Field and Laboratory Evaluation of Asphalt-Treated Base and Full-Depth Pavements in Ohio

Kamran Majidzadeh, George J. Ilves, and Faiz Makdisi-Ilyas, Department of Civil Engineering, Ohio State University

This paper reports the results of laboratory and field evaluation of three full-depth asphaltic pavement in Ohio. The performance of these flexible pavements was investigated in the field by using nondestructive dynamic deflection measurements, and the in situ pavement moduli were calculated. The data presented show that the in situ pavement moduli and other deflection parameters can accurately characterize pavement conditions. The field specimens were evaluated in the laboratory under controlled conditions, and the dynamic moduli, tensile strength, and fatigue life were determined. Based on the results of laboratory data and fatigue life simulation, the structural equivalency of asphaltic concrete surface and base course layers was also determined.

During their service lives, bituminous pavements are exposed to environmental and traffic loading conditions that can alter the characteristics of paving materials and reduce anticipated performance. Exposure of bituminous mixtures to environmental elements results in a progressive hardening of the asphaltic binder, which, in turn, effects rigidity of the pavement structure at the expense of the flexibility needed to withstand repeated loading conditions. Such changes in the material characteristics can result in pavement cracking and, subsequently, in reduction of anticipated pavement life.

Various forms of pavement disintegration have been attributed to the durability of asphaltic materials. However, the rate of structural deterioration in the field is doubtless affected by other properties, such as asphalt percentage and type, aggregate type and gradation, loading, and environmental conditions. The structural deterioration due to the combined influence of repeated load applications and adverse environmental effects generally takes two distinct forms: cracking and rutting.

The problem of damage accumulation and the resulting pavement deterioration due to cracking has been studied extensively in the last 30 years, and considerable research has been conducted on fatigue behavior of asphalt mixes. In this paper, the results of an investigation of the durability of flexible pavements relative to crack resistance of bituminous mixtures under actual traffic and environmental conditions are reported. This study, concerned with the improvement of material selection specifications and revision of design and construction practices, was divided into three phases:

1. A laboratory investigation to determine mixture characteristics affecting the crack resistance of bituminous paving mixtures;
2. A field study to determine the variability of material parameters affecting crack resistance and to determine the significance of various material characteristics; and
3. Establishment of guidelines to improve material selection specifications, prediction of field performance based on results of laboratory and field studies, and examination of the applicability of those techniques developed to predict material response.

The results of phase 1 of this study were reported previously (<u>1</u>). The results of phase 2, which involved analysis of crack resistance parameters, evaluation of in situ support conditions, evaluation of paving component materials, and prediction of pavement performance, are presented here.

FIELD INVESTIGATION AND VERIFICATION

Site Selection and Evaluation

Three flexible pavements were selected for detailed laboratory and field evaluation. The following project sites were chosen in consultation with the Ohio Department of Transportation: project 673-70, Ohio-161 in Union County; project 4-71, Ohio-316 in Franklin County; and project 432-70, Ohio-124 in Pike County.

1. Project 673-70. Project 673-70 is a flexible, full-depth pavement constructed on Ohio-161, section 11.24. The total project length is slightly more than 1.6 km (1 mile) and consists of 23 cm (9 in) of asphalt-aggregate base (Ohio mix item 301), 3.2 cm (1.25 in) of asphaltic concrete (Ohio mix item 402), and 3.2 cm (1.25

Publication of this paper sponsored by Committee on Characteristics of Bituminous Paving Mixtures to Meet Structural Requirements.

in) of asphaltic concrete (Ohio mix item 404).

2. Project 4-71. Project 4-71 is a 4.3-km-long (2.7-mile) flexible pavement in the southeastern section of Columbus and consists of 10.2 cm (4 in) of granular base (Ohio mix 304), 15.2 cm (6 in) of asphalt-aggregate base course (mix 301), and asphaltic concrete layers of 3.2 cm (1.25 in) of mix 402 and 3.2 cm (1.25 in) of surface course mix 404.
3. Project 432-70. Project 432-70 is a full-depth bituminous concrete pavement structure located in Pike County on Ohio-124. Although the total project length is more than 6.4 km (4 miles), the test section for this study was located between stations 970 and 1080. The pavement structure consists of 23 cm (9 in) of bituminous-aggregate (tar) base course (mix 301), 3.2 cm (1.25 in) of asphaltic concrete (mix 402), and 1.9 cm (0.75 in) of asphaltic concrete surface course (mix 404).

Selection of test sites was based on subgrade support values and their variability within each project. A preliminary investigation of the subgrade of potential test locations within each site was carried out by using Dynaflect deflection. The dynamic deflection measurements were then translated into load spreadability characteristics and modulus response of the subgrade soil. Based on results of this preliminary evaluation, sections with good, intermediate, and poor support conditions were selected.

