RESEARCH

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DRAFT USER'S GUIDE FOR UDOT MECHANISTIC-EMPIRICAL PAVEMENT DESIGN

Prepared For:

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INSIDE COVER

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16. Abstract

Validation of the new AASHTO Mechanistic-Empirical Pavement Design Guide's (MEPDG) nationally calibrated pavement distress and smoothness prediction models when applied under Utah conditions, and local calibration of the new hot-mix asphalt (HMA) pavement total rutting model, were recently completed as documented in UDOT Research Report No. UT-09.11, *Implementation of the Mechanistic-Empirical Pavement Design Guide in Utah: Validation, Calibration, and Development of the UDOT MEPDG User's Guide*, dated October 2009. This Draft User's Guide incorporates the findings of the model validation and local calibration report and provides information for use by UDOT's pavement design engineers during trial implementation of the MEPDG. This information includes an overview of the MEPDG procedure, information on installation of the software, guidelines for obtaining all needed inputs, guidance to perform pavement design using the software for new and rehabilitated HMA pavement and jointed plain concrete pavement (JPCP), and pavement design examples for new HMA pavement and new JPCP using the MEPDG software. This Draft User's Guide must be considered as preliminary as the MEPDG implementation process in Utah is not complete. The UDOT Materials Division expects to provide regular updates to this document as the MEPDG software is updated and as UDOT gains more experience with the MEPDG.

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PREFACE

This document describes a new and greatly improved methodology for pavement design that considers basic engineering (mechanistic) principles and is validated with pavement performance data. The need for and benefits of a mechanistically based pavement design procedure were clearly recognized at the time when the 1986 American Association of State Highway and Transportation Officials (AASHTO) *Guide for Design of Pavement Structures* was adopted. From the early 1960's through to the 1986/1993 Guide, all versions of the Guide were based on limited empirical performance equations developed at the American Association of State Highway Officials (AASHO) Road Test conducted near Ottawa, Illinois, in the 1950's. Utah was an early lead state to adopt the Interim Guide in the 1960's after extensive local calibration to Utah conditions and materials and has utilized the various updated versions of the guide through the 1993 version.

However, since the time of the AASHO Road Test, there have been many significant changes in trucks and truck volumes, materials, construction, rehabilitation, and design needs. In fact, by 1986 it had become apparent that there was a great need for an improved design procedure that could account for changes in loadings, materials, and design features as well as direct consideration of climatic effects on performance. For example, the design of heavily trafficked highways of today is far out of the scope of the existing AASHTO design guide. Therefore, the AASHTO Joint Task Force on Pavements (JTFP), in cooperation with the National Cooperative Highway Research Program (NCHRP) and the Federal Highway Administration (FHWA), has encouraged and sponsored the development of an AASHTO mechanistic-empirical pavement design procedure. NCHRP Project 1-37A, Development of the 2002 Guide for Design of New and Rehabilitated Pavement Structures: Phase II was awarded to Applied Research Associates, Inc. (ARA) in 1998. The project called for the development of a guide that utilized existing mechanistic-based models and databases reflecting current state-of-the-art pavement design procedures. The guide was to address all new and rehabilitation design issues and provide an equitable design basis for all pavement types.

The Mechanistic-Empirical Pavement Design Guide (or MEPDG, as it has become known) was developed by a large team of nationally recognized engineers from ARA and Arizona State University along with several expert consultants. It was completed in 2004 and released to the public for review and evaluation (ARA 2004). A final version (1.000) was submitted in April 2007 to the NCHRP, FHWA, and AASHTO for further consideration as an AASHTO Standard. The MEPDG Guide Document was balloted and approved as an Interim AASHTO standard in October 2007. A lead state organization exists (Utah is a member) and many states have begun implementation activities (since 2002) in terms of staff training, collection of input data (materials library, traffic library), acquiring of test equipment, and setting up of field sections for local calibration. FHWA has a web site for knowledge exchange for the MEPDG (http://knowledge.fhwa.dot.gov) which is active with many people making comments, asking questions, and receiving answers. The key AASHTO document "AASHTO Mechanistic-Empirical Pavement Design Guide, Interim Edition: A Manual of Practice" (AASHTO 2008) provides the best available engineering documentation of the new pavement design procedure.

This guide provides the information necessary for Utah Department of Transportation (UDOT) pavement design engineers to begin to use the MEPDG software. This guide has not been fully integrated with the UDOT Pavement Management & Pavement Design Manual. Local calibration and additional validation have taken place in Utah during 2006-2009 which resulted in changes and additions to this document. The results of the local calibration and validation study are reported in UDOT Research Report No. UT-09.11, *Implementation of the Mechanistic-Empirical Pavement Design Guide in Utah: Validation, Calibration, and Development of the UDOT MEPDG User's Guide*, dated October 2009. Note that this Draft User's Guide was first published by UDOT in October 2009 and must be considered as preliminary as the MEPDG implementation process in Utah is not complete. The UDOT Materials Division expects to provide regular updates to this document as the MEPDG software is updated and as UDOT gains more experience with the MEPDG. UDOT engineers should forward any questions and comments on the guide to Mr. Steven Anderson of the UDOT Materials Division.

1.0 OVERVIEW OF THE NEW MEPDG DESIGN GUIDE & SOFTWARE INSTALLATION

1.1 Overview

This Draft User's Guide presents the following information to assist UDOT's pavement design engineers in the use of the Mechanistic-Empirical Pavement Design Guide (referred to herein as MEPDG) during trial implementation:

- An overview of the MEPDG procedure.
- Information on installation of the software.
- Guidelines for obtaining all needed inputs.
- Guidance to perform pavement design using the software for the following pavement types:
  - New or reconstructed hot-mix asphalt (HMA) pavement
  - New or reconstructed Jointed Plain Concrete Pavement (JPCP)
  - HMA Rehabilitation – HMA overlay on existing HMA
  - HMA Rehabilitation – HMA on existing JPCP
  - JPCP Rehabilitation – Concrete Pavement Restoration (CPR diamond grinding) and JPCP overlay on an existing pavement.
- Examples of pavement design using the Design Guide software. The following pavement types are considered in the design examples presented:
  - New or reconstructed HMA pavement
  - New or reconstructed JPCP.

The MEPDG is based on mechanistic-empirical design concepts. This means that the design procedure calculates pavement responses such as stresses, strains, and deflections under axle loads and then accumulates the damage over time. Next, the procedure empirically relates calculated damage over time to pavement distresses based on performance of actual projects. The procedure is shown in the flowchart in Figure 1. Note that the pavement design using the MEPDG is an **iterative process.**

The software provides:

1. A User Interface to input design variables,
2. Computational engines for analysis and performance prediction, and
3. Results and outputs from the analyses in formats suitable for use in electronic documents or for making hardcopies.

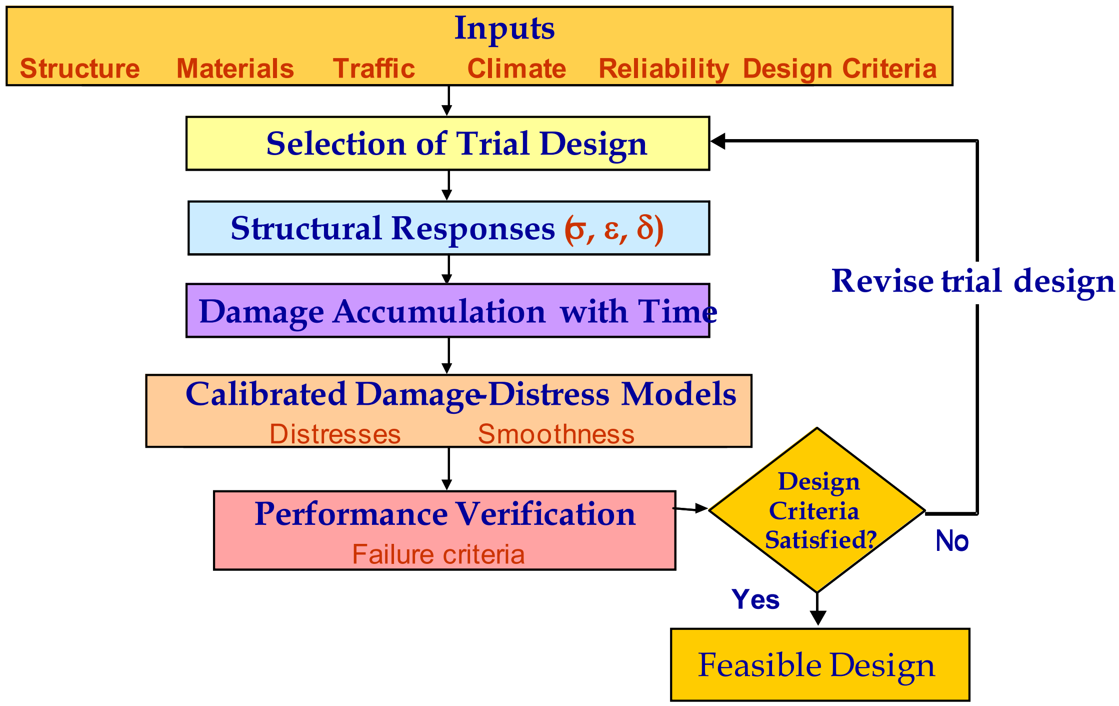

Figure 1. MEPDG overall trial & error process.

MEPDG Iterative Process

1. The designer inputs a trial design.

2. The software estimates the damage, key distresses, and International Roughness Index (IRI) over the design life.

3. The predicted performance is compared to the design performance criteria at a desired level of reliability.

4. The design may be modified iteratively as needed to meet performance and reliability requirements.

1.2 Installing Design Guide Software

The Design Guide installation CD uses the Windows auto-run feature. To install the software:

1. Start Windows.
2. Close any applications that are already running.
3. Insert the Design Guide CD into the CD-ROM drive.

If the installation does not start within a few seconds:

1. Double-click on My Computer icon on the Desktop.
2. Double-click on the Design Guide CD-ROM icon.
3. Run setup.exe.

Simply follow the on-screen directions to install Design Guide.

The Design Guide software may also be installed from the Transportation Research Board web site: http://www.trb.org/mepdg/. The complete Design Guide documentation (all volumes and appendices) is available at all times when using the software under the Help menu item. The supporting technical reports are available online in an unrestricted PDF format. NCHRP may revise the software and other documents as necessary and provide updates on the Internet.

Note that for license verification purposes, the user must have either the CD in the CD-ROM tray of the personal computer or the computer must be connected to the Internet.

The default directory for installing the program files is C:\DG2002. The user is provided the option to change the installation directory. The installation program copies several files into the program root directory *DG2002*. *DG2002* will contain the main program file and several Dynamic Linked Libraries (DLLs) and installation files that are necessary for the proper operation of the program. Other directories copied by the installation program are:

- Projects: This directory contains the project files for all projects created by this release. All project files have the ".dgp" file extension. Other files that are used for inter-process communication and archiving purposes are kept in subdirectories of this directory. Each project has its own subdirectory. Three types of files are included: folders that contain many intermediate and output files, "cone" files that include inputs to the MEPDG, and climate files for projects.

- Bin: This directory contains files necessary for the operation of the program. Do not delete, rename, or change any of the files from this directory.
- Defaults: This directory contains default information files that are used by the program to generate default input values. These files have been tailored for Utah conditions.
- HTML Help: This directory contains the Help files.

In addition to installing the Design Guide, the user will also have to install the climate files of interest. The climate files can be installed as follows:

1. Using Windows Explorer, navigate to the CD-ROM drive containing the Design Guide installation CD.
2. Open the "Climate" folder.
3. Click "Setup.Exe."
4. Follow instructions on the ICM Climatic Data Wizard to install climate (weather station data) files for the regions (i.e., States) of interest.

NOTE: 1.4 GB of disk space is required to install the complete set of climate files.

The climate files are stored under a folder titled "hcd" which is created during the climate file installation process under C:\DG2002—the default Design Guide installation directory. Note that if the Design Guide files are saved at a location other than C:\DG2002, it is imperative that the user points to that folder during the installation of the climate files.

As stated earlier, the "hcd" directory contains data from all the weather stations selected for installation. These contain approximately 9 years of data. Download needed stations from the TRB web site.

1.3 Uninstalling Design Guide

Always uninstall the Design Guide using the procedure below. Never just delete the various files under the DG2002 directory. To uninstall the Design Guide software program:

1. Select the Windows Start button.
2. Select or move the mouse to Settings.
3. Select Control Panel.
4. Select Add/Remove Programs.
5. Uninstall the Design Guide software. An updated version of the software can be immediately installed if desired. Note that uninstall does not delete any project files or weather station files.

NOTE: This process does not remove the "hcd" under the C:\DG2002 folder. This folder must be manually deleted if desired. However, it is recommended that this folder not be deleted between installations of successive versions of the MEPDG software unless an updated set of climate data is available with these versions.

1.4 Running the Design Guide

During installation, a Design Guide program will be added to your Windows Start menu and a Design Guide icon to the PC's desktop. To find Design Guide, click the

Start button in the bottom left corner of your screen. Go up to the Programs option with your cursor to see a list of folders and programs. Select the Design Guide folder and click on the design guide icon. Alternatively, the program can also be run by double-clicking the *DG2k2* icon on the desktop. The software opens with a splash screen shown in Figure 2. A new file must be opened for each new project, much like opening a new file for each document on a word processor or other standard Windows applications. To open a new project, select "New" from the "File" menu of the tool bar. A typical layout of the program is shown below in Figure 3.

Figure 2. MEPDG software.

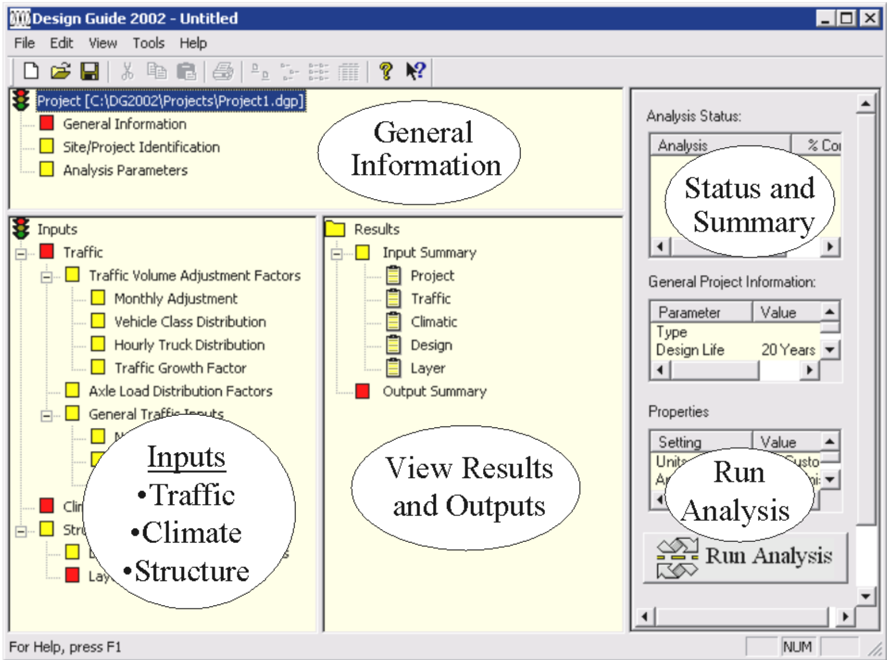

Figure 3. Program layout.

The user first provides the software with the General Information of the project and then inputs in three main categories, Traffic, Climate, and Structure. All inputs for the software program are color coded as shown in Figure 4. Input screens that require user entry of data are coded "red". Those that have default values (but not yet verified and accepted by the user) are coded "yellow." Default inputs that have been verified and accepted by the user or when the user enters design-specific inputs, they are coded "green". The program will not run until all input screens are either yellow or green.

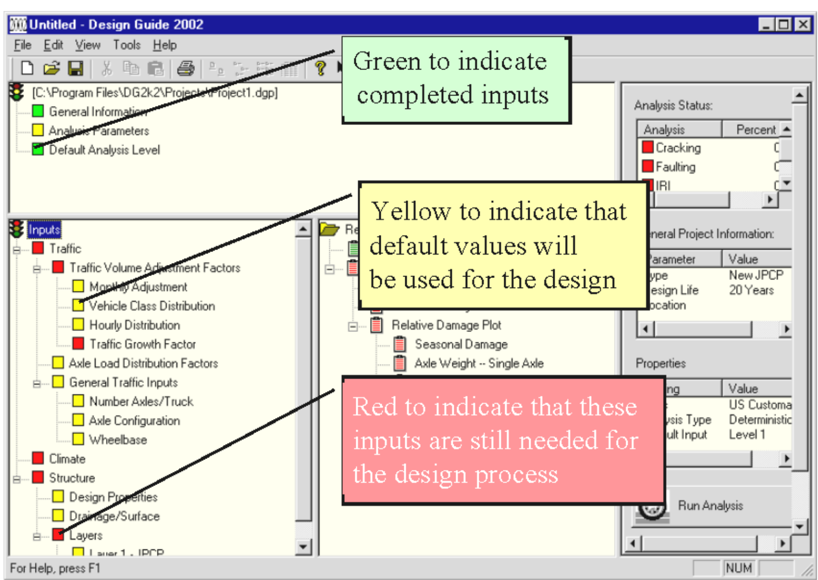

Figure 4. Color-coded inputs to assist user in input accuracy.

Next, after all inputs are provided for the trial design, the user may choose to run the analysis by clicking on the "Run Analysis" button. When this is done, the software now executes the damage analysis and the performance prediction engines for the trial design input. When the execution of the run is complete, the user can view input and output summaries created by the program. The program creates a summary of all inputs of the trial design. It also provides an output summary of the distress and performance prediction in both tabular and graphical formats. All charts are plotted in Microsoft Excel and can be easily incorporated into electronic documents and reports.

The Design Guide software also offers extensive online help to users. Help is available at three levels.

1. Context sensitive and tool tip help as shown in Figures 5 and 6, respectively. Context Sensitive Help (CSH) provides a brief definition of the input variable and its significance to the design. CSH can be accessed by right-clicking the mouse on an input variable. Tool tip help prompts the typical range in values for each input and will be accessed with moving the cursor close to each input.
2. Html help (as in the level of help you are using now) provides the next level of help and is in more detail than level 1 help. It can be accessed by clicking on the "?" on the top right corner of the screen.
3. Link to detailed Design Guide documents. The complete Design Guide text is always available electronically under the HELP menu.

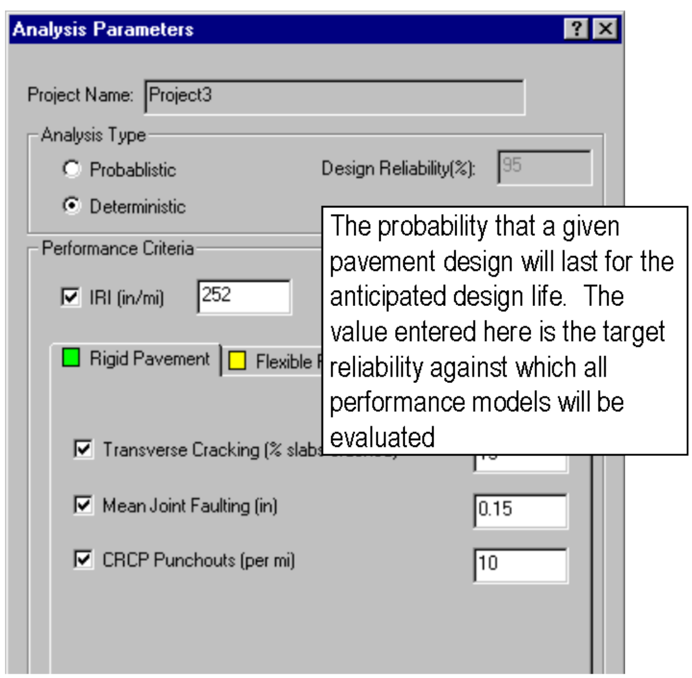

Figure 5. Context sensitive help (a brief description of input).

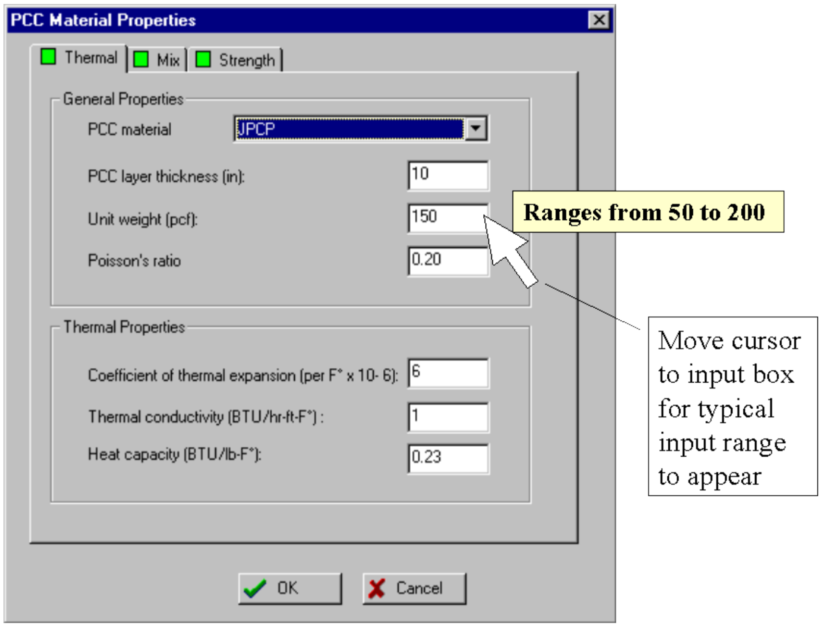

Figure 6. Tool tip help.

1.5 Hierarchical Approach to Design Inputs

The hierarchical approach to design inputs is a feature of the Design Guide not found in previous versions of the AASHTO Guide. This approach provides the designer with a lot of flexibility in obtaining the design inputs for a design project based on the criticality of the project and the available resources. The hierarchical approach is employed with regard to traffic, materials, and environmental inputs. In general, three levels of inputs are provided, as explained in the shaded box on the following page.

For a given design project, inputs may be obtained using a mix of levels, such as concrete modulus of rupture from Level 1 testing and modulus of elasticity from Level 3 correlation, traffic load spectra from Level 2, and subgrade resilient modulus from Level 3. In addition, it is important to realize that no matter what input design levels are used, the computational algorithm for damage is exactly the same. Note that the same models and procedures are used to predict distress and smoothness no matter what levels are used to obtain the design inputs. There is no such thing as a "Level 1" analysis. There is however a design developed using mostly "Level 1 inputs" for example.

At the current time, in the MEPDG, input level has no other effect than accuracy of the input itself (which is important for critical inputs). The only exception to this general rule is the thermal fracture model which has three different formulations of the design reliability equation corresponding to each of the three input levels. Future versions of the MEPDG will link input accuracy level to design reliability for other models.

MEPDG Hierarchical Input Definition

- **Level 1** material input requires laboratory or field testing, such as the dynamic modulus (E*) testing of hot-mix asphalt concrete, coefficient of thermal expansion of concrete (CTE), or Falling Weight Deflectometer (FWD) deflection testing. Level 1 inputs for traffic require on site measurement of axle load distribution, truck lane usage, and truck classification. Obtaining Level 1 inputs requires more resources and time than other levels. Level 1 input would typically be used for designing heavily trafficked pavements or wherever there is dire safety or economic consequences of early failure.

- **Level 2** inputs would be user-selected, possibly from an agency database, could be derived from a limited testing program, or could be estimated through correlations of simpler tests with the more complicated inputs for the MEPDG. Examples include estimating hot-mix asphalt (HMA) dynamic modulus (E*) from binder, aggregate, and mix properties, estimating Portland cement concrete (PCC) elastic moduli from compressive strength tests, or using traffic classification data based on functional class of highway in the state. This level could be used when resources or testing equipment are not available for tests required for Level 1.

- **Level 3** inputs are user-selected values or typical averages for the local region. Examples include Utah default unbound materials resilient modulus values or default Portland cement concrete coefficient of thermal expansion for a given aggregate type. This level might be used for design where there are minimal consequences of early failure (e.g., lower volume roads).

This will provide a powerful tool to show the advantages of good engineering design (using Level 1 inputs) in improving the reliability of the design and the possibility to reduce pavement construction and rehabilitation costs.

It is recommended that the designer obtain the inputs for a given design project that are appropriate and practical for the magnitude of project under design. Larger, more significant projects require more accurate design inputs.

Examples of new HMA pavement and new JPCP trial designs that show the coded MEPDG inputs are presented in Appendices A and B.

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2.0 GENERAL INFORMATION INPUTS

2.1 Design Life

The design life of a new, reconstructed, overlaid, or restored pavement is the time from initial construction until the pavement has structurally deteriorated to the point when significant rehabilitation or reconstruction is needed. The design life is defined by the initial pavement conditions until the specified critical pavement condition has been reached at a selected level of reliability.

The software can handle design lives from 1 year (e.g., detour) to over 50 years. UDOT recommends the time periods shown in Table 1 for design life. Exceptions may be considered for unique situations. The pavement management engineer of the UDOT Region where the project is located should be contacted to obtain the desired design life for the specific pavement project.

Table 1. UDOT recommendations for pavement design life.

Pavement Type	Functional Class	Design Life, Years
New or reconstructed hot-mix asphalt (HMA)	Interstate or other freeway	20
	Secondary or Urban street or highway	15-20
New or reconstructed jointed plain concrete pavement (JPCP)	Interstate or other freeway	40
	Secondary or Urban street or highway	30-40
HMA overlays of flexible or JPCP pavements	Any functional class	10-15
PCC overlays of flexible or JPCP pavements	Any functional class	20-30
Concrete Pavement Restoration (CPR)	Any functional class	10-15

2.2 Construction & Traffic Opening Dates

Construction and traffic opening dates (month/year) (see Table 2) are keyed to the monthly traffic loadings, monthly climatic inputs, and certain material properties which affect all future monthly layer and subgrade modulus values. Aging of asphalt materials is keyed to the date of construction. Construction and traffic opening dates have additional effects on concrete pavements:

- Construction month affects the "set" or "zero stress" solidification temperature of the concrete. Construction during warmer months will result in wider joints (and more faulting) than during cooler months.
- Traffic opening affects the curing time (28-days is minimum for this design procedure) and thus strength and modulus and, over time, slab cracking. The longer the time from slab construction to opening to traffic, the less cracking will occur over the design period.

