# Simplification of Subgrade Resilient Modulus Testing

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**The standard test method (AASHTO T274) for the resilient modulus of cohesive soils can be simplified without affecting the reliability of flexible pavement design by the AASHTO Guide. The traffic life prediction accuracy (standard deviation) of the AASHTO design equation is equivalent to a resilient modulus testing accuracy of about 30 percent. The overall prediction accuracy is not affected substantially as long as the testing error (standard deviation) is 15 percent or less. Three cohesive soils were tested to examine the effects of confining pressure, deviator stress, number of stress cycles, and compaction method. For routine design the standard method of test can be simplified by (1) reducing the number of confining pressures from three to one (3 psi is suggested); (2) reducing the number of deviator stress levels from five to one (8 psi is suggested); and (3) reducing the number of stress cycles from 200 to 50. With these test simplification measures, the time required for testing (excluding sample preparation and test setup) is reduced from 100 minutes per specimen to less than 2 minutes.**

The 1986 AASHTO Guide for the Design of Pavement Structures is affecting the routine testing of soils for pavement design to a great extent. Under the previous Guide, soils were evaluated on an arbitrary "soil support" scale, which was not based on any particular method of test or evaluation. As a result, there was no universally accepted test method or relationship between test results and the soil support. Each highway agency adopted its own test and relationship.

The 1986 Guide uses resilient modulus as the method of test and evaluation for pavement subgrade support. Resilient modulus is a fundamental property that should be included in any rational pavement design procedure. The incorporation of resilient modulus by AASHTO represents a significant advance in pavement design practice. Nevertheless, adoption of resilient modulus created some legitimate concerns: most highway engineers were not familiar with the resilient modulus, nor did most state highway agencies have experience with the test. In addition, few agencies had the proper test equipment for this complex and time-consuming test.

The Arkansas State Highway and Transportation Department initiated a study at the University of Arkansas (*1*) to determine the resilient properties of typical Arkansas soils and to develop specific recommendations for routine resilient modulus testing. According to the study, the method of test for cohesive soils can be greatly simplified.

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## STANDARD TEST REQUIREMENTS

The standard method for resilient modulus testing is AASHTO test method T274 (*2*). The objective of the test is to simulate the in-service behavior of the soil. The test specifications for compaction are intended to produce a test specimen that closely resembles the soil's in-service structure and moisture condition. Three methods of compaction are described: gyratory, kneading, and static. The method to be used depends upon the moisture conditions expected during construction and later in service.

The method of compaction is determined by the degree of saturation (Table 2). If field compaction will result in less than 80 percent and the moisture content is not expected to increase after construction, any method may be used. However, if the degree of saturation will later increase to more than 80 percent, the specimens are to be compacted at the in-service moisture content using the static method. Soils that will be field compacted to greater than 80 percent saturation are to be prepared by the kneading method.

The resilient modulus testing requirements were developed recognizing the stress-dependent nature of soil. Testing is done in a triaxial chamber so that lateral confining pressures can be applied. The standard test for cohesive soils requires three levels of confining pressure: 0, 3, and 6 psi. To simulate traffic loading, a vertical load (called the deviator stress) is applied for 0.1 second at a repeated interval of 1 to 3 seconds. Five levels of deviator stress are required: 1, 2, 4, 8, and 10 psi. Each deviator stress is repeated for 200 cycles at each of the three confining pressures. The resilient modulus is determined for each combination of deviator stress and confining pressure by the equation:

$$M_R = \theta_d/\varepsilon_r$$

in which

$M_R$ = the resilient modulus
$\theta_d$ = the deviator stress
$\varepsilon_r$ = the resilient (or recoverable) strain.

