Evaluation of a New Indirect Tension Test Apparatus

LOUAY N. MOHAMMAD AND HAROLD R. PAUL

Engineering characterization of Louisiana's asphaltic concrete mixtures using the indirect tensile test has been the focus of a recent comprehensive research program sponsored by the Louisiana Transportation Research Center. Large variations in test results were observed between similar specimens. These variations were attributed to variable aggregate orientation, compaction procedure, and the test device. A new indirect tension test device was fabricated locally and used to reduce the test variability. The repeatability and performance of the new indirect tension device was evaluated. A statistically designed test factorial was used to examine the variation between the existing and the modified test devices. Mechanical tests were conducted for indirect tensile strength, diametral resilient modulus, and indirect tensile creep. The effects of the test devices, deformation measurement system, and operator error on the mechanical properties—as measured from the indirect tensile strength, resilient modulus, and creep modulus—of a specific asphalt concrete mixture are presented. The results of the test program indicated that both test devices provided repeatable results; mechanical properties were not significantly different due to operator error; mechanical properties measured with the modified test device were significantly different than those measured with the existing test device; and the modified test device can capture the temperature effect on the resilient modulus better than the existing test device.

Engineering characterization of Louisiana's asphaltic concrete mixtures using the indirect tensile test has been the focus of recent comprehensive research programs sponsored by the Louisiana Transportation Research Center (LTRC). In these studies, large variations between similar specimens were observed. Generally, this variation was attributed to variable aggregate orientation between the individual specimen and the Marshall compaction procedure.

Baladi, in an attempt to integrate material and structural design methods for asphalt concrete pavements, also found variation that he deemed to be unacceptable (*1–3*). He identified specimen placement in the testing apparatus and rotation of the upper loading strip as the principle causes. To minimize this error, Baladi designed and fabricated a new apparatus (*1–3*).

The objective of this study was to evaluate the cost-effectiveness, performance, and repeatability of the new indirect tension test device developed by Baladi. To assess the performance and repeatability of the Baladi test device, a statistically designed test factorial was used to examine the variation of several test parameters for a specific asphaltic concrete mixture between the Baladi and the LTRC test devices.

The effects of the test devices, deformation measurement system, and operator error on the mechanical properties of a specific asphaltic concrete mixture have been investigated. Mechanical tests conducted were the indirect tensile test, the diametral resilient modulus test, and the indirect tensile creep test.

Louisiana Transportation Research Center, P.O. Box 94245, Baton Rouge, La. 70804.

INDIRECT TENSION TEST DEVICE

Test Devices

LTRC Test Device

The current LTRC test device—essentially, the Schmidt device—is a modified shoe die with upper and lower platens constrained to remain parallel during testing. The vertical deformations of the specimen were measured with two linear variable differential transducers (LVDTs) mounted on opposite corners of the top platens. The horizontal deformations of the specimen were obtained through the use of two LVDTs mounted on an adjustable frame that is rigidly attached to the lower platen. Steel curved loading strips were used in the test device.

Louisiana Modified (LM) Test Device

The Baladi device was fabricated locally in the machine shop of Louisiana State University's civil engineering department. It was built according to the engineering drawings provided by FHWA, except for the extension of the support posts outward by 1.25 in. to provide easier access to the specimen and to allow for the placement of an extensometer (Figure 1). Fabricating the new device cost $2,200. During the initial testing program, inconsistencies in the resilient moduli and Poisson's ratio were discovered. The swivel base was causing the specimen to rock, thus distorting the horizontal deformation measurement. As a result, after consultation with FHWA, the Baladi device was further modified. The top loading strip was fixed instead of mounted on the swivel base that was provided in the initial drawing. Also, the vertical deformation was monitored using two LVDTs mounted 180 degrees apart on the top of the piston guided plate to ensure that the specimen was not rocking.

