SYNTHESIS/LITERATURE REVIEW FOR DETERMINING STRUCTURAL LAYER COEFFICIENTS (SLC) OF BASES

FINAL REPORT

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DISCLAIMER

Prepared in cooperation with the State of Florida Department of Transportation and the U.S. Department of Transportation.

METRIC CONVERSION TABLE

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
FORCE and PRESSURE or STRESS				
lbf	pound force	4.45	newtons	N
lbf/in^2	pound force per square inch	6.89	kilopascals	kPa

METRIC CONVERSION TABLE

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
FORCE and PRESSURE or STRESS				
N	newtons	0.225	pound force	lbf
kPa	kilopascals	0.145	pound force per square inch	lbf/in^2

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16. Abstract

FDOT’s current method of determining a base material structural layer coefficient (SLC) is detailed in the Materials Manual, Chapter 2.1, Structural Layer Coefficients for Flexible Pavement Base Materials. Currently, any new base material not approved under FDOT specifications must undergo (1) laboratory testing, (2) test pit investigation, and (3) a project test section for constructability and roadway performance evaluation to determine a SLC for design purposes. The test section evaluation phase can take up to five years to compare the pavement performance of the new base material with a limerock base control section. In this project, a thorough review of literature has been conducted of current and past practices for the determination of structural layer coefficients (SLC) of pavement base materials. The review organizes the methodologies into three broad categories: (1) methods that determine SLCs via relationships with other material parameters; (2) methods that determine SLCs via estimates of the structural number (SN) of existing and available pavement sections; and (3) methods that establish SLCs via equivalencies with a reference material. Several of the strategies reviewed provide opportunities for estimating SLCs of both traditional and new base course materials in a more accelerated fashion and in considerably less time than the five years often required at present.

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EXECUTIVE SUMMARY

FDOT's current method of determining a base material structural layer coefficient (SLC) is detailed in the Materials Manual, Chapter 2.1, Structural Layer Coefficients for Flexible Pavement Base Materials. Currently, any new base material not approved under FDOT specifications must undergo (1) laboratory testing, (2) test pit investigation, and (3) a project test section for constructability and roadway performance evaluation to determine a SLC for design purposes. The test section evaluation phase can take up to five years to compare the pavement performance of the new base material with a limerock base control section. In this project, a thorough review of literature has been conducted of current and past practices for the determination of structural layer coefficients (SLC) of pavement base materials. The review organizes the methodologies into three broad categories: (1) methods that determine SLCs via relationships with other material parameters; (2) methods that determine SLCs via estimates of the structural number (SN) of existing and available pavement sections; and (3) methods that establish SLCs via equivalencies with a reference material. Several of the strategies reviewed provide opportunities for estimating SLCs of both traditional and new base course materials in a more accelerated fashion and in considerably less time than the five years often required at present.

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CHAPTER 1
INTRODUCTION

The Florida Department of Transportation's (FDOT) Flexible Pavement Design Manual, March 2008, provides procedures for determining the design thickness of base course materials. In these procedures, layer coefficients have been developed that represent the relative strength of different pavement materials in Florida. Standard Index 514 identifies the structural layer coefficient (SLC) for combinations of base types and thicknesses for general and limited use optional bases. Contractors can select from the base materials shown on the Typical Section Sheet or from Standard Index 514. Except as limited by Standard Index 514 or as may be justified by special project conditions, the options for base material are not restricted. Allowing a contractor the full range of base materials will permit the contractor to select the least costly material, resulting in the lowest bid price.

