Effects of Unknown Rigid Subgrade Layers on Backcalculation of Pavement Moduli and Projections of Pavement Performance

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More and more highway agencies are obtaining and using highway pavement deflection measuring equipment to infer the elastic modulus of paving materials for design purposes. Layered elastic theory is used in the analysis to arrive at the moduli for individual pavement layers. It is possible under certain conditions to arrive at erroneous values of the elastic moduli, particularly when a rigid layer exists below the subgrade unbeknownst to the engineer. A theoretical study was performed, for flexible pavements, to determine the sensitivity of backcalculated moduli to the existence of this rigid layer. It was found that a rigid layer will adversely affect the accuracy of the backcalculated pavement moduli if the actual depth of the layer is equal to or less than half its assumed depth with respect to the surface of the pavement. These types of errors will result in unconservative pavement evaluations and designs for rehabilitation and reconstruction—leading to early pavement failure.

The practice of using elastic modulus to characterize paving materials for design and evaluation purposes is becoming more common. The 1986 *AASHTO Guide for Design of Pavement Structures* has incorporated this parameter for both new pavement design and evaluation of existing pavements for overlays (*1*). The Strategic Highway Research Program (SHRP) has acquired four falling weight deflectometers (FWD) and will use them nationwide to monitor the structural condition of thousands of pavement test sections (*2*). Undoubtedly, elastic modulus will be used as a primary indicator of structural condition. Many states currently have, or are developing, pavement design methods that use the elastic modulus of subgrade and pavement materials to determine required pavement thicknesses.

Elastic moduli values may be determined in the laboratory using samples of paving material obtained in the field. However, base and subgrade samples are usually disturbed upon acquisition and must be remolded for laboratory testing. Thus, their stiffness characteristics, as measured in the laboratory, may not be representative of those in the field. It has been generally accepted that elastic modulus of paving materials, particularly base and subgrade, should be determined under in-service conditions.

A popular approach to obtaining in situ elastic moduli values is to record the pavement's deflection under various magnitudes of loading on the surface. The FWD, Dynaflect, and Road Rater (among other devices) have been developed specifically for this purpose. Each of these machines is designed to impart a known load to the pavement surface and measure the resulting pavement deflection at various distances from the point of load application. The profile of the deflection at the surface of the pavement is known as the deflection basin, because it resembles a bowl-shaped depression. The magnitude of the deflections and the basin shape are functions of the number of pavement layers making up the pavement cross section, their thicknesses, and moduli values.

A variety of multi-layered linear elastic pavement models is available for use on mainframe and microcomputers to predict stresses, strains, and displacements for pavements under loaded conditions. These programs assume that any deformation occurring within the pavement system under load will completely disappear when the pavement is unloaded, thus the term *elastic*. The term *linear elastic* means that the stiffness of the layers is independent of the rate at which the load is applied and is constant throughout a range of load magnitudes. *Multi-layered* refers to the program's ability to model pavement systems composed of multiple layers (usually four to five), each having different stiffnesses. These programs further assume that the materials in any layer are homogeneous, both in physical and engineering properties, and that the layers extend to infinity in the lateral directions. Some examples of these programs are BISAR, ELSYM5, and CHEVRON. The programs calculate stresses, strains, and displacements at any point on the surface and within the pavement system given a loading magnitude and the elastic moduli, thickness, and Poisson's ratio of the pavement layers.

The programs have also been modified to run in a reverse-iterative fashion to determine elastic moduli from pavement surface deflections, given the layer thicknesses, Poisson's ratios, and loading conditions. The engineer inputs a range of moduli values for the pavement layers, and the program calculates a deflection basin. This calculated basin is compared with the deflection basin measured by the equipment. The moduli values resulting in the best fit between the calculated and measured deflection basin are assumed to be the correct in situ moduli values for that pavement. Examples of these modified programs are BISDEF, ELSDEF, and CHEVDEF. Because these programs can run on microcomputers, the programs have become quite popular and are enjoying widespread use.

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It is possible, however, under certain conditions, to generate erroneous answers with these programs. First, many combinations of moduli values will result in an acceptable basin fit, and the engineer must use judgment and experience to select the combination that is representative of the materials being used. For example, for flexible pavements, it is usually assumed that, for any given pavement layer, the one above is of higher stiffness while the one below is of lower stiffness. This is not always the case, especially where stabilized materials are placed under a granular base or where a pavement has begun to deteriorate severely. It is sometimes necessary to take cores of the pavement to determine the material types that are involved.

Another source of error occurs when the material stiffnesses are a function of the magnitude of the load or the rate of loading. The AASHTO guide provides guidelines to identify the stress dependency of the pavement structure. Visco-elastic properties may be identified with the Road Rater by changing the frequency of the load application.

A possible major source of error in the process of backcalculating moduli values is a result of the presence of stiff layers below the subgrade. The presence of these layers is either unknown to the engineer or assumed to be deep enough so as not to affect the results of the deflection test. If, in fact, these stiff layers are influencing the deflections and this fact is not taken into account, the subgrade modulus will be overestimated, leading to pavement and overlay designs of inadequate thickness and subsequent premature failure.

This paper deals with the *theoretical* errors introduced into the backcalculation process as a result of the presence of these stiff layers. The paper does not, however, deal with errors resulting from modeling the effects of a dynamic load with a static analysis technique, or errors resulting from inaccuracies in the deflection measuring equipment.

OBJECTIVE OF THE STUDY

The objective of this study was to document the theoretical effects of unknown rigid layers below the subgrade, at various depths and for a range of stiffnesses, on the backcalculation of pavement moduli and subsequent structural analysis procedures. Linear elastic multi-layer theory was used for the analysis. The effects studied include possible errors in (a) backcalculation of moduli values, (b) calculation of strains, and (c) projected remaining life of the pavement.

PROCEDURES

The first step was to construct a data base of theoretical pavement structures comprising a predetermined range of layer moduli, thicknesses, and rigid layer depths. These characteristics were entered into the BISAR program to determine pavement deflections directly under a 9,000-lb circular load and at six points at 12-in. centers on a line away from the load. The deflection basins generated are referred to as the measured deflections, as they simulate pavement deflections obtained by the FWD on the theoretical pavement sections. Also obtained were stresses and strains at various points in the pavement systems. These values are referred to as the actual stresses and strains.

A four-layer system was chosen for the analysis to represent a typical three-layer system with an additional rigid layer below. Layer 1 was intended to represent asphaltic concrete; Layer 2, granular base; and Layer 3, a typical subgrade.