In addition to the preliminary subgrade evaluation, dynamic deflection measurements were carried out on the entire length of the projects during construction. Deflection testing preceded final proof rolling of the subgrade.

The pavement layers were also investigated by using Dynaflect instruments. Upon construction of each intermediate layer, dynamic deflection measurements were carried out at 15.3 and 30.5-m (50 and 100-ft) intervals. Areas showing high deflection or questionable displacement under dynamic loads were tested at closer intervals to approximate zones of potential problems. The results of deflection measurements were then analyzed to obtain an estimate of the moduli of the component layers.

To evaluate the engineering properties of the pavement component layers, field specimens were taken from each pavement layer. During construction, the layers and locations to be sampled were identified and covered with a double layer of plastic sheet. After compaction but before placement of the upper layers, the plastic-covered sections were sawed, and field specimens were retrieved.

Specimen retrieval involved sawing a section 1.2 by 1.2 m (4 by 4 ft) and dividing it into smaller sections. For the asphalt-aggregate base course (mix 301), field specimens were 10.2 by 10.2 by 122 cm (4 by 4 by 48 in). The asphalt concrete binder and surface course (mixes 402 and 404) were sampled together as one layer because the 404 layer was not thick enough to tolerate the sawing and sampling operation. These field specimens were sawed to dimensions of 5.1 by 5.1 by 61 cm (2 by 2 by 24 in). To ensure that specimens were representative of subgrade support characteristics at selected test sections required that undisturbed specimens be obtained from locations identified in the preliminary study.

Moisture-density and temperature variations within the subgrade were accurately evaluated at each site by using in situ instrumentation. The instrument sites were selected during the preliminary site evaluation. Deep-probe nuclear gauge pipes were installed at these sites and properly protected by special covers. Temperature measurements were performed by using thermocouples installed at different depths.

Field Evaluation

The field investigation and site evaluation programs used in this study were initiated during construction and continued after completion of the paving operation. The program included routine daily visits to each project site during construction and seasonal visits afterward as needed.

The structural condition of the pavement was evaluated in the field by using nondestructive dynamic deflection measurements. The dynamic deflection equipment (Dynaflect) induces a constant dynamic load of constant frequency and, by using geophones or sensors, detects displacements in the layered system. From the slope and magnitude of the measured displacement profile, the characteristics and support capacity of each test layer can be determined. The results of dynamic deflection measurements can then be analyzed to obtain an estimate of the pavement layer moduli. These analytic procedures are reported elsewhere (2).

The theoretical concepts and mathematical relationships involved in the use of dynamic deflections have been discussed in more detail (2) and will not be repeated here; but, briefly, theoretical and experimental data have indicated that each test layer can be evaluated by using the following performance parameters:

w_1, the maximum deflection or first sensor reading, is a measure of the pavement's structural characteristics and support conditions;

$SCI = w_1 - w_2$, the surface curvature index, is predominantly an indicator of the structural conditions of the surface layer;

$BCI = w_4 - w_5$, the base curvature index, measures the base support conditions;

$$SP = \left(\sum_{i=1}^{i=5} w_1 \Big/ 5w_1 \right) 100,$$ spreadability or average deflection as a percentage of maximum deflection, measures the load-carrying capacity and stiffness ratio of the pavement structure; and

w_5, the fifth sensor reading, has been shown to be an indirect measure of subgrade support moduli.

Dynamic deflection measurements were carried out on the subgrade and pavement structures. The subgrade support moduli were calculated by using either the Ohio elastic modulus programs or suitable graphic procedures (Figure 1).

The measured deflection profiles were found to be dependent on the structural and material variables as well as prevailing environmental conditions. The construction of successive layers of asphaltic pavement components increases the support characteristics of the pavement component layers and results in a reduction of maximum deflection and surface curvature index. The spreadability or percentage of SP, as a function of the moduli ratio E_1/E_2, is affected by the relative stiffness of the pavement structure as well as its support characteristics E_2.

Figure 2 shows typical variations of the pavement deflection profile for the component layers of project 673-70. As noted, the construction of successive layers of 301, 402, and 404 resulted in a reduction in the maximum deflection and surface curvature index. The spreadability of all three layers also increased, indicating a stiffening or increase in slab action.

Figure 3 shows the maximum deflection measurements for project 432-70. This project exhibited the greatest magnitude of variability in deflection when compared to the other two pavement systems.

The results of dynamic deflection measurements were

Figure 1. Subgrade modulus values for project 4-71.