TABLE 1 ROUTINE SOIL PROPERTIES

| | Jackport | Gallion | Sawyer | Clarksville | Leadvale |
|---|---|---|---|---|---|
| AASHTO T99 | | | | | |
| Maximum Density (pcf) | 94 | 94 | 96 | 109 | 99 |
| Opt. Moisture (%) | 20 | 25 | 23 | 15 | 22 |
| Liquid Limit | 55 | 68 | 48 | 24 | 38 |
| Plast. Index | 34 | 43 | 28 | 6 | 15 |
| Gradation (% Passing) | | | | | |
| #4 | | | | 100 | |
| #10 | 100 | 100 | 100 | 93 | 100 |
| #40 | 97 | 95 | 94 | 85 | 90 |
| #80 | 92 | 88 | 88 | 84 | 89 |
| #200 | 89 | 85 | 81 | 82 | 82 |
| 0.02 mm | 70 | 73 | 66 | 49 | 61 |
| 0.002 mm | 41 | 55 | 41 | 16 | 37 |
| 0.001 mm | 38 | 54 | 36 | 13 | 36 |

With three levels of confining pressure and five levels of deviator stress, 15 $M_R$ values are found for each test. Using 2 seconds between stress cycles, the testing time is 100 minutes, exclusive of sample preparation and conditioning.

## Design Resilient Modulus

In addition to the 15 $M_R$ values from a single test, the AASHTO Guide design procedure calls for testing at moisture contents that simulate the primary moisture seasons. Assuming four seasons, as many as 60 $M_R$ values are determined. Nevertheless, a single $M_R$ value must be selected as the effective roadbed resilient modulus to be used in the design procedure. The engineer is faced with (1) estimating seasonal moisture conditions, (2) testing at each of these moisture contents, (3) selecting a single $M_R$ value from among the 15 test values for each moisture season, and (4) selecting the effective roadbed resilient modulus from an analysis of the seasonal values.

The AASHTO Guide provides a procedure for selecting the design $M_R$ once the seasonal values are identified. The procedure is based on a relative damage concept. Relative damage factors are determined for the seasonal $M_R$'s. From these, the annual average damage factor is calculated. The $M_R$ value consistent with the average damage factor is identified as the effective roadbed resilient modulus that is used for design.

As an example of the AASHTO selection procedure, $M_R$ tests were used to establish a relationship with subgrade moisture content (Figure 1). This relationship was then used with estimated monthly moisture contents to select an $M_R$ for each month. The monthly $M_R$ values were then used with the scale along the right side of Figure 1 to determine monthly relative damage factors. This scale was then used with the average of the monthly relative damage factors to determine the effective roadbed soil resilient modulus.

## Required Testing Accuracy and Precision

From an analytical and conceptual point of view the testing and selection process is appealing. However for routine design, the "measure-with-a-micrometer, mark-with-a-grease-pencil, cut-with-an-ax" syndrome seems to be at work. The ability to predict traffic, moisture conditions, and pavement performance is currently much less precise than the sophistication required by AASHTO T274 and the $M_R$ selection process would imply.

The sophistication required for routine testing depends on the accuracy and precision needed from the test. Three factors must be considered in determining the accuracy and precision required for subgrade resilient modulus testing: these are (1) the sensitivity of the design to the test parameter, (2) the capability to predict the in-service variables that affect the test result (i.e., moisture content and freeze-thaw), and (3) the accuracy of the prediction models used for design.

