Using Georgia Loaded-Wheel Tester To Predict Rutting

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The feasibility of using the Georgia Loaded-Wheel Tester (GLWT) to predict rutting in the laboratory was analyzed. 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 data base, and conducting statistical analyses. The analyses resulted in regression models that can be used to predict field rutting on the basis of rut depth measurements from the GLWT.

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 caused by 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 resistances. With this dilemma many state agencies are looking for reliable alternative methods for predicting the rut resistance of asphalt mixes. Construction of test sections is one method of determining whether an asphalt mix has adequate rut resistance, but this procedure is expensive and requires years of field measurements and analysis. On the other hand, by using accelerated rut testing devices in the laboratory, the rutting characteristics of an asphalt mix can be determined in a matter of days.

Accelerated rut testers have been used by several countries for quite some time. The Europeans have taken the leading role in developing 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*). Two slabs can be tested simultaneously. Slabs are prepared with the Laboratoire Central des Pons et Chaussees (LCPC) plate compactor. During testing the slabs are loaded with 5000 N (1,124 lb) by a pneumatic tire inflated to 0.6 MPa (87 lb/in.^{2}). The environmental chamber enclosing the specimen can be set to any temperature between 35 and 60°C. Tests are typically conducted at 60°C (140°F). Rut depth measurements are taken from 100 up to 100,000 cycles. A successful test will have a rut depth that is less than 10 percent of the slab thickness after 30,000 cycles. A pair of slabs can be tested in approximately 9 hr. 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 is 6 to 9 cm (2.4 to 3.5 in.) thick. Two slabs can be tested simultaneously. 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 with a steel wheel. The temperature can be varied from 30°C to 65°C (86°F to 149°F). The wheel is loaded with 705 N (158 lb). The machine is automated and records the deformation after each cycle. A successful test will have less than 4 mm (0.16 in.) of rut depth after 20,000 cycles. A pair of slabs can be tested in approximately 6 hr. 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 being tested. The cost of this accelerated tester is $150,000. This device is being considered for use by the Strategic Highway Research Program (SHRP) to predict the permanent deformation characteristics of asphalt pavements (*2*).

A device being developed at Oregon State University is the Environmental Conditioning System (ECS). The cost for this device is $45,000. ECS is being considered for use by SHRP to predict moisture sensitivity characteristics (*2*).

The Accelerated Loading Facility (ALF) used by FHWA is a duplicate of an Australian model. ALF is a full-scale pavement testing facility with programmable transverse distribution-of-load passes to simulate the random nonuniformity of actual traffic patterns. 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 cost of an ALF is in excess of $1,000,000.

The Georgia Loaded-Wheel Tester (GLWT) was originally developed to test asphalt slurry seals (*4*). It has since been modified and shown by Lai and Lee (*5*) to potentially distinguish between the levels of rut resistance in asphalt mixes. The Georgia Institute of Technology developed a testing system similar to the GLWT. The primary difference with 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 the Georgia Institute of Technology's accelerated rut tester came from one developed at the University of Nottingham, Nottingham, England (*6*).

The state of Wyoming, like other states, has its share of pavement rutting. Predicting pavement rutting before construction is at the top of the Wyoming Department of Transportation's (DOT's) priority list. As a first step, the University of Wyoming investigated the feasibility of using the GLWT to predict field rutting in the laboratory. The major findings of that investigation are described.