The designer should select the most likely month for construction and month for opening to traffic. If these are totally unknown, then different months can be tried and the one resulting in the most distress selected for design.

Table 2. Description of construction and traffic opening dates.

Activity	**Best Estimate**
Base/Subgrade construction (flexible pavement only)	Month/Year (program begins with 1st day of month) to calculate moisture content in unbound layers
Pavement construction month	Month/Year (program assumes 1st day of month). Selecting August would result in the August climate being used and the August 1 date for timing of material properties.
Traffic opening date	Month/Year (program begins computing damage on 1st day of month). Selecting June would start traffic on June 1. June would be the first month listed in the MEPDG output.

2.3 New/Reconstructed Pavement and Rehabilitated Pavement Types Considered by the MEPDG

New and reconstructed pavements of relevance are described in Tables 3 through 5.

Table 3. Description of new pavement types considered by the MEPDG.

Type of Pavement	Description
Flexible pavement	HMA of all types including conventional thin HMA, deep strength HMA, & full depth HMA.
Rigid Pavement	Jointed plain concrete pavement (JPCP), with or without dowels at joints
	Continuously reinforced concrete pavements (not used in Utah), has no regular transverse joints

Table 4. Description of restored JPCP.

Type of Pavement	Description
Existing JPCP	An engineered design that may include cracked slab replacement, joint spall repair, shoulder replacement, dowel bar retrofit, and diamond grinding (required)

Table 5. Description of HMA and PCC overlays.

Type of Overlay	Existing Pavement
HMA Material	Existing flexible pavements Existing intact JPCP Existing JPCP that has been cracked & seated or rubblized
PCC Material	Existing flexible pavements (conventional PCC overlays, 6-in minimum only) Existing intact JPCP (separated overlay) Existing JPCP that has been cracked & seated or rubblized

2.4 Site/Project Identification

Enter appropriate information to identify the project for pavement design purposes.

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3.0 PERFORMANCE CRITERIA INPUTS

Performance criteria (or Analysis Parameters on the software window) are used to ensure that a pavement design will perform satisfactorily over its design life. Critical limits are selected and used by the designer to judge the adequacy of a design. The IRI criteria are similar to the 1993 AASHTO Design Guide use of the initial and terminal serviceability. Other important distress types have been added. These criteria must be selected in consideration with the Design Reliability in Section 4. Selection of too tight of a criterion (e.g. 0.1-in rutting) at a very high reliability (e.g., 97 percent) may find it impossible to obtain an acceptable design, or the design may be excessively costly.

These criteria represent the pavement condition at the time of rehabilitation at a given level of design reliability. Thus, for example, selecting a percent fatigue cracking (for either HMA or PCC pavements) of 10 percent at a 90 percent reliability level indicates that the designer is specifying this amount of fatigue cracking that requires rehabilitation (e.g. structural improvement in this case) and does not want this amount of cracking to be exceeded in 9 out of 10 projects over the specified design period.

Newly constructed HMA (initial IRI)

HMA with Alligator Cracking

HMA with transverse cracking

The criteria presented in Table 6 should be used to determine whether a pavement design meets minimum performance standards during its design life for a given level of reliability shown in Section 4. These are tentative and may need revision after a period of use by UDOT. Initial IRI is selected at a value being achieved regularly in construction with the UDOT smoothness specifications. The initial IRI values for HMA, JPCP, and CPR of JPCP projects were examined and an average was obtained for each as presented in Table 7. Unusual conditions for HMA overlays or CPR of an existing pavement with heaves or settlements may require a higher value if the effects of the existing pavement settlements or heaves are not removed by the overlay or CPR.

Table 6. Suggested performance criteria for use in pavement design.

Pavement Type	Performance Criteria	Maximum Value at End of Design Life at Design Reliability***
HMA pavement & overlays	HMA bottom up fatigue cracking (alligator cracking)	Interstate:10 percent lane area Primary: 20 percent lane area Secondary: 45 percent lane area
	HMA longitudinal fatigue cracking (top down)**	Interstate:2,000-ft/mile Primary: 2,500-ft/mile Secondary: 3,000-ft/mile
	Permanent deformation (total mean rutting of both wheel paths)	Interstate: 0.40-in mean Primary: 0.50-in mean Others <40 mph: 0.75-in mean
	Thermal fracture (transverse cracks)	Interstate: Crack spacing > 70-ft (Crack length < 905-ft/mile) Primary/Secondary: Crack spacing > 50-ft (Crack length < 1267-ft/mile)
	IRI	Interstate/Primary: 169 in/mile maximum* Secondary: 223 in/mile maximum*
JPCP new, CPR, and JPCP overlays	Mean joint faulting	Interstate: 0.12-in mean all joints Primary: 0.20-in mean all joints Secondary: 0.25-in mean all joints
	Percent transverse slab cracking	Interstate: 10 percent Primary: 15 percent Secondary: 20 percent
	IRI	Interstate: 169 in/mile* Primary/Secondary: 223 in/mile maximum*

*Initial IRI for HMA and JPCP pavements shall be set within the range of 70 in to 85 in/mile.
**Top down longitudinal HMA cracking can be examined but is not currently used in Utah.
***At levels of reliability given in Section 4 Design Reliability Input. These criteria are in accordance with current MEPDG (version 1.1, 2009) national defaults. They are tentative and may need revision after a period of use by UDOT.

Table 7. Suggested initial IRI values for new and rehabilitated pavement design.

Pavement Type	IRI, in/mi		
	Average	Minimum	Maximum
New HMA & HMA/HMA	70	32	106
New JPCP	84	52	116
JPCP subjected to CPR	74	65	85

4.0 DESIGN RELIABILITY INPUT

The design reliability is the probability that the pavement will not exceed specific performance criteria over the design period. For example, for rutting, a design reliability of 90 percent represents the probability (9 out of 10 projects) that the mean rutting for the project will not exceed the mean 0.40-in criteria.

Design reliability must be selected for each distress and IRI performance criteria and they can vary between types. The design reliability should be selected in consideration of and balance with the performance criteria. For example, the selection of a high design reliability level (e.g., 99 percent) and a very low performance criterion (3 percent alligator cracking) might make it impossible or very costly to obtain an adequate design (see Figures 7 and 8).

The selection of a very high level of design reliability (e.g., > 96%) is not recommended at the present time. This may significantly increase costs. The consequences of a project exceeding a performance criteria usually requires earlier than programmed maintenance or rehabilitation. It does not have dire structural collapse consequence.

The following recommended values are believed to be in balance with the performance criteria selected in Section 3 and should be used for UDOT designs. The same level of reliability should be used for all distress types and IRI. Higher design reliability will require more substantial designs (thicker, improved materials, etc.). Further implementation studies may show that these will need to be adjusted.

Tentative Recommended Level of Reliability

Functional Classification	Urban	Rural
Interstate/Freeways	95	92
Principal Arterials	90	85
Collectors	80	75
Local	70	60

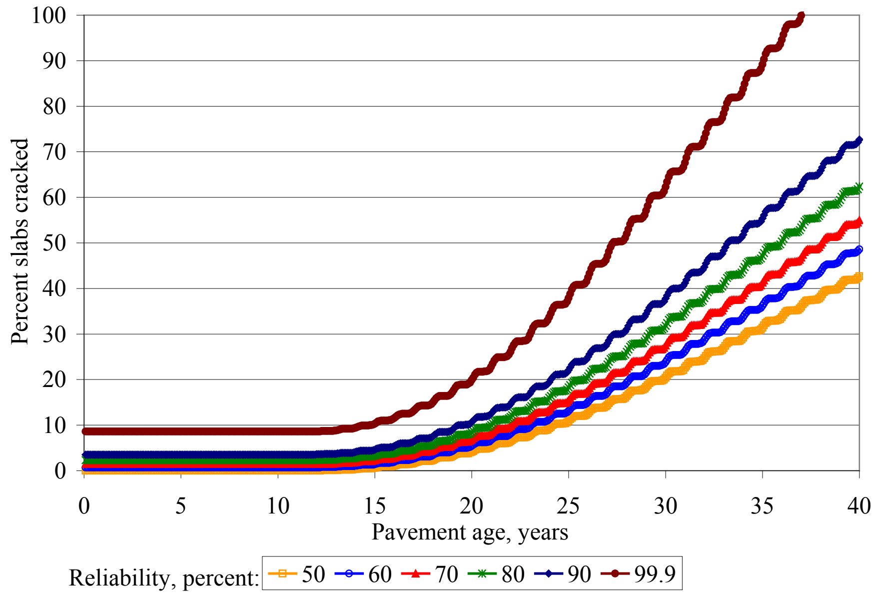


Figure 7. Illustration of the effect of design reliability on JPCP fatigue cracking. (Note the very large effect when reliability approaches 99.9 percent)

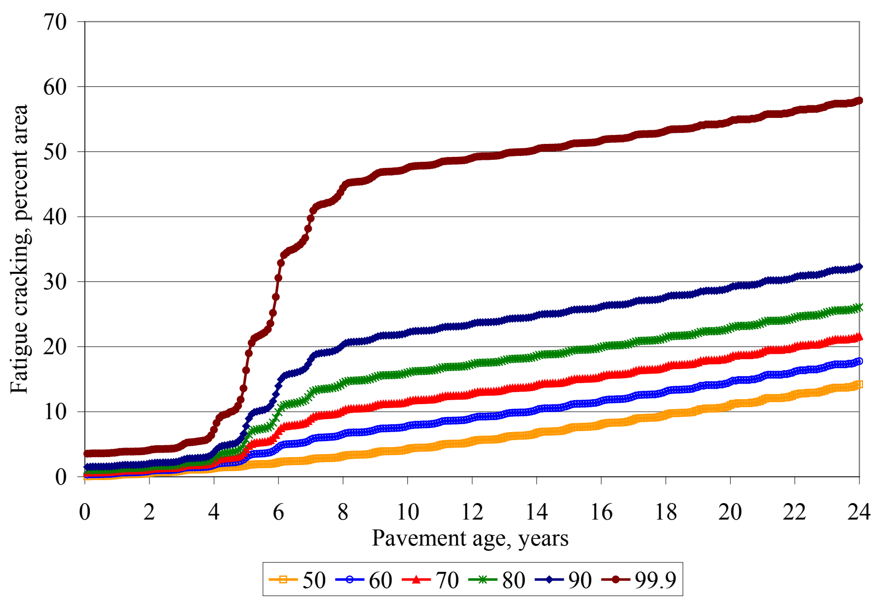


Figure 8. Illustration of the effect of design reliability on HMA fatigue cracking. (Note the very large effect when reliability approaches 99.9 percent)

5.0 TRAFFIC INPUTS

5.1 Introduction

Several inputs are required for characterizing traffic for the MEPDG. The MEPDG contains default traffic distributions for all required inputs with the exception of initial truck volume and future truck volume growth estimates that should always be project specific. UDOT collects truck traffic data among other vehicles types at automatic traffic recorder (ATR) stations. UDOT has three different traffic types of ATR stations that measure (1) volume only, (2) volume by length, and (3) volume by vehicle class. As of 2008/2009 (Saito and Jin 2009), UDOT has a total of 90 working ATR stations across the state from which valuable truck traffic type and volume data was collected.

UDOT collects axle load data from 15 permanent Weigh-In-Motion (WIM) sites (i.e., 9 piezoelectric sites and 6 load cell sites) across and around the State (Seegmiller 2006). All sites are under the jurisdiction of UDOT with the exception of the I-80 Evanston and I-70 Loma sites, which are maintained by the Wyoming and Colorado Departments of Transportation, respectively. Data collected at each of the WIM site include a listing of time and date for each vehicle, as well as detailed classification data, vehicle length, aggregate vehicle weight, disaggregate axle spacing, and disaggregate axle weight for each vehicle that crosses the WIM location.

Combining information from the ATR and WIM sites in Utah provided traffic data in sufficient detailed for developing MEPDG traffic inputs for several pavement sites across the State as part of MEPDG implementation. From this database of default MEPDG traffic inputs, pavement designers can obtain level 3 inputs for preliminary designs. The level 3 inputs must be selected based on similarity of pavement project characteristics such as functional class, location, and so on. A description of the default pavement project sites is presented in Table 8. Default data is presented throughout this section as needed. For final designs and designs of special projects with unique needs, it is recommended the engineers obtain level 1 or 2 traffic inputs from UDOT traffic engineers.

5.2 Traffic Volume

5.2.1 Initial Volume

Current and future truck traffic volumes are estimated using the parameters presented in Table 9.

Table 8. Location of highway sites with MEPDG traffic inputs.

Project ID*	Highway	County	MilePost		Location
			Begin	End	
CPR1	I-80	Salt Lake	121.0	126.0	State Street to 2300 East
CPR2	I-15	Juab	211.2	216.0	Diamond grind at Levan Ridge South of Nephi
CPR3	I-70	Sevier	42.0	48.0	North Richfield to Sigard
CPR4	SR-120	Sevier	1.0	3.4	SR-120 MP 1 to MP 3
CPR5	I-84	Weber	42.0	44.0	Riverdale to Uintah junction
CPR6	I-15	Box Elder	354.2	364.8	Hot Springs to Brigham
CPR7	I-215	Salt Lake	3.7	5.7	5600 S to 4500 S. Salt Lake East Side
CPR8	I-15	Juab	216.0	230.0	S Nephi to N. Nephi
CPR9	I-70	Sevier	7.0	17.0	Clear Creek Canyon MP 7 to 17
JPCP1	I-15	Davis	315.0	321.0	Pages Lane lagoon
JPCP2	I-84	Morgan	112.3	102.2	Morgan to Summit county
JPCP3	I-80	Summit	191.9	196.7	Wahsatch to WY State line
JPCP4	I-80	Summit	181.0	196.7	Wahsatch to Castle Rock
JPCP5	I-15	Salt Lake	293.0	309.0	10800 South to 500 N. SLC valley
JPCP6	I-215	Salt Lake	13.3	17.0	Redwood Rd. to 4700 South, Salt Lake West Side Belt
JPCP7	I-80	Summit	181.0	196.7	Wyoming state line to Castle Rock
JPCP10	US-89 & US-50	Sevier	194.8	195.6	Salina Main Street
JPCP11	I-15	Millard	188.0	194.0	Scipio to Juab County
JPCP13	I-70	Sevier	17.0	31.0	Belknap to Elsenor
JPCP14	I-70	Sevier	31.0	37.7	Elsenor to South Richfield
JPCP15	1-70	Sevier	37.8	46.8	North Richfield to Sigard
JPCP16	I-15	Box Elder	382.0	388.5	Plymouth to Idaho
JPCP17	I-15	Box Elder	387.0	396.7	Riverside to Plymouth
HMA_R1 01	SR-226	Weber	0.0	3.2	Snow Basin Rd.
HMA_R1 02	US-89	Cache	392.7	397.8	Logan Canyon; Tony Grove to Franklin Basin
HMA_R1 03	SR-104	Weber	0.0	0.7	Wilson Lane in Ogden; SR-126 to I-15
HMA_R1 04	I-15	Weber	346.9	352.0	450 North to Hot Springs
HMA_R2 01	SR-248	Summit	1.4	30.7	High School to US-40
HMA_R2 02	SR-224	Summit	6.0	9.4	Bear Hollow to SR-248
HMA_R2 03	SR-71	Salt Lake	16.7	14.1	700 East; 6300 S. to 6000 S.
HMA_R2 04	SR-36	Tooele	62.1	65.6	Mills Junction to I-80, Tooele Co
HMA_R3 01	SR-73	Utah	20.8	31.9	Tickville Wash to Fairfield
HMA_R3 02	SR-73	Utah	31.5	36.5	Tickville Wash to SR-68
HMA_R3 03	I-15	Utah	285.9	282.7	I-15, Point of Mountain to Lehi
HMA_R3 04	I-15	Juab	200.1	211.2	Sevier River to Mills
HMA_R4 01	US-89	Sanpete	204.6	207.9	US-89; Centerfield to Gunnison
HMA_R4 02	SR-10	Emery	48.4	53.4	SR-10; Huntington to Poison Springs Bench
HMA_R4 03	SR-56	Iron	56.0	57.5	I-15 to Iron Springs, Iron Co
HMA_R4 04	US-191	Grand	125.0	132.0	Moab to I-70 at Crescent Junction
HMA_OVLY_1	I-15	Washington	0.0	6.0	Arizona State Line to Bluff Street MP 0-6
HMA_OVLY_2	I-15	Millard	138.6	143.9	Dog Valley through Baker Canyon
HMA_OVLY_3	US-191	San Juan	86.0	89.0	Junction SR-211 to RP 93 North of Monticello
HMA_OVLY_4	SR-10	Sevier	0.0	7.0	Fremont junction to Quitchupah Hill, Emery

*Project ID's or locations in this document with the prefix CPR, JPCP, or HMA indicate UDOT pavement management system (PMS) projects.

Table 9. Current and future truck traffic volumes estimates for pavement design.

Traffic Input	**Recommended Value**
Initial two-way Average Annual Daily Truck Traffic (AADTT—class 4 and above)	Projected for month of opening to traffic from measured historical data at site is desirable.
Number of lanes in design direction	Actual, from design plans.
Percent of two-directional trucks in design direction (%)	50%, unless higher truck volume is measured in design direction (note this is volume, not weight).
Percent of trucks in design lane (% of all trucks in design direction in design lane. For example, of 100% of trucks in design direction, 60% may be in design lane, the other 40% in other lanes)	Actual measured in design (heaviest truck volume) lane over 24-hours, otherwise use the following based on Utah measurements: • 100% for 1 lane in design direction • 90% for 2 lanes in design direction • 60% for 3 lanes in design direction • 50% for 4 or more in design direction For unusual truck traffic situations (mountainous terrain or urban usage complexity), conduct on site truck lane usage counts over 24-hour period.
Operational speed (mph)	Posted or Design Speed

5.3 Traffic Volume Adjustment Factors

These are adjustment factors used to distribute annual truck traffic estimates by month. The distribution is made for each truck class type. Table 10 presents default monthly truck distributions for three sites. Data for all the sites listed in Table 8 are available in electronic format and can be obtained from the UDOT Traffic Statistics office.

Monthly Adjustment Factors
Level 1 is the actual measured site data and must be used for highways with heavy seasonal recreational and agricultural traffic. Levels 2 and 3 are available in electronic format and can be obtained from the UDOT Traffic Statistics office. Selection of the appropriate site input must be based on project location and functional class as a minimum. Where no data in the default tables are suitable, use the MEPDG default of 1.0.

Table 10. Examples of default monthly adjustment factors for pavement design.

Location	Month	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13
HMA_R1 01	January	1.82	1.59	1.68	1.57	1.72	0.46	0.67	1.07	0.77	0.78
	February	1.86	1.56	1.68	1.54	1.73	0.52	0.75	1.13	0.86	0.87
	March	1.73	1.37	1.51	1.34	1.58	0.51	0.67	1.11	0.75	0.76
	April	0.82	0.94	0.89	0.95	0.87	0.58	0.46	0.67	0.43	0.43
	May	0.48	0.72	0.63	0.74	0.58	0.68	0.65	0.54	0.63	0.63
	June	0.54	0.64	0.6	0.65	0.58	0.92	1.07	0.71	1.11	1.11
	July	0.6	0.79	0.72	0.8	0.68	1.02	1.54	0.71	1.69	1.7
	August	0.66	0.8	0.75	0.81	0.72	0.99	1.46	0.73	1.6	1.61
	September	0.68	0.77	0.74	0.77	0.72	2.3	1.76	1.68	1.55	1.53
	October	0.59	0.63	0.62	0.64	0.62	2.18	1.18	1.66	0.82	0.8
	November	0.6	0.61	0.61	0.61	0.61	1.16	0.56	1.01	0.36	0.35
	December	1.61	1.58	1.59	1.58	1.59	0.67	1.23	0.99	1.43	1.45
JPCP16	January	0.65	0.76	0.71	0.77	0.72	0.96	0.92	0.96	0.76	0.72
	February	0.69	0.8	0.75	0.82	0.76	1.01	0.96	1.01	0.8	0.75
	March	0.89	1.02	0.96	1.04	0.95	1.05	1.03	1.05	0.95	0.93
	April	0.99	1.07	1.03	1.07	1.02	1.06	1.05	1.06	1.02	1.02
	May	1.21	1.43	1.32	1.45	1.25	1.05	1.07	1.05	1.17	1.19
	June	1.48	1.84	1.67	1.88	1.53	1.03	1.1	1.03	1.32	1.38
	July	1.68	2.04	1.87	2.08	1.71	1.02	1.1	1.03	1.39	1.47
	August	1.31	1.23	1.27	1.23	1.25	1	1.02	1.01	1.09	1.11
	September	0.98	0.54	0.75	0.49	0.85	0.98	0.97	0.99	0.92	0.91
	October	0.86	0.49	0.67	0.44	0.77	1.04	1.03	1.04	0.99	0.97
	November	0.7	0.43	0.56	0.4	0.65	0.94	0.92	0.94	0.84	0.82
	December	0.55	0.37	0.46	0.35	0.53	0.86	0.83	0.85	0.74	0.72
CPR7	January	0.68	0.78	0.73	0.79	0.72	0.84	0.74	0.85	0.65	0.64
	February	0.68	0.79	0.73	0.8	0.71	0.77	0.71	0.77	0.65	0.64
	March	0.76	0.82	0.79	0.82	0.78	0.9	0.84	0.9	0.79	0.79
	April	1.02	1.05	1.03	1.06	1.03	1.07	1.02	1.08	0.97	0.97
	May	1.16	1.07	1.12	1.06	1.13	1.11	1.11	1.12	1.11	1.11
	June	1.12	1.02	1.07	1.01	1.09	1.1	1.2	1.09	1.29	1.3
	July	1.38	1.22	1.3	1.19	1.32	1.09	1.23	1.09	1.35	1.36
	August	1.31	1.22	1.27	1.21	1.27	1.07	1.23	1.07	1.35	1.37
	September	1.14	1.08	1.11	1.07	1.12	1.09	1.12	1.09	1.15	1.15
	October	1.15	1.2	1.18	1.21	1.16	1.01	1.07	1	1.12	1.13
	November	0.9	0.94	0.92	0.94	0.91	0.91	0.86	0.92	0.82	0.82
	December	0.71	0.82	0.76	0.83	0.76	1.02	0.87	1.02	0.74	0.73

Each column in Table 10 must add to 12 regardless of monthly variation. If no trucks use the facility for a given month, then a value of 0 for that month must be entered. Most highways will be reasonably uniform across months (1.0). Exceptions may be highways used for heavy seasonal recreational and agricultural purposes.

5.4 Vehicle Class Distribution

Vehicle class types are defined according to FHWA and AASHTO definitions (see Figure 9). For the MEPDG, vehicle class distributions are basically adjustment factors used to distribute annual truck traffic estimates by vehicle/truck type. Table 11 presents default truck class distributions. Each row in Table 11 must add to 100 regardless of truck class variation. If a given truck class does not use the highway facility, then the distribution factor for that truck class is zero.

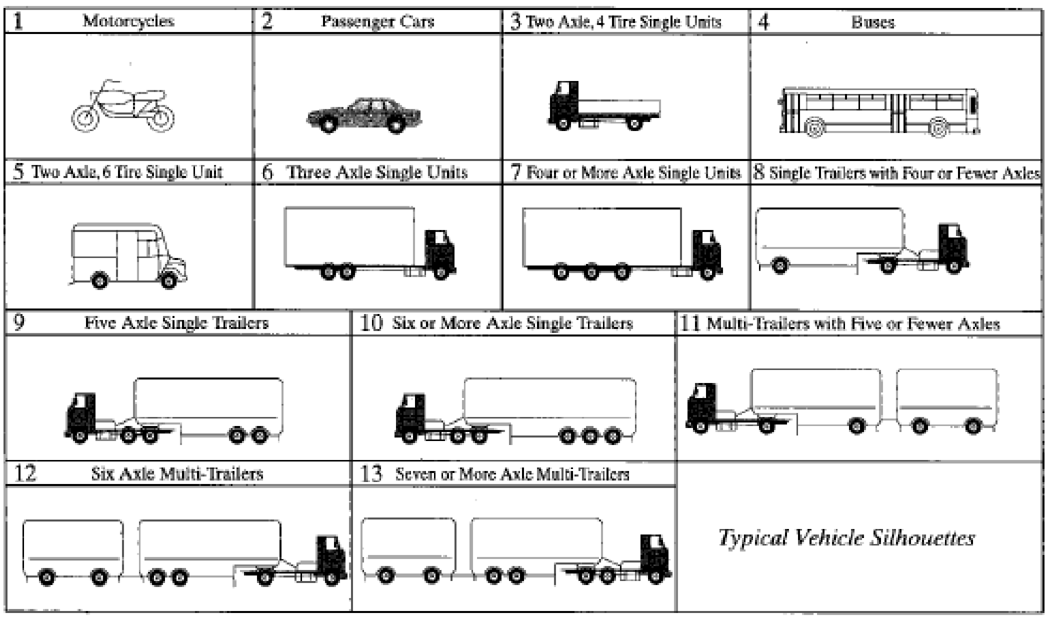


Figure 9. Illustration of FHWA/AASHTO vehicle class type description.

Vehicle Class Distribution
Level 1 is the actual measured site data (over 24-hours) and must be used for highways with heavy seasonal recreational and agricultural traffic (see Traffic Statistics office). Levels 2 is Utah average values for highway class (see Table 11). Selection of the appropriate site input must be based on project location and functional class as a minimum. Where no data in the default tables are suitable, use Level 3, that is the appropriate MEPDG default Truck Traffic Class (TTC) group.

Table 11. Default level 2 vehicle class distribution for pavement design.

