Abridgment

Effects of Repeated Tensile Stresses on the Resilient Properties of Asphalt Mixtures

Adedare S. Adedimila,* Department of Civil Engineering, University of Lagos, Nigeria
Thomas W. Kennedy, Council for Advanced Transportation Studies, University of Texas at Austin

The resilient, or elastic, characteristics of asphalt materials were studied in the laboratory using the repeated-load indirect tensile test to demonstrate its use and to obtain information on the elastic properties. Previous work (1, 2, 3, 4) has indicated that this test is economical and easy to conduct by an operating agency such as a highway department (as opposed to a research agency). The primary objectives of the study were

1. To demonstrate the use of the repeated-load indirect tensile test for the study of the elastic and permanent deformation characteristics of asphalt mixtures,
2. To determine the effect of selected factors on the resilient characteristics, and
3. To investigate the effects of repeated tensile stresses on the resilient characteristics.

EXPERIMENTAL PROGRAM

The factors investigated were the aggregate type, asphalt content, testing temperature, and stress level. The aggregates were a crushed limestone and a rounded river gravel, which were combined to produce a well-graded mixture. These aggregates were combined with an AC-10 asphalt cement at five levels of asphalt content (4, 5, 6, 7, and 8 percent by total weight of the mixture). The resulting mixtures were tested at 10, 24, and 38°C (50, 75, and 100°F) at stress levels ranging between 5.5 and 83 kPa (8 and 120 lb/in^2).

The method of specimen preparation, the characteristics of the materials, the repeated-load test procedure, and the equipment have been described previously (4). A typical load pulse and the resulting load deformation versus time relations are shown in Figures 1 and 2.

The fatigue life was defined as the number of load applications required to completely fracture the specimen (Figure 2). The following resilient properties, which are based on the deformations illustrated in Figures 1 and 2, were estimated in various forms.

ϵ_{RIH}, ϵ_{RIV} = instantaneous resilient horizontal and vertical strains, based on H_{RI} and V_{RI}
ϵ_{RTH}, ϵ_{RTV} = total resilient horizontal and vertical strains, based on H_{RT} and V_{RT}
ϵ_{TH}, ϵ_{TV} = individual total horizontal and vertical strains, based on H_T and V_T
ν_{RI} = Poisson's ratio, based on instantaneous resilient strains, ϵ_{RIH} and ϵ_{RIV}
ν_{RT} = Poisson's ratio, based on total resilient strains, ϵ_{RTH} and ϵ_{RTV}
ν_T = Poisson's ratio, based on individual total strains, ϵ_{TH} and ϵ_{TV}
E_{RI} = instantaneous resilient modulus, based on ϵ_{RIH}, ϵ_{RIV}, and ν_{RI}
E_{RT} = total resilient modulus, based on ϵ_{RTH}, ϵ_{RTV}, and ν_{RT}
E_T = modulus of individual total deformation, based on ϵ_{TH}, ϵ_{TV}, and ν_T

Equations for calculating these properties have been given by Adedimila and Kennedy (4).

DISCUSSION OF RESULTS

Strain Characteristics

The instantaneous resilient strains, the total resilient strains, and the individual total strains of the asphalt mixtures increased slightly with increasing load applications during about the first 70 percent of the fatigue life and then very rapidly with further applications of load. The shapes of the curves are similar to those given by Papazian and Baker (5) for the center deflection of an asphalt-concrete beam subjected to repeated flexure.

