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Implementation of the Mechanistic-Empirical Pavement Design Guide (MEPDG)

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IMPLEMENTATION OF THE MECHANISTIC–EMPIRICALPAVEMENT DESIGN GUIDE (MEPDG)

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Disclaimer

ABSTRACT

Current pavement design methodology based on the AASHTO Design Guide uses an empirical approach based on the results of the AASHTO Road Test conducted in 1958. But limitations of the current guide led AAHSTO to publish the new Mechanistic Empirical Pavement Design Guide (MEPDG), which combines mechanistic and empirical methodology by using calculations of pavement responses, such as stress, strains, and deformations (mechanistic) using site specific inputs from climate, material, and traffic properties. As a new design guide and with large data inputs required, there are bound to be challenges. In this respect, the MEPDG is currently undergoing many changes with further research being conducted at the national, regional, and local levels into various aspects of the guide, especially in the areas of materials, climate, and traffic characteristics. It is hoped that the findings from various research studies will facilitate the implementaion of the MEPDG within national, regional, and local transporation agencies and professionals. Consequently, a North-West States' MEPDG User Group meeting was held in Oregon on March 9–10 to discuss the region's implementation plans and progress, related technical issues, and the future direction of the MEPDG. This report summarizes the findings from the meeting and seeks to outline the research needs necessary to facilitate the implementation of the MEPDG in the North-West region.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 Background

In the past, pavement design was performed on an experience only basis. Today, most states use an empirical approach in pavement design. The empirical methodology is the statistical modeling of pavement performance. The future direction of the design guide is aimed at using a mechanistic–empirical approach. This methodology uses calculations of pavement responses such as stresses, strains, and deformations (mechanistic) and then adjusts accordingly based on performance models (empirical). The ultimate goal is to have pavement designed on a mechanistic approach only (AASHTO).

The empirical design of pavements resulted from the AASHTO road test in 1958. The design parameters created by AASHTO from the road test included pavement serviceability, supporting value of the sub-grade, quantity of the predicted traffic, quality of the construction materials, and climate. Design equations were based on the conditions at the AASHTO road test site in which multiple surfacing sections were tested with loaded trucks. By 1972, the AASHTO guide for pavement design was published. The design guide was rationally based on the experience of the pavement engineers and their knowledge of how to avoid structural failures (AASHTO). But the AASHTO guide had limitations because it was based on the AASHTO road test, which only included one climate, one sub-grade, two years' duration, limited cross sections and 1950s materials, traffic volumes, specifications and construction methods. Due to these limitations a dilemma of how to project beyond the AASHTO road test limits came about (AASHTO).

The AASHTO Guide was updated in 1986 and 1993, but in the mid 1990s AASHTO undertook research for a new guide to pavement design. A 2003 survey showed that three DOTs used the 1972 design guide, two used the 1986 guide, 26 used the 1993 guide, and 17 used their own agency's design guide or a combination of the AASHTO and agency's guides (Wagner). The critical items for the new design guide were identified as mechanistic, empirically calibrated, allow for user calibration, include existing theory and models, create software and provide a rational engineering approach. This became the mechanistic–empirical approach to pavement design and known as the NCHRP 1-37A project (AASHTO). Figure 1.1 shows the mechanistic–empirical design process in a basic flow chart.

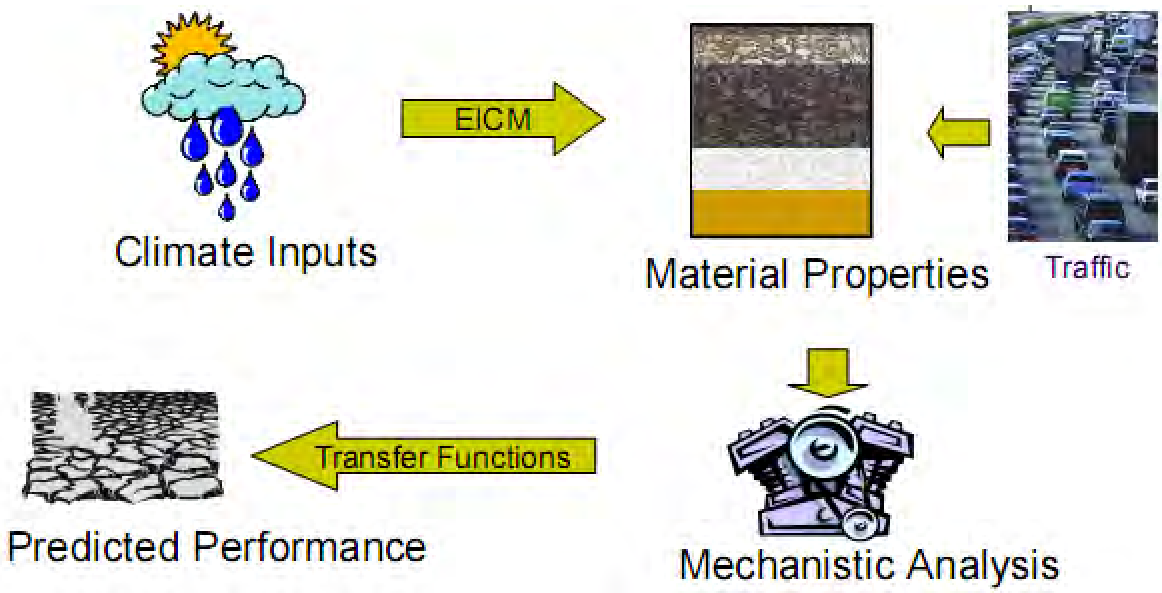

Figure 1.1 M–E Design Process (Wagner)

The mechanistic–empirical design process contains more than 100 total inputs with 35 or more for flexible pavement and 25 or more for Portland Cement Concrete (PCC). This can be compared with the 1993 AASHTO guide, which contains five inputs for flexible pavement and 10 inputs for rigid pavements (AASHTO). The mechanical–empirical inputs come from climate, material, and traffic properties. Material factors come from modulus values and thermal properties of the specific materials. Climate factors are based on site specific climate considerations. The mechanistic–empirical design process uses 800 or more weather sites to narrow these factors to the specific site, while the AASHTO guide uses extrapolation from the road test site in Ottawa, Illinois. Traffic inputs will come from local data collected and will be the number of axles by type and weight. ESAL's will no longer be used. With the Mechanistic–Empirical Pavement Design Guide (MEPDG), it is anticipated that a more reliable design will be created and there will no longer be a dependence on extrapolation of empirical relationships. It will also allow for calibration nationally, or regionally or to local performance data for materials, climate, and traffic (Wagner). But the mechanistic–empirical design process is not yet an approved AASHTO design guide. With so many inputs and factors, it is expected that problems will arise. These problems stem from the lack of ability to collect the desired inputs and the lack of research. It is in these critical inputs in which the desired performance models are created; for example, the Integrated Climatic Model (ICM) for climate factors uses temperature and moisture inputs to run the model. For the mechanistic–empirical performance models of pavement materials, inputs come from modulus values, thermal properties and strength properties (AASHTO). In this regard, more time and equipment are needed by the DOTs to collect the necessary data to create the required inputs. Also calibration and sensitivity efforts are an ongoing process. By consulting with the DOTs in the northwestern states, the specific problems occurring in each state could be identified. These problems will then be summarized with the goal of determining the necessary equipment and/or research that is needed. In addition, where necessary, recommendations will be made for needed regional research. It is through these recommendations that the facilitation of the implementation of the MEPDG throughout the MPC region will be performed in order to fulfill the goal of complete implementation of the mechanistic–empirical pavement design process.

1.2 Problem Statement and Objectives

At the Mountain-Plains Consortium (MPC) Pavement Research Workshop in Denver, Colorado in March 2008, a roadmap for future pavement related research studies was laid out. During the workshop, it was concluded that the top priority for the region will be the implementation of the Mechanistic–Empirical Pavement Design Guide (MEPDG). The represented agencies at the workshop included WYDOT, CDOT, SDDOT, NDDOT, SDLTAP, SDSU, FHWA, Colorado State University, North Dakota State University, South Dakota State University, University of Utah, and University of Wyoming. It was determined that there were currently some issues regarding the smooth implementation of the new MEPDG. A follow-up to this meeting was a North-West User Group Meeting held at Oregon State University in Corvallis on March 9-10, 2009 to discuss participating states' implementation plans and progress, technical issues related to the MEPDG and other related issues with the MEPDG. The attending states included Alaska, Idaho, Montana, North Dakota, Oregon, South Dakota, Washington, and Wyoming. It is in this respect that the main objective of this study is to address the necessary means needed to facilitate the implementation of the MEPDG for the northwestern states. The study will seek to obtain information from the DOTs throughout the MPC Region, process the gathered data and provide an approach to help with the implementation of the MEPDG.

1.3 Report Organization

A comprehensive literature review focusing on the performance of the MEPDG is summarized in Section 2 of this report. Section 3 focuses on the national as well as the regional implementation of the MEPDG and includes a summary of the findings of the user group meeting. Section 4 summarizes the main challenges likely to be faced in the implementation of the MEPDG and Section 5 outlines any future research needs. Finally, summary conclusions and recommendations for the way forward in MEPDG implementation are presented in Section 6.

2. LITERATURE REVIEW

2.1 Background

In the past, empirical design methods were the only available pavement design choices. The limitations of the empirical methods resulted in some pavements meeting design requirements and others not meeting their design requirements. The mechanistic–empirical design approach provides for more information about the development of pavement distresses during the design life of the pavement to be obtained. From this information, pavement engineers can decide on when and how to go about the maintenance of pavements while still meeting the requirements of its users(Petry, Han and Ge 2007). The MEPDG provides significant benefits over the 1993 AASHTO Pavement Design Guide. These benefits allow for achieving cost effective new and rehabilitated pavement designs. The MEPDG utilizes a user friendly software interface that uses an integrated analysis approach to predict pavement behavior over time. The MEPDG software accounts for the interaction among traffic, climate, and materials used in the pavement structure. The ultimate goal of an accurately predicted long run evaluation of the pavement and determination of the subsequent pavement design can be achieved by using the MEPDG(Rabab'ah and Liang 2007).

The MEPDG is also a significant improvement in pavement performance prediction methodology. The MEPDG is mechanistic because the model uses stresses, strains, and deformations in the pavement that have been calculated from real-world pavement response models to predict its performance. It is also empirical because the pavement performance predicted from lab developed performance models are adjusted according to observed performance in the field in order to reflect the differences between the predicted and actual field performance. The performance models used are calibrated using limited national databases. As a result, it is necessary for these models to be calibrated locally by taking into account local materials, traffic, and environmental conditions (Muthadi and Kim 2007). A well calibrated prediction model can result in reliable pavement designs and enable precise maintenance plans for agencies (Kang and Adams 2007). The concept of mechanistic–empirical design is to employ the fundamental pavement responses under repeated traffic loadings. These calculations consist of stresses, strains, and deflections in a pavement structure. Pavement responses are related to distresses in the field as well as performance using existing empirical relationships. The design process starts with a trial design, and, through many iterations, ends with predicted distresses that meet requirements based on the desired level of statistical reliability as defined by the user(Daniel and Chehab 2007). The MEPDG is not at the point where this goal is achieved seamlessly and its implementation is an ongoing endeavor.

2.2 Design Process

The design process of a pavement either new or reconstructed requires an iterative approach with control in the hands of the pavement engineer. The designer must select and perform a design and determine if it meets the performance demands created by the user. The process can be outlined in the following steps:

i. Create the trial design for the specified location based on traffic, climate, and material conditions.
ii. Define the pavement layer arrangement, hot mix asphalt (HMA), and other material properties.
iii. Establish the necessary criteria for acceptable performance at the end of the design period (acceptable levels of the different cracking types, rutting, International Roughness Index [IRI], etc.)
iv. Select the desired level of reliability for each of the performance criteria.
v. Process inputs to gather monthly data for traffic, material, and climate inputs needed in the design evaluations of the entire design life.

vi. Compute the structural responses (stress, strain, etc.) using the finite element or layered elastic analysis program for each damage calculation throughout the design period.
vii. Calculate the accumulated damages at each month for the entire design life.
viii. Predict vital distress, like cracking and rutting, on a month-by-month basis of the design period using the calibrated mechanistic–empirical performance models provided in the MEPDG.
ix. Predict the smoothness as a function of the initial IRI, distresses over time, and site factors at the end of each month.
x. Evaluate the expected performance of the trial design at the given reliability level for adequacy.
xi. If trial design does not meet the performance criteria, modify the design and repeat steps 5 to 10 until the criteria are met.

The definition of reliability within the MEPDG is the reliability of the design, and it is the probability that the performance of the pavement predicted for that particular design will be satisfactory over the time period under consideration (Khazanovich, Wojtkiewicz and Velasquez 2007). In other words, the performance indicators such as cracking and rutting will not exceed the design criteria established over the design analysis period. As with any process to create a design and analyze the given design, there are many sources of variation that can occur in the prediction, such as:

i. Traffic loading estimation errors
ii. Climate fluctuation that the EICM (Enhanced Integrated Climate Model) may miss
iii. Variation in layer thickness, material property and subgrade characteristics throughout the project
iv. Differences in the designed and actually built materials and other layer properties
v. Limitations and errors in the prediction models
vi. Measurement errors
vii. Human errors that may occur along the way (Khazanovich, Wojtkiewicz and Velasquez 2007).

2.3 Calibration

Calibration, as defined in the MEPDG, means to reduce the total error between the measured and predicted distresses by varying the appropriate model coefficients(Muthadi and Kim 2007). In general, there are three important steps involved in the process of calibrating the MEPDG to local materials and conditions. The first step is to perform verification runs on pavement sections using the calibration factors from the national calibration effort under the NCHRP 1-37A project. Step two involves calibrating the model coefficients to eliminate bias and reduce standard error between the predicted and measured distresses. Once this is accomplished and the standard error is within the acceptable level set by the user, the third step is performed. Validation, the third step, is used to check if the models are reasonable for performance predictions. The validation process determines if the factors are adequate and appropriate for the construction, materials, climate, traffic and other conditions that may be encountered within the system. This is done by selecting a number of independent pavement sections that were not used in the local calibration effort and testing those(Muthadi and Kim 2007).

2.4 Traffic

The MEPDG traffic criteria were developed around axle load spectra. It is through axle load spectra that the unique traffic loadings of a given site are characterized. By means of these loading characteristics, pavement responses and resulting damages can be computed. Full axle load spectra traffic inputs are used for estimating the magnitude, configuration and frequency of traffic loads (Wang, et al. 2007). The benefit of load distributions is that they provide a more direct and rational approach for the analysis and design of pavement structures. The approach estimates the effects of actual traffic on pavement response and distress. Until complete use of mechanistic–empirical design methods are fully implemented, it is anticipated that the use of equivalent single-axle loads (ESALs) will continue to be applied by pavement engineers in pavement design and rehabilitation for some time(Haider, Harichandran and Dwaikat 2007). The problem occurs in the transition between solely utilizing ESALs to only using axle load spectra. A possible solution is characterizing axle load spectra as a bimodal (two distinct peaks) mixture distribution and using its parameters to approximate ESALs. Dr. Haider and his colleagues have observed that axle load spectra can be reasonably described as a mix of two normal distributions. By developing closed-form solutions to estimate the parameters of the mixed distribution, traffic levels in terms of ESALs can then be estimated from the axle load spectra from a specific site(Haider, Harichandran and Dwaikat 2007). It is in the linkage between ESALs (empirical) and axle load spectra (mechanistic) in which the implementation of the MEPDG is being moved along. Type, weight, and number of axles are the criteria in which axle loads need to be estimated. The data gathered to follow the criteria should be site specific; if that is not possible, site related, regional, or agency-wide traffic data need to be substituted. The MEPDG software includes default axle load spectra and other traffic parameters if no other sources of traffic data can be obtained. To fully benefit from the MEPDG it is important to characterize pavement traffic loads using detailed traffic data including axle load spectra. This traffic data should be specific to the project area, and if that is not possible, default data will have to be used.

Generally, there is noticeable difference between the default traffic inputs included in the MEPDG and the regional traffic data collected in terms of axle load spectra. Volume and type of trucks along with axle load spectra are the main influences for predicting pavement performance. There are also main input factors that do not have significant influence on pavement performance predictions, such as axle spacing and hourly volume adjustment factors (Swan, et al. 2007). The software used in the MEPDG looks at each axle load individually then estimates the stresses and strains imposed on the pavement structure by each axle load. The stresses and strains are related to pavement damage and the damage is then accumulated. Finally, a report of the total damage caused by all axle loads is created. Throughout the process, the calculations take into account the climatic conditions of the pavement structure; the temperature of the asphalt concrete layers and the moisture content of the unbound material layers and subgrade. The calculations performed make up the mechanistic side of the guide, whereas the relation of the stresses and strains to pavement damage is the empirical part(Swan, et al. 2007). The data that are required to run the traffic analysis in the MEPDG are Average Annual Daily Truck Traffic (AADTT) data, vehicle classification, axle load distribution, and number of axles per truck. When weigh-in-motion (WIM) sites are close to the project site, these data can be used in a Level 1 analysis(Muthadi and Kim 2007).

2.4.1 Hierarchal Approach

Based on the different pavement needs and the availability of traffic input data, the MEPDG accommodates three levels of input data that are progressively more reliable and accurate. The quality of the data in terms of reliability and accuracy, not detail makes up the difference in the hierarchal input levels. In other words, the same amount and type of data are used in every level, but level selection is based on the quality of the data. The hierarchal input levels are as follows:

i. Level 1 – The input data are gathered from direct and project-specific measurements. This level represents the greatest knowledge of the input parameters for the specific job. In particular, the input data are site-specific truck volumes for individual truck types and the axle load spectra is project site specific.
ii. Level 2 – The input data come from regional data, such as measured regional values that encompass the project but are not site specific. For traffic data, estimated classified truck volumes are used. These estimations come from volumes gathered on sections with similar traffic characteristics to those of the current project.
iii. Level 3 – These data are based on best estimation data or default values. These data are based on global or agency-wide default values, such as the median value from a group of similar projects.

For example, this data may come from an agency published look-up table of averages for classified truck volumes.

It is recommended by the MEPDG to use the best available data regardless of the overall input level. That is, it is possible for Level 1 inputs to be classified truck volumes, Level 2 data to be axle configuration, and Level 3 inputs to be axle load. This is solely based on the quality of each individual piece of data and where it fits best in the hierarchal scheme(Swan, et al. 2007).

2.4.2 Traffic Elements

Traffic input data in the MEPDG are entered for the base year. The base year is the year the pavement is expected to open to traffic. Within the MEPDG software, there is a provision for future growth in truck volumes after the base year. Throughout the analysis of traffic data in the MEPDG there are many elements used. These elements are as follows:

i. **Truck Volume and Highway Parameters**. Truck volume is calculated by multiplying the Average Annual Daily Traffic (AADT) volume by the percentage of heavy trucks of FHWA class 4 or higher. The result is AADTT or Average Annual Daily Truck Traffic, but site specific AADTT data are usually available through an agency.

ii. **Monthly Traffic Volume Adjustment Factors**. These factors are used to distribute the AADTT volume a year's time. Once the monthly traffic volume adjustment factors have been created, they are assumed to be the same for the design life. Monthly traffic volume adjustment factors are used if there is significant monthly variation in truck volumes that affect pavement performance. This variation is most likely due to seasonal traffic, such as in summer or winter.

iii. **Vehicle Classification Distribution**. The MEPDG uses the FHWA scheme of classifying heavy vehicles as shown in Table 2.1. Ten different vehicle classes are used (classes 4 to 13). The subsequent three light vehicle classes (classes 1 to 3, motorcycle, passenger car, and pickup) are not used in the MEPDG.

Table 2.1 FWHA System of Vehicle Classification (Source: www.fhwa.dot.gov)

Vehicle Class	Vehicle Type	Description
4	Buses	All vehicles manufactured as traditional passenger-carrying buses with two axles and six tires or three or more axles. This category includes only traditional buses (including school buses) functioning as passenger-carrying vehicles. Modified buses should be considered to be a truck and should be appropriately classified.
5	Two-Axle, Six-Tire, Single-Unit Trucks	All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., with two axles and dual rear wheels.
6	Three-Axle Single-Unit Trucks	All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., with three axles.
7	Four or More Axle Single-Unit Trucks	All trucks on a single frame with four or more axles.
8	Four or Fewer Axle Single-Trailer Trucks	All vehicles with four or fewer axles consisting of two units, one of which is a tractor or straight truck power unit.
9	Five-Axle Single-Trailer Trucks	All five-axle vehicles consisting of two units, one of which is a tractor or straight truck power unit.
10	Six or More Axle Single-Trailer Trucks	All vehicles with six or more axles consisting of two units, one of which is a tractor or straight truck power unit.
11	Five or fewer Axle Multi-Trailer Trucks	All vehicles with five or fewer axles consisting of three or more units, one of which is a tractor or straight truck power unit.
12	Six-Axle Multi-Trailer Trucks	All six-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit.
13	Seven or More Axle Multi-Trailer Trucks	All vehicles with seven or more axles consisting of three or more units, one of which is a tractor or straight truck power unit.

iv. **Hourly Traffic Volume Adjustment Factors**. Hourly traffic adjustment factors are expressed as a percentage of the AADT volumes during each hour of the day. These factors apply to all vehicle classes and are constant throughout the design life of the pavement system. These factors can be adjusted and customized by the user, but virtually no effect on the predicted pavement performance is seen with the current version of the MEPDG software.

v. **Axle Load Distribution Factors**. The distribution of the number of axles by load range is the definition of axle load spectra. An axle load spectrum distribution is referred to as axle load distribution factors in the MEPDG. The MEPDG software allows the user to enter a different set of axle load distribution factors for each vehicle class and each month.

vi. **Traffic Growth Factors**. Anticipation of truck volume growth after a road has opened is expressed in traffic growth factors. These factors are applied to individual vehicle classes. Axle load distributions are assumed to beconstant with time and no growth factors are applied to them. The MEPDG also had no provision for reduction in truck volume.

vii. **Number of Axles per Truck**. For each class, the number of axles per truck by axle type is required. The axle type is single, tandem, tridem, and quad. The number of axles per truck has a significant influence on the predicted pavement performance.

viii. **Lateral Traffic Wander**. Lateral traffic wander is defined as a lateral distribution of truck tire imprints across the pavement. Traffic wander plays an important role in the prediction of distresses associated with rutting. Default values for traffic wander are recommended unless quality data are available on a regional or local basis. Traffic wander data may be hard to gather and quantify so default values are highly recommended.

ix. **Axle Configuration**. The MEPDG software allows the user to enter two types of axle spacing. The first is axle spacing within the axle group, and it is defined as the average spacing between individual axles within the axle group (for example, the average spacing for all tridem axles for all vehicle types). Separate entries for tandem, tridem and quad axles are required. The second possibility is axle spacing between major axle groups. This is defined as the spacing between the steering axle and the first subsequent axle. Axle spacing between the major axle groups is required for short, medium, and long trucks. Axle configuration has a marginal effect on pavement performance predicted by the MEPDG, and is at the discretion of the user to pick default values or use measured values.

Within the MEPDG there are several traffic input factors that may not have significant influence on predicted pavement performance. As a result, sensitivity to these elements should be further investigated to gain a better understanding of their impact on predicted pavement performance(Swan, et al. 2007).

2.5 Climate/Environment and EICM

The MEPDG fully considers the influences of the climate and surrounding environment on pavement performance. This is achieved through a climatic modeling tool called the Enhanced Integrated Climate Model (EICM). The EICM requires two major types of input. Groundwater table depth is one input that is manually entered into the EICM. Weather related information, the second type of input, is primarily obtained from weather stations close to the project. The five weather related parameters used in the EICM include sunshine, rainfall, wind speed, air temperature, and relative humidity. These figures are collected on an hourly basis from the designated weather stations (Wang, et al. 2007). The data collected in the United States may come from the National Climatic Data Center (NCDC), National Oceanic and Atmospheric Association (NOAA) or other reliable sources. The EICM is a one-dimensional coupled heat and moisture flow model initially developed by the FHWA and adapted for use in the MEPDG. The purpose of the EICM is to predict and simulate the behavioral and characteristic changes in pavement and unbound materials related to environmental conditions over the service life of the pavement system (NCHRP 2008).

Climate and the surrounding environment (weather) play an important role in pavement performance. It can exert significant influences on the pavement structure, especially where seasonal changes are large. Changes in temperature, precipitation, and frost depth can drastically affect pavement performance. The MEPDG requires these inputs to be locally calibrated. As a result, these climate conditions are needed to be observed and correlated to pavement performance. One climatic factor that greatly influences pavement material properties is moisture. Moisture can affect properties such as stiffness and strength and therefore needs to be examined. In the MEPDG, a drainable base layer is to be included in the design. Water that has entered the pavement through this layer must be removed. The layer needs to maintain optimal thickness and structural capacity while having optimal permeability(Rabab'ah and Liang 2007).

The effectiveness of permeable bases in actual service is an ongoing process and more field monitoring, evaluation, and research is needed to satisfy the needs of the MEPDG.

In pavement design, the MEPDG requires the dynamic modulus for asphalt mixtures and the resilient modulus for unbound materials. Unsurprisingly, these properties are dependent upon changes, seasonal or otherwise, in temperature and moisture content. The MEPDG considers these changes in the pavement structure and subgrade over the design life of the pavement. This is achieved through the use of EICM. The model predicts temperature and moisture variations in the pavement structure throughout the seasons and adjusts material properties according to each particular environmental condition(Rabab'ah and Liang 2007). The user has two options within the EICM for adjusting the resilient modulus for each design period. In the first option, the user can provide the resilient modulus for each design period. The second option is to provide the resilient modulus for the optimum moisture content. When choosing the second option, the EICM in the MEPDG software would predict the seasonal variation of the moisture content in any unbound layers(Rabab'ah and Liang 2007).

2.6 Materials

The MEPDG requires the use of material properties of the pavement layers to create a mechanistic analysis of the pavement responses. The parameters used in the MEPDG greatly outnumber those used by the 1993 AASHTO guide. In fact, the 1993 AASHTO guide material property factors only included structural layer coefficients, layer drainage coefficients, and the subgrade resilient modulus. It has been found that these parameters are insufficient to portray the complex material behaviors that occur in pavement structures. Some of these complex behaviors include stress dependent stiffness in unbound materials along with time and temperature dependent responses of asphalt mixes (Rabab'ah and Liang 2007). With the implementation of the MEPDG underway, it is important to understand the performance of pavement materials under differing conditions. Better and more accurate simulations of different pavement distress levels can be achieved when a complete spectrum of a material's performance under altering conditions are entered into the design method(Petry, Han and Ge 2007).

2.6.1 Resilient Modulus and Unbound Layers

One material characteristic used in the MEPDG is the resilient modulus, which provides a way for evaluating dynamic response and fatigue behavior of a pavement under vehicle loading. This material property and the test methods to obtain it have become an accepted standard approach for pavement engineers. The results of resilient modulus testing along with other properties of the materials are used to calibrate the design parameters used in the MEPDG (Petry, Han and Ge 2007). The resilient modulus of unbound materials is not a constant stiffness property. Rather, it is highly dependent on factors like state of stress, soil structures, and water content(Rabab'ah and Liang 2007). Generally, a soil with the same dry density that has higher water content yields a lower resilient modulus. One of the considerations found within the broad range MEPDG in the materials section is the characterization of unbound materials. Unbound materials consist of base, subbase(s) and subgrade. All play a vital role in a pavement system and the base layer is where the unbound materials start. The base layer is placed immediately under the surface course and above the subbase(s). The base layer is designed to distribute the load from the pavement course to the underlying subbase(s) and subgrade layers. In order to prevent failure in the layers below and handle the stresses in the base itself, the base layer thickness and quality must be sufficient. Proper characterization of the materials used in the base layer and subsequent layers used in pavement design is a very important task. By means of the MEPDG, these material properties can be adequately characterized(Hill, Yohannes and Khazanovich 2007).

2.6.2 Hierarchal Approach

The MEPDG uses various models to estimate pavement performances from material properties that are measured or predicted. Depending on the available information and the desired reliability, different levels of analysis are available in the MEPDG's hierarchal approach. The MEPDG hierarchal levels are based on design and analysis options and classified into three levels. The levels are based on accuracy, reliability, state-of-knowledge, and available data. Level 3 is the lowest level of the hierarchy. Level 3 uses predicted material properties and have the lowest degree of reliability. Level 1 is on top of the hierarchy and uses lab or field measured values for material properties resulting in the highest extent of reliability in the design and analysis of a pavement(Daniel and Chehab 2007). The MEPDG also uses a hierarchal approach to characterize materials. The resilient modulus at optimum moisture content is a desired property found by the MEPDG. The MEPDG hierarchy consists of three levels with different inputs based on the data available to the user. The overall objective of the three levels is to calculate or estimate the resilient modulus depending on what data has been collected.

A Level 1 input requires the use of lab testing of the resilient modulus as an input. If no resilient modulus lab test data are available, the MEPDG will calculate the resilient modulus using other properties in a Level 2 approach. These properties generally are the California Bearing Ratio (CBR) and/or the Dynamic Cone Penetrometer indexes obtained through standard AASHTO or NCHRP testing methods. Finally, the Level 3 analysis will estimate the resilient modulus at optimum water content based on the material classification(Hill, Yohannes and Khazanovich 2007). The three levels in the hierarchal approach are expounded on in the following list:

i. Level 1 input requires the highest quality of data. The data are collected from direct testing of the actual material. The desired data for Level 1 designs are the resilient modulus values of base, subbase, subgrade, and bedrock, which are determined from direct testing. The recommended test to obtain the resilient modulus is through the repeated triaxial test. The standard testing procedure can be followed by using the NCHRP 1-28 A method or the AASHTO T307 method(Rabab'ah and Liang 2007).

ii. Level 2 designs are used when direct lab test results are not available but other test results are. Although lab test results for the resilient modulus are the preferable source of data, the resilient modulus can be obtained using correlations. These correlations may be between the resilient modulus and physical properties of the material, such as dry unit weight, Atterberg limits, and specific gravity or between resilient modulus and strength properties such as the CBR, DCP, or unconfined compressive strength. All of the physical and strength properties can be obtained by following standard NCHRP or AASHTO procedures(Rabab'ah and Liang 2007). As with any correlations, having them locally calibrated is desired.

iii. Level 3 design is typically used for lower volume roads because it uses the lowest level of data accuracy. In this level, the resilient modulus for the optimum moisture content of the material is estimated based on the classification of the material. The ICM then adjusts the resilient modulus for the seasonal effects of the climate(Rabab'ah and Liang 2007).

Along with the hierarchal approach, the MEPDG recommends the use of available correlation relationships when using inputs to calculate or estimate the resilient modulus. It is highly encouraged that locally calibrated models be developed to make these calibrations more site-specific. This is where one of the problems is found. It is time consuming and expensive to develop locally calibrated correlation models. Whether it be lack of equipment, lack of manpower, or lack of money, locally calibrated models are hard to create. The other problem involves figuring out how to create these models. The answer is to create a unified model for tests of unbound materials. More time, money and research are being applied to achieving this goal, and a unified approach to creating locally calibrated correlation models is underway(Hill, Yohannes and Khazanovich 2007).

2.6.3 Material Inputs

All of the inputs required for the material side of the MEPDG are extensive and better shown in tabular form. Kelvin Wang and his colleagues have created a tabular summary of the material inputs that can be seen in Table 2.2 (Wang, et al. 2007).

2.7 Challenges and Opportunities

With the ongoing efforts of trying to adapt the MEPDG, there are many challenges and opportunities that have arisen in the implementation of the MEPDG. One of the major challenges is the participation or "buy-in" of agencies to eventually make the MEPDG a tool for routine, day-to-day production work. This includes the agency as a whole to accept and embrace the change brought about by the MEPDG; and also the staff including, but not limited to, administrators, regional offices, designers, engineers, material specialists, etc. Following the buy-in by agencies, comes an effective implementation plan. This includes responsibilities, timelines, and gathering and allocating resources, such as people, equipment, training, etc. Also involved in an effective implementation plan are the calibration tasks and schedule to allow for more localized use of the MEPDG. Another challenge in the implementation of the MEPDG is developing the criteria to warrant implementation. This may include objectively based performance indicators (rutting, cracking, etc.), a committee to oversee and steer the use of the MEPDG, an audit process, and update and improvement assessments(Haas, et al. 2007). Finally, the development of database support is a lofty challenge but a necessary step towards the calibration and implementation of the MEPDG(Wang, et al. 2007).

The above mentioned challenges are important to the implementation of the MEPDG; but are still overlooked as the biggest challenge and opportunity facing many agencies are calibration and validation. There is a need for actual calibration and validation models for all aspects of the MEPDG. Calibration or adjustment factors for the IRI and distresses (rutting, cracking, etc.) are needed. Databases of local and regional material and subgrade properties along with climatic or environmental conditions are necessary. Moreover, guidelines for the calibration and validation procedures are going to be needed. Finally, data collection is a must for the calibration effort. This includes traffic data (axle load spectra, volume variations, lane distribution, etc.) and climate and moisture data for the EICM. With these challenges come opportunities, mainly the opportunity to create a new level of advance pavement design that is based on the best science and engineering available. In other words, designing and constructing the most cost effective, longest lasting roadways that are of the highest level of reliability(Haas, et al. 2007).

2.8 Section Summary

It can be seen that the MEPDG provides a powerful tool for pavement performance predictions. By taking into account elements from traffic, climate, and material data, a more extensive and complete view of pavement performance is created. Also, through the use of the EICM, needed environmental adjustments are made to the predictions. Furthermore, the hierarchal approach allows the MEPDG to be somewhat customizable based on the available data and the desired needs of the user. Due to the extensive nature of the MEPDG, there are definite challenges and opportunities that arise. By overcoming these challenges, the implementation of the MEPDG is being moved along and used in the accepting agencies throughout the United States and Canada.

Table 2.2 Major Material Input Considerations (Wang et al. 2007)

Materials Category	Material Inputs Required		
	Materials inputs required for critical response computations	**Additional materials inputs required for distress/transfer functions**	**Additional materials inputs required for climatic modeling**
Hot-Mix Asphalt Materials (this covers surface, binder, base and subbase courses)	• Time-temperature dependent dynamic modulus (E*) of HMA mixture. • Poisson's ratio.	• Tensile strength, creep compliance, coefficient of thermal expansion	• Surface shortwave absorptivity (only required for surface course), thermal conductivity, and heat capacity of HMA. • Asphalt binder viscosity (stiffness) characterization to account for aging.
PCC Materials (this covers surface layer only)	• Static modulus of elasticity (E) adjusted with time. • Poisson's Ratio • Unit Weight • Coefficient of thermal expansion	• Modulus of rupture, split tensile strength, compressive strength, cement type, cement content, water-to-cement (w/c) ratio, ultimate shrinkage, amount of reversible shrinkage.	• Surface shortwave absorptivity, thermal conductivity, and heat capacity of PCC.
Chemically Stabilized Materials (this covers lean concrete, cement treated, soil cement, lime-cement-fly ash, lime-fly ash, and lime stabilized layers)	• Elastic modulus (E) for high quality lean concrete, cement treated material, soil cement, and lime-cement-fly ash. • Resilient modulus (Mr) for lime stabilized soil. • Poisson's Ratio. • Unit weight.	• Minimum resilient modulus (used in flexible design), modulus of rupture (used in flexible design), base erodibility (for rigid design).	• Thermal conductivity and heat capacity of PCC.
Unbound Base/ Subbase and Subgrade Materials	• Seasonally adjusted resilient modulus (Mr). • Poisson's Ratio. • Unit weight. • Coefficient of lateral pressure.	• Gradation parameters and base erodibility (for rigid design).	• Plasticity index, gradation parameters, effective grain sizes, specific gravity, saturated hydraulic conductivity, optimum moisture contents, parameters to define the soil water characteristic curve.
Recycled Concrete Materials - Fractured PCC Slabs	• Resilient Modulus (Mr). • Poisson's Ratio.	•Base erodibility (for rigid design).	• Thermal conductivity and heat capacity.
Recycled hot asphalt mix (central plant processed)	Treated same as hot-mix asphalt surface course.		
Recycled cold asphalt mix (central plant or on-grade)	Treated same as hot-mix asphalt surface course.		
Cold recycled asphalt pavement (used as aggregate)	Treated same as granular materials with no moisture sensitivity		
Bedrock	• Elastic modulus (E) • Poisson's Ratio. • Unit weight.	None.	None.

3. REGIONAL IMPLEMENTATION OF MEPDG

3.1 Background

To help gather the necessary information and data on the MEPDG in the MPC region, it was intended that survey questionnaires be sent to all DOTs in the region to solicit their views on the MEPDG for which the results would be analyzed. However, just as the survey was to be undertaken, a user group meeting was organized by the various DOTs in the region to present their views and implementation plans on the MEPDG. It was decided to attend the meeting and record proceedings and findings and analyze the results. A copy of the survey questionnaire and the presentations of the representatives of the DOTs who attended the meeting are included in Appendix A and B respectively of this report. The summary of the findings of the MEPDG user group meeting is presented in the subsequent sections.

3.2 User Group Meeting Summary

On March 9-10, 2009, a North-West states MEPDG User Group Meeting was held at Oregon State University in Corvallis, Oregon. The objective of the meeting was to look at the participating states' implementation plans and progress, technical issues related to the MEPDG and the future direction of the MEPDG. The attending states included Alaska, Idaho, Montana, North Dakota, Oregon, South Dakota, Washington, and Wyoming. At least one representative from each state's department of transportation was present at the meeting. In order for others to attend the meeting, a teleconference network was set up in Cheyenne for both days of the meeting. Day one consisted of two sessions, with the first session involving a general overview and national update along with state-specific implementation plans and progress. The second session involved general technical issues presented by the states. Day two also contained two sessions. Session three involved more specific technical issues. The meeting was concluded with the fourth session that focused on the future direction of the MEPDG. Each DOT representative gave a presentation about their own implementation plans and progress so far on the MEPDG. A summary of these presentations are outlined below. Copies of the full versions are included in Appendix B.

3.2.1 National Implementation of MEPDG

Harold Von Quintus of Applied Research Associates (ARA) delivered a presentation during session one of the meeting, which focused on the MEPDG at the national level. The presentation provided a national update regarding the MEPDG, the new version of DARWin M-E, discussed implementation plans of the MEPDG, and presented some key steps to the implementation and views on future updates. According to Von Quintus, the DARWin M-E version 2.0 was initiated in February 2009 and is an 18-month process that involves 19 states participating in a pooled fund effort along with the FHWA and one Canadian province. Further mentions of the changes that will be made to specific areas when the DARwin 2.0 is released include:

i. Computation Methodology
ii. Appearance – changes in data input screens
iii. Distress transfer function and/or distress mechanism

It was added that even though these changes are proposed, AASHTO will be the one to decide what final changes will be made and that any significant changes will probably require a re-ballot. Ongoing studies associated with version 2.0 of DARWin-ME were also outlined. These studies include:

i. NCHRP 9-30A – Calibration of Rutting Models for HMA Structural and Mix Design
ii. NCHRP 9-41 – Reflection Cracking of HMA Overlays

iii. NCHRP 9-42 – Top-Down Cracking of HMA
iv. NCHRP 9-38, 9-44, 9-44A – Application of the Endurance Limit for HMA mixes

The presentation outlined implementation of the MEPDG as an integration into the day-to-day design practice as well as the validation and calibration of distress transfer functions to local conditions, materials, and policies. Attendees were informed that a questionnaire was sent to all states asking if the respective agency has an implementation plan of the MEPDG. Agencies in 23 states replied, indicating either having completed an implementation plan, being in the process, or being initiated in the near future. At the national level of the implementation of the MEPDG, four critical elements have been identified as key steps to a successful implementation program. These include:

i. A champion to lead the implementation effort and program
ii. Communication
iii. Training
iv. Adequate funding

It was further mentioned that the following five items will be needed for the integration of the MEPDG in practice activities:

i. Set up implementation committee and communications plan
ii. Confirm default input values and set up input libraries (traffic and material inputs)
iii. Complete concurrent designs with the MEPDG
iv. Verify reasonableness of final designs
v. Begin training in the use of MEPDG software

At the meeting it was learned that training may be one of the major issues in the implementation of the MEPDG since at the moment there are currently many unknowns associated with the MEPDG. It was revealed that currently there are two National Highway Institute (NHI) training courses, which are:

i. NHI Course 131064 – Introduction to M-E Pavement Design
ii. NHI Course 131109 – Analysis of New and Rehabilitated Pavement Performance with MEPDG Software

Von Quintus' presentation concluded with a plan for future national updates. The main point was to plan for updates and improvements since the system is not perfect but can still be used. In order to plan for future updates, it was suggested to maintain a calibration-validation database along with input libraries; monitor the test sections and input parameters, update the database, and verify local calibration or agency-specific factors for future MEPDG versions. Currently, there is a calibration-validation database being developed under NCHRP Project 9-30 and enhanced under NCHRP 9-30A. This will provide features to store and manage data for calibrating M-E based methods at the national level.

3.2.2 Regional Implementation of MEPDG

Of the eight states represented at the user group meeting, Montana is the only state that has completed its implementation program. The rest are either in the process or will initiate their implementation plan in the near future. At the user group meeting, session one focused on the implementation plans of the attending states even though not all states had a solid enough plan to present at the meeting. The implementation plans of Washington, Oregon, South Dakota, and Wyoming were presented and will be discussed.

Washington DOT Implementation of MEPDG

The Washington Department of Transportation (WSDOT) uses the 1993 AASHTO Guide for Design of Pavement Structures as its current design tool. WSDOT is making many efforts on the MEPDG, including data preparation and calibration-validation. Areas of data preparation include traffic, material properties, and pavement performance. They have both concrete pavement and flexible pavement sites laid for calibration-validation efforts. WSDOT released some major findings in their process of getting ready to implement the MEPDG in their agency. These major findings are:

i. MEPDG is an advanced tool for pavement design and evaluation
ii. Calibration is required prior to implementation
iii. The concrete pavement calibration results need to be adjusted before use
iv. The distress models for new flexible pavement have been calibrated to WSDOT conditions, except the IRI model
v. The calibration, along with implementation, is a contual process
vi. Local agencies need to balance the input data accuracy and costs
vii. WSDOT will continue to monitor future works related to MEPDG

WSDOT has also created some future works, which include refining the calibration results for doweled JPCP slabs and Superpave, testing and calibrating rehab models for HMA overlay on HMA, and HMA overlay on PCCP; and preparing specific designs on high traffic loads, weak soil support, and mountain passes. Part of WSDOT's implementation plan is to develop a user guide, prepare sample files for typical designs, and train pavement designers.

Oregon DOT Implementation of MEPDG

The Oregon Department of Transportation (ODOT) plans to have full implementation of the MEPDG by 2012. They are working closely with Oregon State University (OSU) researchers to help with the implementation process. Research was completed by OSU pertaining to back calculation software, and it was recommended that EVERCALC be utilized for this process. OSU also performed research on AC Dynamic Modulus and Axle Load Spectra. OSU is still researching traffic lane instrumentation. OSU also has ongoing research for perpetual pavement instrumentation as well as M-E pavement design inputs. For pavement instrumentation, research is being performed on I-5 and US-97. Design input research includes material characterization, climate data, and calibration. Future research that will be conducted by OSU includes:

i. HMA density
ii. Open graded HMA
iii. Recycled Asphalt Pavement (RAP) mixtures
iv. Recycled Asphalt Shingle (RAS) mixtures
v. Asphalt Mixture Performance Tester (AMPT) pool fund study

From all the research performed by OSU, ODOT plans to have staff use the MEPDG for pavement design on some interstate projects. They plan to use interim guidance for the use of the MEPDG with their own pavement design guide until full implementation. During this time, individual agreements with the contractors will be made to decide what guide will be utilized and how it will be used.