Measurement System

Displacement measurement of the specimen due to dynamic loading is a critical factor in determining resilient modulus. A typical range of the deformation along the horizontal di-

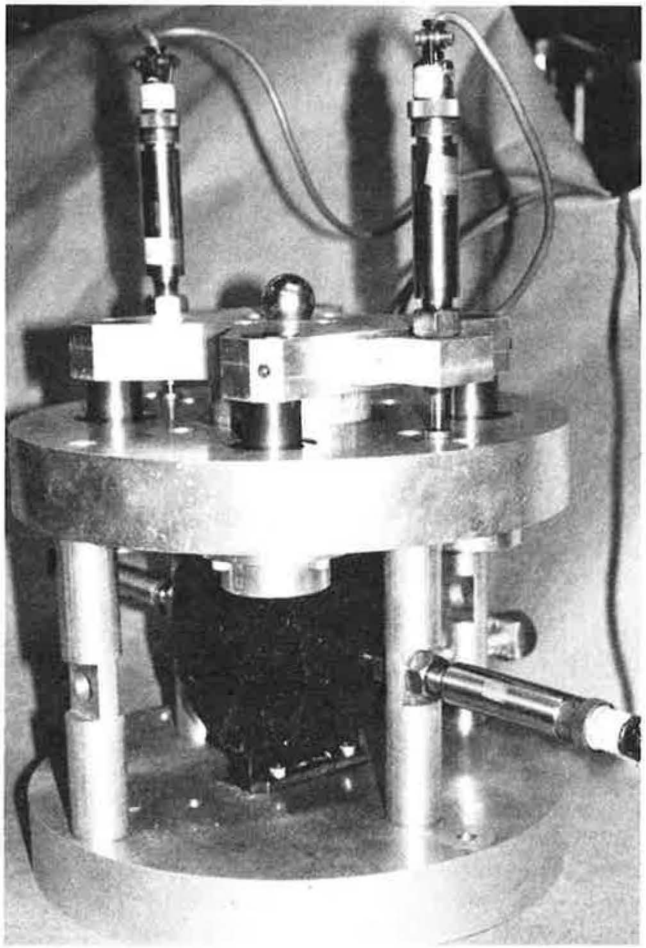

FIGURE 1 LM test device.

ameter is 40 to 100 μin. Thus, the measurement device must have this sensitivity range to respond to dynamic change of sample deformation.

Horizontal Deformation Measurement

Two LVDTs were used to measure the horizontal deformation, and the outputs from each LVDT were monitored independently and summed for analysis. This was accomplished through software developed for acquisition and control of the MTS test system in the concurrent parametric research study.

Two types of LVDT were used for each test device. The first type was an existing set manufactured by TransTek (Model 351-000), hereafter called old LVDT (LVDT-O). The second set of LVDTs was made by Schaevitz (Model GCD-121-050), hereafter called new LVDT (LVDT-N). The maximum strokes for LVDT-O and LVDT-N were ±0.31 in. (±7.9 mm) and ±0.05 in. (±1.3 mm) full scale, respectively. The LVDT-N was selected because of the higher resolution needed to capture the small amount of horizontal deformation during dynamic loadings.

In addition, a modified strain gauge clip-on extensometer system developed by MTS Systems Corp. was used with the LM device. The extensometers have a special bracket that attached to the specimen and provided positive spring loading.

The lateral constraint of the horizontal deformation of the specimen due to the tension in the springs used to hold the extensometer assembly in place was investigated. During the initial system calibration, the diametral resilient modulus test at 40°F (5°C) was used to test the possibility of lateral constraint in the same sample at 40°F. Both the spring assembly and adapter brackets glued to the specimen were examined. Because the results appear to be similar, the spring assembly was used for the test factorial.

Vertical Deformation Measurement

The vertical deformation was measured with two LVDTs mounted 180 degrees apart on the piston-guided plate. The output from each LVDT was monitored independently and simultaneously compared with the output of the other LVDT. If the difference between the peak value was not within 10 percent, the seating of the loading device was adjusted. The LVDTs used for both test devices were manufactured by Schaevitz (Model GCD-121-050).

EXPERIMENTAL DESIGN

A statistically designed laboratory experiment was used to examine the influences of the test device, measurement system, and operator error on the mechanical properties of a specific asphalt concrete mixture. Previous work on more than 550 samples of different mix types and materials had a standard deviation of 23 psi in the indirect tensile test. The mean range for any triplicate set of specimen was 12.9 psi. Assuming that the standard deviation of 23 psi of this sample was a fair estimate of the population standard deviation, the number of samples for each cell in the test factorial was determined to be 12 with 95 percent confidence. This cell size was further subdivided to six specimens to investigate operator error.

