Evaluation of Indirect Tensile Test for Determining Structural Properties of Asphalt Mix

LOUAY N. MOHAMMAD AND HAROLD R. PAUL

The indirect tensile test can be used to establish the structural properties of asphalt mixtures. Existing indirect tension test devices have several problems that can affect the accuracy and repeatability of test results. Because of these problems, a new indirect tension test device, developed by Michigan State University and further modified by Louisiana Transportation Research Center (LTRC), was fabricated locally and used to reduce the test variability. The variation between several structural properties was investigated for specimens tested in two different indirect tension test devices—the current LTRC test device and the Louisiana modified device—within the parameters of mixture type, asphalt cement source, and compaction effort. Mechanical tests conducted were the indirect tensile strength test, the diametral resilient modulus test, and the indirect tensile creep test. The results of the test program indicated that the mechanical properties measured with the modified test device were significantly different from those measured with the existing test device; the modified test device can capture the temperature effect on the resilient modulus better than the existing test device; and resilient modulus and Poisson's ratio were significantly different between mixture types.

The indirect tensile test can be used to establish several structural properties of asphalt mixtures. Existing indirect tension test devices have several problems that can affect the accuracy and repeatability of test results. Measured horizontal and vertical deformations often are inconsistent because of the arbitrary placement of specimen in the test device and a slight rocking motion of the loading head. Because of these problems, a new indirect tension test device, developed by Michigan State University (*1–3*) and further modified by Louisiana Transportation Research Center (LTRC) (*4,5*), was fabricated locally and used to reduce the test variability.

Mohammad and Paul (*4*) recently have conducted a research study on the effects of the indirect tension test device, the deformation measurement system, and operator error on the mechanical properties of a specific asphaltic concrete mixture. This study is extended in this paper to investigate the variation between several structural properties for specimens tested in two different indirect tension test devices—the current LTRC test device and the Louisiana modified (LM) device—within the parameters of mixture type, asphalt cement source, and compaction effort.

Louisiana Transportation Research Center, 4101 Gourrier Lane, Baton Rouge, La. 70808.

TEST SETUP

A detailed description of the test setup can be found in previously published works (*4,5*). Only the main components of the test setup are discussed in this paper.

Test Devices

Two test devices were used in the testing program, the current LTRC and the LM test devices (Figures 1 and 2, respectively).

Measurement System

- Horizontal Deformation Measurement. Two linear variable differential transformers (LVDTs) were used to measure the horizontal deformation with the outputs from each LVDT monitored independently and then summed for analysis.
- Vertical Deformation Measurement. The vertical deformations were 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 to monitor whether rocking motion of the loading head was occurring. If the difference between the peak values was not within 10 percent, further adjustment in seating the loading device was made.

Loading System and Data Acquisition

The loading system used was a 22,000-lb MTS model 810 servohydraulic test system equipped with an environmental chamber. Fully automated test software, developed at LTRC, was used for data acquisition and analysis.

Specimen Preparation

Materials for this research were secured from existing Louisiana Department of Transportation and Development (LADOTD) construction projects. The actual production JMFs obtained from the plant were used during sample preparation (i.e., optimum asphalt cement content and aggregate proportioning process). Three sources of AC-30 asphalt cement