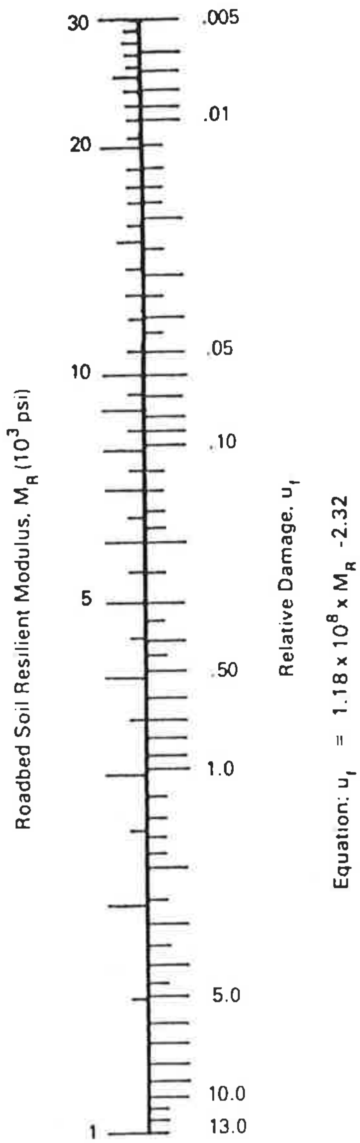
### *Design Sensitivity*

The sensitivity of the design thickness to subgrade resilient modulus is illustrated in Figure 2. In practical terms, Figure 2 shows that a 30 percent change in the resilient modulus will result in a change in total asphalt thickness of 1 to 1.5 inches.

### *In-Service Variables*

Figures 3 and 4 illustrate the moisture and freeze-thaw sensitivity of an Arkansas soil. Moisture and freeze-thaw significantly affect the subgrade support capability and should be considered. However, reliable procedures for predicting moisture and freeze-thaw cycles are not available. Until better methods are available for predicting seasonal moisture variation, testing at several moisture contents does not appear to be justified.

| Month | Roadbed Soil Modulus, $M_R$ (psi) | Relative Damage, $u_f$ |
|---|---|---|
| Jan. | 30,000 | .005 |
| Feb. | 5,500 | .25 |
| Mar. | 9,500 | .070 |
| Apr. | 8,900 | .081 |
| May | 8,600 | .088 |
| June | 11,000 | .050 |
| July | 12,700 | .038 |
| Aug. | 13,000 | .034 |
| Sept. | 13,100 | .033 |
| Oct. | 12,800 | .035 |
| Nov. | 12,700 | .036 |
| Dec. | 12,300 | .038 |
| Summation: $\Sigma u_f$ = | | .758 |




Average: $\bar{u}_f = \frac{\Sigma u_f}{n} = $ .063

Effective Roadbed Soil Resilient Modulus, $M_R$ (psi) = 9,900 (corresponds to $\bar{u}_f$)

**FIGURE 1 Example determination of the effective roadbed resilient modulus.**

For Arkansas, a moisture content of 120 percent of optimum has been identified as a reasonable estimate of in-service moisture content; and a 50 percent reduction in resilient modulus for one month in the spring is considered appropriate for the northern band of counties that experience some subgrade frost penetration (*3*).

### *Prediction Models*

The prediction models used for design include traffic projection and the pavement performance equation. The inability to accurately predict future traffic is well recognized. Less well recognized is the inherent inaccuracy in the pavement performance equation.

The pavement performance equation is based on the AASHO Road Test (*4*). The basic equation, developed to predict the traffic life of the Road Test pavements, has a standard error of estimate of 0.31 on the logarithm of axle applications (log *W*). By the modified equation used in the AASHTO Guide, the 0.31 error in log *W* is equivalent to an error of about 30 percent in the subgrade resilient modulus. No amount of sophisticated testing can reduce the error or improve the inherent prediction accuracy.

The significance of accurate testing can be examined with regard to its effect on the overall standard deviation

