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GUIDANCE FOR M-E PAVEMENT DESIGN IMPLEMENTATION

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CHAPTER 1 – INTRODUCTION

BACKGROUND

The Mechanistic-Empirical Pavement Design Guide (MEPDG) developed under National Cooperative Highway Research Program (NCHRP) Project 1-37A represents a dramatic change in how both rigid and flexible pavements are analyzed and designed. Recognizing the limitations of the current design system (AASHTO, 1993), based upon the results of the AASHO Road Test (HRB, 1962), the new design approach utilizes mechanistic-empirical (M-E) concepts to execute pavement design. This approach is believed to be a more robust design system that can adapt to advances in pavement materials, account for changes in trucking and tire technology, better characterize environmental effects and improve predictions of pavement distresses.

While the benefits of M-E design are well documented and generally agreed upon by the pavement engineering community, the practical implications of an agency adopting the MEPDG can be daunting. Pictured in Figure 1.1, the new design software involves a level of complexity yet to be encountered in typical pavement design practice. For example, in the existing AASHTO Pavement Design Guide (1993), traffic is represented by the number of equivalent single axle loads (ESALs) expected over the design life of the pavement. This input parameter is typically calculated from the average annual daily traffic, expected traffic growth rate and average ESAL/truck determined from local traffic weight data. As shown in Figure 1.1, the MEPDG requires much more detailed input, including:

- Monthly traffic volume adjustment factors

- Vehicle classification distribution
- Hourly truck volume distribution
- Traffic growth factors
- Number of axles per truck
- Axle weight distributions
- Axle configurations
- Wheelbase

Further detail regarding some of the inputs listed above is shown in Figure 1.2.

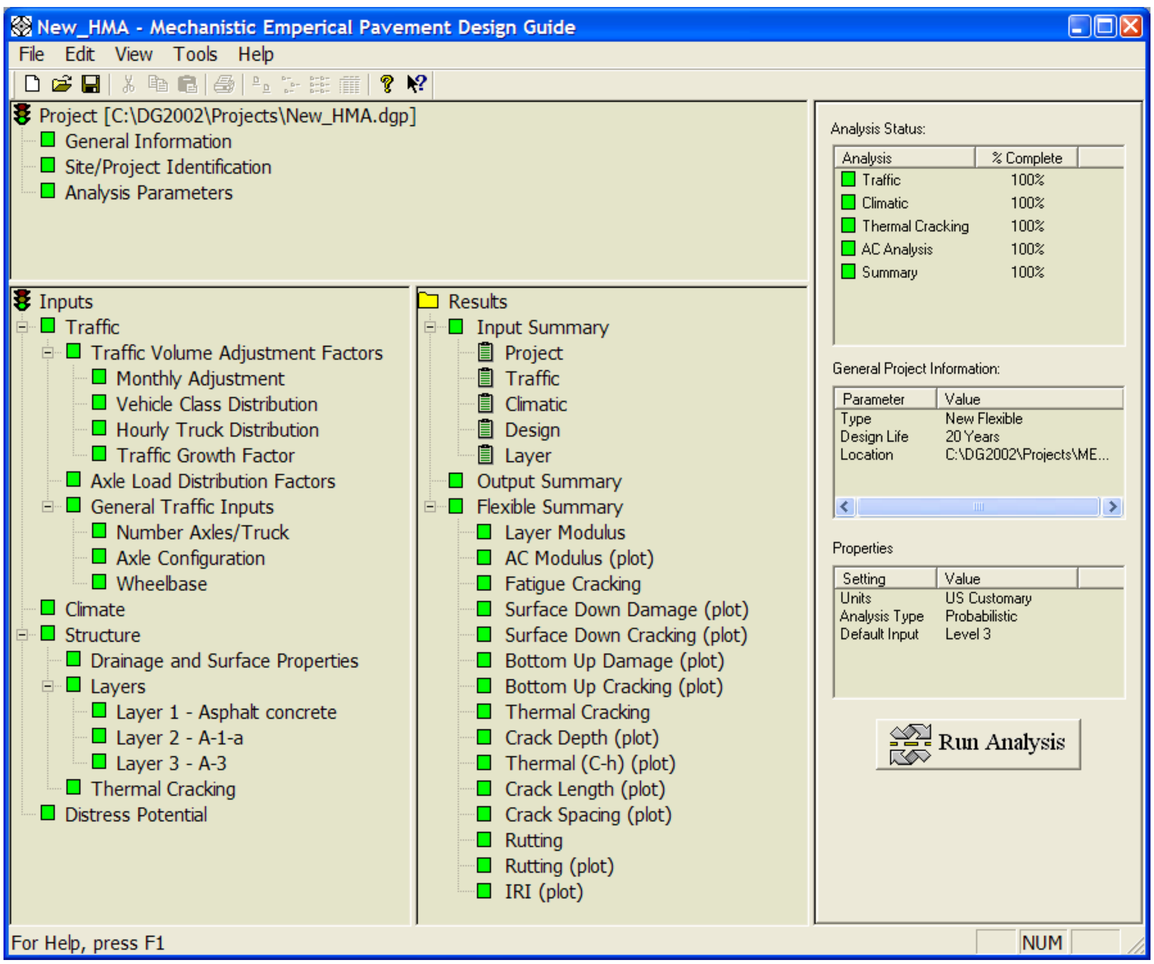

FIGURE 1.1 MEPDG Main Window.

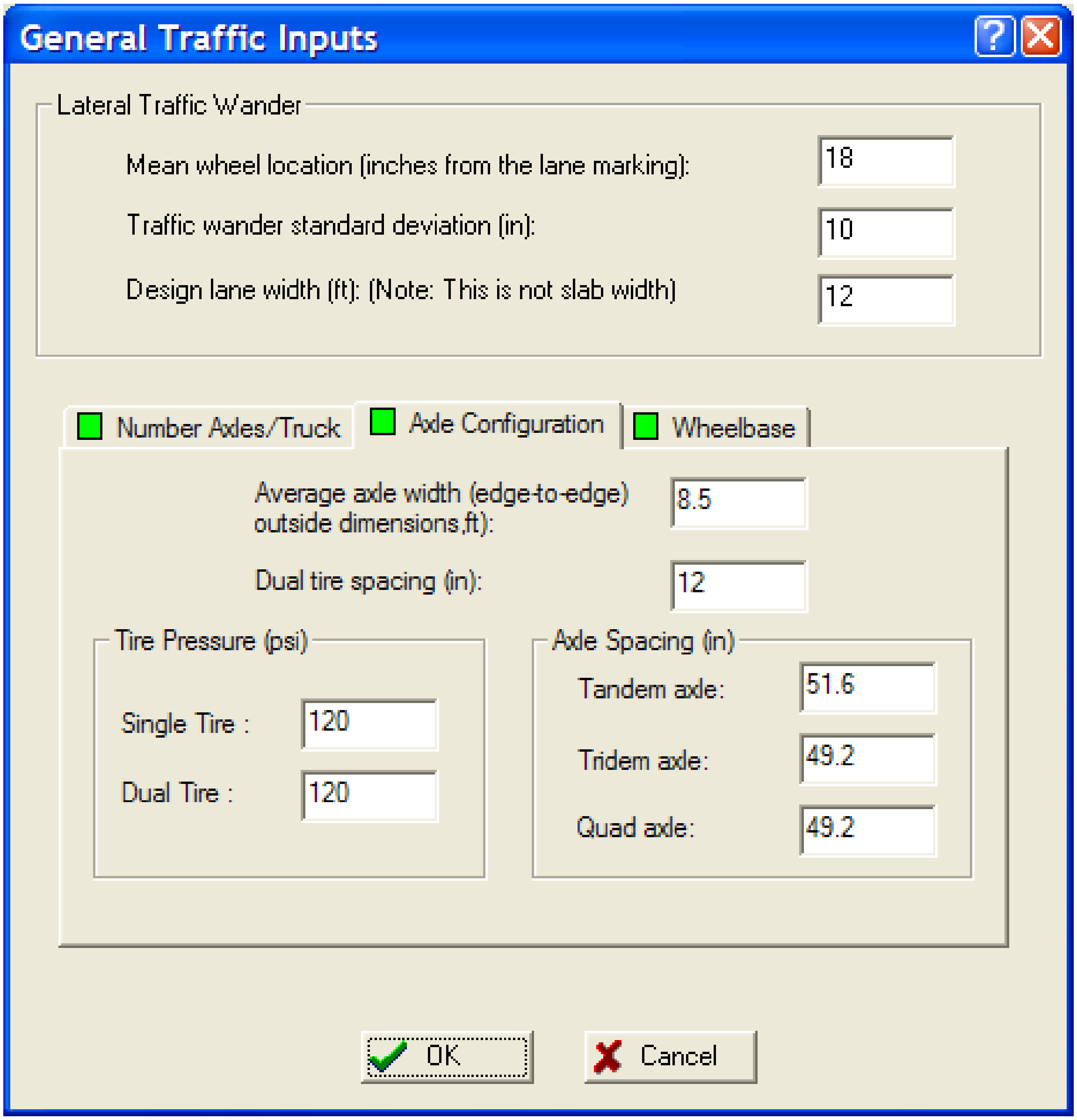

FIGURE 1.2 MEPDG General Traffic Inputs.

Another example of the level of detail and complexity in the MEPDG lies within the material characterization portion of the methodology. In the existing AASHTO Design Guide (1993), the designer selects a structural coefficient (a_1) at a reference temperature of 68°F to characterize the load-carrying capacity of the hot-mix asphalt (HMA). Many agencies, including ALDOT, have adopted a default value based upon local experience with their HMA. In contrast, Figures 1.3 through 1.5 illustrate some of the required inputs for the MEPDG. Note that the figures depict inputs for a “Level 3” design which represents the simplest level of design where correlations based upon generic data are used to develop the design. Some of the inputs, such as selection of performance graded binder (Figure 1.3), may be relatively straightforward to obtain. Others, such as gradation (Figure 1.4), may also be readily available from current practice, but require some manipulation since gradation is usually recorded as cumulative percent passing rather than percent retained. Inputs such as thermal conductivity and heat capacity (Figure 1.5) are typically not part of an agency’s routine material characterization framework. This illustrates the challenges faced by transportation agencies regarding allocation of resources required to collect and process the data necessary to make full use of the MEPDG program, for even the simplest level of design.

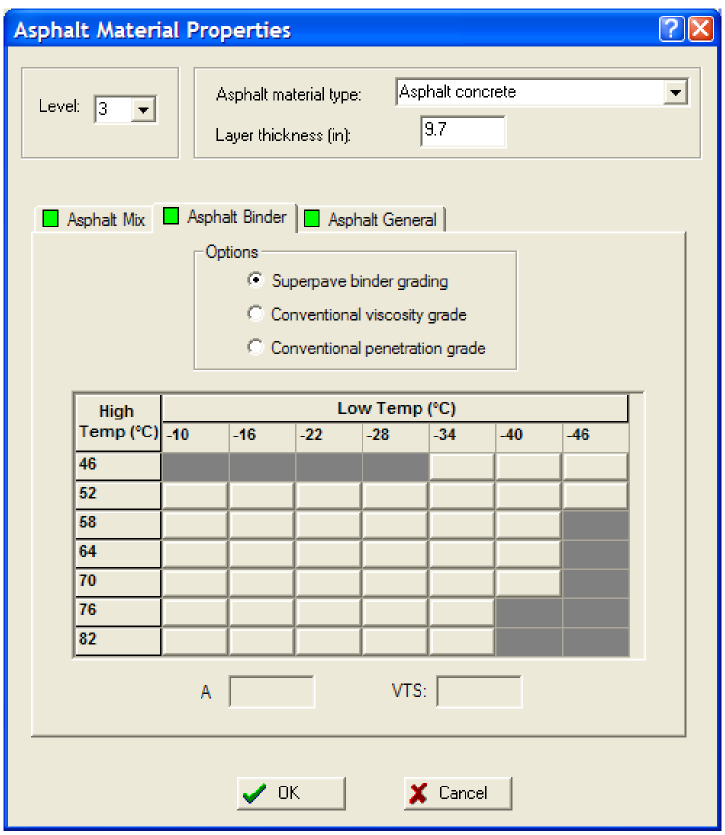

FIGURE 1.3 Performance Graded Binder Selection in MEPDG.

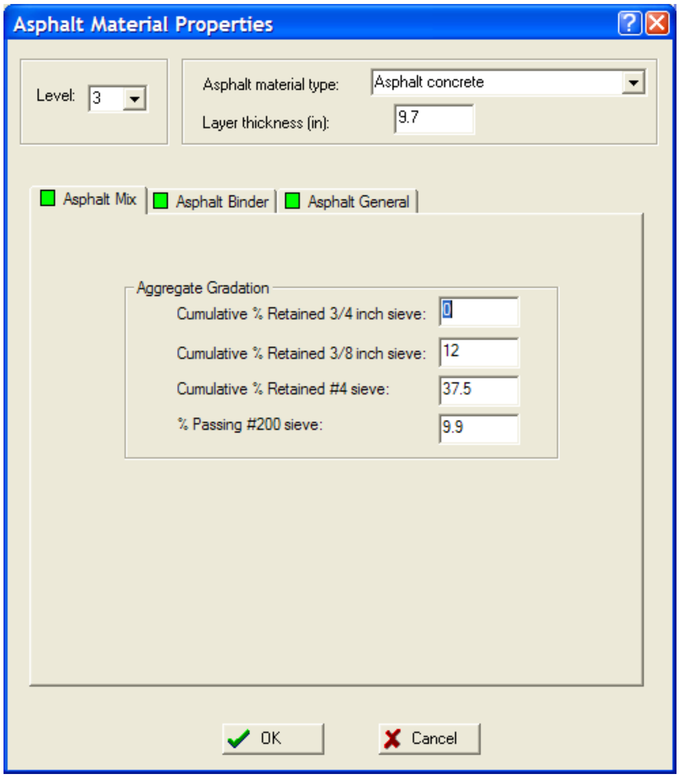

FIGURE 1.4 Asphalt Mixture Gradation in MEPDG.

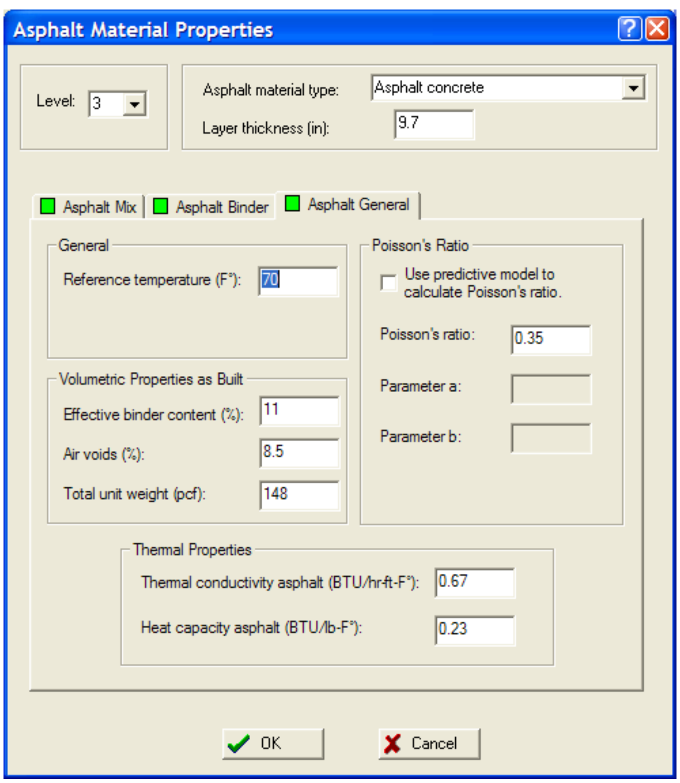

FIGURE 1.5 General Asphalt Inputs in MEPDG.

It must also be emphasized that the inputs depicted in Figures 1.3 through 1.5 are for "Level 3" design. Portions of the MEPDG can operate at different levels of complexity. Level 1 requires detailed knowledge of the material property or input, typically through lab testing. Level 2 requires less detailed knowledge and may correlate from certain laboratory test results to get the required input. Level 3 requires the least amount of knowledge and depends on a catalogue of default information based on very basic information. For example, the dynamic modulus (E^*) and binder shear modulus (G^*) are required in place of aggregate gradation information when switching from Level 3 to Level 1 as shown in Figures 1.6 and 1.7.

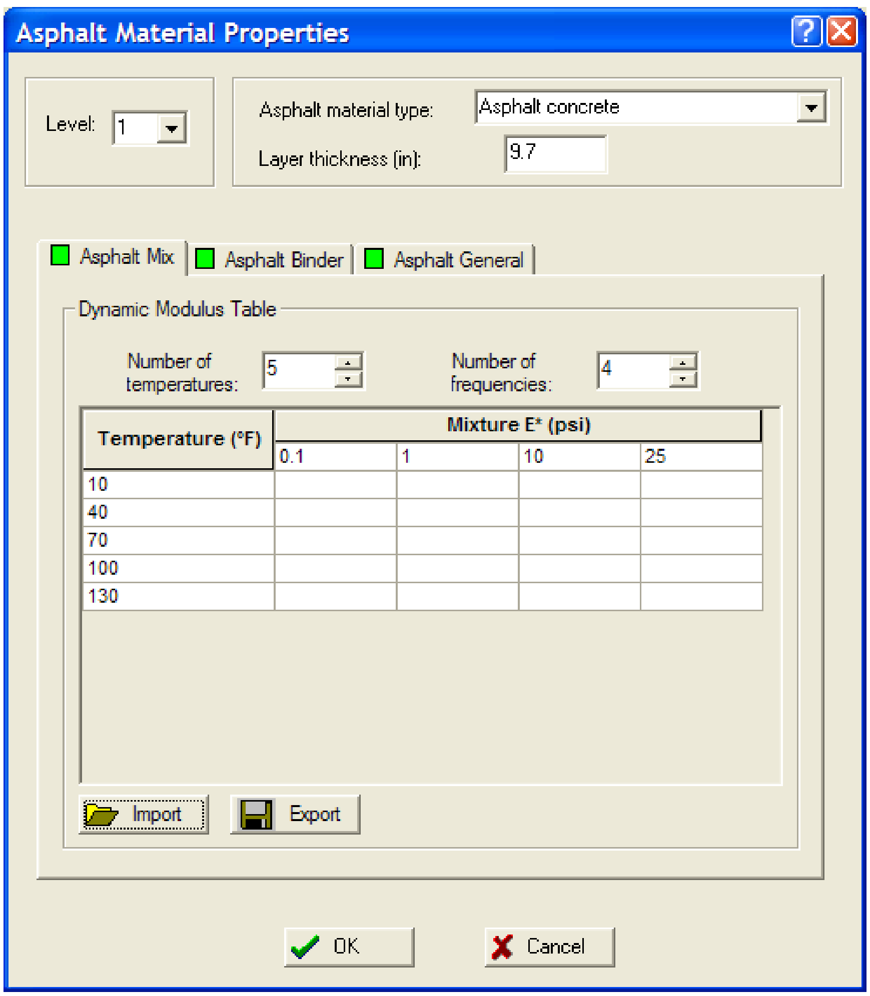

FIGURE 1.6 E* Input for MEPDG Level 1.

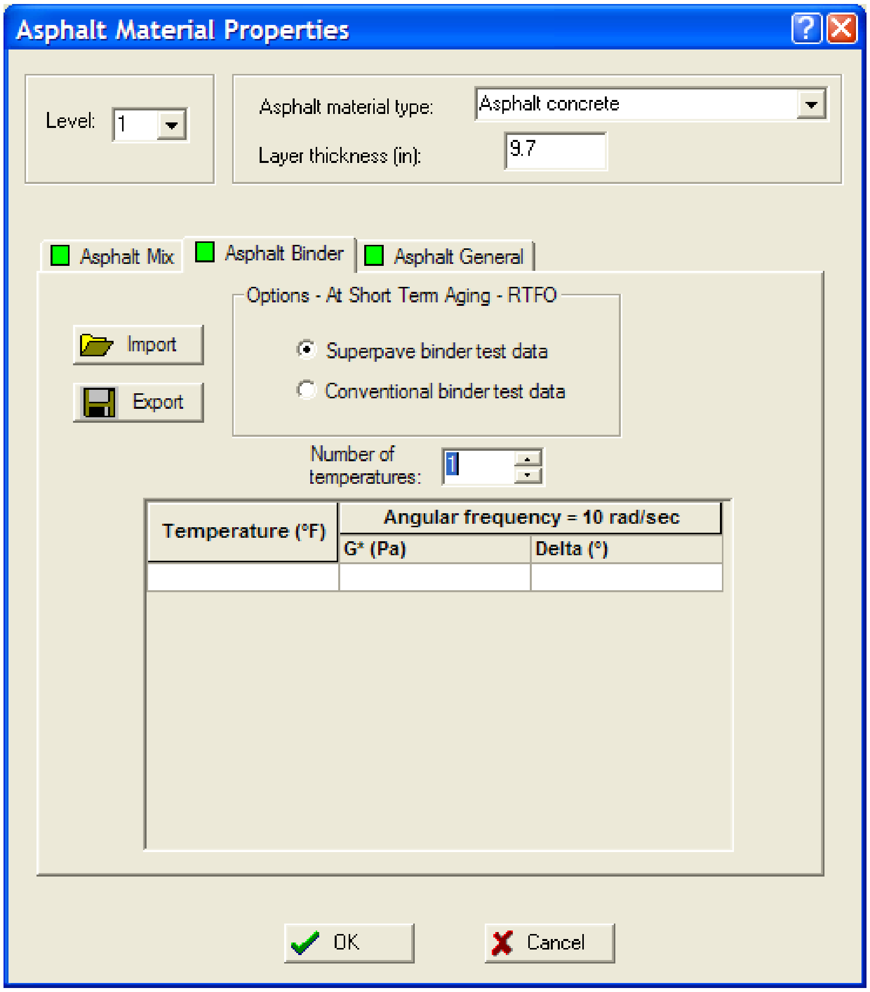

FIGURE 1.7 G* Input for MEPDG Level 1.

The output of the MEPDG is also very detailed and complex in contrast to the existing AASHTO Design Guide (1993). In the latter, the output of the design system was a required pavement thickness (flexible or rigid) to meet the traffic conditions to some predetermined level of terminal serviceability. The new MEPDG, in contrast, may best be described as an iterative pavement analysis tool. This requires that a pavement cross section be devised and then evaluated for performance in terms of specific modes of distress. For example, Figure 1.8 illustrates the design criteria used for jointed plain concrete pavement (JPCP). Terminal levels of roughness (IRI), transverse cracking and joint faulting are specified by the designer. A design is then checked against these to judge adequacy at a specified level of reliability. Figure 1.9 illustrates the prediction of joint faulting with the pre-defined terminal level also indicated. By assessing each of the distress vs. time plots, a designer can identify problem areas and target design changes to meet a particular deficiency. For example, if faulting is a problem, more closely-spaced dowel bars may be the solution. If, as shown in Figure 1.9, the distresses are well below the failure criteria, other adjustments to the design may be made. In either case, more efficient designs can be developed based upon specific distress predictions rather than predictions of serviceability loss.