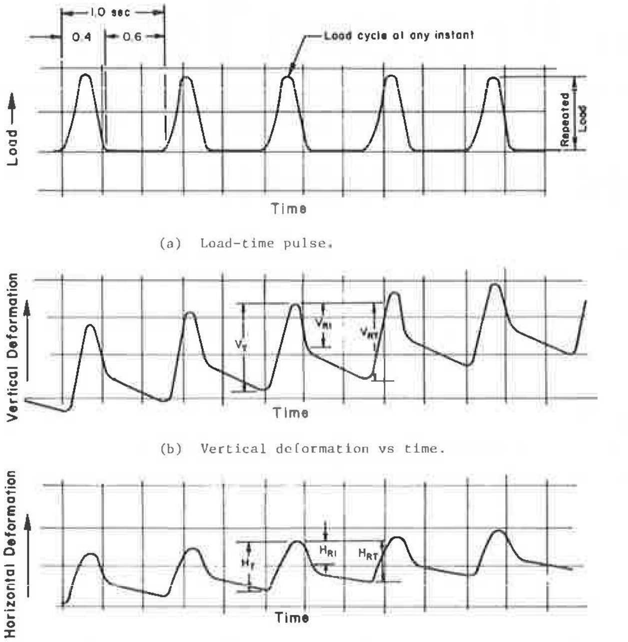
Resilient and Individual Total Moduli

The instantaneous resilient moduli were the largest, and the moduli of individual total deformation were the smallest.

Publication of this paper sponsored by Committee on Strength and Deformation Characteristics of Pavement Sections.

*Mr. Adedimila was at the Council for Advanced Transportation Studies, The University of Texas at Austin when this research was performed.

Figure 1. Typical load and deformation versus time relations for repeated-load indirect tensile test.

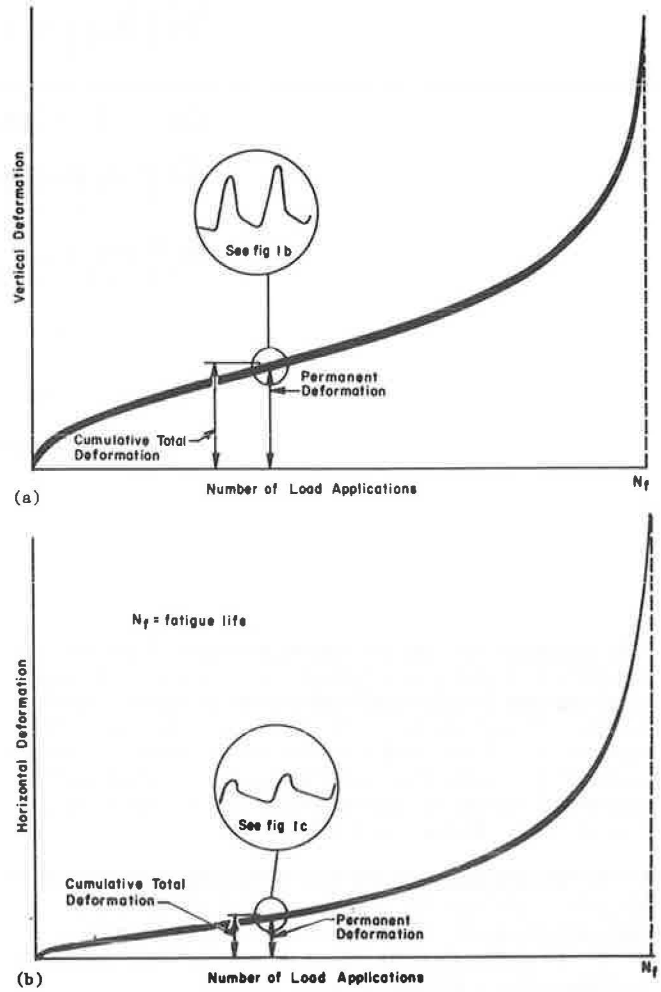


(a) Load-time pulse.

(b) Vertical deformation vs time.

(c) Horizontal deformation vs time.

Figure 2. Relations between number of load applications and vertical and horizontal deformation for repeated-load indirect tensile strength.



The relations between the modulus and the number of load applications were characterized by (a) a conditioning zone—the initial portion of the curves, up to about 10 percent of the fatigue life, in which the shape varied from concave up to concave down; (b) a stable zone—the portion of the curves between 10 and about 80 percent of the fatigue life, which was approximately linear, with a gradual decrease in modulus with increasing application of load; and (c) a failure zone—the last 20 percent of the fatigue life in which the curve exhibited a sharp curvature and a rapid drop in modulus.

