Project Number ST 2019-7

Summary Report

METHODS FOR EVALUATING RESILIENT MODULI OF PAVING MATERIALS

sponsored by

The State of Alabama Highway Department
Montgomery, Alabama

Frazier Parker, Jr.
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The ELMOD backcalculation procedure was determined to be the best available for estimating moduli of three layer pavement models of typical Alabama flexible pavements. Simple procedures were developed to account for seasonal variations and to estimate average or effective moduli values for granular base/subbase and subgrade soils from limited FWD measurements. A procedure for adjusting asphalt-aggregate moduli to standard design temperature (70°F) was developed.

Laboratory moduli for asphalt-aggregate mixtures measured with indirect tension tests (ASTM D4123) produce moduli that compare well with moduli backcalculated from FWD pavement deflection basin measurements. Therefore, FWD or laboratory moduli input to thickness design procedures will be reasonably consistent for in-situ or new materials, respectively.

As expected, characterization of granular base/subbase was most difficult. There were some large differences between FWD moduli and laboratory moduli from triaxial testing (AASHTO T274). Although some inconsistencies in input to thickness design procedures may result, FWD moduli are recommended for characterizing in-situ granular base/subbase and typical values provided in the 1986 AASHTO Guide are recommended for new construction.

In general, good agreement was demonstrated between FWD and laboratory (AASHTO T274) moduli for subgrade soils. Therefore, FWD moduli for overlay design of existing pavements will be reasonably consistent with laboratory moduli for design of new pavements.

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ABSTRACT

The emergence of "mechanistic" pavement thickness design procedures or "semiempirical" design procedures, as contained in the 1986 AASHTO Guide for Design of Pavement Structures, has created a need for methods of evaluating elastic moduli of paving materials and subgrade soils. This study was conducted to develop methods for using FWD measurements to determine moduli of pavement materials.

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INTRODUCTION

The emergence of "mechanistic" design procedures or "semiempirical" design procedures, as contained in the 1986 AASHTO Guide for Design of Pavement Structures, has created a need for methods of evaluating elastic moduli of paving materials. In addition, the increased emphasis on pavement rehabilitation and maintenance activities has focused the need for in-situ evaluation. Laboratory testing procedures for resilient modulus and techniques for utilizing test results for characterizing pavement materials have been extensively researched. Standardization of test procedures has begun with AASHTO T274, Standard Method of Test for Resilient Modulus of Subgrade Soils and ASTM D4123, Standard Method of Indirect Tension Test for Resilient Modulus of Bituminous Mixtures. After years of utilization and evaluation of in-situ testing devices (beginning with the static Benkelman Beam and progressing through various vibratory loading devices), the falling weight deflectometer (FWD) has gained widespread acceptance as the best device available.

The Alabama Highway Department (AHD), in preparation for implementation of the 1986 AASHTO Guide and for utilization of the FWD, funded the study described herein. Objectives of the study were 1) to develop methods for using FWD measurements to determine moduli of in-situ pavement materials, and 2) to compare FWD estimated moduli with laboratory estimated resilient moduli in order to achieve consistent input to design procedures. The developed methodology were attuned to pavement materials and structures peculiar to Alabama.

DESCRIPTION OF STUDY

To accomplish study objectives the following five tasks were identified:

1. develop guidelines for modeling pavement structures for backcalculation of layer moduli,
2. select a backcalculation procedure,
3. develop factors for converting estimated moduli to standard design conditions,
4. compare moduli generated from FWD data with laboratory resilient moduli, and
5. develop recommendations for laboratory testing.

To accomplish tasks 1 and 2, data provided by the AHD Bureau of Materials and Tests from FWD measurements on the interstate system (designated 4R sites) were utilized. This data was used to develop techniques for modeling pavement structures and to compare layer moduli generated with four backcalculation procedures: ELMOD, CHEVDEF, BISDEF and ELSDEF. In addition, deflection basins generated for theoretical pavement structures with layered elastic computational models were used in evaluating backcalculation procedures.

