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ABSTRACT

A majority of states in the U.S. had adopted the Superpave volumetric mix design system in the year 2000. However, this system does not have a standard mechanical test to evaluate the potential for permanent deformation (rutting) of the designed asphalt mix. National studies are underway to develop a fundamental test for this purpose but it will be a few years before that test is standardized and implemented. In the meantime, several states are considering loaded-wheel testers to proof-test the Superpave designed asphalt mixture.

This paper describes the Georgia loaded wheel tester and its most recent version called Asphalt Pavement Analyzer (APA). Preliminary test results from the National Cooperative Highway Research Project 9-17 "Accelerated Laboratory Rutting Tests: Asphalt Pavement Analyzer" are given. This project has the objective of recommending a test protocol for the APA based on the correlation of laboratory rut depths to actual rut depths in controlled field experiments.

Key Words: loaded wheel tester, Asphalt Pavement Analyzer, permanent deformation, rutting, asphalt mixtures, hot mix asphalt, asphalt concrete

EVALUATION OF PERMANENT DEFORMATION OF ASPHALT MIXTURES USING LOADED WHEEL TESTER

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INTRODUCTION

Prior to the 1920s, no strength test was available to evaluate asphalt mixtures. The mixes were designed based on experience in the field. Hubbard-Field was the first test method developed in the mid-1920s which quantified the strength of asphalt mixtures. This method was used until the mid-1950s when two new methods of mix design—Marshall and Hveem— were adopted by a majority of states. According to a survey conducted in 1984 (1) 75 percent of states were using Marshall, and 25 percent of states were using the Hveem method of mix design.

Based on the research conducted in the Strategic Highway Research Program (SHRP) during 1987-1992, a Superpave volumetric mix design system has been adopted by a majority of states in the year 2000. Unfortunately, this system does not have any mechanical test to evaluate the potential for permanent deformation (rutting) of the designed asphalt mixture. National studies are underway to develop a fundamental test for this purpose but it will be a few years before that test is standardized and implemented. In the meantime several states are considering the use of loaded wheel testers to proof-test the Superpave designed asphalt mixture.

In the recent past, several loaded wheel testers (mentioned below) have been developed and used in Europe and the United States.

- Hamburg wheel tracking device (Germany)
- French rutting tester (France)
- Nottingham rutting tester (U.K.)
- Georgia loaded wheel tester (U.S.)
- Asphalt Pavement Analyzer (U.S.)

This paper will address the use of Georgia loaded wheel tester and Asphalt Pavement Analyzer in the U.S.

DEVELOPMENT OF LOADED WHEEL TESTERS IN U.S.

The Georgia loaded wheel tester (GLWT), shown in Figure 1, was developed during the mid-1980s through a cooperative research study between the Georgia Department of Transportation and the Georgia Institute of Technology (*2*). Development of the GLWT consisted of modifying a wheel tracking device originally designed by C.R. Benedict of Benedict Slurry Seals, Inc. to test slurry seals (*3*). The primary purpose for developing the GLWT was to perform efficient, effective, and routine laboratory rut proof testing and field production quality control of asphalt mixtures (*4*).

The GLWT is capable of testing asphalt beam or cylindrical specimens. Beam dimensions are generally 125 mm wide, 300 mm long, and 75 mm high (5 in x 12 in x 3 in). Compaction of beam specimens for testing in the GLWT has varied greatly according to the literature. The original work by Lai (*2*) utilized a “loaded foot” kneading compactor. Heated asphalt mixture was “spooned” into a mold as a loaded foot assembly compacted the mixture. A sliding rack, onto which the mold was placed, was employed as the kneading compactor was stationary. West et al. (*5*) utilized a static compressive load to compact specimens. Heated asphalt mixture was placed into a mold and a compressive force of 267 kN (60,000 lbs) was applied across the top of the sample and then released. This load sequence was performed a total of four times. In 1995,

Figure 1. Georgia Loaded Wheel Tester

Lai and Shami (6) described a new method of compacting beam samples. This method utilized a rolling wheel to compact beam specimens.

Laboratory prepared cylindrical specimens are generally 150 mm in diameter and 75 mm high. Compaction methods for cylindrical specimens have included the “loaded foot” kneading compactor (2) and a Superpave gyratory compactor (7).

