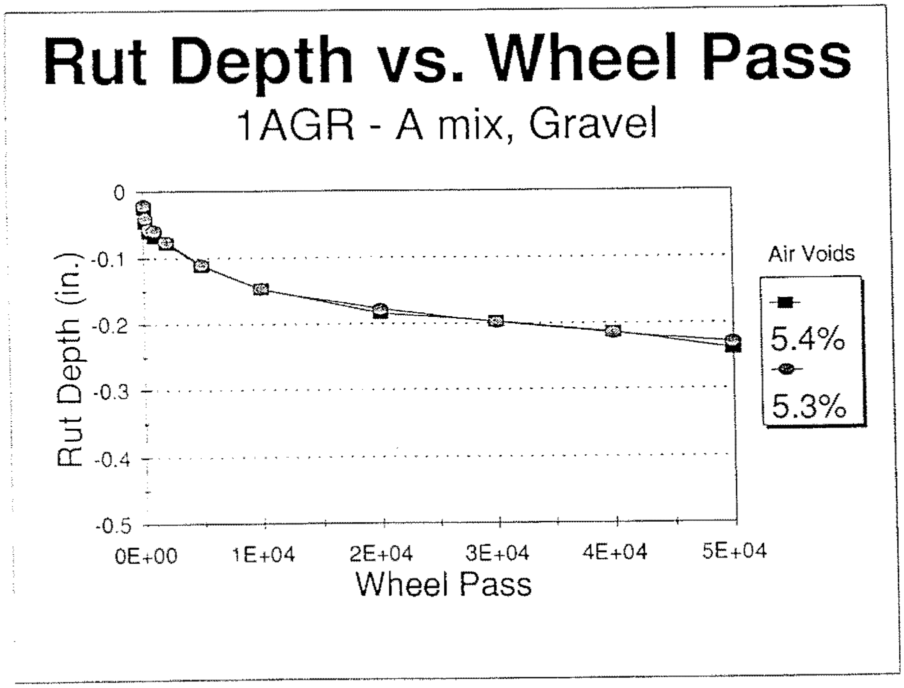
Mix Type	Average Rut Depth @ 50,000 reps (in.)		Average Rut Potential* ($\times 10^{-6}$)	
	Gravel	Quarry	Gravel	Quarry
A-40	0.23	0.20	2.2	2.0
B-40	0.18	0.19	1.3	1.4
B-60	0.38	0.28	3.62	2.47
C-40	0.19	0.21	1.4	1.58
F-40	0.48	0.44	6.46	3.42
F-60	0.61	0.77 @ 5000 reps	5.52	47.0
BE-40	0.27	0.29	1.98	2.80
AE-40	0.28	0.38	2.48	2.75
BF-40	0.22	0.32	1.25	2.07
F-40 (low void foam)	0.199	0.23	1.47	1.0
F-40 (plaster)	0.03	0.11	0.2	0.62

1 inch = 25.4 mm

$$* \quad \frac{\text{Rut depth @ 50,000 wheel passes} - \text{Rut depth @ 10,000 wheel passes}}{50{,}000 - 10{,}000}$$

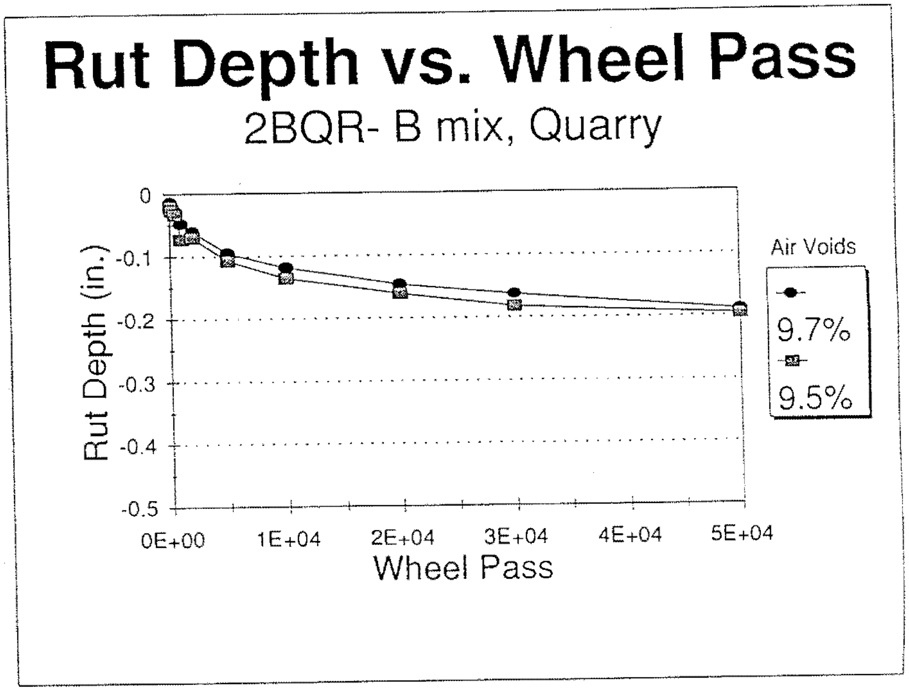


a) Quarry

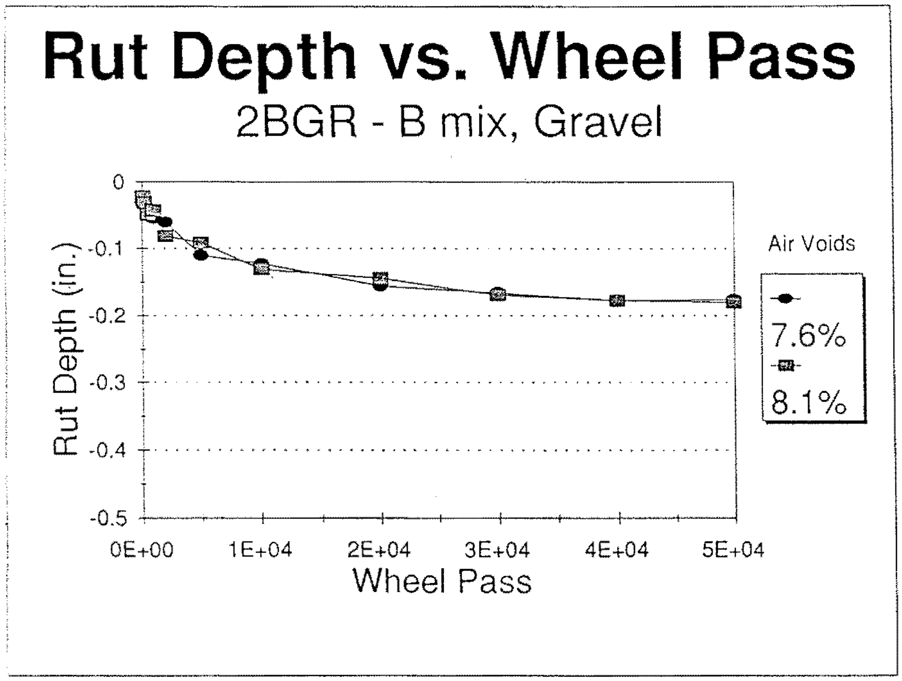


b) Gravel

Figure 4.4. Rut Depth vs. Number of Repetitions for A-Mix (40°C).

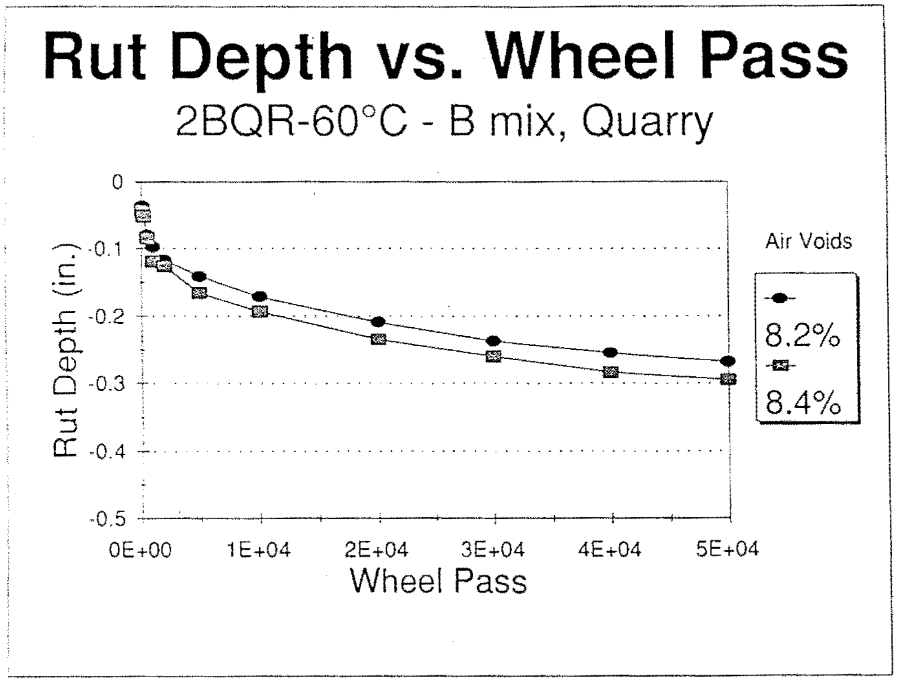


a) Quarry

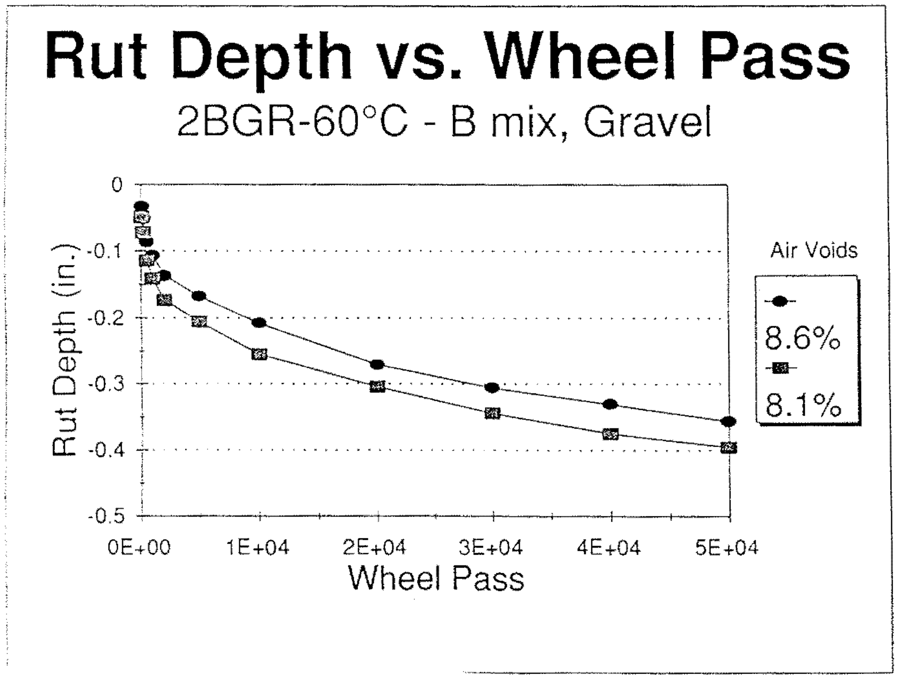


b) Gravel

Figure 4.5. Rut Depth vs. Number of Repetitions for B-Mix (40°C).

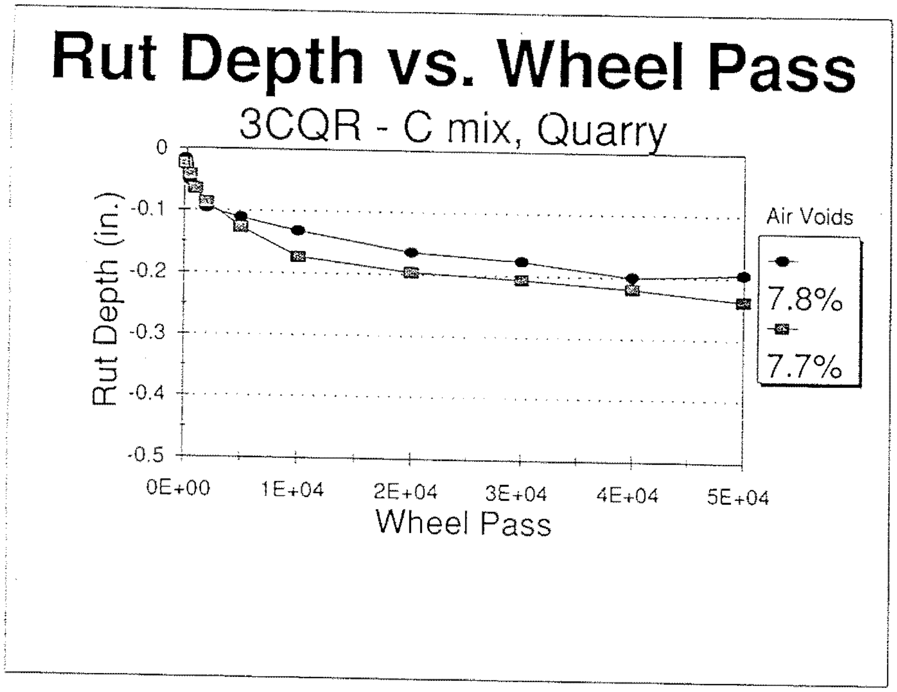


a) Quarry

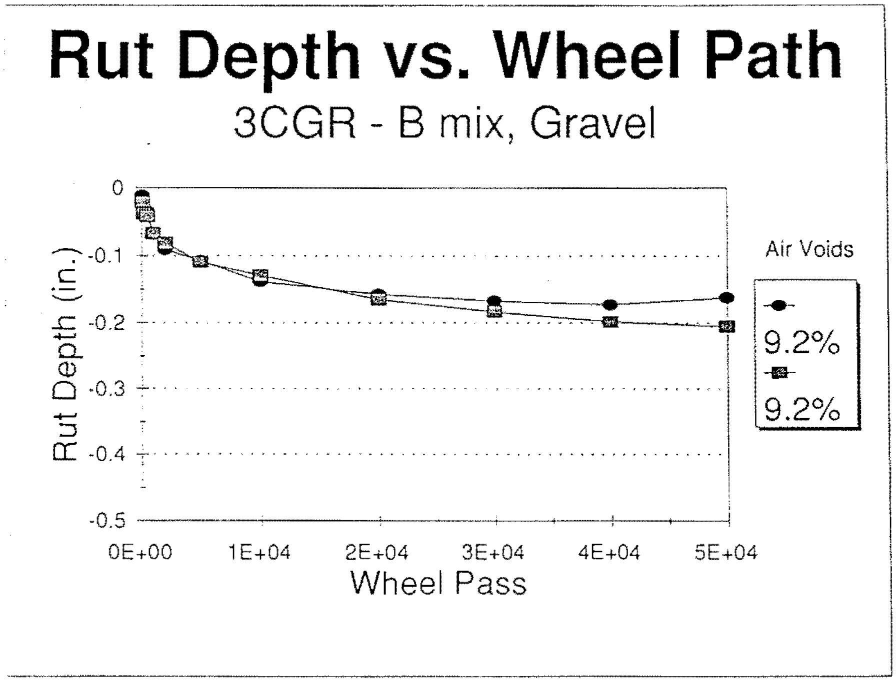


b) Gravel

Figure 4.6. Rut Depth vs. Number of Repetitions for B-Mix (60°C).

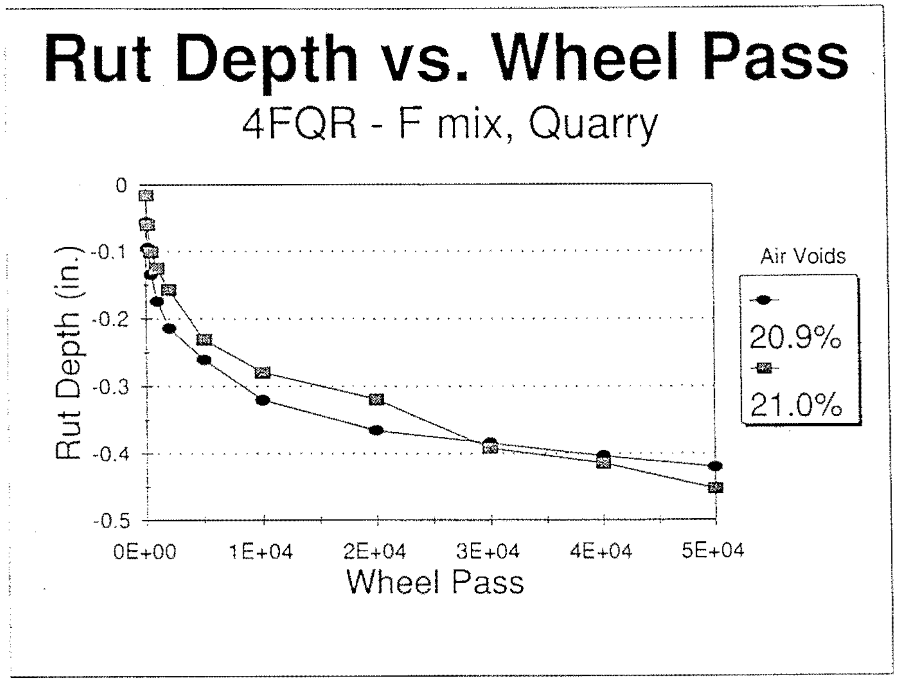


a) Quarry

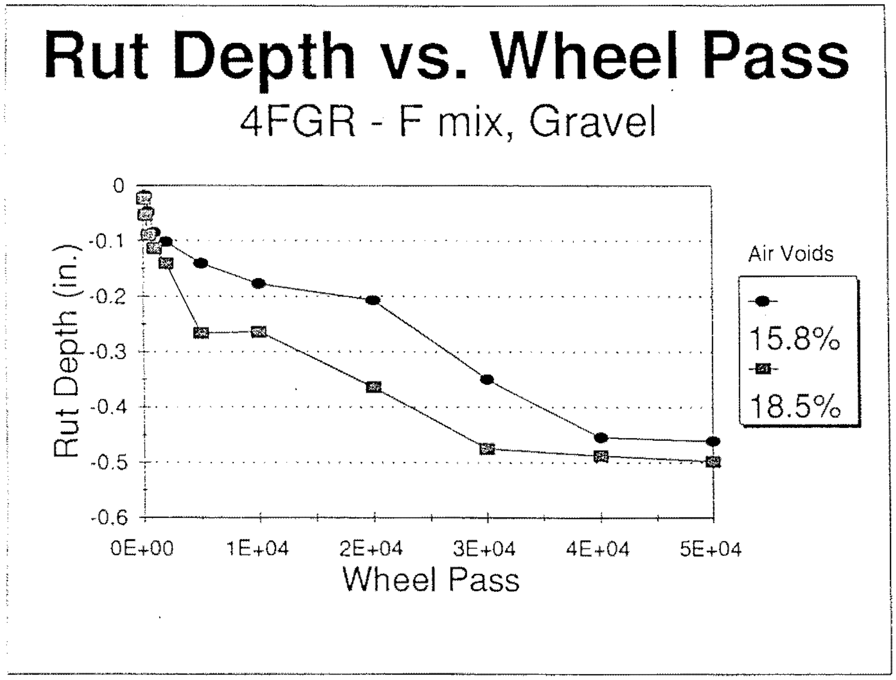


b) Gravel

Figure 4.7. Rut Depth vs. Number of Repetitions for C-Mix (40°C).

