IN-SITU DEFLECTION TESTS

KANSAS STATE UNIVERSITY
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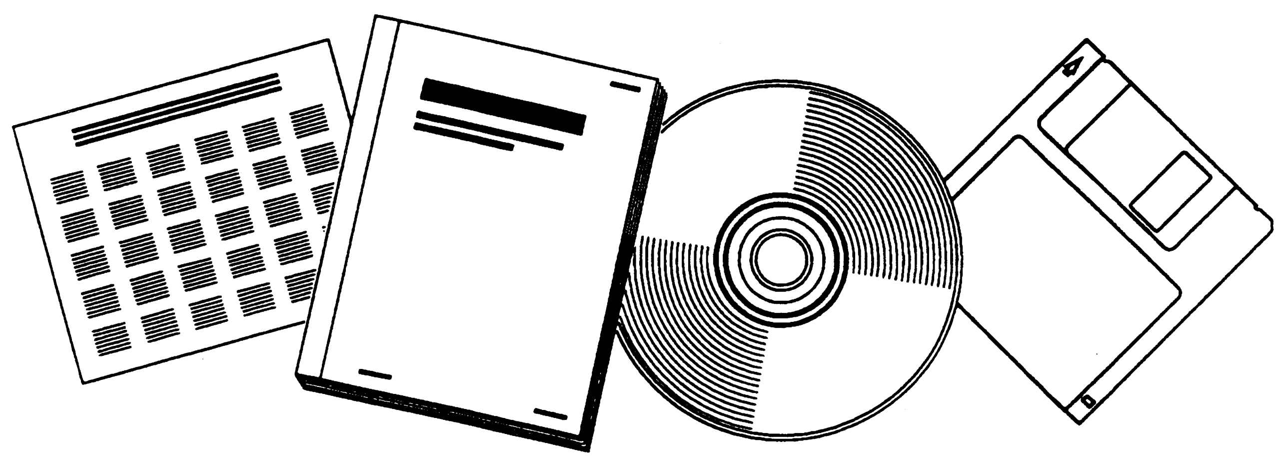

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DEVELOPMENT OF STRUCTURAL LAYER COEFFICIENTS OF CRUMB RUBBER MODIFIED ASPHALT MIXES FROM IN-SITU DEFLECTION TESTS

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Manhattan, Kansas

April 1997

K-TRAN

A COOPERATIVE TRANSPORTATION RESEARCH PROGRAM BETWEEN:
KANSAS DEPARTMENT OF TRANSPORTATION
THE KANSAS STATE UNIVERSITY
THE UNIVERSITY OF KANSAS

DEVELOPMENT OF STRUCTURAL LAYER COEFFICIENTS OF CRUMB RUBBER-MODIFIED ASPHALT MIXES FROM IN-SITU DEFLECTION TESTS

Final Report
K-TRAN Project: KSU 96-2

Prepared for

Kansas Department of Transportation

by

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April 1997

PREFACE

This research project was funded by the Kansas Department of Transportation K-TRAN research program. The Kansas Transportation Research and New-Developments (K-TRAN) Research Program is an ongoing, cooperative and comprehensive research program addressing transportation needs of the State of Kansas utilizing academic and research resources from the Kansas Department of Transportation, Kansas State University and the University of Kansas. The projects included in the research program are jointly developed by transportation professionals in KDOT and the universities.

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16. Abstract

This report includes the results of testing Crumb Rubber Modified Asphalt (CRM) to quantify the layer coefficient values for CRM mixes. Several test sections were selected from recently constructed CRM pavement. The Falling Weight Deflectometer (FWD) data was collected at 15 meter intervals on each test section during a one month period. The first sensor of the FWD was located at the center of the loading plate with six others at a uniform radial distance of 306 mm apart. Three drops of the FWD load were used for target loadings of 31, 40 and 67KN. Tests were done in the outer wheel path of the travel lane. Cores were retrieved at 33 m intervals on each section to get the layer thickness and to test for resilient modulus in the laboratory. The pavement surface temperatures during test time were also recorded at each test location.

Two independent methods, AASHTO and Equal Mechanistic Approach, were followed in the layer coefficient computation process. In each approach, the back-calculated resilient moduli values for the different layers within the pavement structure were used. Backcalculation was done independently using two software programs: MODULUS and BKCHEVM. Manual approach using ELSYM5 was also used in backcalculation. Backcalculated resilient moduli for the asphalt layers were corrected to standard 20°C following the methodology outlined in the 1993 AASHTO guide. The computed layer coefficient values for CRM mixes were found consistently lower than for conventional asphalt concrete. Large variabilities in computed layer coefficients for the overlay sections were also observed.

The asphalt cores were tested to determine resilient moduli following ASTM D4123 test procedures. Poor correlation was found between laboratory and backcalculated layer moduli values.

Good correlation was found between backcalculated resilient moduli and structural layer coefficients computed by the Equal Mechanistic Approach. A regression equation relating backalculation layer moduli to the structural layer coefficient has been developed.

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Backcalculation, resilient modulus, crumb rubber modified asphalt(CRM), structural layer coefficient, pavement.

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EXECUTIVE SUMMARY

The Kansas Department of Transportation (KDOT) has built a number of pavements using crumb-rubber modified (CRM) asphalt concrete mixtures in Kansas. However, little is known about the material properties of CRM mixes, e.g., the structural layer coefficient, which is one of the important design inputs in the AASHTO design method for designing the new asphalt pavements and asphalt overlays on existing pavements. In absence of any guidelines as to the actual layer coefficient values for the CRM mix, KDOT had to rely on experience and judgement on this issue. However, engineering judgements indicate that the layer coefficients can be determined by analyzing pavement surface deflections from Falling Weight Deflectometer (FWD) tests. Based on this idea, the present study, a cooperative effort between the Kansas Department of Transportation and Kansas State University, was initiated in 1995 to quantify the layer coefficient values for the CRM mix.

Several test sections of recently built crumb-rubber modified pavement on three routes, I-135, US-56 and K-32, were selected for this research project. I-135 is a newly built asphalt pavement incorporating CRM mix and the other two are gap-graded CRM overlays. FWD deflection data were collected at 15 meter intervals on each test section in the month of July in 1995. The first sensor of the FWD was located at the center of the loading plate with six others at a uniform radial distance of 306 mm apart. Three drops of FWD load were used for target loadings of 31, 40 and 67 KN. Tests were done on the outer wheel path of the travel lane. Cores were retrieved at 33 m intervals on each section to get the layer thickness and to test for resilient modulus in the laboratory. The pavement surface temperatures during test time at each test location were also recorded.

Two independent methods, AASHTO method and Equal Mechanistic Approach, were followed in the layer coefficient computation process. In each approach, the backcalculated resilient moduli values for the different layers within the pavement structure were used. Backcalculation was done independently using two software programs: MODULUS and BKCHEVM. Manual approach using ELSYM5 was also used in backcalculation. Backcalculated resilient moduli for the asphalt layers were corrected to standard 20 °C following the methodology outlined in the 1993 AASHTO guide. The computed layer coefficient values for CRM mixes were found consistently lower than the conventional asphalt concrete. Large variabilities in computed layer coefficients for the overlay sections were also observed.

The asphalt cores were tested at the KDOT Materials Laboratory to determine resilient moduli values following ASTM D4123 test procedures. Poor correlation was found between laboratory and backcalculated layer moduli values.

Good correlation was found between backcalculated resilient moduli and structural layer coefficients computed by the Equal Mechanistic Approach. A regression equation relating backcalculated layer moduli to the structural layer coefficient has been developed.

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The financial support for this study was provided by the Kansas Department of Transportation (KDOT) under the Kansas Transportation and New Developments (K-TRAN) program. Todd LaTorella, P.E., Pavement Engineer, Bureau of Materials and Research, KDOT, was the project monitor for this project. The authors wish to acknowledge his invaluable cooperation and patience throughout this project. Cooperation of Mr. Glenn Fager of KDOT in laboratory testing is greatly acknowledged.

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CHAPTER 1

INTRODUCTION

Introduction

It is well known that among the different cost elements of the highway system, pavement structure happens to be the single most costly element. The various inputs of the pavement design are, therefore, subject to frequent changes and improvements over the years. Some of these changes are reflected in the AASHTO Guide. One such important improvement is the computation of structural layer coefficient. Both 1986 and 1993 AASHTO Guide acknowledge that structural layer coefficients can be determined from the moduli of materials.

Structural layer coefficients (a_i) are required for standard flexible pavement structural design. A value for this coefficient is assigned to each layer of material in the pavement structure in order to convert actual layer thicknesses into structural number (SN). This layer coefficient expresses the empirical relationship between SN and thickness and is a measure of the relative ability of the material to function as a structural component of the pavement. The following general equation for structural number reflects the relative impact of the layer coefficients (a_i) and thickness (D_i):

$$SN = \sum_{i=1}^{n} a_i D_i$$

The 1986 AASHTO Guide and 1993 AASHTO Guide provide graphs and nomographs to estimate layer coefficients for different layer materials (*1*,*2*).

Although the elastic (resilient) modulus has been adopted as the standard material quality measure, it is still necessary to identify (corresponding) layer coefficients because of their treatment in the structural number design approach (2). Though there are correlations available to determine the modulus from tests, such as, R-value, the procedure recommended is direct measurement using AASHTO Method T 274 (subbase and unbound granular materials) and ASTM D 4123 for asphalt concrete and other stabilized materials (*2*). Research and field studies indicate that many factors influence the layer coefficients, thus the agency's experience must be included in implementing the results from the procedures presented. The layer coefficient may vary with thickness, underlying support, position in the pavement structure, etc. (2). For example, a granular material with a certain modulus will get a lower layer coefficient if used as a base course material than if used as a subbase. If an asphalt concrete and a bituminous- treated base have the same modulus, the asphalt concrete will get a considerably higher layer coefficient than the bituminous-treated base. The layer coefficients for cement-treated base layers appear to be very low when compared to other materials (*3*).

One reason for the peculiarities could be that the layer coefficient not only reflects the stress distributing ability of the material but also to some extent, is a measure of the strength of the material. The position of the material in the structure and the mode of distress may, therefore, influence the relation between layer coefficient and elastic modulus (3).

The AASHTO Guide admits that laboratory resilient modulus values can be obtained that are significantly different from what may exist for an in-situ condition. For example, the presence of a very stiff unbound layer over a low stiffness layer may result in decompaction and a corresponding reduction of stiffness. Previous research shows that the discrepancy between laboratory and in-situ moduli values can be very prominent for conventional asphalt mixes (4). At the same time, laboratory resilient moduli determined from small CRM samples show lower values than conventional asphalt mixes (5). This will result in lower layer coefficient values for CRM mixes. In this study, layer coefficients for CRM mixes were developed from the backcalculated moduli values from the Falling Weight Deflectometer (FWD) test results on in-situ pavements.

Report Organization

This report is divided into five chapters. Chapter 1 is the introduction to the problem. Chapter 2 describes the literature review on this problem and the methodologies followed in the analysis process. Chapter 3 provides information on site selection and data collection. Chapter 4 presents the analysis and the results of the study. Finally, Chapter 5 includes the conclusions and recommendations based on this study.

CHAPTER 2

LITERATURE REVIEW AND ANALYSIS METHODOLOGY

Literature Review

Currently, there is no standard method for the determination of layer coefficients. As mentioned earlier, the AASHTO guide (2) recommends the use of resilient modulus of the material in question to establish the required coefficient. Several methods have been used by different investigators to determine layer coefficients for certain paving materials. Another parameter, the layer thickness equivalency, has been used by several investigators mainly for the purpose of evaluating the support capacity of a given material as compared to a standard or commonly used material (6, 7). This factor, however, is not usually used for design purposes. The layer thickness equivalency is determined as the thickness of the material in question required to replace 25.4 mm (1 inch) of the standard material.

Most of the methods used to evaluate either the layer coefficient or the layer thickness equivalency are based on the evaluation of limiting criteria at some points in the pavement structure (8). Three mechanistic responses to loads are generally considered in structural pavement analyses:

a) surface deflection,
b) maximum tensile strain at the bottom of the surface layer, and
c) vertical compressive strain (or deformation) on top of the subgrade.

The following is a brief summary of some of the evaluation methods reported in the literature.

<u>AASHTO PERFORMANCE METHOD</u>: Kutz and Larson (9) used this method to determine the structural coefficients of two stabilized base course materials which were included in the test track located at the Pennsylvania Transportation Research facility. The investigators used the following design equation, developed at the AASHO Road Test as the basis for their analysis.

$$G_t = \beta (\log W_t - \log \rho) \quad (2.1)$$

where

G_t = a function of the ratio of loss in serviceability at time t to the potential loss taken at a point $p_t = 1.5$

β = a function of design and load variables that influence the shape of p versus W serviceability curve

ρ = a function of design and load variables that denotes the expected number of axle applications to a $p_t = 1.5$

W_t = axle load applications at the end of time t

p = present serviceability index

p_t = serviceability at end of time t.

A statistical model similar to that utilized at the AASHO Road Test was selected to study the changes in β and ρ across levels of surface and base layer thicknesses for data collected at the test track. Terms related to the subbase were not included in the model since all test sections had a constant subbase thickness. The results of the statistical analysis were compared to the structural number equation and new layer coefficients were determined.

LIMITING CRITERIA APPROACH: Wang et al. (10) used this method to determine the structural coefficients of two base courses constructed on the test track of the Pennsylvania Transportation Research facility. The same method has also been used by Hicks et al. (6).

Wang et al. (10) related rutting data collected from the test track to the compressive strain on top of the subgrade. The equivalent 18-kip axle load (EAL_{18}) required to produce 25 mm rutting for each section was compared to the maximum compressive strain on top of the subgrade. The strain associated with one million EAL_{18} was estimated and used as the limiting compressive strain in the determination of the structural layer coefficients of the two materials. A similar analysis was utilized for the criteria of surface deflection and tensile strain at the bottom of the surface layer. Both of these criteria were evaluated when significant surface cracking appeared.

The base layer thickness required to satisfy each limiting criteria was computed at different levels of surface and subbase layer thicknesses. The final base thickness was required to satisfy all three criteria simultaneously. The selected thickness was then plugged into the structural number equation and the corresponding layer coefficient was calculated.