Location	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13
CPR1	2.1	46.7	2.6	0.0	9.7	22.8	0.2	0.3	3.8	11.8
CPR2	1.0	18.5	1.1	0.0	5.0	62.9	0.4	0.8	3.0	7.4
CPR3	0.9	14.6	1.0	0.0	4.8	66.4	0.4	0.9	3.1	7.8
CPR4	2.4	66.5	2.9	2.6	11.0	4.2	0.4	4.3	3.2	2.4
CPR5	7.5	37.7	4.5	0.3	14.8	25.8	1.1	2.0	1.4	5.0
CPR6	1.4	21.6	1.5	0.0	6.4	51.4	0.3	0.7	4.3	12.4
CPR7	1.4	32.8	1.8	0.0	6.5	25.8	0.3	0.3	7.4	23.7
CPR8	1.0	18.5	1.1	0.0	5.0	62.9	0.4	0.8	3.0	7.4
CPR9	2.0	12.4	1.4	0.1	20.3	46.0	2.1	4.9	3.0	7.8
JPCP1	1.8	41.6	2.3	0.0	8.3	30.5	0.2	0.4	3.7	11.2
JPCP10	1.9	29.5	2.7	0.1	13.9	15.2	1.1	1.2	0.9	33.4
JPCP11	0.9	19.9	1.1	0.0	4.9	59.0	0.4	0.8	3.6	9.5
JPCP13	6.7	26.7	6.6	0.1	26.7	20.8	0.3	4.0	2.0	6.1
JPCP14	6.7	26.7	6.6	0.1	26.7	20.8	0.3	4.0	2.0	6.1
JPCP15	16.7	34.5	3.2	0.1	29.9	4.4	0.1	7.0	2.0	2.1
JPCP16	1.1	32.9	1.6	0.0	5.8	45.3	0.3	0.6	3.3	9.2
JPCP17	1.1	32.9	1.6	0.0	5.8	45.3	0.3	0.6	3.3	9.2
JPCP2	1.0	29.9	1.4	0.0	5.4	48.7	0.3	0.7	3.4	9.3
JPCP3	1.1	8.1	0.9	0.0	5.1	81.1	0.4	1.1	1.3	0.9
JPCP4	0.9	14.6	1.0	0.0	4.8	66.4	0.4	0.9	3.1	7.8
JPCP5	1.5	66.3	4.2	1.2	9.1	14.2	1.5	0.6	0.1	1.3
JPCP6	1.5	66.3	4.2	1.2	9.1	14.2	1.5	0.6	0.1	1.3
HMA_OVLY1	0.9	14.0	0.9	0.0	4.5	66.0	0.4	0.9	3.5	9.1
HMA_OVLY2	0.9	19.9	1.1	0.0	4.9	59.0	0.4	0.8	3.6	9.5
HMA_OVLY3	0.9	37.5	1.1	0.1	10.1	41.7	0.3	0.9	2.6	4.8
HMA_OVLY4	1.3	10.1	0.6	0.1	9.7	24.9	0.8	1.5	1.5	49.5
HMA_R1 01	1.5	80.9	4.4	0.0	11.0	0.7	0.7	0.0	0.0	0.7
HMA_R1 02	2.3	65.1	3.2	0.0	11.2	14.5	0.1	0.2	0.9	2.4
HMA_R1 03	2.7	49.0	7.1	2.0	17.3	7.8	1.9	2.1	1.9	8.2
HMA_R1 04	1.0	20.0	1.2	0.0	5.0	54.1	0.4	0.7	4.6	13.2
HMA_R2 01	3.0	54.8	16.9	0.0	17.8	3.8	2.4	0.1	0.0	1.1
HMA_R2 02	3.1	54.0	11.3	3.0	16.6	3.8	1.0	3.1	2.3	1.8
HMA_R2 03	2.1	81.1	3.5	0.0	11.1	2.2	0.0	0.1	0.0	0.0
HMA_R2 04	6.9	54.5	6.4	1.2	12.4	5.4	3.0	3.7	1.6	5.1
HMA_R3 01	2.1	57.1	3.8	0.4	17.1	11.6	2.0	1.0	0.5	4.4
HMA_R3 02	2.1	66.7	3.1	0.0	10.5	11.5	0.1	0.2	1.4	4.3
HMA_R3 03	1.4	35.9	5.0	1.2	10.5	34.5	2.2	0.7	1.0	7.7
HMA_R3 04	1.0	18.5	1.1	0.0	5.0	62.9	0.4	0.8	3.0	7.4
HMA_R4 01	1.7	23.5	1.8	0.0	19.7	13.1	0.8	2.2	2.9	34.4
HMA_R4 02	1.2	39.2	3.2	0.3	11.4	5.5	1.4	0.3	0.7	37.0
HMA_R4 03	5.9	56.7	5.3	0.3	15.6	10.0	1.4	1.1	0.4	3.3
HMA_R4 04	1.4	27.6	1.6	0.0	6.6	55.2	0.3	0.8	2.0	4.5

5.5 Hourly Truck Distribution

This input, needed only for concrete pavements, is keyed to climatic inputs over 24 hours.

Hourly Truck Distribution
Since UDOT specific defaults are not available at this time, the use of MEPDG defaults is recommended for highways with heavy seasonal recreational and agricultural traffic (see Traffic Statistics office).

5.6 Truck Traffic Growth Factor

These inputs are unique to a given pavement project and only site specific inputs must be used.

Truck Traffic Growth Factor

- Vehicle class specific traffic growth
  - Blank (assume all vehicle classes grow equally unless knowledge of growth variation is available)
- Default Growth Function
  - Use either linear or compound growth. Base decision on historical growth trends and/or additional information for site.
- Default Growth Rate
  - Varies long term from 0 to 10 percent on Utah highways. Base estimate on historical growth or modify based on additional information for site.

5.7 Axle Load Distribution

Axle load distributions are basically adjustment factors used to distribute the total number of axles for each axle type (single, tandem, tridem, and quad) considered by the MEPDG into axle load groupings as shown below:

- Single axles: from 3,000 to 41,000 lbs in 1,000 lbs increments.
- Tandem axles: from 6,000 to 82,000 lbs in 2,000 lbs increments.
- Tridem axles: from 12,000 to 102,000 lbs in 3,000 lbs increments.
- Quad axles: from 12,000 to 102,000 lbs in 3,000 lbs increments.

Figures 10 though 12 present single, tandem, tridem, and quad axle distributions for three sites in Utah (urban Interstate, rural Interstate, and rural local route). Note that axle load distributions vary between urban and rural sites because rural trucks are nearly all loaded, whereas a significant proportion of urban trucks are partially empty.

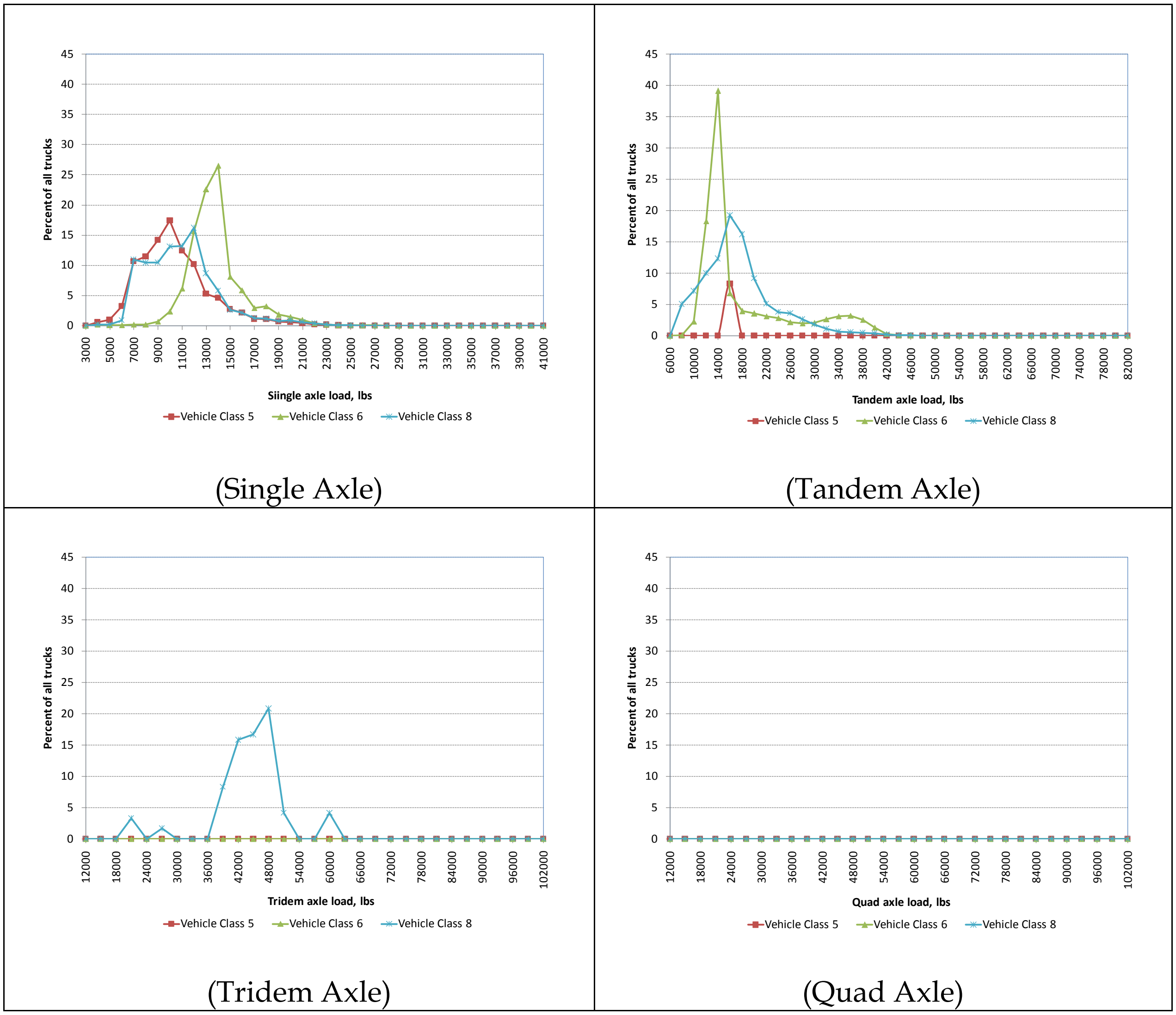


Figure 10. Example of axle load distributions for site HMA_R1 01 (local route).

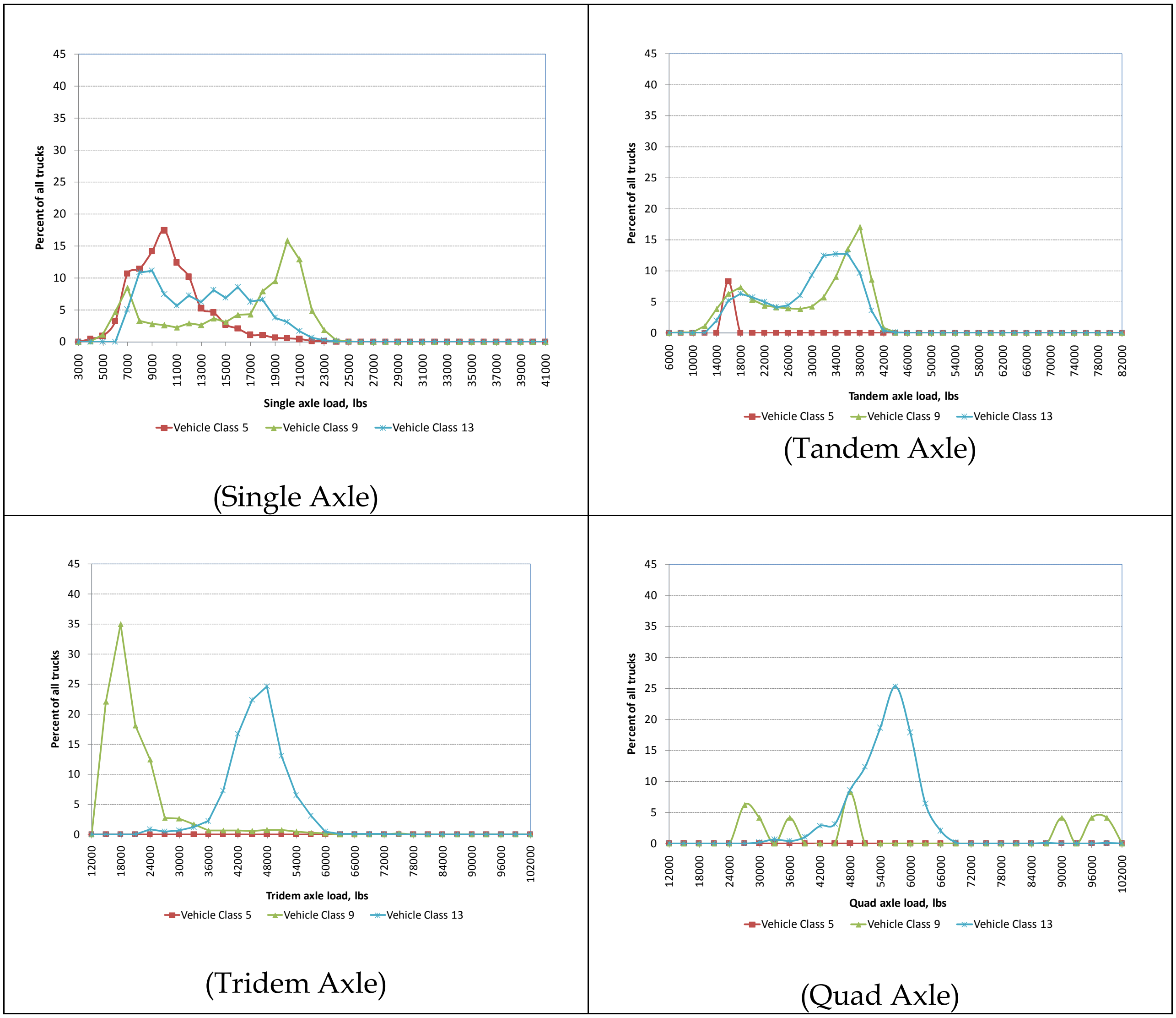


Figure 11. Example of axle load distributions for site JPCP16 (rural Interstate).

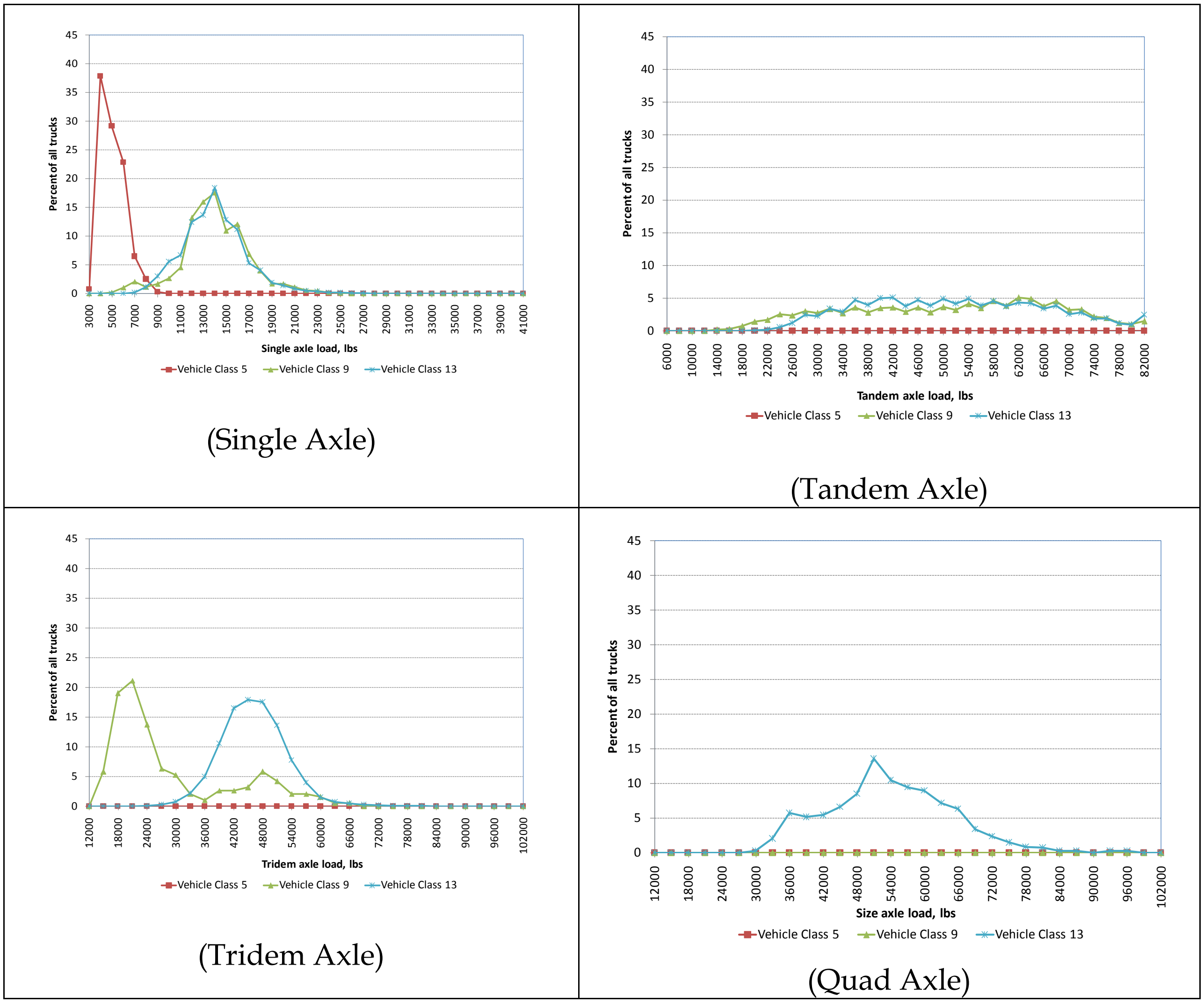


Figure 12. Example of axle load distributions for site CPR7 (urban Interstate).

Axle Load Distribution
Level 1 is the actual measured site data and must be used for highways with unique traffic characteristics (e.g., mining, recreational, and agricultural routes) (see Traffic Statistics office). Level 2 is Utah average axle load distribution factors for highway sites described in Table 8. Graphical examples are provided in Figures 10 through 12. Electronic versions of the Level 2 axle load distribution factors can be obtained from the UDOT Traffic Statistics office. Selection of the appropriate site input must be based on project location and functional class as a minimum. Where no data in the default tables are suitable, use the MEPDG default axle load distribution (Level 3).

5.8 Number of Axles per Truck Type/Class

Number of single, tandem, tridem, and quad axles per truck are basically adjustment factors used to estimate the total number of single, tandem, tridem, and quad axles for a given distribution of truck traffic. As shown in Figure 9, each truck class type has a unique range of combination of axle types. Based on the distribution of truck traffic types and volume, the average number of single, tandem, tridem, and quad axles per truck varies from site to site.

For the MEPDG, Table 12 presents default number single, tandem, tridem, and quad axles per truck distributions for three sites within Utah. Data for all the sites presented in Table 8 can be obtained in electronic format from the UDOT Traffic Statistics office.

Table 12. Default level 2 Number single, tandem, tridem, and quad axles per truck for pavement design.

Location	Vehicle Class	Single	Tandem	Tridem	Quad
R101	Class 4	1.66	0.33	0.01	0
	Class 5	2	0	0	0
	Class 6	1	1	0	0
	Class 7	1.16	1.2	0.38	0.36
	Class 8	2.13	0.87	0	0
	Class 9	2.33	1.83	0	0
	Class 10	1.03	0.96	0.99	0.05
	Class 11	4.88	0.01	0.03	0
	Class 12	3.93	1	0.03	0
	Class 13	2.27	2.18	0.41	0.03
JPCP16	Class 4	1.38	0.62	0	0.07
	Class 5	2	0	0	0
	Class 6	1	1	0	0
	Class 7	0.83	0.39	0.57	0.23
	Class 8	2.28	0.72	0	0
	Class 9	1.28	1.86	0	0
	Class 10	1.08	0.79	0.94	0.26
	Class 11	4.89	0.01	0.03	0
	Class 12	3.44	0.89	0.09	0.13
	Class 13	3.02	1.73	0.44	0.04
CPR7	Class 4	1.58	0.42	0	0
	Class 5	2	0	0	0
	Class 6	0.84	1	0	0
	Class 7	0.49	0.91	0.27	0.26
	Class 8	2.09	0.82	0.01	0
	Class 9	1.3	1.84	0.005	0
	Class 10	1.02	0.97	0.98	0.04
	Class 11	3.52	0.28	0.32	0
	Class 12	2.69	1.07	0.14	0.19
	Class 13	2.19	1.28	0.89	0.04

Number of Axles per Truck Type/Class
Level 1 is the actual measured site data and must be used for highways with heavy seasonal mining, recreational, or agricultural traffic (see Traffic Statistics office). Level 2 is Utah average values for specific sites in Utah (see Table 8). Level 2 data can be obtained from UDOT Traffic Statistics office. Selection of the appropriate site input must be based on project location and functional class as a minimum. Where no data in the default tables is suitable, use MEPDG national default (Level 3).

General Traffic Inputs

- Mean wheel location (in) (see Figure 13a)
  - 18-in from edge of lane stripe to outside of dual tires (if traffic lane width is < 12-ft, then reduce to 12-in)
- Traffic wander standard deviation (in)
  - 10-in lateral wander standard deviation.
- Design lane width (ft) (see Figure 13d)
  - 12-ft (note: this value is not slab width, it is measured between lane longitudinal paint stripes.)
- Axle Configuration (see Figure 13b)

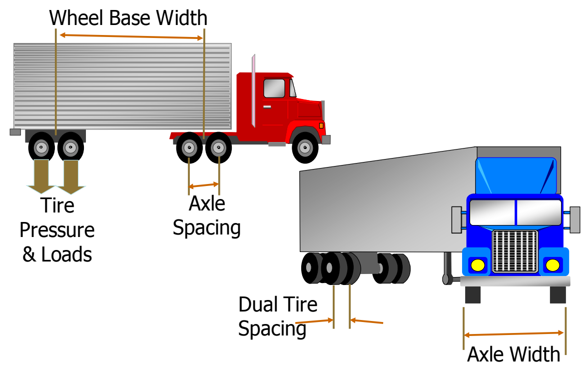
Average axle width (ft)	8.5 (outside to outside of truck tires)
Dual tire spacing (in)	12
Dual Tire Pressure (psi)	120
Tandem Axle Spacing (in)	51.6
Tridem Axle Spacing (in)	49.2
Quad Axle Spacing (in)	49.2

- Wheelbase (see Figures 13b and 13c)

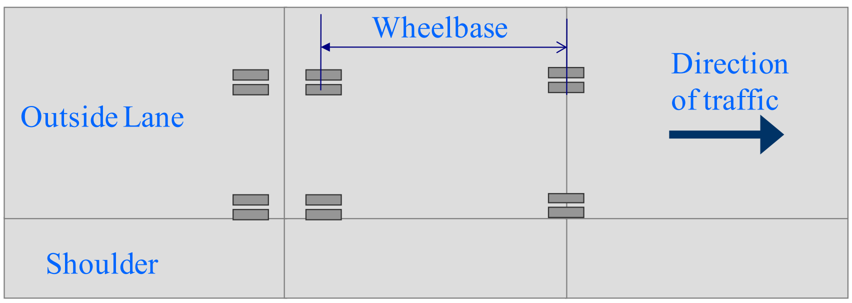
Wheelbase	Short	Medium	Long
Average Axle Spacing (ft)	12 (10 to 13.5)	15 (13.5 to 16.5)	18 (16.5 to 20.0)
Percent of trucks (%)	2*	42*	56*

*Based on limited Utah data.

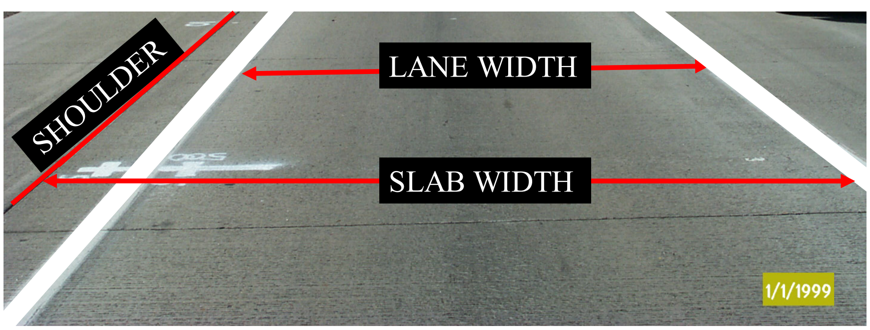
(a)



(b)



(c)



(d)

Figure 13. Schematic illustration of mean wheel location (a), axle configuration and wheelbase (b and c), and lane width (d).

5.9 Traffic Sensitivity Analysis

Examples of the impact of key traffic inputs on JPCP and HMA pavement predicted performance are presented in Figures 14 and 15.

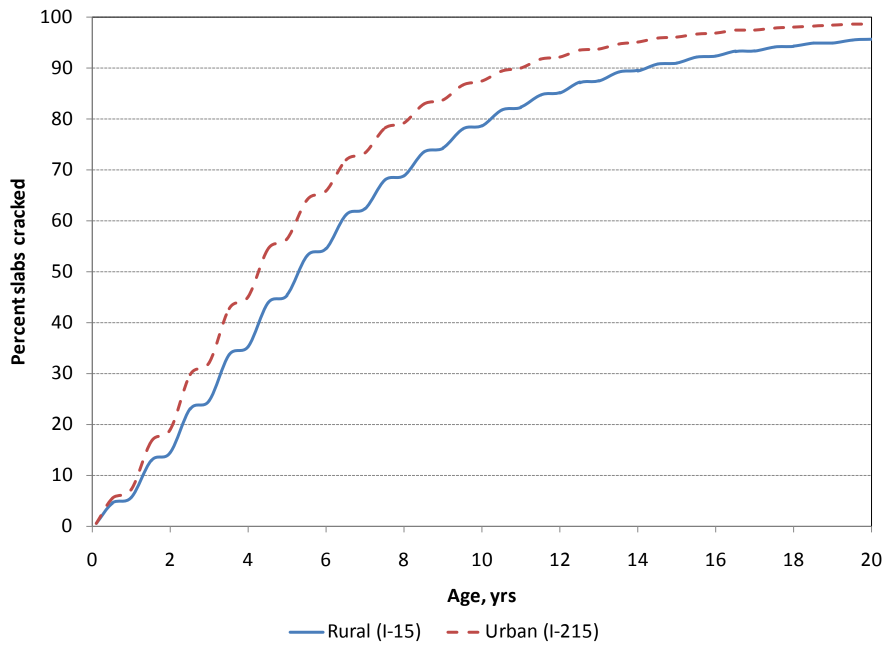


Figure 14. Effect of axle load distribution (urban & rural) on JPCP transverse "fatigue" cracking.

