UTILIZING THE GEORGIA LOADED-WHEEL TESTER TO PREDICT RUTTING

by

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PREFACE

In this research, the feasibility of using the Georgia Loaded-Wheel Tester (GLWT) to predict rutting in the laboratory was investigated. The study consisted of modifying the GLWT to handle 15.2 cm (6 in) cores, obtaining asphalt pavement cores from several test sites throughout Wyoming, collecting rut depth data, compiling the data in a computerized database, and conducting statistical analyses. The analyses resulted in preliminary regression models that can be used to predict field rutting based on rut-depth measurements from the GLWT. More data will be obtained to verify the regression models.

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CHAPTER 1

INTRODUCTION AND BACKGROUND

In the last decade, pavement rutting has become a major problem for many state highway agencies. Increased truck tire pressure and heavier axle loads are the two leading causes of this problem. Rutting stems from the permanent deformation in any of the pavement layers or the subgrade, usually caused by the consolidation or lateral movement of the materials due to traffic loads. Significant rutting can lead to major structural failures and hydroplane potentials [1].

Most mix design procedures currently used by state highway agencies are reliable in eliminating extremely poor asphalt mixes. However, they offer little assistance in distinguishing among mixes with high, moderate, or even low rut resistance. With this dilemma, many state agencies are looking for reliable alternative methods to predict the rut resistance of asphalt mixes. Constructing test sections is one method to determine whether an asphalt mix has adequate rut resistance but this procedure is very expensive and requires years of field measurements and analysis. On the other hand, by using laboratory accelerated rut testing devices, the rutting characteristics of an asphalt mix can be determined in a matter of days.

Accelerated Pavement Testing Devices

Accelerated rut testers have been used by several countries for quite some time. The Europeans have the leading role in the development of accelerated pavement testing devices. The French Rutting Tester evaluates the resistance to permanent deformation on slabs 50 by 18 cm (19.7 by 7.1 in) and 2 to 10 cm (0.8 to 3.9 in) thick [2]. Slabs are prepared with the Laboratoire Central des Pons et Chaussees (LCPC) plate compactor. During testing the slabs are loaded with 5000 N (1124 lbs) by a pneumatic tire inflated to 0.6 MPa (87 psi). The environmental chamber enclosing the specimen is typically heated to 60°C (140°F). Rut depth measurements are taken from 100 cycles up to 100,000 cycles. A successful test will have a rut depth that is less than 10% of the slab thickness after 30,000 cycles. The cost of the French rutting tester and LCPC plate compactor is $185,000 [2].

The Hamburg Wheel Tracking Device was developed in Germany to measure the resistance to moisture damage. The slab size is 25 by 28 cm (9.8 by 11 in) and 6 to 9 cm (2.4 to 3.5 in) thick. This device is similar to the French rutting tester except that the slabs are immersed in a 50°C (122°F) water bath and loaded by a steel wheel. The wheel is loaded with 705 N (158 lbs). The machine is automated and records the deformation after each cycle. A successful test will have less than 4 mm (0.16 in) rut depth after 20,000 cycles. The cost of the Hamburg Wheel Tracking Device is $45,000 [2].

The Simple Shear Testing Device was developed at the University of California at Berkeley. Several prototypes are currently being tested. This device is being considered by the Strategic Highway Research Program (SHRP) to predict permanent deformation characteristics of asphalt pavements [2]. A device being developed at the Oregon State University is the Environmental Conditioning System (ECS). The ECS is being considered by SHRP to predict moisture sensitivity characteristics [2].

The Accelerated Loading Facility (ALF) used by the Federal Highway Administration (FHWA) is a duplicate of an Australian model. The ALF is a full-scale pavement testing facility with programmable transverse distribution of load passes to simulate the random non-uniformity of actual traffic patterns. The ALF is capable of loading the pavement with 4 to 10 tons in a unidirectional motion to provide the most realistic testing possible [3].

The Georgia Loaded-Wheel Tester (GLWT) was originally developed to test asphalt slurry seals [4]. It has since been modified and shown by Lai [5] to potentially distinguish between levels of rut resistance in asphalt mixes. Georgia Tech developed a testing system similar to the Georgia Loaded-Wheel Tester. The primary difference from the Georgia Tech device is that the loaded-wheel is stationary and the beam moves back and forth on a steel plate and bearing apparatus. The general concept for Georgia Tech's accelerated rut tester came from one developed at the University of Nottingham, England [6].

The state of Wyoming, like other states, has its share of pavement rutting. Predicting pavement rutting prior to construction is on top of the Wyoming DOT's priority list. As a first step, the University of Wyoming investigated the feasibility of using the Georgia Loaded-Wheel Tester to predict field rutting in the lab. This report describes the preliminary findings of that investigation.

CHAPTER 2

DESIGN OF EXPERIMENT

Figure 1 shows the overall testing and analysis strategies in this research project. First, the GLWT was modified to test 15.2 cm (6 in) cores instead of beams. Several cores with identical characteristics were later prepared in the laboratory and tested with the GLWT to verify the repeatability of the results. Thirteen pavement test sections were selected for inclusion in this experiment. All of these sections were primary roads in the state of Wyoming. Three cores were obtained from each site to test with the GLWT. Actual field rut depth measurements were obtained for all sections. After the testing was completed, the field and laboratory rut depth values were summarized in a computerized database. Additional data stored in the database were asphalt surface type, pavement elevation, age of asphalt specimen, and height of test specimen. Statistical analyses were later conducted on the data to correlate laboratory and field rut-depth measurements and to verify the repeatability of the GLWT. The cores were divided into two elevation categories and two surface treatment categories. Good correlations were shown statistically when models were developed for the rut depths.