DESIGN OF EXPERIMENT

Figure 1 shows the overall testing and analysis strategies used in the research project described here. First, the GLWT was modified to test 15.2-cm (6-in.) cores instead of beams. Several cores with identical

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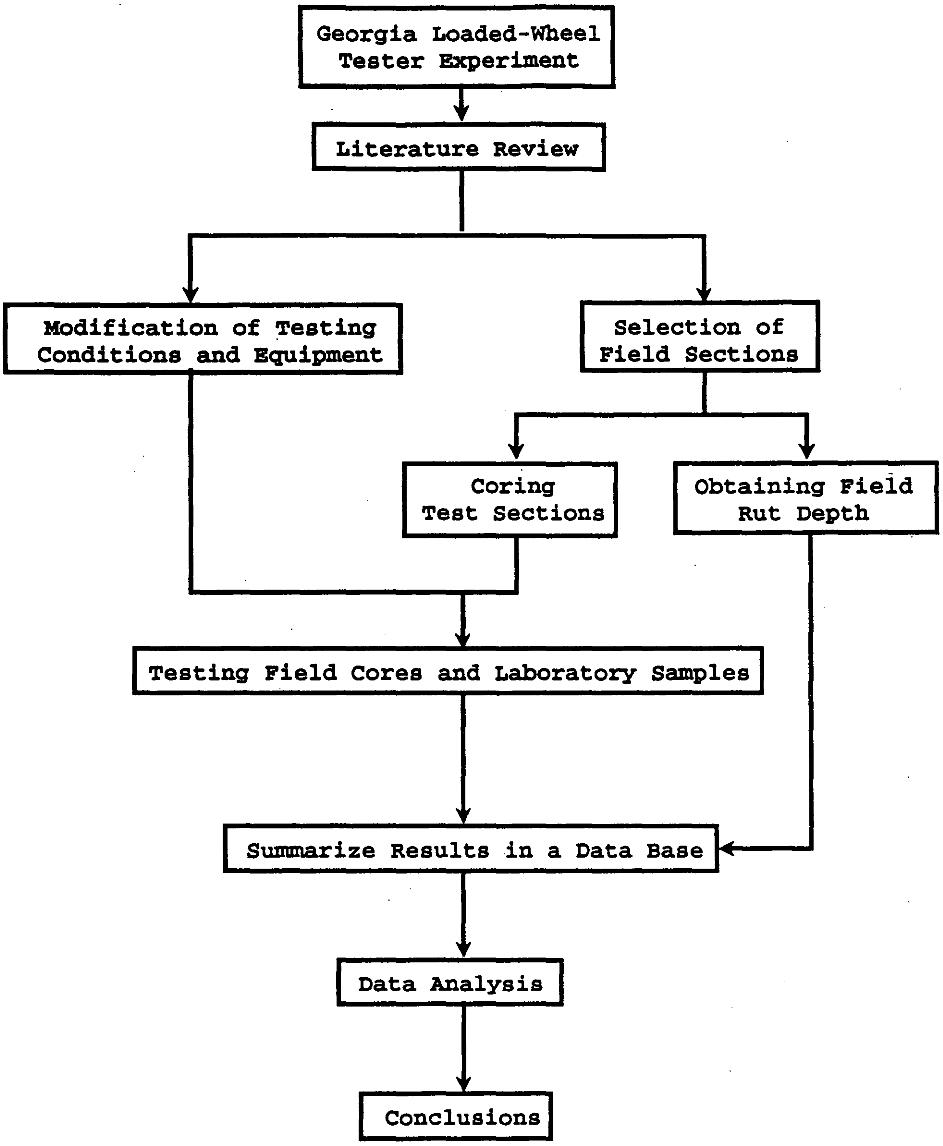

FIGURE 1 Evaluation of asphalt mixes with GLWT.

characteristics were later prepared in the laboratory and were 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 for testing with the GLWT. After the testing was completed, the field and laboratory rut depth values were summarized in a computerized data base. Statistical analyses were later conducted on the data to correlate laboratory and field rut depth measurements and to verify the repeatability of the GLWT.

MODIFICATIONS TO GLWT

The GLWT was developed by Benedict Slurry Inc. for the Georgia DOT 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 on which a loaded metal wheel traverses. This eliminated most of the excess rutting on the ends of the test specimens caused by the skidding and shoving actions of the tire. Another modification to the GLWT was the addition of a temperature-controlled environmental chamber that could maintain temperatures up to 51.7°C (125°F) for testing. This made the GLWT portable and capable of testing elevated pavement temperatures corresponding to summer conditions.

