ence of bedrock near the surface of the subgrade.

The values of the load-carrying capacity and required overlay thickness obtained by using the PAVEVAL computer program for AC pavements fall in between the values predicted by the DSM and CBR methods. Both the DSM method and the layered-elastic theory method (PAVEVAL) predict load-bearing capacities for AC pavements that are somewhat lower than the values predicted by the CBR method. There is reasonable agreement among the three pavement evaluation methods for PCC pavements. Further study on more airfield pavement sites will be required before more definite comparisons among these three methods of pavement evaluation can be made.

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Pavement Evaluation by Using Dynamic Deflections

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Dynamic test deflections were duplicated by elastic theory by using the Chevron N-layered computer program. Dynamic surface deflections obtained by using the road rater were used in conjunction with elastic theory to analyze pavement behavior. A procedure was developed to use field-measured road rater deflections for the estimation of the elastic modulus of the foundation material and the determination of the equivalent thicknesses of new material that approximate the behavior of the structure. The estimated moduli and the equivalent thicknesses can be used as inputs to design overlay thicknesses. An analysis of the deflections of the first three sensors of the road rater also makes it possible to distinguish weaknesses in asphalt concrete layers from weaknesses in the supporting foundation.

The stiffness of the foundation (subgrade) is one of the factors that affect the behavior of a pavement structure. Variations in subgrade support occur mainly as a result of variations in moisture content or of soil type. A significant decrease in subgrade stiffness (modulus of elasticity) will result in a decrease in ability to support the pavement structure and lead to increased distress in the layers of the structure. Signs of distress are rutting, increased roughness, and cracking (1).

Nondestructive tests have been empirically correlated with field-strength tests. There has been considerable use of elastic theory and dynamic testing for the estimation of layer moduli (2-7). The equipment used includes the Dynaflect, the California traveling deflectometer, the Benkelman beam, and the road rater. Since 1971, road rater deflections have been under study in Kentucky, as indicators of the characteristics of individual layer components of the pavement structure.

An estimate of subgrade strength is necessary for the evaluation of the overall condition of a pavement. A design condition exists when there has been no loss of effective thickness in any of the layers. A knowledge of the as-built thicknesses of the layers is necessary before an evaluation of the pavement structure can be made. Those thicknesses should be available from construction or maintenance records. Generally, the pavement condition involves deterioration in the layers of the structure. This means that the individual layers are behaving in a way similar to a different combination of layer thicknesses of new-quality materials; i.e., the structure is behaving as an effective structure. In this case, it becomes necessary to estimate the layer thicknesses of the deteriorated or effective structure.

The analysis of deflections involves the shape of the deflection bowl (2, 6). When the logarithms of road rater deflections are plotted against the distance from the load, a secant line can be drawn through two points on the deflection bowl. The combination of the slope of this line and the magnitudes of the deflections is indicative of the types of problems in the pavement structure.

SIMULATION OF ROAD RATER BY ELASTIC THEORY

Characteristics of Road Rater

The testing head on the Kentucky road rater consists of a vibrating mass that weighs 72.6 kg (160 lb) that impulses the pavement; the forced motion of the pavement is measured by velocity sensors normally located at 0, 305, 610, and 914 mm (0, 1, 2, and 3 ft) from the center of the test head. Frequency of the vibrator can be chosen from preselected frequencies of 10, 20, 25, 30, and 40 Hz. The vibrating mass is lowered to the pavement by a hydraulic system. At a hydraulic pressure of 4.82 MPa (700 lbf/in^2), the static load is 7.43 kN (1670 lbf).

The response to the vibrating mass of the road rater was determined for several full-depth asphalt concrete (AC) pavements and conventional three-layer pavements. Resonant frequencies of the total pavement structure were usually multiples of approximately 7 Hz. The thickness of the AC layer appeared to cause the resonant frequency to shift 1 or 2 Hz at the 21 and/or 28 Hz normal resonant frequencies. Resonance at these frequencies was indicated by oscillations of the needle of the meter as opposed to its normally rock-steady behavior. In all cases, the meter response remained steady at 25 Hz, which thus was chosen as the reference frequency.

At a frequency of 25 Hz and an amplitude of vibration of 1.52 mm (0.06 in), the road rater has a peak-to-peak dynamic force of 2.67 kN (600 lbf). Once the dynamic force is set for a given frequency and amplitude, the other preset frequencies will vary the amplitude of the vibrating mass such that the dynamic force remains constant for all of the preselected frequencies. The composite loading thus consists of a static load of 7.43 kN and a peak-to-peak dynamic force of 2.67 kN that oscillates about the static load.

Superposition Principles

The road rater loading is transmitted to the pavement by means of two feet symmetrically located on either side of a beam that extends ahead and carries the sensors. Superposition principles can be applied to the computation of the deflection at each sensor location. A combined load can be subdivided into its component loads. Superpositioning is applicable provided the deformations are small and do not substantially affect the action of external forces. If the principles of superpositioning are to apply, a linear relationship between displacement and external force must exist or be assumed to exist (8-10). When superposition principles are applied to the road rater, the deflection that results from the load applied to one foot must be added to the deflection that is due to the load applied by the other foot. For the symmetrical conditions of the road rater, deflection calculations need be made only for one foot and the radii corresponding to each sensor location.

The dynamic loading (sine wave) of the road rater can be approximated by a square wave such that the maximum value of the square wave is equal to $1/\sqrt{2}$ times the peak value of the sine wave. The peak-to-peak loadings of the road rater are 8.37 and 6.49 kN (1882 and 1458 lbf). From symmetry, the loads on each foot of the test head are equal to 4.19 and 3.24 kN (941 and 729 lbf). The dynamic deflection is defined by $\Delta_{\text{total}} = (\Delta_{4.19} - \Delta_{3.24}) \times 2$ where $\Delta_{4.19}$ and $\Delta_{3.24}$ represent the deflections calculated by using the Chevron computer program and the peak loading conditions.

Input Parameters for Simulation by Using Chevron Computer Program

In addition to the load, the inputs required by the Chevron computer program include a contact pressure corresponding to the load; the number of layers; and the thickness, Young's modulus, and Poisson's ratio of each layer. The contact pressure of the low and high loads are input to maintain the correct area for each foot. The constants used in simulating the road rater (11) are summarized in Table 1.

Reference Conditions

The modulus of elasticity of AC varies as a function of frequency of loading and temperature. Conditions for the current Kentucky thickness-design procedures and the method for conducting Benkelman beam tests correspond to a modulus of 3.31 GPa (480 000 lbf/in^2) at 0.5 Hz and a pavement temperature of 21°C (70°F). A reference frequency of 25 Hz was selected for the road rater; the corresponding AC modulus at 21°C is 8.27 GPa (1 200 000 lbf/in^2).

The modulus of a granular base (E_2) is a function of the moduli of the confining layers, i.e., the modulus of the AC layer (E_1) and the modulus of the subgrade (E_3). Estimation of the modulus of the crushed-stone layer (E_2) can be determined from the relationship $E_2 = F \times E_3$, where there is an inverse linear relationship between $\log F$ and $\log E_3$. The ratio of E_2 to E_3 is equal to 2.8 at a California bearing ratio (CBR) of 7 and to 1 when E_1 equals E_3: $E_1 = E_2 = E_3$ (11)—which is the case of a Boussinesq semi-infinite half space. [E_3s (in lbf/in^2) can be approximated by the product of the CBR and 1500 (11-13), a method of estimating base moduli that appears adequate for normal design considerations up to a CBR of 18-20 (11-14).]