To accomplish task 3, data provided by AHD Bureau of Materials and Tests from FWD measurements at eight sites distributed throughout the state were utilized. These sites were designated seasonal sites and had a wide range of pavement types. Data was collected at approximately two month intervals for a period of about three years, beginning in the fall of 1985. The range of climatic and pavement conditions at the sites, combined with seasonal variations allowed typical patterns to be established.

From these patterns conversion factors were developed to convert estimated moduli to standard design conditions.

To accomplish tasks 4 and 5, data from FWD measurements at 4R and seasonal sites were combined with a program of sampling, at selected sites, and laboratory testing. Cores of asphalt-aggregate mixtures and disturbed samples of granular base/subbase and subgrade soils were secured from trenches at selected sites. Asphalt-aggregate cores were tested in indirect tension and recompacted specimens of granular base/subbase materials and subgrade soils were tested in triaxial compression for resilient modulus. These resilient moduli were compared with moduli generated from FWD data to ascertain consistency of input for design.

BACKCALCULATION OF MODULI FROM FWD DATA

Procedures for modeling typical Alabama flexible pavements and backcalculating layer moduli from FWD surface deflection basins were studied by applying several backcalculation algorithms to FWD measurements on a number of real pavements and to deflection basins generated for a series of hypothetical pavements. Procedures for adjusting backcalculated moduli for seasonal and temperature variations were developed by applying the ELMOD backcalculation algorithm to FWD measurements made at eight seasonal sites over a period of approximately two years.

A three layer model was determined adequate for modeling typical Alabama flexible pavements. Asphalt bound and, where occasionally present, cement stabilized base courses should be included in layer 1.

The modeling of layer 2 is the most difficult. Flexible pavements in Alabama generally contain granular (soil-aggregate) base/subbase layer(s). Processed or stabilized roadbed layers comprising the top of the subgrade are also common. These processed roadbed layers contain select soil, may contain stabilizers and receive greater compaction than the remainder of the subgrade. They often have properties more like the base/subbase than the remainder of the subgrade and should be included in layer 2, unless density and moisture content measurements indicate that they are more like the subgrade.

The inclusion of a rigid boundary layer in the subgrade (layer 3) was determined desirable. Inclusion of the rigid boundary layer simulates "real" conditions, improves variability of estimated moduli and insures the correct relationship between E_2 and E_3, i.e., $E_2 > E_3$.

Four backcalculation algorithms were evaluated: ELMOD (1,2), CHEVDEF, BISDEF (3), and ELSDEF. CHEVDEF, BISDEF and ELSDEF are similar and involve an iterative process for selecting layer moduli that will produce a deflection basin matching the measured deflection basin to required tolerances. The primary difference between the three is the layered elastic computational model used in the algorithm for calculating load-deflections. ELMOD is based on the method of equivalent thickness (4,5) and is noniterative. It is provided by Dynatest Engineering and designed to analyze data from Dynatest FWD's. Based on the ease of operation, compatibility with data from Dynatest FWD's and estimated moduli that are at least as good as any of the other algorithms evaluated; ELMOD is recommended.

FWD load magnitude does not appear to be a major consideration for surface, base/subbase or subgrade modulus. However, the variation that may occur at some sites provides justification for testing at representative multiple load levels and use of average values.

Asphalt-aggregate modulus from the eight seasonal sites exhibited expected trends with temperature, although, there was considerable variability between sites reflecting the wide range of types of materials involved. The following relationship developed with data from all eight seasonal sites provided a good fit and agreed reasonably well with moduli-temperature relationships proposed by others (6,7):

$$E_1 = 322{,}000T^{(-1.591)} \ldots\ldots\ldots\ldots (1)$$

where

E_1 = asphalt-aggregate modulus (ksi)

T = temperature (°F).

Based on the composite data from the eight seasonal sites, the curve provided in the 1986 AASHTO Guide for adjusting modulus to design (70°F) temperature, was modified.