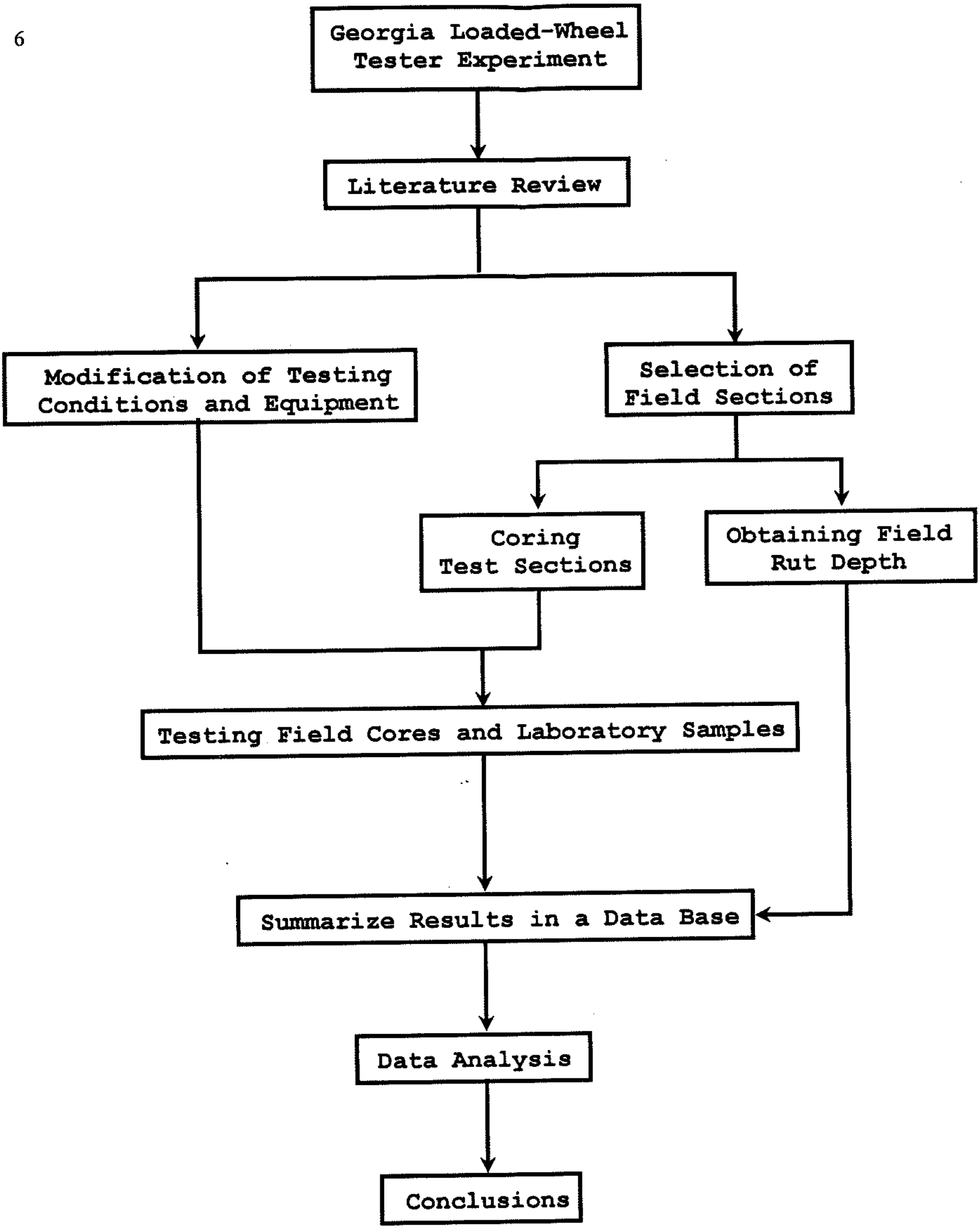

Figure 1. Evaluation of Asphalt Mixes using the Georgia Loaded-Wheel Tester

CHAPTER 3

MODIFICATIONS TO THE GEORGIA LOADED-WHEEL TESTER

Background

The GLWT was developed by Benedict Slurry, Inc., for the GaDOT Materials Testing Laboratory to test asphalt slurry seals [4]. The original version of the GLWT included a loaded-wheel driven by an electric motor, a weight holding box, and a mounting plate for the asphalt specimen. The original GLWT device was modified by replacing the rubber tire assembly with an inflated, stationary, rubber hose over which a loaded metal wheel traverses. Another modification to the GLWT was the addition of a temperature controlled environmental chamber which could maintain temperatures up to 51.7°C (125°F) for testing.

The dimensions of a typical GLWT test specimen are 7.5 X 7.5 X 38.1 cm (3 X 3 X 15 in). These beams are normally prepared in the laboratory using a press, a kneading compactor, or a combination of the two. The primary disadvantage of performing tests with beams is the difficulty of obtaining them from the field. Therefore, this research project concentrated on modifying the GLWT to test 15.2 cm (6 in) cores. Cores are much easier to remove from existing pavement sections and they require less time to prepare in the laboratory.

Testing at the University of Wyoming

Several attempts were made to test cores in the GLWT. First, modifications had to be made to the GLWT apparatus prior to testing cores. New holes were drilled in the base plate so the sample-holding mold could handle 15.2 cm (6 in) cores. Cores were tested simultaneously in the GLWT. This endeavor was quickly abandoned due to excessive rocking of the cores during testing. To overcome the rocking problem, fresh concrete was placed around individual cores and allowed to set before testing. This procedure was time consuming. Finally, single cores were tested by placing pre-cast concrete spacers on both sides of the cores to accommodate the 30.5 cm (12 in) travel length of the loaded-wheel. Figure 2 demonstrates how pavement cores are tested in the GLWT. This has become the standard procedure for testing cores in the GLWT at the University of Wyoming.

A measuring device was also developed at the University of Wyoming to provide standardized and accurate rut depth measurements. The measuring device is a 63.5 cm (25 in) long aluminum dowel, 3.175 cm (1.25 in) in diameter, machined on the ends to slide into the hose clamping brackets. Three dial indicators were permanently attached to the dowel with set screws to take a center measurement and measurements 5.08 cm (2 in) off center. Figure 3 shows the developed rut-depth measuring device.

