Test Device for Evaluating Rutting of Asphalt Concrete Mixes

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A loaded wheel test apparatus for direct laboratory comparison of the rutting susceptibility of asphalt concrete mixes is described. The test consists of applying a loaded, rubber-tired wheel to a small rectangular beam specimen. For the mechanical apparatus described, the wheel, which is loaded by deadweight, remains stationary while the beam moves back and forth. The stress state applied by this system is similar to that which occurs in the field, including the application of stress reversals. About 50 two-directional loads are applied to a specimen each minute with the total number of repetitions being 8,000. A test can be performed in about 3 hr. The testing concept is straightforward, and the loading system is entirely mechanical. Hence, the test can be conducted and the tester can be maintained at a minimum of cost by a laboratory technician having a very modest level of technical and mechanical ability. Also, complicated electronic instrumentation is not required to obtain good results, which significantly reduces the equipment cost and makes setting up and performing the rutting test simple.

Field studies reported in 1967 indicated that rutting in flexible pavements at that time was generally not a problem within the United States (*1*). However, during the 25 years following that study, rutting has become an important factor in pavement design. For example, excessive rutting has been reported in asphalt concrete pavements in Florida, Georgia, Illinois, Pennsylvania, Tennessee, and Virginia (*2*). A number of factors help to account for the observed increase in the rutting problem associated with asphalt concrete pavements, including increase in overall vehicle traffic volume, increase in the percentage of truck traffic, increase in tire pressures, increase in axle loadings, and the occurrence of several years of higher than average summer temperatures in at least some areas of the United States.

A Federal Highway Administration study has shown that a 20 percent increase in total interstate traffic occurred from 1970 to 1984 (*3*). Accompanying this increase in traffic was a 49 percent increase in the number of trucks and a 126 percent increase in the number of 80-kN (18-kip) equivalent single-axle loads applied to the pavements. Also, with the advent of steel-belted radial tires, truck tire pressures have increased from about 586 kN/m^2 (85 psi) to 758 to 861 kN/m^2 (110 to 125 psi).

To design asphalt concrete mixes with good resistance to rutting, a simple but reliable test is needed. This paper describes the construction and operation of a small loaded wheel tester suitable for routine laboratory use and also gives a suggested test procedure. The proposed test is suitable for comparing one asphalt concrete mix directly with another, is simple to perform, and does not require complicated instrumentation and test equipment.

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METHODS FOR EVALUATING RUTTING OF ASPHALT CONCRETE

Sousa et al. (*4*), as a part of the SHRP program, have given a good summary and general review of available methods for measuring the susceptibility of asphalt concrete mixes to rutting. For evaluating rutting in asphalt concrete, the repeated load simple shear test was given the best overall ranking by Sousa et al., and the repeated load, triaxial shear test was given the next-to-highest ranking. The loaded wheel test, which was not given a good ranking in the SHRP report, offers a practical alternative to the simple shear and triaxial tests rated so highly by Sousa et al.

The repeated simple shear test appears to have been ranked the highest by Sousa et al. for the following reasons:

1. The simple shear test applies a pure state of shear to a specimen. Sousa et al. point out that permanent deformation in asphalt concrete is primarily caused by a change in shape due to the application of shear stress rather than a change in volume associated with a mean normal stress. The change in shape of the asphalt concrete through plastic shear flow is evidenced in the field, for example, by shoving of asphalt concrete to the sides of the loaded area (*5,6*). Deformation is also caused by densification of the asphalt concrete.
2. The direction of the applied shear stress reverses as a wheel moves toward and then away from a given small element of material beneath the pavement. This reversal of shear stress can be readily applied in the simple shear laboratory test.

An important concept in materials testing, emphasized in the SHRP report and by many other researchers, is that the stress state applied during testing should duplicate, as closely as practical, the stress state caused in the field by the applied loading. The repeated, simple shear test offers a practical trade-off for applying a realistic stress state compared with more sophisticated tests such as the complicated hollow cylinder test. The test, however, is more suited for research than routine laboratory testing.