Next, the BISDEF program was used to backcalculate layer moduli from the measured deflections. The pavement thicknesses assumed for the backcalculation procedure were identical to those in the BISAR run except the rigid layer was fixed at 240 in. below the surface of the pavement. The deflection basin representing the best fit for each pavement section is referred to as the calculated basin. The resulting moduli were again input to BISAR, and strains were calculated. The calculated moduli and strains were compared with the actual values. Also compared were the calculated and actual 18-kip equivalencies to failure projected from the stress-strain data. The entire process is outlined in Figure 1.

Development of the Actual Pavement Data Base

Seventy-one theoretical pavement cross sections and corresponding deflection basins were developed for the study, each with unique rigid-layer thicknesses and moduli. These represented the actual pavement structures and the simulated deflections expected when a 9,000-lb FWD load was placed on each. A 6-in. radius was assumed for the circular load. The deflections were calculated at the center of the load and at 1-ft intervals away for a distance of 6 ft. Seven deflections were obtained for each basin.

The upper illustration in Figure 2 summarizes the combinations of moduli and layer thicknesses used to generate the data base of measured deflections. Note that the moduli values used to develop the measured deflection basins were held constant, except for Layer 4. The thickness of Layer 3 varied from 42 to 222 in. All other thicknesses were held constant. The modulus of Layer 3 was fixed at 10,000 psi because, for the purposes of the experiment, it was intended to represent the subgrade. The modulus of the rigid layer was set at 10,000 psi for one run to represent a system without a rigid layer. BISAR was used to calculate the deflection basins on an IBM PC–compatible microcomputer.

In the process of generating the deflection basins, the strains at various points within the pavement sections were calculated. The horizontal tensile strain at the bottom of Layer 1 and the vertical compressive strain at the top of Layer 3 were recorded.

Backcalculation Process

The bottom illustration in Figure 2 represents the structural parameters assumed for the backcalculation process using BISDEF. These values remained constant throughout the basin-fitting process for all 71 deflection basins. The maximum and minimum moduli values were obtained through iterative runs of the BISDEF program, adjusting them to allow the best fit between the observed and backcalculated deflection basins for all conditions of rigid layer depth and stiffness. The modulus of the rigid layer was held constant at 240 in. below the surface, and its modulus was restricted to 1,000,000 psi at all times. A 9,000-lb load was assumed for the backcalculation process.

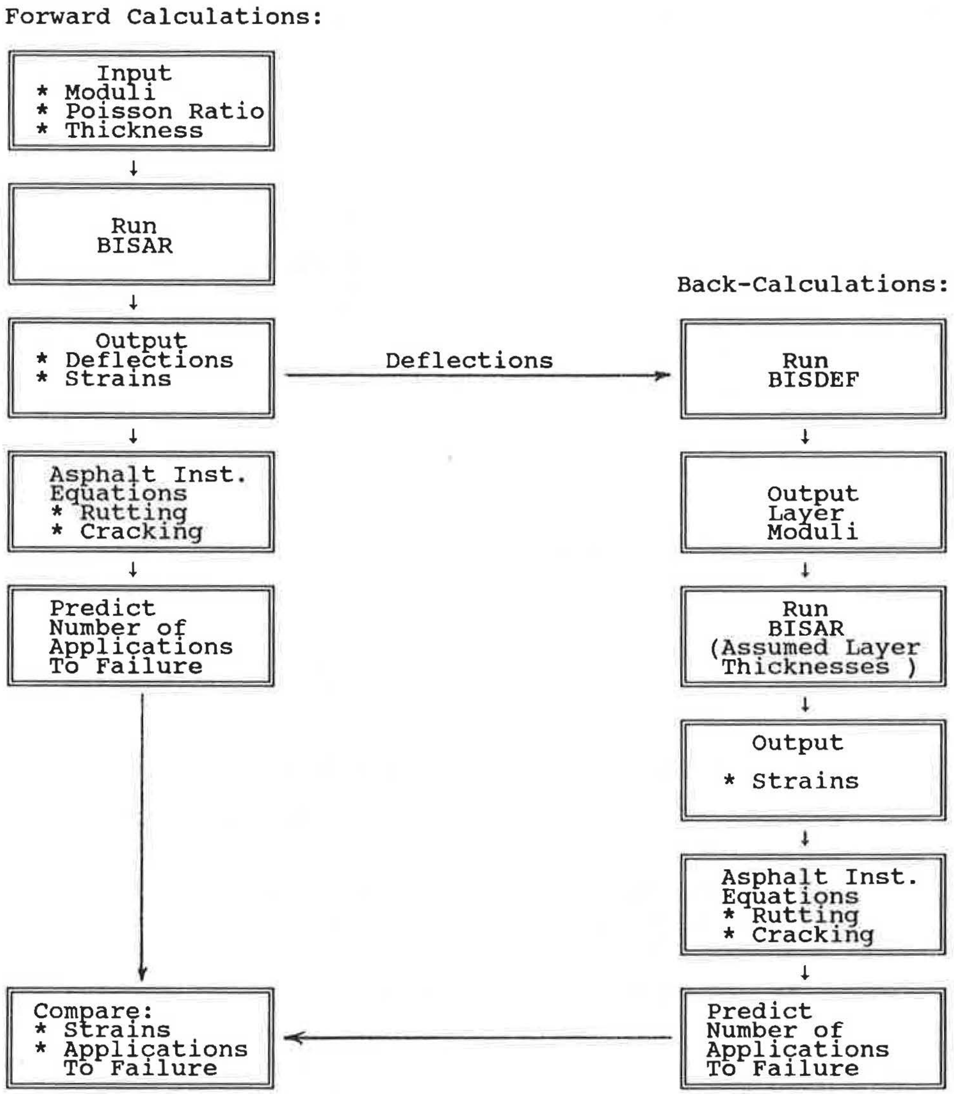

FIGURE 1 Flowchart of analysis process.

BISDEF was altered to allow up to 10 iterations before the program stopped. Generally, it stopped at two or three but in some cases it went the entire 10. The accuracy with which it fit the deflection basins varied widely and, in some cases, was extremely poor. This was to be expected, as the assumed pavement structure at times varied significantly from the actual structure used in the development of the deflection basins.

The backcalculated moduli were then entered into the BISAR program to determine the horizontal and tensile strains for comparison with the actual values.