South Dakota DOT Implementation of MEPDG

The South Dakota Department of Transportation (SDDOT) started their implementation process in 2005 with a research project called SD2005-01. The objective of the project was to identify the requirements and resources that will be needed for SDDOT to implement the MEPDG and develop a plan. These objectives were met by means of:

i. Conducting sensitivity analysis
ii. Recommending input levels
iii. Determine resource requirements
iv. Identify calibration requirements
v. Developing an implementation plan

SDDOT's current implementation plan is a result of the previous research. There are three main aspects of the current plan. First, create an MEPDG Implementation team called the SDDOT Transportation Implementation Group (SDDOT TIG). This will contain 12 SDDOT representatives, one FHWA representative, and two industry representatives. The industry representatives are from the South Dakota Concrete Pavement Association and the Dakota Asphalt Pavement Association. The second aspect is the development of a communication plan. This has been completed by SDDOT. The third aspect involves MEPDG training. This was completed in the fall of 2008. SDDOT wants to review and appraise the MEPDG software relative to its performance for South Dakota soils, materials, climate, traffic, and other considerations. This will be accomplished through the following active research projects:

i. SD2008-10 with Lance Roberts from the South Dakota School of Mines and Technology to determine resilient modulus and dynamic modulus values for soils and asphalt mixes typically used in South Dakota
ii. M-E/PDG design, validation testing, and monitoring through the Asphalt Research Consortium (ARC) with Peter Sebaaly from the University of Nevada Reno
iii. SD2008-03 with Sebaaly to evaluate Warm Mix in South Dakota
iv. Evaluate coefficient of thermal expansion in SDDOT's concrete lab and develop a database based on SDDOT's concrete mixes

SDDOT has created a short-term, mid-term, and long-term implementation plan. In these stages, they hope to move towards full implementation after the next four years. Table 3.1 displays these termed plans and the associated goals.

Table 3.1 SDOT Implementation Term Plans

Short-Term (1-3 years)	• Review inputs' significance using MEPDG Version 1.0 • Assess training needs and begin training • Begin database compilation using non-project specific data • Review recommendations for model calibration
Mid-Term (2-4 years)	• Conduct preliminary calibration of models • Acquire new equipment as needs define • Train personnel in new testing requirements • Begin using MEPDG alongside existing pavement design procedure • Develop MEPDG documentation and guidelines • Calibrate and validate models • Determine any further data collection needs
Long-Term (> 4 years)	• Move towards full implementation of MEPDG • Develop a design catalog for standard designs

Wyoming DOT Implementation of MEPDG

The Wyoming Department of Transportation (WYDOT) wants a program that is implementable in a reasonable amount of time. Pavement design is housed within the materials program in WYDOT and is centralized. This results in good communications among the pavement engineers who are also the materials engineers. As a result of the program being centralized, there is a small staff which means training and implementation should be fairly easy. However, because of the small staff, difficulties arise in calibration and input development. That is, the centralized operation doesn't have district advice from the various regions in the state. WYDOT feels the MEPDG would be utilized well for the state's high volume roads, such as I-80, but the 1993 AASHTO guide is adequate for other roads. This led to the desire to implement the MEPDG because the 1993 AASHTO guide kept adding pavement thickness to I-

80. WYDOT started an implementation plan in 2006 but it primarily focused on the materials side of the MEPDG and went onto the "back burner." It was found that this plan was too aggressive at the time. WYDOT has created new implementation goals. These goals include finding a good funding source and starting a program that will be usable and implementable by 2011. WYDOT wants to use existing information wherever possible and reduce the level of inputs. WYDOT has begun working with Applied Research Associates (ARA) to get the experience desired to run the program. WYDOT wants to utilize ARA because they are also working with neighboring states that have a more aggressive implementation plan. WYDOT narrowed things down to focus on primary design and rehab alternatives. They plan to utilize existing sites for calibration and focus on level 2 and level 3 inputs. One goal is to create a Wyoming specific design manual that focuses on the inputs. Eventually, WYDOT wants to implement it for all pavement designs. WYDOT is in more of a rehabilitation mode rather than new construction mode; for example, most projects in Wyoming involve widening and/or overlays. This is a weaker area in the guide, but it is where WYDOT wants to focus. WYDOT faces challenges with climate data, traffic inputs, and materials inputs. For climate inputs, there are not enough existing weather stations, so interpolation will have to suffice. WYDOT has good count and classification data for the traffic inputs, but there is a limited number (only 9) of weigh in motion (WIM) sites in the state. The result is limited WIM coverage because most of them are on high traffic routes, such as I-80 and I-25. In the materials area, correlation of the R-Value to M_R and back-calculations from FWD will pose a challenge. Furthermore, the properties of existing HMA layers are insufficient and there are not a lot of existing data for concrete inputs. Finally, the challenges with calibration-validation involve few granular base sites, no Superpave mixture sites, and no dowelled PCCP sites.

3.2.3 Ongoing Research

Throughout the North-West states involved in the user group meeting, there is a lot of ongoing research to move the implementation of the MEPDG forward. This research has focused primarily on three main areas in the MEPDG: traffic, climate, and materials. Also, calibration and validation of the model specific to the agency is an area of research.

Traffic

The majority of research in this area is being performed by OSU and is focused on Axle Load Spectra, which is a valuable dataset that can be used for traffic inputs within the MEPDG. OSU recently completed research on WIM sites throughout Oregon. They are currently working on traffic lane instrumentation. WSDOT is also performing research on the traffic data collection effort, focusing on traffic data preparation, Axle Load Spectra development, and sensitivity analysis. The main objective of both WSDOT and OSU is how to best collect traffic data for use in the MEPDG.

Climate

Research in Illinois is being conducted on the effects of climate change on rigid pavements in that state. Five regions in Illinois host research tools for climate effects, and give a large range of coverage with varying types of climates. A preliminary conclusion is that climate effects may change the slab thickness by 1.5 inches. Illinois is also researching temperature curling in their rigid pavements. The Idaho Department of Transportation and the University of Idaho have been researching the environmental variation effects in the MEPDG design. They are developing seasonal shift factors for various regions and trying to implement these shift functions into the M-E design process to predict the accumulated seasonal damage. From this research, they are developing a software package called WINFLEX that is M-E overlay design software for Idaho.

Materials

There is a great amount of research being performed on the materials side of the MEPDG. These research projects are being performed by a majority of the states and include:

i. ODOT & OSU - How to run pavement rehabilitation using FWD back calculations. The current recommendation of this research is to utilize EVERCALC as the software program for back calculations.
ii. ODOT – How to model composite pavements. This research is focusing on the MEPDG modeling of composite pavements such as HMA overlays on top of CRCP, JPCP, or Rubblized PCC.
iii. SDDOT - SD2008-10 determine resilient modulus and dynamic modulus values for soils and asphalt mixes typically used in South Dakota
iv. SDDOT - M-E/PDG design, validation testing, and monitoring through the Asphalt Research Consortium (ARC) with Peter Sebaaly from the University of Nevada Reno
v. SDDOT - SD2008-03 with Peter Sebaaly from the University of Nevada Reno to evaluate warm mix in South Dakota
vi. SDDOT - Evaluate coefficient of thermal expansion in SDDOT's concrete lab and develop a data base based on SDDOT's concrete mixes
vii. Jon Epps – Characterizing asphalt mixtures with RAP. This research studies the influence of RAP on MEPDG models
viii. Alaska DOT –How to characterize non-standard materials
ix. Alaska DOT – How to characterize soils and unbound materials
x. Harold Von Quintus of ARA – How to characterize wearing surfaces such as SMA, OGFC, and rubber modified surfaces.

Calibration-Validation

Oregon DOT, OSU, and Washington DOT are currently working on how to calibrate and validate performance curves within the MEPDG.

3.2.4 Future Direction of MEPDG

Session four of the meeting focused on the future direction of the MEPDG. This was an open forum type of discussion where challenges and barriers were discussed and established. The group decided that the following are the challenges and barriers associated with the MEPDG:

i. Cost of the software through AASHTO Darwin M-E is a big issue for the participating states. The states may be able to afford the software but consultants, cities, and counties may not be able to purchase it.
ii. Acquiring field performance data to calibrate, e.g., top-down or bottom-up AC fatigue cracking identification.
iii. Lack of a design catalog and the creation of a design catalog
iv. Communicating to industry about MEPDG and future changes
v. Posting or Web hosting discussions and presentations from other regions
vi. Sharing calibration information from other states in the region

It was also evident at the user group meeting that Washington and Oregon are the furthest along with evaluating the MEPDG, and so these agencies were deemed the regional experts for the North-West region. These agencies will therefore be the leaders of the implementation process for the region and will be the ones to turn to for guidance. Furthermore, the group discussed the limitations they have found with the MEPDG. This was also an open discussion where the following limitations were voiced:

i. Studded tire / mechanical wear and IRI prediction for PCC (WSDOT)
ii. Longitudinal cracking prediction on concrete pavement (WSDOT)
iii. Field definition of top-down and bottom-up fatigue cracking
iv. Rehabilitation and back calculation
v. Use of geotextiles (Wyoming)
vi. Low volume roads
vii. Aggregate base rutting is too high, which forces more AC (Idaho)
viii. Thermal cracking model prediction (SDDOT)
ix. Non-standard materials (FDR, foamed asphalt, RAP, OGFC)
x. Thin AC surfacing and predicted distresses

Finally, the group discussed the need for MEPDG regional pooled fund studies and future meetings. The following ideas were developed by the user group:

i. Asphalt Research Consortium (ARC) study from the University of Nevada-Reno to monitor and test Superpave mixtures and MEPDG flexible structures
ii. Regional material and performance database
iii. MEPDG forum to share and discuss technical issues in the northwest region. This will be more useful than a training class on operating software. Face-to-face meeting was useful, but Webinar helps meet larger audience. Host Webinar meetings at FHWA division office.

This concluded the North-West states user group meeting related to the implementation of the MEPDG.

3.3 Section Summary

This section outlined the regional as well as the national implementation of the MEPDG. The section focused on the presentations delivered by the various DOTs in the North-West states for the implementation plans of the MEPDG that attended the user group meeting in Oregon. The section also outlined areas in which more research was needed and also the future direction of the MEPDG.

4. CHALLENGES AND LIMITATIONS TO MEPDG IMPLEMENTATION

4.1 Background

With the ongoing efforts of trying to adapt the MEPDG, there are many challenges and opportunities that have arisen in the implementation of the MEPDG. One of the major challenges is the participation or “buy-in” of the agencies to eventually make the MEPDG a tool for routine, day-to-day production work. This includes the agency as a whole to accept and embrace the change brought about by the MEPDG, and also the staff, including, but not limited to, administrators, regional offices, designers, engineers, material specialists, etc. Following the buy-in by agencies come effective implementation plans. These include responsibilities, timelines and gathering and allocating resources, such as people, equipment, training, etc. Also involved in an effective implementation plan are the calibration tasks and schedule to allow for more localized use of the MEPDG. Another challenge in the implementation of the MEPDG is developing the criteria to warrant implementation. This may include objectively based performance indicators (rutting, cracking, etc.), a committee to oversee and steer the use of the MEPDG, an audit process and update and improvement assessments(Haas, et al. 2007).

Finally, the development of database support is a lofty challenge but a necessary step towards the calibration and implementation of the MEPDG(Wang, et al. 2007). The above named challenges are important to the implementation of the MEPDG; but overlooked as the biggest challenge and opportunity facing many agencies are calibration and validation. There is a need for actual calibration and validation models for all aspects of the MEPDG. Calibration or adjustment factors for the IRI and distresses (rutting, cracking, etc.) are needed. Two key aspects are critical to a successful rutting model calibration: data and method. Regarding data, existing in-field information only provides total rut depth, which could not meet the requirement of permanent deformation in each structural layer by the MEPDG. Concerning the method, existing work either fails to address calibration factors from a holistic perspective by only focusing on individual sections separately or ignores variability inherent in those factors. In this study, layer-wise permanent deformation from instrumented pavement under accelerated pavement testing serves to accommodate the models calibration. A systematic calibration procedure is established, which globally optimizes all available information across all test sections. Through simulation and numerical optimization, optimal calibration shift factors for three typical flexible pavement materials, asphalt mixture, unbound granular base, and fine grain soil are obtained as 0.60, 0.49, and 0.84, respectively (Hong and Chen 2008). This implies that the uncalibrated MEPDG is biased toward over prediction of rut depth. It is further suggested that a more rational result for each calibrated factor is to introduce an appropriate distribution to characterize its uncaptured variability (Hong and Chen 2008). Databases of local and regional material and subgrade properties, along with climatic or environmental conditions, are necessary. Moreover, guidelines for the calibration and validation procedures are going to be needed. Finally, data collection is a must for the calibration effort. This includes traffic data (axle load spectra, volume variations, lane distribution, etc.) and climate and moisture data for the EICM. With these challenges come opportunities, mainly the opportunity to create a new level of advance pavement design that is based on the best science and engineering available. In other words, designing and constructing the most cost effective, longest lasting roadways that are of the highest level of reliability(Haas, et al. 2007).

Also at the North-West MEPDG User Group meeting held at OSU, the group concluded that the following are the challenges associated with the MEPDG:

i. Cost of the software through AASHTO Darwin M-E is a big issue for the participating states. The states may be able to afford the software but consultants, cities, and counties may not be able to purchase it.
ii. Acquiring field performance data to calibrate, e.g., top-down or bottom-up AC fatigue cracking identification.
iii. Lack of and the creation of a design catalog
iv. Communicating to industry about MEPDG and future changes
v. Posting or Web hosting discussions and presentations from other regions
vi. Sharing calibration information from other states in the region

The user group also came up with the following limitations associated with the MEPDG:

i. Studded tire / mechanical eear and IRI prediction for PCC (WSDOT)
ii. Longitudinal cracking prediction on concrete pavement (WSDOT)
iii. Field definition of top-down and bottom-up fatigue cracking
iv. Rehabilitation and back calculation
v. Use of geotextiles (Wyoming)
vi. Low volume roads
vii. Aggregate base rutting is too high, which forces more AC (Idaho)
viii. Thermal cracking model prediction (SDDOT)
ix. Non-standard materials (FDR, foamed asphalt, RAP, OGFC)
x. Thin AC surfacing and predicted distresses

4.2 Section Summary

This section described the challenges to the MEPDG implementation in the MPC region. Among the challenges identified at the MEPDG user group meeting included cost of the software through AASHTO, acquiring field performance data to calibrate, lack of and the creation of a design catalog, communicating to Industry about MEPDG and future changes, posting or Web hosting discussions and presentations from other regions, and sharing calibration information from other states in the region. It was also determined that training may be one of the major issues in the implementation of the MEPDG. There are a lot of unknowns associated with the MEPDG.

5. IDENTIFYING RESEARCH NEEDS

5.1 Background

It is obvious that the future adoption of the MEPDG will have considerable effects on data collection, material testing, and pavement design procedures. The mechanistic–empirical procedures upon which the guide is based will require greater quantity and quality of input data in the following four major categories: traffic, material characterization, environmental variables, and historical pavement performance (pavement response and distress) (Schwartz 2007). Input data requirements for the MEPDG are much more extensive than for the current AASHTO Design Guide procedure. Although some of the data for the MEPDG are similar to that for the AASHTO guide (e.g., annual average daily truck traffic, vehicle class distributions, subgrade resilient modulus, concrete modulus of rupture and modulus), much is significantly different; more detailed input information may be required (e.g., axle load distributions by axle type, asphalt concrete dynamic modulus, thermo-hydraulic properties for unbound materials, etc.). Due to the extensive data requirement for the MEPDG, there is currently extensive ongoing research into different areas of the guide in order to facilitate the implementation of the MEPDG in the North-West states' DOTs. Most DOTs in the region are currently concentrating their research efforts in the areas of traffic, climate, materials, and pavement response and distress models (pavement performance). Calibration and validation of the MEPDG to local conditions, which are agency specific, are also areas most of the agencies are studying. Research studies being undertaken at the national level are mostly associated with the prediction models of the MEPDG and with version 2.0 of DARWin-ME. These include NCHRP 9-30A – Calibration of Rutting Models for HMA Structural and Mix Design, NCHRP 9-41 – Reflection Cracking of HMA Overlays, and NCHRP 9-42 – Top-Down Cracking of HMA and NCHRP 9-44A – Application of the Endurance Limit for HMA mixes. This report classifies the MEPDG research needs in to national and regional categories, and are detailed in the following sections.

5.2 National Research Needs

Current national research focuses on the predictive models and other areas of the MEPDG, and are associated with version 2.0 of DARwin-ME. The predictive models being studied related to Hot Mix Asphalt (HMA) mixes. Some of these studies are currently ongoing, and it is envisaged that when completed will address various aspects of the guide and help facilitate its implementation. The research being undertaken as part of the predictive models of the MEPDG would still have to be calibrated and validated to local conditions specific to an agency, since the calibration and validation efforts are a continuous process. Research areas are discussed in detail in the following sections.

5.2.1 NCHRP 9-30A – Calibration of Rutting Models for HMA Structural and Mix Design

This research study is currently ongoing and seeks to recommend revisions to the current HMA rutting prediction model in the MEPDG and software developed in NCHRP Project 1-37A. The research is being undertaken by ARA Inc. When completed, the company will submit its recommendation to NCHRP Project 1-40 panel and the AASHTO Joint Task Force on Pavements for consideration. According to ARA Inc., the recommended revisions will be based on the calibration and validation of distress models with measured materials properties and performance data from existing fields and other full-scale pavement sections that incorporate modified as well as unmodified asphalt binders. It is intended that this research will enhance the accuracy of the distress prediction model in the MEPDG and offer an acceptable correlation between the levels of permanent deformation observed in the field and the levels predicted with the HMA distress models used in the structural and mix design. Also according to the company, this study will be building on the product of NCHRP Project 9-30. The results from these measured materials properties will then be used to calibrate and validate the HMA rutting distress model in the MEPDG to further improve its goodness-of-fit and overall accuracy. The ARA indicates that consideration will also be given to calibration and validation of other promising models of HMA rutting distress (Quintus and Harrigan 2005).

5.2.2 NCHRP 1-41 – Reflection Cracking of HMA Overlays

Even though preliminary models for predicting the extent and severity of reflection cracking in HMA overlays have been developed, only limited research has been performed to evaluate and validate these models. Research is therefore needed to address the issues of reflection cracking and develop mechanistic-based models for use in the MEPDG for the analysis and design of HMA overlays. In this respect, the Texas A&M Research Foundation is currently undertaking a study called Reflection Cracking of Hot-Mix Asphalt Overlays. The purpose of the study is to identify and develop mechanistic-based models for predicting reflection cracking in HMA overlays of flexible and rigid pavements and associated computational software for use in mechanistic–empiricalprocedures for overlay design and analysis. Studies show that reflection cracking is one of the primary forms of distress in HMA overlays of flexible and rigid pavements. Not only does the penetration of water and foreign debris into these cracks accelerate the deterioration of the overlay and the underlying pavement, but it also affects ride quality, consequently reducing service life. Research indicates that the basic mechanism that causes reflection cracking is strain concentration in the overlay due to movement in the existing pavement near joints and cracks. This movement may be induced by bending or shear action resulting from traffic loads or temperature changes and is influenced by traffic volume and characteristics, daily and seasonal temperature variations, and other factors (e.g., pavement structure and condition, HMA mixture properties, and the degree of load transfer at joints and cracks). The research is intended to help account for the effects of reflection cracking on pavement performance, thus improving the analysis and design of HMA overlays of flexible and rigid pavements (Lytton and Hanna 2005).

5.2.3 NCHRP 1-42A – Top-Down Cracking of HMA

Studies have determined that load-related HMA fatigue cracks do not always initiate at the bottom of the HMA layer and propagate to the top, but can also be initiated at the surface of the pavement and propagate downward through the HMA layer. These studies have determined that environmental conditions, tire-pavement interaction, mixture characteristics, pavement structure, and construction practices are among the factors that influence the occurrence of these cracks. Hypotheses regarding the top-down cracking mechanisms have been suggested; test methods for evaluating HMA mixture susceptibility to cracking have been proposed; and preliminary models for predicting crack initiation and propagation have been developed. However, only limited research has been performed to evaluate and validate these hypotheses, test methods, and models. Thus, research is needed to evaluate these hypotheses and develop models for predicting initiation and propagation of top-down cracking in HMA layers. This research, currently being undertaken by the University of Florida is a follow up from NCHRP Project 1-42, which was completed in 2005 and provided further review of some of the issues related to top-down cracking. The project identified mechanisms that govern initiation and propagation of top-down cracking, laboratory tests of HMA mixtures for determining susceptibility to top-down cracking, significant factors associated with the occurrence of top-down cracking, and models for predicting the initiation and propagation of top-down cracking in HMA layers. The report further indicated that additional research was needed to address the issues associated with top-down cracking and to develop mechanistic-based models for use in mechanistic–empirical procedures for design and analysis of new and rehabilitated flexible pavements. It was in this regard that the NCHRP Project 1-42A was initiated. But a recent Transportation Research Board report indicates that the follow-up to research NCHRP Project 1-42A has just been completed with a revised report due last February. The purpose of the

NCHRP Project 1-42A was to identify and develop mechanistic-based models for predicting top-down cracking in HMA layers for use in the MEPDG for design and analysis of new and rehabilitated flexible pavements (Reynaldo and Hanna 2006).

5.2.4 NCHRP 9-44A – Application of the Endurance Limit for HMA mixes

Performance data from well-constructed flexible pavements with a thick HMA structure, some of which have been in service for more than 40 years, show that bottom-up fatigue cracking does not occur in these pavements. This field experience suggests that an endurance limit, which is the level of strain below which fatigue damage does not occur for any number of load repetitions, is a valid concept for HMA mixtures; its quantification could aid in the efficient design of long-life flexible pavements with a significantly reduced life cycle cost (National Center for Asphalt Technology - NCAT). But reports suggest that no strain level in an asphalt layer below which fatigue damage does not occur, known as the endurance limit, has been established for HMA pavements. Defining an endurance limit for HMA mixtures will result in more efficient structural design of pavements for mixtures of different characteristics. Pavement design approaches, such as the 1993 AASHTO pavement design guide and the Mechanistic–Empirical Pavement Design Guide developed in NCHRP Projects 1-37A and 1-40, do not recognize endurance limits for HMA pavements. This is because research into the fatigue of HMA mixtures has been limited. According to a report released by the TRB, in order to conduct research into this area of HMA pavements, studies were conducted in three parts with the first part, NCHRP Project 9-38, initiated in 2004 and completed in December 2009 with the final report due to be published in early 2010. This part was conducted by the National Center for Asphalt Technology at Auburn University. NCHRP Project 9-38 was conducted to establish the existence of an endurance limit for HMA mixes. This was followed by the second part, NCHRP Project 9-44, initiated in 2007 and completed in 2009 by Advanced Asphalt Technologies, LLC. Having already undertaken NCHRP 9-38, the purpose of this research was to prepare research plans to validate the existence of an endurance limit for HMA mixes in pavements through an analysis of laboratory and field data, determine the difference between the endurance limits for HMA mixes measured in the laboratory and the field, and identify and recommend methodologies for incorporating an endurance limit in HMA mixes for the mechanistic–empirical pavement design. Currently the only active part of this three-part research NCHRP Project 9-44A, is being undertaken by Arizona State University and due to be completed in 2012. The purpose of the third research study in the series on endurance limits for HMA pavements is to undertake laboratory investigation to identify the mixture and pavement layer design features related to an endurance limit for bottom-initiated fatigue cracking of HMA and develop a systematic procedure for incorporating this endurance limit into the MEPDG and other selected pavement design methods. It is intended that the implementation of a fully characterized and validated endurance limit in the mechanistic–empirical pavement design guide (MEPDG) software will enhance the ability to prepare long-life HMA pavement designs that achieve a balance between practical layer thickness and desired fatigue performance. It is also suggested by those undertaking the research that a future Project 9-44B is anticipated to conduct field validation of the endurance limit algorithm and further revise the algorithm as determined by the results of the field validation (Witczak and Harrigan 2009).

5.2.5 Rehabilitation of Flexible and Rigid Pavements

Another area that appears to have a national research focus is the recommendations on the rehabilitation of both flexible and rigid pavements. From all indications this appears to be the weakest part of the recently developed MEPDG. The guide seems to have focused mainly on the issue of new flexible and rigid pavement design rather than techniques for selecting the optimal pavement rehabilitation. This is a challenge as most DOTs are now frequently more interested in selecting the optimal rehabilitation technique for existing roadway pavements than designing new ones. A study is therefore proposed to update the rehabilitation recommendations in the MEPDG and to provide DOTs with state of the art approaches for both pavement forensic investigations and strategy selection guidelines. The proposed study will provide DOTs with guidelines on how to conduct failure investigations based on the existing pavement distress and type (Claros 2007).

5.2.6 Coefficient of Thermal Expansion

The coefficient of thermal expansion of concrete is another area with a national research focus. Several studies in the past few years have identified the coefficient of thermal expansion (CTE) as one of the most significant inputs or classified as an extremely sensitive input in the MEPDG for designing rigid pavements. The CTE can affect the performance of concrete pavement and its service life. CTE tends to affect the curling and axial stresses and, as a result, affects the performance and serviceability of the pavement structure and also has influence on early age cracking, fatigue cracking, faulting, and joint spalling from CTE. Values of CTE tend to depend on the concrete composition, age, and moisture state and can vary extensively among aggregates due to mineralogical differences. Even the same aggregate type can present different CTEs as a result of the differences in the mineralogical content (Elfino, et al. 2009). Recent studies by the FHWA have identified an error in the method used to measure the CTE of concrete. The report indicates that both LTPP and non-LTPP rigid pavement projects were used to calibrate the rigid pavement models for the MEPDG (LTPP accounted for over 85% of the sections used in the calibration). Therefore, all of the CTE results reported in the LTPP database need to be adjusted. This data were used to nationally calibrate the models in the MEPDG, and due to the magnitude of the adjustment required, the models need to be recalibrated to avoid improper designs due to the use of lower CTE values with models based on the higher CTE values. If the models are not recalibrated, the pavement thickness may be underestimated (NCHRP Report 20-7 2009).

5.2.7 Effect of Geogrids and Geotextiles

Studies have shown that properly installed geosynthetics can generate considerable cost savings and improved performance of aggregate base courses used in highway pavement construction. The use of geosynthetics can produce significant economic benefits, such as the reduction in required thickness of the pavement structure for a given level of performance, with reductions as great as 11 inches being reported in some cases. Other advantages of using geosynthetics in pavement construction include the ability to extend pavement service life without increasing pavement thickness and without sacrificing performance. Reports suggest that while many agencies are currently using geosynthetics, there is a significant lack of understanding of the fundamental properties of these materials, thereby forcing designers to rely on conservative estimates when considering the contribution of geosynthetics in the performance of the pavement structure. It is imperative that a deeper understanding of the interactions between geosynthetics and aggregate base courses is needed, as well as a more fundamental method and guidelines for incorporating the properties of geosynthetics into existing pavement design practices, such the new MEPDG (AASHTO Joint Technical Committee on Pavements 2009).

5.3 Regional Research Needs

Inasmuch as further research and study are needed and being undertaken on the MEPDG at the national level, state DOTs seeking to implement the MEPDG have also identified various areas in which further research is needed to help facilitate the regional implementation of the MEPDG. At the North-West user group meeting, held at Oregon State University March 9-10, 2009, it was evident that additional research into the MEPDG was necessary. It is against this background that almost all the states in the North-West region are undertaking further research into the MEPDG. The areas that most DOTs are focusing on are traffic, climate, materials, and pavement response and distress. Calibration and validation of the MEPDG to local conditions also needs to be undertaken on a continual basis. These research areas are outlined in the subsequent paragraphs.

5.3.1 Traffic Data Characteristics

Traffic characteristics are one of the major inputs of the MEPDG and are expected to require significant attention. The current AASHTO Pavement Design Guide requires traffic data in ESALs as a major design input. The MEPDG traffic criteria have been developed around axle load spectra, which are a valuable dataset that can be used for traffic inputs within the MEPDG. It is through axle load spectra that the unique traffic loadings of a given site are characterized. By means of these loading characteristics, pavement responses and resulting damages can be computed. Full axle load spectra are used for estimating the magnitude, configuration, and frequency of traffic loads (Wang, et al. 2007). The benefit of load distributions is that they provide a more direct and rational approach for the analysis and design of pavement structures. The approach estimates the effects of actual traffic on pavement response and distress. Currently in the North-West Region, the Oregon Department of Transportation (ODOT) in collaboration with Oregon State University, is concentrating their research efforts mostly in the area of the axle load spectra before going on to other areas. Consequently, OSU recently completed research on Weigh in Motion (WIM) sites throughout Oregon and is now working on traffic lane instrumentation. The other area of traffic characteristics is traffic data collection, which is being undertaken by the Washington State Department of Transportation (WSDOT). As part of the research, WSDOT is working on traffic data preparation, axle load spectra development, and sensitivity analysis. The underlying objective for both WSDOT and OSU in undertaking this research is how best to collect realistic traffic data for use in the MEPDG. Data sources may include site-specific data from Average Vehicle Counts (AVC) and WIM stations and default data from the FHWA LTPP program and the MEPDG software. The traffic data should contain the following elements if possible: truck volume and highway parameters, monthly traffic volume adjustment factors, vehicle classification distribution, hourly traffic volume adjustment factors, axle load distribution factors, traffic growth factors, number of axles per truck, lateral traffic wander, and the axle configuration.

5.3.2 Climatic/Environment Factors

Climate and the surrounding environment (weather) play an important role in pavement performance and thus have a major impact on the pavement’s long-term performance. It can exert significant influences on the pavement structure, especially where seasonal changes are large. These factors include precipitation, temperature, and free-thaw cycles together. Changes in temperature, precipitation, and frost depth can drastically affect pavement performance. The behavior of layers in the pavement system is affected by climatic factors (Johanneck and Khazanoch 2009), and the MEPDG requires these inputs to be locally calibrated. As a result, these climate conditions need to be observed and correlated to pavement performance. One climatic factor that greatly influences pavement material properties is moisture, which can affect properties such as stiffness and strength and therefore needs to be examined. A preliminary conclusion, deduced from research conducted in Illinois on the effects of climate change on rigid pavements in that state, indicates that this may change slab thickness by 1.5 inches. The Idaho Department of Transportation and the University of Idaho have also been researching the environmental variation effects in the MEPDG design. They are developing seasonal shift factors for various regions and are trying to implement these shift functions into the MEPDG process to predict the accumulated seasonal damage. From this research, they are developing a software package called WINFLEX, a mechanistic–empirical overlay design software for Idaho.

5.3.3 Materials Characterization

Material characterization for the mechanistic–empirical design procedure is significantly more fundamental and extensive than in the current empirically-based AASHTO Design Guide. The MEPDG requires the use of material properties of the pavement layers to create a mechanistic analysis of the pavement responses. It is therefore imperative that databases or libraries of typical material property inputs must be developed. Due to the extensive nature of the material inputs, a great deal of current research is being performed on pavement materials characterization of the MEPDG. One study focuses on how to run pavement rehabilitation using FWD back calculations. The ODOT and OSU are undertaking this study for which their current recommendation for this research is to utilize EVERCALC as the software program for back calculations. ODOT is researching MEPDG modeling of composite pavements such as HMA overlays on top of CRCP, JPCP, or rubblized PCC. Other future research that OSU/ODOT plans to undertake includes HMA density, open graded HMA, Recycled Asphalt Pavement (RAP) mixtures, Recycled Asphalt Shingle (RAS) mixtures and Asphalt Mixture Performance Tester (AMPT) pool fund study. The South Dakota Department of Transportation, on the other hand, is currently undertaking research on how to determine resilient modulus and dynamic modulus values for soils and asphalt mixes typically used in South Dakota. Also in collaboration with Peter Sebaaly from the University of Nevada Reno, SDDOT is undertaking validation testing and monitoring through the Asphalt Research Consortium (ARC). SDDOT is also seeking to evaluate coefficient of thermal expansion and develop a database based on the DOT's concrete mixes. In addition to this, they are seeking to evaluate warm mixes as applied to the MEPDG. Other areas of research into pavement materials being undertaken include characterization of asphalt mixtures with RAP to observe the influence of RAP on MEPDG models and how to characterize wearing surfaces such as SMA, OGFC, and rubber modified surfaces. The Alaska DOT is also currently studying how to characterize non-standard materials, soils, and unbound materials.

5.3.4 Pavement Performance

Pavement performance data are required for local calibration and validation of the MEPDG procedure and are mainly associated with pavement distresses. These include fatigue cracking (alligator and longitudinal), rutting and roughness. An accurate record of historical pavement performance, which in most cases is within an agency's PMS, is therefore a necessity. The MEPDG does not provide a design thickness but it uses mechanistic–empiricalnumerical models to analyze input data for traffic, climate, material, and proposed structure and then estimates the damage accumulation over the service life of the pavement. The pavement performance predictions within the MEPDG are made in terms of the distresses, which are often evaluated to determine rehabilitation and reconstruction needs in HMA pavements (Hoegh, et al. 2009).

5.3.5 Calibration and Validation

Currently, the MEPDG includes empirical distress models that have been calibrated using a national database. Most of the data used for the national calibration were obtained from the Long Term Pavement Performance (LTPP). It is therefore necessary that calibration of the MEPDG models be undertaken using local pavement condition data (Souliman, et al. 2009). In order to successfully calibrate and validate the MEPDG procedure to local conditions, pavement performance data are required. The process involves the replacement of the of the national calibration coefficients in the empirical distress prediction models with values more suited to local conditions. The calibration process usually requires the selection and identification of a set of experimental pavement sections; MEPDG inputs, such as traffic, environment, and material properties, can be well quantified and for which a history of pavement performance data, such as rutting, fatigue cracking, and roughness, are available. All of the above mentioned pavement distresses need to be calibrated to local conditions. Studies have shown that local calibration of the MEPDG procedures can be very beneficial in improving pavement performance predictions for local conditions. A well calibrated prediction model results in a reliable pavement design and enables precise maintenance plans for state highway agencies. The process, however, requires a significant amount of effort to perform (Schwartz 2007).

5.4 Section Summary

This section described the areas in which further research is needed, both on the national and regional level in order to successfully implement the MEPDG. The main areas of research that most DOTs are focusing on in the region are the traffic, materials, and climate inputs and pavement performance distress models. These model inputs are required in order for the MEPDG distress models to reliably predict the pavement performance. These areas of research are also needed in order to successfully calibrate and validate the MEPDG to local pavement conditions. It is by calibrating and validating the MEPDG to local pavements conditions that reliable predictions of the pavement can be obtained.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Ongoing research suggests that with the Mechanistic Empirical Pavement Design Guide (MEPDG), it is anticipated that a more reliable design will be created (Wagner), which provides significant potential benefits over the 1993 AASHTO guide in achieving cost-effective pavement designs and rehabilitation strategies (Coree, et al. 2005). A very important aspect of the MEPDG is its user-oriented computational software program, which uses an integrated approach for predicting pavement condition over the design life by accounting for the interaction of traffic, climate, and pavement structure, and also allows for evaluating design variability and reliability. The software will also serve as a forensic tool for analyzing the condition of existing pavements and pinpointing deficiencies in past designs (Coree, et al. 2005). The MEPDG will allow pavement engineers and designers to make better informed decisions and take cost effective advantage of new materials and features. The adoption of the MEPDG will significantly improve pavement material testing, design procedures, and, most importantly, data collection (Schwartz 2007). The design guide will also allow for calibration to national, regional, or local performance data for materials, climate, and traffic (Wagner), thereby allowing agencies the greatest possible flexibility for applying and calibrating the design procedures to their local conditions (Schwartz 2007). Despite the significant benefits associated with the implementation of the MEPDG, its extensive data requirements from traffic, material, and climate inputs, however, pose some challenges. A number of further research areas have also been identified for the MEPDG at the national, regional, and local levels which, when successfully completed, will facilitate its implementation. It was therefore the objective of this study report to identify further research needs which are considered very important and necessary to facilitate the implementation of the MEPDG. Consequently, at the North-West States MEPDG User Group Meeting held March 9-10 in Oregon, the main national research areas of the MEPDG identified included: NCHRP 9-30A – Calibration of Rutting Models for HMA Structural and Mix Design, NCHRP 9-41 – Reflection Cracking of HMA Overlays, NCHRP 9-42 – Top-Down Cracking of HMA, and NCHRP 9-38, 9-44, 9-44A – Application of the Endurance Limit for HMA mixes. Most of these research efforts are being undertaken under the National Cooperative Highway Research Program (NCHRP). Other research areas also being undertaken at the national level include the recommendation on the rehabilitation of both flexible and rigid pavements, the coefficient of thermal expansion, and the effects of geogrids and geotextiles, which can generate considerable cost savings in highway pavement construction. Further research areas at the regional level are concentrating on traffic, material and climate characteristics, and pavement performance. At the local level, the main area of research deals with the calibration of the MEPDG models to local conditions. National and regional research studies and calibration efforts being undertaken by most DOTs in the North-West region are discussed in detail in Sections 4 and 5.

6.2 Recommendations

Four critical elements have been identified as the key steps to a successful implementation of the MEPDG (North-West States User Group Meeting). These include:

i. A champion to lead the implementation effort and program
ii. Communication
iii. Training
iv. Adequate funding

It is recommended that agencies seeking to implememnt the MEPDG should seriuosly consider these critical elements as well as monitor the progress of the above mentioned ongoing further researches

(North-West States User Group Meeting). Other activities also noted and recommended that were considered necessary for an effective integration of the MEPDG in practice included:

i. Setting of up implementation committee and communications plan
ii. Confirmation of default input values and set up input libraries (traffic and material inputs)
iii. Completion of concurrent designs with the MEPDG
iv. Verification of reasonableness of final designs
v. Training in the use of MEPDG software

Of particular importance to the application of the MEPDG to local conditions was the calibration and validation of the guide, which is a continuous process. To assist in overcoming these challenges, it was recommended that agencies should:

i. Plan for and monitor future works related to updates and improvements of the MEPDG on a continuous basis
ii. Maintain a calibration-validation database along with input libraries
iii. Periodically monitor test sections, input parameters, and update the database
iv. Verify local calibration or agency specific factors for future MEPDG versions

The current calibration-validation database being developed under NCHRP Project 9-30 and being enhanced under NCHRP 9-30A provides features to store and manage data for calibrating mechanistic–empirical based methods at the national level (North-West States User Group Meeting).

At the user group meeting, it also became evident that training may be one of the current major issues in the facilitation of the MEPDG. For this, two National Highway Institute (NHI) training courses are currently available in the MEPDG, and it is recommended that agencies assist and encourage not only their pavement designers but other personnel from the areas of traffic, materials, and Pavement Management Systems (PMS) to attend these courses (North-West States User Group Meeting). These courses include:

i. NHI Course 131064 – Introduction to Mechanistic Empirical Pavement Design
ii. NHI Course 131109 – Analysis of New and Rehabilitated Pavement Performance with MEPDG Software.

It is anticipated that the MEPDG will continue to be updated with new research areas being developed, and that it will take a considerable amount of time before it becomes an accepted design guide; hence, extremely important that agencies plan and monitor future works related to updates and improvements of the MEPDG on a continual basis. It is by so doing that agencies can effectively calibrate and validate the MEPDG to suit their local conditions.

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APPENDIX A - MEPDG SURVEY QUESTIONNAIRE

MEPDG Survey Questionnaire

This survey is performed as part of an informational study conducted by the Wyoming T^2/LTAP Center. The objective of this survey is to collect information from the MPC Region DOTs about the implementation of the Mechanistic–empiricalPavement Design Guide (MEPDG). Such information will help in the facilitation of the implementation of the MEPDG in the Region. A secondary objective of this survey is to identify where research is needed to further the use of the MEPDG. The survey consists of 4 parts. Part One: General Information, Part Two: Climate/Environment, Part Three: Traffic and Part Four: Materials.

Please answer all questions as clearly as possible. Your input is very important to us and we appreciate your answers and suggestions. If you have any questions please contact Dr. Khaled Ksaibati at the Wyoming T^2 /LTAP Center (1-800-231-2815).

Name and address of person completing this survey:

____
____
____

Tel No.___________________________ Fax No.___________________________

Email: ___________________________ Date: ___________________________

PART ONE: GENERAL INFORMATION *(brief overall descriptions, more specific questions in following sections)*

1. Does your DOT currently use the MEPDG?

- ☐ Yes
- ☐ No (If no, please explain why the MEPDG is not being used and return this survey in the enclosed envelope)

____
____
____

2. Please identify who is responsible for the implementation of the MEPDG in your state.

____
____
____

3. In general, how far a long do you feel your jurisdiction is in implementing the MEPDG? (Estimated percent and brief description)

____
____
____
____

PART TWO: CLIMATE /ENVIRONMENT

1. Are you having trouble with the climate section in the MEPDG?

- ☐ Yes
- ☐ No (skip to Part Three)

2. Are your troubles in the climate section of the MEPDG coming from the Integrated Climatic Model (ICM) or collecting the necessary data for inputs?

- ☐ ICM (go to question # 3)
- ☐ Collecting Data (go to question # 4)
- ☐ Neither (please explain)

____
____
____

3. In where are your problems occurring in the ICM?

- ☐ Software problems
- ☐ Data Input problems
- ☐ Calibration
- ☐ Other

Please Explain:

____
____
____

4. In where are your problems occurring for collecting climate data?

- ☐ Weather Stations
- ☐ Temperature
- ☐ Moisture Content
- ☐ Ground Water Table
- ☐ Other

Please Describe The Problems:

____
____
____
____

5. **Do you feel the ICM correctly calibrates to your climate using local inputs?**

- ☐ Yes
- ☐ No

Please explain

____
____
____

6. **Based on the data being collected, what level of inputs are you using for the climate section?**

- ☐ Level 1 Data (most reliable and accurate)
- ☐ Level 2 Data
- ☐ Level 3 data (least reliable)
- ☐ Default Data or Other

Please explain

____
____
____

PART THREE: TRAFFIC

7. **Are you having troubles with the Traffic section in the MEPDG?**

- ☐ Yes
- ☐ No (skip to Part Four)

8. **Are your troubles in the Traffic section of the MEPDG coming from the software or collecting the necessary data for inputs?**

- ☐ Software (go to question # 9)
- ☐ Collecting Data (go to question # 10)
- ☐ Neither (please explain)

____
____
____

9. **In where are your problems occurring in the software?**

- ☐ Data Input problems
- ☐ Calibration
- ☐ Other

Please explain

____
____
____

10. In where are your problems occurring for collecting traffic data?

- ☐ Weigh-In-Motion collection
- ☐ Traffic Counters
- ☐ Axle Loads
- ☐ Axle Configuration
- ☐ Proximity to project site
- ☐ Other

Please Describe The Problems:

____
____
____
____
____

11. What type of axle distribution are you using and what problems are occurring, if any?

- ☐ Axle Load Spectra
- ☐ ESAL's

Please Describe The Problems:

____
____
____
____
____

12. Based on the data being collected, what level of inputs are you using for the traffic section?

- ☐ Level 1 Data (most reliable and accurate)
- ☐ Level 2 Data
- ☐ Level 3 data (least reliable)
- ☐ Default Data or Other

Please explain

____
____
____

PART FOUR: MATERIALS

13. Are you having trouble with the Materials section in the MEPDG?

- ☐ Yes
- ☐ No (skip to End)

14. Are y our troubles i n t he Ma terials se ction o f the ME PDG c oming from the software o r collecting the necessary data for inputs?

- ☐ Software (go to question # 15)
- ☐ Collecting Data (go to question # 16)
- ☐ Neither (please explain)

____
____
____

15. In where are your problems occurring in the software?

- ☐ Data Input problems
- ☐ Calibration
- ☐ Other

Please explain

____
____
____

16. In where are your problems occurring for collecting material data?

- ☐ Laboratory testing
- ☐ Lack of necessary equipment
- ☐ Lack of research
- ☐ Resources (human, time, etc.)
- ☐ In Sutu testing
- ☐ Other

Please Describe The Problems:

____
____
____
____

17. Based on the data being collected, what level of inputs are you using for the materials section?

- ☐ Level 1 Data (most reliable and accurate, Lab data)
- ☐ Level 2 Data (Interpolating from other data, i.e. CBR, DCP)
- ☐ Level 3 data (least reliable, based on material properties/classification)
- ☐ Default Data or Other

Please explain

____
____
____

Thank you for taking your time to answer these questions. The information you provided is essential to our project.