LOADED WHEEL TESTER

The loaded wheel test consists of placing a loaded wheel on the surface of an asphalt concrete specimen and moving the wheel in a line back and forth across the surface of the specimen. The loaded wheel tester (LWT) applies a stress state similar to that within the asphalt concrete when subjected to a wheel loading moving in a straight line. Stresses due to a wheel turning and breaking are not applied in this type of test.

An element of material within the pavement near the surface is subjected to both reversal of shear stress and rotation of principal planes. The LWT reproduces these general stress conditions except that the scale is changed. In contrast, the simple shear test can apply shear stress reversals but does not reproduce the complete stress state or rotation of principal stress planes that occurs in the field.

The LWT offers an excellent device for quantitatively comparing the relative rut susceptibility of one asphalt concrete mix with another. The testing concept is straightforward and the loading system is entirely mechanical. Hence, the tester can be maintained at a minimum of cost by a laboratory technician having a very modest level of mechanical ability. Also, electronic instrumentation is not required to obtain good results. Because of these features, the loaded wheel test offers an excellent alternative to other laboratory testing techniques when the performance of one mix is to be compared with that of another.

This does not necessarily imply that the LWT is a better test than the simple shear test. Considerably more testing and field validation is necessary before a conclusion can be reached. An important advantage of the simple shear test over the LWT is that the resilient shear modulus, G_r, can be directly obtained from the simple shear test. The well-known resilient modulus of elasticity, M_r, is related to the resilient shear modulus, G_r, for a linearly elastic, isotropic material by the following expression:

$$M_r = 2(1 + \nu) G_r \quad (1)$$

where ν is Poisson's ratio.

Thus, M_r can be estimated from simple shear test results if a value of Poisson's ratio is measured or assumed. M_r is required for use in mechanistic-based pavement design procedures and for selecting structural coefficients from the 1986 AASHTO *Design Guide*.

Neither the resilient modulus nor the structural coefficients can be obtained from the loaded wheel test at this time. This is because a relationship has not been found between rutting, which is a permanent deformation mechanism, and the resilient modulus, which is associated with recoverable deformation. Following the 1986 AASHTO *Design Guide*, structural coefficients are determined using resilient moduli values.

LOADED WHEEL TEST APPARATUS

The LWT described in this paper was developed to carry out an investigation for the Georgia Department of Transportation (Georgia DOT) to study the influence of aggregate properties on rutting in asphalt concrete mixes (*7*). Georgia DOT has for a number of years used an LWT to investigate the susceptibility of asphalt concrete mixes to rutting. In the Georgia DOT LWT apparatus, the loaded wheel is pulled back and forth by a large vertically oriented cam and arm system; the specimen remains fixed in position during the test.

The primary advantages of the Georgia Tech testing system over the Georgia DOT's system include (*a*) a much smoother and more consistent operation, (*b*) the ability to easily change the loaded length of specimen, and (*c*) the ability to change the speed of the wheel loading. Figures 1 through 4 show general views of the Georgia Tech LWT. The LWT applies a constant load, through a wheel, to the surface of a rectangular asphalt concrete beam specimen. The asphalt concrete beam, which is placed in an adjustable steel box for alignment and to provide a small degree of confinement, rests on a rectangular steel plate. The steel plate, which rolls on precision bearing wheels, is pulled back and forth by a mechanical system driven by a motor. The general concept for the Georgia Tech LWT was obtained from the one developed at the University of Nottingham, England.

Wheel Loading

Load is applied to the rectangular asphalt concrete beam specimen by a wheel 28.6 mm (1.125 in.) wide and having a diameter of 203 mm (8 in.). In the future, a wheel 32 to 38 mm (1.25 to 1.5 in.) wide will be used for most tests to give a better ratio of wheel width to maximum aggregate size. The wheel used to date has a hard rubber cover and must be periodically replaced because of wear. During operation of the system, the wheel remains at one location but rotates through a little less than one-half revolution as the beam moves back and forth. A constant dead load weight is applied to the wheel through a lever arm arrangement consisting of a load hanger, lever arm, and pivot as shown in Figures 1, 2, and 4. The lever arm supporting the dead load hanger is attached to a test frame 1.52 m (5 ft) long by 0.61 m (2 ft) wide by 0.9 m (3 ft) high. The load lever arm and test frame are constructed of 51- by 51-mm (2- by 2-in.) steel box sections 6.4 mm (0.25 in.) in thickness.