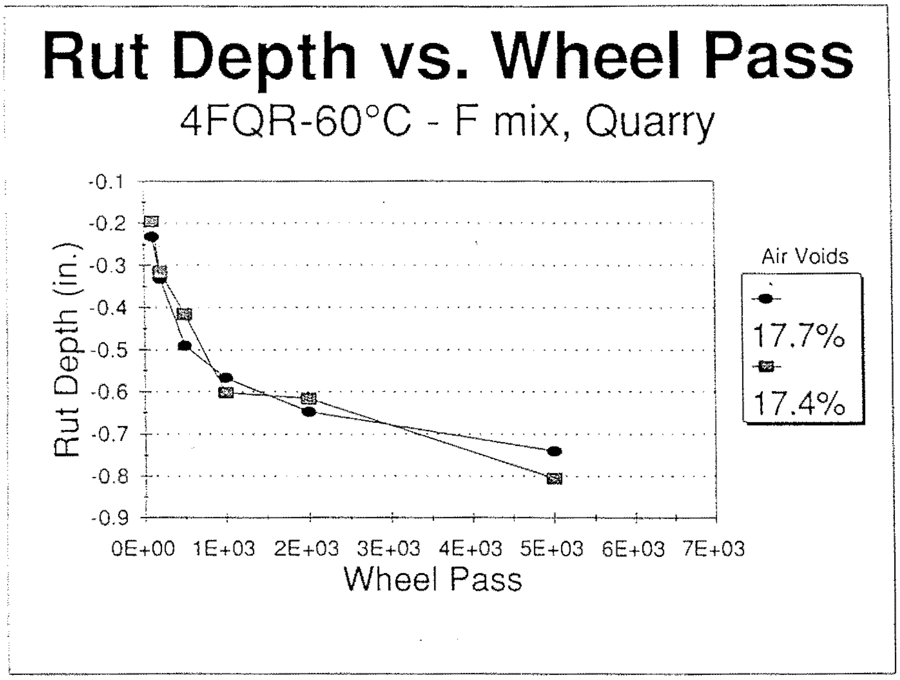


a) Quarry

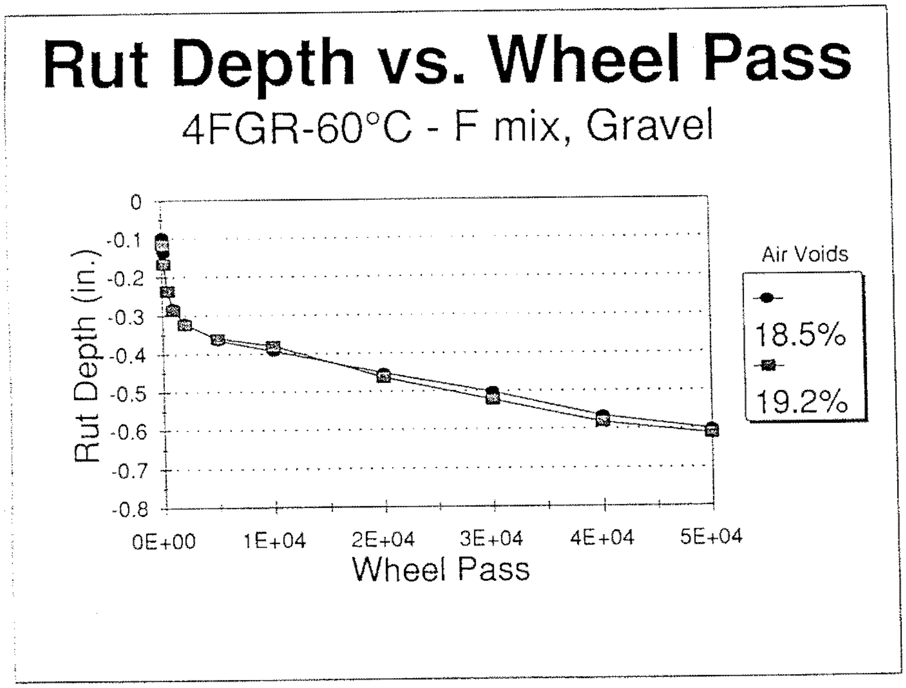


b) Gravel

Figure 4.8. Rut Depth vs. Number of Repetitions for F-Mix (40°C).

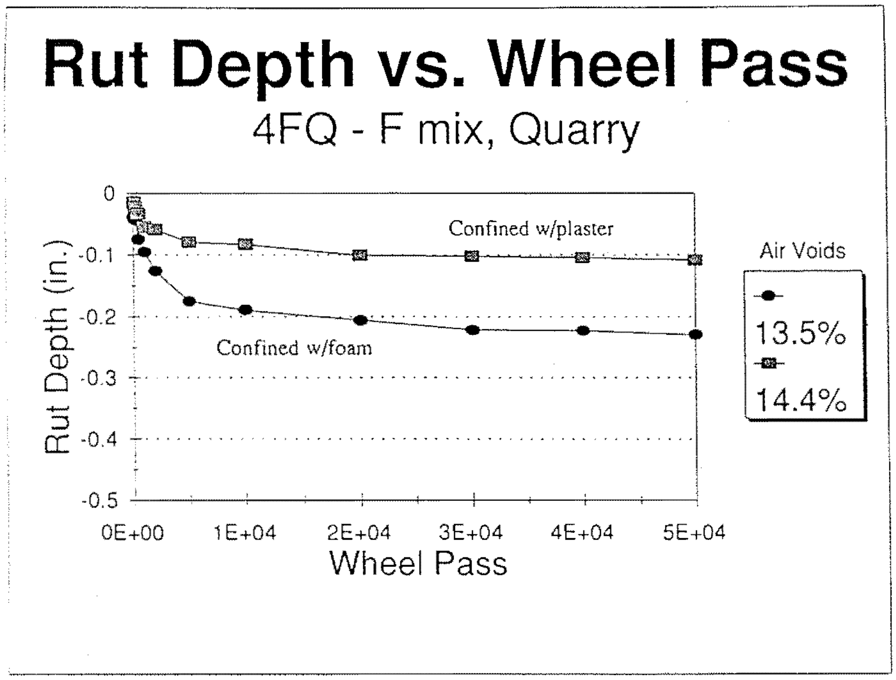


a) Quarry

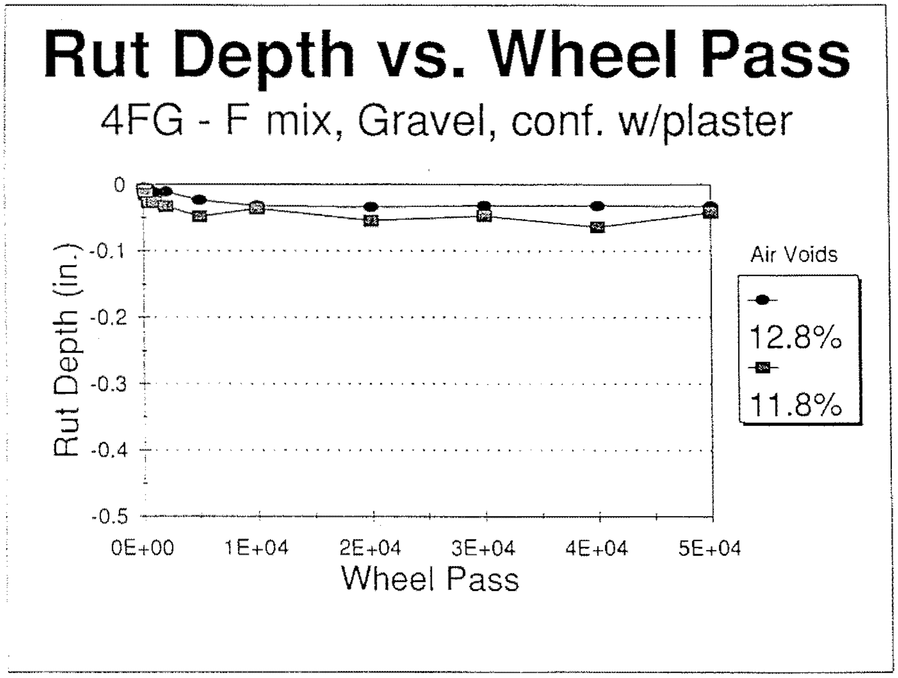


b) Gravel

Figure 4.9. Rut Depth vs. Number of Repetitions for F-Mix (60°C).

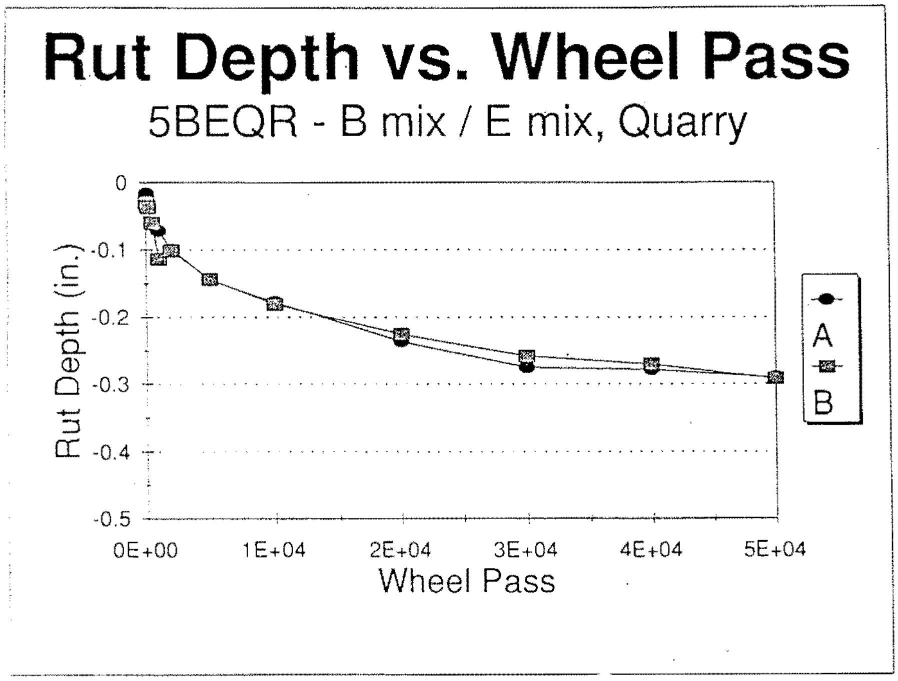


a) Quarry

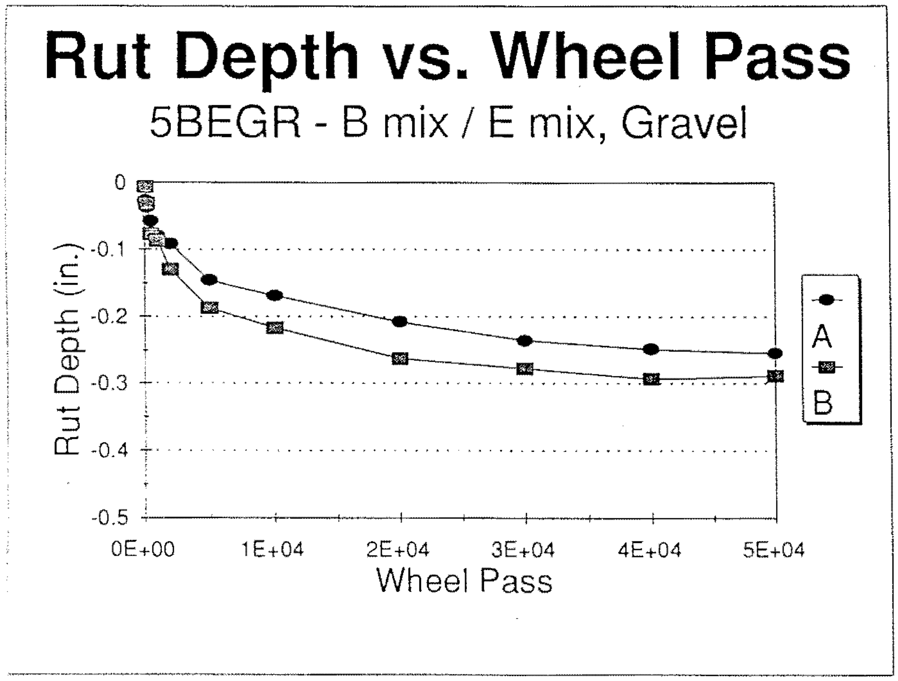


b) Gravel (Confined with plaster)

Figure 4.10. Rut Depth vs. Number of Repetitions for F-Mix (40°C - Low Voids).

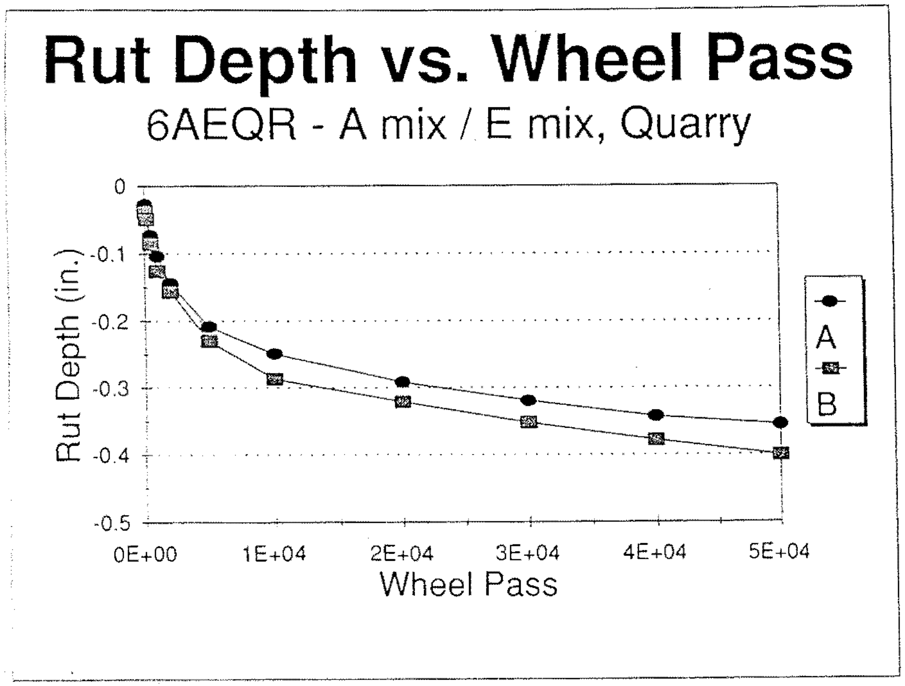


a) B/E - Quarry

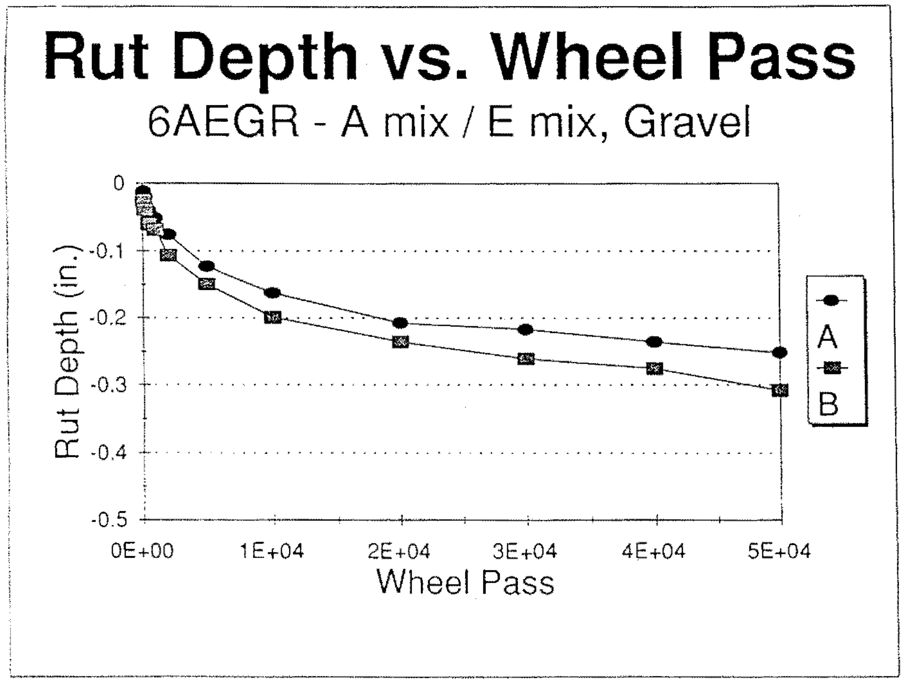


b) B/E - Gravel

Figure 4.11. Rut Depth vs. Number of Repetitions for Layered Mixes.

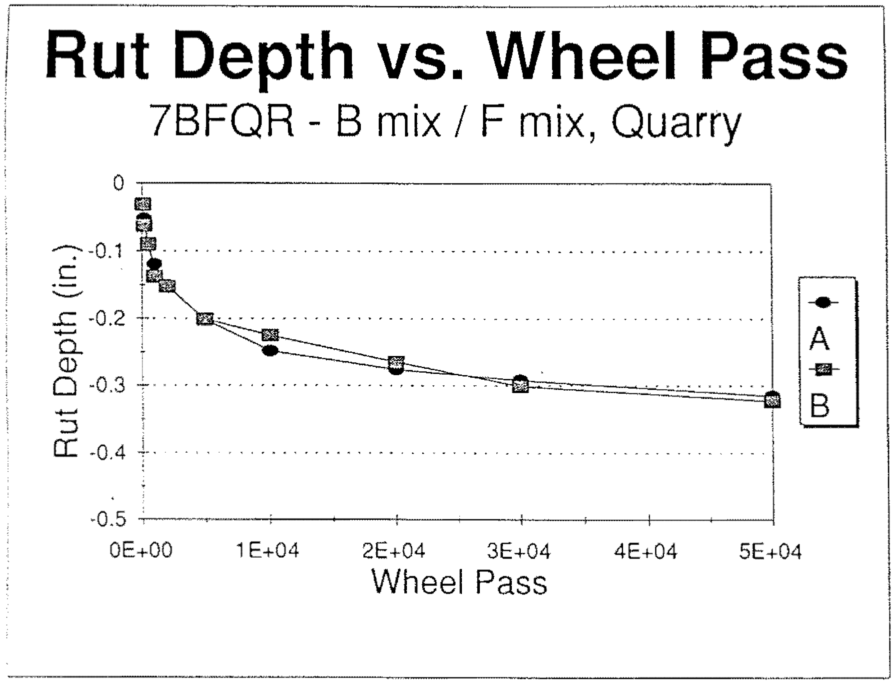


c) A/E - Quarry

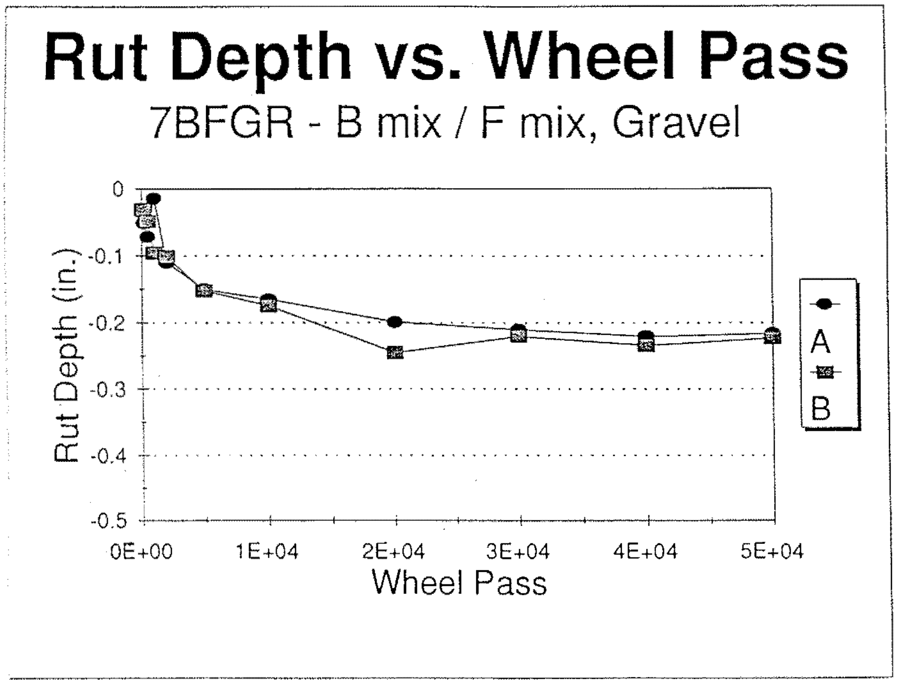


d) A/E - Gravel

Figure 4.11. Rut Depth vs. Number of Repetitions for Layered Mixes (cont.).



e) B/F - Quarry



f) B/F - Gravel

Figure 4.11. Rut Depth vs. Number of Repetitions for Layered Mixes (cont.).