APPENDIX B. USER GROUP MEETING PRESENTATION

MEPDG Implementation Plan -WSDOT

March, 2009

Washington State Department of Transportation

Background

- WSDOT's current design tool
  - *The 1993 AASHTO Guide for Design of Pavement Structures*
- WSDOT's efforts on MEPDG

Washington State Department of Transportation

WSDOT's Efforts

- Data Preparation
  - Traffic
  - Materials properties
  - Pavement performance data
- Calibration and validation
  - New concrete pavements in 2005 (version 0.6)
  - New flexible pavements in 2008 (version 1.0)

Washington State Department of Transportation

Major Findings

- MEPDG is an advanced tool for pavement design and evaluation.
- Calibration is required prior to implementation.
- The concrete pavement calibration results need to be adjusted before use.
- The distress models for new flexible pavement have been calibrated to WSDOT conditions, except the IRI model.

Washington State Department of Transportation

Major Findings (cont.)

- The calibration is a continual process along with implementation.
- Local agencies need to balance the input data accuracy and costs.
- WSDOT will continue to monitor future works related to MEPDG.

Washington State Department of Transportation

Future Works

- **Expecting MEPDG upgrades**
  - Version 2.0 from AASHTO
  - Software bugs
- **Refining the calibration results.**
  - Doweled JPCP slabs
  - Superpave
- **Testing and calibrating the rehabilitation models**
  - HMA overlay on HMA
  - HMA overlay on PCCP

Washington State Department of Transportation

Future Works (cont.)

- **Preparing special designs on**
  - High traffic loads
  - Weak soil support
  - Mountain passes

Washington State Department of Transportation

Implementation Plan

- **Updating AASHTO design table (current).**
  - Performance based
  - MEPDG outputs
- **Developing a user guide.**
- **Preparing sample files for typical designs.**
- **Training pavement designers.**

Washington State Department of Transportation

Updated AASHTO Design Table

ESALs (50 yesrs)	Layer Thicknesses (inches)					
	M_R=10,000 psi		M_R=20,000 psi		M_R=10,000psi	M_R=20,000psi
	HMA	CSBC	HMA	CSBC	PCC Slab	PCC slab
1,000,000	5	8	5	2	6.7	6.1
5,000,000	6.5	9.5	6.5	3	9.1	8.6
10,000,000	7.5	10	7.5	3.5	10.4	10
25,000,000	9	11	9	3.5	11.6	11.2
50,000,000	10.5	12.5	10.5	4	12.6	12.3
≥100,000,000	11.5	14	11.5	4	13.1	12.7

Washington State Department of Transportation

Note: Has not been finalized yet.

EXPANDING THE REALM OF POSSIBILITY

Northwest MEPDG User Group
Corvallis, OR
March 9, 2009

Session 1—General Overview
MEPDG National Update

Harold L. Von Quintus, P.E.

APPLIED RESEARCH ASSOCIATES, INC.
An Employee-Owned Company

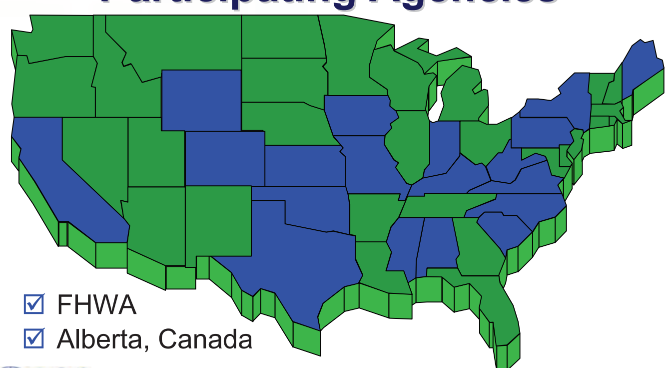
Outline

1. Version 2.0—DARWin M-E
2. Implementation—Defined
3. Key Elements or Steps of an Implementation Plan
4. Plan for Future Updates

Version 2.0—DARWin M-E

1. Initiated in February 2009.
2. 18-month duration.
3. 19 States participating in pool fund effort.

Version 2.0—DARWin M-E Participating Agencies



- ☑ FHWA
- ☑ Alberta, Canada

Version 2.0—DARWin M-E

What's going to change?

1. Computation methodology.
2. Appearance—changes in data input screens.
3. Distress transfer functions and/or distress mechanism.

AASHTO will decide what changes will be made; significant change will probably require re-ballot.

Version 2.0—DARWin M-E

How will the changes affect use of and calibration of version 1.0 transfer functions?

1. Appearance change in input screens, reduced run times—probably no affect.
2. If transfer function changes—validation & recalibration may be needed.

MEPDG Manual of Practice will be updated by contractors recommending changes to transfer functions.

Version 2.0—DARWin M-E

On-Going Studies:

1. **NCHRP 9-30A** – *Calibration of Rutting Models for HMA Structural and Mix Design.*
2. **NCHRP 9-42** – *Top-Down Cracking of HMA.*
3. **NCHRP 9-41** – *Reflection Cracking of HMA Overlays.*
4. **NCHRP 9-38, 9-44, 9-44A** – *Application of the Endurance Limit for HMA Mixes.*

Outline

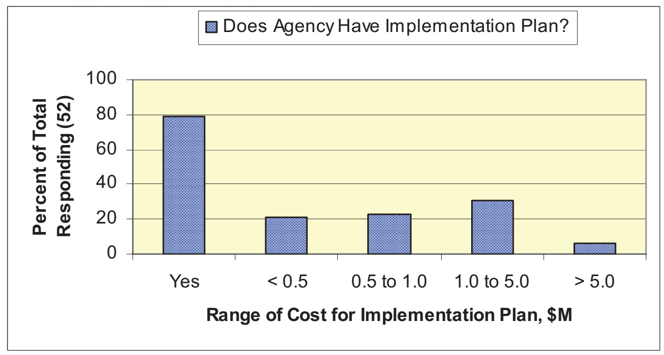
1. Version 2.0—DARWin M-E
2. **Implementation—Defined**
3. Key Steps of an Implementation Plan
4. Plan for Future Updates

Implementation—Defined

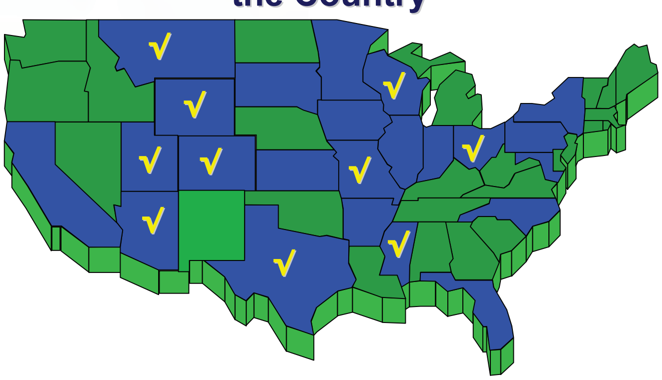
What does implementation mean?

1. Integration into day-to-day design practice.
2. Validation-Calibration of distress transfer functions to local conditions, materials, & policies.

Summary of FHWA Questionnaire



Implementation Programs Around the Country



Selected Implementation Programs Around the Country

Completed Programs:
- Missouri
- **Montana**
- Ohio
- Wisconsin

Programs, In-Process
- Arizona
- Mississippi
- Texas
- Utah

Programs to be initiated in near future:
- Colorado
- FHWA – Federal Lands
- **Wyoming**

State	Out-Source, $M	Testing Progr.	Input Libraries	Cal. Effort	Data Source	Comp. Design	Train Progr.
AZ	0.5-1.0	Ext.	Yes	Yes	LTPP	Yes	Yes
CO	>1.0	Ext.	Yes	Ext.	LTPP & PMS	Yes	Formal
MO	<1.0	Yes	Yes	Ext.	LTPP & PMS	Yes	Limit
MS	>2.0	Ext.	Yes	Ext.	LTPP & PMS	Yes	Formal
MT	**>0.5**	**Yes**	**Yes**	**Ext.**	**LTPP & Test Sec**	**No**	**Yes**
OH	<0.5	No	Limited	Yes	LTPP	Yes	Yes
TX	<0.5	Yes	Limited	Limited	LTPP	Yes	Limit
UT	>0.5	Ext.	Yes	Future	LTPP	Yes	Formal
WS	<0.5	No	Limited	Limited	LTPP	No	Yes
WY	**<0.5**	**No**	**Limited**	**Limited**	**LTPP**	**Yes**	**Formal**

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14

Local Calibration – Number of Sites

Agency	Type of Sites	Number
Missouri	LTPP & PMS Sections	HMA – 50+ PCC – 30+
Montana	**LTPP & Special Test Sections**	**HMA - 40+** **PCC - 0**
Mississippi	LTPP & PMS Sections	HMA – 100+ PCC – 30+
Utah	LTPP & Non-LTPP	Limited
Wyoming	**LTPP**	**HMA-40+**

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15

Outline

1. Version 2.0—DARWin M-E
2. Implementation—Defined
3. **Key Steps of an Implementation Plan**
4. Plan for Future Updates

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16

Key Steps of an Implementation Program

Critical Elements:

1. A champion to lead the implementation effort and program.
2. Communications
3. Training
4. Adequate funding

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Key Steps of an Implementation Program

Integration into practice activities.

1. Set up implementation committee & communications plan
2. Confirm default input values and set up input libraries (traffic & material inputs)
3. Complete concurrent designs with the MEPDG
4. Verify reasonableness of final designs
5. Training in use of MEPDG software

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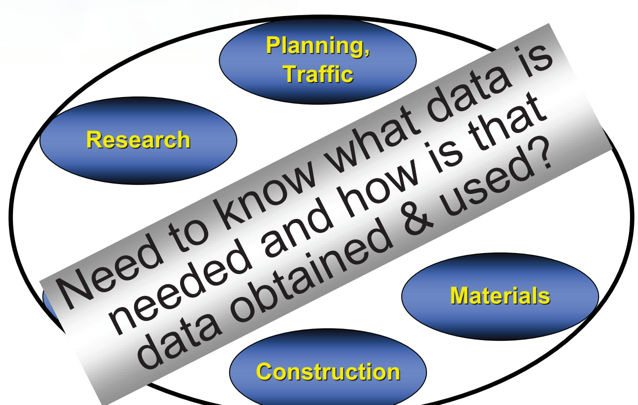
18

Communications



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Training

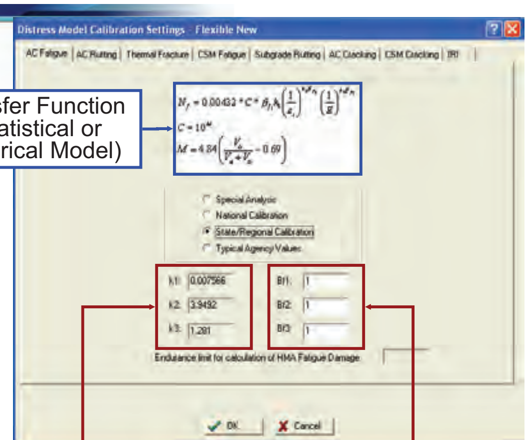
A Major Issue – The Unknowns!!

- Determination of properties & other inputs.
- Factors affecting properties needed for design!!!!
  - Source of Materials
  - Contractor
  - Construction Equipment

How do I get this input level 1 or 2 for design?

NHI Training Courses

- NHI Course 131064, Introduction to M-E Pavement Design
- NHI Course 131109, Analysis of New & Rehabilitated Pavement Performance with MEPDG Software

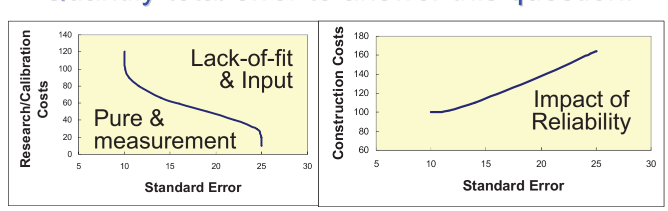


Preparing a Calibration-Validation Plan

How Close is Close Enough?

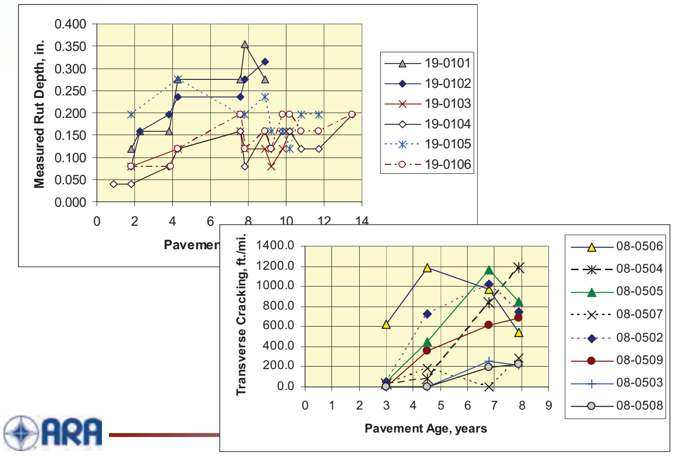
$$(\sigma_{Total})^2 = (\sigma_{Measurement})^2 + \boxed{(\sigma_{Lack-of-Fit})^2 + (\sigma_{Input})^2} + (\sigma_{Pure})^2$$

Quantify total error to answer this question!



25

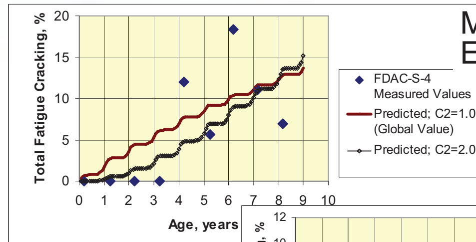
Quantify Error Components



ARA

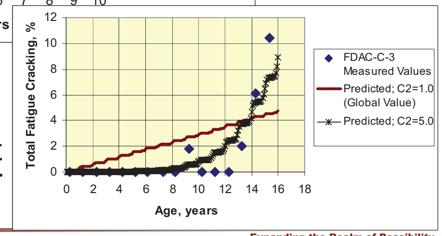
26

Quantify Error Components



Measurement Error

Lack-of-Fit Error



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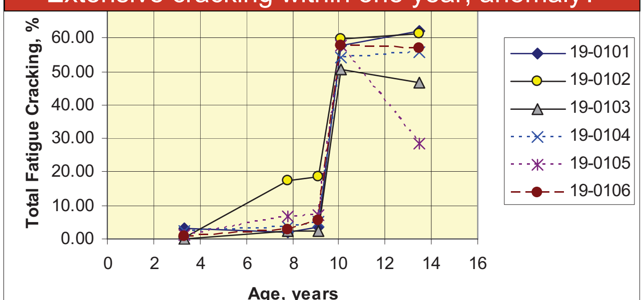
27

Quantify Error Components

Extensive cracking within one year; anomaly?



Loss of bond between HMA layers
Stripping of HMA Mixtures

ARA

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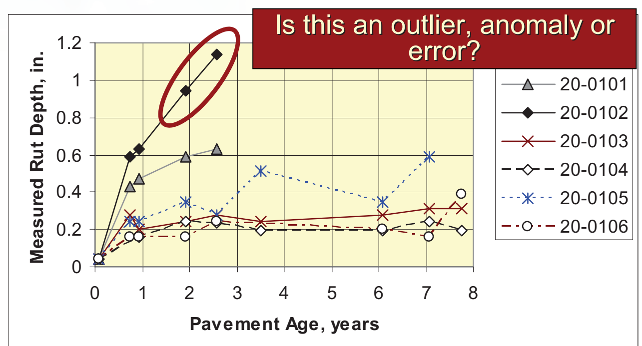
28

Quantify Error Components



Construction problems & weather delays.
Weak unbound layers.

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29

Local Validation/Calibration Guide; NCHRP Project 1-40B

Manual of Practice for Calibration:

- Mathematical models – assumed to be correct.
  - Pavement response models
  - Climatic model – ICM
  - HMA aging & PCC strength-gain model
- *Statistical or empirical models (transfer functions) may result in bias.*
  - Revision of model coefficient values to remove bias.

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30

Outline

1. Version 2.0—DARWin M-E
2. Implementation—Defined
3. Key Steps of an Implementation Plan
4. **Plan for Future Updates**

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31

Should we wait until its *PERFECT*?

- If we wait until there are no more changes, *we will never use it*.
- If we wait for perfection, *it will be impractical and cost will restrict its use*.

There is ***NO*** perfect procedure & it will never be perfect! ***SO***, plan for updates & improvements

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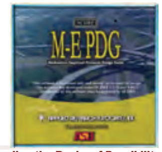
32

Planning for Future Updates

1. Maintain calibration-validation database along with the input libraries.
2. Periodically monitor test sections & input parameters & update database.
3. Verify local calibration or agency specific factors for future MEPDG versions.



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Planning for Future Updates

- **M-E_DPM**

  Calibration-validation database developed under NCHRP Project 9-30 and enhanced under NCHRP Project 9-30A. Provides features to store and manage data for calibrating M-E based methods.

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Thank you.
Any Questions?

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ODOT M-E IMPLEMENTATION PLAN

PAVEMENT SERVICES UNIT

Pavement Services Engineer
Elizabeth Hunt, P.E.
Pavement Design Engineer
Rene' Renteria, P.E.
Pavement Quality/Materials Engineer
Larry Ilg, P.E.
Pavement Management Engineer
John Coplantz, P.E.

Oregon Department of Transportation

ODOT M-E PAVEMENT DESIGN IMPLEMENTATION PLAN

OREGON STATE UNIVERSITY RESEARCHERS

Todd Scholz, Ph.D., P.E.
Pavement Design & Asphalt Materials
Jason Ideker, Ph.D.
PCC & Innovative Materials

Oregon Department of Transportation

ODOT IMPLEMENTATION PLAN

- Mechanistic-Empirical Design Literature Review
  - Research by OSU 2005-2006
- Backcalculation Software Literature Review & Evaluation
  - Research by OSU 2005-2006
  - Recommendation ***EverCalc*** (WsDOT)

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ODOT IMPLEMENTATION PLAN

- AC Dynamic Modulus Research - OSU
  - Completed November 2005
- Axle Load Spectrum Research - OSU
  - WIM - Completed January 2008
  - On-going traffic lane instrumentation

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ODOT IMPLEMENTATION PLAN

- Perpetual Pavement Instrumentation (On-going Research by OSU)
  - I-5 Jefferson Installed 2005
  - US-97 Redmond Installed 2008
  - Future installations TBD
    - I-5 Victory to Lombard (2009?)
    - I-5 South Medford Interchange (2009?)

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ODOT IMPLEMENTATION PLAN

- M-E Pavement Design Inputs Research
  - Material Characterization – Current OSU Research, Completion 2009
  - Climatic Data – OSU Research (2009) & ODOT Staff
  - Calibration – Proposed Research (Potential for FY10)

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ODOT IMPLEMENTATION PLAN

- M-E Pavement Design Inputs Research
  - HMA Density Research – OSU 2010?
  - Open Graded HMA Research –UW 2010?

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ODOT IMPLEMENTATION PLAN

- M-E Pavement Design Inputs Research
  - RAP and RAS Mixtures – Proposed Research FY10
  - Asphalt Mixture Performance Tester (AMPT) – Pooled Fund Study, Equipment Delivery Fall of 2009

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ODOT IMPLEMENTATION PLAN

- M-E Pavement Design Validation
  - Perpetual Pavement, On-going Research with OSU
  - MEPDG Program, Proposed Research (unfunded) and ODOT Staff

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ODOT IMPLEMENTATION PLAN

- ODOT Staff Pavement Design Using MEPDG
  - Interstate Projects Starting 2008
- ODOT Pavement Design Guide
  - Interim Guidance for MEPDG Use with 2009 PDG Revision (April/May 2009)
  - Individual Agreements with Consultants

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ODOT IMPLEMENTATION PLAN

- Full Implementation by 2012?

Wyoming DOT

Implementation of the MEPDG

North West States User Group Meeting
Corvallis, Oregon
March 9, 2009
Rick Harvey
State Materials Engineer

WYDOT Pavement Design

- Materials Program
- Centralized Pavement Design
- Small Staff
- Materials Engineers=Pavement Design Engineers
- MEPDG Training & Implementation
- Calibration and Input Development

2006 Implementation Plan

- DIGIT Training for Key Personnel
  - Pavement Designers
  - Traffic Data Collection Personnel
- Review of Existing Sensitivity Studies
- To be conducted by WYDOT
  - Subgrade Soils
  - M_R Testing
  - Other Inputs
- Calibrate Using PMS Data

Hibernation

- Loss of Staff
- Resilient Modulus Testing
  - M_R Pooled Fund
- Elastic Modulus Testing
  - AMPT Pooled Fund
- Software Development
  - AASHTOWare Pooled Fund

New Implementation Goals

- 2006 Plan Too Aggressive
- Research Funding
- Reduce Level of Inputs
- Reduce Calibration & Validation
- Useable and Implemented by 2011
- Use Existing Information if Possible
- Experienced Help Wanted

New Implementation Plan

- Applied Research Associates (ARA)
  - What Do We Need?
  - Developed Design Guide
  - Developed Calibration Guide
  - Working with Neighboring States
  - Help with Existing Software
- 18 Month Schedule
- Research Approved – Jan. 2009
- Initial Meeting - ARA – March 4, 2009

Implementation Plan

- Primary Design & Rehab. Alternatives
- Level 2/3 Inputs
- Existing Sites for Calibration
- Wyoming Specific Design Manual
- Implement for all Pavement Designs

Design Alternatives

- New Construction
  - HMA + Granular Base
  - Deep Strength HMA + Granular Base
  - Un-doweled PCCP on Granular Base
  - Doweled PCCP on Granular Base

Design Alternatives

- Rehabilitation
  - HMA Overlays over HMA
    - Granular Bases
    - Flexible & Rigid Treated Bases
    - Reclaimed Bases?
  - HMA Overlays on Cracked & Seated PCCP
  - Concrete CPR

Climate Inputs

- Existing Weather Stations
- Interpolate Weather Stations
- Challenges
  - No Stations in Rural Areas
  - No Stations in Unique Areas (Mountains)

Traffic Inputs

- Counts and Classification
  - 65 Sites with 5 Years of Data
  - 12 More Sites with 2 Years of Data
- Weight Information
  - 9 WIM Sites
- Challenges
  - Limited WIM Coverage
  - WIMs on High Traffic Routes

Soils & Granular Base Inputs

- R-Value Correlated to M_R
- Back Calculated from FWD
- Challenges
  - Correlation Method?
  - Back Calculation Method?

HMA Inputs

- Catalog of Mix Designs
- Calculated from Volumetrics and Materials Properties
- Challenges
  - Properties of Existing HMA Layers

Concrete Inputs

- Catalog of Materials & Mix Properties
  - Compressive Strength Data
  - Flexural Strength Data
- Challenges
  - Not a lot of Existing Data

Sites for Calibration & Validation

- LTPP Sites
- LTPP Sites in Neighboring States
- 15 Years of PMS Data
- Challenges
  - Few Granular Base Sites
  - No Superpave Mixture Sites
  - No Dowelled PCCP Sites

Opportunities for Cooperation

- Data Base of Information on New Sites
- Sharing of Traffic Data
- R-Value Calibration Procedures
- Procedures to Classify In-Place HMA
- Sharing of Materials Property Data
- Developing Models for In-place Recycling

Thank You

Mechanistic-Empirical Pavement Design Guide Implementation at South Dakota DOT

Gill L. Hedman
Pavement Design Engineer
South Dakota DOT

March 9, 2009

M-E PDG Implementation At the SDDOT

Research Project SD2005-01 (APTech)

- **Conduct Sensitivity Analysis**
- **Recommend Input Levels**
  - High, Intermediate, Defaults
- **Determine Resource Requirements**
- **Identify Calibration Requirements**
- **Develop an Implementation Plan**

* All activities based on Version 0.9, M-E PDG Software

SD2005-01 Project Objectives

- **Identify the requirements and resources that will be needed for SDDOT to implement the M-E Design Guide**
- **Develop M-E Pavement Design Implementation Plan for SDDOT**

SD2005-01 Key Project Activities

- **Sensitivity Analysis**
  - Determined which inputs have the most significant impact on predicted pavement performance
- **Recommended Input Levels**
  - Used results to produce a ranked listing of significant inputs for 5 standard designs (both new pavement and overlay designs with both flexible and rigid surfaces)
  - Developed recommendations for the appropriate input level (Level 1, Level 2, or Level 3)
  - Identified differences between targeted input levels and current SDDOT practices

SD2005-01 Key Project Activities (cont)

- **Resource Requirements to Meet Target Levels**
  - Changes to data collection and testing procedures
  - New testing equipment needed
  - Training needs
  - Other resources needed
- **Calibration Requirements**
  - Process for evaluating transverse cracking on rigid pavements
- **Implementation Plan**

SD2007-08 SDDOT M-E/PDG Implementation Plan (Current)

- **M-E/PDG Implementation Team**
  - **SDDOT Transportation Implementation Group (TIG)**
    - 12 - SDDOT Representatives
    - 1 - Federal Highway Representative
    - 2 - Industry Representatives
      - South Dakota Concrete Pavement Association
      - Dakota Asphalt Pavement Association
- **Develop a Communication Plan (Completed)**
- **Conduct M-E/PDG training (Completed in fall of 2008)**

SD2007-08
SDDOT M-E/PDG Implementation Plan (Current)

- Review and appraise M-E/PDG software relative to its performance for South Dakota soils, materials, climate, traffic, and other considerations.
  - Research Projects underway
    - SD2008-10 with Lance Roberts from the South Dakota School of Mines and Technology to determine Resilient Modulus and Dynamic Modulus Values for soils and asphalt mixes typically used in South Dakota
    - M-E/PDG design, validation testing, & monitoring through the Asphalt Research Consortium (ARC) with Peter Sebaaly from the University of Nevada Reno
    - SD2008-03 with Peter Sebaaly from the University of Nevada Reno to evaluate Warm Mix in South Dakota
    - Evaluate Coefficient of Thermal Expansion in our Concrete Lab and develop a data base based on our concrete mixes

SD2007-08
SDDOT M-E/PDG Implementation Plan - Short term (1 to 3 years)

- Review inputs' significance using Version 1.0
- Assess training needs and begin training
- Begin database compilation using non-project specific data
- Review recommendations for model calibration

SD2007-08
SDDOT M-E/PDG Implementation Plan - Mid-term (2 to 4 years)

- Conduct preliminary calibration of models
- Acquire new equipment as needs define
- Train personnel in new testing requirements
- Begin using MEPDG alongside existing pavement design procedure
- Develop MEPDG documentation and guidelines
- Calibrate and validate models
- Determine any further data collection needs

SD2007-08
SDDOT M-E/PDG Implementation Plan - Long-term (> 4 years)

- Move towards full implementation of MEPDG
- Develop a design catalog for standard designs

SD2007-08
SDDOT M-E/PDG Implementation Plan - Expected Benefits

- The recommendations represent a large commitment of resources for 3 to 5 years
  - Model enhancements will continue
  - New procedures are expected to be adopted by AASHTO
  - Documentation lags behind development
- Expected to result in a better understanding of the significant inputs that impact pavement performance
  - Improved designs
  - Potential use in construction acceptance

- ftp://ftp.state.sd.us/DOT/Research/MEPDG/Some Apparent Problems with the MEPDG Model for JCP Pavements.doc
- http://www.state.sd.us/Applications/HR19ResearchProjects/Projects/sd2005-01_Final_Report.pdf

Questions?

Thank You!

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M-E PDG/TIG

TIG Members:

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Gill Hedman (Materials & Surfacing)
Brett Hestdalen (FHWA)
Darin Hodges (Materials & Surfacing)
Dave Huft (Research)
Denny Johnson (Research)
Ryan Johnson (Operations Support)
Dan Johnston (Research)
Bob Longbons (Materials & Surfacing)
Blair Lunde (Project Development)
Ken Marks (Trans Inventory Mgt)
Tony Ondricek (Pierre Region)
Rick Rowen (Materials & Surfacing)
Ken Swedeen (DAPA)
Dennis Winters (SD BIT)

Oregon Department of Transportation

Calibrate Performance Curves

Guidance to ODOT Staff

- "Back-calculation" of existing roads
- Issues Identified
  - Traffic Volumes & Axle Loads
  - Materials Characterization
  - Distress/Condition definitions

Oregon Department of Transportation

Calibrate Performance Curves

Current Results

- ODOT ESALS over-estimated?
- "Fatigue" is more likely top down than bottom up for our highways
- AC stripping modeling?

Oregon Department of Transportation

Calibrate Performance Curves

Current Results

- Historical Binders
  - AC or AR
  - PBA
  - PG and PG xx-xx ER
- Use of Rap
  - Effects to Stiffness
  - Long Term Performance
  - Need for Blend Charts?

Oregon Department of Transportation

Composite Pavements

- What is a Composite Pavement?

Oregon Department of Transportation

Composite Pavements

- What is a Composite Pavement?

•The FHWA "composite pavement" category is defined as a "mixed bituminous or bituminous penetration roadway" of more than 25 mm (1 inch) of compacted material on a rigid base

(source: WsDOT Interactive)

Oregon Department of Transportation

Composite Pavements

- What is a Composite Pavement?

•Occasionally, they are initially constructed as composite pavements, but more frequently they are the result of pavement rehabilitation (e.g., HMA overlay of PCC pavement)

(source: WsDOT Interactive)

Oregon Department of Transportation

Composite Pavements

- Modeling of Composite Pavements
  - •Modeling these pavements depends on the composite action
    - ❖A deep HMA overlay of a PCC pavement is typically classified as a flexible pavement
    - ❖An HMA overlay of a PCC pavement with no fracture preparation typically responds with rigid pavement characteristics

Oregon Department of Transportation

Composite Pavements

- MEPDG Modeling
  - •HMA Overlay
    - ❖CRCP, JPCP or Rubblized PCC
    - ❖Pre-overlay repairs are critical
  - •HMA over CTB
    - ❖National Model not Calibrated
  - •HMA over New PCC
    - ❖MEPDG does not allow HMA over new PCC
    - ❖Model as HMA overlay on PCC

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Composite Pavements

- Observations
  - •MEPDG overlay on PCC matches our experience
    - ✓Thin HMA overlays do work on Interstate CRCP or JRCP (no JPCP on Oregon Interstate)
    - ✓Thick HMA over CTB does not prevent top down cracking but does mitigate transverse reflective cracking

Oregon Department of Transportation

Composite Pavements

- More Observations
  - Rubblized PCC performing well, potential to reduce HMA overlay thickness
    - *Deflection data indicates rubblized PCC stronger than design estimates*
    - *At construction, deflection data can help determine proper rubblizing effort*
    - *One of oldest projects 1997, I-5 Evans Cr to Grants Pass, current PCI=85*

Oregon Department of Transportation

Composite Pavements

Questions?

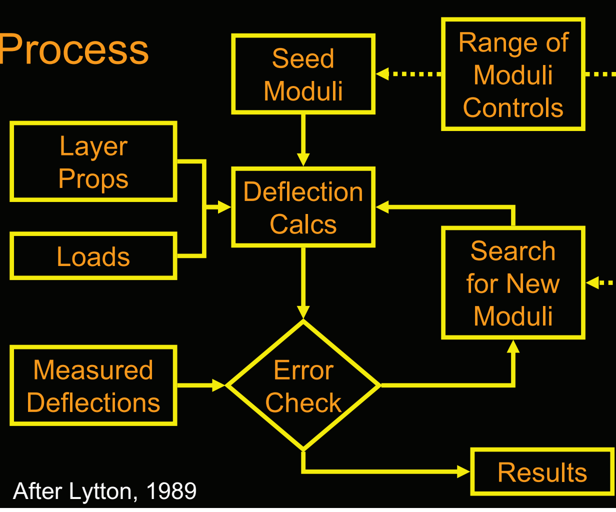
FWD Backcalculation

Todd Scholz, P.E.
Oregon State University

Backcalculation Software

- OSU conducted a study to evaluate backcalculation programs to determine:
  - Comprehensive list of programs
  - Algorithms and pros and cons of each
  - Operating system on which the programs run
  - Sources/licensing/purchasing details
  - Cost (if any)
  - Recommended program

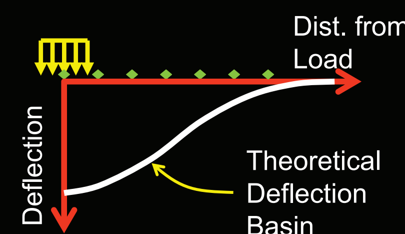
Process



After Lytton, 1989

Forward Calculation – LEA

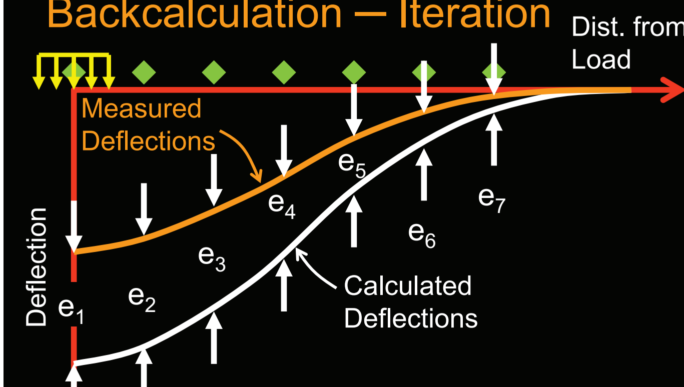
- Two methods:
  - Odemark-Boussinesq
  - Integration



Backcalculation

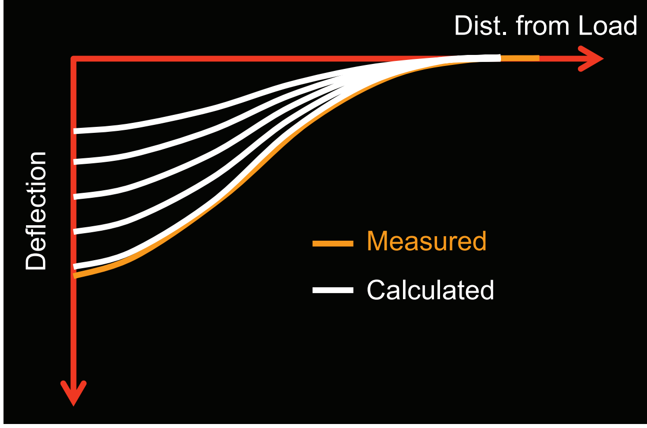
- Two common methods:
  - Iteration
  - Database

Backcalculation – Iteration

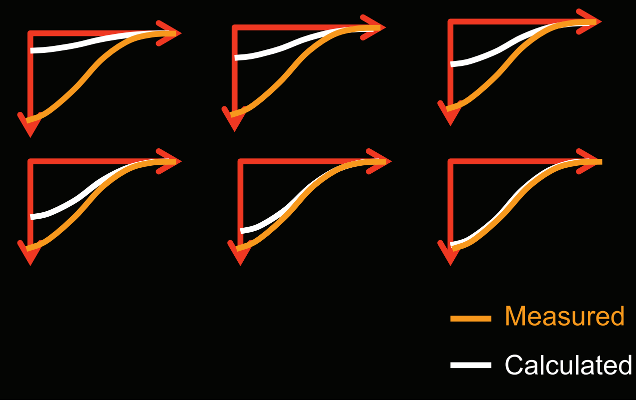


$$RMSE = \left\{\Sigma\left[\frac{1}{n}\left(\frac{e_i}{d_{mi}}\right)\right]\right\}^{1/2}$$

Backcalculation – Iteration



Backcalculation – Database



Programs – LEA & Backcalculation
(from literature review)

ABAQUS	CLEVERCALC	ELSDEF	ISSEM4	NUS-DEF	UMPED
ANN	COMDEF	ELSYM5	JULEA	OAF	WESDEF
AYMA	DAMA	EPLOPT	LEEP	PADAL	WESLEA
BACK	DARWIN	ERI Analysis	LMBS	PEACH	WESTERX
BISAR	DBCONPAS	EVERCALC	MICHBACK	PEDD	WINSASW
BISDEF	DEFMET	FAABACKCAL	MICHPAVE	PEDMOD	
BKGREEN	DIPLOMAT	FALMAN	MODCOMP	PHONIX	
BOUSDEF	EFROMD	ILLIBACK	MODULUS	PROBE	
CHEVDEF	ELCON	ILLI-PAVE	NIKE3D	RPEDD1	
CIRCLY	ELMOD5	ILSL2X	NUS-BACK	SEARCH	

Initial Selection Criteria
(from literature review)

- SHRP Study
- FHWA Study
- Mn/ROAD

SHRP Study – PCS/Law

- Look at both slab theory and an elastic layer model for rigid pavements;
- Use layered elastic theory for flexible pavements;
- Allow variable slip conditions at layer interfaces;
- Allow flexible plate boundary conditions;
- Allow user input for seed moduli required, with independent moduli results;
- Report goodness of fit for each deflection measurement;
- Allow user-defined depth to rigid layer;
- Have a non-linear modeling capability for base and subgrade materials;
- Have the capability for the user to fix a layer modulus;
- Be able to model at least five layers for flexible pavements;
- Be readily available at a reasonable price;
- Have an available source code;
- Be capable of applying a weighing function to the error tolerances.

FHWA Study – Simpson & Von Quintus

- Accuracy of program
- Operational characteristics
- Ease of use of program
- Stability of program
- Probability of success

Mn/ROAD Study

- Accuracy of backcalculated moduli and forward calculated response results;
- Use of the same forward calculation program for both back and forward calculations;
- Calculated moduli, stresses, and strains contained in one output file;
- Flexibility in selection of deflection sensor positions;
- Adaptability for users with different computer resources; obtain source: code if possible; ability to run in Windows, DOS, and/or UNIX environments;
- Ability to interface with MnROAD database;
- Computational efficiency; ability to process data files in batch mode;
- Program documentation with examples and case studies.

Initial Shortlist

Software Title	Rating	Cost	OS
EVERCALC	5	Free	Win
MODULUS 6.0	5	Free	Win
MODCOMP5	5	Free	Win
ELMOD5	4	$65	Win
SW-1 (DAMA)	4	$400	Win
BAKFAA	3	Free	Win
CIRCLY	3	Not Free	Win, Excel
DARWIN	3	$2,300	Win
ERI Pavement Analysis	2	Not Free	Win
MICHBACK	2	Free	Dos
MICHPAVE	2	Free	Dos
ELSYM5	2	$50	Dos
ILLI-PAVE	2	$50	Dos
ILLIBACK	2	$225	Dos

Shortlist & Some Program Details

	ELMOD	EVERCALC	MODCOMP	MODULUS
Developed by	Ullidtz	Mahoney et al	Irwin/ Szebeyi	TTI
Forward Calc. Meth.	Odemark-Boussinesq	LEA (WESLEA)	LEA (Chevron)	LEA (WESLEA)
Backcalc. Method	Iterative	Iterative	Iterative	Database
Converge Method	Relative error (5 sensors)	Sum of rel. squared error	Rel. defl. error at sensors	Sum of rel. squared error

Planned Evaluation

- Side-by-side comparison of programs from the shortlist to determine:
  - "Accuracy"
  - Ease of use
  - Stability
  - Program recommended for use by ODOT

Trouble in River City

- MODCOMP
- ELMOD
- MODULUS

Plan B

- The programs from the shortlist utilize similar methods for determining convergence
- Hence, it was reasoned that the forward calculation method likely contributes to the bulk of the differences between programs:
  - MEPDG utilizes JULEA
  - EVERCALC utilizes WESLEA

JULEA vs. WESLEA

- Ran comparisons for same structure, layer properties, and loading characteristics
- Found insignificant differences in calculated stresses, strain, and deflections for the conditions evaluated

Recommendation

- EVERCALC

MEPDG

- Master curve (undamaged, but aged):

$$\log(E^*) = \delta + \frac{\alpha}{1 + e^{\beta + \gamma \log t_r}}$$

MEPDG

- Estimate damage:

$$d_j = \frac{E_i(NDT)}{E^*(pred)}$$

- Define α':

$$\alpha' = (1 - d_j)\alpha$$

MEPDG

- Develop field damaged master curve:

$$\log(E^*) = \delta + \frac{\boxed{(1 - d_j)\alpha} \leftarrow \alpha'}{1 + e^{\beta + \gamma \log t_r}}$$

Consideration of Environmental Variation Effects in M-E Design – Idaho WINFLEX 2006

By

Mike Santi
Idaho Transportation Department

Fouad Bayomy and Ahmad Abu Abdo
University of Idaho

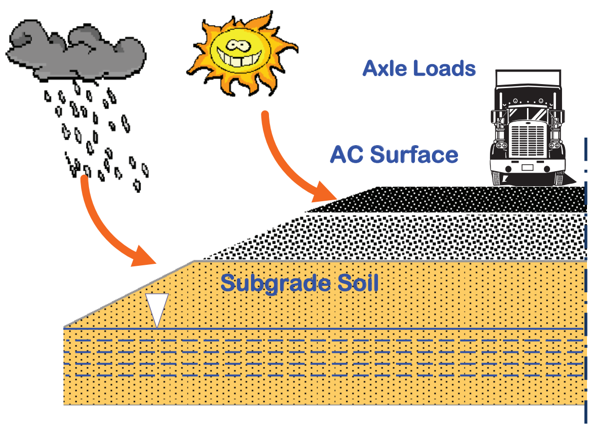
1

Projects

1996 - FMK128_Pilot Study by Bayomy and Hardcastle
1997 - FMK173_ Soil Moisture Monitoring by Bayomy and Hardcastle
2000 - KLK459_Soil Moisture Monitoring (Cont.) by Bayomy
1996 - 2006 – Series of projects to develop the WINFLEX (M-E Overlay Design System)

2

Seasonal variations



Objectives

- Replicate LTPP Seasonal sites at various regions of the state
- Develop Seasonal Shift Factors (SAF's) for various regions.
- Implement the developed shift functions in the M-E design process to predict the accumulated seasonal damage.