Both specimen types are most commonly compacted to either four or seven percent air void content. However, some work has been accomplished in the GLWT at air void contents as low as two percent (8).

Testing of samples within the GLWT generally consists of applying a 445 N (100 lb) load onto a pneumatic linear hose pressurized to 690 kPa (100 psi). The load is applied through an aluminum wheel onto the linear hose, which resides on the sample. Test specimens are tracked back and forth under the applied stationary loading. Testing is typically accomplished for a total of 8,000 loading cycles (one cycle is defined as the backward and forward movement over samples by the wheel). However, some researchers have suggested fewer loading cycles may suffice (5).

Test temperatures for the GLWT have ranged from 35 to 60 C (95 to 140 F). Initial work by Lai (2) was conducted at 35 C (95 F). This temperature was selected because it was Georgia’s mean summer air temperature (*3*). Test temperatures within the literature subsequently tended to increase to 40.6°C (105°F) (*3*, *5*, *9*, *10*, *11*), 46.1°C (115°F) (*11*), 50°C (122°F) (*3*, *8*), and 60°C (140°F) (*8*).

At the conclusion of the 8,000 cycle loadings, permanent deformation (rutting) is measured. Rut depths are obtained by determining the average difference in specimen surface profile before and after testing. A template with seven slots that fits over the sample mold and a micrometer are typically used to measure rut depth (*2*).

The Asphalt Pavement Analyzer (APA), shown in Figure 2, is a modification of the GLWT and was first manufactured in 1996 by Pavement Technology, Inc. The APA has been used to evaluate the rutting, fatigue, and moisture resistance of HMA mixtures. Since the APA is the second generation of the GLWT, it follows the same rut testing procedure. A wheel is loaded onto a pressurized linear hose and tracked back and forth over a testing sample to induce rutting. Similar to the GLWT, most testing is carried out to 8,000 cycles. Unlike the GLWT, samples can also be tested while submerged in water.

Figure 2. Asphalt Pavement Analyzer (APA)

Testing specimens for the APA can be either beam or cylindrical (Figure 3). Currently, the most common method of compacting beam specimens is by the Asphalt Vibratory Compactor (*12*). However, some have used a linear kneading compactor for beams (*13*). The most common compactor for cylindrical specimens is the Superpave gyratory compactor (*14*). Both specimen types are most commonly compacted to four or seven percent air voids (*13*). Tests can also be performed on cores or slabs taken from an actual pavement.

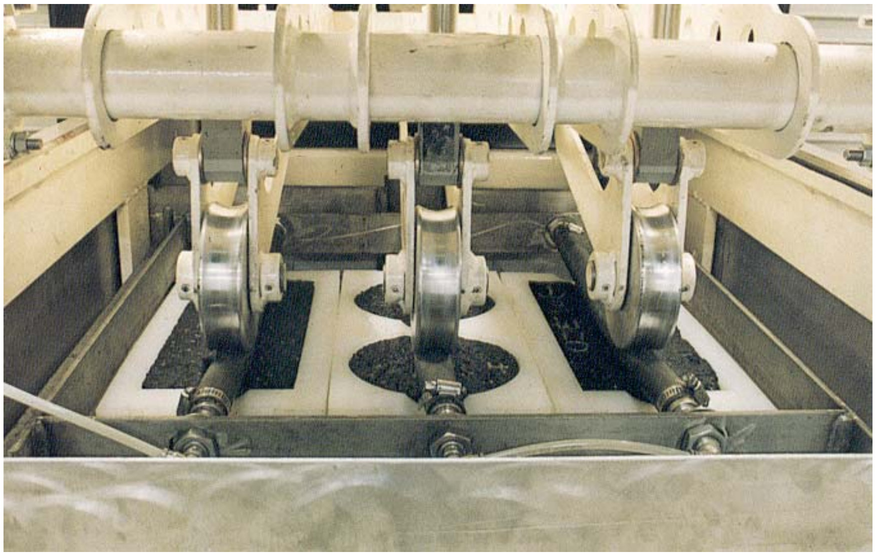

Figure 3. Close-up of beam and cylindrical specimens being tested in APA

Test temperatures for the APA have ranged from 40.6 to 64°C (105 to 147°F). The most recent work has been conducted at or slightly above expected high pavement temperatures (*14*, *15*).