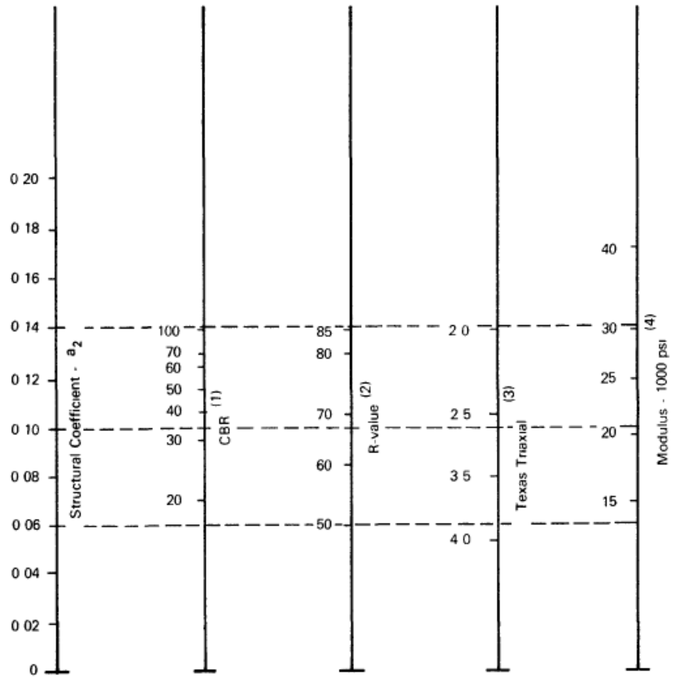
FDOT's current method of determining a base material SLC are detailed in the Materials Manual, Chapter 2.1, Structural Layer Coefficients for Flexible Pavement Base Materials. Currently, any new base material not approved under FDOT specifications must undergo (1) laboratory testing, (2) test pit investigation, and (3) a project test section for constructability and roadway performance evaluation to determine a SLC for design purposes. The test section evaluation phase can take up to five years to compare the pavement performance of the new base material with a limerock base control section. Materials that perform equivalently to a limerock control section may obtain a recommendation of a SLC of 0.18 in/in.

The objective of this project was to produce a synthesis of current and past practices for the determination of structural layer coefficients (SLC) of pavement base materials. A thorough review of literature has been conducted and is presented in the following sections. The synthesis does not rank or evaluate the differences or advantages of various methods. In general, the review organizes the methodologies into three broad categories: (1) methods that determine SLCs via relationships with other material parameters, (2) methods that determine SLCs via estimates of the structural number (SN) of existing and available pavement sections, and (3) methods that establish SLCs via equivalencies with a reference material. The three categories are discussed sequentially in the following sections.

CHAPTER 2
MATERIAL PARAMETER RELATIONSHIPS

The AASHTO Guide for Design of Pavement Structures (AASHTO 1993) provides a chart (Figure 1) for determining the structural layer coefficient of granular base materials using various known material parameters, such as California Bearing Ratio (CBR) and elastic (resilient) modulus. Alternatively, the following equation may be used to estimate the SLC for a granular base material, a_2, from its elastic modulus, E_{BS} (AASHTO 1993):

$$a_2 = 0.249(\log_{10}E_{BS}) - 0.977 \qquad (1)$$



(1) Scale derived by averaging correlations obtained from Illinois
(2) Scale derived by averaging correlations obtained from California, New Mexico and Wyoming
(3) Scale derived by averaging correlations obtained from Texas
(4) Scale derived on NCHRP project *(3)*

Figure 1. Variation in Granular Base Layer Coefficient (a_2) with Various Material Parameters (from AASHTO 1993)

A number of researchers have utilized these relationships to determine SLCs for both traditional and new base course material applications.

- Bahia et al. (2000) determined the SLC of reprocessed asphaltic mixtures used in Wisconsin as base materials via the AASHTO correlation with elastic (resilient) modulus. The resilient modulus of the materials was measured with standard laboratory techniques. Trends observed in resilient modulus compared with measured rutting performance of the materials did not match, and the researchers suggest that SLC determination should combine both elastic and damage behavior of pavement materials.
- Baus and Li (2006) determined the SLC of various graded aggregate bases used in South Carolina via the AASHTO correlation with elastic (resilient) modulus. The resilient modulus of the materials was measured with a plate load method in test pit experiments. The researchers were concerned to report SLC values ranging from 0.05 to 0.24 for the various graded aggregates investigated, despite the fact that South Carolina uses a constant value of 0.18 for all graded aggregate bases.
- Butalia et al. (2011) determined the SLC of full-depth reclaimed asphalt pavements mixed with coal ash, lime, and lime kiln dust used as a base material in Ohio via the AASHTO correlation with elastic (resilient) modulus. Full-depth reclamation (FDR) is a recycling technique where the existing asphalt pavement and a predetermined portion of the underlying granular material are blended to produce an improved base course. The resilient modulus of the materials was determined via backcalculation from measured falling weight deflectometer (FWD) deflections on the actual reclaimed pavement sections. For one test pavement, the SLCs estimated from resilient modulus ranged from 0.27 to 0.54