4

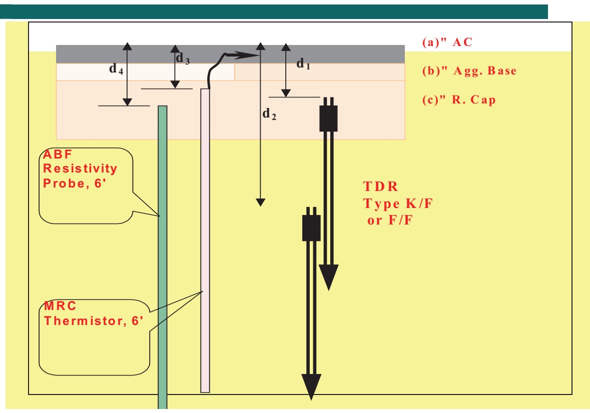
Idaho Sites' Map

Instrumentation and Data Collection

- Instrumented Five sites (8 installations) in Idaho
  - TDR Moisture Probes
  - MRC Thermistor sensors
  - ABF Resistivity sensors
  - Piezometers
- Climatic Data
- Traffic Data
- FWD
- LTPP-SMP Database

6

Instrumentation



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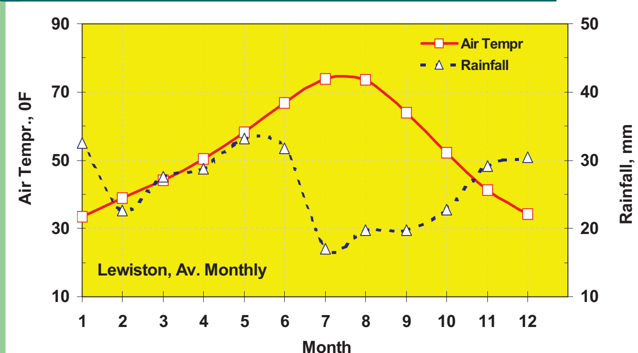
Implementation of the findings

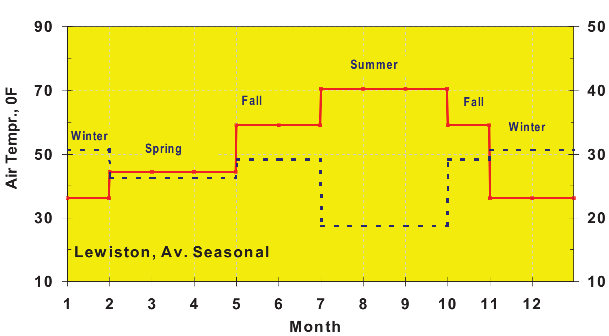
9

Seasonal timing



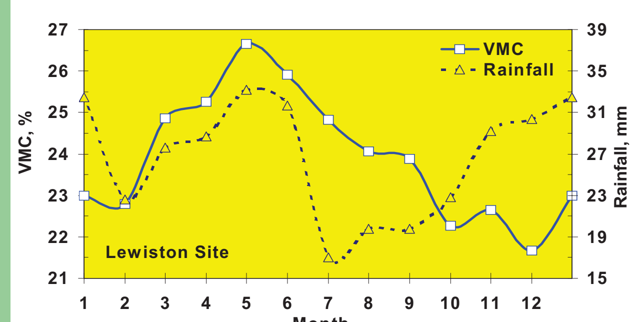
10

Seasonal timing (cont.)



11

Moisture vs. rainfall



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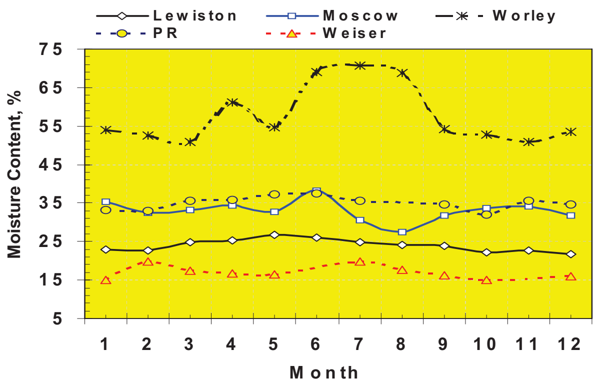
Moisture variation



13

Seasonal Adjustment Factors

$$M_f = C_f \times M_n$$

$$M_t = C_t \times M_n$$

$$M_W = C_W \times M_n$$

Subgrade Seasonal Adjustment Factors

SAF's

Site	$SAF_s = K_1 * W^{k2}$			
	Summer	Fall	Winter	Spring
Lewiston	1.00	0.96	1.11	1.00
Moscow (A)	1.00	0.83	0.85	0.86
Worley	1.00	1.05	1.24	1.27
Pack River (B)	1.00	0.98	1.02	1.03
Weiser (B)	1.00	1.23	1.27	1.05

(Ref: Table 8.5)

15

Subgrade Monthly Adjustment Factors

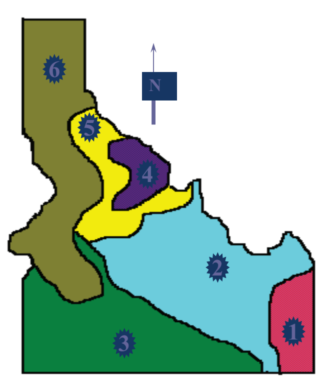
MAF's

Month	1	2	3	4	5	6	7	8	9	10	11	12
Lewiston	1.05	1.06	0.95	0.93	0.86	0.90	0.95	0.99	1.00	1.10	1.07	1.14
Moscow (A)	0.89	0.97	0.95	0.92	0.97	0.82	1.04	1.17	1.00	0.94	0.92	1.00
Worley	1.01	1.03	1.07	0.88	0.99	0.77	0.75	0.77	1.00	1.03	1.07	1.02
P. River (B)	1.06	1.06	0.96	0.95	0.91	0.90	0.96	0.98	1.00	1.11	0.96	1.00
Weiser (B)	1.11	0.77	0.91	0.96	0.98	0.87	0.78	0.90	1.00	1.12	1.07	1.02

(Ref: Table 8.6)

16

IDAHO PAVEMENT CLIMATE ZONES



Seasonal Factors for Subgrade

Air Temperature for ID Zones

Season and Condition	Zone 1 Driggs	Zone 2 Idaho Falls	Zone 3 Twin Falls	Zone 4 Powell	Zone 5 McCall	Zone 6 Moscow
Winter - Freeze	-0.6	0.0	6.7	0.6	0.6	8.9
Spring - Thaw	13.3	14.4	14.4	11.7	13.3	15.0
Summer - Normal	16.1	18.3	18.9	16.7	15.6	18.3
Fall/ Winter - Normal	1.1	0.6	2.2	2.2	1.7	1.1

* Shown values are the 68th percentile

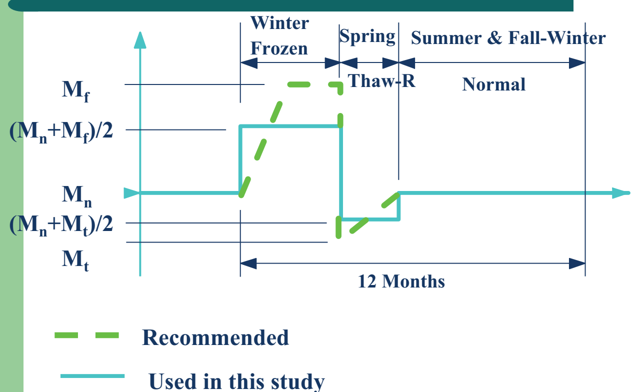
Climatic Parameters

Climatic Parameter	Zone 1 Driggs	Zone 2 Idaho Falls	Zone 3 Twin Falls	Zone 4 Powell	Zone 5 McCall	Zone 6 Moscow
Frost Depth, mm	1321	1372	660	940	1067	559
Freezing Index, degree-days	1507	1587	543	873	1062	442
Thaw Index, degree-days	395	415		230	279	
Freeze Transition Period, days	15	9		44	24	
Onset of Frozen period	10-Jan	3-Jan	1-Feb	10-Feb	30-Jan	15-Feb
Frozen period*, days	120	126	90	82	110	90
Frozen period, % time of the year	33%	35%	25%	22%	30%	25%
Onset of Thaw period	10-May	9-May	1-May	3-May	16-May	16-May
Thaw period**, days	38	36	15	27	24	30
Thaw period, % time of the year	10%	10%	4%	7%	7%	8%
Normal period, Days	192	194	260	212	207	245
Normal period, % time of the year	53%	53%	71%	58%	57%	67%

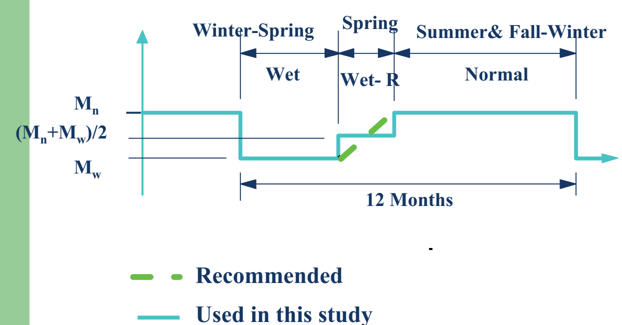
* Calculated based on Thaw Index of 24 degrees-days

** Calculated based on Thaw Index = 4.154+0.259(AFI)

SEASONAL VARIATION E_{SUG} FOR ZONES 1,2,4&5



SEASONAL VARIATION E_{SUG} FOR ZONES 3 & 6



Seasonal Adjustment Factors for Zones 1, 2, 4 and 5

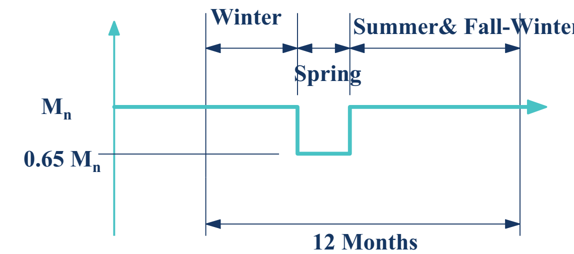
Climate Zone	Seasonal Adjustment Factors, SAF	Winter Frozen	Spring Thaw	Summer Normal	Fall Normal
Zone 1	Subgrade	Eqn. 7	Eqn. 8,9,10	1	1
	Base/Subbase	1	0.65	1	1
	Traffic	User Input			
	Temperature, F	31	55	62	34
	Period, Months	4	1.5	3.5	3
Zone 2	Subgrade	Eqn. 7	Eqn. 8,9,10	1	1
	Base/Subbase	1	0.65	1	1
	Traffic	User Input			
	Temperature, F	32	58	65	33
	Period, Months	4	1.5	3.5	3
Zone 4	Subgrade	Eqn. 7	Eqn. 8,9,10	1	1
	Base/Subbase	1	0.65	1	1
	Traffic	User Input			
	Temperature, F	33	53	62	36
	Period, Months	3	1	4	4
Zone 5	Subgrade	Eqn. 7	Eqn. 8,9,10	1	1
	Base/Subbase	1	0.65	1	1
	Traffic	User Input			
	Temperature, F	33	56	60	35
	Period, Months	4	1	4	3

Seasonal Adjustment Factors for Zones 3 and 6

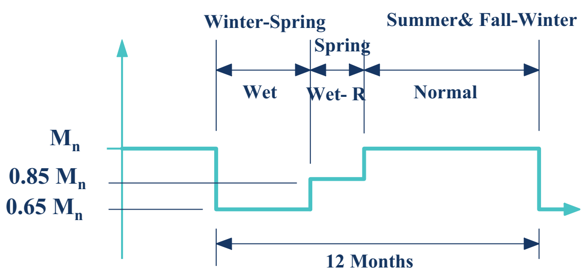
Climate Zone	Seasonal Adjustment Factors, SAF	Subgrade Classification	Winter Wet	Spring Wet	Summer Normal	Fall Normal
Zone 3	Subgrade	GW,GP,SW,SP	Eqn. 13,14,15	Eqn. 13,14,15	1	1
		GC,SC,CL	Eqn. 16,17,18	Eqn. 16,17,18	1	1
		GM,SM,ML	Eqn. 19,20,21	Eqn. 19,20,21	1	1
		MH,CH	Eqn. 22,23,24	Eqn. 22,23,24	1	1
	Base/Subbase		0.65	0.85	1	1
	Traffic		User Input			
	Temperature, F		44	58	66	36
	Period, Months		3	1	4	4
Zone 6	Subgrade	GW,GP,SW,SP	Eqn. 13,14,15	Eqn. 13,14,15	1	1
		GC,SC,CL	Eqn. 16,17,18	Eqn. 16,17,18	1	1
		GM,SM,ML	Eqn. 19,20,21	Eqn. 19,20,21	1	1
		MH,CH	Eqn. 22,23,24	Eqn. 22,23,24	1	1
	Base/Subbase		0.65	0.85	1	1
	Traffic		User Input			
	Temperature, F		48	59	65	34
	Period, Months		3	1	4	4

Seasonal Factors for Granular **Base/Sub-base**

SEASONAL VARIATION $E_{SB/SBS}$ FOR ZONES 1,2,4 &5



SEASONAL VARIATION $E_{BS/SBS}$ FOR ZONES 3 & 6



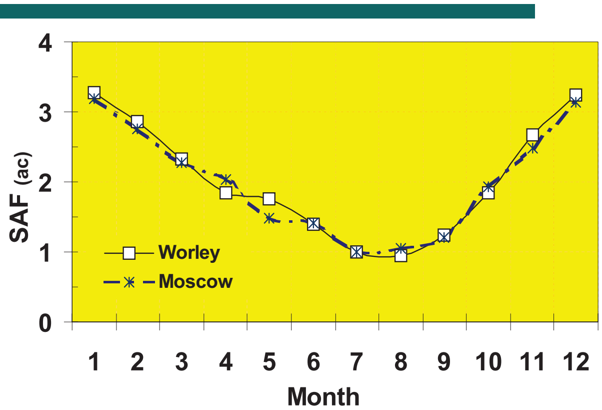
Example

Seasonal Shift Factors

Calculated by WINFLEX for a given Subgrade modulus value

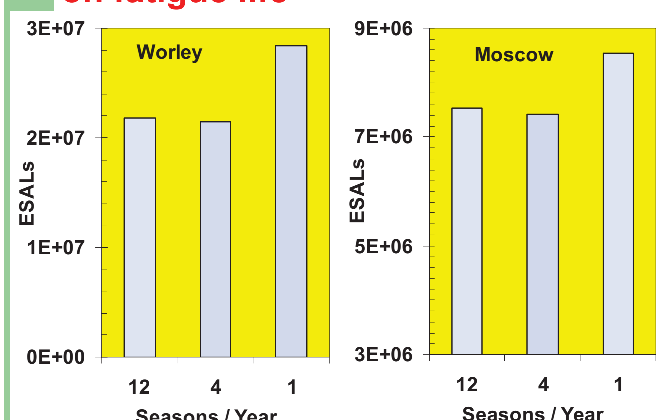
Climatic Zone		Seasonal Variation Factor for: Subgrade Classification where Needed	Winter Frozen	Spring Thaw	Summer Normal	Fall Normal
Zone 1	Subgrade		11.2	0.43	1	1
	Base / SubBase		1	0.65	1	1
	Traffic		User Input			
	Temperature, C		-0.56	12.78	16.67	1.11
	Period (Month)		4	1.5	3.5	3
Zone 2	Subgrade		11.2	0.43	1	1
	Base / SubBase		1	0.65	1	1
	Traffic		User Input			
	Temperature, C		0.00	14.44	18.33	0.56
	Period (Month)		4	1.5	3.5	3
Zone 3	Subgrade	GW, GP, SW, SP	0.81	0.9	1	1
		GC, SC, CL	0.48	0.74	1	1
		GM, SM, ML	0.6	0.8	1	1
		MH, CH	0.35	0.68	1	1
	Base / SubBase		0.65	0.85	1	1
	Traffic		User Input			
	Temperature, C		6.67	14.44	18.89	2.22
	Period (Month)		3	1	4	4
Zone 4	Subgrade		11.2	0.43	1	1
	Base / SubBase		1	0.65	1	1
	Traffic		User Input			
	Temperature, C		33	53	62	36
	Period (Month)		3	1	4	4
Zone 5	Subgrade		11.2	0.43	1	1
	Base / SubBase		1	0.65	1	1
	Traffic		User Input			
	Temperature, C		0.56	13.33	15.56	1.67
	Period (Month)		4	1	4	3
Zone 6	Subgrade	GW, GP, SW, SP	0.73	0.87	1	1
		GC, SC, CL	0.38	0.69	1	1
		GM, SM, ML	0.52	0.76	1	1
		MH, CH	0.27	0.63	1	1
	Base / SubBase		0.65	0.85	1	1
	Traffic		User Input			
	Temperature, C		8.89	15.00	18.33	1.11
	Period (Month)		3	1	4	4

SAF (AC)



29

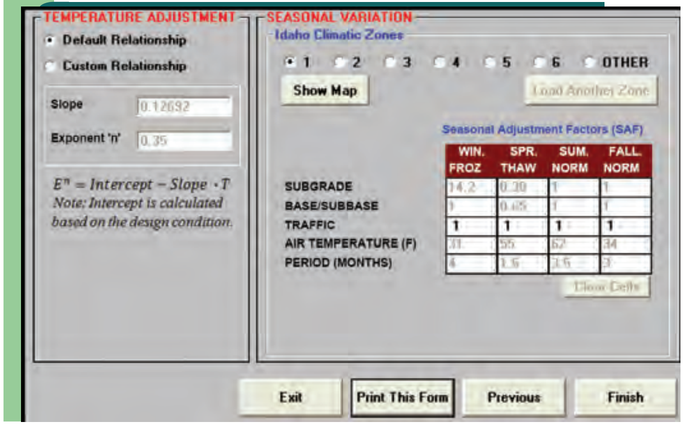
Effect of seasonal approximation on fatigue life



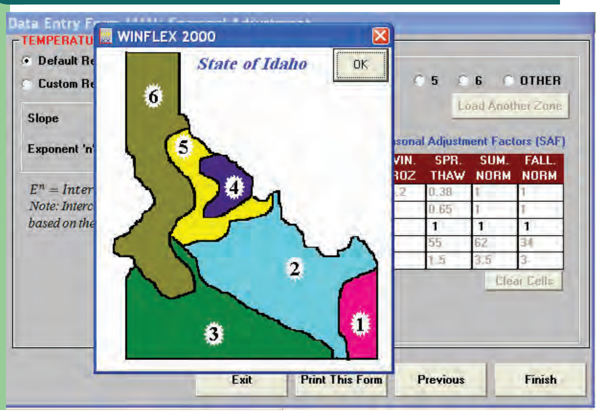
Implementation in WINFLEX (Idaho M-E Overlay Design Software)

31

Seasonal Adjustment Screen



Seasonal Adjustment Screen



MEPDG Calibration -WSDOT

Jianhua Li
Jeff Uhlmeyer

March, 2009

Washington State Department of Transportation

Outline

- Bench Testing
- Distress Model Analysis
- Data Preparation
- Calibration
- Calibration Results Discussion
- Conclusions and Recommendations

Washington State Department of Transportation

Bench Testing

- Bench testing is to check software run-time issues, model prediction reasonableness, and identify calibration needs.
- Input sensitivity on estimated pavement distresses.

Input Factors	Longitudinal Cracking	Transverse Cracking	Alligator Cracking	AC Rutting	IRI
Climate	Med.	High		High	High
PG Binder	High	Med.	Med.	Med.	
AC Thickness	High	Med.	Med.	High	
Base Type	Med.			High	Med.
AADTT	Med.			High	Med.
AC Mix Stiffness			High		
Soil Type	Med.				

Note: Blank means low sensitivity level or not related

Washington State Department of Transportation

Model Analysis

- Elasticity is used to describe the effects of the calibration factors on the pavement distress models.

$$E_{\text{distress}}^{C_i} = \frac{\partial(distress)/distress}{\partial(C_i)/C_i}$$

Where

$\partial(distress)$	Change in the estimated distress
$\partial(C_i)$	Change in the calibration factor C_i
distress	Estimated distress using default calibration factors
C_i	Default value of C_i

Washington State Department of Transportation

Data Preparation

- Input values were generally taken from typical WSDOT values. Where options of input level were given, level 2 was preferred.
- Input data categories
  - Traffic
  - Climate
  - Pavement structure
- Pavement performance data

Washington State Department of Transportation

Calibration

- New concrete pavements in 2005 (version 0.6)
- New flexible pavements in 2008 (version 1.0)
- *Recommended Practice for Local Calibration of ME Pavement Design Guide*
  - Split-sample approach
  - Jack-knife testing approach

Washington State Department of Transportation

Calibration Steps

- Define calibration categories.
  - Traffic (low. Med, high)
  - Climate (Western and Eastern Washington)
  - Soil modulus (weak, strong)
- Choose typical sections.
  - WSPMS
  - WSDOT previous studies about pavement material and performance
  - LTPP sections
- Calibrate the models.
- Validate the calibration results.

Calibration Results – Undoweled JPCP, V0.6

Calibration Factor		Defaults For New PCC	New Undoweled	New Undoweled – MP	Reha. DBR
Cracking	C_1	**2**	2.4	2.4	2.4
	C_2	**1.22**	1.464	1.464	1.464
	C_4	**1**	1	1	1
	C_5	**-1.68**	-1.68	-1.68	-1.68
Faulting	C_1	**1.29**	0.4	0.4	0.934
	C_2	**1.1**	0.341	0.341	0.6
	C_3	**0.001725**	0.000535	0.000535	0.001725
	C_4	**0.0008**	0.000248	0.000248	0.0004
	C_5	**250**	77.5	77.5	250
	C_6	**0.4**	0.0064	0.064	0.4
	C_7	**1.2**	2.04	9.67	0.65
	C_8	**400**	400	400	400
Roughness	C_1	**0.8203**	0.8203	0.8203	0.8203
	C_2	**0.4417**	0.4417	0.4417	0.4417
	C_3	**1.4929**	1.4929	1.4929	1.4929
	C_4	**25.24**	25.24	25.24	25.24

Discussion – Undoweled JPCP, version 0.6

- The calibration factors are significantly different from the default values.
- Predicted trends and values are reasonable for transverse cracking and faulting, except that
  - Longitudinal cracking is significant in WSDOT PCC pavements but not modeled in MEPDG.
  - MEPDG understandably does not model studded tire wear.
  - The roughness model always underestimates actual WSDOT roughness.

Calibration Results - New HMA, version 1.0

Calibration Factor		Default	Calibrated Factors
AC Fatigue	B_{f1}	1	0.96
	B_{f2}	1	0.97
	B_{f3}	1	1.03
Longitudinal cracking	C1	7	6.42
	C2	3.5	3.596
	C3	0	0
	C4	1000	1000
Alligator cracking	C1	1	1.071
	C2	1	1
	C3	6000	6000
AC Rutting	B_{r1}	1	1.05
	B_{r2}	1	1.109
	B_{r3}	1	1.1
Subgrade Rutting	B_{s1}	1	0

Discussion – New HMA, version 1.0

- The calibration factors are significantly different from the default values.
- The default transverse cracking calibration factors reasonably estimate WSDOT transverse cracking conditions.
- Predicted trends and values are reasonable for cracking and rutting.
- The default roughness model always underestimate actual roughness, but the differences are small.

Conclusions

- The MEPDG is an advanced tool for pavement design and evaluation.
- Calibration is required prior to implementation.
- The concrete pavement calibration results need to be adjusted before use.
- The distress models for new flexible pavement have been calibrated, except the IRI model.

Recommendations

- Local agencies need to balance the input data accuracy and costs.
- The calibration is a continual process along with implementation.
- States with similar climate and material conditions may test the calibration results for their local use.
- WSDOT will continue to monitor future works related to MEPDG.

Performance Curve Calibration (Oregon Plan)

Todd Scholz, P.E.
Oregon State University

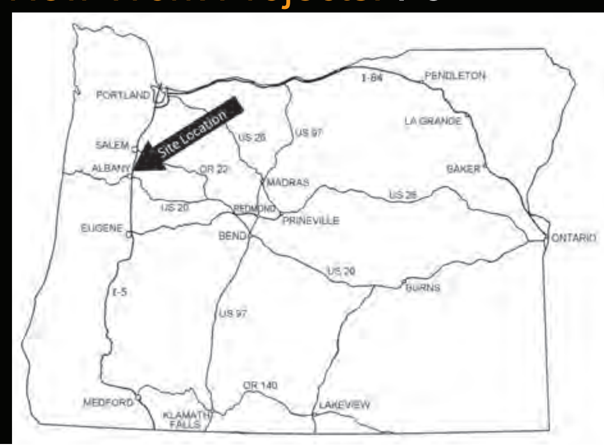
Topics

- New Work HMAC Projects
- Rehabilitation with HMAC Overlays

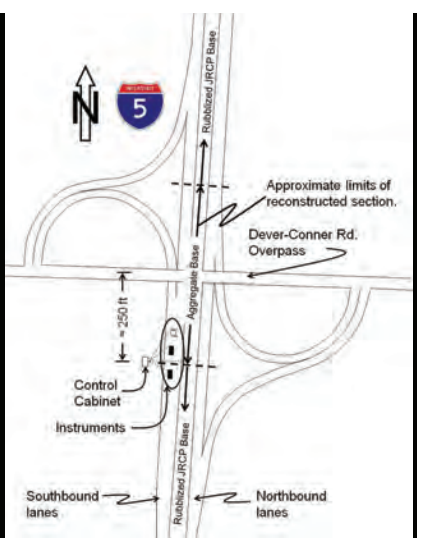
New Work Projects

- On-going research to:
  - Validate JULEA
  - Initial validation of performance models:
    - Fatigue cracking
    - Rutting

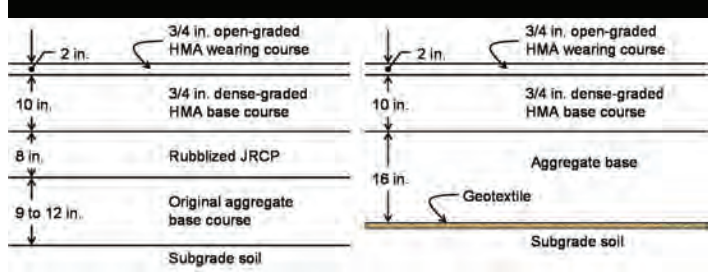
New Work Projects: I-5



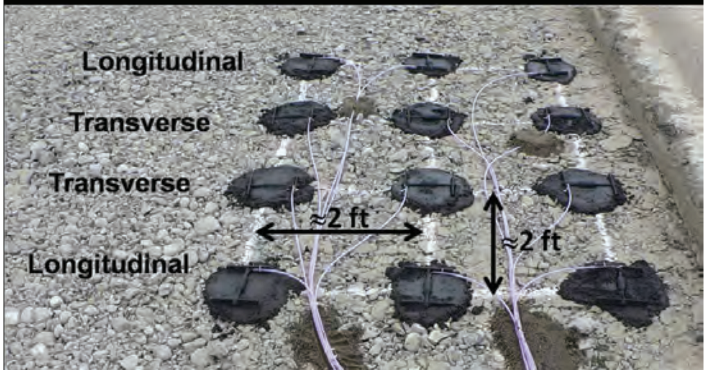
New Work Projects: I-5



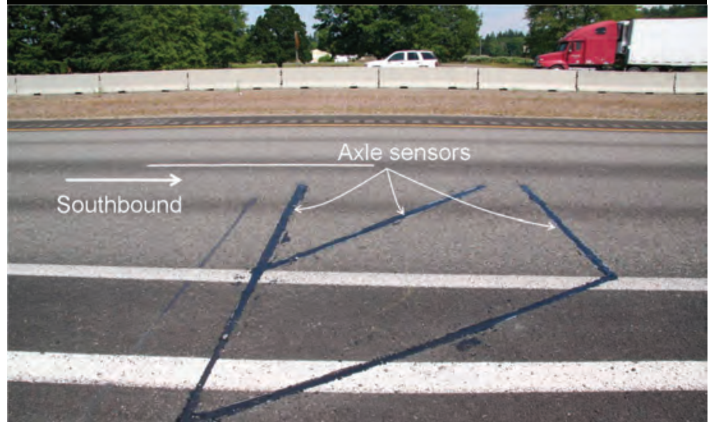
New Work Projects: I-5



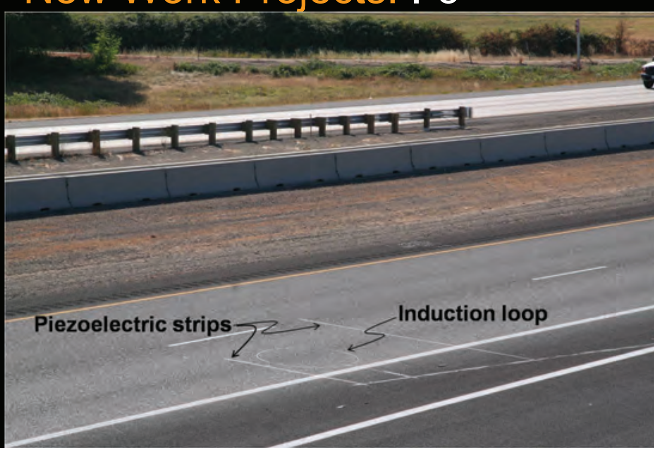
New Work Projects: I-5



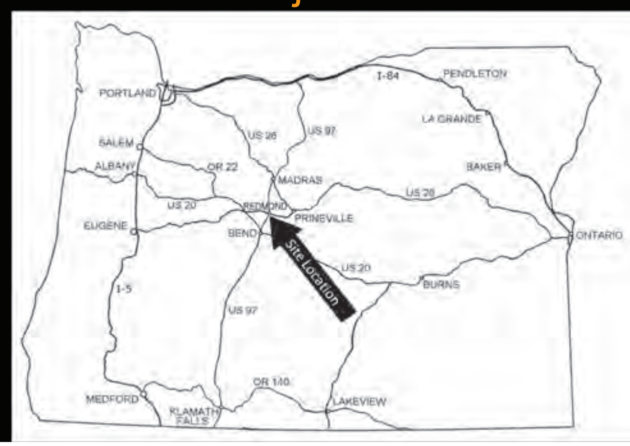
New Work Projects: I-5



New Work Projects: I-5



New Work Projects: Redmond



New Work Projects: Redmond

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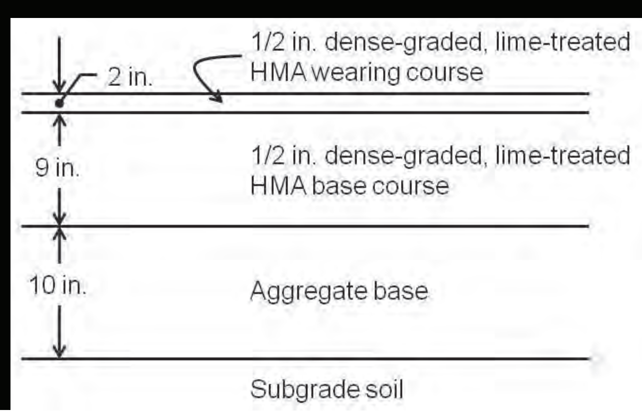
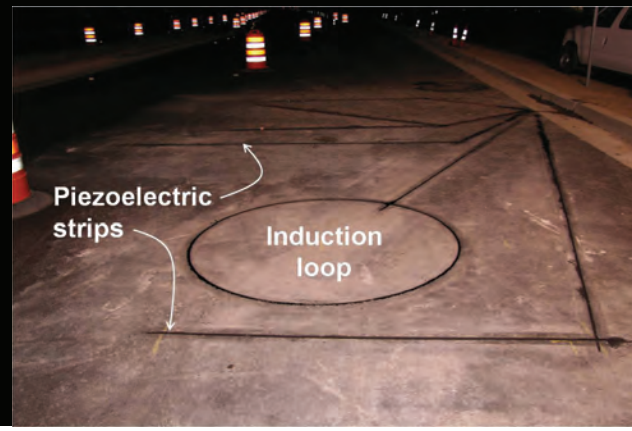
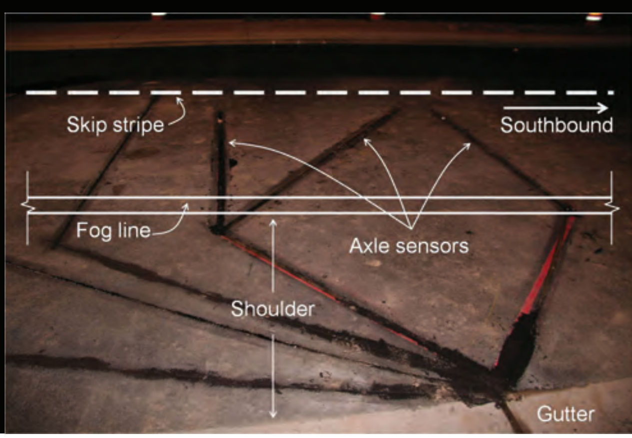


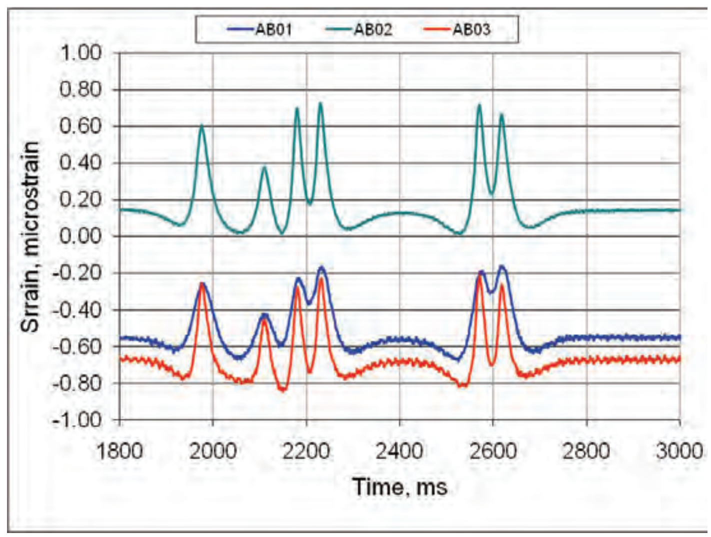
New Work Projects: Redmond

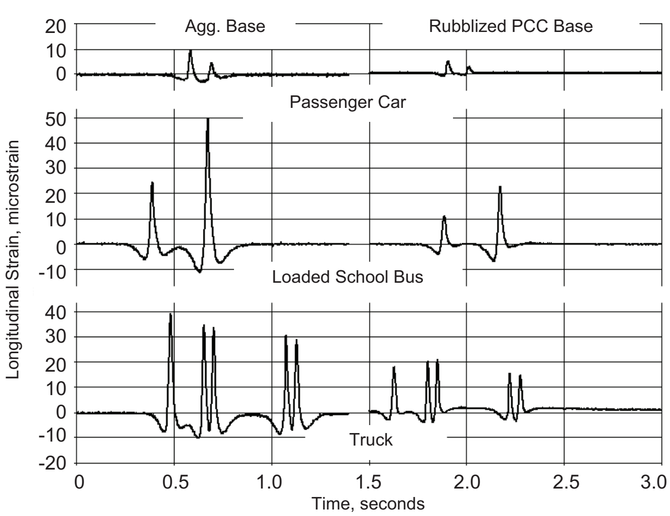
New Work Projects: Redmond



New Work Projects: Redmond



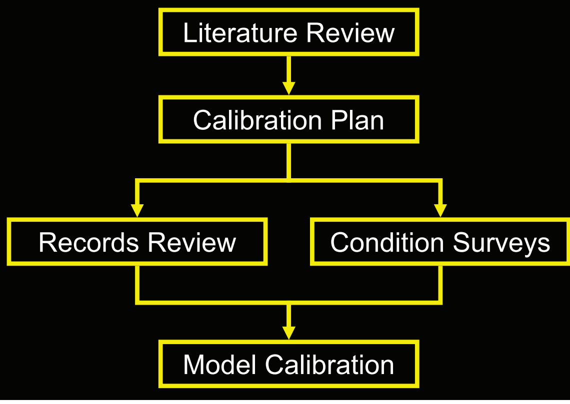




Rehabilitation Projects

- New project beginning July 2009
- Objective – provide ODOT with HMAC overlay performance models for rutting and cracking (fatigue, thermal, and reflective) calibrated to Oregon conditions

Work Plan Overview

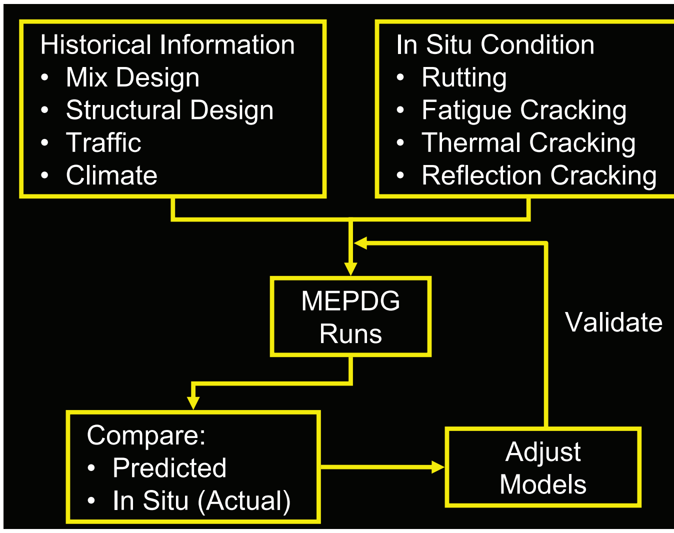


Task 1 - Literature Review

- NCHRP 01-40B: *"User Manual and Local Calibration Guide for the Mechanistic-Empirical Pavement Design Guide and Software"*
- Efforts from other states

Task 2 - Calibration Plan

- Develop comprehensive plan based on findings from literature review
- Initial thoughts include the following…



Task 3 – Records Review

1. Mine the ODOT PMS to identify candidate projects
2. Identify projects for which requisite information (mix design, structural design, etc.) exists
3. Select specific projects for further investigation
4. Obtain and summarize requisite information

Task 4 – Condition Surveys

- Perform detailed condition surveys on projects selected in Task 3 to quantify:
  - Rutting
  - Fatigue cracking
  - Thermal cracking
  - Reflective cracking

Task 5 – Model Calibration

For each distress type:

1. Using info from records review, run MEPDG to get predicted distress
2. Compare predicted distress to measured distress from condition surveys
3. If significant differences exist, adjust model coefficients
4. Repeat Steps 1 - 3 until differences are reduced to an acceptable level

Scope

- Structures
- Traffic levels
- Pavement condition
- Climate zones

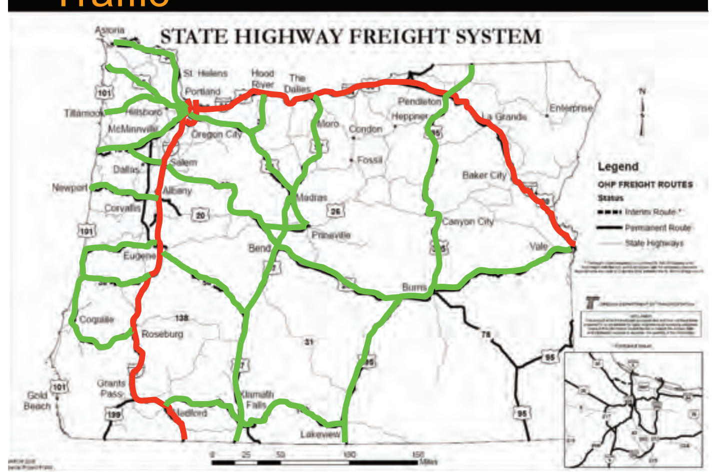
Structures

- HMAC over HMAC
- HMAC over JPCP
- HMAC over CRCP

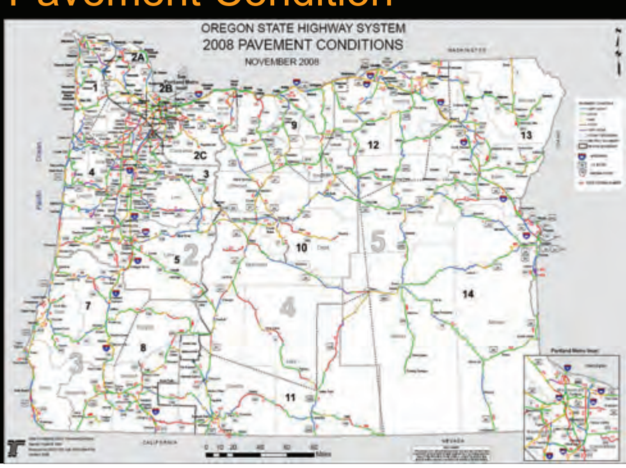
} ?

- HMAC over Rubbilized concrete – oldest project built in 1997

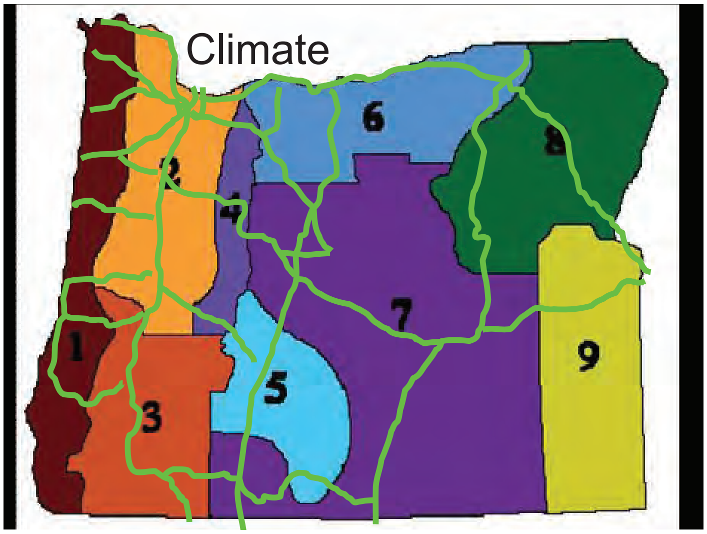
Traffic



Pavement Condition



Pavement Condition



Principal Challenges

- Requisite information for MEPDG runs:
  - Traffic:
    - Volume adjustment factors (MAF, truck dist., hourly dist., growth)
    - Axle load distribution
    - General (axles/truck & configuration)
  - Structure (layer properties, mix design, etc.)
- In situ condition

Rigid Pavement Climatic Effects in Illinois

Jeffery Roesler, Ph.D., P.E.
Associate Professor
Department of Civil and Environmental Engineering
University of Illinois

North-West MEPDG User's Group Meeting
Corvallis, OR
March 9-10, 2009

ILLINOIS CENTER FOR TRANSPORTATION

Acknowledgements

- ICT R57 – Technical Review Panel (2005-08)
  - Illinois Department of Transportation
    - Amy Schutzbach et al.
- UIUC Students
  - Jake Hiller
  - Dong Wang
  - Victor Cervantes
  - Matt Beyer
  - Amanda Bordelon

ILLINOIS CENTER FOR TRANSPORTATION

Overview

- Illinois has existing M-E JPCP method by Zollinger and Barenberg (1989)
  - No direct climate consideration
- IDOT has an semi-empirical method to determine CRCP thickness
  - No direct climate consideration
- Update/refine existing JPCP procedure and develop M-E CRCP design method

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Existing IDOT JPCP Method

- Traffic = ESALs
- MOR = 703 psi *(?)*
- k-value = 50, 100, 200 psi/in
- Temperature curling (k=100 psi/in)
- Joint Spacing = 15ft
- Shoulder Type = AC or Tied [widen]
- Reliability (95% curves)
- Failure = 20% slabs cracked – TF>10
- COPES data calibration

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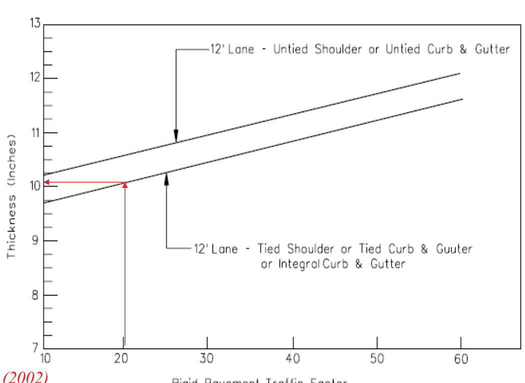
IDOT M-E JPCP Method



IDOT (2002)

K=50 psi/in

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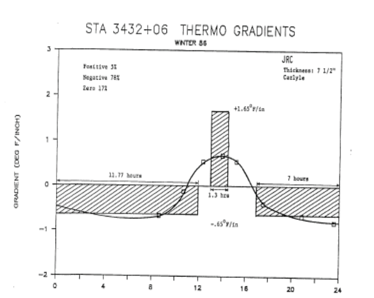
IDOT assumed Thermal Gradients

35% Night (-0.65°F/in)
25% Day (+1.65°F/in)
40% Zero (0°F/in)



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M-EPDG Evaluation

- Objective
  - Evaluate version 0.91 vs. 1.0
  - Determine effect of Climate on PCC thickness in Illinois
  - Is there a need for a geography / climate-based design method in Illinois?