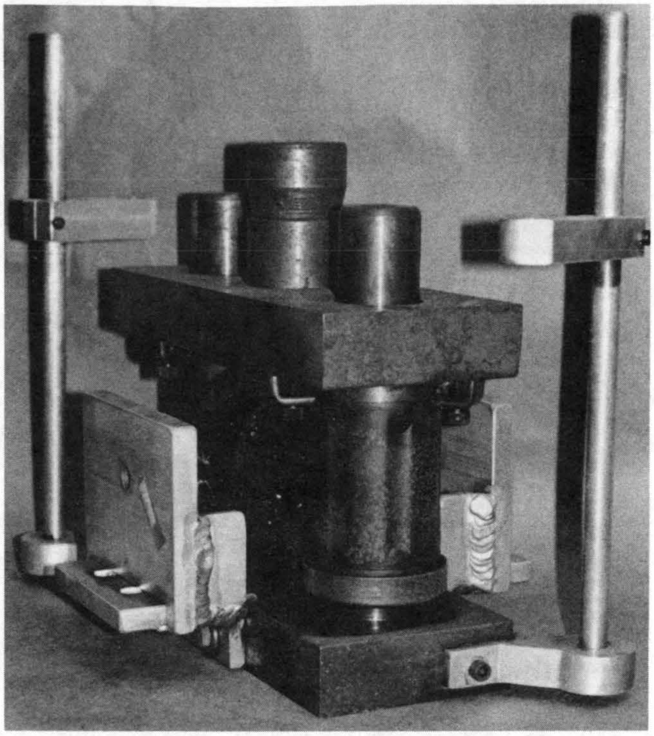

FIGURE 1 LTRC test device.

(Source A, Source B, and Source C), two LADOTD mixture types (Type 1 and Type 8, low and high stability, respectively), and three void levels were used for each test device. The initial intent of the two levels of mix type was to incorporate low and high stability; however, once the materials were secured from two different construction sites, the gradations were very similar. Thus, the two levels of mix type can be considered as different aggregate sources. To produce three consistent void levels, samples were compacted using the U.S. Army Corps of Engineers Gyratory Test Machine at 1.0-degree gyration angle and 100 psi vertical pressure rather than varying the Marshall compaction effort. The three void levels for Type 1 were 5.0, 6.3, and 8.3 (±0.50) and for Type 8 were 4.0, 5.0, and 7.0 (±0.50). These levels were achieved by compacting mixtures using 80, 40, and 15 gyrations, respectively. The total number of samples fabricated for this research was 432. Each specimen was 4 in. in diameter by 2.5 (±0.125) in. high. For each target air-void level 24 samples were compacted and statistically grouped in triplicate sets such that each cell in the test factorial would have air voids with similar means and standard deviations.

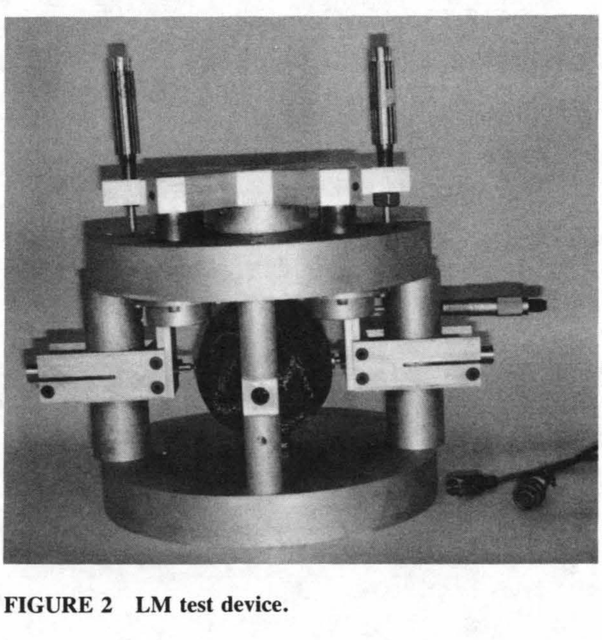

FIGURE 2 LM test device.

EXPERIMENTAL DESIGN

Indirect tensile strength test at two temperatures [40°F (5°C) and 77°F (25°C)], diametral resilient modulus at three temperatures [40°F (5°C), 77°F (25°C), and 104°F (60°C)], and indirect tensile creep tests at 77°F (25°C) were evaluated for each test device.

The factorial for each device incorporated two levels of mix type (low and high stability), three levels of asphalt cement source, and three levels of compaction effort (Figure 3). To examine the effect of these factors for a particular type of test required 108 specimens including replication. The test results from both the LTRC and the LM test devices were statistically analyzed using an analysis of variance (ANOVA) procedure. A multiple-comparison procedure with a risk level of 5 percent was performed on the means. The independent variables (i.e., test device, mixture type, asphalt cement source, compaction effort) had populations with normal distributions.

