It's Still Dirt, Rocks, and Asphalt — Right?

By Dave Newcomb, David Timm, and Joe Mahoney

Yes, they are the same materials we've always used in Hot Mix Asphalt (HMA) pavement construction. But the way we need to think about them when designing pavements using a mechanistic method is different from what we've done in the past.

This is the third *HMAT* article dealing with the shift of pavement structural design from empirical practices to more mechanistic approaches. The first article presented an overview of the mechanistic design process, and the second discussed the models used to simulate pavement behavior under traffic loads. The latter article introduced the idea that material properties we will be using in the models need to be in the form of an elastic modulus (E) and Poisson's ratio (μ). In this article, the focus will be on how to estimate these properties and how to measure them for different materials used in a pavement.

But, first, what are E and μ? The elastic modulus of a material is measured by applying a load to it and measuring the strain (change in length) that results (Figure 1). It equals the stress (σ) (internally distributed load) divided by the strain (ε):

$$E = \frac{\sigma}{\varepsilon}$$

The elastic modulus is a measure of a material's stiffness; the larger ε is, the lower E is, and the softer the material is for a particular stress. This is only true when a material is within its elastic range, before any kind of permanent deformation has taken place.

Poisson's ratio is the ratio of the strain of the material along the axis of the load (longitudinal) to the strain in the transverse direction. It is a measure of the deformability of the material, and can range from 0 to 0.5. A lower value of μ is associated with more rigid materials. Poisson's ratio for a pavement material is not easily measured, so it is usually assumed as will be discussed shortly.

I Feel the Need – The Need for E!

With apologies to Tom Cruise, the selection of the right value of elastic modulus in a given condition is as important to a pavement designer as the selection of either guns or a Sidewinder missile is to a fighter pilot engaged in a dog fight. Okay, so it's not life and death, but it is darned important.

The elastic modulus of a pavement material is not constant throughout a pavement's life. For wetter times of the year, a soil or base material may soften significantly when compared to dryer times. If a wet soil becomes frozen, its modulus will increase many times over its modulus in a thawed condition. HMA modulus will fluctuate according to temperature - in winter, it will be greater than in the summer. Also HMA may age and harden with time, so that E gradually increases with time while seasonal fluctuations are going on.

The designer needs to select modulus values that are representative of the pavement's condition as time passes. Relatively short periods of the year when materials are soft, such as spring thaw, are important because of the large amount of damage that can be accrued during these times. These periods can be as short as two weeks. This topic will be discussed in greater detail when the subject of cumulative damage is presented.

Table 1 shows typical values and ranges of modulus values for materials used in flexible pavement. HMA modulus values can vary considerably over a range of

Table 1. Typical Modulus of Elasticity Values for HMA Pavement Materials

Material	Elastic Modulus	
	MPa	psi
HMA (32 °F (0 °C))	14,000	2,000,000
HMA (70 °F (21 °C))	3,500	500,000
HMA (120 °F (49 °C))	150	20,000
Crushed Stone	150-300	20,000-40,000
Silty Soils	35-150	5,000-20,000
Clayey Soils	35-100	5,000-15,000

temperatures, with more than a thousand times difference between 120°F and 32°F. High quality granular materials may have modulus values in the range of 40,000 to 50,000 psi. Soils such as silts and clays may be as soft as 5,000 psi. Table 1 is presented only as a reference and not as a guide for values to be used in design. Testing is needed to establish the right modulus values in a given situation.

Values normally assumed for Poisson's ratio for various pavement materials are given in Table 2. As stated earlier, this is a difficult parameter to measure, and making reasonable assumptions concerning the value of Poisson's ratio is usually close enough. Although HMA is usually thought to have a Poisson's ratio of about 0.35, it can vary from about 0.25 for cold temperatures to 0.45 for hot temperatures. Granular materials are normally assigned a value of 0.40, and fine-grained soils are assumed to have a value of 0.45, although they may vary according to moisture content.