Concrete Coefficient of Thermal Expansion (COTE)

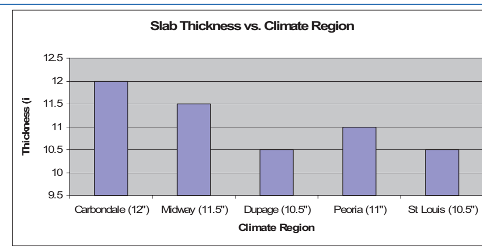
- Illinois SHRP Test Sites
  - 84 total cores
- $AVERAGE_{80\%} = 5.7 \times 10^{-6}/°F$ (69 cores)
- $STD\ DEV_{80\%} = 0.33 \times 10^{-6}/°F$
- COV = 6%

SHRP Test Site cores in Illinois

Climate Effect Inputs

- Changes in Climatic Effects
  - Climate data for several Illinois cities ran with E-ICM
- Concrete thickness was changed to ensure less than 20% slab cracking for each climate
  - *No faulting or IRI criteria limit!*

Climatic Effects (v. 0.91)



- Five regions in Illinois
- Range of slab thickness – 10.5” to 12”
- Pavement at all sites had less than 20% cracking at 30 yrs

MEPDG Summary *(Feb. 2007)*

- Climate may change a slab thickness
  - V0.8 - limited effect
  - V0.91 - 1.5” statewide
- All cracking is *top-down* except Class 5 vehicle analysis

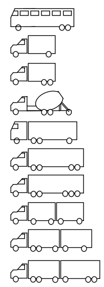
V.1.0 MEPDG / IDOT Inputs

- MEPDG (v1.0) default load spectra (TTC1)
- Illinois Vehicle Class Distribution
- Variables
  - Shoulder type (AC, tied, widen lane)
  - slab length (12, 15, 18 ft)
  - fatigue algorithm (MEPDG)
  - temperature profile (linear, nonlinear)
  - built-in curl (-10°F)

j2

Vehicle Class distribution

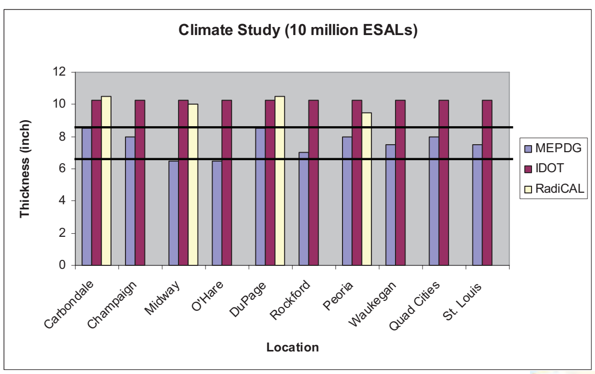
Class	Illinois	California	M-EPDG
Class 4	1.4%	1.1%	1.8%
Class 5	3.8%	23.0%	24.6%
Class 6	2.3%	5.2%	7.6%
Class 7	0.0%	0.3%	0.5%
Class 8	3.8%	6.7%	5.0%
Class 9	84.4%	50.6%	31.3%
Class 10	0.5%	0.6%	9.8%
Class 11	2.8%	8.8%	0.8%
Class 12	0.3%	1.1%	3.3%
Class 13	0.3%	0.1%	15.3%



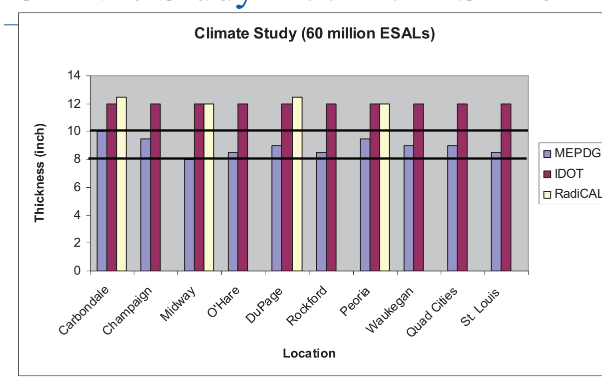
Slide 13

j2 add california distribution here.
jroesler, 7/23/2007

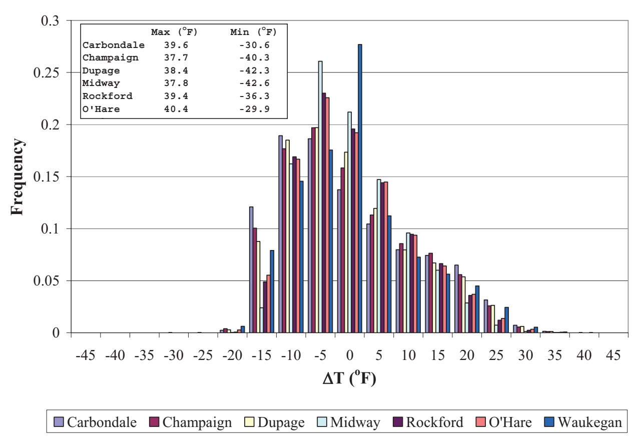
Climate Study – 10x10^6 ESALs



Climate Study – 60x10^6 ESALs



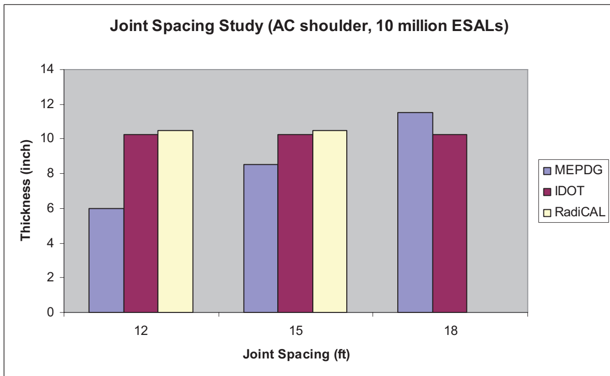
Temperature Differential Freq.



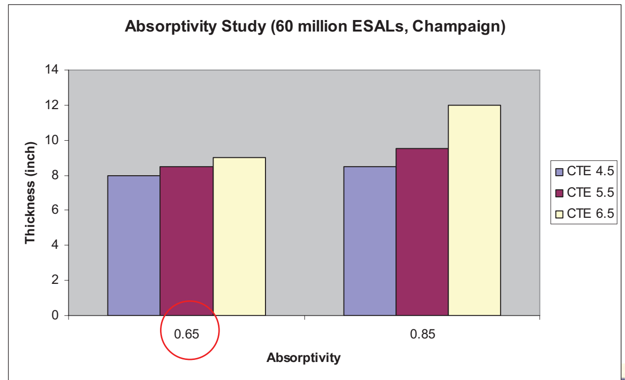
MEPDG Temperature Data Files

1. Carbondale 8/1/98 - 7/31/05
2. Champaign 8/1/97 - 7/31/05
3. Dupage 8/1/97 - 7/31/05
4. Midway 8/1/97 - 7/31/05
5. O'Hare 8/1/96 - 7/31/05
6. Rockford 8/1/96 - 7/31/05
7. Waukegan 8/1/00 - 7/31/05

Joint Spacing – 10M ESALs and AC Shoulder



Thermal Properties



Findings – CLIMATE -JPCP

Climate

- Sensitive (1.5” to 2”)
- How to accommodate?

- Temperature Curling
  - Nonlinear is more representative

(IL) Climatic Zone Consideration

- Separate CHART for state zones (?)

Design Feature limitations (h>10 inches)

- ≤15’ south of I-80?
- 18’ use structural fibers or higher specified strength

- For h ≤ 10 inches
- 12’ south of I-80?

Acknowledgements

The Illinois Center for Transportation (ICT) is an innovative partnership between the Illinois Department of Transportation (IDOT) and the University of Illinois at Urbana-Champaign (UIUC).

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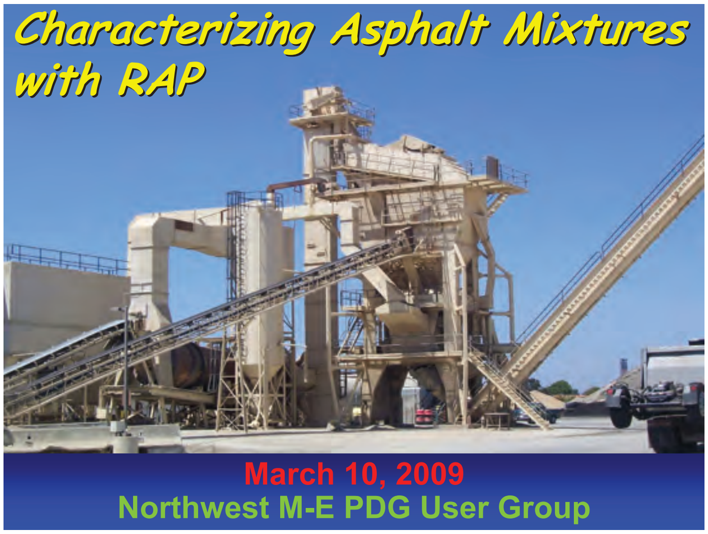
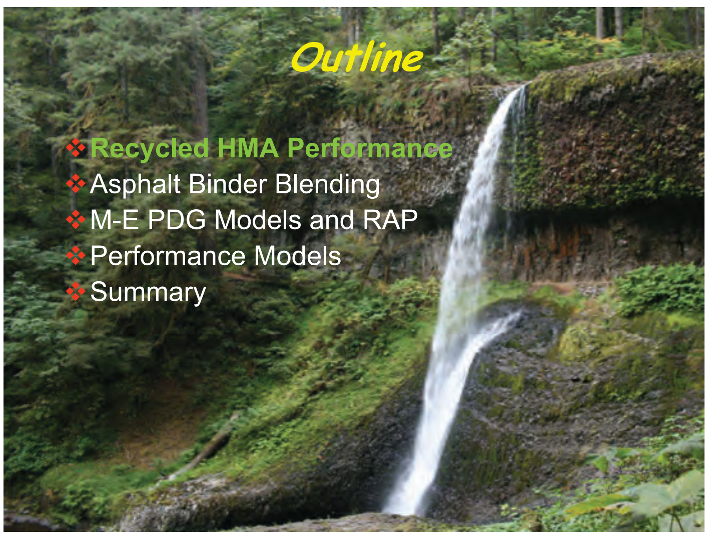
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Illinois Department of Transportation


Characterizing Asphalt Mixtures with RAP
March 10, 2009
Northwest M-E PDG User Group


Outline
Recycled HMA Performance
Asphalt Binder Blending
M-E PDG Models and RAP
Performance Models
Summary


Outline
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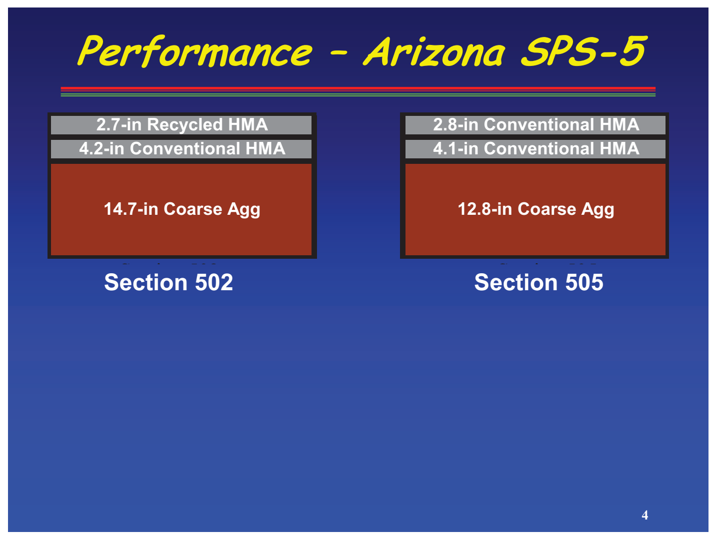
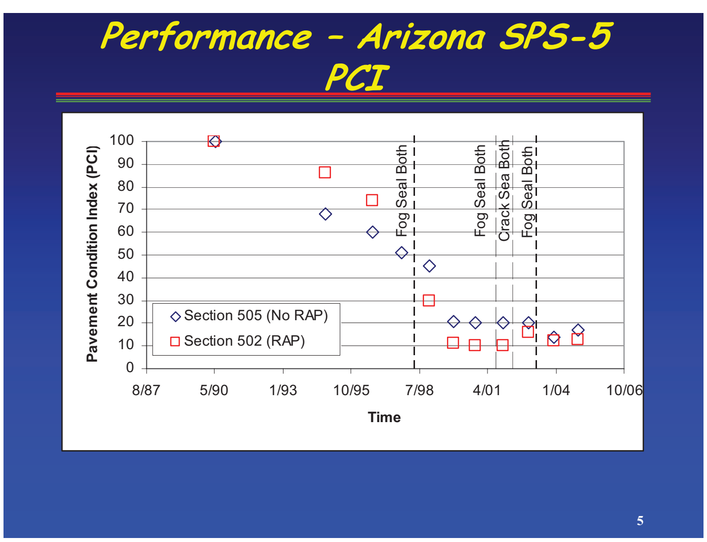
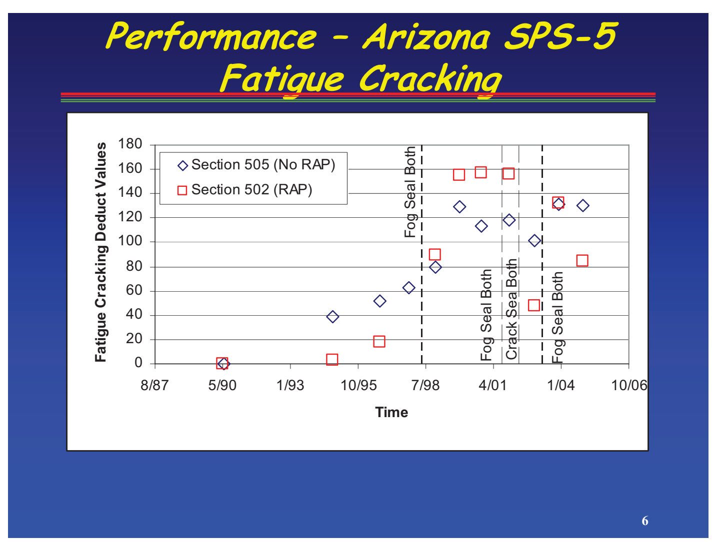
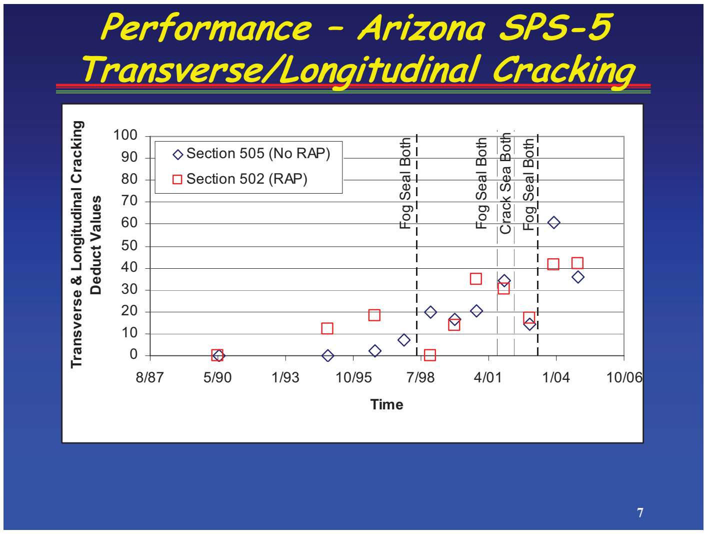
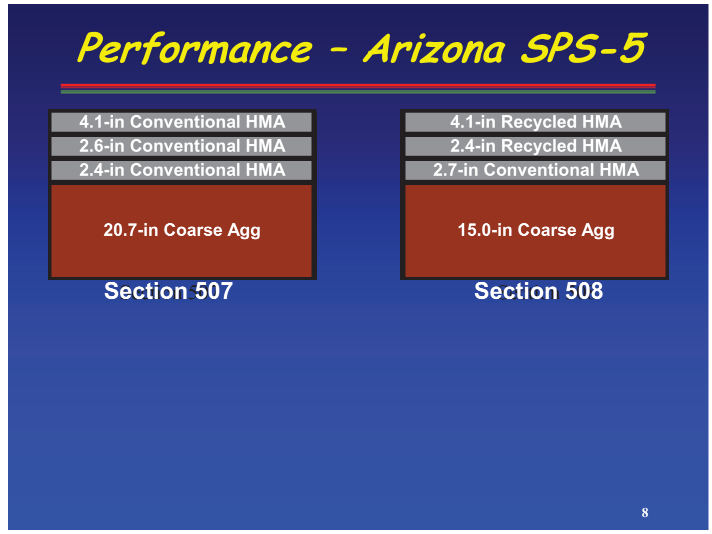
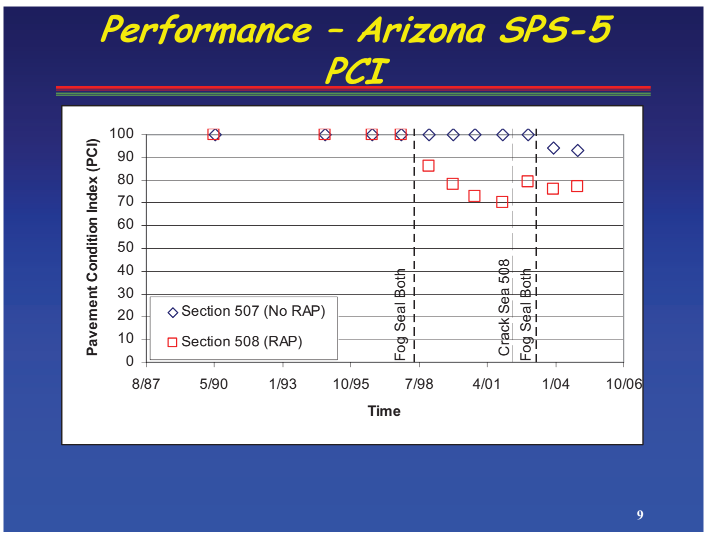

Performance – Arizona SPS-5
2.7-in Recycled HMA
4.2-in Conventional HMA
14.7-in Coarse Agg
Section 502
2.8-in Conventional HMA
4.1-in Conventional HMA
12.8-in Coarse Agg
Section 505
4


Performance – Arizona SPS-5
PCI
Pavement Condition Index (PCI)
Time
Section 505 (No RAP)
Section 502 (RAP)
Fog Seal Both
Fog Seal Both
Crack Sea Both
Fog Seal Both
8/87
5/90
1/93
10/95
7/98
4/01
1/04
10/06
5


Performance – Arizona SPS-5
Fatigue Cracking
Fatigue Cracking Deduct Values
Time
Section 505 (No RAP)
Section 502 (RAP)
Fog Seal Both
Fog Seal Both
Crack Sea Both
Fog Seal Both
8/87
5/90
1/93
10/95
7/98
4/01
1/04
10/06
6


Performance – Arizona SPS-5
Transverse/Longitudinal Cracking
Transverse & Longitudinal Cracking Deduct Values
Section 505 (No RAP)
Section 502 (RAP)
Fog Seal Both
Fog Seal Both
Crack Sea Both
Fog Seal Both
100 90 80 70 60 50 40 30 20 10 0
8/87 5/90 1/93 10/95 7/98 4/01 1/04 10/06
Time
7


Performance – Arizona SPS-5
4.1-in Conventional HMA
2.6-in Conventional HMA
2.4-in Conventional HMA
20.7-in Coarse Agg
Section 507
4.1-in Recycled HMA
2.4-in Recycled HMA
2.7-in Conventional HMA
15.0-in Coarse Agg
Section 508
8


Performance – Arizona SPS-5
PCI
Pavement Condition Index (PCI)
Section 507 (No RAP)
Section 508 (RAP)
Fog Seal Both
Crack Sea 508
Fog Seal Both
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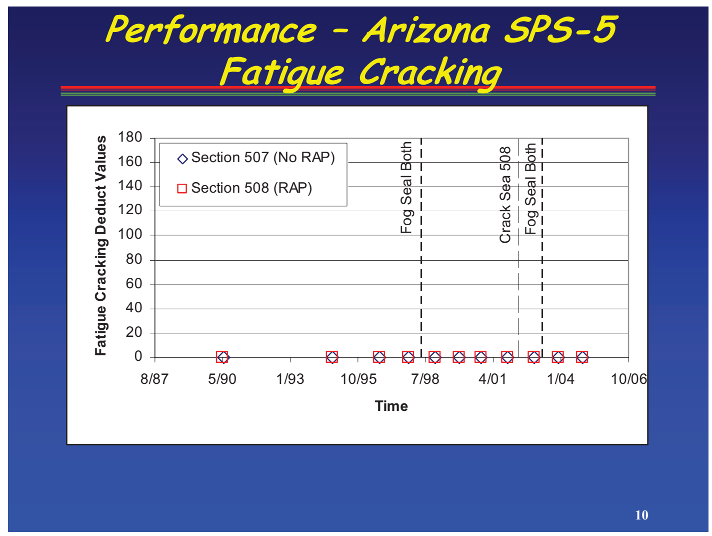
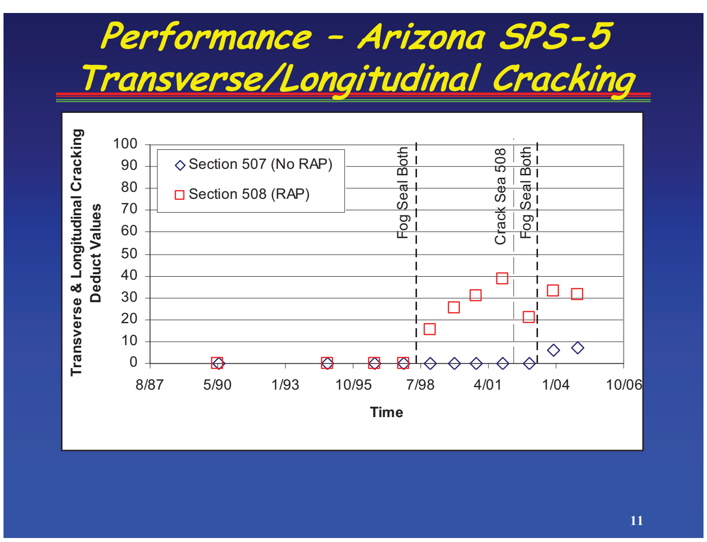
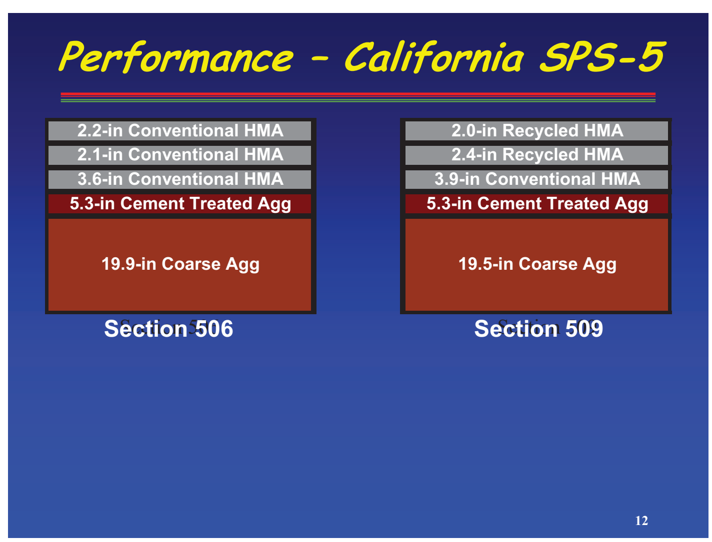
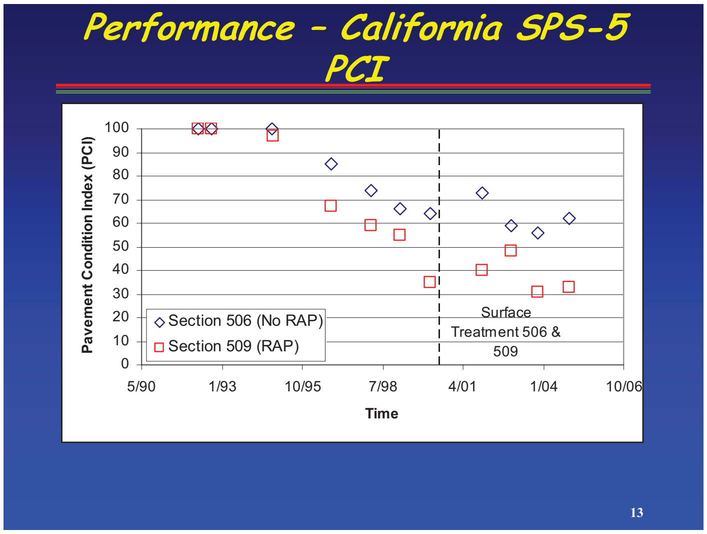
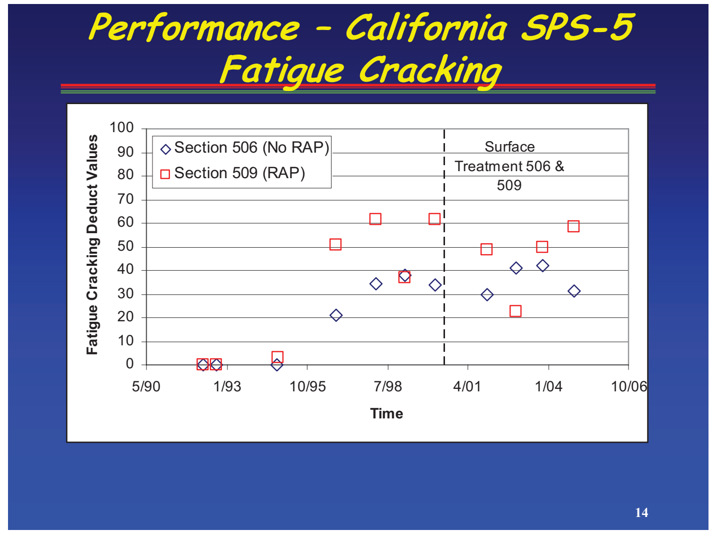
8/87 5/90 1/93 10/95 7/98 4/01 1/04 10/06
Time
9

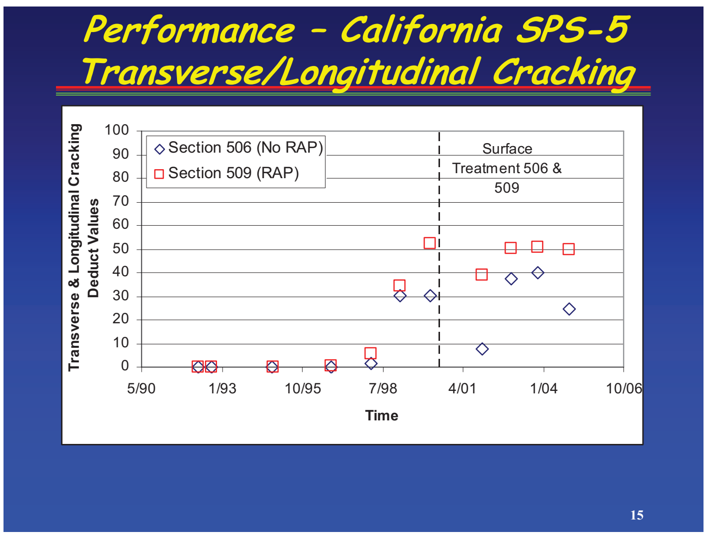

Performance – Arizona SPS-5
Fatigue Cracking
Fatigue Cracking Deduct Values
Section 507 (No RAP)
Section 508 (RAP)
Fog Seal Both
Crack Sea 508
Fog Seal Both
180 160 140 120 100 80 60 40 20 0
8/87 5/90 1/93 10/95 7/98 4/01 1/04 10/06
Time
10

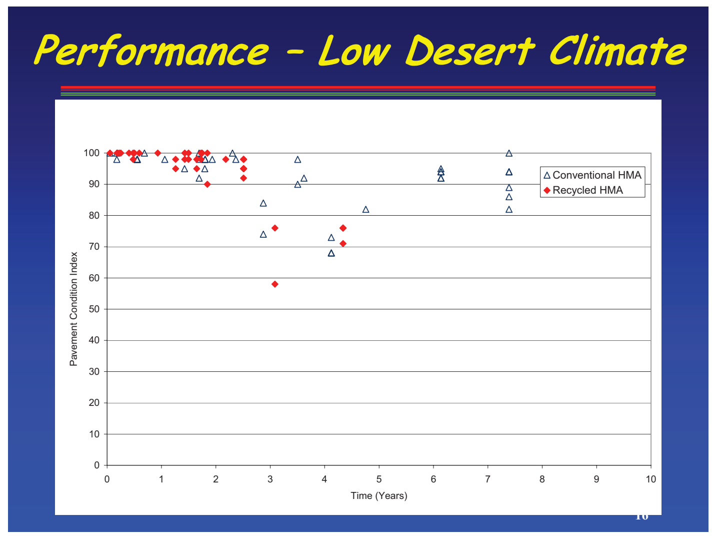

Performance – Arizona SPS-5
Transverse/Longitudinal Cracking
Transverse & Longitudinal Cracking Deduct Values
Section 507 (No RAP)
Section 508 (RAP)
Fog Seal Both
Crack Sea 508
Fog Seal Both
100 90 80 70 60 50 40 30 20 10 0
8/87 5/90 1/93 10/95 7/98 4/01 1/04 10/06
Time
11

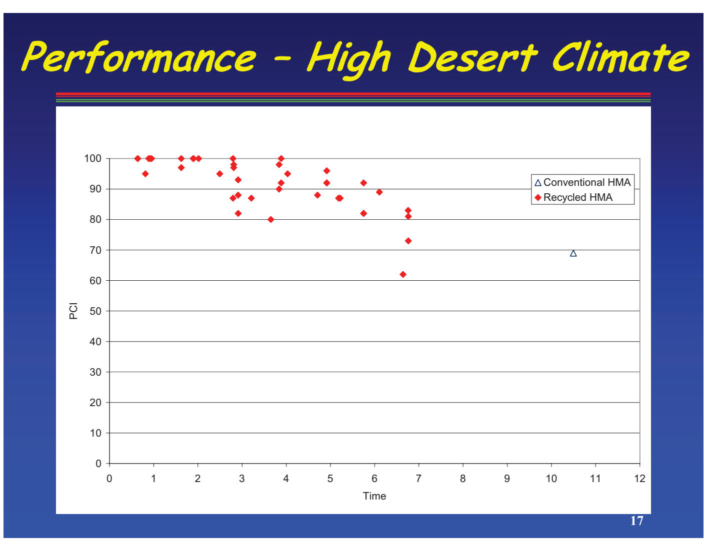

Performance – California SPS-5
2.2-in Conventional HMA
2.1-in Conventional HMA
3.6-in Conventional HMA
5.3-in Cement Treated Agg
19.9-in Coarse Agg
Section 506
2.0-in Recycled HMA
2.4-in Recycled HMA
3.9-in Conventional HMA
5.3-in Cement Treated Agg
19.5-in Coarse Agg
Section 509
12

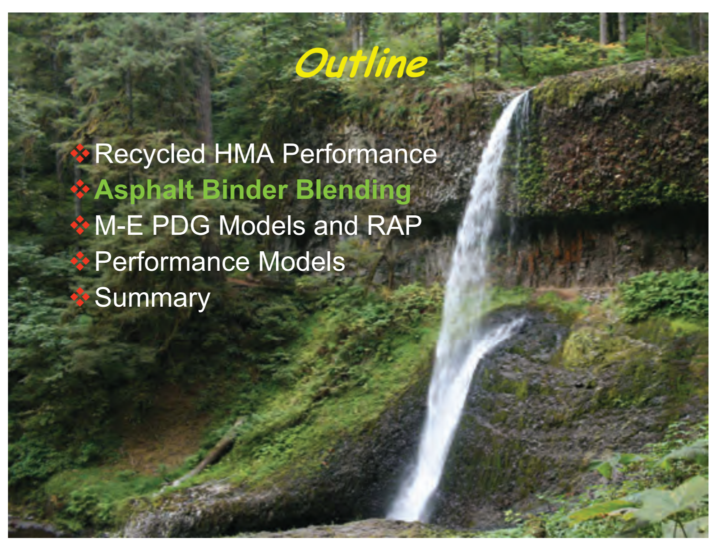

Performance – California SPS-5
PCI
Pavement Condition Index (PCI)
Section 506 (No RAP)
Section 509 (RAP)
Surface
Treatment 506 &
509
5/90
1/93
10/95
7/98
4/01
1/04
10/06
Time
13


Performance – California SPS-5
Fatigue Cracking
Fatigue Cracking Deduct Values
Section 506 (No RAP)
Section 509 (RAP)
Surface
Treatment 506 &
509
5/90
1/93
10/95
7/98
4/01
1/04
10/06
Time
14


Performance – California SPS-5
Transverse/Longitudinal Cracking
Transverse & Longitudinal Cracking
Deduct Values
Section 506 (No RAP)
Section 509 (RAP)
Surface
Treatment 506 &
509
5/90
1/93
10/95
7/98
4/01
1/04
10/06
Time
15


Performance – Low Desert Climate
Pavement Condition Index
Conventional HMA
Recycled HMA
Time (Years)

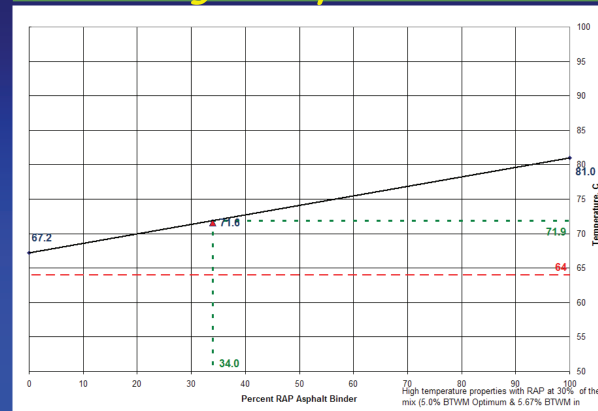

Performance – High Desert Climate
PCI
Conventional HMA
Recycled HMA
Time
17


Outline
Recycled HMA Performance
Asphalt Binder Blending
M-E PDG Models and RAP
Performance Models
Summary

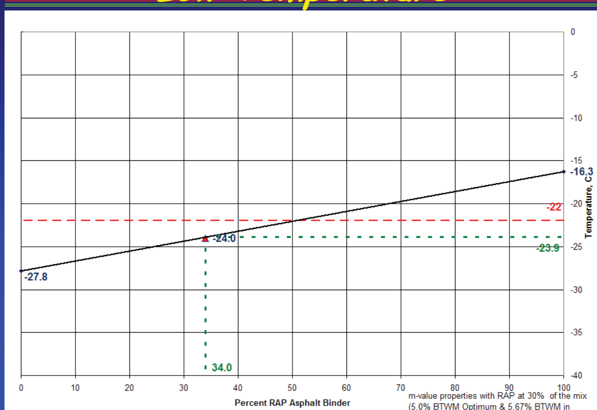
Virgin Asphalt Considerations

- 0 to 15% no change in binder grade
- 16 to 25% one temperature grade lower (high and low end)
- >25% use blending charts

Blended Virgin/RAP Asphalt Binder – High Temperature

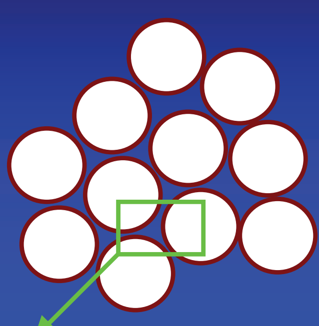


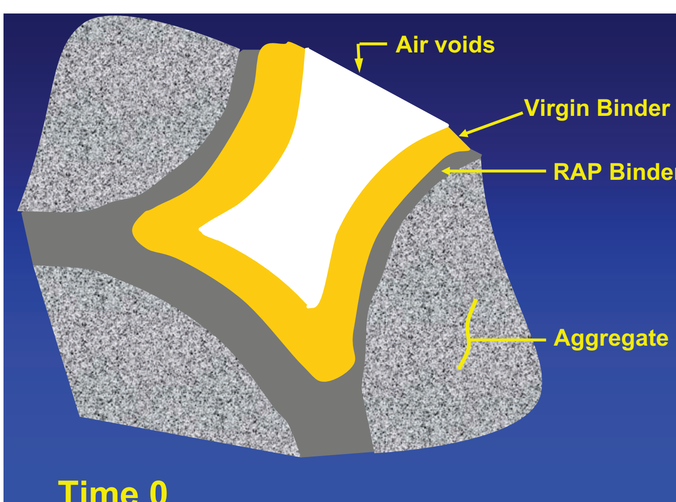
Blended Virgin/RAP Asphalt Binder – Low Temperature

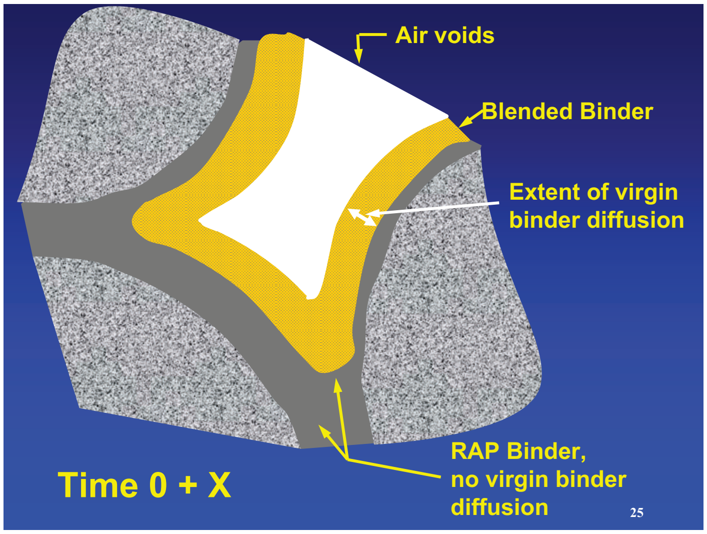


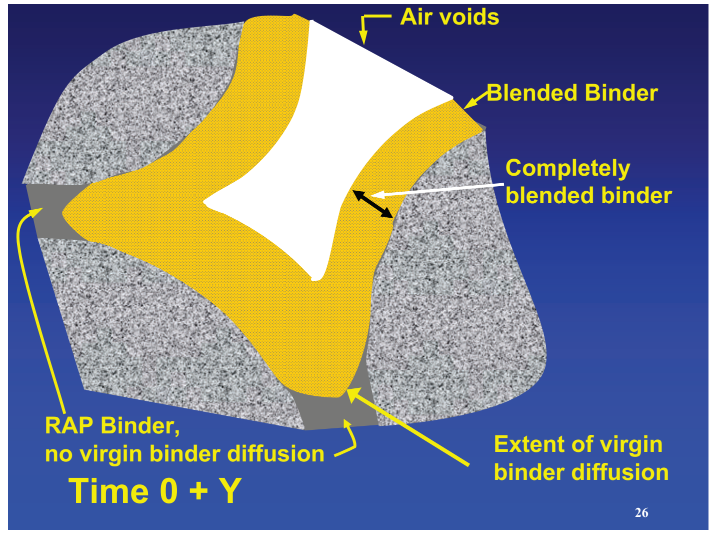
What Happens During Mixing with RAP?