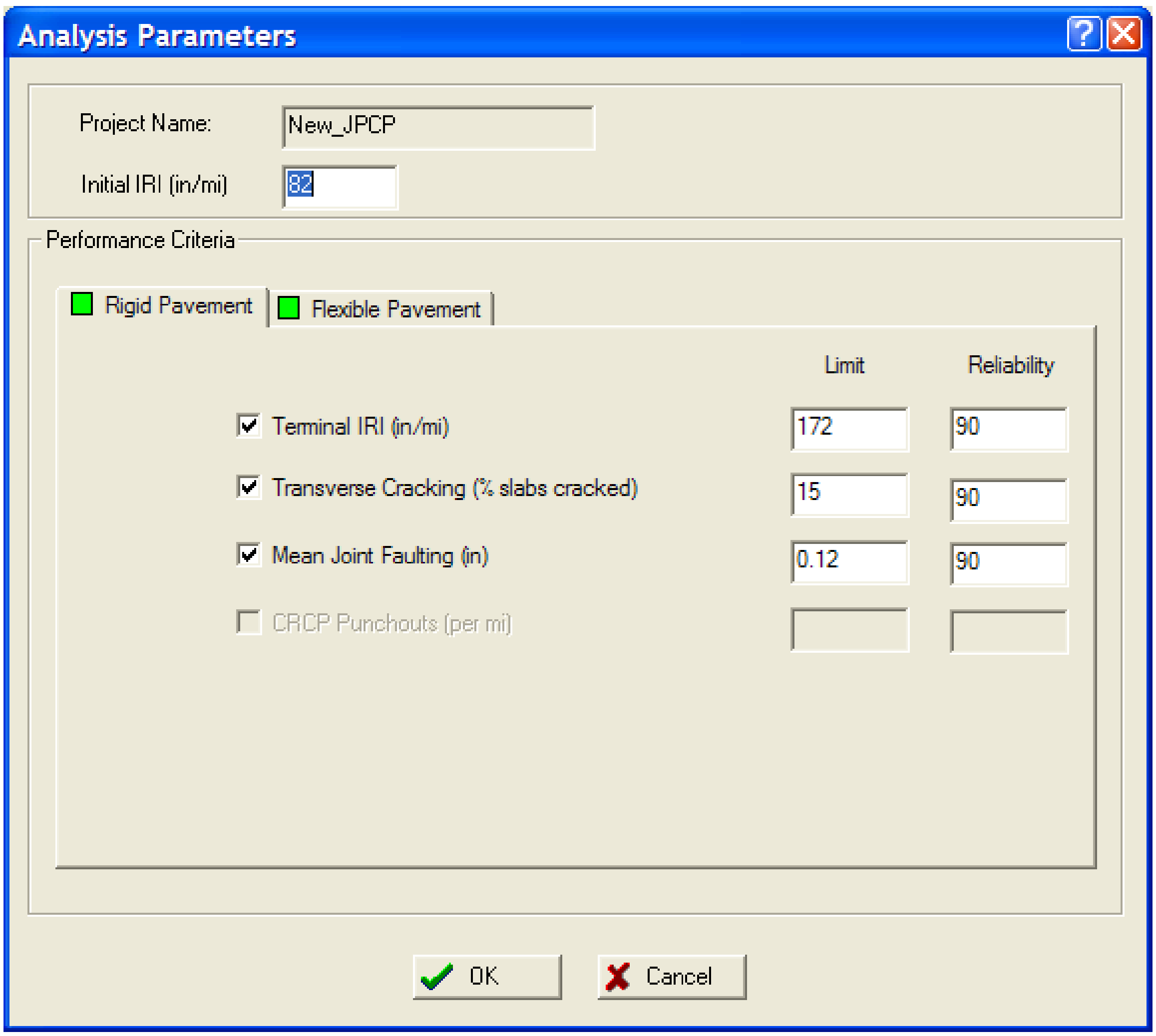

FIGURE 1.8 JPCP Design Criteria.

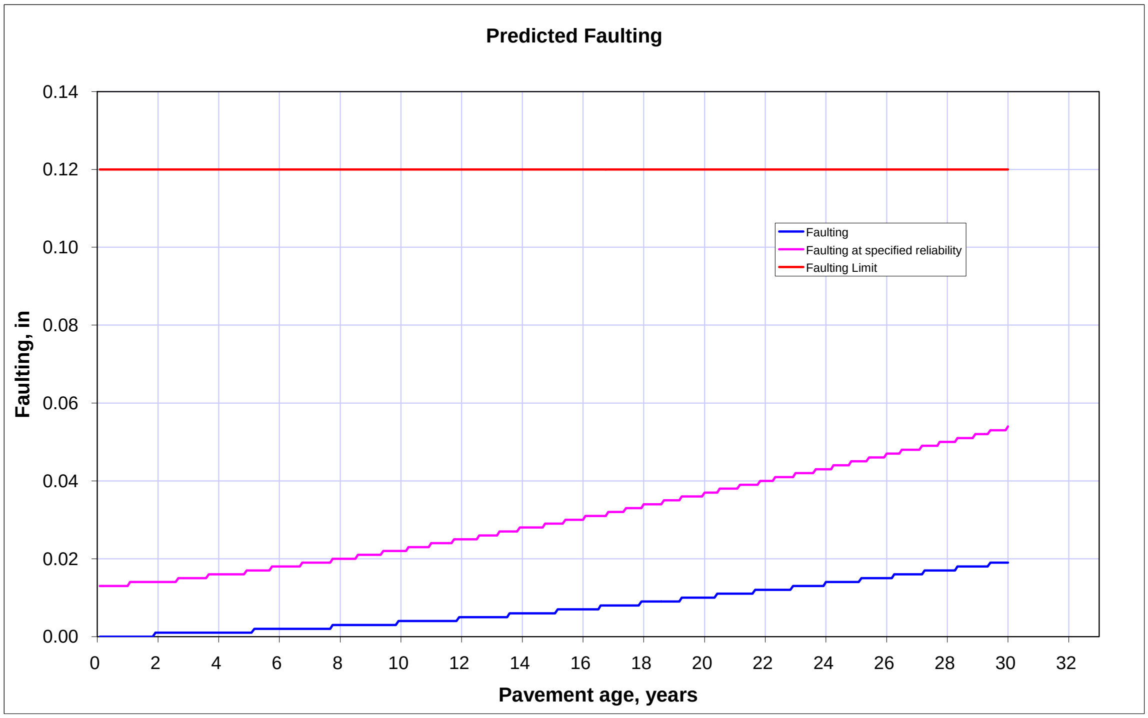

FIGURE 1.9 JPCP Faulting Output.

As discussed above, the differences between current practice and the MEPDG are substantial. This will require transportation agencies to closely evaluate their current practices relative to the MEPDG if it is to be fully adopted. Some areas of design may only require slight modifications, while others may require new materials testing equipment, traffic data collection infrastructure, and personnel training in order to generate the necessary design inputs and execute design. Regardless, a careful needs analysis must be executed before full implementation can be achieved.

RESEARCH OBJECTIVES

Given the needs described above, the goal of this research was to assess current ALDOT practice relative to the requirements of the MEPDG and make recommendations as to the necessary resources, testing procedures, testing equipment and training that will be required to implement the MEPDG. Specific objectives were:

1. Assess current ALDOT pavement design practice.
2. Identify the MEPDG requirements at the three levels of design.
3. Characterize current ALDOT practice within the MEPDG framework.
4. Develop a set of recommendations, in the form of an implementation plan, for the adoption of the MEPDG in Alabama.

SCOPE OF WORK

To meet the specified objectives, the MEPDG required inputs were first catalogued. Detailed information regarding each required input was gathered. The inputs were divided according to the MEPDG architecture that included:

- General information
- Traffic
- Climate
- Material properties (unbound materials, asphalt materials, concrete materials)

After the MEPDG had been catalogued, meetings were held with groups at ALDOT responsible for generating data and conducting design in the existing pavement design framework (1993 AASHTO). These meetings established a detailed knowledge of how design is currently conducted within ALDOT and what tests/practices/data sets are currently in place that can be used for MEPDG design. This information was then integrated within the MEPDG framework to identify areas ready for MEPDG implementation versus areas requiring new sets of tests/practices/data.

Recommendations are made regarding items that may benefit from further study prior to full implementation of the MEPDG within ALDOT. One part of this effort was to create a web-based MEPDG program that can be used as a training and updateable on-line resource. Finally, an implementation plan was developed that provides an overall implementation plan with sub-projects identified needing further research for full implementation.

CHAPTER 2 – MEPDG OVERVIEW AND CATALOGUE

GENERAL OVERVIEW

The MEPDG uses mechanistic-empirical concepts to design new, reconstructed, and rehabilitated asphalt and concrete pavements. The MEPDG is organized according to input type and level of design. The four primary categories of inputs are general, traffic, climate and structural. Many of the inputs can be specified according to a hierarchal level of design. The three design levels are defined as follows:

- Level 1 inputs are the most accurate, but are generally more resource and time intensive. They typically require test data, or site-specific information, to be directly input into the software.
- Level 2 inputs are considered the intermediate level of accuracy. The inputs are typically correlated from other properties or data that are easier to obtain than the level 1 data. They may also represent regional or statewide data sets, rather than site-specific ones.
- Level 3 inputs are default values that are based upon historical data for a specific material type, region of the country, etc., and are the least accurate of the three input levels.

It is important to note that different design levels can be used for different inputs for the same pavement design. For example, the designer can specify a level 1 design for asphalt binder (enter Superpave binder test data from AASHTO TP5), and use a level 3 design for the asphalt mix properties (provide gradation information). The program provides flexibility based upon the resources and time available at a particular transportation agency.

INPUTS

The first task for this project was to catalogue all the inputs of the MEPDG (version 1.0). There are many inputs required for even the least detailed design; therefore, the inputs will only be discussed briefly in the body of this report. A Microsoft Excel database was created to catalogue the inputs required by the MEPDG. A sample of this database is shown in Figure 2.1. All the inputs were categorized based upon their location within the MEPDG (window title, heading information, and tab), how they should be selected (from a pull down menu, fill in the blank, etc.) and the design level (1, 2 or 3) chosen. Other parameters were specified for each input including whether a default value was available, the appropriate ASTM or AASHTO test procedure needed to determine an input (if applicable), and a short definition. The full catalogue created for the inputs of the MEPDG can be found in Appendices A through F.

Window Title	Main Heading	Sub Heading	Tab	Check Box/ Pull Down Menu/ Choose From	Fill in the Blank (Values or Text)	Has Default Value?	Level	ASTM Test Procedure	AASHTO Test Procedure	Description
Asphalt Material Properties	Dynamic Modulus Table		Asphalt Mix		E* values for different loading rates & temperatures	NO	1	D 3497	TP 62	Dynamic modulus (E*) values for each corresponding loading rate and temperature
Asphalt Material Properties	Aggregate Gradation		Asphalt Mix		Various gradation information	NO	2	NA	T 27	Percent retained on 3/4", 3/8" and #4 sieves, and percent passing #200 sieve
Asphalt Material Properties	Aggregate Gradation		Asphalt Mix		Various gradation information	NO	3	NA	T 27	Percent retained on 3/4", 3/8" and #4 sieves, and percent passing #200 sieve
Asphalt Material Properties	Options - At Short Term Aging -		Asphalt Binder	Superpave binder test data	Number of Temperatures	NA	1	NA	NA	Defines the number of temperatures at which the binder dynamic complex modulus, G*, and phase angle, δ, test results were compiled for a given
Asphalt Material Properties	Options - At Short Term Aging -		Asphalt Binder	Superpave binder test data	Dynamic complex modulus (G*) and phase angle values	NO	1	NA	T 315	Dynamic complex modulus (G*) and phase angle (δ) values for each corresponding temperature tested
Asphalt Material Properties	Options - At Short Term Aging -		Asphalt Binder	Conventional binder test data	Number of penetrations	NA	1	NA	NA	Defines the number of penetration values collected
Asphalt Material Properties	Options - At Short Term Aging -		Asphalt Binder	Conventional binder test data	Number of Brookfield viscosities	NA	1	NA	NA	Defines the number of Brookfield viscosities collected

FIGURE 2.1 Sample of Asphalt Inputs from Database.

General

The purpose of the general inputs required by the MEPDG is to provide the designer with a way to identify the project type, timeline, design criteria, and other miscellaneous information for identifying the project files. The general inputs can be entered through three different screens: General Information, Site/Project Identification, and Analysis Parameters. The General Information Screen requires basic inputs such as design type (new pavement, overlay or rehabilitation), design life, pavement type, and the construction timeframe. The Site/Project Identification screen includes inputs that classify the particular location and stationing of a project. The Analysis Parameters involve user-specified limits for specific pavement distresses, as well as reliabilities for each respective pavement distress. The designer can also choose which distresses the MEPDG should analyze. For flexible pavements, the distresses include roughness (IRI), top-down and bottom-up cracking, thermal fracture, fatigue fracture in chemically stabilized layers, and rutting within the HMA layer and in the complete pavement structure. For rigid pavements, the distresses include roughness (IRI), transverse cracking, mean joint faulting for jointed plain pavements and existing punchouts, maximum crack width, load transfer efficiency, and crack spacing for continuously reinforced pavements.

Traffic

There are numerous traffic inputs in the MEPDG. Traffic is considered on an axle-by-axle basis in the design guide rather than by ESALs. To characterize traffic in the MEPDG, input screens are available for the monthly and hourly adjustment of traffic, the distribution of traffic by vehicle class, the traffic growth over the design life, the distribution of traffic according to axle type and load level, as well as other general traffic inputs. The monthly adjustment factors can be entered for FHWA vehicle classes 4 through 13 for each month of the year. The hourly adjustment factors are a distribution of traffic over a 24-hour period, and require an input for each hour. The vehicle class distribution can be entered for each truck class, and default distributions are available based upon the road classification. Traffic growth can be entered as one growth rate across all classes or as class-specific growth. Axle load distribution factors are required for each axle type (single, tandem, tridem and quad), for each month of the year and for a predetermined range of load levels. General traffic inputs include the average number of axles per truck for each truck class and axle type, and the typical configuration and dimensions of the different axle types. For most all of these inputs, default values and distributions are available in the MEPDG.

Climate

The MEPDG uses a complex model known as the Enhanced Integrated Climate Model (EICM) to predict temperature and moisture profiles throughout the pavement structure over the design life. However, the inputs are surprisingly simple and straightforward. The designer is required to select a climate file for a weather station in an existing database or create a virtual weather station for a specific location by interpolating using data from surrounding weather stations. The depth to the water table is also an input, and can be entered as an annual or seasonal average.

Structural

The structural inputs required are dependent upon what pavement type is used (flexible or rigid) and whether the design is a new construction, overlay or rehabilitation. In general, for flexible pavements the designer is required to specify information about the binder properties, the asphalt mix properties, inputs for thermal cracking prediction, and general mix information such as air voids, binder content, etc. The inputs required for these categories are largely dependent upon the level of input selected as mentioned previously. For the binder information, a PG, viscosity or penetration grade can be selected for a level 3 input. For a level 1 or level 2 design, binder dynamic complex modulus (G*) test data are required in accordance with AASHTO TP5 if Superpave data are to be used; otherwise, conventional binder test data such as viscosity, penetration, and softening point information is required. For hot mix asphalt (HMA), a level 2 or 3 design calls for gradation information, and a level 1 design requires dynamic modulus (E*) test data acquired from ASTM D3497. The general asphalt inputs needed include binder content, percent air voids, unit weight, thermal conductivity, heat capacity, and Poisson ratio.

For concrete pavement designs, some of the inputs depend upon the concrete pavement type: jointed plain or continuously reinforced. Jointed plain concrete pavements (JPCP) require inputs for slab temperature, joint design, edge support and base properties. A temperature difference throughout the slab is required to quantify thermally-induced stresses. For joint design, joint spacing, sealant type, and dowel bar spacing and size are required inputs. Edge support inputs include specifying if PCC shoulders are tied, the load transfer efficiency, and widened slab information. The base properties needed are the status of the PCC and base interface (whether bonded or unbonded) as well as an erodibility classification. Continuously reinforced concrete pavements (CRCP) require the designer to specify the shoulder type, slab temperature difference, steel reinforcement information, base property inputs similar to those of JPCP pavements, and crack spacing values.

The other concrete pavement inputs can be classified into three groups: thermal, mix and strength. The thermal inputs required include the layer thickness, unit weight, Poisson ratio, coefficient of thermal expansion, heat capacity and thermal conductivity. The concrete mix inputs include concrete type (Type I, II or III), cementitious material content, water to cement ratio, aggregate type, the temperature at which the concrete becomes stiff enough to develop interior stresses, various shrinkage inputs and the curing method used. The strength inputs depend upon the design level selected. For a level 3 design, the 28-day modulus of rupture, compressive strength or elastic modulus can be specified. Level 2 design requires compressive strength data for 7, 14, 28 and 90 days as well as the ratio of the 20-year strength (long-term) to the 28-day strength. A level 1 design calls for data from flexural strength and modulus of elasticity testing at 7, 14, 28 and 90 days as well as the ratio of long-term strength to 28-day strength for JPCP designs. For CRCP pavements, test data from modulus of elasticity, flexural strength and tensile strength tests are required.

Base, subbase and subgrade materials all require similar inputs in the MEPDG. All require a selection of the material classification or description as well as the layer thickness. Strength properties and other properties used in the EICM model are needed for analysis. For a level 1 design, the strength property inputs require resilient modulus (M_R) test data in accordance with AASHTO T 307. A level 2 design allows the user to correlate the strength from other more commonly used parameters such as CBR, R-value, layer coefficient (a), penetration from DCP, or based upon the plasticity index and gradation. Level 3 allows the user to select a typical M_R value based upon the AASHTO or Unified soil classification. The inputs needed for use in the EICM model include the plasticity index, liquid limit, and compaction and gradation data. These are required regardless of level of design.

Bedrock can also be added to a design in the MEPDG. It requires that the designer specify the condition of the bedrock (massive and continuous or fractured and weathered), as well as the unit weight, Poisson ratio and resilient modulus.

For a JPCP restoration design, the same thermal, mix and strength inputs that are required for a new pavement are required for the existing concrete pavement. In addition, the condition of the pavement before the restoration (percent of slabs cracked) is a required input as well as the predicted condition of the slabs after the restoration is performed.

For all overlay designs, the condition of the existing pavement structure is required. The inputs needed are the same as those of new pavement layers, and have been discussed previously. In addition, if the existing pavement being overlaid is asphalt, the level of rehabilitation (level 1, 2 or 3) and the planned milling depth need to be specified. The rehabilitation levels are similar to the input levels for MEPDG design; level 1 requires the most extensive details for inputs, and level 3 is the least detailed. If the rehabilitation level selected is 1, then backcalculated modulus data found from nondestructive testing can be entered in the asphalt mix screen of the MEPDG. Level 1 rehabilitation also requires the specification of existing rutting in each pavement layer (asphalt, base and subgrade) and layer interface (bond) properties. Level 2 requires the amount of existing cracks (expressed as a % of lane) and existing rutting in each pavement layer (asphalt, base and subgrade). Level 3 requests a pavement rating (ranging from very poor to excellent) and the total existing rutting (entered as one value for all layers). If the existing pavement is JPCP, the amount of cracking present is required (as in restoration design mentioned previously), and if the existing pavement is CRCP, the amount of existing punchouts is a required input.

OUTPUTS

There is no succinct output of the MEPDG that specifies whether a certain pavement design will or will not be sufficient. The outputs of the MEPDG include material property versus time plots as well as distress versus time plots. Figure 2.2 shows a sample output material plot from the MEPDG. This plot shows the change in HMA modulus over the design life, which is two years for this example. The pavement is separated into 7 layers, and the modulus is calculated for each layer each month. Figure 2.3 shows a sample output distress versus time plot. The figure shows the predicted rutting over the two-year design life. The plot shows the user-specified failure criteria for rutting: 0.25 inches in HMA and 0.75 inches in total pavement rutting (also on graph as total rutting design limit line). These limits are briefly discussed under the “General” subheading in this chapter. The rutting in individual pavement layers is displayed on the graph as well as the total pavement rutting and the rutting reliability level. This level corresponds to the level specified by the designer as mentioned previously in this chapter.

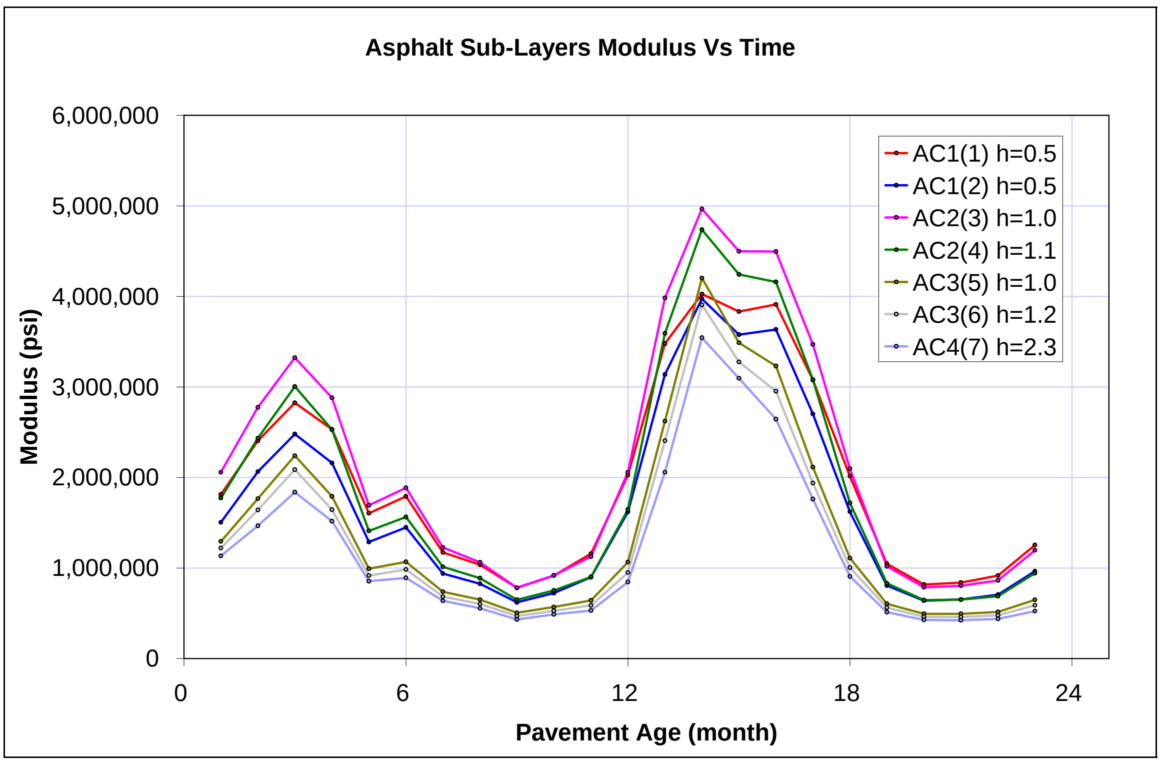

Figure 2.2 Asphalt Modulus versus Time Output Graph.