DISCUSSION OF RESULTS

This research effort has generated many data for the test factorial described above. The actual data used in the analyses can be found elsewhere (*5*). Only the statistical analyses are presented herein.

Indirect Tensile Strength

Table 1 shows the influence of the test device, asphalt cement source, mix type, compaction effort, and temperature on the test results. It is summarized as follows:

- Effect on indirect tensile strength (ITS): The mean ITS was not significantly different between the two devices. However, samples containing Source B asphalt cement had a significantly higher mean ITS than those containing Source A asphalt cement, which in turn were higher than those made with Source C asphalt cement. Furthermore, the ITS was not sensitive to the mix type. As expected, the denser mixes compacted by 80 gyrations had a higher strength than the 15 gyration mixes. Also, as anticipated, samples tested at 40°F (5°C) were stiffer than those tested at 77°F (25°C).
- Effect on vertical and horizontal deformations: Specimens tested with the LM device had a significantly higher vertical deformation than those tested with the LTRC device, whereas there were no significant differences in the horizontal

MIX TYPE	LOW STABILITY			HIGH STABILITY		
ASPHALT CEMENT SOURCE	3	3	3	3	3	3
AIR VOID LEVEL 1	3	3	3	3	3	3
AIR VOID LEVEL 2	3	3	3	3	3	3
AIR VOID LEVEL 3	3	3	3	3	3	3

FIGURE 3 Test factorial.

deformation for samples tested in the two devices. The influence of the asphalt cement source shows that samples made with Source A and Source B asphalt cement presented significantly lower vertical deformation than those made with Source C asphalt cement, whereas no significant difference in the horizontal deformations was observed among the three asphalt cement sources. The horizontal deformations were more sensitive to the mix type than the vertical deformations. As for compaction effort, no significant differences were observed for the vertical deformations. However, denser mixes had lower horizontal deformations than mixes made with 15 gyrations. Both deformations captured the temperature influence.

Table 2 displays the effect of the test device on each of the independent treatments, that is, asphalt cement source, mix type, compaction effort, and temperature, on the basis of the combined data for all variables except the indicated one. Significant differences between the two devices were observed only for the following: vertical and horizontal deformations with Source A asphalt cement and vertical deformations with Source C asphalt cement, vertical deformations for Type 8 mixes, vertical deformation for samples compacted by 40 and 80 gyrations, and vertical deformations for specimens tested at 40°F (5°C) and 77°F (25°C). Thus, the magnitude of the vertical deformations was large enough to capture the variation between the two devices.

TABLE 1 Effect of Test Device, Asphalt Cement Source, Mix Type, Compaction Effort, and Temperature on Indirect Tension Test Properties

Treatment	Test Device		Asphalt Cement Source			Mix Type		Compaction Effort			Temperature	
Property	LM	LTRC	Source A	Source B	Source C	1	8	15 Rev	40 Rev	80 Rev	40 °F	77 °F
ITS	A *	A	B	A	C	A	A	B	B/A	A	A	B
Ver. Def.	A	B	B	B	A	A	A	A	A	A	B	A
Hor. Def.	A	A	A	A	A	A	B	A	B	B	B	A

* Rows with similar letters indicate no significant difference in the mean for each treatment

Rev : Revolutions

ITS : Indirect Tensile Strength

Ver. Def. : Vertical Deformation

Hor. Def. : Horizontal Deformation

TABLE 2 Effect of Test Device on Indirect Tension Test Properties Caused by Variation of Asphalt Cement Source, Mix Type, Compaction Effort, and Temperature

Treatment	Asphalt Cement Source						Mix Type				Compaction Effort						Temperature			
	Source A		Source B		Source C		1		8		15 Rev		40 Rev		80 Rev		40 °F		77 °F	
Mechanical	Test Device		Test Device		Test Device		Test Device		Test Device		Test Device		Test Device		Test Device		Test Device		Test Device	
Properties	LM	LTRC	LM	LTRC	LM	LTRC	LM	LTRC	LM	LTRC	LM	LTRC	LM	LTRC	LM	LTRC	LM	LTRC	LM	LTRC
ITS	A *	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Ver. Def.	A	B	A	A	A	B	A	A	A	B	A	A	A	B	A	B	A	B	A	B
Hor. Def.	A	B	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

