Multiaxial Testing of Subgrade

B. E. Wilson, S. M. Sargand, G. A. Hazen, and Roger Green

A unique testing apparatus consisting of a low-pressure multiaxial device has been applied to resilient testing of subgrade soil. Tests were conducted by applying dynamic loading under constant confining pressure. Soils from seven Ohio sites were evaluated. Laboratory results indicate that resilient behavior of the subgrade was dependent on moisture content, stress level, soil type, and density. Critical sensitivity of the resilient modulus to the moisture content was demonstrated by experiments. The testing procedure and results are discussed.

The resilient modulus is used most often in the design and rehabilitation of pavements. This parameter is given by the ratio of repeated deviator stress to the recoverable strain. The advantages of using this modulus can be seen by comparing results with data collected from a nondestructive testing apparatus, such as Dynaflect and the Falling Weight devices, where back-calculation techniques determine material moduli under dynamic loading. Nondestructive test procedures indicate that resilient modulus is a function of moisture, stress level, soil type, and density. Attempts to model the response of in situ subgrade material have been largely unsuccessful. A number of investigators have determined the resilient modulus of subgrade materials by using conventional laboratory testing devices such as unconfined compression or triaxial testing procedures (*1–3*).

This paper reports the results of a dynamic testing procedure that utilizes the multiaxial testing apparatus to obtain the resilient modulus. The low-pressure cubical system can easily be modified for dynamic testing of complex stress paths.

TESTING DEVICE

In a multiaxial device, a cubical specimen is loaded on six orthogonal faces by six flexible pressurized membranes. Any of the principal stresses can be varied independently, allowing for the simulation of complex stress histories. The three applied stresses in the direction of opposite surfaces are considered to be principal stresses. This loading will ensure that a properly prepared specimen will float between unconstrained deformations (*4–6*). A constant stress state is maintained in the horizontal planes by applying air pressure to two axes to simulate a subgrade loading. The pressure is applied with oil for the remaining axis. Here, the dynamic loading is simulated in the vertical direction by applying an alternating pressure loading. Figure 1 presents the multiaxial testing apparatus. Pressure measurements are taken in the membrane reservoir to record sample loading accurately.

Deformations were monitored along the axis of loading with six linear variable differential transformers (LVDTs). There were three LVDTs located on each face so that they were directly in line with those on the opposite face. Measurements were averaged to get the displacement of each face. Rigid body motion of the specimen could also be accounted for with this arrangement.

Pressure changes and displacements were directly measured as voltage changes. Voltages from the pressure transducer and the six LVDTs were continuously monitored with a PC-based data acquisition system. Data were recorded and stored automatically to be used in subsequent data analysis.

SAMPLE PREPARATION

Specimens were obtained from seven sites in Ohio. The location and soil classification of each site are found in Table 1.

Subgrade materials were prepared and tested in accordance with AASHTO testing procedures. The soils were sieved over a ¾-in. sieve, and coarse materials were discarded. Water was added to obtain the desired moisture content, and the sample was double bagged in plastic and stored for a minimum of 24 hr to ensure uniform moisture distribution. The specimens were compacted in a 4-in. × 4-in. × 4-in. mold to meet Ohio Department of Transportation (ODOT) field density specifications. Specimen density of each site, however, was not consistent because the varying of the moisture content made compaction of the specimens to a specific density a trial-and-error procedure. The required density was specified for a

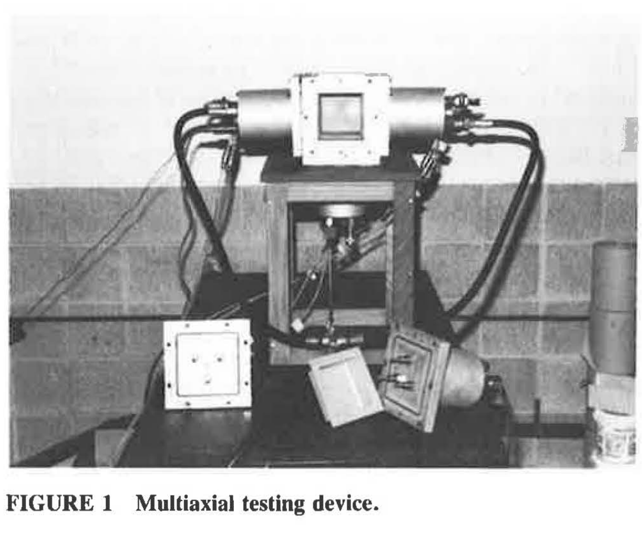

FIGURE 1 Multiaxial testing device.