For a constant structure [depth of AC and depth of dense-graded aggregate (DGA)] and AC modulus, a theoretical relationship between deflection and subgrade modulus of elasticity can be developed from the simulated road rater deflections. An example of such a relationship is illustrated in Figure 1. There is a separate line for each sensor on the road rater. Figure 1 also con-

Table 1. Input parameters for simulation of road rater.

Input	Value
Poisson's ratio	
Asphalt concrete	0.40
Granular base	0.40
Subgrade	0.45
Contact pressure (MPa)	
Low (3.24-kN) load	0.183
High (4.19-kN) load	0.231
Layer thicknesses (mm)	
Asphalt concrete	50.8, 127, 203, 279, and 356
Dense-graded aggregate	50.8, 203, 356, 508, and 686
Full-depth asphalt concrete	102, 152, 203, 254, 305, 356, 406, 457, and 508
E (GPa)	
Asphalt concrete	1.38, 2.76, 4.14, 5.52, 6.90, 8.28, 9.66, 11.04, 12.42, and 13.80
Subgrade	0.041, 0.082, 0.123, 0.164, 0.205, 0.246, 0.287, 0.328, 0.369, and 0.41

Note: 1 MPa = 145 lbf/in^2; 1 kN = 225 lbf; 1 mm = 0.04 in.

tains a fourth line labeled no. 1 projection. This line was calculated by using the no. 2 and no. 3 deflections and will be discussed below.

ADJUSTMENTS FOR NONREFERENCE CONDITIONS

Moduli of Asphalt Concrete from Field-Test Data

Field measurements made include road rater deflections, surface temperature, time of day, and frequency of vibration. The surface temperature, time of day, and mean air-temperature history for the previous five days are necessary to determine the temperature distribution by using the method developed by Southgate and Deen (15, 16). The five-day mean air-temperature history can be obtained from weather records.

The modulus of elasticity of AC is a function of frequency of loading and mean pavement temperature, as illustrated in Figure 2 (17). Figure 2 can be used to develop a relationship between modulus and temperature for the reference frequency of 25 Hz or any other frequency desired, which may be representative of other dynamic loads. Thus, a distribution of the modulus through the AC layer for the reference frequency of 25 Hz can be determined for any temperature distribution. For layers thinner than 152 mm (6 in), the results were better when the pavement modulus was taken as the average of the moduli on 12.7-mm (0.5-in) intervals beginning at the 25.4-mm (1-in) level. For asphalt thicknesses greater than 152 mm, the most representative modulus appeared to be the mean of the moduli on 25.4-mm intervals beginning at the 25.4-mm level.

Adjustment Factors for Road Rater Deflections

Because of the significant effect of temperature on the modulus of elasticity of AC, it was necessary to develop a system with which to adjust the deflection measurements to a reference temperature and modulus. This adjustment-factor system uses ratios of deflections at reference conditions to deflections that result from arrayed variables of layer thicknesses and moduli.

For a given thickness of AC, the adjustment factors vary according to changes in the thickness of DGA and the value of E_3 but these variations are minimal when compared with the variation in adjustment factor for variations in AC thicknesses. Thus, the adjustment factors for all DGA thicknesses for a constant subgrade modulus and thickness of AC were averaged into a single line. Treating other thicknesses in the same manner produces similar relationships. Investigation of other subgrade moduli indicated only minor variation in adjustment-factor values for the same thickness of AC. The adjustment-factor curves shown in Figure 3a were produced by averaging the adjustment factors for each thickness of AC and across subgrade moduli.

Two-layered pavements show similar variations in adjustment factor relative to E_3s and AC thicknesses. The adjustment-factor curves shown in Figure 3b were produced by averaging the adjustment factors for all E_3s and a constant thickness of AC.

A mean pavement modulus can be found by using the distribution of AC moduli through the pavement. The necessary adjustment factor (a multiplier) required to bring the field deflection to a deflection at a reference modulus is determined by using the appropriate adjustment-factor chart (see Figure 3) and the mean pavement modulus of elasticity.

An alternative method of presenting the adjustment factors shown in Figure 3 is shown in Figure 4. The system shown in Figure 4 adjusts the deflections to a specific condition—25 Hz, a mean pavement temperature of 21°C, and $E_1 = 8.27$ GPa. The same method of calculating ratios of deflections was used to develop Figure 4 as was used to develop Figure 3. The only difference is that Figure 3 was developed on a basis of mean pavement modulus and Figure 4 was developed on a basis of mean pavement temperature. A reduction in frequency while holding pavement modulus constant results in a reduced pavement temperature. Thus, if the frequency is reduced, the adjustment-factor curves will not shift but the mean pavement-temperature scale will shift according to the chosen frequency. Also, mean pavement temperature is a function of AC thickness. The effects of AC thickness and subgrade modulus were averaged in the development of Figure 4. Figure 3 adjusts the road rater deflections to a reference modulus of $E_1 = 8.27$ GPa regardless of the the frequency of loading. Figure 4 adjusts the road rater deflections to a reference temperature and frequency and the corresponding AC modulus (25 Hz, 21°C, and $E_1 = 8.27$ GPa).

The adjustment-factor system presented in Figures 3 and 4 was developed by using theoretical deflection data corresponding to the no. 1 sensor of the road rater. A similar system could have also been developed by using deflection data corresponding to either the no. 2 or no. 3 sensors. For comparison, adjustment factors corresponding to the no. 2 and no. 3 sensors were developed for the same conditions and by using the same methodology. A comparison of the three different adjustment factors indicated an average difference of ±0.032 for the adjustment factors corresponding to the no. 1 and no. 2 sensors and an average difference of ±0.048 for the no. 1 and no. 3 sensors for a range of AC moduli of 1.38 to 13.79 GPa (200 000 to 2 000 000 lbf/in^2). The greatest differences in adjustment factors occurred at lower values of moduli and thin layers of AC. For example, a comparison of the differences in adjustment factors for moduli greater than 4.14 GPa (600 000 lbf/in^2) indicated differences of ±0.021 and ±0.037 for the no. 1 sensor versus the no. 2 and no. 3 sensors, respectively. Based on these analyses, the deflection adjustment-factor curves shown in Figures 3 and 4 were assumed to be adequate for use with the deflections of the no. 1, no. 2, and no. 3 sensors of the Kentucky road rater.

Figure 1. Theoretical relationships: road rater deflection versus modulus of elasticity for a constant structure and modulus of asphalt concrete.