Looking at the Asphalt Films









Witczak's E* Predictive Equation

$$\log E^* = 3.750063 + 0.02932\rho_{200} - 0.001767(\rho_{200})^2 - 0.002841\rho_4 - 0.058097V_a - 0.802208\left(\frac{V_{beff}}{V_{beff}+V_a}\right) + \frac{3.871977 - 0.0021\rho_4 + 0.003958\rho_{38} - 0.000017(\rho_{38})^2 + 0.005470\rho_{34}}{1 + e^{(-0.603313 - 0.313351\log(f) - 0.393532\log(\eta))}}$$

- E* = dynamic modulus, psi
- η = bitumen viscosity, 10^6 Poise
- f = loading frequency, Hz
- V_a = air void content, %
- V_{beff} = effective bitumen content, % by volume
- ρ_{34} = cumulative % retained on ¾-in sieve
- ρ_{38} = cumulative % retained on 3/8-in sieve
- ρ_4 = cumulative % retained on No. 4 sieve
- ρ_{200} = percent passing No. 200 sieve

RAP High Temperature Properties

Property	Test Method	Test Temp, C	RAP No.	RAP Ave.	RAP Std. Dev.	RAP COV
Absolute Viscosity, P	ASTM D2171	60	2	1,020,651	279,868	27.4
DSR G*/sinδ, kPa	AASHTO T315	60	8	436.01	143.94	33.0
		64	8	216.88	73.73	34.0
		70	8	78.86	27.82	35.3
		76	8	29.27	9.97	34.0
		82	8	11.70	3.95	33.7
		88	8	4.96	1.68	33.8
DSR Critical Temp	AASHTO T315	Critical Temp	8	93.3	2.6	2.7

RAP Low Temperature Properties

Property	Test Method	Test Temp, C	RAP No.	RAP Ave.	RAP Std. Dev.	RAP COV
BBR, Stiffness, MPa	AASHTO T313	6	3	254.0	5.3	2.1
		0	3	391.7	5.5	1.4
		-6	3	511.7	26.3	5.1
BBR, m-value	AASHTO T313	6	3	0.302	0.0010	0.3
		0	3	0.256	0.0020	0.8
		-6	3	0.209	0.0042	2.0
BBR Critical Temp	AASHTO T313	Critical Temp	3	5.9	0.1	1.0

RAP Viscosity (ASTM D2171) – 60C

Location	No. of Tests	Average	Std. Dev.
1	2	1,020,651	279,868
2	2	26,824	3,306
3	2	279,224	4,885
4	2	424,478	66,424
5	2	357,182	35,099
6	2	72,443	5,464

RAP Properties

Extraction Method	Statistic	¾-in Sieve, % Retained	3/8-in Sieve, % Retained	No. 4 Sieve, % Retained	No. 200, % Passing	Asphalt Binder Content, %DWA
Ignition	No.	3	3	3	3	3
	Ave.	0.0	3.0	19.0	10.5	5.71
	Std. Dev.	0.0	1.7	7.5	1.32	0.32
Solvent	No.	10	10	10	10	10
	Ave.	0.0	4.0	22.0	11.1	5.11
	Std. Dev.	0.0	1.1	4.7	0.92	0.27

Witczak's E* Predictive Equation

$$\log E^{*} = 3.750063 + 0.02932\rho_{200} - 0.001767(\rho_{200})^2 - 0.002841\rho_4 - 0.058097V_a - 0.802208\left(\frac{V_{beff}}{V_{beff}+V_a}\right) + \frac{3.871977 - 0.0021\rho_4 + 0.003958\rho_{38} - 0.000017(\rho_{38})^2 + 0.005470\rho_{34}}{1+e^{(-0.603313-0.313351\log(f)-0.393532\log(\eta))}}$$

- E* = dynamic modulus, psi
- η = bitumen viscosity, 10^6 Poise
- f = loading frequency, Hz
- V_a = air void content, %
- V_{beff} = effective bitumen content, % by volume
- ρ_{34} = cumulative % retained on ¾-in sieve
- ρ_{38} = cumulative % retained on 3/8-in sieve
- ρ_4 = cumulative % retained on No. 4 sieve
- ρ_{200} = percent passing No. 200 sieve

RAP Impact on Performance Models – Permanent Deformation

$$\Delta_{p(HMA)} = \varepsilon_{p(HMA)} h_{HMA} = \boxed{\beta_{1r}} k_z \boxed{\varepsilon_{r(HMA)}} 10^{k_{1r}} n^{k_{2r}\boxed{\beta_{2r}}} T^{k_{3r}\boxed{\beta_{3r}}}$$

- $\Delta_{p(HMA)}$ = accumulated permanent or plastic vertical deformation in the HMA layer/sublayer, inches
- Components affected
  - $\varepsilon_{r(HMA)}$ = resilient or elastic strain calculated by structural response model at mid-depth of each HMA sublayer, in/in
- Possibly affected
  - β_{r1}, β_{r2}, β_{r3} = local or mixture field calibration constants

RAP Impact on Performance Models – Fatigue and Longitudinal Cracking

$$N_{f-HMA} = k_{f1}\boxed{(C)}(C_H)\boxed{\beta_{f1}}(\varepsilon_t)^{k_{f2}\boxed{\beta_{f2}}}\boxed{(E_{HMA})}^{k_{f3}\boxed{\beta_{f3}}}$$

- N_{f-HMA} = allowable number of axle load applications for a flexible pavement and HMA overlays
- Components affected
  - C = function of effective asphalt content by volume and percent air voids in the HMA mixture
  - E_{HMA} = dynamic modulus of the HMA measured in compression, psi
- Possibly affected
  - β_{r1}, β_{r2}, β_{r3} = local or mixture field calibration constants

RAP Impact on Performance Models – Transverse Cracking

$$\Delta C = A\left(\Delta K\right)^{n} \qquad A = 10^{k\,\boxed{\beta_t}\,(4.389-2.52\,Log(\boxed{E_{HMA}}\,\boxed{\sigma_m}\,n))}$$

- $N_{f\text{-}HMA}$ = allowable number of axle load applications for a flexible pavement and HMA overlays
- Components affected
  - E_{HMA} = dynamic modulus of the HMA measured in compression, psi
- Possibly affected
  - β_r = local or mixture field calibration factor
  - σ_m = mixture tensile strength, psi

37

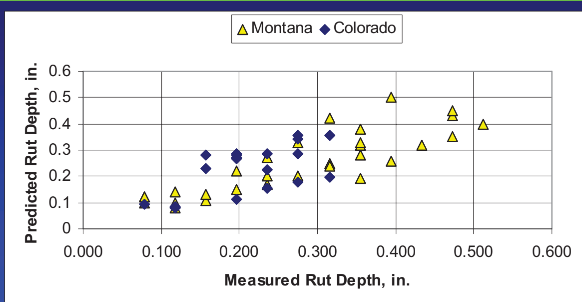
RAP Impact on Performance Models – IRI – New Pavements

$$IRI = IRI_o + 0.0150(SF) + 0.400\boxed{(FC_{Total})} + 0.0080\boxed{(TC)} + 40.0\boxed{(RD)}$$

- IRI = international ride index after construction, in/mi
- Components affected
  - FC_{Total} = area of fatigue cracking, percent of area
  - TC = length of transverse cracking, ft/ mi
  - RD = average rut depth, in

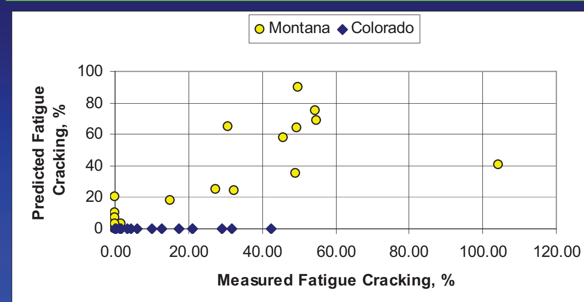
38

Actual and Predicted Performance Rutting



39

Actual and Predicted Performance Fatigue



40

Outline

- Recycled HMA Performance
- Asphalt Binder Blending
- M-E PDG Models and RAP
- Performance Models
- Summary

Summary

- Limited performance information
- National research on binders
- RAP properties
- Influence of RAP on M-E PDG models

42


Questions/Discussion

Characterization of Unbound Materials

NW-MEPDG User Group Meeting
Corvallis, 10-Mar-09
Steve Saboundjian, P.E.
State Pavement Engineer
Alaska DOT&PF

Impact of Fines Content on Resilient Modulus Reduction of Base Courses during Thawing

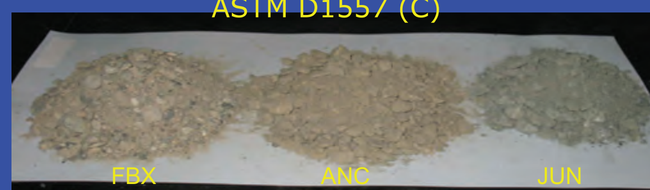
- Research work by UAF (Dr. Jenny Lu et al.)
- Funding by AUTC and ADOT&PF

Project Scope

Experimental design
- 3 base course materials (D-1): 3 AK Regions
- 1 gradation
- 3 Fines contents: P200 = 6%, 8%, 10%
- 4 Temperatures: 0, 15, 30, 68°F
- 3 Moisture contents (OMC, x% ± OMC)

Laboratory Tests
- Pressure plate *suction* test
- Frost-heave test
- **Resilient modulus test**

Compaction Testing
ASTM D1557 (C)



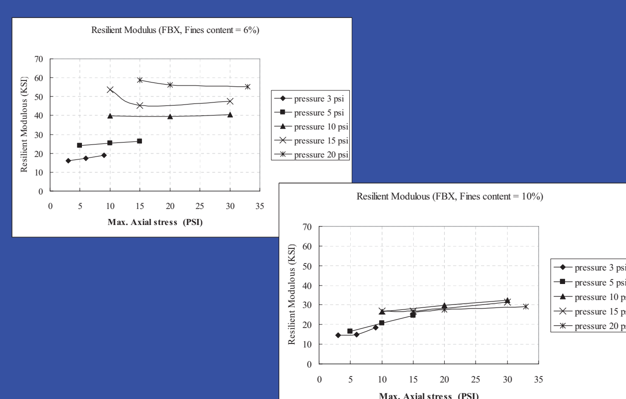
- A-1-a
- 3 P200 contents

Results: As P200 increases:
- Increase in MDD
- No change in OMC
- OMC (5.3%)
- OMC+0.7% (6%)
- OMC-2% (3.3%)

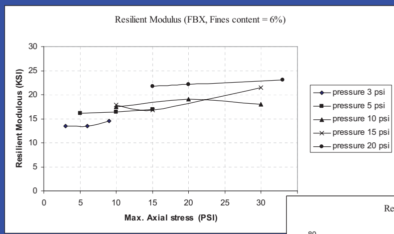
Resilient Modulus (M_R) Testing
AASHTO T307

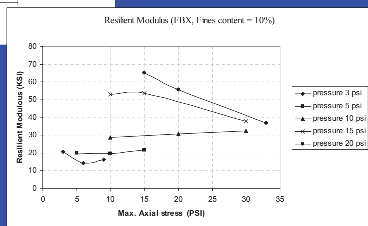
Work completed:
- D-1 base courses from 3 Regions
- Temperature: 68°F
- Fines content: 6, 8, 10%
- Moisture content:
  - OMC (5.3%)
  - OMC+0.7% (6.0%)
  - OMC-2% (3.3%)

M_R Results: Fairbanks @ 3.3% (OMC-2%)

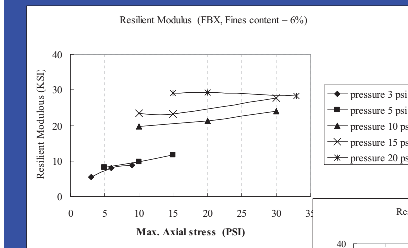


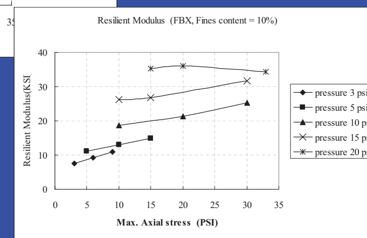
M_R Results: Fairbanks @ 5.3% (OMC)





M_R Results: Fairbanks @ 6% (OMC+0.7%)





Range of values M_R (ksi) Data, 68F

Material Type	Water Content	Fines Content			
		3.15%	6%	8%	10%
Fairbanks	OMC-2%	15-45	15-60	20-65	15-35
	OMC	10-20	10-25	5-15	15-65
	OMC+0.7%	5-25	5-30	5-30	5-35
Anchorage	OMC-2%	15-55	20-70	20-55	20-70
	OMC	15-35	15-35	10-40	10-25
	OMC+0.7%	5-25	5-20	5-20	5-25
Juneau	OMC-2%	20-60	25-70	30-70	30-85
	OMC	10-40	10-20	15-30	10-30
	OMC+0.7%	5-20	5-25	5-30	5-30

M_R Model 1

May and Witczak (1981):

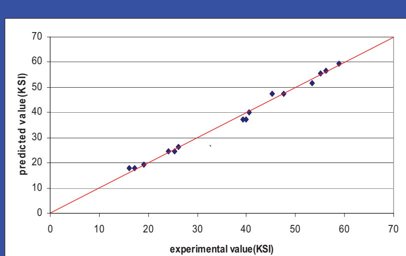
$$M_R = k_1 p_a \left(\frac{\theta}{p_a}\right)^{k_2} \left(\frac{\sigma_d}{p_a}\right)^{k_3}$$

where:

M_R = resilient modulus
θ = bulk stress
s_d = deviator stress
P_a = reference pressure
k_1, k_2, k_3 = regression constants

M_R Data Fitting (Fairbanks)

Water content = OMC-2%; Fines content = 6%

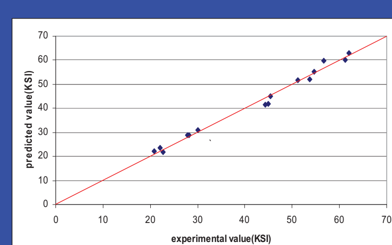


$$M_R = k_1 p_a \left(\frac{\theta}{p_a}\right)^{k_2} \left(\frac{\sigma_d}{p_a}\right)^{k_3}$$

K_1= 937
K_2= 1.53
K_3=-0.9285
R^2= 99%

M_R Data Fitting (Fairbanks)

Water content = OMC-2%; Fines content = 8%

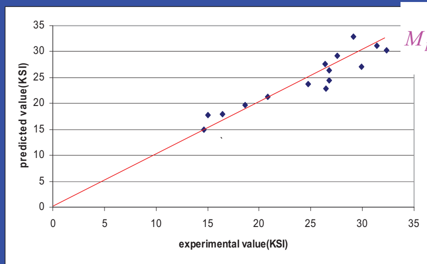


$$M_R = k_1 p_a \left(\frac{\theta}{p_a}\right)^{k_2} \left(\frac{\sigma_d}{p_a}\right)^{k_3}$$

K_1= 1201
K_2= 1.3277
K_3=-0.794
R^2= 98.6%

M_R Data Fitting (Fairbanks)

Water content = OMC-2%; Fines content = 10%



$$M_R = k_1 p_a \left(\frac{\theta}{p_a}\right)^{k_2} \left(\frac{\sigma_d}{p_a}\right)^{k_3}$$

K_1= 1462

K_2= 0.2912

K_3= 0.06

R^2= 85.3%

Work in Progress

- Data analysis for M_R Testing:
  k_1, k_2, k_3 =
  f (source, PI, P200, density, w/c, suction, Temp., …)

- Permanent deformation modeling

- Frost-heave testing

Additional slides!

M_R Model 2

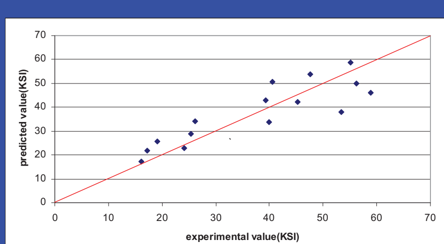
K- θ model (Seed et al.1962):

$$M_R = k_1 \left(\frac{\theta}{p_a}\right)^{k_2}$$

where:

M_R	=	resilient modulus
θ	=	bulk stress
P_a	=	reference pressure
k_1, k_2	=	regression constants

M_R Data Fitting (Fairbanks)



$$M_R = k_1 \left(\frac{\theta}{p_a}\right)^{k_2}$$

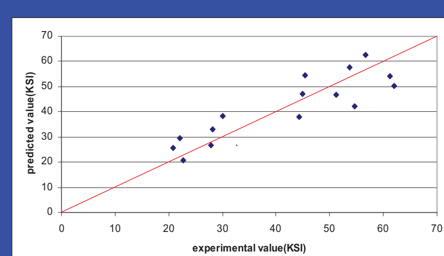
K_1= 27403

K_2= 0.562

R^2= 75.3%

Water content: OMC-2%; fines content: 6%

M_R Data Fitting (Fairbanks)



$$M_R = k_1 \left(\frac{\theta}{p_a}\right)^{k_2}$$

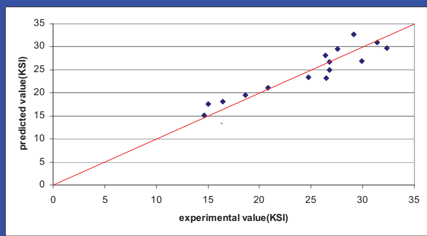
K_1= 31481

K_2= 0.5077

R^2= 77%

Water content: OMC-2%; fines content: 8%

M_R Data Fitting (Fairbanks)



$$M_R = k_1\left(\frac{\theta}{p_a}\right)^{k_2}$$

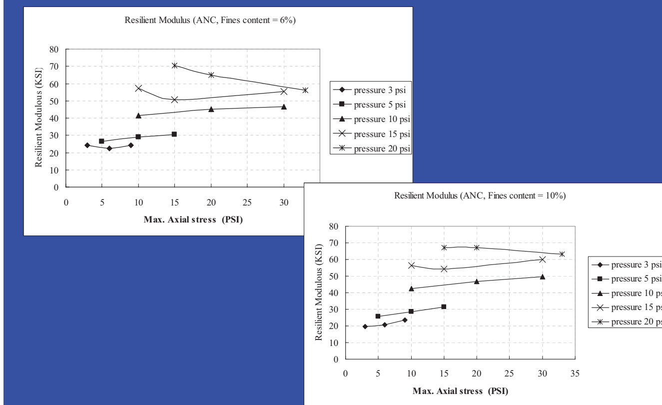
K_1= 20305

K_2= 0.3523

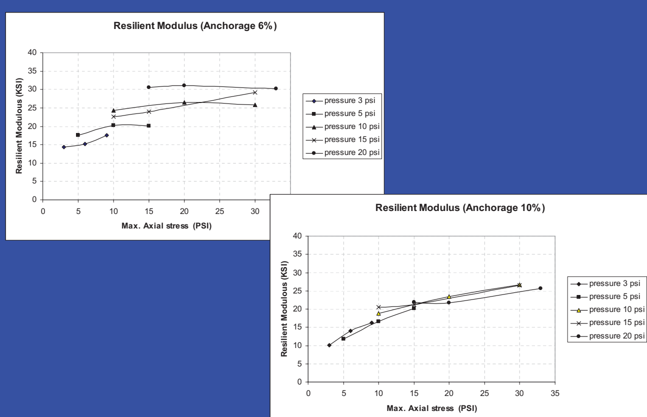
R^2= 87%

Water content: OMC-2%; fines content: 10%

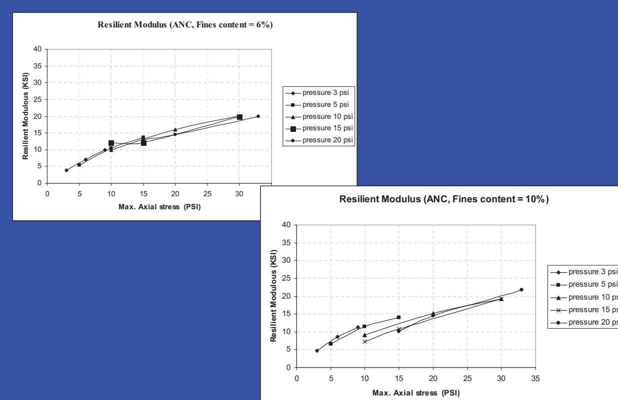
M_R Results: Anchorage @ 3.3% (OMC-2%)



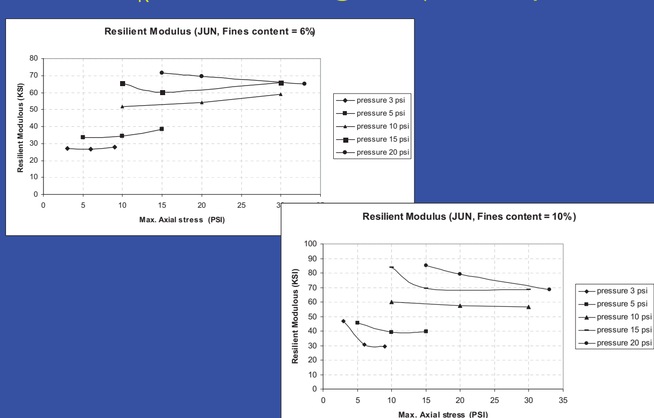
M_R Results: Anchorage @ 5.3% (OMC)



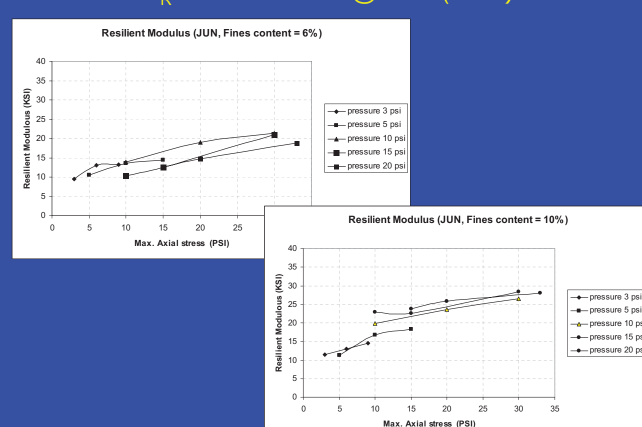
M_R Results: Anchorage @ 6% (OMC+0.7%)



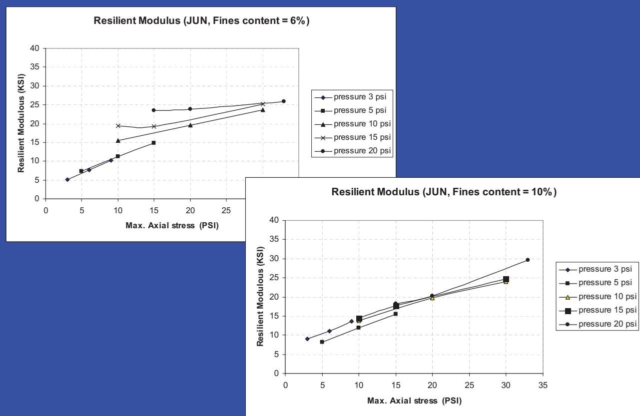
M_R Results: Juneau @ 3.3% (OMC-2%)



M_R Results: Juneau @ 5.3% (OMC)



M_R Results: Juneau @ 6% (OMC+0.7%)



M-E Concrete Pavement Design in Illinois

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North-West MEPDG User's Group Meeting
Corvallis, OR
March 9-10, 2009

Acknowledgements

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    - Amy Schutzbach et al.
- UIUC Students
  - Jake Hiller, Dong Wang, Victor Cervantes
  - Matt Beyer, Amanda Bordelon

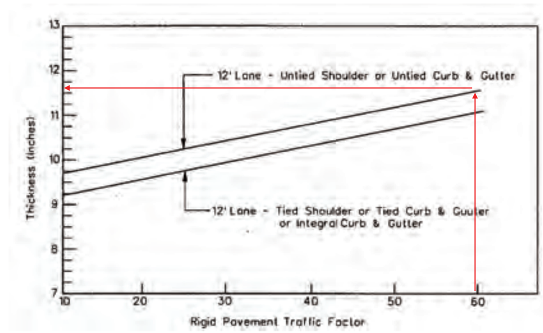
- Bordelon, A., Roesler, J.R., and Hiller, J.E., *Mechanistic-Empirical Design Concepts for Jointed Plain Concrete Pavements in Illinois*, Final Report for Illinois Center for Transportation, University of Illinois, Urbana, IL, March 2009, 252 pp.
- Beyer, M. and Roesler, J.R., *Mechanistic-Empirical Design Concepts for Continuously Reinforced Concrete Pavements in Illinois*, Final Report, Illinois Center for Transportation, University of Illinois, Urbana, IL, March 2009, 80 pp.

Outline

- Existing IDOT Design methods
  - JPCP and CRCP
- M-EPDG Evaluation
- Traffic
- Proposed JPCP/CRCP design
- Recommendations

Example, IDOT JPCP design curve

Subgrade = Fair



IDOT M-E JPCP Curves (1992)

- k=50, 100, or 200 psi
- Flexural Strength = 750 psi
- D-bar = 18 inch
- Slab length = 15ft w/dowels
- ESALs: 1 to 60 million
- Temperature Curling
- Shoulder type (tied, asphalt, ~~widen~~)
- Zero-Maintenance Fatigue Equation
- 95% Reliability

M-EPDG for Illinois DOT?

IDOT has M-E flexible and rigid pavement design guide since 1989.

- Approved method by IDOT
- IDOT has confidence in JPCP
- Fundamental principles similar to M-EPDG

- M-EPDG makes it difficult to make future changes/refinement to JPCP or CRCP design method
  - Limits further independent design research
  - No ability to check the models and coding of the M-EPDG
  - IDOT can easily update their own code

2006

M-EPDG, con't

- M-EPDG sensitivity checks
  - Load spectra vs. ESALs
  - Climate vs. joint spacing limit
- M-EPDG is very good for states w/o M-E experience

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Illinois DOT Traffic Questions

- How does load spectra variations for Illinois conditions affect thickness design of concrete pavement?
- Is load spectra necessary over ESALs?
  - For IDOT, expensive to collect load spectra

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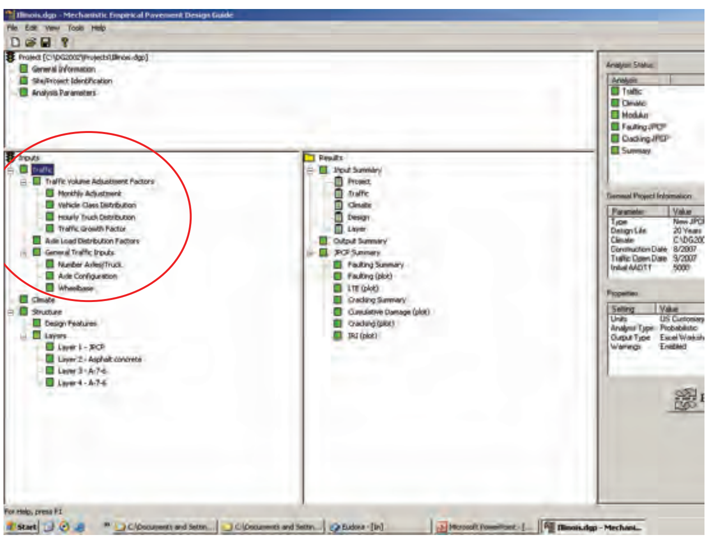
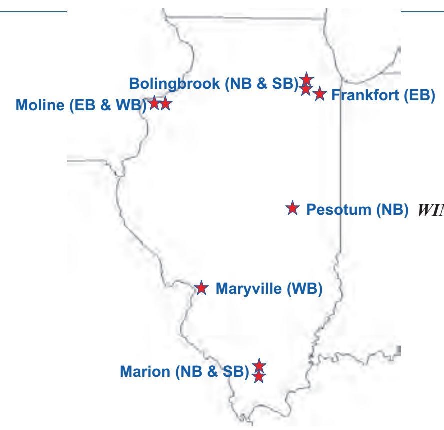


IL Weigh Station Data



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Vehicle Class Distribution

Vehicle Class	Bolingbrook (NB)	Bolingbrook (SB)	Frankfort (EB)	Moline (EB)	Moline (WB)	Marion (NB)	Marion (SB)	Maryville (WB)	Pesotum (NB)
4	1.6	1.6	3.7	0.9	1.1	1.1	1.1	1.0	1.8
5	4.6	4.0	1.5	1.3	1.1	2.4	2.7	1.8	6.7
6	3.7	4.0	1.4	2.9	1.8	2.4	2.8	2.1	1.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	6.7	6.2	3.0	2.6	2.2	4.1	3.7	2.3	2.7
9	79.0	80.1	87.5	88.8	90.4	85.2	84.0	85.9	84.3
10	0.9	1.0	1.5	0.8	0.7	0.7	1.1	1.2	0.3
11	3.5	2.9	1.2	2.4	2.6	4.1	3.3	4.9	1.8
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
13	0.0	0.3	0.1	0.2	0.0	0.1	1.2	0.6	0.1

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Vehicle Class distribution

Class	Illinois*	California	M-EPDG
Class 4	1.4%	1.1%	1.3%
Class 5	3.8%	23.0%	8.5%
Class 6	2.3%	5.2%	2.8%
Class 7	0.0%	0.3%	0.3%
Class 8	3.8%	6.7%	7.6%
Class 9	84.4%	50.6%	74%
Class 10	0.5%	0.6%	1.2%
Class 11	2.8%	8.8%	3.4%
Class 12	0.3%	1.1%	0.6%
Class 13	0.3%	0.1%	0.3%

TTC1

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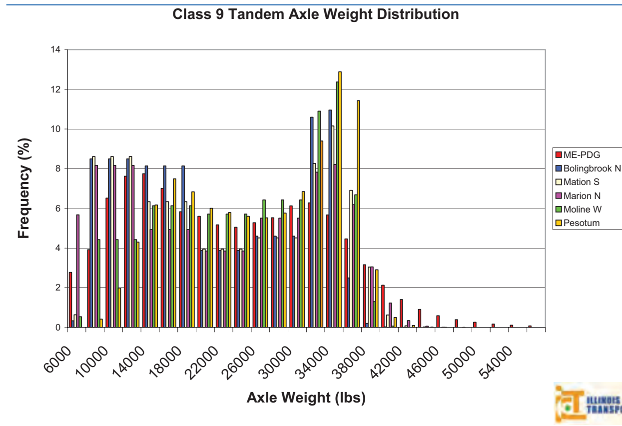
Slide 12

j6 add california distribution here.
jroesler, 7/23/2007

Comparison - Axle Weight Distribution

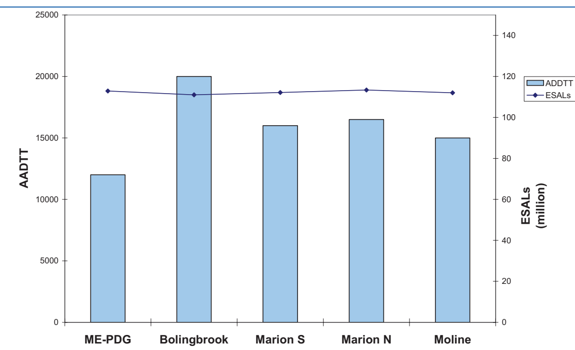


M-EPDG (v.1.0) Inputs Assumptions

- 20-year design
- Slab thickness = 10-inch
- 4” Asphalt Concrete Base (PG64-22)
- A-7-6 soil (13,000 psi)
- Joint spacing = 15 ft (1.5” dowels @ 12in. c-c)
- AC shoulder
- ***MOR = 650 psi***
- 95% reliability & 20% slab cracking @ failure

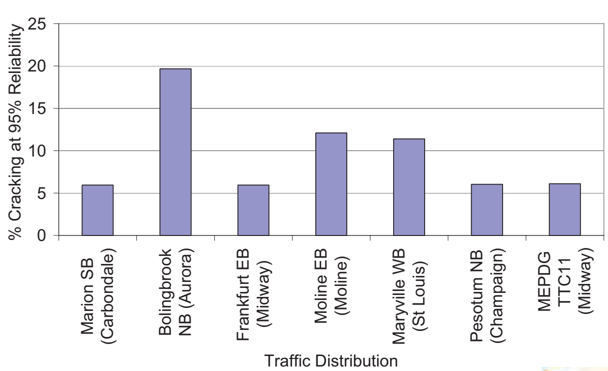
-Use site specific vehicle and axle load distributions

AADTT vs. ESALs



- **Higher AADTT to reach same ESAL count**
- **Illinois has lighter axle weight distribution**

Traffic and Climate Effect on Slab Cracking Level = 80x10^6 ESALs

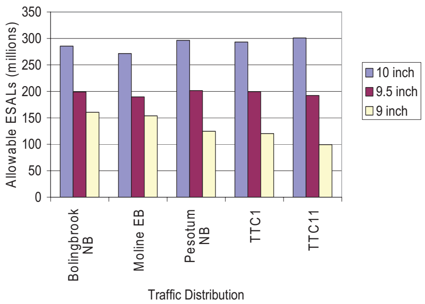


Effect of Load Spectra on Slab Cracking

St. Louis Climate

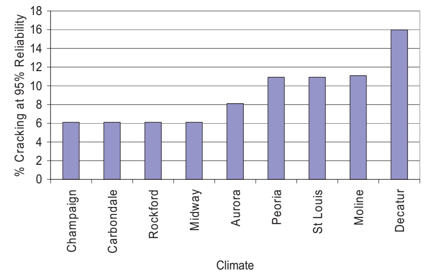
ESALs versus Load Spectra (MEPDG)

- For the same climate (Aurora, IL)
- Different weigh-scales and WIM sites – similar thickness for same amount of ESALs



Climate Effect, M-EPDG

- Same traffic distribution (MEPDG TTC11) and same ESALs/AADTT
- No clear trend in climatic zones throughout IL



Proposed JPCP Design - Overview

- Stress Calculations
  - Westergaard
  - Adjustment Factors
- Fatigue Models
- Failure Criteria - Slab Cracking

- Same approach as ILLICON (Barenberg 1994)

Stress Calculation

- Westergaard edge stress
- Factors: $\sigma_{total} = \sigma_{west} * f_1 * f_2 * f_3 + R * \sigma_{curl}$
  - f_1 Slab Geometry
  - f_2 Bonded/Unbonded Base
  - f_3 Shoulder Type
- Temperature curling stress
- Superposition correction factor, **R**

Equations from Salsilli (1991)

Westergaard Stress

$$\sigma_{west} = \frac{3(1+\mu)P}{\pi(3+\mu)h^2}\left[\ln\frac{Eh^3}{100ka^4} + 1.84 - \frac{4\mu}{3} + \frac{1-\mu}{2} + 1.18(1+2\mu)(a/l)\right]$$

$$l = \left(\frac{Eh^3}{12(1-\mu^2)k}\right)^{0.25}$$

a_{eq} = Equivalent Radius of Load,
P = Equivalent Load

$$a_{eq} = a[0.909 + 0.339485\left(\frac{S}{a}\right) + 0.103946\left(\frac{a}{l}\right) - 0.017881\left(\frac{S}{a}\right)^2 - 0.045229\left(\frac{S}{a}\right)^2\left(\frac{a}{l}\right) + 0.000436\left(\frac{S}{a}\right)^3 - 0.301805\left(\frac{S}{a}\right)\left(\frac{a}{l}\right)^3 + 0.034664\left(\frac{S}{a}\right)^2\left(\frac{a}{l}\right)^2 + 0.001\left(\frac{S}{a}\right)^3\left(\frac{a}{l}\right)]$$

Equations from Salsilli (1991)

Slab Geometry Factor

- Infinite slab assumed for L/l > 5
- Equation only valid for L/l > 3 – corresponds to joint spacing L of approximately 10 ft or more

$$f_1 = [0.582282 - 0.533078\left(\frac{a_{eq}}{l}\right) + 0.181706\left(\frac{L}{l}\right) - 0.019824\left(\frac{L}{l}\right)^2 + 0.109051\left(\frac{a_{eq}}{l}\right)\left(\frac{L}{l}\right)]$$

Equations from Salsilli (1991)

Bonded/Unbonded Base

- Unbonded $h_{eff} = \left[h^3 + h_2{}^3 \frac{E_2 h_2}{Eh} \right]^{1/3}$

$$\sigma_{eff} = \frac{3(1+\mu)P}{\pi(3+\mu)h_{eff}{}^2}\left[ln \frac{Eh_{eff}{}^3}{100\,ka_{eq}^4} + 1.84 - \frac{4\mu}{3} + \frac{1-\mu}{2} + 1.18(1+2\mu)(a_{eq}/l_{eff})\right]$$

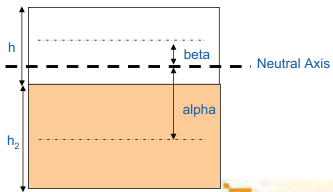
$$\sigma_{1,u} = \frac{h}{h_{eff,u}}\sigma_{eff}$$

- Bonded

$$h_f = (h^3 + 12 * h * beta^2)^{1/3}$$

$$h_{2f} = (h_2{}^3 + 12 * h_2 * alpha^2)^{1/3}$$

$$\sigma_{1,b} = \frac{h - NA}{h_{eff}/2}\sigma_{eff}$$



Equations from Ioannides et al. (1992)

Shoulder Type

- Asphalt Shoulder
- Widen Lane

$$f_{3w} = [0.454147 + 0.013211\left(\frac{l}{D}\right) + 0.386201\left(\frac{a_{eq}}{D}\right) - 0.24565\left(\frac{a_{eq}}{D}\right)^2 + 0.053891\left(\frac{a_{eq}}{D}\right)^3]$$

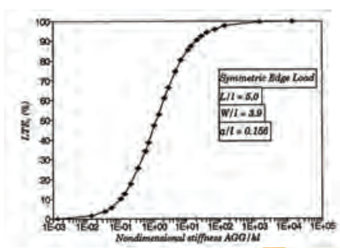
  - Based on RadiCAL – widen lane case no thinner than tied shoulder *Hiller (2007)*
- Tied Concrete Shoulder
  - Load Transfer Efficiency
    - *How to define LTE across shoulder?*

$$f_{3T} = func\left(\frac{AGG}{kl}, \frac{a_{eq}}{l}\right)$$

Load Transfer Efficiency

- Currently new design assumes 10 ft concrete shoulder is tied with an LTE as user input
- Suggested LTE levels?
  - Monolithic shoulder 70% LTE
  - Construction joint or separated shoulder 40% LTE

$$\frac{AGG}{kl} = \left[\frac{\frac{1}{LTE} - 0.01}{0.012}\right]^{\frac{-1}{0.849}}$$



Ioannides and Korovesis (1990)

Temperature Curling Stress

- Curling Stress

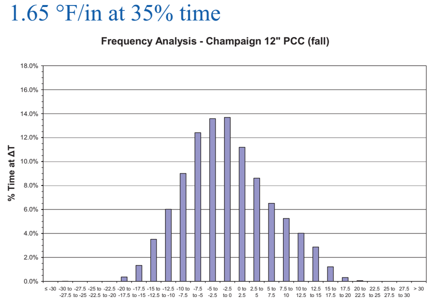
$$\sigma_{curl} = \frac{CE\alpha\Delta T}{2} \qquad DT = \alpha\Delta T * 10^5$$

- R factor for superposition
  - Many equations available and included in design spreadsheet
  - After comparison to ILLI-SLAB (1994), ILIJOINT equation which was originally used is still recommended

Equations from Salsilli (1991)

Temperature Determination

- Temperature Distribution <u>*or*</u>
- Equivalent Temperature Gradient
  - 1.65 °F/in at 35% time



Fatigue Equations

$$SR = \frac{\sigma_{total}}{MOR}$$

- Zero Maintenance
  Darter (1977)

$$\log N = 17.67 - 17.61 * SR$$

- ACPA
  - Includes reliability *R*
  - laboratory concrete beams

  Titus-Glover et al. 2005; Riley et al. (2005)

$$\log N = \left[-\frac{SR^{-10.24}\log(R^*)}{0.0112}\right]^{0.217}$$

$$R^* = 1 - \frac{(1-R) * P_{cr}}{0.5}$$

- MEPDG
  ARA (2007)

$$\log N = 2 * SR^{-1.22}$$

Equivalent Damage Ratio (EDR)

Wander Factor

TABLE A

EQUIVALENT DAMAGE RATIOS

Bituminous Shoulders

THICKNESS	$\bar{D}$-18" K-100	K-200	$\bar{D}$-12" K-100	K-200
8	.05	.05	.12	.12
10	.05	.05	.12	.12
12	.06	.06	.14	.14

10' Concrete Shoulder (HLT)

THICKNESS	$\bar{D}$-18" K-100	K-200	$\bar{D}$-12" K-100	K-200
8	.12	.13	.24	.18
10	.21	.22	.27	.23
12	.34	.33	.36	.32

10' Concrete Shoulder (MLT)

THICKNESS	$\bar{D}$-18" K-100	K-200	$\bar{D}$-12" K-100	K-200
8	.07	.06	.18	.17
10	.09	.09	.19	.19
12	.17	.17	.22	.22

Two Foot Extended Driving Lane

THICKNESS	$\bar{D}$-18" K-100	K-200	$\bar{D}$-12" K-100	K-200
8	.11	.14	.17	.19
10	.17	.20	.24	.25
12	.25	.28	.31	.34

Zollinger and Barenberg (1989)

Percent Slab Cracking Models

- Zero-Maintenance

$$P_{cr}^{50\%} = 1/\left[0.01 + .00000421 * \left(44.5^{-LogFD}\right)\right]$$

$$P_{cr}^{95\%} = 1/\left[0.01 + .00000235 * \left(32.6^{-LogFD}\right)\right]$$

- MEPDG

$$P_{cr}^{50\%} = \frac{1}{1 + FD^{-1.98}}$$

$$P_{cr}^{95\%} = P_{cr}^{50\%} + 1.64 * Se$$

$$Se = (5.3116 P_{cr}^{50\%})^{0.3903} + 2.99$$

- ACPA (Input P_{cr})
  - Failure is determined when the fatigue damage = 1.0

Equations from IDOT JPCP Curve Reliability (1991) and ARA (2007)

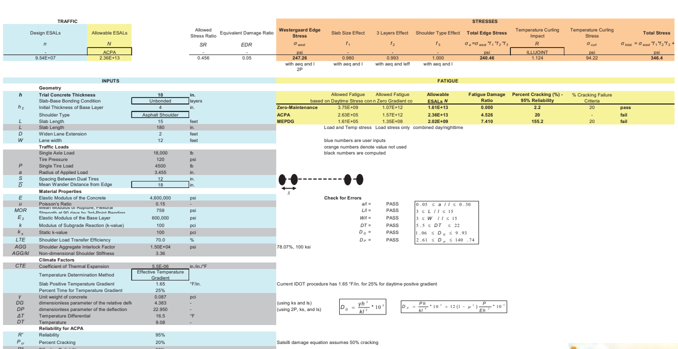
Fatigue Limit

- New design does not include stress for erosion
- Failure at
  - 100% slab cracking (95% reliability) at TF=3
  - 20% slab cracking (95% Reliability) at TF≥10
  - Fatigue Damage = 1.0 for ACPA

Inputs

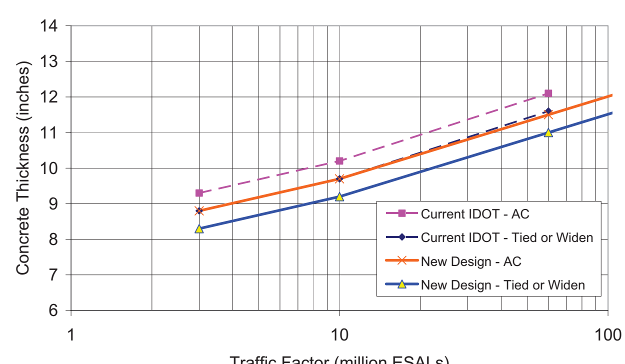
Symbol	Description	Unit	Typical Value
ESALs	Cumulative Equivalent Single Axle Loads	-	<100 million ESALs
h	Concrete Thickness	in.	variable
E	Concrete Elastic Modulus	ksi	4,600 ksi
k	Modulus of Subgrade Reaction	pci	50, 100, 200
h_2	Base Layer Thickness	in.	0 to 24
S	Spacing between dual tires	in.	12
L	Slab length	ft	15 (L/l > 3)
D	Offset distance between outer face of the wheel and the slab edge	in.	18
MOR	Modulus of rupture – mean flexural strength from 3rd-point bending at 90 days	psi	750

JPCP Spreadsheet Demo



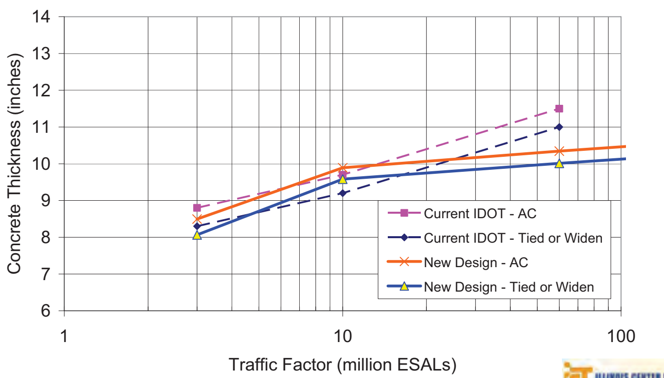
Design Charts

SSR poor (k=50 pci)

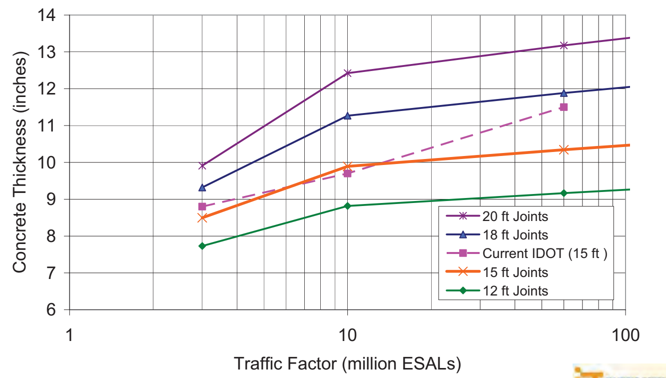


Design Charts

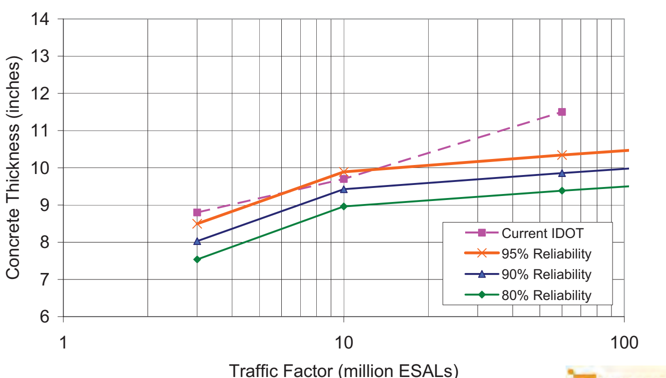
SSR fair (k=100 pci)



Joint Spacing



Reliability



Summary

- Spreadsheet-based JPCP design method
- No need for site specific climate or load spectra
- New concrete fatigue algorithm w/ reliability
- No calibrated damage model required

Summary of Proposed M-E Design for JPCP in Illinois

- Single climatic zone
- Fatigue algorithm –
  - ACPA with 95% reliability and 20% cracking for TF>10
- Assume unbonded interface condition
- Widen lane no thinner than Tied shoulder (based on RadiCAL)
- MOR used in design = 750 psi (based on mean design strengths used in field)

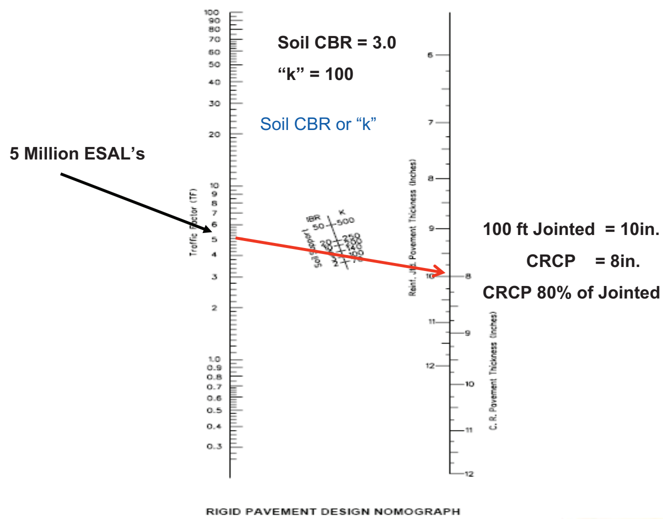
What is not included in JPCP?

