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.

17. Key Words

Asphalt concrete, rutting, wheel-tracking, SHRP shear device, open-graded, large stone

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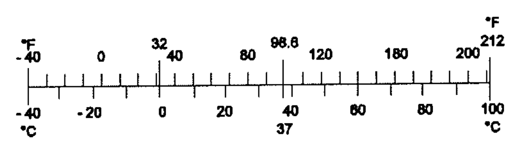
SI* (MODERN METRIC) CONVERSION FACTORS

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.				
		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.

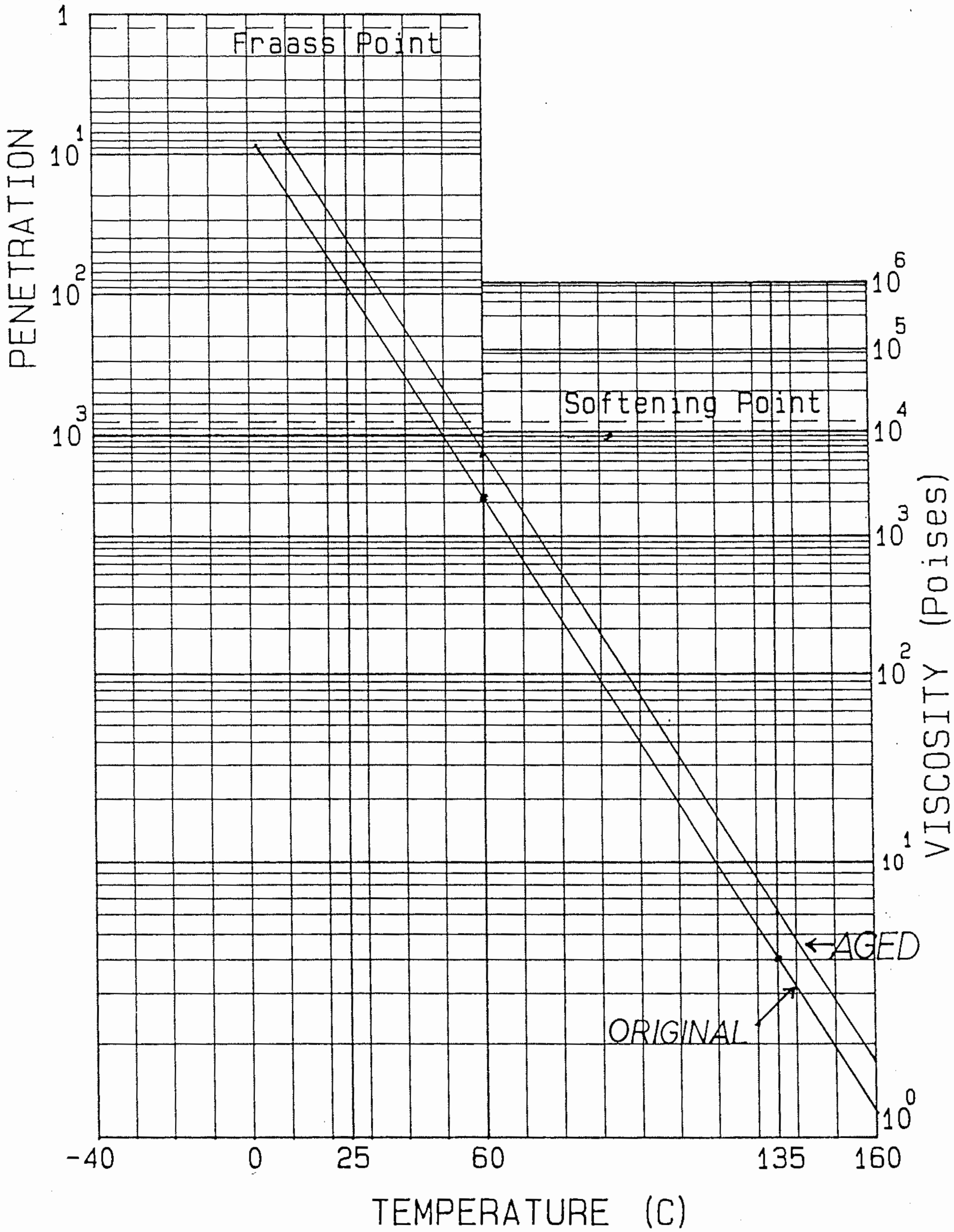


Figure 2.1. Temperature Viscosity Curves for PBA-5.

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.

<table>
<tr><th rowspan="2">Size</th><th colspan="7">% Passing for each mix</th></tr>
<tr><th>A</th><th>B-Single Mix</th><th>B-Layered</th><th>C</th><th>E-Layered</th><th>F-Single Mix</th><th>F-Layered</th></tr>
<tr><td>1½</td><td>100</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>1¼</td><td>97.9</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>1</td><td>87.0</td><td>100</td><td>100</td><td></td><td></td><td>100</td><td>100</td></tr>
<tr><td>¾</td><td>79.1</td><td>97.0</td><td>97.0</td><td>100</td><td>100</td><td>91.5</td><td>90.4</td></tr>
<tr><td>½</td><td>64.5</td><td>85.3</td><td>85.4</td><td>98.2</td><td>95.2</td><td>69.9</td><td>67.7</td></tr>
<tr><td>3/8</td><td>56.0</td><td>75.1</td><td>74.9</td><td>80.1</td><td>69.6</td><td>41.8</td><td>42.3</td></tr>
<tr><td>¼</td><td>47.4</td><td>61.7</td><td>61.9</td><td>61.4</td><td>38.8</td><td>24.6</td><td>24.1</td></tr>
<tr><td>10</td><td>25.0</td><td>28.3</td><td>29.0</td><td>30.8</td><td>9.4</td><td>13.6</td><td>13.9</td></tr>
<tr><td>40</td><td>11.5</td><td>12.2</td><td>12.2</td><td>13.3</td><td>4.5</td><td>6.3</td><td>6.6</td></tr>
<tr><td>200</td><td>5.0</td><td>5.1</td><td>5.4</td><td>5.2</td><td>2.1</td><td>3.6</td><td>3.9</td></tr>
<tr><td>AC % of total mix</td><td>5.8</td><td colspan="2">5.5</td><td>5.8</td><td>6.5</td><td colspan="2">6.0</td></tr>
<tr><td>Rice Specific Gravity</td><td>2.463</td><td colspan="2">2.467</td><td>2.455</td><td>2.429</td><td colspan="2">2.456</td></tr>
</table>

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.

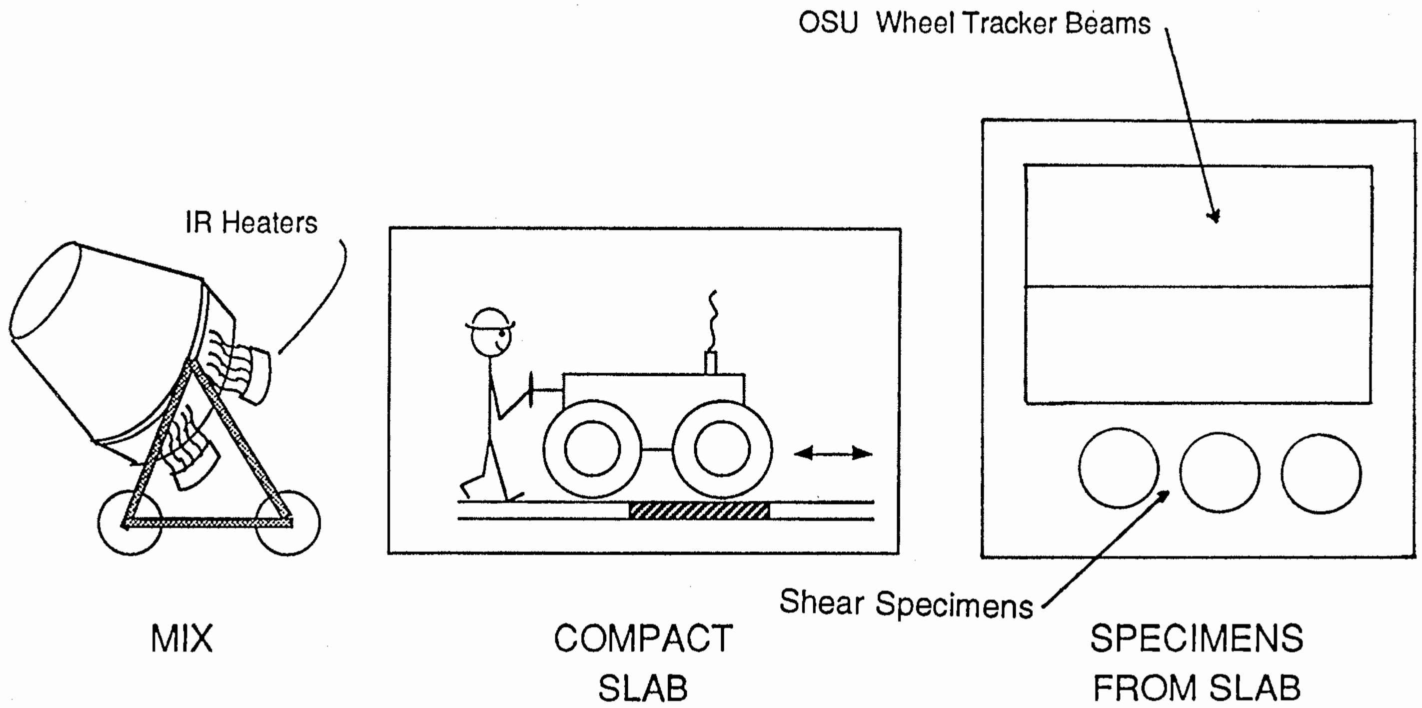


Figure 3.1. Mixing, Compaction and Sampling Process.