AASHTO FACTORIAL DESIGN APPROACH: Little and Epps (11) utilized this method during the evaluation of certain structural characteristics of recycled pavement materials and later in the evaluation of foamed-asphalt aggregate mixtures (7). The authors computed the maximum vertical subgrade deformation (W_s) for the pavement sections included in Loop 4 of the AASHO Road Test. A stress-sensitive layered elastic computer program was utilized to model the pavement sections. The elastic properties of the AASHO material were used as inputs. The subgrade deformation was related to the number of EAL_{18} applications required to bring the pavement to a terminal serviceability index of 2.5. The following correlation was established.

$$EAL_{18\,(2.5)} = 0.098\ e^{-3.39 \ln Ws} \qquad (2.2)$$

The elastic properties of the recycled asphalt concrete were substituted for the AASHO material properties, and changes in the pavement responses were evaluated. The new subgrade deformations were inserted in the above equation to compute the $EAL_{18\,(2.5)}$ for the recycled pavement. The calculated allowable load applications were, in turn, used to estimate the required structural number (SN) from the AASHTO design equation. The structural layer coefficient (a_1) was finally calculated using the SN equation, where a_1 is the only unknown parameter.

AASHTO DESIGN NOMOGRAPH APPROACH: Hicks et al. (12) used this method to compute layer equivalencies for open-graded emulsion mixtures. The researchers based their analysis on determining the EAL_{18} already carried by the pavement. The surface layer coefficient was backcalculated using the AASHTO interim design guide for a terminal serviceability of 2.0, a knowledge of the surface layer thickness, traffic (EAL_{18}), regional factor, and soil support of the base. The weighted structural number was obtained from the design nomograph and divided by the surface thickness to determine the required layer coefficient.

EQUAL MECHANISTIC RESPONSE APPROACH: Several investigators have used this procedure to determine layer equivalencies (7) or structural layer coefficients (13) for different materials. Little et al. (7) used this method to compare the structural ability of foamed asphalt-aggregate mixture to an asphalt-treated base. The compressive strain on top of the subgrade was selected as the mechanistic response to be used in the comparison. Identical pavement structures, except for the layer in question, were analyzed using a layered elastic computer program. The thickness required to obtain an equal response for the two structures were calculated. The ratio of the thickness of the layer studied to that of the standard material is defined as the layer thickness equivalency of the material.

Majidzadeh and Elmitiny (13) used a similar approach to study the structural ability of open-graded asphalt stabilized base. The maximum compressive vertical deformation on top of the subgrade was used as the critical pavement response. The structural layer coefficient of the open-graded base was then calculated by multiplying the inverse of the layer equivalency factor by the layer coefficient of the reference material.

Methodology used in the Current Study

In this study, the AASHTO Design Method and the Equal Mechanistic Approach were followed to determine the structural layer coefficients for the CRM mix. In both approaches, backcalculated layer moduli values were used to determine the layer coefficient values. A brief description of the backcalculation process followed by these two methods is outlined below.

Backcalculation of Layer Moduli

Pavement response models, such as, elastic layer theory, can estimate pavement deflections as a function of the load condition, pavement cross section and material properties. However, the analysis of NDT data requires the estimation of material properties from measured deflections. No direct analytical solution exists for determining material properties from measured response. The lack of a direct solution method has forced the development of iterative techniques for altering the pavement properties, and comparing the computed and measured response. This general process has been termed "backcalculation" in the technical literature. Several authors have developed backcalculation schemes, varying in the method used to alter the moduli between iterations and the closure criteria (3). Two backcalculation programs were used: MODULUS and BKCHEVM.

MODULUS

In MODULUS, a linear elastic program generates a data base of deflection basins corresponding to different modulus ratios of the layers, and a pattern search technique is used to fit measured and calculated deflections by minimizing the objective function:

$$\epsilon^2 = \Sigma\,[(w_i^m - w_i^c) / (w_i^m)]^2 \qquad (2.3)$$

for i = 1,......,n.

In equation (2.3), ϵ^2 is the squared error, w_i^m is the measured deflection, w_i^c is the calculated deflection and n is the number of sensors (usually 7). The search routine finds the optimum set of modulus ratios, or in other words, a set of backcalculated layer moduli, so that a minimum ϵ^2 value is obtained.

BKCHEVM

BKCHEVM is a minor modification of CHEVDEF done at Arizona State University. It also uses a layered elastic analysis program for response calculation and a search algorithm to minimize an objective function as shown in Equation (2.3).

AASHTO Design Guide Method

As mentioned earlier, AASHTO provides the following general equation for structural number reflecting the relative impact of the layer coefficients (a_i) and thickness (D_i):

$$SN = \sum_{I=1}^{n} a_i D_i \qquad (2.4)$$

The layer co-efficient values for the different layers except layers with the asphalt-rubber materials were determined using the following equations given by Ullidz (3) :

Asphalt concrete :

$$a_1 = 0.40*\log(E/(3000\ MPa)) + 0.44, \qquad 0.20 < a_1 < 0.44 \qquad (2.5)$$

Granular Subbase:

$$a_3 = 0.23*\log(E/(160\ MPa)) + 0.15, \qquad 0.06 < a_3 < 0.20 \qquad (2.6)$$

Bituminous-treated Base:

$$a_2 = 0.30*\log(E/(3000\ MPa)) + 0.33, \qquad 0.10 < a_2 < 0.30 \qquad (2.7)$$

Cement -Treated Base:

$$a_2 = 0.52*\log(E/(3000\ MPa)) + 0.08, \qquad 0.10 < a_2 < 0.28 \qquad (2.8)$$

Broken (and seated) Portland Cement Concrete:

$$a_2 = 0.27*\log(E/(3000\ MPa)) + 0.35, \qquad 0.10 < a_2 < 0.44 \qquad (2.9)$$

For each section under study, the backcalculated layer moduli can be used to find the layer coefficient values for all layers except for the asphalt-rubber surface and base layers (on a composite basis). The effective structural number (SN_{eff}) can be computed from the following equation given in the AASHTO Design Guide (1):

$$SN_{eff} = 0.0045 * D * E_p^{1/3} \qquad (2.10)$$

where: D = total thickness of all pavement layers above subgrade (inch)
E_p= effective modulus of the pavement layers above subgrade (psi)

In equation (2.10), E_p is determined using backcalculated subgrade modulus (M_r) value. The AASHTO algorithm for determining M_r suggests that M_r be calculated from a single deflection measurement at a distance sufficiently large enough so that the point falls outside the stress bulb at the subgrade-pavement interface and the measured deflection is solely due to the subgrade deformation. The following equation is used to calculate the M_r value :

$$M_r = \frac{0.24P}{(d_r)r} \qquad (2.11)$$

where

M_r = backcalculated subgrade resilient modulus
P = applied load
d_r = deflection at a distance r from the center of the load
r = distance from the center of the load

To use a particular sensor deflection for estimating the subgrade resilient modulus, the sensor location must be far enough so that it corresponds to the deflection of the subgrade only, but also be close enough so that it is not too small to be measured accurately. AASHTO further suggests that the minimum distance be determined by the radius of the stress bulb (a_e) at the subgrade-pavement interface. This is accomplished by choosing the 3rd or 4th sensor arbitrarily and checking whether it falls outside a radial distance of $0.7a_e$ from the center of the load or not. The calculated M_r value, in turn, is used to calculate E_p/M_r. Since the actual layer thicknesses and the structural layer coefficients of other layer materials are known, the layer coefficient for the CRM asphalt mix can be calculated using equation (2.4) and using the structural number value found in equation (2.10).

Equal Mechanistic Response Approach (EMA)

In this approach, the vertical compressive strain on top of the subgrade of a control section (conventional material) can be compared to the same response for the CRM sections for which the layer coefficient is unknown. In this approach, identical pavement structures except for the layer in question are analyzed using a layered elastic computer program, ELSYM5. The thicknesses required to obtain equal vertical compressive strain on top of the subgrade for the two pavement structures are calculated. The ratio of the thickness of the layer studied to that of the standard (conventional) material is defined as the layer thickness equivalency of the material for each section. The structural layer coefficient of any section is then calculated by multiplying the inverse of the layer equivalency factor by the layer coefficient for the standard material (conventional asphalt concrete).

CHAPTER 3

SITE SELECTION AND DATA COLLECTION

Site Selection

Several test sections of recently built crumb-rubber modified pavements on three routes of the Kansas Department of Transportation (KDOT), I-135, K-32 and US-56, were selected in this study. Among these, I-135 has four different structural sections as tabulated in Table 3.1. Section Nos. 1, 2 and 3 have CRM as surface (ARS) and base (ARB) courses, while the fourth, denoted as control section, has conventional asphalt mix for both layers. The ARS mix is a gap-graded mix with slightly higher asphalt-rubber binder content than ARB, which is a dense-graded mix. All sections on I-135, except Section No. 1, were built on rubblized, jointed, reinforced concrete pavement (JRCP). Section No. 1 is a reconstructed section with a lime-treated subbase. The sections on K-32 and US-56 have CRM overlays over conventional asphalt mix bases. The subbase on US-56 consists of jointed reinforced concrete pavement built in 1948. In this study, it was considered as a broken and seated JRCP. Table 3.1 provides a summary of the cross-sectional features of the test sections.

Data Collection

Deflection data were collected at twenty one locations at 15 meter intervals on each test section on I-135 with a Dynatest 8000 FWD during June and July of 1995, approximately one year after construction. The sections were in excellent condition and the CRM mixes in these pavements were adequately compacted. On US-56, an urban arterial, and on K-32, a two-lane two-way highway, tests were conducted at eleven points at 15 meter intervals. The first sensor was located at the center of the loading plate with six others at a uniform radial distance of 306 mm apart. Three drops of FWD load were used for target loadings of 31, 40 and 67 kN. Tests were done on the outer wheel path of the travel lane. The test temperature varied from 25 to 44 °C. Cores were retrieved at 33 meter intervals on each section to get the layer thicknesses and to test in the laboratory.

Laboratory resilient modulus tests were conducted on randomly selected 64 mm thick core samples from each test section following ASTM D 4123 test procedure. The samples were representatives of ARS-ARB, ARB and existing asphalt mix layers. Tests were conducted at 20° C using a pulse load of 0.1 sec duration and 0.9 sec period. Indirect tensile loads applied varied from 580 N to 5560 N to obtain measurable deflections in the range of 100 to 200 μm.

TABLE 3.1 Layer Types and Thicknesses of Different Test Sections

Route	Test Section No.	Layer					
		Surface		Base		Subbase	
		Material Type	Thickness (mm)	Material Type	Thickness (mm)	Material Type	Thickness (mm)
I-135	1	ARS	42	ARB	322	Lime-Treated Subbase	151
	2	ARS	41	ARB	176	Rubblized JRCP	230
	3	ARS	29	ARB	217	Rubblized JRCP	230
	Control	Conventional Asphalt Mix	25	Asphalt Base	200	Rubblized JRCP	230
K-32		ARS	28	Asphalt Base	165	Soil-Cement	74
US-56		ARS	25	Asphalt Base	103	JRCP	358

ARS: Asphalt Rubber Surface
ARB: Asphalt Rubber Base
JRCP: Jointed Reinforced Concrete Pavement

Falling Weight Deflectometer (FWD)

FWDs typically employ a mass (or two masses in some models) falling on to a buffered circular load plate. These devices were primarily developed in Europe and have since become popular in the United States. FWDs can transmit relatively heavy loads to the pavements compared to the other deflection testing devices. Usually the load range is 6,672 N to 155,687 N depending on the FWD model. Variations in the applied load levels are achieved by varying the magnitude and number of the dropping mass and the height of the drop. The FWD has a relatively small preload (3 to 14% of the maximum load) compared to the maximum generated load. The maximum load is recorded by a load cell in the load plate. The load pulse is characterized by approximately a half-sine-wave form with pulse duration of about 30-40 ms and is known to simulate moving-wheel load better than any other device. The peak vertical deflections are measured by velocity transducers, commonly known as geophones, or, in some models, with seismometers at the center of the loading plate and several locations away from the center of the load. The distance between the sensors or the seismometers can be adjusted for special studies, but they are normally spaced at intervals of 300 mm. The sensors are mounted on a bar which is automatically lowered with the loading plate. Measured deflections can be plotted as deflection basins.

CHAPTER 4

BACKCALCULATION OF LAYER MODULI AND COMPUTATION OF STRUCTURAL LAYER COEFFICIENT

PAVEMENT MODELING AND BACKCALCULATION OF LAYER MODULI

Three independent methods were used in the backcalculation process by modeling the pavements as multi-layered elastic systems. The methods are: (a) manual- using the ELSYM5 multi-layered elastic analysis program, (b) an automated backcalculation program, MODULUS (7) and (c) another automated method, BKCHEVM, developed by the Corps of Engineers and later slightly modified at Arizona State University (8). The deflection basins corresponding to the target loading of 40 kN are used in this study.

In the back calculation process, very good convergence was obtained by assuming bedrock at a depth of around 8.5 m from the surface for sections on I-135. The presence of bedrock at this site was also supported by the soil survey maps of the Soil Conservation Service of USDA. Subgrade depth of 6.7 meter was assumed for all sections on I-135. This value of bed rock depth was checked with those calculated by MODULUS for different sections and the differences were found to be not significant. The depth of bedrock for K-32 and US-56 were assumed to be 2.75 meter and 6.4 meter, respectively, and were obtained by trial-and-error for good convergence and subsequent comparison with the depth values calculated by MODULUS.

Since BKCHEVM cannot handle more than four layers (including the subgrade layer), the surface and base layers of I-135 were considered on a composite basis while running BKCHEVM, and thus identical results for layer moduli are shown for both layers for BKCHEVM results. In general, consistent values were obtained using BKCHEVM compared to the other two methods. The backcalculated layer moduli values for asphalt concrete and CRM mix were then corrected to standard 68°C according to the AASHTO guideline (1). However, corrected asphalt concrete or CRM moduli values greater than 13.8 GPa were discarded since 13.8 GPa (2 million psi) can be considered as the upper limit for asphalt concrete modulus under normal weather condition prevailing in Kansas.

Due to the non-uniqueness nature of the backcalculation results, three independent backcalculation approaches were followed in this study. The RMS (Root Mean Square) values were calculated manually at each FWD point. For manual backcalculation, RMS values of up to 4% were assumed satisfactory. The manual method did not show good convergence for Section No. 1 and control section on I-135 and on K-32. Thus the results were ignored and are not reported here. However, on K-32, higher root-mean-square (RMS) error values were allowed (about 8%) for BKCHEVM and MODULUS compared to only 4% for I-135 and US-56. On those routes, backcalculated layer moduli where RMS values exceeded 4% were discarded. However, this happened only for a few deflection basins (one or two per test section) and may very well be because of FWD test loading directly over a "rocking" section in the underlying rubblized JRCP layer. However, no anomalies in the individual sensor deflection values were observed compared to other deflection basins where very good convergence were obtained.