- Calibration / Verification
  - Video surveys
  - Calibration of cracking model to MEPDG data or IDOT projects
- Erosion stress analysis (after Zollinger & Barenberg)

Continuously Reinforced Concrete Pavements (CRCP)

Illinois CRCP Thickness Determination

- Currently using IL-Modified AASHTO
- In use since 1970's
- Performance indicates design is conservative



Typical Illinois CRCP Thickness Design

Thickness	ESAL, Millions
8 in.	5
10 in.	20
12 in.	100
14 in. (max)	300+

Proposed CRCP Design

- Use framework of M-EPDG
- Simplify and implement into a spreadsheet
  - ESALs
  - Single Climate
  - Delete some internal M-EPDG models
  - Calibrate for Illinois CRCP sections

CRCP Inputs

- Pavement thickness
- Design life
  - percent steel, bar size, depth to steel
- Climatic data (seasonal)
  - temperature gradients through pavement, temperature at steel depth, ambient temperature
- Shoulder type
  - tied PCC, asphalt, gravel
- Design ESALs

CRCP Inputs

- Concrete properties
  - modulus, COTE, strength, ultimate shrinkage, cementitious content
- Base/subgrade properties
  - modulus, thickness, type, k-value → unbounded case
- Construction season
  - spring, summer, fall, winter
- Fatigue equation
  - MEPDG, IDOT

CRCP Design Process

1. Environmental Effects

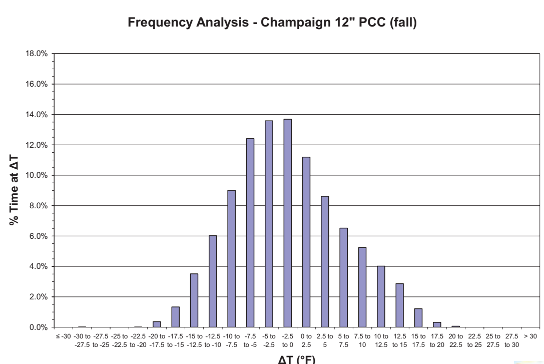
- Climatic data for Champaign, IL
  - Pavement thickness = 8”, 10”, 12” 14”

$$\sigma_{\mathrm{CURL}} = \mathrm{C}\frac{\mathrm{E}\alpha\Delta\mathrm{T}}{2}$$

$$\sigma_{\mathrm{TOT}} = \sum\left(\sigma_{\mathrm{LOAD}} + \mathrm{R}\sigma_{\mathrm{CURL}}\right)$$

R=1.0 for now

CRCP Design Procedure



CRCP Design Procedure

2. Mean Crack Spacing

$$\overline{L} = \frac{f_{t28} - C\sigma_0\left(1 - \frac{2d}{h_{PCC}}\right)}{\frac{f}{2} + \frac{U_m P_b}{c_1 d_b}}$$

MEPDG (2007)

CRCP Design Procedure

3. Crack Width

$$CW = \overline{L}\left(\varepsilon_{shr} + \alpha_{PCC}\Delta T_{steel} - \frac{c_2 f_\sigma}{E_{PCC}}\right)\cdot 1000$$

MEPDG (2007)

CRCP Design Procedure

4. LTE across cracks
   - Dimensionless shear capacity
   - Crack stiffness
     - Agg/kl
   - Assume no shear capacity loss

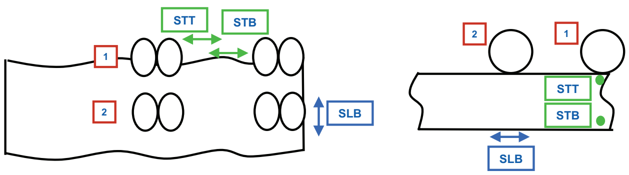
$$LTE_c = 100 * \left(1 - \left(1 - \frac{100}{1 + \log^{-1}\left[\left(0.214 - 0.183(a/l) - \log(J_{ci}) - R\right)/1.18\right]}\right)\left(1 - \frac{LTE_{BASE}}{100}\right)\right)$$

MEPDG (2007)

CRCP Design Procedure

5. Traffic Stresses

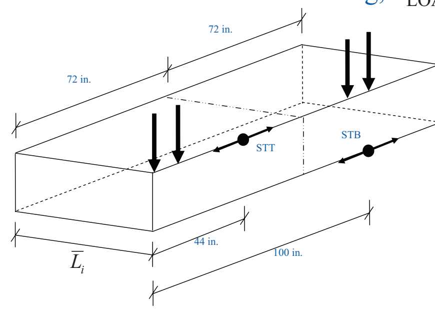
- STT, STB, SLB functions of LTE_s, LTE_c CS/RRS
- Cataloged ILLISLAB results
- Calculate stress due to traffic loading, σ_{LOAD}



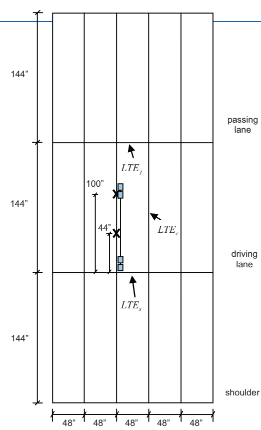
CRCP Design Procedure

5. Traffic Stresses

- STT, STB functions of LTE_s, LTE_c CS/RRS
- Calculate stress due to traffic loading, σ_{LOAD}



ISLAB2000 Model



CRCP Design Procedure

6. Damage

- Fatigue equations
  - MEPDG: Log N = $2.0(M_R/\sigma_{TOT})^{1.22} - 1$
  - IDOT: Log N = $17.61 - 17.61(\sigma_{TOT}/M_R)$
- Damage equation (*Seasonal calculation*)

$$D_i = \sum f_i \frac{n_i}{N_i} + D_{i-1}$$

Equivalent Damage Ratio (EDR)

$$EDR_{STT,i} = \begin{cases} IF \quad LTE_s \le 60 & , \; -0.1424\left(\bar{L}_i/\ell_i\right) + 0.2806 \\ IF \quad 60 < LTE_s \le 85 & , \; -0.1138\left(\bar{L}_i/\ell_i\right) + 0.2688 \\ IF \quad 85 < LTE_s \le 98 & , \; -0.0965\left(\bar{L}_i/\ell_i\right) + 0.3064 \\ IF \quad LTE_s > 98 & , \; -0.0933\left(\bar{L}_i/\ell_i\right) + 0.3414 \end{cases}$$

$$EDR_{STB,i} = -0.2264\left(\bar{L}_i/\ell_i\right) + 0.5533$$

j5

CRCP Design Procedure

7. Punchouts (PO) / mile

$$PO_i = \sum_{i=1}^{m} \frac{1}{a + b \cdot c^{-\log \bar{D}_{TOT,i}}}$$

a, b, c = calibration constants of 0.02, $1.0\text{x}10^{-32}$, 32386

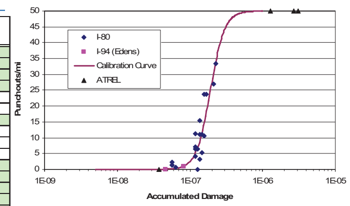
- 50 Punchout/mile saturation limit

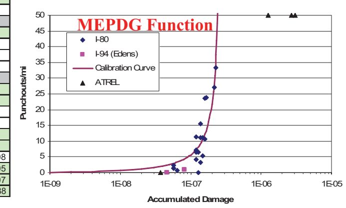
Slide 59

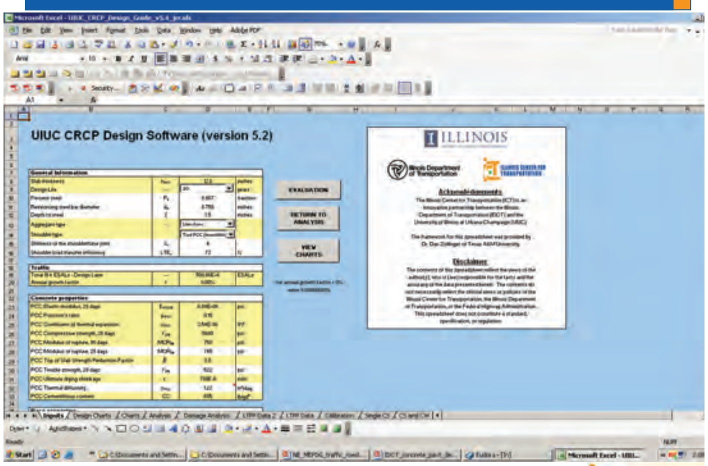
j5 calibration coefficients
jroesler, 12/17/2008

CRCP Calibration Sections

Section	Age, yr	Damage	Observed PO/mile	Predicted PO/mile	Error
I80_EB_137.65	9.04	5.69E-08	1.3	0.21	1.19
I80_EB_137.65	17.04	1.19E-07	4.2	5.33	1.28
I80_EB_137.65	19.04	1.38E-07	3.23	9.29	36.70
I80_EB_137.65	21.04	1.58E-07	10.7	14.76	16.48
I80_EB_143.79	17.04	1.19E-07	7.1	5.33	3.13
I80_EB_143.79	19.04	1.38E-07	15.5	9.29	38.59
I80_EB_151.12	10.04	6.39E-08	0.748	0.35	0.16
I80_EB_152.33	18.04	1.29E-07	6.4	7.11	0.51
I80_EB_152.33	20.04	1.48E-07	11.15	11.84	0.48
I80_EB_152.33	27.04	2.27E-07	33.33	34.13	0.64
I80_WB_137.65	9.04	5.69E-08	1.3	0.21	1.19
I80_WB_137.65	17.04	1.19E-07	6.45	5.33	1.25
I80_WB_137.65	19.04	1.38E-07	11.15	9.29	3.47
I80_WB_137.65	21.04	1.58E-07	23.7	14.76	79.93
I80_WB_137.65	26.04	2.14E-07	27	31.22	17.78
I80_WB_143.79	17.04	1.19E-07	11.34	5.33	36.10
~~I80_WB_143.79~~	~~26.04~~	~~2.14E-07~~	~~50.88~~	~~31.22~~	~~386.64~~
I80_WB_148.39	9.04	5.69E-08	2.26	0.21	4.20
I80_WB_152.33	18.04	1.29E-07	0	7.11	50.59
I80_WB_152.33	20.04	1.48E-07	5.28	11.84	43.07
I80_WB_152.33	22.04	1.68E-07	23.76	17.94	33.91
~~I80_WB_152.33~~	~~27.04~~	~~2.27E-07~~	~~60~~	~~34.13~~	~~669.19~~
I94_edens_ 28.46	14.04	4.59E-08	0	0.08	0.01
I94_edens_ 28.46	22.04	8.26E-08	1	1.11	0.01
I94_edens_ 30.11	14.04	4.59E-08	0	0.08	0.01
I94_edens_ 30.11	22.04	8.26E-08	1	1.11	0.01
I94_edens_ 32.90	14.04	4.59E-08	0	0.08	0.01
I94_edens_ 32.90	22.04	8.26E-08	1	1.11	0.01
ATREL1-10",#5	30	3.06905E-06	50	49.99981653	3.366E-08
ATREL2-10",#6	30	1.27022E-06	50	49.99019357	9.617E-05
ATREL3-10",#7	30	2.68071E-06	50	49.99966228	1.141E-07
ATREL4-14",#7	30	3.71699E-08	0	0.030803108	0.0009488

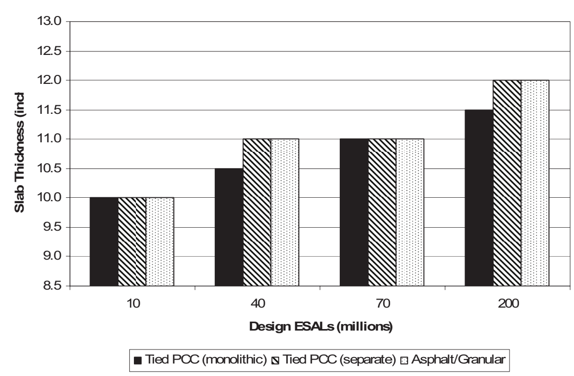






Design Charts

30 year, K_d = 50 psi/in, Reliability=95%



Design Comparisons

k-value (psi/in.)	Design ESALs (millions)							
	10		40		70		200	
	IDOT	New M-E	IDOT	New M-E	IDOT	New M-E	IDOT	New M-E
50	9.5	10.0	11.0	10.5	12.0	11.0	12.5	11.5
100	9.0	9.5	11.0	10.0	12.0	10.5	12.5	11.5
200	9.0	9.0	11.0	9.5	12.0	10.0	12.5	11.0

*Both design procedures assume 20 year designs and tied concrete shoulders
*M-E design procedure assumes 95 percent reliability

Summary of New Features

- Proposed CRCP Design Process
  - Crack spacing prediction
  - Fatigue-based thickness design
- New Equivalent damage ratios
- Top of slab strength reduction factor

CRCP Program Limitations

- Erosion analysis
- Reliability is a Traffic Multiplier of 4 *(?)*
- Load and temperature stress superposition

  $$\sigma_{TOT} = \sum(\sigma_{LOAD} + R\sigma_{CURL})$$

  - R=1.0
- Widen Lane stresses - none
- Tied shoulder*

Limitations, con't

- Calculated stresses are extremely low
  - Is this the right approach or are we using the wrong thickness?
- CRCP = 0.8*JRCP
  - No guarantee that CRCP will be thinner

Future Tasks

- Validate CS values with video survey*
- Acquire punchout data from IDOT videos*
- Endurance limit*
- How to define Reliability or confidence level?*
- Erosion effects (Dr. Zollinger)

* *Mechanistic-Empirical Design Implementation and Monitoring for Rigid Pavements* (ICT R27-61)
-Sponsored by IDOT (2009-2011)

Acknowledgements

The Illinois Center for Transportation (ICT) is an innovative partnership between the Illinois Department of Transportation (IDOT) and the University of Illinois at Urbana-Champaign (UIUC).

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Illinois Department of Transportation

MEPDG RELATED ACTIVITIES

Peter E. Sebaaly
Western Regional Superpave Center
UNIVERSITY OF NEVADA

Two activities

- MEPDG Field sections
- Full Depth Reclamation

MEPDG Field Sections

- Validation Sites for the Asphalt Research Consortium:
  - WRI
  - Texas A&M
  - UNR
  - UWM
  - AAT

ARC Validation Sites

- ARC is working on:
  - Fatigue
  - Moisture damage
  - Thermal Cracking
  - RAP
  - WMA

ARC Validation Sites

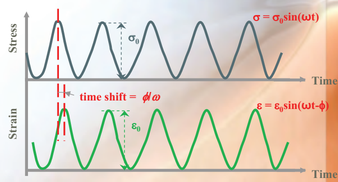
- PG Binder
- Superpave Mix Design
- MEPDG Structural Design

One-mile long section or half-day production

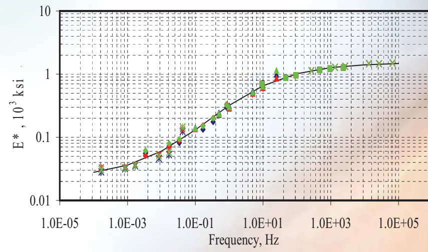
ARC Validation Sites

- ARC will:
  - Conduct Materials Characterization
    - E* Master Curve
    - Fatigue Characteristics
    - Rutting Characteristics
    - Thermal Cracking
    - Moisture Damage

Dynamic Modulus

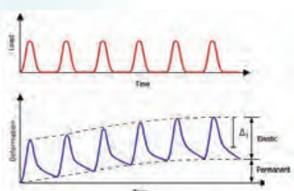


$$|E^*| = \sigma_0/\varepsilon_0$$



Resistance to Permanent Deformation

- Repeated Load triaxial test (RLT)



Before After

ARC Validation Sites

- ARC will:
  - Conduct MEPDG structural design
  - Sample materials during construction
  - Evaluate construction mixtures
  - Monitor performance until end of 2011
  - Develop a long-term monitoring plan

ARC Validation Sites

- Agency gets:
  - Implement MEPDG on a pavement section
  - Full characterization of the materials
  - At no cost

ARC Validation Sites

- ARC gets:
  - Test new concepts
  - Validate with field performance

www.arc.unr.edu

Interested:

Psebaaly@unr.edu

WHO JOINED

- NV RTC
- SDDOT
- WIDOT

FULL DEPTH RECLAMATION

- SD School of Mines
- SDDOT
- Sebaaly: team member

OBJECTIVES

- Develop a mix design procedures
- Construct test sections/performance
- Measure properties for MEPDG

Types of FDR

- Unstabilized
- Mechanically stabilized: add virgin aggregate
- Stabilized FDR with Portland Cement
- Stabilized FDR with Fly Ash
- Stabilized FDR with Asphalt Emulsion with 1% Lime
- Stabilized FDR with Foamed Asphalt with 1-2% Portland Cement

Compositions of FDR

- Source of FDR: Poor and Good (SDDOT experience)
- Quality: Dirty and Clean (passing # 200)
- RAP: 0, 25, 50, and 75%
- Virgin Agg.: single source
- Lab-fabricated mixes

FDR Type				
Unstabilized	Stabilized with PC (3, 5, 7 %)	Stabilized with Fly Ash (10, 12, 15 %)	Stabilized with Asphalt Emulsion (3, 4.5, 6 %)+ Lime	Stabilized with Foamed Asphalt (2.5, 3, 3.5 %) + PC
-Moisture-density -Mr and CBR	-Moisture-density - Comp strength -Moisture sensitivity	-Moisture-density - Comp strength -Moisture sensitivity	-Moisture-Density -Superpave Gyratory - Density with Corelok -Moisture sensitivity	-Moisture-Density -Superpave Gyratory -Density with Corelok -Moisture sensitivity

Mix design Issues

- Optimum Moisture Content
- Strength: UC, TS, Mr
- Moisture Sensitivity:
  - Tube Suction
  - AASHTO T-283 w and w/o FT

Mix Design Issues

- What works and what does not
- What criteria to implement
- Repeatability and reliability
- Does the measurement make engineering sense

FDR + PC and FA

• PC:	3, 5, 7 %
• FA:	10, 12, 15 %
• Dry UC:	300 – 500 psi
• Coeff. of Variation:	< 20%
• Tube Suction:	max. 9.0

Proctor Compactor

FDR + PC

FDR + PC

UC Test

FDR + PC and FA

Material	OPT PC (%)	UC (psi)	OPT FA (%)	UC (psi)
GC-25%	5	283	12	895
GC-50%	7	407	12	362
GC-75%	7	409	12	335
GD-25%	3	352	10	579
GD-50%	5	413	10	412
GD-75%	7	374	12	330

FDR + PC and FA

Material	OPT PC (%)	UC (psi)	OPT FA (%)	UC (psi)
PC-25%	3	295	10	558
PC-50%	5	379	12	404
PC-75%	5	256	12	327
PD-25%	3	454	15	170
PD-50%	3	421	15	159
PD-75%	5	409	15	63

FDR + Emulsion and Foamed

- Emulsion: 3.0, 4.5, 6.0 %
- Foamed: 2.5, 3.0, 3.5 %
- Dry TS (77F): > 30 psi
- Coeff. of Variation: < 20%
- TS Ratio: > 70%

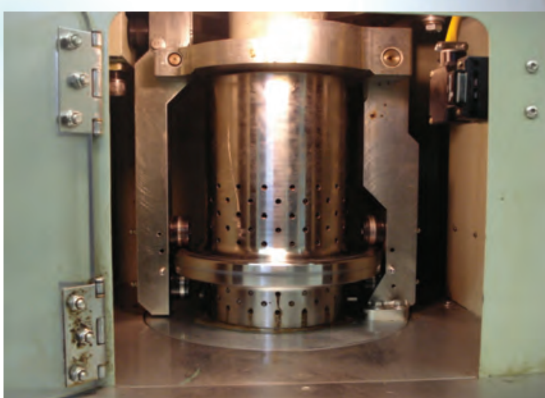
FDR + Emulsion + Lime

FDR + Emulsion + Lime

FDR + Emulsion + Lime

Gyratory Compactor

SGC Slotted Mold



Compacted Sample

FDR + Emulsion and Lime

Material	Emulsion (%)	Dry TS, 77F (psi)	Emulsion + 1% HL (%)	Dry TS, 77F (psi)
GC-25%				
GC-50%				
GC-75%				
GD-25%	4.5	47	4.5	45
GD-50%	4.5	47	4.5	37
GD-75%	4.5	46	4.5	44

FDR + Emulsion and Lime

Material	Emulsion (%)	Dry TS, 77F (psi)	Emulsion + 1% HL (%)	Dry TS, 77F (psi)
PC-25%				
PC-50%				
PC-75%				
PD-25%	4.5	30	4.5	22
PD-50%	4.5	50	4.5	38
PD-75%	4.5	51	4.5	34

Foaming Machine

Foamed FDR

FDR + Foamed and PC

Material	Foamed + 1% PC (%)	Dry TS, 77F (%)	Foamed + 2% PC (%)	Dry TS, 77F (%)
GC-25%	3.5	33	3.0	53
GC-50%	3.5	30	3.0	51
GC-75%	3.5	39	3.0	58
GD-25%	3.5	45	3.0	56
GD-50%	3.5	44		
GD-75%	3.5	51		

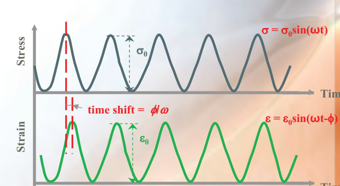
FDR + Foamed and PC

Material	Foamed + 1% PC (%)	Dry TS, 77F (%)	Foamed + 2% PC (%)	Dry TS, 77F (%)
PC-25%	3.5	54	3.0	46
PC-50%	3.5	53	3.0	47
PC-75%	3.5	48	3.0	56
PD-25%	3.0	43	3.0	43
PD-50%	3.0	48		
PD-75%	3.0	55		

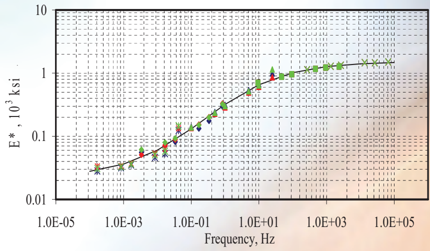
Tests to Be Evaluated

	Resilient Modulus	Repeated Loading Triaxial	Unconfined Compression	Modulus of Rupture	Dynamic Modulus
Unstabilized	X	X			
Cement Stabilized		X	X	X	
Fly Ash Stabilized		X	X	X	
Emulsion Stabilized		X			X
Foamed Asphalt Stabilized		X			X

Dynamic Modulus

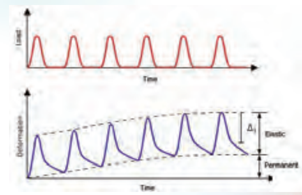


$$|E^*| = \sigma_0/\varepsilon_0$$



Resistance to Permanent Deformation

- Repeated Load triaxial test (RLT)



Before After

Mechanistic-Empirical Pavement Design: Materials Testing of Resilient and Dynamic Modulus

Lance A. Roberts, Ph.D., P.E.

Assistant Professor

South Dakota School of Mines and Technology

Rapid City, South Dakota

Presented at:

North-West MEPDG User Group Meeting
Oregon State University
Corvallis, Oregon
March 9-10, 2009

Scope/Objectives of Research Project

- Obtain resilient modulus (M_r) and dynamic modulus values of construction materials through test performed using a Simple Performance Tester (SPT). The HMA and soil materials would be those that are typically used in South Dakota.
- Develop a Mechanistic-Empirical pavement design database for these material properties for use in the M-E design process (i.e. design software).
- Gain an assessment on the possible need for acquisition of an SPT machine and other laboratory testing equipment by the SDDOT.

This presentation will focus on the resilient modulus testing of the base and subgrade materials.

Resilient Modulus Testing

Base and subgrade material sampling locations.
US-212 and US-281 in South Dakota.

Resilient Modulus Testing

The MEPDG utilizes a constitutive model to predict the resilient modulus of base, subbase, and subgrade materials. The model recommended by the MEPDG is:

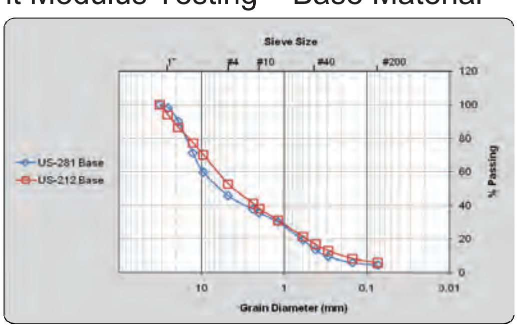
$$M_R = k_1 * Pa * \left(\frac{\theta}{Pa}\right)^{k_2} * \left(\frac{\tau_{oct}}{Pa} + 1\right)^{k_3}$$

where: M_R = Resilient Modulus
Pa = Atmospheric pressure (psi)
θ = Bulk stress ($\sigma_1 + \sigma_2 + \sigma_3$)
τ_{oct} = Octahedral Shear Stress $= \frac{1}{3}\sqrt{(\sigma_1-\sigma_2)^2 + (\sigma_2-\sigma_3)^2 + (\sigma_3-\sigma_1)^2}$
k_1, k_2, k_3 = Regression coefficients

The regression coefficients will be determined based on the results of the resilient modulus testing.

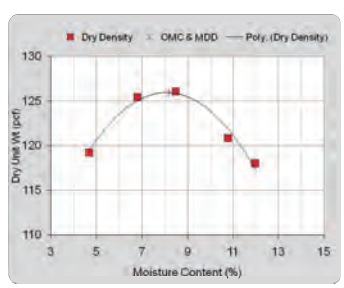
Resilient Modulus Testing – Base Material

- Classification based on sieve analysis.
- Optimum moisture content (OMC) and maximum dry density (MDD) based on modified Proctor compaction test.
- Base contains 50% RAP.

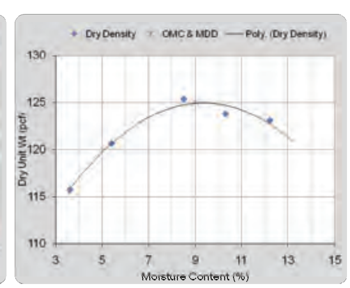


Sample	AASHTO			USCS				
	% Passing #10	% Passing #40	% Passing #200	% Gravel	% Sand	% Silt & Clay	Cu	Cc
US-281 Base	35	14	4	54	41	4	32	0.5
US-212 Base	38	17	6	47	47	6	25	1.4

Resilient Modulus Testing – Base Material



US-212 Base Material



US-281 Base Material

Base Specimen	Classification		MDD (lb/ft^3)	OMC (%)
	AASHTO	USCS		
US-281	A-1-a	GP poorly graded gravel with sand	125	9.0
US-212	A-1-a	SW-SM well graded sand with silt and gravel	126	8.2

Resilient Modulus Testing - Base Material

Split mold and vibratory compaction device used for preparation of samples consisting of granular base materials (Type 1).

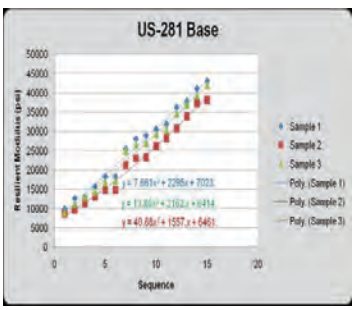
Sample assembled in SPT machine and ready for testing.

Resilient Modulus Testing – Base Material

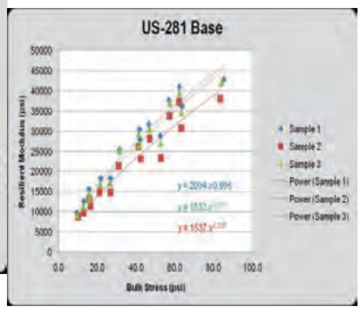
Sequence	Confining Pressure, σ_3 (psi)	Max Axial Stress, σ_{max} (psi)	Cyclic Stress, σ_{cyclic} (psi)	Constant Stress, $0.1\sigma_{max}$ (psi)	# of Load Applications
0	15	15	13.5	1.5	500-1000
1	3	3	2.7	0.3	100
2	3	6	5.4	0.6	100
3	3	9	8.1	0.9	100
4	5	5	4.5	0.5	100
5	5	10	9.0	1.0	100
6	5	15	13.5	1.5	100
7	10	10	9.0	1.0	100
8	10	20	18.0	2.0	100
9	10	30	27.0	3.0	100
10	15	10	9.0	1.0	100
11	15	15	13.5	1.5	100
12	15	30	27.0	3.0	100
13	20	15	13.5	1.5	100
14	20	20	18.0	2.0	100
15	20	40	36.0	4.0	100

Testing was conducted based on AASHTO T-307.

Resilient Modulus Testing – Base Material



M_r versus Test Sequence



M_r versus Bulk Stress

Results for resilient modulus testing of US-281 base.

Resilient Modulus Testing – Base Material

Sample	k_1	k_2	k_3	w(%) target = 9 ± 1%	R^2	M_R value with σ_3=4psi & σ_d=30psi
1	967.74	0.76	-0.44	8.7	0.99	21,765
2	806.79	0.83	-0.60	8.7	0.99	17,410
3	909.19	0.79	-0.46	8.7	0.99	20,757
average	894.57	0.79	-0.50	8.70		
std dev	81.46	0.04	0.09	0.00		
CV	9.11%	4.43%	-17.44%	0.00%		

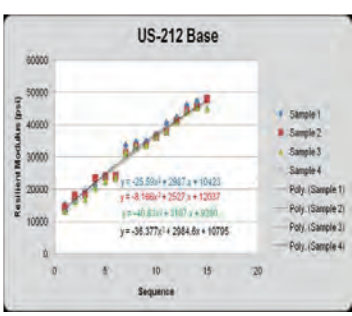
Results of regression analysis US-281 base:

k_1 = 895

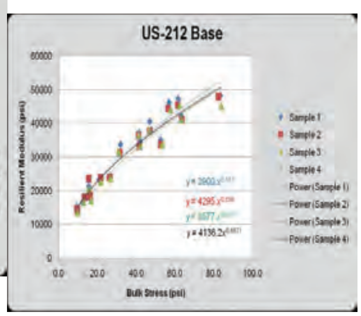
k_2 = 0.79

k_3 = -0.50

Resilient Modulus Testing – Base Material



M_r versus Test Sequence



M_r versus Bulk Stress

Results for resilient modulus testing of US-212 base.

Resilient Modulus Testing – Base Material

Sample	k_1	k_2	k_3	w(%) target = 8.2 ± 1%	R^2	M_R value with σ_3=4psi & σ_d=20psi
1	1350.24	0.66	-0.49	9.16	0.99	26,701
2	1359.00	0.62	-0.42	8.3	0.98	27,122
3	1276.06	0.67	-0.50	8.3	0.99	25,304
4	1340.42	0.62	-0.37	8.3	0.99	27,668
average	1331.43	0.64	-0.45	8.52		
std dev	37.69	0.03	0.06	0.43		
CV	2.83%	4.09%	-13.79%	5.05%		

Results of regression analysis US-212 base:

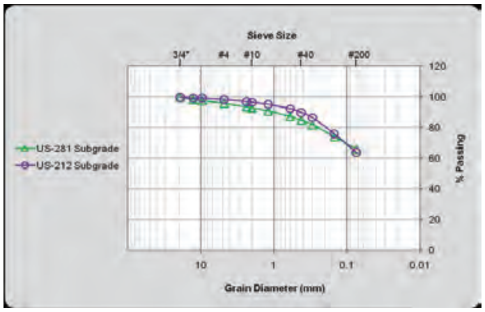
k_1 = 1330

k_2 = 0.64

k_3 = -0.45

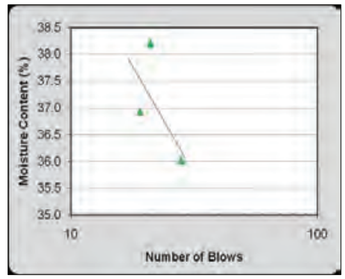
Resilient Modulus Testing – Subgrade Material

- Classification based on sieve analysis and Atterberg limits.
- Optimum moisture content (OMC) and maximum dry density (MDD) based on modified Proctor compaction test.

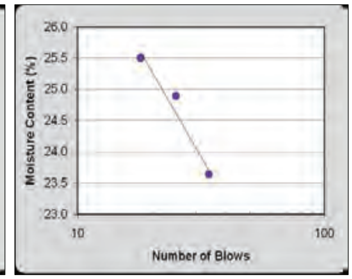


Sample	AASHTO			USCS		
	% Passing #10	% Passing #40	% Passing #200	% Gravel	% Sand	% Silt & Clay
US-281 Subgrade	93	85	66	4	30	66
US-212 Subgrade	97	90	64	1	35	64

Resilient Modulus Testing – Subgrade Material



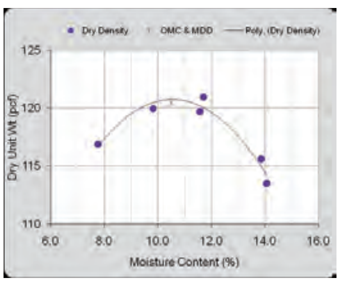
US-281



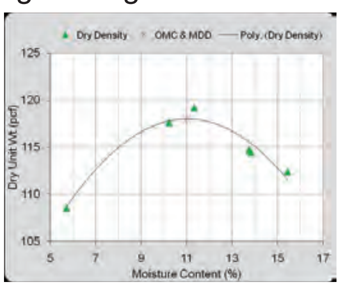
US-212

Liquid Limit Testing of Subgrade Materials

Resilient Modulus Testing – Subgrade Material



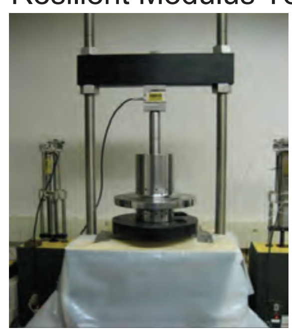
US-212 Subgrade Material



US-281 Subgrade Material

Subgrade Specimen	Classification		LL (%)	PL (%)	PI (%)	MDD (lb/ft³)	OMC (%)
	AASHTO	USCS					
US-281	A-6	CL sandy lean clay	37	16	21	118	11
US-212	A-4	CL sandy lean clay	25	15	10	120.5	10.5

Resilient Modulus Testing – Subgrade Material



Static compaction device used for preparation of samples consisting of clay subgrade materials (Type 2)

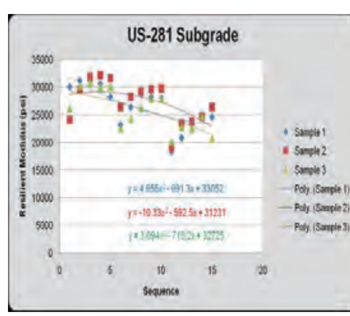
Sample assembled in SPT machine and ready for testing.

Resilient Modulus Testing – Subgrade Material

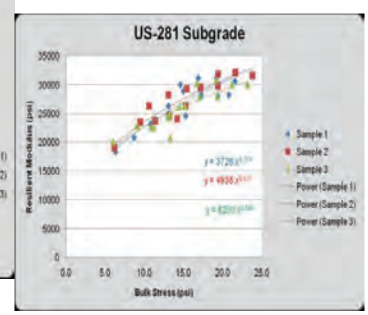
Sequence	Confining Pressure, σ_3 (psi)	Max Axial Stress, σ_{max} (psi)	Cyclic Stress, σ_{cyclic} (psi)	Constant Stress, $0.1\sigma_{max}$ (psi)	# of Load Applications
0	6	4	3.6	0.4	500-1000
1	6	2	1.8	0.2	100
2	6	4	3.6	0.4	100
3	6	6	5.4	0.6	100
4	6	8	7.2	0.8	100
5	6	10	9.0	1.0	100
6	4	2	1.8	0.2	100
7	4	4	3.6	0.4	100
8	4	6	5.4	0.6	100
9	4	8	7.2	0.8	100
10	4	10	9.0	1.0	100
11	2	2	1.8	0.2	100
12	2	4	3.6	0.4	100
13	2	6	5.4	0.6	100
14	2	8	7.2	0.8	100
15	2	10	9.0	1.0	100

Testing was conducted based on AASHTO T-307.

Resilient Modulus Testing – Subgrade Material



M_r versus Test Sequence



M_r versus Bulk Stress

Results for resilient modulus testing of US-281 subgrade.

Resilient Modulus Testing – Subgrade Material

Sample	k_1	k_2	k_3	w(%) target = 11 ± 0.5%	R^2	M_R value with σ_3=2psi & σ_d=6psi
1	1930.30	0.81	-0.99	11.1	0.97	17,448
2	1877.90	0.66	-0.63	11.0	0.97	19,161
3	1946.90	0.58	-0.43	11.0	0.93	21,220
average	1918.37	0.68	-0.68	11.03		
std dev	36.01	0.12	0.28	0.06		
CV	1.88%	17.09%	-41.53%	0.52%		

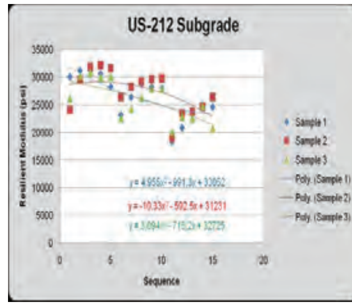
Results of regression analysis US-281 subgrade:

k_1 = 1918

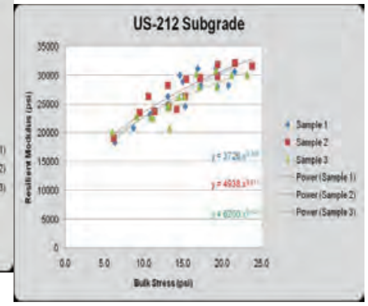
k_2 = 0.68

k_3 = -0.68

Resilient Modulus Testing – Subgrade Material



M_r versus Test Sequence



M_r versus Bulk Stress

Results for resilient modulus testing of US-212 subgrade.

Resilient Modulus Testing – Subgrade Material

Sample	k_1	k_2	k_3	w(%) target = 10.5 ± 0.5%	R^2	M_R value with σ_3=2psi & σ_d=6psi
1	1918.30	0.45	-0.47	10.1	0.88	21,828
2	1957.40	0.42	-0.43	10.1	0.90	22,691
3	1903.30	0.39	-0.61	10.7	0.87	21,625
average	1926.33	0.42	-0.50	10.30		
std dev	27.93	0.03	0.09	0.35		
CV	1.45%	7.14%	-18.78%	3.36%		

Results of regression analysis US-212 subgrade:

k_1 = 1926

k_2 = 0.42

k_3 = -0.50

THANK YOU.

QUESTIONS?

Non-Standard Materials Characterization

NW-MEPDG User Group Meeting

Corvallis, 10-Mar-09

Steve Saboundjian, P.E.

State Pavement Engineer

Alaska DOT&PF

Characterization of Asphalt Treated Base Course Material

- Research work by UAF (Dr. Jenny Lu et al.)
- Funding by AUTC and ADOT&PF

Project Scope

To determine stiffness, fatigue, and permanent deformation characteristics

Experimental design
- 3 base course materials (D-1): 3 AK Regions
- ATB: PG 52-28 neat asphalt binder
- EATB: CSS-1 emulsion
- FASBC: foamed-asphalt
- 3 Temperatures: -10, 0, 20°C
- 3 Stabilizer contents

Laboratory tests
- Flexural Fatigue
- **Resilient Modulus**

Asphalt-Treated Base

- SGC compaction
- Target air voids = 6%
- Coring and trimming specimen
- Final specimen size: 4" x 6"

Resilient Modulus (M_R) Testing

AASHTO T307 *mod*

Northern Region ATB results:

- Binder content: 2.5 , 3.5 , 4.5%
- Temperature: -10, 0, 20°C
- 3 replicates

Modeling

$$M_R = k_1 S_3^{k_2} e^{k_3 \sigma_d}$$

where:

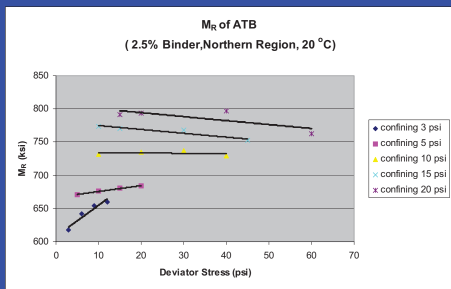
M_R = resilient modulus

S_3 = confining pressure

s_d = deviator stress

k_1, k_2, k_3 = regression constants

Northern Region ATB



$$M_R = k_1 S_3^{\ k_2} e^{k_3 \sigma_d}$$

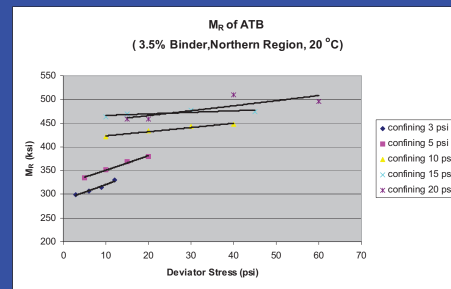
K_1=569.5

K_2=0.1127

K_3=-0.0004

R^2=0.96

Northern Region ATB



$$M_R = k_1 S_3^{\ k_2} e^{k_3 \sigma_d}$$

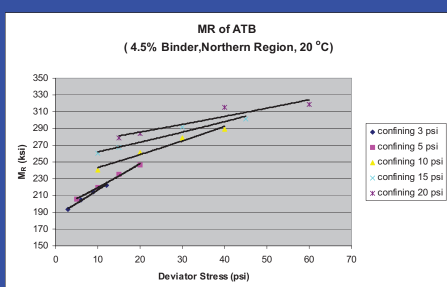
K_1=248.3

K_2=0.2097

K_3=0.0023

R^2=0.96

Northern Region ATB



$$M_R = k_1 S_3^{\ k_2} e^{k_3 \sigma_d}$$

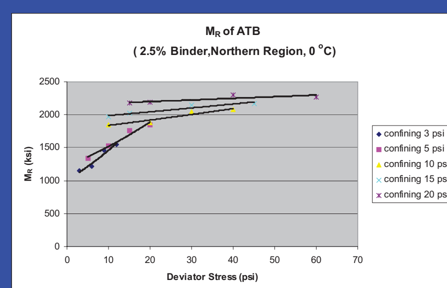
K_1=174.6

K_2=0.1290

K_3=0.0052

R^2=0.95

Northern Region ATB



$$M_R = k_1 S_3^{\ k_2} e^{k_3 \sigma_d}$$

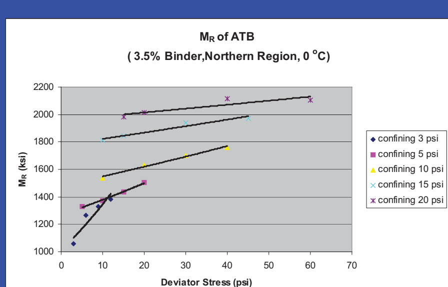
K_1=984.3

K_2=0.2391

K_3=0.0045

R^2=0.78

Northern Region ATB



$$M_R = k_1 S_3^{\ k_2} e^{k_3 \sigma_d}$$

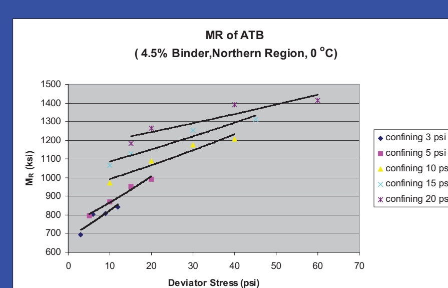
K_1=952.0

K_2=0.2214

K_3=0.0032

R^2=0.93

Northern Region ATB



$$M_R = k_1 S_3^{\ k_2} e^{k_3 \sigma_d}$$

K_1=614.2

K_2=0.1899

K_3=0.0064

R^2=0.95

Work in Progress

- Data analysis for M_R Testing:
  k_1, k_2, k_3 = f (source, ac%, Temperature, …)

- Permanent deformation modeling

- M_R testing of CR, SE regions ATB at:
  3 Temperatures
  3 Binder contents

- Fabrication of foamed-asphalt M_R specimens

Foamed-asphalt specimen fabrication

EXPANDING THE REALM OF POSSIBILITY

Northwest MEPDG User Group
Corvallis, OR
March 9, 2009

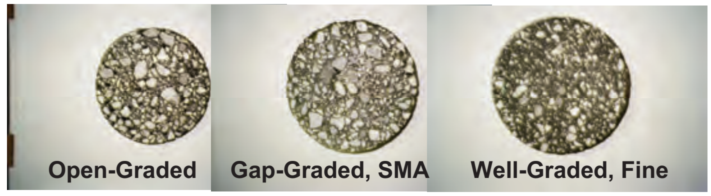
Session 3—Technical Issues
SMA, OGFC, PMA, & Rubber Modified Surfaces

Harold L. Von Quintus, P.E.