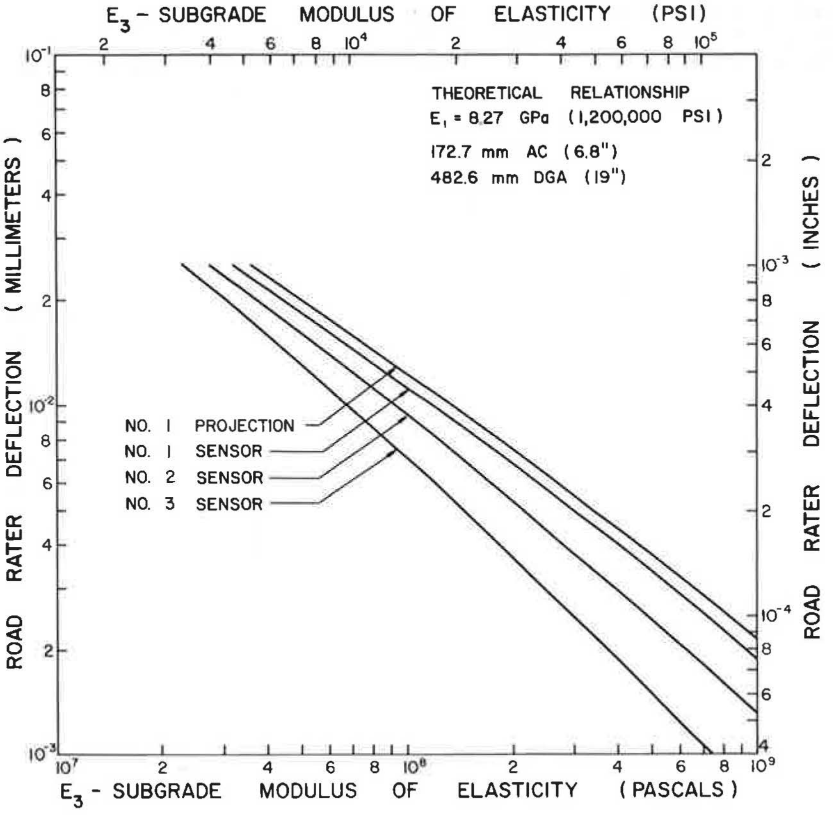


Figure 2. Effect of temperature and frequency on dynamic modulus of elasticity.

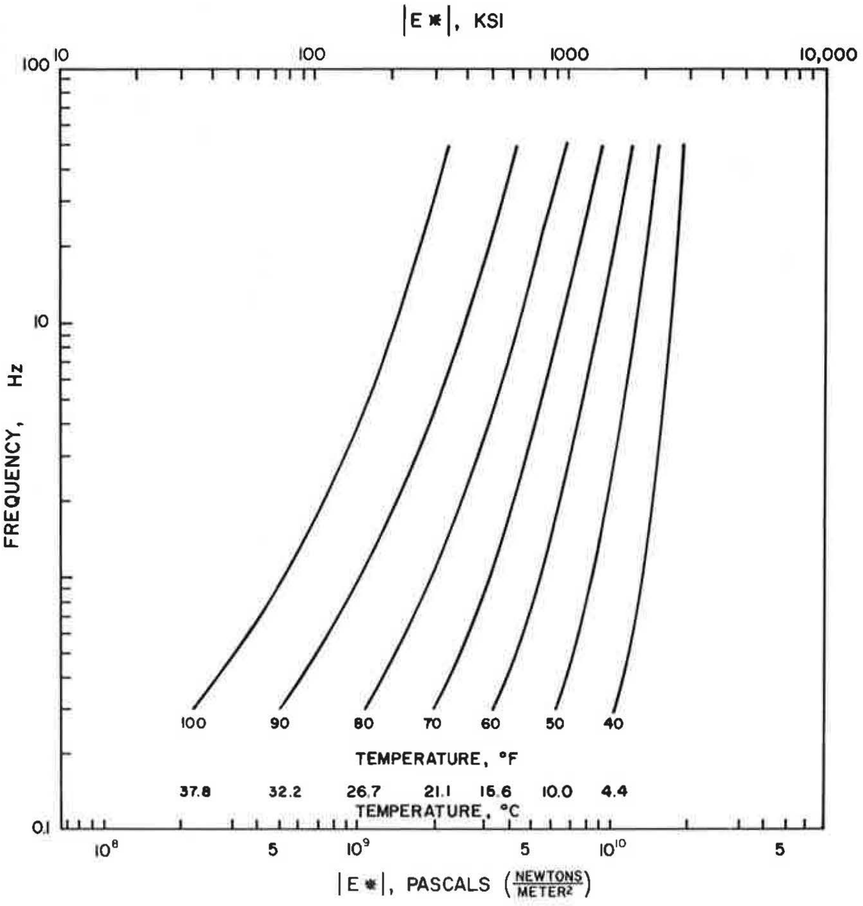


Figure 3. Relationship between thickness of asphalt concrete and temperature adjustment factor: (a) three-layered pavements and (b) two-layered pavements.

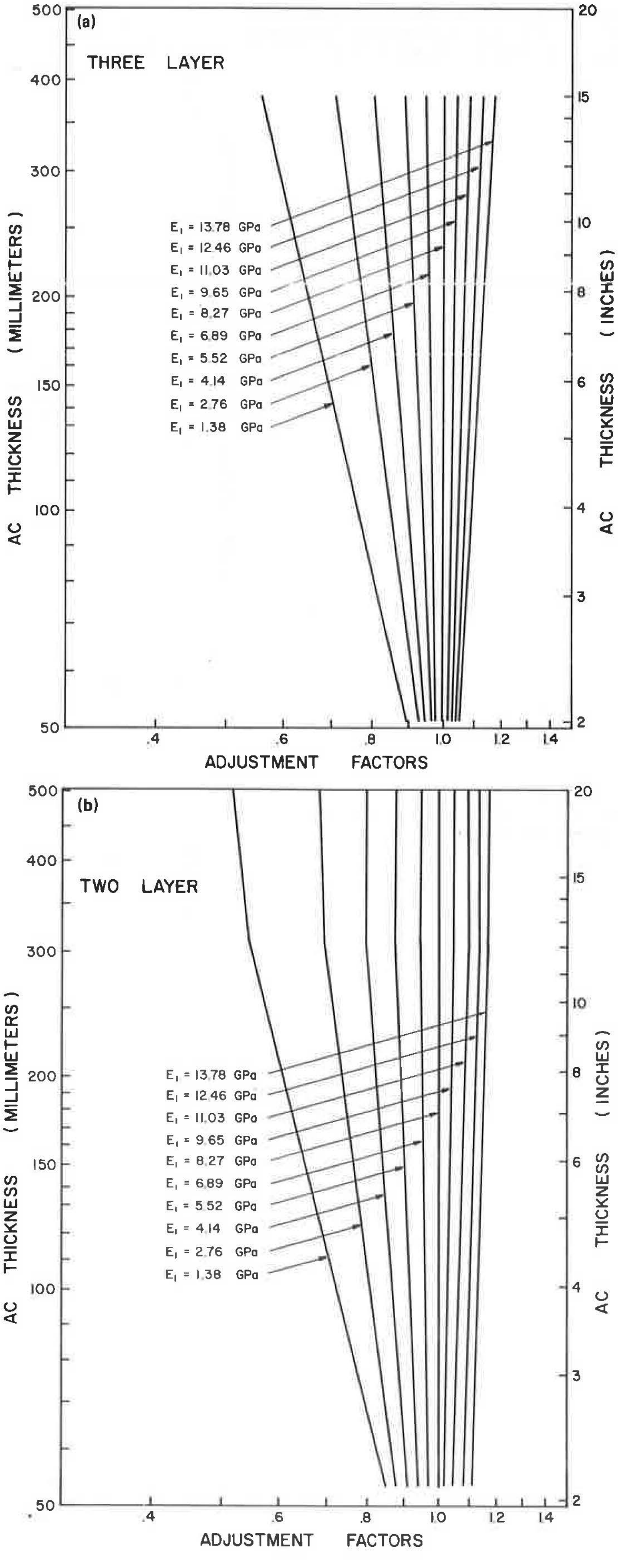
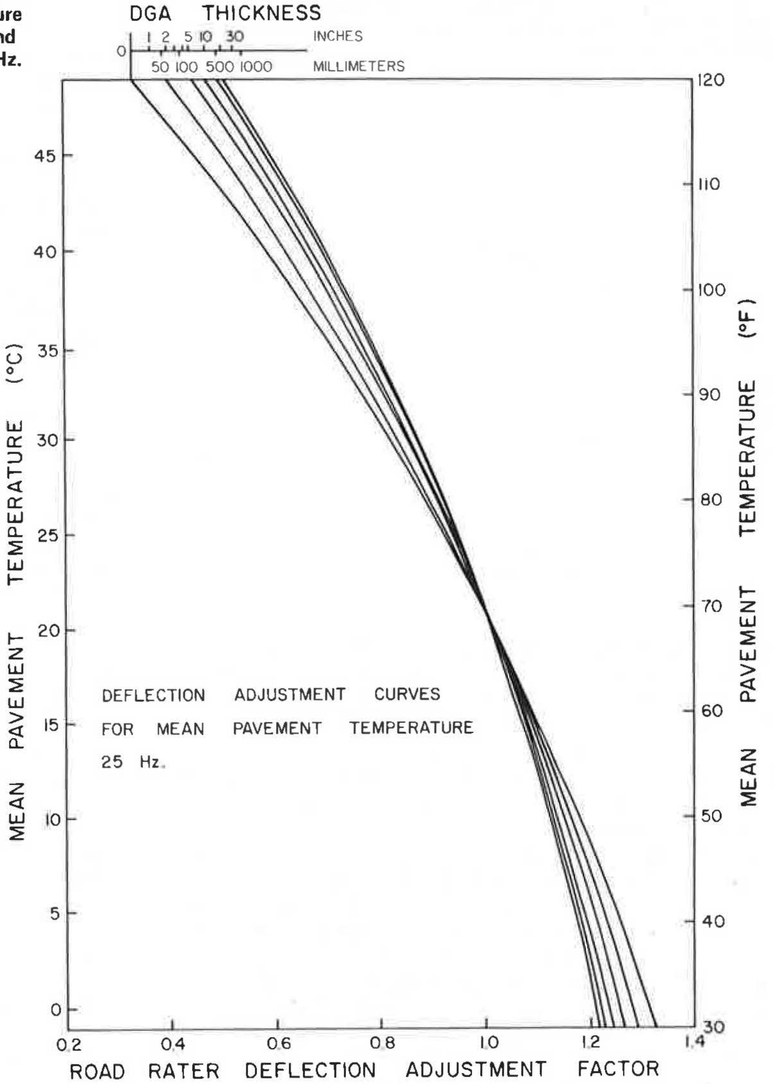