Backcalculated Layer Moduli for I-135

Table 4.1 tabulates the summary statistics of backcalculated layer moduli values of the layers on different sections of I-135. The results, in general, show high variabilities across a section as well as between the sections. The variabilities for rubblized subbase layer of Section Nos 2, 3 and 4 were higher compared to the other layers. The variabilities in the sizes of the rubblized pieces of the original concrete pavement might induce this type of high variabilities. Very high values for the rubblized subbase on section 3 were observed in all the three backcalculation approaches. However, no difference in the construction procedure for that section was reported or found. In general, the moduli values of ARS and ARB obtained from BKCHEVM and manual computation were found to be in good agreement. The backcalculated subgrade moduli values were more or less consistent in all three computation approaches. Figure 4.1, 4.2, 4.3 and 4.4 show the backcalculated layer moduli values for ARS, ARB, rubblized subbase and subgrade, respectively, obtained by different backcalculation methods for the sections on I-135.

Backcalculated Layer Moduli for US-56

Table 4.2 gives the summary statistics of backcalculated layer moduli values of the different layers on US-56. Large coefficient of variation values were observed for the backcalculated ARS moduli value of ARS layers in all three approaches. This observation is due to the fact that backcalculation process does not give very good results for thin overlays which is the case here where only 25 mm ARS overtops comparatively very thick 230 mm JRCP. Since the subbase is the original JRCP, very high moduli values were observed as expected. Figure 4.5 shows the layer moduli of ARS, AC base and JRCP layers on US-56.

Backcalculated Layer Moduli for K-32

The summary statistics for backcalculated layer moduli values for K-32 is shown in Table 4.3. Since the surface layer is a thin overlay (25 mm), large variabilities in the backcalculated moduli for ARS layer were observed. The layer moduli of ARS, AC base on K-32 are shown in Figure 4.6.

TABLE 4.1 Backcalculated Layer Moduli Values for Different Layers on I-135

		Moduli values (in GPa)											
		Section 1			Section 2			Section 3			Control Section		
		ARS	ARB	Sub-base	ARS	ARB	Sub-base	ARS	ARB	Sub-base	AC	Asp. Base	Sub-base
BKCHEVM	Mean	3.11	3.11	0.09	5.62	5.62	0.35	4.41	4.41	1.58	10.34	10.34	0.21
	Std. Dev	0.53	0.53	0.04	1.71	1.71	0.28	0.81	0.81	1.37	1.89	1.89	0.13
	C.V.(%)	17	17	40	31	31	81	18	18	87	18	18	62
	Range	1.86 - 4.28	1.86 - 4.28	0.03 - 0.19	3.34 - 10.61	3.34 - 10.61	0.10 - 1.19	3.13 - 6.77	3.13 - 6.77	0.11 - 5.51	8.13 - 13.77	8.13 - 13.77	0.08 - 0.50
	n	21			20			20			20		
MODULUS	Mean	3.36	2.82	0.10	2.51	4.70	0.55	3.90	6.05	2.62	7.80	9.31	0.66
	Std. Dev	1.53	0.45	.06	1.19	1.14	0.44	3.37	3.53	2.75	2.25	2.23	0.27
	C.V.(%)	46	16	52	48	24	81	86	58	105	29	24	40
	Range	1.03 - 7.59	1.96 - 3.99	0.04 - 0.23	1.14 - 6.26	2.77 - 6.76	0.15 - 1.92	0.71 - 10.44	2.91 - 13.00	0.17 - 10.18	5.39 - 12.76	5.87 - 13.06	0.29 - 1.11
	n	21			20			20			20		
Manual	Mean	-	-	-	5.27	5.98	0.43	5.29	5.57	2.24	-	-	-
	Std. Dev	-	-	-	1.38	1.61	0.37	0.86	1.06	1.58	-	-	-
	C.V.(%)	-	-	-	26	27	86	16	19	71	-	-	-
	Range	-	-	-	3.96 - 9.24	4.22 - 10.56	0.12 - 1.72	3.81 - 7.21	3.81 - 7.46	0.59 - 6.20	-	-	-
	n				20			20			-	-	-

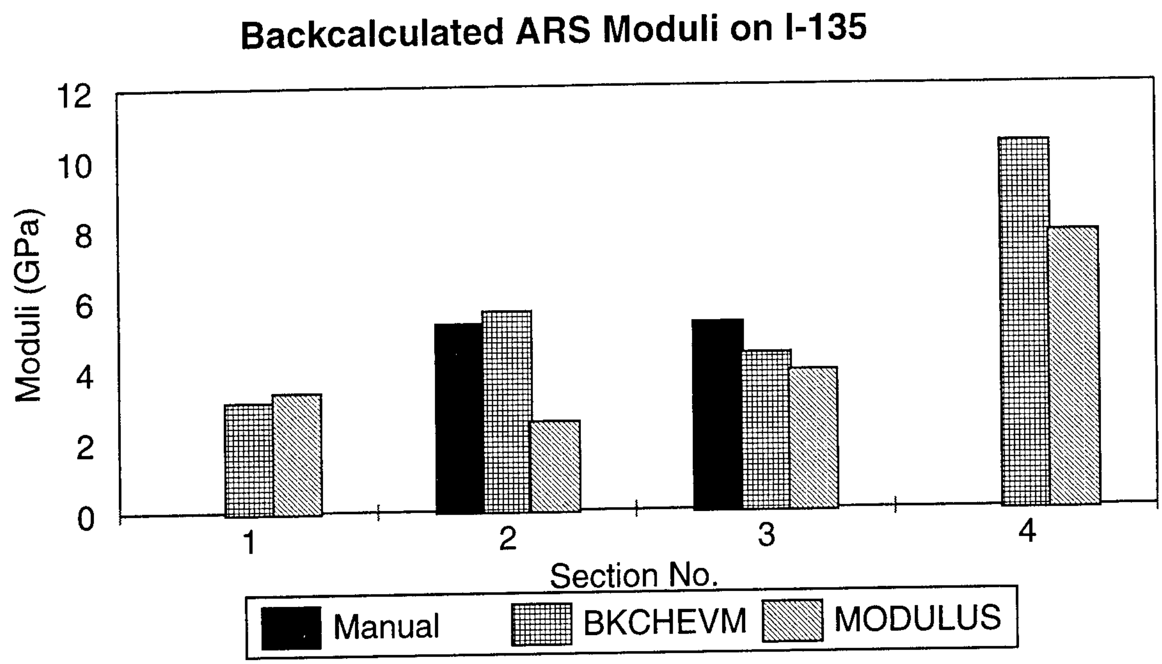

Figure 4.1 Backcalculated Layer Moduli Values for ARS at Different Sections on I-135

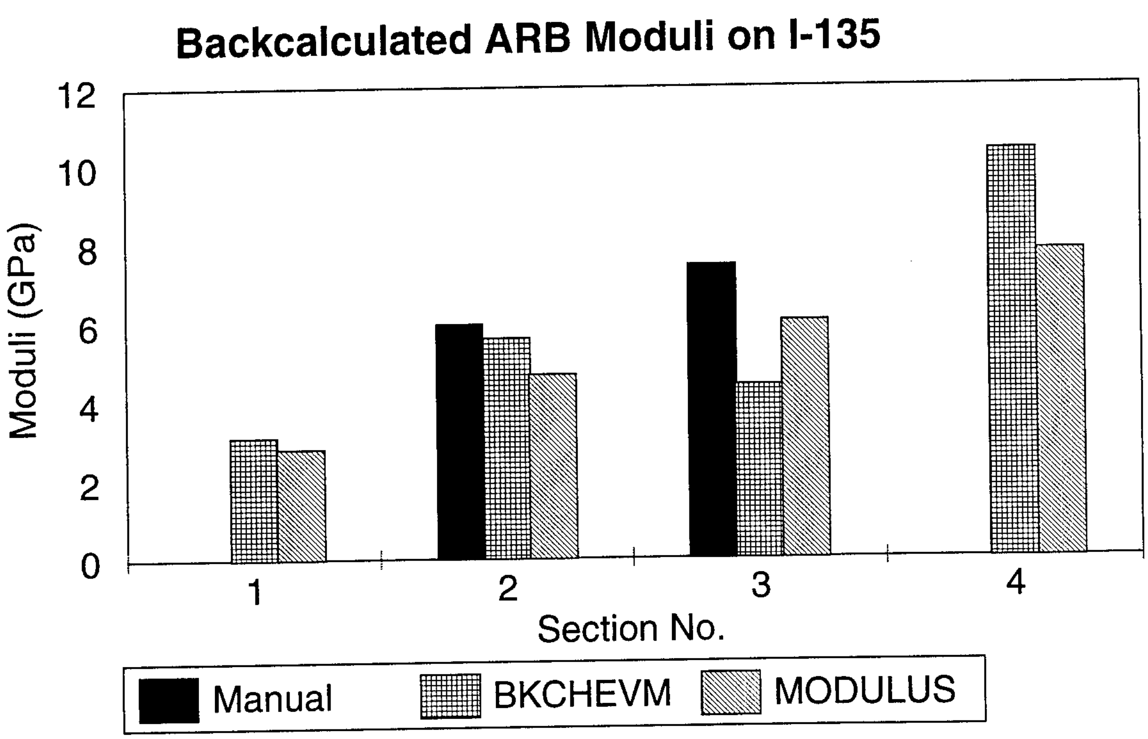

Figure 4.2 Backcalculated Layer Moduli Values for ARB at Different Sections on I-135

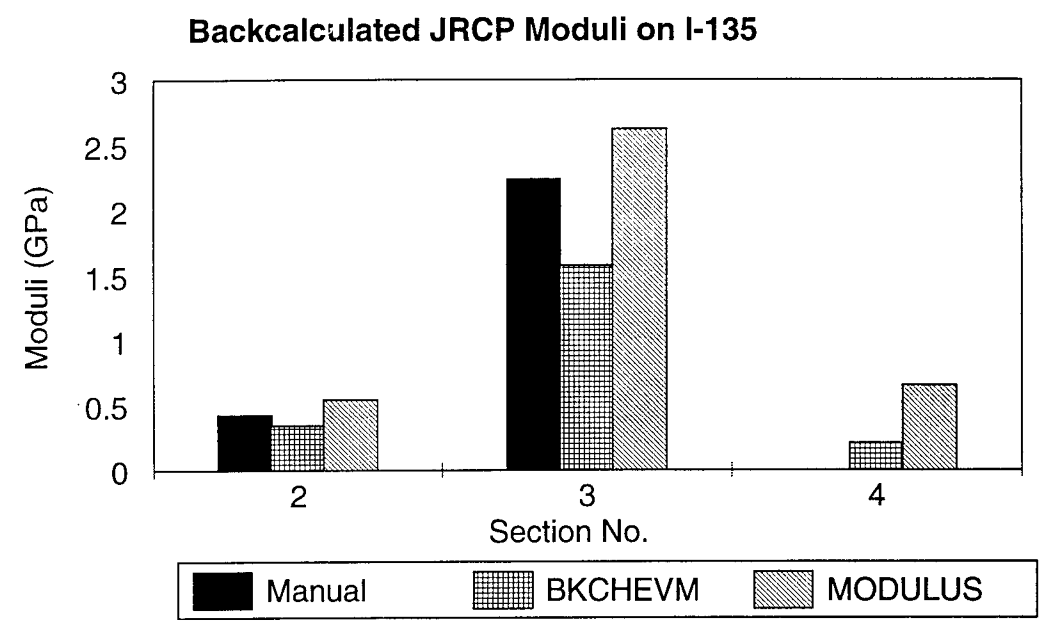

Figure 4.3 Backcalculated Layer Moduli Values for Rubblized JRCP at Different Sections on I-135

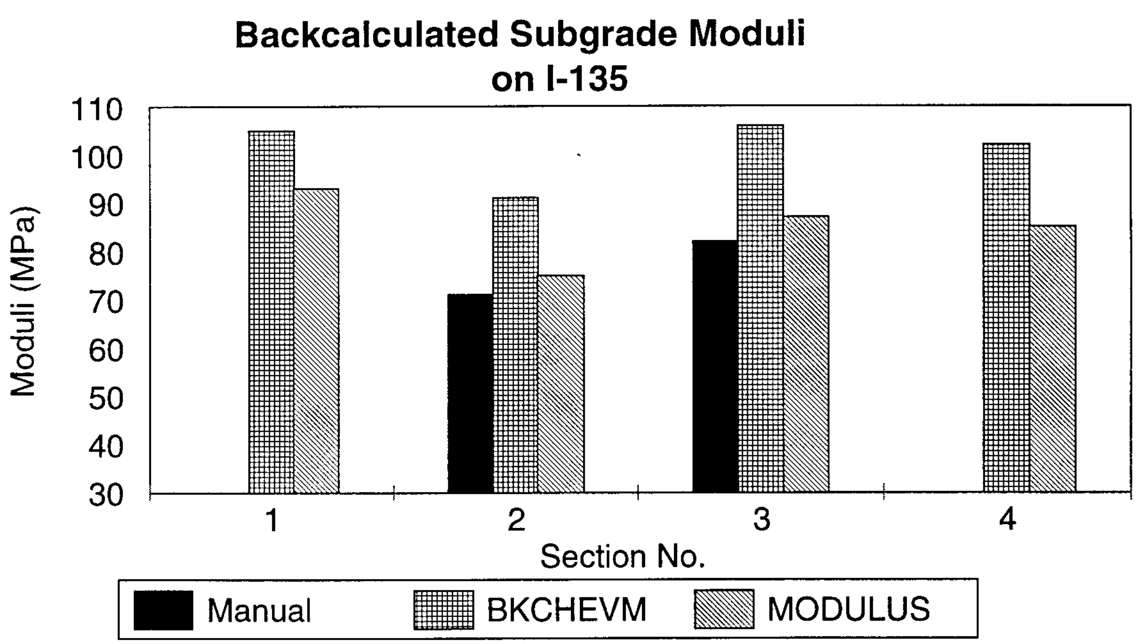

Figure 4.4 Backcalculated Layer Moduli Values for Subgrade at Different Sections on I-135

TABLE 4.2 Backcalculated Layer Moduli Values for Different Layers on US 56

	Statistics	Backcalculated Layer Moduli (GPa)		
		ARS	Asphalt Base	Subbase
BKCHEVM	Mean	3.51	3.51	6.09
	Std. Dev.	1.40	1.40	2.35
	C.V.(%)	40	40	39
	Range	1.78-6.29	1.78-6.29	1.31-10.27
	n	11		
MODULUS	Mean	3.77	3.91	12.17
	Std. Dev.	0.90	4.66	5.09
	C.V.(%)	24	119	42
	Range	2.61-5.19	1.48-16.25	2.94-18.78
	n	11		
Manual	Mean	4.22	5.57	6.31
	Std. Dev.	1.95	2.41	1.35
	C.V.(%)	46	43	21
	Range	2.21-7.38	2.14-7.87	3.44-8.27
	n	11		