APPLIED RESEARCH ASSOCIATES, INC.
An Employee-Owned Company

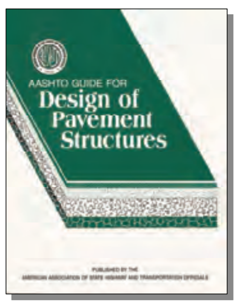
Outline/Questions

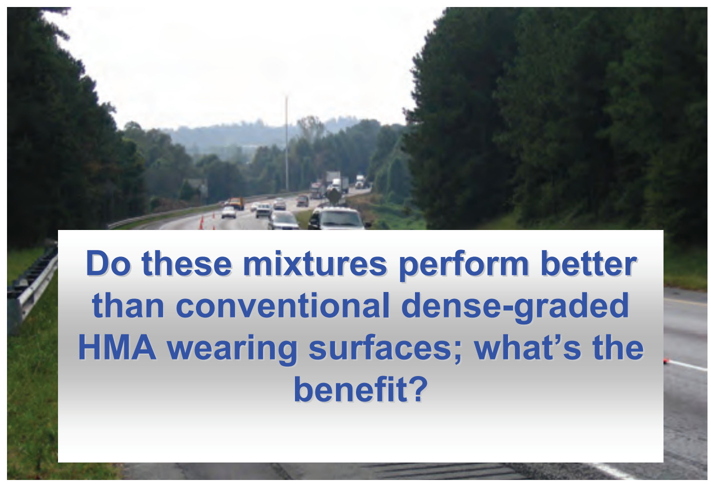
1. Material Testing & Characterization.
2. Impact of Surface Layer on Predicted Distress.
3. MEPDG Simulation of Beneficial Effect.



MEPDG – Design Applicability to Surface Mixtures

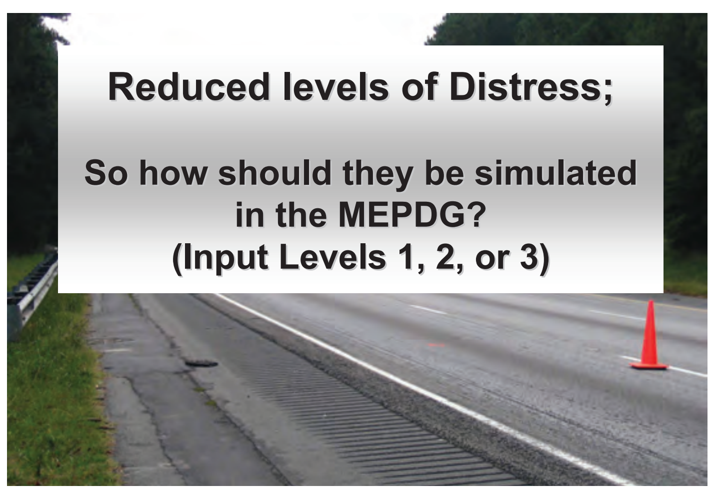
- How do we characterize these wearing surface mixtures using the current design method; 1993 AASHTO Design Guide?
  - Different layer coefficient?
  - Combine with other layers?





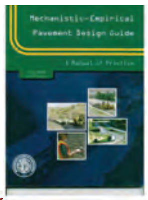
Performance Issues

Wearing Surface	Better Performance?	Key Distress
SMA	Yes	Same as HMA
PMA	Yes	Same as HMA
Rubber Modified Surface	Location Specific	Same as HMA & Raveling
OGFC	Location Specific	Raveling



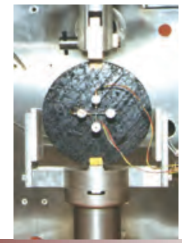
MEPDG Inputs for HMA Mixtures

- Air voids @ construction
- Effective asphalt content by volume
- Gradation
- Density
- Asphalt grade
- Asphalt properties
- Indirect tensile strength
- Creep compliance
- Dynamic modulus
- Poisson's ratio
- Absorptivity



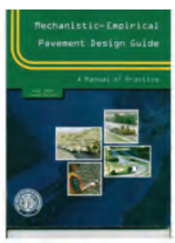
MEPDG – Applicability of Test Methods to Thin Layers

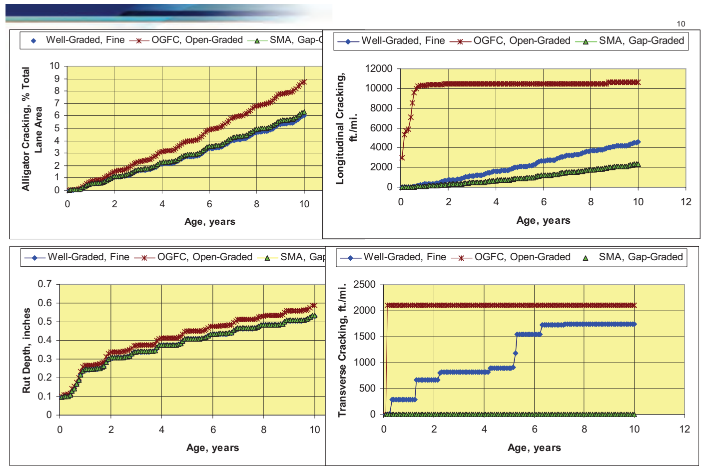
- Should (or can) these materials be tested in the laboratory & field?

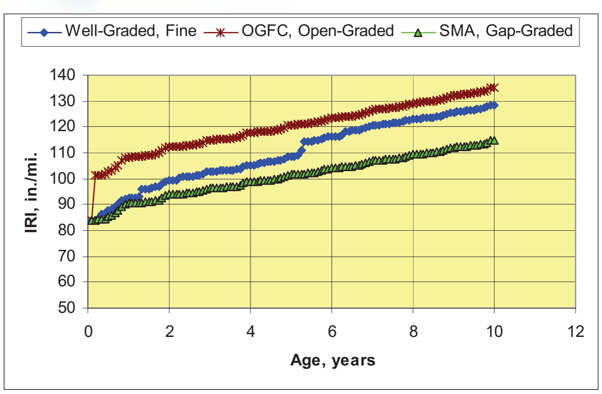


Example

- Is there a difference in the distress predictions between the use of these thin layers using version 1.0?
  - Well-graded, fine mix
  - Gap-graded, SMA mix
  - OGFC, open-graded mix







MEPDG & Wearing Surfaces

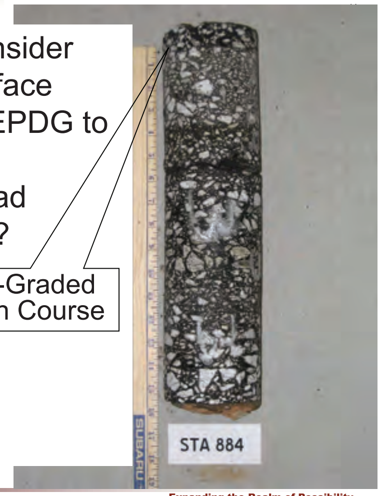
- Rutting—Nil to minor effect.
- Alligator Cracking—Minor effect.
- Longitudinal Cracking—Huge effect.
- Transverse Cracking—Huge effect.
- IRI—Significant effect, because of transverse & longitudinal cracking differences.

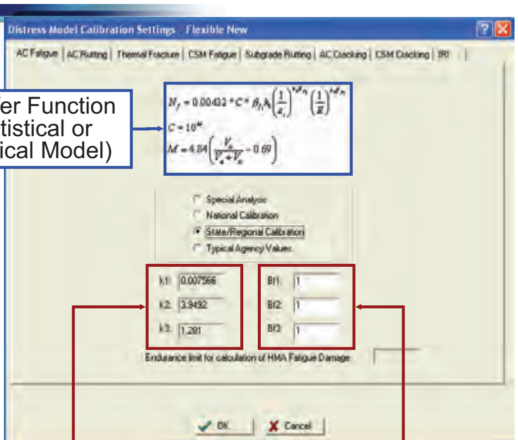
- Do these thin wearing surfaces provide structural benefit or reduce load-related distresses in terms of structural response?

PMA	**Yes**	**Reduces rutting & cracking**
SMA	**Yes**	**Reduces rutting & cracking**
Rubber Modified Surface	**Yes**	**Reduces rutting & cracking**
OGFC	**No**	**May provide less structural support**

- How does one consider these wearing surface mixtures in the MEPDG to accurately predict performance or load related distresses?

Open-Graded Friction Course





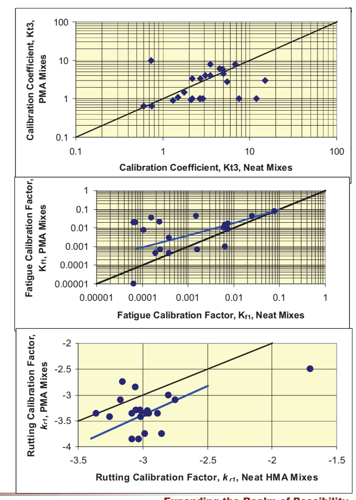
Transfer Function (Statistical or Empirical Model)

"Typical Agency Values"

"State/Regional Cal. Values"

PMA Mix Calibration Factors

- Asphalt Institute study comparing PMA and SMA mixtures to conventional neat HMA mixtures.

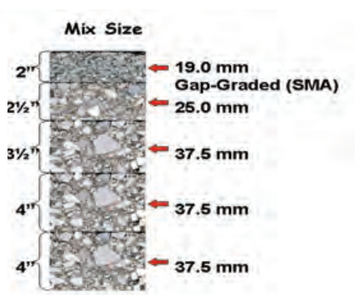


MEPDG & Surface Mixtures

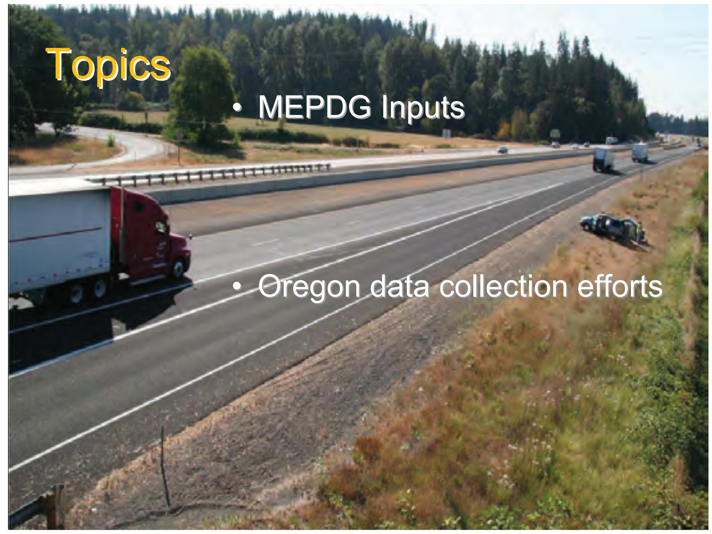
Options for Simulation:

- Simulate individual layer; or
- Combine surface mixture into binder layer.

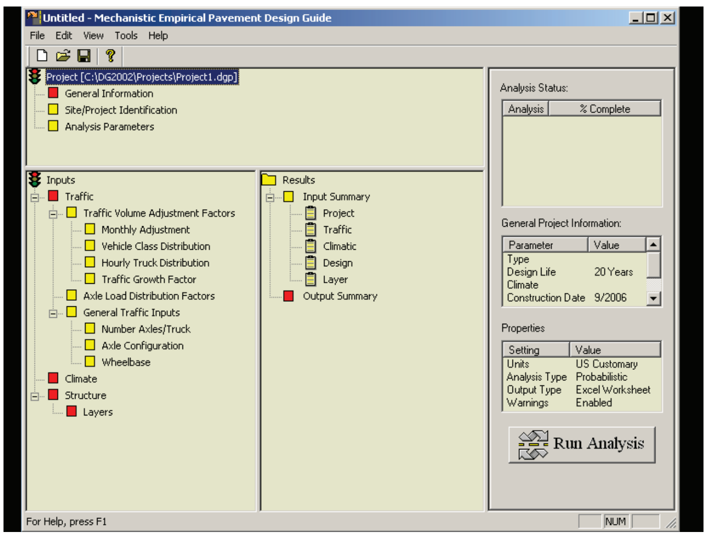
Then, determine local or agency specific calibration factors.



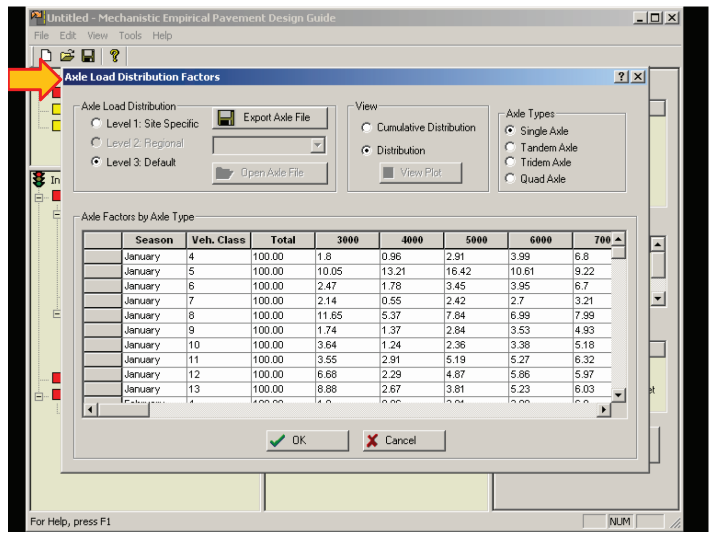
Traffic Data
Todd Scholz, P.E.
Oregon State University



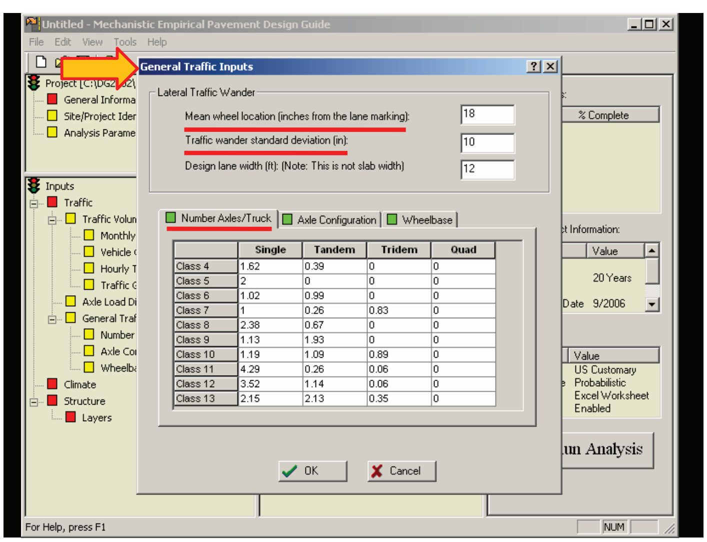
Topics
• MEPDG Inputs
• Oregon data collection efforts



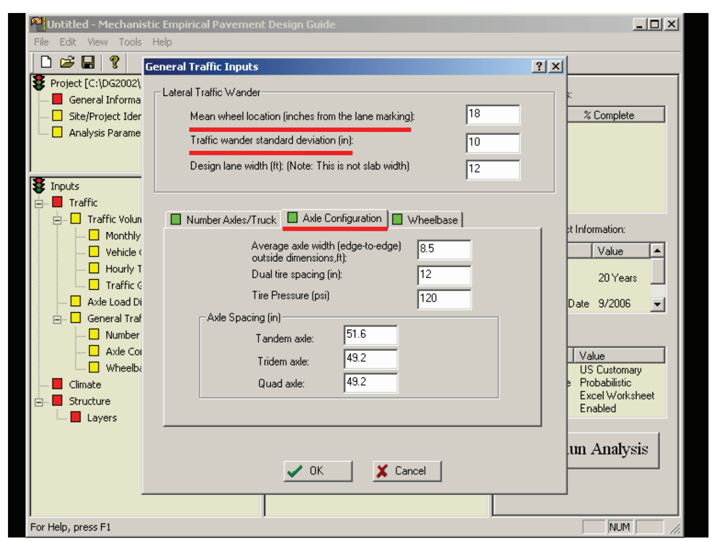
Untitled - Mechanistic Empirical Pavement Design Guide
File Edit View Tools Help
Project [C:\DG2002\Projects\Project1.dgp]
General Information
Site/Project Identification
Analysis Parameters
Inputs
Traffic
Traffic Volume Adjustment Factors
Monthly Adjustment
Vehicle Class Distribution
Hourly Truck Distribution
Traffic Growth Factor
Axle Load Distribution Factors
General Traffic Inputs
Number Axles/Truck
Axle Configuration
Wheelbase
Climate
Structure
Layers
Results
Input Summary
Project
Traffic
Climatic
Design
Layer
Output Summary
Analysis Status:
Analysis
% Complete
General Project Information:
Parameter
Value
Type
Design Life 20 Years
Climate
Construction Date 9/2006
Properties
Setting
Value
Units US Customary
Analysis Type Probabilistic
Output Type Excel Worksheet
Warnings Enabled
Run Analysis
For Help, press F1
NUM



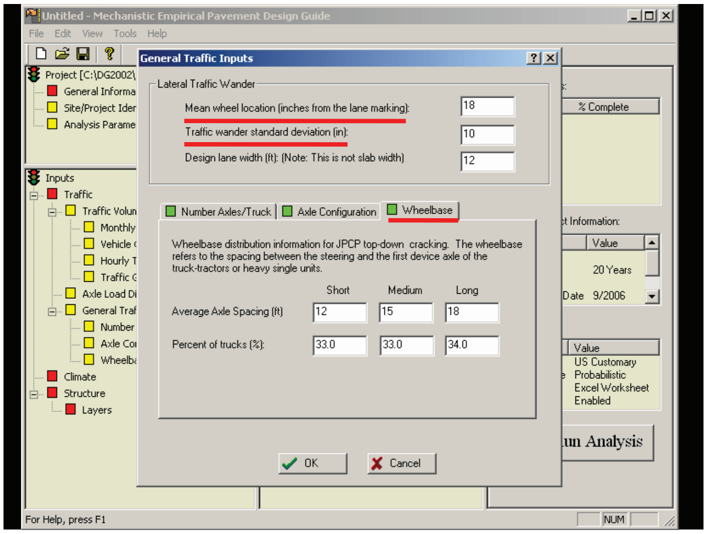
Untitled - Mechanistic Empirical Pavement Design Guide
Axle Load Distribution Factors
Axle Load Distribution
Level 1: Site Specific
Level 2: Regional
Level 3: Default
Export Axle File
Open Axle File
View
Cumulative Distribution
Distribution
View Plot
Axle Types
Single Axle
Tandem Axle
Tridem Axle
Quad Axle
Axle Factors by Axle Type
Season | Veh. Class | Total | 3000 | 4000 | 5000 | 6000 | 700
January | 4 | 100.00 | 1.8 | 0.96 | 2.91 | 3.99 | 6.8
January | 5 | 100.00 | 10.05 | 13.21 | 16.42 | 10.61 | 9.22
January | 6 | 100.00 | 2.47 | 1.78 | 3.45 | 3.95 | 6.7
January | 7 | 100.00 | 2.14 | 0.55 | 2.42 | 2.7 | 3.21
January | 8 | 100.00 | 11.65 | 5.37 | 7.84 | 6.99 | 7.99
January | 9 | 100.00 | 1.74 | 1.37 | 2.84 | 3.53 | 4.93
January | 10 | 100.00 | 3.64 | 1.24 | 2.36 | 3.38 | 5.18
January | 11 | 100.00 | 3.55 | 2.91 | 5.19 | 5.27 | 6.32
January | 12 | 100.00 | 6.68 | 2.29 | 4.87 | 5.86 | 5.97
January | 13 | 100.00 | 8.88 | 2.67 | 3.81 | 5.23 | 6.03
OK
Cancel
For Help, press F1
NUM



Untitled - Mechanistic Empirical Pavement Design Guide
General Traffic Inputs
Lateral Traffic Wander
Mean wheel location (inches from the lane marking): 18
Traffic wander standard deviation (in): 10
Design lane width (ft): (Note: This is not slab width) 12
Number Axles/Truck
Axle Configuration
Wheelbase
| Single | Tandem | Tridem | Quad
Class 4 | 1.62 | 0.39 | 0 | 0
Class 5 | 2 | 0 | 0 | 0
Class 6 | 1.02 | 0.99 | 0 | 0
Class 7 | 1 | 0.26 | 0.83 | 0
Class 8 | 2.38 | 0.67 | 0 | 0
Class 9 | 1.13 | 1.93 | 0 | 0
Class 10 | 1.19 | 1.09 | 0.89 | 0
Class 11 | 4.29 | 0.26 | 0.06 | 0
Class 12 | 3.52 | 1.14 | 0.06 | 0
Class 13 | 2.15 | 2.13 | 0.35 | 0
OK
Cancel
For Help, press F1
NUM



Untitled - Mechanistic Empirical Pavement Design Guide
General Traffic Inputs
Lateral Traffic Wander
Mean wheel location (inches from the lane marking): 18
Traffic wander standard deviation (in): 10
Design lane width (ft): (Note: This is not slab width) 12
Number Axles/Truck
Axle Configuration
Wheelbase
Average axle width (edge-to-edge) outside dimensions,ft): 8.5
Dual tire spacing (in): 12
Tire Pressure (psi) 120
Axle Spacing (in)
Tandem axle: 51.6
Tridem axle: 49.2
Quad axle: 49.2
OK
Cancel
For Help, press F1
NUM


Untitled - Mechanistic Empirical Pavement Design Guide
File Edit View Tools Help
General Traffic Inputs
Lateral Traffic Wander
Mean wheel location (inches from the lane marking): 18
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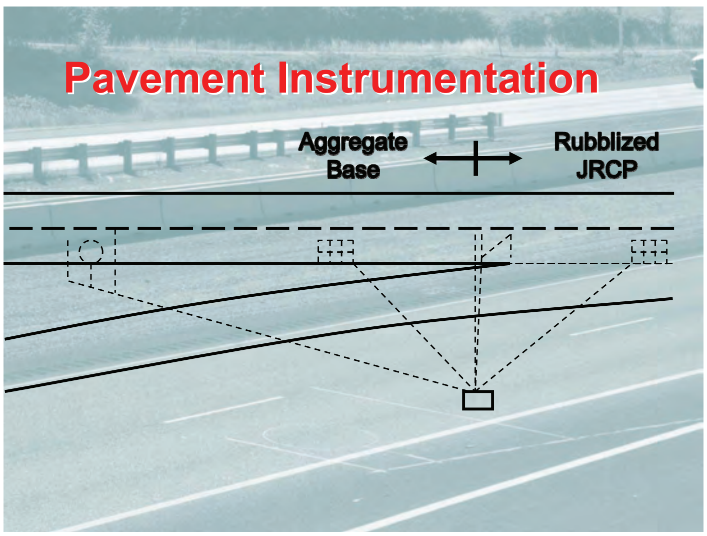
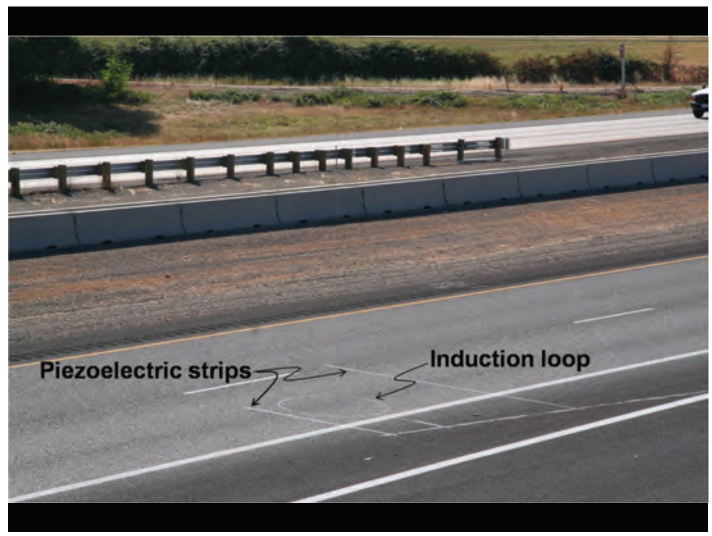
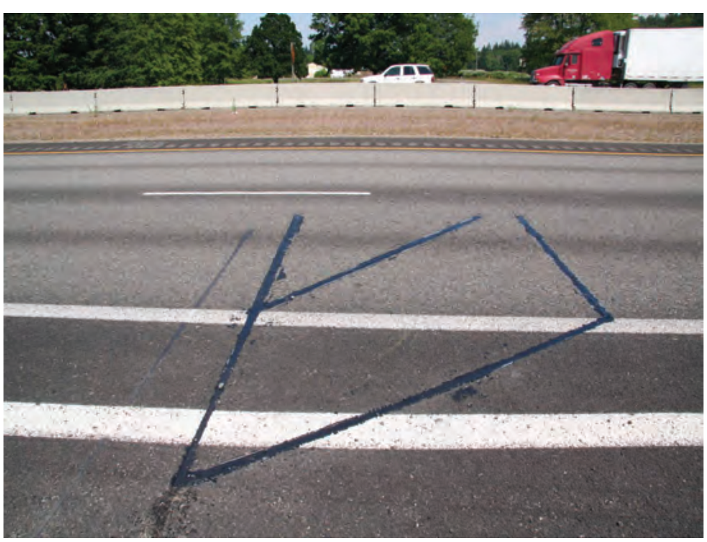
Axle Configuration
Wheelbase
Wheelbase distribution information for JPCP top-down cracking. The wheelbase refers to the spacing between the steering and the first device axle of the truck-tractors or heavy single units.
Short
Medium
Long
Average Axle Spacing (ft) 12 15 18
Percent of trucks (%): 33.0 33.0 34.0
OK
Cancel
Inputs
Traffic
Climate
Structure
Layers
% Complete
Value
20 Years
9/2006
US Customary
Probabilistic
Excel Worksheet
Enabled
For Help, press F1
NUM

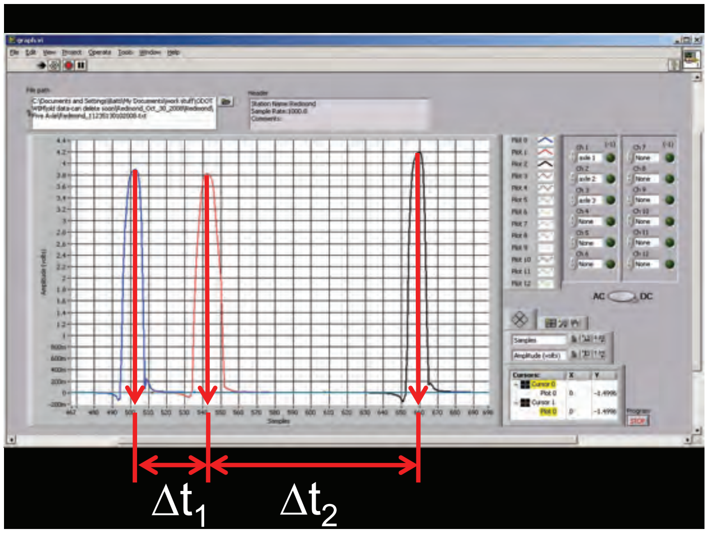

Rubblized PCC Base
Aggregate Base


Pavement Instrumentation
Aggregate Base
Rubblized JRCP


Piezoelectric strips
Induction loop

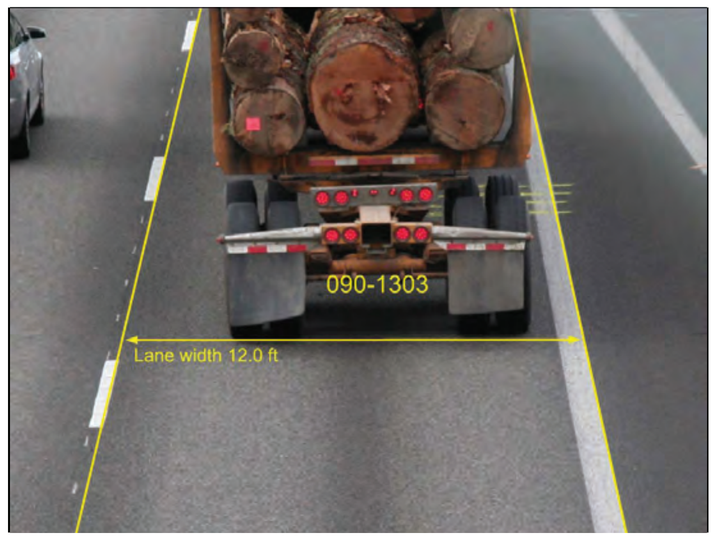



UPS Freight


Δt_1
Δt_2


Wander

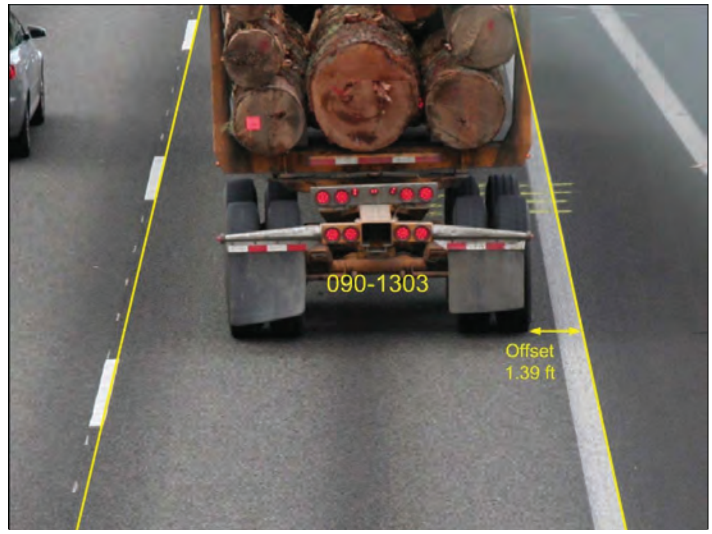

090-1303

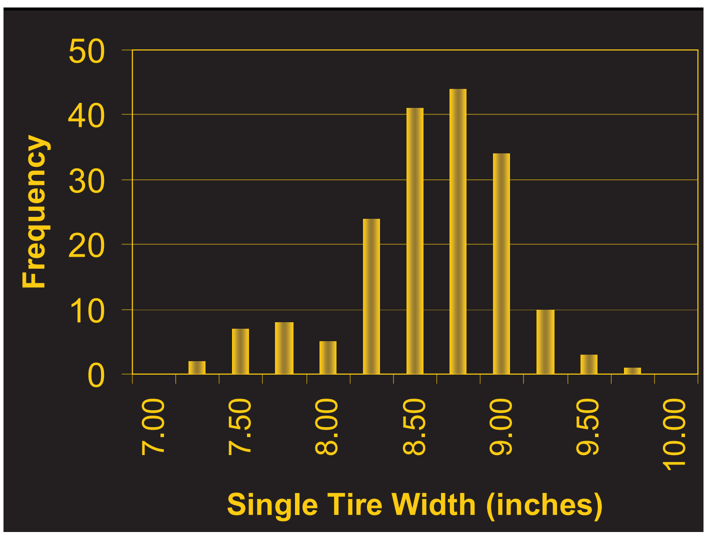

090-1303
Lane width 12.0 ft

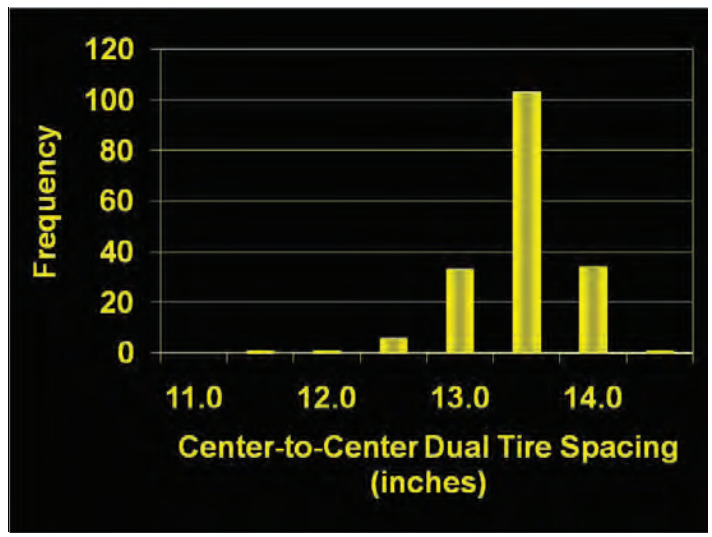

090-1303
Single tire width 0.72 ft

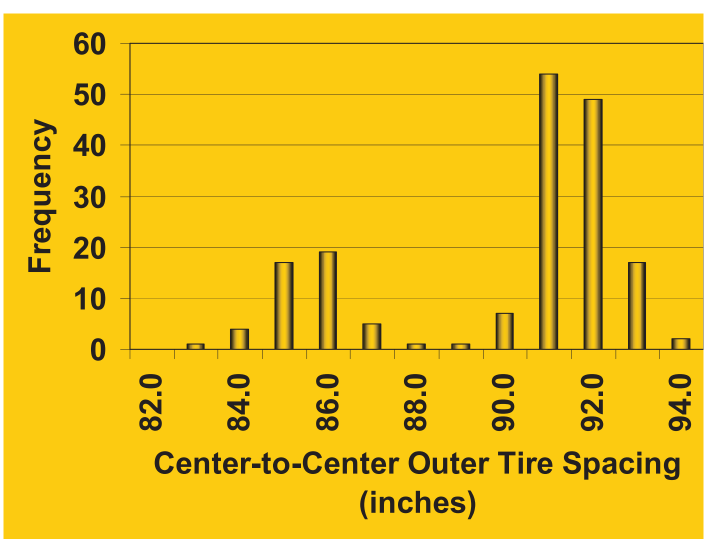

090-1303
Dual tire width 1.85 ft

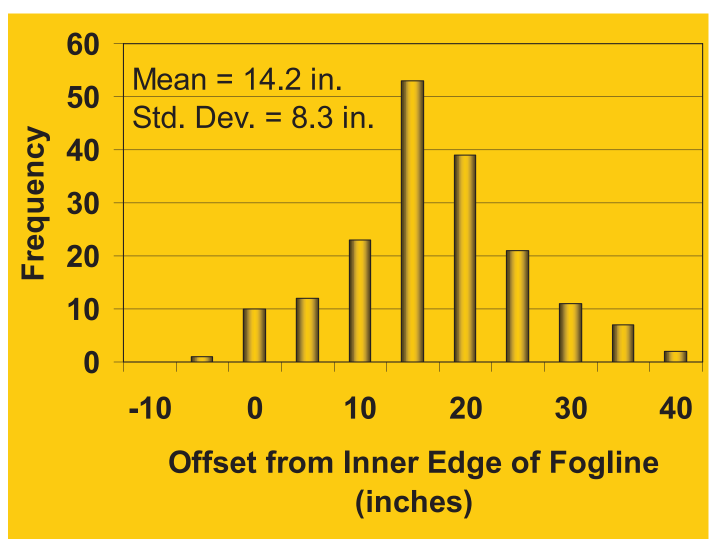

090-1303
"Axle" width 7.85 ft

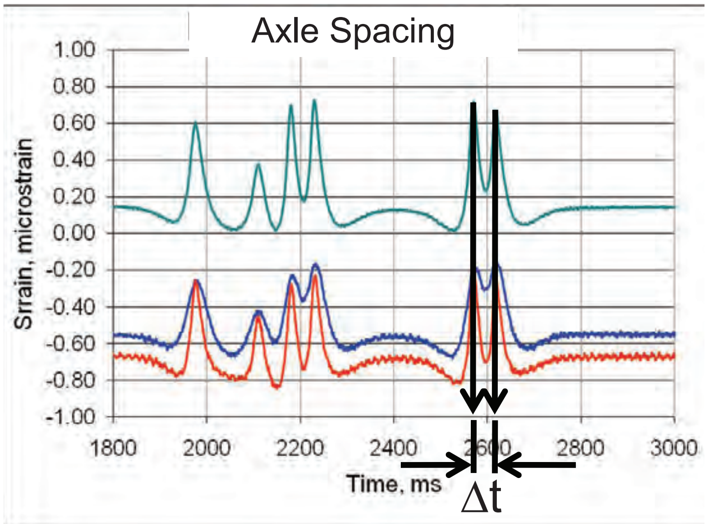

090-1303
Offset
1.39 ft

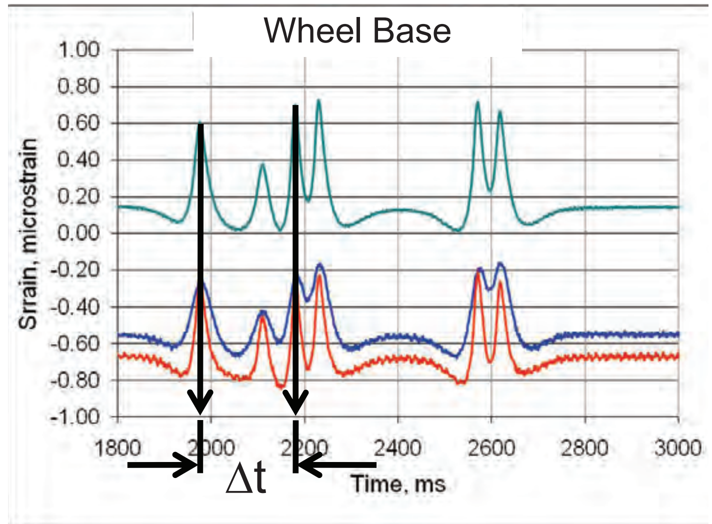

Frequency
50
40
30
20
10
0
7.00
7.50
8.00
8.50
9.00
9.50
10.00
Single Tire Width (inches)


Frequency
120
100
80
60
40
20
0
11.0
12.0
13.0
14.0
Center-to-Center Dual Tire Spacing
(inches)


Frequency
60
50
40
30
20
10
0
82.0
84.0
86.0
88.0
90.0
92.0
94.0
Center-to-Center Outer Tire Spacing
(inches)


Mean = 14.2 in.
Std. Dev. = 8.3 in.
Frequency
60
50
40
30
20
10
0
-10
0
10
20
30
40
Offset from Inner Edge of Fogline
(inches)


Axle Spacing
Srain, microstrain
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
1800
2000
2200
2400
2600
2800
3000
Time, ms
Δt


Wheel Base
Srain, microstrain
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
1800
2000
2200
2400
2600
2800
3000
Time, ms
Δt


Thank You!

Traffic Data in MEPDG -WSDOT

Jianhua Li
Jeff Uhlmeyer

March, 2009

Washington State Department of Transportation

Research Approach

- Traffic Data Preparation
- Axle Load Spectra Development
- Sensitivity Analysis

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MEPDG Traffic Data

- AADTT, truck speed and annual growth rate
- General traffic inputs
  - Truck-traffic directional distribution factor
  - Lane distribution factors
  - Wheel base configurations
  - Tire characteristics
- Axle load spectra
  - Axle load distribution factors for single, tandem, tridem and quad axle types
  - Truck volume adjustment factors by month, hour and truck class

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Data Preparation

- Data source
  - WSPMS
  - The WSDOT Pavement Guide
  - WIM stations
- Data processing
  - Access
  - TrafLoad
  - MEPDG Utility Program
  - Excel

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WSDOT WIM Stations

Site	SR	MP	County	AADT	Truck (%)		
					Single	Double	Train
P03	97	66.3	Wapato	11,000	3	4	1
P05	12	377	Columbia	2,200	10	11	2
P06	14	11.9	Clark	3,500	6	2	1
P07	14	17.7	Clark	6,200	6	4	1
P08	82	48.5	Yakima	24,000	5	9	2
P09	82	121	Wapato	15,000	7	15	2
P10	90	218	Adams	9,900	6	14	2
P13	195	6	Ritzville	4,800	9	7	1
P14	195	22	Whiteman	3,100	9	10	2
P15	195	87.7	Pullman	8,900	7	4	1
P17	221	13.1	Benton	1,800	6	29	9
P30	27	77.3	Spokane	6,100	8	1	0

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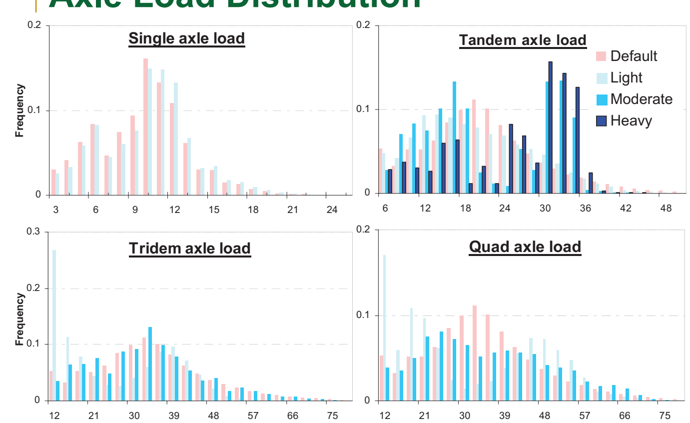
Axle Load Distribution



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Spectra Development

- Based on the potential impacts on pavement performance, three general load spectra were presented.
  - **Light axle load spectra** with light single, tandem, tridem and quad axle load distributions.
  - **Moderate axle load spectra** with the light single axle load distribution, and moderate tandem/tridem/quad axle load distributions.
  - **Heavy axle load spectra** with the light single axle load distribution, heavy tandem axle load distribution, and moderate tridem/quad axle load distributions.

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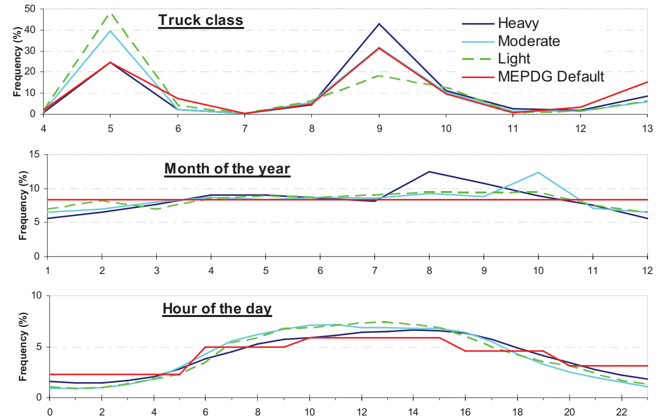
Truck Volume Adjustment Factor



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Sensitivity Analysis

- MEPDG outputs were more sensitive to AADTT and annual growth rate than the developed load spectra.
- The three developed axle load spectra have similar effects on MEPDG outputs.
- Special Investigations are needed
  - For roads with anticipated traffic change in future.
  - For design of high-volume roads or heavy-loading vehicles.

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Conclusions

- MEPDG is only moderately sensitive to the developed axle load spectra for typical WSDOT pavement designs.
- One group of axle load spectra can present the axle load characteristics in MEPDG for WSDOT.

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