Figure 4. Relationship between mean pavement temperature and road-rater-deflection adjustment factors: full-depth and three-layered asphalt concrete pavements at 21°C and 25 Hz.



EVALUATION OF PAVEMENT STRUCTURE

Describing Shape of Deflection Bowl

An empirical evaluation of road-rater-deflection data involves extrapolating a straight line through the magnitudes of the deflections of the no. 2 and no. 3 sensors when the logarithm of the deflection is plotted against the arithmetic distance from the load head. Extrapolation of this line to the position corresponding the no. 1 sensor gives the no. 1 projection (Figure 5):

$$\text{No. 1 projection} = 10^{[(2\log \text{no. 2 deflection}) - \log \text{no. 3 deflection}]} \qquad (1)$$

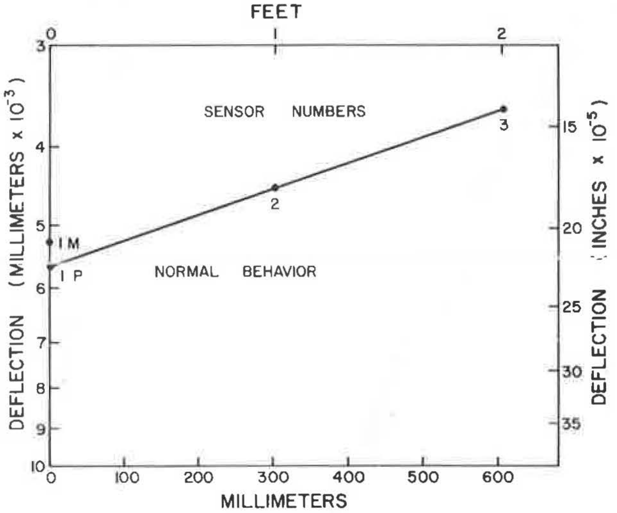
The slope of the semilog line (secant line), the difference in magnitude between the no. 1 projection and the no. 1 sensor deflection, and the magnitudes of all deflections are indicative of the shape of the deflection bowl. This concept can also be applied to theoretical deflections.

Estimating Subgrade Moduli

If the layer thicknesses are known, relationships can be developed (from elastic theory) between theoretical deflections and subgrade moduli. An example for one structure is shown in Figure 1. Field deflections for the no. 2 and no. 3 sensors and their corresponding no. 1 projections can be used as inputs in the subgrade-moduli estimation process to obtain three values for the subgrade modulus. The average modulus of the subgrade is calculated from the three estimates. The no. 1 sensor is closest to the point of application of the load and is most indicative of the condition of the pavement slab. For this reason, the deflection of the no. 1 sensor is not used in estimating the subgrade modulus. Sensors no. 2 and no. 3 are farther from the point of application of the load and are therefore more indicative of the condition of the foundation or supporting layers of the structure. The deflection of the no. 4 sensor is not used in the pavement evaluation process because there is little variability in its deflection with changes in structural conditions of the pavement.

Subgrade moduli corresponding to the no. 2 and no. 3 deflections and the no. 1 projections were estimated for four pavements (54 test sites). At the time of testing, each of these test pavements was less than two years old and showed no visible signs of deterioration. The average difference between subgrade moduli for any of the three predictors was 24.8 MPa (3600 lbf/in^2) with a standard deviation of 22.1 MPa (3200 lbf/in^2). When these three estimates of subgrade modulus were averaged and compared with the magnitude of the subgrade modulus estimated from the deflection of the no. 2 sensor,

Figure 5. Determination of no. 1 projection from relationship between deflection and distance from load head: example of normal pavement behavior.



the mean difference between the average subgrade modulus and the modulus estimated from the no. 2 sensor deflection was only 4.95 MPa (718 lbf/in^2) with a standard deviation of 7.58 MPa (1100 lbf/in^2). By using the data from these four pavements and in the interest of simplification of the system, the deflection of the no. 2 sensor was selected as the one to be used for the estimation of the subgrade modulus.

The variability in estimated subgrade modulus may be related to the operator's ability to read the correct deflection on the meters of the road rater, the selection of the most appropriate deflection adjustment factor, and the accuracy of the graphical interpolations in reading the subgrade modulus corresponding to a given deflection. Some error of interpolation for the correct structure could also be introduced during the development of the theoretical curves (Figure 1) from the matrix of conditions used in the road rater simulation.

A log-log plot of the sensor no. 1 deflections against the estimated subgrade moduli (from sensor no. 2) should be made for field deflections (see Figure 6). The sensor no. 1 measured deflection was selected because it showed the greatest sensitivity to the condition of the AC layer; the sensor no. 2 deflections were more indicative of the condition of the supporting foundation.