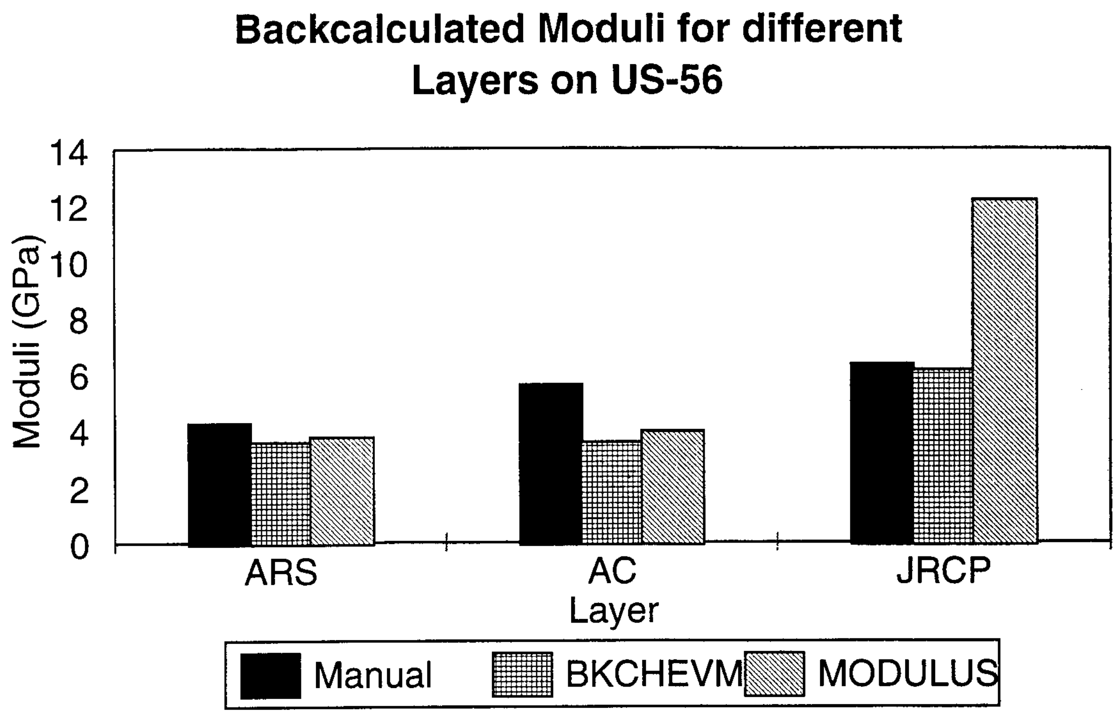

Figure 4.5 Backcalculated Layer Moduli Values for Different Layers on US-56

TABLE 4.3 Backcalculated Layer Moduli Values for Different Layers on K-32

	Statistics	Backcalculated Layer Moduli (GPa)		
		ARS	Asphalt Base	Subbase
BKCHEVM	Mean	1.61	5.01	0.09
	Std. Dev	2.41	4.17	0.02
	C.V.(%)	150	83	22
	Range	0.26-7.85	0.93-13.52	0.06-0.12
	n	10	10	10
MODULUS	Mean	3.15	2.44	0.19
	Std. Dev	2.63	0.85	0.22
	C.V.(%)	84	35	115
	Range	1.19-8.15	1.09-4.23	0.03-0.78
	n	12	12	12

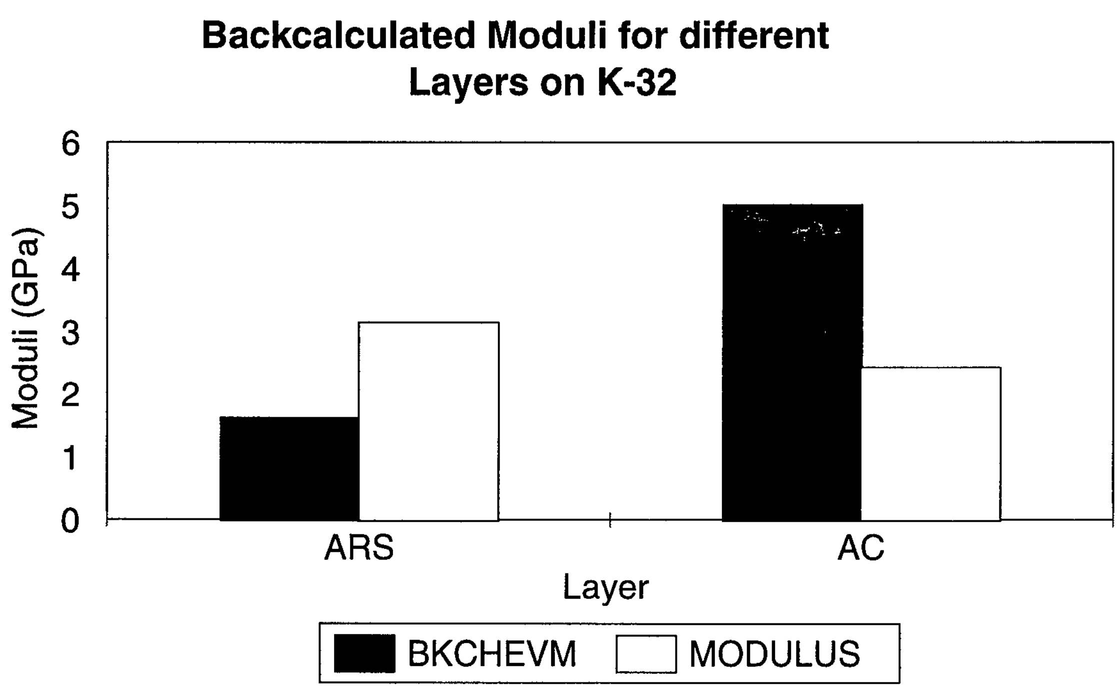

Figure 4.6 Backcalculated Layer Moduli Values for Different Layers on K-32

ANALYSIS OF COMPUTED LAYER COEFFICIENT VALUES

Table 4.4 tabulates the summary statistics of the computed layer coefficient values for I-135 obtained in this study. The values fall around 0.3 and the coefficient of variation values were not high. However, in general, higher variabilities were observed for the AASHTO results compared to the EMA values. Detailed results at each deflection location for all four sections on I-135 are shown in Tables 4.5, 4.6, 4.7 and 4.8, respectively. On I-135, the average layer coefficient values for the CRM layers varied from 0.31 on Section No. 1 to 0.39 on Section No. 3 for BKCHEVM-moduli values. The coefficients of variation were 7 to 11%, much lower than the AASHTO-approach variabilities. Similar results were obtained using the moduli backcalculated from the three methods used in the study. The same is true for the results on US-56. The average layer coefficient for the CRM mixes on US-56 are similar to those obtained on Section No. 1 of I-135. However, variabilities in computed layer coefficients were higher on US-56 than on I-135. Figures 4.7, 4.8 and 4.9 show the layer coefficient values obtained by both AASHTO and EMA approaches for Section Nos. 1, 2 and 3 on I-135, respectively.

Table 4.9 and 4.11 tabulate the summary statistics of the layer coefficient values for US-56 and K-32, respectively. For both routes, large variabilities in layer coefficient values were observed. This is probably due to the variabilities in the backcalculated layer moduli obtained for these routes. Like I-135, variabilities in the AASHTO results are higher than those obtained in EMA. The layer coefficient values, in general, were found to be lower compared to I-135. Again, the very thin overlays on these routes are probably the reason for that since structural contribution of very thin ARS overlay is almost negligible compared to thicker base and subbase. Detailed results for these routes at each deflection location are presented in Tables 4.10 and 4.12, respectively. The layer coefficient values for US-56 and K-32 obtained from different approaches are shown in Figures 4.10 and 4.11, respectively.

For each of the three routes, correlation among the layer coefficient values obtained were also investigated and the correlation coefficients are tabulated in Table 4.14. The best correlation was obtained using the BKCHEVM-calculated moduli values.

TABLE 4.4 Structural Layer Coefficient Values for CRM Asphalt Layers on I-135

	Statistics	Section 1		Section 2		Section 3	
		AASHTO	EMA	AASHTO	EMA	AASHTO	EMA
BKCHEVM	Mean	0.32	0.31	0.38	0.39	0.32	0.36
	Std. Dev.	0.02	0.02	0.06	0.04	0.04	0.02
	C.V.(%)	7	7	16	11	13	7
	n	21	21	20	20	20	20
MODULUS	Mean	0.32	0.31	0.31	0.35	0.28	0.39
	Std. Dev.	0.02	0.02	0.05	0.03	0.04	0.06
	C.V.(%)	8	8	16	8	15	16
	n	21	20	20	20	20	20
Manual	Mean	-	-	0.34	0.39	0.29	0.39
	Std. Dev.	-	-	0.04	0.04	0.04	0.03
	C.V.(%)	-	-	11	10	14	7
	n	-		20	20	20	20

TABLE 4.5 (a) Structural Layer Coefficient Values for Section 1 Obtained by BKCHEVM

Station	Backcalculated layer moduli (Gpa)				RMS value (%)	Layer Coefficient by	
	Surface	Base	Subbase	Subgrade		AASHTO	EMA
395.000	2.75	2.75	0.07	0.11	1.90	0.32	0.30
395.025	3.12	3.12	0.11	0.11	1.30	0.29	0.31
395.050	2.91	2.91	0.08	0.10	1.20	0.32	0.30
395.075	2.26	2.26	0.13	0.12	1.00	0.27	0.27
395.100	2.87	2.87	0.12	0.12	1.50	0.31	0.30
395.125	3.12	3.12	0.15	0.11	1.00	0.30	0.31
395.150	3.14	3.14	0.07	0.10	1.00	0.33	0.31
395.175	2.67	2.67	0.12	0.10	1.10	0.29	0.29
395.200	3.02	3.02	0.08	0.10	0.50	0.31	0.31
395.225	2.98	2.98	0.19	0.10	1.10	0.30	0.31
395.250	2.98	2.98	0.05	0.11	1.20	0.33	0.31
395.275	2.83	2.83	0.12	0.10	1.40	0.30	0.30
395.300	3.33	3.33	0.08	0.10	0.80	0.34	0.32
395.325	1.86	1.86	0.04	0.12	1.50	0.29	0.25
395.350	3.54	3.54	0.06	0.09	1.10	0.35	0.33
395.375	3.91	3.91	0.06	0.10	0.40	0.34	0.34
395.400	3.67	3.67	0.03	0.10	1.10	0.36	0.33
395.425	3.64	3.64	0.11	0.10	1.40	0.33	0.33
0.10395.450	3.02	3.02	0.09	0.10	1.30	0.32	0.31
395.475	3.39	3.39	0.12	0.10	1.40	0.33	0.32
395.500	4.28	4.28	0.12	0.10	1.60	0.36	0.35
Mean	3.11	3.11	0.19	0.11		0.32	0.31
Std. Dev	0.53	0.53	0.04	0.01		0.02	0.02
C.V. (%)	17	17	40	8		7	7
Range	1.86-4.28	1.86-4.28	0.03-0.19	0.09-0.12		0.27-0.36	0.25-0.35
No.	21						

TABLE 4.5 (b) Structural Layer Coefficient Values for Section 1 Obtained by MODULUS

Station	Backcalculated layer moduli (Gpa)				RMS value (%)	Layer Coefficient by	
	Surface	Base	Subbase	Subgrade		AASHTO	EMA
395.000	1.78	2.90	0.60	0.10	3.50	0.33	0.32
395.025	1.03	2.83	0.40	0.10	3.70	0.33	0.29
395.050	2.28	2.71	0.90	0.09	2.80	0.31	0.29
395.075	3.74	1.97	0.15	0.10	3.20	0.27	0.27
395.100	3.06	2.58	0.13	0.10	3.50	0.30	0.29
395.125	3.85	2.78	0.15	0.10	2.10	0.30	0.30
395.150	5.96	2.65	0.07	0.09	3.10	0.33	0.31
395.175	3.73	2.35	0.13	0.09	1.60	0.29	0.29
395.200	2.78	2.77	0.09	0.09	2.60	0.31	0.30
395.225	2.23	2.85	0.22	0.09	3.10	0.,30	0.30
395.250	2.76	2.71	0.06	0.10	3.50	0.32	0.29
395.275	3.31	2.58	0.12	0.10	3.60	0.30	0.29
395.300							
395.325							
395.350	4.16	3.08	0.07	0.08	2.00	0.34	0.31
395.375	3.39	3.20	0.08	0.08	3.60	0.33	0.31
395.400	2.83	3.44	0.05	0.08	3.30	0.35	0.32
395.425							
395.450	7.59	2.50	0.09	0.09	2.70	0.32	0.31
395.475							
395.500	2.69	3.99	0.23	0.09	1.90	0.33	0.34
Mean	3.36	2.82	0.11	0.09		0.32	0.31
Std. Dev	1.53	0.45	0.06	0.01		0.02	0.02
C.V.(%)	46	16	52	8		7	8
Range	1.03-7.59	1.96-3.99	0.04-0.23	0.08-0.10		0.27-0.35	0.27-0.36
No.	21						

TABLE 4.6(a) Structural Layer Coefficient Values for Section 2 Obtained by Manual Computation

Station	Backcalculated layer moduli (Gpa)				RMS value (%)	Layer Coefficient by	
	Surface	Base	Subbase	Subgrade		AASHTO	EMA
406.000							
406.250	4.39	4.50	1.72	0.09	1.80	0.25	0.36
406.500							
406.750	6.07	6.33	0.39	0.07	1.90	0.33	0.41
407.000	5.28	6.33	0.37	0.07	1.90	0.33	0.40
407.250	5.54	5.94	0.30	0.08	3.80	0.36	0.40
407.500							
407.750	9.24	10.56	0.55	0.08	2.60	0.37	0.49
408.000	7.39	7.92	0.34	0.07	2.40	0.36	0.44
408.250	4.35	4.75	0.19	0.06	2.20	0.36	0.36
408.500	5.39	6.69	0.45	0.07	2.60	0.32	0.41
408.750	5.21	5.21	0.21	0.07	1.60	0.37	0.38
409.000	5.21	5.69	0.12	0.06	1.70	0.41	0.39
409.250	3.96	4.22	0.39	0.07	2.00	0.30	0.35
409.500	4.36	4.84	0.26	0.07	1.80	0.35	0.36
409.750							
410.000	4.18	6.89	0.38	0.08	2.40	0.34	0.41
410.250	4.27	4.98	0.52	0.07	1.70	0.29	0.37
410.500	4.15	4.35	0.18	0.07	3.10	0.36	0.35
410.750	5.32	6.53	0.49	0.08	1.40	0.32	0.41
411.000							
Mean	5.27	5.98	0.43	0.07		0.34	0.39
Std. Dev	1.38	1.62	0.37	0.01		0.04	0.04
C.V.(%)	26	27	86	9		11	11
Range	3.96-9.240	4.22-10.56	0.12-1.72	0.06-0.09		0.25-0.41	0.35-0.49
No.	20						