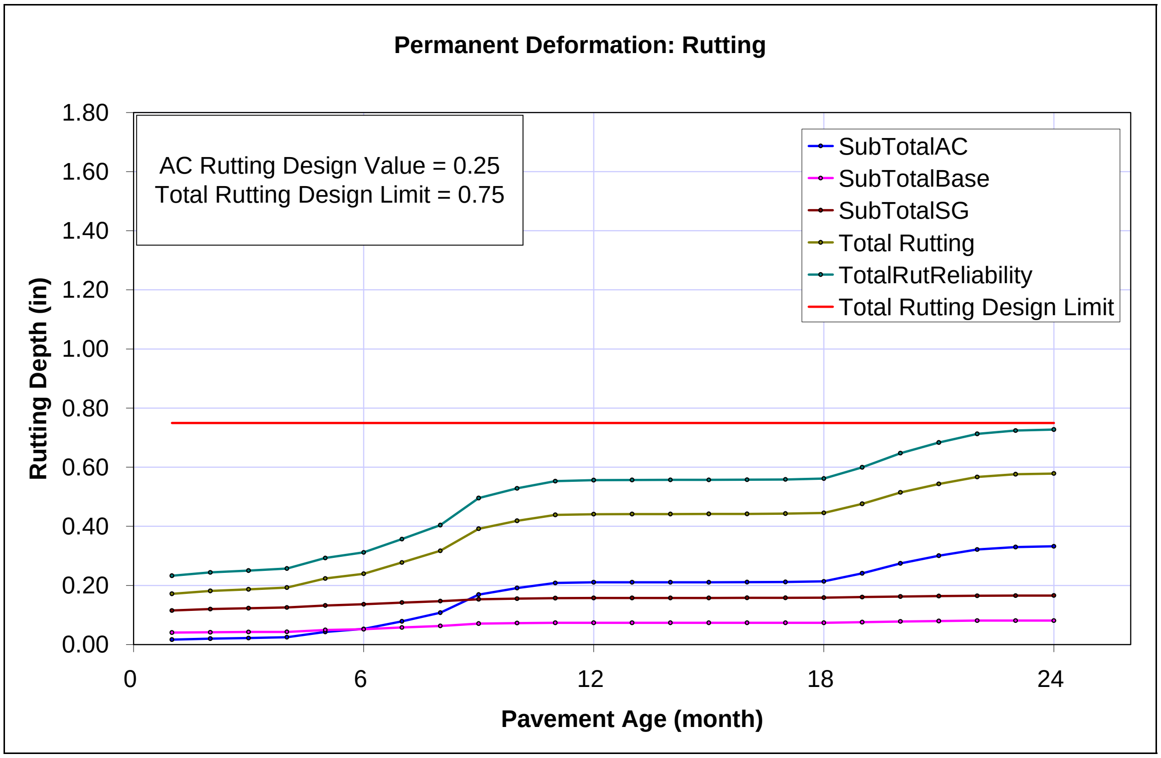

Figure 2.3 Rutting versus Time Output Graph.

These plots allow the designer to view specific distresses and pavement weaknesses, and target those problems when altering the design. For example, if a flexible pavement has an unacceptable level of predicted rutting at the end of the design life but no other major distress problems, the PG grade can be increased to offset this problem. The designer can then rerun the analysis to observe the difference in rutting over time, and thereby target certain distresses to mitigate. This concept of targeting specific weaknesses and distresses for a particular design is one of the primary benefits of using the MEPDG.

CHAPTER 3 – ALDOT PRACTICE AND THE MEPDG

INTRODUCTION

Two of the objectives of this research were to assess current ALDOT pavement design practice and characterize current practice in the context of the MEPDG. This chapter begins with an overview of current ALDOT practice. Details are then provided regarding how current practice can be utilized within the MEPDG. This information was developed primarily from meetings held with ALDOT staff regarding current practices. Table 3.1 lists the relevant meetings, dates and lead staff present at the meetings. Finally, a web-based resource developed for this project is presented that can be used as a dynamic training and resource tool.

Table 3.1 Meetings with ALDOT Staff Regarding Current Practice and MEPDG

Meeting Topic	Date	ALDOT Lead Staff
Pavement Design	May 1, 2007	Scott George, Robert Shugart
Soils and Unbound Materials	September 5, 2007	Becky Keith
Asphalt	October 10, 2007	Randy Mountcastle
Concrete	February 11, 2008	Sergio Rodriguez
Traffic	March 26, 2008	Charles Turney

OVERVIEW OF CURRENT ALDOT PAVEMENT DESIGN PRACTICE

When consultants or ALDOT Division Materials Engineers are developing pavement designs, they currently follow ALDOT Procedure 390 (ALDOT, 2004). The procedure includes specifics regarding materials testing, obtaining relevant traffic information and guidance for conducting pavement design according to the 1993 AASHTO Design Guide methodology. The outcome of this procedure is a “materials report” that requires, among a comprehensive list of deliverables, these pavement design components:

- AASHTO pavement structural design printouts from DARWin™ software

- Results of all tests performed on the project (these tests will be discussed later)
- Traffic data

The DARWin output is the core component of the structural design with the traffic data and materials test results serving as primary inputs for the process. The DARWin software is the electronic embodiment of the 1993 AASHTO Pavement Design Guide, currently in use at ALDOT. The following subsections detail how the relevant inputs are determined for both flexible and rigid design within the current ALDOT procedure.

Current Flexible Pavement Design Method

The current ALDOT flexible pavement design, employed through DARWin, uses the flexible pavement design equation presented in Figure 3.1. Therefore, flexible pavement design amounts to establishing inputs for the following:

W_{18} = number of equivalent single axle loads (ESALs) over the design period

Z_R = z-statistic corresponding to desired level of reliability

S_o = assumed level of input variability

ΔPSI = designed loss of serviceability over the design period

M_R = design subgrade soil modulus, psi

The above inputs are then used to solve the equation (or nomograph) to find the required structural number, SN:

where:

SN = design structural number = $a_1D_1 + a_2m_2D_2 + \ldots + a_nm_nD_n$

a_i = structural coefficient for layer "i"

m_i = drainage coefficient for layer “i”

Once SN is determined, and the “a_i” and “m_i” terms have been defined, the appropriate layer thicknesses can be computed for design.

NOMOGRAPH SOLVES:

$$\log_{10}W_{18} = Z_R{*}S_o + 9.36{*}\log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2 - 1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32{*}\log_{10}M_R - 8.07$$

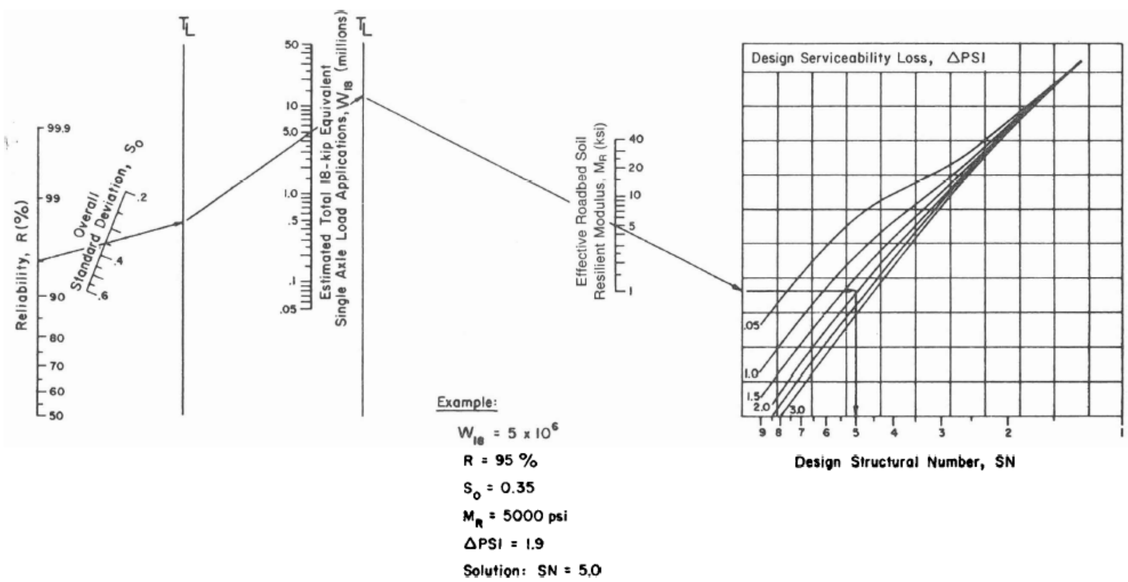

FIGURE 3.1 AASHTO Flexible Pavement Design Nomograph (AASHTO, 1993).

Separate from the ALDOT Procedure 390 document, there is another guidance document, “Guidelines for Flexible Pavement Design in Alabama” (Holman, 1990(a)) that prescribes how to determine each of the inputs stipulated above to be entered into the DARWin software. A brief summary is provided here while more details can be obtained from the original document (Holman, 1990(a)).

The design traffic, expressed as 18-kip equivalent single axle loads, is derived on a project-by-project basis from quantifying the average annual daily traffic ($AADT_i$) and percent trucks (%Trucks) for the design. These data are available from the Traffic Monitoring Division within the ALDOT Transportation Planning and Modal Programs

Bureau. Along the length of a project under design, truck volumes are computed at nodes within the project length and an average is computed. The truck volume from the node closest to, but just over, the average value is used as the design value. This design value is then multiplied by appropriate factors (365 days/year, Lane Distribution, Directional Distribution, Growth Factor, Truck Damage Factor) to arrive at the design ESALs. It should be noted that ALDOT uses a single set of Truck Damage Factors that are a function of terminal serviceability (p_t) and SN. So, for a given design, all trucks are assumed to have equivalent damage factors. However, as reported by Turochy et al. (2005) these truck damage factors are based on an evaluation of truck weights from five weigh-in-motion (WIM) sites within Alabama.

Reliability level is selected within the ALDOT procedure as a function of traffic level (Holman, 1990(a)). Low traffic levels (<500 ESAL/day, both directions) require 85% reliability, medium traffic levels (500-1,750 ESAL/day) require 90% reliability and high traffic levels (>1,750 ESAL/day) require 95%. These reliability levels, in turn, correspond to the appropriate z-statistic. Variability (S_o) is assumed at 0.49 which corresponds to the AASHTO (1993) recommendation for flexible pavements.

Within the current AASHTO method, the performance measure is the design change in serviceability (ΔPSI). It is important to point out that this parameter, in practice, encompasses other more specific measures such as pavement roughness, cracking, rutting, etc. These parameters are more directly predicted within the MEPDG, but are aggregated into ΔPSI in the current method. Following AASHTO (1993) recommendations, ALDOT uses an initial serviceability (p_o) of 4.2 for flexible pavements and sets terminal serviceability (p_t) as a function of traffic level (low traffic = 2.5;

medium traffic = 3.0; high traffic = 3.5). The traffic levels are consistent with those used to determine reliability level.

The ALDOT procedure (Holman, 1990(a)) has a provision for estimating subgrade soil modulus (M_R) from California Bearing Ratio (CBR) testing according to:

$$M_R = 10^{(0.851*\log CBR + 2.971)} \tag{3.1}$$

As noted in the procedure, this value is assumed to be consistent throughout the year unless there are data to the contrary.

While determining M_R from CBR is acceptable within the ALDOT framework, for the past seven years ALDOT has been conducting extensive triaxial resilient modulus tests (AASHTO T307) of their subgrade materials for pavement design and analysis. As specified within Procedure 390 (ALDOT, 2004), the design M_R for soils classified as A-1, A-3, A-2-4 and A-2-5 shall be the average M_R values generated by AASHTO T307 at a confining pressure of 4 psi and optimum moisture content. For other soil classes, the design M_R is the average M_R value generated at 2 psi confining pressure and optimum moisture content. If the soil is an A-6 or A-7 (A-7-5 or A-7-6), 2 psi confining pressure is used, but samples are compacted on the wet side of optimum moisture to generate lower, and more conservative, design soil moduli. These tests are conducted by the Soils Section of the Testing Division within the Bureau of Materials and Tests. More details regarding the soil testing program are provided later in this chapter.

The drainage coefficients (m_i) are calculated based upon the percent passing the number 200 sieve (P_{200}) of the material in question and the average annual rainfall in inches (AAR) for the project location, as expressed by the following equations (Holman, 1996):

$$S_i = 1.2 - 0.6 \cdot (AAR)/100 \qquad (3.2a)$$

$$D_q = 1.2 - 0.6 \cdot (P_{200})/100 \qquad (3.2b)$$

$$m_i = S_i \cdot D_q \qquad (3.2c)$$

where: S_i = saturation level

D_q = drainage quality.

As noted in the SN equation shown in Figure 3.1, the designer must also select appropriate structural coefficients for design. Within the ALDOT procedure (Holman, 1990(a)), there is a table of recommended structural coefficients for a variety of materials used in the surface course (HMA), base course (unbound or bound materials), subbase course (unbound material) and improved roadbed (unbound or bound materials). The table also contains estimated moduli for each material that can be entered into the DARWin software for design purposes. It should be noted that ALDOT does not currently conduct tests for the purposes of determining structural coefficients.

In summary, for typical flexible pavement design, project-specific ESALs, design soil modulus and drainage coefficients are developed based on field sampling, laboratory testing and rainfall data. The remaining inputs are based on default values that represent "statewide" design conditions.

Current Rigid Pavement Design Method

Similar to current flexible pavement design, ALDOT also uses the DARWin software for rigid pavement design. The program solves the equation depicted in Figure 3.2 using the following terms:

W_{18} = number of equivalent single axle loads (ESALs) over the design period

Z_R = z-statistic corresponding to desired level of reliability

S_o = assumed level of input variability

ΔPSI = designed loss of serviceability over the design period

D = design slab thickness, in.

S_c' = modulus of rupture of concrete, psi

E_c = concrete elastic modulus, psi

C_d = drainage coefficient

J = load transfer coefficient to account for tied shoulders and dowel bars

k = modulus of subgrade reaction, psi/in.

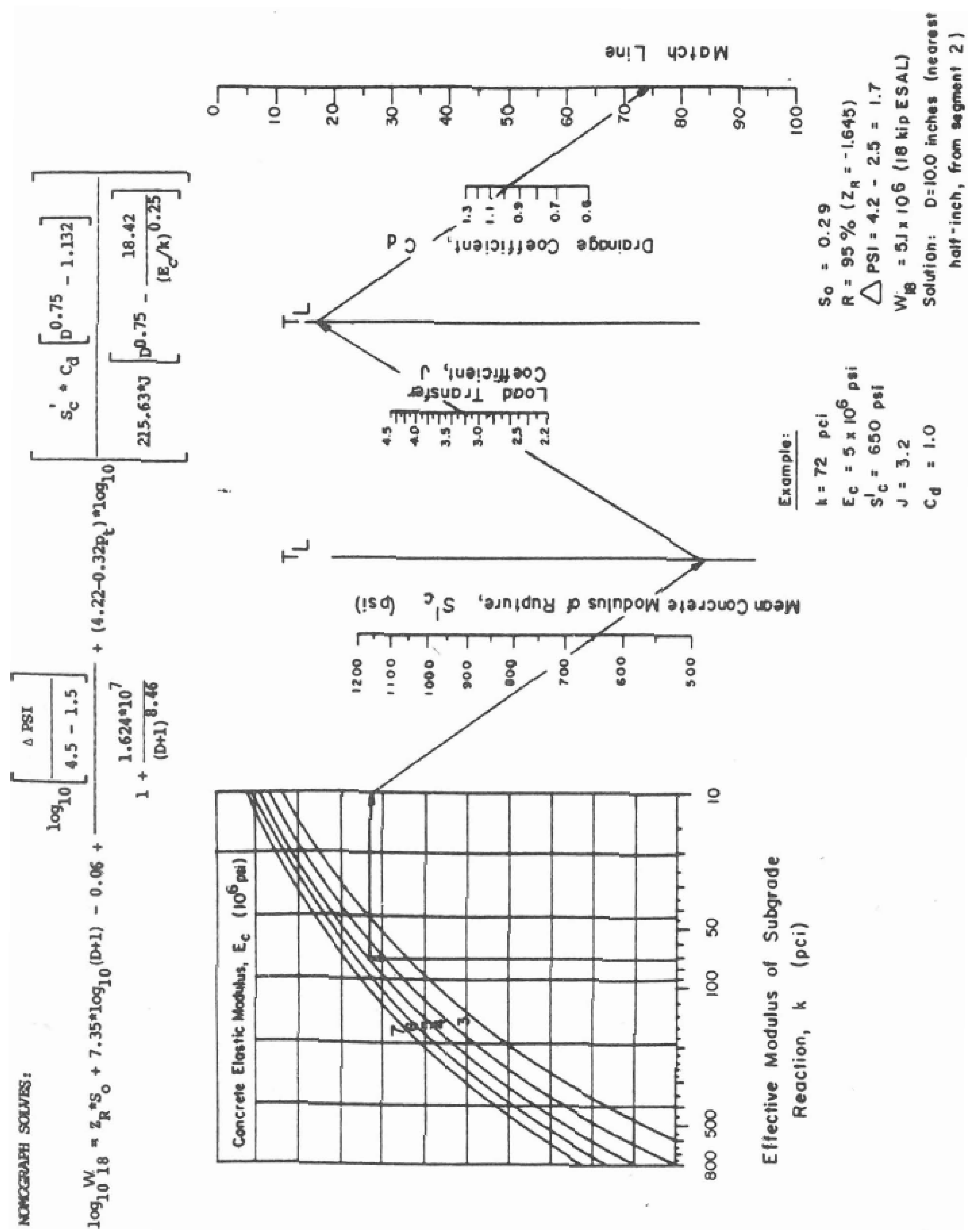

FIGURE 3.2 AASHTO Rigid Pavement Design Nomograph (AASHTO, 1993).

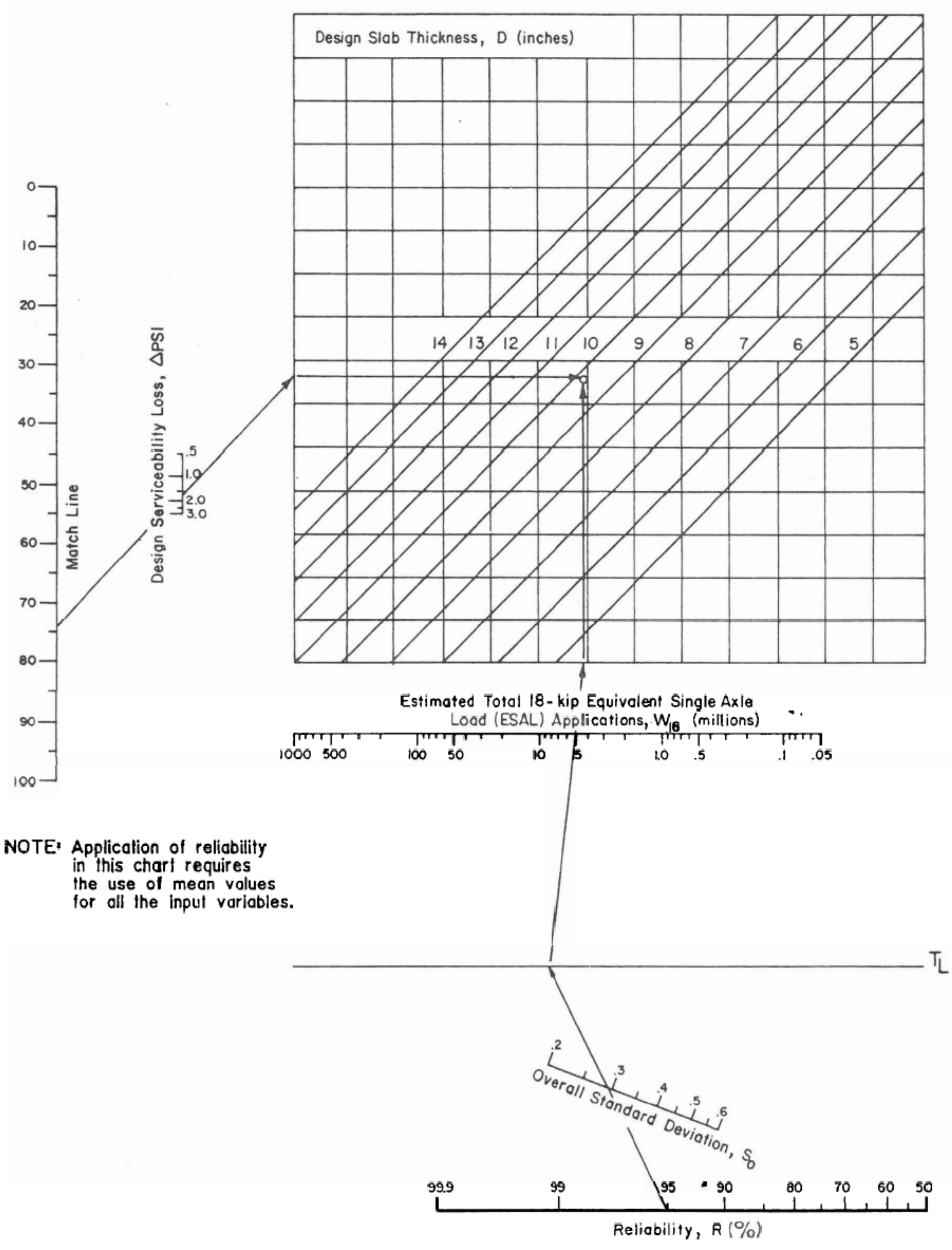

FIGURE 3.2 - Continued

Like the previously-discussed “Guidelines for Flexible Pavement Design in Alabama” (Holman, 1990(a)), ALDOT has a companion document, “Guidelines for Rigid Pavement Design in Alabama” (Holman, 1990(b)). A brief summary is provided here while more details can be obtained from the original document (Holman, 1990(b)).