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TABLE 1 SITE LOCATION AND SOIL DESCRIPTION

County	Route #	Station	Description	Ohio Dept. of Transportation Classification
Jackson	32	8.68	Clay Subgrade	A-7-6
Jackson	32	20.41	Silt Clay Subgrade	A-6a
Vinton	32	1.61	Silt Clay Subgrade	A-6a
Auglaize	33	-	Clay subgrade	A-7-6
Fairfield	37	11.24	Silt Clay Subgrade	A-6a
Clark	68	-	Granular Subgrade	A-1a
Clark	675	-	Granular Subgrade	A-16

-Data Unavailable

particular soil as a percentage of the maximum dry weight that corresponded to the following specifications of ODOT.

Maximum Laboratory Dry Weight (pcf)	*Minimum Compaction Requirement (% laboratory maximum)*
90.0–104.9	102
105.0–119.9	100
120.0 and more	98

TEST PROCEDURE

Tests were performed at 5 psi confining pressure to reasonably simulate field conditions. The confining pressure was applied with air along two axes and controlled by a precision gauge and regulator. Pressure was applied with hydraulic oil to the third coordinate axis. An incompressible fluid was required because this pressure variation was used to apply dynamic loads. Pressure variation was accomplished with a simple cylinder/piston device filled with hydraulic oil and installed between loading platens of an MTS series 810 test machine. Cyclic pressure applied by the piston device was transmitted through hydraulic hoses to horizontal faces of the specimen. Loads applied were monitored with a pressure transducer.

For this application, a stress pulse with rise time of 60 to 70 msec was applied at the rate of 1 pulse/sec. Initially, a conditioning cycle consisting of 200 repetitions of five increasing increments of deviator stress was applied to minimize initial loading effects. This cycle was then repeated and the recoverable deformation recorded at or about the 200th repetition for each deviator stress level.

DISCUSSION OF RESULTS

The subgrade materials tested in this study exhibit the sensitivity of resilient modulus to percent variation of moisture content. The degree of dependence varied with soil type. As shown in Figures 2 and 3, the resilient modulus for sample JAC-32-8.68 was drastically reduced by an increase of moisture content as low as 2 percent above optimum. A similar

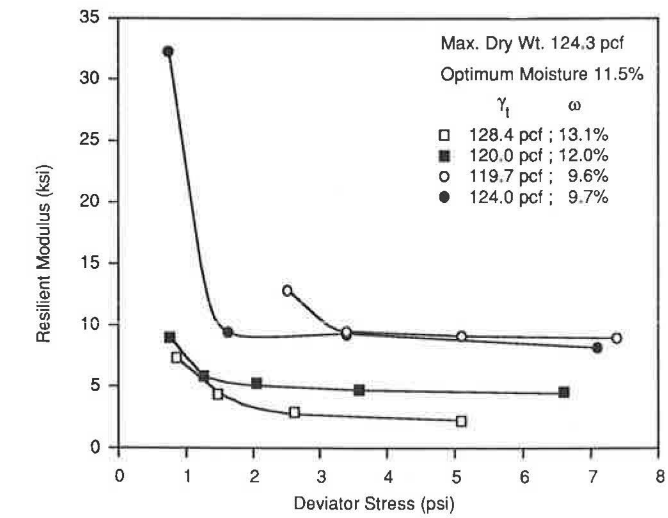

FIGURE 2 Resilient response curves for JAC-32-8.68 subgrade.

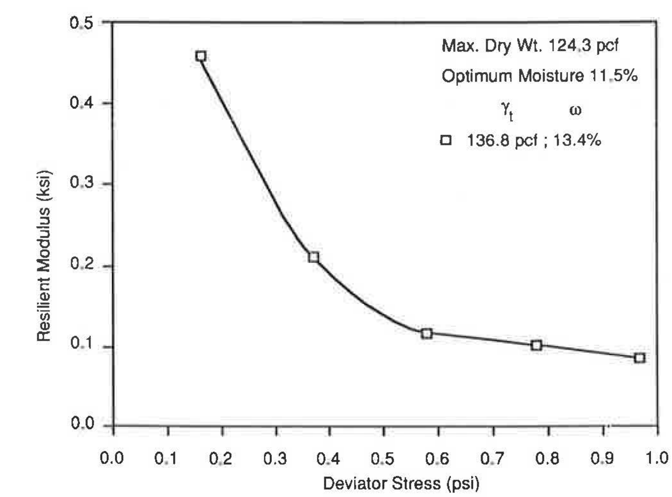

FIGURE 3 Resilient response curves for JAC-32-8.68 subgrade, γ_t, 136.8; ω, 13.4 percent.