The results from the LTRC and the LM test devices were statistically analyzed using the analysis of variance procedure provided in the Statistical Analysis System (SAS) program from SAS Institute, Inc. A multiple comparison procedure with a risk level of 5 percent was performed on the means. A REGWF test was selected to control the experimentwise error. The REGWF test was selected because it can detect significant differences in the mean that might not be detected with other multiple comparison procedures. The independent variables (i.e., test device, measurement system, and operator error) had populations with normal distributions. In addition, the repeatability of the test results have been examined using the single-operator, one-sigma limit as described in ASTM C670.

EXPERIMENTAL SETUP

Loading System and Data Acquisition

The loading system was a 22,000-lb MTS Model 810 servo-hydraulic test system equipped with an environmental chamber. Specimens were thermally conditioned before being tested. A thermostatically controlled probe was inserted in a drilled hole in a dummy specimen of the same size and shape as the test specimen to ensure an equilibrium test temperature for the samples tested. Fully automated test software for equipment control and data acquisition was developed to perform tests, acquire and analyze data, and calculate and print out the test results.

Specimen Preparation

A total of 168 specimens were fabricated and tested using the LTRC and the LM test devices. Each specimen was 4 in. in diameter and about 2.5 in. high. A typical Louisiana Type 1 mixture was used with 65 percent by weight crushed gravel, 25 percent coarse sand, and 10 percent fine sand. Southland AC-30 asphalt cement was used. Specimens were prepared using 75 blows per face of the Marshall hammer. Each cell in the test factorial of Figure 2 was statistically grouped. The average air void content was 4.3 percent, with a standard deviation of 0.22. The optimum binder content was determined from preliminary standard Marshall mix design. Each sextuplicate specimen was tested under the same conditions (temperature and load) for indirect tensile strength, diametral resilient modulus, and indirect tensile creep for each of the LTRC and the LM test devices.

TESTING PROCEDURE

Indirect Tensile Test

This test was conducted at 40 and 77°F (5 and 25°C) according to AASHTO T245-82. Test specimens were loaded to failure at a deformation rate of 2 in./min. The load to failure was then recorded.

Diametral Resilient Modulus Test

The tests were conducted at 40, 77, and 104°F (5, 25, and 40°C) according to ASTM D4123, with the following modifications:

1. Test samples were seated with a sustained load of 50 lb, and then a cyclic haversine load of 10 percent of the indirect tensile strength was applied. The two vertical deformations were monitored independently. If the two measurements were not within 10 percent, then further adjustment to the loading device was made in order to not exceed this tolerance. The average of the two measurements was used in the data analyses.
2. With the sustained load applied to the sample, the specimen was conditioned by monitoring the deformation continuously until the deformation rate of the specimen was essentially constant. The transducers were then rezeroed.
3. A repetitive haversine waveform load with a peak value equal to 10 percent of the indirect tensile strength was applied to the specimen. The load frequency was 2 Hz with a 0.1-sec loading time and a 0.4-sec relaxation period. All materials response parameters were measured with the data acquisition system at a rate of 500 Hz.
4. The response curves (load, vertical deformation, and horizontal deformation) over the 2 cycles were digitized. The data from these curves were then scanned to determine the instantaneous and total recoverable horizontal and vertical deformation. Data associated with the beginning of the relaxation period were used to compute instantaneous properties; values associated with the end of the relaxation period were used to compute total properties.

Each specimen was tested at each of the three temperatures starting with the lowest temperature to minimize permanent damage to the sample. At each temperature, the sample was tested twice; after the first test, the sample was rotated approximately 90 degrees and the test was repeated (Steps 1 through 4).