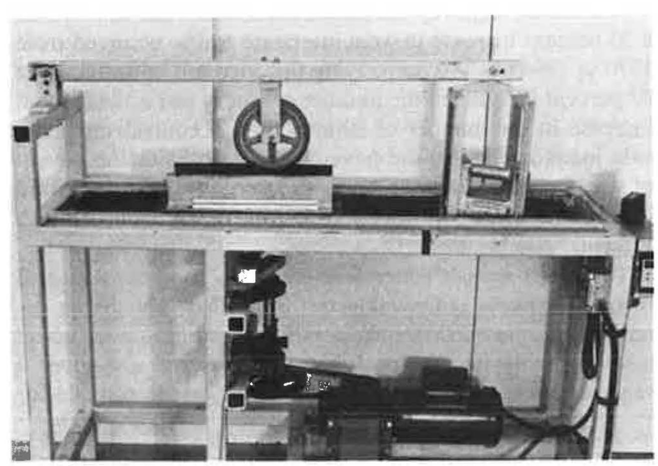

FIGURE 1 Photograph of LWT.

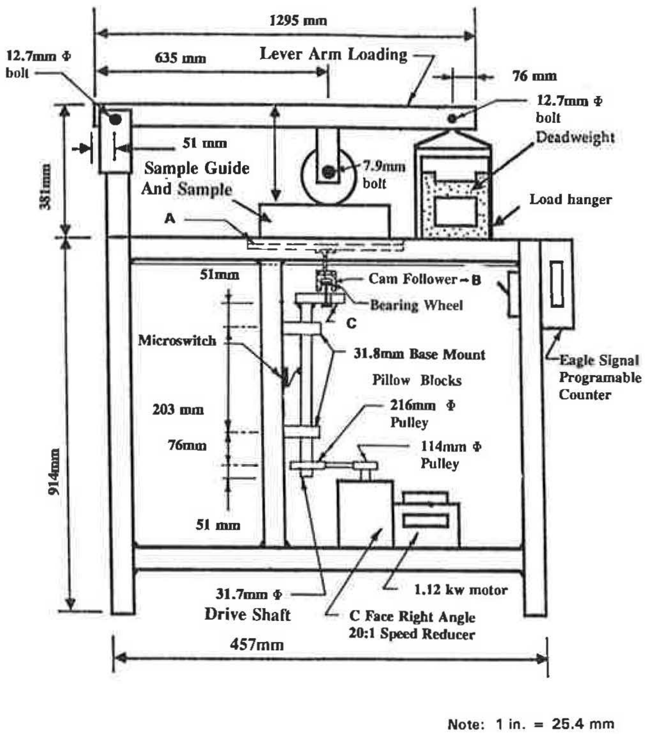

FIGURE 2 LWT—elevation view.

Mechanical Movement of Beam Specimen

The flat steel plate (labeled A in Figure 2), and hence the asphalt concrete specimen, is pulled back and forth through a travel path 292 mm (11.5 in.) long by a 1.12-kW (1.5-hp) motor operating at a speed of 1,725 rpm. Fifty load repetitions per minute are applied to the asphalt concrete beam using the following mechanical system shown in Figures 2 and 3:

1. The 1,725-rpm motion of the motor is reduced to 86 rpm by using a 20 to 1 (nominal) gear reduction box attached to the end of the motor.
2. The 86-rpm motion coming out of the gear reduction box is further reduced by going from a pulley 114 mm ($4\frac{1}{2}$ in.) in diameter attached to the drive shaft leaving the gear reduction box to a pulley 216 mm ($8\frac{1}{2}$ in.) in diameter. The two pulleys lie in the same horizontal plane. The axes of the two pulleys are 254 mm (10 in.) apart and connected by a flexible drive belt.
3. The larger pulley turns a vertical drive shaft 31.8 mm (1.25 in.) in diameter attached by two pillow blocks to a vertical member of the test frame.
4. The drive shaft, in turn, has a cam lever arm system attached to it that drives the horizontal beam support plate back and forth (A, Figure 2).