Figure 4.10(a) that when a lower void F-mix is tested with foam confinement the rut depth is more in line with what is expected in relation to field performance. Due to time and material constraints the researchers were unable to remake more of the F-mix specimens at the lower void level.

As shown in Figure 4.12, mix types A, B and C performed comparably at 104 °F (40°C), regardless of aggregate type or air void content. Similar results for average rutting potential are shown in Figure 4.13. Both parameters (average rut depth and rutting potential) indicate that the B mix, when tested at 140 °F (60°C), exhibits more rutting. When the data are normalized to try to account for the difference in air voids (Figures 4.14 and 4.15), the interpretation is slightly different. Figures 4.14 and 4.15 indicate that mixes B and C perform similarly, but differently from A. Furthermore, the difference between the aggregate types is also more pronounced, but mixed.

- **Effect of aggregate type.** In most cases (8 of 11) the crushed quarry rock resulted in higher rut depths at 50,000 repetitions and generally exhibited a higher rutting potential. This was unexpected as the average void contents were similar (11.4% for the quarry and 11.1% for the gravel). However slight, the differences in gradation may have influenced the results.
- **Effect of mix temperature.** As expected, tests conducted at 140 °F (60°C) resulted in greater rut depths and higher values of rutting potential. At 104 °F (40°C), rut depths for quarry and gravel B mixes were essentially identical. When tested at 140 °F (60°C), however, the rut depth of the B mix containing the gravel doubled, whereas the mix with the quarry increased by only 50%.
- **Effect of layer thickness.** According to the data shown in Table 4.1 and Figure 4.11, the E-mix placed over the B-mix performed better than the E-mix placed over the A-mix. The F-mix placed over the B-mix performed significantly better than the F-mix alone.

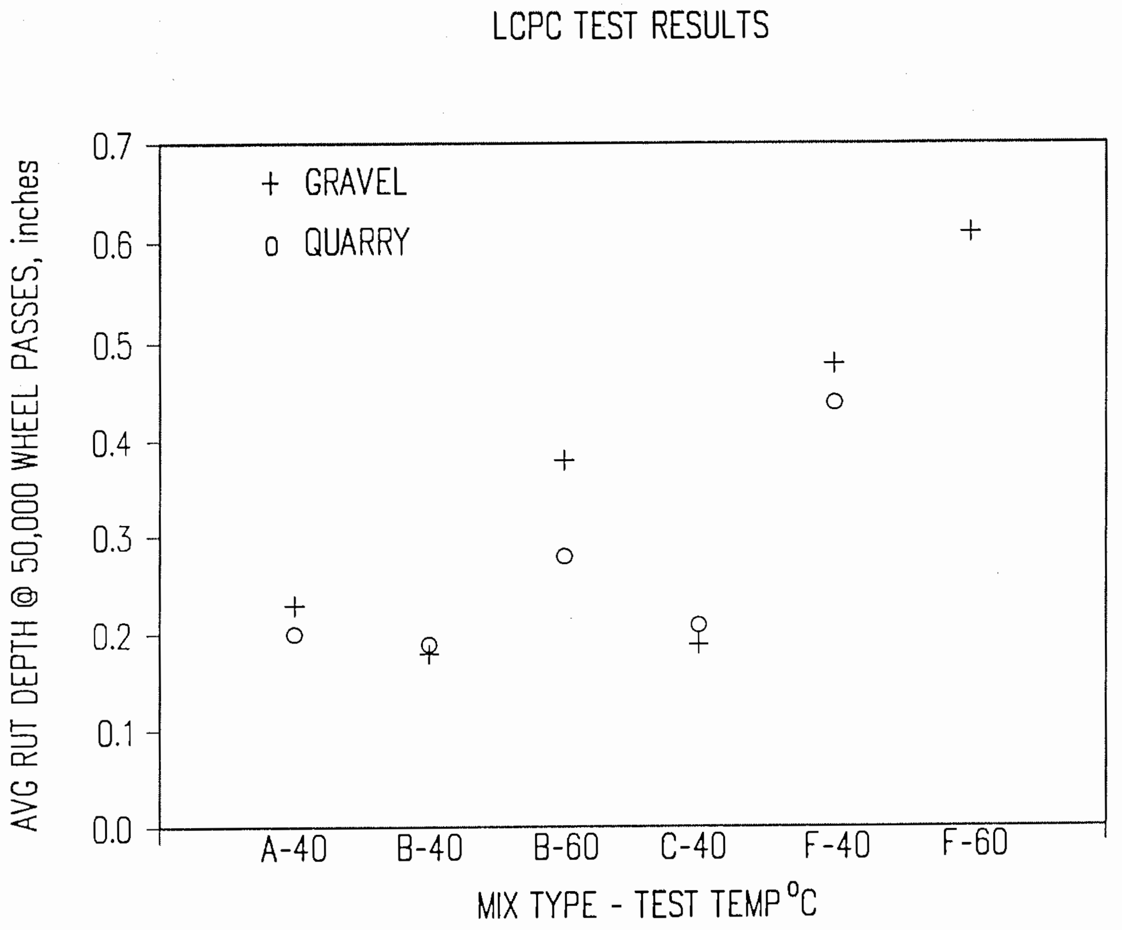


Figure 4.12. LCPC - Average Rut Depth.

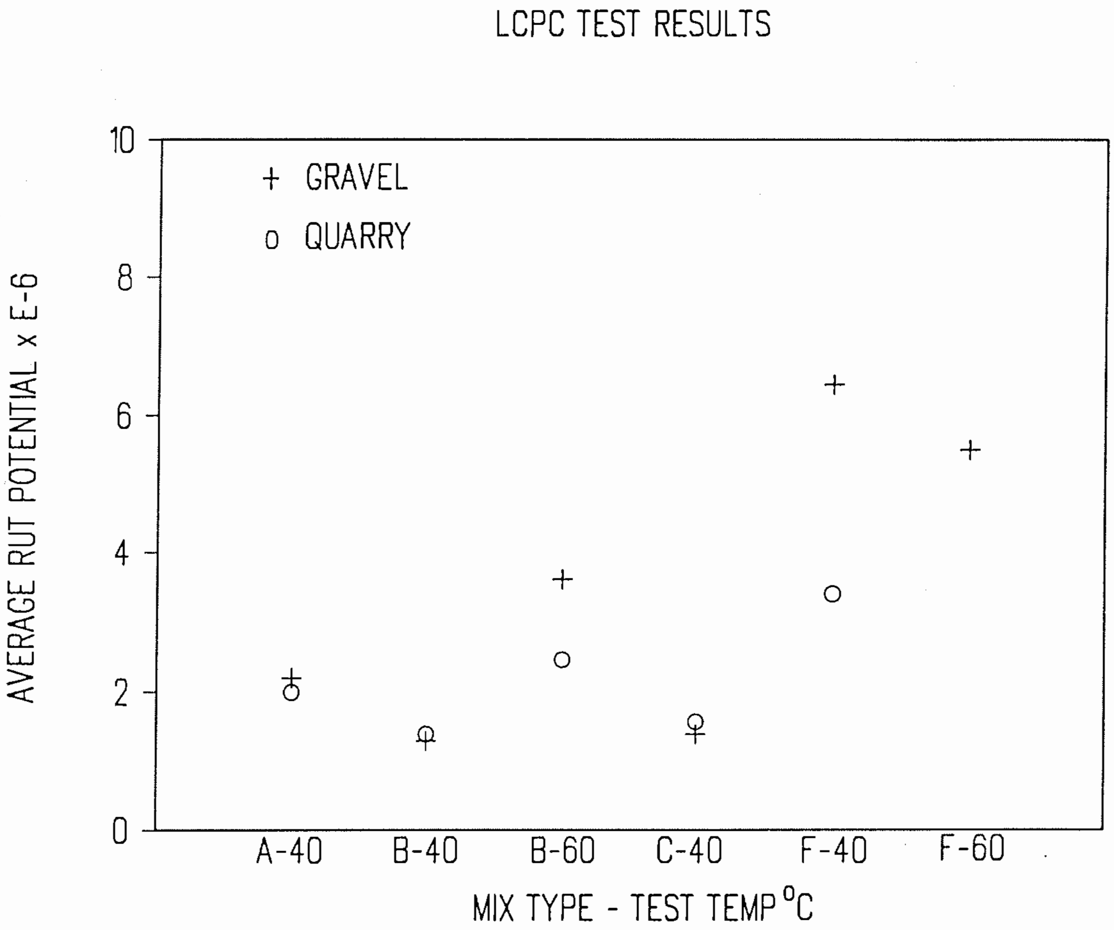


Figure 4.13. LCPC - Average Rut Potential.

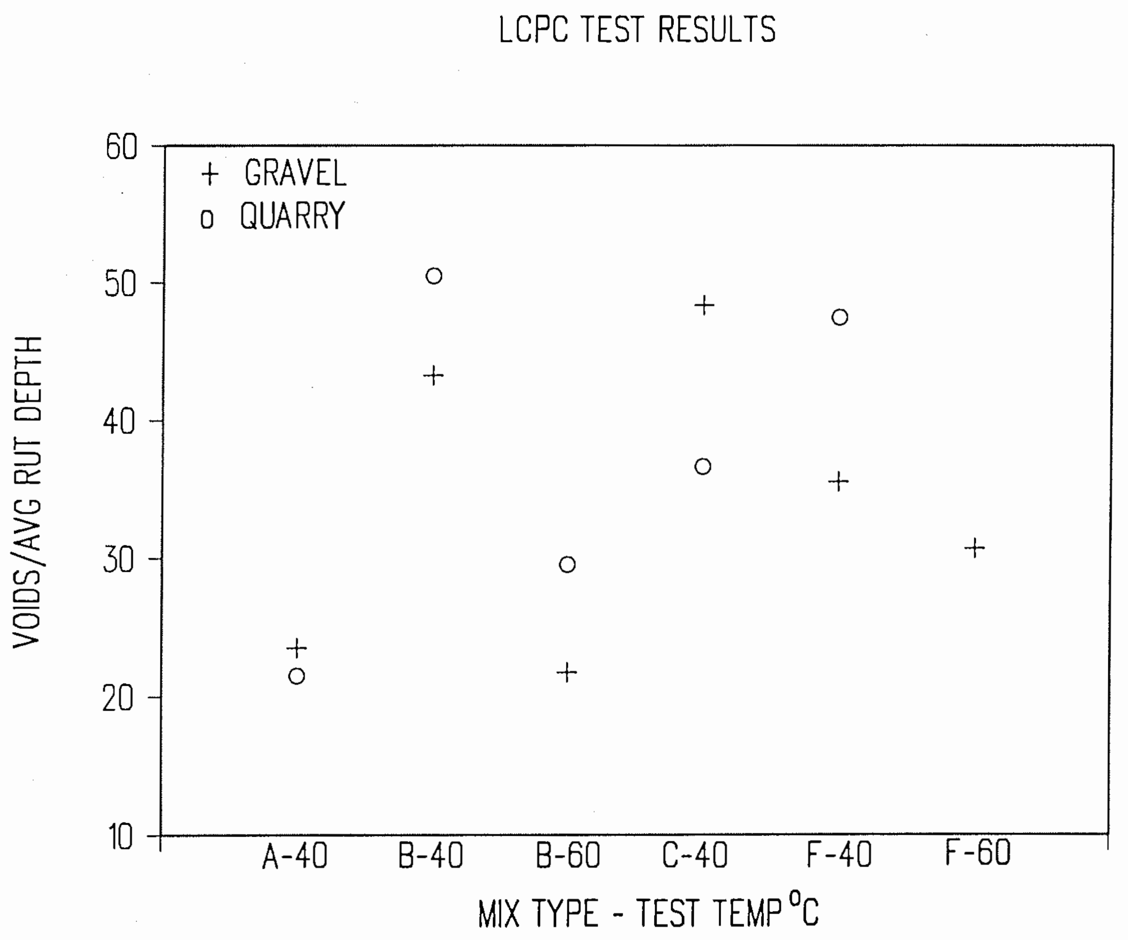


Figure 4.14. Rut Depth Normalized for Voids.

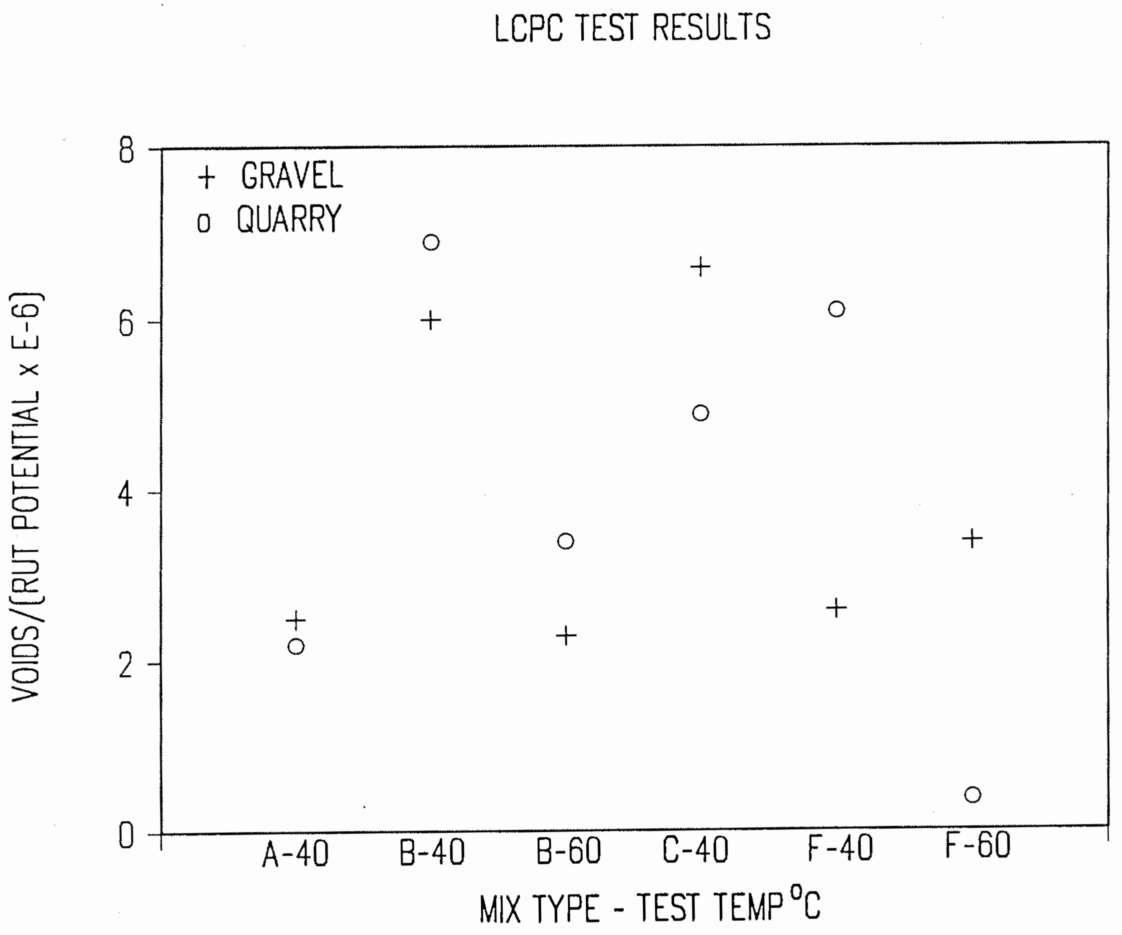


Figure 4.15. Rut Potential Normalized for Voids.

The rut depth of the layered F-mix was 1/3 to 1/2 the rut depth of the F-mix alone. All the layered mixes containing the Riverbend gravel performed better than mixes containing crushed quarry rock.

- **Effect of confinement.** For F mixes, the degree of confinement was very important. It is recommended that all mixes be tested with foam confinement.
- **Comparison with LCPC criteria.** The mix types would all meet the rut criteria currently used by LCPC as shown in Table 4.2

Table 4.2. Specifications for the LCPC Rut Tester (Brousseaud et al., 1993).

Mix Type	Pavement Thickness	Pavement Type	Number of Cycles	Maximum % Rutting
Dense-Graded Wearing Course (A,B,C mix)	2.4-3.1 in. (60-80 mm)	Base Course Wearing Course	30,000	≤ 10
Open-graded Friction Course (F, E mix)	1.2-1.6 in. (30-40 mm)	Wearing Course	1,000 3,000	≤ 10 ≤ 20

5.0 SIMPLE SHEAR TEST RESULTS

This chapter addresses the ODOT mix evaluation conducted by means of the SHRP shear test device at UCB. Additionally, the ODOT mixes are ranked in terms of performance using both the LCPC and shear device test data. Finally, the relationship between the two laboratory test devices (LCPC wheel tracking and repetitive shear test) is established using field performance data (measured rut depths and ESALs) accumulated in the SHRP validation effort.

5.1 Procedures

The constant height repetitive simple shear test (CHRSST) was used throughout this study and is described in Appendix D. The procedures followed are described below.