Deterioration of Instantaneous and Total Resilient Moduli

The deterioration of the moduli was evaluated in terms of the slope of the relationship between the resilient moduli and the number of cycles for the linear portions of the relationships, i.e., between 10 and 80 percent of the fatigue life. The mean slopes ranged from 4.8 to 2070 kPa/cycle (7 to 3000 lb/in^2/cycle) for the instantaneous resilient moduli and from 3.4 to 680 kPa/cycle (5 and 990 lb/in^2/cycle) for the total resilient moduli. The deterioration values increased with increasing stress level and increasing testing temperature. The gravel mixtures generally had larger slopes than did the limestone mixtures. The values are exploratory in nature and, because of the limited number of factors considered and the high variations in the slopes, can provide only general estimates of the magnitudes of the deterioration of the instantaneous and total resilient moduli.

Factors Affecting Resilient Moduli

Values of the resilient modulus that can be used for design purposes were estimated by averaging the values at 30, 40, 50, 60, and 70 percent of the fatigue life.

The mean values of the instantaneous resilient modulus ranged from 87 to 633 MPa (126 000 to 918 000 lb/in^2), and those for the total resilient modulus ranged from 63 to 533 MPa (91 000 to 802 000 lb/in^2) (5). These values compare reasonably well with the values obtained for various mixtures in other studies (6, 7). The coefficients of variation for the total resilient modulus were generally smaller than those for the instantaneous resilient modulus, probably due to the fact that there is more error in the measurement of the instantaneous resilient deformations. Nevertheless, both the instantaneous and the total resilient moduli are estimate measures of the stiffness of the mixtures and can be used for design purposes.

Stress Level

The effect of stress level on the values of both the instantaneous and the total resilient moduli was inconsistent and shown by an analysis of variance to be not significant. Schmidt (8) has also presented data indicating that the magnitude of the indirect tensile stress has a very slight effect on the resilient modulus, and Howeedy and Herrin (9), using a constant-displacement, repeated compressive-stress test on cold mixes, have found that there is no regular relation between the resilient modulus and the stress.

Thus, it is concluded that the stress does not significantly affect the resilient modulus of elasticity.

Asphalt Content

The effect of the asphalt content on the dynamic modulus has not been definitely established (8, 10). In this study, the maximum dynamic modulus occurred at asphalt contents of 5 percent for the gravel mixtures and 7 percent for the limestone mixtures and the analysis of variance indicated a significant quadratic effect. An optimum, however, was not readily apparent or well defined.

Testing Temperature

A decrease in testing temperature caused a substantial increase in the repeated-load resilient modulus; this change was more significant in the lower temperature range.

Aggregate Type

The resilient moduli of the gravel mixtures were generally slightly larger than the resilient moduli of the limestone mixtures. The analysis, however, indicates that the differences were not significant.

Poisson's Ratio

There was a gradual increase in Poisson's ratio with increasing number of load applications until, at about 70 to 80 percent of the fatigue life, the increase became very rapid. This corresponded approximately to the point at which both the resilient and permanent strains increased rapidly and the resilient modulus decreased sharply. In most cases, Poisson's ratio exceeded 0.5 in value.

Service Life

As the specimen was subjected to repeated load applications, there were increasing permanent and resilient strains with an associated decrease in the resilient modulus. This continued to about 70 to 80 percent of the eventual fatigue life, at which time the specimen had cracked sufficiently, causing a sharp increase in the permanent and resilient strains and a sharp decrease in the resilient modulus. This is probably the point at which a field pavement ceases to render useful service without excessive maintenance. Thus, a point lying somewhere between 70 and 80 percent of the fatigue life can possibly be used to define the service life of the specimen.