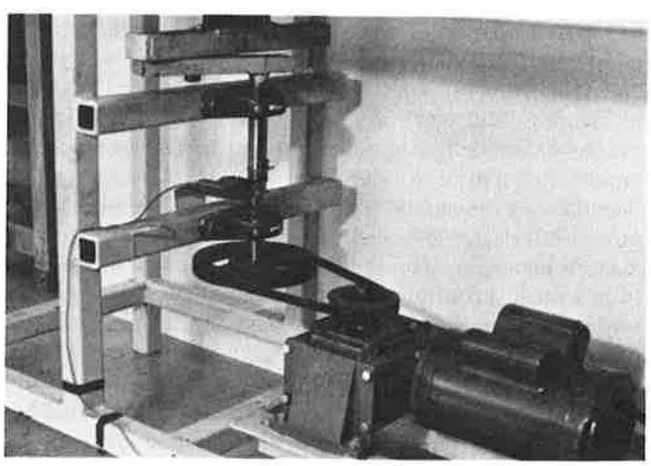

FIGURE 3 Mechanical system used to achieve linear motion.

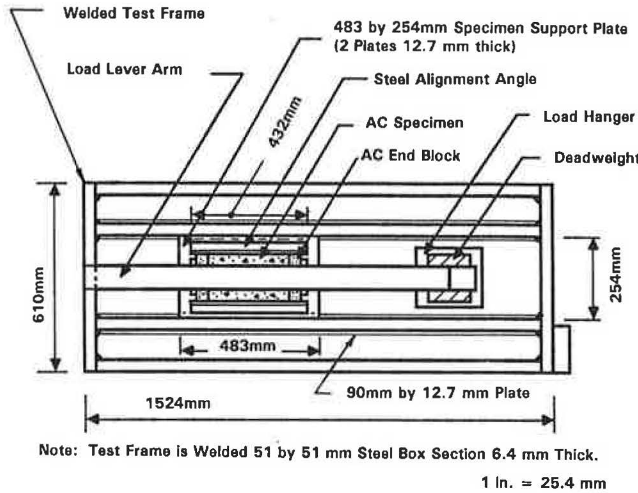

FIGURE 4 Plan view drawing of LWT.

The articulated arm system consists of a cam and cam follower. The cam follower segment, labeled B in Figure 2, is rigidly attached by means of a 152-mm (6-in.) length of steel channel to the specimen support plate (A). This segment of the articulated lever arm system consists of a steel channel 51 mm (2 in.) wide and 445 mm (17.5 in.) long. The inside of the channel is machined to form a slot so that a precision bearing 41.3 mm ($1\frac{5}{8}$ in.) in diameter can roll back and forth inside it.

The cam segment of the articulated system (C in Figure 2) consists of a flat steel plate 267 mm ($10\frac{1}{2}$ in.) long by 51 mm (2 in.) wide by 25 mm (1 in.) thick. A hole drilled through one end of this plate allows it to be welded to the vertical drive shaft. Nine additional holes 16 mm ($\frac{5}{8}$ in.) in diameter are drilled in this plate, which allows quick adjustment of the length of travel of the wheel across the specimen. To achieve the desired 292-mm (11.5-in.) length of travel, the pivot point of the cam-follower system is located 63.5 mm ($2\frac{1}{2}$ in.) from the drive shaft.

To change the circular motion of the drive shaft to linear motion of the specimen support plate, the cam, which is connected to the drive shaft, is also connected using a precision bearing to the channel. The channel in turn is rigidly attached to the specimen support plate. A steel bolt extends vertically through the cam plate and has a horizontally oriented precision bearing fitted to the bolt above the plate. This bearing rolls back and forth in the machined slot of the channel that comprises the cam follower. Thus, as the vertical drive shaft rotates, the cam lever arm also rotates. The cam, in turn, pulls the support plate back and forth as the bearing rolls along the slot in the channel that is rigidly attached to the specimen support plate.