reduction is seen in Figures 4 and 5 for the VIN-32-1.61 sample at an increase of moisture level 3 percent above optimum. The third sample from Route 32, JAC-32-20.41, does not show the sharp decrease. At 2 percent above optimum, and where the curve levels (Figure 6), a resilient modulus of approximately 5 ksi is observed. This suggests that a threshold moisture content exists that is dependent on soil type. Beyond this threshold, soil strength rapidly deteriorates. If this is true, then the threshold value was not crossed in the latter case.

The CLA-68 sample shows the least modulus variation with respect to moisture. In Figure 7 optimum moisture for CLA-68 is found to be 6.0 percent, where results are shown at moisture levels of 5.0, 5.9, and 6.3 percent. The narrow moisture range results from the sandy, granular nature of this particular soil. Increasing the moisture content further would result in drainage from the specimen during the test procedure. All tests performed on the CLA-68 soil gave slight increases in resilient modulus at higher deviator stresses.

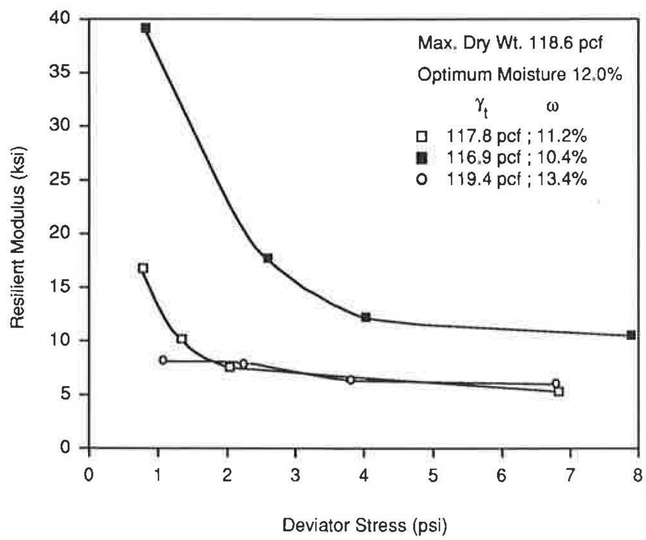

FIGURE 4 Resilient response curves for VIN-32-1.61 subgrade.

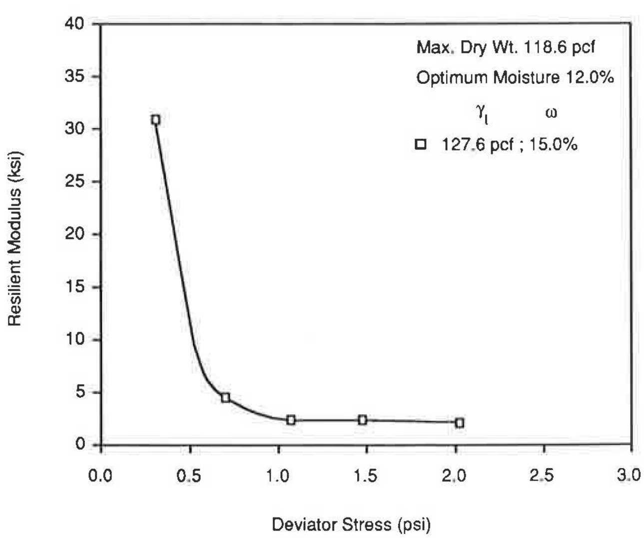

FIGURE 5 Resilient response curves for VIN-32-1.61 subgrade, γ_t, 127.6; ω, 15.0 percent.

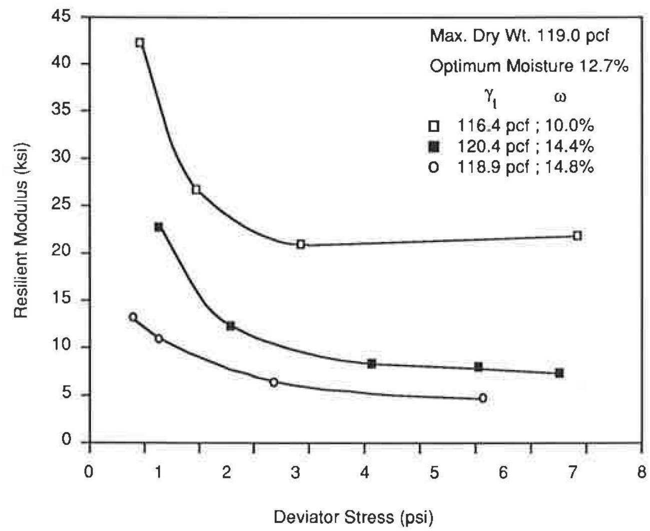

FIGURE 6 Resilient response curves for JAC-32-20.41 subgrade.