The dimensions of a typical GLWT test specimen are 7.5 by 7.5 by 38.1 cm (3 by 3 by 15 in.). These beams are normally prepared in the laboratory by using a press, a kneading compactor, or a combination of the two. This research project concentrated on modifying the GLWT to test 15.2-cm (6-in.) cores as opposed to beams. The use of 15.2-cm cores is beneficial for several reasons. First, cores can be extracted from recently constructed projects. These cores would have characteristics identical to those achieved in the field. Second, cores could be extracted from between the wheelpaths of existing pavements with known levels of performance in the field. With aging in consideration these cores could be tested in the GLWT. From the standpoint of feasibility of collection cores are much easier to obtain from the field than beams. The final advantage that 15.2-cm cores have over beams is that they are easier to compact in the laboratory and require less time and material to prepare.

Modifications had to be made to the GLWT apparatus before testing the cores. New holes were drilled in the base plate so that the sample-holding mold could handle 15.2-cm (6-in.) cores.

The initial attempt to test cores was performed by placing three samples simultaneously in the GLWT. This endeavor was quickly abandoned because of excessive rocking of the cores during testing. To overcome the rocking problem, fresh concrete was placed around individual cores and was allowed to set before testing. This procedure was time-consuming. Single cores were finally tested by placing precast concrete spacers on both sides of the cores to accommodate the 30.5-cm (12-in.) travel path of the loaded wheel. Several spacers were made in advance to accommodate slight fluctuations in core heights. Figure 2 demonstrates how cores are arranged in the GLWT. This has become the standard procedure for testing cores in the GLWT at the University of Wyoming.

A measuring device was developed in the laboratory to provide standardized rut depth measurements. The measuring device is a 63.5-cm (25-in.)-long aluminum dowel, 3.175 cm (1.25 in.) in diameter, that is 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 in both directions. Figure 3 shows this rut depth measuring device being used.

RESULTS FROM REPEATABILITY STUDY

After modifying the GLWT, 22 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 lb/in.^{2}) for a 0.5-sec duration from a kneading compactor. A static leveling load of 4536 kg (10,000 lb) for 1 min was later applied to achieve actual field densities for similar mixes. After the compacted specimen cooled it was extracted. The time required to prepare a sample is approximately 4 hr.

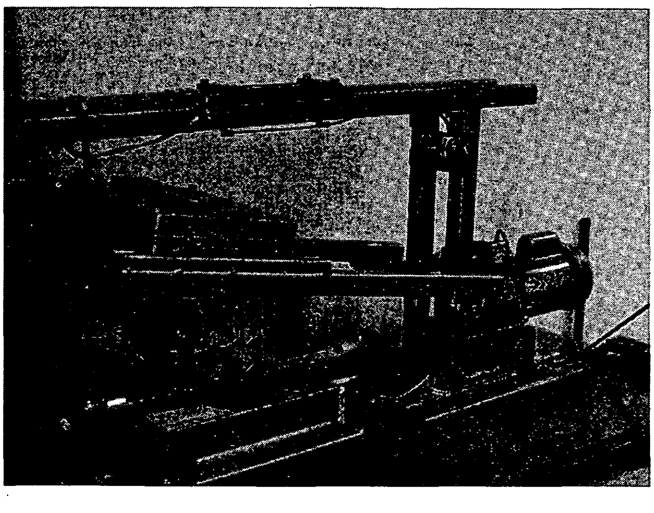

FIGURE 2 Modified GLWT: (1) weights, (2) electric motor, (3) sample-holding mold, (4) rut depth measuring device, and (5) machined aluminum wheel.

