

# Selection of Subgrade Modulus for AASHTO Flexible Pavement Design

ROBERT P. ELLIOTT

The resilient modulus value (3,000 psi) used to represent the AASHTO Road Test subgrade in the AASHTO flexible pavement design equation is examined. The subgrade modulus for pavements designed by the AASHTO *Guide for Design of Pavement Structures* must be consistent with this value for the guide to be used correctly. For cohesive soils, it is shown that this requires that laboratory values be based on tests conducted unconfined using a deviator stress of 6 psi. For backcalculated modulus values from cohesive soils to be consistent with the guide, the backcalculated modulus must be multiplied by a factor no greater than 0.33. Unmodified backcalculated values are unconservative. Laboratory values are also unconservative when the tests are conducted with a confining pressure and deviator stresses less than 6 psi. However, if the subgrade soils are noncohesive, it is not clear what the laboratory test conditions need to be or whether backcalculated  $M_r$ -values need to be adjusted to be consistent with the AASHTO subgrade value. Appropriate values for noncohesive soils need further study.

The 1986 AASHTO *Guide for Design of Pavement Structures* (1) adopted the resilient modulus as the subgrade soil property controlling the design of flexible pavements. The introduction of the resilient modulus into routine pavement design caused considerable concern and discussion among engineers responsible for pavement design and materials testing. Most engineers routinely involved in these activities had little if any knowledge or understanding of the resilient modulus at the time that this variable was adopted, and practically none of the highway agencies had the capability to perform resilient modulus tests. Even today, the number of agencies equipped to perform resilient modulus tests on a routine basis are limited. Most agencies continue to perform the soil tests they used before the 1986 guide and rely on "correlations" between those tests and the resilient modulus to obtain the subgrade values needed in design.

Most of the discussions concerning the resilient modulus to date have centered on test methods, equipment, and repeatability. The concern has been so great, in fact, that AASHTO voted out the method of test that was adopted as a standard before the 1986 guide (AASHTO T274). As a result, there has been no standard method test for the resilient modulus even though the AASHTO guide uses it as a controlling design parameter. AASHTO recently balloted on the adoption of a revised method of test that may remedy this unusual situation.

However, there are other, more fundamental questions that need to be discussed, questions that probably were considered by the developers of the 1986 guide but that have not been conveyed adequately to the designers who bear the respon-

sibility of using and interpreting the guide. These questions relate to the selection of the "correct" resilient modulus value to use in design. The "normal" practice of selecting a design modulus based on expected stress conditions under the pavement leads to the use of an unconservative value. Similarly, backcalculated resilient modulus values typically used for overlay design are unconservative unless reduced to be consistent with the modulus value used in the AASHTO design equation for the AASHTO Road Test subgrade.

## BASIC CONCEPT OF SUBGRADE RESILIENT MODULUS

The resilient modulus test is intended to examine the behavior of the soil as a support system for the pavement. In this respect the concept and basic approach to testing are very simple. When a heavy vehicle passes over the pavement, a dynamic stress pulse is transmitted to the soil. This stress causes the soil to deform, which in turn permits the pavement to deflect and bend. The stresses and strains generated within the pavement as a result of the deflection and bending are the factors that control the pavement performance. Thus, the pavement performance is directly influenced by the load-deformation behavior of the soil.

The basic concept of the resilient modulus test is to duplicate and measure this behavior in the laboratory. The test is normally conducted by placing the soil specimen in a triaxial cell and subjecting it to a confining pressure. The confining pressure is intended to simulate the confinement the soil would experience under the pavement. Dynamic load pulses are applied to the soil, and the resulting deformation or specimen strain is measured. The load pulse durations are typically about 0.1 sec and are intended to simulate the stress pulse in the subgrade caused by the passage of a heavy vehicle. The resilient modulus ( $M_r$ ) is calculated from the load and deformation using the following equation:

$$M_r = \sigma_d / \epsilon_r$$

where  $\sigma_d$  is the stress caused by dynamic load pulse, also referred to as the deviator stress, and  $\epsilon_r$  is the resilient or recoverable strain.