5.1.1 Specimen Preparation

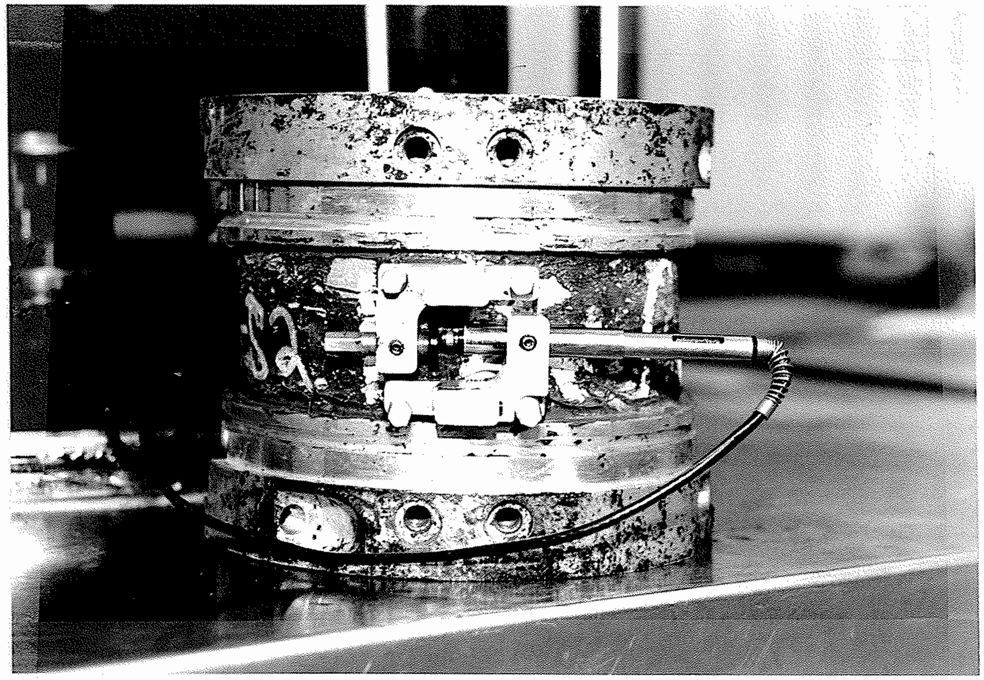
The specimens used in the CHRSST are 6 in. (150 mm) diameter by 2 in. (50 mm) high cylindrical specimens. To obtain the 2 in. (50 mm) high specimens, the 4 in. (100 mm) high specimens compacted at OSU were cut at UCB using a double-blade saw. The precision of the saw allows for specimens to be cut within 1/16 in. (1.5 mm) of parallel, which is critical for the CHRSST test. After the specimens were cut, they were then measured for bulk specific gravity and thickness.

After the specimens were dried, end caps were then glued onto the specimen. A 5-min epoxy resin was used to secure the end cap to the specimen. After the resin had set, 4 holes were drilled in the side of the specimen and 4 screws were glued into the holes to anchor the linear variable differential transducer (LVDT) holders (see Figure 5.1).

5.1.2 Test Procedure

Prior to testing, the specimens were preconditioned to the test temperature. The specimens were placed in a forced-draft oven pre-heated to the test temperature for a minimum of 2 hours.

a) Gluing Sample



b) Sample with LVDT

Figure 5.1. Preparation of Samples for Simple Shear Test

After reaching temperature equilibrium, the specimen was transferred to the universal testing machine (UTM) for testing (Figure 5.2). Two LVDT holders were attached to the specimen assembly, one to control the vertical actuator and one to measure the horizontal strain (ϵ_p). Once the LVDTs were attached, the specimen was clamped into the UTM. After the clamping procedure, the chamber was re-heated to the testing temperature (approximately 10 min). Once the temperature was properly adjusted, the test was started by means of the computer software. During the test, the software controls the horizontal and vertical actuators, unless the test is terminated manually by the operator. Typical results for the CHRSST are presented in Figure 5.3.

5.2 Test Results

All tests were performed at 104 or 140 °F (40 or 60°C), using 10 psi (69 kPa) shear stress. In addition, two specimens, one dense graded and the other open graded, were tested with a radial confining stress of 10 psi.

The test results for the A and B gradation mixes at 104°F are shown in Figure 5.4. The results for the C and F gradation mixes at 104°F are shown in Figure 5.5. The results for the B and F mixes at 140°F are shown in Figures 5.6 and 5.7, respectively. Although not shown, the data indicate that the radial confining stress had little or no effect on the test results. Figure 5.8 shows the results for the low voids F-mix. All of the results are based on testing of duplicate specimens and are summarized in Table 5.1. The complete summary of results is given in Appendix E.

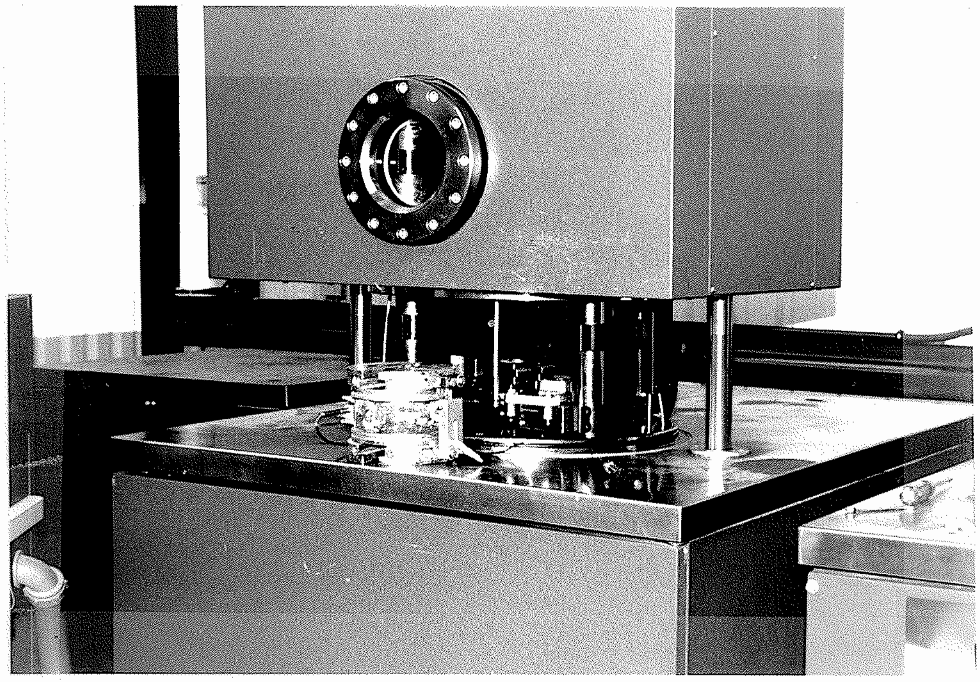
5.3 Discussion of Test Results

The results from the CHRSST are summarized below:

- **Effect of mix type.** Mix type greatly affects performance. The laboratory data suggest that dense-graded mixes outperform the open-graded mix. It should be noted, however, that the laboratory compacted F-mixes had void contents about 5% higher than typically found in the field. As a result, the laboratory compacted specimens were not truly representative of field mixes and may account for the discrepancy between laboratory and

04 22 93

a) Overview



b) View of Specimen

Figure 5.2. Photo of Test Equipment

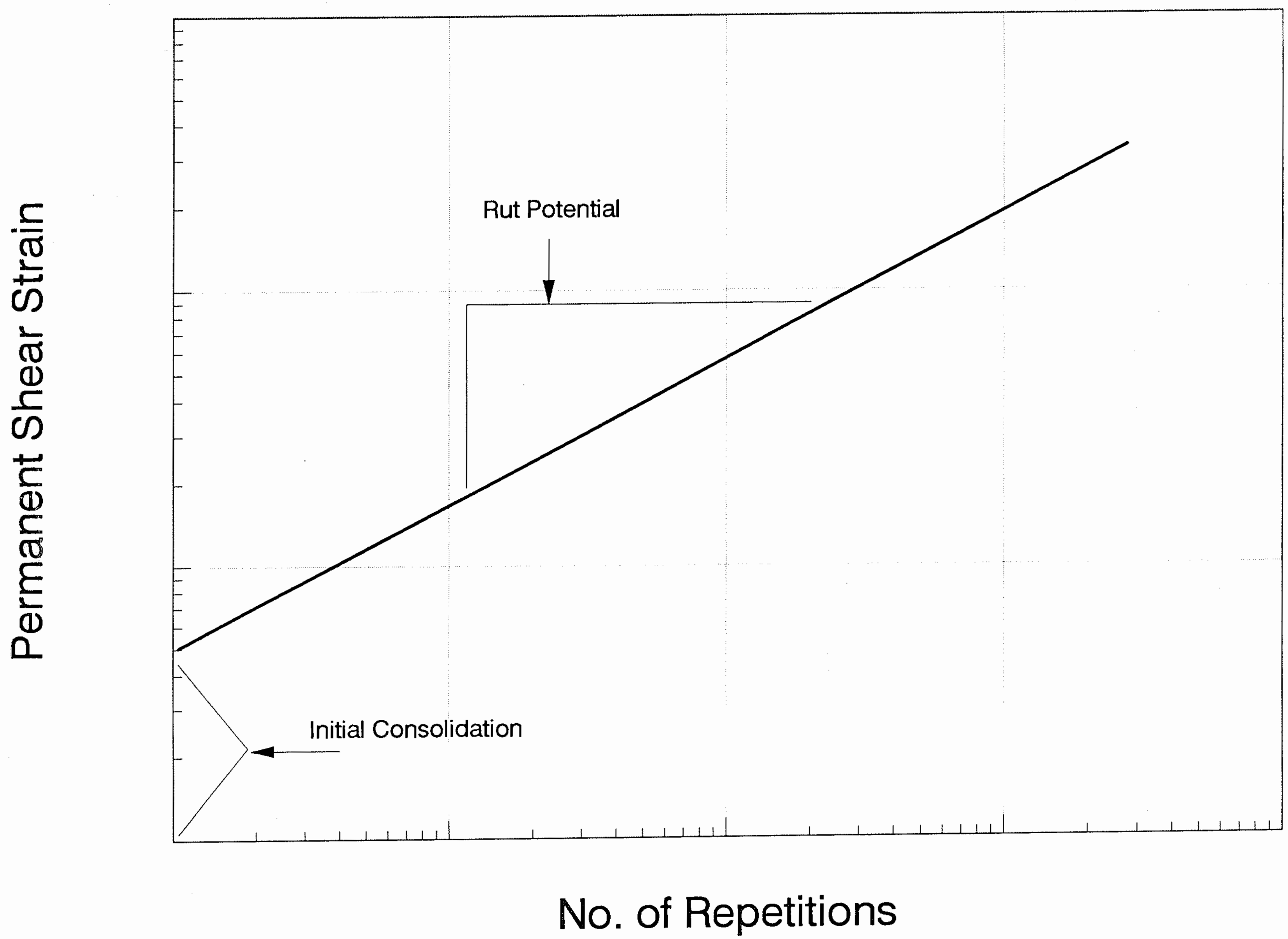
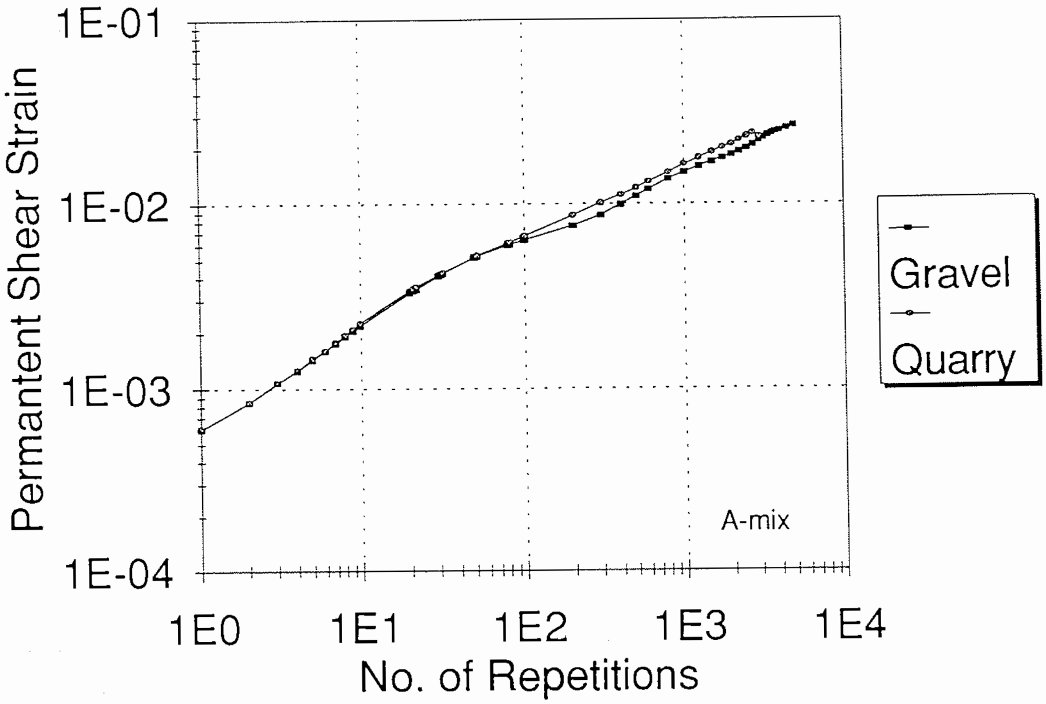
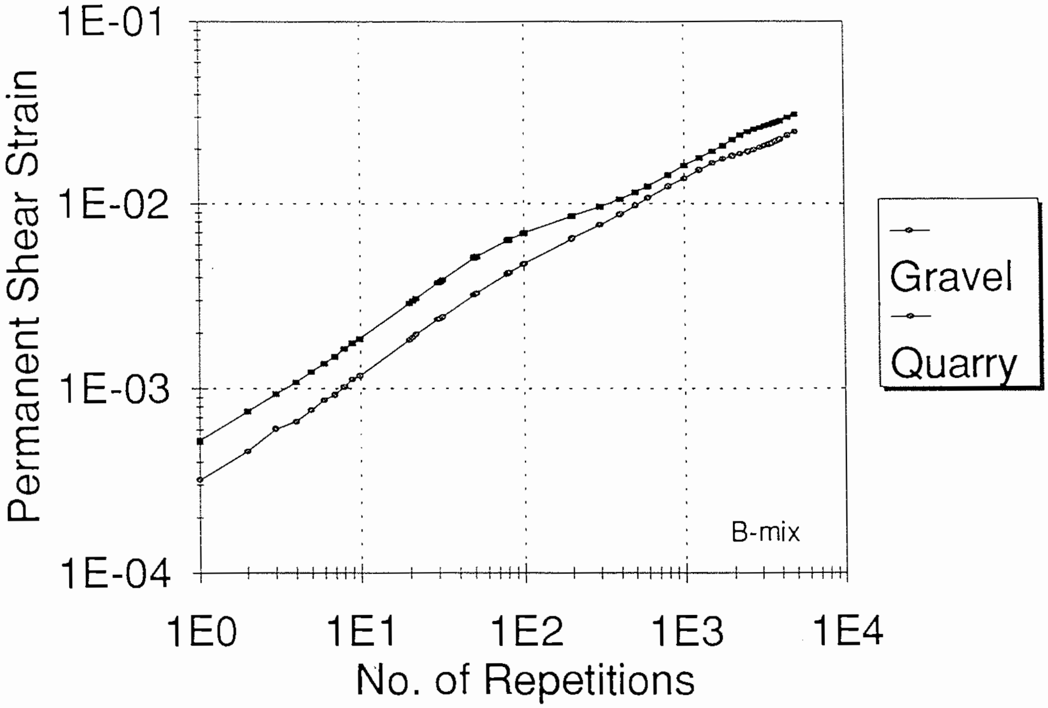


Figure 5.3. Format of Test Results from CHRSST.

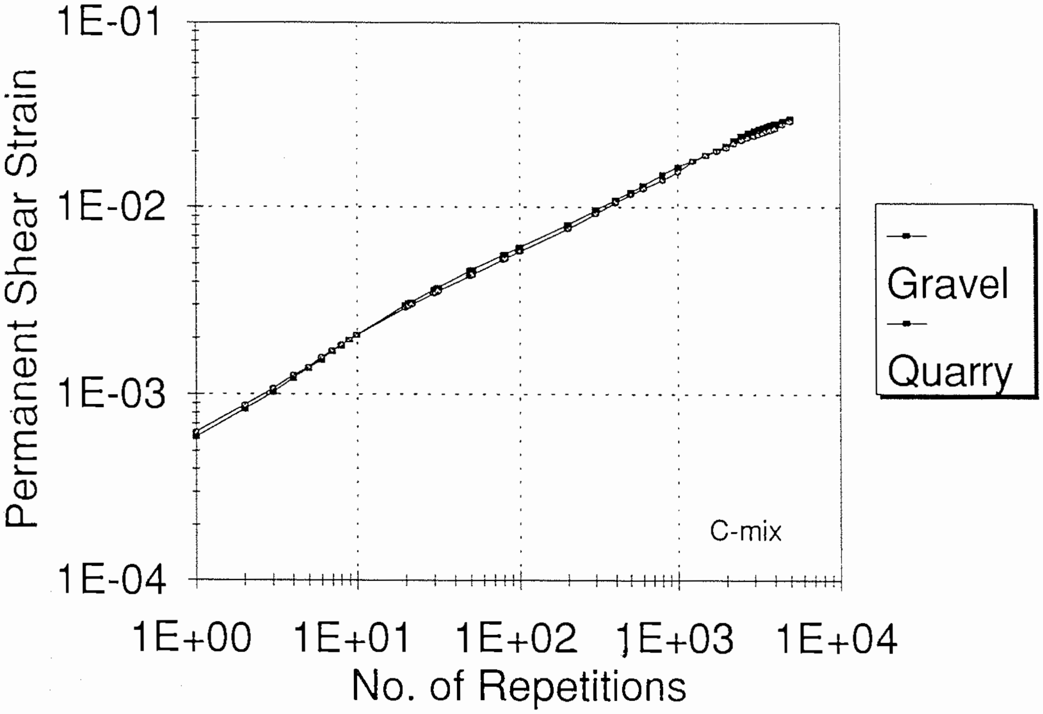


a) A Mix

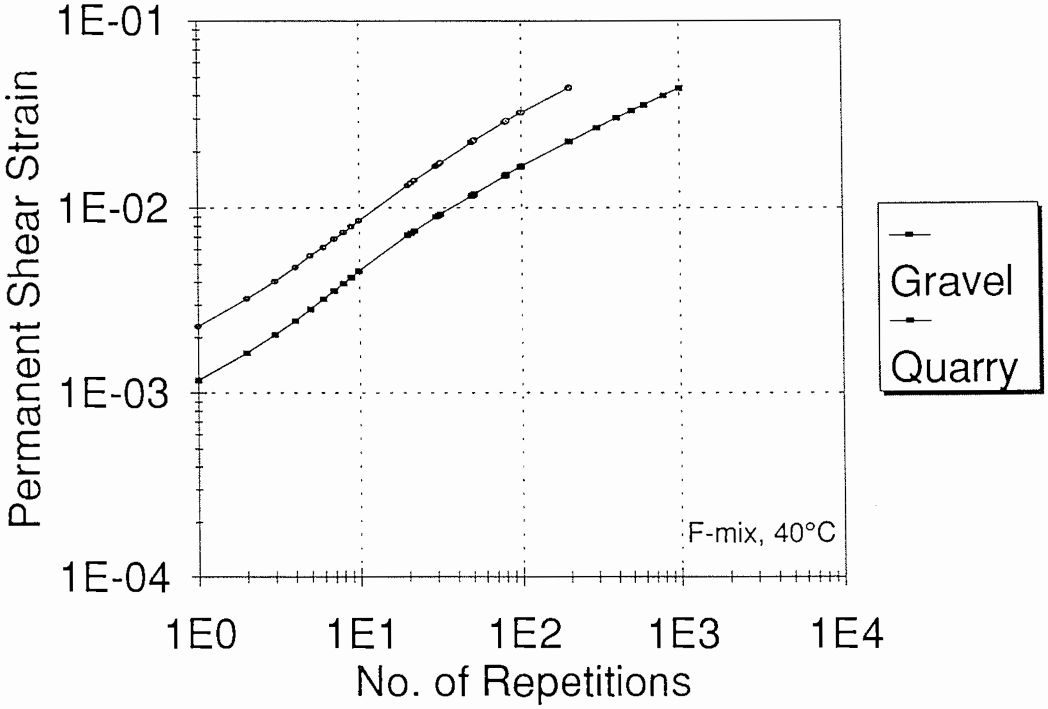


b) B Mix

Figure 5.4. Constant Height Repeated Shear Test (CHRSST) Results for Type A and B Mixes @ 40°C.



a) C Mix



b) F Mix

Figure 5.5. Constant Height Repeated Shear Test (CHRSST) Results for Type C and F Mixes @ 40°C.