Most of the cores were then tested at either 40.6°C (105°F) or 46.1°C (115°F). In studies described in nearly all of the literature reviewed, testing was conducted at 40.6°C (105°F) but testing at higher temperatures was also recommended. In the present research it was believed that the 40.6°C (105°F) testing temperature may not be severe enough to predict pavement rutting. This was determined after comparing laboratory rut depth measurements with field rut depth measurements. Tests were then conducted at 51.7°C (125°F), which was the highest temperature that could be sustained by the GLWT without possibly overheating the mechanical apparatus. After testing only a few cores it was determined that this temperature was too high. All of the samples either failed or approached failure. Therefore, 46.1°C (115°F) was selected for the remainder of the testing.

Table 1 provides the average rut depth measurements after 1,000, 4,000, and 8,000 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 1,000, 4,000, and 8,000 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 1,000 cycles to 0.381 cm (0.15 in.) after 8,000 cycles. The standard deviation also increased from 0.056 cm (0.022 in.) to 0.081 cm (.032 in.).

SELECTION OF FIELD TEST SECTIONS

After verifying the repeatability of testing cores with the GLWT, 13 actual pavement test sections were selected for inclusion in this experiment. These sections were selected according to their geographic locations and rut depth severity levels. Field rut depth measurements, ages, elevations, equivalent daily 18-kip axle loads (EDLAs), highest monthly mean temperature, and type of surface treatment were obtained for all test sections. Three cores from each site were extracted between the wheelpaths. Initially, the cores were used to determine actual pavement thicknesses and later for testing in the GLWT. Table 2 provides the thicknesses of all of the pavement test sections.

Average field rut depth data were obtained for all sections from the Wyoming Rut Depth Report (*7*) and are summarized in Table 2. The rut depth data consisted of an average of 2,640 measurements

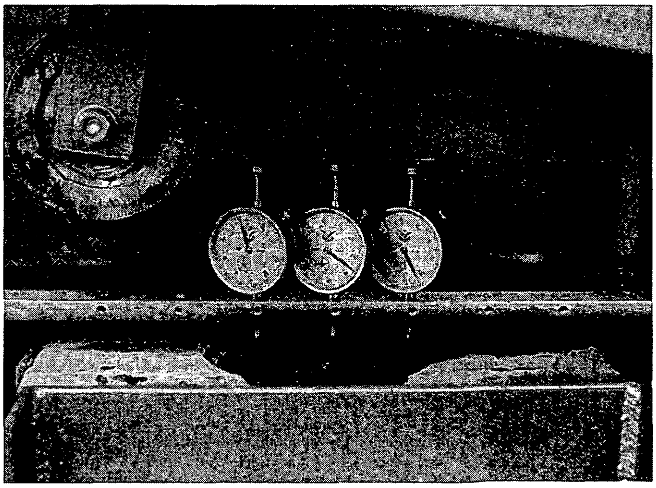

FIGURE 3 Demonstration of rut depth measuring device for GLWT.

TABLE 1 Average Rut Depth Measurements from 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

taken per mile with a Wyoming version of the South Dakota Road Profiler. Average annual daily truck traffic volumes were converted to EDLAs to analyze the differences between traffic volumes on the test sections. Traffic volumes are summarized in Table 3. Since all of the test sections were more than 5 years old, it was believed that the majority of rutting had already occurred. For this reason cumulative equivalent single axle loads were not included in the analysis.

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 by the standard method of testing for bulk specific gravity of compacted bituminous mixtures (AASHTO standard T 166-88). The densities and heights of the cores were determined and are summarized in Table 4. At least 12 hr before testing each core was placed in the preheating box of the GLWT.

To begin testing 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 lb/in.^{2}) 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. Cycles are recorded with an internal electronic counter. 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 1,000, 4,000, and 8,000 cycles. Single cores can be tested in approximately 3.5 hr.