TABLE 4.6(b) Structural Layer Coefficient Values for Section 2 Obtained by BKCHEVM

Station	Backcalculated layer moduli (Gpa)				RMS value (%)	Layer Coefficient by	
	Surface	Base	Sub0.6base	Subgrade		AASHTO	EMA
406.000	3.94	3.94	0.81	0.11	1.10	0.29	0.34
406.250	4.20	4.20	1.19	0.10	1.30	0.29	0.35
406.500	6.47	6.47	0.40	0.13	1.50	0.39	0.41
406.750	6.54	6.54	0.26	0.08	2.60	0.38	0.42
407.000	5.91	5.91	0.26	0.08	2.70	0.37	0.40
407.250	7.07	7.07	0.14	0.09	1.90	0.45	0.43
407.500	4.11	4.11	0.74	0.10	2.60	0.28	0.35
407.750	10.61	10.61	0.26	0.10	1.70	0.46	0.49
408.000	8.42	8.42	0.19	0.09	2.20	0.43	0.45
408.250	5.41	5.41	0.10	0.08	2.00	0.44	0.39
408.500	5.63	5.63	0.35	0.08	3.10	0.35	0.39
408.750	5.59	5.59	0.12	0.08	2.80	0.43	0.39
409.000							
409.250	4.06	4.06	0.26	0.08	2.10	0.34	0.35
409.500	5.48	5.48	0.14	0.08	2.20	0.42	0.39
409.750	3.32	3.32	0.45	0.09	1.10	0.30	0.32
410.000	6.00	6.00	0.27	0.09	3.10	0.38	0.40
410.250	4.62	4.62	0.36	0.08	1.40	0.34	0.36
410.500	4.03	4.03	0.11	0.08	1.40	0.41	0.34
410.750	4.86	4.86	0.44	0.09	2.50	0.33	0.37
411.000	6.09	6.09	0.10	0.10	0.60	0.46	0.40
Mean	5.62	5.62	0.35			0.38	0.39
Std. Dev	1.71	1.71	0.28			0.06	0.04
C.V.(%)	31	31	81			16	11
Range	3.33-10.61	3.33-10.61	0.10-1.19			0.28-0.46	0.32-0.49
No.	20						

TABLE 4.6(c) Structural Layer Coefficient Values for Section 2 Obtained by MODULUS

Station	Backcalculated layer moduli (Gpa)				RMS value (%)	Layer Coefficient by	
	Surface	Base	Sub0.6base	Subgrade		AASHTO	EMA
406.000							
406.250	3.15	3.60	1.92	0.09	3.70	0.24	0.33
406.500							
406.750	2.16	5.78	0.47	0.08	3.20	0.31	0.38
407.000	2.32	4.96	0.47	0.08	3.50	0.30	0.36
407.250	4.06	5.78	0.26	0.08	2.10	0.37	0.39
407.500	1.76	3.85	1.29	0.08	3.10	0.22	0.33
407.750							
408.000	2.90	6.76	0.40	0.08	2.60	0.34	0.40
408.250	2.80	4.35	0.20	0.07	3.10	0.35	0.35
408.500	1.14	6.21	0.63	0.07	3.50	0.28	0.38
408.750	1.56	4.95	0.27	0.07	3.60	0.34	0.36
409.000	1.56	5.99	0.15	0.06	4.00	0.38	0.38
409.250	1.85	3.51	0.44	0.07	9.00	0.28	0.32
409.500	1.14	4.92	0.32	0.07	2.00	0.33	0.356
409.750	2.92	2.78	0.70	0.08	3.60	0.25	0.30
410.000	1.80	5.36	0.51	0.08	3.30	0.31	0.37
410.250	2.82	3.67	0.60	0.08	4.00	0.28	0.33
410.500	2.59	3.20	0.21	0.07	2.70	0.34	0.32
410.750	2.06	4.16	0.80	0.08	3.40	0.26	0.32
411.000	6.26	4.72	0.19	0.08	1.90	0.39	0.38
Mean	2.51	4.70	0.55	0.08		0.31	0.35
Std. Dev	1.19	1.14	0.44	0.01		0.05	0.03
C.V.(%)	48	24	81	9		16	8
Range	1.14-6.26	2.28-6.76	0.15-1.92	0.06-0.09		0.22-0.39	0.30-0.42
No.	20						

TABLE 4.7(a) Structural Layer Coefficient Values for Section 3 Obtained by Manual Computation

Station	Backcalculated layer moduli (Gpa)				RMS value (%)	Layer Coefficient by	
	Surface	Base	Subbase	Subgrade		AASHTO	EMA
417.000	4.85	4.73	1.52	0.09	1.70	0.25	0.37
417.250	4.58	4.82	1.52	0.08	2.20	0.27	0.37
417.500	5.87	7.05	1.52	0.09	0.80	0.34	0.43
417.750	5.40	5.17	1.76	0.08	3.60	0.29	0.38
418.000	5.50	5.98	3.17	0.08	2.10	0.30	0.40
418.250	5.05	5.29	1.73	0.08	3.10	0.29	0.38
418.500	3.83	3.83	2.55	0.08	2.10	0.23	0.34
418.750	5.02	5.14	3.31	0.08	3.00	0.26	0.38
419.000	4.78	6.46	5.17	0.09	2.40	0.27	0.41
419.250	5.50	6.22	6.20	0.09	2.10	0.25	0.41
419.500	5.61	5.61	3.45	0.09	1.40	0.29	0.40
419.750	6.59	7.07	1.93	0.08	2.10	0.34	0.43
420.000							
420.250	7.21	7.46	0.69	0.08	2.30	0.36	0.43
420.500	4.88	4.88	1.31	0.08	3.70	0.28	0.37
420.750	5.82	5.94	0.69	0.08	2.60	0.34	0.37
421.000							
421.250							
421.500	5.56	5.18	0.59	0.07	2.60	0.30	0.38
421.750	3.81	3.81	0.99	0.08	2.50	0.22	0.34
Mean	5.29	5.57	2.24	0.08		0.29	0.39
Std. Dev	0.86	1.06	1.58	0.01		0.04	0.03
C.V.(%)	16	19	71	5		14	7
Range	3.81-7.21	3.81-7.46	0.59-6.20	0.07-0.09		0.23-0.36	0.34-0.43
No.	20						

TABLE 4.7(b) Structural Layer Coefficient Values for Section 3 Obtained by BKCHEVM

Station	Backcalculated layer moduli (Gpa)				RMS value (%)	Layer Coefficient by	
	Surface	Base	Sub.base	Subgrade		AASHTO	EMA
417.000	3.95	3.95	1.14	0.11	1.70	0.28	0.35
417.250	3.85	3.85	1.09	0.11	1.60	0.31	0.34
417.500	5.17	5.17	1.28	0.11	2.50	0.35	0.38
417.750	4.14	4.14	1.32	0.11	0.90	0.32	0.35
418.000	4.06	4.06	2.80	0.10	1.20	0.31	0.35
418.250	3.76	3.76	1.43	0.10	1.10	0.31	0.34
418.500	3.13	3.13	1.81	0.11	1.30	0.26	0.32
418.750	3.78	3.78	2.44	0.11	1.50	0.29	0.34
419.000	4.23	4.23	4.13	0.12	1.60	0.29	0.35
419.250	4.04	4.04	5.51	0.12	1.90	0.26	0.35
419.500	4.22	4.22	2.72	0.12	2.20	0.32	0.35
419.750	5.073	5.073	1.83	0.10	2.90	0.34	0.38
420.000	5.64	5.64	0.59	0.10	4.20	0.35	0.38
420.250	6.76	6.76	0.51	0.10	3.20	0.39	0.43
420.500	4.32	4.32	0.79	0.10	1.30	0.33	0.36
420.750	4.89	4.89	0.65	0.10	2.00	0.35	0.38
421.000	4.70	4.70	0.43	0.10	1.30	0.33	0.37
421.250	4.25	4.25	0.11	0.11	1.20	0.42	0.35
421.500	5.26	5.26	0.37	0.09	1.90	0.34	0.38
421.750	3.42	3.42	0.67	0.10	1.50	0.26	0.33
Mean	4.41	4.41	1.58	0.11		0.32	0.36
Std. Dev	0.81	0.81	1.37	0.01		0.04	0.02
C.V.(%)	18	18	87	7		13	7
Range	3.31-6.77	3.31-6.77	0.11-5.51	0.09-0.12		0.26-0.42	0.32-0.43
No.	20						

TABLE 4.7(c) Structural Layer Coefficient Values for Section 3 Obtained by MODULUS

Station	Backcalculated layer moduli (Gpa)				RMS value (%)	Layer Coefficient by	
	Surface	Base	Sub.base	Subgrade		AASHTO	EMA
417.000							
417.250	0.71	9.75	1.58	0.08	5.20	0.27	0.46
417.500	0.82	10.83	2.33	0.08	3.30	0.29	0.48
417.750	6.70	3.62	1.81	0.10	1.20	0.29	0.35
418.000	2.80	3.99	5.16	0.09	1.00	0.25	0.34
418.250	2.98	3.60	2.28	0.09	1.30	0.26	0.33
418.500	3.68	2.92	2.90	0.09	0.50	0.21	0.31
418.750	2.70	3.73	4.20	0.10	1.50	0.23	0.33
419.000	2.70	4.18	8.19	0.10	1.00	0.22	0.35
419.250	2.20	4.30	10.18	0.10	1.30	0.20	0.35
419.500							
419.750	0.73	13.00	2.84	0.08	4.50	0.30	0.50
420.000	0.72	10.28	1.03	0.08	7.40	0.29	0.47
420.250	0.85	11.74	1.01	0.08	5.30	0.32	0.49
420.500	10.44	3.71	0.93	0.09	1.60	0.31	0.37
420.750	10.37	3.82	0.81	0.08	2.70	0.33	0.37
421.000	5.65	4.08	0.58	0.09	1.90	0.30	0.36
421.250	6.39	3.56	0.17	0.08	6.10	0.37	0.35
421.500	0.91	8.90	0.44	0.08	2.10	0.33	0.44
421.750	8.93	2.91	0.76	0.08	0.90	0.25	0.34
Mean	3.90	6.05	2.62	0.09		0.28	0.39
Std. Dev	3.37	3.53	2.75	0.01		0.05	0.06
C.V.(%)	86	58	105	9		16	17
Range	0.70-10.44	2.91-13.00	0.17-10.18	0.08-0.10		0.20-0.37	0.31-0.50
No.	20						

TABLE 4.8(a) Structural Layer Coefficient Values for Control Section Obtained by BKCHEVM

Station	Backcalculated layer moduli (Gpa)				RMS value (%)	Layer Coefficient by AASHTO
	Surface	Base	Subbase	Subgrade		
585.250						
585.500	10.1	10.1	0.08	0.09	1.40	0.49
585.750	9.03	9.03	0.26	0.10	1.60	0.44
586.000	9.28	9.28	0.11	0.10	1.30	0.46
586.250	8.59	8.59	0.10	0.09	1.60	0.49
586.500	8.13	8.13	0.50	0.10	1.40	0.45
586.750	8.35	8.35	0.18	0.10	1.10	0.44
587.000	11.21	11.21	0.46	0.12	3.30	0.37
587.250	11.47	11.47	0.35	0.12	0.90	0.57
587.500	13.64	13.64	0.19	0.11	0.70	0.63
587.750	9.92	9.92	0.08	0.10	1.60	0.59
588.000	8.35	8.35	0.19	0.10	1.50	0.39
588.250	9.29	9.29	0.08	0.10	0.70	0.51
588.500	8.75	8.75	0.39	0.10	0.80	0.34
588.750						
589.000	12.16	12.16	0.22	0.11	1.60	0.46
589.250	12.99	12.99	0.23	0.10	1.70	0.55
589.500	11.88	11.88	0.19	0.10	1.70	0.56
589.750	9.54	9.54	0.08	0.10	1.80	0.51
590.000	12.77	12.77	0.16	0.10	1.70	0.57
Mean	10.03	10.03	0.21	0.10		0.50
Std. Dev	1.89	1.89	0.13	0.-01		0.08
C.V.(%)	18	18	62	10		16
Range	8.12-13.77	8.12-13.77	0.08-0.50	0.09-0.12		0.34-0.63
No.						

TABLE 4.8(b) Structural Layer Coefficient Values for Control Section Obtained by MODULUS

Station	Backcalculated layer moduli (Gpa)				RMS value (%)	Layer Coefficient by AASHTO
	Surface	Base	Sub.base	Subgrade		
585.250						
585.500	5.42	9.25	0.29	0.07	1.00	0.35
585.750	6.38	6.94	0.79	0.08	2.30	0.31
586.000	12.76	9.54	0.32	0.08	3.00	0.33
586.250					0.90	0.39
586.500	6.94	8.75	1.11	0.08	3.80	0.34
586.750	6.72	8.01	0.48	0.08	2.40	0.32
587.000	5.39	5.86	0.70	0.08	2.70	0.30
587.250	10.17	12.16	0.99	0.10	3.40	0.45
587.500	9.50	13.06	0.94	0.10	3.80	0.45
587.750	7.38	9.01	0.52	0.09	1.70	0.37
588.000						
588.250	5.53	8.00	0.59	0.08	2.60	0.29
588.500						
588.750						
589.000						
589.250	8.66	8.60	0.75	0.09	0.40	0.41
589.500						
589.750						
590.000	8.79	12.54	0.44	0.08	2.10	0.46
Mean	7.80	9.31	0.66	0.08		
Std. Dev	2.25	2.23	0.27	0.01		
C.V.(%)	29	24	40	12		
Range	5.39-12.76	5.87-13.06	0.289-1.11	0.07-0.10		0.29-0.46
No.	20					