Indirect Tensile Creep Test

Creep tests were conducted at 77°F (25°C) using a ramp load of 250 lb (1112 N) applied as quickly as possible using the stress-controlled mode of the MTS servohydraulic system. The load and vertical and horizontal deformations were monitored continuously with the data acquisition system. The test was terminated either after 60 min of load duration or at failure. The mean horizontal deformations and mean vertical deformations were computed by summing the deformation at a particular time for each cell of the test factorial described in Figure 2 and dividing the sum by the number of specimen. The creep modulus, $S(t)$, is computed from the measured deformations as follows:

$$S(t) = \frac{P_o(\mu + 0.27)}{t\delta H(t)}$$

where

$S(t)$ = creep modulus at time t,
P_o = applied vertical load,
μ = Poisson's ratio,
t = sample thickness, and
$\delta H(t)$ = horizontal deformation at time t.

The mean creep modulus was computed similar to the mean creep deformations. Mean values of vertical deformation,

Test Device	LTRC		LM		
Deformation Measurement System	LVDT – O	LVDT – N	LVDT – O	LVDT – N	Extensometer
Operator 1	6	6	6	6	6
Operator 2	6	6	6	6	6

FIGURE 2 Test factorial.

horizontal deformation, and creep modulus were used in the statistical analyses.

DISCUSSION OF RESULTS

Indirect Tensile Strength Test

Table 1 presents a comparison of the test results for the indirect tensile strength test at 40°F (5°C) and 77°F (25°C) along with their means, standard deviations, coefficients of variation, and test repeatability. For any sextuplicate, the variation in the test results was between 2 and 9 percent. At low temperature, with increased stiffness, test results measured with the LTRC device have more variation that those tested with the LM device. The indirect tensile strength test was highly repeatable for a single operator. In the tables, columns having the same letter indicate there is no significant difference in the mean. Table 2 indicates that there is no significant difference in the mean indirect tensile strength due to operator error. Table 3 shows that the mean indirect tensile strength measured with the LTRC device at 40°F was significantly higher than the mean measured with the LM device; the means at 77°F were not significantly different between the two devices. Similar findings were obtain when test results were analyzed for each operator (Table 4).

Diametral Resilient Modulus Test

Tables 5, 6, and 7 present the results of the effects of operator error, test devices, and measurement system, respectively, on resilient modulus and Poisson's ratio. Table 5 indicates no significant difference in the means due to operator error except for the instantaneous moduli measured with the LTRC and LVDT-O, so the data from the two operators were combined for further analyses. Table 6 indicates that the mean of the mean instantaneous and total resilient moduli and instantaneous and total Poisson's ratios were significantly different between the two test devices. The diametral test results were repeatable for a single operator at the three temperature levels.

Table 7 indicates that the instantaneous and total moduli were not significantly different using the various measuring devices. This is because the resilient modulus is a function of the vertical deformation only when computed using a calculated Poisson's ratio. Both devices used the same vertical deformation system, that is, LVDT-N. In order to investigate the effect of the measurement devices on the mechanical properties, one needs to look at Poisson's ratio, which is function of the vertical and the horizontal deformations. Instantaneous and total Poisson's ratios were significantly different between the LVDT-O and the LVDT-N except for the total Poisson's ratio of samples tested with the LTRC device. The extensometer assembly was tested with the LM device only because the LTRC device did not have the requisite space. Instantaneous Poisson's ratio calculated with the extensometer was significantly different than the one computed using the LVDT-O; the total Poisson's ratio is significantly different computed from the LVDT-N and the extensometer.

The temperature influence on the mechanical properties of specimen tested with the LTRC and LM devices is shown in Table 8. Generally, the LM device–LVDT-N and the LM device–extensometer combinations seem to capture the temperature effect on the resilient modulus and Poisson's ratio better than the LM device–LVDT-O and LTRC device–LVDT-O combinations. The results of Tables 7 and 8 demonstrate that the LTRC–LVDT-O combination is not as sen-

TABLE 1 Indirect Tensile Strength, Present Serviceability Index

Test Device	LM		LTRC	
Temperature (°F)	40	77	40	77
Operator 1	265	78	328	77
	260	75	318	68
	276	77	311	76
	268	79	307	83
	260	78	314	74
	275	76	310	77
Mean	267	77	315	76
STD	6	1	7	4
(%) CV	2	2	2	6
Repeatability	Y	Y	Y	Y
Operator 2	291	72	374	57
	278	74	347	72
	249	75	321	72
	267	68	363	74
	271	76	313	77
	262	80	295	70
Mean	270	74	336	70
STD	13	4	28	6
(%)CV	5	5	8	9
Repeatability	Y	Y	Y	Y

STD : Standard Deviation
CV : Coefficient of Variation
Y : Indicates Test is Repeatable as per ASTM C670.