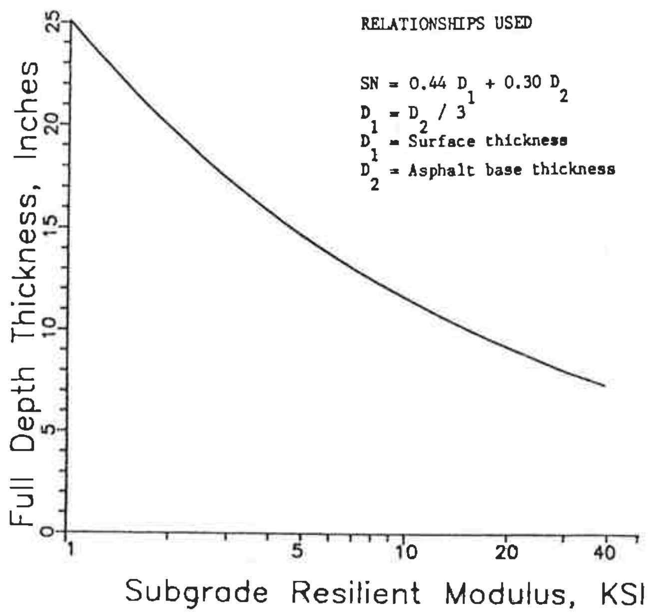



**FIGURE 2 Effect of resilient modulus on design thickness.**

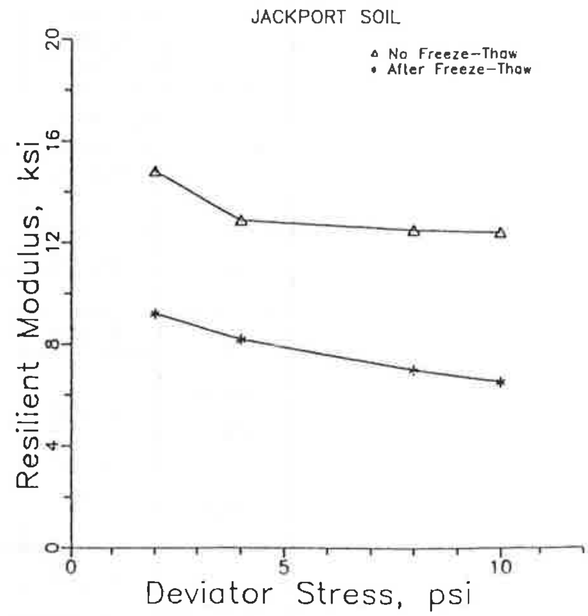



**FIGURE 4 Effect of freeze-thaw on resilient modulus.**

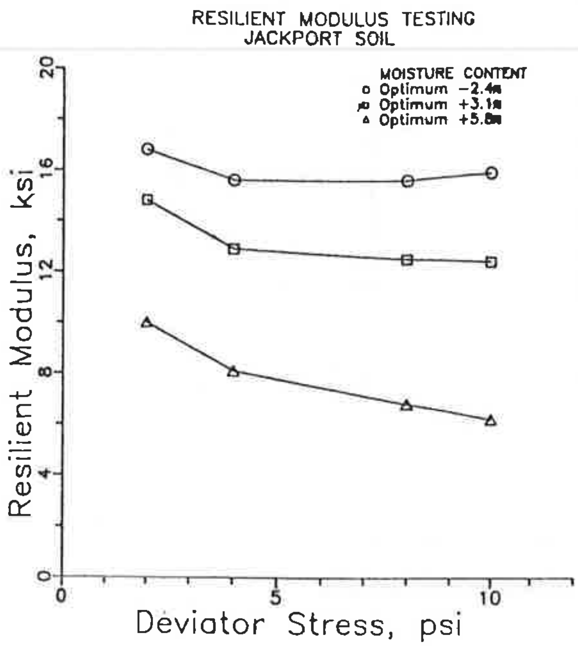



**FIGURE 3 Effect of moisture content on resilient modulus.**

of predicted pavement life ($S_o$). $S_o$, which is used with the design reliability concept of the AASHTO Guide, possesses two major components: (1) pavement performance prediction error, and (2) traffic usage prediction error. Any error in subgrade testing is reflected in $S_o$ as an increase in the pavement performance prediction error.