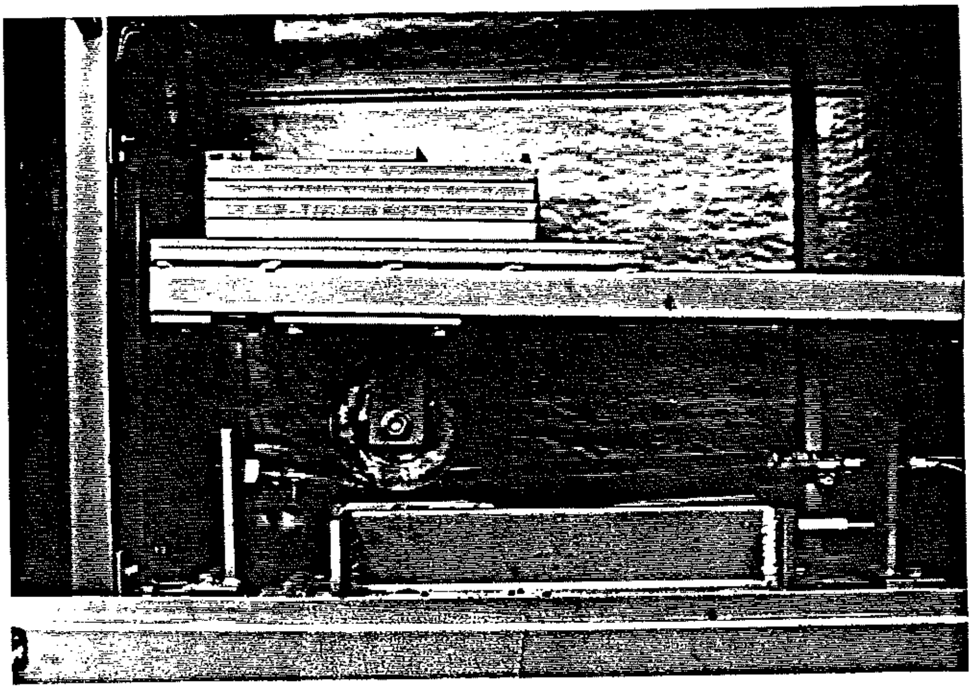

Figure 2. Testing cores in the GLWT

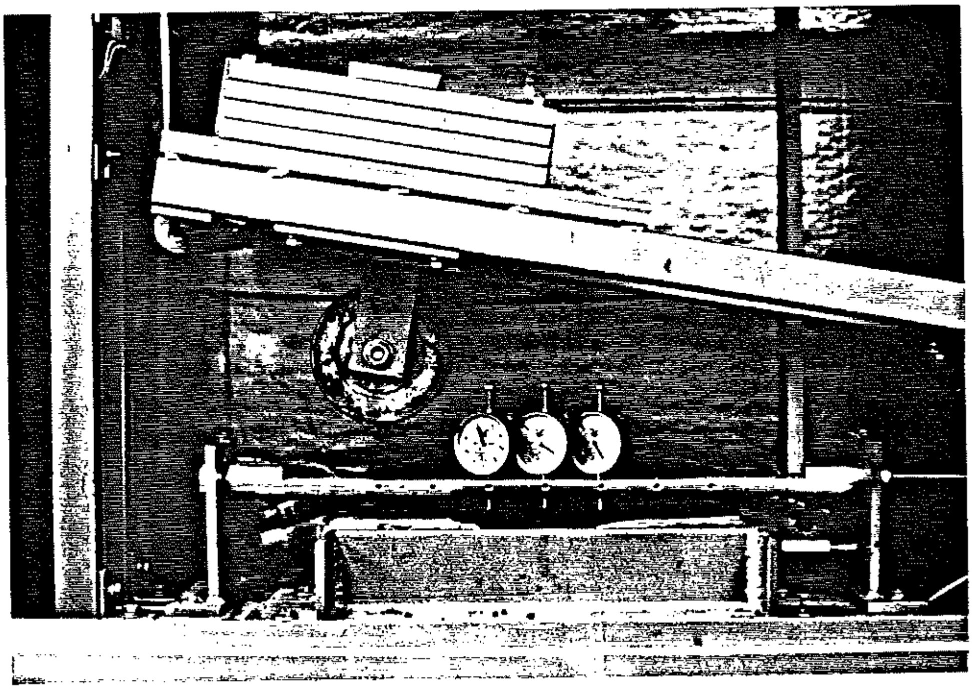

Figure 3. Rut-depth measuring device being used

Results from the Repeatability Study

After modifying the GLWT, several identical laboratory cores were prepared. A standard technique was followed in compacting the cores with a combination of kneading and static compaction efforts. Cores were first compacted with 100 blows at 2413 kPa (350 psi) for a 0.5 second duration from a kneading compactor. A static leveling load of 4536 kg (10,000 lb) was later applied to achieve actual field densities for similar mixes. All cores were then tested at either 40.6°C (105°F) or 46.1°C (115°F). Most of the literature reviewed recommend testing pavement samples at 40.6°C (105°F). In this research, it was felt that the 40.6°C (105°F) testing temperature may not be severe enough to predict pavement rutting. Therefore, samples were also tested at an elevated temperature of 46.1°C (115°F).

Table 1 shows the average rut depth measurements after 1000, 4000, and 8000 cycles for the cores tested at 46.1°C (115°F). The coefficients of variance for the measurements were 0.243, 0.215, and 0.213 after 1000, 4000, and 8000 cycles respectively. These levels of variance were expected since the cores were hand mixed and individually prepared in the laboratory. The average rut depth increased from 0.230 cm (0.091 in) after 1000 cycles to 0.381 cm (0.15 in) after 8000 cycles. The standard deviation also increased from 0.056 cm (0.022 in) to 0.081 cm (0.032 in). Similar conclusions were found when testing the cores at 40.6°C (105°F).

Table 1. **Average Rut Depth Measurements from the Repeatability Study at 46.1°C (115°F)**

	AVERAGE RUT DEPTH AFTER 1000 CYCLES (cm)	AVERAGE RUT DEPTH AFTER 4000 CYCLES (cm)	AVERAGE RUT DEPTH AFTER 8000 CYCLES (cm)
	.211	.312	.373
	.180	.264	.305
	.264	.401	.450
	.168	.198	.221
	.363	.432	.483
	.152	.224	.251
	.221	.323	.401
	.249	.353	.429
	.224	.312	.409
	.234	.335	.419
	.274	.386	.445
	.216	.315	.386
Mean	.230	.321	.381
Coefficient of Variance	.243	.215	.213
Standard Deviation	.056	.069	.081

CHAPTER 4

SELECTING AND TESTING FIELD TEST SECTIONS

Selection of Test Sections

After verifying the repeatability of testing cores with the GLWT, thirteen actual pavement test sections were selected for inclusion in this experiment. These sections were selected according to their geographic locations and rut depth severity level. All sections were cored in the summer of 1992. Initially, the cores were used to determine actual pavement thicknesses and later for testing in the GLWT. Table 2 shows the thicknesses for all of the pavement test sections. Average field rut depth data were obtained for all sections from the Wyoming Rut Depth Report [7] and summarized in Table 3. The rut depth data were the average of 2640 measurements per mile taken by a South Dakota Road Profiler.

Laboratory Testing of Field Cores

All field cores were cut to an approximate height of 8 cm (3.1 in). The bulk specific gravities were determined for all cores using the standard method of test for bulk specific gravity of compacted bituminous mixtures (AASHTO T 166-88). The densities and heights of the cores were determined and summarized in Table 4. At least 12 hours prior to testing, each core was placed in the preheating box of the GLWT.

Table 2. Thicknesses of Pavement Test Sections

PROJECT	MILEPOST	ASPHALT THICKNESS (cm)
P-34-10	202	14.0
P-23-03	423.5	17.1
P-25-04	97	10.8
P-12-27	33	11.4
P-34-09	251	12.1
P-12-26	36	12.1
P-20-15	120	15.2
P-20-17	96	18.4
P-40-13	35	19.1
P-30-18	108	
P-12-20	93	13.3
P-12-21	61	15.2
P-12-28	16	17.1

Table 3. Average Field Rut Depths for Test Sections

PROJECT	MILEPOST	AVERAGE FIELD RUT DEPTH (cm)
P-34-10	202	0.28
P-23-03	423.5	0.18
p-25-04	97	0.84
p-12-27	33	0.61
p-34-09	251	0.33
p-12-26	36	0.51
P-20-15	120	0.13
P-20-17	96	0.46
P-40-13	35	0.53
P-30-18	108	0.84
P-12-20	93	0.41
P-12-21	61	0.53
P-12-28	16	0.46

Table 4. Heights and Densities of Field Cores

PROJECT	CORES TESTED AT 40.6°C (105°F)		CORES TESTED AT 46.1°C (115°F)	
	HEIGHT (cm)	DENSITY (kg/m^3)	HEIGHT (cm)	DENSITY (kg/m^3)
P-25-04	8.1	2353.1	8.3	2332.3
P-34-10	7.6	2338.7	7.0	2329.1
P-23-03	7.6	2265.0	7.6	2263.4
p-12-27	7.6	2289.0	8.3	2289.0
p-34-09	8.4	2319.5	8.1	2324.3
p-20-17	7.5	2329.1	7.3	2327.5
P-12-26	7.6	2284.2	7.3	2293.8
P-20-15	8.3	2330.7	7.0	2338.7
P-40-13	7.0	2357.9	7.6	2337.1
P-12-21	7.8	2277.8	7.6	2277.8
P-30-18	7.5	2271.4	8.3	2295.4
p-12-28	7.1	2319.5	6.4	2327.5
P-12-20	8.1	2287.4	8.9	2269.8

Procedure

To test a mix, a preheated core is secured in the temperature-controlled GLWT. The measuring device is placed in the hose mounting brackets and initial dial indicator readings are recorded. The measuring device is removed and the rubber hose is placed in the mounting brackets. The hose is inflated and maintained at 690 kPa (100 psi) with a compressor and regulator. With the hose tightened to the mounting brackets, the loaded-wheel is lowered on top of the hose. When the door is closed the testing can proceed. At a preset number of cycles the loaded-wheel automatically stops. The hose is removed and the dial indicator readings are recorded. Rut depths are recorded at 1000, 4000, and 8000 cycles.

CHAPTER 5

RESULTS AND ANALYSIS

Cores from the test sections included in this experiment were tested at 40.6°C and 46.1°C (105°F and 115°F). All rut depth measurements after 8000 cycles are summarized in Table 5. Figures 4 and 5 show the relationship between rut depth and number of cycles for the field cores. The mean rut depths for all samples after 8000 cycles were 0.26 cm (0.10 in) and 0.41 cm (0.16 in) at 40.6°C and 46.1°C (105°F and 115°F), respectively.