Simplified procedures were developed for accounting for seasonal variations in base/subbase and subgrade moduli. These procedures permit conversion of moduli backcalculated from FWD deflections at any time to average or effective moduli. To convert to average conditions the moduli should be multiplied by the following factors:

	January-May	June-December
Granular Base/Subbase	1.10	0.92
Subgrade	1.07	0.94

Adjusted moduli for granular base/subbase should be used for estimating structural layer coefficients and adjusted moduli for subgrade soils should be used as the effective roadbed resilient modulus.

LABORATORY TESTING

Samples were obtained from ten sites where FWD measurements had been made. These samples consisted of cores of asphalt-aggregate surfaces and disturbed samples of granular base/subbase and subgrade soils. In addition, water content and density measurements were made during sampling.

Asphalt aggregate cores were sawed into specimens approximately 2 inches thick for indirect tension testing. The specimens were tested according to ASTM D4123 at 41, 77 and 104°F. Weighted average moduli for each core and then averages for each site were obtained. The moduli exhibited expected trends with temperature, although, there was considerable variability between sites reflecting the wide range of material types involved. For comparison with FWD moduli, a load rate adjustement was applied. The following relationship developed from load rate adjusted data at all ten sites provided a good fit for the data:

$$E_1 = 80{,}700T^{(-1.284)} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

Within the temperature range 40-120°F, the above relationship agrees reasonably well with Equation 1. For temperatures below 80°F, the above equation gives lower moduli, but overall the comparisons between FWD and laboratory moduli were quite good. Ratios of FWD to laboratory moduli at 77°F ranged from 0.35 to 1.91 with a mean of 0.96 and a standard deviation of 0.44. The closeness to unity for the average ratio indicates that reasonably consistent moduli input to thickness design procedures can be achieved with FWD or indirect tension laboratory testing.

Triaxial specimens of granular base/subbase and subgrade soils were recompacted and tested according to AASHTO T274. Specimens were compacted using a kneading compactor to water contents and densities simulating, as near as possible, in-situ conditions. The use of 4 inch diameter specimens required removal of particles larger than 3/4 inch. Because of the lack of cohesion in some base/subbase material, additional water and special care was necessary during sample preparation and handling.

Results for granular base/subbase and subgrade soils were both presented in two ways. Plots of resilient modulus and first stress invariant ($\theta = \sigma_1 + 2\sigma_3$) and resilient modulus and deviator stress ($\sigma_d = \sigma_1 - \sigma_3$) were made. The relationship with the first stress invariant proved most useful and the familiar relationship

$$M_R = k_1 \theta^{k_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where

M_R = resilient modulus and

k_1 and k_2 = material constants

was fit to the data to quantify the material constants k_1 and k_2.

Comparison of the material constants for granular base and subbase with typical values provided in the 1986 AASHTO Guide revealed fair agreement. For damp base, the typical range for k_1 is 4 to 6 ksi and for k_2 is 0.5 to 0.7. Average values from the laboratory testing were k_1 = 6.09 ksi (standard deviation = 3.27 ksi) and k_2 = 0.43 (standard deviation of 0.14). For damp subbase, the typical range for k_1 is 4 to 6 ksi and for k_2 is 0.4 to 0.6. Average values from laboratory testing were k_1 = 5.45 ksi (standard deviation = 3.16 ksi) and k_2 = 0.45 (standard deviation = 0.19).

Laboratory moduli compared poorly with FWD moduli. Ratios of FWD to laboratory moduli ranged from 0.77 to 8.35 with an average of 2.83. The average greater than one indicates FWD moduli are consistently higher than those from laboratory testing. There are a number of possible reasons for this poor comparison including differences in moisture and density, removal of coarse (+3/4") particles from laboratory specimens, disturbance of cementation and/or thixotropic bonds during sampling, and inaccurate estimation of the in-situ state of stress.

Laboratory moduli for subgrade soils compared fairly well with FWD moduli. Ratios of FWD to laboratory moduli ranged from 0.61 to 2.73 with an average of 1.34. The average value greater than one indicates FWD moduli are generally higher than laboratory moduli. As with granular base/subbase, there are several possible reasons for the observed differences. The two most probable reasons are the effects of disturbance during sampling and inaccurate estimation of the in-situ stress state.