* Rows with similar letters indicate no significant difference in the mean for each treatment

Rev : Revolutions

ITS : Indirect Tensile Strength

Ver. Def. : Vertical Deformation

Hor. Def. : Horizontal Deformation

Diametral Resilient Modulus Test

Table 3 shows the effect of the test device on the resilient modulus and Poisson's ratio as a result of the variation of mix type, asphalt cement source, and compaction effort. Results of the specimen tested with the LTRC test device were significantly different from those tested with the LM test device for each level of mix type, asphalt cement source, and compaction effort. Thus, in the diametral resilient modulus test, the results were significantly different for samples tested using the LTRC and the LM test devices.

Table 4 examines the influence of the test device, asphalt cement source, mix type, and compaction effort on the resilient modulus and Poisson's ratio on the basis of combined data for all variables except the indicated treatment. As presented earlier, results were significantly different for the two test devices. In addition, the comparison of means for asphalt cement source shows that the instantaneous and total resilient modulus of samples made with Source C were significantly different from those made with Source A and Source B, the instantaneous Poisson's ratio was significantly different for each source, and the total Poisson's ratio of Source A and Source C were significantly different from samples made with Source B. Resilient modulus and Poisson's ratio were significantly different for samples of Type 1 mix from those containing a Type 8 mix except for the total moduli, where results were not significantly different. The compaction effort effect indicated that the total moduli are not sensitive to the void level; furthermore, the instantaneous resilient moduli and instantaneous and total Poisson ratios were not significantly different between samples compacted by 40 and 80 gyrations, whereas those properties were significantly different from samples compacted by 15 gyrations. This insensitivity to the compaction effort can possibly be attributed to the overlap of the void contents at the three compaction levels.

The influence of temperature on the mechanical properties shows, as expected, that the test results were significantly different for the three temperature levels.

Figure 4 presents a typical relationship between the instantaneous and total resilient modulus and temperature for each level of mixture type and asphalt cement source (graph shown for Type 8, Source A mixtures). Two distinct groupings of lines were shown in these graphs: one was for the LTRC device, and the other was for the LM device. These lines show a steeper slope for the LM test device; therefore, more sensitivity to temperature.

Indirect Tension Creep Test

The creep modulus for calculated and assumed Poisson's ration at intervals of 5, 10, 100, 200, and 500 sec was used in

TABLE 3 Effect of Test Device on Diametral Resilient Modulus Properties Caused by Mix Type, Asphalt Cement Source, and Compaction Effort

Treatment	Mix Type				Asphalt Cement Source						Compaction Effort					
Mechanical Properties	1		8		Source A		Source B		Source C		15 Revolutions		40 Revolutions		80 Revolutions	
	Test Device		Test Device		Test Device		Test Device		Test Device		Test Device		Test Device		Test Device	
	LTRC	LM	LTRC	LM	LTRC	LM	LTRC	LM	LTRC	LM	LTRC	LM	LTRC	LM	LTRC	LM
MRI	A *	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
MRT	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
MUI	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
MUT	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B

*** Rows with similar letters indicate no significant difference in the mean for each treatment**
MRI : Instantaneous Resilient Modulus
MRT : Total Resilient Modulus
MUI : Instantaneous Poisson's Ratio
MUT : Total Poisson's Ratio

TABLE 4 Effect of Test Device, Asphalt Cement Source, Mix Type, Compaction Effort, and Temperature on Diametral Resilient Modulus Properties

Treatment	Test Device		Asphalt Cement Source			Mix Type		Compaction Effort			Temperature		
Properties	LTRC	LM	Source A	Source B	Source C	1	8	15 Rev	40 Rev	80 Rev	40 °F	77 °F	104 °F
MRI	A *	B	A	A	B	A	B	A	B	B	A	B	C
MRT	A	B	A	A	B	A	A	A	A	A	A	B	C
MUI	A	B	A	B	C	A	B	A	B	A	A	B	C
MUT	A	B	A	B	A	A	B	A	B	B	A	B	C