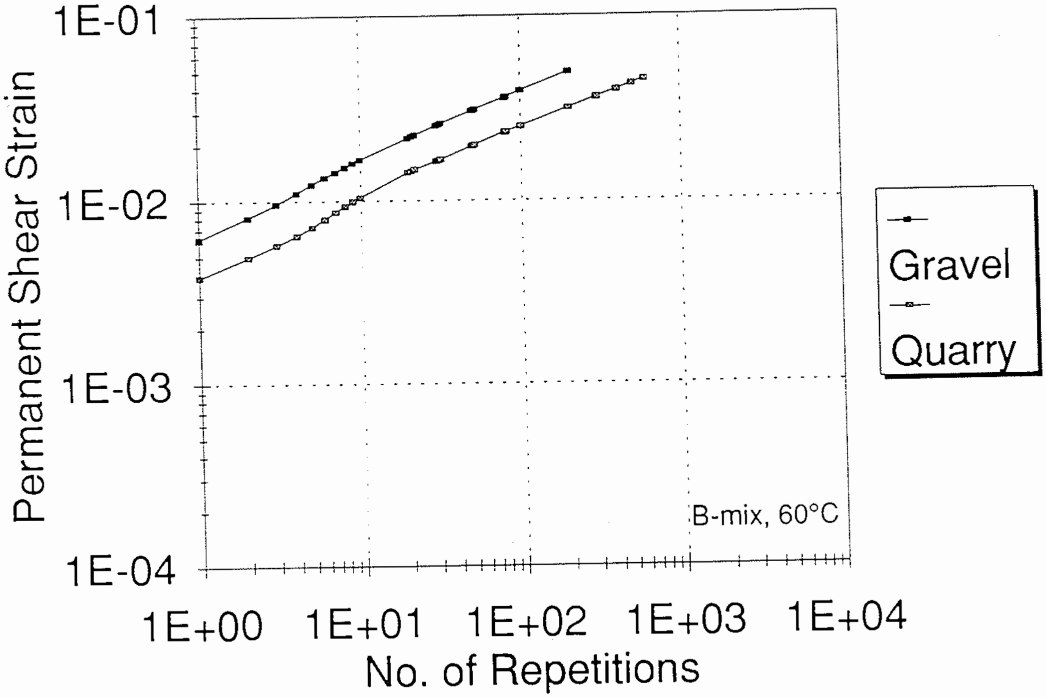


Figure 5.6. Constant Height Repeated Shear Test (CHRSST) Results for Type B Mixes @ 60°C.

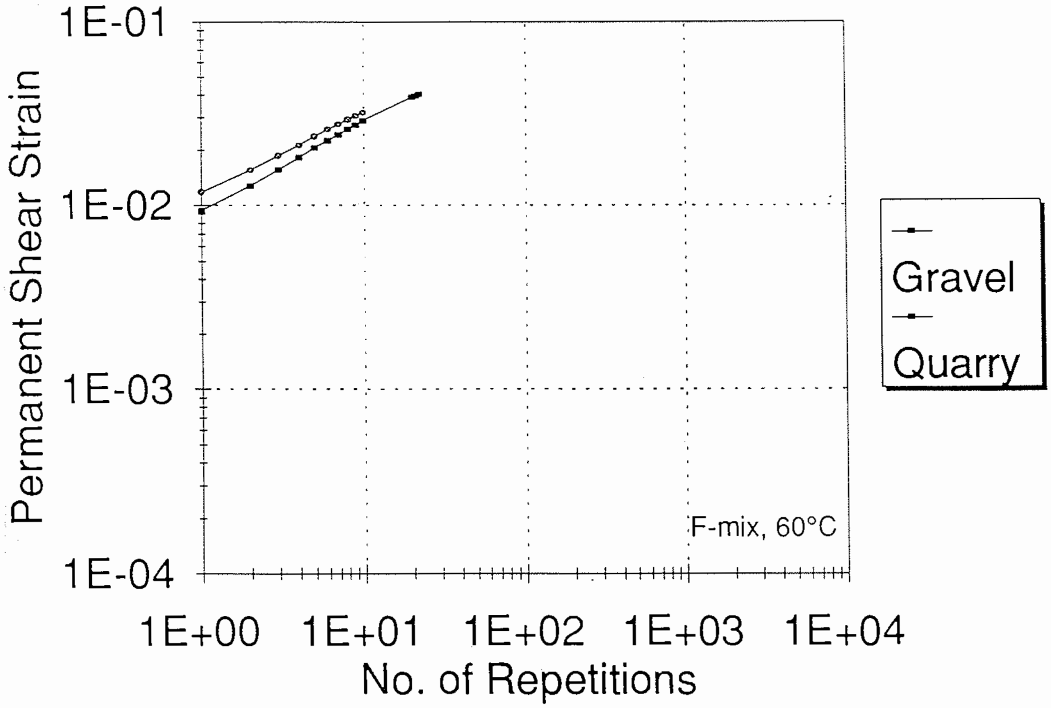


Figure 5.7. Constant Height Repeated Shear Test (CHRSST) Results for Type F Mixes @ 60°C.

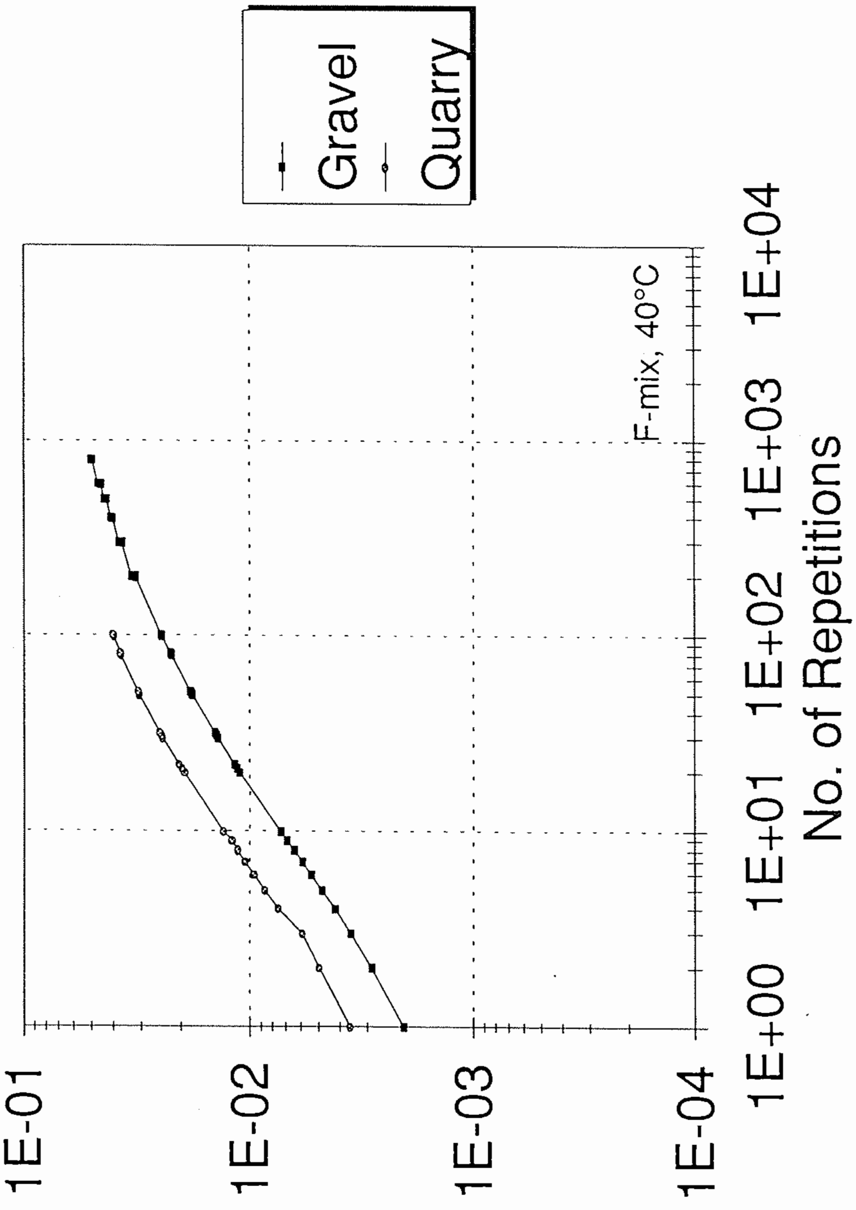


Figure 5.8. CHRSST Results for Type F Mixes (Low Voids) at 40°C.

Table 5.1. Summary of Constant Height Simple Shear Test Results.

Mix Type	Average ϵ_p @ 5,000 reps or reps to 5% Strain		Average Rut Potential (in./1000 passes) 1,000 to 5,000 reps	
	Gravel	Quarry	Gravel	Quarry
A-40	2.6	1.8	0.376	0.311
B-40	3.1	2.48	0.469	0.433
B-60	250 reps	1050 reps	0.352	0.339
C-40	3.0	4.3	0.416	0.418
F-40 (high voids)	2750 reps	300 reps	0.436	0.498
F-60 (high voids)	50 reps	80 reps	0.458	0.413
F-40 (low voids)	975 reps	450 reps	0.430	0.418

observed field performance. When F-mixes with lower void contents ($\simeq$13 to 14%) were tested with foam confinement, the rut depth measured with the LCPC wheel tracking device was comparable to that observed in the field. Due to time and budget constraints, the researchers were unable to fabricate and test additional F-mixes at the lower void content.

- **Effect of aggregate type.** In all instances, except the C-mix at 104 °F (40°C) and F-mix at 140 °F (60°C), the quarry rock resulted in low ϵ_p at 5000 repetitions. The rut potential for the quarry rock was also less than the gravel mix except for C-mix at 104 °F and F-mix at 104 °F (high voids).
- **Effect of mix temperature.** For the B- and F-mixes, higher test temperature greatly increases ϵ_p at 5000 repetitions and the rut potential. For both the B- and F- mixes there was a five-fold increase in shear strain from the 104 to 140 °F testing temperatures.
- **Effect of void content.** For the F-mix at 104 °F, the reduction in void content had only a slight effect on ϵ_p at 5000 repetitions and rut potential.
- **Effect of confinement.** For the F-mix, a few tests were performed with confinement (σ_3 = 10 psi (69 kPa)). Confinement did not result in a significant change in performance. However, preliminary calculations would suggest the level of confinement required would be between 50 to 100 psi (345 to 690 kPa).

The results of these tests indicate the CHRSST is acceptable for dense mixes, but does not capture the field performance of open-graded mixes for the conditions evaluated.

5.3.1 Correlation of CHRSST and Wheel Track Results

The following procedure was used to evaluate the correlation between the results from the two tests:

1) For each temperature, the minimum rut depth from all the wheeltrack test results was selected as the reference. For the wheel track tests conducted at 104°F

(40°C), the rut depth of 0.165 in. (4.2 mm) was selected from Figure 2.b (mix BG); for the 140°F (60°C) tests, the ruth depth of 0.25 in. (64 mm) was selected from Figure 3.a (mix BQ).

2) The corresponding permanent shear strain from the CHRSST was then calculated using the relationship proposed by Sousa and Solaimanian (1993), ie,
rut depth = 11 x permanent shear strain.

3) The repetitions to the reference rut depth, and repetitions to the reference permanent shear strain were then found graphically using the procedure described by Sousa and Solaimanian and are shown in Table 5.2.

4) The results were converted to log values, and regression analysis was performed for both temperatures, and the combined data set, as shown in Table 5.3.

The equations found from this evaluation can be compared with the Sousa and Solaimanian (1993) equation shown below:

Sousa and Solaimanian

log (CHRSST reps) = -4.09 + 1.204 log (ESALS) $R^2 = 0.68$

40°C OSU

log (CHRSST reps) = -1.109 + 0.971 log (wheel reps) $R^2 = 0.53$

60°C OSU

log (CHRSST reps) = -1.781 + 0.819 log (wheel reps) $R^2 = 0.95$

Combined 40°C and 60°C OSU

log (CHRSST reps) = -2.233 + 1.154 log (wheel reps) $R^2 = 0.44$

It is interesting to note the similar slopes for the Sousa and Solaimanian equation, which is from a data set that encompasses the temperature range of 104°F to 131°F (40°C to 55°C), and the equation derived from the combined OSU data set (104°F and 140°F). The difference in intercepts indicates that one pass of the LCPC wheeltrack device is equivalent to approximately 40 ESALs.

Table 5.2. Summary of LCPC and CHRSST Test Data.

a) 104 °F (40°C) Test Temperature

Mix	Air Voids, %	0.165 in. = 11*0.015	
		LCPC Wheel Reps. to 0.165 in.	CHRSST 10 psi Reps to 1.5%
AG	5.9	8500	
	6.4	3000	
	6.7		550
	8.3		2300
AQ	8.5	7000	
	8.4	3500	
	7.8		600
	8.0		4000
BG	7.6	35000	
	8.1	35000	
	7.1		900
	6.0		900
BQ	9.7	36000	
	9.5	24000	
	4.8		3500
	4.1		800
CG	9.2	22500	
	9.2	33000	
	7.7		2500
	6.7		500
CQ	7.8	13000	
	7.7	13000	
	6.8		1400
	7.2		1000
FG	15.8	9000	
	18.5	2000	
	17.7		140
	16.4		80
FQ	20.9	1000	
	21.0	2000	
	18.7		20
	16.5		30

N.B. Air voids were determined by UCB on trimmed cores. Therefore they are slightly different from values in Tables 3.2, 3.3, and 3.4.

Table 5.2. Summary of LCPC and CHRSST Test Data (continued).

b) 140 °F (60°C) Test Temperature

Mix	Air Voids, %	0.25 in. = 11*0.023 LCPC Wheel Reps. to 0.25 in.	CHRSST 10 psi Reps to 2.3%
BG	8.6	16000	
	8.1	10000	
	8.4		30
	8.9		30
BQ	8.2	35000	
	8.4	25000	
	3.6		80
	5.7		220
	6.5		50
FG	18.5	1000	
	19.2	1000	
	15.2		4
	14.7		8
	15.1		8
FQ	17.7	2000	
	17.4	2000	
	12.0		3
	9.8		4
	16.4		20

N.B. Air voids were determined by UCB on trimmed cores. Therefore they are slightly different from values in Tables 3.2, 3.3, and 3.4.

Table 5.3. Regression of OSU CHRSST Data.

<table>
<tr><th colspan="7">a) 104 °F (40°C) (log-log)</th></tr>
<tr><th>Avg. LCPC</th><th>Avg. CHRSST</th><th>Mix</th><th></th><th>Regression</th><th>Avg. LCPC</th><th>Avg. CHRSST</th></tr>
<tr><td>3.703</td><td>3.05</td><td>AG</td><td>int</td><td>-1.109</td><td>5050</td><td>1125</td></tr>
<tr><td>3.695</td><td>3.190</td><td>AQ</td><td>slope</td><td>0.971</td><td>4950</td><td>1549</td></tr>
<tr><td>4.544</td><td>2.954</td><td>BG</td><td>R^2</td><td>0.529</td><td>35000</td><td>900</td></tr>
<tr><td>4.468</td><td>3.224</td><td>BQ</td><td></td><td></td><td>29394</td><td>1673</td></tr>
<tr><td>4.435</td><td>3.048</td><td>CG</td><td></td><td></td><td>27249</td><td>1118</td></tr>
<tr><td>4.114</td><td>3.073</td><td>CQ</td><td></td><td></td><td>13000</td><td>1183</td></tr>
<tr><td>3.628</td><td>2.025</td><td>FG</td><td></td><td></td><td>4243</td><td>106</td></tr>
<tr><td>3.151</td><td>1.389</td><td>FQ</td><td></td><td></td><td>1414</td><td>24</td></tr>
<tr><td colspan="7">b) 140 °F (60°C) (log-log)</td></tr>
<tr><td>4.102</td><td>1.477</td><td>BG</td><td>int</td><td>-1.781</td><td>12649</td><td>30</td></tr>
<tr><td>4.471</td><td>1.981</td><td>BQ</td><td>slope</td><td>0.819</td><td>29580</td><td>96</td></tr>
<tr><td>3.000</td><td>0.803</td><td>FG</td><td>R^2</td><td>0.947</td><td>1000</td><td>6</td></tr>
<tr><td>3.301</td><td>0.793</td><td>FQ</td><td></td><td></td><td>2000</td><td>6</td></tr>
<tr><td colspan="7">c) All Data (log-log)</td></tr>
<tr><td>3.703</td><td>3.051</td><td>AG40</td><td>int</td><td>-2.233</td><td>5050</td><td>1125</td></tr>
<tr><td>3.695</td><td>3.190</td><td>AQ40</td><td>slope</td><td>1.154</td><td>4950</td><td>1549</td></tr>
<tr><td>4.544</td><td>2.954</td><td>BG40</td><td>R^2</td><td>0.444</td><td>35000</td><td>900</td></tr>
<tr><td>4.468</td><td>3.224</td><td>BQ40</td><td></td><td></td><td>29394</td><td>1673</td></tr>
<tr><td>4.435</td><td>3.048</td><td>CG40</td><td></td><td></td><td>27249</td><td>1118</td></tr>
<tr><td>4.114</td><td>3.073</td><td>CQ40</td><td></td><td></td><td>13000</td><td>1183</td></tr>
<tr><td>3.628</td><td>2.025</td><td>FG40</td><td></td><td></td><td>4243</td><td>106</td></tr>
<tr><td>3.151</td><td>1.389</td><td>FQ40</td><td></td><td></td><td>1414</td><td>24</td></tr>
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<tr><td>4.471</td><td>1.981</td><td>BQ60</td><td></td><td></td><td>29580</td><td>96</td></tr>
<tr><td>3.000</td><td>0.803</td><td>FG60</td><td></td><td></td><td>1000</td><td>6</td></tr>
<tr><td>3.301</td><td>0.793</td><td>FQ60</td><td></td><td></td><td>2000</td><td>6</td></tr>
</table>

5.3.2 Ranking of Mixes

- **Rank of Mix Types**. Table 5.4 shows the ranking of the mixes by both the LCPC and CHRSST data. With respect to the single layer mixes, it is interesting to note that the two LCPC criteria (rut depth and rutting potential) provide different rankings, although general trends are evident. The B-mix, regardless of criterion and aggregate, is consistently ranked the best, with only one exception (rutting potential with the quarry aggregate). Also, for the single layer mixes, the LCPC data indicate that the A-mix consistently ranked among the poorest, except mixes made with the quarry aggregate (as measured by rut depth). Although the simple shear data are consistent in terms of criterion and across aggregate type, the A-mixes are ranked the best, and B- or F-mixes the poorest. These overall rankings suggest that neither the LCPC wheel tracking device nor the simple shear test truly capture the behavior of the F-mix as rutting in the field has been minimal. This disparity between laboratory and field performance is likely due to the lack of adequate confinement in the both laboratory test procedures. For the multi-layer mixes, the BF mix ranks the best and the AE ranks the poorest in three of four cases.