(with an average of about 0.35), following reclamation with fly ash and lime, while the SLCs for the control section (no admixture, just mill and overlay) were much lower (average of about 0.1). For a second test pavement, the researchers report SLCs from resilient modulus as follows: (1) 0.35 to 0.45 with an average of about 0.37 for a section reclaimed with fly ash and lime kiln dust; (2) 0.25 to 0.5 with an average of about 0.4 for a section reclaimed with fly ash and lime; (3) 0.4 to 0.5 with an average of about 0.46 for a section reclaimed with cement; and (4) much lower values for the control section (no admixture, just mill and overlay).

- Janoo (1994) determined the SLC of various base materials used in New Hampshire via the AASHTO correlations with both elastic (resilient) modulus and CBR. The base materials investigated included crushed gravel, reclaimed asphalt and gravel base stabilized with asphalt, asphalt concrete base, and pavement millings. The resilient modulus of the materials was determined via backcalculation from measured FWD deflections on 10 experimental pavement test sections. The CBR values were determined via correlation with measured results from Clegg hammer and dynamic cone penetrometer (DCP) tests on the 10 experimental pavement test sections. Further comments on the Janoo (1994) results are found in Section 3.3 below.
- Rada and Witczak (1983) determined the SLC of various graded aggregate base and subbase materials used in Maryland via the AASHTO correlation with elastic (resilient) modulus. The resilient modulus of the materials was measured with standard laboratory techniques. The wide range of materials and conditions

investigated in this study subsequently provided significant basis for AASHTO to recommend SLC design ranges for unbound base and subbase materials.

- Richardson (1996) determined the SLC of cement-stabilized soil bases used in Missouri via the AASHTO correlation with elastic (resilient) modulus. The moduli of the materials were determined from standard static compression tests on laboratory cylinders. The SLCs ranged from 0.09 to 0.27, depending on soil type and cement content. The researcher indicates that these values match well with values from 10 state departments of transportation reported in the literature.

CHAPTER 3
STRUCTURAL NUMBER (SN) OF PAVEMENT SECTIONS

3.1 Introduction

A formulation of the AASHTO equation for the structural number (SN) of a flexible pavement section with two layers above the subgrade is as follows:

$$SN = a_1D_1 + a_2D_2 \qquad (2)$$

where the ai and Di represent the structural layer coefficients and the thicknesses, respectively, of the asphalt surface and base layers in the pavement. A simple algebraic solution for an unknown SLC, a_2, for example, can be made if the layer thicknesses, remaining SLCs, and the structural number (SN) of the pavement section are all known:

$$a_2 = \frac{SN - a_1D_1}{D_2} \qquad (3)$$

Two approaches have typically been applied for determination of the structural number (SN) of the pavement section, and each are described in the following sections.

3.2 SN from Performance Relationship

The structural number (SN) of an existing pavement section can be determined from the original AASHTO performance equation or from a similar AASHTO-like performance relationship if the performance of the pavement section has been observed under known loading conditions. For example, the SN can be determined from the original AASHTO performance equation if the subgrade resilient modulus is known, and the change in serviceability index (from initial design to terminal) is observed for a known application of 18,000-lb equivalent single axle loads. This process is well described by Timm et al. 2014. A number of researchers have utilized observed pavement section performance and performance relationships to determine SLCs for both traditional and new base course material applications.