ESALs, reliability, variability and change in serviceability are determined for rigid design in the same manner as flexible with the following exceptions:

1. Rigid ESALs are computed using truck damage factors corresponding to rigid pavements.
2. Variability (S_o) is set at 0.39, consistent with AASHTO’s (1993) recommendation.
3. Initial serviceability (p_o) is set at 4.5 for rigid pavements, consistent with AASHTO’s (1993) recommendation.

The concrete modulus of rupture (S_c') and elastic modulus (E_c) are typically set at default values, though ALDOT has the capability to test for these parameters according to AASHTO T97 (S_c') and ASTM C469 (E_c). As documented in the ALDOT procedure (Holman, 1990(b)), the recommended S_c' value is 620 psi, though through personal communication with ALDOT staff, it was learned that this value is now set at 650 psi. The default value for elastic modulus is 4,200,000 psi.

Like the drainage coefficients for flexible design (m), the drainage coefficients for rigid design (C_d) are set at 1.0 for pavements without edge drains and 1.2 for pavements with edge drains (Holman, 1990(b)). The ALDOT load transfer coefficient (J), follows AASHTO (1993) recommendations where it varies according to the type of shoulders, pavement type and whether dowels are used. ALDOT selected the average load transfer coefficient in situations where AASHTO recommended a range of values.

The determination of a design modulus of subgrade reaction (k-value) is a bit more complex than the design resilient modulus in flexible pavement design. This complexity results from AASHTO's requirement of assimilating layers between the concrete slab and subgrade soil into an adjusted k-value. Furthermore, the presence of bedrock also calls for a k-value adjustment. ALDOT's procedure (Holman, 1990(b)) follows the AASHTO procedures in determining the k-value. However, to determine a k-value, the procedure first requires a design M_R value of the soil. According to ALDOT practice, this is determined in the same way as for flexible pavement design. The soil is tested for triaxial resilient modulus (AASHTO T307) and the design value is based on averaging the results at the requisite confining pressure which is a function of the soil type. The value is then processed through the AASHTO procedures to determine the design k-value that accounts for presence of a subbase, bedrock and loss of support.

As with flexible pavement design, the only site-specific data developed for rigid design are ESALs and k-value of the soil. The remaining inputs are based on default or recommended values representing "statewide" conditions. It should be further noted that the ALDOT procedure (Holman, 1990(b)) includes documentation for designing dowels, tie bars and reinforcing steel. These procedures follow AASHTO (1993) procedures directly and do not include testing to determine any of the requisite inputs.

ALDOT PRACTICE WITHIN THE MEPDG

As discussed above, the primary data sources developed on a design-by-design basis are the traffic volume and soil modulus. The remaining inputs are based on default values recommended within guidance documents developed by ALDOT. Since the MEPDG requires these inputs, in addition to many more as presented in Chapter 2, meetings were held with ALDOT staff (Table 3.1) to ascertain what other testing capabilities/data sources are currently available to facilitate MEPDG design. The following subsections set ALDOT practice and capabilities in the context of the MEPDG.

Project-Level Parameters

Within the MEPDG software, the "Project Level" information for a pavement design is divided into three categories that include "General Information," "Site/Project Identification" and "Analysis Parameters." The "Site/Project Identification" input window should facilitate designers in maintaining their current project identification practice of utilizing a project number, location information and mileposts.

Within the "General Information" inputs, the most problematic will typically be the dates of expected construction and opening to traffic. Often, design work is done years in advance and it would be very difficult to pinpoint these dates. In this case, for large projects, it may be necessary to execute several pavement designs with different construction/open to traffic dates and establish a range of likely pavement thicknesses.

The "Analysis Parameters" input window requires the designer to select terminal serviceability levels for each distress type and corresponding level of reliability. Since ALDOT currently uses ∆PSI as the pavement design performance indicator, there needs to be policy decisions made regarding ALDOT-specific terminal levels of each distress. Decisions should also be made about which distresses to consider in design since the MEPDG allows the designer to select specific distresses. It may be, for example, that designers should only consider fatigue, rutting and ride quality (IRI) and ignore the rest of the predicted distresses. In any case, there is a need to develop agreed-upon values. Provisionally, it is recommended that ALDOT use the default values built into the MEPDG.

Traffic

Traffic information required to execute pavement designs in the MEPDG consists of considerably more inputs than the 1993 AASHTO Design Guide and the DARWin software. Many of these variables are not directly used in the existing procedure, and default values for them are provided in the MEPDG. In fact, a pavement design can be executed using the AASHTO design method with as few as two of the following three inputs provided by the designer: AADT (annual average daily traffic), AADTT (annual average daily truck traffic), which considers only FHWA vehicle classes 4-13, and the percent of total traffic that is comprised of heavy vehicles (defined as vehicle classes 4-13). This vehicle classification is shown in Figure 3.3; when reference is made to vehicle class distributions in this report, this is the scheme used. For all other required traffic parameters, a set of default values is available for use in the MEPDG.

Traffic inputs are grouped into the following four categories in the MEPDG:

- Traffic volume parameters
- Traffic volume adjustment factors
- Axle load distribution factors
- General traffic inputs

This section of the report discusses the traffic inputs according to this categorization, highlighting current ALDOT traffic data collection practices and capabilities, the use of default values in the MEPDG, and possible future improvements to current practice. Prior to describing the inputs in each of these categories, it may be useful to briefly address how the three levels of specificity in pavement design as given in the MEPDG relate to availability of traffic data.

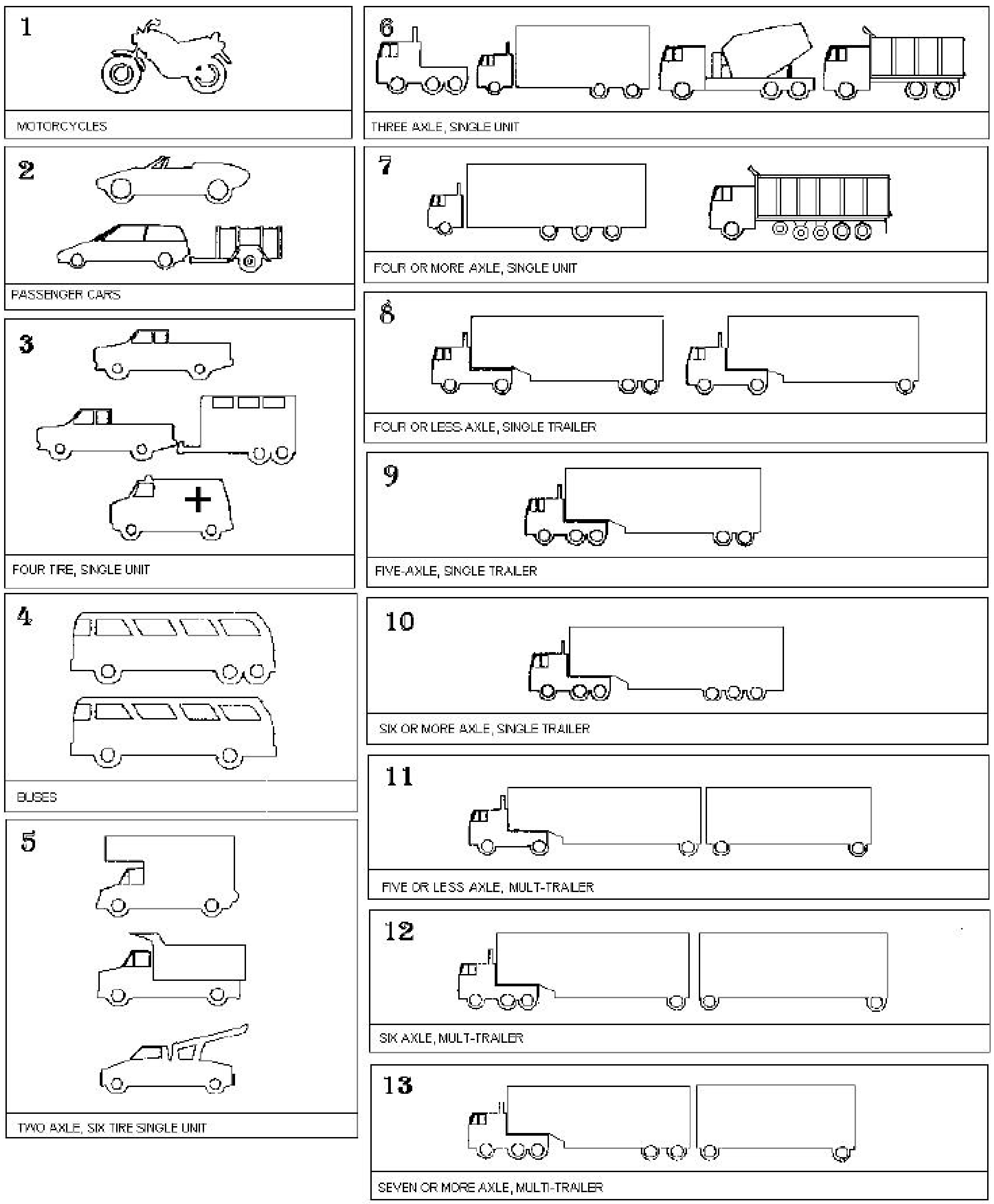

FIGURE 3.3 FHWA Vehicle Classification Scheme F.

Traffic Volume Parameters

The most critical site-specific traffic data item is, of course, the truck traffic volume, expressed as AADTT. ALDOT currently maintains AADTT information for approximately 5,000 sites statewide. These locations include ALDOT's 120 permanent continuous count stations, approximately 2,100 count sites at which data collected to meet the requirements of FHWA's Highway Performance Monitoring System, and other locations at which short-term (typically 7-day) count data are collected and then adjusted to represent annual averages. These data collection efforts are conducted by the Traffic Monitoring Division of ALDOT's Transportation Planning and Modal Programs Bureau. The percent of traffic comprised of heavy vehicles (defined in the MEPDG as vehicle class 4-13), which relates AADT to AADTT, is also generated through these data collection efforts.

The remaining traffic volume parameters all have default values provided in the MEPDG for use when site-specific data are not available. These items include number of lanes in the design direction, percent of trucks in design direction, percent of trucks in design lane, and operational speed. These data are not typically generated through current ALDOT practice. The number of lanes, of course, is a project-specific design decision made prior to commencing the pavement design process; there is no traffic data corollary for this item. Regarding percent of trucks traveling in the design direction, the default value given in the MEPDG is 55%. More detail on this value and breakdown by vehicle classification can be found in supporting documentation provided for the MEPDG. Traffic requirements are specifically discussed in Part 2, Chapter 4 of the MEPDG documentation (Eres, 2004). Percent of trucks in the design lane, sometimes referred to as the truck lane distribution factor (LDF), is the largest proportion of truck traffic that can be expected to use a particular lane (typically the rightmost lane in a particular direction). The default values for LDFs are 1.0, 0.9, 0.6, and 0.45 for roadways with one, two, three, and four lanes in each direction, respectively. More detail on this value and breakdown by vehicle classification can be found in supporting documentation provided for the MEPDG (ref). Operational speed, an input does that not exist in the pavement design procedure provided in 1993 AASHTO Design Guide, is set at 60 miles per hour in the MEPDG.

When executing a pavement design, the distribution (percent) of trucks by direction and lane can be obtained through a site visit, outputs of the transportation planning process, experience with similar facilities, or by use of the default values. Project design speed, as well as highway capacity analyses could be used to determine an operational speed to replace the default value.

Traffic Volume Adjustment Factors

This category includes data items that are used to modify the general traffic patterns represented by the data described in the previous section in order to portray a more detailed and thorough use of the roadway over its design life. These factors reflect a detailed distribution of vehicle classification and volume trends by month of the year, time of day, and growth trends over the duration of the pavement design life. The MEPDG, by its incremental nature of modeling traffic loading and associated pavement damage, requires knowledge of these patterns as temperatures change both daily and seasonally. Because of the data collection effort (beyond typical data collection efforts conducted by state DOTs) that would be required to obtain site-specific data in this category, default values are provided for all of these parameters in the MEPDG. A description of these parameters is provided below, as well as the relationship of the routinely collected data and the data derived by ALDOT to the required inputs.

The data items in the category of traffic volume adjustment factors include monthly adjustment factors, vehicle class distribution, growth rate, and growth rate by vehicle class. Monthly adjustment factors divide the AADTT into monthly proportions; these factors are developed for each vehicle class such that the monthly distribution of annual traffic can differ among classes 4-13. For data collected at its permanent count stations (approximately 120 statewide), a monthly distribution is routinely developed; however, it is for all heavy vehicles as a group, rather than by individual vehicle classes. Monthly adjustment factors for each vehicle class can be extracted from the data collected at these permanent sites with additional effort beyond regular practice. Beyond these locations, ALDOT does not routinely collect this information.

Vehicle class distributions (dividing the total AADTT into proportions by vehicle class) are currently generated from data collected at the permanent count stations. These data are collected using typical vehicle classification technology such as inductive loop detectors and piezoelectric sensors. At the approximately 2,100 sites that are part of the federally-mandated Highway Performance Monitoring System (HPMS), classification data are typically collected once every 3 years; the classification data for these locations are based solely on axle spacing data recorded using pneumatic tubes. At other sites, these data are not routinely collected. Before deciding upon whether to use the provided default vehicle class distributions or some form of the distributions that ALDOT has developed from the permanent count stations and/or the HPMS sites, further study should investigate the variability among the vehicle class distributions obtained at these sites, the feasibility of application of averages by highway functional classification or at the statewide level, and the differences between these distributions and the default distribution given in the MEPDG software.

Growth in traffic volumes can be treated as either no growth, linear growth, or compound growth. With linear growth, traffic volumes increase by a constant amount (constant percentage of the base year traffic), whereas with compound growth, the annual amount of growth is a percentage of the previous year's traffic volume (rather than that of the base year). From a particular base year traffic volume and a particular growth rate (percentage), compound growth produces larger volumes than does simple growth. Some roadways may be more accurately modeled with simple growth and others using compound growth. ALDOT currently generates compound growth rates for all sites (permanent count stations, HPMS sites, and non-HPMS sites).

The final item in this category is one that allows for selection of growth rate and type (none, linear, or compound) by vehicle class, rather than using one growth rate across all vehicle types. These data are not routinely collected by ALDOT; however, for its permanent count stations, these rates could be developed by vehicle class with additional effort.

Axle Load Distribution Factors

This category of traffic parameters addresses the distribution of actual weights of individual axles. This is an example of the greater sophistication provided by the

MEPDG over more traditional empirical methods of pavement design that use gross vehicle weights or that convert all axle weights to an equivalent single axle load. The MEPDG provides default distributions of axle weights, or loads, for each category of axle group (single, tandem, tridem, and quad). However, axle load distributions can vary by type of roadway (such as functional classification or administrative system), by region or state, and at the site-specific level. This issue has been studied widely but not yielded a consensus of results. In the case of axle load distributions in Alabama, a study conducted at Auburn University examined data for single and tandem axle loads from 13 weigh-in-motion sites in Alabama; the data were collected in 2001. For these sites, all located on rural principal arterials, it was noted that for designs on rural principal arterials, "statewide axle load spectra for M-E design are recommended when site-specific data are not available" (Turochy et al., 2005). In a follow-up study which examined the impact of differences among the axle load distributions at these 13 sites on thickness of HMA pavement using a mechanistic-empirical approach to pavement design, it was found that "…86% of the design scenarios (combinations of site-specific load spectra and soil strength) required HMA thickness within ½-inch of that for the statewide distribution." (Timm et al., 2006).

Although previous studies have shown that for most of the 13 sites studied, the use of a statewide axle load distribution (in lieu of site-specific data) does not substantially affect resulting pavement thickness, there are still many reasons as to why a general recommendation for use of a statewide distribution cannot be made at this time. In the previous studies noted above, only 13 sites (12 bidirectional and one for a single direction) were considered. Additionally, these sites represented one functional classification (rural principal arterials, including a mix of Interstates, U.S., and State Highways). The study that examined differences in resulting pavement thickness only examined flexible pavements. When the fact that the data utilized in the previous studies is eight years old (at the time of this writing) is coupled with the previously noted caveats, it is apparent that additional study of axle load distributions and their effects on pavement thickness is prudent before ALDOT implements the MEPDG. Such study should include examination of updated data sets that also reflect the increase in WIM data collection sites maintained by ALDOT in recent years. Analyses of the effect of substitution of a general axle load distribution for site-specific data on both flexible and rigid pavements should be conducted. Finally, comparison of site-specific and statewide average axle load spectra to the default (nationwide) distribution given in the MEPDG software should also be undertaken.

General Traffic Inputs

This category of traffic parameters pertains to other traffic characteristics, such as placement and variability of wheelpaths, tire pressures, and other items that can be used in a mechanistic-empirical, simulation-based approach to modeling the impacts of traffic on pavements. These inputs are not typically collected as part of routine traffic data collection efforts in transportation agencies such as ALDOT. Therefore, default values are provided for these inputs in the MEPDG.

Mean wheel location, traffic wander standard deviation, and average axle width pertain to placement of axle loads laterally in the lane as shown schematically in Figure 3.4. Specifically, mean wheel location is defined as the distance from the outer edge of the wheel to the pavement marking, and traffic wander standard deviation captures the variability in lateral placement among traffic. Design lane width is defined as the actual lane width between pavement markings. Average axle width is the distance between outside edges of wheels on a given axle. Dual tire spacing and tire pressure are self-explanatory. Tandem, tridem, and quad axles spacing and wheelbase (distance from steer axle to next axle on vehicle) are similarly self-explanatory. As noted previously, these data are not routinely collected by transportation agencies such as ALDOT, and it is anticipated that use of the default values within the MEPDG software would be sufficient for the inputs in this category.

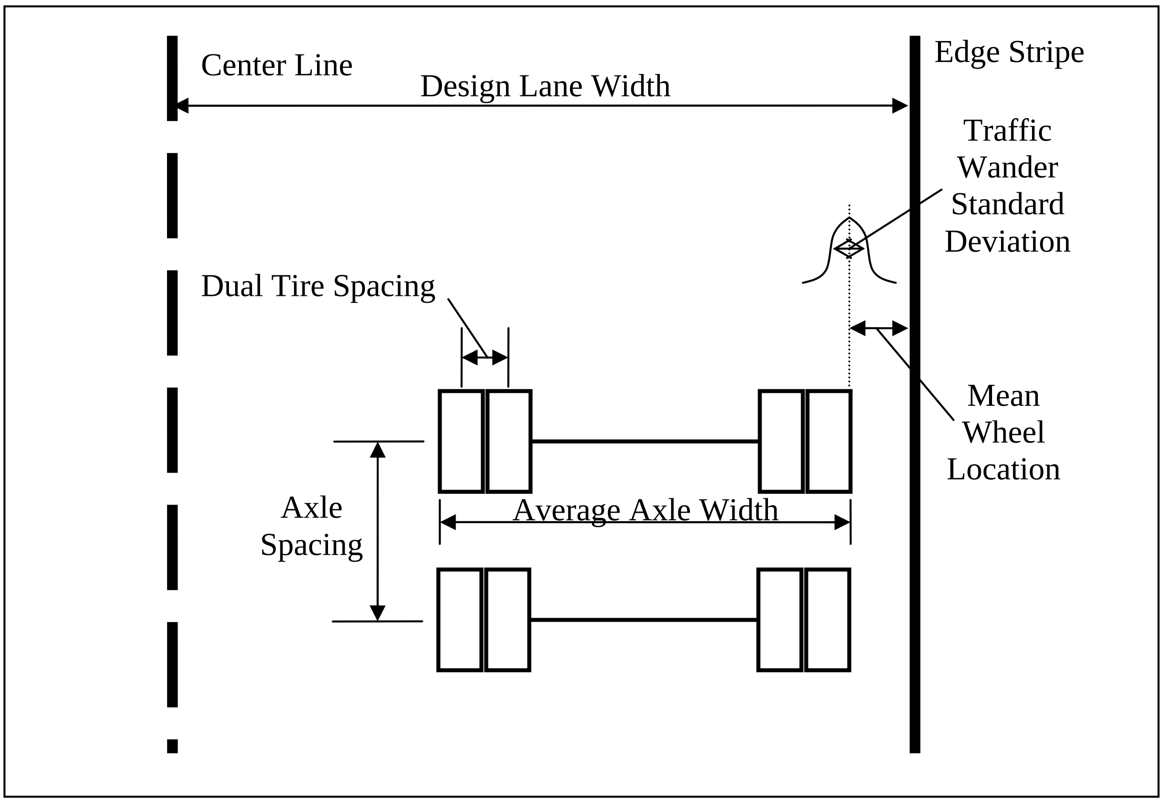

Figure 3.4 Axle and Lane Geometry Definitions.

Climate

Though the climate computations within the MEPDG are very complex, the required inputs are mercifully straightforward. The MEPDG contains a comprehensive climate database which requires the designer to either select a nearby location or interpolate from several weather stations. This decision should be made on a design-by-design basis. In either case, the water table depth is required. This could be obtained from the soil boring procedures required in ALDOT Procedure 390 (ALDOT, 2004).

Structure

Depending upon the type of pavement selected (Asphalt, Jointed Plain Concrete or Continuously Reinforced Concrete), the MEPDG requires different sets of inputs. The following subsections focus on the three general classes of materials (HMA, PCC and Base/Subgrade) and their assorted MEPDG input requirements.

Hot Mix Asphalt

Table 3.2 lists the pertinent tests to be conducted on HMA or liquid binder for various MEPDG design levels. The table includes what the test is used for within the MEPDG and commentary regarding current ALDOT practice.