The flat support plate (A) is guided along the test frame by means of eight precision steel bearings, with two of these bearings located at each corner of the plate. One bearing is oriented vertically and rides along a flat steel plate welded to the bottom of the two center members of the test frame (Figure 4). The other bearing is oriented horizontally and rides along the side of the steel box section.

Specimen Alignment and Confinement

The specimen is placed in a rectangular box to provide alignment and a small degree of confinement. The box consists of four independent lengths of steel angle. Each steel angle has either two or three slots machined in it. The slots allow adjustment of the angles snugly against the specimen. In practice, the angles on two adjacent orthogonal sides are tightly fastened after being properly aligned to the horizontal plate that supports the specimen. The remaining two angles are tightened down after the asphalt concrete specimen is positioned in the apparatus.

Rut Depth Measurement Template

The maximum rut depth resulting from wheel loading is measured at a different number of load repetitions at several locations along the beam. To reestablish the exact position of these measurements each time, a template was developed that can be repositioned on an asphalt concrete beam specimen at exactly the same location each time. To accomplish this, a horizontally oriented rectangular template is placed on top of two parallel sides of the steel angle box that holds the specimen in place. The template, which is machined from aluminum, has 13 rectangular slots oriented perpendicular to the direction of the wheel movement and spaced 25.4 mm (1 in.) apart. The slots are 38 mm (1.5 in.) long and 9.5 mm ($\frac{3}{8}$ in.) wide. To measure rut depth, a 0.025-mm (0.001-in.) dial indicator is placed successively in each desired slot and slowly moved across the transverse rut profile. The largest observed dial reading is recorded as the maximum rut depth. The transverse rut profile at some locations has been observed to be nonuniform. The nonuniformity is usually caused by the presence of aggregate particles near the surface (see Figure 5). Measuring the maximum rut depth in the manner described tends to produce less scatter in test results than taking a reading at a fixed location.

To accurately reposition the template over the specimen after each series of load repetitions, one corner of the template and one corner of one of the steel angles that hold the asphalt concrete specimen in position have a notch machined in them so that the template fits into the notched angle exactly the same way each time.

The method described for measuring rut depth worked satisfactorily. However, readings must be taken manually at the desired number of load repetitions. A potential improvement to this testing system would be to rigidly mount a single spring-loaded LVDT to measure the rut depth as the beam moves

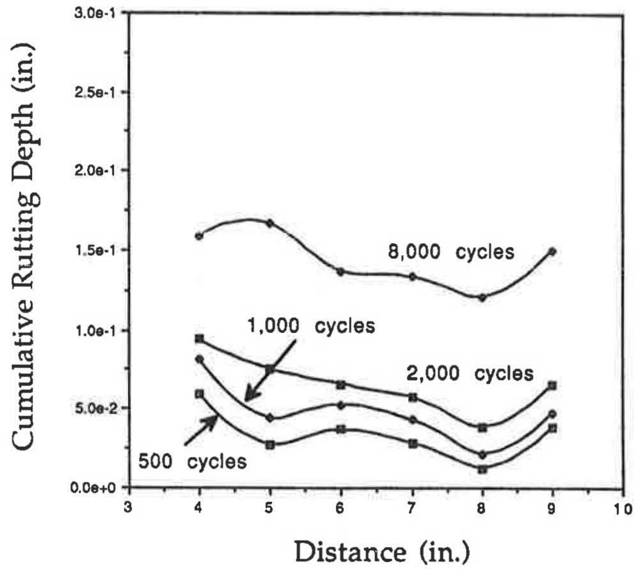

FIGURE 5 Transverse rut profile obtained using LWT.

back and forth. The LVDT would have a roller mounted at its tip. Rut depths would then be measured over the center 50 to 75 mm (2 to 3 in.) of the beam at the desired number of load repetitions. Measurements could be performed automatically and stored digitally using a data acquisition system. The average value of rutting would then be calculated using the stored data. The data acquisition could be triggered externally with the data then being collected at a specified rate and for a specified time. A microswitch could be used to trigger the data acquisition system when the beam reaches a position near its midpoint of travel.