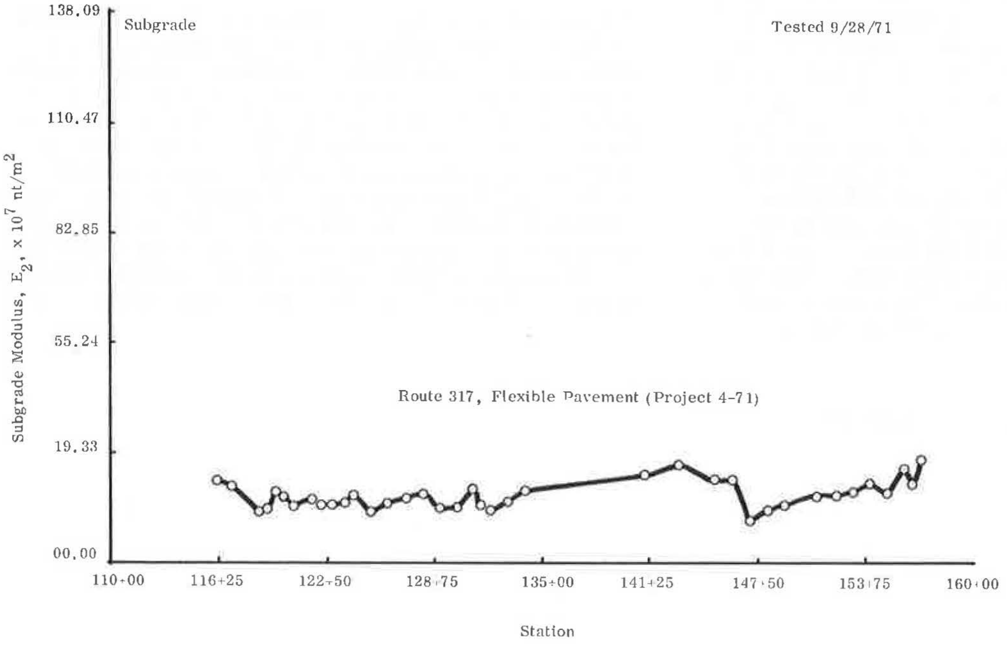
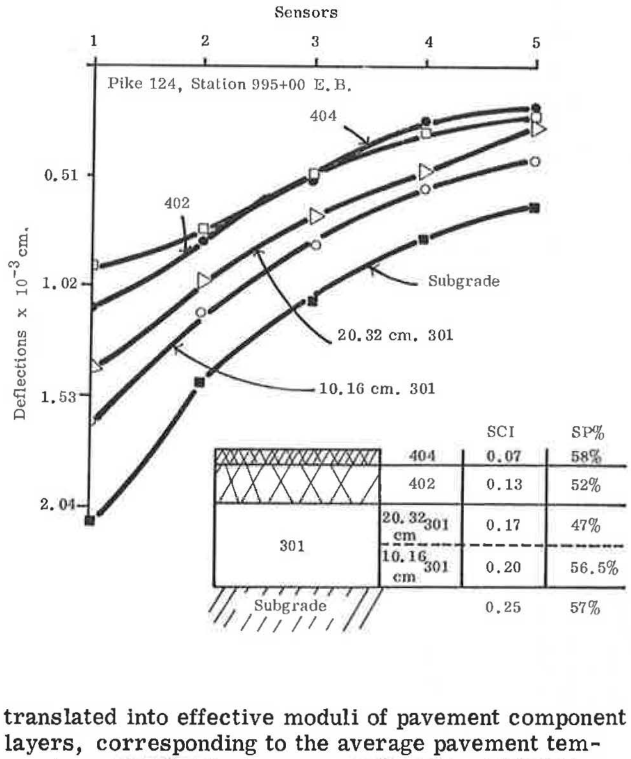


Figure 2. Variation of pavement deflection with layered structure stiffness.



translated into effective moduli of pavement component layers, corresponding to the average pavement temperature at which tests were performed. Figure 4 shows the average or effective moduli of the asphalt layer E_1 of project 432-70. The time and temperature of testing appear to have significant influence on the calculated modulus of the structure; the pavement modulus E_1 varies with the station site, time of measurement, and climatic conditions prevailing during the test. This temperature dependency of pavement response is also reflected in the measurements of deflection, SCI, and spreadability. Figure 5 shows the variation of deflection profile with air temperature. It was found that lower pavement deflections undoubtedly correspond to lower temperatures.

Figures 6 and 7 show variations of spreadability and SCI with air temperature. The data in these figures represent measurements conducted on the three projects at different times of the year. Figure 8 shows the variation of average pavement modulus, as calculated by the Ohio elastic moduli program, in terms of the average pavement temperature. That figure also shows the modulus-temperature relationship of asphaltic concrete surface course (404), as reported by other researchers. The lower values of in situ moduli are due to the average moduli effects of mixtures 404, 402, and 301. The variability of these measured moduli (Figure 8) not only shows the temperature dependency of the material but also reflects the inherent variations in the engineering properties of asphaltic mixtures and the pavement structure response at different stations.