Estimation of Remaining Life

The objective of most pavement evaluation and analysis procedures, for either reconstruction or rehabilitation, is to determine pavement layer thicknesses that will perform adequately over a specified period of time given a design traffic loading. Therefore, a study of the effects of erroneous assumptions in the design procedure should be assessed on the basis of the impact it has on the ultimate answer (i.e., required additional thickness or estimated time to failure). For this analysis, the impact of unknown or neglected rigid layers in the subgrade shall be assessed on the basis of errors in estimation of remaining life in the form of 18-kip equivalencies.

The design procedure developed by the Asphalt Institute for *Thickness Design—Asphalt Pavements for Highways and Streets* (*3*) was adopted for this study. This method was selected for the following reasons:

1. It is based on layered elastic design theory;
2. It is a widely accepted and used design method;
3. It assumes that the subgrade extends infinitely in the vertically downward and horizontal directions; and
4. Estimations of pavement performance are based on strain criteria.

The introduction of the Asphalt Institute's design manual states as follows:

> Criteria for maximum tensile strains induced at the bottom of the asphalt layer and vertical compressive strains induced

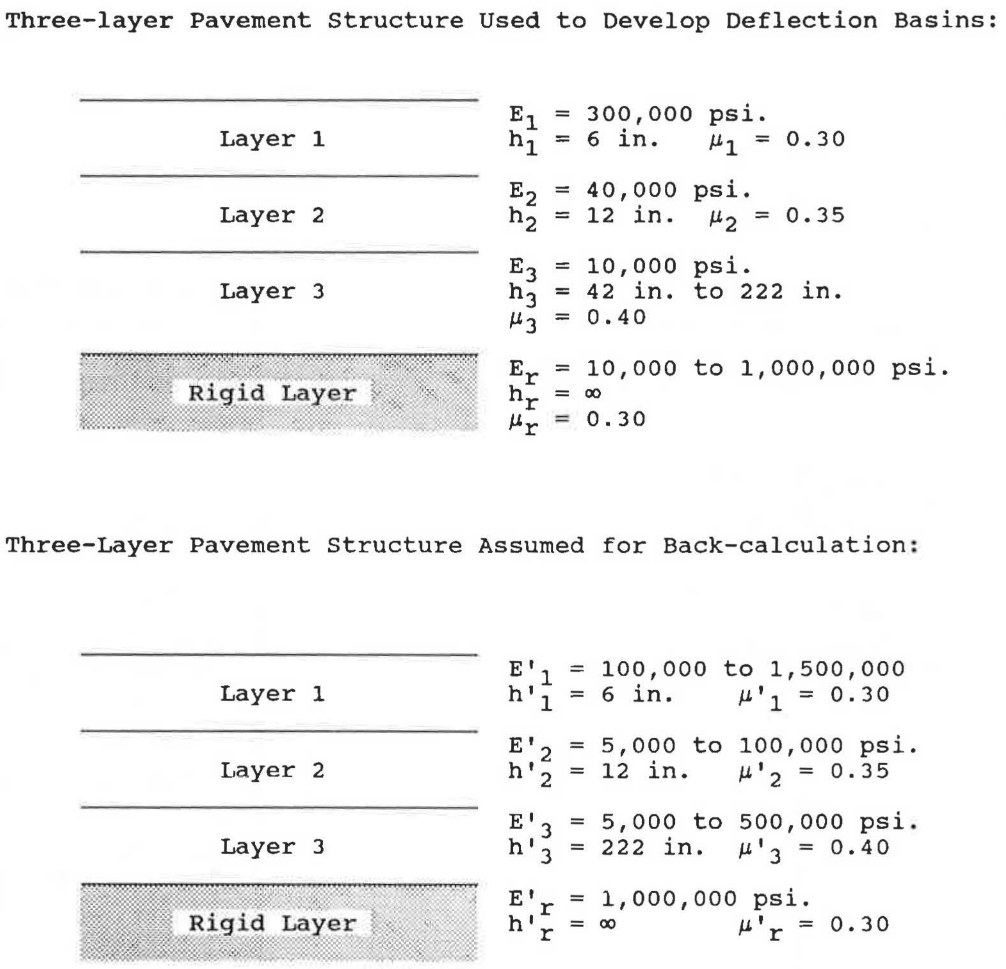

FIGURE 2 Pavement structures assumed for the study.

> at the top of the subgrade layer by wheel loads have been adopted and used in producing the thickness design charts included in this manual.

In the Asphalt Institute's Research Report No. 82-2 (*4*), the following equations were presented as the criteria used in the developing of the manual:

Allowable Asphalt Tensile Strain Criteria

$$N = 18.4\,(4.32 \times 10^{-3} * \varepsilon_t^{-3.29}\ |E^*|^{-0.854}) \tag{1}$$

where

N = number of 18-kip single-axle loads to cause cracking;
ε_t = tensile strain in asphalt layer; and
$|E^*|$ = asphalt mixture dynamic modulus.

Allowable Subgrade Vertical Strain Criteria

$$N = 1.365 \times 10^{-9}\ \varepsilon_c^{(-4.477)} \tag{2}$$

where

N = number of 18-kip single-axle loads to cause rutting, and
ε_c = vertical subgrade strain at top of subgrade layer.

These two equations were used to predict remaining life for each of the 71 pavement cross sections using the actual and backcalculated modulus values obtained from BISAR and BISDEF.

PRESENTATION OF RESULTS

Deflection Basin Fitting

As a rule, the basin fitting results using BISDEF were fairly good. Figure 3 shows the absolute sum of percent error for each deflection basin matched with BISDEF, versus the ratio of the actual/assumed depth to the rigid layer. The absolute sum of percent error, E, was calculated as follows:

$$E = \Sigma\ |\ 100[\mathrm{def}(a_i) - \mathrm{def}(b_i)]/\mathrm{def}(a_i)\ |\ \text{for } i = 1 \text{ to } 7 \tag{3}$$

where def(a_i) equals measured deflection at position i, and def(b_i) equals backcalculated deflection at position i.

Only six of the original 11 rigid-layer moduli used to develop the measured deflection basins are shown (100, 300, 500, 700, 900, and 1,000 ksi). It was not necessary to show all the results, because the omitted values fell within the lines shown on the plot. (This applies to the remaining figures as well.)