Figure 3.2. Photo of Mixer.

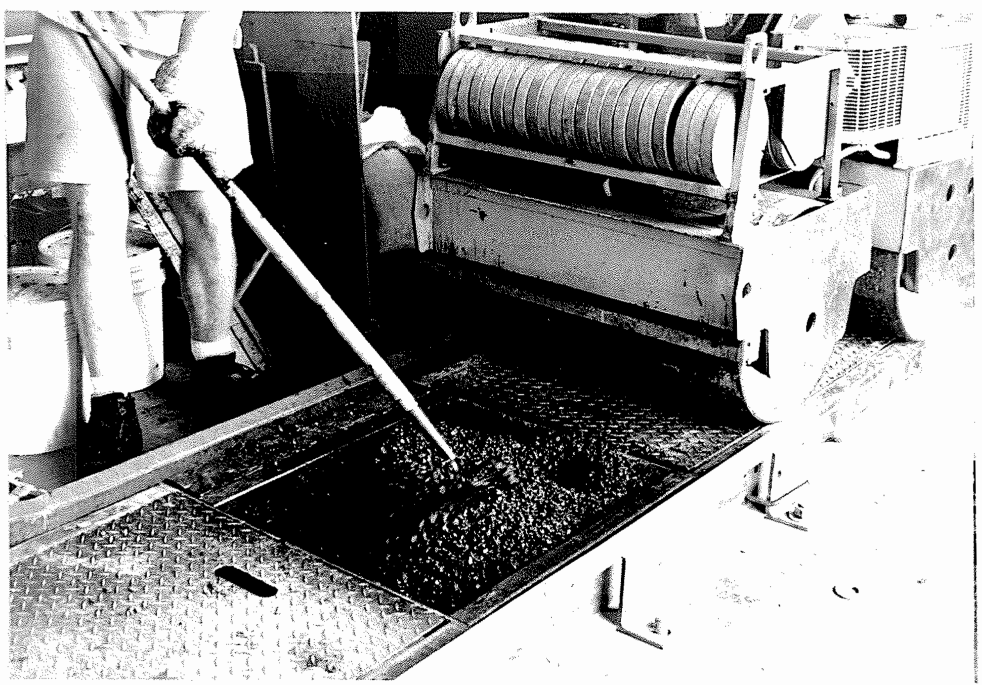


Figure 3.3. Photo of Compaction Process.

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.

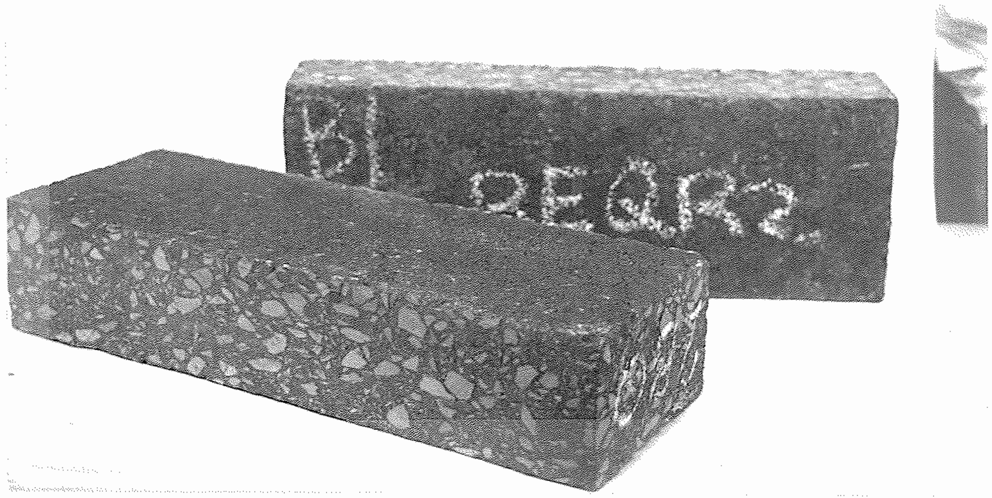
3.1.3 Cutting

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.

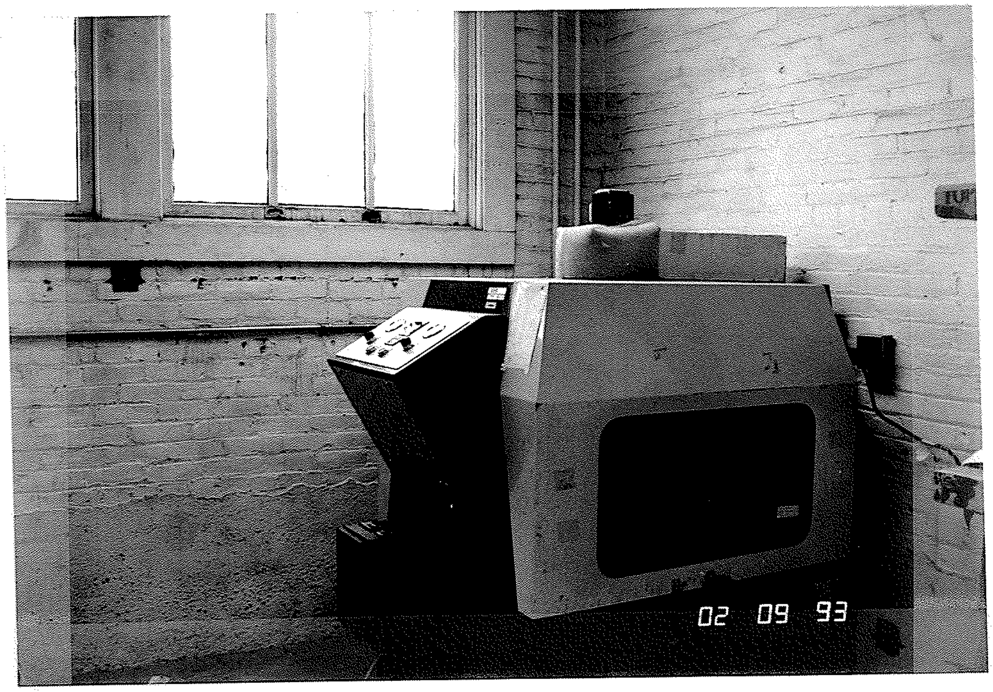
4.0 LCPC TEST RESULTS

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.

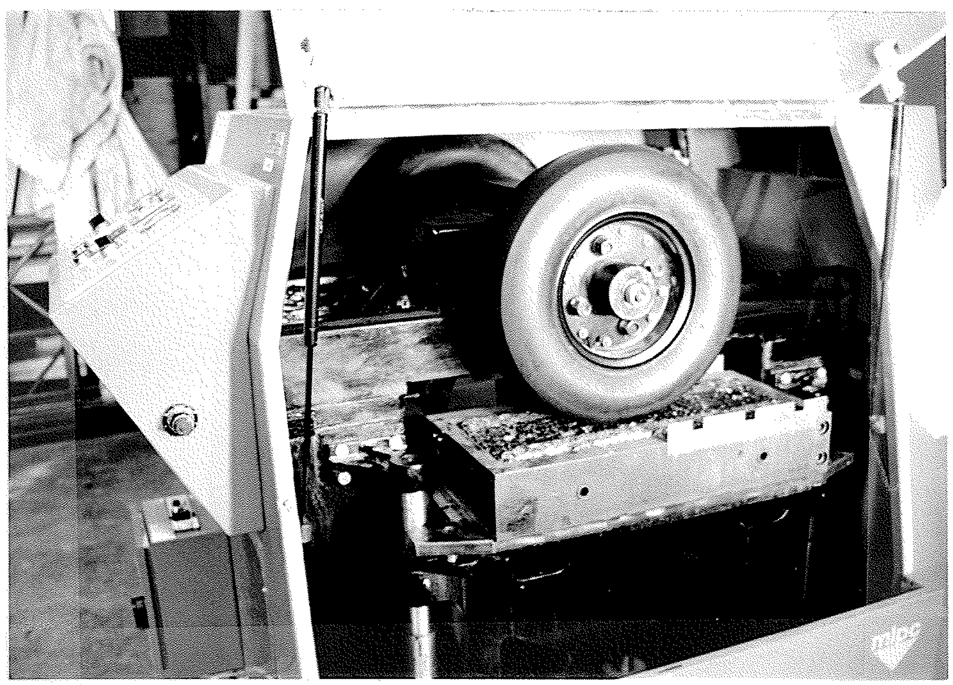
4.1 Procedure

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.