Wheel load and hose pressure have basically stayed the same as for the GLWT, 445 N and 690 kPa (100 lb and 100 psi), respectively. However, two recent research studies (15. 16) did use a wheel load of 533 N (120 lb) and hose pressure of 830 kPa (120 psi) with good success.

Several states, including Georgia, Florida, and Virginia, have used the APA successfully in ranking a limited number of different asphalt mixtures for their potential for rutting. However, the correlation between APA rut depths and field rut depths of ten WesTrack test pavements subjected to the same traffic was attempted for the first time by Williams and Prowell (*15*). The R^2 value of 82.3 percent obtained in this correlation was encouraging (Figure 4).

As mentioned earlier, researchers have used different test protocols in the past for GLWT and APA in terms of specimen type (beam or cylinder), specimen dimensions, compaction method, air voids content in specimens, test temperature, hose pressure, and load. There was a need to optimize the test protocol for APA which led to the undertaking of NCHRP Project 9-17, “Accelerated Laboratory Rutting Tests: Asphalt Pavement Analyzer.” The discussion of this NCHRP project with preliminary findings follows.

REFINEMENT OF ASPHALT PAVEMENT ANALYZER

The primary objective of NCHRP Project 9-17, which is still underway, is to fine-tune the APA by attempting different testing variables and correlating the laboratory APA rut depth data to actual field rut depth data obtained from controlled test sections in the field.

Based upon the review of literature, a controlled laboratory experimental plan was developed. The experimental plan was formulated with the primary objective of evaluating variables that could potentially influence the ability of the APA to predict the rutting potential of asphalt

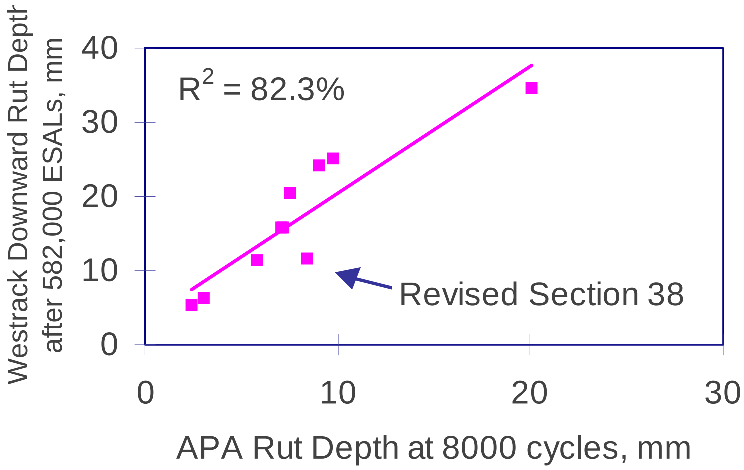

Figure 4. Evaluation of WesTrack Pavement Samples by Williams and Prowell

mixtures in the field and to select the combination of variables that best predict the rutting potential.

The overall research approach is shown in Figure 5. After completion of the main experiment, the data was analyzed and conclusions drawn about the ability of the APA to predict rut depths.

Four factors (test variables) were included within the experimental plan. These factors along with their levels are as follows:

- Specimen Type: (1) Beams compacted with an Asphalt Vibratory Compactor. (2) Cylinders compacted with a Superpave Gyratory Compactor.
- Hose Diameter: (1) The standard hose diameter of 25 mm (outside diameter). (2) Hose with a diameter of 38 mm (outside diameter).
- Test Temperature: (1) High temperature of standard PG grade based upon climate. (2) 6 C higher than high temperature of standard PG grade.
- Air Void Content: (1) 4.0 ± 0.5 percent (2) 7.0 ± 0.5 percent

A wheel load and hose pressure of 534 N (120 lbs) and 827 kPa (120 psi), respectively, was used during the entire study because these values had been used successfully by Williams and Prowell (15) in evaluating WesTrack test pavements as mentioned earlier.