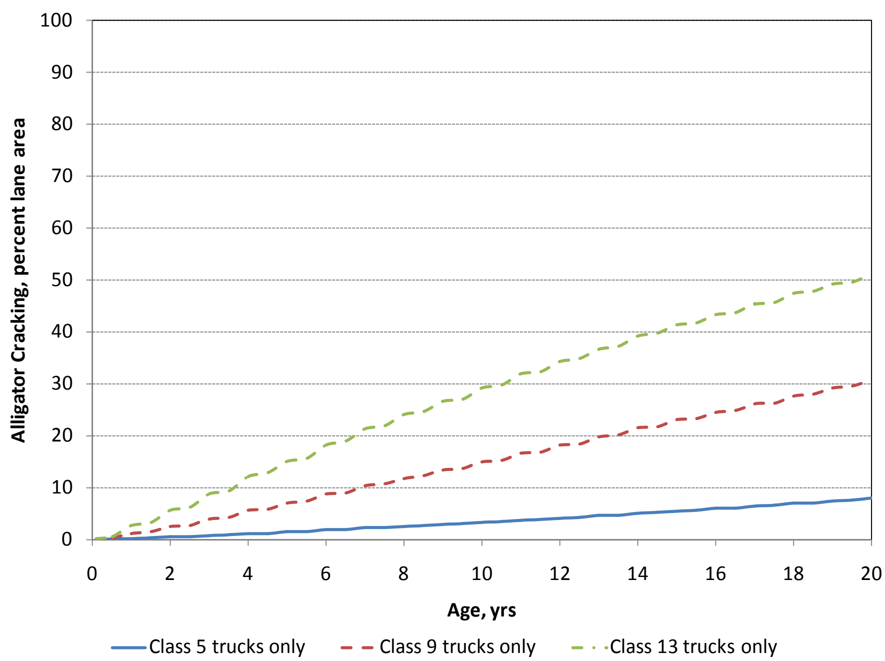


Figure 15. Effect of vehicle class distribution (same number of class 5, class 9, & class 13 trucks) HMA fatigue cracking.

6.0 CLIMATE INPUTS

One or more weather stations are selected as close to the project as possible to provide hourly temperature, precipitation, wind speed, relative humidity, and cloud cover information. The project is located based on Longitude and Latitude. The software will then identify the 6 closest weather stations. The Utah weather stations presented in Table 13 contain up to 9 years of data. The data is currently available in the MEPDG software. Figure 16 shows the location of weather stations.

In addition, there are several weather stations in surrounding states of Wyoming, Colorado, New Mexico, Arizona, Idaho, and Nevada for projects located near the state lines. A single weather station can be selected when the project is within reasonable proximity, or up to six surrounding weather stations can be selected and combined into a virtual weather station for a project. This is all done automatically by the software after selection by the user. The use of more than one weather station is recommended so that a better estimate of the climate at the project site would be obtained.

- Idaho: Burley, Pocatello, Twin Falls.
- Wyoming: Evanston, Rock Springs
- Colorado: Cortez, Durango, Grand Junction, Montrose.
- New Mexico: Farmington.
- Arizona: Page, Flagstaff, Grand, Las Vegas.
- Nevada: Elko, Ely.

Table 13. Weather stations with default climate data for use in pavement design in Utah.

Climate Station	Mean annual air temperature (°F)	Mean annual rainfall (in)	Freezing index (°F-days)	Average Annual Number of Freeze/Thaw Cycles
Bryce Canyon Airport	41.38	10.54	1499	185
Cedar City Regional Airport	51.13	10.57	578	142
Logan - Cache Airport	46.68	13.37	1083	109
Milford Municipal Airport	52.38	9.53	448	127
Moab - Canyonlands Field Airport	55.52	7.22	435	117
Ogden-Hinckley Airport	52.40	15.61	425	73
Price-Carbon County Airport	50.03	13.09	679	123
Salt Lake City International Airport	53.85	13.98	341	75
Vernal Airport	47.92	9.43	954	126

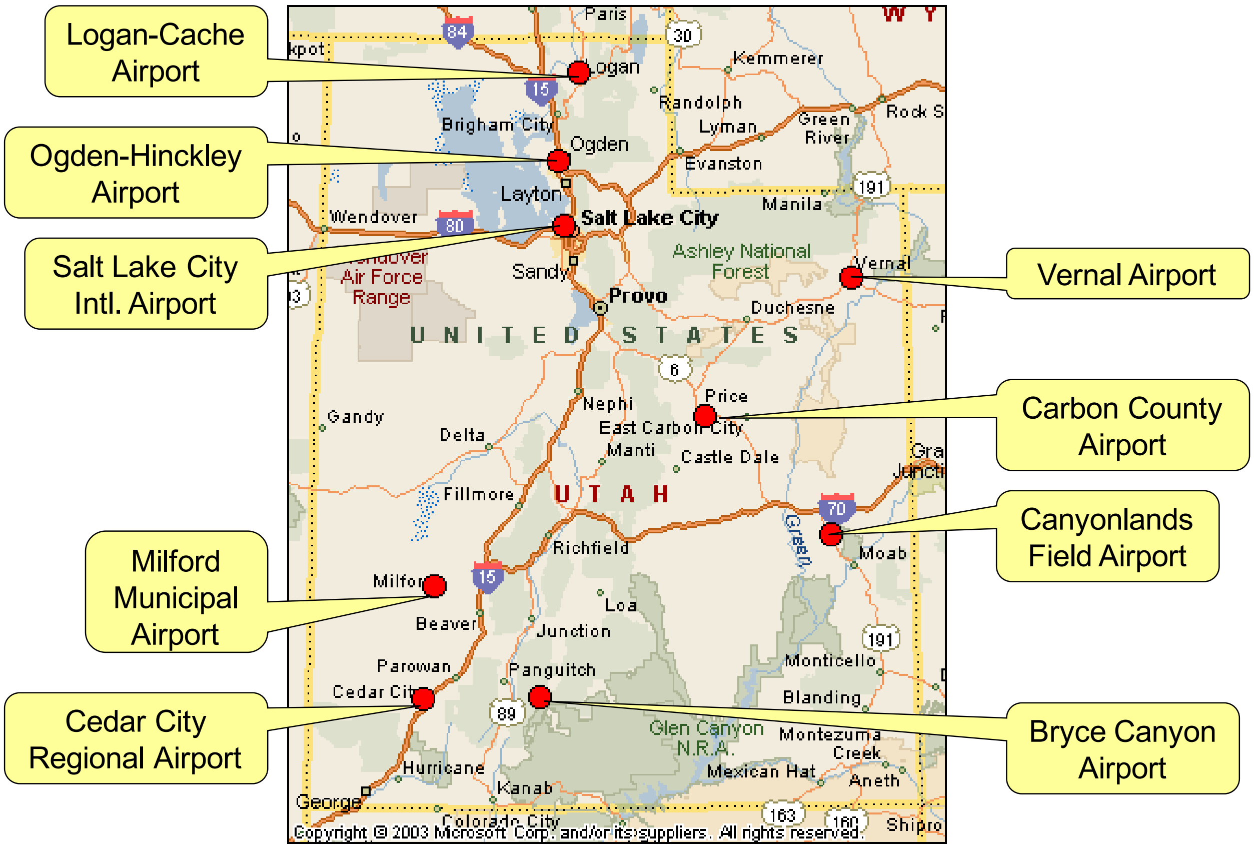


Figure 16. Location of Utah weather stations used to obtain climate data for pavement design.

Climate Inputs

Climate Inputs	Definitions
Weather station within 50 miles	Import specific weather station
Weather station more than 50 miles	Create virtual weather station from 2 to 6 surrounding weather stations
Depth of water table (ft)	Actual (see County Soil Reports* or project geotechnical reports) or estimate based on area (typically ranges from 3 to 40-ft)

* The United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database. Note that another available resource for estimating depth of water table for a project site is the Utah Division of Water Rights well drilling database and geologic well logs available online at http://www.waterrights.utah.gov/wellinfo/default.asp.

Selection of Weather Stations for Pavement Design
The following indicates weather stations that are in or near each Utah county. Some may not be appropriate throughout the county.

Utah County	Potential Weather Station(s)
Beaver	Milford
Box Elder	Ogden, Logan, Burley, Pocatello, Twin Falls.
Cache	Logan
Carbon	Price
Daggett	Vernal
Davis	Ogden
Duchesne	Price, Vernal
Emery	Price, Moab
Grand	Moab, Price, Grand Junction
Garfield	Bryce Canyon
Iron	Cedar City
Juab	Milford, Ely
Kane	Cedar City, Page
Millard	Milford, Ely
Morgan	Ogden
Piute	Cedar City, Milford, Moab
Rich	Ogden, Logan, Evanston, Rock Springs
Salt Lake	Salt Lake City
San Juan	Moab, Cortez, Farmington
Sevier	Milford, Moab, Price
Summit	Vernal, Ogden, Evanston, Rock Springs
Sanpete	Price
Tooele	Salt Lake City, Elko
Uintah	Vernal
Utah	Salt Lake City
Wasatch	Salt Lake City, Vernal, Price
Washington	Cedar City, Las Vegas
Wayne	Moab
Weber	Ogden

Figures 17 through 19 show the effect of climate on pavement performance. These plots show that climate has a very significant effect on flexible and rigid pavement performance in Utah. It is therefore important to select a representative weather station for the project under design.

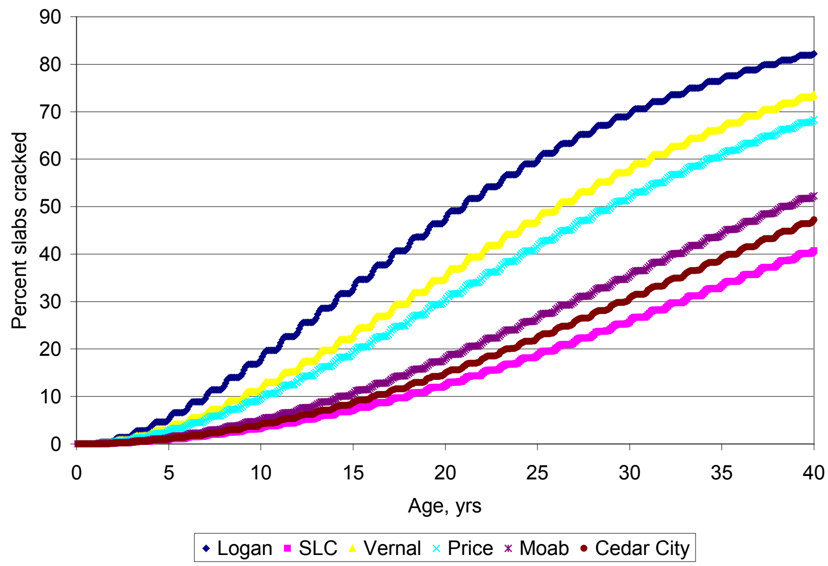


Figure 17. Significant Effect of Utah Climates on JPCP transverse cracking.

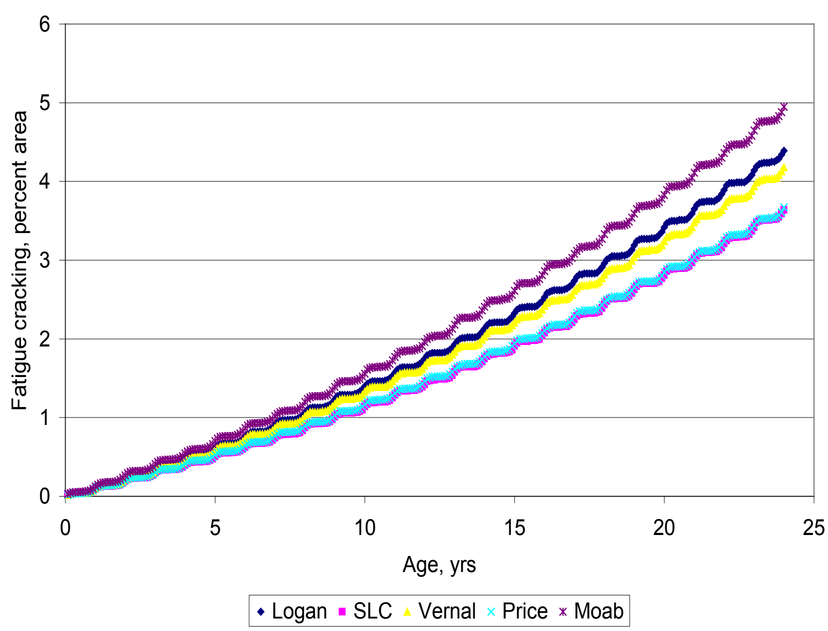


Figure 18. Significant Effect of Utah climates on HMA fatigue (alligator) cracking.

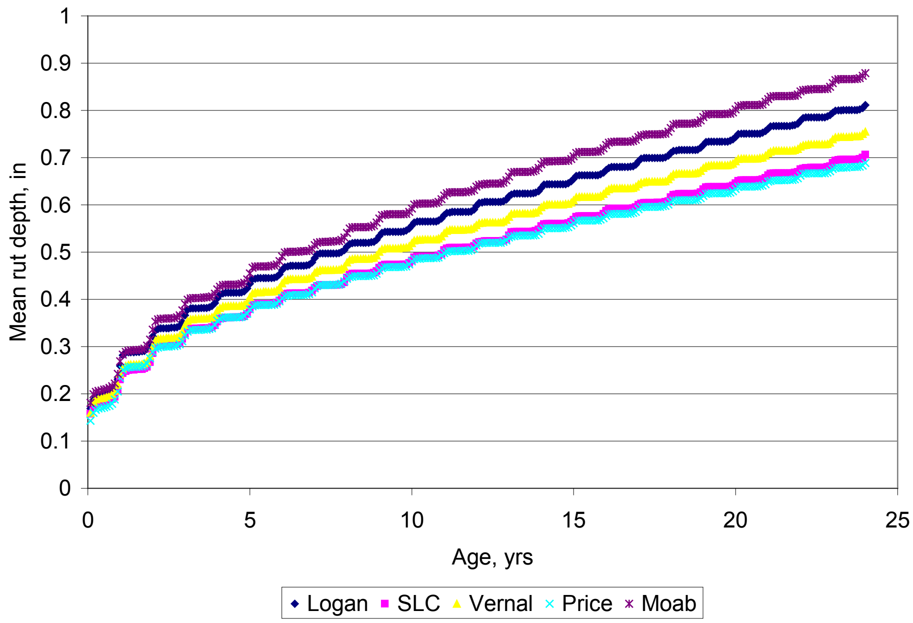


Figure 19. Significant Effect of Utah climates on HMA rutting.

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7.0 STRUCTURE & MATERIALS INPUTS

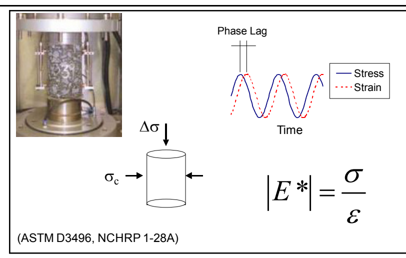
7.1 Introduction

The design engineer must select a trial design which is analyzed by the MEPDG software for adequacy. This trial design could be based on the current 1993 AASHTO Design Guide as used by UDOT or an alternative of interest to the designer. The inputs required are layer thicknesses (plus joint design for JPCP) and material properties for the following material types:

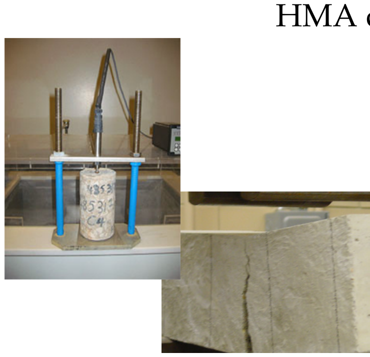
- Asphalt materials, including new and existing dense-graded and open-graded HMA materials.
- Concrete materials, including new and existing PCC.
- Chemically stabilized materials for base and subbase.
- Unbound aggregate layers and embankment and subgrade soils.

7.2 Recommended Level 1 Lab Testing for Charactering New and Existing Materials

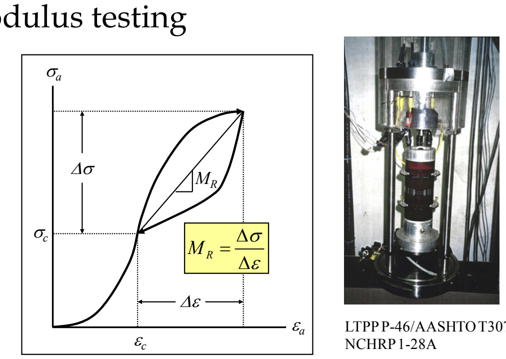
Tables 14 through 17 summarize all the **level 1 inputs** testing required for the HMA, PCC, chemically stabilized, and unbound aggregate and soils material types listed above. Figure 20 shows some common HMA, PCC, and unbound materials/subgrade tests performed in the lab as part of level 1 testing.



HMA dynamic modulus testing



PCC thermal expansion and flexural strength testing



Unbound granular material & subgrade soil resilient modulus testing

Figure 20. Level 1 material testing program.

Table 14. Asphalt materials level 1 input requirements and corresponding testing protocols for new asphalt, asphalt overlays and existing asphalt materials.

Design Type	Measured Property	Source of Data		Recommended Test Protocol and Data Source
		Test	Estimate	
New asphalt and asphalt overlay mixtures	Dynamic modulus (E*) *(new asphalt as-constructed)*	X		AASHTO TP62
	Tensile strength	X		AASHTO T322
	Creep Compliance	X		AASHTO T322
	Effective asphalt content *(new as-built)*	X		AASHTO T308
	Air voids	X		AASHTO T166
	Voids filled with asphalt (VFA)	X		AASHTO T209
Existing asphalt layer mixture	FWD backcalculated pavement modulus	X		ASTM* D4694 (in-situ) and backcalculation
	Asphalt content	X		AASHTO T164 (cores)
	Gradation	X		AASHTO T166 (cores)
	Air voids	X		AASHTO T209 (cores)
	Asphalt recovery	X		ASTM D5404 (cores)
New asphalt, asphalt overlays, and existing asphalt mixture	Unit weight	X		AASHTO T166
	Short term oven aging	X		AASHTO R30
	Poisson's ratio		X	Select MEPDG defaults
	Surface shortwave absorptivity		X	National test protocol not available. Estimate using agency historical data or select MEPDG defaults
	Thermal conductivity	X		ASTM E 1952
	Heat capacity	X		ASTM D 2766
	Coefficient of thermal contraction		X	Estimate using prediction equation or with other historical input data (see level 2 and 3 recommendations)
Asphalt binder (new, overlay, and existing mixtures)	Asphalt binder complex shear modulus (G*) and phase angle (δ) OR Penetration OR Ring and Ball Softening Point Absolute Viscosity Kinematic Viscosity Specific Gravity OR Brookfield Viscosity		X	AASHTO T315 AASHTO T49 OR AASHTO T53 AASHTO T 202 AASHTO T201 AASHTO T228 OR AASHTO T316
Existing asphalt (surface) layer	FWD backcalculated pavement modulus *(existing in-place)*	X		ASTM D4694 and backcalculation

* ASTM stands for the American Society for Testing and Materials.

Table 15. PCC materials level 1 input requirements and corresponding testing protocols for new PCC, PCC overlays and existing PCC.

Design Type	Measured Property	Source of Data		Recommended Test Protocol and/or Data Source
		Test	Estimate	
New PCC and PCC overlays and existing PCC when subject to a bonded PCC overly	Elastic modulus	X		ASTM C469
	Poisson's ratio	X		ASTM C469
	Flexural strength	X		AASHTO T97
	Indirect tensile strength (CRCP only)	X		AASHTO T198
	Unit weight	X		AASHTO T121
	Coefficient of thermal expansion	X		AASHTO TP60
	Surface shortwave absorptivity		X	Estimate using agency historical data or select MEPDG defaults
	Thermal conductivity	X		ASTM E 1952
	Heat capacity	X		ASTM D 2766
	PCC zero-stress temperature		X	National test protocol not available. Estimate using agency historical data or select MEPDG defaults
	Cement type		X	Select based on actual or expected cement source
	Cementitious material content		X	Select based on actual or expected concrete mix design
	Water to cement ratio		X	Select based on actual or expected concrete mix design
	Aggregate type		X	Select based on actual or expected aggregate source
	Curing method		X	Select based on agency recommendations and practices
	Ultimate shrinkage		X	Testing not practical. Estimate using prediction equation in MEPDG
	Reversible shrinkage		X	Estimate using agency historical data or select MEPDG defaults
	Time to develop 50 percent of ultimate shrinkage		X	Estimate using agency historical data or select MEPDG defaults
Existing intact and fractured PCC	Elastic modulus	X		ASTM C469 (extracted cores) ASTM D4694 (non-destructive deflection testing)
	Poisson's ratio	X		ASTM C469 (extracted cores)
	Flexural strength	X		AASHTO T97 (extracted cores)
	Unit weight	X		AASHTO T121 (extracted cores)
	Surface shortwave absorptivity		X	National test protocol not available. Estimate using agency historical data or select MEPDG defaults
	Thermal conductivity	X		ASTM E 1952 (extracted cores)
	Heat capacity	X		ASTM D 2766 (extracted cores)

Table 16. Chemically stabilized materials level 1 input requirement and corresponding testing protocols for new and existing chemically stabilized materials.

Design Type	Material Type	Measured Property	Source of Data		Recommended Test Protocol and Data Source
			Test	Estimate	
New	Lean concrete & Cement-treated aggregate	Elastic modulus	X		ASTM C 469
		Flexural strength (Required only when used in HMA pavement design)	X		AASHTO T97
	Lime-cement-flyash	Resilient modulus		X	No test protocols available. Estimate using levels 2 and 3
	Soil cement	Resilient modulus	X		Mixture Design and Testing Protocol (MDTP) in conjunction with AASHTO T307[3]
	Lime stabilized soil	Resilient modulus		X	No test protocols available. Estimate using levels 2 and 3
	All	Unit weight		X	No testing required. Estimate using levels 2 and 3
		Poisson's ratio		X	No testing required. Estimate using levels 2 and 3
		Thermal conductivity	X		ASTM E 1952
		Heat capacity	X		ASTM D 2766
		Surface short wave absorptivity		X	No test protocols available. Estimate using levels 2 and 3
Existing	Lean concrete & Cement-treated aggregate	FWD backcalculated modulus	X		ASTM D4694
	Lime-cement-flyash	FWD backcalculated modulus	X		ASTM D4694
	Soil cement	FWD backcalculated modulus	X		ASTM D4694
	Lime stabilized soil	FWD backcalculated modulus	X		ASTM D4694
	All	Unit weight		X	No testing required. Estimate using levels 2 and 3
		Poisson's ratio		X	No testing required. Estimate using levels 2 and 3
		Thermal conductivity	X		ASTM E 1952 (cores)
		Heat capacity	X		ASTM D 2766 (cores)
		Surface short wave absorptivity		X	No test protocols available. Estimate using levels 2 and 3

Table 17. Unbound aggregate base, subbase, embankment, and subgrade soil materials level 1 input requirements and corresponding testing protocols for new and existing materials.

Design Type	Measured Property	Source of Data: Test	Source of Data: Estimate	Recommended Test Protocol and/or Data Source
New (lab samples) and existing (extracted materials)	Regression coefficients k_1, k_2, k_3 for the generalized constitutive model that define resilient modulus as a function of stress state	X		AASHTO T307 or NCHRP 1-28A The generalized model (NCHRP 1-28A) used in design procedure is as follows: $M_r = k_1 p_a \left(\frac{\theta}{P_a}\right)^{k_2}\left(\frac{\tau_{oct}}{P_a}+1\right)^{k_3}$ Where M_r = resilient modulus, psi θ = bulk stress = $\sigma_1 + \sigma_2 + \sigma_3$ σ_1 = major principal stress. σ_2 = intermediate principal stress σ_3 = minor principal stress confining pressure τ_{oct} = octahedral shear stress = $\frac{1}{3}\sqrt{(\sigma_1-\sigma_2)^2+(\sigma_1-\sigma_3)^2+(\sigma_2-\sigma_3)^2}$ P_a = normalizing stress k_1, k_2, k_3 = regression constants
	Maximum dry density	X		AASHTO T99
	Optimum moisture content	X		AASHTO T180
	Specific gravity	X		AASHTO T100
	Saturated hydraulic conductivity	X		AASHTO T215
	Soil water characteristic curve parameters	X		Pressure plate (AASHTO T99) OR Filter paper (AASHTO T180) OR Tempe cell (AASHTO T100)
Existing in situ material	FWD backcalculated modulus	X		ASTM D4694 and backcalculation of layer moduli and modulus of subgrade reaction

Although level 1 inputs are the preferred inputs for pavement design, most agencies are not equipped with the testing facilities required for materials testing and developing level 1 inputs. Thus, for the more likely situation where agencies have only limited or no testing capability for characterizing materials, level 2 and 3 inputs are recommended. It is noted that for most situations designers used a combination of levels 1, 2, and 3 material inputs based on their unique needs and testing capabilities. Also, since level 1 inputs are generally not available prior to construction, designers must use most likely values for these inputs such as averages from previous projects.