TABLE 2 Effect of Operator Error on Mean Indirect Tensile Strength

Test Device	LM		LTRC	
Temperature (°F)	40	77	40	77
Operator 1	A	A	A	A
Operator 2	A	A	A	A

TABLE 3 Effect of Test Device on Mean Indirect Tensile Strength by Temperature

Mechanical Property	Test Device	Temperature (°F)	
		40	77
Indirect Tensile Strength	LTRC	A	A
	LM	B	A

TABLE 4 Effect of Loading Device on Mean Indirect Tensile Strength

Operator	1		2	
Temperature (°F)	40	77	40	77
LM Device	A	A	A	A
LTRC Device	B	A	B	A

TABLE 5 Effect of Operator Error on Mean Diametral Resilient Modules Test Results

DEVICE	LM												LTRC							
Measurement Device	Extensometer				LVDT–N				LVDT–O				LVDT–N				LVDT–O			
Mechanical Properties	MRI	MRT	MUI	MUT	MRI	MRT	MUI	MUT	MRI	MRT	MUI	MUT	MRI	MRT	MUI	MUT	MRI	MRT	MUI	MUT
Operator 1	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Operator 2	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	B	A	A	A

MRI = Instantaneous Resilient Modulus
MRT = Total Resilient Modulus
MUI = Instantaneous Poisson's Ratio
MUT = Total Poisson's Ratio

TABLE 6 Effect of Test Device on Mean Diametral Resilient Modulus Test Results

Measurement System	LVDT – N				LVDT – O			
Mechanical Properties	MRI	MRT	MUI	MUT	MRI	MRT	MUI	MUT
LM	A	A	A	A	A	A	A	A
LTRC	B	B	B	B	B	B	B	B

MRI = Instantaneous Resilient Modulus
MRT = Total Resilient Modulus
MUI = Instantaneous Poisson's Ratio
MUT = Total Poisson's Ratio

TABLE 7 Influence of Measurement System on Diametral Resilient Modulus Test Results

Test Device	LM				LTRC			
Mechanical Properties	MRI	MRT	MUI	MUT	MRI	MRT	MUI	MUT
LVDT – O	A	A	B	B	A	A	B	A
LVDT – N	A	A	A	A	A	A	A	A
Extensometer	A	A	A	B	N/A	N/A	N/A	N/A

MRI = Instantaneous Resilient Modulus
MRT = Total Resilient Modulus
MUI = Instantaneous Poisson's Ratio
MUT = Total Poisson's Ratio

sitive as the LM–LVDT-N or extensometer combination especially in the dynamic, instantaneous mode, thus not differentiating between properties at different temperatures.

A typical relationship of the effect of temperature on the resilient moduli between the LTRC and LM test devices for each operator is presented in Figure 3. Generally, a distinct cluster of lines is exhibited between the LTRC and LM device for each operator. However, the LM device seems to capture the temperature effect on the moduli better than the LTRC

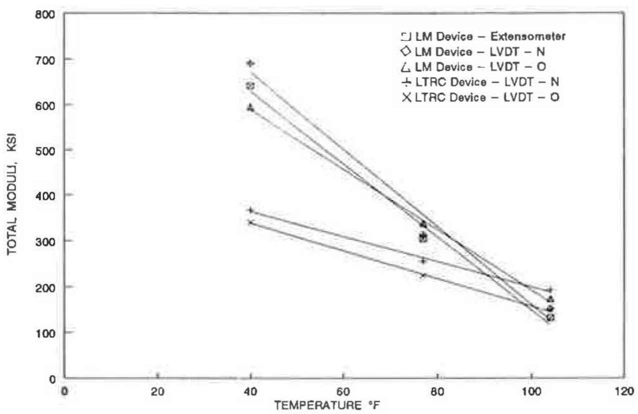

FIGURE 3 Total resilient modulus, temperature dependency (Operator 2).

device. This could be because of friction in the guiding post, weight of the loading mechanism, and the sensitivity of the measurement system.