Ten asphalt mixtures of known rutting performance in the field were included within a full factorial experiment designed to determine the combination of the aforementioned testing conditions for the APA that best predicts field rutting. These ten mixtures were selected from three full-scale pavement research projects and encompass climatic regions, project characteristics, and materials from throughout the United States. The three full-scale research projects include WesTrack (Nevada), MnRoad (Minnesota), and the FHWA Accelerated Loading Facility (ALF) at Turner-Fairbank Highway Research Center (Virginia).

Three test sections (15, 19, and 24) selected from WesTrack represent different gradations. Three test sections (cells 16, 20, and 21) selected from MnRoad represent different asphalt binders and optimum asphalt contents. Four test sections (Lane 5, 7, 10, and 12) from the FHWA ALF represent different asphalt binders and nominal maximum aggregate sizes.

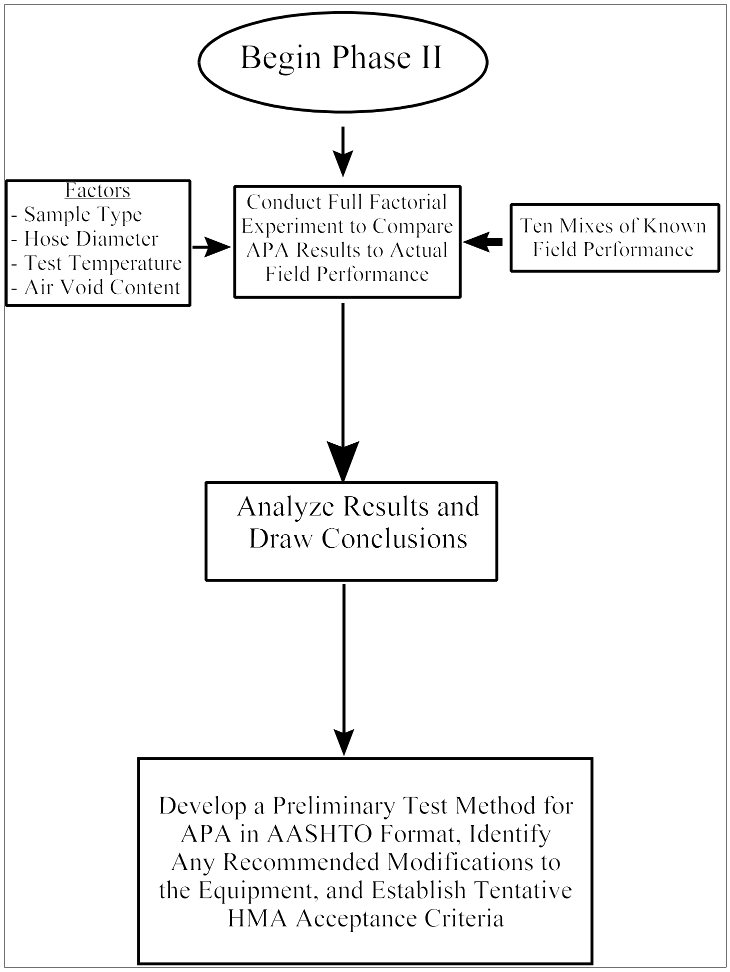

Figure 5. Overall Research Approach

Therefore, this experiment involved 160 factor-level combinations (2 sample types * 2 hose diameters * 2 test temperatures * 2 air void contents * 10 mixes). Three replicates of each factor-level combination were tested. Testing was conducted on mixes fabricated from original materials and subjected to short-term aging per AASHTO TP 2-96.

The detailed discussion of the experimental plan is given elsewhere (*16*).

The primary analysis tool selected for comparing laboratory and field rut depths was a simple correlation/regression analysis. For each factor-level combination investigated in the APA, a scatter plot was developed that has the results of laboratory and field rut depths. Each plot reflected actual field rutting versus laboratory rut depth for a given factor-level combination, for a given pavement. A correlation/regression analysis was then conducted on the data in order to determine the best fit line and the coefficient of determination (R^2).

Selection of the optimum factor-level combination for testing conditions in the APA was based upon the highest R^2 value obtained from the regression analyses. If one combination shows a significantly higher R^2 value than all other combinations, it will be selected and included in the tentative standard procedure.