Table 3.2 HMA and Asphalt Binder Tests

Test	Name	MEPDG Input	Current ALDOT Practice?
ASTM D 3497	Standard Test Method for Dynamic Modulus of Asphalt Mixtures	Asphalt mix - level 1: dynamic modulus information	No
AASHTO T 27	Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates	Asphalt mix - levels 2 & 3: gradation information	Yes
AASHTO T 315	Standard Method of Test for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer	Asphalt binder - levels 1 & 2: dynamic complex modulus and phase angle values	Yes
ASTM D 36	Standard Test Method for Softening Point of Bitumen	Asphalt binder - levels 1 & 2: conventional binder test data - softening point	Have equipment but only test on emulsions
AASHTO T 202	Standard Method of Test for Viscosity of Asphalts by Vacuum Capillary Action	Asphalt binder - levels 1 & 2: conventional binder test data - absolute viscosity	
AASHTO T 201	Standard Method of Test for Kinematic Viscosity of Asphalts	Asphalt binder - levels 1 & 2: conventional binder test data - kinematic viscosity	
ASTM D 70	Standard Test Method for Specific Gravity and Density of Semi-Solid Bituminous Materials (Pycnometer method)	Asphalt binder - levels 1 & 2: conventional binder test data - specific gravity	
ASTM D 5	Standard Test Method for Penetration of Bituminous Materials	Asphalt binder - levels 1 & 2: conventional binder test data - penetration test data	
ASTM D 4402	Standard Test Method for Viscosity Determination of Asphalt at Elevated Temperatures Using a Rotational Viscometer	Asphalt binder - levels 1 & 2: conventional binder test data - Brookfield viscosity	Yes
AASHTO MP1	Standard Specification for Performance Graded Asphalt Binder	Asphalt binder - level 3: Superpave performance grade	Yes
ASTM D 3381	Standard Specification for Viscosity-Graded Asphalt Binder	Asphalt binder - level 3: viscosity grade	Yes
AASHTO T 49	Standard Method of Test for Penetration of Bituminous Materials	Asphalt binder - level 3: penetration grade	Yes
ASTM E 1952	Standard Test Method for Thermal Conductivity and Thermal Diffusivity	Asphalt general	No
ASTM D 2766	Standard Test Method for Specific Heat of Liquids and Solids	Asphalt general	No

One of the most important inputs for M-E design is the dynamic modulus (E*) of the HMA. This is a direct input to the layered elastic model contained within the MEPDG. As noted in Table 3.2, ALDOT does not currently conduct this test so true "Level 1" mixture characterization is not possible. However, other methods are available to obtain E* data through indirect means. The MEPDG contains two regression models that predict E* from more commonly available mixture parameters that include aggregate gradation, binder properties and mixture volumetrics. The so called "NCHRP 1-37A" and "NCHRP 1-40D" models are available within the MEPDG and are of the form (as reported by Robbins, 2009):

Witczak 1-37A Model

$$\log E^* = -1.25 + 0.029\rho_{200} - 0.0018(\rho_{200})^2 - 0.0028\rho_4 - 0.058V_a - 0.0822\frac{V_{beff}}{V_{beff} + V_a}$$
$$+ \frac{3.872 - 0.0021\rho_4 + 0.004\rho_{38} - 0.000017(\rho_{38})^2 + 0.0055\rho_{34}}{1 + e^{(-0.603313 - 0.313351\log(f) - 0.393532\log(\eta))}}$$

(Eq. 3-1)

where:
E^* = dynamic modulus of mix, 10^5 psi
η = viscosity of binder, 10^6 poise
f = loading frequency, Hz
ρ_{200} = % passing #200 sieve
ρ_4 = cumulative % retained on #4 sieve
ρ_{38} = cumulative % retained on 3/8 in. sieve
ρ_{34} = cumulative % retained on 3/4 in. sieve
V_a = air voids, % by volume
V_{beff} = effective binder content, % by volume

Witczak 1-40D Model

$$\log E^* = -0.349 + 0.754\left(|G_b^*|^{-0.0052}\right)\times\left(\begin{array}{l} 6.65 - 0.032\rho_{200} + 0.0027(\rho_{200})^2 + 0.011\rho_4 \\ -0.0001(\rho_4)^2 + 0.006\rho_{38} - 0.00014(\rho_{38})^2 \\ -0.08V_a - 1.06\left(\dfrac{V_{beff}}{V_a + V_{beff}}\right) \end{array}\right)$$

$$+\frac{2.56 + 0.03V_a + 0.71\left(\dfrac{V_{beff}}{V_a + V_{beff}}\right) + 0.012\rho_{38} - 0.0001(\rho_{38})^2 - 0.01\rho_{34}}{1 + e^{(-0.7814 - 0.5785\log|G_b^*| + 0.8834\log\delta_b)}}$$

(Eq. 3-2)

where:
E* = dynamic modulus of mix, psi
$|G_b^*|$ = dynamic shear modulus of binder, psi
δ_b = phase angle of binder
ρ_{200} = % passing #200 sieve
ρ_4 = cumulative % retained on #4 sieve
ρ_{38} = cumulative % retained on 3/8 in. sieve
ρ_{34} = cumulative % retained on 3/4 in. sieve
V_a = air voids, % by volume
V_{beff} = effective binder content

The primary difference between these two models is how the asphalt binder is characterized. In the 1-37A model, viscosity and loading frequency are direct inputs. In the 1-40D model, these parameters have been replaced with dynamic shear modulus (G*) and phase angle (δ). In either case, E* data are generated from more commonly-available mixture properties for which ALDOT currently has the capability to test. More specifically, given the information in Table 3.2, it appears that current practice would fit well with the 1-40D model since it is currently a routine test according to AASHTO T-315.

Hirsch Model

A third model, not contained within the MEPDG, but also used to generate E* data from commonly-available tests is the so-called "Hirsch" model. This model is also a regression equation, but requires fewer inputs than the NCHRP models and is of the form (as reported by Robbins, 2009):

$$|E^*|_{mix} = Pc\left[4{,}200{,}000\left(1-\frac{VMA}{100}\right)+3|G^*|_b\left(\frac{VFA\times VMA}{10{,}000}\right)\right]+$$
$$(1-Pc)\left[\frac{1-(VMA/100)}{4{,}200{,}000}+\frac{VMA}{3VFA|G^*|_b}\right]^{-1} \qquad (3\text{-}3)$$

where:

$$Pc=\frac{\left(20+\dfrac{VFA\times 3|G^*|_b}{VMA}\right)^{0.58}}{650+\left(\dfrac{VFA\times 3|G^*|_b}{VMA}\right)^{0.58}}$$

where:
$|E^*|_{mix}$ = dynamic modulus, psi
VMA = voids in mineral aggregate, %
VFA = voids in aggregate filled with mastic, %
VFA = 100*(VMA-V_a)/VMA
V_a = air voids, %
$|G^*|_b$ = dynamic shear modulus of binder, psi

Since ALDOT does not currently test for E*, there is a need for a best practice of determining E* according to one of the methods described above. A recent investigation of NCAT Test Track mixtures used in the 2006 experiment showed that the Hirsch model provided the most accurate and reliable data (Robbins, 2009). Figure 3.5 summarizes the findings which shows the 1-37A model with the greatest amount of scatter, though it generally follows the line of equality. The 1-40D model tends to overpredict the measured E* while the Hirsch model followed both the line of equality and had the least amount of scatter (highest R^2).

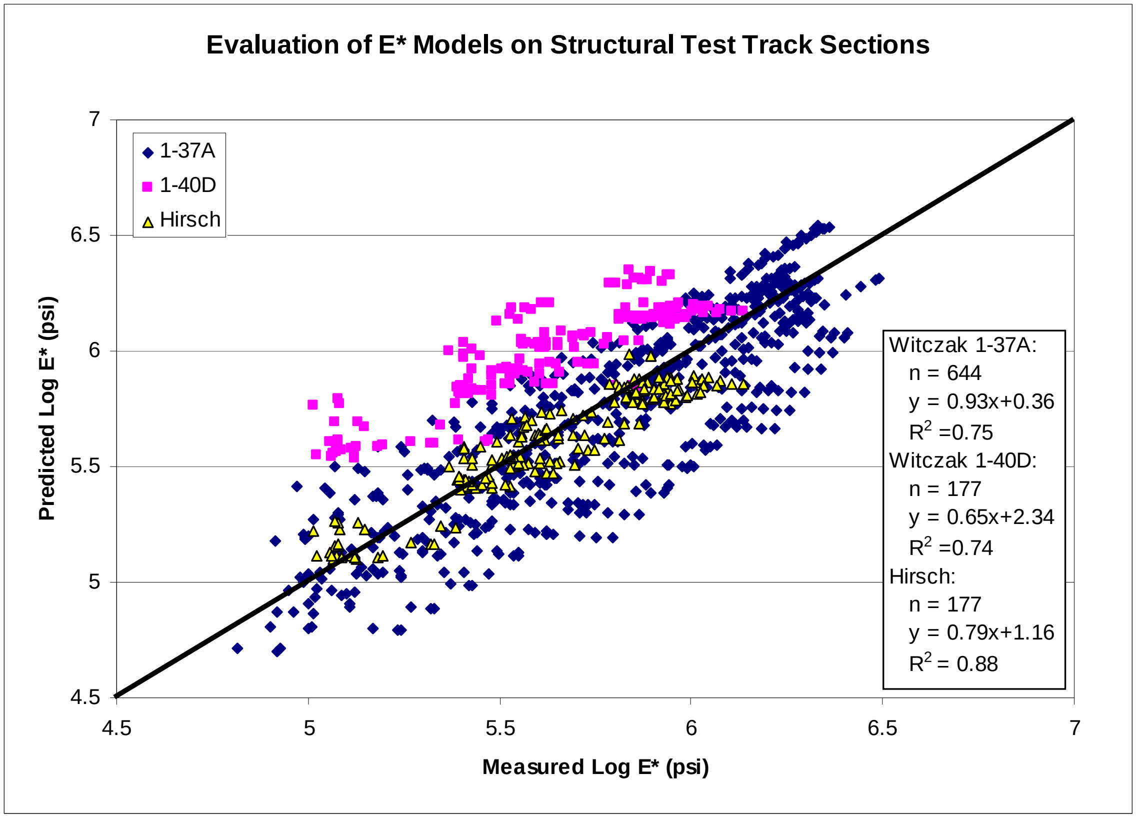

FIGURE 3.5 Predicted vs. Measured E* (Robbins, 2009).

While further investigation of more mixtures is certainly warranted to validate the findings presented in Figure 3.5, it is reasonable to provisionally accept the Hirsch predictive equation as a viable option for generating E* data. As noted in the equation, it requires volumetric properties and G*. For design, G* can be tested a priori, however the volumetric properties are not truly known until the mixture has been placed. Therefore, during the structural design phase, ALDOT should consider using volumetric properties from mix design as a surrogate for as-built properties.

Another challenge with using the Hirsch model is that it is not built directly into the MEPDG, although future versions may contain it. This can be overcome by computing E* separate from the MEPDG at the required number of temperatures and frequencies and then entering the E* data as if they were Level 1.

Two parameters that are required regardless of input level are the thermal conductivity (ASTM E 1952) and specific heat of asphalt (ASTM E 2766). Since these tests are not routinely run, it is recommended that the default values be used. However, an investigation should be conducted to validate the defaults for typical ALDOT mixtures.

Other tests listed in Table 3.2 such as viscosity (ASTM D3381) and penetration (AASHTO T49) that ALDOT currently performs would aid in conducting a level 3 characterization. However, since current practice also allows for level 1 design, it is recommended that level 1 be conducted.

In summary, for asphalt materials, it is recommended that ALDOT provisionally use the Hirsch model to generate E* data for direct input to the MEPDG. The Hirsch model will require generation of volumetric data in addition to G* testing of the binder on a design-by-design basis. An investigation should be conducted to validate the thermal properties of typical ALDOT mixtures.

Portland Cement Concrete

Table 3.3 lists the relevant tests on PCC required by the MEPDG and ALDOT's current practice for each test. Within the MEPDG, the inputs for PCC design are divided into "Thermal", "Mix" and "Strength" properties. The MEPDG requires the same inputs regardless of input level for the Thermal and Mix properties. The strength properties, however, are level-specific as discussed below.

TABLE 3.3 PCC Tests.

Test	Name	MEPDG Input	Current ALDOT Practice?
ASTM C 469	Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression	Poisson's ratio of concrete	Capable, but not routine
AASHTO TP 60	Standard Test Method for the Coefficient of Thermal Expansion of Hydraulic Cement Concrete	Coefficient of thermal expansion	No
ASTM E 1952	Standard Test Method for Thermal Conductivity and Thermal Diffusivity by Modulated Temperature Differential Scanning Calorimetry	Thermal conductivity	No
ASTM D 2766	Standard Test Method for Specific Heat of Liquids and Solids	Heat capacity	No
AASHTO T 160	Standard Method of Test for Length Change of Hardened Hydraulic Cement Mortar and Concrete	Shrinkage inputs	Yes
ASTM C 78	Standard Test Method for Flexural Strength of Concrete	Level 1 - flexural strength (modulus of rupture)	Capable, but not routine
ASTM C 39	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens	Level 2 - compressive strength	Yes
AASHTO T121	Standard Method of Test for Mass per Cubic Meter (Cubic Foot), Yield, and Air Content (Gravimetric) of Concrete	Concrete Unit Weight	Routinely done in Mix Design Phase; not routinely done in field

<u>Thermal Properties</u>

The MEPDG requires the unit weight, Poisson ratio, coefficient of thermal expansion, thermal conductivity and heat capacity of the concrete. As shown in Table 3.3, ALDOT currently has the capability to determine Poisson's ratio, although this is not considered a routine test. Heat capacity and thermal conductivity are not currently in ALDOT's testing program. Test data should be reviewed to verify the MEPDG Poisson ratio default of 0.20. The unit weight is determined during the mix design phase but not routinely measured in the field. Therefore, values from mix design could be entered into the MEPDG. The MEPDG default values can be provisionally used for the other parameters, but a study should be conducted to verify the values for ALDOT mixtures.

The coefficient of thermal expansion is also not currently within the testing capabilities of ALDOT. However, a recently-completed study at Auburn University (Sakyi-Bekoe, 2008) has recommended values according to coarse aggregate type for commonly used materials in the Alabama Concrete Industry. Table 3.4 lists the range and average recommended values, respectively.

Table 3.4 Coefficient of Thermal Expansion (CTE) Values for Concretes Made from Common Rock Types in the Alabama Concrete Industry (Sakyi-Bekoe, 2008).

Coarse Aggregate Type	CTE Range ($x10^{-6}$ in./in./^{o}F	Average CTE ($x10^{-6}$ in./in./^{o}F)
Siliceous River Gravel	6.82 – 7.23	6.95
Granite	5.37 – 5.91	5.60
Dolomitic Limestone	5.31 – 5.66	5.52

Mix Properties

The mix properties required by the MEPDG include standard mix design properties (cement content, water cement ratio, aggregate type) in addition to shrinkage properties. As noted in Table 3.3, ALDOT currently executes AASHTO T160 which can provide the needed inputs for the shrinkage inputs.

Strength Properties

Concrete strength properties are level specific within the MEPDG. At Level 3, the designer has the option of entering either the 28-day modulus of rupture or the 28-day compressive strength. Since, from Table 3.3, it appears that compressive strength is more commonly run, it is recommended that the designer input compressive strength data. However, as with HMA design, the actual mix used in construction may not be known at the time of structural design. Therefore, it is recommended that ALDOT establish some typical values to be entered for common mix designs used in Alabama.

A Level 2 design requires concrete compressive strength at 7, 14, 28 and 90 days in addition to the ratio between 20-year and 28-day strength. Again, it may be necessary to conduct a study or evaluate existing data sets to develop typical strength curves for Alabama mixtures. The MEPDG recommends using a ratio of 20-year/28-day strength equal to 1.44. This default value should be validated for ALDOT typical mixtures.

A Level 1 design requires both elastic modulus and modulus of rupture over time and the ratio between 20-year and 28-day values. Additionally, for continuously reinforced concrete pavement (CRCP) pavement at Level 1, the MEPDG requires split tensile strengths over time. Since none of these properties is routinely tested by ALDOT, a Level 1 characterization is not recommended at this time.

In summary, ALDOT should rely primarily on compressive strength and shrinkage testing to provide inputs on a design-by-design basis. It may be necessary to develop recommended values for use in the design phase. Coefficient of thermal expansion can be selected according to Table 3.4 as a function of aggregate type. Given the current procedures in place at ALDOT, the requirements for concrete characterization could easily be met at Level 3, and with some further investigation/testing required for Level 2 design.

Base/Subgrade Materials

Many of the test procedures listed in Table 3.5 for base and subgrade layers pertain to stabilized materials (e.g., lean concrete, cement treated aggregate). Since these materials are not currently often used by ALDOT, they are not currently tested according to the procedures listed in Table 3.5. As such, they will not be further discussed in this report.

Similar to the HMA and PCC inputs, the primary input for bases and subgrades is the resilient modulus of the respective material. At Level 3, choosing the material type will automatically select a modulus value based upon MEPDG default values. At Level 2, the designer must input either a seasonal or representative (annual) modulus. Level 1 requires the non-linear model parameters derived from triaxial resilient modulus testing, although the MEPDG does not recommend this level of characterization for bases/subgrades since it has not been calibrated with non-linear materials. Interestingly, ALDOT currently has the capability and data needed to enter non-linear model parameters for subgrade materials. For the past seven years, ALDOT has been conducting triaxial resilient modulus tests (AASHTO T307) as part of Procedure 390 discussed previously. However, since the MEPDG is not currently calibrated for non-linear soil characterization, it is recommended that ALDOT use a Level 2 approach and enter a representative soil modulus according to their current practice of averaging the results of triaxial testing at moisture contents and confining pressures as a function of soil type.

While ALDOT has a wealth of triaxial resilient modulus data pertaining to soils, this test has not been routinely run on aggregate base materials. In their current design practice, default moduli have been used. Therefore, with respect to the MEPDG, a Level

3 analysis could be completed by simply selecting the material type and letting the MEPDG assign a modulus. It is recommended, however, that further investigation be done to evaluate the resilient modulus of commonly used base materials to develop a set of values that can be used for Level 2 characterization.

To illustrate the need for aggregate base testing, ALDOT uses 25,000 psi for crushed granite aggregate base in their current design procedure (Holman, 1990). This value is the same used within the MEPDG for a crushed gravel base at Level 3. However, recent triaxial testing of crushed aggregate base as part of the 2006 NCAT Test Track (Taylor and Timm, 2009) indicates the value may be somewhat lower which requires some detailed explanation below.

Laboratory testing of crushed granite aggregate base used in Section S11 at the Test Track was conducted by Burns, Cooley and Dennis. The test data provided the necessary information to generate the model parameters for the MEPDG equation (Taylor and Timm, 2009):

$$M_r = 716.28 * p_a * \left(\frac{\theta}{p_a}\right)^{0.8468} * \left[\left(\frac{\tau_{oct}}{p_a}\right) + 1\right]^{-0.4632} \quad (3\text{-}4)$$

where:

M_r = resilient modulus, psi

p_a = atmospheric pressure = 14.7 psi

θ = bulk stress = $\sigma_1+\sigma_2+\sigma_3$

τ_{oct} = octahedral shear stress $= \frac{1}{3}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}$

σ_1, σ_2, σ_3 = principal stresses, psi

The R^2 for this equation was 0.93 with all parameters statistically significant (p-values < 0.0001).

Dynamic vertical stress measurements were made in Section S11 at the top of the aggregate base layer over the course of the 2006 experiment. Figure 3.6 summarizes the measurements, by axle type, in which the seasonal trends are evident. Also shown in Figure 3.6 is the weighted average vertical stress. The weighted average was computed by considering the relative frequency of each axle type (steer = 1/8, tandem = 2/8, single = 5/8) on the triple-trailer vehicles used at the Test Track. These measurements were combined with geostatic stresses to determine in situ average of measured stress states from which an MEPDG design value could be determined according to equation 3-4. The average measured bulk stress was 19.9 psi with an average octahedral shear stress of 3.5 psi. These two stresses resulted in a computed in situ modulus of 12,304 psi which was approximately half of the assumed ALDOT value. This discrepancy highlights the need for laboratory testing of base materials and careful consideration of the in situ stress state when executing design.

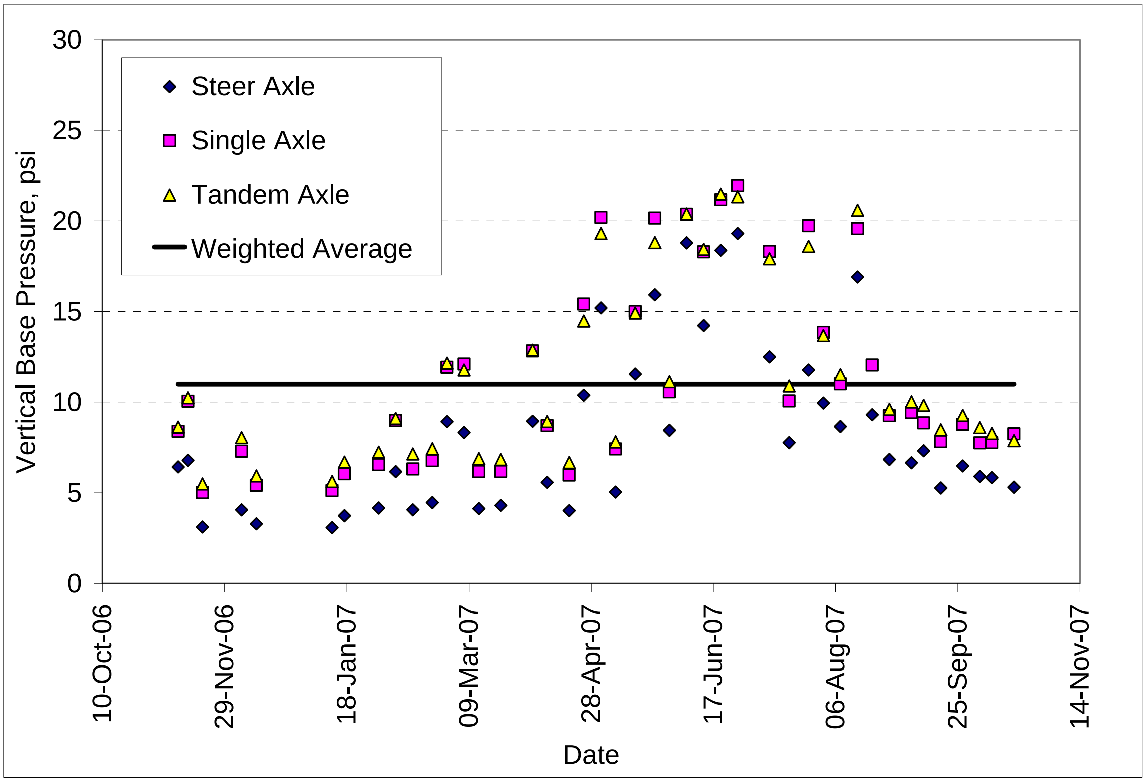

FIGURE 3.6 Vertical Stress Measurements in Section S11 of 2006 Test Track.

The other set of properties needed for both base and subgrades includes gradation and Atterberg limits (plasticity index and liquid limit). These are both routinely tested by ALDOT and can be directly input to the MEPDG.