Note that there are two components to the total specimen deformation, a resilient or recoverable portion and a permanent portion. Only the resilient portion is included in the resilient modulus. Except when the load applied is very close to the shear strength of the soil, the permanent deformation portion is very small and generally can only be measured as

an accumulation of deformation over a large number of load repetitions.

To this point the concept, testing, and application of subgrade resilient modulus appear reasonably simple. It becomes quite complicated, however, when one discovers that there is no single resilient modulus for the soil, but rather an almost infinite number of values depending on test and sample conditions. For example, the resilient modulus of cohesive soils typically decreases quite significantly as the dynamic load or deviator stress increases. Conversely, higher confining pressures can result in some increase in resilient modulus. Specimen moisture content can have an overwhelming effect on the modulus value (which is lower with higher moisture contents). Other factors that can have an effect are density, freeze-thaw cycles, and method of compaction.

The selection of a design resilient modulus may still seem reasonably straightforward, because the objective of the test is to duplicate the soil's behavior as a pavement support system. It would appear, therefore, that the appropriate modulus would be the modulus determined for conditions consistent with the soil in its final location and condition under the pavement and at stress levels consistent with the stresses generated by a heavy vehicle load.

Ideally, this would be the case and should be the case for a fully developed mechanistic design procedure. However, determination of the modulus in the foregoing manner is not correct when the AASHTO guide procedure is used. In most cases, resilient modulus values selected on the basis of deviator stresses and confining pressures consistent with actual pavement conditions will be unconservative when used with the AASHTO guide. As a result, pavements designed using such values may be underdesigned or at least will have a lower level of reliability than the designer intends them to have. This is due to the empirical nature of the guide procedure.

### AASHTO ROAD TEST TO AASHTO GUIDE

The AASHTO guide design procedure was developed as a modification of the AASHTO Road Test performance equation (2). As such, all design inputs must be consistent with either Road Test conditions or conditions used in extending the performance equation beyond the Road Test. In particular, the subgrade resilient modulus value must be consistent with the modulus value used to represent the AASHTO Road Test subgrade.

Soil type and condition were not variables in the AASHTO Road Test. Every possible effort was made to ensure that the subgrade under all portions of the Road Test pavements was as uniform as possible. As a result, the performance equations developed from the Road Test did not include any measure of soil strength or condition. In adapting the equations for design, the earlier AASHTO guides simply used a "soil support scale" to represent changing subgrade conditions without fully defining the scale or what test should be used with it.

In the development of the 1986 guide, the soil support scale was abandoned and replaced with a relationship based on the resilient modulus. When this was done, a value of 3,000 psi was used to represent the AASHTO Road Test subgrade. For the guide to be used correctly, the subgrade resilient modulus value used must be consistent with the 3,000 psi used for the AASHTO subgrade.

The AASHTO guide and appendixes (1) do not indicate how or why this value was selected. However, a basis for the 3,000-psi value can be found in the literature. A value of 3,000 psi for the AASHTO subgrade was suggested (perhaps for the first time) by Skok and Finn in a paper presented at the 1962 International Conference on the Structural Design of Asphalt Pavements (3). Skok and Finn derived this value from Benkelman beam deflection data. At the same conference, Seed et al. (4) presented laboratory resilient modulus data from tests on the AASHTO subgrade soil (Figure 1). Their data show 3,000 psi to be a reasonable value if the deviator stress is greater than 12 psi when kneading compaction was used or 25 psi when static compaction was used. The confining pressure with their tests was 3.5 psi.

Thompson and Robnett (5) reported the most complete study of the resilient behavior of the AASHTO subgrade. They performed detailed resilient modulus testing on a number of soils found in the state of Illinois. Their data from tests on the AASHTO subgrade soil are summarized in Figure 2, from which it can be concluded that 3,000 psi is appropriate for the AASHTO soil when it is about 1 percent wet of optimum and subjected to a deviator stress of about 6 psi or more. What is not apparent in Figure 2 but is discussed by Thompson and Robnett is that these values are based on tests without confining pressure. Their study found little effect due to confining pressure in the 3- to 5-psi range if the soil being tested was cohesive and compacted at or wet of optimum.