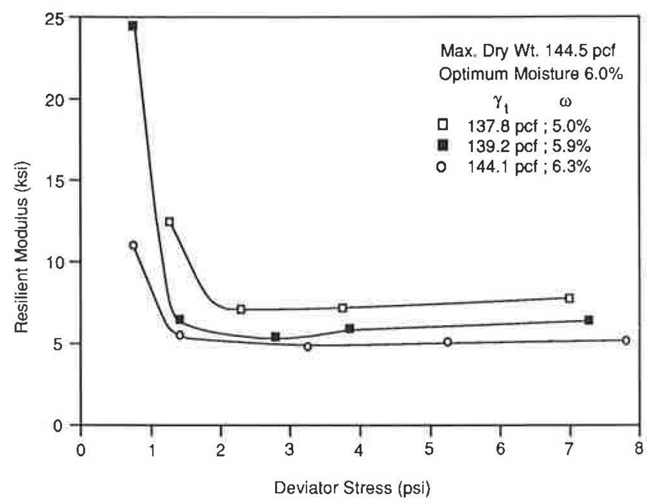

FIGURE 7 Resilient response curves for CLA-68 subgrade.

Experimental results from the remaining three sites (AUG-33, FAI-37-11.24, and CLA-675) (Figures 8–12) follow the established trend. Although the moisture content for the CLA-675 site ranged as high as 2.6 percent above optimum, it, as for the JAC-32-20.41 specimen, does not exhibit the dramatic reduction in resilient modulus common to the other samples.

All figures show higher moduli at low stress levels, followed by sharp decreases before becoming essentially constant. Also, it is important to note that although the specimen density varied in addition to the moisture content, a small variation of moisture content greatly affected the resilient moduli.

CONCLUSIONS

The multiaxial apparatus functions well when subgrade materials are tested in a dynamic environment. With this unique

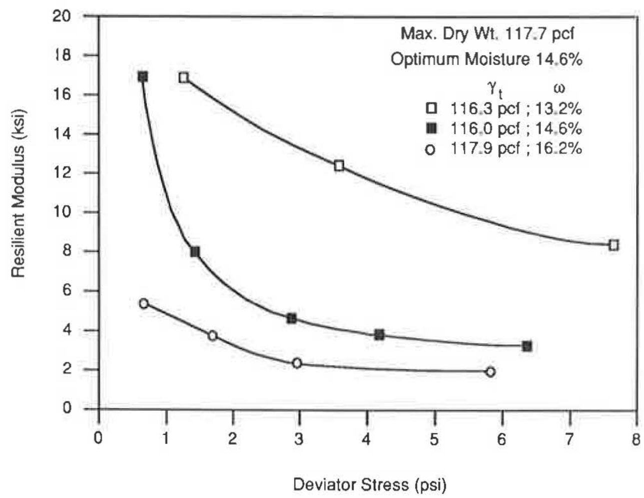

FIGURE 8 Resilient response curves for AUG-33 subgrade.

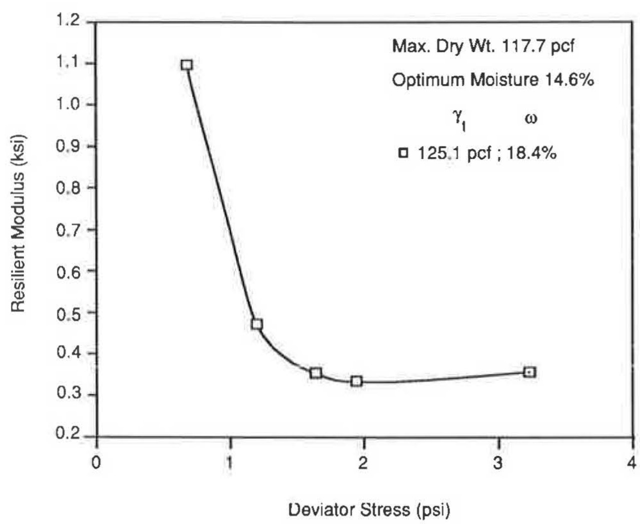

FIGURE 9 Resilient response curves for AUG-33 subgrade, γ_t, 125.1; ω, 18.4 percent.