The effect of testing error on $S_R$ was examined for two levels of traffic prediction accuracy using the AASHTO Guide design performance equation. With no traffic prediction error and no testing error, $S_o$ is 0.31 (the standard error from the AASHO Road Test). With a traffic prediction error of 75 percent (standard deviation of log $W$ = 0.24) and no testing error, $S_o$ becomes 0.39. When testing error is added, $S_o$ increases as shown in Figure 5. However, the testing error is seen to have little effect as long as the error remains below about 15 percent. (The change in $S_o$ represents less than 0.25 inches in asphalt thickness.)

## Test Simplification

To identify ways that the standard test requirements might be simplified, three typical Arkansas soils (Table 1) were tested extensively in accordance with AASHTO T274. The test data were analyzed to determine the relative effect of the various test requirements, including (1) the three confining pressures, (2) the five deviator stresses, (3) the 200 stress cycles, and (4) the compaction methods.

### *Confining Pressure*

As a matter of routine there appears to be no reason for testing at more than one confining pressure. Ideally, that pressure would represent the confining pressure expected in the completed subgrade. Analysis using the ILLI-PAVE finite element model (*5*) indicates that the subgrade confining pressure is typically 2 to 3 psi.

Increasing confining pressure was found to increase the resilient modulus of the three Arkansas soils. Typical trends are shown in Figure 6. The increase from 0 to 3 psi was found to be greater than the increase from 3 to 6 psi. With increasing moisture content, however, the effect of confining pressure was found to decrease. At 120 percent of optimum, which approximates the normally expected in-service moisture content, the difference between 0 and 3 psi ranged from none to about 15 percent.

Testing can normally be conducted at a single confining pressure. Because the effect of confining pressure is low at the expected in-service moisture content, unconfined testing (0 psi) might be considered. The unconfined test would be both somewhat conservative and easier to perform. However, testing at 3 psi is more consistent with the confining pressure expected in the field and more in keeping with the design reliability concept used in the AASHTO Guide. The reliability approach requires that average material property values be used in design. Any conservatism is to be incorporated into the reliability of the traffic life prediction (i.e., the probability of not failing early). The 3 psi confining pressure also provides the lateral support sometimes needed when testing low PI soils.

### *Deviator Stress*

Five levels of deviator stress are used in AASHTO T274 to determine the stress-dependent nature of the soil. While stress dependency is a significant material property, it is not included in the current design methodology. Consequently, testing at five levels of deviator stress does not provide data useful for routine purposes.

In an extensive study of Illinois soils, Thompson and Robnett (*6*) found that the resilient modulus stress dependency could be adequately characterized as two intersecting straight line relationships. The slopes of these relationships did not vary significantly, and the deviator stress at the point of intersection was always around 6 psi. Therefore, the resilient behavior (at least of Illinois soils) can be reasonably determined by testing at a deviator stress of about 6 psi.

Another approach would be to test at the deviator stress expected in the subgrade. Deviator stress will vary with vehicle loading, pavement design, and the resilient modulus itself. The expected range of deviator stress for different pavement designs (structural numbers) under the standard 18 kip single-axle load is given in Figure 7. The deviator stress is generally in the range of 2 to 8 psi.

For routine testing, Figure 7 can be used to select a testing deviator stress based on a preliminary estimate of the design structural number and the expected resilient modulus. If the test produces a resilient modulus much different from that expected, the test might be continued at a second deviator stress consistent with the first test result.