7.3 Recommended Levels 2 & 3 HMA Inputs

New HMA Dynamic Modulus (E*) Recommended Level 2 or 3 Input

- No E* laboratory testing required.
- Use E* predictive equation. Inputs are gradation, bitumen viscosity, loading frequency, air void content, and effective bitumen content by volume. Input variables can be obtained through testing of lab prepared mix samples or from agency historical records. See recommendations below.
- Use typical Ai-VTS- values based on asphalt binder grade (PG, or viscosity, or penetration grades).

Recommended Typical Utah HMA Mix Gradations Input

Gradation Mix Designation	Percent Retained				Percent Passing
	¾-in Sieve	½-in Sieve	3/8-in Sieve	#4-in Sieve	#200 Sieve
1-in	15	30	48	62	4
¾-in	5	20	40	58	5
½-in	0	5	25	52	6
⅜-in	0	0	5	45	6

Recommended Typical Utah HMA Mix VMA & Binder Content

Gradation Mix Designation	In-situ VMA, percent	In-situ Effective Binder Content, percent by volume
1-in	16.5	10.0
¾-in	18.0	11.5
½-in	19.5	13.0
⅜-in	21.0	14.5

New HMA Dynamic Modulus (E*) Recommended Level 2 or 3 Input (continued)

Asphalt Binder Grades

Level 3: Use PG grade defaults: PG 58-34, PG 64-34, PG 70-34, PG 64-28, PG 70-28, PG 76-28, PG 70-22, PG 76-22

As-Built Air Voids (Not mixture design)

Note this is the in situ field air voids at construction, NOT mixture design air voids (based on percent compaction in specifications), % **[Critical]**

- Range 3.5 to 9.5 (90.5 to 96.5)
- Target 6.5 (93.5)

Recommended Input: 6.5%

As-Built Unit Weight

Actual, typical

Range 142 to 155, 148 typical dense graded

Existing HMA Dynamic modulus, E*

- No E* laboratory testing required.
- Use E* predictive equation. Inputs are gradation, bitumen viscosity, loading frequency, air void content, and effective bitumen content by volume. Input variables can be obtained through testing of extracted cores or from agency historical records
- Use typical Ai-VTS- values based on asphalt binder grade (PG, or viscosity, or penetration grades).
- Determine existing pavement condition rating (excellent, good, fair, poor, very poor)

Other New & Existing HMA Properties

Tensile Strength

Use the relationship below (developed under NCHRP 1-37A)

$$TS(psi) = 7416.712 - 114.016 * Va - 0.304 * Va^2 - 122.592 * VFA + 0.704 * VFA^2 + 405.71 * Log10(Pen77) - 2039.296 * log10(A)$$

where:

- TS = indirect tensile strength at 14 °F
- Va = as construction HMA air voids, percent
- VFA = as construction voids filled with asphalt, percent
- Pen77 = binder penetration at 77 °F, mm/10
- A = viscosity-temperature susceptibility intercept

Input variables can be obtained through testing of lab prepared mix samples, extracted cores (for existing pavements), or from agency historical records

Creep Compliance D(t)

Use the relationship below (developed under NCHRP 1-37A)

$$D(t) = D_1 * t^m$$

$$\log(D_1) = -8.524 + 0.01306 * Temp + 0.7957 * log10(Va) + 2.0103 * log10(VFA) - 1.923 * log10(A)$$

$$m = 1.1628 - 0.00185 * Temp - 0.04596 * Va - 0.01126 * VFA + 0.00247 * Pen77 + 0.001683 * Temp * Pen77^{0.4605}$$

where:

- t = time
- Temp = temperature at which creep compliance is measured, °F.
- Va = as construction air voids, %
- VFA = as construction voids filled with asphalt, %
- Pen77 = binder penetration at 77 °F, mm/10

Input variables can be obtained through testing of lab prepared mix samples, extracted cores (for existing pavements), or from agency historical records.

Other New & Existing HMA Properties (continued)

Air Voids (Not mixture design)
Use as-constructed mix type specific values available from previous construction

Volumetric Binder Content
Use as-constructed mix type specific values available from previous construction

Total Unit Weight
Use as-constructed mix type specific values available from previous construction

Poisson's Ratio
Use typical values:

Reference Temperature °F	Dense-Graded HMA* $\mu_{typical}$	Open-Graded HMA* $\mu_{typical}$
< 0 °F	0.15	
0 – 40 °F	0.20	0.35
40 – 70 °F	0.25	0.40
70 – 100 °F	0.35	0.40
100 – 130 °F	0.45	0.45
> 130 °F	0.48	0.45

*Level 3

Surface Shortwave Absorptivity
Use MEPDG default of 0.85.

Thermal Conductivity
Typical values for asphalt concrete range from 0.44 to 0.81 Btu(ft)(hr)(°F). Use default value set in program—0.67 Btu(ft)(hr)(°F).

Heat Capacity
Typical values for asphalt concrete range from 0.22 to 0.40 Btu(lb)(°F).Use default value set in program—0.23 Btu/lb. °F

Other New & Existing HMA Properties (continued)

Coefficient of Thermal Contraction

Use the relationship below (developed under NCHRP 1-37A)

$$L_{MIX} = \frac{VMA * B_{ac} + V_{AGG} * B_{AGG}}{3 * V_{TOTAL}}$$

where

LMIX = linear coefficient of thermal contraction of the asphalt concrete mixture (1/°C)

Bac = volumetric coefficient of thermal contraction of the asphalt cement in the solid state (1/°C)

BAGG = volumetric coefficient of thermal contraction of the aggregate (1/°C)

VMA = percent volume of voids in the mineral aggregate (equals percent volume of air voids plus percent volume of asphalt cement minus percent volume of absorbed asphalt cement)

VAGG = percent volume of aggregate in the mixture

VTOTAL = 100 percent

Typical values for linear coefficient of thermal contraction, volumetric coefficient of thermal contraction of the asphalt cement in the solid state, and volumetric coefficient of thermal contraction of aggregates measured in various research studies are as follows:

- LMIX = 2.2 to 3.4*10-5 /°C (linear).
- Bac = 3.5 to 4.3*10-4 /°C (cubic).
- BAGG = 21 to 37*10-6 /°C (cubic)

Notes on HMA Levels 2 and 3 Inputs

1. The MEPDG computes level 2 and 3 dynamic modulus, tensile strength, creep compliance, etc. internally once all the required input variables required by the various equation are provided.
2. The MEPDG computes level 2 and 3 coefficient of thermal contraction, etc. internally once all the required equation input variables are available.

Special Notes on HMA Transverse Cracking Model Inputs

Use levels 1 and 2 inputs only as described below:

- Level 1: Lab testing of creep compliance at 3 temperatures, indirect tensile strength (of first HMA layer only)
- Level 2: Lab testing of creep compliance at one temperature, indirect tensile strength (of first HMA layer only)

Transverse cracking predicted using default MEPDG Level 3 inputs (basically calculated from mix volumetrics) was found to be inadequate for HMA mixes with conventional binders. For HMA mixes with SuperPave binders, outcome was tentative with early predictions being reasonable and no clear long term assessment.

7.4 Recommended Levels 2 & 3 PCC Inputs

Elastic Modulus and Flexural Strength

New PCC (Mean Values, Not Specification limits must be input)

	28-day Modulus Elasticity, psi*	28-day Flexural Strength, psi**	28-day Compressive Strength, psi*
Mean	3,952,229	723	5,027
Minimum	3,268,113	632	4,389
Maximum	5,399,955	866	5,771
Std Dev	601,071	87	437
No. of samples	14	10	10

*Measured at long-term age and adjusted to 28-day value
**Estimated from measured compressive strength value.

Existing Intact PCC

- Determine the overall condition of the existing pavement using the guidelines presented in Section 8.
- Based on the pavement condition, select typical modulus values from the range of values given below:

Qualitative Description of Pavement Condition	Typical Modulus Ranges, psi
Good/Adequate	3 to 4 x 10^6
Marginal	1 to 3 x 10^6
Poor/inadequate	0.3 to 1 x 10^6

Existing Fractured PCC

- The three common methods of fracturing PCC slabs include crack and seat, break and seat, and rubblization. In terms of materials characterization, cracked or broken and seated PCC layers are considered in a separate category from rubblized layers. Select typical modulus values from the range of values given below:

Fractured PCC Type	Typical Modulus Ranges, psi
Crack & seat or break & seat	150,000 to 250,000*
Rubblized	50,000 to 75,000

*Use of too high of modulus will prevent obtaining fatigue based design. This will make it impossible to design an HMA overlay over a crack & seat project.

Poisson's Ratio

(New, Existing Intact, & Fractured PCC)

Poisson's ratio (μ) for new PCC typically ranges between 0.11 and 0.21, and values between 0.15 and 0.18 are typically assumed for PCC design. See below for typical Poisson's ratio values for PCC materials.

PCC Material Type	Level 3 μ typical
PCC Slabs (newly constructed or existing)	0.20
Fractured Slab	
Crack/Seat	0.20
Break/Seat	0.20
Rubblized	0.30

Unit Weight

(New, Existing Intact, & Fractured PCC)

Select agency historical data or from typical range for normal weight concrete: 140 to 160 lb/ft^3

Surface Shortwave Absorptivity (New & Existing Intact PCC)
Use level 3 MEPDG default of 0.85

Thermal Conductivity (New & Existing Intact PCC)
Typical values for PCC range from 0.2 to 2.0 Btu/(ft)(hr)(°F). Use default value set in program—1.25 Btu/(ft)(hr)(˚F).

Heat Capacity (New & Existing Intact)
Typical values for PCC range from 0.1 to 0.5 Btu/(lb)(°F). Use default value set in program—0.28 Btu/lb.˚F

Typical Utah PCC Mix Properties

	PCC Unit Weight, pcf	PCC Poisson's Ratio	PCC Cementitious Material Content, lb/yd³	Water-to-Cement Ratio
Average	142.8	0.175	574	0.419
Minimum	137.5	0.110	513	0.381
Maximum	152.0	0.210	612	0.500
Std Dev	4.8	0.035	43	0.042

Data obtained from testing several pavements across Utah

Cement Type
Estimate based on agency practices

Aggregate Type
Estimate based on agency practices

Curing Method
Determine based on agency practices

Coefficient of Thermal Expansion **(New & Existing Intact PCC)**

Select agency historical values or national MEPDG typical values based on PCC coarse aggregate type.

Utah Defaults

Aggregate Type	No. of Tests	Coefficient of Thermal Expansion (10^{-6}/°F)			
		Average	Minimum	Maximum	Standard Deviation
Basalt	2	5.59	5.06	6.11	0.742
Diabase	1	4.78	4.78	4.78	
Dolomite	1	6.33	6.33	6.33	
Limestone	3	6.24	5.56	7.06	0.759
Quartzite	1	5.11	5.11	5.11	
Sandstone	2	6.70	6.56	6.83	0.191
Siliceous gravel	3	6.33	5.00	7.83	1.42

MEPDG National Defaults

Coarse Aggregate Type	Coefficient of Thermal Expansion (10^{-6}/°F) (Standard Deviation)
Andesite	5.3 (0.5)
Basalt	5.2 (0.7)
Diabase	4.6 (0.5)
Gabbro	5.3 (0.6)
Granite	5.8 (0.6)
Schist	5.6 (0.5)
Chert	6.6 (0.8)
Dolomite	5.8 (0.8)
Limestone	5.4 (0.7)
Quartzite	6.2 (0.7)
Sandstone	6.1 (0.8)
Expanded shale	5.7 (0.5)

Where coarse aggregate type is unknown, use MEPDG default value of $5.5*10^{-6}$/°F

Zero-Stress Temperature **<u>(New & Existing Intact PCC)</u>**

Zero stress temperature, Tz, can be input directly or can be estimated from monthly ambient temperature and cement content using the equation shown below:

$$Tz = (CC*0.59328*H*0.5*1000*1.8/(1.1*2400) + MMT)$$

where,

Tz = zero stress temperature (allowable range: 60 to 120 ˚F).
CC = cementitious content, lb/yd^3.
H = -0.0787+0.007*MMT-0.00003*MMT^2
MMT = mean monthly temperature for month of construction, ˚F.

An illustration of the zero stress temperatures for different mean monthly temperatures and different cement contents in the PCC mix design is presented below:

Mean Monthly Temperature	H	Cement Content lbs/cy			
		400	500	600	700
40	0.1533	52*	56	59	62
50	0.1963	66	70	74	78
60	0.2333	79	84	88	93
70	0.2643	91	97	102	107
80	0.2893	103	109	115	121
90	0.3083	115	121	127	134
100	0.3213	126	132	139	145

*Mean PCC temperature in degrees F.

Ultimate Shrinkage (New)
Computed based on cement type, Cementitious material content, w/c ratio, curing type, and compressive strength.

Reversible Shrinkage (New)
Use MEPDG default of 50 percent unless more accurate information is available

Time to Develop 50 Percent of Ultimate Shrinkage (New)
Use MEPDG default of 35 days unless more accurate information is available

Notes on PCC Levels 2 and 3 Inputs

Although some project specific testing is required for level 2, this is not required at level 3. For level 3, historical agencies' test values assembled from past construction with tests conducted using the list of protocols provided earlier are all that is required.

7.5 Recommended Levels 2 & 3 Inputs for Chemically Stabilized Materials

Elastic Modulus
Use level 2 or 3 inputs, that is compressive strength of lab samples or extracted cores converted into elastic modulus, OR select typical E and Mr values in psi as follows:

Chemically Stabilized Material Type	E or Mr, psi
Lean concrete	2,000,000
Cement stabilized aggregate	1,000,000
Open graded cement stabilized aggregate	750,000
Soil cement	500,000
Lime-cement-flyash	1,500,000
Lime stabilized soils	45,000

Flexural Strength
Use level 2 or 3 inputs, that is compressive strength of lab samples or extracted cores converted into flexural strength, OR select typical Mr values in psi as follows:

Chemically Stabilized Material Type	Mr, psi
Chemically stabilized material placed under flexible pavement (base)	750
Chemically stabilized material used as subbase, select material, or subgrade under flexible pavement	250

Poisson's Ratio
Select typical Poisson's ratio values as follows:

Chemically Stabilized Material Type	Value
Lean concrete & cement stabilized aggregate	0.1 to 0.2
Soil cement	0.15 to 0.35
Lime-Fly Ash Materials	0.1 to 0.15
Lime Stabilized Soil	0.15 to 0.2

Unit Weight
Use default MEPDG values of 150 pcf

Thermal Conductivity & Heat Capacity
Use default MEPDG values of 1.25 Btu/hr.-ft-F and 0.28 Btu/lb. °F, respectively

7.6 Recommended Level 2 and 3 Input Parameters for Unbound Aggregate Base, Subbase, Embankment, and Subgrade Soil Materials

FWD deflection testing along the project, backcalculation of the situ elastic modulus, and then an adjustment to optimum moisture and "lab" condition is the most practical and accurate way to establish a Level 2 subgrade resilient modulus (Mr). The procedure to obtain an appropriate input to the MEPDG is given in Section 10 Rehabilitation Inputs, Table 18 for HMA pavements and Table 19 for JPCP.

If FWD testing and backcalculation are not feasible, the Level 3 Mr values below are recommended for base, subbase, and embankments/subgrades. These values were established during the national calibration of the MEPDG using the procedure described in Section 10, Tables 18 and 19. They represent the mean Mr values for each AASHTO soil class for base/subbase, and embankment/subgrade. These values were validated for Utah conditions by FWD testing all of the HMA and JPCP sections and backcalculation and adjustment as described in Section 10.

Resilient Modulus
Use level 3 inputs based on the unbound aggregate base, subbase, embankment, and subgrade soil material AASHTO Soil Classification. AASHTO Soil Class is determined using material gradation, plasticity index, and liquid limit.

AASHTO Soil Classification	Resilient Modulus at Optimum Moisture, psi		
	Base/Subbase for Flexible and Rigid Pavements	Embankment & Subgrade for Flexible Pavements	Embankment & Subgrade for Rigid Pavements
A-1-a	40,000	29,500	18,000
A-1-b	38,000	26,500	18,000
A-2-4	NA	21,500	16,000
A-2-5	NA	21,000	16,000
A-2-6	NA	20,500	16,000
A-2-7	NA	16,500	16,000
A-3	NA	24,500	16,500
A-4	NA	16,500	15,000
A-5	NA	15,500	8,000
A-6	NA	14,500	14,000
A-7-5	NA	13,000	10,000
A-7-6	NA	11,500	13,000

Notes on Unbound Aggregate Base and Subgrade Soil Materials Inputs

Note 1: These resilient modulus values represent the mean recommended Level 3 input resilient modulus at **optimum moisture content and density** for a specific AASHTO soil classification required by the MEPDG software. They represent the mean values used in the national calibration of the distress and IRI models. These values were compared to the results obtained from 50 Long Term Pavement Performance (LTPP) and UDOT PMS calibration sections using FWD backcalculation and adjustment described in Section 10 to obtain appropriate input Mr (Mr at optimum moisture and density) for each section. The Utah specific values agreed with the national calibration.

Note 2: If bedrock or a very stiff layer exists within 20-ft of the surface, it should be considered in the backcalculation. Bedrock may exist if the backcalculated modulus is much higher than those provided above. The MEPDG can add bedrock as the lowest layer. The above Mr values were derived by considering bedrock where ever it existed. Use of Mr input for a project that is very different than these recommendations may result in erroneous predictions.

Note 3: The subgrade can be represented by more than one layer: an A-1-a embankment 4-ft thick which exists over an A-6 subgrade. The program divides the pavement/subgrade into many sublayers and occasionally this becomes greater than 20, the maximum possible. If this occurs, the designer will have to select a composite Mr for the composite "subgrade" between the two values.

Maximum Dry Density
Compute using MEPDG predictive equations based on the following inputs: gradation, plasticity index, and liquid limit

Optimum Moisture Content
Compute using MEPDG predictive equations based on the following inputs: Gradation, plasticity index, and liquid limit

Specific Gravity
Compute using MEPDG predictive equations based on the following inputs: Gradation, plasticity index, and liquid limit

Saturated Hydraulic Conductivity
Compute using MEPDG predictive equations based on the following inputs: Gradation, plasticity index, and liquid limit

Soil Water Characteristic Curve Parameters
Select based on aggregate/subgrade material class

Guidance on Coding Unbound Aggregate for Base & Subbase Layer Properties into the MEPDG

Unbound Material	Crushed Stone, Gravel, or AASHTO Class A-1-a through A-3
Thickness (in)	Actual
Strength Properties Input Level	Level 3
Poisson's ratio	0.35
Coefficient of lateral pressure	0.5
Compacted unbound material or uncompacted natural unbound material	Click on "Compacted" option for all base/subbase layers
Resilient Modulus Mr (psi) (at optimum moisture content)	See table of recommended Mr values for base/subbase (note that base/subbase to subgrade Mr ratio should be between 2 and 3 to prevent decompaction of the base/subbase. **[Critical]**
Plasticity Index, PI	Actual, or default (always use 1 minimum, even if non-plastic for drainage reasons) **[Critical]**
Liquid Limit, LL	Actual or default
Gradation	Actual, or use defaults for soil class, or use UDOT table below
User Override Index Properties (Unit maximum dry unit weight, specific gravity, sat. hydraulic conductivity, optimum gravimetric water content, degree of saturation at optimum)	If available, user may enter specific values for these parameters. Measured values will be more accurate than these estimated values.

UDOT Untreated Base Course (UTBC) Specifications (Adapted from UDOT 2008 Standard Specifications for Road and Bridge Construction)

Aggregate Properties				
	Aggregate Class			
	A	B	C	
Dry Rodded Unit Weight	Not less than 75 lb/ft^3			AASHTO T 19
Liquid Limit/Plastic Index	Non-plastic		PI < 6	AASHTO T 89 AASHTO T 90
Gradation	See below			AASHTO T 11 AASHTO T 27
CBR with a 10 lb surcharge measured at 0.2 inch penetration	70 percent minimum		N/A	AASHTO T 193

Gradation Limits		
Sieve Size	**Job Mix Gradation Target Band**	**Job Mix Gradation Tolerance**
1½ inch	100	
1 inch	90 - 100	±9.0
¾ inch	70 - 85	±9.0
½ inch	65 - 80	±9.0
⅜ inch	55 - 75	±9.0
No. 4	40 - 65	±7.0
No. 16	25 - 40	±5.0
No. 200	7 - 11	±3.0

Guidance on Coding Unbound Soils for Embankment & Subgrade Layer Properties into the MEPDG

Unbound Material	**Actual, from soil report (AASHTO Class A-1-a through A-7-6)**
Thickness (in)	Actual, or Semi-infinite if Last Layer
Strength Properties Input Level	Level 2
Poisson's ratio	0.4
Coefficient of lateral pressure	0.5
Compacted unbound material or uncompacted natural unbound material	Click on "Uncompacted" option for subgrade regardless if top is compacted. **[Critical]**
Resilient Modulus Mr (psi) at optimum moisture content and density	See table of recommended Mr values for subgrades. **[Critical]**
Plasticity Index, PI	Actual, or use default for soil classification (Note: If non-plastic, still use PI = 1 for drainage reasons) **[Critical]**
Liquid Limit, LL	Actual or use default for soil classification
Gradation	Actual or use defaults for soil classification
User Override Index Properties (Unit maximum dry unit weight, specific gravity, sat. hydraulic conductivity, optimum gravimetric water content, degree of saturation at optimum)	If available, user may enter specific values for these parameters. Measured values will be more accurate than these estimated values.

8.0 SENSITIVITY ANALYSIS

A sensitivity analysis was conducted to determine the impact of all key inputs on predicted pavement performance. Results are presented in this section. Figures 21 through 28 show the effect of material properties on predicted HMA pavement performance. Figures 29 through 34 show the effect of material properties on the predicted PCC (JPCP) pavement performance.

Summary of MEPDG Sensitivity Results for Utah New/Reconstructed HMA Pavements

Design/Material Variable	Distress/Smoothness			
	Alligator Fatigue Cracking	Rutting	Transverse Cracking	IRI
HMA thickness	XXX	XX	X	XX
Tire load, contact area, and pressure	XX	XXX		
HMA Tensile Strength			XXX	
HMA Coefficient of Thermal Contraction			XX	
Mixture Gradation	XX	XXX		
HMA air voids in situ	XXX	XX	XX	XX
Effective HMA binder content	XXX	XX	XX	X
HMA binder grade	XX	XX	XXX	XXX
Bonding with base	XXX	X		
Base type/modulus	XXX	XX		
Base thickness	X			
Subgrade type/modulus	XX	XX		
Ground water table	X	X		
Climate	XX	XX	XXX	X
Truck volume	XXX	XXX		
Truck axle load dist.	XX	XX		
Truck speed	XX	XXX		
Truck wander	XX	XX		
Initial IRI				XXX

Key: X Factor has small effect on distress/IRI,
XX Factor has moderate effect on distress/IRI
XXX Factor has large effect on distress/IRI

Summary of MEPDG Sensitivity Results for Utah New/Reconstructed JPCP

Design/Material Variable	Distress/Smoothness		
	Transverse Joint Faulting	**Transverse Cracking**	**IRI**
PCC thickness	XX	XXX	XXX
PCC modulus of rupture & elasticity		XXX	XX
PCC Coefficient of thermal expansion	XXX	XXX	XXX
PCC unit weight	X	XX	X
Joint spacing	XX	XXX	XX
Joint load transfer efficiency	XXX		XXX
Edge support*	XXX	XXX	XX
Permanent curl/warp	XXX	XXX	XXX
Zero-stress temp	XX		X
Friction between slab & base		XXX	XX
Base type	XXX	XX	X
Climate	XXX	XXX	XXX
Subgrade type/modulus	X	XX	X
Ground water table	X	X	X
Truck speed		X (with HMA base only)	
Truck axle load distribution	X	XX	X
Truck Volume	XXX	XXX	XXX
Tire pressure		X	
Truck lateral offset	XX	XXX	XX
Truck wander		XX	X
Initial IRI			XXX

Key: X Factor has small effect on distress/IRI
XX Factor has moderate effect on distress/IRI
XXX Factor has large effect on distress/IRI
***Free edge vs. tied shoulder vs. widened lane**

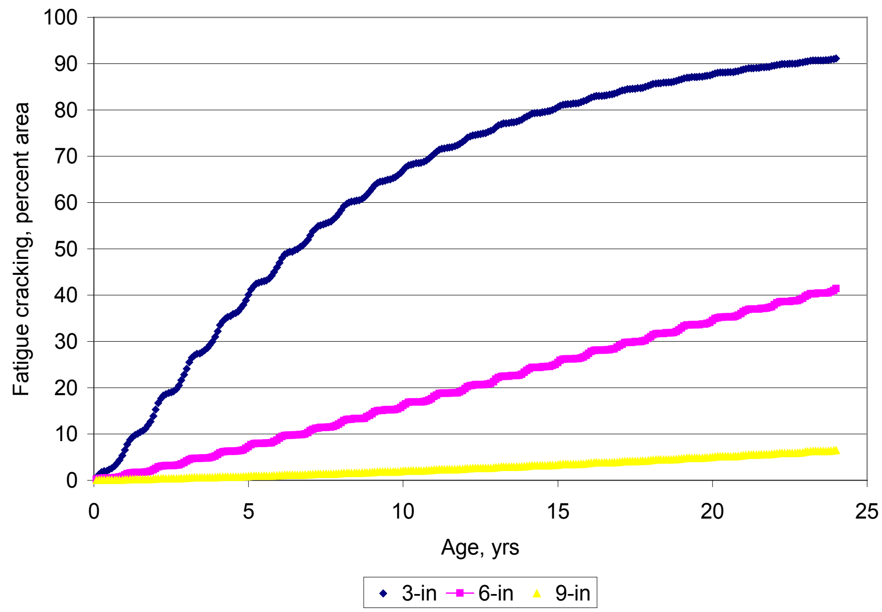


Figure 21. Large Effect of HMA thickness on HMA bottom up alligator fatigue cracking.