Table 2. Normally Assumed Values of Poisson's Ratio

Material	Poisson's Ratio
Asphalt Concrete	0.35 (±)
Crushed Stone	0.40 (±)
Soils (fine-grained)	0.45 (±)

Laboratory Modulus Testing for Base and Subgrade Materials

Direct testing for modulus in the laboratory is relatively complicated and time consuming, both in terms of sample preparation and test execution. This is not a routine procedure for the vast majority of agencies, and to this point, it has largely been done for research or data collection purposes. The procedure most often used is AASHTO T 292: Resilient Modulus of Subgrade Soils and Untreated Base/Subbase Materials.

The test specimen is cylindrical (Figure 2), having a length at least two times greater than its diameter. It may be either a laboratory-molded sample or a core sample taken from the field. The moisture content of the soil or granular material has a big impact on the test results, as does the degree of compaction. Usually, the same procedures are followed here as for typical moisture and density relationships. In some instances, it may be desirable to try to match expected field conditions.

Once the sample is prepared, it is placed in a test chamber with loading platens at either end. This is a triaxial test, meaning that a confining stress is applied all the way around the sample in addition to the pulsating applied load on the ends of the sample. The confining stress helps to duplicate the condition in the road where the specimen would be surrounded by other materials. The load applied to the ends of the sample is pulsed to simulate a traffic load. By varying the amount of confining stress and applied stress, different values of modulus are obtained. This is because soils and base materials are stress sensitive, or, as this behavior is often called, non-linear.

Granular materials usually demonstrate an increase in modulus with an increase in bulk stress, as shown in Figure 3. This means that as load is applied to the material, it reacts by becoming stiffer. Conversely, fine-grained soils such as clay and silt usually show a softening with increasing stress as shown in Figure 4. It is important to use the modulus which corresponds to the stress expected in the pavement. In other words, materials closer to the surface should have modulus values corresponding to higher stresses than those lower in the pavement.

Given that the direct testing of elastic modulus is fairly rare, it should be noted that correlations exist between more common soil strength measurements and expected modulus. These correlations are rough, at best, and should be used with some caution. For fine-grained soils with a CBR

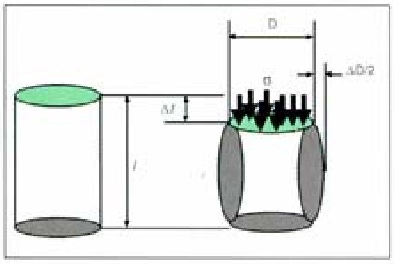

Figure 1. Definitions of E and μ.

Figure 2.
Photograph of Triaxial Soil Sample.

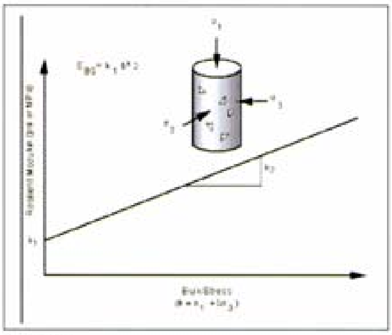

Figure 3.
Stress Sensitivity of Granular Material.

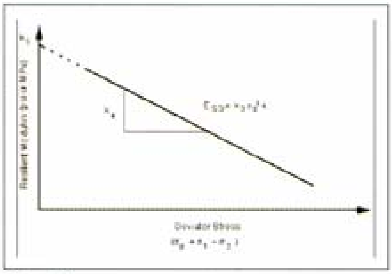

Figure 4.
Stress Sensitivity of Fine-Grained Soils.

less than 10, the following relationship may be used:

$$E=1500xCBR$$

For the R-value test, the following may be used:

$$R=1000+555R$$

These are presented in a graphical form in the 1993 *AASHTO Guide for Design of Pavement Structures*. In the event that CBR or R-value results are not available, other correlations exist which allow one to estimate modulus from various scales of soil classification. It would be best to work from a locally developed catalog of modulus values, rather than rely on such general relationships.

Laboratory Testing for HMA Modulus

There are a number of ways of pounding, tapping, and twisting HMA samples to obtain values of modulus. The problem is that as you change your method of beating the truth out of it, it changes its version of the truth. Discussed here will be the diametral resilient modulus test, the dynamic modulus test, and the simple shear test, since these represent the more common and recent means of testing. They all rely upon repeated loading in the range of small strains so that the recoverable (elastic) properties can be measured. In any of these tests, it application (frequency) to understand what effect the speed of traffic may have on the materials · behavior. The faster the loading is, the stiffer the material will respond. They may each be done over a range of temperatures to characterize the effect of roadway service temperature on the mix behavior.