*** Rows with similar letters indicate no significant difference in the mean for each treatment**
MRI : Instantaneous Resilient Modulus
MRT : Total Resilient Modulus
MUI : Instantaneous Poisson's Ratio
MUT : Total Poisson's Ratio
Rev : Revolutions

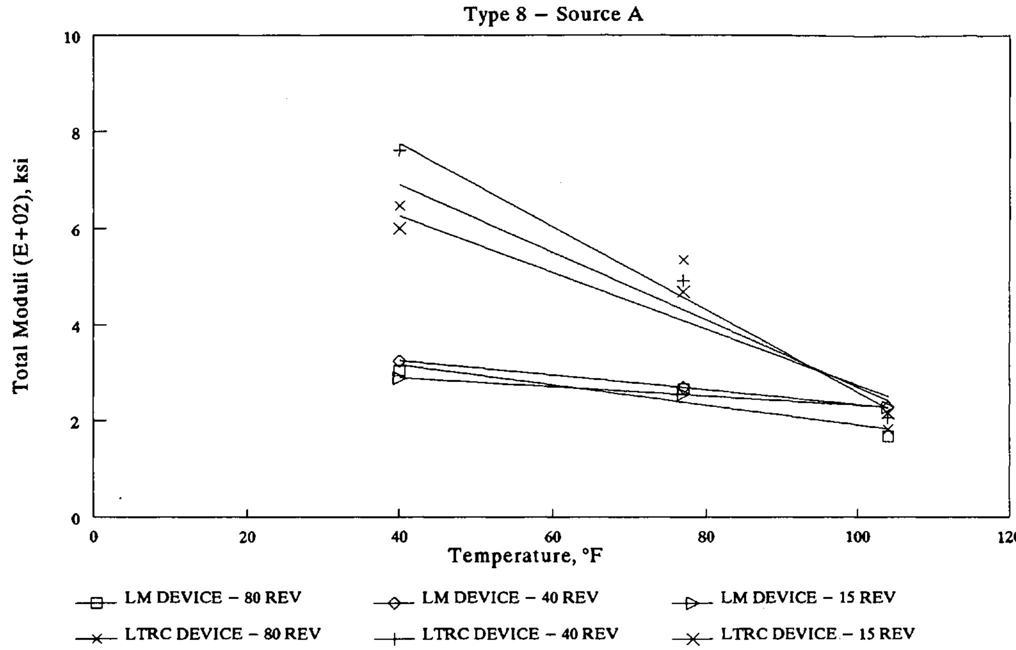

FIGURE 4 Total resilient modulus: temperature dependency.

the analyses of the test data. Several samples having a compaction of 80 and 40 revolutions failed between 200 and 500 sec, whereas most samples compacted at 15 revolutions failed between 200 and 500 sec. Therefore, discussion of the statistical analyses will be focused on test durations of up to 100 sec and is based on combined data for all variables except for the indicated one.

Table 5 shows the influence of the test device on the mean creep modulus for computed and assumed Poisson's ratio. Creep modulus values were more sensitive to the horizontal deformation during the first 100 sec than the vertical deformation for the two test devices. As expected, there were no significant differences between the two test devices for the moduli with calculated Poisson's ratio except for the initial 5 sec of loading. This can be attributed to factors related to seating of the samples. Meanwhile, results were significantly different between the two test devices for the first 100 sec of the creep modulus with assumed Poisson's ratio.

Table 6 presents the influence of the mix type on the creep modulus. No significant differences were observed between the mix types except for the first 10 sec of the modulus with computed Poisson's ratio. This could be the result of the inherent variations of the test at small deformation coupled with the effect of the other treatments.

TABLE 5 Effect of Test Device on Mean Creep Modulus by Time

Test Device	Creep Modulus									
	Calculated					Assumed MU = 0.35				
	Time (secs)					Time (secs)				
	5	10	100	200	500	5	10	100	200	500
LTRC	A *	A	A	A	A	A	A	A	A	A
LM	B	A	A	A	A	B	B	B	A	A

* : Columns with similar letters indicate no significant difference in the mean.