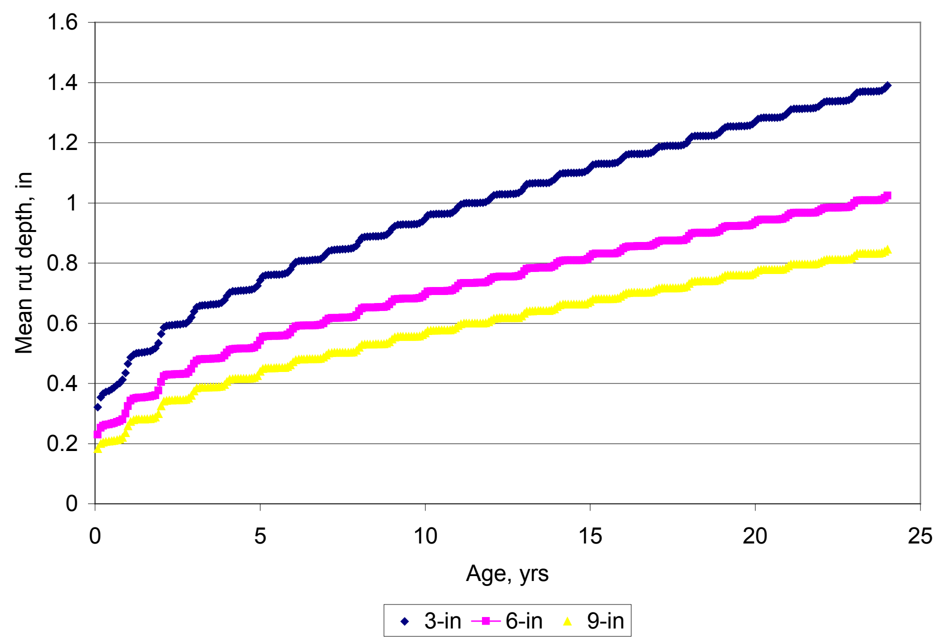


Figure 22. Large Effect of HMA thickness on rutting.

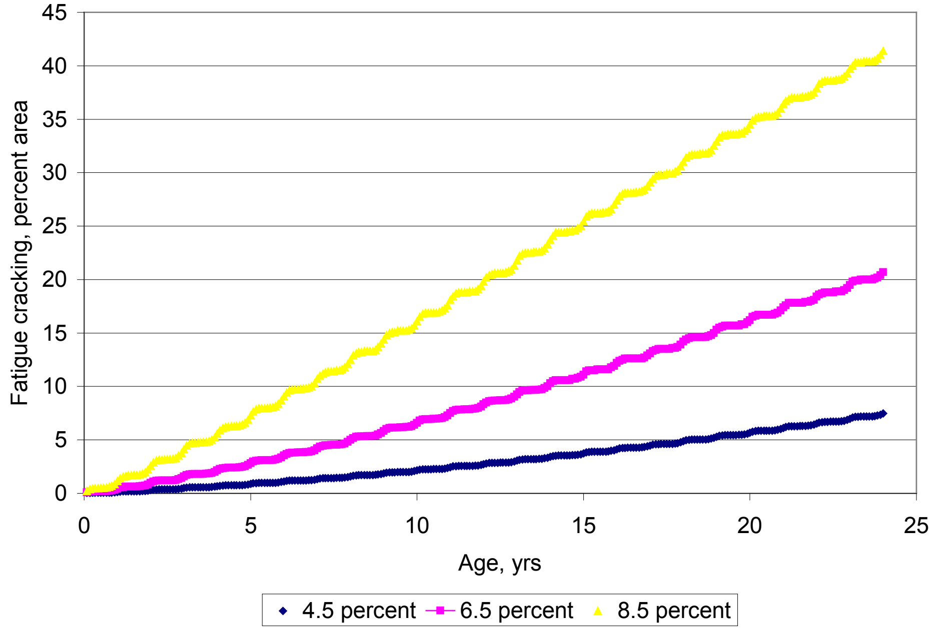


Figure 23. Large Effect of HMA in situ air void content on fatigue (alligator) cracking.

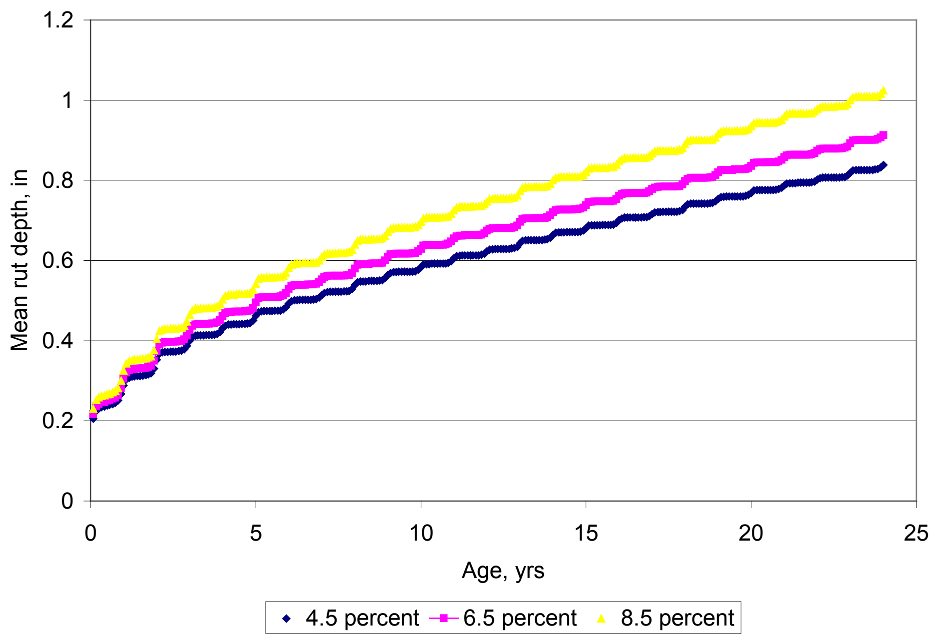


Figure 24. Significant Effect of HMA in situ air void content on rutting.

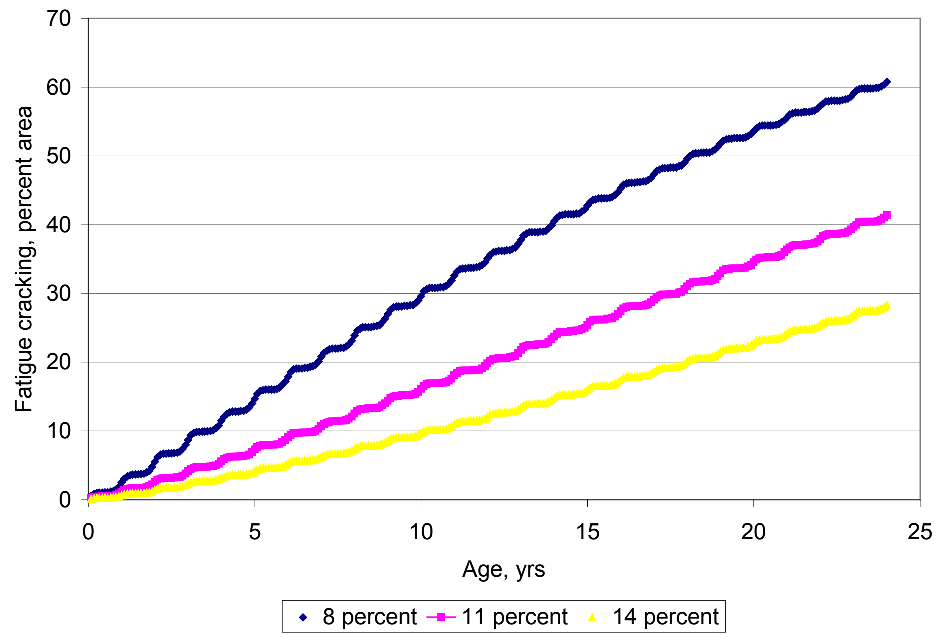


Figure 25. Large Effect of HMA volumetric binder content on fatigue (alligator) cracking.

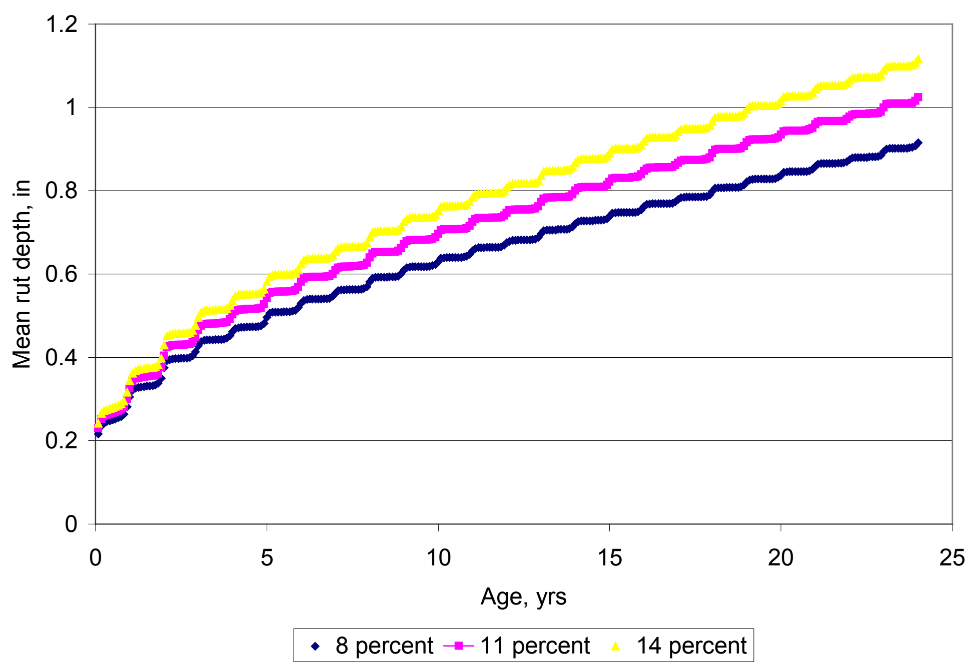


Figure 26. Significant Effect of HMA volumetric binder content on rutting.

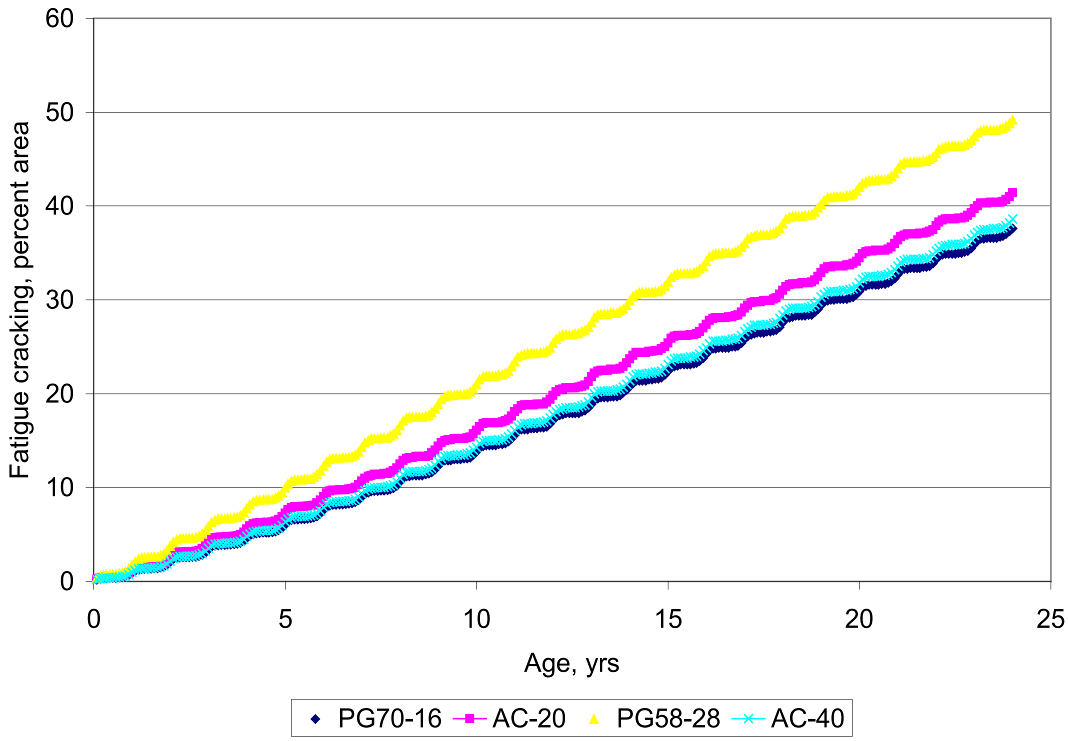


Figure 27. Effect of HMA binder type on fatigue (alligator) cracking.

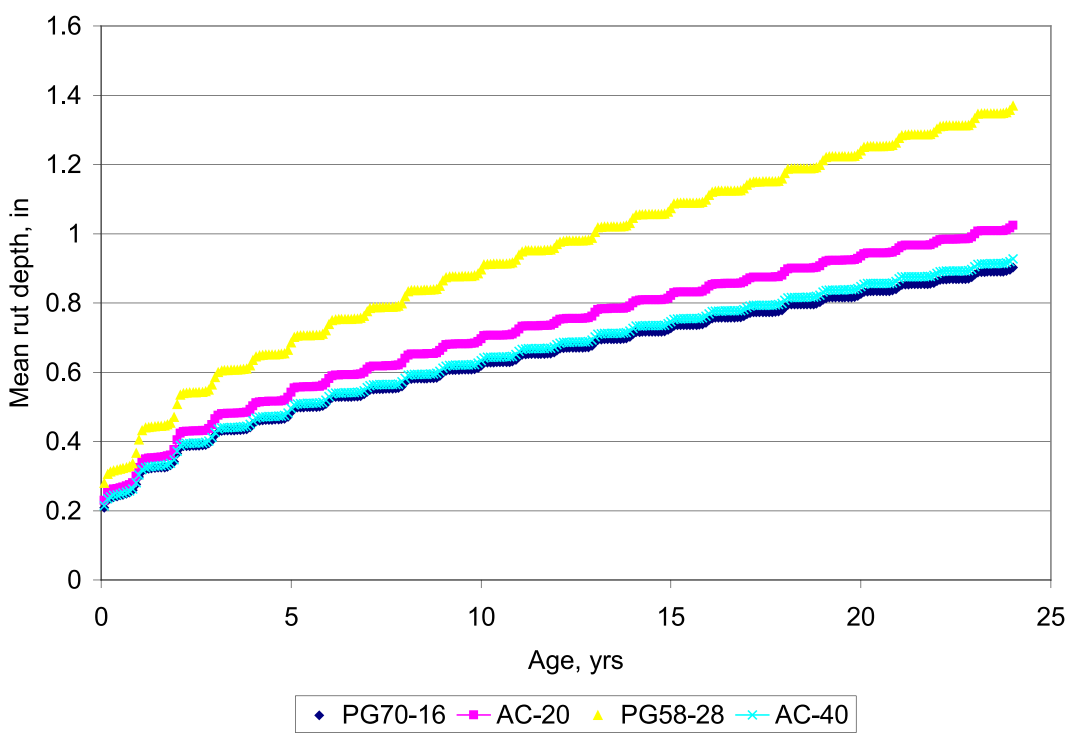


Figure 28. Effect of HMA binder type on rutting.

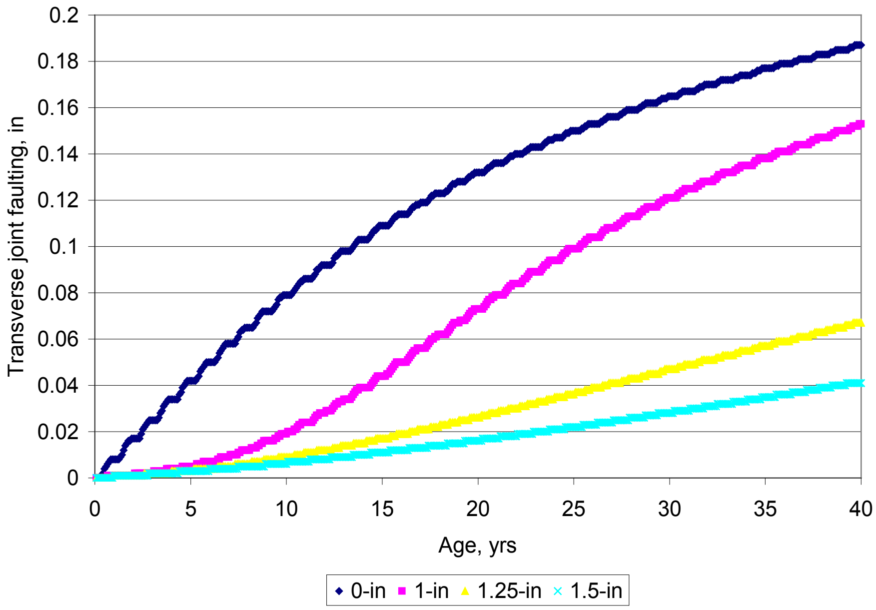


Figure 29. Large effect of JPCP transverse joint load transfer efficiency (LTE) on joint faulting.

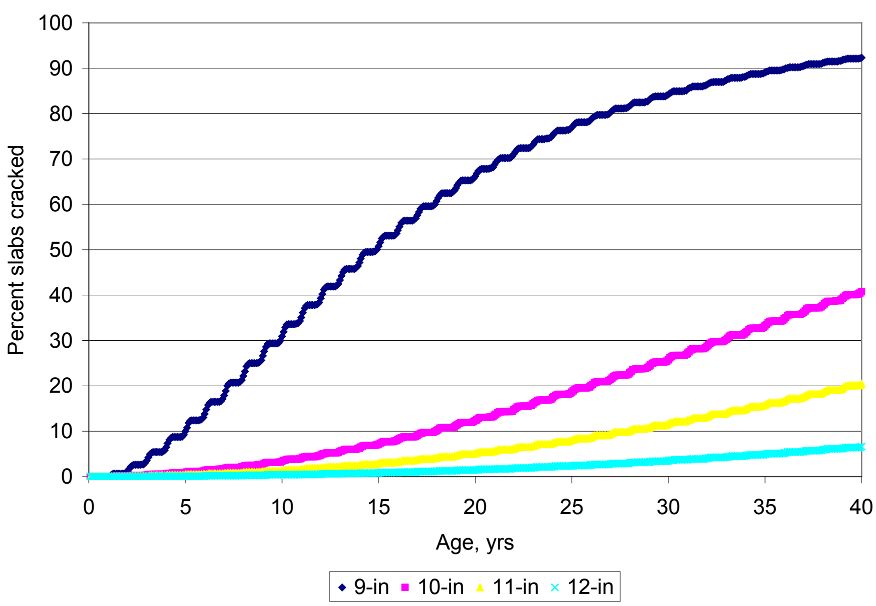


Figure 30. Large effect of PCC slab thickness on transverse cracking of JPCP.

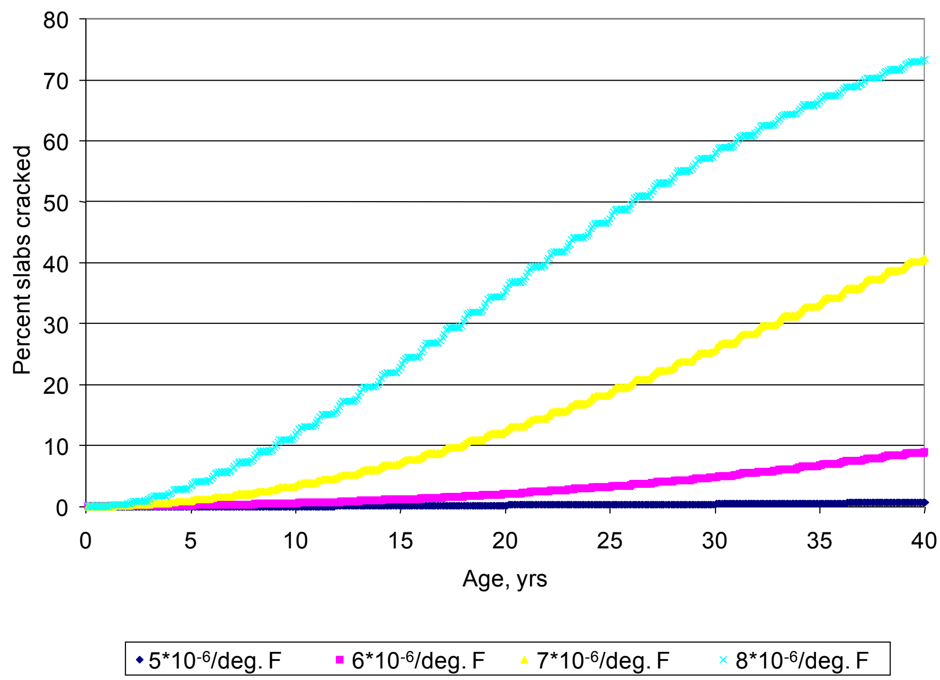


Figure 31. Large effect of PCC coefficient of thermal expansion on transverse cracking of JPCP.

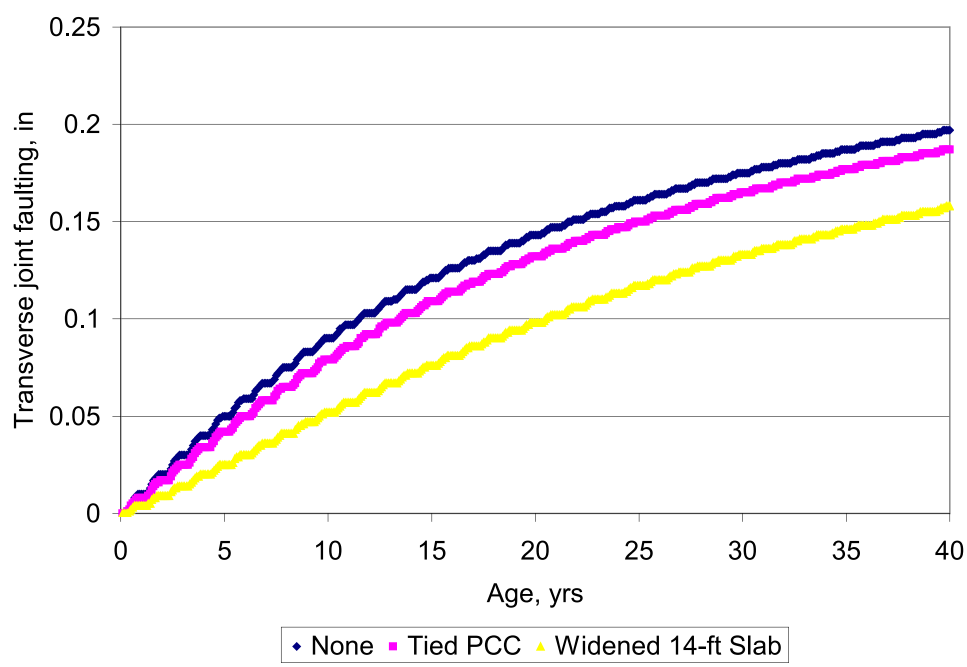


Figure 32. Effect of shoulder or widening edge support on transverse joint faulting of JPCP.

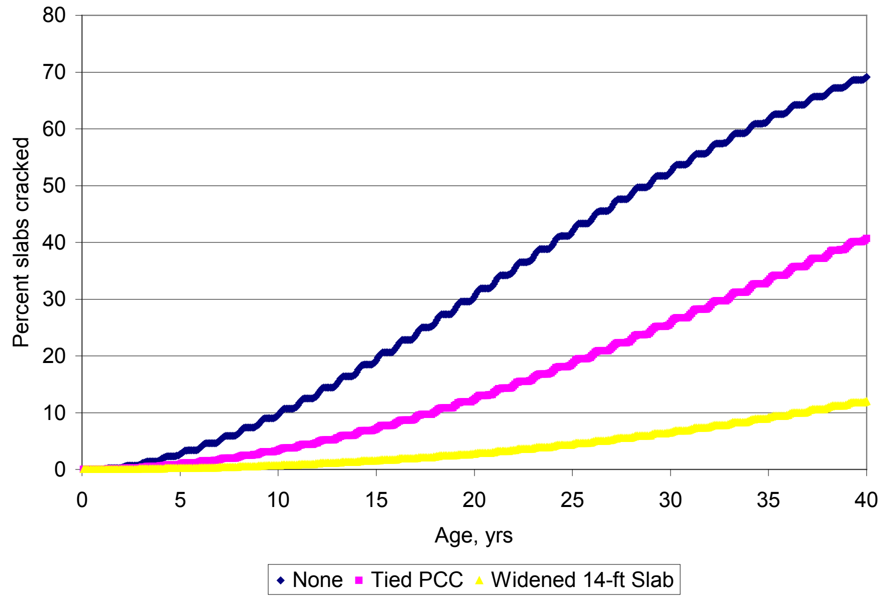


Figure 33. Large effect of edge support on slab transverse cracking for JPCP.

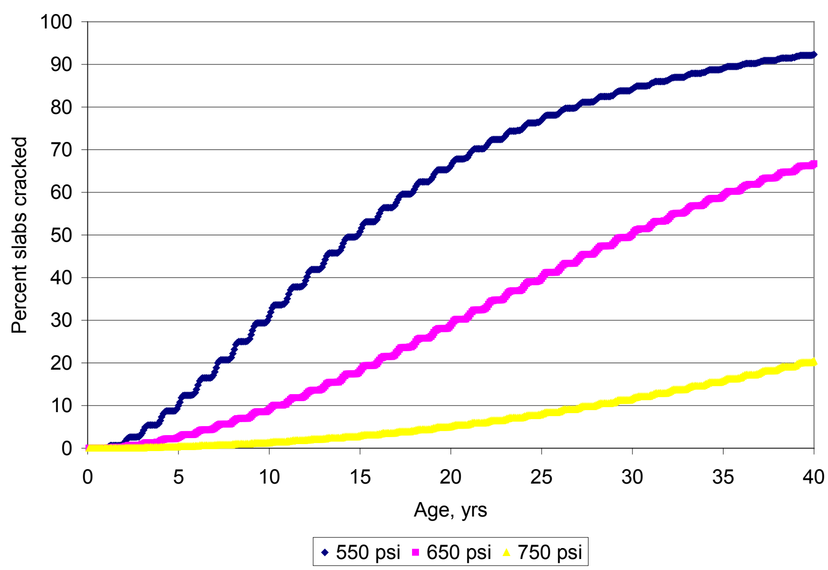


Figure 34. Large effect of PCC flexural strength on slab transverse cracking for JPCP.