- Peter-Davis and Timm (2009) determined the SLC of asphalt surface layers used in Alabama via observed performance (rut depth, surface cracking, and surface roughness) and traffic data from experimental test sections. The researchers determined the unknown layer coefficient by adjusting its value until load repetitions to failure computed from the original AASHTO performance equation matched the load repetitions to failure observed in the field test sections. This approach yielded an average layer coefficient of 0.51, versus a value of 0.44 used for design in Alabama.
- Hicks et al. (1979) and Hicks et al. (1983) backcalculated the SLC of open-graded asphalt emulsion surface layers used on in-service U.S. Forest Service roads in Oregon and Washington via observed performance (rut depth, surface cracking, and surface roughness), estimates of other input parameters, and the original AASHTO performance equation. The researchers indicate that this method is particularly useful for the estimation of conservative, minimum values of layer coefficients.
- Little and Epps (1980) backcalculated the SLCs of recycled asphalt concrete pavement layers from 26 field projects in 11 states using the AASHTO performance equation and the known thicknesses and SLCs of the other pavement layers. Because these were all recently-constructed pavements and performance and traffic loading information of the pavement sections was not available for the AASHTO performance equation, the researchers developed and

utilized an empirical relationship between load repetitions and the computed elastic deflection of the subgrade to estimate the anticipated performance of the pavement sections. The empirical relationship was developed from the known performance results of the original AASHO Road Test pavement sections, and the subgrade deflections were computed via an elastic layer analysis of the pavement sections. The SLCs of recycled asphalt pavement used as a surface layer were found to typically exceed the value of 0.44 established for an AASHO Road Test conventional asphalt surface layer. The SLCs of recycled asphalt pavement used as a base layer were found similar to bituminous stabilized and cement and lime stabilized bases at the AASHO Road Test.

- Wang and Larson (1977, 1979) determined the SLCs of asphaltic concrete base, cement-stabilized limestone aggregate base, and limestone aggregate subbase materials used in Pennsylvania via observed performance (rut depth, surface cracking, and surface roughness) and traffic data from experimental test sections at the Pennsylvania State Test Track. The SLCs were backcalculated from an AASHTO-type relationship developed at the Test Track between observed performance and load repetitions and the known thicknesses and SLCs of the other pavement layers.
- Wu et al. (2012) determined the SLCs of base course materials constructed from blended calcium sulfate (BCS) stabilized with slag and fly ash in Louisiana via observed performance and traffic data from experimental test sections. The test sections were constructed and loaded at the Accelerated Loading Facility (ALF) at the Louisiana Transportation Research Center (LTRC), and the experiment

data was used to construct a performance relationship between the number of load repetitions to failure and structural number. The unknown base SLC was backcalculated from the performance equation and using the known SLCs and thicknesses of the remaining pavement layers. A value of 0.34 was reported for the BCS/slag and 0.29 for the BCS/fly ash.

3.3 SN from FWD Deflections

The structural number (SN) of an existing pavement section can be determined from deflections measured with a falling weight deflectometer (FWD). Several methods are available, including AASHTO (1993), Rohde (1994), Crovetti (1998), Romanoschi and Metcalf (1999), and Kim et al. (2013). All of the methods utilize fundamental equations of pavement mechanics and empirical relationships from pavement studies to estimate the structural number of a pavement section from measured FWD deflections. A number of researchers have utilized such measurements on available pavement sections to determine SLCs for both traditional and new base course material applications. The AASHTO (1993) procedure is most widely used and is well described by Timm et al. (2014).

- In addition to the resilient-modulus-based results reported above, Baus and Li (2006) determined the SLC of a graded aggregate base used in South Carolina via the AASHTO FWD procedure. Two test sections were investigated that incorporated three base thicknesses and with and without a cement stabilized subgrade. The researchers were concerned to report inconsistent SLC values ranging from 0.13 to 0.36 for the same graded aggregate investigated, and despite the fact that South Carolina uses a constant value of 0.18 for all graded aggregate bases. This range of values is also notably higher than the range reported above based upon resilient modulus measurements.

- Gautreau et al. (2008) determined the SLC of clayey subgrade soil treated with cement, lime, and lime-fly ash used as a subbase layer in Louisiana via the AASHTO FWD procedure. Test sections were constructed and loaded at the Accelerated Loading Facility (ALF) at the Louisiana Transportation Research Center (LTRC). Based upon FWD deflections, the researchers found that layer coefficients for the cement-stabilized soil may be assigned a value of 0.06, while for lime-treated soil, no structural contribution should be allowed. Unfortunately, the researchers did not determine an SLC for the materials using performance data from the loaded test sections.
- Hossain et al. (1997) determined the SLCs of crumb-rubber-modified (CRM) asphalt mixtures used in Kansas for both surface and base layers via the AASHTO FWD procedure. Several test sections of recently constructed pavements along three routes in Kansas were used for the study. The researchers found average values for the layer coefficients typical of practice, but also reported very high variability in the results across the multiple test sections investigated. Further comments on the Hossain et al. (1997) results are found in Section 4.3, below.
- In addition to the material-parameter-based results reported above, Janoo (1994) determined the SLC of various base materials used in New Hampshire via the Rohde (1994) FWD procedure on 10 experimental pavement test sections. The researcher notes that the SLC for asphalt concrete base from the Rohde