RUT TEST PROCEDURE

Load Repetitions

A total of 8,000 wheel passes are applied to an asphalt concrete specimen. When the wheel moves in either direction over a particular point, one wheel loading is considered to have been applied. The maximum transverse rut depth is usually measured before the beginning of the test and at the end of 500, 1,000, 2,000, and 8,000 load repetitions as shown in Figure 6. Rut depth is measured at the middle three locations of the deflection template, which correspond to the middle 50.8 mm (2 in.) of a specimen. Measurement of deflection over the middle 50.8 mm (2 in.) was found, because of end effects, to give slightly better results than if the rut measurements are averaged over a longer length of beam. A programmable controller is used to automatically stop the test at the end of each load sequence. Use of the programmable controller greatly minimizes the time required to monitor the test. A counter was also used to measure the total cumulative number of load repetitions applied. The counter was used as a check to verify the total number of repetitions applied since the programmable counter must be set back to zero after each load increment.

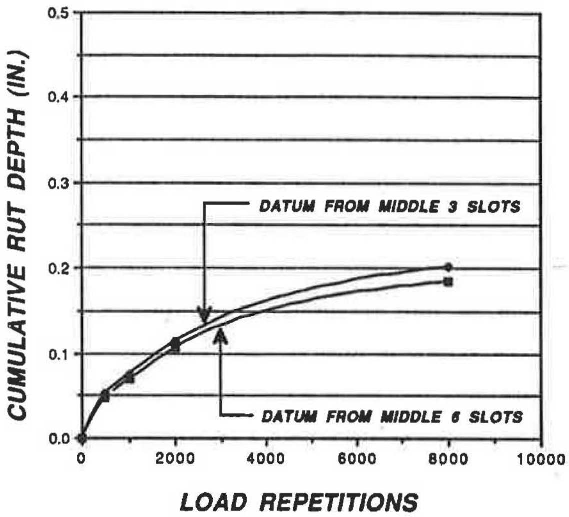

FIGURE 6 Typical variation of observed maximum rut depth with load repetitions.

Wheel Loading

The asphalt concrete beams are subjected to a 903-kN/m^2 (131-psi) average tire pressure through a solid rubber tire. A solid rubber tire has been used in the United Kingdom for a number of years. This type of wheel is considered acceptable by the authors for general comparisons of rut resistance between different mixes. The rubber tire is dead loaded by means of 223 N (50 lb) of lead weight suspended from the loaded hanger. The weight of the wheel and support frame, load hanger, and lever arm supporting the load hanger is also included in determining the total weight applied to the specimen. The load applied by the lever arm load system to a specimen should be accurately measured by temporarily replacing the wheel with a calibrated proving ring. The total applied load is then equal to this value plus the weight of the wheel and its support frame.

Use of a pneumatic rubber tire would be most desirable. A rather extensive search, however, has not identified a suitable source of tire. An alternative approach, developed by Lai (*8*), is to use a heavy hose with plugs inserted in the ends of the hose and clamped. The hose is inflated to the desired air pressure and then stretched out along the wheelpath on the surface of the asphalt concrete beam. A solid metal wheel specially machined to fit the top half of the rubber hose is run back and forth over the hose. The use of a long rubber hose, however, does not give the same loading as a circular pneumatic tire.

For comparisons involving the effect of different tire pressures, a pneumatic tire system should certainly be used. For other types of direct comparisons between mixes, it is the belief of the authors that a solid rubber tire is satisfactory. The LWT test involves a significant reduction in scale of the load and size of the loaded area from the field. This effect is considered a more important possible limitation of the test than whether a solid or pneumatic tire is used. When a suitable source of a pneumatic tire is located, it will be incorporated into the test.