- **Effect of Aggregate Type**. Table 5.5 shows the ranking of rutting resistance by aggregate type for both the LCPC and CHRSST data. As is evident from the table, the results are mixed. Only in the case of the A and C mixes are the results identical across test type: the quarry aggregate consistently ranks better for the A mix, whereas the gravel aggregate ranks better for the C mix. Results are mixed for both the B and F mixes. Because the comparisons were made on the 104 °F (40°C) test data, it is possible that the aggregate interlock was not fully mobilized, i.e., test data at 140 °F (60°C) may have been more likely to reflect the influence of aggregate type. The simple shear data

Table 5.4. Ranking of Rutting Resistance by Mix Type – 104°F (40 °C).

a) Rut Depth @ 50,000 wheel passes			
LCPC		CHRSST	
Gravel	Quarry	Gravel	Quarry
B	B	A	A
C	A	C	B
F	C	B	C
BF	F	F	F
A	BE		
BE	BF		
AE	AE		
b) Rutting Potential			
B	F	A	A
C	B	C	C
BF	C	F	F
F	A	B	B
BE	BF		
A	AE		
AE	BE		

Table 5.5. Ranking of Rutting Resistance by Aggregate Type – 104°F (40 °C).

a) Rut Depth @ 50,000 Wheel Passes			
LCPC		CHRSST	
A	Quarry	A	Quarry
B	Gravel	B	Quarry
C	Gravel	C	Gravel
F	Gravel	F	Gravel
b) Rut Potential			
A	Quarry	A	Quarry
B	Gravel	B	Quarry
C	Gravel	C	Gravel
F	Quarry	F	Quarry

do suggest, however, that the maximum size of aggregate is more influential than is aggregate type in rutting response. Recall that the maximum size of aggregate in mixes A, B, C and F is 1½ in, ¾ in, ½ in and ¾ in, (38 mm, 19 mm, 13 mm and 19 mm) respectively. The simple shear data ranking of mixes parallels that of aggregate size, i.e., the rutting resistance decreases with decreasing size of aggregate, except for the F mix. As noted previously, neither laboratory test captured the behavior of the F-mixes.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1) The LCPC wheel tracking and simple shear devices both discriminate between mix types as measured by rut depth and rutting potential. Although the ranking of mixes is not identical for the two devices, there are general trends. In both the laboratory tests, the open-graded F-mixes typically performed poorly, despite field performance data to the contrary. Two possible reasons for the disparity between laboratory and field performance are the lack of adequate confinement in both laboratory test procedures and voids in the laboratory specimens that were not representative of field conditions. However, some F-mix specimens were tested at a lower void content closer to the field voids and these specimens exhibited less rutting. For the multilayer mixes, the BF ranks the best and the AE ranks the poorest in three of four cases.

2) The F-mix placed over the B-mix performed significantly better than the F-mix alone. The rut depth of the layered F-mix was 1/3 to 1/2 the rut depth of the F-mix alone. This is not surprising when considering conclusion 1, above. The F-mix specimens were at a void level that was unrepresentative of the field conditions. The lab specimens were compacted to a void level that was much higher than the field and probably not to a refusal compaction density. This would indicate that there was continued compaction under the LCPC wheel load. Given the fact that the full depth specimens had twice the depth to continue to consolidate as did the layered specimens, the rut depth would intuitively be higher. Due to the limited time and materials available, the layered specimens could not be reproduced at the lower void levels. From the research conducted in this project, no definite conclusions can be drawn on the effect of layer thickness on pavement rutting.

3) In most cases (8 of 11), calculated rut depth at 50,000 load repetitions based on LCPC and CHRSST data was greater for mixes containing the crushed quarry rock than for mixes containing

the gravel. This was unexpected as the average void contents were similar (11.4% for the quarry and 11.1% for the gravel). However slight, the differences in gradation may have influenced the results. The influence of aggregate type on rutting resistance is somewhat variable. Only in the case of the A and C mixes are the results identical across test type: the quarry aggregate consistently ranks better for the A-mix, whereas the gravel aggregate ranks better for the C-mix. Results are mixed for both the B and F-mixes. Because the comparisons were based on the 104 °F (40°C) test data, it is possible that the aggregate interlock was not fully mobilized, i.e., test data at 140 °F (60°C) may have been more likely to reflect the influence of aggregate type. The simple shear data do suggest, however, that the maximum size of aggregate is more influential than is aggregate type in rutting response. The simple shear data ranking of mixes (A > B > C > F) parallels that of maximum aggregate size, i.e., the rutting resistance decreases with decreasing size of aggregate, except for the F-mix. As noted previously, neither laboratory test captured the field behavior of the F-mixes.

4) With refinements to the type and magnitude of confinement (plaster vs. foam for the LCPC wheel tracking device and radial confining pressure for the simple shear device), both devices can be used to generate data which would allow one to predict rutting in the field. Using the general pavement studies (GPS) field performance data and the procedure suggested by Sousa and Solaimanian, the relationship between ESALs and laboratory data (LCPC wheel passes or simple shear load repetitions) allows one to predict rut depth.

5) More information in the area of field validation is needed before any conclusions and/or recommendations with regards to asphalt type or aggregate gradation can be made.

6) Both the B- and C-mixes meet the LCPC criteria for rut resistant asphalt mixes at 104 °F (40°C).

7) Both the E- and F-mix performed better when placed over the B-mix.

6.2 Recommendations

After analyzing the data from the LCPC and simple shear devices, the following are recommended.

Recommendations for Implementation:

1) To improve the rut resistance of the large stone A-mix, it will be necessary to increase the amount of coarse stone.

Recommendations for Further Research:

1) As temperature has a significant impact on rut resistance, it is imperative that a database be developed to establish maximum pavement temperatures so that mix testing is performed at these temperatures.
2) F-mixes do not exhibit as good of performance (in terms of rutting) in the laboratory as compared to the field. All future testing on F-mixes must include voids and confinement which are representative of field conditions. The magnitude of the confinement is currently being determined in an ODOT study on porous mixes.

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APPENDIX A

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

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December 1992

TABLE OF CONTENTS

LIST OF TABLES

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.

<u>Calculation of Batch Quantities.</u> 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 = $\sum$(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.

<u>Subdividing Asphalts.</u> 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 B

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,

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

and

$$\text{shove}_{\text{right}} = \frac{P15_i + P25_i + P35_i}{3} - \frac{P15_0 + P25_0 + P35_0}{3}$$

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 C

LCPC Data

						RUT DEPTH AT WHEEL PASS #, inches										
Specimen ID	Mix Type	% AC	AGG	% voids	Test Temp, C	100	200	500	1000	2000	5000	10000	20000	30000	40000	50000
1AGR1	A	5.8	G	7.9	40	0.0250	0.0469	0.0610	0.0690	0.0780	0.1130	0.1460	0.1840	0.1970	0.2130	0.2390
1AGR2	A	5.8	G	7.5	40	0.0210	0.0400	0.0580	0.0590	0.0760	0.1100	0.1470	0.1770	0.1980	0.2150	0.2290
2BGR	B	5.5	G	9.7	40	0.0300	0.0260	0.0510	0.0550	0.0610	0.1100	0.1200	0.1550	0.1660	0.1770	0.1760
2BGR	B	5.5	G	10.3	40	0.0210	0.0310	0.0490	0.0420	0.0810	0.0910	0.1310	0.1440	0.1690	0.1770	0.1800
2BGR	B	5.5	G	11.6	60	0.0320	0.0510	0.0860	0.1060	0.1370	0.1670	0.2070	0.2710	0.3060	0.3300	0.3560
2BGR	B	5.5	G	11.6	60	0.0490	0.0710	0.1140	0.1410	0.1730	0.2050	0.2540	0.3040	0.3430	0.3740	0.3950
3CGR1	C	5.8	G	12	40	0.0100	0.0350	0.0350	0.0690	0.0920	0.1080	0.1380	0.1570	0.1670	0.1720	0.1620
3CGR2	C	5.8	G	12.3	40	0.0220	0.0380	0.0420	0.0670	0.0810	0.1100	0.1290	0.1640	0.1830	0.1980	0.2050
4FGR1	F	6	G	18.5	40	0.0210	0.0180	0.0477	0.0849	0.1023	0.1410	0.1770	0.2070	0.3500	0.4530	0.4600
4FGR2	F	6	G	15.8	40	0.0250	0.0540	0.0890	0.1130	0.1410	0.2660	0.2640	0.3640	0.4740	0.4870	0.4970
4FGR3	F	6	G	18.5	60	0.0960	0.1380	0.2380	0.2800	0.3190	0.3650	0.3940	0.4520	0.5020	0.5660	0.6020
4FGR4	F	6	G	19.2	60	0.1150	0.1660	0.2350	0.2860	0.3240	0.3590	0.3800	0.4640	0.5230	0.5830	0.6140
4FGR5	F	6	G	12.8	40	0.0260	0.0430	0.0510	0.0760	0.0960	0.1070	0.1380	0.1560	0.1730	0.1870	0.1950
4FGR6	F	6	G	11.8	40	0.0380	0.0500	0.0770	0.0980	0.1080	0.1200	0.1440	0.1660	0.1860	0.1960	0.2040
4FG-PLAS	F	6	G	12.8	40	0.0060	0.0009	0.0075	0.0110	0.0100	0.0230	0.0320	0.0340	0.0320	0.0320	0.0330
4FG-PLAS	F	6	G	11.8	40	0.0070	0.0150	0.0270	0.0270	0.0320	0.0480	0.0360	0.0540	0.0470	0.0640	0.0420
1AQR1	A	6.2	Q	6.6	40		0.0210	0.0320	0.0370	0.0840	0.1050	0.0170	0.1620	0.1960		0.2320
1AQR2	A	6.2	Q	6.6	40	0.0220	0.0310	0.0420	0.0770	0.0780	0.1040	0.1770	0.1290	0.1530		0.1760
2BQR	B	5.8	Q	11.7	40	0.0140	0.0240	0.0270	0.0470	0.0610	0.0940	0.1170	0.1460	0.1630		0.1880
2BQR	B	5.8	Q	11.5	40	0.0210	0.0266	0.0320	0.0730	0.0700	0.1070	0.1350	0.1610	0.1820		0.1960
2BQR	B	5.8	Q	10.1	60	0.0367	0.0480	0.0800	0.0970	0.1170	0.1400	0.1710	0.2090	0.2360	0.2540	0.2670
2BQR	B	5.8	Q	10.8	60	0.0420	0.0520	0.0840	0.1200	0.1260	0.1650	0.1930	0.2340	0.2590	0.2830	0.2940
3CQR1	C	6.5	Q	10.3	40	0.0170	0.0280	0.0510	0.0630	0.0960	0.1110	0.1310	0.1640	0.1760	0.2000	0.1930
3CQR2	C	6.5	Q	9.5	40	0.0240	0.0003	0.0420	0.0650	0.0870	0.1270	0.1730	0.1960	0.2060	0.2190	0.2370
4FQR1	F	6.5	Q	20.8	40	0.0560	0.0950	0.1340	0.1740	0.2140	0.2610	0.3200	0.3650	0.3840	0.4030	0.4020
4FQR2	F	6.5	Q	21	40	0.0158	0.0600	0.1000	0.1250	0.1560	0.2310	0.2790	0.3180	0.3910	0.4140	0.4520
4FQR3	F	6.5	Q	17.7	60	0.2300	0.3300	0.4900	0.5600	0.6400	0.7400					
4FQR4	F	6.5	Q	17.4	60	0.1940	0.3150	0.4150	0.6010	0.6160	0.8040					
4FQR5-FOAM	F	6.5	Q	13.5	40	0.0390	0.0430	0.0740	0.0950	0.1260	0.1750	0.1890	0.2060	0.2210	0.2230	0.2290
4FQR6-PLAS	F	6.5	Q	14.4	40	0.0140	0.0210	0.0320	0.0540	0.0580	0.0790	0.0830	0.1000	0.1020	0.1040	0.1080
5BEGR1	B/E	5.5/6.5	G		40	0.0270	0.0360	0.0570	0.0790	0.0910	0.1450	0.1680	0.2070	0.2350	0.2480	0.2540
5BEGR2	B/E	5.5/6.5	G		40	0.0060	0.0316	0.0765	0.0865	0.1290	0.1860	0.2160	0.2620	0.2770	0.2930	0.2880
5BEQR1	B/E	5.8/7.0	Q		40	0.0150	0.0370	0.0600	0.0710	0.0990	0.1440	0.1770	0.2360	0.2740	0.2780	0.2900
5BEQR2	B/E	5.8/7.0	Q		40	0.0290	0.0360	0.0600	0.1140	0.1010	0.1440	0.1810	0.2250	0.2570	0.2710	0.2920
6AEGR1	A/E	5.8/6.5	G		40	0.0120	0.0190	0.0410	0.0510	0.0755	0.1230	0.1630	0.2070	0.2160	0.2350	0.2520
6AEGR2	A/E	5.8/6.5	G		40	0.0249	0.0387	0.0600	0.0680	0.1060	0.1490	0.1980	0.2350	0.2610	0.2750	0.3080
6AEQR1	A/E	6.2/7.0	Q		40	0.0270	0.0440	0.0730	0.1040	0.1440	0.2080	0.2490	0.2910	0.3190	0.3430	0.3550
6AEQR2	A/E	6.2/7.0	Q		40	0.0370	0.0480	0.0850	0.1260	0.1560	0.2290	0.2860	0.3210	0.3520	0.3780	0.4000
7BFGR1	B/F	5.5/6.0	G		40	0.0340	0.0510	0.0710	0.0140	0.1090	0.1500	0.1650	0.1990	0.2100	0.2200	0.2170
7BFGR2	B/F	5.5/6.0	G		40	0.0300	0.0314	0.0488	0.0957	0.1010	0.1520	0.1750	0.2450	0.2200	0.2340	0.2230
7BFQR1	B/F	5.8/6.5	Q		40	0.0320	0.0522	0.0890	0.1190	0.1510	0.2020	0.2470	0.2760	0.2920		0.3150
7BFQR2	B/F	5.8/6.5	Q		40	0.0310	0.0620	0.0890	0.1380	0.1520	0.2000	0.2240	0.2650	0.3000		0.3220

APPENDIX D

Simple Shear Protocol

Standard Method of Test for

Determining the Shear and Stiffness Behavior of Modified and Unmodified Hot Mix Asphalt with the SUPERPAVE® Shear Test Device

SHRP Designation: M-003[1]

1. SCOPE

1.1 This standard is used to determine the permanent deformation and fatigue cracking characteristics of a bituminous mix. A series of tests are conducted at several temperatures and frequencies in during which the specimen is subjected to repeated axial and shear loads.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *This standard may involve hazardous materials, operations and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. APPLICABLE DOCUMENTS

2.1 *AASHTO Standards:*

T269	Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixes

2.2 *Other documents*:

M002	Preparation of Test Specimens by Means of Gyratory Compaction
M008	Preparation of Test Specimens by Means of Rolling Wheel Compaction
	The SUPERPAVE® Mix Design Manual for New Construction and Overlays

3. APPARATUS AND MATERIALS

NB: The following instructions relate specifically to the SHRP Shear Test Device. These instructions may be inappropriate for other test equipment.

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[1] This standard is based on SHRP Product 1017.

3.1 *Test System*—The test system is capable of applying both vertical and horizontal loads to a specimen. It is also capable of applying static, ramped (increasing or decreasing) and repetitive loads of various waveforms. Loading is provided by two hydraulic actuators (vertical and horizontal) and controlled by closed-loop feedback. Figure 1 illustrates a typical loading condition.

The computer-controlled system is capable of recording load cycles, applied horizontal and vertical loads, and specimen deformation in all directions (axial, horizontal and radial). Provisions have also been made for environmental control and monitoring.

As a minimum, the test system should meet the following requirements.

Load Measurement and Control

Range:	0 to 32 kN
Resolution:	0.02 kN
Accuracy:	± 0.04 kN

Confining Pressure Measurement and Control

Range:	0 to 700 kPa
Resolution:	0.7 kPa
Accuracy:	± 1.4 kPa

Deformation Measurement and Control

Horizontal (Repetitive Shear)		Horizontal (Frequency Sweep) Vertical (Constant Height, Frequency Sweep)	
Range:	5 mm	Range:	± 0.05 mm
Resolution:	0.0025 mm	Resolution:	0.0013 mm
Accuracy:	± 0.005 mm	Accuracy:	± 0.0025 mm

Radial

Range:	± 1.02 mm
Resolution:	0.005 mm
Accuracy:	± 0.01 mm

Temperature Measurement and Control

Range:	−10°C to 80°C
Resolution:	0.25°C
Accuracy:	± 0.5°C

3.2 *Platen-Specimen Assembly Device* (figure 2)—This device is used to facilitate bonding of the specimen to loading platens. The device maintains the platens in a parallel position (relative to each other) when the specimen is glued to them. The platens must be parallel so that stresses do not develop in the specimen when the specimen-platen assembly is clamped in the test system.

3.3 *Miscellaneous Apparatus and Materials:*

3.3.1 calipers for measuring specimen height and diameter;

3.3.2 aluminum loading platens;

3.3.3 quick-set adhesive with a minimum hardened stiffness modulus of 2,070 MPa for bonding platens to specimen ends;

3.3.4 rubber membrane for uniform application of confining pressure;

3.3.5 silicone sealant to seal membrane against platens;

3.3.6 O-rings to secure ends of rubber membrane on platens;

3.3.7 6-mm diameter plastic tube to be inserted between membrane and specimen so as to relieve any internal air pressure;

3.3.8 device(s) for mounting LVDTs.

4. TEST SPECIMENS

4.1 *Compact Asphalt Concrete Specimens*—Specimens should be compacted in accordance with procedures outlined in section 2.2. Specimen dimensions should be 150 mm in diameter and 50 to 65 mm in height for mixes containing a maximum aggregate size of 19 mm or less.[1]

4.2 *Measure Specimen Size*—Measure the height and diameter of the specimen at three different points around its perimeter and report to the nearest 0.025 mm. Average the three measurements and report to the nearest 0.25 mm.

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[1] It is recommended that specimen dimensions be 200 mm in diameter by 75 mm in height for mixes containing a maximum aggregate size greater than 38 mm.

4.3 *Determine Air Void Content*—Determine the air void content in accordance with AASHTO T-269-80.