procedure was similar to that used by the New Hampshire DOT (NHDOT), which gave the researcher confidence in using this procedure for the other base materials. Further, the layer coefficients from the Clegg hammer and DCP were all close to those obtained from Rohde, which provided further confidence in the suggested SLC values. On the other hand, the researcher found that the values determined from backcalculated elastic moduli results were typically higher than those from the Rohde, Clegg, and DCP methods, noting that the discrepancies could be due to difficulty in obtaining a good fit to the measured FWD deflection measurements during the backcalculation process.

- Marquis et al. (2003) determined the SLC of a recycled asphalt concrete base with foamed asphalt additive in Maine via the AASHTO FWD procedure. Sections of four pavement projects were investigated, and the layer coefficients were found to be 0.22, 0.23, 0.22, and 0.35.
- Pologruto (2001) utilized the AASHTO FWD procedure to determine the SLCs of all pavement layers on a pilot project using representative materials for the construction of pavements in Vermont. Three different test locations were specified and constructed with the same type of materials: three different types of asphalt concrete for surface, binder, and base, a densely-graded crushed stone base/subbase, and a sand subbase. At each of the three test site locations, three structural configurations of the materials were implemented. The FWD testing was conducted on the surface of each successive layer during construction as means for determining each SLC. The average SLC values were found to be 0.60 for all asphalt layers, 0.14 for crushed stone base/subbase, and 0.07 for

sand subbase. The researcher notes that: (1) the value of 0.14 for crushed stone falls within the range established by AASHTO for an unbound base material, (2) the value of 0.07 for sand is on low side of AASHTO range for subbase, and (3) the value of 0.60 for asphalt concrete is considerably higher than the AASHTO value of 0.44. The researcher does note that the average value of 0.60 is partially substantiated by other properties measured on these materials, including Marshall stability and moduli backcalculated from FWD deflections.

- Romanoschi et al. (2003a, 2003b, 2004) determined the SLC of base layers from full-depth reclamation of an asphalt-bound pavement constructed in Kansas and stabilized with foamed asphalt via the AASHTO FWD procedure. Four experimental test pavements were constructed at research facilities at Kansas State University, and the average SLC found for the materials was 0.18.
- Wen et al. (2004) determined the SLC of of a base layer constructed from full-depth reclamation (FDR) of an asphalt-bound pavement stabilized with fly ash and constructed in Wisconsin via the Crovetti (1998) FWD procedure. An initial SLC of 0.16 was determined following construction of the pavement section, and a value of 0.23 was calculated the following year, indicating that improvement of the material occurred with time. The improvement was attributed to pozzolanic reaction in the mixture due to the fly ash stabilizer.

CHAPTER 4
EQUIVALENCY WITH REFERENCE MATERIAL

4.1 Introduction

The equivalency methods are based upon a fundamental premise of the AASHTO pavement design methodology that two differing materials will provide the same structural capacity (or number) in a pavement if the product of their layer coefficient and thickness are equal:

$$a_uD_u = a_rD_r \tag{4}$$

where a_u = structural layer coefficient of unknown material, D_u = thickness of unknown material, a_r = structural layer coefficient of known reference material, and D_r = thickness of known reference material. Using this equivalency premise, the structural layer coefficient of a previously unknown material can be determined as follows:

1. Choose a reference material with a known SLC, a_r, and a relevant pavement cross section.
2. Determine the thickness required for the known reference material, $D_{r,}$ that provides an acceptable pavement section according to a chosen design criterion.
3. Determine the thickness required for the unknown material, $D_{u,}$ that provides an acceptable pavement section according to the same chosen design criterion.
4. Solve for the unknown structural layer coefficient, a_u, using the above equation.