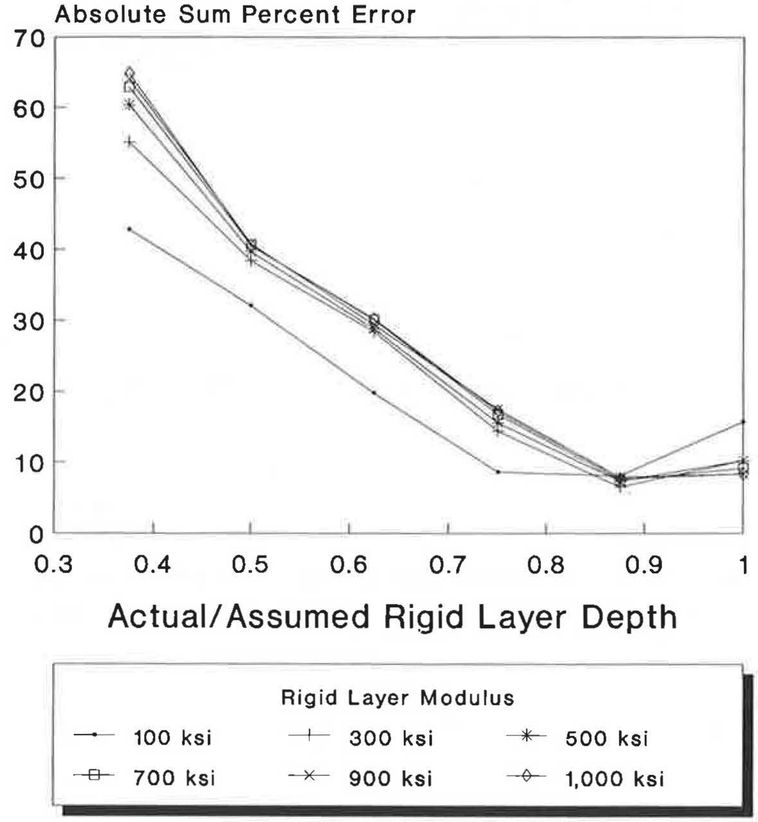

FIGURE 3 Effect of erroneously assumed rigid layer depths on quality of basin fitting.

Also not shown on the plot are the errors obtained for rigid layer depths of 60 in. Backcalculation efforts resulted in errors that were considered too large to be acceptable or layer moduli values that were way out of range.

It is evident from the plot that the backcalculation procedure is more sensitive to variations in rigid layer depths than to the actual modulus of the rigid layer. There is an indication, however, that rigid-layer modulus becomes increasingly influential as the ratio of actual/assumed rigid layer depth drops below 0.5.

Note that the error does not reach zero when the actual/assumed rigid layer depth approaches one. This occurs because the seed value for the subgrade modulus used was 40,000 psi. If the seed value for the subgrade modulus was close to the actual value of 10,000 psi, the basin fit improved for rigid layer depth ratios greater than 0.5 but became worse for values less than 0.5. The result is a compromise.

When no rigid layer existed (E_r = 10,000 psi) but was assumed to be at a 240-in. depth with a modulus of 1,000,000 psi, the sum of the absolute values of errors in backcalculation was 64 percent.

Figure 4 shows the ratio of backcalculated-to-measured or actual deflections, D1, versus the ratio of assumed-to-actual rigid layer depth. Figure 5 is a similar plot for D7. D1 is the deflection under the load (r = 0 in.), while D7 is the deflection farthest from the load (r = 72 in.). It is apparent that, in most instances, the fit was good for D1 and D7. Again, the quality of the basin fitting was influenced more by the depth of the rigid layer than by its modulus, except at rigid-layer depth ratios less than 0.5.

Backcalculation of E_1: Rigid Layer Effects

Figure 6 shows the ratio of the backcalculated-to-actual value of the modulus of Layer 1, versus the ratio of the actual-to-assumed rigid-layer depth. It is apparent that, as the rigid layer depth ratio decreases below 0.5, the modulus of Layer 1 is overestimated by a factor of greater than 3. If the rigid layer depth ratio increases to 0.75 the backcalculated modulus of Layer 1 closely resembles its actual value.

The backcalculated modulus of Layer 1 is affected more by errors in estimating the depth to the rigid layer than by errors in assumed modulus of the rigid layer.

When no rigid layer actually existed (E_r = 10,000 psi) but was assumed at 240 in. deep and 1,000,000 psi, the backcalculated modulus of Layer 1 was found to be 765,000 psi, which is in error by a factor of greater than 2.

Backcalculation of E_2: Rigid Layer Effects

Figure 7 shows the ratio of backcalculated-to-actual modulus of Layer 2, versus the ratio of the actual-to-assumed rigid layer depth. The ratio of the backcalculated-to-actual modulus of Layer 2 varied between 0.8 and 0.2. From the plot, it is apparent that by overestimating the depth to the rigid layer by half, one underestimates the modulus of Layer 2 by a factor of 5. As with Layer 1, the backcalculated modulus of Layer 2 is more sensitive to errors in estimating the rigid layer depth than by errors in estimating its modulus.

When no rigid layer existed, but was assumed at 240 in.

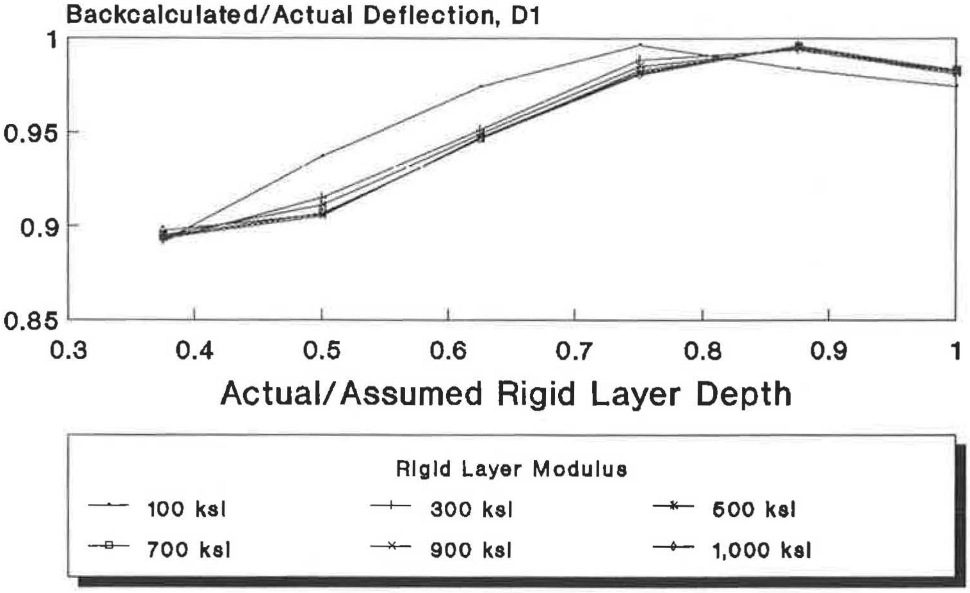

FIGURE 4 **Effect of erroneously assumed rigid layer depths on backcalculated deflections under the load (R = 0 in.).**