RESULTS AND ANALYSIS

Cores from the test sections included in the experiment described here were tested at 40.6°C and 46.1°C (105°F and 115°F). All rut depth measurements obtained after 8,000 cycles are summarized in Table 5. Figure 4 shows the relationship between rut depth and number of cycles for the field cores tested at 46.1°C. The mean rut depths for all samples after 8,000 cycles were 0.26 cm (0.10 in.) and 0.41 cm (0.16 in.) at 40.6°C (105°F) and 46.1°C (115°F), respectively.

TABLE 2 Field Conditions for Test Sections

PROJECT	AVERAGE PAVEMENT THICKNESS (cm)	AVERAGE FIELD RUT DEPTH (cm)
P 23-03	17.1	0.18
P-25-04	10.8	0.84
P-34-09	12.1	0.33
P-34-10	14	0.28
P-40-13	19.1	0.53
P-20-15	15.2	0.13
P-20-17	18.4	0.46
P-30-18	15.9	0.84
P-12-20	13.3	0.41
P-12-21	15.2	0.53
P-12-26	12.1	0.51
P-12-27	11.4	0.61
P-12-28	17.1	0.46

TABLE 3 Traffic Volumes for Projects

PROJECT	AVERAGE ANNUAL DAILY TRAFFIC	AVERAGE ANNUAL DAILY TRUCK TRAFFIC	EDLAs
P-23-03	4555	1045	199
P-25-04	6475	635	121
P-34-09	1720	240	46
P-34-10	3360	370	70
P-40-13	2110	360	68
P-20-15	3310	620	118
P-20-17	2730	440	84
P-30-18	1265	145	28
P-12-20	3005	995	189
P-12-21	3120	1050	200
P-12-26	2400	830	158
P-12-27	2400	830	158
P-12-28	2550	860	163

An attempt was made to correlate all field and laboratory rut depth data at 46.1°C (115°F). Several regression models incorporating linear, quadratic, and cubic relationships were used. However, regression models with appropriate R^2 values could not be obtained. Therefore, the data set was split into two categories, first on the basis of the elevations of the sections and second on the basis of the pavement surface types. Statistical analyses were then performed separately on each data set. The ages of the test sections were not included in the models because all of the sections were more than 5 years old and had achieved most of their permanent deformation. The effects of traffic volumes and temperature were found to be insignificant in the models because all of the test sites had similar traffic levels and average ambient air temperatures.

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

$$\text{rut depth} = -3.71 + 1.50 \cdot A + 0.461 \cdot H \tag{1}$$

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/m³)	HEIGHT (cm)	DENSITY (kg/m³)
P-23-03	7.6	2265.0	7.6	2263.4
P-25-04	8.1	2353.1	8.3	2332.3
P-34-09	8.4	2319.5	8.1	2324.3
P-34-10	7.6	2338.7	7.0	2329.1
P-40-13	7.0	2357.9	7.6	2337.1
P-20-15	8.3	2330.7	7.0	2338.7
P-20-17	7.5	2329.1	7.3	2327.5
P-30-18	7.5	2271.4	8.3	2295.4
P-12-20	8.1	2287.4	8.9	2269.8
P-12-21	7.8	2277.8	7.6	2277.8
P-12-26	7.6	2284.2	7.3	2293.8
P-12-27	7.6	2289.0	8.3	2289.0
P-12-28	7.1	2319.5	6.4	2327.5

TABLE 5 Average Laboratory Rut Depths for Field Cores After 8,000 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-23-03	0.191	0.452
P-25-04	0.193	0.466
P-34-09	0.213	0.218
P-34-10	0.592	0.445
P-40-13	0.262	0.526
P-20-15	0.406	0.462
P-20-17	++	0.528
P-30-18	0.277	0.762+
P-12-20	0.191	0.297
P-12-21	0.130	0.201
P-12-26	0.284	0.328
P-12-27	0.086	0.175
P-12-28	0.310	++

\+ Test was stopped after rutting exceeded 0.762 cm (0.3 in)
++ Cores failed during testing

where

rut depth = predicted field rut depth (cm),
A = average laboratory rut depth after 8,000 cycles at 46.1°C (115°F) (cm), and
H = height of the field core tested in the GLWT (cm).