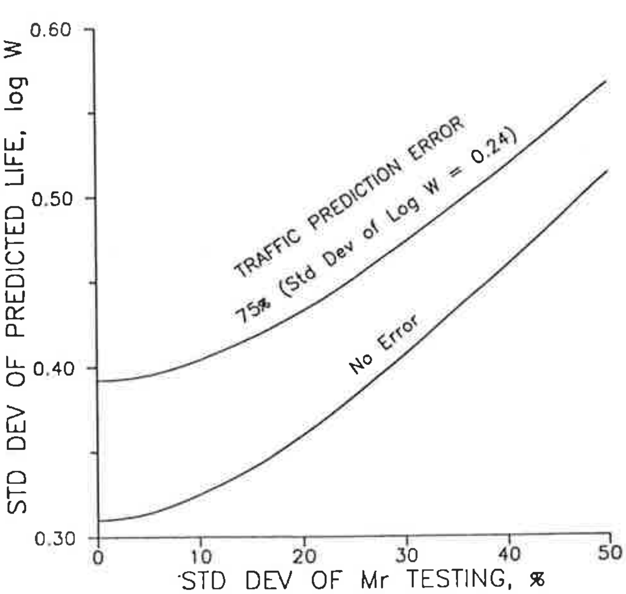



**FIGURE 5 Effect of testing accuracy on the standard deviation of predicted pavement life.**

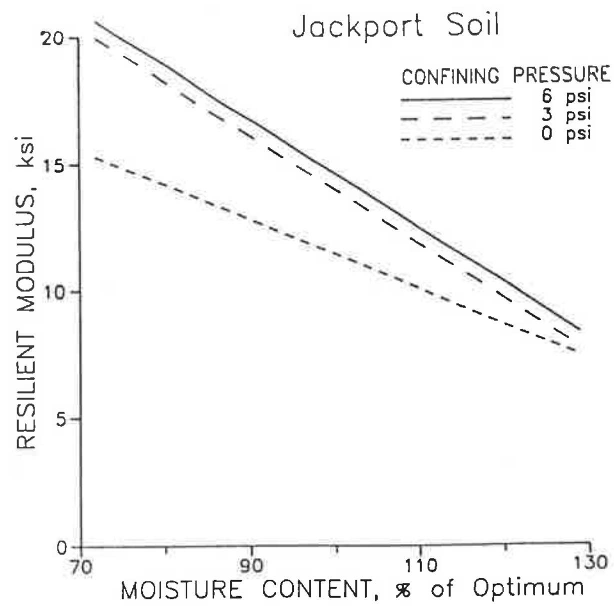



**FIGURE 6 Typical influence of confining pressure on $M_R$.**

TABLE 2 COMPACTION METHOD REQUIREMENTS BY AASHTO T274

| Degree of Saturation (%) | | |
|---|---|---|
| As Compacted | In-Service | Compaction Method[a] |
| < 80 | < 80 | Gyratory, kneading, or static |
| < 80 | > 80 | Static |
| > 80 | > 80 | Kneading |

[a] At in-service moisture content.

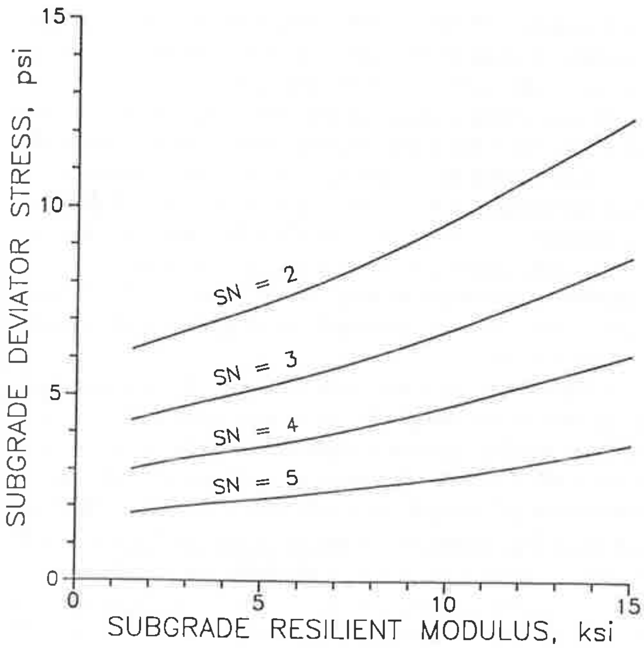



**FIGURE 7 Subgrade deviator stress versus $M_R$ for various design structural numbers.**

Alternatively, all testing might be conducted at a single, standard deviator stress. Testing at 8 psi would be at the high end of the range of expected deviator stress. Since the resilient modulus decreases with increasing deviator stress, an 8 psi test would produce a resilient modulus that would be slightly conservative for most pavements.