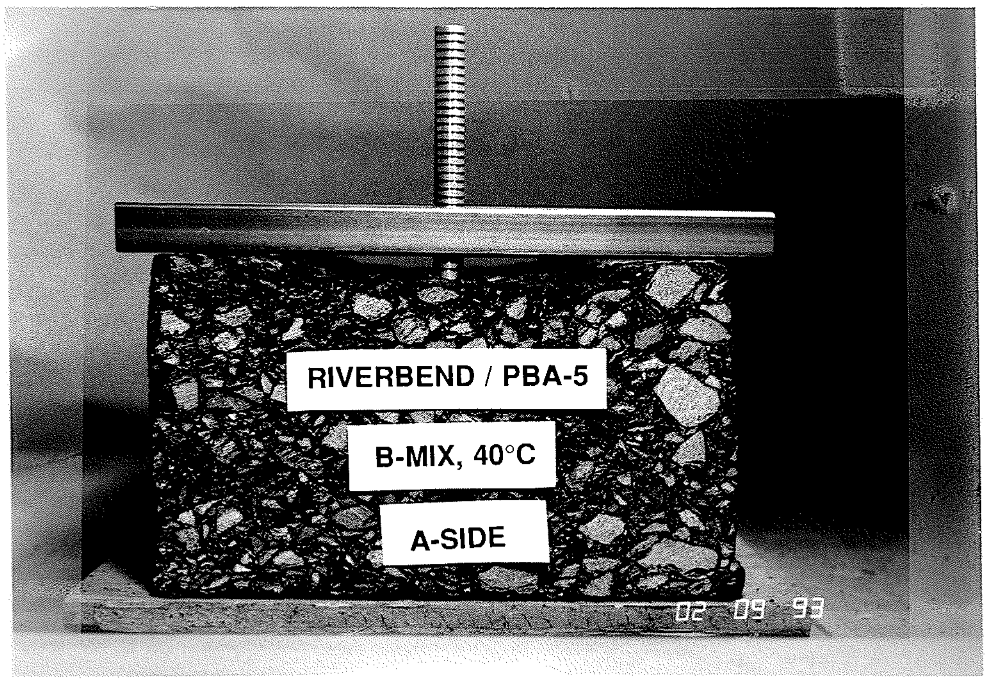


a) Overview

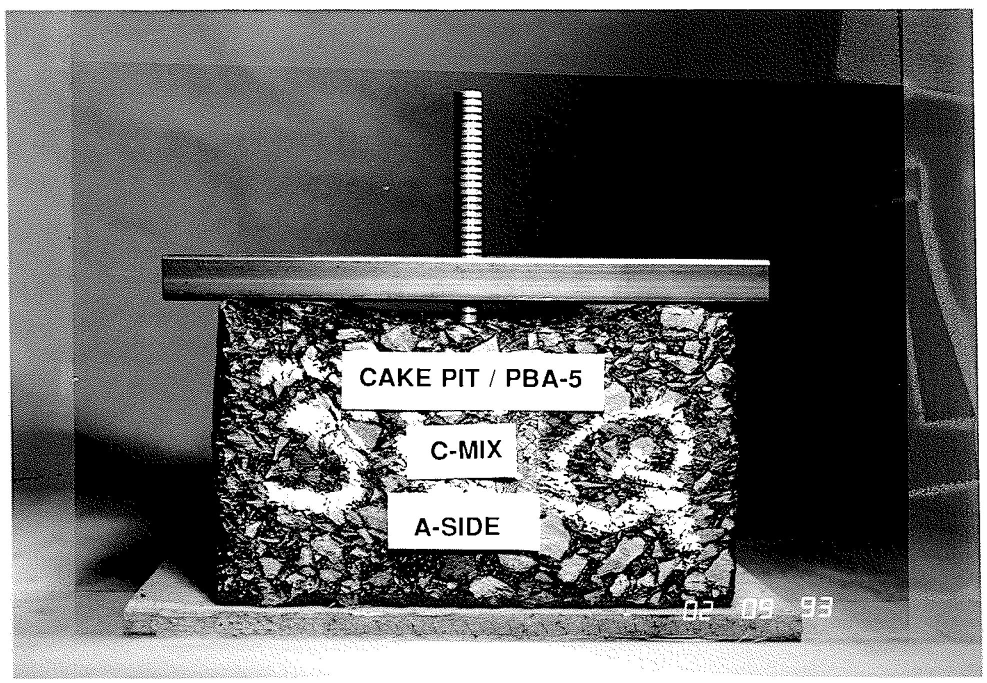


b) Close Up of Specimen

Figure 4.1. Photo of Test Equipment

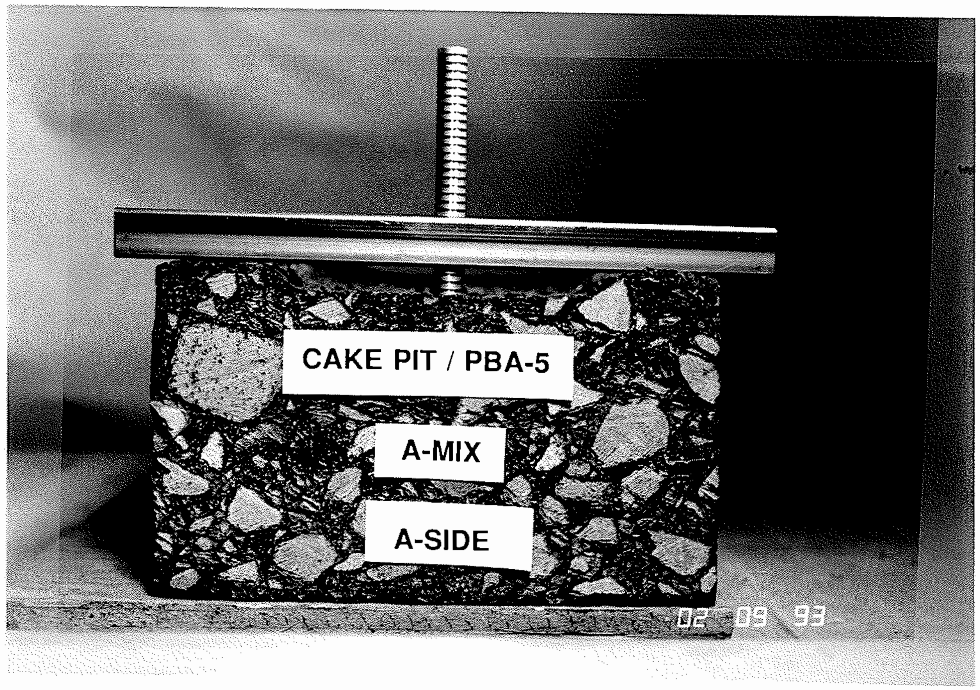


a) B-Mix

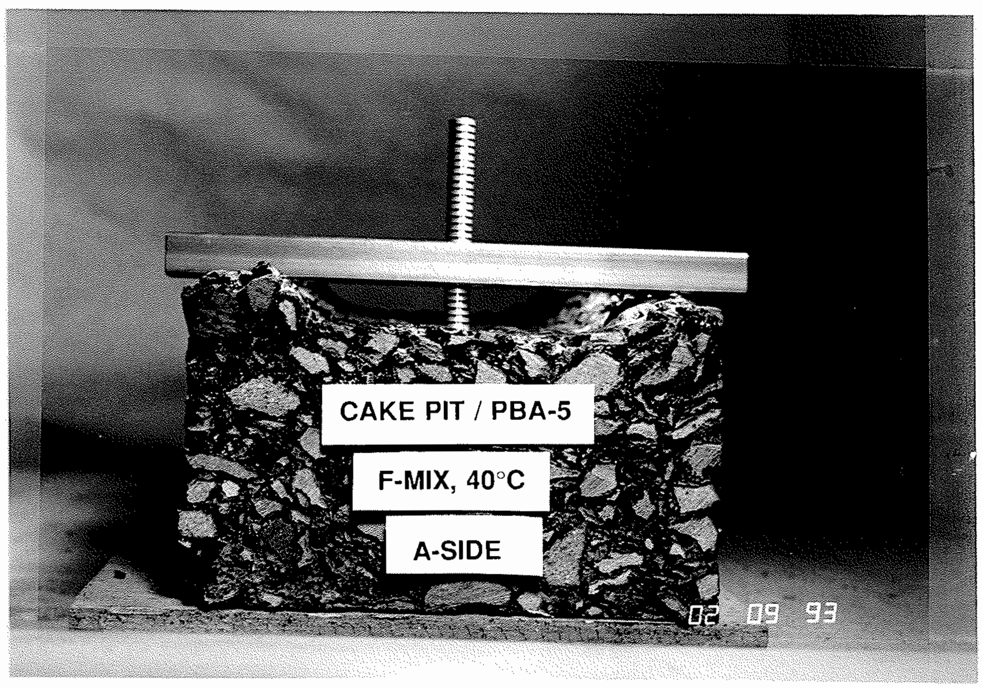


b) C-Mix

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

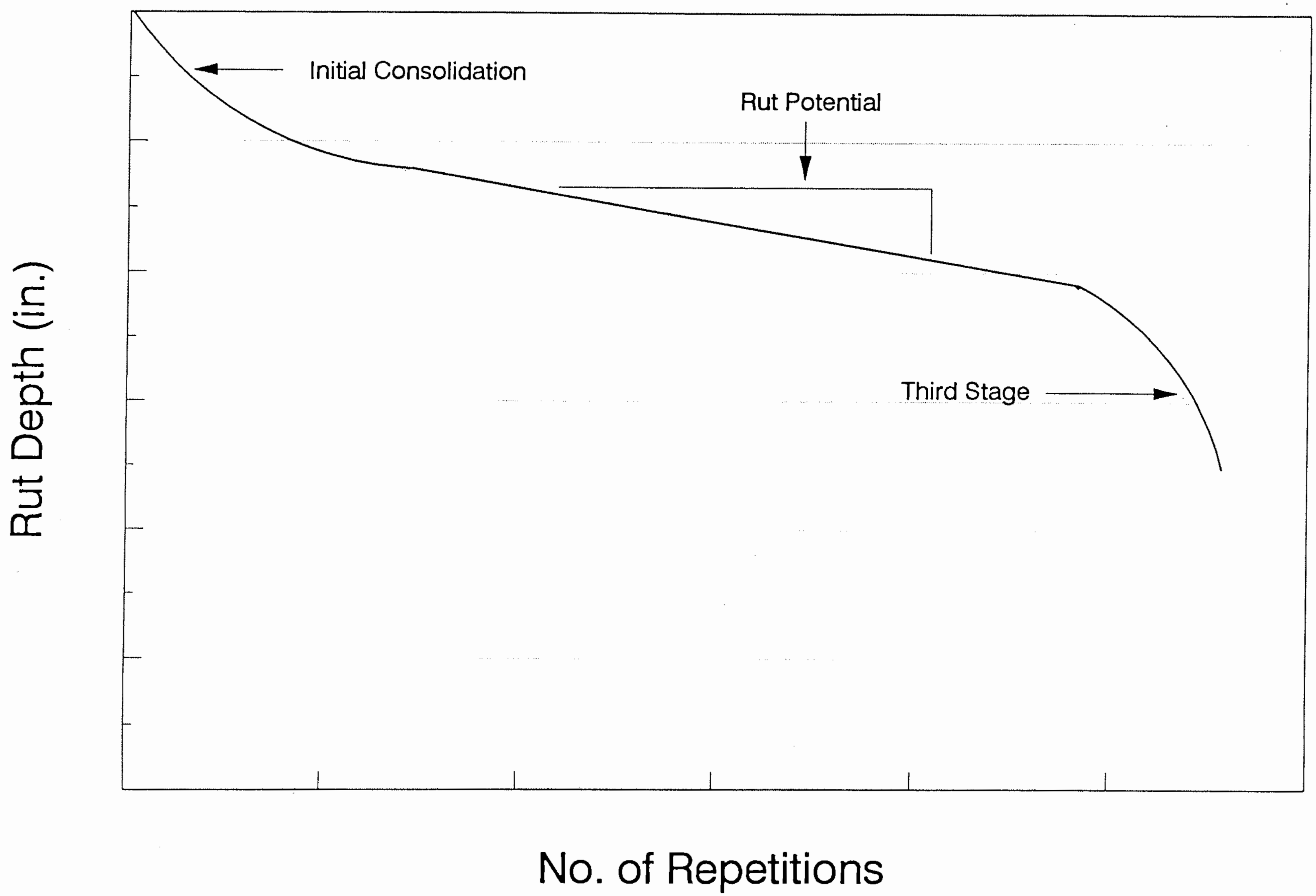


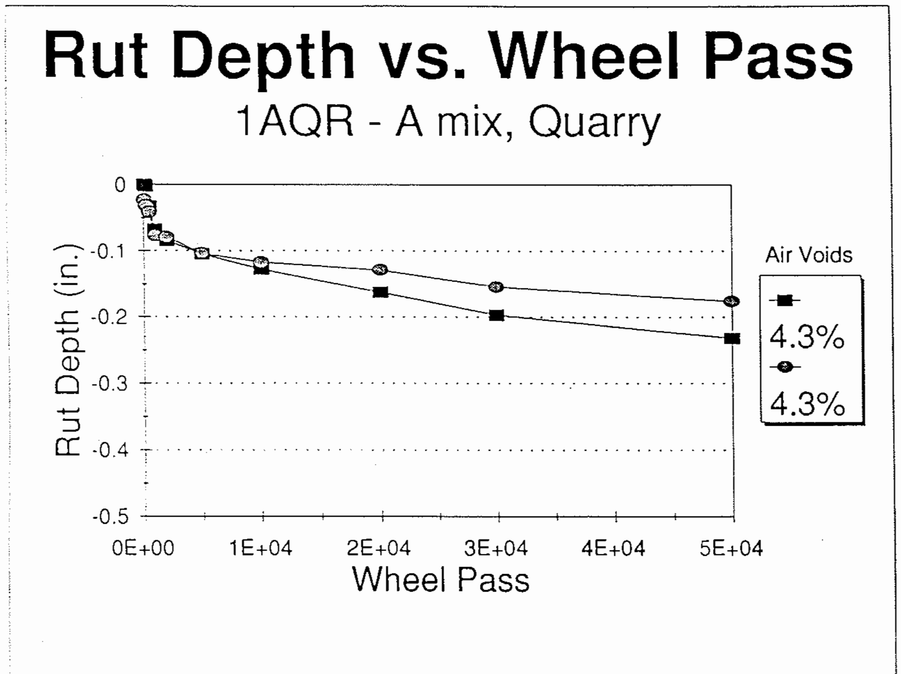
Figure 4.3. Reporting Format for Wheel Tracking Data.