LABORATORY EVALUATION OF FIELD SPECIMENS

Material Preparation

The laboratory study was initiated to evaluate the material characteristics of the field specimen. This investigation was primarily aimed at determining those material characteristics that affect the performance of flexible pavement structures. The laboratory study was also aimed at verifying the applicability to field-compacted specimens of fracture and crack resistance concepts developed previously.

Field specimens procured at selected sites of each project included both core and beam specimens. The cores were taken at the full depth of the pavement so that all layers of 301, 402, and 404 mixtures would be included. The beam specimens, on the other hand, were sawed from the lower and upper layers of 301 and from layers 402 and 404 together.

These field samples were sawed to prepare specimens of uniform dimensions, as needed for laboratory testing. The cylindrical specimens were first sawed at each end and then capped with capping compound.

The beam specimens were prepared for both fatigue and dynamic modulus testing. The specimens used for dynamic modulus testing were obtained from a 402-404 composite mix layer. The asphaltic beams were then sawed into beams of separate 404 and 402 layers, each 5.1 cm (2 in) wide and 30.5 cm (12 in) long, with a variable thickness (approximately 1.8 to 2.5 cm or 7 to 10 in). Before these 402 and 404 beams were sawed and separated, each field specimen was X-rayed to determine the boundary between the 404 and 402 layers.

The beam specimens used for fatigue testing required less preparation because the beams were cut to almost the required dimensions in the field. However, most specimens had to be trimmed to obtain smooth testing surfaces for proper seating of the beams.

Testing Procedures

The evaluation of material characteristics was carried out by using the loading function, the pattern and frequency of load-time history, and testing procedures discussed previously. Dynamic moduli of the 301 cylindrical specimens were determined by using half-sine dynamic loads. A static load of 89.3 N (20.1 lbf) was used for seating, and a maximum dynamic load of 1340 N (300 lbf) or 172 kPa (25 psi) was used. Vertical deflections were measured by using a Roving LVDT where readings are taken at four obliquely opposite points of the loading head.

The elastic dynamic modulus of the asphaltic concrete beams of layers 402 and 404 was determined by using a

Figure 3. Maximum deflection at stations on project 432-70.