TABLE 3.5 Base and Subgrade Material Tests

Test	Name	MEPDG Input	Current ALDOT Practice?
ASTM C 469	Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression	Chemically stabilized materials - lean concrete or cement-treated aggregate (level 1)	No-but could be tested by PCC Group
AASHTO T 307	Standard Method of Test for Determining Resilient Modulus of Soils and Aggregate Materials	Chemically stabilized materials - lime stabilized soils (level 1)	Yes
AASHTO T 22	Standard Method of Test for Compressive Strength of Cylindrical Concrete Specimens	Chemically stabilized materials - lean concrete or cement-treated aggregate correlation equation (level 2)	No - but could be tested by PCC group
ASTM D 1633	Standard Test Method for Compressive Strength of Molded Soil-Cement Cylinders	Chemically stabilized materials - soil cement correlation equation (level 2)	No - but could be tested by PCC group
ASTM C 593	Standard Specification for Fly Ash and Other Pozzolans for Use with Lime for Soil Stabilization	Chemically stabilized materials - lime-cement-flyash correlation equation (level 2)	No
ASTM D 5102	Standard Test Method for Unconfined Compressive Strength of Compacted Soil-Lime Mixtures	Chemically stabilized materials - lime stabilized soils correlation equation (level 2)	Yes
AASHTO T 97	Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)	Chemically stabilized materials - lean concrete, cement-treated aggregate, or lime-cement flyash (level 1)	No
ASTM D 1635	Standard Method of Test of Flexural Strength of Soil-Cement Using Simple Beam with Third-Point Loading	Chemically stabilized materials - soil cement (level 1)	No
ASTM E 1952	Standard Test Method for Thermal Conductivity and Thermal Diffusivity by Modulated Temperature Differential Scanning Calorimetry	Chemically stabilized materials – thermal conductivity	No
ASTM D 2766	Standard Test Method for Specific Heat of Liquids and Solids	Chemically stabilized materials - heat capacity	No
AASHTO T 27	Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates	Unbound materials - gradation information, and correlation (levels 1 and 2)	Yes
AASHTO T 89	Standard Method of Test for Determining the Liquid Limit of Soils	Unbound materials - liquid limit (LL)	Yes
AASHTO T 90	Standard Method of Test for Determining the Plastic Limit and Plasticity Index of Soils	Unbound materials - plastic limit (PL) and plasticity index (PI), and correlation (levels 1 and 2)	Yes
AASHTO T 99	Standard Method of Test for Moisture-Density Relations of Soils Using a 2.5 kg (5.5 lb) Rammer and a 305 mm (12 inch Drop)	Unbound materials - maximum dry unit weight, optimum moisture content, degree of saturation at optimum and soil-water curve parameters	Yes
AASHTO T 100	Standard Method of Test for Specific Gravity of Soils	Unbound materials - specific gravity (G)	Yes
AASHTO T 215	Standard Method of Test for Permeability of Granular Soils (Constant Head)	Unbound materials - saturated hydraulic conductivity	Capable, but rarely run
AASHTO T 193	Standard Method of Test for the California Bearing Ratio	Unbound materials - CBR correlation (level 2)	Modified procedure, not often run
AASHTO T 190	Standard Method of Test for Resistance R-Value and Expansion Pressure of Compacted Soils	Unbound materials - R-value correlation (level 2)	No
ASTM D 6951	Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications	Unbound materials - DCP correlation (level 2)	No

WEB-BASED TRAINING/REFERENCE RESOURCE

When implementing a new and unfamiliar technology it is important to consider that training will be needed. Beyond training, there is a need for a reference guide that designers can rely upon for more detailed information on a daily basis. Because the MEPDG is so large in scope and somewhat dynamic (it is expected that updated versions will be released both in the near and distant future), there is a need to develop a training tool that can handle these two challenges. To meet this need, an ALDOT-specific web-based tool was developed to serve as a training and reference resource.

The home page for the training and resource guide is pictured in Figure 3.7. The resource was designed to follow the architecture of the MEPDG software and contains screen captures of each input window within the MEPDG. As shown by example in Figure 3.8, within a given input window pop-up information was created to provide a brief definition, the recommended ALDOT procedure (if any) and any tips/warnings for the designer.

The advantages of using a web-based platform for the training/reference resource rather than a conventional paper document include:

1. The resource is easily updated. When new testing procedures, recommended values and/or recommended practices are implemented, the resource can be modified to reflect these changes. Also, if/when changes are made to the program itself, the web-page can be updated to reflect these changes.
2. The resource provides needs-based, just-in-time information in a format that mirrors the MEPDG software. This feature makes the retrieval of information easier since it

only requires the designer to navigate to the web page that matches the input screen for which they need more information.

3. A web-based resource can be linked to online databases. As ALDOT works toward developing libraries of material properties, these can be linked to the web-page so a designer can easily obtain the necessary data for a particular input. This feature has only currently been incorporated in the resource by linking the traffic page to the ALDOT Traffic Website which contains vehicle count data in a user-friendly GIS interface (Figure 3.9).
4. The resource can be used as a training tool in a conventional classroom or through webinars.

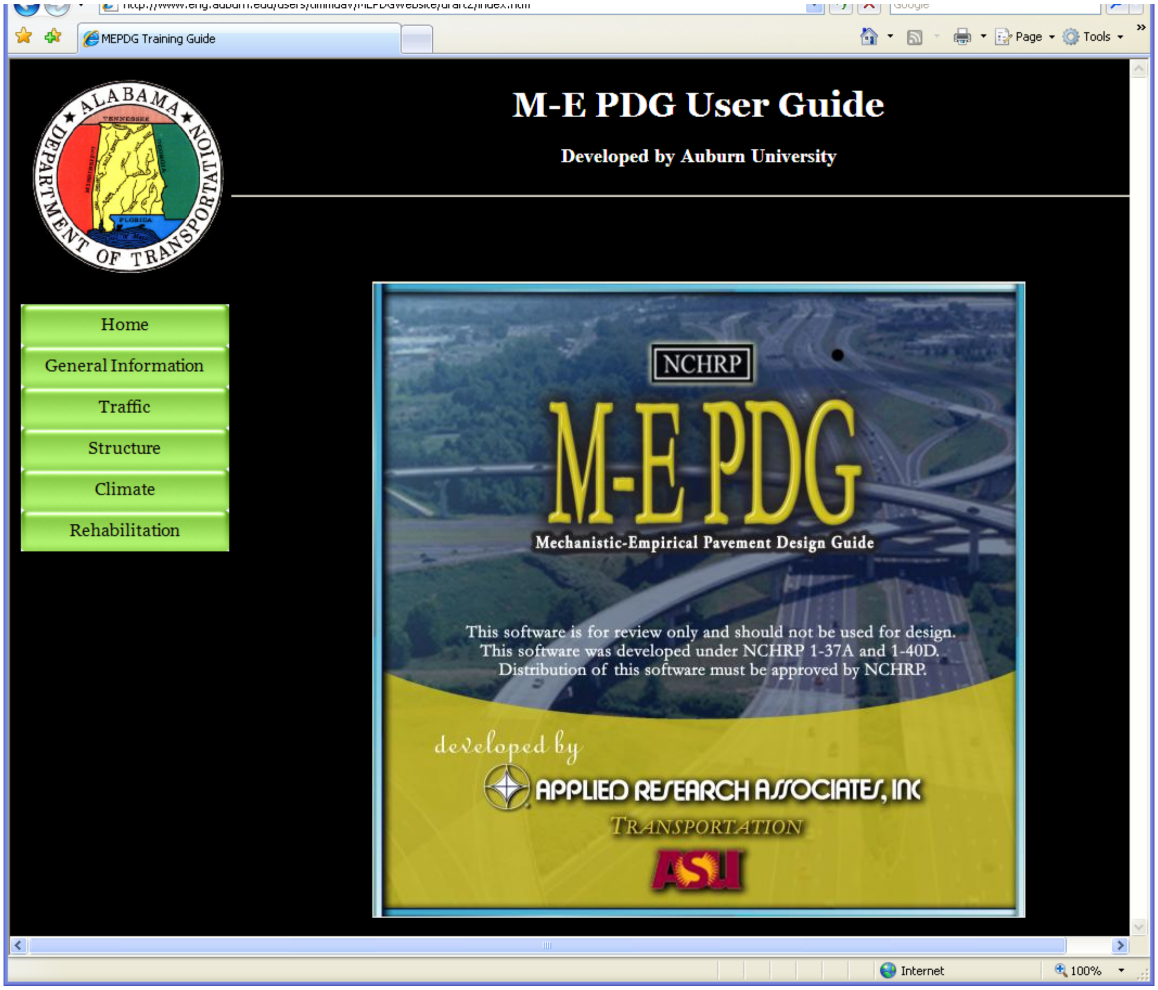

Figure 3.7 ALDOT MEPDG Training/Resource Guide.

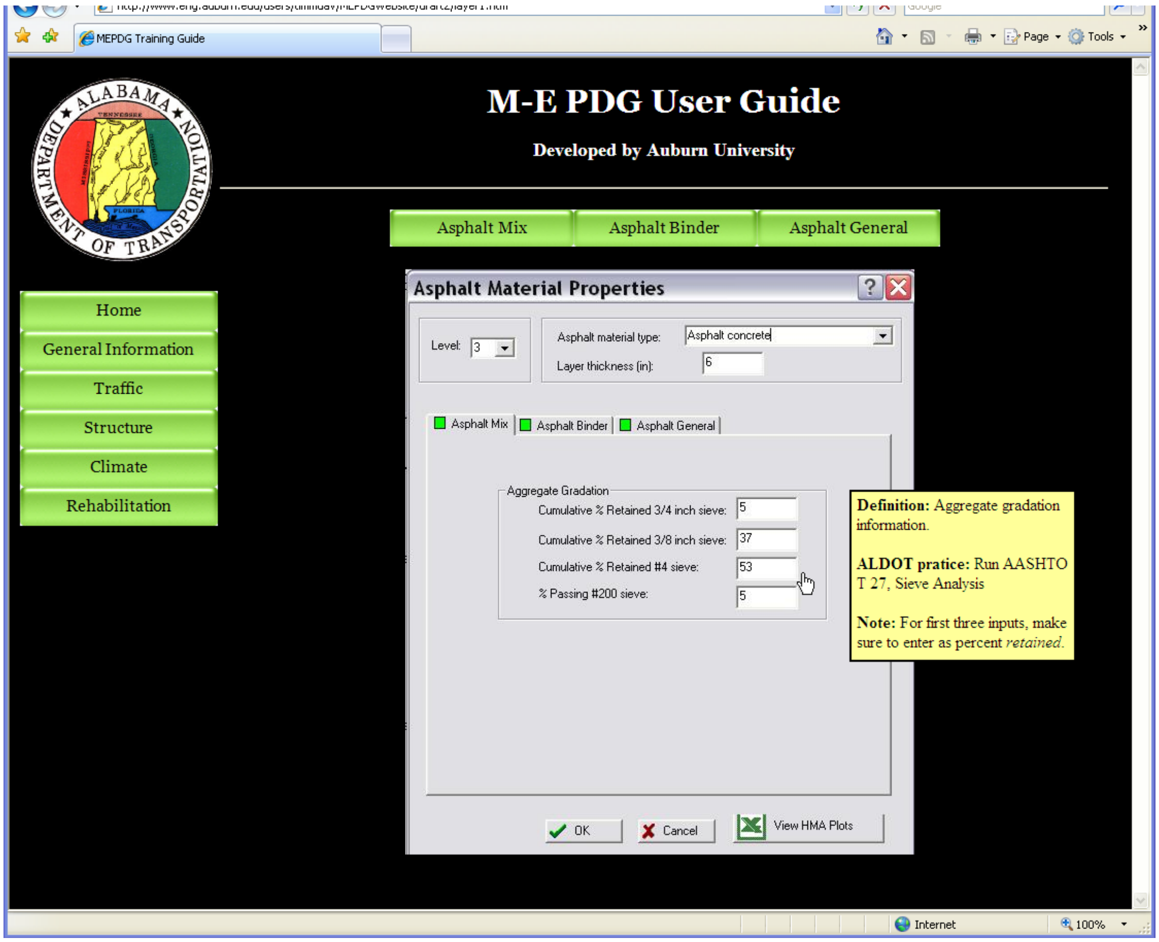

Figure 3.8 Example Pop-Up Information in Training/Resource Guide.

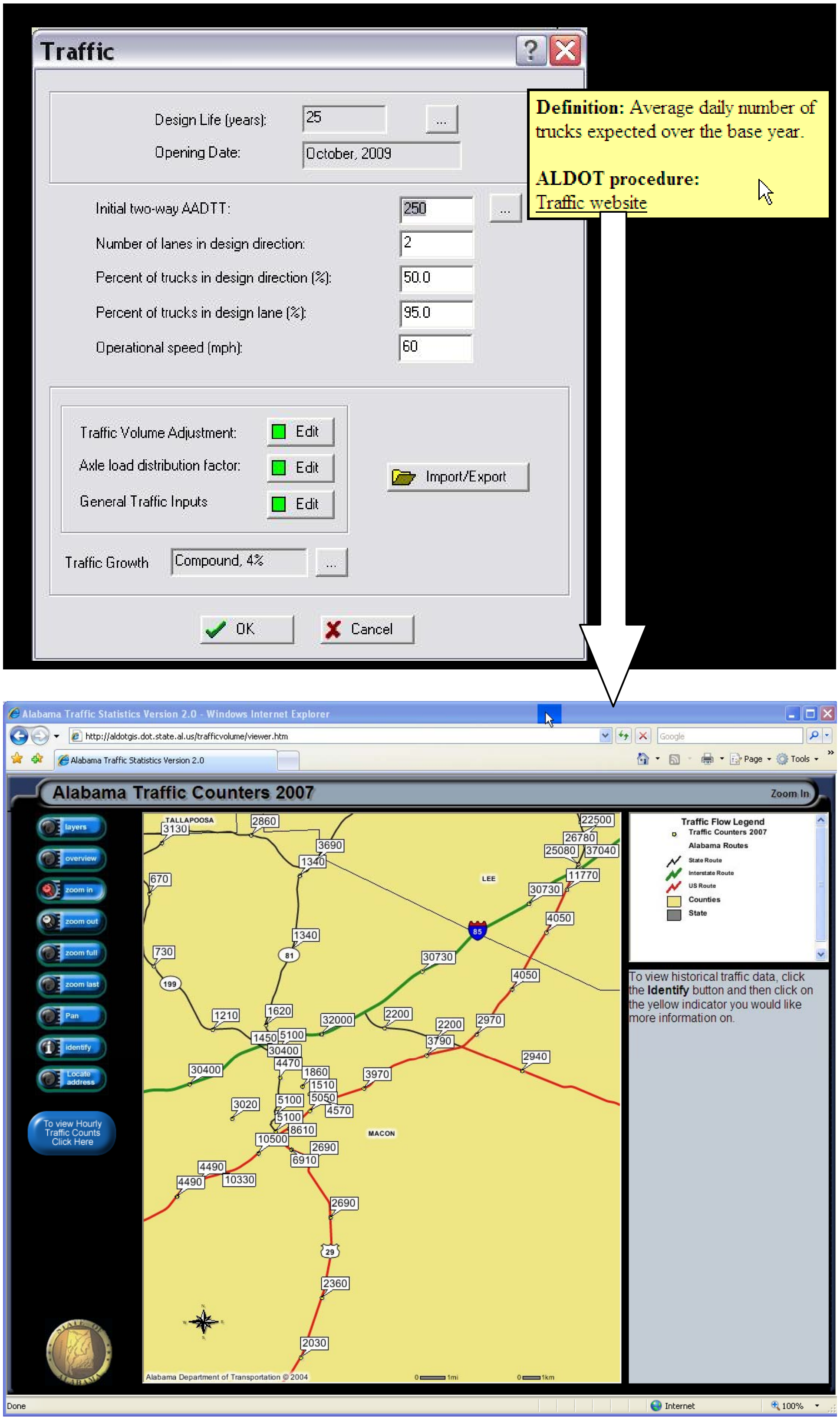

Figure 3.9 Example of Linking Training/Resource Guide to External Data Sources.

CHAPTER 4 – IMPLEMENTATION PLANS

INTRODUCTION

Based on information presented in the previous two chapters, there are five major areas that ALDOT should consider towards the implementation of the MEPDG. These areas include the following and are discussed in the subsequent sections:

1. Training in the MEPDG
2. Executing parallel designs using the existing and new methodologies
3. Development of a material reference library for MEPDG
4. Development of monthly, vehicle class, and axle load distributions
5. Local calibration

MEPDG TRAINING

Training will be essential to successful implementation of the MEPDG. Consideration should be given to familiarizing ALDOT engineers and consultants not only with the MEPDG, but in general with mechanistic-empirical concepts. A two-day short course should be developed that could be offered either in-person or via webinar. The intended audience would be division and central-office engineers in addition to consultants currently responsible for pavement design. The course would contain modules consistent with the MEPDG architecture (i.e., general design properties, traffic, climate, materials, interpreting performance predictions). The web-based resource described in Chapter 3 would serve as a primary training tool. However, ancillary materials, including example problems, would need to be developed. Special focus should be placed on linking current ALDOT practice with MEPDG requirements.

EXECUTING PARALLEL DESIGNS

To gain greater familiarity and confidence in the MEPDG, after training, a number of parallel designs should be executed using the current ALDOT procedure and the MEPDG. It would be useful to select at least one recent pavement design that has been constructed within each division in addition to one currently under development. The recently constructed design would enable the designer to consider as-built properties while the new (not yet built) design would more closely represent how designs will be done in the future. Comparisons should be made between thicknesses developed using the current method and those generated with the MEPDG. The data from each division should be combined to provide a statewide data set on which to base an initial, practical, assessment of the MEPDG.

MATERIAL REFERENCE LIBRARY

Chapter 3 highlighted that material properties beyond those required by the current design system will be required by the MEPDG. There is a need to develop a materials reference library for commonly used HMA, PCC and unbound materials. Though the Hirsch model was recommended for HMA, further validation using more non-Test Track mixtures should be conducted. Though there is a wealth of subgrade soil data available within ALDOT, the data sets need to be organized into a database to develop sets of recommended values for design. Finally, with respect to aggregate bases, a study should be conducted to characterize common base types with respect to resilient modulus.

TRAFFIC DISTRIBUTIONS

As noted in Chapter 3, the traffic inputs most worthy of additional study to develop input data specifically for Alabama are monthly adjustment factors, vehicle class distributions, and axle load distributions. Currently, ALDOT develops monthly adjustment factors from its approximately 120 permanent count stations; however, these factors are for all heavy vehicles combined. With additional data processing resources, these factors could be developed for each individual vehicle class (classes 4–13). Developing these factors at additional locations would likely require additional data collection infrastructure. Vehicle class distributions are currently generated for the permanent count stations, and could be derived from data collected on three-year cycles at the approximately 2,100 HPMS sites with additional data processing effort.

Development of axle load distributions for comparison with and substitution for the default values would require a more intensive effort. Currently, these data are not being generated in a form useful for inputs to the MEPDG. A study conducted using data from 13 weigh-in-motion sites collected in 2001 found that at most of these sites, use of a statewide axle load distribution, or spectrum, resulted in flexible pavement thickness differences of less than ½ inch (Turochy et al., 2005). However, the number of sites studied was relatively small, limited to one highway functional classification, and only asphalt pavements were considered. Further study is recommended to overcome these limitations, make use of more recent data and any expansions in relevant data collection infrastructure that have occurred in recent years. The purpose of such a study could include comparisons of the default axle load distributions contained in the MEPDG, newly-generated statewide distributions, and site-specific data, as well as their effects on resultant pavement designs, both flexible and rigid. The differences among sites, functional classifications, statewide, and nationwide distributions could be quantified and related recommendations for use in pavement design made accordingly.

LOCAL CALIBRATION

Local calibration has not yet been discussed within this report, but it is a critical component to the successful implementation of the MEPDG. The MEPDG must be locally calibrated to optimize pavement designs in the future. For flexible pavements, calibration should start at the NCAT Test Track. Rigid pavements will require examining open-access highway pavements.

For flexible pavements, the 2003 and 2006 Test Track research cycles both included test sections intended to provide calibration points for M-E design. Provisional fatigue cracking transfer functions were developed in the 2003 research cycle based on the eight structural test sections (Priest and Timm, 2006). Further MEPDG fatigue and rutting validation has just begun on the 2006 test sections. Figure 4-1 illustrates predicted and measured rut depths from Section S11 at the Test Track. This figure shows that the MEPDG captures the seasonal trends (i.e., rutting rate increases in warmer months) and is accurate to within 2 to 4 mm. Figure 4.2, however, shows the inability of the MEPDG to capture the fatigue cracking trend, but makes a reasonable prediction of that the section would fail in fatigue cracking. Forensic investigations are currently ongoing to pinpoint failure within the structure and conduct further validation/calibration. However, calibration will also need to be conducted outside of the Test Track. Guidelines for conducting local calibration have been published by NCHRP 9-30 and 9-30A.

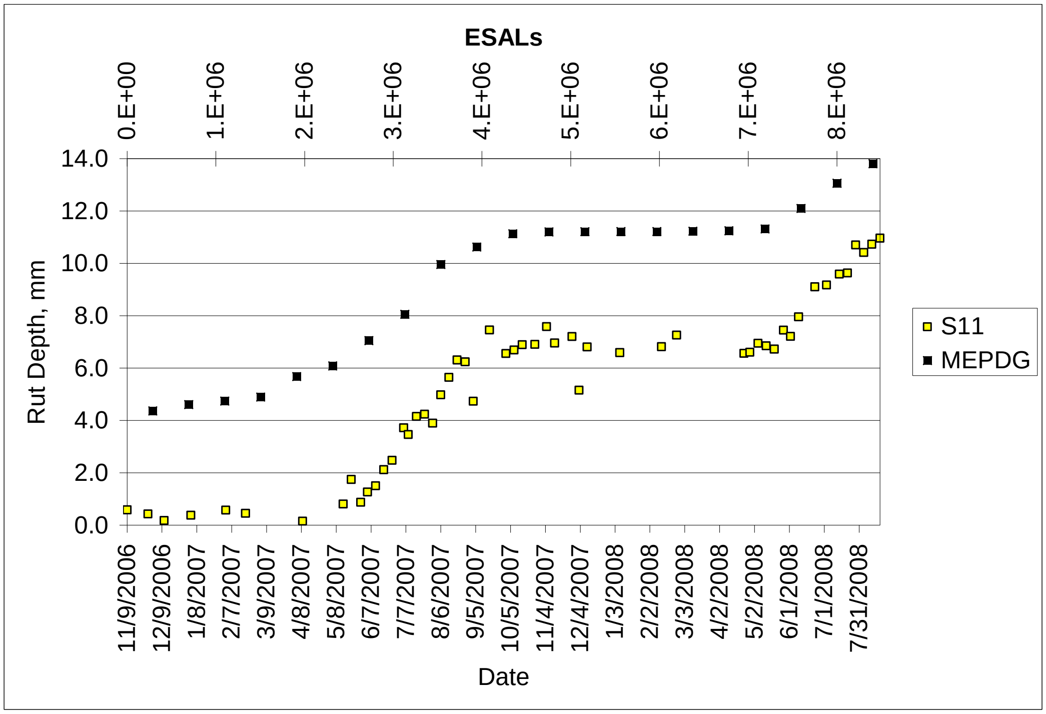

FIGURE 4.1 Measured and MEPDG Rut Depths on Section S11.