Test Temperature

Rutting in asphalt concrete is very sensitive to test temperature (*5*). Therefore, the loaded wheel test must be conducted at a realistic temperature that is constant to within about $\pm 0.6°C$ ($\pm 1°F$). The testing temperature used for conditions in Georgia is 104°F, which is about 10°F higher than the average pavement temperature at which rutting occurs in Georgia (*5*).

The loaded wheel tests are performed in a large constant temperature room. After a slight modification of the control system, a temperature controller and a 1350-W heater were used to maintain the temperature within a $\pm 0.2°F$ temperature control. The thermostat in the heater was removed with the heater being controlled only by the controller. An electrical relay was placed between the temperature controller and the heater. Good air circulation must also be maintained to achieve a high level of temperature control.

Use of a large temperature-controlled room 4 m by 4 m (13 by 13 ft) in plan and 2.3 m (7.5 ft) high permits storage of specimens at the desired testing temperature and gives free access to a specimen being tested without causing a measurable reduction in temperature of the specimen. Because of the large volume of air in the temperature-controlled room and its large mass of material, rapidly opening and closing the door has no noticeable effect on temperature of the specimen. A thermometer is embedded in a dummy block of asphalt concrete located by the beam to be tested to measure changes in temperature. The asphalt concrete temperature is recorded three times during the test.

Asphalt Concrete Specimens

To date, asphalt concrete beams 127 mm (5 in.) wide and either 76 mm (3 in.) or 90 mm (3.5 in.) thick have been tested in the LWT device described in this paper. The beams 76 mm (3 in.) thick were used to model surface mixes that are usually placed at this thickness in the field. When beams 76 mm (3 in.) thick are used, a steel plate 12.7 mm (0.5 in.) thick is placed in the bottom of the mold. Binder and base mixes tested have been 90 mm (3.5 in.) thick.

The test system is presently set up to take an asphalt concrete beam up to 457 mm (18 in.) long. However, to reduce the required materials used and specimen preparation time, to date only beams that are 254 mm (10 in.) long have been prepared and tested. To account for the shorter length of beam, asphalt concrete filler blocks 76 mm (3 in.) long, which are frequently replaced, are positioned at the ends of the beam to permit using a 292-mm (11.5-in.) length of wheel travel. Use of this length of wheel travel reduces the effects of the wheel stopping and reversing direction that would have occurred for a shorter travel length associated with using just a 254-mm (10-in.) beam length without the extra blocks. Use of 254-mm (10-in.) beams with filler blocks has worked well while reducing the required volume of the asphalt concrete mix by 33 percent.

DISCUSSION AND TEST RESULTS

More than 300 tests have been performed on asphalt concrete surface, binder, and base mixes using the LWT described in this paper. The only problem encountered has been that one precision bearing required replacement. The system requires periodic maintenance such as the greasing of moving parts. The LWT apparatus can be readily fabricated in a machine shop using about $2,500 in materials and equipment. A list of mechanical and electrical parts used in the apparatus is available from the senior author.

The present Georgia Tech LWT system (as well as the Georgia DOT's system) applies a two-directional loading to the beam. That is, the loaded wheel causes rutting in each direction as the beam (or load) moves back and forth. In contrast, the loading on a pavement is in only one direction. The LWT system described in this paper could easily be changed to one-directional loading by using a pneumatic cylinder to apply the downward force through the wheel while the beam is moving in one direction. While the beam is returning, the pressure on the pneumatic cylinder would be released and then reapplied as the next cycle begins. Also, the Georgia Tech system is designed so that two beams can be tested simultaneously, although this has not yet been done.

The reproducibility of the rut depths determined from the loaded wheel test results, including the effects of sample preparation, is an important consideration. On the basis of 93 tests, the average standard deviation of the test between similar specimens (which should exhibit the same rut depth) is about 14 percent of the average measured rut depth. The standard deviation increases from 11.5 percent for surface mixes to 13 percent for binders and 16 percent for base mixes. The maximum aggregate sizes for the surface, binder, and base mixes are 13 to 19 mm (0.5 to 0.75 in.), 19 to 25 mm (0.75 to 1.0 in.), and 25 to 38 mm (1.0 to 1.5 in.), respectively. The top sizes given correspond to the size for which 100 percent of the particles pass. A study has not been carried out to determine the effect of the 127-mm (5-in.) specimen width on specimen performance. A limited study carried out using a wider wheel [about 37 mm (1.5 in.)] indicated that similar comparisons were obtained between the 28.6-mm (1.125-in.) and 37-mm (1.5-in.) wheels.