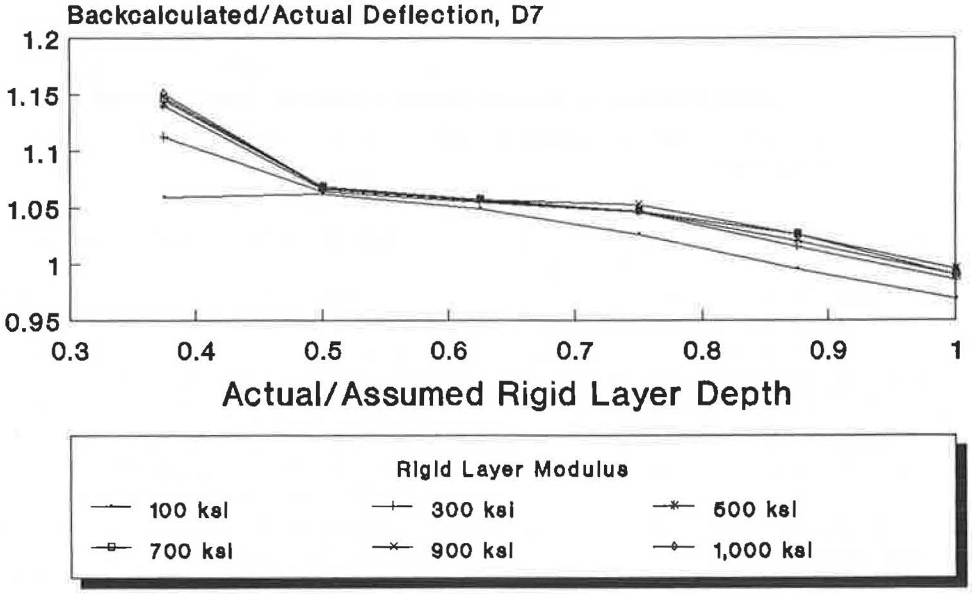

FIGURE 5 **Effect of erroneously assumed rigid layer depths on backcalculated deflections 72 in. from the load.**

and 1,000,000 psi, the modulus of Layer 2 was found to be 23,000 psi, which is off by a factor of 0.5.

Backcalculation of E_3: Rigid Layer Effects

Figure 8 shows the ratio of backcalculated-to-actual modulus of Layer 3 (subgrade), versus the ratio of the actual-to-assumed rigid layer depth. This ratio varied from 3 to about 1, indicating that, if the depth to the rigid layer were underestimated, the subgrade modulus will be overestimated. Again, the backcalculated modulus of Layer 3 is more sensitive to errors in estimating rigid layer depth than to its modulus.

When no rigid layer existed but was assumed at 240 in. and 1,000,000 psi, the modulus of Layer 3 was underestimated by 25 percent.

Calculation of Tensile and Compressive Strains

Figures 9 and 10 show the effects of errors in assumed rigid layer depths for tensile and compressive strains in a three-layer pavement system. The tensile strain was calculated at the bottom of Layer 1 (asphalt), while the compressive strain was calculated at the top of Layer 3 (subgrade).

Note that both strain levels are underestimated when the

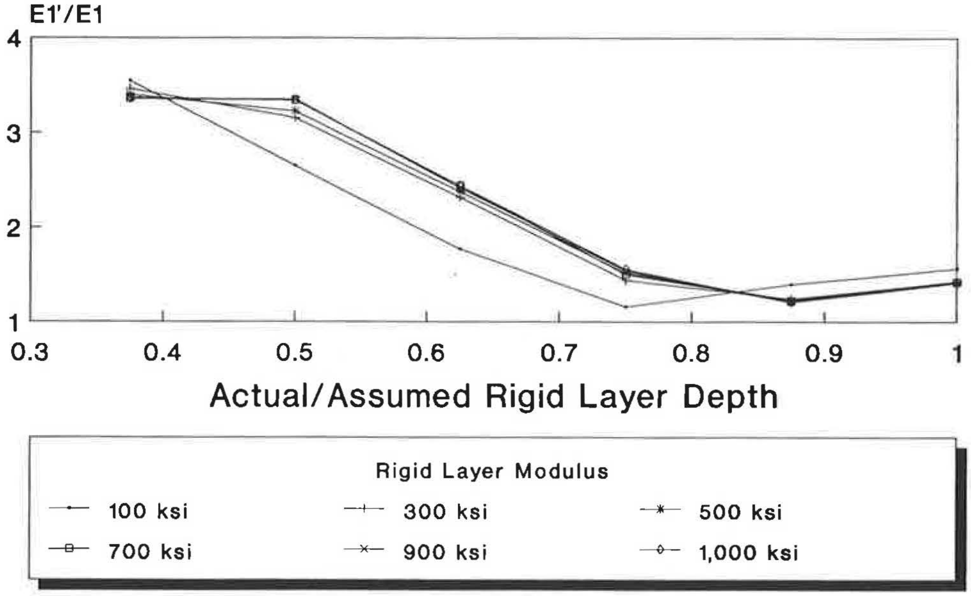

FIGURE 6 Effect of erroneously assumed rigid layer depths on backcalculated surface layer moduli.