On the basis of the extensive testing of the AASHTO soil by Thompson and Robnett, it may be concluded that the appropriate test conditions for subgrade resilient modulus when using the 1986 AASHTO guide are zero confining pressure and a 6-psi deviator stress. Nevertheless, the resilient modulus test method recently voted on by AASHTO calls for testing at a 3-psi confining pressure with deviator stress levels "selected to cover the expected in-service range." If the expected in-service range is less than 6 psi, the measured resilient modulus can be expected to be too high and unconservative (lower stresses generally result in higher resilient modulus values; see Figure 2).

For granular soils, the selection of appropriate test conditions is more complex and questionable. Obviously, noncohesive material cannot be tested in an unconfined state. Also the effects of stress level and confining pressure differ with granular materials. Figure 3 shows the typical stress state-resilient modulus behavior of a granular material. The bulk stress ( $\theta$ ) referred to in Figure 3 is the summation of the deviator stress and three times the confining pressure (confining pressure in all three directions). Note that as the stress state increases, the resilient modulus also increases. How to consider this stress-dependent behavior within the empirical framework of the AASHTO guide so as to be consistent with the 3,000 psi used for the AASHTO Road Test soil is not clear. Additional research on this point is needed. Thus, selection of the appropriate resilient modulus for a granular subgrade requires much thought and judgment from the designer.

### OVERLAY DESIGN AND BACKCALCULATED MODULI

The potential for selecting an unconservative resilient modulus value becomes even greater for the design of flexible

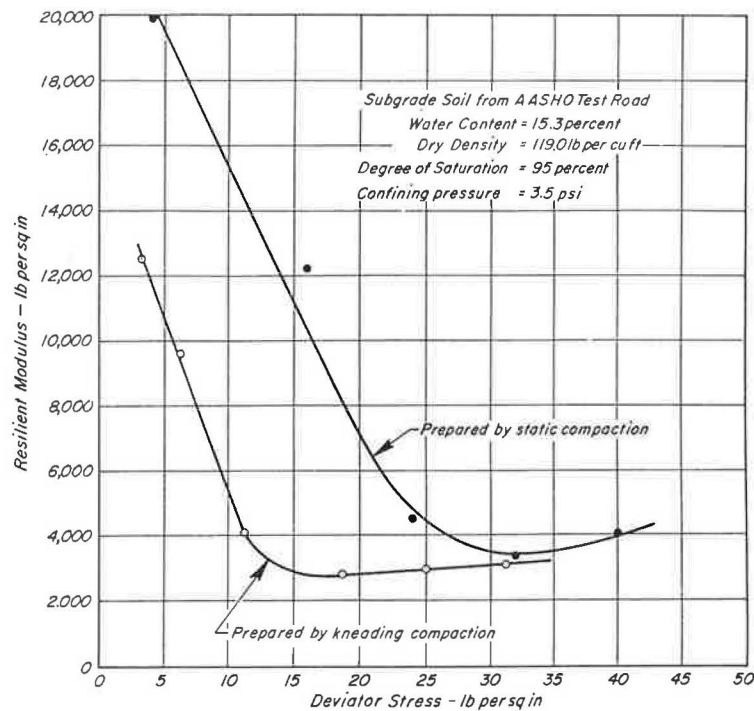


FIGURE 1 AASHO Road Test subgrade resilient modulus tests reported by Seed et al. (4).