Table 4.1. Summary of LCPC Test Results.

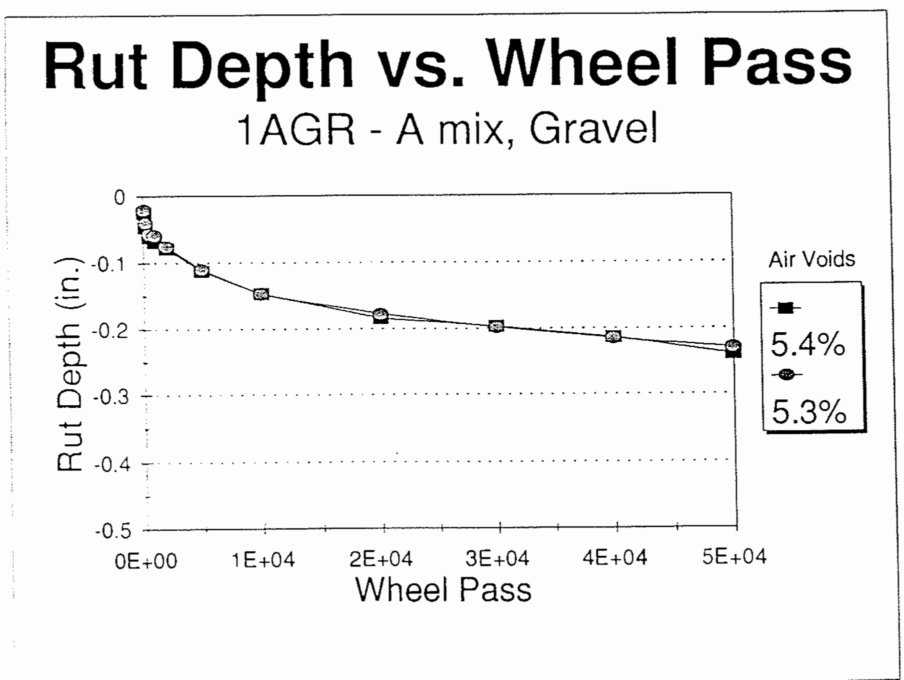
Mix Type	Average Rut Depth @ 50,000 reps (in.)		Average Rut Potential* ($\times 10^{-6}$)	
	Gravel	Quarry	Gravel	Quarry
A-40	0.23	0.20	2.2	2.0
B-40	0.18	0.19	1.3	1.4
B-60	0.38	0.28	3.62	2.47
C-40	0.19	0.21	1.4	1.58
F-40	0.48	0.44	6.46	3.42
F-60	0.61	0.77 @ 5000 reps	5.52	47.0
BE-40	0.27	0.29	1.98	2.80
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