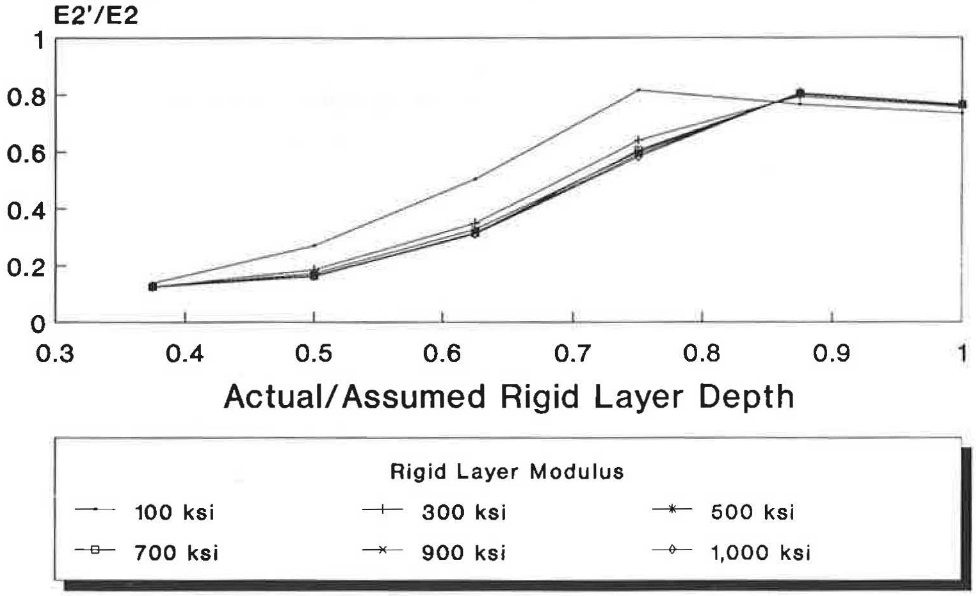

FIGURE 7 Effect of erroneously assumed rigid layer depths on backcalculated modulus of Layer 2.

depth to the rigid layer is overestimated. The compressive strain is affected more so than the tensile strain.

When no rigid layer existed but was assumed at 240 in. and 1,000,000 psi, the tensile strain was underestimated by 25 percent and the compressive strain was underestimated by 14 percent.

Failure Under 18-kip Single-Axle Loads

Figures 11 and 12 illustrate the effect of erroneous assumptions regarding the depth to the rigid layer on estimations of time to failure by both cracking and rutting.

As Figure 11 shows, the ratio of the predicted-to-actual number of repetitions to failure by cracking under an 18-kip single-axle load increases from 1 to 3 as the ratio of the actual-to-assumed rigid layer depth decreases from 1.0 to 0.4.

Similarly (from Figure 12), for rutting, the ratio increases from 1 to 1,000 as the ratio of the rigid layer depth decreases (note that the *y* axis is a log scale). This means that, if the actual rigid layer depth is less than half that assumed in the backcalculation process, the pavement will fail due to rutting 1,000 times faster than expected under a given traffic loading.

Note again that the predicted number of 18-kip single-axle loads to failure is relatively unaffected by errors in assump-

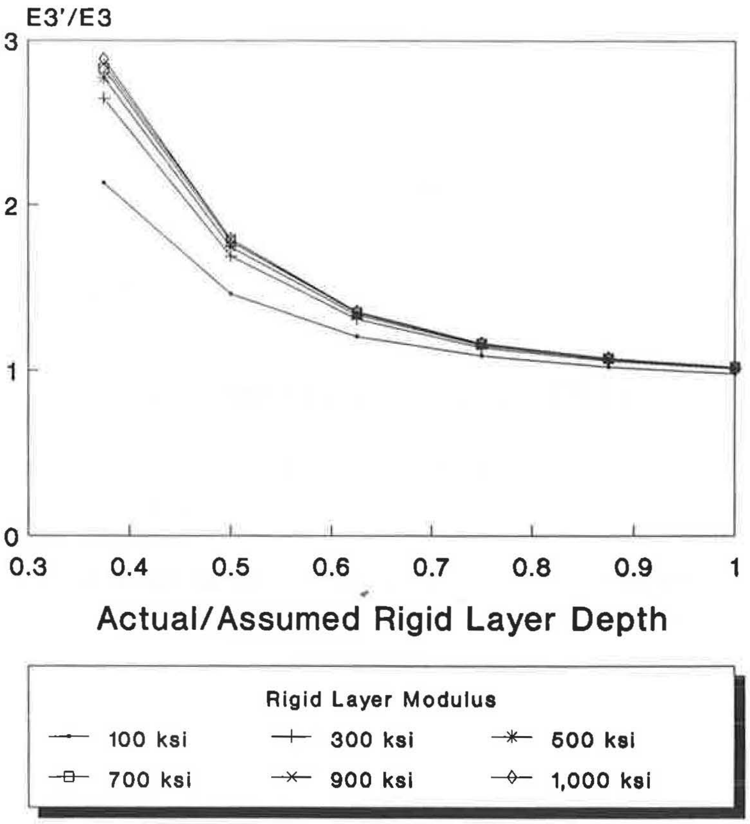

FIGURE 8 Effect of erroneously assumed rigid layer depths on back-calculated subgrade moduli.

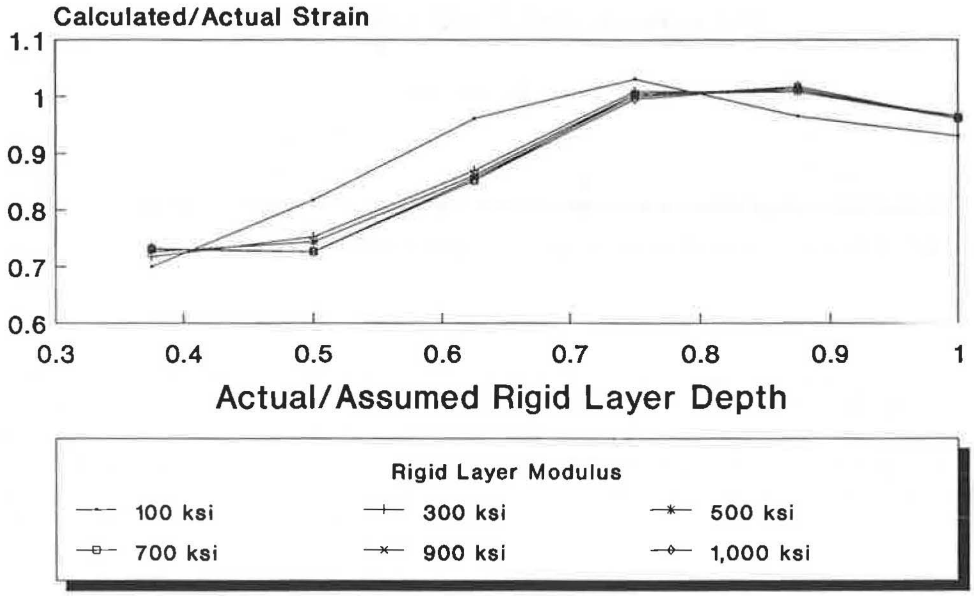

FIGURE 9 Effect of erroneously assumed rigid layer depths on horizontal tensile strain at bottom of surface layer.