The diametral resilient modulus test was developed for HMA in the 1970s by Roger Schmidt. In this test, a cylindrical sample of HMA is placed on its side and loaded vertically across its diameter creating a tensile condition in the horizontal direction (Figure 5). The load is applied and the amount of deformation is measured in the horizontal direction. The resilient modulus is calculated as a function of the tensile stress in the sample and the recoverable strain. The complete procedure can be found in AASHTO TP 31: Determining the Resilient Modulus of Bituminous Mixtures by Indirect Tension. Although this test was developed about 30 years ago, and despite the fact that it has undergone numerous changes, it is still somewhat plagued with problems in repeatability, especially between laboratories. However, it is accurate enough to be used to establish general values of modulus for use in design. It has the advantages of being a relatively quick test that can be run on a sample representing a realistic lift thickness.

The dynamic modulus test has also been around for some time, and resembles the loading condition mentioned above for the triaxial test in soils. In this approach, a cylindrical specimen is loaded in compression over its circular face, and the recoverable deformation is measured along the vertical axis. The main difference here is that a confining stress is not applied to the specimen. The procedure is documented in ASTM D 3497: Dynamic Modulus of Asphalt Mixtures. The test result is [illegible] simple performance test being developed under a National Cooperative Highway Research Program project, the 4-inch test specimen will be cored out of a 6-inch gyratory compactor and the ends would be sawed off before testing. The repeatability and utility of this test will be evaluated in the coming years. It is anticipated that this procedure will be one of the fundamental tests proposed for use in the upcoming *2002 Pavement Design Guide*.

The simple shear test was developed under the Strategic Highway Research Program in the early 1990s, and provides yet another way to measure the elastic modulus of HMA. In this case, a sample similar to the one used in the diametral test is placed on its flat side in the loading apparatus. The sample is gripped on its flat surfaces by gluing loading platens on them. The bottom platen

Figure 5. Diametral Resilient Modulus Device.

Figure 6. Falling Weight Deflectometer.

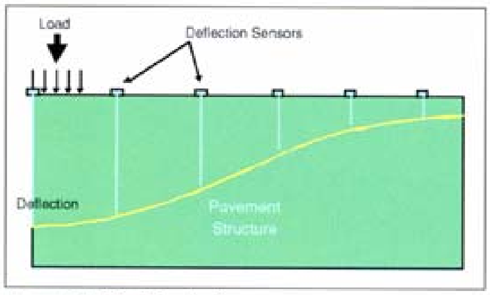

Figure 7. Deflection Basin.

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remains stationary while a horizontal load is applied to the top platen, providing a shear effect. The shear stress is divided by the recoverable shear strain to obtain a shear modulus. Through equations that relate shear modulus to elastic modulus, a value for E may be obtained. This test method may be found in AASHTO TP7: Test Method for Determining the Permanent Deformation and Fatigue Cracking Characteristics of Hot Mix Asphalt (HMA) Using the Simple Shear Test (SST) Device.

One note of caution when evaluating laboratory data, HMA laboratory modulus test results may not relate well to expected field performance for certain mixture types. For instance, open-graded friction course (OGFC) and Stone Matrix Asphalt (SMA) mixtures will typically produce low laboratory modulus values. This can result in the erroneous conclusion that rutting will take place when these mixtures are used in the field. In fact, these mixtures have proven to provide excellent performance with respect to rutting.

Field Testing for Modulus Values

While laboratory tests are readily performed on laboratory-prepared samples in a controlled environment and have some measurable repeatability, they lack the "reality" aspect of pavement behavior. It is of genuine value to verify laboratory results with deflection measurements, and the use of backcalculation to estimate the modulus of materials in actual roadways. Why? Because laboratory-prepared samples may not have the same internal structure of field-placed materials, and in the laboratory, they are tested independently of their interactions with other material layers in the field. Plus, field testing generally allows for a greater number of tests, and the opportunity to discern features of roadway composition and geology that cannot be found in the laboratory.