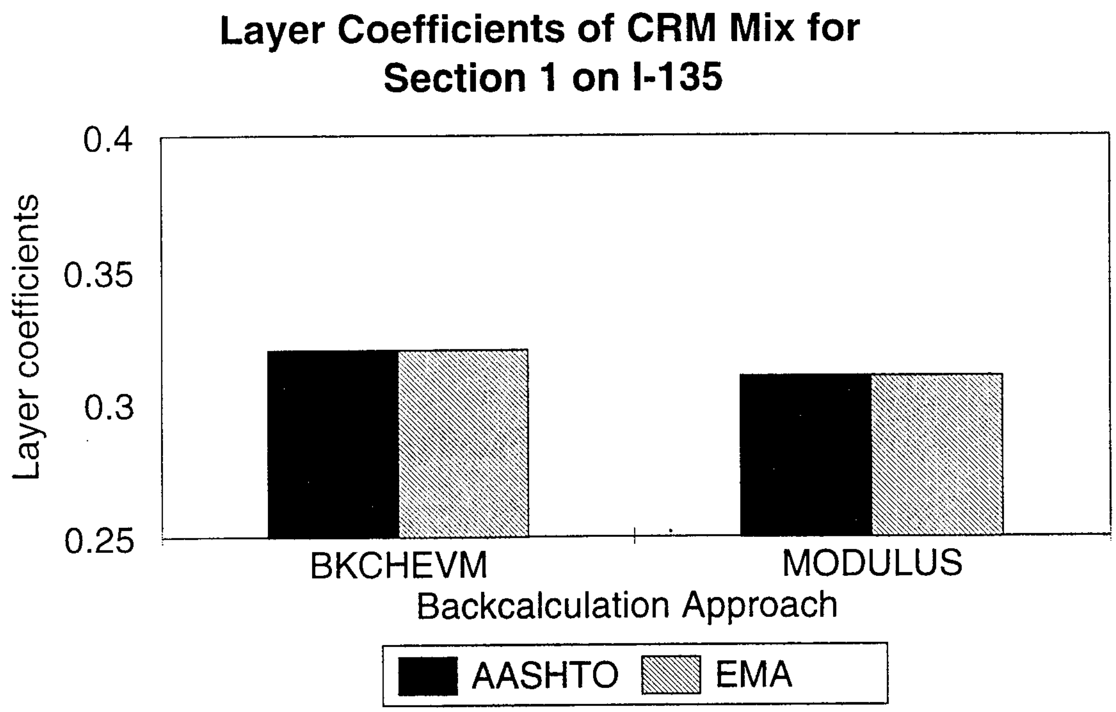

Figure 4.7 Structural Layer Coefficient Values for Section 1 on I-135

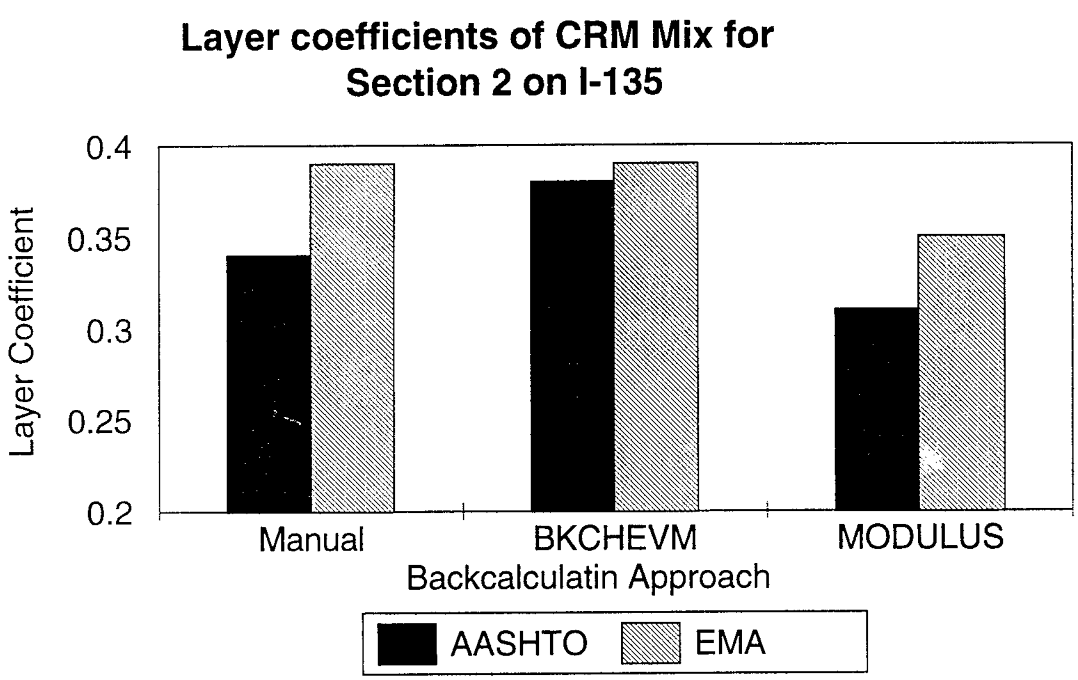

Figure 4.8 Structural Layer Coefficient Values for Section 2 on I-135

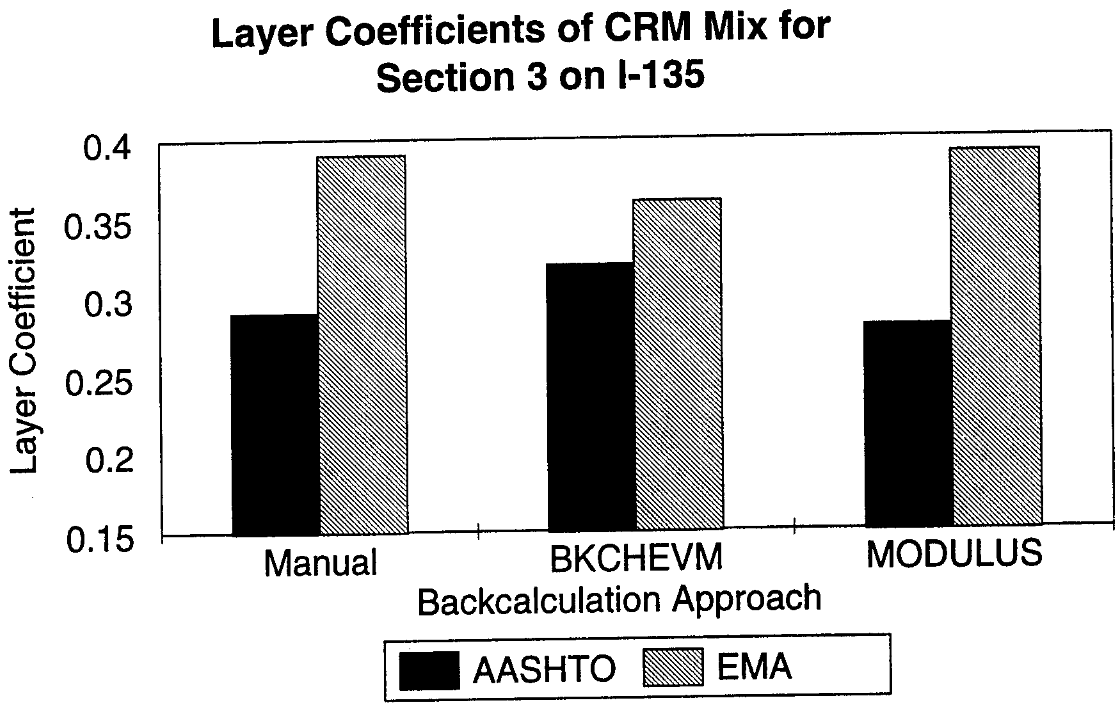

Figure 4.9 Structural Layer Coefficient Values for Section 3 on I-135

TABLE 4.9 Structural Layer Coefficient Values for CRM Asphalt Layers on US-56

Method	Statistics	Layer Coefficient	
		AASHTO	EMA
Manual	Mean	0.20	0.34
	Std. Dev.	0.13	.07
	C.V.(%)	66	21
	Range	0.06-0.47	0.24-0.42
	n	11	11
BKCHEVM	Mean	0.15	0.30
	Std. Dev.	0.09	0.06
	C.V.(%)	62	19
	Range	0.01-0.24	0.22-0.39
	n	11	11
MODULUS	Mean	0.20	0.30
	Std. Dev.	0.28	0.03
	C.V.(%)	137	10
	Range	0.04-0.52	0.26-0.34
	n	11	11

TABLE 4.10 (a) **Structural Layer Coefficient Values for US-56 Obtained by Manual Computation**

Station	Backcalculated layer moduli (Gpa)				RMS value (%)	Layer Coefficient by	
	Surface	Base	Subbase	Subgrade		AASHTO	EMA
0.00	6.53	7.74	3.45	0.12	5.40	0.47	
50.00	7.38	7.87	7.17	0.08	2.80	0.19	
100.00	2.42	7.26	7.17	0.10	2.10	0.10	
150.00							
200.00	2.21	6.89	8.27	0.10	3.70	0.06	
250.00	4.67	5.90	5.86	0.09	1.90	0.21	
300.00	2.46	2.34	6.20	0.10	1.50		
350.00	4.92	7.87	5.37	0.09	2.50	0.22	
400.00	2.26	2.14	5.86	0.10	2.10		
450.00	6.02	5.27	6.20	0.11	1.50	0.16	
500.00	3.34	2.38	7.58	0.12	2.60		
Mean	4.21	5.57	6.31	0.10		0.20	
Std. Dev	1.95	2.41	1.35	0.01		0.13	
C.V.(%)	46	43	21	12		66	
Range	2.21-7.38	0.31-1.14	0.50-1.20	0.01-0.02		0.06-0.47	
No.	20						

TABLE 4.10 (b) Structural Layer Coefficient Values for US-56 Obtained by BKCHEVM

Station	Backcalculated layer moduli (Gpa)				RMS value (%)	Layer Coefficient by	
	Surface	Base	Sub.base	Subgrade		AASHTO	EMA
0.00	6.29	6.29	1.31	0.13	6.80		
50.00	5.22	5.22	6.85	0.10	3.20	0.20	
100.00	2.86	2.86	7.95	0.14	3.50	0.06	
150.00							
200.00	3.00	3.00	10.27	0.12	4.10		
250.00	3.39	3.39	5.31	0.12	3.10	0.24	
300.00	1.77	1.77	5.31	0.12	3.00		
350.00	4.03	4.03	5.65	0.11	4.20	0.21	
400.00	2.17	2.17	4.53	0.14	1.80	0.01	
450.00	3.96	3.96	6.48	0.14	4.00	0.15	
500.00	2.51	2.51	7.30	0.15	4.10		
Mean	3.52	3.52	6.09	0.13		0.15	
Std. Dev	1.40	1.40	2.35	001		0.09	
C.V.(%)	40	40	39	11		62	
Range	1.78-6.29	1.78-6.29	1.31-10.27	0.10-0.15		0.01-0.24	
No.	20	20					

TABLE 4.10 (c) Structural Layer Coefficient Values for US-56 Obtained by MODULUS

Station	Backcalculated layer moduli (Gpa)				RMS value (%)	Layer Coefficient by	
	Surface	Base	Sub.base	Subgrade		AASHTO	EMA
0.00	2.90	16.25	2.94	0.12	3.60	0.52	
50.00					4.00	0.10	
100.00	4.06	2.54	15.93	0.08	1.40		
150.00					2.20	0.30	
200.00	5.19	2.48	16.97	0.08	3.70		
250.00	4.06	2.85	9.49	0.08	1.70	0.05	
300.00	2.61	1.57	8.35	0.06	1.00		
350.00	4.08	3.05	9.54	0.08	2.80	0.04	
400.00	2.63	1.48	15.65	0.06	2.50		
450.00	4.67	2.81	11.89	0.10	2.60		
500.00	3.72	2.18	18.79	0.08	1.50		
Mean	3.77	3.91	12.17	0.08		0.20	
Std. Dev	0.90	4.66	5.09	0.02		0.21	
C.V.(%)	24	119	42	24		103	
Range	2.61-5.19	1.48-16.25	2.94-18.79	0.06-0.12		0.04-0.52	
No.	11						

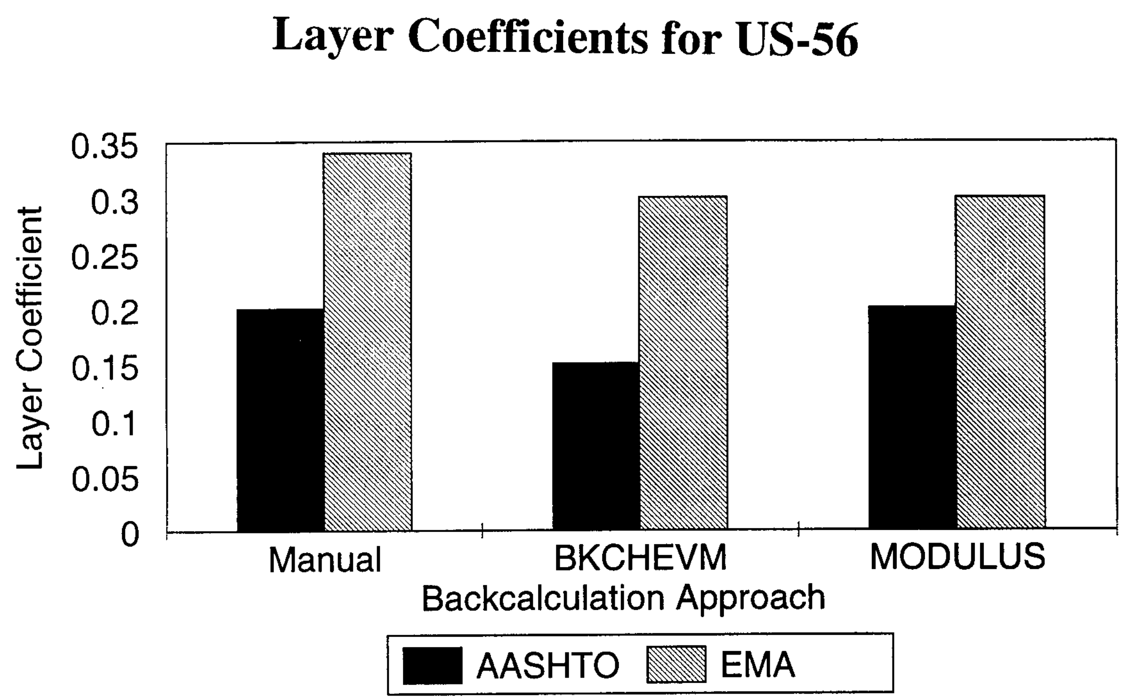

Figure 4.10 Structural Layer Coefficient Values for US-56

TABLE 4.11 Structural Layer Coefficient Values for CRM Asphalt Layers on K-32

Method	Statistics	Layer Coefficient	
		AASHTO	EMA
BKCHEVM	Mean	0.22	0.20
	Std. Dev.	0.18	0.12
	C.V.(%)	86	60
	Range	0.05-0.59	0.11-0.46
	n	10	10
MODULUS	Mean	0.25	0.28
	Std. Dev.	0.17	0.09
	C.V.(%)	70	32
	Range	0.06-0.59	0.19-0.44
	n	12	12