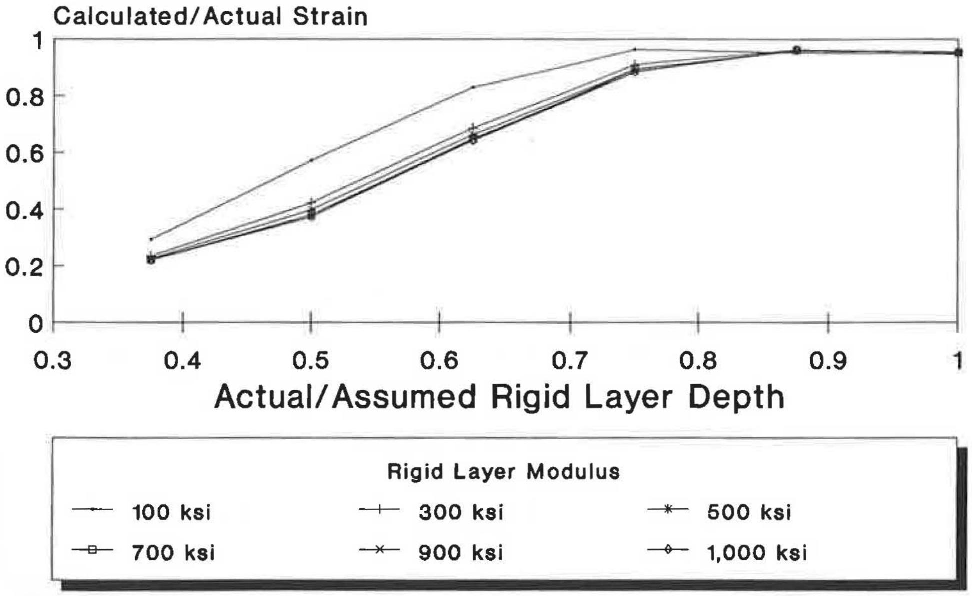

FIGURE 10 Effect of erroneously assumed rigid layer depths on vertical compressive strain at top of subgrade.

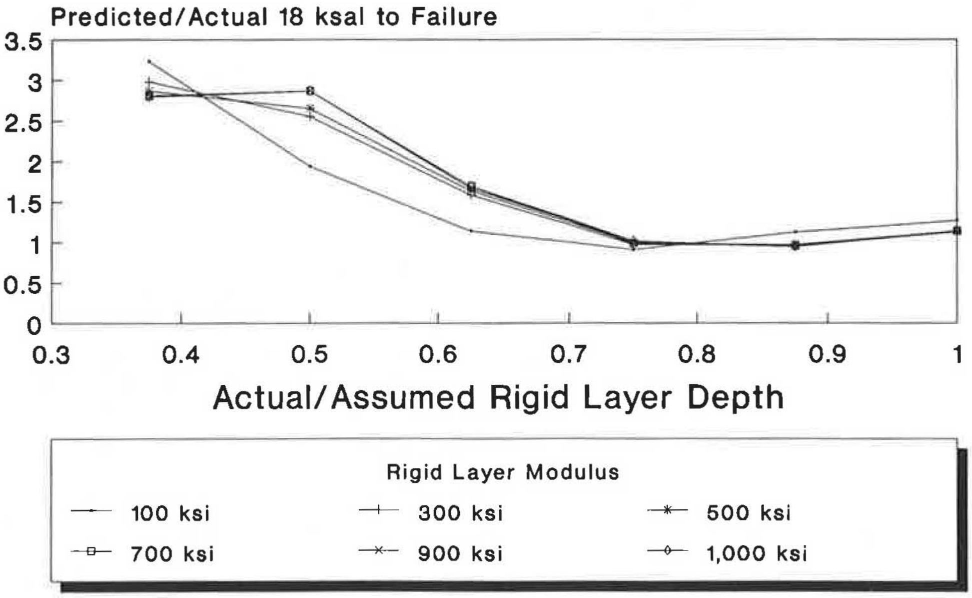

FIGURE 11 Effect of erroneously assumed rigid layer depths on rate of surface layer cracking.

tions regarding the stiffness of the rigid layer, but is most sensitive to errors regarding its depth.

When no rigid layer existed but was assumed at 240 in. and 1,000,000 psi, the repetitions to failure by cracking were overestimated by a factor of 2.35. The repetitions to failure by rutting were overestimated by a factor of 1.90.

DISCUSSION OF RESULTS

To explain fully the consequences of the results of this study on structural analysis of pavements, it will be useful to expand on one case presented in this report, for example, the case in which a rigid layer exists at 150 in. and the elastic modulus of the rigid layer is 100,000 psi. The pavement structure is as follows:

Layer 1
Asphalt Concrete
$E = 300{,}000$ psi $h = 6$ in.

Layer 2
Granular Base
$E = 40{,}000$ psi $h = 12$ in.

Layer 3
Subgrade
$E = 10{,}000$ psi $h = 132$ in.

Rigid Layer
$E = 100{,}000$ psi $h = \infty$

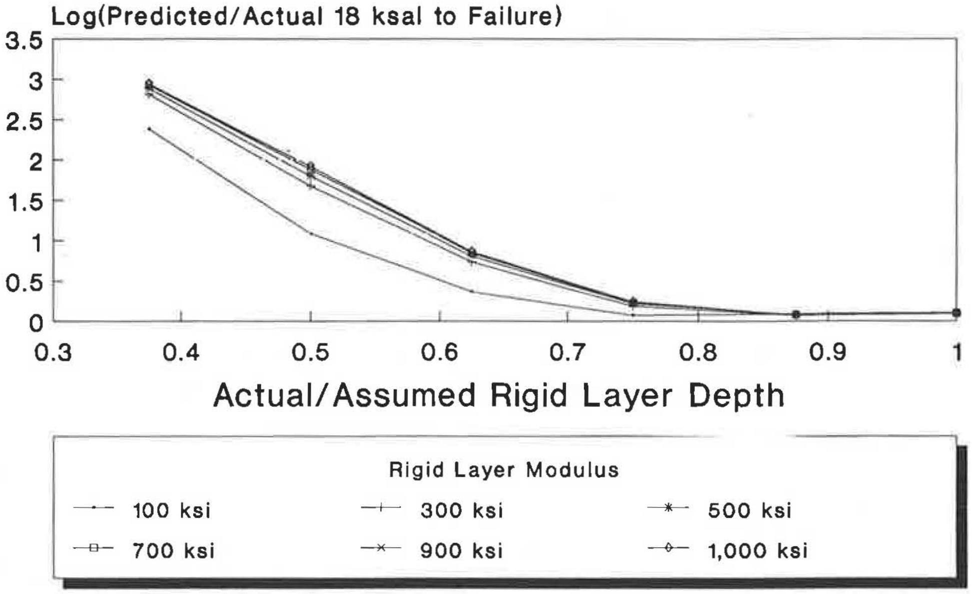

FIGURE 12 Effect of erroneously assumed rigid layer depths on predictions of rutting.