Statistical Evaluation

An attempt was made to correlate all field and laboratory rut depth data at 46.1°C (115°F). However, regression models with appropriate R-squared values could not be obtained. Therefore, the data set was split into two categories; first based on the elevations of the sections, and second based on pavement surface types. Statistical analysis was then performed on each data set separately.

All test sections at elevations between 1158 m and 1676 m (3800 ft and 5500 ft) were grouped together. The following regression model was then obtained for this category:

$$\textbf{Rut Depth} = -1.46 + 1.50*A + 0.461*B$$

where : Rut Depth = Predicted Field Rut Depth (cm)

A = Average laboratory rut depth in cm after 8000 cycles at 46.1°C (115°F)

Table 5. Average Laboratory Rut Depths for Field Cores after 8000 Cycles

PROJECT	AVERAGE LABORATORY RUT DEPTH AT 40.6°C (105°F) (cm)	AVERAGE LABORATORY RUT DEPTH AT 46.1°C (115°F) (cm)
P-25-04	0.193	0.466
P-34-10	0.592	0.445
P-23-03	0.191	0.452
P-12-27	0.086	0.175
P-34-09	0.213	0.218
P-20-17	++	0.528
P-12-26	0.284	0.328
P-20-15	0.406	0.462
P-40-13	0.262	0.526
P-12-21	0.130	0.201
P-30-18	0.277	+
P-12-28	0.310	++
P-12-20	0.191	0.297

\+ Test was stopped after rutting exceeded 0.762 cm (0.3 in)

++ Cores failed during testing

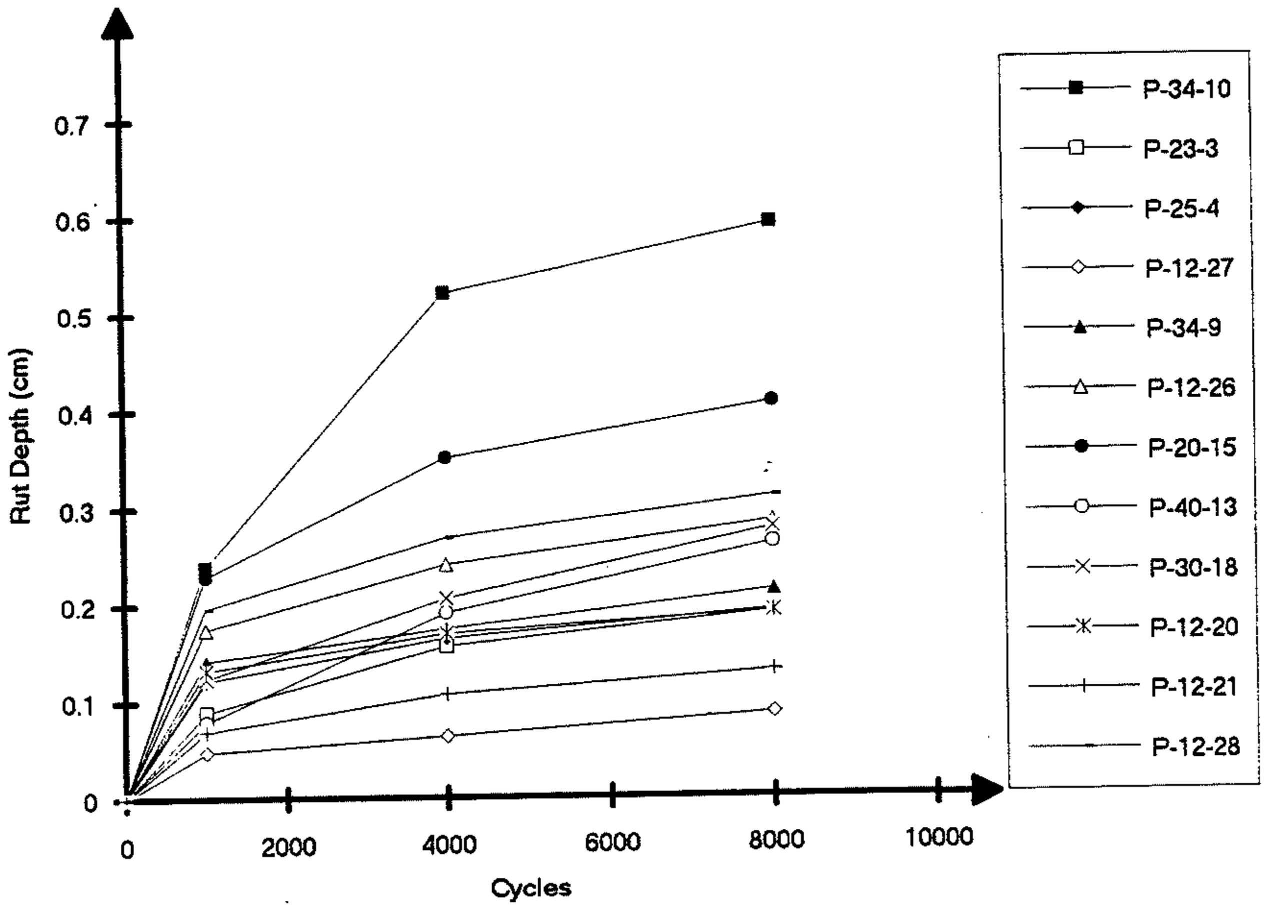

Figure 4. Rut Depth Plot for Field Cores Tested at 40.6°C (105°F)