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

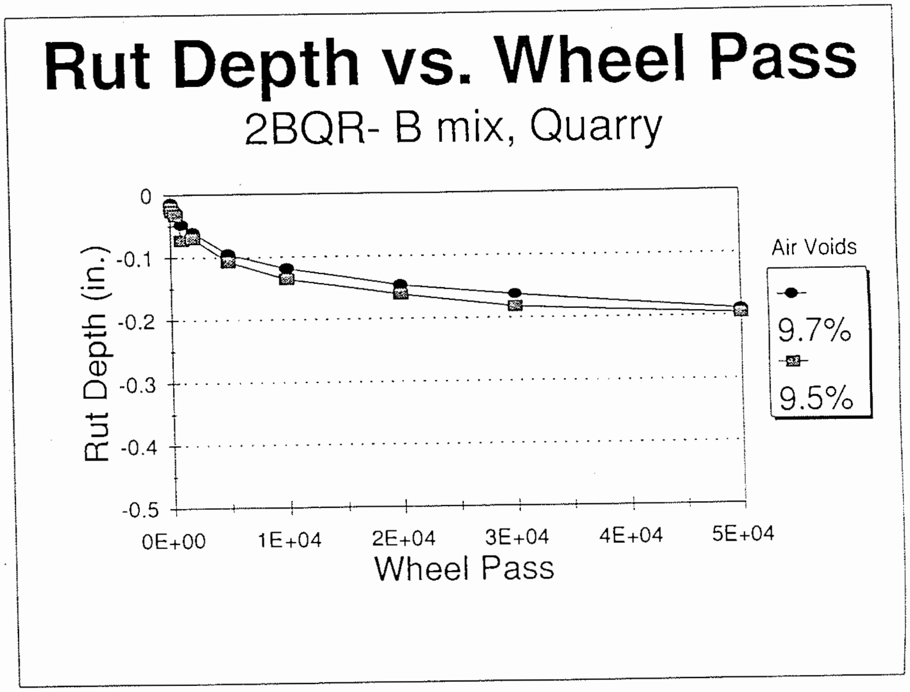


a) Quarry

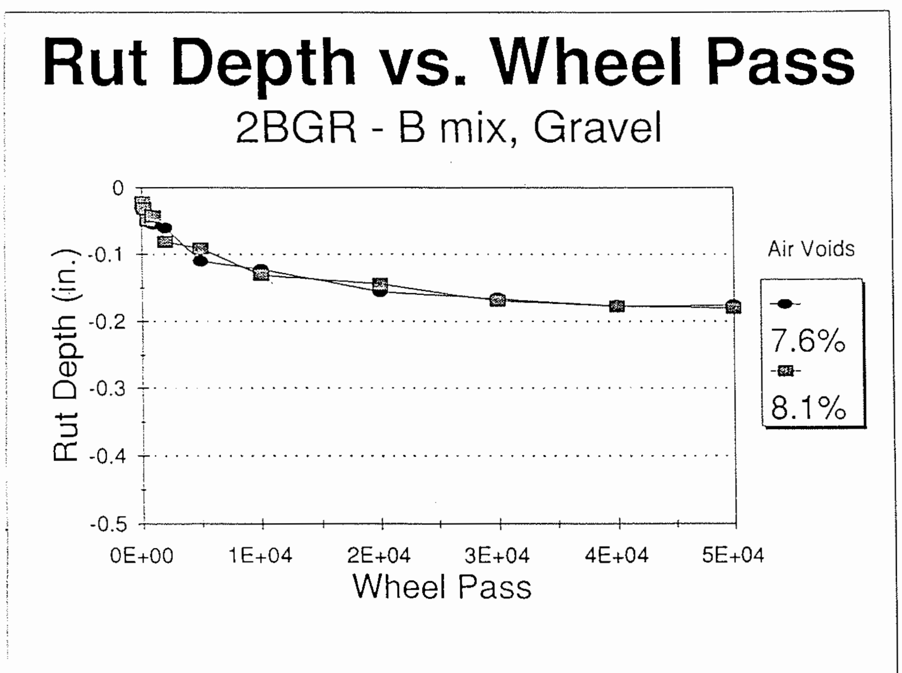


b) Gravel

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

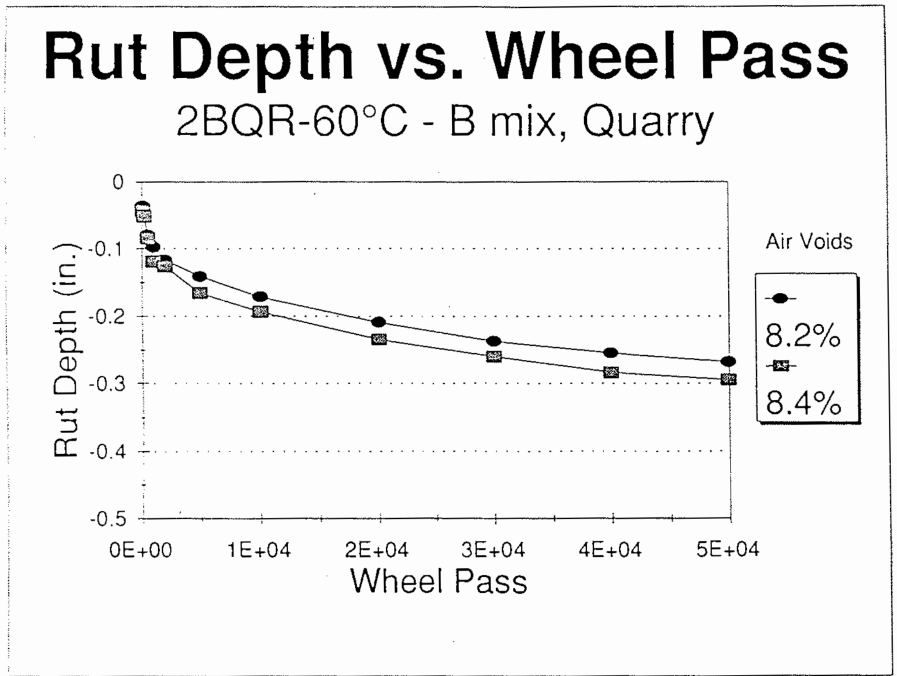


a) Quarry

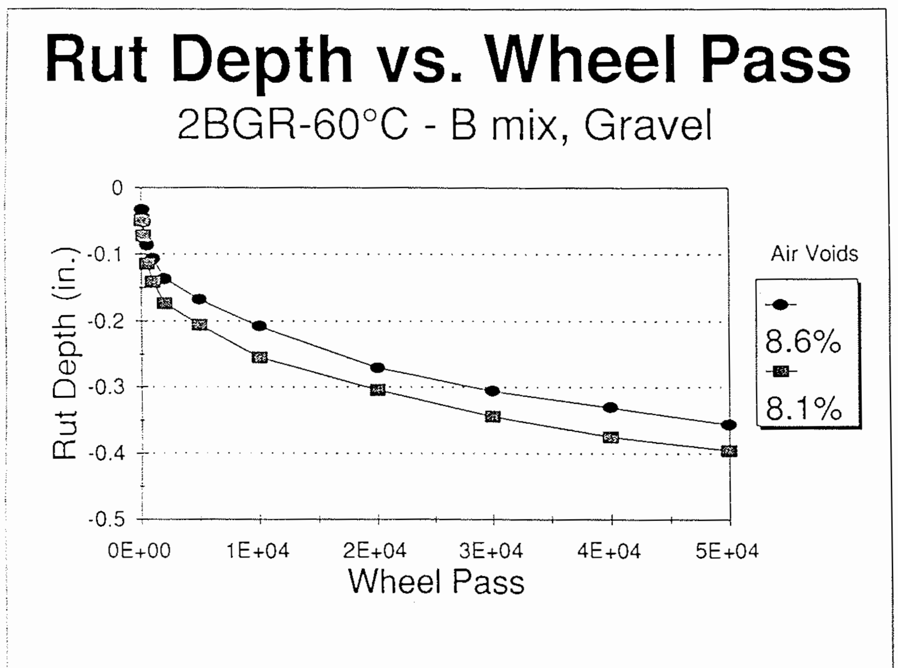


b) Gravel

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