The R^2 for this regression model was 92.6 percent. Figure 5 illustrates the relationship between field rut depths and the rut depths predicted by this model. The heights of the cores tested were found to be significant in this relationship. A similar regression model was developed for elevations between 1676 and 2316 m (5500 and 7600 ft). The model equation for these higher elevations is

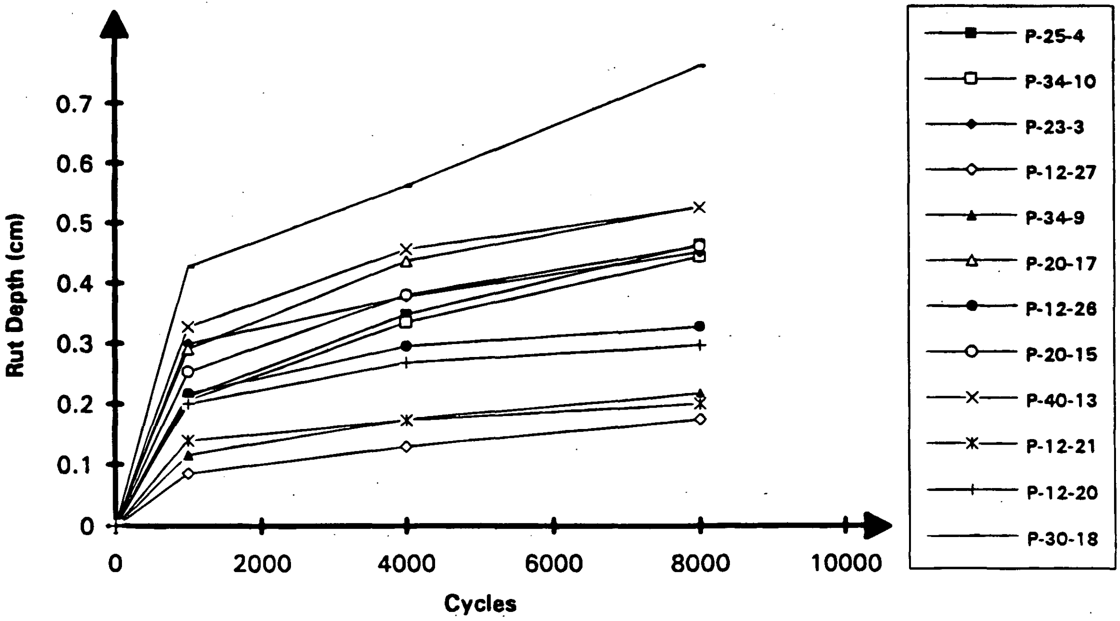

FIGURE 4 Rut depth plot for field cores tested at 46.1°C (115°F).