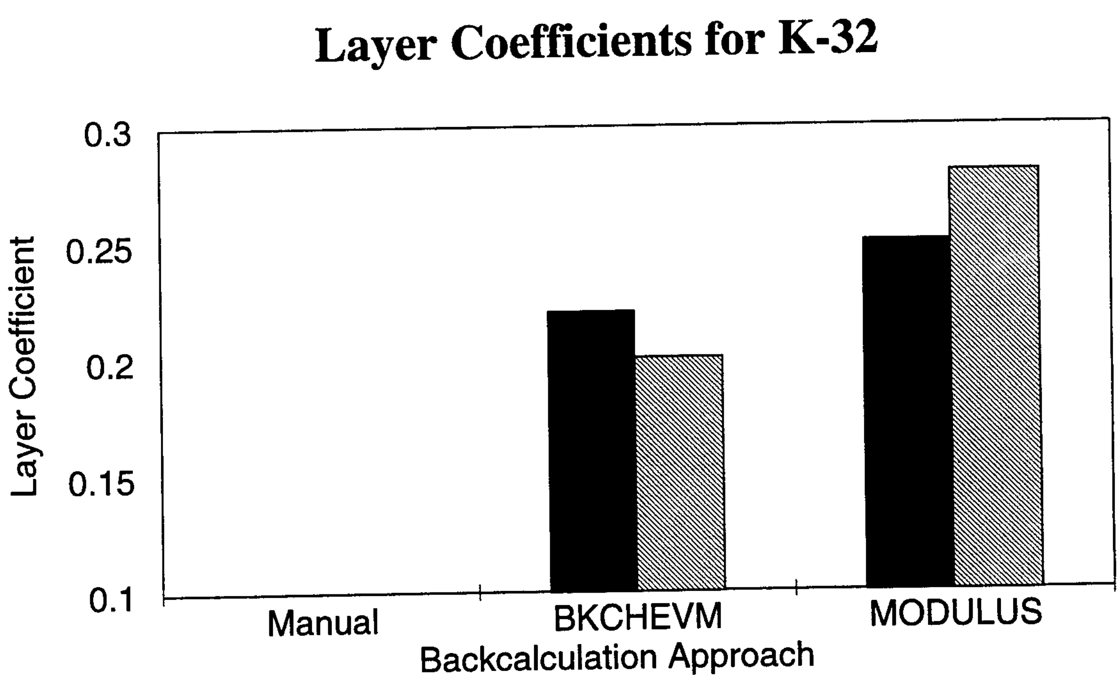

Figure 4.11 Structural Layer Coefficient Values for K-32

TABLE 4.12(a) Structural Layer Coefficient Values for K-32 Obtained by BKCHEVM

Station	Backcalculated layer moduli (Gpa)				RMS value (%)	Layer Coefficient by	
	Surface	Base	Subbase	Subgrade		AASHTO	EMA
5.000	0.29	2.42	0.06	0.27	2.63	0.10	0.12
50.00	0.32	3.55	0.09	0.22	1.80	0.05	0.13
105.00	0.31	7.70	0.10	0.33	4.36	-	0.12
150.00	0.73	13.52	0.12	0.37	1.56	0.07	0.16
205.00	1.51	7.75	0.11	0.23	2.13	0.18	0.18
250.00	0.26	8.72	0.10	0.20	1.93	-	0.11
305.00	3.51	0.93	0.09	0.14	8.12	-	0.37
405.00	0.32	1.90	0.07	0.15	2.09	0.25	0.13
450.00	0.97	2.26	0.07	0.16	3.96	0.27	0.18
505.00	7.85	1.36	0.08	0.15	1.43	0.59	0.46
Mean	1.61	5.10	0.09	0.22		0.22	0.20
Std. Dev	2.41	4.18	0.02	0.08		0.18	0.12
C.V.(%)	150	83	22	36		86	60
Range	0.26-7.85	0.93-13.52	0.06-0.12	0.14-0.37		0.05-0.59	0.11-0.46
No.	10						

TABLE 4.12 (b) Structural Layer Coefficient Values for K-32 Obtained by MODULUS

Station	Backcalculated layer moduli (Gpa)				RMS value (%)	Layer Coefficient by	
	Surface	Base	Sub.base	Subgrade		AASHTO	EMA
5.00	1.06	1.09	0.43	0.6	9.80	-	0.22
50.00	1.59	1.43	0.78	0.07	16.91	-	0.25
30500	1.44	1.65	0.21	0.07	16.97	0.31	0.23
1505.00	8.15	4.23	0.03	0.08	14.05	0.06	0.44
1550.00	7.43	3.13	0.03	0.10	15.48	0.06	0.42
1605.00	6.63	3.21	0.03	0.08	8.89	0.08	0.41
1650.00	2.38	2.65	0.05	0.05	8.77	0.18	0.25
1750.00	2.42	2.42	0.27	0.06	18.99	0.40	0.26
1850.00	1.19	2.36	0.06	0.06	5.51	0.18	0.19
1905.00	2.69	2.69	0.18	0.06	13.03	0.59	0.27
1950.00	1.38	2.25	0.11	0.06	6.52	0.25	0.20
2005.00	1.56	2.14	0.12	0.06	11.42	0.37	0.22
Mean	3.15	2.44	0.19	0.07		0.25	0.28
Std. Dev	2.63	0.85	0.22	0.02		0.17	0.09
C.V.(%)	84	35	115	23		70	32
Range	1.19-8.14	1.09-4.22	0.03-0.78	0.05-0.10		0.06-0.59	0.19-0.44
No.	12						

Comparison of Backcalculated Moduli with Laboratory Tested Value

Resilient Modulus tests were conducted on randomly selected 64 mm thick core samples from each test section following ASTM D 4123 test procedure. The samples were representatives of ARS-ARB, ARB and existing asphalt mix layers. Tests were conducted at 20° C using a pulse load of 0.1 sec duration and 0.9 sec rest period. Indirect tensile loads applied varied from 580 N to 5,560 N to obtain measurable deflections in the range of 100 µm to 200 µm. Very high variabilities in the labortatory tested moduli values were observed. This indicates the necessity of testing large number of samples in the laboratory to have any definite conclusion about the lab result. Figures 4.12 and 4.13 illustrate the comparisons of laboratory tested ARS-ARB and ARB moduli with backcalculated values for I-135 respectively. Figure 4.14 shows the comparison of laboratory tested ARS-AC moduli with backcalculated values for US-56 and K-32.

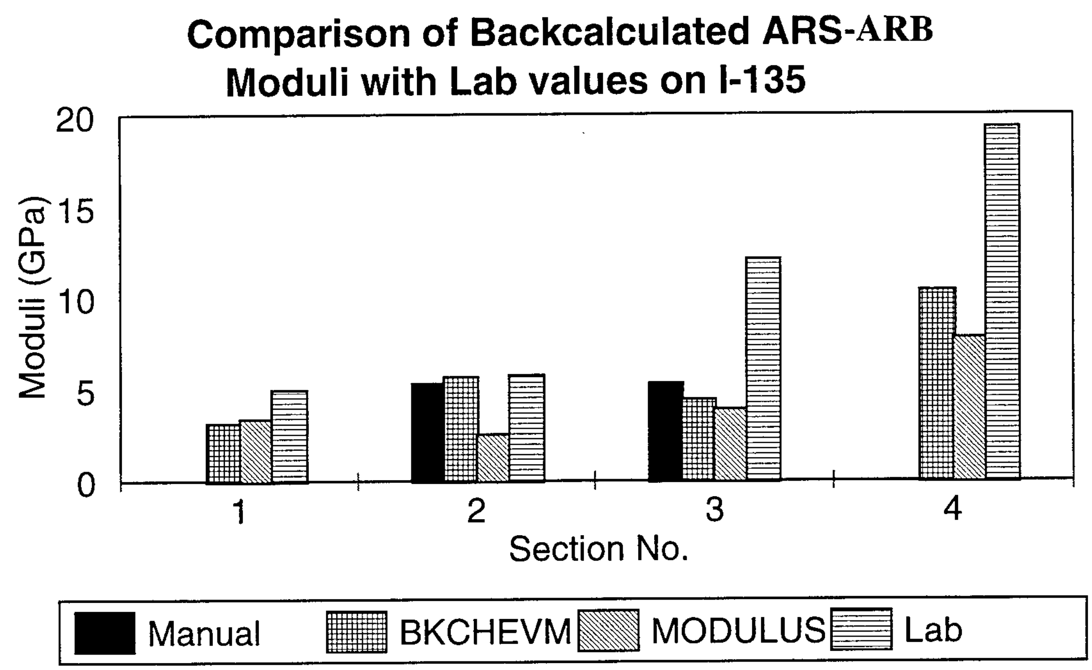

Figure 4.12 Comparison of Backcalculated ARS-ARB Moduli with Laboratory Tested Values on I-135

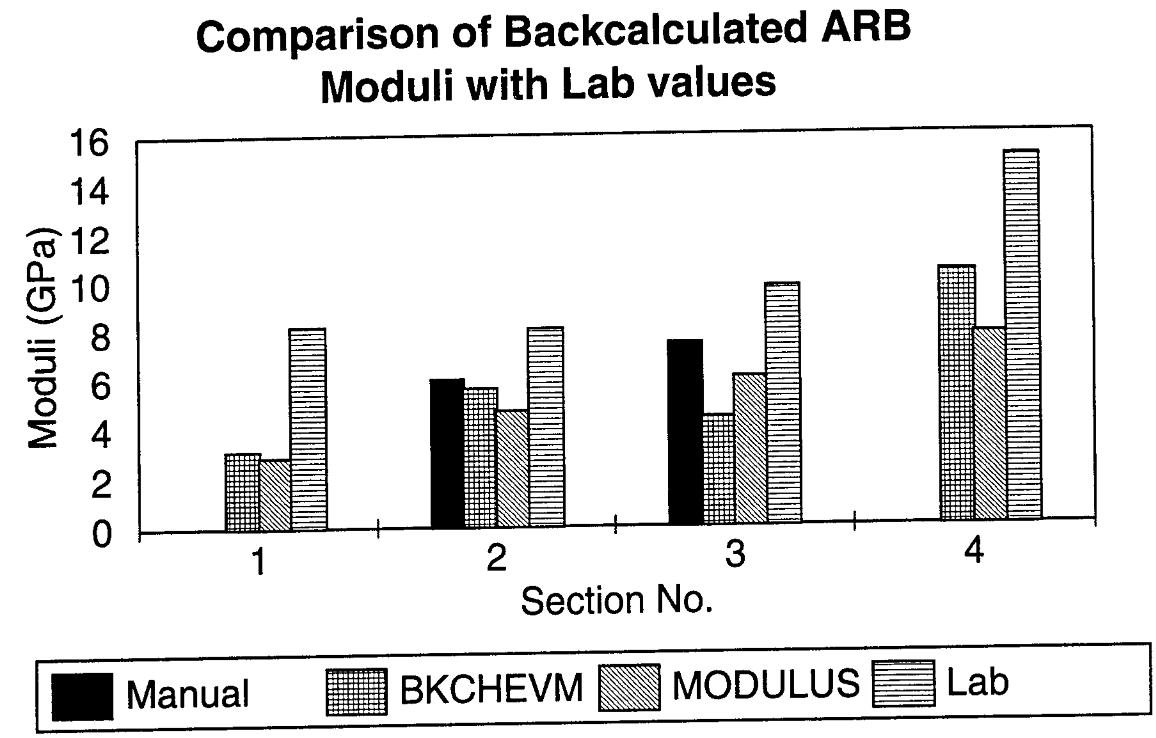

Figure 4.13 Comparison of Backcalculated ARB Moduli with Laboratory Tested Values on I-135

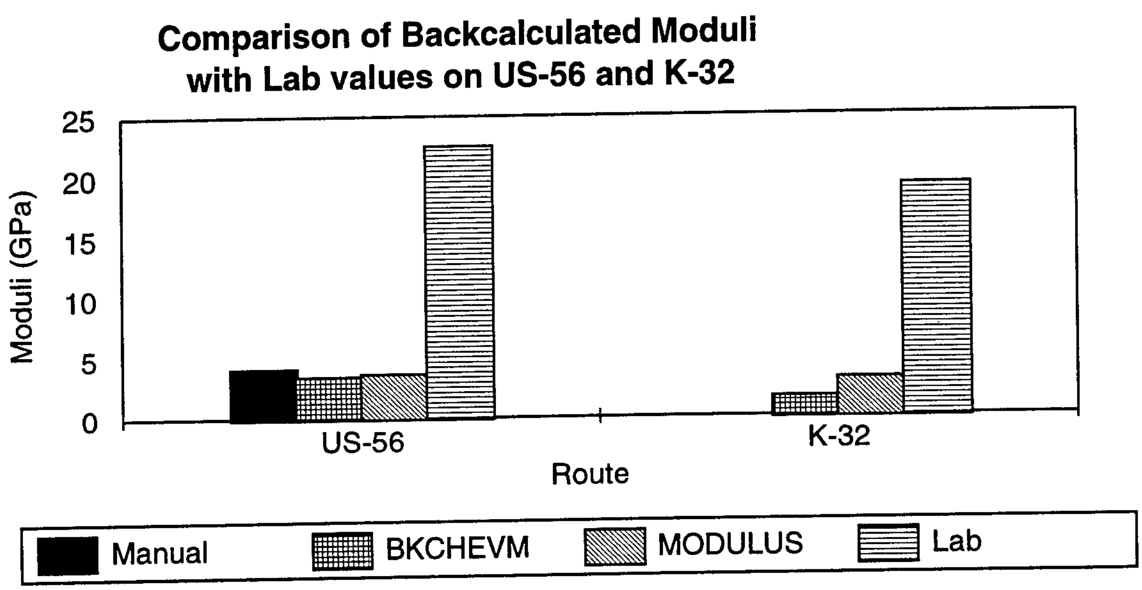

Figure 4.14 Comparison of Backcalculated ARS-AC Moduli with Laboratory Tested Values on US-56 and K-32

control section on I-135 which has conventional asphalt surface and base. As the CRM mix gets different coefficient values depending whether it is used in surface or base layers, in order to compare the results of the study with those used by KDOT, weighted average of the KDOT-layer coefficient values for the whole section were calculated and presented in Table 4.13. The table also tabulates the average layer coefficient values obtained by the AASHTO and EMA approaches. It appears that the layer coefficients for the CRM overlays are lower than KDOT-designated values (on US-56 and K-32). Thus, the asphalt-rubber surfaces (ARS), though may be used in the top-most layer, appears to have lower layer coefficient values. As mentioned earlier, these layers showed lower backcalculated moduli. Laboratory tests on 64 mm thick core samples with 25 to 37 mm of ARS layer also showed lower moduli than the ARB mixes for most of the cases. Figures 4.12 and 4.13 show the comparison of the backcalculated layer moduli with the laboratory values for ARS-ARB and ARB layers respectively on the four sections of I-135. Figure 4.14 shows the comparison of the laboratory tested moduli with the backcalculated moduli values for the ARS-AC layer on US-56 and K-32. August 4, 1997For the full-depth CRM pavements on rubblized subbases, it is apparent that the design values are very close to the values obtained in this study, indicating that asphalt-rubber coefficient values are very close to or slightly higher than the conventional asphalt mix for new pavement structural design. The apparent discrepancy for these two mixes happened because the CRM overlays on the existing structural really represent inverted structures, i.e., they have a more rigid layer somewhere in the structure below the surface layer. It is apparent that these rigid layers have overwhelming effects on the structural performance of the CRM overlays. The AASHTO structural number approach for design of overlays may not be applicable for such a flexible layer with relatively lower modulus.