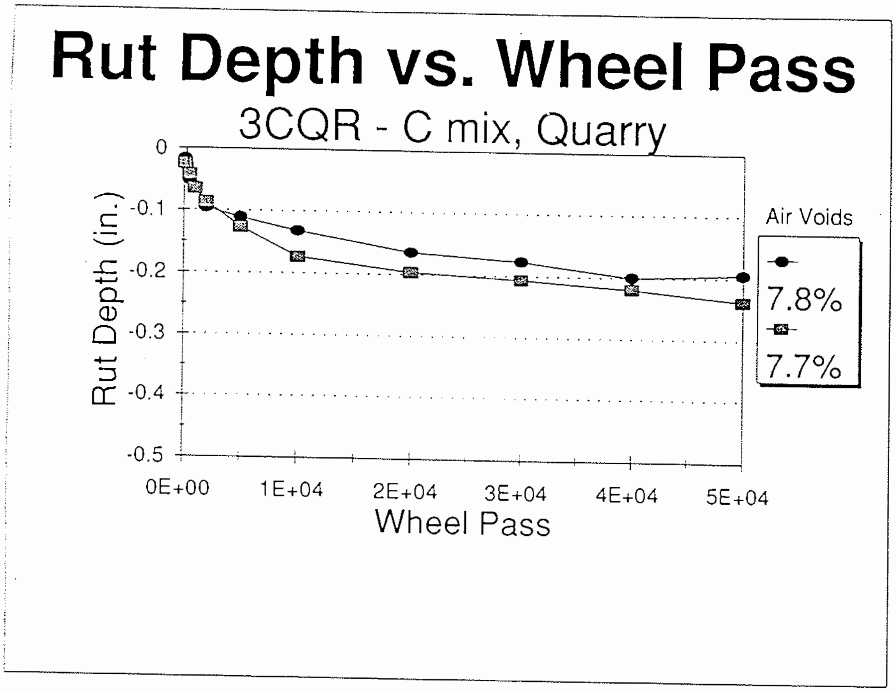


a) Quarry

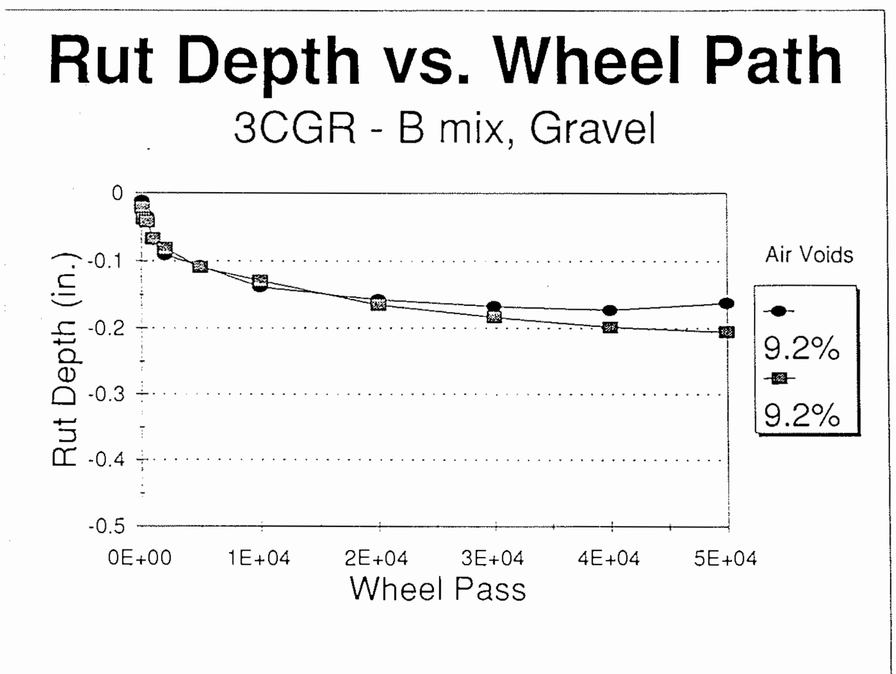


b) Gravel

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

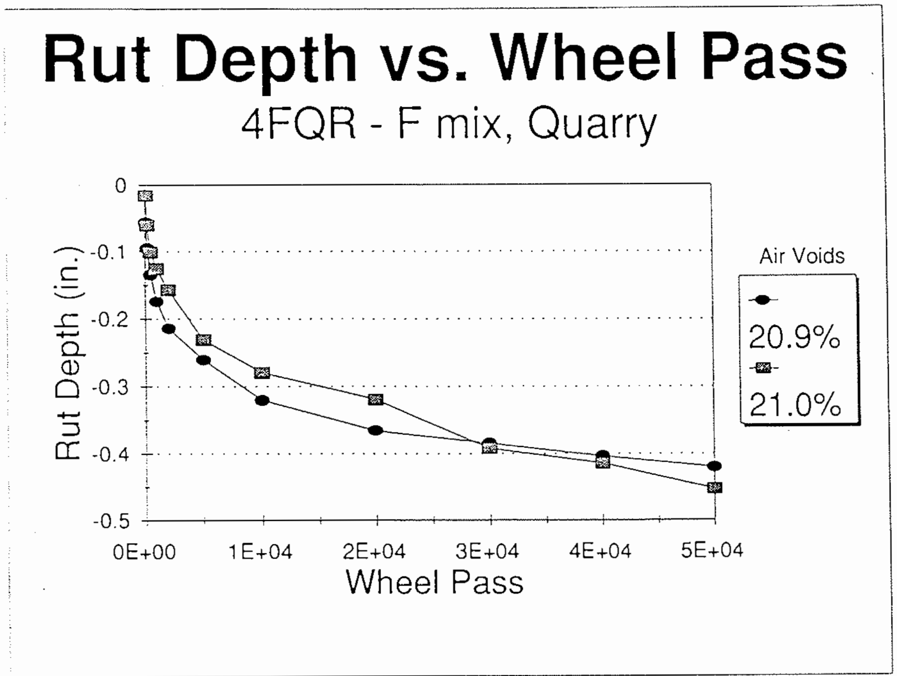


a) Quarry

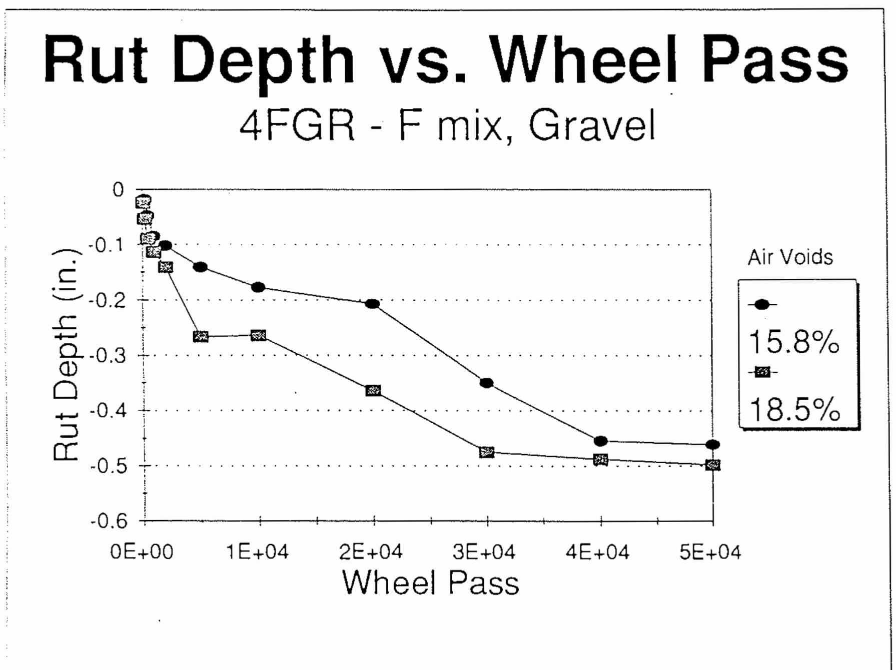


b) Gravel

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

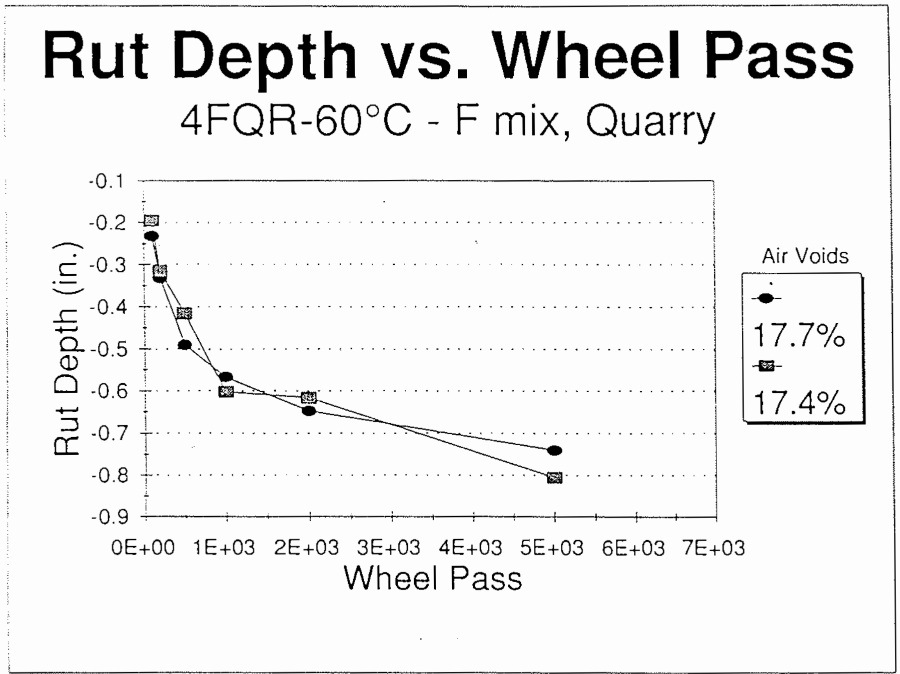


a) Quarry