An engineer performs nondestructive testing with the FWD on this pavement with the intention of determining its time to structural failure by rutting or cracking. The pavement is tested and the following results are obtained with a load of 9,000 lb:

Distance from Load (in.)	*Deflection (mils)*
0.0	17.20
12.0	11.50
24.0	7.42
36.0	4.97
48.0	3.39
60.0	2.34
72.0	1.63

Because the engineer has only limited data on the subgrade, he is unaware that the rigid layer exists and models the pavement as follows:

Asphalt Concrete
$h = 6$ in.

Granular Base
$h = 12$ in.

Subgrade
$h = 222$ in.

Rigid Layer
$h = \infty$

After using BISDEF to backcalculate the moduli for each layer, the following are obtained:

$E_{\text{acp}} = 530{,}000$ psi,

$E_{\text{base}} = 20{,}173$ psi,

$E_{\text{subqr}} = 12{,}039$ psi.

The results look reasonable, but the engineer compares the measured versus the calculated deflections and finds the following deflections (absolute sum of percent error is 19.8 percent):

Deflection (mils)	
Measured	*Calculated*
17.20	16.80
11.50	11.90
7.42	7.47
4.97	4.81
3.39	3.26
2.34	2.32
1.63	1.71

The engineer concludes that this is a reasonable fit and proceeds to calculate the tensile strain at the bottom of the asphalt layer and the compressive strain at the top of the subgrade. The tensile and compressive strains were found to be 2.21×10^{-4} and -3.84×10^{-4}, respectively. In reality, the strains are 2.30×10^{-4} and -4.63×10^{-4}.

Using the Asphalt Institute Equations 1 and 2, the engineer predicts the pavement to fail by cracking after 1.7 million 18-kip equivalencies and by rutting after 2.7 million. In reality, the values are 1.6 and 1.2 million, respectively. Thus, he has predicted cracking accurately, but has underestimated by half the rate at which the pavement will rut.

If these modulus values are used to design an overlay to handle additional traffic, the design will be unconservative and will be subject to early failure.

Note that, in this example, the modular ratio of the rigid layer to the subgrade was only 10 and was sufficient to influence significantly the results of the analysis in a unconservative fashion. Additionally, the actual rigid layer modulus is only 100,000 psi, which is far below the value of 1,000,000 psi assumed during backcalculation.

CONCLUSIONS

From the results of this study, one can conclude the following regarding rigid layer depths when backcalculating pavement layer moduli from deflection data:

1. Theoretically, rigid layer depths are an important parameter in the process of backcalculating pavement layer moduli and estimating remaining life of pavement structures.
2. The accuracy with which rigid layer depths are estimated affects the quality of the backcalculated moduli values, especially when the rigid layer depth is half that assumed in the backcalculation process.
3. If the rigid layer is ignored completely or is assumed to be twice its actual depth and its stiffness is just ten times the layer above, the modulus values calculated for Layers 1 and 2 will in no way resemble their actual values.
4. The surface layers are most sensitive to errors caused by improperly assumed rigid layer depths. Under these conditions, the stiffnesses of the surface and subgrade layers (1 and 3) are overestimated, while the modulus of the base layer (2) is underestimated.
5. The remaining life of the pavement will be drastically overestimated, leading to unconservative overlay designs, when the rigid layer is half its assumed depth or is ignored in the analysis.
6. Poor basin fitting may not be a result of nonlinearity or time dependency of the system; it may be an indication of a rigid layer near the surface. In fact, it was found that when the ratio of the actual to assumed depth to the rigid layer was less than 0.3, it was impossible to match to basins using reasonable values of layer moduli.

RECOMMENDATIONS

The study results indicate that it is possible to fit deflection basins closely, even though the backcalculated layer moduli do not reflect their actual values. This suggests that deflection data taken with a FWD, Dynaflect, or Road Rater alone may be insufficient, particularly when difficulty is experienced in the basin fitting routine. Subsurface investigations may be required as a supplement to more accurately determine (a) layer thicknesses of the pavement structure, (b) approximate modular ratios of the individual layers with respect to each other, and (c) depth to rigid layers.

Currently, few types of nondestructive subsurface investigative equipment exist in a production mode to determine the above characteristics. However, several are in the development or research stages. Three methods currently in existence are Spectral Analysis of Surface Waves (SASW), cone penetrometers, and subsurface interface radar.

SASW

SASW can determine layer thicknesses and moduli and is especially good for determining depths to any rigid layer in the pavement structure (*5*). It is a simple test, can be done quickly, and requires little equipment. However, the data reduction is complicated and, at this time, can be done only on a mainframe computer. The process of obtaining moduli values is similar to backcalculating moduli from deflection basins, in that it is iterative and requires a knowledgeable individual to obtain accurate answers. Researchers are now in the process of automating data collection and reduction for this technique.

Cone Penetrometers

Cone penetrometers have been around for decades and have been used in the area of foundation investigations for bridges and buildings. Only recently have they been used on pavement. Researchers have obtained reasonable correlations for pavement modulus values from cone penetrometer data (*6*). A profile of stiffness versus depth can be obtained from these devices as well as a host of other information. The test requires much more time to perform than deflection testing and involves a substantial amount of equipment. A limited number of points may be tested with this equipment.

Subsurface Interface Radar

Several engineering firms and highway agencies are using subsurface interface radar for pavement investigations. The test is fast, covers miles of pavement in short periods of time, and requires a modest amount of equipment and personnel to collect data. Thicknesses of the individual pavement layers can be obtained through this test technique; however, the test yields no information regarding their stiffness. The data analysis and reduction portion of the test is subjective and requires the services of a highly qualified technician or engineer. Currently, a specification (ASTM D 4748-87) exists for using radar to obtain thicknesses of bound pavement layers within ± 0.5 in. but is not applicable to depths greater than 20 in. from the surface of the pavement.

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