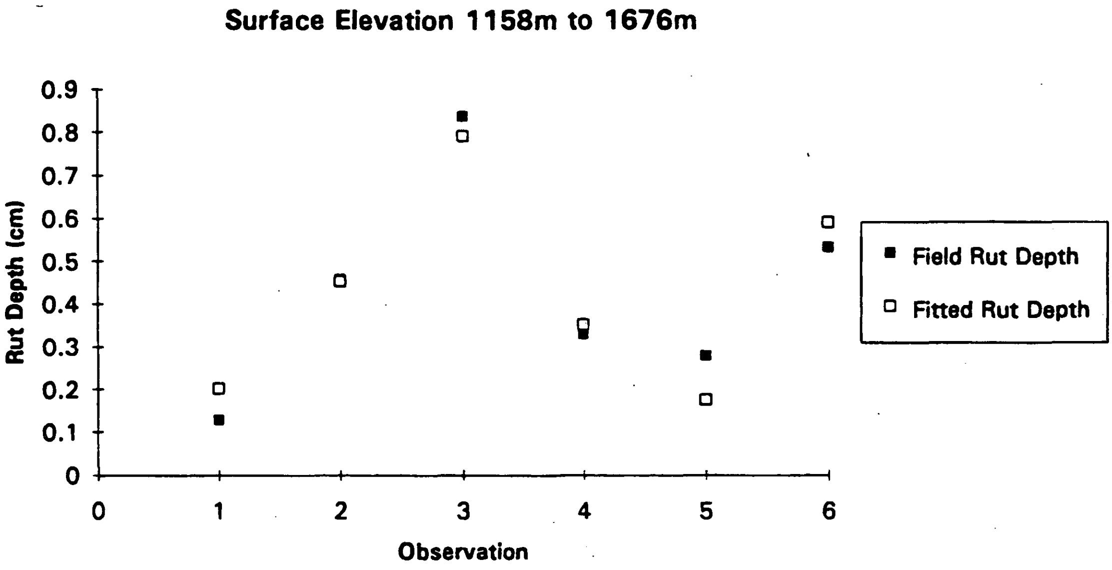

FIGURE 5 Fitted versus actual rut depth measurements for Regression Model 1.

$$\text{rut depth} = 0.776 + 0.39 \cdot A - 1.39 \cdot B \qquad (2)$$

where

rut depth = predicted field rut depth (cm),
A = average laboratory rut depth after 8,000 cycles at 46.1°C (115°F) (cm), and
B = center laboratory rut depth after 8,000 cycles at 46.1°C (115°F) (cm).

The R^2 coefficient for this model was 91.9 percent. Five projects were used in the determination of this regression model.

Next the field test sections were divided into two categories according to their surface types. 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 that analysis:

$$\text{rut depth} = -4.32 + 1.63 \cdot A + 0.53 \cdot H \qquad (3)$$

where

rut depth = predicted field rut depth (cm),
A = average laboratory rut depth after 8,000 cycles at 46.1°C (115°F) (cm), and
H = height of the field core tested in the GLWT (cm).

The R^2 coefficient for this model was 97.3 percent. Four cores were used in the determination of this regression model.

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

$$\text{rut depth} = 0.784 + 0.59 \cdot A - 1.60 \cdot B \qquad (4)$$

where

rut depth = predicted field rut depth (cm),
A = average laboratory rut depth after 8,000 cycles at 46.1°C (115°F) (cm), and
B = center laboratory rut depth after 8,000 cycles at 46.1°C (115°F) (cm).

The R^2 coefficient for this model was 93.4 percent. Seven cores were used in the determination of this regression model. All of the cores in the upper elevation category (Regression Model 2) had a surface treatment.

Problems developed while testing a few of the surface-treated cores in the GLWT. Some of the more rigid surface treatments fractured. This effect became apparent when cracking developed on the core adjacent to the hose. In these cases rutting was a function of structural failure instead of plastic flow. Another problem was noticed with cores that had extremely rough surfaces. When repeated cycles are applied to the samples some of the larger surface aggregates tilt or shift. The rut depth-measuring device takes measurements at identical locations each time. The movements inflate the initial dial indicator readings, which causes all successive rut depth measurements to be inflated. The rut depth measurements in these samples are masked by the shifting surface aggregate. Since Regression Models 2 and 4 contain the cores with surface treatments their validities are questioned. Further laboratory analysis will determine the effects of the shifting aggregates.

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.

CONCLUSIONS

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

1. The GLWT 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 well with actual field measurements.
3. Rut depth measurements from the GLWT at 46.1°C (115°F)

correlated with actual field rut depths after considering factors such as elevation and pavement surface type.

4. Surface-treated cores are sensitive to rut depth measurements because the aggregates on the surface tend to shift during testing. Future analyses should study removing surface treatments before testing in the GLWT.
5. The GLWT may not be the most accurate device for predicting 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 data base in the future to verify the results that were obtained.

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