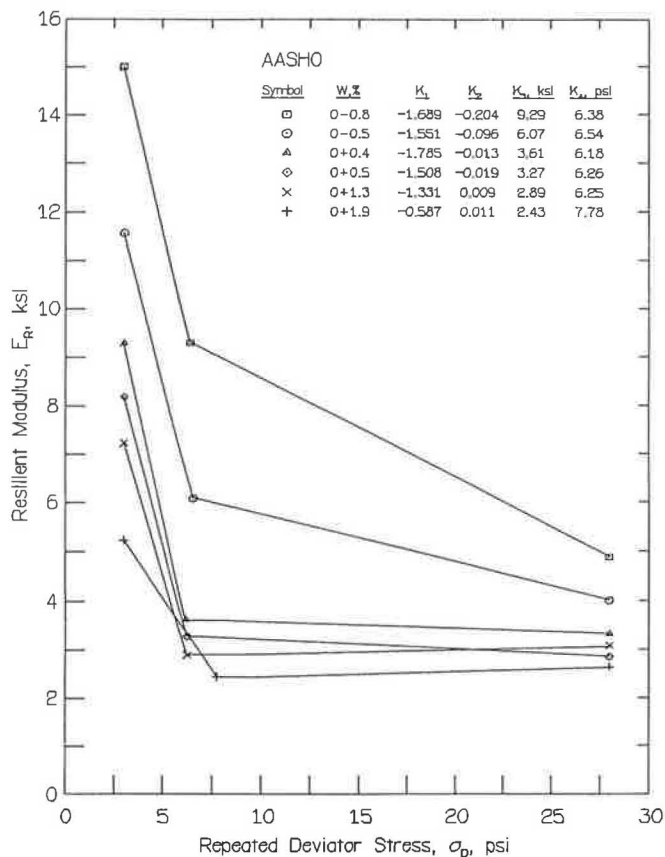


FIGURE 2 Resilient modulus of AASHO Road Test subgrade reported by Thompson and Robnett (3).

pavement overlays when nondestructive testing (NDT) and backcalculation are used (6). Most backcalculation schemes use the concept that load stresses are spread over a progressively greater area as depth into the pavement and subgrade increases (Figure 4). With this concept the surface deflection at some point sufficiently distant from the point of load application is due only to compression within the subgrade. The subgrade resilient modulus, therefore, is determined using only the surface deflection at this point.

An obvious problem with this concept when it is applied to the AASHTO guide is that the stress levels at this distant point are almost always much less than 6 psi. As a result of

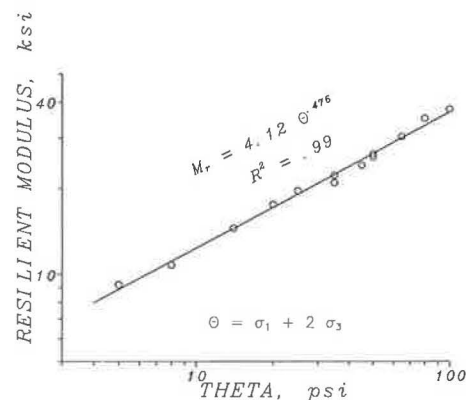


FIGURE 3 Resilient modulus stress dependency typical of a noncohesive material.