Table 9 shows that there was no significant difference in the resilient moduli between samples tested at the 0-degree and 90-degree positions.

A typical variation of Poisson's ratio due to temperature, calculated from measured horizontal and vertical deformations during resilient modulus testing, is presented in Figure 4. Clusters similar to the resilient modulus are found with respect to the two test devices. The variation ranges from −0.2 to 0.93 depending on the combination of the loading device and measurement system used. Poisson's ratio should increase as testing temperature increases. Theoretically, Poisson's ratio ranges from 0 to 0.50. This increase was more

TABLE 8 Effect of Temperature on Diametral Resilient Modulus Test Results

Mechanical Properties	MRI			MRT			MUI			MUT		
Measurement System	LVDT – N	LVDT – O	EXTE	LVDT – N	LVDT – O	EXTE	LVDT – N	LVDT – O	EXTE	LVDT – N	LVDT – O	EXTE
LM	Y	Y	Y	Y	Y	Y	40 77 104	N	Y	Y	40 77 104	Y
LTRC	40 77 77 104	40 77 104	N/A	Y	Y	N/A	Y	Y	N/A	Y	Y	N/A

Y – Indicates Significant Difference in the Mean Between the 40, 77, and 104 °F Tests
N – Indicates No Significant Difference in the Mean Between the 40, 77, and 104 °F Tests
40 – Indicates Significant Difference in the Mean Between the 40 °F Test and the 77 and 104 °F Tests
40 –
77 – Indicates No Significant Difference in the Mean Between the 40 and 77 °F Tests
77
104 – Indicates No Significant Difference in the Mean Between the 77 and 104 °F Tests

TABLE 9 Effect of Sample Rotation on Diametral Resilient Modulus Test Results

DEVICE	LM												LTRC							
Measurement Devices	Extensometer				LVDT–N				LVDT–O				LVDT–N				LVDT–O			
Mechanical Properties	MRI	MRT	MUI	MUT	MRI	MRT	MUI	MUT	MRI	MRT	MUI	MUT	MRI	MRT	MUI	MUT	MRI	MRT	MUI	MUT
0° Position	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
90° Position	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

Note: Columns with similar letters indicate no significant difference in the mean.
MRI = Instantaneous Resilient Modulus; MRT = Total Resilient Modulus
MUI = Instantaneous Poisson's Ratio'; MUT = Total Poisson's Ratio

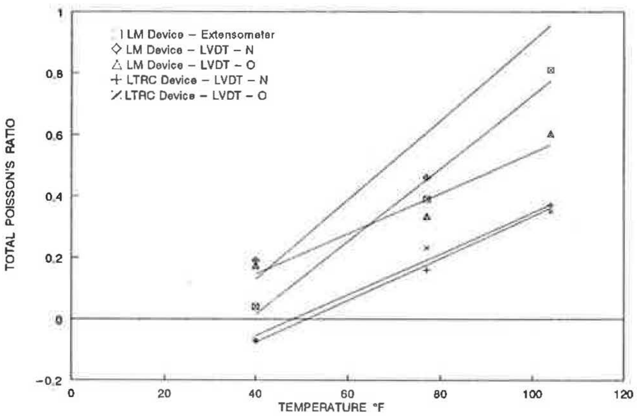

FIGURE 4 Total Poisson's ratio, temperature dependency (Operator 2).

pronounced with the LM device than the LTRC device. At high temperature the applied load was too high, which produces the higher-than-theoretical value of Poisson's ratio. This indicates that Poisson's ratio at high temperature should be calculated using deformations from a lower load magnitude than the load at 77°F (25°C).

Indirect Tension Creep Test

The creep modulus was calculated using either a computed Poisson's ratio from the measured horizontal and vertical deformations or an assumed Poisson's ratio of 0.35. The indirect tension creep modulus was statistically analyzed at time intervals of 5, 10, 100, and 500 sec. The test results were repeatable at those time intervals.