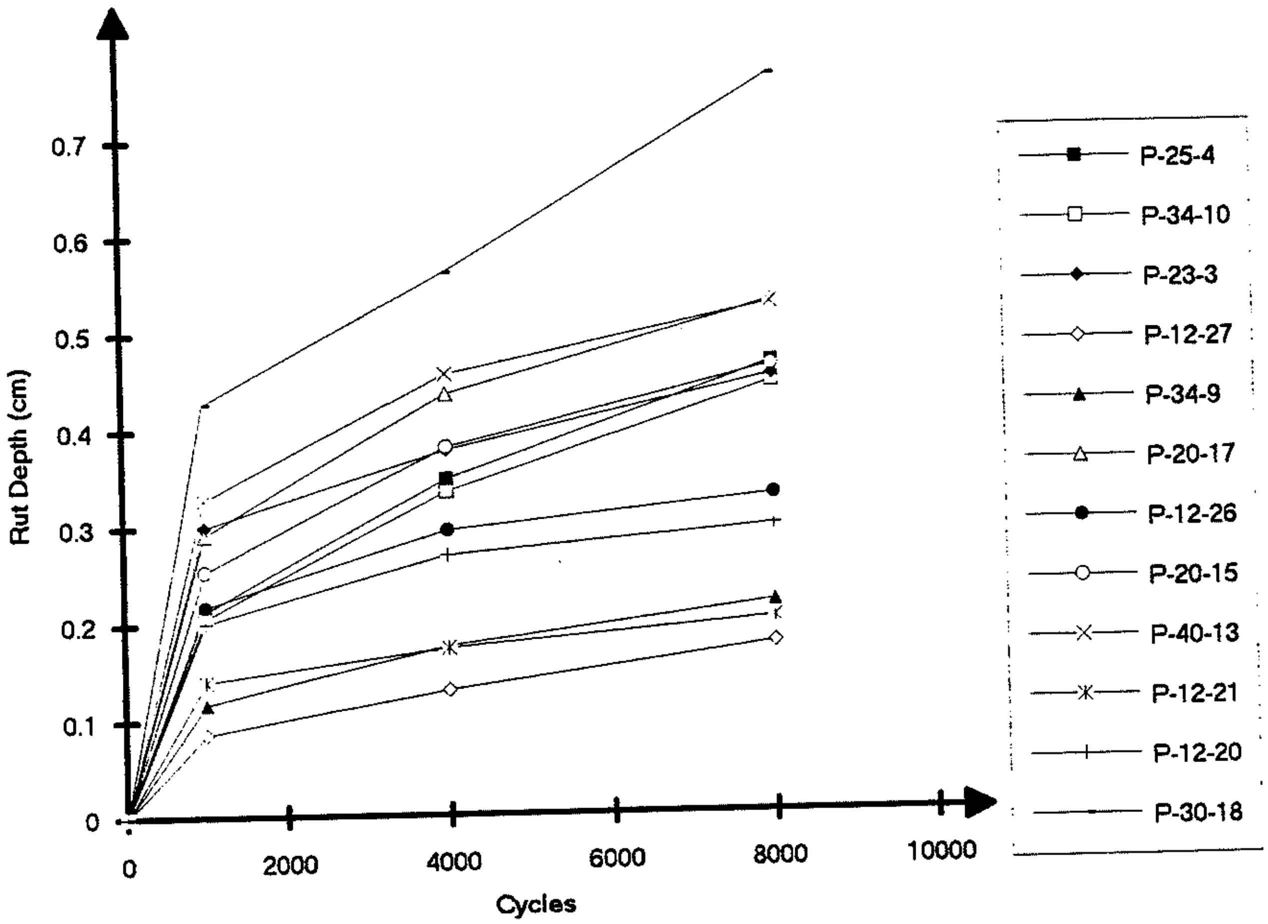

Figure 5. Rut Depth Plot for Field Cores Tested at 46.1°C (115°F)

B = Height of the field core tested in the GLWT (cm)

The R-square for this regression model was 92.6%. This model demonstrates the relationship between field and laboratory rut-depth measurements. The heights of the cores tested were found significant in the relationship. A similar regression model was developed for elevations between 1676 m and 2316 m (5500 ft and 7600 ft). The model equation for these higher elevations is:

Rut Depth = 0.306 + 0.39*A - 1.39*B

where : Rut Depth = Predicted Field Rut Depth (cm)

A = Average laboratory rut depth in cm after 8000 cycles at 46.1°C (115°F)

B = Center laboratory rut depth in cm after 8000 cycles at 46.1°C (115°F)

The R-square coefficient for this model was 91.9%.

Next, the field test sections were divided into two categories according to their surface type. The cores were classified as either having a surface treatment (wearing course or chip seal) or not having a separate surface treatment (single layer of dense graded asphalt). An analysis was first performed on the data from cores with no surface treatments. The following regression equation resulted from this analysis:

Rut Depth = -1.71 + 1.64*A + 0.532*B

where : Rut Depth = Predicted Field Rut Depth (cm)

A = Average laboratory rut depth in cm after 8000 cycles at 46.1°C (115°F)

B = Height of the field core tested in the GLWT (cm)

The R-square coefficient for this model was 97.3%.

Finally, similar analysis was performed on test sections with surface treatments. The following linear model was found:

Rut Depth = 0.308 + 0.60*A - 1.61*B

where: Rut Depth = Predicted Field Rut Depth (cm)

A = Average laboratory rut depth in cm after 8000 cycles at 46.1°C (115°F)

B = Center laboratory rut depth in cm after 8000 cycles at 46.1°C (115°F)

The R-square coefficient for this model was 93.4%.

When statistical analyses were performed at 40.6°C (105°F), the GLWT rut depth values did not correlate well with the field rut depth data.

CHAPTER 6

CONCLUSIONS

In this research project the Georgia Loaded-Wheel Tester was modified to test 15.2 cm (6 in) cores instead of beams. The feasibility of using the modified Georgia Loaded-Wheel Tester to predict field rutting in the laboratory was later examined. The following conclusions can be drawn from this study:

1. The Georgia Loaded-Wheel Tester can be used to test pavement cores instead of beams. The repeatability of the GLWT measurements is acceptable.
2. Rut-depth measurements from the GLWT at 40.6°C (105°F) did not correlate very well with actual field measurements.
3. Rut-depth measurements from the GLWT at 46.1°C (115°F) correlated well with actual field rut depths after considering factors such as elevation and pavement surface type.
4. The Georgia Loaded-Wheel Tester may not be the most accurate device to predict rutting but it is an inexpensive device that can produce quick results and an idea about the rut resistance of new asphalt mixes.

Although the data set used in this research project was limited, the GLWT showed some promising results. More test sections will be added to the database in the future to verify the results obtained.

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APPENDIX A: REPEATABILITY STUDY

Core #: 20

Project: N/A

Sieve	% Retained	Weight (g)
3/4"	0	0
5/8"	1	30.6
3/8"	31	948.4
# 4	27	826
# 8	16	489.5
# 30	13	397.7
#200	8	244.8
Pan	4	122.4
Lime		30.6
AC - 20		154.1
Total		3244.1

Compaction Date: 3-23-94

Compaction Procedure:

100 @ 350 psi (kneading)

10,000 lb static levelling load (1 min)

Gmb Calculations

A = 3209.4 g

B = 3235.4 g

C = 1813.8 g

Gmb = A/(B-C) = 2.26

Density = Gmb * 62.4pcf = 140.9 pcf

Testing Date: 4-5-94

Testing Temperature: 115 F

Height: 3 1/8 in

Comments:

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.527	0.547	0.503	0	0	0
1000	0.451	0.456	0.42	0.076	0.091	0.083
4000	0.416	0.408	0.385	0.111	0.139	0.118
8000	0.382	0.382	0.371	0.145	0.165	0.132

Core #: 21

Project: N/A

Sieve	% Retained	Weight (g)
3/4"	0	0
5/8"	1	30.6
3/8"	31	948.4
# 4	27	826
# 8	16	489.5
# 30	13	397.7
#200	8	244.8
Pan	4	122.4
Lime		30.6
AC - 20		154.1
Total		3244.1

Compaction Date: 3-24-94

Compaction Procedure:

100 @ 350 psi (kneading)

10,000 lb static levelling load (1 min)

Gmb Calculations

A = 3210.4 g

B = 3247.4 g

C = 1820.8 g

Gmb = A/(B-C) = 2.25

Density = Gmb * 62.4pcf = 140.4 pcf

Testing Date: 4-6-94

Testing Temperature: 115 F

Height: 3 1/8 in

Comments:

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.497	0.525	0.501	0	0	0
1000	0.441	0.456	0.412	0.056	0.069	0.089
4000	0.42	0.423	0.369	0.077	0.102	0.132
8000	0.407	0.403	0.352	0.09	0.122	0.149

Core #: 22

Project: N/A

Sieve	% Retained	Weight (g)
3/4"	0	0
5/8"	1	30.6
3/8"	31	948.4
# 4	27	826
# 8	16	489.5
# 30	13	397.7
#200	8	244.8
Pan	4	122.4
Lime		30.6
AC - 20		154.1
Total		3244.1

Compaction Date: 3-24-94

Compaction Procedure:
100 @ 350 psi (kneading)
10,000 lb static levelling load (1 min)

Gmb Calculations
A = 3212.4 g
B = 3234.4 g
C = 1828.8 g
Gmb = A/(B-C) = 2.29

Density = Gmb * 62.4pcf = 142.6 pcf

Testing Date: 4-19-94
Testing Temperature: 115 F
Height: 3 1/8 in

Comments:

	Dial Indicator Reading (in)			Rut Depths (in)		
Cycles	LOC	Center	ROC	LOC	Center	ROC
0	0.497	0.506	0.481	0	0	0
1000	0.424	0.389	0.36	0.073	0.117	0.121
4000	0.341	0.345	0.325	0.156	0.161	0.156
8000	0.328	0.323	0.302	0.169	0.183	0.179

34 Core #: 36

Project: N/A

Sieve	% Retained	Weight (g)
3/4"	0	0
5/8"	1	30.6
3/8"	31	948.4
# 4	27	826
# 8	16	489.5
# 30	13	397.7
#200	8	244.8
Pan	4	122.4
Lime		30.6
AC - 20		154.1
Total		3244.1

Compaction Date: 5-10-94

Compaction Procedure:

100 @ 350 psi (kneading)

10,000 lb static levelling load (1 min)

Gmb Calculations

A = 3201.4 g

B = 3230.4 g

C = 1830.8 g

Gmb = A/(B-C) = 2.29

Density = Gmb * 62.4pcf = 142.7 pcf

Testing Date: 6-14-94

Testing Temperature: 115 F

Height: 3 1/16 in

Comments:

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.547	0.577	0.562	0	0	0
1000	0.469	0.521	0.497	0.078	0.056	0.065
4000	0.462	0.504	0.486	0.085	0.073	0.076
8000	0.45	0.494	0.48	0.097	0.083	0.082

Core #: 39

Project: N/A

Sieve	% Retained	Weight (g)
3/4"	0	0
5/8"	1	30.6
3/8"	31	948.4
# 4	27	826
# 8	16	489.5
# 30	13	397.7
#200	8	244.8
Pan	4	122.4
Lime		30.6
AC - 20		154.1
Total		3244.1

Compaction Date: 5-11-94

Compaction Procedure:
100 @ 350 psi (kneading)
10,000 lb static levelling load (1 min)

Gmb Calculations

A = 3212.9 g
B = 3223.9 g
C = 1823.8 g
Gmb = A/(B-C) = 2.29

Density = Gmb * 62.4pcf = 143.2 pcf

Testing Date: 6-14-94
Testing Temperature: 115 F
Height: 3 1/8 in

Comments:

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.672	0.683	0.634	0	0	0
1000	0.54	0.533	0.486	0.132	0.15	0.148
4000	0.515	0.496	0.468	0.157	0.187	0.166
8000	0.495	0.469	0.456	0.177	0.214	0.178

Core #: 40

Project: N/A

Sieve	% Retained	Weight (g)
3/4"	0	0
5/8"	1	30.6
3/8"	31	948.4
# 4	27	826
# 8	16	489.5
# 30	13	397.7
#200	8	244.8
Pan	4	122.4
Lime		30.6
AC - 20		154.1
Total		3244.1

Compaction Date: 5-11-94

Compaction Procedure:
100 @ 350 psi (kneading)
10,000 lb static levelling load (1 min)

Gmb Calculations

A = 3219.4 g
B = 3253.4 g
C = 1824.8 g
Gmb = A/(B-C) = 2.25

Density = Gmb * 62.4pcf = 140.6 pcf

Testing Date: 6-15-94
Testing Temperature: 115 F
Height: 3 3/16 in

Comments:

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.604	0.632	0.626	0	0	0
1000	0.544	0.566	0.571	0.06	0.066	0.055
4000	0.506	0.536	0.556	0.098	0.096	0.07
8000	0.502	0.519	0.545	0.102	0.113	0.081

Core #: 41

Project: N/A

Sieve	% Retained	Weight (g)
3/4"	0	0
5/8"	1	30.6
3/8"	31	948.4
# 4	27	826
# 8	16	489.5
# 30	13	397.7
#200	8	244.8
Pan	4	122.4
Lime		30.6
AC - 20		154.1
Total		3244.1

Compaction Date: 5-11-94

Compaction Procedure:
100 @ 350 psi (kneading)
10,000 lb static levelling load (1 min)

Gmb Calculations
A = 3220.4 g
B = 3257.4 g
C = 1819.8 g
Gmb = A/(B-C) = 2.24

Density = Gmb * 62.4pcf = 139.8 pcf

Testing Date: 6-16-94
Testing Temperature: 115 F
Height: 3 3/16 in

Comments:

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.652	0.674	0.613	0	0	0
1000	0.574	0.579	0.525	0.078	0.095	0.088
4000	0.534	0.534	0.491	0.118	0.14	0.122
8000	0.494	0.5	0.47	0.158	0.174	0.143

Core #: 50

Project: N/A

Sieve	% Retained	Weight (g)
3/4"	0	0
5/8"	1	30.6
3/8"	31	948.4
# 4	27	826
# 8	16	489.5
# 30	13	397.7
#200	8	244.8
Pan	4	122.4
Lime		30.6
AC - 20		154.1
Total		3244.1

Compaction Date: 6-27-94

Compaction Procedure:
100 @ 350 psi
10,000 lb static levelling load (1 min)

Gmb Calculations

A = 3201.9 g
B = 3225.4 g
C = 1825.8 g
Gmb = A/(B-C) = 2.29

Density = Gmb * 62.4pcf = 142.8 pcf

Testing Date: 7-5-94
Testing Temperature: 115 F
Height: 3 1/8 in

Comments:

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.53	0.562	0.537	0	0	0
1000	0.448	0.457	0.43	0.082	0.105	0.107
4000	0.405	0.407	0.4	0.125	0.155	0.137
8000	0.382	0.371	0.37	0.148	0.191	0.167

Core #: 51

Project: N/A

Sieve	% Retained	Weight (g)
3/4"	0	0
5/8"	1	30.6
3/8"	31	948.4
# 4	27	826
# 8	16	489.5
# 30	13	397.7
#200	8	244.8
Pan	4	122.4
Lime		30.6
AC - 20		154.1
Total		3244.1

Compaction Date: 6-27-94

Compaction Procedure:

100 @ 350 psi (kneading)

10,000 lb static levelling load (1 min)

Gmb Calculations

A = 3221.4 g

B = 3245.4 g

C = 1831.8 g

Gmb = A/(B-C) = 2.28

Density = Gmb * 62.4pcf = 142.2 pcf

Testing Date: 7-6-94

Testing Temperature: 115 F

Height: 3 1/8 in

Comments:

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.586	0.623	0.569	0	0	0
1000	0.495	0.53	0.489	0.091	0.093	0.08
4000	0.458	0.481	0.471	0.128	0.142	0.098
8000	0.434	0.406	0.456	0.152	0.217	0.113

Core #: 52

Project: N/A

Sieve	% Retained	Weight (g)
3/4"	0	0
5/8"	1	30.6
3/8"	31	948.4
# 4	27	826
# 8	16	489.5
# 30	13	397.7
#200	8	244.8
Pan	4	122.4
Lime		30.6
AC - 20		154.1
Total		3244.1

Compaction Date: 6-28-94

Compaction Procedure:
100 @ 350 psi (kneading)
10,000 lb static levelling load (1 min)

Gmb Calculations
A = 3203.4 g
B = 3214.4 g
C = 1832.8 g
Gmb = A/(B-C) = 2.32

Density = Gmb * 62.4pcf = 144.7 pcf

Testing Date: 7-7-94
Testing Temperature: 115 F
Height: 3 1/16 in

Comments:

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.521	0.526	0.513	0	0	0
1000	0.414	0.425	0.444	0.107	0.101	0.069
4000	0.368	0.384	0.411	0.153	0.142	0.102
8000	0.334	0.343	0.389	0.187	0.183	0.124