Two typical plots with highest R^2 values for ALF and MnRoad mixtures are shown in Figures 6 and 7, respectively. The legends for the combination of test variables in the figures has the following order. First, the air void content (4, 5, or 7 percent); second, test temperature (PG or PG+6 C); third, large (L) or small (S) hose; and fourth, specimen type: cylinder (C) and beam (B).

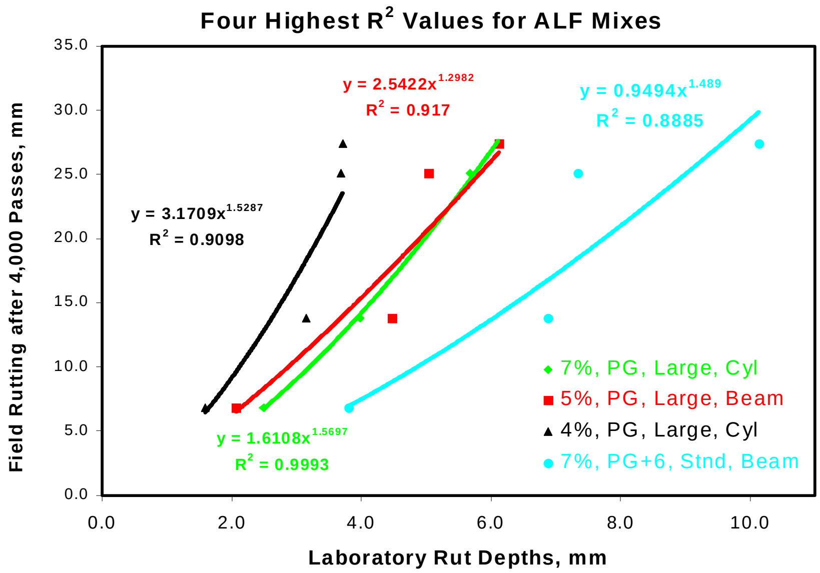

Figure 6. Typical Plots for Laboratory Rut Depth versus Field Rut Depth (ALF Mixes)

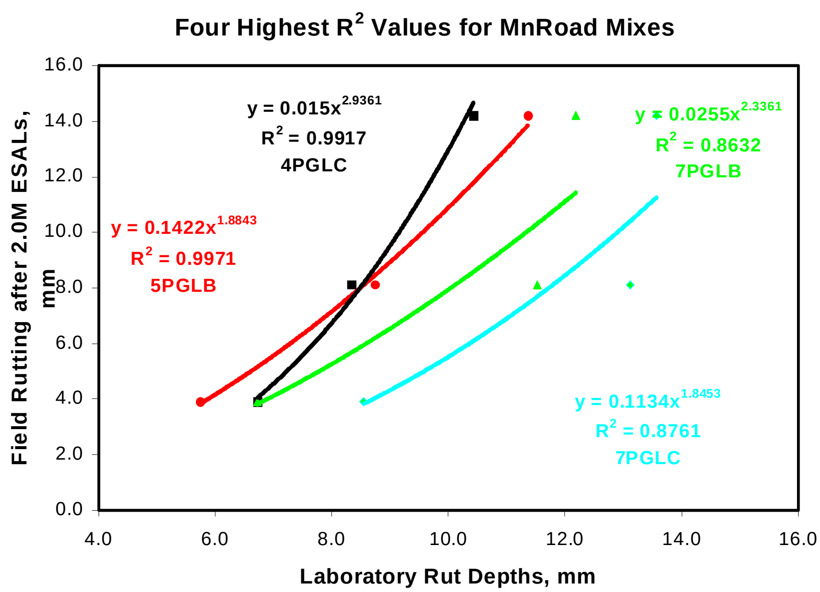

Figure 7. Typical Plots for Laboratory Rut Depth versus Field Rut Depth (MnRoad Mixes)

The tentative findings from this phase of NCHRP 9-17 are as follows:

- Both gyratory (cylinder) and beam specimens are acceptable
- Four percent air voids in cylinders and five percent in beams gave better results
- 25 mm standard, small hose gave acceptable results
- PG high temperature gave better results compared to PG+6 C.