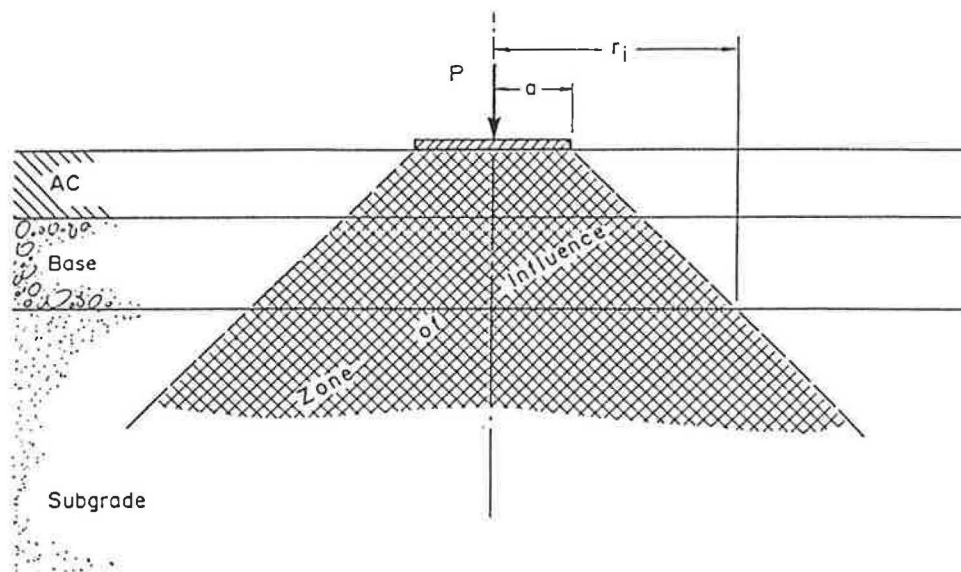


FIGURE 4 Concept of the spreading of load stresses with depth below the pavement surface.

the stress dependency of most soils, the backcalculated resilient modulus can almost always be expected to be too great to be consistent with the 3,000 psi used for the AASHTO subgrade. Therefore, backcalculated resilient modulus values need to be adjusted when used with the 1986 AASHTO guide.

Unfortunately, NDT data suitable to be used to evaluate this backcalculation scheme are not available from the AASHTO Road Test. However, Traylor (7) reported some NDT data that are reasonably suitable from measurements taken on Loop 1 of the Road Test several years after its conclusion. (Loop 1 pavements were not subjected to traffic during the Road Test and are still in place.) The NDT device was the FHWA Thumper used in the impulse load mode with a load magnitude of about 4,000 lb. In addition to the NDT tests, Traylor also reported laboratory resilient modulus results from Shelby tube samples taken shortly after the deflection measurements. The resilient modulus of these samples was measured using a deviator stress of 6 psi and no confining pressure. Therefore, the test results are consistent with the 3,000-psi value used in the AASHTO guide equation.

These data were used in an analysis directed at determining an appropriate adjustment factor for use of backcalculated resilient moduli with the AASHTO guide. The backcalculation was performed using the equation recommended for use in the AASHTO overlay design procedures (6):

$$M_r = 0.24P/d_r r$$

where  $P$  is the applied load and  $d_r$  is the deflection at a distance  $r$  from the center of loading. Figure 5 is a plot of the backcalculated  $M_r$ -values versus the laboratory values from the Shelby tube samples. Except for one value, the laboratory results are reasonably consistent with the 3,000 psi used for the AASHTO soil in the guide equation. However, the backcalculated moduli are greater than the laboratory values by a factor of 4.8 on average.

Two other analyses were performed to examine the need for the adjustment of backcalculated  $M_r$ -values. These anal-

yses used the ILLI-PAVE finite-element program with the AASHTO Road Test soil data reported by Thompson and Robnett. ILLI-PAVE models the stress dependency of cohesive soils as two intersecting lines, as shown by the Thompson and Robnett data. The inputs to the model are the slopes of the lines ( $K_1$  and  $K_2$ ), the point of intersection ( $E_{ri}$  and  $S_{di}$ ), and lower-limit deviator stress that sets a maximum limit on the resilient modulus. Using the data from Figure 2, the following values were selected to model the AASHTO subgrade:  $E_{ri} = 3,000$  psi,  $S_{di} = 6$  psi,  $K_1 = 1.4$  ksi/psi,  $K_2 = 0.01$  ksi/psi, and lower-limit deviator stress = 2 psi (maximum possible  $M_r = 8,600$  psi).