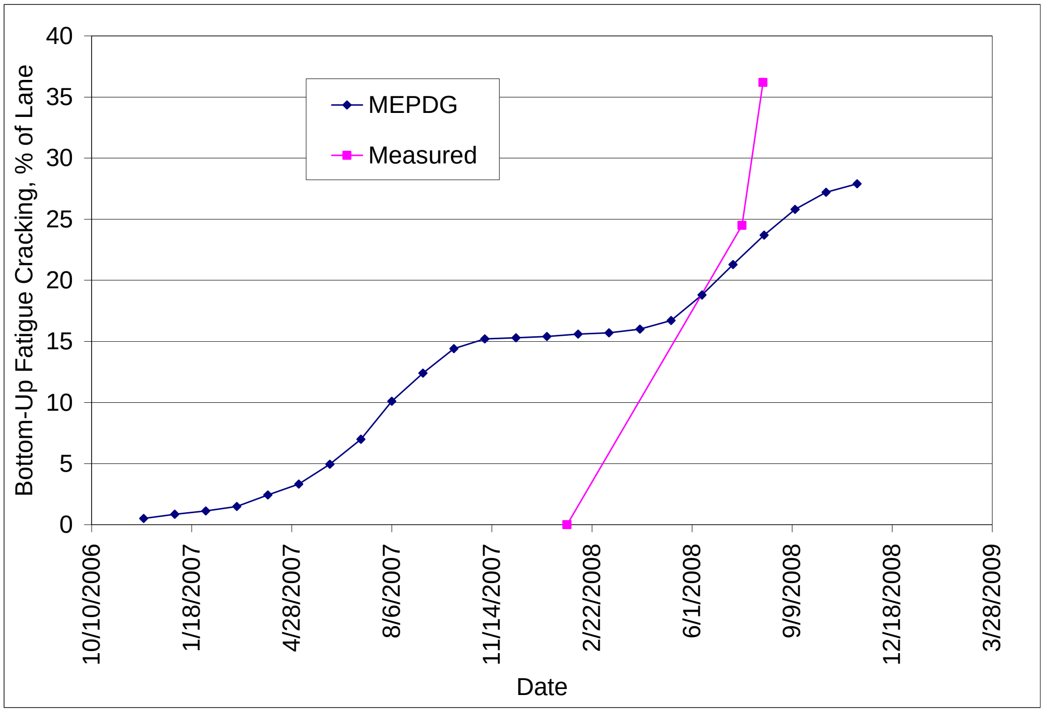

FIGURE 4.2 Measured and MEPDG Fatigue Cracking on Section S11.

SUMMARY

Though each of the above five areas can be considered distinct research projects, their successful completion and integration within the MEPDG is needed for full implementation of this design method. Execution of these projects should reflect subsequent changes in future versions of the program. Despite the level of complexity and wide range of inputs required by the MEPDG, current ALDOT practice does provide sufficient information to begin executing parallel designs and comparing resulting pavement thicknesses. Developing the materials, local calibration and traffic data sets described above should enable ALDOT to improve the highway infrastructure through more efficient use of resources in pavement design and construction.

REFERENCES

AASHTO Guide for Design of Pavement Structures. Washington D.C.: American Association of State and Highway Transportation Officials, 1993.

Alabama Department of Transportation, "Procedure for Conducting Soil Surveys and Preparing Materials Reports," ALDOT Procedure 390, 2004.

Alabama Department of Transportation, "Traffic Polling Data System," http://aldotgis.dot.state.al.us/traffic_counts/ , accessed June 26, 2006.

Eres Consultants Division. "Guide For Mechanistic-Empirical Pavement Design of New and Rehabilitated Pavement Structures," Final Report, NCHRP 1-37A, 2004.

Highway Research Board, "The AASHO Road Test", Report 5, Pavement Research Special Report 61E, National Academy of Sciences – National Research Council, Washington, DC, 1962.

Holman F., "Drainage of Water from Pavement Structures", Alabama Department of Transportation. Research Project No. 930-275. 1996.

Holman, F., "Guidelines for Flexible Pavement Design in Alabama", Alabama Department of Transportation, 1990 (a).

Holman F., "Guidelines for Rigid Pavement Design in Alabama," , Alabama Department of Transportation, 1990 (b).

Priest, A.L. and D.H. Timm, "Methodology and Calibration of Fatigue Transfer Functions for Mechanistic-Empirical Flexible Pavement Design," Report No. 06-03, National Center for Asphalt Technology, Auburn University, 2006.

Taylor, A.J. and D.H. Timm, "Mechanistic Characterization of Resilient Moduli for Unbound Pavemetn Layer Materials," NCAT Draft Report, 2009.

Timm, David H., Julia M. Bower, and Rod E. Turochy. "Effect of Load Spectra on Mechanistic-Empirical Flexible Pavement Design," Journal of the Transportation Research Board: Transportation Research Record 1947, pp. 146-154, Transportation Research Board, Washington, D.C., 2006.

Turochy, R.E., D.H. Timm and S.M. Tisdale, "Truck Equivalency Factors, Load Spectra Modeling and Effects on Pavement Design," Report No. 930-564, Auburn University Highway Research Center, 2005.

APPENDIX A – GENERAL INPUTS

Window Title	Main Heading	Sub Heading	Tab	Check Box/ Pull Down Menu/ Choose From	Fill in the Blank (Values or Text)	Has Default Value?	Level	ASTM Test Procedure	AASHTO Test Procedure	Description
General Information					Project Name	NA	NA	NA	NA	Name of project
General Information					Design Life (years)	NA	NA	NA	NA	Expected service life of the pavement in years
General Information					Base/Subbase Construction Month & Year	NA	NA	NA	NA	Month and year when the subgrade is prepared for pavement construction
General Information					Pavement Construction Month & Year	NA	NA	NA	NA	Month and year when surface layer is placed
General Information					Traffic Open Month & Year	NA	NA	NA	NA	Month and year when traffic is expected to move on pavement
General Information					Existing Pavement Construction Month & Year	NA	NA	NA	NA	Input is only for restoration and rehabilitation. Month and year existing pavement was built
General Information					Pavement Restoration Month & Year	NA	NA	NA	NA	Input is only for restoration. Month and year existing pavement will be restored
General Information					Pavement Overlay Construction Month & Year	NA	NA	NA	NA	Input is only for rehabilitation. Month and year overlay will be placed
General Information	Type of Design	New Pavement		Flexible Pavement		NA	NA	NA	NA	Pavement with asphalt concrete surface
General Information	Type of Design	New Pavement		Jointed Plain Concrete Pavement		NA	NA	NA	NA	Pavement with portland cement concrete surface and transverse joints between slabs
General Information	Type of Design	New Pavement		Continuously Reinforced Concrete Pavement		NA	NA	NA	NA	Pavement with portland cement concrete surface and contains longitudinal reinforcement and cracks for construction purposes only
General Information	Type of Design	Restoration		Jointed Plain Concrete Pavement		NA	NA	NA	NA	Restoration of JPCP pavement
General Information	Type of Design	Overlay		Asphalt Concrete Overlay		NA	NA	NA	NA	Overlay of pavement with asphalt concrete
General Information	Type of Design	Overlay		PCC Overlay		NA	NA	NA	NA	Overlay of pavement with portland cement concrete

Window Title	Main Heading	Sub Heading	Tab	Check Box/ Pull Down Menu/ Choose From	Fill in the Blank (Values or Text)	Has Default Value?	Level	ASTM Test Procedure	AASHTO Test Procedure	Description
General Information					Description	NA	NA	NA	NA	Project description
Site/Project Identification					Location	NA	NA	NA	NA	Project location
Site/Project Identification					Project ID	NA	NA	NA	NA	Project identification
Site/Project Identification					Section ID	NA	NA	NA	NA	Roadway section identification
Site/Project Identification					Date	NA	NA	NA	NA	Current date
Site/Project Identification					Station/milepost format	NA	NA	NA	NA	Format for reporting stations and mileposts of project
Site/Project Identification					Station/milepost begin	NA	NA	NA	NA	Beginning station/milepost of project
Site/Project Identification					Station/milepost end	NA	NA	NA	NA	End station/milepost of project
Site/Project Identification					Traffic direction	NA	NA	NA	NA	Direction of traffic lanes being used for design
Analysis Parameters					Project Name	NA	NA	NA	NA	Name of project
Analysis Parameters					Initial IRI (in/mile)	YES	NA	NA	NA	Expected level of pavement smoothness immediately after construction, expressed in terms of International Roughness Index (IRI)
Analysis Parameters	Performance Criteria		Rigid Pavement (see concrete)			NA	NA	NA	NA	NA
Analysis Parameters	Performance Criteria		Flexible Pavement	Terminal IRI (in/mile)	Limit	YES	NA	NA	NA	Limit set that will be criteria for pavement "failure" for roadway smoothness (in/mile)

Window Title	Main Heading	Sub Heading	Tab	Check Box/ Pull Down Menu/ Choose From	Fill in the Blank (Values or Text)	Has Default Value?	Level	ASTM Test Procedure	AASHTO Test Procedure	Description
Analysis Parameters	Performance Criteria		Flexible Pavement	Terminal IRI (in/mile)	Reliability	YES	NA	NA	NA	Probability that smoothness will be less than the selected critical limit over the design life
Analysis Parameters	Performance Criteria		Flexible Pavement	AC Surface Down Long. Cracking (ft/mi)	Limit	YES	NA	NA	NA	Limit set that will be criteria for pavement "failure" for cracking that starts from the pavement surface and goes down (ft/mile)
Analysis Parameters	Performance Criteria		Flexible Pavement	AC Surface Down Long. Cracking (ft/mi)	Reliability	YES	NA	NA	NA	Probability that top-down cracking will be less than the selected critical limit over the design life
Analysis Parameters	Performance Criteria		Flexible Pavement	AC Bottom Up Alligator Cracking (%)	Limit	YES	NA	NA	NA	Limit set that will be criteria for pavement "failure" for bottom-up fatigue cracking (%)
Analysis Parameters	Performance Criteria		Flexible Pavement	AC Bottom Up Alligator Cracking (%)	Reliability	YES	NA	NA	NA	Probability that bottom-up cracking will be less than the selected critical limit over the design life
Analysis Parameters	Performance Criteria		Flexible Pavement	AC Thermal Fracture (ft/mile)	Limit	YES	NA	NA	NA	Limit set that will be criteria for pavement "failure" for thermal fracture (ft/mile)
Analysis Parameters	Performance Criteria		Flexible Pavement	AC Thermal Fracture (ft/mile)	Reliability	YES	NA	NA	NA	Probability that thermal fracture will be less than the selected critical limit over the design life

APPENDIX B – TRAFFIC INPUTS

Window Title	Main Heading	Sub Heading	Tab	Check Box/ Pull Down Menu/ Choose From	Fill in the Blank (Values or Text)	Has Default Value?	Level	ASTM Test Procedure	AASHTO Test Procedure	Description
Traffic					Initial two-way AADTT	NO	NA	NA	NA	Average daily number of trucks (FHWA vehicle classes 4-13) expected over the base year
Traffic					Two way AADT	NO	NA	NA	NA	Average daily traffic (all classes) expected over the base year
Traffic					Percent of Heavy Vehicles	NO	NA	NA	NA	Percentage of traffic that is FHWA class 4-13 vehicles
Traffic					Number of lanes in design direction	YES	NA	NA	NA	Number of lanes that are going to carry truck traffic in the design direction
Traffic					Percent of trucks in design direction	YES	NA	NA	NA	Percentage of trucks (from the entire two -way truck count) that is expected to travel in the design direction
Traffic					Percent of trucks in design lane	YES	NA	NA	NA	Fraction of trucks from the total trucks in one direction (expressed as a percentage) expected to use the design lane in the design direction
Traffic					Operational speed (mph)	YES	NA	NA	NA	Expected speed of the traffic expected to be traveling in the design direction
Traffic Volume Adjustment Factors	Monthly Adjustment Factors		Monthly Adjustment		Monthly adjustment factors for each vehicle class (4-13)	YES	1	NA	NA	Proportion of the AADTT for a specific truck class that will occur on an average 24-hour day within a given month of the year. It is a ratio used to adjust the annual daily truck traffic into monthly truck traffic
Traffic Volume Adjustment Factors	Monthly Adjustment Factors		Monthly Adjustment		Monthly adjustment factors for each vehicle class (4-13)	YES	3	NA	NA	Proportion of the AADTT for a specific truck class that will occur on an average 24-hour day within a given month of the year. It is a ratio used to adjust the annual daily truck traffic into monthly truck traffic
Traffic Volume Adjustment Factors	AADTT distribution by vehicle class		Vehicle Class Distribution		Class 4-13 (%)	YES	1	NA	NA	Distribution of truck classes in the design traffic
Traffic Volume Adjustment Factors	AADTT distribution by vehicle class		Vehicle Class Distribution		Class 4-13 (%)	YES	3	NA	NA	Distribution of truck classes in the design traffic
Traffic Volume Adjustment Factors	Hourly truck traffic dist. by period		Hourly Distribution		% distribution for each hour in a 24 hour period	YES	NA	NA	NA	Fraction (in percentage) of truck traffic traveling in a given hour relative to the 24-hour period
Traffic Volume Adjustment Factors	Default Growth Function		Traffic Growth Factors	No Growth		NA	NA	NA	NA	Traffic volume remains constant throughout the design life
Traffic Volume Adjustment Factors	Default Growth Function		Traffic Growth Factors	Linear Growth	Default Growth Rate (%)	YES	NA	NA	NA	Traffic volume increases by constant percentage of the base year traffic across each truck class
Traffic Volume Adjustment Factors	Default Growth Function		Traffic Growth Factors	Compound Growth	Default Growth Rate (%)	YES	NA	NA	NA	Traffic volume increases by constant percentage of the preceding year traffic across each truck class

Window Title	Main Heading	Sub Heading	Tab	Check Box/ Pull Down Menu/ Choose From	Fill in the Blank (Values or Text)	Has Default Value?	Level	ASTM Test Procedure	AASHTO Test Procedure	Description
Traffic Volume Adjustment Factors			Traffic Growth Factors	Vehicle class-specific traffic growth	Class 4-13 % growth and function (linear, no growth, etc.)	YES	NA	NA	NA	Traffic volume increases by each truck class by user-specified percentages
Axle Load Distribution Factors	View			Cumulative Distribution or Distribution		NA	NA	NA	NA	Select to view axle load factors either as the actual distribution for each load level or as a cumulative distribution for each load level
Axle Load Distribution Factors	Axle Types			Single, Tandem, Tridem, Quad		NA	NA	NA	NA	Select axle type to view
Axle Load Distribution Factors	Axle Factors by Axle Type				Daily distribution of axles in each load category	YES	1	NA	NA	Percentage of axles in each load interval by single, tandem, tridem or quad axle type for a specific truck class
Axle Load Distribution Factors	Axle Factors by Axle Type				Daily distribution of axles in each load category	YES	3	NA	NA	Percentage of axles in each load interval by single, tandem, tridem or quad axle type for a specific truck class
General Traffic Inputs	Lateral Traffic Wander				Mean wheel location	YES	NA	NA	NA	Distance from the outer edge of the wheel to the pavement marking
General Traffic Inputs	Lateral Traffic Wander				Traffic wander standard deviation	YES	NA	NA	NA	Standard deviation of the lateral traffic wander is used to estimate the number of axle load repetitions over a single point in a probabilistic manner for predicting distress and performance
General Traffic Inputs	Lateral Traffic Wander				Design lane width	YES	NA	NA	NA	Actual width of the lane as defined by the distance between the lane markings on either side of the design lane
General Traffic Inputs			Number Axles/Truck		Class 4-13 average number of single - quad axles per truck	YES	NA	NA	NA	Number of axles for each truck class (classes 4-13) for each axle type (single, tandem, tridem, and quad)
General Traffic Inputs			Axle Configuration		Average axle width	YES	NA	NA	NA	Distance between two outside edges of an axle
General Traffic Inputs			Axle Configuration		Dual tire spacing	YES	NA	NA	NA	Center-to-center transverse spacing between dual tires on an axle
General Traffic Inputs			Axle Configuration		Tire pressure (psi)	YES	NA	NA	NA	Hot inflation pressure of the tire. It is assumed that the hot inflation pressure equals the contact pressure and is 10% above cold inflation pressure
General Traffic Inputs	Axle Spacing		Axle Configuration		Tandem, Tridem & Quad Axle Spacing (in)	YES	NA	NA	NA	Center-to-center longitudinal spacing between the axles
General Traffic Inputs	Wheelbase							NA	NA	For JPCP top-down cracking. See concrete spreadsheet.

APPENDIX C – CLIMATE

Window Title	Main Heading	Sub Heading	Tab	Check Box/ Pull Down Menu/ Choose From	Fill in the Blank (Values or Text)	Has Default Value?	Level	ASTM Test Procedure	AASHTO Test Procedure	Description
Environment/ Climatic				Import	Import climate file obtained from MEPDG website	NA	NA	NA	NA	Import a previuosly generated climate file
Environment/ Climatic	Select weather station			Generate - Climatic data for a specific weather station	Choose appropriate weather station	NA	NA	NA	NA	Generate a climate file by selecting a nearby weather station
Environment/ Climatic				Generate - Climatic data for a specific weather station -	Input annual average or seasonal depth of water table	NA	NA	NA	NA	Depth of the ground water table from the top surface of the subgrade
Environment/ Climatic				Generate - Interpolate climatic data for given location	Choose nearby weather stations to interpolate between	NA	NA	NA	NA	Create a virtual weather station by interpolating weather data from the six closest weather stations

APPENDIX D – ASPHALT MATERIALS

Window Title	Main Heading	Sub Heading	Tab	Check Box/ Pull Down Menu/ Choose From	Fill in the Blank (Values or Text)	Has Default Value?	Level	ASTM Test Procedure	AASHTO Test Procedure	Description
Structure					Surface short-wave absorbtivity	YES	NA	NA	NA	Measure of the amount of available solar energy that is absorbed by the pavement surface
Structure	Layers			Insert, Edit, or Delete Layers		NA	NA	NA	NA	Allows user to insert, edit or delete pavement layers (material type, thicknesses)
Asphalt Material Properties					Asphalt material type	YES	1	NA	NA	Choose asphalt type (asphalt concrete only choice)
Asphalt Material Properties					Layer thickness	NA	1	NA	NA	Thickness of asphalt layer (in)
Asphalt Material Properties	Dynamic Modulus Table		Asphalt Mix		Number of Temperatures	NA	1	NA	NA	Defines the number of temperatures at which the E* test was run for a given mixture at a given frequency
Asphalt Material Properties	Dynamic Modulus Table		Asphalt Mix		Number of Frequencies	NA	1	NA	NA	Defines the number of frequencies at which the E* test was run for a given mixture at a given temperature
Asphalt Material Properties	Dynamic Modulus Table		Asphalt Mix		E* values for different loading rates & temperatures	NO	1	D 3497	TP 62	Dynamic modulus (E*) values for each corresponding loading rate and temperature
Asphalt Material Properties	Aggregate Gradation		Asphalt Mix		Various gradation information	NO	2	NA	T 27	Percent retained on 3/4", 3/8" and #4 sieves, and percent passing #200 sieve
Asphalt Material Properties	Aggregate Gradation		Asphalt Mix		Various gradation information	NO	3	NA	T 27	Percent retained on 3/4", 3/8" and #4 sieves, and percent passing #200 sieve
Asphalt Material Properties	Options - At Short Term Aging - RTFO		Asphalt Binder	Superpave binder test data	Number of Temperatures	NA	1	NA	NA	Defines the number of temperatures at which the binder dynamic complex modulus, G*, and phase angle, δ, test results were compiled for a given binder
Asphalt Material Properties	Options - At Short Term Aging - RTFO		Asphalt Binder	Superpave binder test data	Dynamic complex modulus (G*) and phase angle values	NO	1	NA	T 315	Dynamic complex modulus (G*) and phase angle (δ) values for each corresponding temperature tested
Asphalt Material Properties	Options - At Short Term Aging - RTFO		Asphalt Binder	Conventional binder test data	Number of penetrations	NA	1	NA	NA	Defines the number of penetration values collected
Asphalt Material Properties	Options - At Short Term Aging - RTFO		Asphalt Binder	Conventional binder test data	Number of Brookfield viscosities	NA	1	NA	NA	Defines the number of Brookfield viscosities collected
Asphalt Material Properties	Options - At Short Term Aging - RTFO		Asphalt Binder	Conventional binder test data	Softening point temperature	YES	1	D 36	NA	Temperature at which an asphalt cement cannot support the weight of a steel ball of certain mass and starts flowing