*Number of Stress Cycles*

To determine the number of stress cycles needed before reading the resilient deformation, deformation readings were taken at 50, 100, and 200 cycles. The 50- and 100-cycle readings were subsequently compared to the 200-cycle readings to determine whether there were any significant differences.

The number of variations between the 50- or 100-cycle and the 200-cycle reading increased as the deviator stress increased. The 50-cycle reading varied from the 200-cycle reading 17 of 324 times (5 percent of the time) at 8 psi and 53 of 324 times (16 percent of the time) at 10 psi. However, the maximum variation amounted to less than 6 percent of the 200-cycle deformation. Therefore, for routine testing the number of stress cycles can be reduced from 200 to 50 with no significant effect on the test results.

*Compaction Methods*

Field data were obtained from several Arkansas projects to determine the magnitude and variability of density and moisture content during construction. The data were used to estimate the variability in degree of saturation following compaction. Seventy-five to 80 percent of the soils were compacted at moisture contents that resulted in greater than 80 percent saturation after compaction. According to AASHTO T274 (Table 2), kneading compaction should be used for specimen preparation.

To determine the significance of type of compaction, specimens were prepared using both kneading and static methods. Of the three soils tested initially, two (Gallion and Jackport) were found to be significantly affected by the compaction method (Figures 8 and 9). To further investigate the significance of the method of compaction, two additional soils (Leadvale and Clarksville, [Table 1]) were prepared using both compaction methods and tested. Neither of these was significantly affected by the type of