CONCLUSIONS

Within the limits of load, temperature, and mixture variables considered in this study, it was concluded that

1. The repeated-load indirect tensile test can be used to estimate the resilient characteristics of asphalt materials;
2. The relations between the instantaneous resilient modulus, the total resilient modulus, or the modulus of individual total deformation and the number of stress applications can be divided into three zones. During the first 10 percent of the fatigue life, the shape of the relationship varies because of initial adjustment to load and possible additional compaction; between 10 and 80 percent, the moduli decreased linearly with increasing stress applications; and beyond about 80 percent, the moduli decreased very sharply until complete fracture;
3. The average values of the instantaneous resilient modulus at 10, 24, and 38°C (50, 75, and 100°F) ranged from 87 to 633 MPa (126 000 to 918 000 lb/in^2), and similar values of the total resilient modulus of elasticity ranged from 63 to 533 MPa (91 000 to 802 000 lb/in^2);
4. The effects of stress level and asphalt content on the average instantaneous and total resilient moduli are uncertain; however, there was an increase in these moduli with decreasing testing temperature;
5. The rate of deterioration or decay of the total resilient modulus with stress applications, evaluated in terms of the slope of the approximately linear portion, ranged from 3.45 to 680 kPa/cycle (5 to 990 lb/in^2/cycle). For the instantaneous resilient modulus, the slopes ranged from 4.8 to 2070 kPa/cycle (7 to 3000 lb/in^2/cycle). For both moduli, the rate of decay increased with increasing stress level and increasing testing temperature;
6. Poisson's ratio increased with increasing stress applications; and
7. The service life of a laboratory specimen subjected to indirect tensile fatigue loading was estimated to be between 70 and 80 percent of its fracture (fatigue) life.

ACKNOWLEDGMENTS

This investigation was conducted at the Center for Highway Research, the University of Texas at Austin. We wish to thank the sponsors, the Texas Department of Highways and Public Transportation and the Federal Highway Administration, U.S. Department of Transportation.

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

REFERENCES

1. R. K. Moore and T. W. Kennedy. Tensile Behavior of Stabilized Subbase Materials Under Repetitive Loading. Center for Highway Research, Univ. of Texas at Austin, Research Rept. 98-12, Oct. 1971.
2. D. Navarro and T. W. Kennedy. Fatigue and Repeated-Load Elastic Characteristics of Inservice Asphalt-Treated Materials. Center for Highway Research, Univ. of Texas at Austin, Research Rept. 183-2, Jan. 1975.
3. B. P. Porter and T. W. Kennedy. Comparison of Fatigue Test Methods for Asphalt Materials. Center for Highway Research, Univ. of Texas at Austin, Research Rept. 183-4, April 1975.
4. A. S. Adedimila and T. W. Kennedy. Fatigue and Resilient Characteristics of Asphalt Mixtures by Repeated-Load Indirect Tensile Test. Center for Highway Research, Univ. of Texas at Austin, Research Rept. 183-5, Aug. 1975.
5. H. S. Papazian and R. F. Baker. Analyses of Fatigue Type Properties of Bituminous Concrete. Proc., AAPT, Vol. 28, 1959, pp. 179-210.
6. B. F. Kallas. Dynamic Modulus of Asphalt Concrete in Tension and Tension-Compression. Proc., AAPT, Vol. 39, 1970, pp. 1-23.
7. C. L. Monismith, J. A. Epps, D. A. Kasianchuk, and D. B. McLean. Asphalt Mixture Behavior in Repeated Flexure. Office of Research Services, Univ. of California, Berkeley, Rept. TE-70-5, Dec. 1970.
8. R. J. Schmidt. A Practical Method for Measuring the Resilient Modulus of Asphalt Treated Mixes. HRB, Highway Research Record 404, 1972, pp. 22-32.

9. M. F. Howeedy and M. Herrin. Behavior of Cold Mixes Under Repeated Compressive Loads. HRB, Highway Research Record 404, 1972, pp. 57-70.
10. J. F. Shook and B. F. Kallas. Factors Influencing Dynamic Modulus of Asphalt Concrete. Proc., AAPT, Vol. 38, 1969, pp. 140-178.