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9.0 JPCP DESIGN FEATURES

JPCP design features have a significant impact on predicted JPCP performance. By selecting these inputs carefully, designers can optimize JPCP design to produce the most cost effective pavement solution. General guidance on selection of JPCP design inputs are provided in this section.

Summary of MEPDG Sensitivity Results for Utah New/Reconstructed JPCP

JPCP Design Parameter	Recommended Inputs for JPCP Optimization
Slab thickness	Range: 6 to 16-in
Permanent curl/warp effective temperature difference (°F)	-10 **[Critical] Do not change this input.**
Joint spacing (ft)	15 **[Critical] Do not exceed 15-ft, shorter may be used for slabs thinner than 7-in.**
Sealant type	Liquid
Doweled transverse joints	Yes, for most projects, except low volume roads **[Critical]**
Dowel diameter (in)	1.25 for <u><</u>10-in **[Critical]** 1.5 for <u>></u>10-in Note this is for transverse joints only. These values are based on MEPDG default recommendations. Smaller diameters could be considered for slabs less than 8-in. However, the MEPDG software will indicate joint faulting as not passing if the chosen bar is too small. Note that current UDOT standards for dowel diameter vs. slab thickness do differ from these recommendations.
Dowel bar spacing (in)	12 (Use 12 inches even for designs with five dowels per wheelpath). Note this is for transverse joints only.
Edge Support, Tied PCC shoulder, Long-term LTE (%)	• 40, for tied shoulders separately placed • 60, for tied shoulders monolithically placed
Base type	Actual specified
PCC-Base Interface Friction	The following lengths of time for full contact friction between the PCC slab and base course are recommended (means and range obtained from calibration): • Asphalt stabilized base: use full design analysis period. • Cement stabilized or lean concrete base: use 136 months (range of 0 to 360 mo.). • Unbound material base: use full design analysis period. • Unbonded overlay (with HMA separation layer): default set by MEPDG.
Erodibility index of Base 1 Extremely erosion resistant 2 Very erosion resistant 3 Erosion resistant 4 Fairly erodible 5 Very erodible	Recommendations: • Permeable Base-extremely erosion resistant, Use 1. • Asphalt concrete-extremely erosion resistant, Use 1 if granular subbase placed below; otherwise 2 or 3. • Lean concrete (Ec > 2,000,000 psi- extremely erosion resistant), Use 1 if granular subbase placed below; otherwise 3. • Untreated dense graded aggregate- fairly erodible, Use 4. • Subgrade soil- very erodible, Use 5.

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10.0 REHABILITATION INPUTS

Rehabilitation design is very similar to new/reconstructed design. Therefore, these recommendations to these inputs will not be repeated. Rehabilitation design does require a few new inputs and some modifications of other inputs that are related to the existing pavement. The existing pavement has typically deteriorated from its original as-constructed condition through fracture, distortion, and/or disintegration of its materials. Some of the material properties may also have aged and changed over time such as the oxidation of asphalt and the hardening of concrete. The MEPDG can account for these effects through modification of various design inputs and through a few new inputs related to the condition of the existing pavement. These modifications are basically used to adjust the various moduli of the existing pavement.

This section covers the modifications required of previously described inputs and the new inputs required for rehabilitation design. These inputs vary depending on the existing pavement and on the type of rehabilitation. Input recommendations are given for the following combinations of existing pavement and rehabilitation type:

- HMA or JPCP overlay of existing HMA pavement (see Table 18);
- JPCP unbonded overlay of existing JPCP (Table 19);
- HMA overlay of existing JPCP (intact slab and fractured slab) (Table 20);
- CPR (diamond grinding) of existing JPCP (Table 20).

Table 18. Characterizing existing HMA or existing HMA overlaid HMA pavement for HMA overlay or JPCP overlay (conventional whitetopping) design.

<table>
<tr><th>Existing Pavement</th><th>Rehabilitation Action</th><th>Rehabilitation Design Inputs
Existing Pavement</th></tr>
<tr><td rowspan="3">HMA or HMA overlaid HMA</td><td rowspan="3">HMA Overlay, or JPCP Overlay</td><td>Dynamic modulus of existing HMA:
• Condition survey of alligator fatigue cracking in wheelpaths.
• Compute percent area of traffic lane with alligator cracking, all levels of severity.
• Select Pavement Rating
o Excellent: <3%
o Good: 4-5%
o Fair: 6-10%
o Poor: 11-20%
o Very Poor: >20%</td></tr>
<tr><td>Base course resilient modulus:
• Backcalculate from FWD testing and adjust for unusual conditions.
• Use default values from Section 7
• Limit resilient modulus of unbound base to 2-3 times that of subgrade.</td></tr>
<tr><td>Subgrade resilient modulus:
• Determine AASHTO Soil Class from county soil maps* for the predominant soil. This also provides gradations and Atterberg limits. See also project geotechnical report.
• Conduct FWD testing along the project in the outer wheelpath at regular intervals.
• Backcalculate subgrade field (elastic solid) Es at in situ moisture from FWD deflections using an appropriate elastic layered model (including bedrock if needed) or use the AASHTO 93 model outer sensor approach (if no bedrock). Clean data by removing unusual points.
• Adjust each backcalculated Es elastic modulus from a "field" elastic half space to a "lab" value and from an "in situ" moisture content to optimum moisture through the following multiplier adjustment:
o Coarse Grained Soils use 0.67
o Fine Grained Soils use 0.55.
• This is the "lab adjusted Mr at in situ moisture content." Use for the MEPDG input subgrade resilient modulus.
This approach provides for a Mr that can be used as a direct input for the subgrade of either a reconstruct or for an overlay design using the FWD to obtain the subgrade Mr. This is the same approach used in the 2007 national calibration and the results should agree reasonably with Level 3 results in Section 7.</td></tr>
</table>

* The USDA-NRCS soil survey database.

Table 19. Characterizing existing JPCP for unbonded JPCP overlay design.

<table>
<tr><th>Existing Pavement</th><th>Rehabilitation Action</th><th>Rehabilitation Inputs for Existing Pavement</th></tr>
<tr><td rowspan="5">JPCP</td><td rowspan="5">Unbonded JPCP overlay</td><td>Effective elastic modulus of intact concrete slab:
• Determine percent slab cracking of existing JPCP.
• Select condition for input: "Good" (10% slabs cracked), "Moderate" (20%), "Severe" (50%) transverse cracking of all severity levels.
• Determine EBASE/DESIGN = CBD * ETEST
Where:
EBASE/DESIGN = Design modulus of elasticity of existing slab, psi
CBD = Coefficient reduction factor: 0.42 to 0.75 existing pavement in "Good" condition, 0.22 to 0.42 existing pavement in "Moderate" condition, 0.042 to 0.22 existing pavement in "Severe" condition.
ETEST = Elastic modulus of the existing uncracked concrete, psi. (estimate by testing of cores by ASTM C469 or using 28-day modulus and multiplying by 1.2 for approximate long term modulus)</td></tr>
<tr><td>Modulus of Fractured JPCP:
• Crack and seat JPCP: 150,000 to 250,000 psi
• Rubblized JPCP: 50,000 to 75,000 psi</td></tr>
<tr><td>Unbound base course modulus:
• Use default values from Section 7
• Limit resilient modulus of unbound base to 2-3 times that of subgrade.</td></tr>
<tr><td>Stabilized base course modulus:
• Estimate cement stabilized E from Section 7.
• Estimate asphalt stabilized dynamic modulus through volumetric and gradation inputs (Level 3).</td></tr>
<tr><td>Subgrade resilient modulus:
• Determine AASHTO Soil Class from county soil maps* for the predominant soil. This also provides gradations and Atterberg limits. See also the project geotechnical report.
• Conduct FWD testing along the project in the center of the slab at regular intervals.
• Backcalculate "field" subgrade k value at in situ moisture content from FWD deflections on top of the slab.
• Run the MEPDG program with default INPUT Mr for the subgrade based on AASHTO Classification.
• The MEPDG OUTPUT k-values for given months must be compared to the backcalculated k-values for same months. The input Mr subgrade Mr (lab value at optimum moisture) must be adjusted until the FWD backcalculated k-value matched that k-value in the MEPDG output.
This approach is exactly what was done in the original 2007 MEPDG work under NCHRP 1-40D. It ensures that the Mr and k-value used to compute stresses and deflections were reasonable and generally matched the field. This approach was applied to all of the Utah LTPP and PMS sections and found to produce Mr values that were similar.</td></tr>
</table>

* The USDA-NRCS soil survey database.

Table 20. Characterizing existing JPCP for HMA overlay design or CPR.

<table>
<tr><th>Existing Pavement</th><th>Rehabilitation Action</th><th>Rehabilitation Inputs for Existing Pavement</th></tr>
<tr><td rowspan="4">JPCP</td><td rowspan="4">HMA overlay or CPR</td><td>Elastic modulus of concrete slab:
Determine percent slab cracking of existing JPCP.
Input this percentage into MEPDG Rehabilitation window.
Determine what percentage of cracked slabs will be replaced prior to HMA overlay or CPR and enter this into Rehabilitation window.
Estimate elastic modulus of existing slab by testing of cores using ASTM C469, or estimate using 28-day modulus and multiplying by 1.2 for approximate long term modulus.</td></tr>
<tr><td>Modulus of Fractured JPCP (for HMA overlay):
Crack and seat JPCP: 150,000 to 250,000 psi
Rubblized JPCP: 50,000 to 75,000 psi
Unbound base course modulus:
Use default values from Section 7.
Limit resilient modulus of unbound base to 2-3 times that of subgrade.</td></tr>
<tr><td>Stabilized base course modulus:
Estimate cement stabilized E from Section 7.
Estimate asphalt stabilized dynamic modulus through volumetric and gradation inputs (Level 3).</td></tr>
<tr><td>Subgrade resilient modulus:
Determine AASHTO Soil Class from county soil maps* for the predominant soil. This also provides gradations and Atterberg limits. See also the project geotechnical report.
Use procedure described for JPCP overlay for FWD testing and backcalculation.</td></tr>
</table>

* The USDA-NRCS soil survey database.

11.0 PERFORMING NEW/RECONSTRUCT PAVEMENT AND REHABILITATION DESIGNS

Design of a new or reconstructed HMA or JPCP pavement, CPR, and HMA and JPCP overlays require the following major steps.

1. **Select a trial design.** Use the current UTOT/AASHTO procedure or the experience of the designer as a starting point.
2. **Select the appropriate performance criteria and design reliability level for the project at hand.**
3. **Obtain all inputs for the pavement under consideration.** These inputs can be obtained using three different levels of effort as previously described. If a given input is unknown, run a small sensitivity to see how much it affects the design. Note that the MEPDG software allows users to directly import all the traffic electronic files (see Figure 35). Traffic data can be obtained from UDOT Traffic Statistics office.
4. **Run the MEPDG software**. Examine the inputs and outputs.
5. **Examine carefully the input summary.** Ensure the inputs are correct and what the designer intended.
6. **Examine all of the layer material moduli outputs.** Do this month by month over time to determine their reasonableness.
7. **Assess if the trial design.** Has it met each of the performance criteria at the design reliability level?
8. **If criteria are not met.** Determine how this design deficiency can be remedied by altering the materials used, the layering, or other design details (e.g., thickness of layers, grade of asphalt, dowel bar diameter).
9. **Revise trial design as needed.** If the trial design has either input errors, material output problems, other potential problems, or has exceeded the performance criteria at the given level of reliability, revised the inputs/trial design and rerun the program. Iterate until the performance criteria have been met. When they have, this design is a feasible design for further consideration in the pavement selection process.

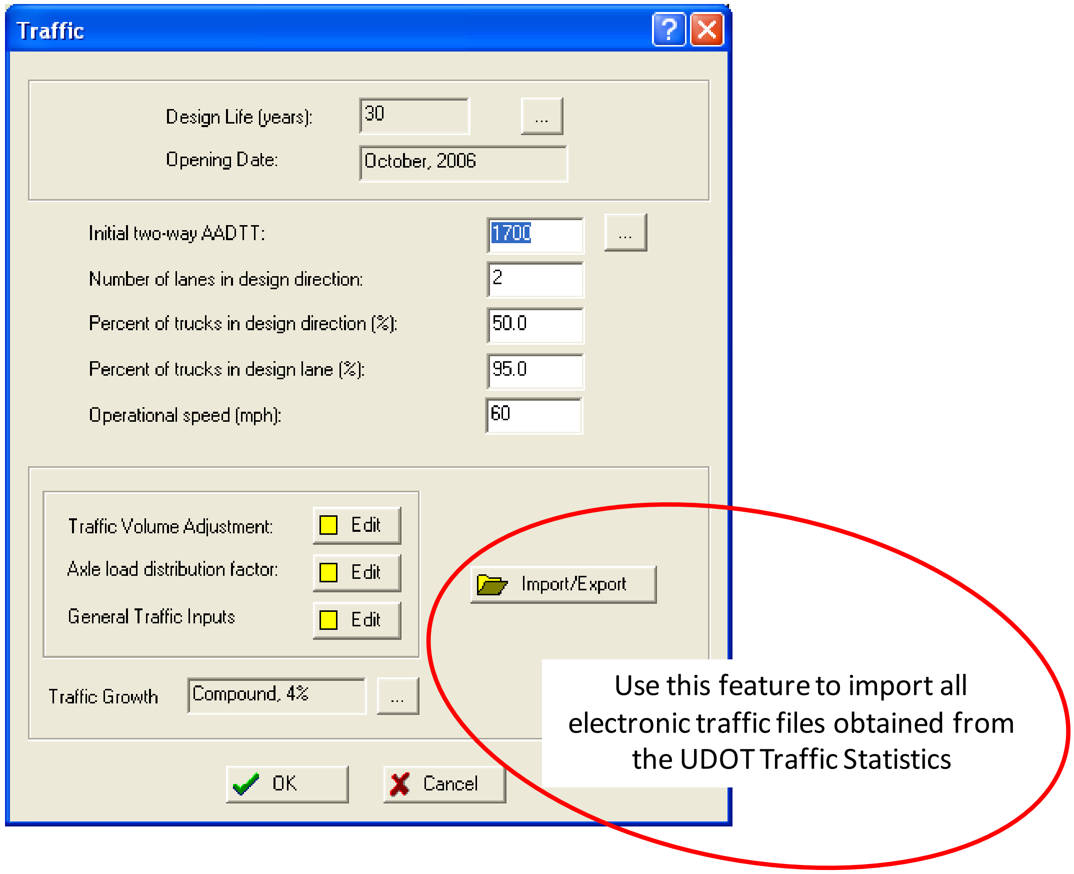

Figure 35. MEPDG features used for directly importing traffic inputs in electronic format.

12.0 MEPDG OUTPUTS USED FOR PERFORMANCE ASSESSMENT

The MEPDG software analyzes a given trial design that is input and predicts its performance in terms of key distress types and smoothness. In addition, materials properties and other factors are output on a month by month basis over the design period. Each pavement type and rehabilitation type has its own specific output tables and charts. The designer should examine the output materials properties and other factors to see if reasonable results are being obtained. Occasionally, a weather station may contain erroneous temperatures, precipitation, and other values that cause major problems with the layer moduli output from the MEPDG. These must be reviewed and new weather stations used to provide reasonable moduli.

For asphalt pavements, the output provides the HMA Dynamic Modulus (E*) and the resilient modulus (Mr) for unbound layers for each month over the design period. Note that vehicle speed and temperature affect the HMA material E* greatly. Moisture content and frost condition affects the unbound materials Mr greatly. The designer can observe these and assess their reasonableness.

For concrete pavements, the output provides the PCC modulus of rupture and modulus of elasticity for each month over the design period. The backcalculated subgrade k-value is also output monthly. Load transfer efficiency LTE at joints is also output. If the LTE drops below 70 percent, a larger dowel should be used. Note that moisture content and frost condition affects the unbound materials Mr and k-value greatly. The designer can observe these and assess their reasonableness.

The designer should examine the key distress type outputs and smoothness to see if they are meeting the performance criteria. The first two years of key distress output is shown for an HMA pavement below. The distress and IRI are output at the end of each month over the design period. The number of cumulative Heavy Trucks (Class 4 and above) are also shown in the design traffic lane. Examples of MEPDG output tables and plots for new HMA pavement and new JPCP analysis are presented in Tables 21 and 22 and Figures 36 through 47.

The red horizontal line (for all distress/IRI plots) represents the limiting performance criteria at a given level of reliability. If distress/IRI at the specified reliability is less than the red line over the entire design period, then the design is acceptable from that standpoint. Another method for assessing design adequacy is to review the Reliability Output (see Figure 36). The Distress Target and its corresponding Reliability Target are the first right hand columns listed followed by the Distress Predicted and the Reliability Predicted. If the Reliability Predicted is greater than the Reliability Target then the pavement passes. If the reverse is true then the pavement fails. If any key distress fails the designer must alter the trial design to correct the problem. This "trial and error" process allows the pavement designer to essentially "build the pavement in his/her computer" prior to building it in the field to see if it will perform. If there is a problem with the design and materials for the given subgrade, climate, and traffic, it can be corrected and an early failure avoided. This is the power of the ME PDG methodology.

New HMA and Rehabilitation with HMA

- MS Excel Workbook named (conefile_name).xls with the following key Worksheets:
    - **Input Summary:** Summary of all inputs (traffic, climate, design, construction, etc.) information.
    - **Climate:** Summary of all computed climate related data (rainfall, freezing index, temperature profiles within the pavement, and so on) for the given project.
    - **Reliability Summary:** Summary of reliability for each distress/IRI prediction at the end of the analysis period
    - **Distress Summary:** Summary of all predicted distress @ 50 percent reliability (provided IRI predictions at specified reliability level).
    - **Layer Modulus:** Summary of internal computations of layer moduli for all layers at various depth (presented for the entire analysis period).
    - **HMA Modulus:** Plot of HMA layers modulus over the analysis period
    - **Fatigue cracking:** Detailed summary of fatigue cracking prediction outputs.
    - **Bottom-up Damage Graph:** Plot of bottom-up damage versus age.
    - **Bottom-up Crack Graph:** Plot of bottom-up cracking versus age (@ 50 and specified reliability levels).
    - **Thermal cracking:** Detailed summary of thermal cracking prediction outputs.
    - **Thermal Cracking Length:** Plot of predicted thermal cracking versus age (@ 50 and specified reliability levels).
    - **Rutting:** Detailed summary of rutting prediction outputs.
    - **Total Rutting:** Plot of predicted rutting (total, HMA, base, and subgrade) versus age (@ 50 and specified reliability levels).
    - **IRI:** Plot of predicted IRI versus age (@ 50 and specified reliability levels).

New JPCP and Rehabilitation with JPCP (including CPR)

- MS Excel Workbook named (conefile_name).xls with the following key Worksheets:
  - **Input Summary:** Summary of all inputs (traffic, climate, design, construction, etc.) information.
  - **Climate:** Summary of all computed climate related data (rainfall, freezing index, temperature profiles within the pavement, and so on) for the given project.
  - **Reliability Summary:** Summary of reliability for each distress/IRI prediction at the end of the analysis period
  - **Distress Summary:** Summary of all predicted distress @ 50 percent reliability (provided IRI predictions at specified reliability level).
  - **Faulting Summary:** Detailed summary of faulting prediction outputs.
  - **Faulting:** Plot of predicted faulting versus age (@ 50 and specified reliability levels).
  - **LTE:** Plot of predicted transverse joint load transfer efficiency versus age.
  - **Cracking Summary:** Detailed summary of cracking prediction outputs.
  - **Cumulative Damage:** Plot of predicted top-down and bottom-up damage versus age.
  - **Cracking:** Plot of predicted transverse fatigue cracking versus age (@ 50 and specified reliability levels).
  - **IRI:** Plot of predicted IRI versus age (@ 50 and specified reliability levels).

Table 21. Distress summary output worksheet for new HMA.

Predicted distress: Project HMA

Pavement age mo	Pavement age yr	Month	Longitudinal Cracking (ft/mi)	Alligator Cracking (%)	Transverse Cracking (ft/mi)	Subtotal AC Rutting (in)	Total Rutting (in)	IRI (in/mi)	Heavy Trucks (cumulative)	IRI at Reliability (in/mi)
1	0.08	October	0.02	0.0008	0	0.002	0.073	66.2	4809	89.81
2	0.17	November	0.03	0.0014	0	0.002	0.082	66.6	9618	90.31
3	0.25	December	0.05	0.0019	0	0.002	0.087	66.8	14427	90.62
4	0.33	January	0.08	0.0026	0	0.003	0.096	67.2	19237	91.17
5	0.42	February	0.12	0.0036	0	0.003	0.103	67.5	24046	91.59
6	0.5	March	0.2	0.0052	0	0.003	0.11	67.8	28855	92.06
7	0.58	April	0.28	0.0065	0	0.004	0.115	68	33664	92.34
8	0.67	May	0.41	0.009	0	0.006	0.122	68.4	38473	92.83
9	0.75	June	0.56	0.0127	0	0.011	0.134	68.9	43282	93.52
10	0.83	July	0.72	0.0166	0	0.016	0.143	69.3	48091	94.12
11	0.92	August	0.89	0.0201	0	0.018	0.149	69.6	52900	94.51
12	1	September	1.03	0.0227	0	0.019	0.152	69.7	57710	94.73
13	1.08	October	1.14	0.0244	0	0.019	0.154	69.8	62519	94.88
14	1.17	November	1.21	0.0254	0	0.019	0.155	69.9	67328	94.98
15	1.25	December	1.26	0.0261	0	0.019	0.155	70	72137	95.07
16	1.33	January	1.32	0.0269	0	0.019	0.156	70	76946	95.18
17	1.42	February	1.41	0.028	0	0.019	0.157	70.1	81755	95.3
18	1.5	March	1.52	0.0293	0	0.019	0.158	70.2	86564	95.43
19	1.58	April	1.72	0.032	0	0.019	0.16	70.3	91373	95.61
20	1.67	May	1.96	0.0356	0	0.02	0.163	70.5	96183	95.87
21	1.75	June	2.22	0.04	0	0.023	0.168	70.8	100992	96.23
22	1.83	July	2.48	0.0447	0	0.026	0.175	71.1	105801	96.67
23	1.92	August	2.74	0.049	0	0.029	0.179	71.3	110610	97.01
24	2	September	2.95	0.052	0	0.029	0.181	71.5	115419	97.18
25	2.08	October	3.08	0.0535	0	0.029	0.182	71.5	120228	97.3
26	2.17	November	3.15	0.0543	0	0.029	0.182	71.6	125037	97.4
27	2.25	December	3.23	0.0552	0	0.029	0.183	71.7	129846	97.51
28	2.33	January	3.27	0.0556	0	0.029	0.183	71.8	134656	97.6
29	2.42	February	3.32	0.0561	0	0.029	0.183	71.8	139465	97.7
30	2.5	March	3.51	0.0579	0	0.029	0.184	71.9	144274	97.84
31	2.58	April	3.76	0.0601	0	0.029	0.185	72	149083	98
32	2.67	May	4.15	0.0648	0	0.03	0.188	72.2	153892	98.24
33	2.75	June	4.53	0.0698	0	0.031	0.191	72.4	158701	98.52
34	2.83	July	4.87	0.0745	0	0.033	0.195	72.6	163510	98.8
35	2.92	August	5.2	0.0789	0	0.034	0.197	72.8	168319	99.04
36	3	September	5.48	0.0824	0	0.035	0.199	72.9	173129	99.21

Project: HMA
Reliability Summary

Performance Criteria	Distress Target	Reliability Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	103.1	99.14	Pass
AC Surface Down Cracking (Long. Cracking) (ft/mile):	2000	90	97	88.93	Fail
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90	0.7	99.999	Pass
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90	1	99.999	Pass
Chemically Stabilized Layer (Fatigue Fracture)	25	90			N/A
Permanent Deformation (AC Only) (in):	0.25	90	0.08	99.999	Pass
Permanent Deformation (Total Pavement) (in):	0.75	90	0.31	99.999	Pass

Figure 36. Reliability summary for new HMA.

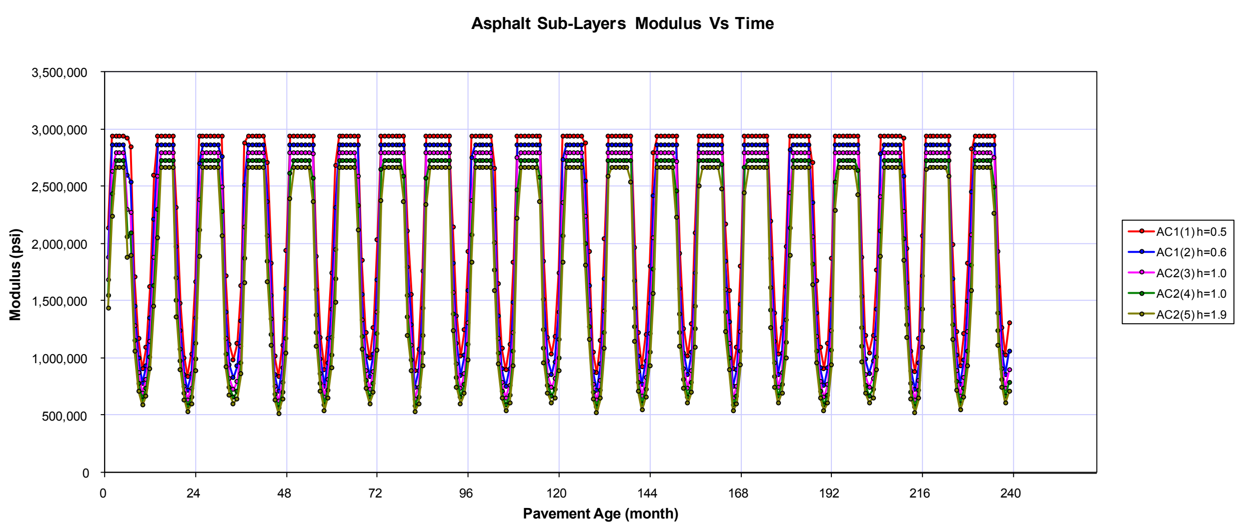

Figure 37. Plot of computed HMA dynamic modulus for new HMA.