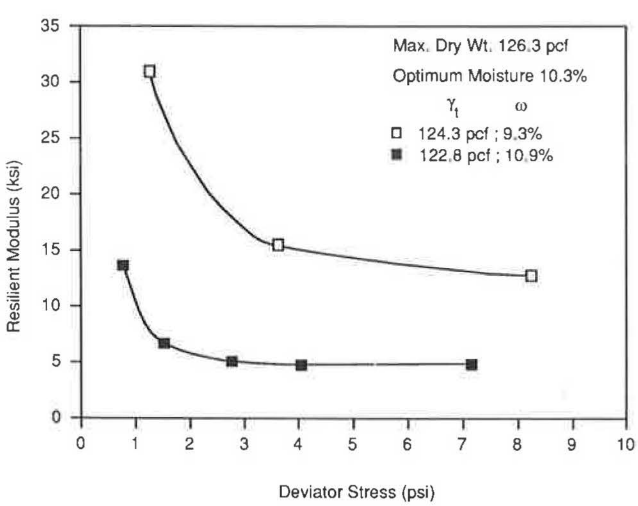

FIGURE 10 Resilient response curves for FAI-37-11.24 subgrade, part 1.

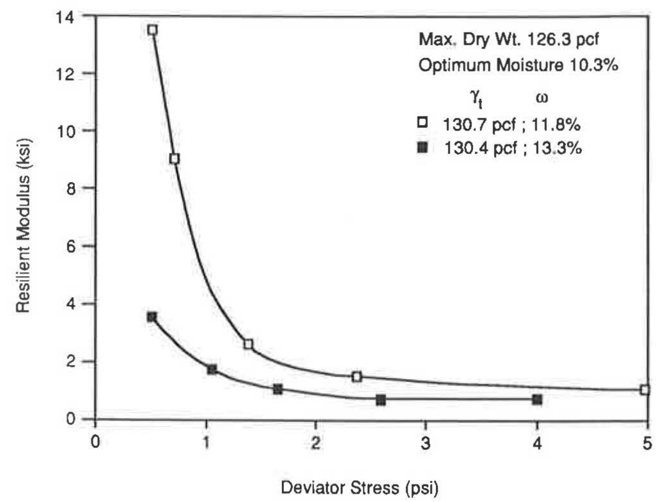

FIGURE 11 Resilient response curves for FAI-37-11.24 subgrade, part 2.

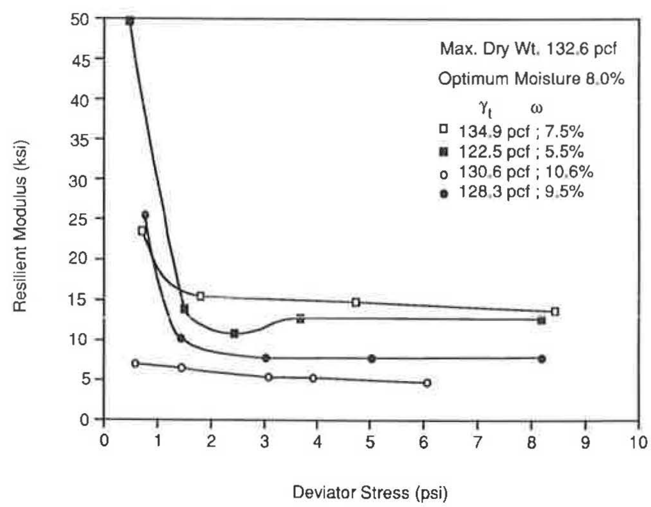

FIGURE 12 Resilient response curves for CLA-675 subgrade.

testing procedure, the following general conclusions can be drawn regarding subgrade response:

1. Resilient moduli are a function of moisture content, density, and deviator stress to varying extents depending on soil type.
2. For a particular soil at a given stress level, resilient modulus is very sensitive to the changes of moisture content.
3. The resilient modulus rapidly decreases with increasing deviator stress at low levels of stress (0 to 2 psi) and generally levels off or slightly increases at higher levels of deviator stress (2 to 8 psi). This indicates that the resilient modulus of the subgrade increases with depth beneath the pavement and cannot be adequately modeled with a single value.

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