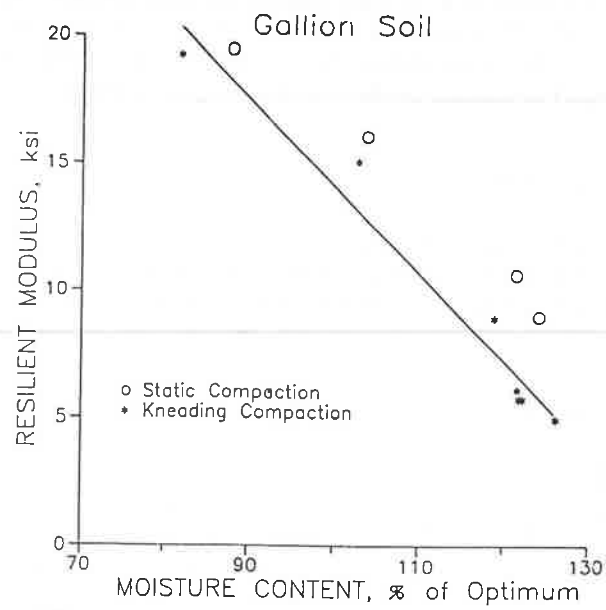



**FIGURE 8 Effect of compaction method on $M_R$ of Gallion soil.**

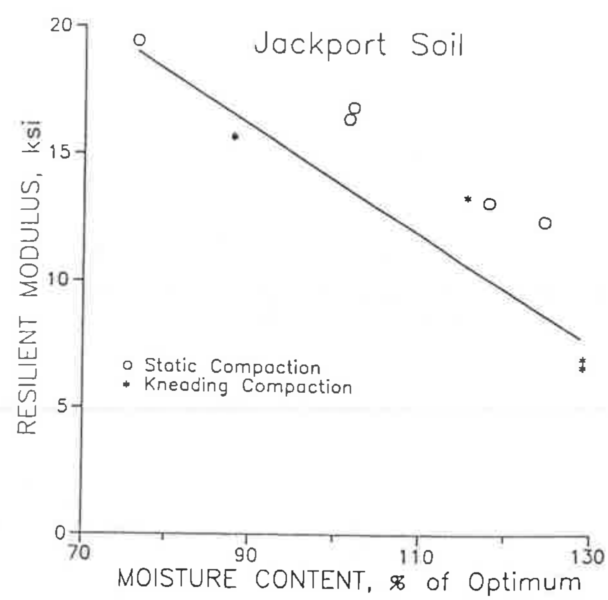



**FIGURE 9 Effect of compaction method on $M_R$ of Jackport soil.**

compaction. The results for Clarksville soil is shown in Figure 10. Additional soils are being tested to examine the significance of the method of compaction.

## CONCLUSIONS

The sophistication required by AASHTO T274 is not necessary for routine soil testing. Testing sophistication should be a function of the required test accuracy and the consequences of inaccurate test results. The prediction error associated with the AASHTO Guide is equivalent to a resilient modulus testing error of about 30 percent. Moreover, there is similar (but currently unsubstantiated) uncertainty associated with the estimation of moisture conditions, freeze-thaw cycling, and future traffic.

A testing error of less than about 15 percent is not significant based on analysis of the overall standard deviation of pavement life prediction ($S_o$).

Of five soils tested, only two were significantly affected by the method of compaction.

## RECOMMENDATIONS

For routine design, the resilient modulus testing of cohesive soils can be simplified by the following measures:

(1) Test at a single confining pressure. A 3 psi confining pressure is realistic and compatible with the AASHTO reliability concept. However, unconfined testing (0 psi) might be considered since it is easier and requires less equipment. The unconfined test would produce conservative results.

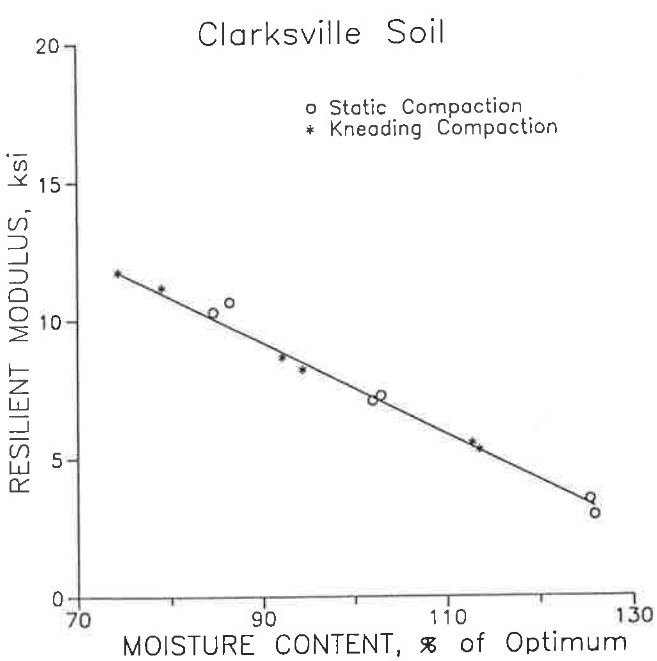



**FIGURE 10 Effect of compaction method on $M_R$ of Clarksville soil.**

(2) Test at a single deviator stress. A deviator stress of 8 psi can be used for all tests, providing a slightly conservative $M_R$ value for most situations. Alternatively, the stress level can be selected from Figure 7, based on expected modulus and design; in this case, a second deviator stress might be necessary if the modulus differs significantly from that expected.

(3) Reduce the deviator stress cycles from 200 to 50.

By adopting these measures, the time required for resilient modulus testing (assuming a 2-second interval between stress applications) will be reduced from 100 minutes to less than 2 minutes.

Although no examination was made of the effect of conditioning, more time might be saved by making similar modifications in conditioning. In particular, conditioning at the three levels of confining pressure and five levels of deviator stress appears to be unwarranted. Two hundred cycles of the testing stress should suffice for both conditioning and testing.

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