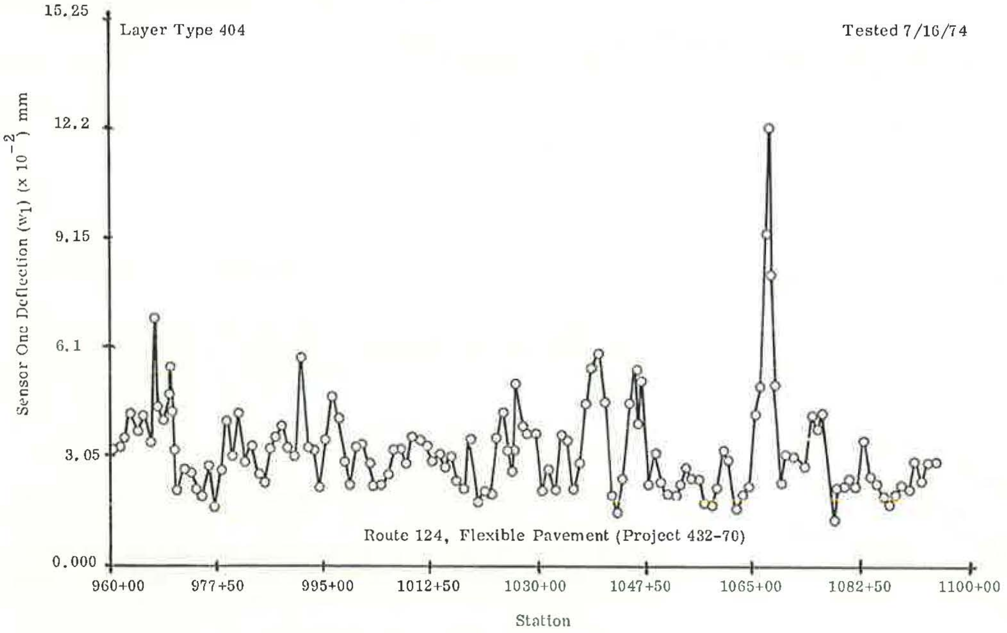
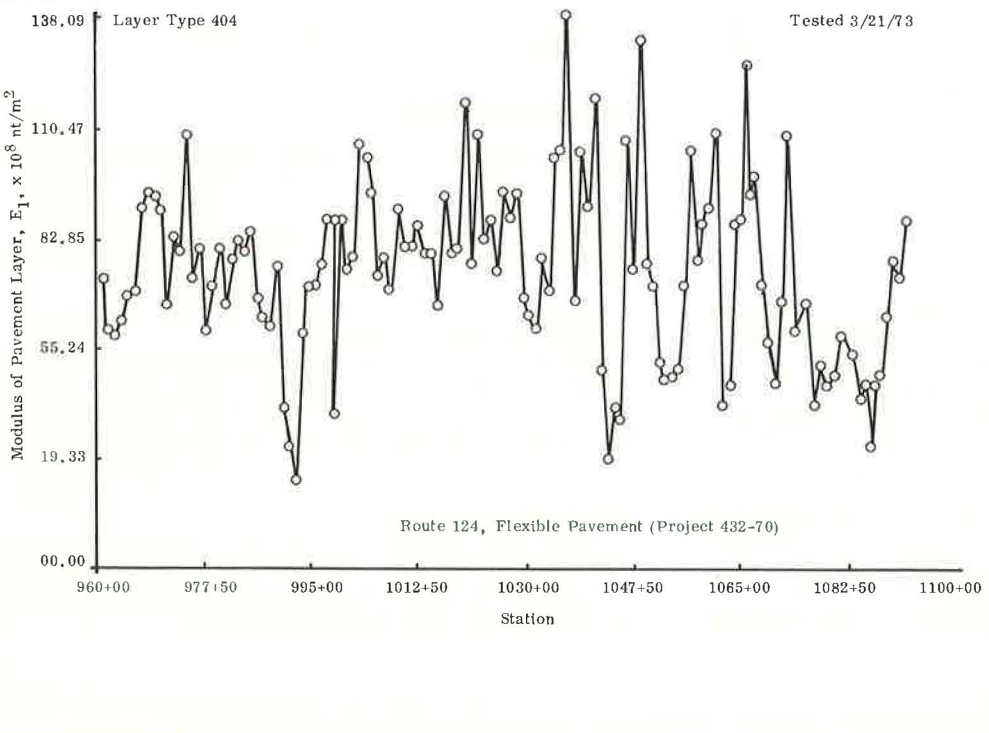
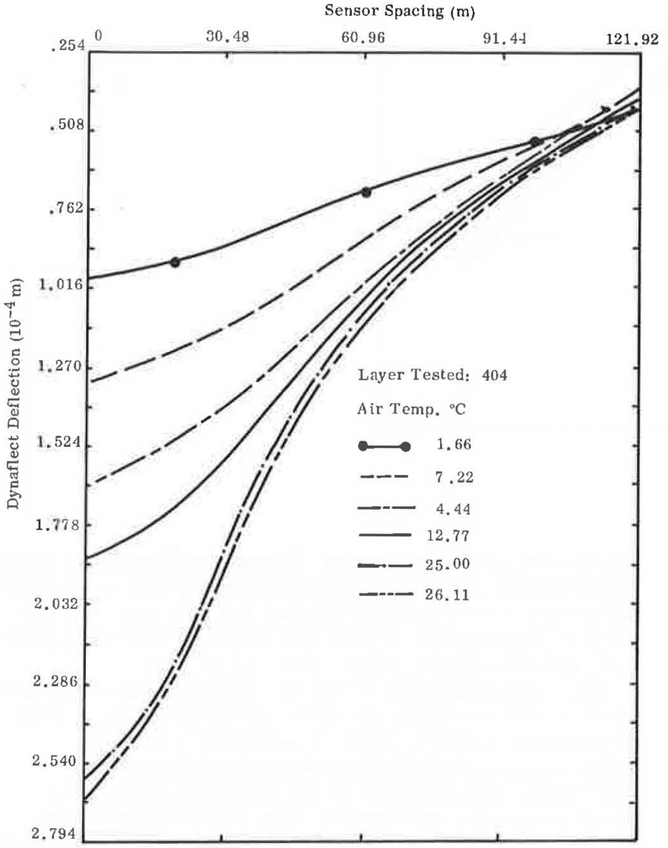


Figure 4. Equivalent pavement layer modulus.



simply supported beam setup in which the specimen was subjected to a half-sine dynamic load superimposed on a small static load of about 4.5 N (1 lbf). The load was applied at the midspan position, and the resultant deflection was measured with an LVDT placed under the midspan of the beam.

Figure 5. Variation of deflection with air temperature.



Fatigue testing of the field specimens was performed in a manner similar to the procedure discussed earlier. All field specimens of layers 402-404 and 301 were supported on an elastic foundation having a modulus value of 1034 kPa (150 lbf/in^2. The 301 beams, because of their length, were tested on an elastic foundation 13 by 10.2 cm (5 by 4 in) in cross section and 1.2 m (4 ft) long. For these specimens, the load was applied with a 10.2 by 10.2-cm (4 by 4-in) steel loading head resting on a cushion of hard rubber.

In addition to the modulus and fatigue life determinations, measurement of indirect tensile strength σ_y was also included in the experimental program.