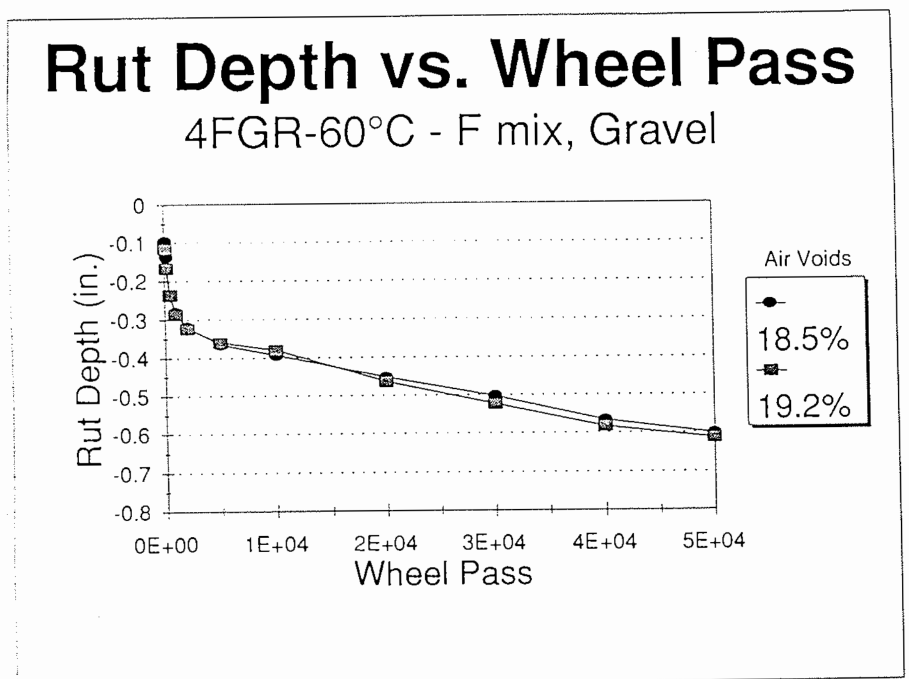


b) Gravel

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

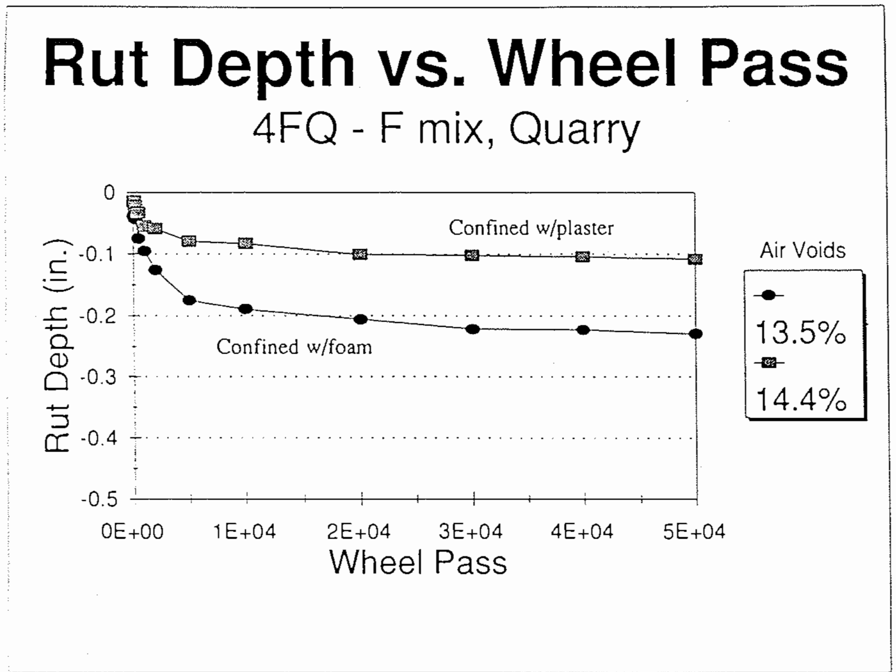


a) Quarry

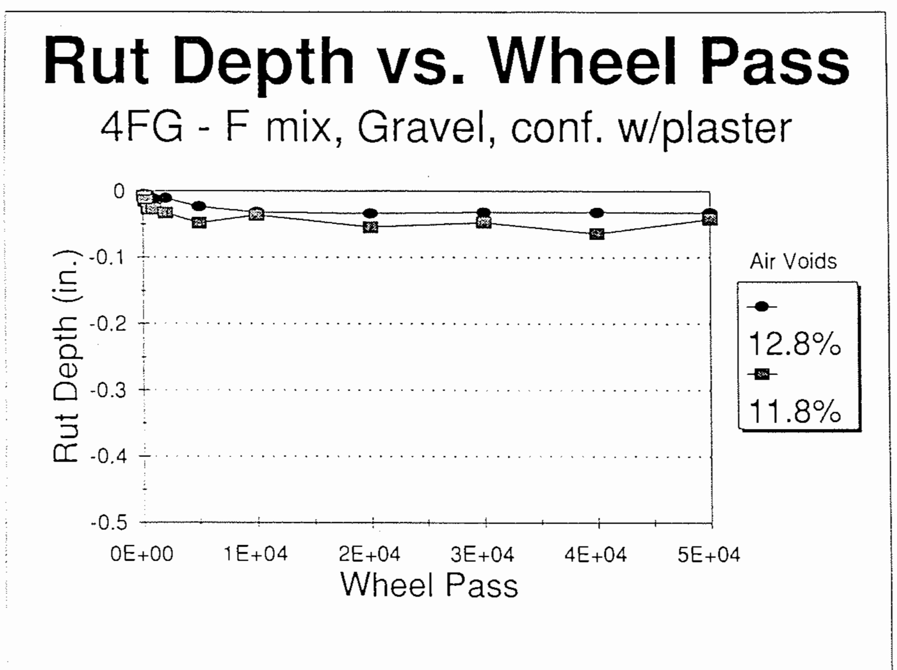


b) Gravel

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

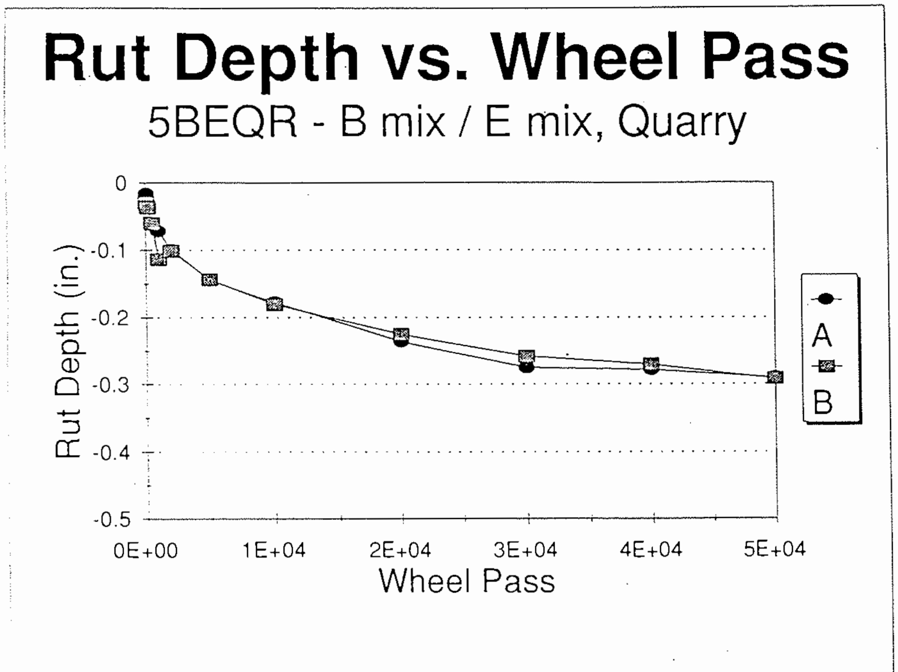


a) Quarry

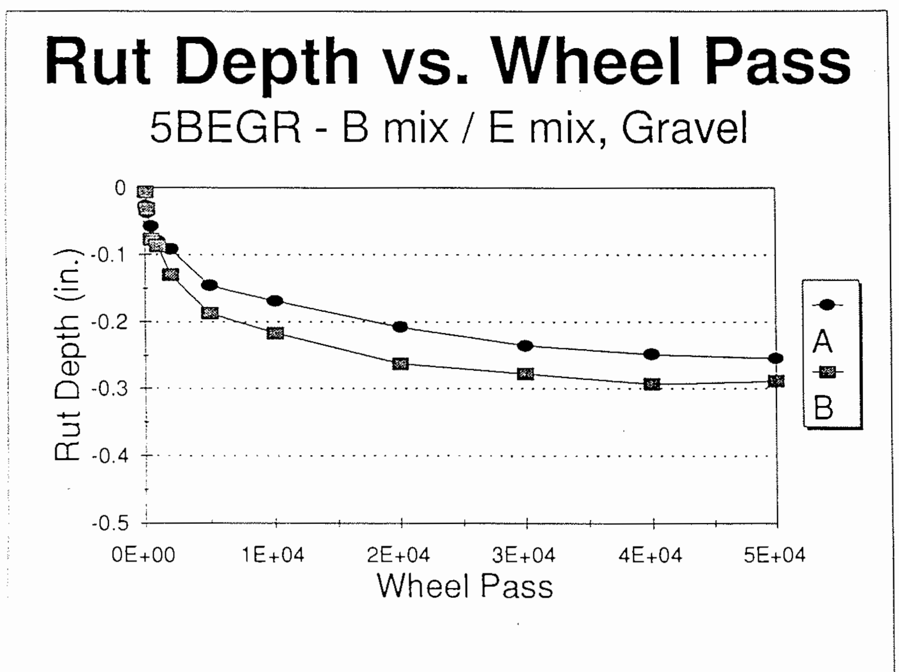


b) Gravel (Confined with plaster)