These results include the effects of a limited number of different personnel preparing and testing specimens. Perhaps some effects of aggregate properties changing with time are included, since aggregates were obtained from several of the sources at two different times.

Samples were prepared in a steel mold preheated to 177°C (350°F) using a static compaction procedure. The preheated materials were mixed by hand. The aggregate was preheated to 177°C (350°F) and the asphalt cement to 171°C (340°F) following the recommendations of the Asphalt Institute. The specimens were compacted by placing the heated mold containing the loose mixture in a testing machine and compressing the material to the desired thickness using a heavy steel plate the size of the mold. Lai (*9*) reports that this compaction procedure gives results similar to those of the kneading compactor. Details of the procedure used are given elsewhere (*7*).

To illustrate how the LWT can be used, some typical rut depth measurement results are given in Table 1. These results are for (*a*) a standard Georgia DOT mix design and (*b*) a coarser mix, having a slightly larger top size, which was designed to reduce rutting. Mixes from a large number of quarries (up to 21) were included in this study. Although the standard (and also the coarse-graded) mixes are similar for all quarries, some slight variations in grading are present. The results developed using the LWT, for example, indicate that the proposed coarser base mix exhibits an average of 16 percent reduction in rutting compared with the standard Georgia DOT base mix presently used. These results were statistically significant at the 95 percent level. Much larger reductions in rutting are, of course, possible by using the coarser mix for only selected quarries.

The reasonably large variation in rutting for a particular type mix (surface, binder or base) suggests the importance that aggregate properties play in rutting of asphalt concrete mixes. The importance of aggregate properties on rutting has been shown on the basis of results obtained from the LWT (*7*). The Georgia DOT is presently conducting a study to determine whether rut depths observed in the laboratory using the loaded wheel test correlate with observed rutting in the field.

CONCLUSIONS

The LWT offers an excellent device for quantitatively comparing the relative rut susceptibility of one asphalt concrete mix with another. The LWT has several advantages. The stress state applied to the asphalt concrete is similar to that occurring in the field. The testing concept is straightforward, and the loading system is entirely mechanical. Hence, the test can be performed and the tester can be maintained at a minimum of cost by a laboratory technician having a very modest level of technical and mechanical ability. Also, expensive and hard-to-use electronic instrumentation is not required to obtain good results. The loaded wheel test offers an excellent alternative to other laboratory testing techniques when the rutting performance of one mix is to be compared with that of another.

A possible disadvantage of the LWT is that the 1986 AASHTO structural coefficients cannot be evaluated using this procedure since the resilient modulus is not obtained from the test.

TABLE 1 Summary of Measured Rut Depths for Georgia Asphalt Concrete Mixes and Quarries

MIX TYPE	AVERAGE (in.)	RANGE (in.)	STANDARD DEVIATION
1. Base Mix Comparisons			
Standard DOT (39 samples)	0.21	0.09-0.34	0.07
Coarse (32 samples)	0.16	0.07-0.28	0.06
2. Binder Mix Comparisons			
Standard DOT (35 samples)	0.24	0.09-0.40	0.09
Coarse (39 samples)	0.21	0.09-0.34	0.07
3. Surface Mix Comparisons			
Standard DOT (15 samples)	0.30	0.13-0.44	0.11
Coarse (14 samples)	0.25	0.11-0.33	0.07

ACKNOWLEDGMENT

The authors are grateful to the Georgia DOT for sponsoring the study involving the influence of aggregate properties on rutting in asphalt concrete. Special appreciation is expressed to Ronald Collins and Lamar Caylor, who coordinated the project, for their assistance.

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Publication of this paper sponsored by Committee on Mineral Aggregates.