Window Title	Main Heading	Sub Heading	Tab	Check Box/ Pull Down Menu/ Choose From	Fill in the Blank (Values or Text)	Has Default Value?	Level	ASTM Test Procedure	AASHTO Test Procedure	Description
Asphalt Material Properties	Options - At Short Term Aging - RTFO		Asphalt Binder	Conventional binder test data	Absolute viscosity (P)	YES	1	NA	T 202	Resistance to flow of a fluid (Poise)
Asphalt Material Properties	Options - At Short Term Aging - RTFO		Asphalt Binder	Conventional binder test data	Kinematic viscosity (CS)	YES	1	NA	T 201	Kinematic viscosity values (centistokes)
Asphalt Material Properties	Options - At Short Term Aging - RTFO		Asphalt Binder	Conventional binder test data	Specific gravity	YES	1	D 70	NA	Ratio of the mass of the material at a given temperature to the mass of an equal amount of water at the same temperature
Asphalt Material Properties	Options - At Short Term Aging - RTFO		Asphalt Binder	Conventional binder test data	Penetration test data	NO	1	D 5	T 53	Empirical test used to measure the consistency of asphalt cement
Asphalt Material Properties	Options - At Short Term Aging - RTFO		Asphalt Binder	Conventional binder test data	Brookfield viscosity data	NO	1	D 4402	T 316	Performed to determine the apparent viscosity of asphalt binder from 100 to 500 °F
Asphalt Material Properties	Options - At Short Term Aging - RTFO		Asphalt Binder	Superpave binder test data	Number of Temperatures	NA	2	NA	NA	Defines the number of temperatures at which the binder dynamic complex modulus, G*, and phase angle, δ, test results were compiled for a given binder
Asphalt Material Properties	Options - At Short Term Aging - RTFO		Asphalt Binder	Superpave binder test data	Dynamic complex modulus (G*) and phase angle values	NO	2	NA	TP 5	Dynamic complex modulus (G*) and phase angle (δ) values for each corresponding temperature tested
Asphalt Material Properties	Options - At Short Term Aging - RTFO		Asphalt Binder	Conventional binder test data	Number of penetrations	NA	2	NA	NA	Defines the number of penetration values collected
Asphalt Material Properties	Options - At Short Term Aging - RTFO		Asphalt Binder	Conventional binder test data	Number of Brookfield viscosities	NA	2	NA	NA	Defines the number of Brookfield viscosities collected
Asphalt Material Properties	Options - At Short Term Aging - RTFO		Asphalt Binder	Conventional binder test data	Softening point (P) temperature tested and value	YES	2	D 36	NA	Temperature at which an asphalt cement cannot support the weight of a steel ball of certain mass and starts flowing
Asphalt Material Properties	Options - At Short Term Aging - RTFO		Asphalt Binder	Conventional binder test data	Absolute viscosity (P) temperature tested and value	YES	2	NA	T 202	Resistance to flow of a fluid (Poise)
Asphalt Material Properties	Options - At Short Term Aging - RTFO		Asphalt Binder	Conventional binder test data	Kinematic viscosity (CS) temperature tested and value	YES	2	NA	T 201	Kinematic viscosity values (centistokes)
Asphalt Material Properties	Options - At Short Term Aging - RTFO		Asphalt Binder	Conventional binder test data	Specific gravity temperature tested and value	YES	2	D 70	NA	Ratio of the mass of the material at a given temperature to the mass of an equal amount of water at the same temperature

Window Title	Main Heading	Sub Heading	Tab	Check Box/ Pull Down Menu/ Choose From	Fill in the Blank (Values or Text)	Has Default Value?	Level	ASTM Test Procedure	AASHTO Test Procedure	Description
Asphalt Material Properties	Options - At Short Term Aging - RTFO		Asphalt Binder	Conventional binder test data	Penetration test data	NO	2	D 5	T 49	Empirical test used to measure the consistency of asphalt cement
Asphalt Material Properties	Options - At Short Term Aging - RTFO		Asphalt Binder	Conventional binder test data	Brookfield viscosity data	NO	2	D 4402	T 316	Performed to determine the apparent viscosity of asphalt binder from 100 to 500 °F
Asphalt Material Properties	Options		Asphalt Binder	Superpave binder grading	Select PG grade of asphalt	NA	3	NA	MP1	Performance grade of the asphalt binder
Asphalt Material Properties	Options		Asphalt Binder	Conventional viscosity grade	Select viscosity grade of asphalt	NA	3	D 3381	NA	Viscosity grade of the asphalt cement
Asphalt Material Properties	Options		Asphalt Binder	Conventional penetration grade	Select pen grade	NA	3	D 3381	NA	Penetration grade of the asphalt cement
Asphalt Material Properties	General		Asphalt General		Reference temperature	YES	NA	NA	NA	Temperature which is used as the "reference" in deriving the dynamic modulus
Asphalt Material Properties	Volumetric Properties as Built		Asphalt General		Effective binder content (%)	YES	NA	NA	T 308	Represents the total asphalt content of the paving mixture minus the portion of asphalt absorbed into the aggregate particles
Asphalt Material Properties	Volumetric Properties as Built		Asphalt General		Air voids (%)	YES	NA	NA	T 166	Total volume of the small pockets of air between the coated aggregate particles throughout compacted paving mixtures, expressed as percent of the bulk volume of the compacted paving mixture
Asphalt Material Properties	Volumetric Properties as Built		Asphalt General		Total unit weight (pcf)	YES	NA	NA	T 166	Mass per unit volume of the asphalt mixture
Asphalt Material Properties	Poisson's Ratio		Asphalt General		Poisson's ratio	YES	NA	NA	NA	Typically ranges between 0.15 and 0.50 and is a function of temperature
Asphalt Material Properties	Poisson's Ratio		Asphalt General	Use predictive model to calc. Poisson ratio	Parameters a & b	YES	NA	NA	NA	Used in equation to estimate Poisson's ratio
Asphalt Material Properties	Thermal Properties		Asphalt General		Thermal conductivity asphalt (BTU/hr-ft-°F)	YES	NA	E 1952	NA	Quantity of heat that flows normally across a surface of unit area per unit of time of temperature gradient normal to the surface
Asphalt Material Properties	Thermal Properties		Asphalt General		Heat capacity asphalt (BTU/lb-°F)	YES	NA	D 2766	NA	Amount of heat required to raise the temperature of a unit mass of material by a unit temperature

APPENDIX E – CONCRETE MATERIALS

Window Title	Main Heading	Sub Heading	Tab	Check Box/ Pull Down Menu/ Choose From	Fill in the Blank (Values or Text)	Has Default Value?	Level	ASTM Test Procedure	AASHTO Test Procedure	Description
Structure					Surface short-wave absorbtivity	YES	NA	NA	NA	Measure of the amount of available solar energy that is absorbed by the pavement surface
Structure	Layers			Insert, Edit, or Delete Layers		NA	NA	NA	NA	Allows user to insert, edit or delete pavement layers (material type, thicknesses)
JPCP Design Features	Joint Design				Joint spacing (ft)	YES	NA	NA	NA	Distance between two adjacent joints in the longitudinal direction and is equal to the length of the slab
JPCP Design Features	Joint Design	Sealant Type		None, Liquid, Silicone or Preformed		NA	NA	NA	NA	Input to the empirical model used to predict spalling
JPCP Design Features	Joint Design			Random Joint Spacing (ft)		NO	NA	NA	NA	If used, the MEPDG uses the average joint spacing for faulting analysis and the maximum joint spacing for cracking analysis when random joint spacing is entered
JPCP Design Features	Joint Design			Doweled Transverse Joints	Dowel diameter (in)	YES	NA	NA	NA	If dowels are used to achieve load transfer, the user needs to click the button corresponding to the doweled transverse joints and make further inputs on the size and spacing of the dowels. Diameter of the dowel bars used for load transfer across the transverse joint
JPCP Design Features	Joint Design			Doweled Transverse Joints	Dowel bar spacing (in)	YES	NA	NA	NA	Center-to-center distance between the dowels used for load transfer across the transverse joint
JPCP Design Features	Edge Support			Tied PCC Shoulder	Long-term LTE (%)	YES	NA	NA	NA	The user needs to click the button corresponding to this feature and specify the LTE, which is the ratio of deflections of the unloaded and loaded slabs. The higher the LTE, the greater the support provided by the shoulder to reduce critical responses of the mainline slabs
JPCP Design Features	Edge Support			Widened Slab	Slab width (ft)	YES	NA	NA	NA	JPCP slab can be widened to accommodate the outer wheel path further away from the longitudinal edge. If this option is chosen, user must specify slab width (note: not the same as lane width)
JPCP Design Features	Base Properties			Base Type (see Layer 2 inputs)		NA	NA	NA	NA	NA
JPCP Design Features	Base Properties	PCC-Base Interface		Choose Full Friction or Zero Friction Contact		NA	NA	NA	NA	This menu allows the user to specify the interface type and the quality of bond between the slab and the base. The interface between a stabilized base and PCC slab is modeled either completely bonded or unbonded for JPCP design.
JPCP Design Features	Base Properties			Erodibility Index (Choose from 5 levels)		NA	NA	NA	NA	Index on a scale of 1 to 5 to rate the potential for erodibility of the base material
JPCP Design Features	Base Properties				Loss of full friction (age in months)	YES	NA	NA	NA	Specify the pavement age at which debonding occurs. Up to the debonding age, the slab-base interface is assumed fully bonded; after the debonding age, the interface is assumed fully unbonded.
PCC Material Properties - Layer #	General Properties		Thermal	PCC Material		YES	NA	NA	NA	JPCP or CRCP - this was already selected in the General Information section

Window Title	Main Heading	Sub Heading	Tab	Check Box/ Pull Down Menu/ Choose From	Fill in the Blank (Values or Text)	Has Default Value?	Level	ASTM Test Procedure	AASHTO Test Procedure	Description
PCC Material Properties - Layer #	General Properties		Thermal		Layer thickness (in)	NA	NA	NA	NA	Thickness of PCC layer used for design
PCC Material Properties - Layer #	General Properties		Thermal		Unit weight (pcf)	YES	NA	NA	NA	Weight of the concrete mix design per unit volume
PCC Material Properties - Layer #	General Properties		Thermal		Poisson's ratio	YES	NA	C 469	NA	Ratio of the lateral strain to the longitudinal strain in an elastic material
PCC Material Properties - Layer #	Thermal Properties		Thermal		Coefficient of thermal expansion (per °F x 10^{-6})	YES	NA	NA	TP 60	Measure of the expansion or contraction a material undergoes with change in temperature. It is defined as the increase in length per unit length for a unit increase in temperature.
PCC Material Properties - Layer #	Thermal Properties		Thermal		Thermal conductivity (BTU/hr-ft-°F)	YES	NA	E 1952	NA	Measure of the ability of the material to uniformly conduct heat through its mass when two faces of the material are under a temperature differential. It is defined as the ratio of heat flux to temperature gradient.
PCC Material Properties - Layer #	Thermal Properties		Thermal		Heat capacity (BTU/lb-°F)	YES	NA	D 2766	NA	The amount of heat required to raise a unit mass of material by a unit temperature
PCC Material Properties - Layer #			Mix	Cement Type (I, II or III)		NA	NA	NA	NA	Select from the drop down menu the cement type that most closely matches the three cement types listed
PCC Material Properties - Layer #			Mix		Cementitious material content (lb/y^3)	YES	NA	NA	NA	Weight of cement per unit volume of concrete as per the mix design
PCC Material Properties - Layer #			Mix		Water/cement ratio	YES	NA	NA	NA	Ratio of the weight of water to the weight of cement
PCC Material Properties - Layer #			Mix	Aggregate type (several available)		NA	NA	NA	NA	Select from the drop down menu the aggregate type that is used in the concrete mix
PCC Material Properties - Layer #			Mix		PCC zero-stress temperature (°F)	YES	NA	NA	NA	Temperature (after placement and during the curing process) at which the PCC becomes sufficiently stiff that it develops stress if restrained
PCC Material Properties - Layer #			Mix	Ultimate shrinkage at 40% R.H.		YES	NA	NA	T 160	Shrinkage strain that the PCC material undergoes under prolonged exposure to drying conditions and is defined at 40 percent humidity
PCC Material Properties - Layer #			Mix		Reversible shrinkage (% of ultimate shrinkage)	YES	NA	NA	T 160	Percentage of the ultimate shrinkage that is reversible in the concrete up on rewetting. A value of 50 percent is typically used for this parameter.

Window Title	Main Heading	Sub Heading	Tab	Check Box/ Pull Down Menu/ Choose From	Fill in the Blank (Values or Text)	Has Default Value?	Level	ASTM Test Procedure	AASHTO Test Procedure	Description
PCC Material Properties - Layer #			Mix		Time to develop 50% of ultimate shrinkage (days)	YES	NA	NA	T 160	Time taken in days to attain 50 percent of the ultimate shrinkage at the standard relative humidity conditions
PCC Material Properties - Layer #			Mix	Curing method (Choose curing compound or wet curing)		NA	NA	NA	NA	Select from the drop down menu the curing method used in the construction
PCC Material Properties - Layer #			Strength		28-day PCC modulus of rupture (psi)	YES	3	C 78	T 97	Value for 28-day modulus of rupture
PCC Material Properties - Layer #			Strength		28-day PCC compressive strength (psi)	YES	3	C 39	T 22	Value for 28-day compressive strength
PCC Material Properties - Layer #			Strength		28-day PCC elastic modulus (psi)	YES	3	C 469	NA	Value for 28-day elastic modulus
PCC Material Properties - Layer #			Strength		7-day compressive strength (psi)	YES	2	C 39	T 22	Value for 7-day compressive strength
PCC Material Properties - Layer #			Strength		14-day compressive strength (psi)	YES	2	C 39	T 22	Value for 14-day compressive strength
PCC Material Properties - Layer #			Strength		28-day compressive strength (psi)	YES	2	C 39	T 22	Value for 28-day compressive strength
PCC Material Properties - Layer #			Strength		90-day compressive strength (psi)	YES	2	C 39	T 22	Value for 90-day compressive strength
PCC Material Properties - Layer #			Strength		Ratio of 20-year to 28-day compressive strength	YES	2	C 39	T 22	Value for the ratio of the 20-year to 28-day compressive strength (typically 1.44)
PCC Material Properties - Layer #			Strength		7-day modulus of elasticity (psi)	YES	1	C 469	NA	Value for 7-day modulus of elasticity
PCC Material Properties - Layer #			Strength		14-day modulus of elasticity (psi)	YES	1	C 469	NA	Value for 14-day modulus of elasticity
PCC Material Properties - Layer #			Strength		28-day modulus of elasticity (psi)	YES	1	C 469	NA	Value for 28-day modulus of elasticity

Window Title	Main Heading	Sub Heading	Tab	Check Box/ Pull Down Menu/ Choose From	Fill in the Blank (Values or Text)	Has Default Value?	Level	ASTM Test Procedure	AASHTO Test Procedure	Description
PCC Material Properties - Layer #			Strength		90-day modulus of elasticity (psi)	YES	1	C 469	NA	Value for 90-day modulus of elasticity
PCC Material Properties - Layer #			Strength		Ratio of 20-year to 28-day modulus of elasticity	YES	1	C 469	NA	Value for the ratio of the 20-year to 28-day modulus of elasticity (typically 1.2)
PCC Material Properties - Layer #			Strength		7-day modulus of rupture (psi)	YES	1	C 78	T 97	Value for 7-day modulus of rupture
PCC Material Properties - Layer #			Strength		14-day modulus of rupture (psi)	YES	1	C 78	T 97	Value for 14-day modulus of rupture
PCC Material Properties - Layer #			Strength		28-day modulus of rupture (psi)	YES	1	C 78	T 97	Value for 28-day modulus of rupture
PCC Material Properties - Layer #			Strength		90-day modulus of rupture (psi)	YES	1	C 78	T 97	Value for 90-day modulus of rupture
PCC Material Properties - Layer #			Strength		Ratio of 20-year to 28-day modulus of rupture	YES	1	C 78	T 97	Value for the ratio of the 20-year to 28-day modulus of rupture (typically 1.2)

APPENDIX F – UNBOUND MATERIALS

Window Title	Main Heading	Sub Heading	Tab	Check Box/ Pull Down Menu/ Choose From	Fill in the Blank (Values or Text)	Has Default Value?	Level	ASTM Test Procedure	AASHTO Test Procedure	Description
Chemically Stabilized Material - Layer #	General Properties			Material Type		NA	NA	NA	NA	Choose chemically stabilized material type
Chemically Stabilized Material - Layer #	General Properties				Layer thickness (in)	NA	NA	NA	NA	Specify chemically stabilized layer thickness
Chemically Stabilized Material - Layer #	General Properties				Unit weight (pcf)	YES	NA	NA	NA	Weight per unit volume of chemically stabilized material
Chemically Stabilized Material - Layer #	General Properties				Poisson's ratio	YES	NA	NA	NA	Ratio of the lateral to longitudinal strain of the material
Chemically Stabilized Material - Layer #	Strength Properties				Elastic/Resilient Modulus (psi)	YES	NA	C 469 (Lean concrete or cement stabilized)	T 294 (soil cement, lime-cement-flyash or lime stabilized) -	28-day modulus value and is a measure of the deformational characteristics of the material with applied load
Chemically Stabilized Material - Layer #	Thermal Properties				Thermal conductivity (BTU/hr-ft-°F)	YES	NA	E 1952	NA	Measure of the ability of the material to uniformly conduct heat through its mass when two faces of the material are under a temperature differential
Chemically Stabilized Material - Layer #	Thermal Properties				Heat capacity (BTU/lb-°F)	YES	NA	D 2766	NA	Amount of heat required to raise a unit mass of material by a unit temperature
Unbound Layer - Layer #				Unbound material (choose from pull down menu)		NA	NA	D 2487	NA	Choose unbound material type
Unbound Layer - Layer #					Thickness (in)	NA	NA	NA	NA	Specify unbound material layer thickness
Unbound Layer - Layer #			Strength Properties		Poisson's ratio	YES	1	None available	None available	Weight per unit volume of unbound material
Unbound Layer - Layer #			Strength Properties		Coefficient of lateral pressure (Ko)	YES	1	NA	NA	Term used to express the ratio of the lateral earth pressure to the vertical earth pressure (eqn)
Unbound Layer - Layer #	Analysis Type	User Input Modulus	Strength Properties	Seasonal input (design value)	Monthly K values (regression constants)	NO	1	NA	NA	Regression constants for each month (obtained by fitting resilient modulus test data to the k-θ model
Unbound Layer - Layer #	Analysis Type	User Input Modulus	Strength Properties	Representative value (design value)	Monthly modulus values	NO	1	NA	T 307	Representative regression constants (one value for each)
Unbound Layer - Layer #			Strength Properties		Poisson's ratio	YES	2	NA	NA	Ratio of the lateral to longitudinal strain of the material

Window Title	Main Heading	Sub Heading	Tab	Check Box/ Pull Down Menu/ Choose From	Fill in the Blank (Values or Text)	Has Default Value?	Level	ASTM Test Procedure	AASHTO Test Procedure	Description
Unbound Layer - Layer #			Strength Properties		Coefficient of lateral pressure (Ko)	YES	2	NA	NA	Term used to express the ratio of the lateral earth pressure to the vertical earth pressure (eqn)
Unbound Layer - Layer #	Analysis Type	ICM Calculated Modulus	Strength Properties	ICM Inputs	Select material property and value (modulus, CBR, R-value, layer coefficient, penetration, or based upon	NA	2	NA	T 307 (modulus) T 190 (R value) T 193 (CBR) or T 206 (penetration)	General correlations between soil index and strength properties and resilient modulus to estimate Mr
Unbound Layer - Layer #	Analysis Type	User Input Modulus	Strength Properties	Seasonal input (design value)	Select material property and monthly value (modulus, CBR, R-value, layer coefficient,	NA	2	NA	T 307 (modulus) T 190 (R value) T 193 (CBR) or T 206 (penetration)	General correlations between soil index and strength properties and resilient modulus to estimate Mr
Unbound Layer - Layer #	Analysis Type	User Input Modulus	Strength Properties	Representative value (design value)	Select material property and value (modulus, CBR, R-value, layer coefficient, penetration, or based upon	NA	2	NA	T 307 (modulus) T 190 (R value) T 193 (CBR) or T 206 (penetration)	General correlations between soil index and strength properties and resilient modulus to estimate Mr
Unbound Layer - Layer #			Strength Properties		Poisson's ratio	YES	3	NA	NA	Ratio of the lateral to longitudinal strain of the material
Unbound Layer - Layer #			Strength Properties		Coefficient of lateral pressure (Ko)	YES	3	NA	NA	Term used to express the ratio of the lateral earth pressure to the vertical earth pressure (eqn)
Unbound Layer - Layer #	Analysis Type	ICM Calculated Modulus	Strength Properties	ICM Inputs	Modulus value	NO	3	NA	T 307	Default value for the resilient modulus of the unbound material
Unbound Layer - Layer #	Analysis Type	User Input Modulus	Strength Properties	Representative value (design value)	Modulus value	YES	3	NA	T307	Default value for the resilient modulus of the unbound material
Unbound Layer - Layer #			ICM		Gradation (either a range or mean values)	YES	NA	NA	T 27	Unbound material gradation information
Unbound Layer - Layer #			ICM		Plasticity Index	YES	NA	NA	T 90	Numerical difference between the liquid limit and the plastic limit of the soil and indicates the magnitude of the range of the moisture contents over which the soil is in a plastic condition
Unbound Layer - Layer #			ICM		Liquid Limit	YES	NA	NA	T 89	The water content of a soil at the arbitrarily determined boundary between the liquid and plastic states, expressed as a percentage of the oven-dried mass of the soil
Unbound Layer - Layer #			ICM	Compacted Layer		NA	NA	NA	NA	Indicates level of compaction achieved during construction phase
Unbound Layer - Layer #	User Overridable Index Properties		ICM		Maximum dry unit weight (pcf)	YES	NA	NA	T 99	Maximum dry unit weight of unbound material (pcf)

Window Title	Main Heading	Sub Heading	Tab	Check Box/ Pull Down Menu/ Choose From	Fill in the Blank (Values or Text)	Has Default Value?	Level	ASTM Test Procedure	AASHTO Test Procedure	Description
Unbound Layer - Layer #	User Overridable Index Properties		ICM		Specific gravity, Gs	YES	NA	NA	T 100	Ratio of the mass of the material at a given temperature to the mass of an equal amount of water at the same temperature
Unbound Layer - Layer #	User Overridable Index Properties		ICM		Sat. hydraulic conductivity (ft/hr)	YES	NA	NA	T 215	Required to determine the transient moisture profiles in compacted unbound materials and to compute their drainage characteristics
Unbound Layer - Layer #	User Overridable Index Properties		ICM		Optimum gravimetric water content (%)	YES	NA	NA	T 99	Optimum water content of unbound material (%)
Unbound Layer - Layer #	User Overridable Index Properties		ICM		Degree of saturation at optimum (%)	YES	NA	NA	T 99 or T 180	Proportion of the void space in an unbound granular or subgrade material occupied by water
Unbound Layer - Layer #	User Overridable Soil Water Characteristic Curve		ICM		af, bf, cf & hr	YES	NA	NA	T 99, T 180, or T100	Overridable default values that determine the soil-water characteristic curve
Bedrock Material	General Properties			Material Type		NA	NA	NA	NA	Choose either "Massive and Continuous Bedrock" or "Highly Weathered and Fractured Bedrock"
Bedrock Material	General Properties				Layer thickness (in)	NA	NA	NA	NA	Thickness of the bedrock layer if it is at a very shallow depth, can also choose "Last Layer"
Bedrock Material	General Properties				Unit weight (pcf)	YES	NA	NA	NA	Weight per unit volume of the bedrock material (pcf)
Bedrock Material	General Properties				Poisson's ratio	YES	NA	NA	NA	Ratio of the lateral strain to the longitudinal strain of the material
Bedrock Material	General Properties				Resilient Modulus (psi)	YES	NA	NA	NA	Modulus of the bedrock layer