Analysis of Results

The experimental procedures followed in this study included determining the dynamic modulus of asphaltic layers, indirect tensile strength, and expected fatigue life. The detailed experimental and analytical procedures for determining these parameters have been presented in the literature and will not be repeated here.

The results of moduli determinations of mixtures 402, 404, and 301 at different test temperatures indicate that the variations of these mixture moduli with test temperatures follow previously recorded trends. These laboratory results also reflect the variability of pavement layer moduli with project, site, and specimen station. These moduli vary at different stations as well as within each test location (Table 1).

The results of indirect tensile strength σ_y tests conducted on the field specimens and at various temperatures are shown in Figure 9.

Analysis of fatigue of field specimens was carried out in accordance with test procedures and specifications reported previously (1). As has been reported, the fatigue crack growth law for asphaltic systems can be simplified by a power law equation given by

$$dc/dN = A K^n \qquad (1)$$

The results of fatigue experiments and evaluation of fatigue life parameters A and n are discussed by

Figure 6. Variation of SCI with air temperature.

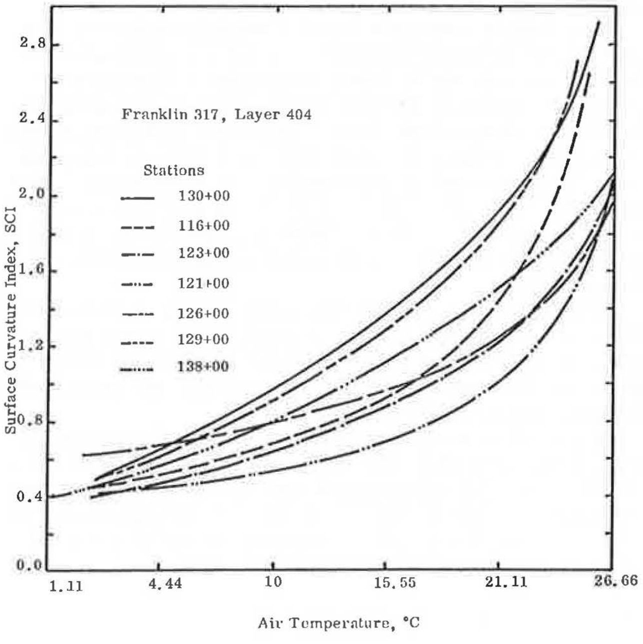


Figure 7. Variation of spreadability with air temperature.

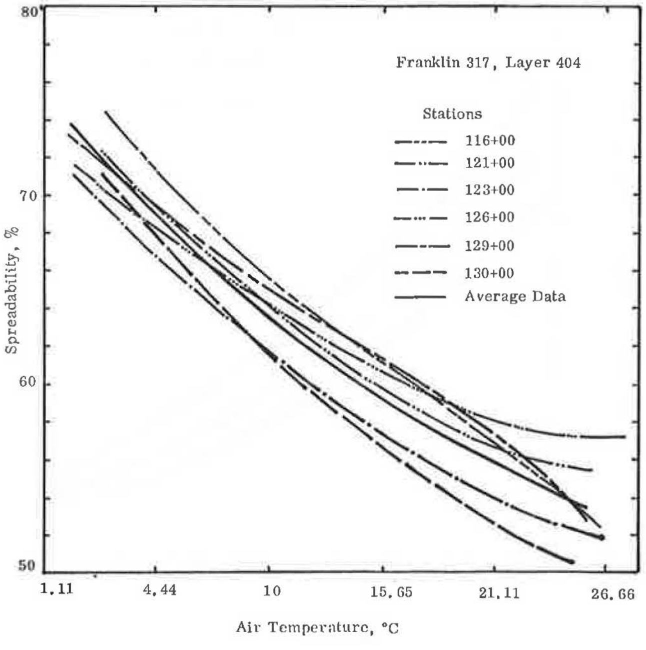


Figure 8. Modulus-temperature relation.