4.4 *Bonding Specimen to Platens* (Required for all tests except volumetric)—Place platens in the platen-specimen assembly device. Spread thin layer of adhesive (≈ 1.5 mm) on the top and bottom of specimen and the matching face of platen. Lower the top platen onto the specimen and rotate the specimen one full revolution to ensure an even distribution of adhesive between specimen and platens. (Do not block pressure-relief port on the platen with adhesive during the gluing process.) Insert a plastic pressure-relief tube into the port provided in the bottom platen. Follow the adhesive manufacturer's instructions for the time and temperature required to achieve full strength in the adhesive. Leave the specimen in the assembly device until the adhesive has set.

4.5 *Application of Elastic Membrane* (Required for volumetric and uniaxial tests)—Spread a very thin layer of silicone sealant around the perimeter of each platen where the elastic membrane will be in contact with the platen. Stretch the membrane over the top platen and slide it down over the specimen, the pressure-relief tube and the bottom platen. Place the rubber O-rings around the top and bottom of the membrane in the grooves provided around the perimeter of each platen (figure 3).

4.6 *Stabilize Specimen to Test Temperature*—Place the specimen in an oven or other environmentally controlled unit for a minimum of two hours prior to testing to ensure that specimen is at the specified test temperature.

5. TEST PROCEDURES

5.1 *Volumetric/Hydrostatic Test*

5.1.1 *Specimen Setup*—Attach 2 vertical and 1 radial LVDTs to the specimen as shown in figure 4. The vertical LVDTs are used to measure changes in specimen height as represented by changes in the distance between the top and bottom platens. The radial LVDT, which measures changes in the specimen perimeter, should be mounted around the specimen at mid-height and move freely. Completely lower the environmental chamber to seal off the specimen from the outside temperature influences. Testing is conducted at temperatures of 4°C, 20°C, and 40°C ± 0.5°C.

5.1.2 *Testing*—Precondition specimen by applying a confining pressure of 70 kPA for 1 second and then immediately reduce the confining pressure to about 7 kPa. After preconditioning, apply the confining pressure at a rate of 70 kPa per second until reaching the desired level: 550, 690, or 830 kPa at 40, 20, or 4°C, respectively (figure 5). The confining pressure is applied for a total of 10 seconds, after which the confining pressure is relieved at a rate of about 23 kPa per second until reaching a residual confining pressure of about 7 kPa. Continue recording deformation for an additional 30 seconds during this recovery period. Axial and radial deformation, as well as axial load and confining pressure, should be recorded at appropriate intervals during the test, i.e., approximately 10 data points per second.

The following test parameters should be recorded.

- $\sigma_{11} = \sigma_{22} = \sigma_{33}$; confining pressure
- δ_v = vertical displacement of the specimen
- δ_h = radial displacement of the specimen

The following engineering quantities should be calculated.

- $\epsilon_{11} = \epsilon_{22} = \epsilon_{33} = \delta_v/h$; uniaxial strain where h is the height of the specimen

5.2 *Uniaxial Test*

5.2.1 *Specimen Setup*—The test setup is essentially identical to that for the volumetric/hydrostatic test with one exception: a 75-mm circular loading unit is placed between the load cell and top cap to create a more nearly uniform stress distribution. Attach 2 vertical and 1 radial LVDTs to the specimen as shown in figure 4. The vertical LVDTs are used to measure changes in specimen height as represented by changes in the distance between the top and bottom platens. The radial LVDT, which measures changes in the specimen perimeter, should be mounted around the specimen at mid-height and move freely. Completely lower the environmental chamber to seal off the specimen from the outside temperature influences. Testing is conducted at temperatures of 4°C, 20°C, and 40°C ± 0.5°C.

Position the vertical test system head to allow the specimen-platen assembly to slide between the bottom horizontal and top vertical heads. Position the horizontal test head such that the top and bottom test heads are aligned vertically. Slide the specimen between the heads so that it is centered between the heads. Secure the platens to the heads by activating the hydraulic clamps.

5.2.2 *Testing*—Precondition the specimen by applying an axial load corresponding to an axial stress of 70 kPa in 1 second, then immediately reduce the load such that the axial stress is about 7kPa. After preconditioning the specimen, apply an axial load to induce an axial stress at a rate of 70 kPa per second until reaching the desired level: 345, 415 and 655 kPa at 40, 20 and 4°C, respectively (figure 6). The axial load is applied for a total of 10 seconds, after which the axial load is relieved to achieve the release of the axial stress at rate of about 23 kPa per second until reaching a residual stress of about 7 kPA. (The confining pressure is adjusted by closed loop feedback control from the radial LVDT measuring the change in perimeter.) Continue recording data for an additional 30 seconds during this recovery period. Axial and radial deformations, as well as axial load and confining pressure should be recorded at appropriate intervals during the test, i.e., approximately 10 data points per second.

The following test parameters should be recorded.

- axial load (P);
- confining pressure ($\sigma_{22} = \sigma_{33}$);

- vertical displacement of the specimen (δ_v);
- radial displacement of the specimen (δ_h);

The following engineering quantities should be calculated.

- $\sigma_{11} = P/A$ + confining stress ($\sigma_{22} = \sigma_{33}$); axial stress where A is the cross-sectional area of the specimen
- $\epsilon_{11} = \delta_v/h$; uniaxial strain where h is the height of the specimen

5.3 *Frequency Sweep Test*

5.3.1 *Specimen Setup*—Attach vertical and horizontal LVDTs to the specimen as shown in figure 4. The vertical LVDT is used to measure changes in specimen height as represented by changes in the distance between the top and bottom platens. The horizontal LVDTs measure the difference in horizontal displacement between two points on the specimen separated by 37.5 mm. The horizontal LVDTs should be mounted such that they contact the specimen at approximately 19 mm on either side of the specimen at mid-height.

Position the vertical test system head to allow the specimen-platen assembly to slide between the bottom horizontal and top vertical heads. Position the horizontal test head such that the top and bottom test heads are aligned vertically. Slide the specimen between the heads so that it is centered between the heads. Secure the platens to the heads by activating the hydraulic clamps.

Completely lower the environmental chamber to seal off the specimen from the outside temperature influences. Testing is conducted at temperatures of 4°C, 20°C, and 40°C.

5.3.2 *Testing*—The test is conducted at constant height requiring the vertical actuator servovalve to be controlled by the vertical LVDT. Furthermore, this is a *strain-controlled* test with the maximum shear strain limited to 0.0001 mm/mm. Precondition the specimen by applying a sinusoidal horizontal shear strain of amplitude $\approx$ 0.0001 mm/mm at a frequency of 10 Hz for 100 cycles. After preconditioning, a series of 10 tests are conducted in *descending* order of frequency at each temperature level beginning with the lowest temperature. (The shear strain is applied at the following frequencies at each test temperature: 10, 5, 2, 1, 0.5, 0.2, 0.1, 0.05, 0.02 and 0.01 Hz.) Recording 50 data points per load cycle is sufficient. Since the test is conducted at a constant height, the axial actuator is under closed loop feedback control from the LVDT measuring the relative displacement between the specimen caps.

The following test parameters should be recorded.

- axial load (P);
- shear load (V);
- δ_v = vertical displacement of the specimen
- δ_h = horizontal displacement of the specimen

The following engineering quantities should be calculated.

- $\sigma_{11} = P/A$; axial stress where A is the cross-sectional area of the specimen
- $\tau_{12} = V/A$; shear stress
- $\epsilon_{12} = \delta_v/2h$; shear strain where h is the height of the specimen
- $G = \tau_{12}/\epsilon_{12}$; complex shear modulus;
- ψ = phase angle in degrees

5.4 *Simple Shear Test (Constant Height)*

5.4.1 *Specimen Setup*—Attach vertical and horizontal LVDTs to the specimen as shown in figure 4. The vertical LVDT is used to measure changes in specimen height as represented by changes in the distance between the top and bottom platens. The horizontal LVDTs measure the difference in horizontal displacement between two points on the specimen separated by 37.5 mm. The horizontal LVDTs should be mounted such that they contact the specimen at approximately .19 mm on either side of the specimen at mid-height.

Position the vertical test system head to allow the specimen-platen assembly to slide between the bottom (horizontal) and top (vertical) heads. Position the horizontal test head such that the top and bottom test heads are aligned vertically. Slide the specimen between the heads so that it is centered between the heads. Secure the platens to the heads by activating the hydraulic clamps.

Completely lower the environmental chamber to seal off the specimen from the outside temperature influences. Testing is conducted at a temperatures of 4°C, 20°C, and 40°C.

5.4.2 *Testing*—This is a *stress-controlled* test with the feedback to the horizontal actuator servovalve from the magnitude of the shear load. The test is conducted at constant height, requiring the vertical actuator servovalve to be controlled by the vertical LVDT. (i.e., the axial actuator is under closed loop feedback control from the LVDT to measure the relative displacement between the specimen caps.) Precondition the specimen by applying a 7 kPa shear stress for 100 cycles. After preconditioning the specimen, increase the shear stress at a rate of 70 kPa/s and hold for 10 seconds in accordance with figure 7 (35, 105, and 350 kPa at 40, 20 and 4°C, respectively). After 10 seconds, reduce the shear stress to zero at a rate of about 21 kPa/s. Continue to record data for an additional 30 seconds during this recovery period. Axial and shear deformations, as well as axial and shear loads, should be recorded at appropriate intervals during the test, i.e., approximately 10 data points per second.

The following test parameters should be recorded.

- axial load (P);
- shear load (V);
- δ_v = vertical displacement of the specimen
- δ_h = horizontal displacement of the specimen

The following engineering quantities should be calculated.

- $\sigma_{11} = P/A$; axial stress where A is the cross-sectional area of the specimen
- $\tau_{12} = V/A$; shear stress
- $\epsilon_{12} = \delta_v/h$; shear strain where h is the height of the specimen

5.5 *Repetitive Shear Test (Constant Stress Ratio)*

5.5.1 *Specimen Setup*—Attach vertical and horizontal LVDTs to the specimen as shown in figure 4. The vertical LVDT is used to measure changes in specimen height as represented by changes in the distance between the top and bottom platens. The horizontal LVDTs measure the difference in horizontal displacement between two points on the specimen separated by 37.5 mm. The horizontal LVDTs should be mounted such that they contact the specimen at approximately 19 mm on either side of the specimen at mid-height.

Position the vertical test system head to allow the specimen/platen assembly to slide between the bottom (horizontal) and top (vertical) heads. Position the horizontal test head such that the top and bottom test heads are aligned vertically. Slide the specimen between the heads so that it is centered between the heads. Secure the platens to the heads by activating the hydraulic clamps.

Completely lower the environmental chamber to seal off the specimen from the outside temperature. This stress-controlled test is usually performed at an *effective temperature for permanent deformation* (see The SUPERPAVE® Mix Design Manual for New Construction and Overlays, chapter 4), calculated from weather data for the site of the paving project.

5.5.2 *Testing*—This is a constant stress ratio test. The vertical actuator servovalve is controlled by the magnitude of axial load as feedback. The horizontal actuator servovalve is controlled by the magnitude of shear load as feedback. Both axial and shear loads are haversine in shape and are applied such that, at every moment in time during the loading phase, the ratio of axial load to shear load remains constant. Precondition the specimen by applying 100 cycles of **synchronized** haversine axial and shear load pulses (0.1 second on and 0.6 seconds off). The axial stress for preconditioning should not exceed 7 kPa with the ratio of axial to shear stress held constant at a value of 1.2 to 1.5. After preconditioning, the synchronized haversine axial and shear stress pulses should be applied for a total of 5000 repetitions or until 5% shear strain is reached. During testing the ratio of axial to shear stress should be held constant at a value of 1.2 to 1.5. The maximum shear stress level should be determined in accordance with the guidelines in table 1. Axial and shear deformations, as well as axial and shear loads, should be recorded at appropriate intervals. Collecting 60 data points per load cycle is sufficient.

The following test parameters should be recorded.

- axial load (P)
- shear load (V)
- ratio of axial to shear load

Table 1. Guidelines for Shear and Compressive Stress

Base Condition	Maximum Shear (τ) and Compressive (σ_v) Stress Levels (kPa) at Asphalt Binder Content					
	Above Design		At Design		Below Design	
	τ	σ_v	τ	σ_v	τ	σ_v
Weak	84	119	63	98	49	56
Strong	98	175	84	105	56	91

Note: A weak base is defined as an unbound granular or crushed stone material (i.e., new construction), whereas a strong base is defined as an existing asphalt concrete or portland cement concrete pavement, a cement-stabilized or asphalt-stabilized base, or a strong crushed stone base material (i.e., a resilient modulus of 560,000 kPa or greater).

- δ_v = vertical displacement of the specimen
- δ_h = horizontal displacement of the specimen

The following engineering quantities should be calculated.

- $\sigma_{11} = P/A$; axial stress where A is the cross-sectional area of the specimen
- $\tau_{12} = V/A$; shear stress
- $\epsilon_{12} = \delta_v/h$; shear strain where h is the height of the specimen

5.6 *Repetitive Shear Test (Constant Height)*

5.6.1 *Specimen Setup*—Attach vertical and horizontal LVDTs to the specimen as shown in figure 4. The vertical LVDT is used to measure changes in specimen height as represented by changes in the distance between the top and bottom platens. The horizontal LVDTs measure the difference in horizontal displacement between two points on the specimen separated by 37.5 mm. The horizontal LVDTs should be mounted such that they contact the specimen at approximately 19 mm on either side of the specimen at mid-height.

Position the vertical test system head to allow the specimen-platen assembly to slide between the bottom horizontal and top vertical heads. Position the horizontal test head such that the top and bottom test heads are aligned vertically. Slide the specimen between the heads so that it is centered between the heads. Secure the platens to the heads by activating the hydraulic clamps.

Completely lower the environmental chamber to seal off the specimen from the outside temperature influences. Testing is conducted at the seven-day maximum pavement temperature occuring at 50 mm depth.

5.6.2 *Testing*—This is a *stress-controlled* test with the feedback to the horizontal actuator servovalve from the magnitude of the shear load. The test is conducted at constant height requiring the vertical actuator servovalve to be controlled by the vertical LVDT (i.e., the axial actuator is under closed loop feedback control from the LVDT measuring the relative displacement between the specimen caps). Precondition the specimen by applying a haversine load corresponding to a 7 kPa shear stress for 100 cycles (0.1 s on, 0.6 s off). After preconditioning the specimen, apply a 70 kPa haversine shear pulse (0.1 s on and 0.6 s off) for 5000 cycles or until 5% shear strain is reached. Axial and shear deformations, as well as axial and shear loads, should be recorded at appropriate intervals. Collecting 60 data points per load cycle is sufficient.

The following test parameters should be recorded.

- axial load (P)
- shear load (V)
- δ_v = vertical displacement of the specimen
- δ_h = horizontal displacement of the specimen

The following engineering quantities should be calculated.

- $\sigma_{11} = P/A$; axial stress where A is the cross-sectional area of the specimen
- $\tau_{12} = V/A$; shear stress
- $\epsilon_{12} = \delta_v/h$; shear strain where h is the height of the specimen

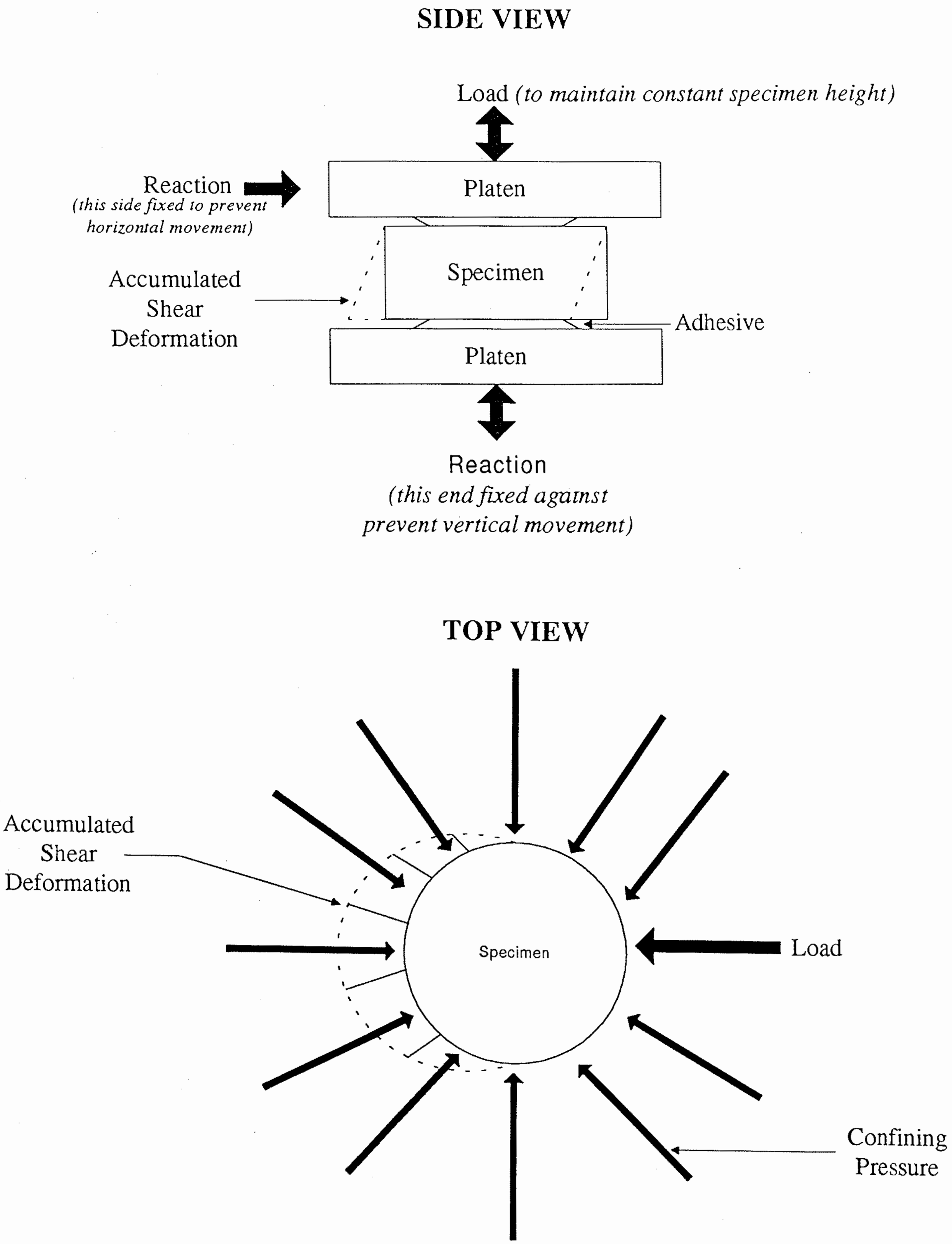

Figure 1. Specimen Loading Conditions

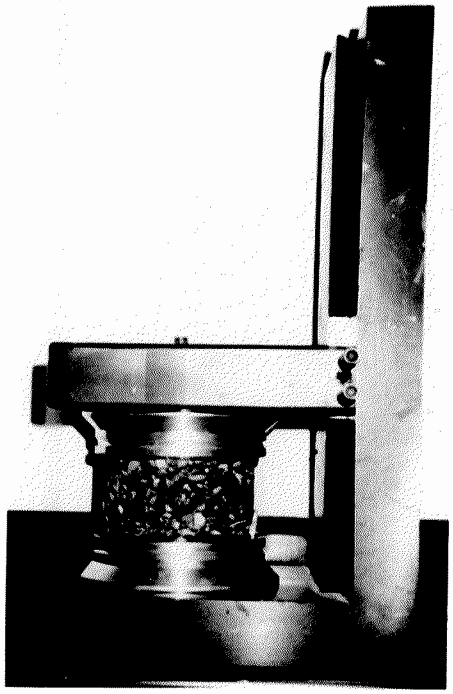

Figure 2. Platen-Specimen Assembly Device

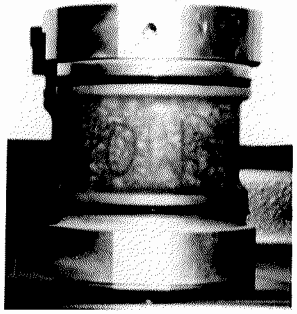

Figure 3. Application of Elastic Membrane and O-rings

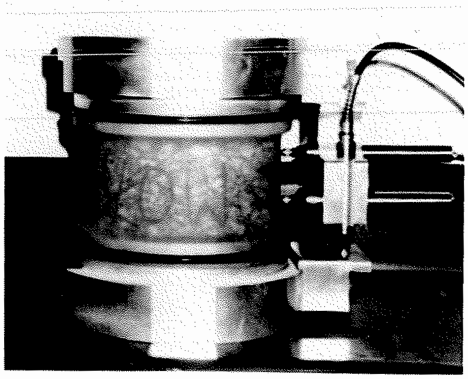

Figure 4. Positioning of Vertical and Horizontal LVDTs (Radial LVDT not shown)