CONCLUSIONS AND RECOMMENDATIONS

Reasonable estimates of pavement material and subgrade soil moduli may be backcalculated using pavement surface deflection basins obtained with a FWD. Deflection basins should be measured at multiple loads representative of anticipated truck traffic. The average temperature at middepth of asphalt-aggregate surface layers should be obtained during FWD testing.

A limited number of small test pits should be excavated to determine layer thicknesses as well as mositure content and density for modeling base and subgrade layers. In some cases as-constructed information can provide reasonable estimates of layer thicknesses, but moisture content and density data will usually be needed to determine where improved roadbed, and possibly subbase, layers should be placed in the three layer model of the pavement structure.

The ELMOD backcalculation program, with a 3 layer pavement structure model, was relatively simple and efficient to use and provided reasonable moduli estimates. Compared to BISDEF, CHEVDEF and ELSDEF; ELMOD is easier to operate and requires less computation time.

Asphalt-aggregate as well as cement stabilized base layers shoud be included in layer 1. Base, subbase and, where density and moisture content measurements indicate applicable, improved roadbed layers should be included in layer 2. Subgrade and, where density and moisture content measurements indicate applicable, improved roadbed layers should be included in layer 3. The stiff boundary layer option in ELMOD should be used to limit the depth of layer 3.

To adjust the asphalt-aggregate modulus backcalculated from FWD data to a standard design temperature of 70°F, a modified version of a curve provided in the 1986 AASHTO Guide is recommended. Comparison of the modified curve and the AASHTO curve indicates less temperature sensitivity for the asphalt-aggregate materials studied.

Seasonal variations have only a limited influence on base/subbase and subgrade moduli. A simplified procedure is recommended to convert values backcalculated from FWD measurements to average conditions. Base moduli from FWD data obtained during June through December and during January through May should be multiplied, respectively, by 0.92 and 1.10 to convert to average conditions. Average moduli should be used for estimating structural layer coefficients. Subgrade moduli from FWD data obtained during June through December and during January through May should be multiplied, respectively, by 0.94 and 1.07 to convert to average conditons. Average subgrade modulus should be used for the effective roadbed soil resilient modulus as defined in the 1986 AASHTO Guide.

Indirect tension tests (ASTM D4123) produce asphalt-aggregate moduli, when adjusted for load-rate differences, that compare reasonably well with moduli backcalculated from FWD pavement deflection basins. Therefore, moduli for in-situ material from FWD deflection measurements and moduli for new material from laboratory indirect tension tests should provide relatively consistent input to thickness design procedures. As is always the case, the influence of cracking and aging of asphalt-aggregate are not well simulated with laboratory testing.

As expected, accurate characterization of granular base/subbase was most difficult. Researchers and practitioners have experienced more problems with granular materials than any other type paving material. These difficulties are attributible to 1) the sensitivity of moduli to the state of stress and difficulties in estimating and simulating in-situ stress states, 2) laboratory sample size which prevents inclusion of (+) 3/4 inch particle sizes, 3) difficulties in preparing samples to field conditions (density and water content) in the laboratory, and 4) the need to lump all granular materials into one layer. Considering the inherent difficulties in characterizing granular materials, the large differences between FWD and laboratory base/subbase moduli and the large variability for the material constants k_1 and k_2 were not unexpected.

The implications are low confidence levels and possible inconsistencies in design values for granular base/subbase moduli obtained from FWD and laboratory testing. However, design values are required and values backcalculated from FWD deflection data are considered the best available for characterizing in-situ materials. Because there was reasonable agreement between typical material constants in the 1986 AASHTO Guide and constants derived from the laboratory testing, typical values from the 1986 AASHTO Guide are recommended for characterizing granular base/subbase for new construction. A study to group and test a wide range of granular base/subbase materials commonly used in Alabama is recommended to provide a better definition of typical material constants, k_1 and k_2.

The agreement demonstrated between subgrade moduli from FWD and laboratory testing indicates that reasonably consistent input to thickness design procedures will be achieved. Therefore, subgrade soil moduli for existing pavements from FWD deflection measurements and for new construction from laboratory tests according to AASHTO T274 are recommended.

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