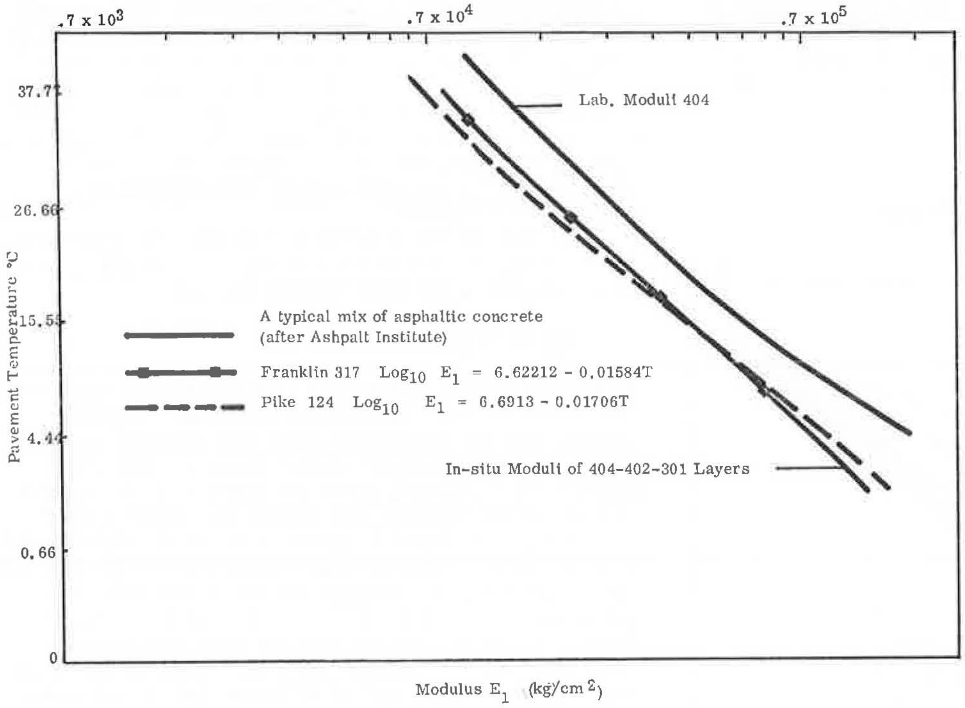
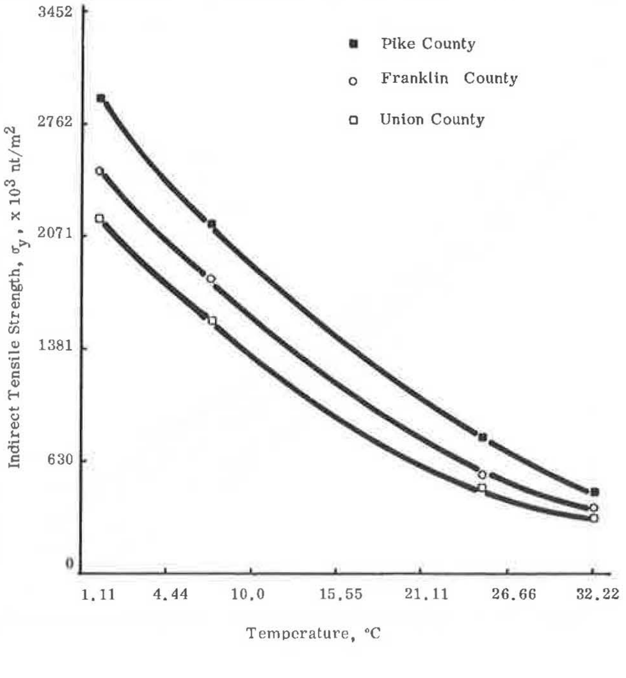


Table 1. Summary of fatigue parameters A and E*.

Project	Type of Asphaltic Sample	A		E*	
		Mean	σ	Mean	σ
Franklin 317	402-404	0.743	0.352	3473	206
Union	402-404	3.131	1.885		
Pike	402-404	12.419	5.84	349	357
Union	301	5.189	2.914	204	101
Pike	301	3.129	2.383	250	249
Franklin 317	301			201	197

Note: A-values are given in billionths; E*-values are given in thousandths.

Figure 9. Ultimate tensile stress T variations for mix 301.



Majidzadeh (3). The results of experimentation on composite beams of 402-404 and 301 indicate that n, in most instances, varies between 2.0 and 4.0. In fact, the results of experiments on 301 specimens at room temperature indicated that n ranges from 2.1 to 3.0.

The observed lower values in n might imply that there exists a retardation of the crack growth process. This retardation of crack growth is probably due to the asphalt-aggregate interface characteristics of field specimens, as compared to the idealized and homogeneous laboratory specimens. The reduction in crack growth rate might also be attributed to the fact that cracks do not always propagate in a straight line and the crack surfaces change their direction. It has been reported that the parameter n is affected by the magnitude of the local stress field ahead of the crack tip.

The fatigue constants A and n exhibit variations that are due to a number of factors, such as differences in testing procedures by different people, differences in inherent material characteristics between test samples, and temperature dependence. Because of the variability of A and n, fatigue life prediction is a tedious task and often leads to cumbersome evaluation procedures. The simplification of the power law, assuming that n is a constant and independent of testing procedures, could result in significant improvement in the evaluation of fatigue life.

Therefore, an attempt was made in this investigation to develop a unified method of analysis of crack growth data where error is minimized and to carefully evaluate the simplified as well as the generalized versions of the fatigue crack growth law.