Three types of design criteria have typically been utilized to establish the equivalency, and each are described in the following sections.

4.2 Material Property Criterion

A simple equivalency between an unknown material and a known reference material can be based upon a relevant material property, with the elastic modulus being the typical property of choice. Several researchers have utilized material property equivalencies to determine SLCs for both traditional and new base course material applications.

- Coree and White (1989) determined the SLCs of 10 asphaltic concrete mixtures used in Indiana via comparison of stiffnesses measured in the laboratory with the stiffness and layer coefficient of an asphalt mixture used in the AASHO Road Test. Using Odemark's equivalent stiffness principle, they developed the following equivalency relationship:

  $$a_u = a_r (E_r/E_u)^{1/3} \tag{5}$$

  where a_u = structural layer coefficient of unknown material, E_u = modulus of unknown material, a_r = structural layer coefficient of known reference material, and E_r = modulus of known reference material. They also utilized a probabilistic approach in which a distribution for the layer coefficient is determined based upon estimates of the uncertainties in the measured moduli and the layer coefficient of the known AASHO reference material.
- Rada et al. (1989) documented two procedures for estimating the structural number (SN) of pavement sections via FWD measurements. In one method, the FWD deflections are used to determine elastic moduli via backcalculation, and then the SLCs of each layer are determined using the moduli and an equivalency technique based upon Odemark as shown by Coree and White (1989) discussed above. With the layer coefficients available, the SN is calculated directly using layer thicknesses and the standard AASHTO equation for SN.

- Tang et al. (2012) determined the granular equivalencies of base layers constructed from full-depth reclamation of asphalt-bound pavements constructed in Minnesota. In some cases, a stabilizer such as fly ash or asphalt emulsion was added to the mixture. Similar to a SLC, granular equivalency (GE) indicates the contribution of a given layer of pavement material relative to the performance of the entire pavement section. It is dependent upon the properties of that layer in relation to the properties of the other layers. The relative thickness between the layers is known as the granular equivalency factor. The layer equivalency can be determined by laboratory and field tests. In this study, the GE of stabilized FDR was determined from several field test sections via a method established in Minnesota using FWD deflections. The equivalency with a standard granular base material (GE=1.0) was found to be about 1.5.

4.3 Pavement Response Criterion

An equivalency between an unknown material and a known reference material can be based upon a relevant response parameter of the chosen pavement section, such as surface deflection, the tensile strain at the bottom of the asphalt surface layer, or the compressive strain at the top of the subgrade. A number of researchers have utilized equivalencies based upon pavement response model criteria to determine SLCs for both traditional and new base course material applications. In all cases the pavement response models will require the determination of relevant input parameters to characterize the pavement sections and materials, including layer thicknesses and elastic moduli.

- In addition to the FWD-based results reported above, Hossain et al. (1997) determined the SLCs of crumb-rubber-modified (CRM) asphalt mixtures used in Kansas for both surface and base layers using an equivalency based upon pavement response modeling. Here, the unknown SLC was computed as shown above using a design thickness for the unknown material and the SLC and design thickness of a reference material. The design thicknesses were determined via an elastic layered analysis of the pavement sections and an equivalency based upon the vertical compressive strain in the subgrade. For CRM asphalt overlays, an average value of 0.30 was reported, which they note is slightly lower than for conventional asphalt concrete. For newly constructed CRM asphalt pavements, an average value of 0.35 was reported, which they note is similar to an AASHTO-recommended value for conventional asphalt concrete. In comparison with the FWD-based results presented above, the researchers note that the average values were similar, but the FWD-based results displayed considerably higher variability across the various test sections.
- Mallick et al. (2002) determined the SLCs of base layers constructed in Maine from full-depth reclamation of an asphalt-bound pavement with additives, including emulsion, lime, and cement, and using an equivalency based upon pavement response modeling. As with Hossain et al. (1997) above, the unknown SLC was computed using a design thickness for the unknown material, and the SLC and design thickness of a reference material. The design thicknesses were determined via an elastic layered analysis of the pavement sections, and an equivalency based upon the surface deflection of the pavement. The SLCs were

found to be 0.24 for emulsion additive, 0.28 for cement additive, and 0.37 for emulsion plus lime additive.