Core #: 53

Project: N/A

Sieve	% Retained	Weight (g)
3/4"	0	0
5/8"	1	30.6
3/8"	31	948.4
# 4	27	826
# 8	16	489.5
# 30	13	397.7
#200	8	244.8
Pan	4	122.4
Lime		30.6
AC - 20		154.1
Total		3244.1

Compaction Date: 6-28-94

Compaction Procedure:
100 @ 350 psi (kneading)
10,000 lb static levelling load (1 min)

Gmb Calculations
A = 3208.4 g
B = 3230.4 g
C = 1825.8 g
Gmb = A/(B-C) = 2.28

Density = Gmb * 62.4pcf = 142.5 pcf

Testing Date: 7-8-94
Testing Temperature: 115 F
Height: 3 1/8 in

Comments:

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.58	0.603	0.573	0	0	0
1000	0.462	0.507	0.464	0.118	0.096	0.109
4000	0.418	0.465	0.418	0.162	0.138	0.155
8000	0.403	0.437	0.392	0.177	0.166	0.181

Core #: 54

Project: N/A

Sieve	% Retained	Weight (g)
3/4"	0	0
5/8"	1	30.6
3/8"	31	948.4
# 4	27	826
# 8.	16	489.5
# 30	13	397.7
#200	8	244.8
Pan	4	122.4
Lime		30.6
AC - 20		154.1
Total		3244.1

Compaction Date: 6-28-94

Compaction Procedure:

100 @ 350 psi (kneading)

10,000 lb static levelling load (1 min)

Gmb Calculations

A = 3217.4 g

B = 3234.9 g

C = 1834.8 g

Gmb = A/(B-C) = 2.30

Density = Gmb * 62.4pcf = 143.4 pcf

Testing Date: 7-10-94

Testing Temperature: 115 F

Height: 3 1/8 in

Comments:

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.563	0.585	0.565	0	0	0
1000	0.475	0.503	0.481	0.088	0.082	0.084
4000	0.421	0.47	0.449	0.142	0.115	0.116
8000	0.387	0.44	0.429	0.176	0.145	0.136

APPENDIX B: FIELD CORES

Core #: 23

Project: P-25-04

Sieve	% Retained	Weight (g)
3/4"	N/A	N/A
5/8"	N/A	N/A
3/8"	N/A	N/A
# 4	N/A	N/A
# 8	N/A	N/A
# 30	N/A	N/A
#200	N/A	N/A
Pan	N/A	N/A
Lime	N/A	N/A
AC - 20	N/A	N/A
Total	N/A	N/A

Compaction Date: N/A

Compaction Procedure: N/A

Gmb Calculations

A = 3376.0 g

B = 3381.0 g

C = 1933.8 g

Gmb = A/(B-C) = 2.33

Density = Gmb * 62.4pcf = 145.6 pcf

Testing Date: 5-10-94

Testing Temperature: 115 F

Height: 3 1/4 in

Comments: No Chip Seal.

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.673	0.677	0.637	0	0	0
1000	0.605	0.583	0.546	0.068	0.094	0.091
4000	0.563	0.511	0.502	0.11	0.166	0.135
8000	0.513	0.441	0.483	0.16	0.236	0.154

Core #: 24

Project: P-34-10

Compaction Date: N/A

Compaction Procedure: N/A

Sieve	% Retained	Weight (g)
3/4"	N/A	N/A
5/8"	N/A	N/A
3/8"	N/A	N/A
# 4	N/A	N/A
# 8	N/A	N/A
# 30	N/A	N/A
#200	N/A	N/A
Pan	N/A	N/A
Lime	N/A	N/A
AC - 20	N/A	N/A
Total	N/A	N/A

Gmb Calculations

A = 2959.9 g

B = 2963.4 g

C = 1692.8 g

Gmb = A/(B-C) = 2.33

Density = Gmb * 62.4pcf = 145.4 pcf

Testing Date: 4-19-94

Testing Temperature: 115 F

Height: 2 3/4 in

Comments: Rough Chip Seal

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.223	0.262	0.257	0	0	0
1000	0.163	0.173	0.163	0.06	0.089	0.094
4000	0.11	0.114	0.123	0.113	0.148	0.134
8000	0.064	0.065	0.089	0.159	0.197	0.168

Core #: 25

Project: P-23-03

Sieve	% Retained	Weight (g)
3/4"	N/A	N/A
5/8"	N/A	N/A
3/8"	N/A	N/A
# 4	N/A	N/A
# 8	N/A	N/A
# 30	N/A	N/A
#200	N/A	N/A
Pan	N/A	N/A
Lime	N/A	N/A
AC - 20	N/A	N/A
Total	N/A	N/A

Compaction Date: N/A

Compaction Procedure: N/A

Gmb Calculations

A = 3098.4 g

B = 3102.4 g

C = 1733.8 g

Gmb = A/(B-C) = 2.26

Density = Gmb * 62.4pcf = 141.3 pcf

Testing Date: 4-25-94

Testing Temperature: 115 F

Height: 3 .0 in

Comments: PMWC

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.451	0.546	0.527	0	0	0
1000	0.364	0.401	0.406	0.087	0.145	0.121
4000	0.329	0.368	0.381	0.122	0.178	0.146
8000	0.303	0.331	0.357	0.148	0.215	0.17

Core #: 26

Project: P-12-27

Sieve	% Retained	Weight (g)
3/4"	N/A	N/A
5/8"	N/A	N/A
3/8"	N/A	N/A
# 4	N/A	N/A
# 8	N/A	N/A
# 30	N/A	N/A
#200	N/A	N/A
Pan	N/A	N/A
Lime	N/A	N/A
AC - 20	N/A	N/A
Total	N/A	N/A

Compaction Date: N/A

Compaction Procedure: N/A

Gmb Calculations

A = 3334.0 g

B = 3337.5 g

C = 1881.8 g

Gmb = A/(B-C) = 2.29

Density = Gmb * 62.4pcf = 142.9 pcf

Testing Date: 4-21-94

Testing Temperature: 115 F

Height: 3 1/4 in

Comments: Medium Rough Chip Seal

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.679	0.632	0.573	0	0	0
1000	0.651	0.59	0.542	0.028	0.042	0.031
4000	0.632	0.569	0.529	0.047	0.063	0.044
8000	0.609	0.553	0.516	0.07	0.079	0.057

Core #: 27

Project: P-34-09

Sieve	% Retained	Weight (g)
3/4"	N/A	N/A
5/8"	N/A	N/A
3/8"	N/A	N/A
# 4	N/A	N/A
# 8	N/A	N/A
# 30	N/A	N/A
#200	N/A	N/A
Pan	N/A	N/A
Lime	N/A	N/A
AC - 20	N/A	N/A
Total	N/A	N/A

Compaction Date: N/A

Compaction Procedure: N/A

Gmb Calculations

A = 3393.5 g

B = 3397.5 g

C = 1937.8 g

Gmb = A/(B-C) = 2.32

Density = Gmb * 62.4pcf = 145.1pcf

Testing Date: 4-21-94

Testing Temperature: 115 F

Height: 3 3/16 in

Comments: No Chip Seal

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.642	0.601	0.544	0	0	0
1000	0.594	0.564	0.492	0.048	0.037	0.052
4000	0.566	0.536	0.479	0.076	0.065	0.065
8000	0.549	0.519	0.461	0.093	0.082	0.083