These tentative optimum combinations of test variables are being validated in the next phase of NCHRP 9-17 using ten test sections from the NCAT Test Track. The selected optimum test variables may change after validation.

POTENTIAL RUT DEPTH CRITERIA FOR ASPHALT PAVEMENT ANALYZER

The APA test is not a fundamental test for permanent deformation. It can be considered as a simulative test which indirectly simulates the traffic loading on compacted asphalt mixtures. It would be interesting to compare the APA test results with the results for fundamental tests obtained on a large variety of asphalt mixtures. This would facilitate development of rut depth criteria for APA corresponding to similar criteria for fundamental tests. Such a study was recently completed by Zhang, Cooley, and Kandhal (*17*).

Forty-one mixes were tested by the APA, Repeated Shear Constant Height (RSCH) test, and the Repeated Load Confined Creep (RLCC) test briefly described as follows.

Asphalt Pavement Analyzer

Testing with the APA was conducted according to the procedure recommended by Georgia DOT Method GDT-115, Method of Test for Determining Rutting Susceptibility Using the Load Wheel Tester. Instead of 50 C, tests were carried out at 64 C. This temperature corresponds to the standard performance grade PG 64 which is mostly widely used in the U.S. The air void content of test specimens was 6.0±0.5 percent to represent in-place air voids in pavements just after construction. Hose pressure and wheel load were 690 kPa and 445 N (100 psi and 100 lb), respectively. Testing was carried out to 8,000 cycles and rut depths were measured continuously.

Repeated Shear at Constant Height

In 1987, the SHRP began a five year, $50 million dollar study to address and provide solutions to the performance problems observed in asphalt pavements. As an important procedure for Superpave volumetric mix analysis system, the Superpave repeated shear at constant height (RSCH) test, using Superpave Shear Tester (SST), was used to evaluate the rutting resistance of HMA mixtures. As outlined in the AASHTO TP7, test procedure F, the RSCH test consists of applying a repeated haversine shear stress of 68 kPa (0.1 second load, 0.6 second rest) to a compacted HMA (150 mm diameter by 50 mm height) specimen while supplying necessary axial stress to maintain a constant height. The test is performed either to 5000 load cycles or until five percent permanent strain is incurred by the sample. Permanent strain is measured as the response variable at certain interval load cycles throughout the test and recorded using LVDTs and a computerized data acquisition system.

All test specimens for RSCH testing were fabricated at 3.0±0.5 percent air voids to the required dimensions and tested at 50 C. This test temperature was selected as per test protocol because it is the effective temperature for permanent deformation (T_{eff} - PD) for hot regions in the U.S. and is believed to be critical for inducing rutting in asphalt pavements. The RSCH was performed to 5000 load cycles. The peak and valley of shear strain were recorded at periodic cycles.

Repeated Load Confined Creep Test

The repeated load confined creep test (RLCC) has been successfully used in the past by NCAT. It is considered to be a fundamental experimental method to characterize the rutting potential of asphalt mixtures, since fundamental creep principles can be applied to deformation of viscoelastic mixes. A Material Test System (MTS) was used to conduct this test. A deviator stress along with a confining stress is applied on an asphalt mix sample for 1 hour (3600 load cycles), with 0.1 second load duration and 0.9 second rest period intervals. After the 3600 load cycles, the load is removed and the rebound measured for 15 minutes. The strain observed at the end of this period is reported as the permanent strain. The permanent strain indicates the rutting potential of the mixtures. The target air void content for mixtures tested by the confined repeated load test was 4.0±0.5 percent in accordance with earlier studies conducted at NCAT. The test temperature was 60 C. Test loading consisted of a 138 kPa (20 psi) confining pressure and an 827 kPa (120 psi) normal pressure.

It is obvious different air voids in the compacted HMA specimens and different test temperatures were used in the proceeding three tests so as to utilize the respective test protocol and test criteria used in the past.

As shown in Figure 8, the APA has fair to good correlation (P-values less than 0.001) with RSCH and RLCC as follows:

	R^2
APA versus RSCH	0.52
APA versus RLCC	0.68

For both relationships, the slope of the regression line is positive which indicates that increases in APA rut depth result in increases in strain (plastic or permanent). These results indicate that the two fundamental and one simulative tests are related. This accomplished the primary objective of the study by Zhang, Cooley, Jr., and Kandhal (*17*).