Although there are a number of methods that can be employed in deflection testing, the most widely used is the falling weight deflectometer (FWD) as shown in Figure 6. The FWD has a circular plate that rests on the pavement surface, and is loaded by means of weights being dropped on a rubber buffer on top of the plate. Deflections are measured at the center of the plate and at various distances out from the plate. This procedure is covered in ASTM D 4694: Standard Test Method for Deflections with a Falling Weight Type Impulse Load Device. These deflections are used to define the deflection basin as shown in Figure 7, and knowing the load and the deflections, the modulus values of the underlying materials may be estimated. This is done by a process known as backcalculation, in which the thicknesses of the various layers are used along with the deflection basin and the load to iteratively determine a set of modulus values for the different pavement layers which would result in the measured deflection basin. In general, the deflections furthest from the load relate well to the subgrade, while those toward the center tend to reflect the response of the whole pavement structure.

Generally speaking, FWD testing should be done on a variety of pavements over the range of expected environmental conditions. Capturing the deflections in different times of the year will indicate how the modulus of the asphalt layers change with temperature, and how soils and base materials change with moisture content. This information is important when it comes to assessing the damage to a pavement over its life as will be discussed in a future article on transfer functions and cumulative damage.

While deflection testing is very useful and reflects the actual conditions in the field, it is subject to its own limitations. For instance, unknown subsurface conditions such as underground sewers, rock ledges, or rapid changes in the thickness of one or more layers can wreak havoc on the process of backcalculation. A judicious review of results should reveal areas that need greater levels of investigation, and comparison with laboratory results should also reveal discrepancies. So, while pavement deflection measurements are the most desirable for obtaining realistic modulus values, especially for rehabilitation projects, you cannot vote laboratory measurements "off the island."

What's It All Mean?

In the past, we have dealt with materials in pavement design largely in terms of "equivalencies" or "structural coefficients." While the application of these values gave designers a warm feeling, they often did not reflect the realities of the pavement in terms of how the material properties related to the response of the structure to traffic loads. In mechanistic design, the objective will be to close this gap between materials characterization, structural behavior, and, eventually, performance.

Obviously, there is much to be done in order to fully implement materials characterization for mechanistic design. One important issue pertains to the variability of measurements and the variability of materials. In establishing the precision of laboratory and field measurements, how close is close enough? As shown in Table 1, asphalt modulus varies by orders of magnitude over a range of temperature, so small changes in the actual number may have a relatively small effect when viewed on a log scale. How much variation can be expected within a project? Uniform soil formations, such as dry lake beds, will show little variation in modulus compared to cut and fill sections in mountain passes. How should we account for these variations in design?

To implement the materials characterization procedures, agencies will have to make decisions concerning the purchase of equipment and the training of personnel. The purchase of the laboratory equipment discussed above is expensive. Will all the testing take place in a central laboratory, will it be done in district laboratories, or will consultants be hired to perform testing? In any case, significant financial resources will need to be allocated to implement the materials testing. Either that, or the decision will be made to rely upon correlations, which could lead to questionable design inputs.

Agencies will need to develop a catalog or data base of modulus values for materials in their area. As the information grows, it is possible that such tools as soils modulus atlases could be developed to help in the selection of design inputs. This idea has been tried with success in Minnesota. In any case, a data base of expected values will be invaluable to pavement designers.

In the soon-to-be-released *2002 Pavement Design Guide*, a hierarchical approach to selecting material properties will be used. Level 1 inputs will be comprised of actual test results on project materials, Level 2 will use correlations as discussed above, and Level 3 will relate index properties like soil classification to modulus values. It has been suggested that Level 1 will provide the highest level of reliability for design.

The Next Installment

The fourth article on mechanistic pavement design will be "Lies, Damned Lies, and Traffic Forecasts." Anticipating the traffic on roadway can be one of the most difficult aspects of pavement design. How traffic is characterized for mechanistic design is pretty much the same as before, you just stop short a couple of steps. HMAT