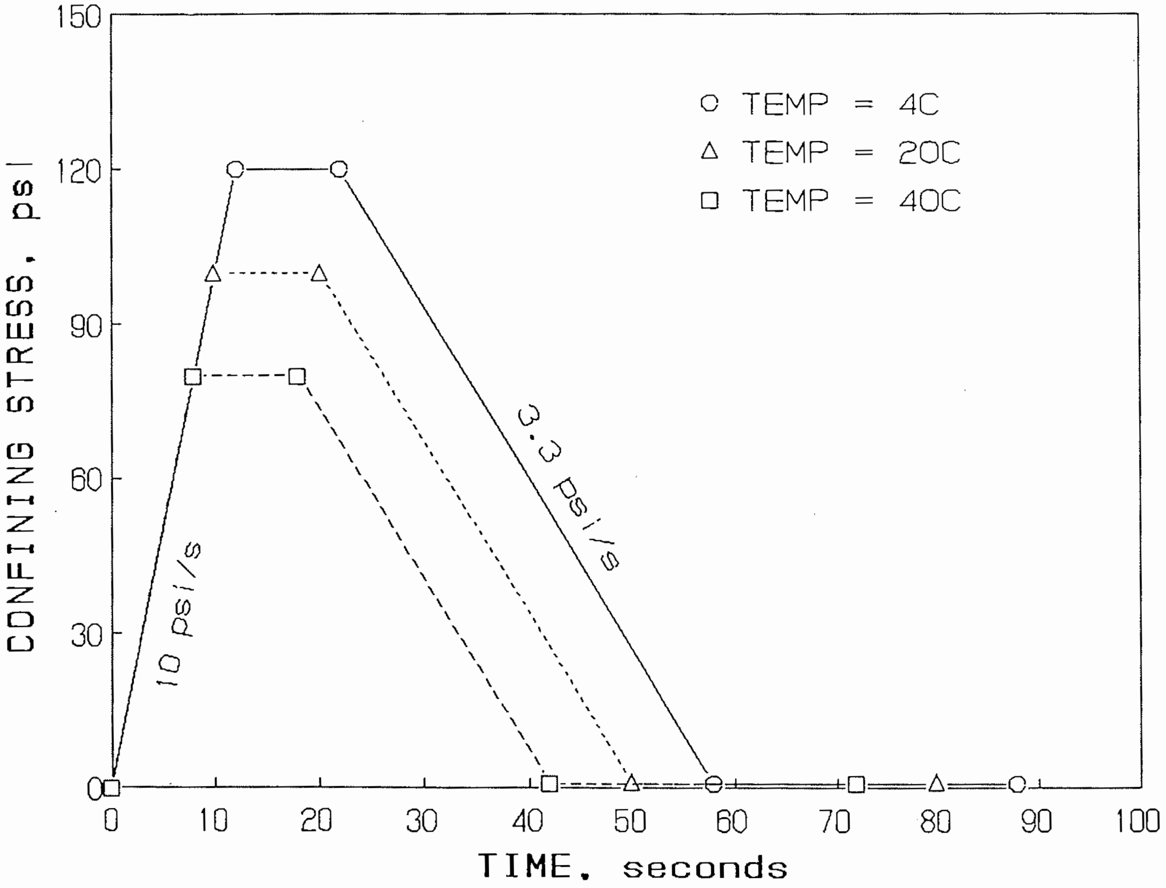

Figure 5. Loading for Volumetric/Hydrostatic Test

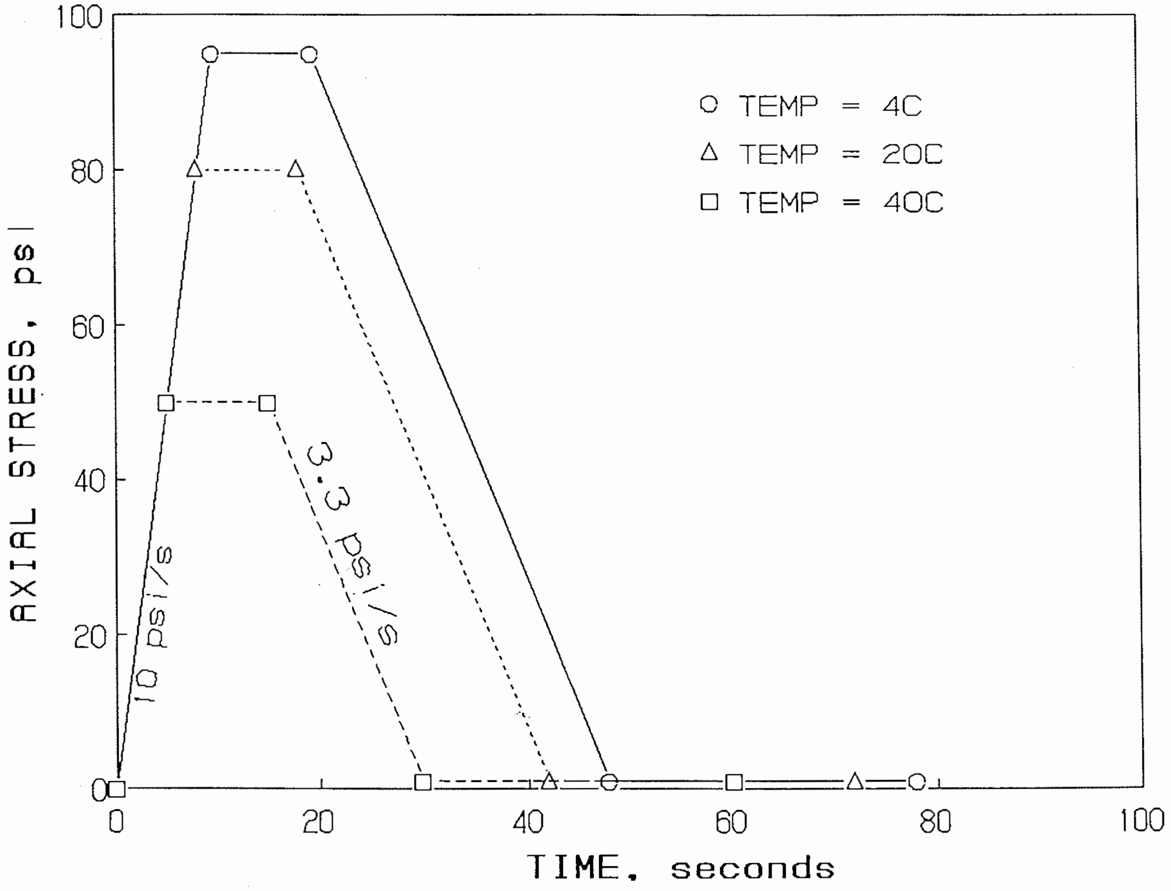

Figure 6. Loading for Uniaxial Strain Test

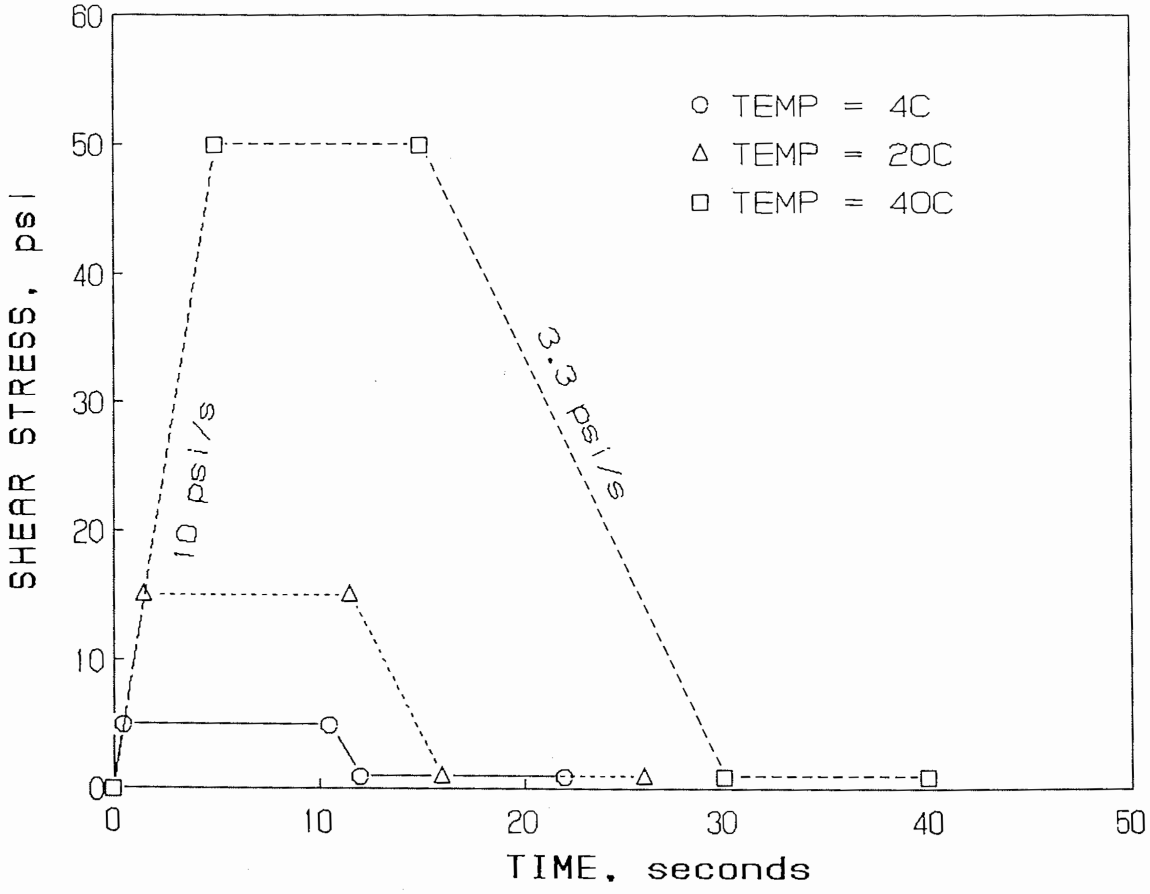

Figure 7. Loading for Simple Shear (Constant Height Test)

APPENDIX E

Simple Shear Test Data

					PERMANENT SHEAR STRAIN @ LOAD CYCLE #																	
Specimen	Mix Type	%AC	Agg	% Air Voids	1	2	3	4	5	6	7	8	9	10	30	50	100	300	500	1000	3000	5000
1ag2c	A	5.8	G	8.7	0.00057	0.00082	0.00107	0.00120	0.00139	0.00155	0.00173	0.00186	0.00202	0.00216	0.00455	0.00609	0.00766	0.01037	0.01332	0.01762	0.02496	0.02971
1ag2a	A	5.8	G	8.3	0.00064	0.00088	0.00109	0.00130	0.00148	0.00164	0.00177	0.00195	0.00207	0.00221	0.00361	0.00423	0.00509	0.00702	0.00871	0.01198	0.01905	0.02314
1aqb	A	8.2	Q	7.8	0.00073	0.00100	0.00127	0.00150	0.00175	0.00195	0.00214	0.00239	0.00257	0.00275	0.00498	0.00602	0.00764	0.01200	0.01480	0.02105	0.02994	
1aqa	A	6.2	Q	8.0	0.00048	0.00068	0.00086	0.00102	0.00116	0.00125	0.00141	0.00152	0.00164	0.00175	0.00332	0.00427	0.00566	0.00821	0.00948	0.01150	0.01589	0.01791
2bq2b	B	5.8	Q	4.1	0.00039	0.00052	0.00070	0.00077	0.00089	0.00100	0.00107	0.00118	0.00127	0.00134	0.00271	0.00366	0.00561	0.00948	0.01230	0.01759	0.02560	0.03096
2bq2a	B	5.8	Q	4.6	0.00025	0.00039	0.00050	0.00055	0.00064	0.00073	0.00077	0.00086	0.00098	0.00100	0.00202	0.00288	0.00373	0.00584	0.00718	0.00987	0.01503	0.01862
2bga	B	5.5	G	7.1	0.00059	0.00084	0.00107	0.00123	0.00141	0.00155	0.00168	0.00186	0.00202	0.00214	0.00448	0.00618	0.00800	0.01000	0.01155	0.01650	0.02735	0.03032
2bgb	B	5.5	G	6.0	0.00045	0.00066	0.00080	0.00093	0.00105	0.00118	0.00130	0.00141	0.00148	0.00157	0.00298	0.00396	0.00575	0.00932	0.01157	0.01591	0.02505	0.03144
2bg3a	B	5.5	G	8.4	0.00607	0.00793	0.00950	0.01093	0.01228	0.01332	0.01425	0.01505	0.01587	0.01659	0.02528	0.02992	0.03787					
2bg3b	B	5.5	G	8.9	0.00643	0.00837	0.00982	0.01116	0.01237	0.01353	0.01453	0.01541	0.01619	0.01684	0.02576	0.03112	0.03994					
2bq3a	B	5.8	Q	6.5	0.00416	0.00539	0.00650	0.00752	0.00862	0.00962	0.01048	0.01121	0.01187	0.01246	0.02009	0.02391	0.03042	0.04326	0.05049			
2bq3b	B	5.8	Q	3.6	0.00452	0.00571	0.00639	0.00687	0.00743	0.00818	0.00909	0.01002	0.01073	0.01128	0.01744	0.02089	0.02641	0.03792	0.04501			
2bq3c	B	5.8	Q	5.7	0.00277	0.00371	0.00443	0.00505	0.00559	0.00607	0.00659	0.00696	0.00732	0.00766	0.01175	0.01439	0.01834	0.02641	0.03126	0.03953		
3cga	C	5.8	G	7.7	0.00050	0.00070	0.00086	0.00105	0.00118	0.00132	0.00145	0.00157	0.00166	0.00173	0.00268	0.00318	0.00386	0.00546	0.00696	0.01046	0.01953	0.02173
3cgc	C	5.8	G	6.7	0.00068	0.00095	0.00118	0.00139	0.00157	0.00173	0.00193	0.00205	0.00225	0.00241	0.00452	0.00593	0.00825	0.01378	0.01712	0.02246	0.03280	0.03869
3cqa	C	6.5	Q	6.8	0.00055	0.00077	0.00095	0.00109	0.00123	0.00139	0.00148	0.00161	0.00173	0.00186	0.00339	0.00443	0.00618	0.00941	0.01173	0.01493	0.02380	0.02551
3cqc	C	6.5	Q	7.2	0.00070	0.00098	0.00118	0.00143	0.00157	0.00177	0.00193	0.00205	0.00216	0.00225	0.00346	0.00409	0.00525	0.00889	0.01148	0.01591	0.02439	0.03230
4fg1a	F	6	G	17.7	0.00100	0.00145	0.00184	0.00221	0.00255	0.00293	0.00325	0.00361	0.00393	0.00430	0.00816	0.01032	0.01407	0.02205	0.02671	0.03455	0.04592	0.05319
4fg1c	F	6	G	18.4	0.00134	0.00184	0.00230	0.00271	0.00311	0.00348	0.00384	0.00421	0.00450	0.00484	0.00973	0.01291	0.01905	0.03167	0.03933	0.05267		
4fqa	F	6.5	Q	18.7	0.00268	0.00375	0.00475	0.00564	0.00648	0.00723	0.00787	0.00855	0.00918	0.00980	0.01914	0.02555	0.03633					
4fqb	F	6.5	Q	16.5	0.00189	0.00266	0.00330	0.00396	0.00455	0.00505	0.00561	0.00614	0.00664	0.00714	0.01443	0.01939	0.02762	0.04437	0.05308			
4fg2a	F	6	G	14.7	0.00830	0.01132	0.01378	0.01614	0.01821	0.01980	0.02116	0.02253	0.02378	0.02489	0.03826	0.04603						
4fg2b	F	6	G	15.2	0.01193	0.01657	0.02028	0.02353	0.02832	0.02869	0.03087	0.03305	0.03487	0.03655								
4fg2c	F	6	G	15.1	0.00791	0.01052	0.01293	0.01516	0.01721	0.01880	0.02041	0.02189	0.02341	0.02480	0.03994	0.04962						
4fq2a	F	6.5	Q	12.0	0.01414	0.01939	0.02382	0.02757	0.03096	0.03392	0.03648	0.03848	0.04044	0.04255								
4fq2b	F	6.5	Q	9.8	0.01305	0.01719	0.02048	0.02325	0.02596	0.02814	0.02998	0.03171	0.03332	0.03483	0.05212							
4fq2c	F	6.5	Q	16.4	0.00816	0.01002	0.01162	0.01296	0.01414	0.01518	0.01607	0.01696	0.01769	0.01632	0.02641	0.03103	0.03862					
4fg3s1	F	6	G	7.2	0.00225	0.00321	0.00405	0.00482	0.00557	0.00618	0.00677	0.00739	0.00796	0.00846	0.01553	0.01969	0.02685	0.03444	0.04558			
4fg3s2	F	6	G	6.8	0.00182	0.00255	0.00318	0.00382	0.00441	0.00505	0.00557	0.00618	0.00677	0.00725	0.01437	0.01891	0.02607	0.03421	0.04642			
4fg3s3	F	6	G	9.2	0.00205	0.00280	0.00336	0.00386	0.00434	0.00484	0.00521	0.00555	0.00591	0.00630	0.01137	0.01464	0.01971	0.02621	0.03617	0.04458		
4fq4s2	F	6.5	Q	7.8	0.00409	0.00564	0.00614	0.00884	0.01021	0.01128	0.01230	0.01330	0.01423	0.01512	0.02785	0.03503	0.04576					
4fqcs3	F	6.5	Q	8.3	0.00409	0.00557	0.00698	0.00825	0.00941	0.01055	0.01157	0.01255	0.01289	0.01453	0.02644	0.03389	0.04492					
4fq4s3	F	6.5	Q	6.0	0.00250	0.00352	0.00455	0.00548	0.00627	0.00700	0.00759	0.00816	0.00873	0.00921	0.01737	0.02200	0.02803	0.03410	0.04437	0.05433		