The secondary objective was to utilize existing critical values of the two fundamental test procedures to recommend guidelines for critical rut depths in the APA. The literature has provided critical values for both the RSCH and RLCC test procedures. Bukowski and Harman (*18*) have suggested that plastic shear strains within the RSCH test of 2-3 percent are acceptable.

Mixes with plastic shear strains above 3 percent are considered poor performing mixes while mixes with strains below 2 percent are mixes considered very rut resistant. Gabrielson (*19*) has indicated that permanent strain values within the RLCC test of 10-13 percent are acceptable.

These critical values for both tests have been superimposed onto Figure 8. Based upon the relationship between RSCH and APA results, a critical range for APA rut depth would be approximately 8.2 to 11.0 mm. For the RLCC critical values, the range of critical APA rut depth would be approximately 8.0 to 9.5 mm. Interestingly, there is an overlap in critical APA rut depth from the two fundamental tests of 8.2 to 9.2 mm. Therefore, a conservative value of 8 mm can be recommended for APA when tested at high temperature of the standard PG grade for a location.

Based upon the established criteria for APA rut depths in Georgia and other states, this range in rut depths seems high. Georgia and others have long specified a maximum rut depth of 5 mm. However, the test temperature associated with this critical rut depth was 50 C. Zhang, et al. used a test temperature of 64 C. In 1997, Shami et. al. (*20*) presented a temperature-effect model to

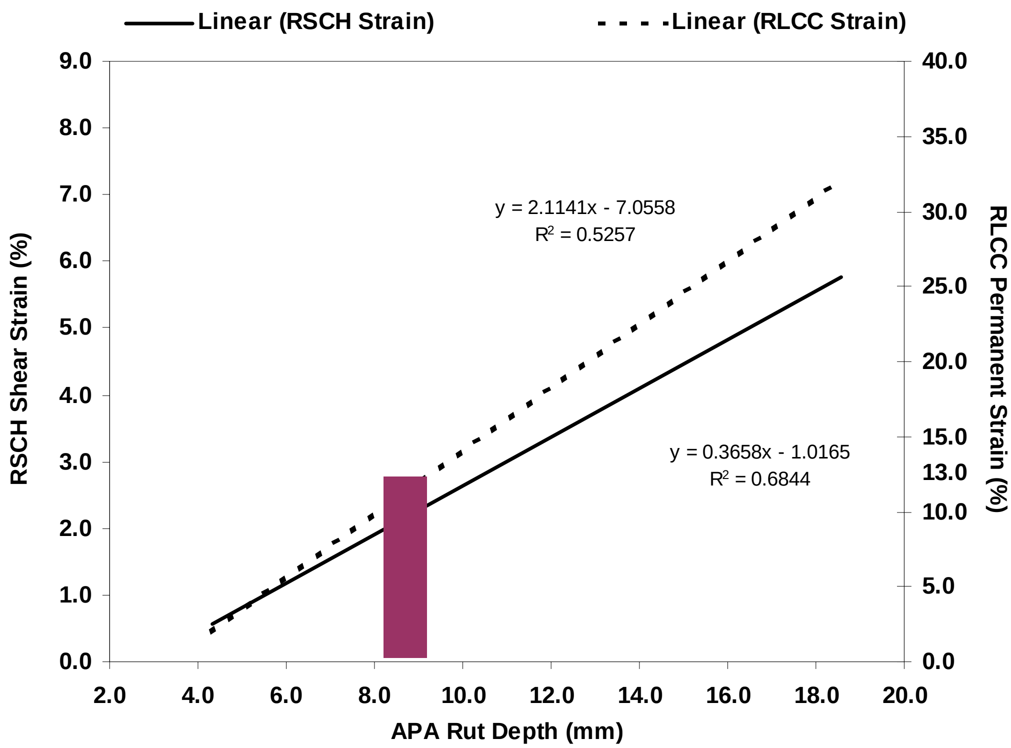

Figure 8. APA versus RSCH and RLCC

predict APA rut depth based upon testing conducted at a given test temperature and given number of cycles. Equation 1 presents the model:

$$\left[\frac{R}{R_0}\right] = \left[\frac{T}{T_0}\right]^{2.625} \quad \left[\frac{N}{N_0}\right]^{0.276} \qquad \text{(Eq. 1)}$$

where,

- R = predicted rut depth;
- R_0 = reference rut depth obtained at the reference test conditions T_0 and N_0;
- T, N = temperature and number of load cycles the rut depth is sought;
- T_0, N_0 = reference temperature and load cycles at the R_0.