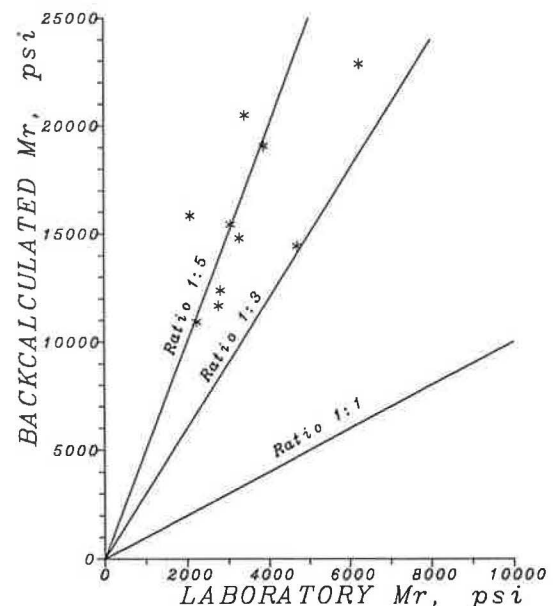


FIGURE 5 Comparison of backcalculated values and laboratory resilient modulus values of AASHTO Road Test subgrade.

The first analysis was used to determine the  $M_r$ -value that ILLI-PAVE would assign for subgrade elements at radial distances from the center of loading and that would typically be used for subgrade backcalculation. The pavements analyzed had 3-in. and 5-in. asphalt concrete surfaces ( $E_{ac} = 500$  ksi) and aggregate bases ranging in thickness from 8 to 22 in. (base  $M_r = 9,000 \theta^{0.33}$ ). The loading was 9,000 lb on a 5.9-in. circular area [equivalent to a typical falling weight deflectometer (FWD) test]. Examination of the ILLI-PAVE output showed that at radial distances typically used for subgrade backcalculation, most elements would have the maximum possible  $M_r$  (8,600 psi).

The second analysis used the deflection basins predicted by ILLI-PAVE. These deflections were used to predict subgrade  $M_r$  using the backcalculation equation shown above. Deflections at distances ranging from 12 to 57 in. were used. The calculated modulus values ranged from 9,280 to 11,800 psi. There was no pattern showing the modulus increasing or decreasing with radial distance. Using the "best estimate"  $M_r$  from each analysis, the mean backcalculated modulus was 9,806 psi.

These results suggest that if appropriate deflection data were available from the AASHTO Road Test, the backcalculated subgrade resilient modulus would be greater than 3,000 psi by a factor of at least 3. Therefore, backcalculated values used with the AASHTO guide equation should be multiplied by a factor no greater than 0.33 to be consistent with the value assumed for the AASHTO subgrade.

Similar results were obtained in a limited comparison study of FWD data and laboratory resilient modulus tests. Data were obtained from several projects located in three states (6–8) in which the FWD was used at a load of 9,000 lb. Subgrade samples from the deflection sites had been tested in the laboratory at a deviator stress of about 6 psi. Data from these tests are as follows:

Soil Type	$M_r$ (psi)		Ratio, Backcalculated to Laboratory
	Laboratory	Backcalculated	
A-2,A-4,A-6	7,000	25,000	3.6
A-2,A-6	4,800	22,700	4.7
A-4	3,000	27,500	9.2
A-4,A-2-5	6,000	13,500	2.3
A-7-6	6,000	19,600	3.3
A-2-4	4,150	14,100	3.4
A-4	4,500	14,300	3.2
A-6	5,700	14,500	2.5
A-4	7,650	13,400	1.8
A-4	7,350	45,000	6.1
A-6	6,000	45,000	7.5
A-6	8,750	24,300	2.8

All of these analyses were for cohesive soils. The results apply primarily to stress-sensitive, fine-grained soils such as the AASHTO subgrade. No attempt has been made to investigate granular, noncohesive soils. The need for adjustment of backcalculated values or for the appropriate laboratory test conditions for such soils is not clear. This subject needs investigation.

Designers need to be aware that the subgrade resilient modulus has a significant effect on the design structural number. They need to be very cautious in selecting the design resilient modulus. When unconservative values are used in design, pavements and overlays may be underdesigned or at least

levels of reliability will be much less than those intended. Unexpected early pavement failures and excess maintenance costs may result.