Core #: 28

Project: P-20-17

Sieve	% Retained	Weight (g)
3/4"	N/A	N/A
5/8"	N/A	N/A
3/8"	N/A	N/A
# 4	N/A	N/A
# 8	N/A	N/A
# 30	N/A	N/A
#200	N/A	N/A
Pan	N/A	N/A
Lime	N/A	N/A
AC - 20	N/A	N/A
Total	N/A	N/A

Compaction Date: N/A

Compaction Procedure: N/A

Gmb Calculations

A = 3117.9 g

B = 3121.4 g

C = 1782.3 g

Gmb = A/(B-C) = 2.33

Density = Gmb * 62.4pcf = 145.3 pcf

Testing Date: 4-24-94

Testing Temperature: 115 F

Height: 2 7/8 in

Comments: No Chip Seal

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.396	0.414	0.399	0	0	0
1000	0.297	0.274	0.293	0.099	0.14	0.106
4000	0.261	0.227	0.205	0.135	0.187	0.194
8000	0.237	0.17	0.177	0.159	0.244	0.222

Core #: 29

Project: P-12-26

Sieve	% Retained	Weight (g)
3/4"	N/A	N/A
5/8"	N/A	N/A
3/8"	N/A	N/A
# 4	N/A	N/A
# 8	N/A	N/A
# 30	N/A	N/A
#200	N/A	N/A
Pan	N/A	N/A
	N/A	N/A
Lime	N/A	N/A
AC - 20	N/A	N/A
Total	N/A	N/A

Compaction Date: N/A

Compaction Procedure: N/A

Gmb Calculations

A = 3056.9 g

B = 3064.4 g

C = 1732.3 g

Gmb = A/(B-C) = 2.29

Density = Gmb * 62.4pcf = 143.2 pcf

Testing Date: 5-2-94

Testing Temperature: 115 F

Height: 2 7/8 in

Comments: Medium Rough Chip Seal

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.447	0.486	0.451	0	0	0
1000	0.339	0.402	0.385	0.108	0.084	0.066
4000	0.308	0.374	0.354	0.139	0.112	0.097
8000	0.297	0.36	0.339	0.15	0.126	0.112

Core #: 30

Project: P-20-15

Sieve	% Retained	Weight (g)
3/4"	N/A	N/A
5/8"	N/A	N/A
3/8"	N/A	N/A
# 4	N/A	N/A
# 8	N/A	N/A
# 30	N/A	N/A
#200	N/A	N/A
Pan	N/A	N/A
Lime	N/A	N/A
AC - 20	N/A	N/A
Total	N/A	N/A

Compaction Date: N/A

Compaction Procedure: N/A

Gmb Calculations

A = 2973.4 g

B = 2978.4 g

C = 1707.3 g

Gmb = A/(B-C) = 2.34

Density = Gmb * 62.4pcf = 146.0 pcf

Testing Date: 5-3-94

Testing Temperature: 115 F

Height: 2 3/4 in

Comments: PMWC

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.291	0.277	0.226	0	0	0
1000	0.207	0.164	0.123	0.084	0.113	0.103
4000	0.156	0.102	0.085	0.135	0.175	0.141
8000	0.124	0.062	0.063	0.167	0.215	0.163

Core #: 31

Project: P-40-13

Sieve	% Retained	Weight (g)
3/4"	N/A	N/A
5/8"	N/A	N/A
3/8"	N/A	N/A
# 4	N/A	N/A
# 8	N/A	N/A
# 30	N/A	N/A
#200	N/A	N/A
Pan	N/A	N/A
Lime	N/A	N/A
AC - 20	N/A	N/A
Total	N/A	N/A

Compaction Date: N/A

Compaction Procedure: N/A

Gmb Calculations

A = 3239.0 g

B = 3243.0 g

C = 1857.8 g

Gmb = A/(B-C) = 2.34

Density = Gmb * 62.4pcf = 145.9 pcf

Testing Date:

Testing Temperature: 115 F

Height: 3.0 in

Comments: No Chip Seal, Apparent Bleeding.

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.469	0.504	0.511	0	0	0
1000	0.37	0.349	0.377	0.099	0.155	0.134
4000	0.338	0.278	0.328	0.131	0.226	0.183
8000	0.323	0.235	0.304	0.146	0.269	0.207

Core #: 32

Project: P-30-18

Sieve	% Retained	Weight (g)
3/4"	N/A	N/A
5/8"	N/A	N/A
3/8"	N/A	N/A
# 4	N/A	N/A
# 8	N/A	N/A
# 30	N/A	N/A
#200	N/A	N/A
Pan	N/A	N/A
Lime	N/A	N/A
AC - 20	N/A	N/A
Total	N/A	N/A

Compaction Date: N/A

Compaction Procedure: N/A

Gmb Calculations

A = 3382.0 g

B = 3388.5 g

C = 1915.8 g

Gmb = A/(B-C) = 2.30

Density = Gmb * 62.4pcf = 143.3 pcf

Testing Date:

Testing Temperature: 115 F

Height: 3 1/4 in

Comments: Rough Chip Seal.

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.763	0.807	0.852	0	0	0
1000	0.651	0.59	0.676	0.112	0.217	0.176
4000	0.597	0.509	0.652	0.166	0.298	0.2
4100	0.594	0.506	0.647	0.169	0.301	0.205
8000						

Core #: 33

Project: P-12-21

Sieve	% Retained	Weight(g)
3/4"	N/A	N/A
5/8"	N/A	N/A
3/8"	N/A	N/A
# 4	N/A	N/A
# 8	N/A	N/A
# 30	N/A	N/A
#200	N/A	N/A
Pan	N/A	N/A
Lime	N/A	N/A
AC - 20	N/A	N/A
Total	N/A	N/A

Compaction Date: N/A

Compaction Procedure: N/A

Gmb Calculations

A = 3156.9 g

B = 3160.4 g

C = 1774.8 g

Gmb = A/(B-C) = 2.28

Density = Gmb * 62.4pcf = 142.2 pcf

Testing Date: 5-10-94

Testing Temperature: 115 F

Height: 3.0 in

Comments: Light Chip Seal.

	Dial Indicator Reading (in)			Rut Depths (in)		
Cycles	LOC	Center	ROC	LOC	Center	ROC
0	0.497	0.501	0.504	0	0	0
1000	0.421	0.442	0.473	0.076	0.059	0.031
4000	0.398	0.435	0.464	0.099	0.066	0.04
8000	0.382	0.429	0.454	0.115	0.072	0.05

Core #: 35

Project: P-12-20

Sieve	% Retained	Weight (g)
3/4"	N/A	N/A
5/8"	N/A	N/A
3/8"	N/A	N/A
# 4	N/A	N/A
# 8	N/A	N/A
# 30	N/A	N/A
#200	N/A	N/A
Pan	N/A	N/A
Lime	N/A	N/A
AC - 20	N/A	N/A
Total	N/A	N/A

Compaction Date: N/A

Compaction Procedure: N/A

Gmb Calculations

A = 3609.5 g

B = 3617.0 g

C = 2027.6 g

Gmb = A/(B-C) = 2.27

Density = Gmb * 62.4pcf = 141.7 pcf

Testing Date:

Testing Temperature: 115 F

Height: 3.5 in

Comments: Medium Chip Seal.

Cycles	Dial Indicator Reading (in)			Rut Depths (in)		
	LOC	Center	ROC	LOC	Center	ROC
0	0.987	0.984	0.969	0	0	0
1000	0.901	0.894	0.907	0.086	0.09	0.062
4000	0.868	0.862	0.892	0.119	0.122	0.077
8000	0.852	0.848	0.89	0.135	0.136	0.079