TABLE 6 Effect of Mix Type on Mean Creep Modulus by Time

Mix Type	Creep Modulus									
	Calculated					Assumed MU = 0.35				
	Time (secs)					Time (secs)				
	5	10	100	200	500	5	10	100	200	500
1	A *	A	A	A	A	A	A	A	A	A
8	B	B	A	A	A	A	A	A	A	A

* : Columns with similar letters indicate no significant difference in the mean.

TABLE 7 Effect of Asphalt Cement Source on Mean Creep Modulus by Time

Asphalt Cement Source	Creep Modulus									
	Calculated					Assumed MU = 0.35				
	Time (secs)					Time (secs)				
	5	10	100	200	500	5	10	100	200	500
Source A	A *	A	A	A	A	A	A	A	A	A
Source B	B	B	B	B	A / B	B	B	B	B	A / B
Source C	B	B	B	B	B	C	C	B	B	B

* : Columns with similar letters indicate no significant difference in the mean.

TABLE 8 Effect of Compaction Effort on Mean Creep Modulus by Time

Compaction Effort	Creep Modulus							
	Calculated				Assumed MU = 0.35			
	Time (secs)				Time (secs)			
	5	10	100	200	5	10	100	200
80 Revolutions	A *	A	A	A	A	A	A	A
40 Revolutions	A	B	B	B	B	B	B	B
15 Revolutions	B	C	C	C	C	C	C	B

* : Columns with similar letters indicate no significant difference in the mean.

The effect of the various asphalt sources on the creep modulus is shown in Table 7. Samples made with Source B had significantly higher moduli for the test duration than those made with Sources A and C. Once again, it is shown that the creep modulus was more sensitive to the horizontal deformation than the vertical deformation during the first 10 sec of the test. Physical properties of the binders indicated no apparent reason for any significant differences.

Table 8 shows the influence of the various levels of compaction effort on the creep modulus. It shows that denser mixtures yielded a higher creep modulus for test durations of up to 100 sec.

CONCLUSIONS

The following conclusions can be drawn from analysis of the data:

- The LM test device can better capture the temperature effect on resilient moduli than can the LTRC test device.
- Static test results (ITS and creep modulus) were not significantly different for the two test devices when the effects of other variables are significant (such as void levels mixture type, etc.), whereas dynamic test results (resilient modulus) were significantly different for each asphalt cement source, mixture type, and compaction effort.
- The ITS was sensitive to asphalt cement source and compaction effort. Also, the ITS was not sensitive to the mixture type.
- The resilient modulus was significantly different for the asphalt cement sources and the void levels.
- The creep stiffness provided significantly different results as demonstrated in asphalt cement sources and compaction effort.

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, Jr., for the statistical analysis of the data and to LTRC's lab technicians for their efforts in specimen preparation.

REFERENCES

1. Baladi, G. Y. *Integrated Material and Structural Design Method for Flexible Pavements*, Vol. 1. Technical Report. Report FHWA-RD-88-109, FHWA, U.S. Department of Transportation, Feb. 1988.
2. Baladi, G. Y. *Integrated Material and Structural Design Method for Flexible Pavements*, Vol. 2. Appendices. Report FHWA-RD-88-110, FHWA, U.S. Department of Transportation, Feb. 1988.
3. Baladi, G. Y. *Integrated Material and Structural Design Method for Flexible Pavements*, Vol. 3. Laboratory Design Guide. FHWA-RD-88-118, FHWA, U.S. Department of Transportation, Feb. 1988.
4. Mohammad, L. N., and H. R. Paul. Evaluation of a New Indirect Tension Test Apparatus. *In Transportation Research Record 1353*, TRB, National Research, Council, Washington, D.C., 1992, pp. 62–68.
5. Mohammad, L. N., H. R. Paul, and R. J. Doucet. *Evaulation of Indirect Tensile Test for Determining the Structural Properties of Asphalt Mix.* FHWA, U.S. Department of Transportation, Aug. 1992.

Publication of this paper sponsored by Committee on Characteristics of Bituminous Paving Mixtures To Meet Structural Requirements.