4.4 Pavement Performance Criterion

An equivalency between an unknown material and a known reference material can be based upon a pavement performance criterion for the chosen pavement section, such as fatigue cracking or rutting. Several researchers have utilized equivalencies based upon pavement performance model criteria to determine SLCs for both traditional and new base course material applications. In all cases the pavement performance models will require the determination of relevant input parameters to characterize the pavement sections and materials, including layer thicknesses, elastic moduli, and other material properties that govern performance or damage.

- George (1984) determined the SLCs of asphalt mixtures used as both surface and base layers, soil-cement base, and soil-lime subbase using an equivalency based upon pavement performance. Here, the unknown SLC was computed as shown above using a design thickness for the unknown material, and the SLC and design thickness of a reference material. The design thicknesses were determined via a fatigue cracking performance model presented by George (1984). The author reports SLCs of 0.44, 0.38, 0.24, and 0.20 for asphalt surface, asphalt base, soil-cement base, and soil-lime subbase, respectively, and demonstrates these values to be in good accord with those of AASHTO.
- In addition to the observed performance-based results reported above, Hicks et al. (1979) determined the SLC of open-graded asphalt emulsion surface layers used on in-service U.S. Forest Service roads in Oregon and Washington via

equivalency based upon pavement performance modeling. As with George (1984) above, the unknown SLC was computed using a design thickness for the unknown material, and the SLC and design thickness of a reference material. Here, the design thicknesses were determined via an elastic layered analysis of the pavement sections, and a fatigue relationship between tensile strain in the surface layer and number of load repetitions. The researchers note that the computed values were in good agreement with those backcalculated from in-service roads.

- Li et al. (2011) revised the SLC of asphalt surface layers in the state of Washington from 0.44 to 0.50 via equivalency based upon pavement performance modeling. Here, the pavement performance modeling was conducted with the Mechanistic Empirical Pavement Design Guide (MEPDG) calibrated locally using pavement performance data observed in Washington.
- Van Wijk et al. (1983) determined the SLC of cold recycled asphalt pavement mixed with emulsion and foamed asphalt and used as a base layer for pavements in Indiana. As with George (1984) above, the unknown SLC was computed using a design thickness for the unknown material, and the SLC and design thickness of a reference material. Here, the design thicknesses were determined via an elastic layered analysis of the pavement sections, and several response and performance criteria were evaluated, including: (1) tensile strain at the bottom of recycled layer, (2) tensile strain at the bottom of remaining initial pavement layer, (3) compressive subgrade strain, (4) subgrade deformation, and (5) surface deformation. Each criteria was evaluated for the test sections

investigated, and the SLC was based on the criterion that produced the shortest service life. For these recycled pavements, the controlling criterion was found to be either the subgrade deformation or the tensile strain at the bottom of the recycled layer. The researchers note that this approach yielded layer coefficients with considerable variability among the pavement sections investigated, and suggested that a single SLC cannot be determined without reliable fatigue performance characteristics for all the pavement layers.

CHAPTER 5
CONCLUSIONS

FDOT's current method of determining a base material structural layer coefficient (SLC) is detailed in the Materials Manual, Chapter 2.1, Structural Layer Coefficients for Flexible Pavement Base Materials. Currently, any new base material not approved under FDOT specifications must undergo (1) laboratory testing, (2) test pit investigation, and (3) a project test section for constructability and roadway performance evaluation to determine a SLC for design purposes. The test section evaluation phase can take up to five years to compare the pavement performance of the new base material with a limerock base control section. In this project, a thorough review of literature has been conducted of current and past practices for the determination of structural layer coefficients (SLC) of pavement base materials. The review organizes the methodologies into three broad categories: (1) methods that determine SLCs via relationships with other material parameters; (2) methods that determine SLCs via estimates of the structural number (SN) of existing and available pavement sections; and (3) methods that establish SLCs via equivalencies with a reference material. Several of the strategies reviewed provide opportunities for estimating SLCs of both traditional and new base course materials in a more accelerated fashion and in considerably less time than the five years often required at present.

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