If the field deflections and the estimated subgrade moduli agree with the theoretical values for the original structure, the pavement is behaving as expected (Figure 6a). Over a length of pavement, it is normal to have a range in subgrade modulus because of variations in moisture content and soil type. If the pavement performance (deflections) does not agree with the original theoretical structure line, the pavement is behaving as a thinner effective structure (see Figure 6b).

The expression of deterioration in terms of reduced thickness is only one of the options available. Deterioration can also be expressed in terms of reduced layer moduli for constant layer thicknesses. Deterioration in terms of reduced thicknesses was selected because of its adaptability to overlay design. The effective structure, expressed in terms of reduced layer thicknesses that have properties similar to new pavement, can be used as an input parameter for overlay design.

Estimating Effective Structure

To evaluate effective structure, lines of equal deflection (no. 1 sensor) were drawn for a matrix of layer thicknesses and subgrade moduli for a constant reference modulus of AC (E_1 = 8.27 GPa) (see Figure 7). It was assumed that the effective structure is defined by the effective layer thicknesses and the modulus of the subgrade. In Figure 7, the subgrade modulus is held constant. One method (18) of estimating the amount of deterioration (percentage net worth) is shown in graphical form in Figure 8 in terms of percentage of residual or net worth versus percentage of design thickness. Figure 8 is a modification of a concept used in Florida. There, it was assumed that the AC had a residual value of 50 percent of its original value at a pavement serviceability index (PSI) of 1.5. Figure 8 is based on the assumption of 30 percent residual value at a PSI of 1.5. A relationship of percentage of original AC thickness versus percentage of the original DGA thickness was developed by using Figure 8 and is shown in Figure 9.

As the thicknesses of the individual layers decrease, the deflection along a deterioration curve (Figure 9) increases. Figure 10 illustrates the relationship between the ratio of the deflection of a deteriorated structure to the deflection of the original structure (an expression of the degree of deterioration) and the deteriorated structure in terms of percentage of the original thickness of each layer, where the modulus of the subgrade is constant. A sensitivity analysis was made of the ratio of deflections against the percentage of AC in the original design thickness as the subgrade modulus varied. The analysis showed that, for a normal range of subgrade moduli [42-206 MPa (6000 to 30 000 lbf/in^2) there was very little change.

Procedure for Evaluating Effective Structure

The effective structure is determined from plots of deflection versus subgrade modulus and of ratio of deflections versus percentage of original thicknesses by the following procedure.

1. For a given subgrade modulus, determine the theoretical deflection that corresponds to the original structure from the plot of the deflections of sensor no. 1 versus subgrade moduli (Figure 6b).
2. For the same subgrade modulus, determine the deflection that corresponds to a line of equal and parallel offset through the field deflection of greatest magnitude (Figure 6b).
3. Use the two deflections to compute the ratio of the field deflection (step 2) to the theoretical deflection (step 1).
4. Use the ratio (step 3) to determine (from Figure 10) the percentages of effective thicknesses of the asphalt and base layers.
5. Multiply these percentages by the original layer thicknesses to obtain the effective structure (Figure 6b).
6. Confirm the effective structure by using an iterative process of computing a new mean pavement temperature and modulus from the respective distributions, readjusting the field deflections for the new AC modulus (based on the thinner structure), and repeating the process of estimating the subgrade modulus. Figure 11 illustrates the confirmation of the example shown in Figure 6b and also compares the effective and original structures. The parallel line through the point of greatest offset from the theoretical deflection-subgrade-modulus line is a short-cut procedure that reduces the number of iterations required. Investigations (19) have shown that this procedure effectively reduces the iteration to one cycle.

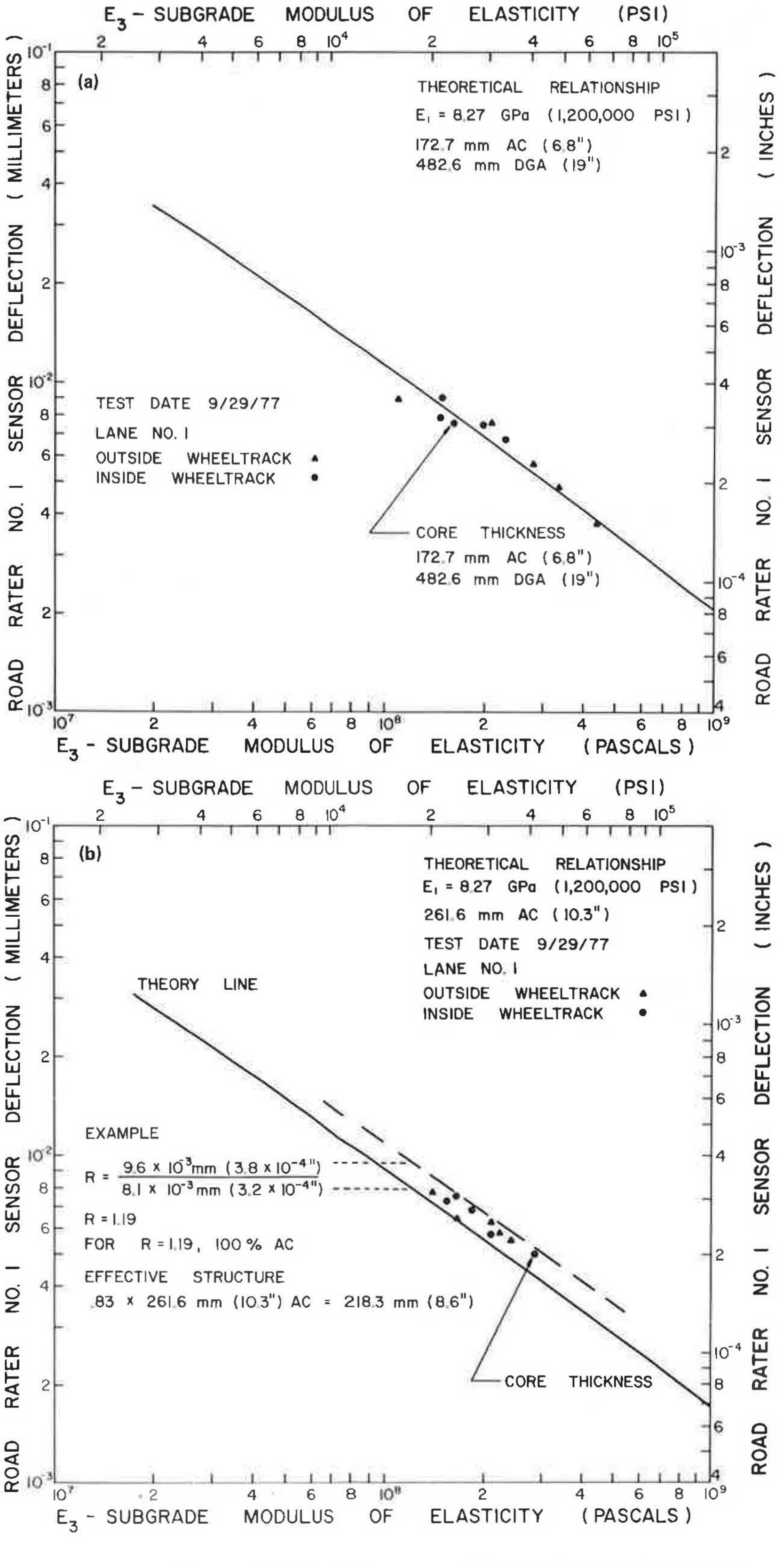


Figure 6. Relationship between no. 1 sensor deflection and modulus of elasticity of subgrade: (a) normal pavement behavior and (b) abnormal pavement behavior and example of determination of effective structure.