## CONCLUSIONS

On the basis of the analyses presented in this paper, the following conclusions are drawn regarding the selection of an appropriate subgrade resilient modulus to use with the AASHTO guide method of flexible pavement design.

1. Laboratory resilient modulus tests on cohesive soils that are conducted at deviator stresses and confining pressures consistent with stress conditions expected below the completed pavement will result in  $M_r$ -values that are unconservative when used in the AASHTO guide.
2. For laboratory resilient modulus values on cohesive soils to be consistent with the value assumed for the AASHTO Road Test subgrade, the test should be conducted unconfined using a deviator stress of 6 psi.
3. Subgrade resilient modulus values for cohesive soils backcalculated from NDT deflection data are unconservative when used directly with the AASHTO guide design equation.
4. Backcalculated  $M_r$ -values for cohesive soils need to be multiplied by a factor no greater than 0.33 to be consistent with the 3,000-psi  $M_r$ -value assumed for the AASHTO Road Test subgrade.
5. If subgrade soils are noncohesive, it is not clear what the laboratory test conditions need to be or whether backcalculated  $M_r$ -values need to be adjusted. These points should be studied.

## ACKNOWLEDGMENT

This paper is based in part on work performed under the National Cooperative Highway Research Program (NCHRP) Project 20-7, Task 39, Revision of AASHTO Pavement Overlay Design Procedures, which was sponsored by AASHTO in cooperation with FHWA. The work was conducted through NCHRP, which is administered by the Transportation Research Board of the National Research Council.

## REFERENCES

1. *Guide for Design of Pavement Structures*. American Association of State Highway and Transportation Officials, Washington, D.C., 1986.
2. *Special Report 61E: Report 5—Pavement Research*. HRB, National Research Council, Washington, D.C., 1962.
3. E. L. Skok, Jr., and F. N. Finn. Theoretical Concepts Applied to Asphalt Concrete Pavement Design. *Proc., International Conference on the Structural Design of Asphalt Pavements*, Ann Arbor, Mich., 1962, p. 421.
4. H. B. Seed, C. K. Chan, and C. E. Lee. Resilience Characteristics of Subgrade Soils and their Relation to Fatigue Failures in Asphalt Pavements. *Proc., International Conference on the Structural Design of Asphalt Pavements*, Ann Arbor, Mich., 1962, p. 622.
5. M. R. Thompson and Q. L. Robnett. *Resilient Properties of Subgrade Soils, Final Report—Data Summary*. Transportation Engineering Series No. 14. Illinois Cooperative Highway Re-



- search and Transportation Program Series No. 160. University of Illinois at Urbana-Champaign, 1976.
6. M. I. Darter, R. P. Elliott, and K. T. Hall. *Revision of AASHTO Pavement Overlay Design Procedures*. Final Report. NCHRP Project 20-7, Task 39, TRB, National Research Council, Washington, D.C., Sept. 1991.
  7. M. L. Traylor. *Characterization of Flexible Pavements by Non-destructive Testing*. Ph.D. thesis. University of Illinois at Urbana-Champaign, 1979.
  8. S. H. Carpenter. *Layer Coefficients for Flexible Pavements*. ERES Consultants, Inc., Urbana, Ill., Aug. 1990.
  9. M. I. Darter, R. P. Elliott, and K. T. Hall. *Revision of AASHTO Pavement Overlay Design Procedures, Appendix: Overlay Design Examples*. NCHRP Project 20-7, Task 39. TRB, National Research Council, Washington, D.C., Sept. 1991.
  10. R. P. Elliott, S. I. Thornton, K. Y. Foo, K. W. Siew, and R. Woodbridge. *Final Report, TRC-94, Resilient Properties of Arkansas Subgrades*. Report UAF-AHTRC-88-002. University of Arkansas, Fayetteville, 1988.

---

*The contents of this paper reflect the views of the author, who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Transportation Research Board, the National Research Council, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, or of any of the individual states participating in the National Cooperative Highway Research Program. This paper does not constitute a standard, specification, or regulation.*