The influence of the operator error on the mean creep modulus is presented in Table 10. It indicates that operator error was not significant for creep modulus based on either a computed or an assumed Poisson's ratio at the different time intervals.

The effect of the test device on the mean creep modulus is presented in Table 11. The creep modulus with an assumed Poisson's ratio was significantly different between the two devices, whereas the modulus with a calculated Poisson's ratio was not significantly different except at 500 sec. The

TABLE 11 Effect of Test Device on Mean Creep Modulus By Time

Mechanical Properties	Test Device	Time (seconds) 5	10	100	500
Calculated Creep Modulus	LTRC	A	A	A	A
	LM	A	A	A	B
Creep Modulus with Assumed MU = 0.35	LTRC	A	A	A	A
	LM	B	B	B	B

TABLE 12 Overall Effect of Measurement System on Mean Creep Modulus

Creep Modulus	Calculated	Assumed MU = 0.35
LVDT – N	A	A
LVDT – O	A / B	B
Extensometer	B	A

creep modulus with an assumed Poisson's ratio depended on the horizontal deformation of the sample where three types of horizontal measuring systems were used: LVDT-O, LVDT-N, and extensometer. The moduli based on computed Poisson's ratio depended on the vertical deformation only where the same LVDT-N was used in both devices. Therefore, for static loading it is anticipated that both test devices will render similar results when using a calculated Poisson's ratio.

The influence of the measurement system on the mean creep modulus is presented in Table 12. The overall effect of the measurement system indicated that there was a significant difference in mean creep modulus between LVDT-N and extensometer for a calculated Poisson's ratio, whereas no significant difference was apparent between LVDT-N and extensometer when using an assumed Poisson's ratio. Because the horizontal deformation influences the moduli when an assumed Poisson's ratio is used, these results indicate similar accuracy in measuring horizontal deformations between the LVDT-N and the extensometer assembly.

CONCLUSIONS

The effects of the test device, deformation measurement system, and operator error on the mechanical properties of a specific asphaltic concrete mixture have been investigated.

TABLE 10 Effect of Operator Error on Mean Creep Modulus By Time

Creep Modulus	Calculated Poisson's Ratio				Assumed Poisson's Ratio, MU = 0.35			
Time (secs)	5	10	100	500	5	10	100	500
Operator 1	A	A	A	A	A	A	A	A
Operator 2	A	A	A	A	A	A	A	A

Mechanical tests conducted were the indirect tensile, diametral resilient modulus, and indirect tensile creep tests. Generally, the LM test device provided less variation in test results than the LTRC test device. Specific conclusions can be drawn from analysis of the data as follows:

1. The use of two LVDTs to measure the vertical deformations has considerably reduced variation in the test results of dynamic mode due to rocking of the sample.
2. Mechanical properties (indirect tensile strength, resilient modulus, and creep modulus) were not significantly different due to operator error.
3. Mechanical properties measured with the LM device are significantly different than those measured with the LTRC device except for indirect tensile strength at 77°F.
4. The LM device captures the temperature effect on resilient moduli better than the LTRC device.
5. Resilient moduli for specimen tested in the LM device and calculated from deformations measured with extensometer did not significantly differ from those measured with the LVDT-N.

ACKNOWLEDGMENTS

The authors are grateful to FHWA and the Louisiana Department of Transportation and Development for their support and sponsorship of this research. The authors express their appreciation to Roland Doucet for the statistical analysis and to LTRC's lab technicians for their efforts in specimen preparation.

REFERENCES

1. G. Y. Baladi. *Integrated Material and Structural Design Method for Flexible Pavements, Volume I—Technical Report.* Report FHWA-RD-88-109. FHWA, U.S. Department of Transportation, Feb. 1988.
2. G. Y. Baladi. *Integrated Material and Structural Design Method for Flexible Pavements, Volume II—Appendices.* Report FHWA-RD-88-110. FHWA, U.S. Department of Transportation, Feb. 1988.
3. G. Y. Baladi. *Integrated Material and Structural Design Method for Flexible Pavements, Volume III—Laboratory Design Guide.* Report FHWA-RD-88-118. FHWA, U.S. Department of Transportation, Feb. 1988.