Identification of Type of Deterioration

For a given pavement structure, AC modulus, and subgrade modulus, there is a difference between the no. 1 projection and the no. 1 sensor deflection for theoretical deflections (Figure 5). There will also be a difference between these values for field-measured deflections. Normally, the differences between the no. 1 projected deflection and the no. 1 sensor deflection for both theory and field measurements are similar although the difference for field measurements should be greater than that for theoretical values. Slab deterioration is indicated when field measurements indicate a no. 1 sensor deflection greater than the no. 1 projection (see Figure

Figure 7. Example pavement-deterioration curves: contours of equal deflection of sensor no. 1 for matrix of asphalt concrete and dense-graded aggregate thicknesses.

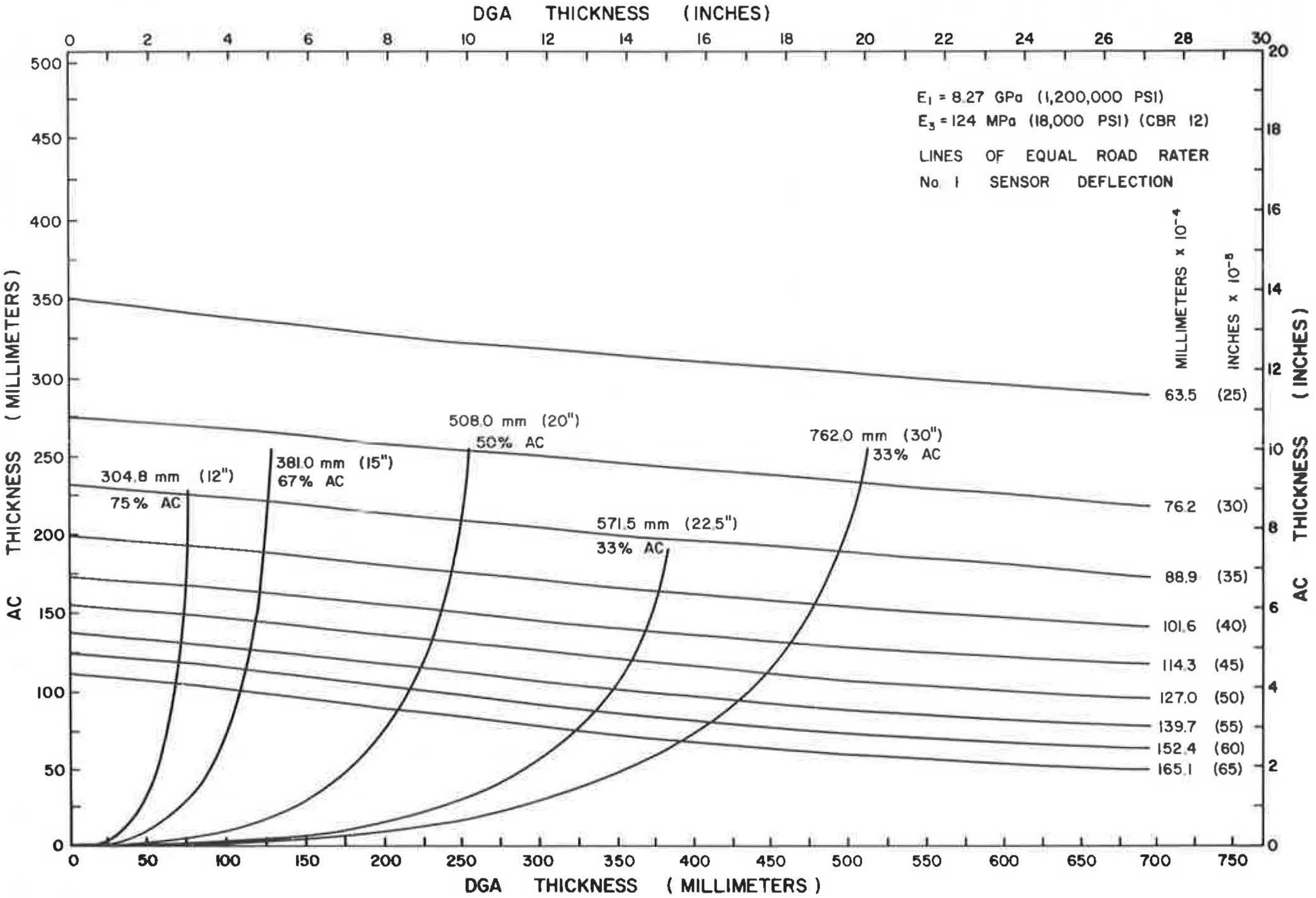
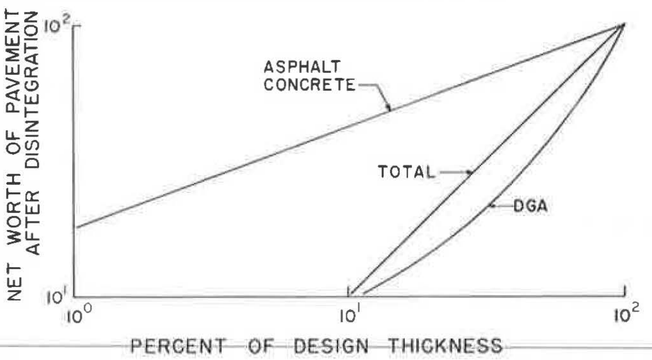


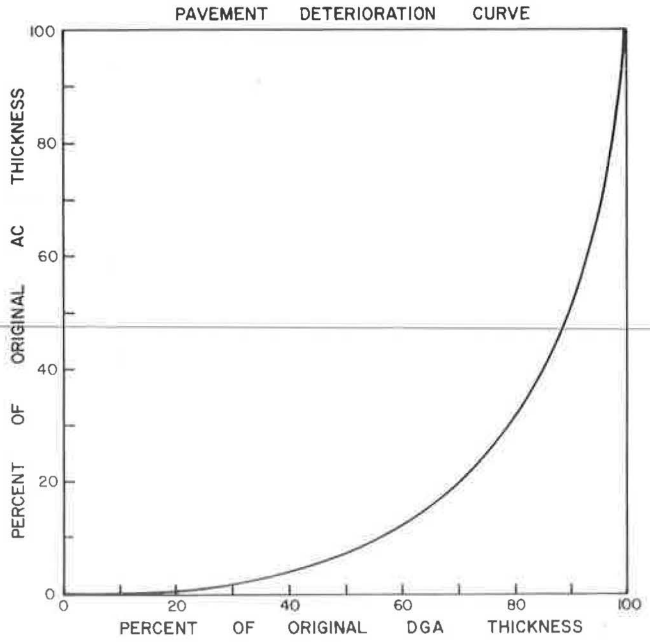
Figure 8. Relationship between percentage of net worth of pavement after beginning of disintegration and percentage of design thickness.



12a) and the difference between these values is greater than the difference for theoretical deflections. A foundation problem or lack of supporting capability is indicated by increased magnitudes of all field deflections and a no. 1 projection greater than the no. 1 sensor deflection (Figure 12b).

Log-log plots of no. 1 projected deflections versus no. 1 sensor deflections can be used to identify variations in pavement structure (see Figure 13). In these figures, the solid lines show the theoretical relationships of no. 1 projected deflections and no. 1 sensor deflections for a constant structure and AC modulus. Subgrade moduli vary along the line. The points about the line represent

Figure 9. Pavement-deterioration curve: relationship between percentage of original thickness of asphalt concrete and percentage of original thickness of dense-graded asphalt.