This temperature-effect model was used to convert Georgia's critical rut depth of 5-mm (R_0) at a temperature of 50 C (T_0) after 8,000 cycles (N_0) to a critical rut depth (R) at a test temperature of 64 C (T) after 8,000 cycles (N). Results of this model yield a critical rut depth of 9.56-mm for testing at 64 C. As shown in Figure 9, this value matches very well with the upper limit of the critical range of APA rut depths developed based upon the two fundamental tests.

Based on this study, a conservative, tentative value of 8.0 mm maximum rut depth can be recommended for APA when tested at the high temperature of the standard PG grade for a location. This criteria has to be adjusted by the states based on experience with their mixtures, traffic, and climatic conditions. Some states may believe this tentative value to be on the high side.

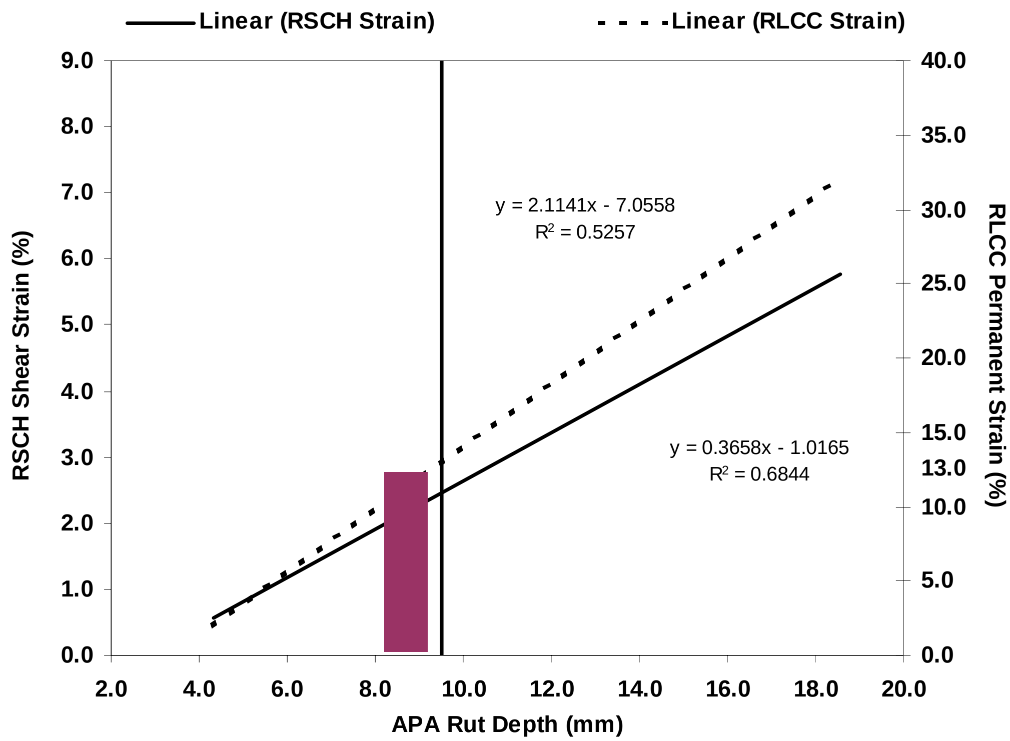

Figure 9. APA versus RSCH and RLCC with Georgia Criteria

CONCLUSIONS

The following conclusions are drawn from the data presented in this paper:

- The Asphalt Pavement Analyzer (APA) can be used as a proof test for rutting performance until a simple performance test based on fundamental engineering principles is developed.
- The APA test equipment is commercially available. The test criteria based on past experience is also available.

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