The review of various theories and analytical procedures indicated that, depending on the degree of mathematical and statistical complexity desired, various procedures could be used for determining the parameter n. For example, the crack growth resistance of asphaltic mixtures could be represented by

$$\text{Rate of crack growth} = A_1K^{n_1} + A_2K^{n_2} + A_3K^{n_3} \tag{2}$$

where A_1, A_2, and A_3 and n_1, n_2, and n_3 can be obtained by statistical analyses of data.

Although the use of equation 2 might provide a higher correlation coefficient on the other hand, it might also hinder the practical application and usefulness of the fracture mechanics approach as a design and material selection tool.

However, because it is desirable from a practical viewpoint for the crack propagation law to be as simple as possible, the use of a single power law with constant n given by

$$\text{Crack growth rate} = A\,K^n \quad (3)$$

has been investigated. In equation 3, A is a material constant and can be represented by an average $\bar{A}$ and a standard derivation σ. The parameter n is also a material constant. The results of analysis indicate that for mixtures 402 and 301, having relatively large aggregates, n could be selected as equal to 2.0. Table 1 gives the fatigue constants A and E^*.

ANALYSIS OF PAVEMENT LAYER EQUIVALENCY

The structural layer equivalency of asphaltic mixtures was investigated by conducting stress analysis by using elastic layer programs. The analysis consisted of a pavement design simulation using varying thicknesses of 404-402 and 301 mixtures. The tensile strain at the bottom of the pavement layer was calculated and the equivalencies were determined by using equal strain concepts. Then the equivalencies were determined by using equal fatigue life concepts.

These analyses indicated that equivalency concepts also depend on the pavement structural arrangement. When the pavement design is implemented by placement of layer 404 or 301 directly on the subgrade, the coefficients are different. In such a case, it has been shown that 10.7 cm (4.2 in) of 404 mix, when constructed on a subgrade, is equivalent to 14.5 cm (5.7 in) of 301 mix. That is, 2.5 cm (1 in) of 404 mix is equivalent to 3.4 cm (1.35 in) of 301. In terms of AASHTO structure coefficients, this corresponds to $A_1 = 0.45$ for mix 404 and $A_2 = 0.33$ for mix 301.

However, when a pavement is constructed with a sequence of 301, 402, and 404 layers, the structural coefficients differ from the above case. The analysis of equivalency values for various structural arrangements indicated that, when 2.5 cm (1 in) of 404 and varying thicknesses of 301 are used, the structural equivalency value is found to be 2.5 cm (1 in) of 404 equivalent to 2.8 cm (1.1 in) of mix 301.

Similarly, when the fatigue life was used as a criterion for structural equivalency, 23.4 cm (9.2 in) of 404 was equivalent to 26.7 cm (10.5 in) of 301, or 2.5 cm (1 in) of 404 was equivalent to 2.8 cm (1.1 in) of mix 301.

As a result, it might be concluded that, for mixtures studied in this investigation, 2.5 cm (1 in) of mix 404 may be taken as equivalent to 2.8 cm (1.1 in) of mix 301. Therefore, if it is assumed that the AASHTO structural coefficient of asphaltic concrete surface base is $A_1 = 0.45$, then the coefficient of asphalt-aggregate base is 0.40, a ratio of 1.0/1.13.

SUMMARY AND CONCLUSIONS

In this paper the structural response and performance characteristics of three selected flexible pavements are investigated. The study included a detailed field evaluation of pavement deflection response under Dynaflect dynamic loadings and a laboratory evaluation of field core and beam specimens. The following conclusions are drawn:

1. Dynamic deflection measurements and analysis of deflection profile can provide an accurate in situ characterization procedure for flexible pavements.
2. The in situ dynamic modulus of pavement layer E_1, as determined by using deflection profile, agrees reasonably well with the laboratory values of moduli of asphaltic concrete.
3. Laboratory data on dynamic modulus, indirect tensile strength, and fatigue life exhibit variabilities associated with material type, test sites and stations, and environmental factors.
4. A multilayer elastic analysis of structural layer equivalency of pavement layers indicates that 2.5 cm (1 in) of asphaltic concrete surface course is equivalent to 2.8 cm (1.1 in) of asphaltic base course layer 301.
5. The structural equivalency analysis using the fatigue failure mode indicates that 2.5 cm (1 in) of asphaltic concrete surface course 404 is equivalent to 2.8 cm (1.1 in) of asphaltic concrete base course 301.

REFERENCES

1. Fatigue of Compacted Bituminous Aggregate Mixtures. ASTM, Special Publ. 508, July 1971.
2. K. Majidzadeh. Dynamic Deflection Study for Pavement Condition Investigation. Ohio Department of Transportation, Final Rept., June 1974.
3. K. Majidzadeh. A Laboratory and Field Durability Study of Asphaltic Mixtures. Engineering Experiment Station, Ohio State University, Final Rept., EES 356, Sept. 1974.