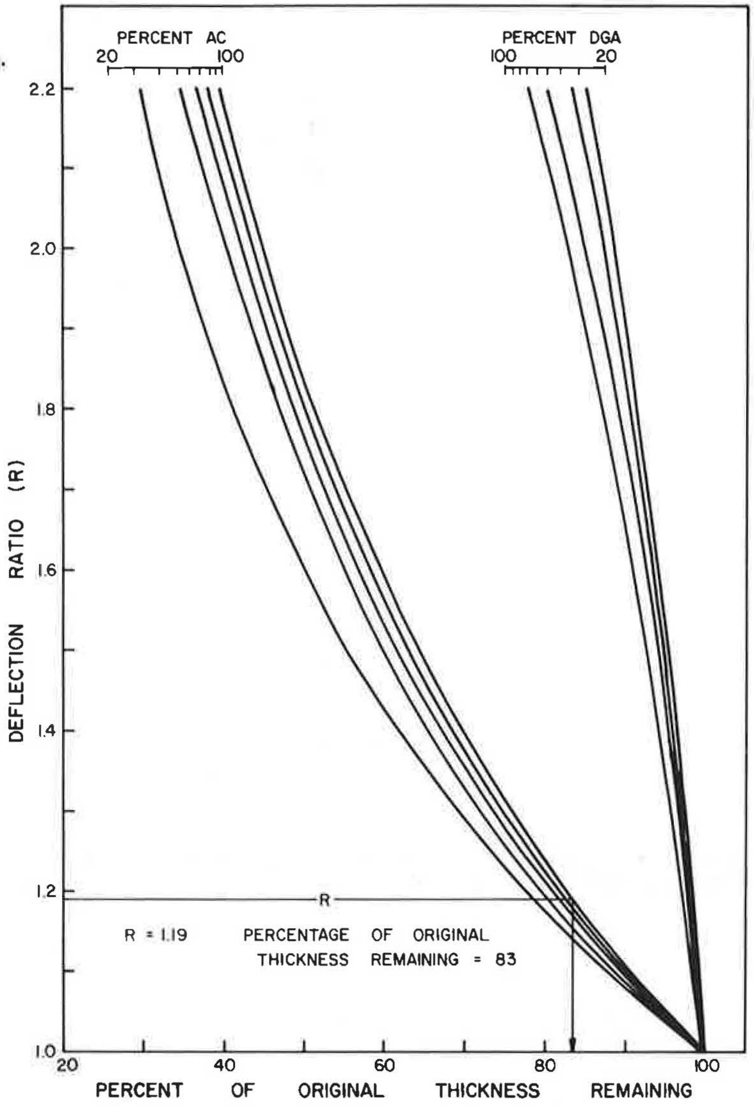


Figure 10. Relationship between ratio of deflection for effective behavior to deflection for theoretical original structure and percentage of original thicknesses remaining.

field-measured deflections. The variation in position of the theoretical line due to changes in the magnitudes of the deflections by ± one unit [0.254 μm (0.000 01 in)] and the associated change in calculated no. 1 projection is indicated by the two dashed lines. The zone inside these lines represents a normal variation due to reading the meters of the road rater.

The following situations have been observed from limited field evaluations.

1. Test data that lie within the zone of normal variation and show relatively low deflection magnitudes: This type of data is indicative of new construction that consists of high-quality materials and had good construction control.
2. Test data that plot on the lower side of the zone of normal variation: This type of data is indicative of a pavement structure in which the subgrade has remained in good condition but cracking or some other problem has caused deterioration of the slab.
3. Test data that plot in the higher range of the zone of normal variation: This type of data is indicative of either of two conditions—changes in type of soil with the pavement remaining in good condition and the layers acting in concert or a deteriorated slab coupled with excessive water content in the subgrade and, again, the layers acting in concert.
4. Test data that plot above the zone of normal variation: This type of data is indicative of subgrades that have an excessive water content.

The fourth condition and pattern of deflections was confirmed by test data obtained in Huntington Beach, California (20). In an investigation there, road rater tests were performed, the pavements were cored, subgrade samples were obtained, and the moisture contents of the subgrade were determined. In those locations that had high water contents (possibly free water) the difference between the no. 1 projected and measured deflections was considerably greater than the theoretical analyses would have indicated. One possible explanation is that water is a much better transmitter of sound or vibrations than is soil. Thus, vibrations are transmitted more easily and their magnitudes remain greater at a fixed distance from the source than those transmitted through normal subgrades. Therefore, the no. 2 and no. 3 sensors measure higher deflections for soils that have excessive water than for those soils that have normal water contents.

Figure 11. Confirmation of determination of effective structure.

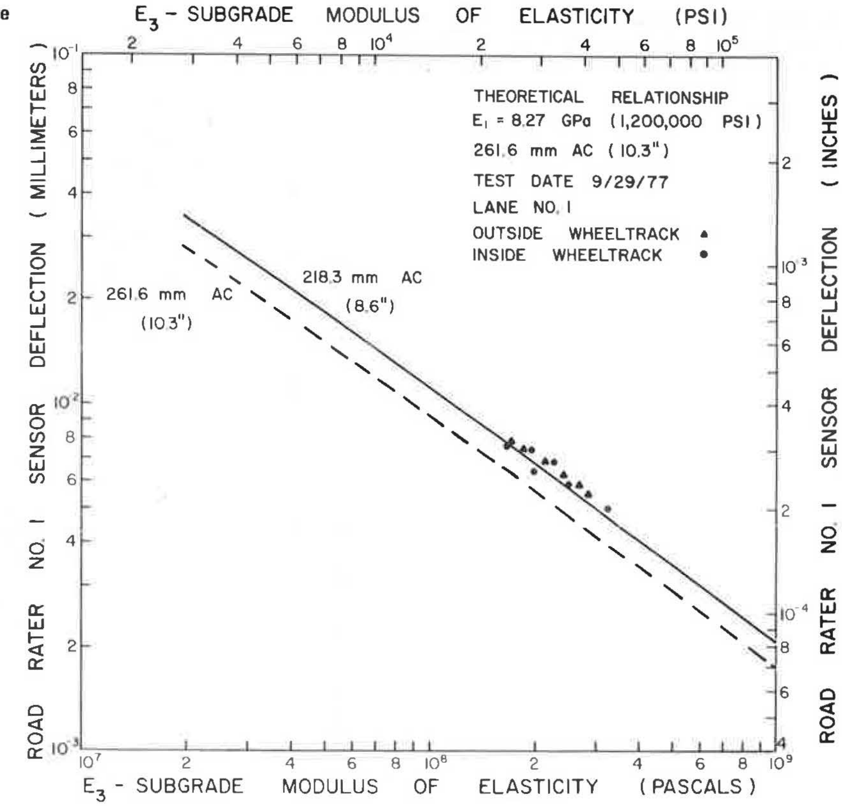
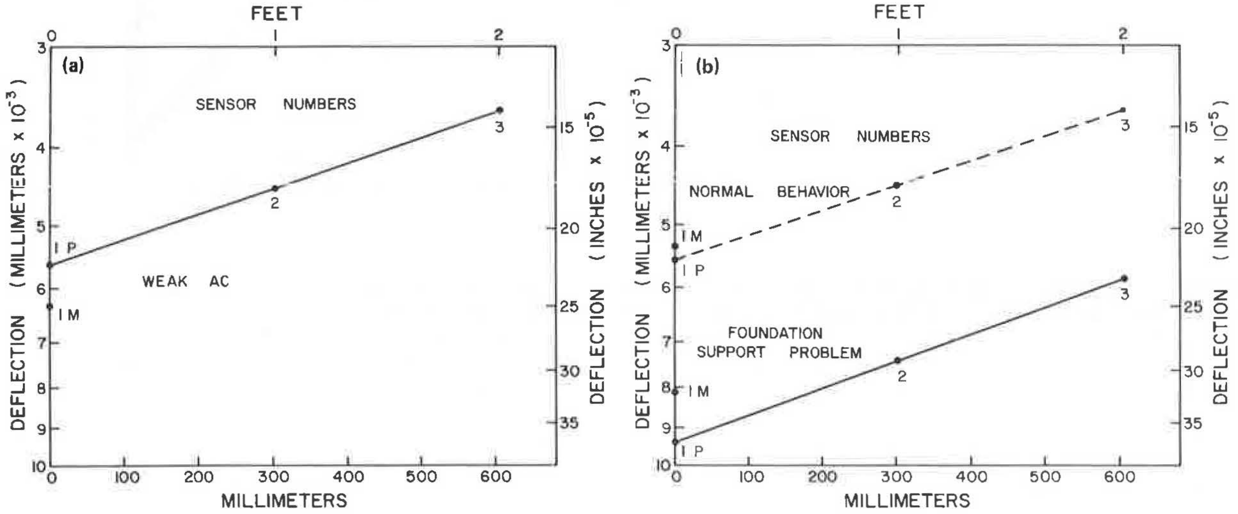