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

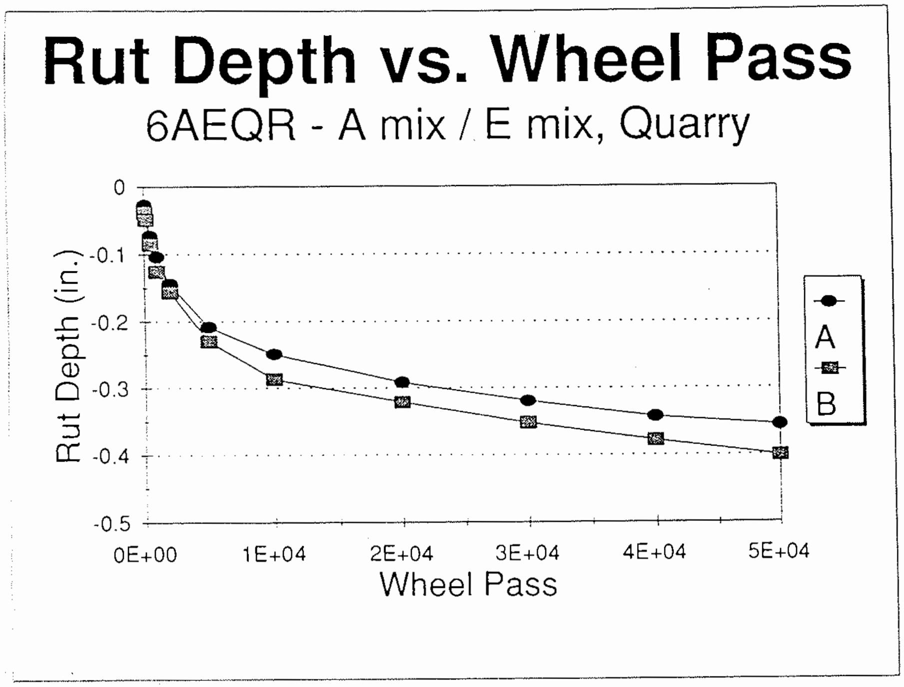


a) B/E - Quarry

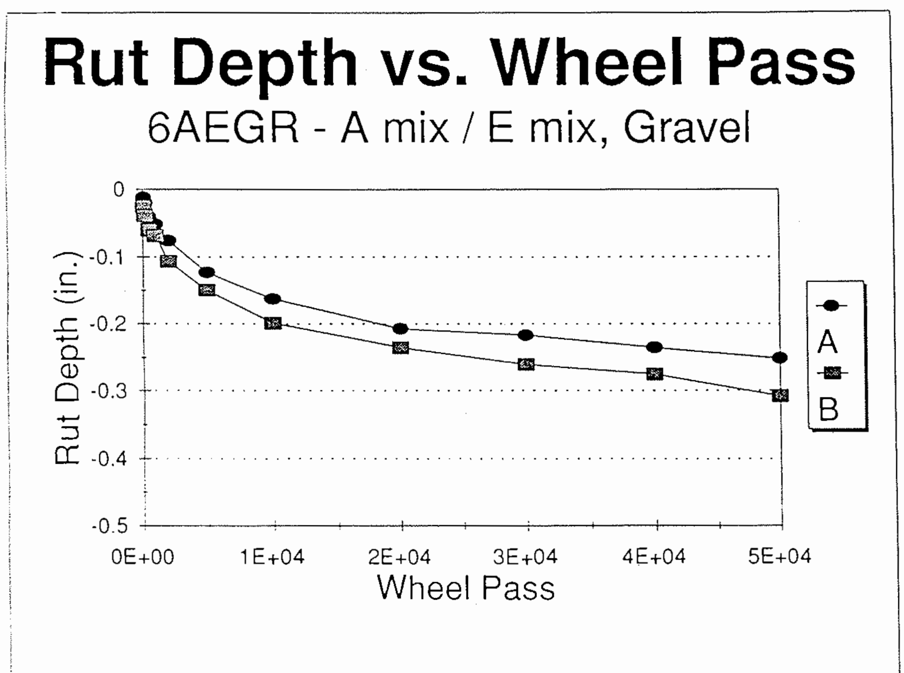


b) B/E - Gravel

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

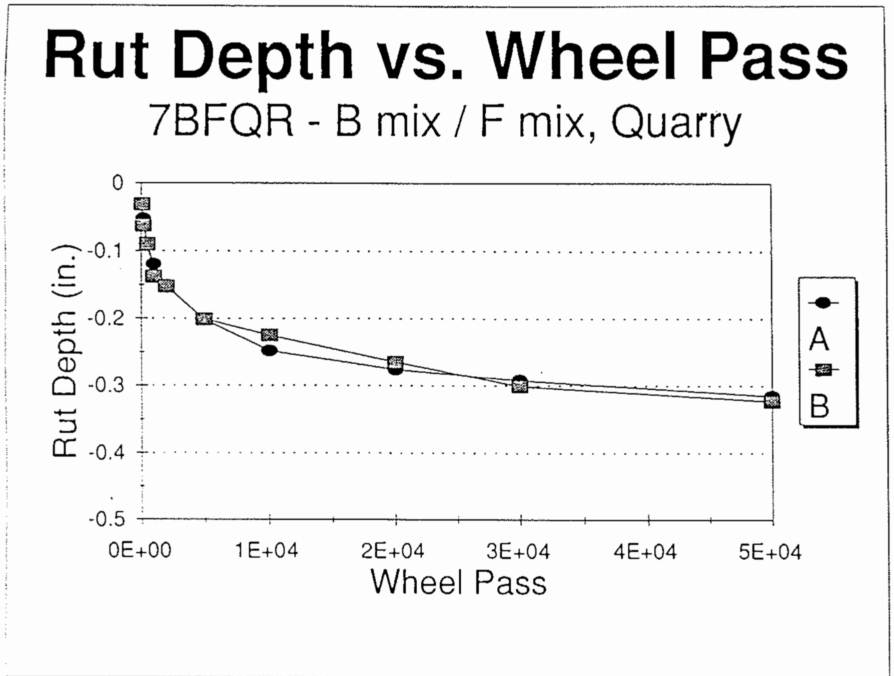


c) A/E - Quarry

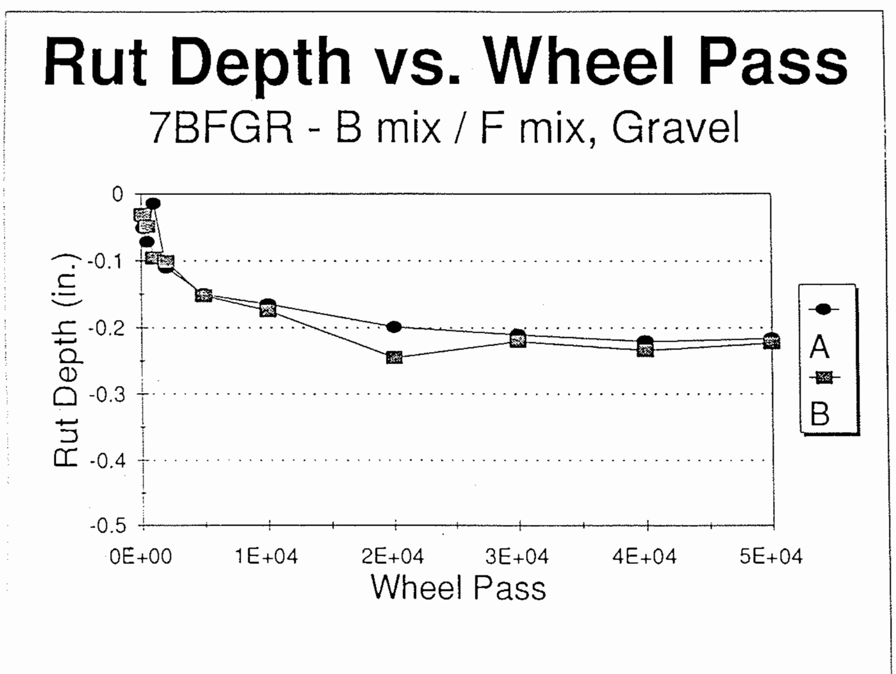


d) A/E - Gravel

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.).

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