For full-depth/thicker CRM asphalt pavements, the asphalt-rubber base (ARB) layers have larger influence than the thin (typically 25 to 37 mm) asphalt-rubber surface (ARS) layer. The layer coefficient values for the CRM mixes largely represent the contribution of this layer. The AASHTO structural number approach appears to be valid for this type of structure thus requiring the structural number for the CRM asphalt pavement

I-135	Section 1	CRM Mix (composite)	0.32	0.31	0.35
		Lime treated subbase	0.09	-	-
	Section 2	CRM Mix (composite)	0.34	0.38	0.36
		Rubl. JRCP	0.20	-	0.18
	Section 3	CRM Mix (composite)	0.30	0.38	0.35
		Rubl. JRCP	0.35	-	0.18
	Section 4	Conventional AC Mix	0.50	-	0.42
		Rubl. JRCP	0.12	-	0.18
US -56		CRM Mix (surface)	0.18	0.30	0.42
K-32		CRM Mix (surface)	0.24	0.24	0.42

As shown in Table 4.13, the average layer coefficients values for the rubblized JRCP layer obtained using the AASHTO equation varied from 0.20 for Section No. 2 to 0.35 for Section No. 3. The design value used by KDOT was 0.18 which is close to 0.20 obtained for Section No. 2. The control section rubblized layer coefficient value obtained was 0.12. As expected, very high variabilities (up to 47%) in computed layer coefficients were also observed. Since there is no apparent difference in rubblization techniques used on these sections, the only plausible explanation is construction control and inherent variabilities of reused in-situ materials. The AASHTO-suggested rubblized PCC layer coefficient value varies from 0.14 to 0.30 (1). This study shows that the range should be from 0.10 to 0.35. One way of taking this variability into account may be to increase the overall standard deviation, S_o used in the AASHTO design guide.

I-135	Section 1	-	0.82	0.41
	Section 2	0.35	0.73	0.48
	Section 3	0.73	0.74	0.42
K-32		-	0.91	-0.60
US-56		0.63	0.93	-0.99

Proposed Equation for Layer Coefficient for CRM Asphalt Mixes

In this study, a relationship between the structural layer coefficient values (a_i) for CRM mixes and moduli, similar to those established by AASHTO, has been developed. Analysis results from both the AASHTO and the Equal Mechanistic Approach for all CRM sections on I-135, US-56 and K-32 were used in the analysis. Figure 4.15 and 4.16 illustrate graphically the relationships between a_i and backcalculated modulus value. Excellent coefficient of determination (R^2) value (greater than 0.90) was obtained for the EMA results. The equation derived from the EMA results is:

$$\mathbf{a_i = 0.315 \log (E) - 1.732}$$

where, E is expressed in Pa.

The equation from the AASHTO results has a R^2 value of 0.387. The use of layer coefficient values for base and subbase from Ullidz's equations which do not exactly represent the materials in question might have resulted in large errors in the estimated a_i values for CRM asphalt mixes in the AASHTO approach. This is also supported by the higher coefficient of variation and wider range for the coefficient values obtained in the AASHTO approach compared to the equal mechanistic approach. However, it should be noted that other than resilient modulus, a number of factors like layer thickness, material type, layer location (base, subbase), traffic level, failure criterion, etc. are known to influence the layer coefficient value.

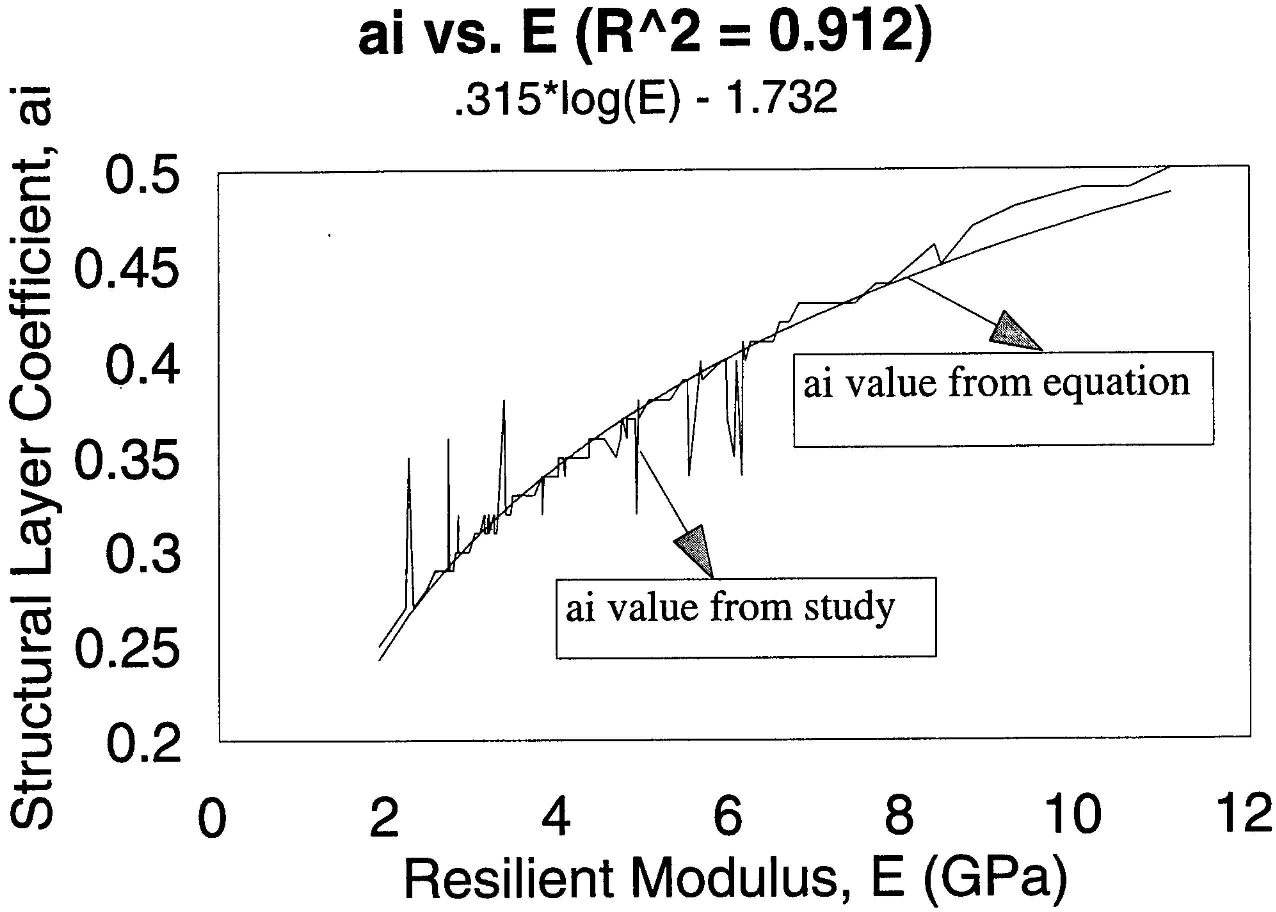

FIGURE 4.15 Structural Layer Coefficient of CRM Asphalt Mixtures from equation and EMA approach

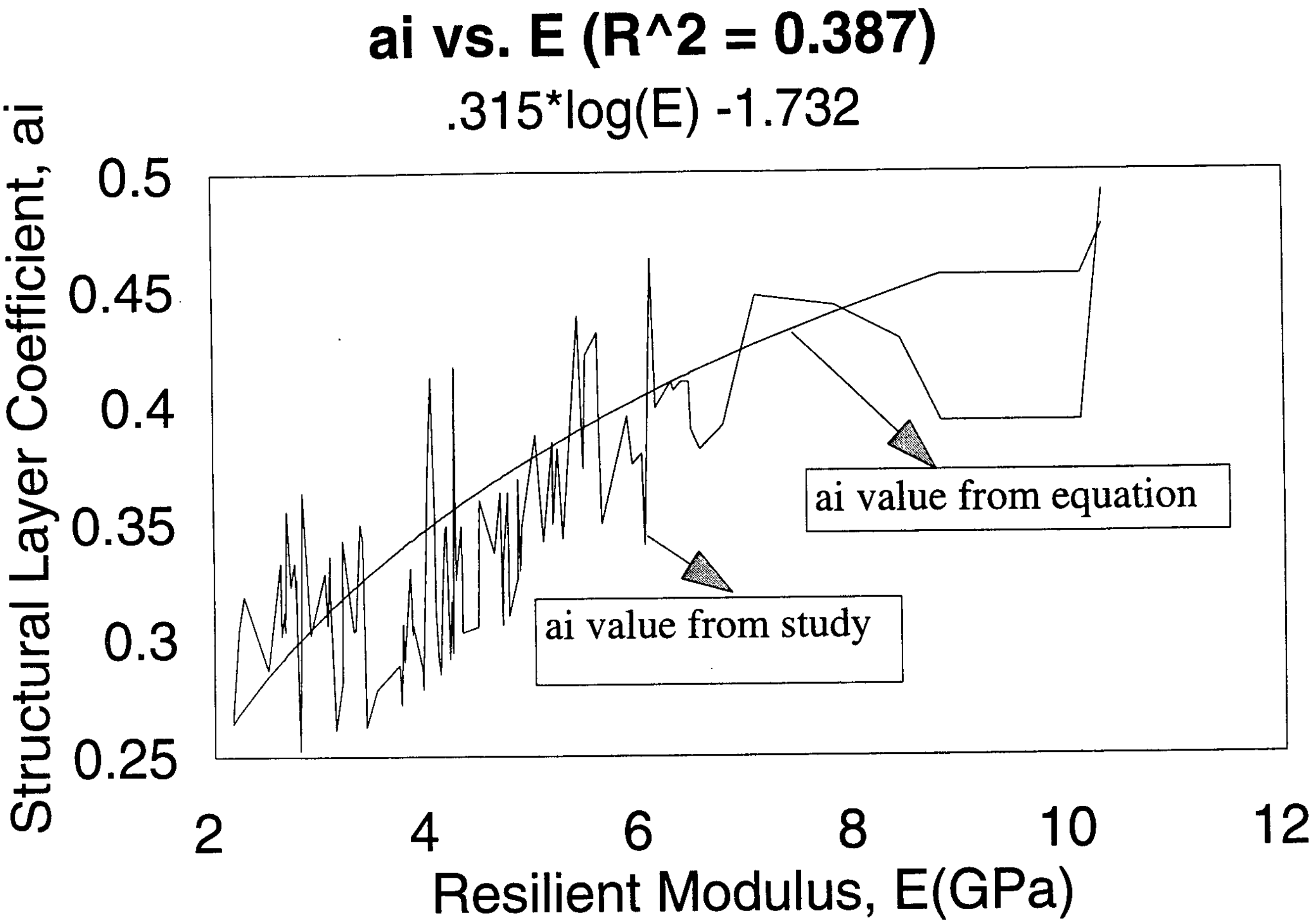

FIGURE 4.16 Structural Layer Coefficient of CRM Asphalt Mixtures from equation and AASHTO approach

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

1. The AASHTO approach of computing layer coefficients results in very high variabilities for CRM asphalt mixes compared to the Equal Mechanistic Approach. The latter method appeared to be suitable for future studies on evaluation of layer coefficients of new materials.

2. For CRM asphalt mix overlays, the average surface layer coefficients from the Equal Mechanistic Approach of analysis was found to vary between 0.11 to 0.46 with most values falling around 0.30. This indicates a lower structural layer coefficient value for the asphalt-rubber mix compared to the conventional asphalt concrete. For newly constructed CRM asphalt pavements, the layer coefficients varied from 0.25 to 0.48, with the average value around 0.35. These values are close to the AASHTO recommended coefficient values for conventional asphalt concrete layers.

3. As expected, large variabilities in computed layer coefficients for rubblized JRCP were observed. The layer coefficients for this layer typically varied from 0.10 to 0.35.

4. Poor correlation was found between backcalculated and laboratory layer moduli values. Large variation in the laboratory determined resilient modulus values emphasizes testing a large number of samples in the laboratory for such comparison.

5. Further study is recommended as to the proposed equation considering the seasonal variation and other influencing parameters.

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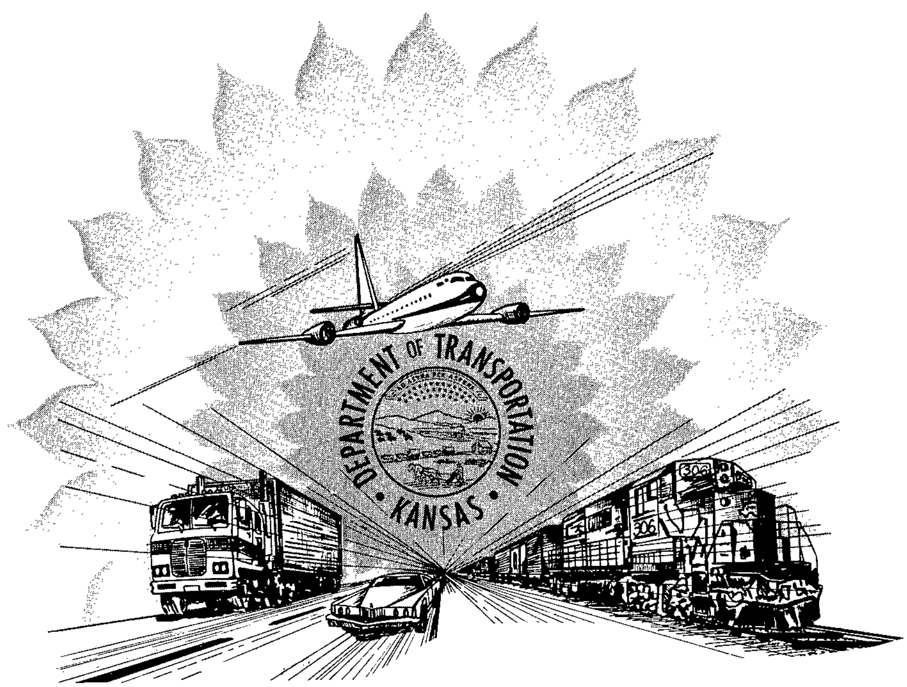

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