Figure 12. Relationship between deflection and distance from load head and determination of no. 1 projection: (a) pavement that has a weak asphalt concrete layer and (b) pavement that has a foundation-support problem.



SUMMARY

1. Dynamic deflections measured by the road rater have been rationally analyzed and duplicated by elastic theory.
2. Road rater deflections have been used to estimate in-place subgrade moduli.
3. A system has been developed that relates the deflection behavior of a pavement to its effective layer thicknesses of new-quality materials. These effective layer thicknesses can be considered as representative of the residual structure after deterioration and used as inputs for overlay design.
4. A method of analyzing road rater deflections has been developed that makes it possible to identify the type of deterioration in the pavement structure.

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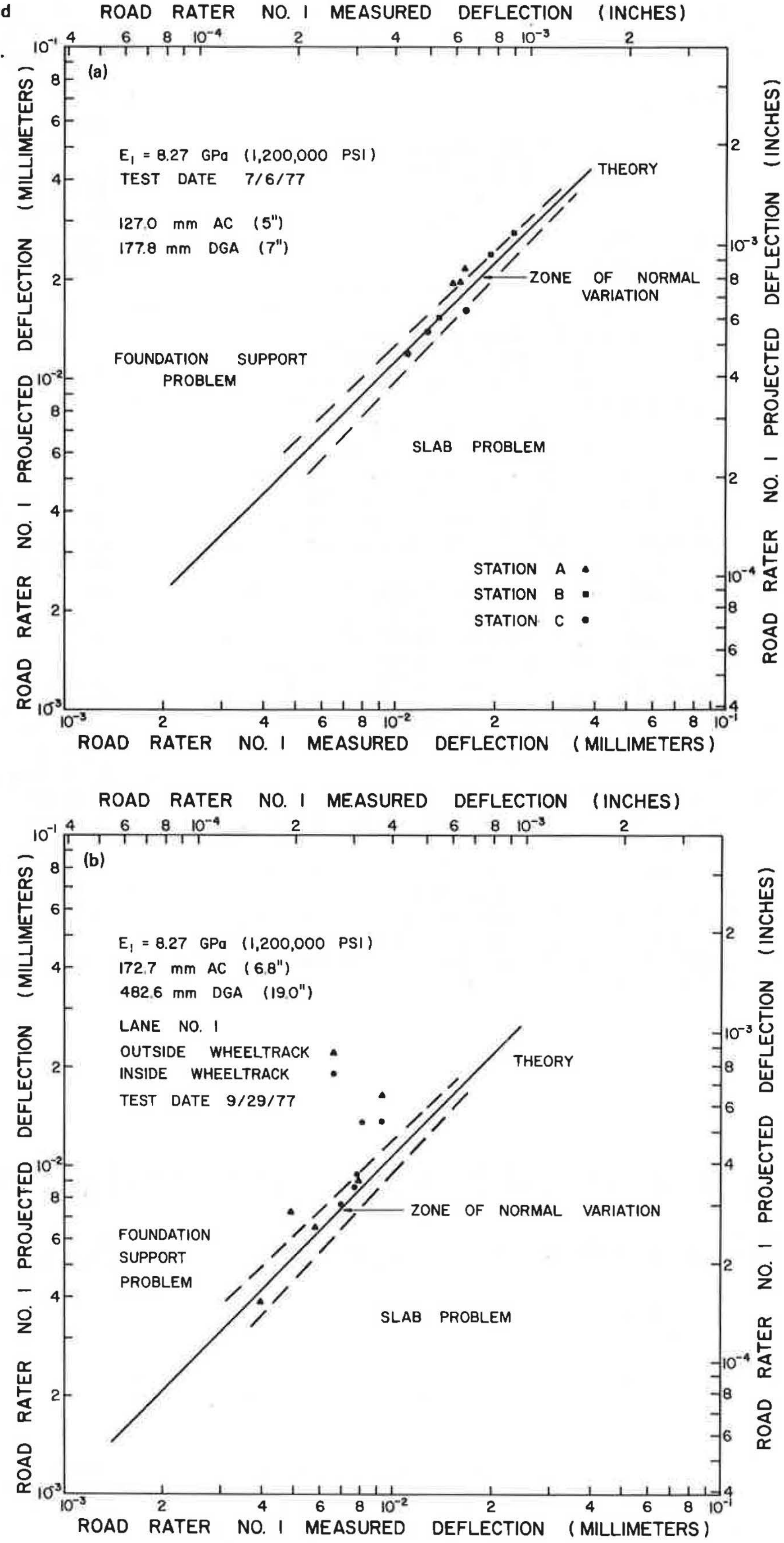
Figure 13. Relationship between no. 1 projection and no. 1 sensor deflection: (a) normal pavement and (b) pavement that has a foundation-support problem.



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A Rational System for Design of Thickness of Asphalt Concrete Overlays

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A method for designing asphalt concrete overlays is presented that uses (a) the Kentucky proposed design curves, (b) an estimation of future traffic and the associated fatigue (five procedures are given according to type of information available), (c) the strength of the subgrade on the subject project (as determined by laboratory California bearing ratio tests or results of dynamic in-place tests such as road rater measurements), and (d) the present condition of the existing pavement (as determined from dynamic in-place tests, roughness measurements, or the present serviceability index). Deterioration is expressed as reduced thicknesses of new-quality materials that produce the same measured dynamic deflections. The overlay thickness required is the total thickness for the predicted traffic minus the effective or reduced thickness of the existing pavement.

The method for the design of overlay thicknesses presented in this paper has evolved from approximately 30 years of experience in thickness design. The earliest pavement-thickness design methods used in Kentucky were based on 22-kN (5000-lbf) equivalent wheel loads