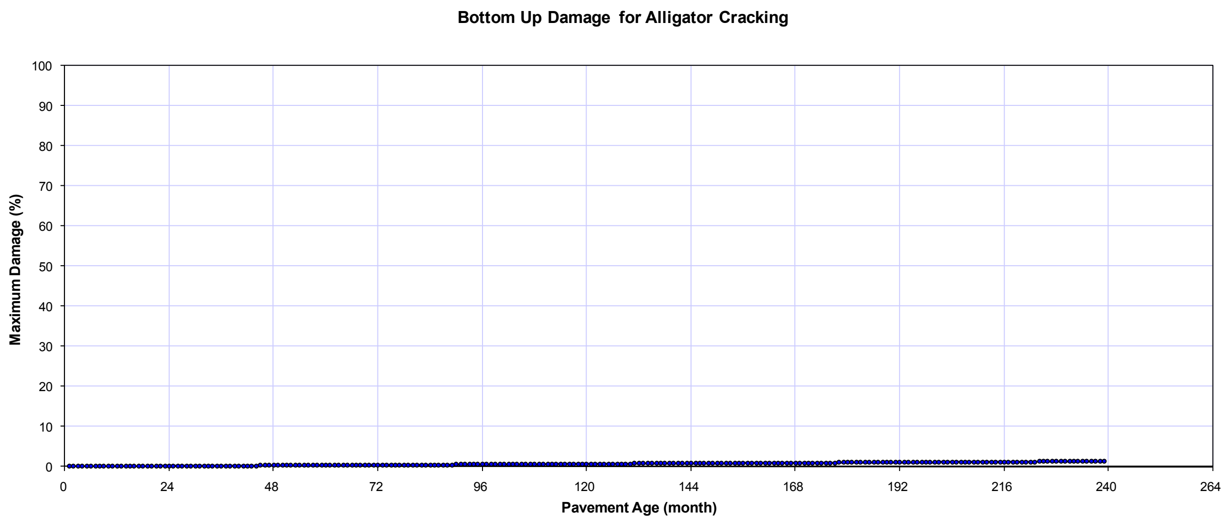

Figure 38. Plot of bottom-up damage over analysis period for new HMA.

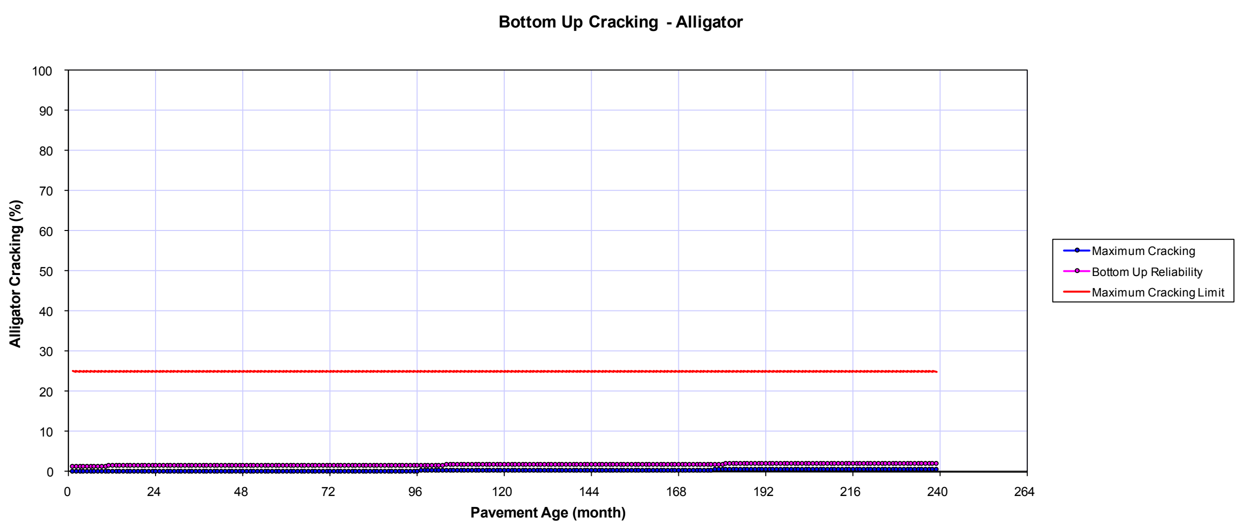

Figure 39. Plot of bottom-up cracking over analysis period for new HMA.

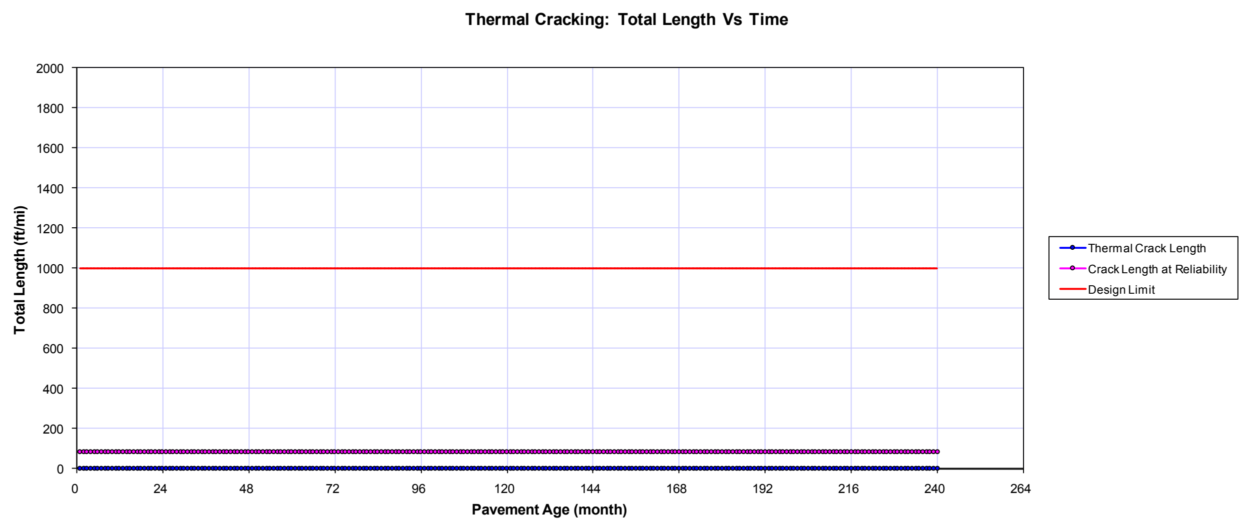

Figure 40. Plot of thermal cracking over analysis period for new HMA.

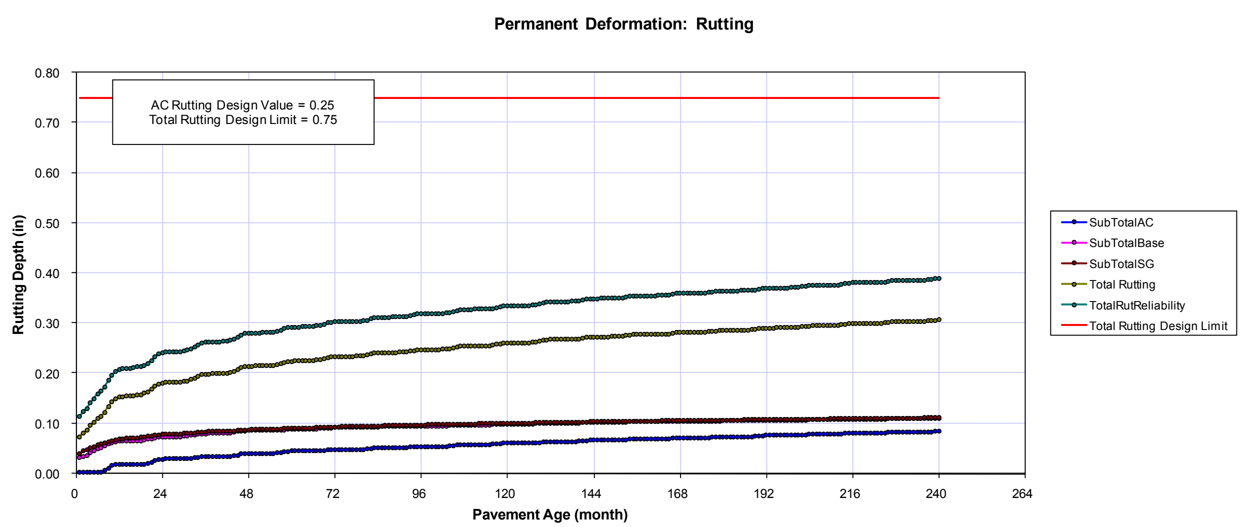

Figure 41. Plot of rutting over analysis period for new HMA.

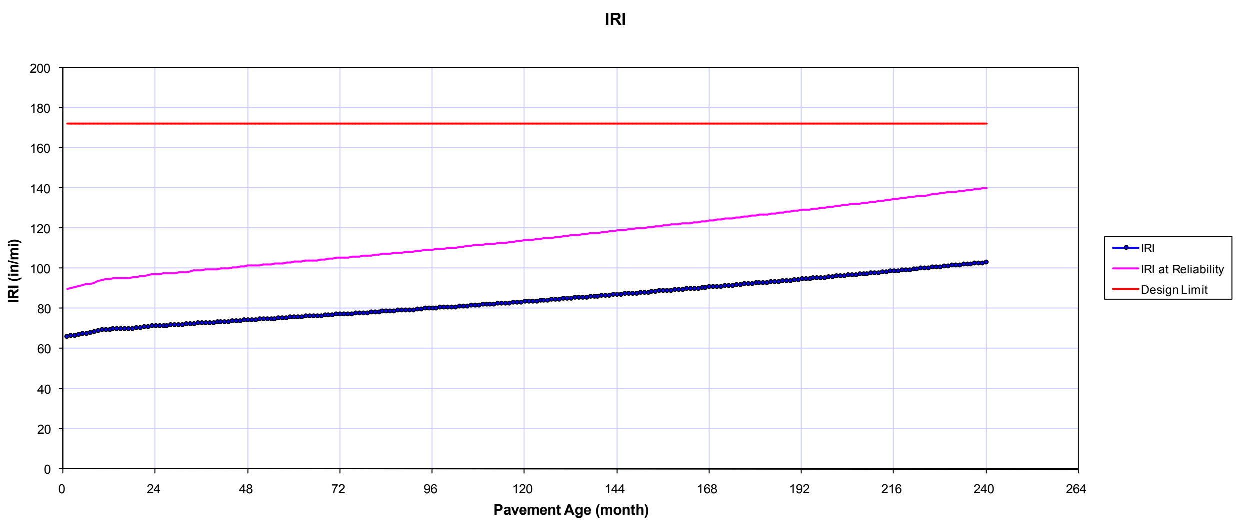

Figure 42. Plot of IRI over analysis period for new HMA.

Table 22. Distress summary output worksheet for new JPCP.

Predicted distress: Project LTPP3015_10.5

Pavement age					Dyn.		Percent			IRI at
			Epcc	Ebase	k	Faulting	slabs	IRI	Heavy Trucks	specified
mo	yr	Month	Mpsi	ksi	psi/in	in	cracked	in/mile	(cumulative)	reliability
1	0.08	September	3.86	2842	298	0	0	116.2	5164	162.3
2	0.17	October	3.97	2842	298	0	0	116.2	10403	162.4
3	0.25	November	4.03	2842	298	0	0	116.4	15040	162.8
4	0.33	December	4.07	2842	298	0	0	116.5	19174	162.9
5	0.42	January	4.11	2842	296	0.001	0	116.5	24519	163.1
6	0.5	February	4.13	2842	296	0.001	0	116.7	30141	163.3
7	0.58	March	4.16	2842	297	0.001	0	116.7	36578	163.5
8	0.67	April	4.18	2842	298	0.001	0	116.9	43256	163.7
9	0.75	May	4.19	2842	298	0.001	0	117	50913	163.9
10	0.83	June	4.21	2842	298	0.001	0	117.1	59664	164.1
11	0.92	July	4.22	2842	298	0.001	0	117.1	68971	164.1
12	1	August	4.24	2842	298	0.001	0	117.2	76004	164.2
13	1.08	September	4.25	2842	298	0.001	0	117.2	81881	164.2
14	1.17	October	4.26	2842	298	0.002	0	117.2	87843	164.3
15	1.25	November	4.27	2842	298	0.002	0	117.3	93119	164.4
16	1.33	December	4.28	2842	298	0.002	0	117.4	97824	164.7
17	1.42	January	4.28	2842	296	0.002	0	117.6	103907	164.9
18	1.5	February	4.29	2842	296	0.002	0	117.7	110304	165
19	1.58	March	4.3	2842	297	0.002	0	117.8	117630	165.2
20	1.67	April	4.31	2842	298	0.003	0	117.9	125229	165.4
21	1.75	May	4.31	2842	298	0.003	0	118.1	133943	165.7
22	1.83	June	4.32	2842	298	0.003	0	118.1	143902	165.8
23	1.92	July	4.32	2842	298	0.003	0	118.2	154493	165.9
24	2	August	4.33	2842	298	0.003	0	118.2	162497	165.9
25	2.08	September	4.33	2842	298	0.003	0	118.3	169185	166
26	2.17	October	4.34	2842	298	0.003	0	118.4	175969	166.1
27	2.25	November	4.34	2842	298	0.003	0	118.5	181974	166.3
28	2.33	December	4.35	2842	298	0.004	0	118.6	187328	166.6
29	2.42	January	4.35	2842	296	0.004	0	118.7	194250	166.7
30	2.5	February	4.36	2842	296	0.004	0	118.8	201531	166.9
31	2.58	March	4.36	2842	297	0.004	0	119	209868	167.1
32	2.67	April	4.36	2842	298	0.004	0	119.2	218515	167.4
33	2.75	May	4.37	2842	298	0.004	0	119.2	228432	167.5
34	2.83	June	4.37	2842	298	0.005	0	119.4	239765	167.7
35	2.92	July	4.37	2842	298	0.005	0	119.4	251817	167.8
36	3	August	4.38	2842	298	0.005	0	119.5	260926	167.8

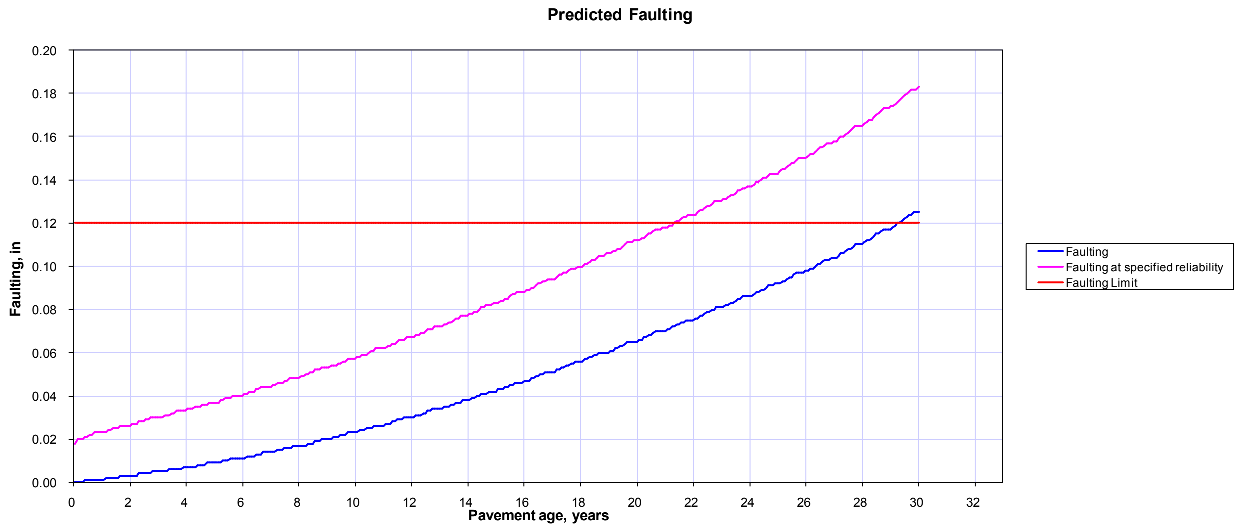

Figure 43. Plot of faulting over analysis period for new JPCP.

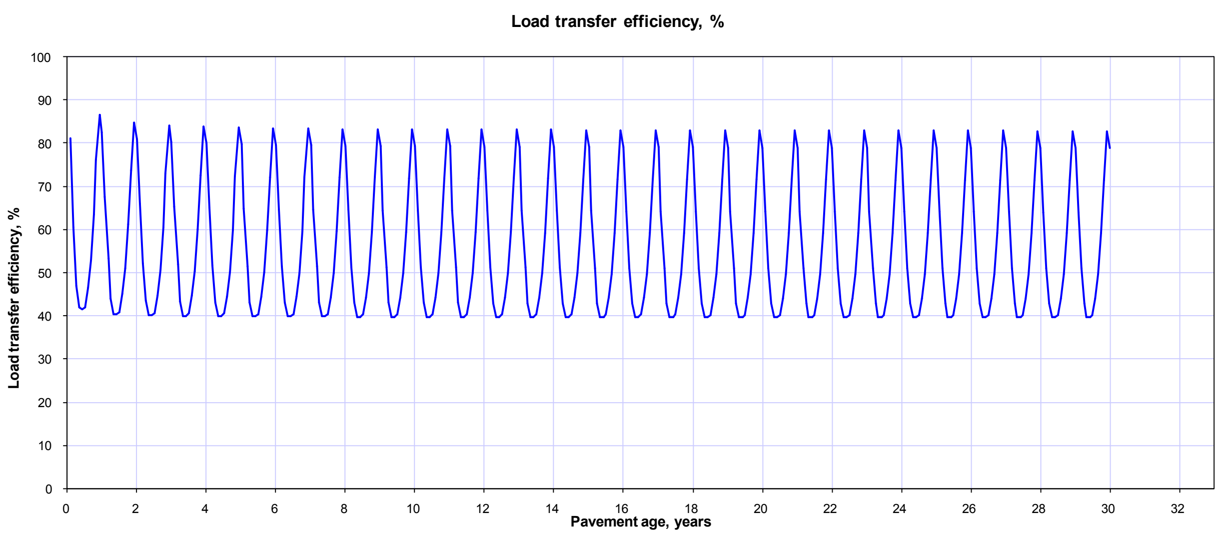

Figure 44. Plot of LTE over analysis period for new JPCP without dowels.

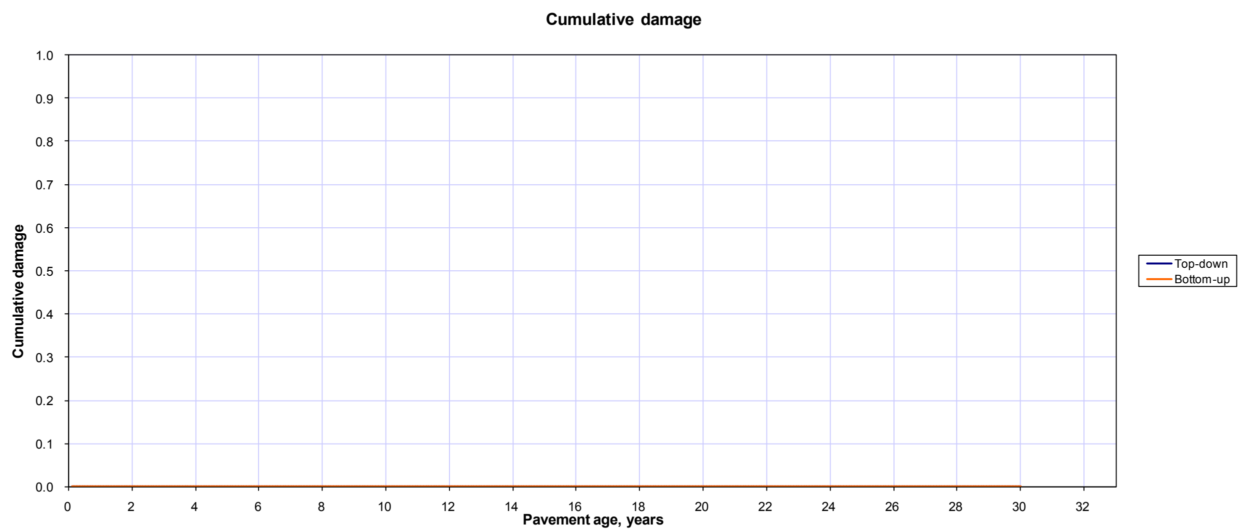

Figure 45. Plot of cumulative damage (cracking) over analysis period for new JPCP.

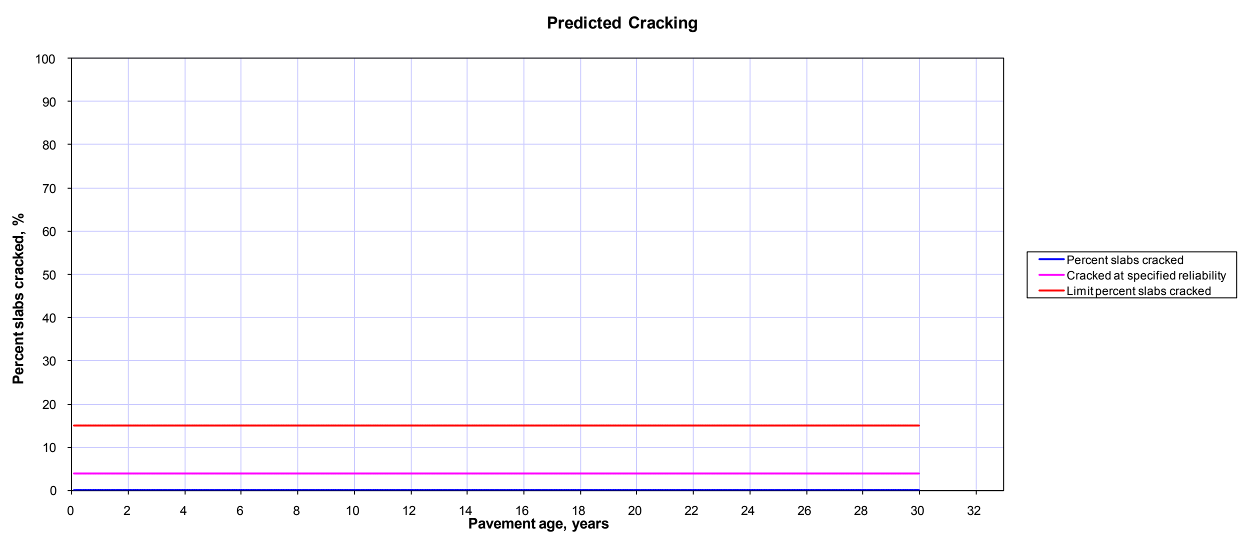

Figure 46. Plot of cracking over analysis period for new JPCP.

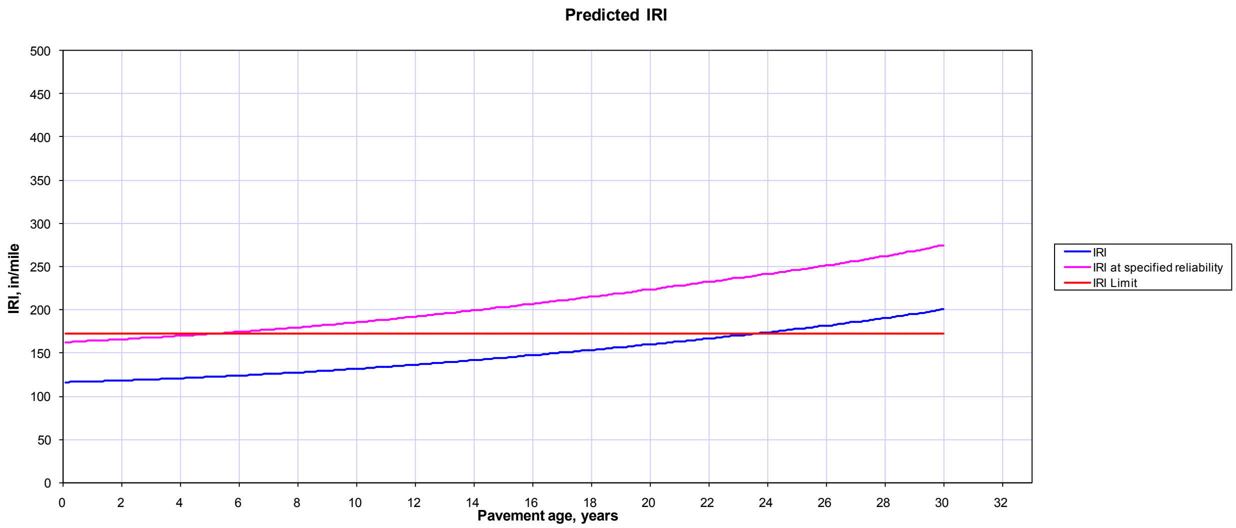

Figure 47. Plot of IRI over analysis period for new JPCP.

REFERENCES

AASHTO. 1986. *Guide for Design of Pavement Structures*. American Association of State Highway and Transportation Officials, Washington, D.C.

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

AASHTO. 2008. *Mechanistic-Empirical Pavement Design Guide, Interim Edition: A Manual of Practice*. American Association of State and Highway Transportation Officials, Washington, D.C.

ARA. 2004. *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures (NCHRP Project 1-37A)*. Online Version (http://www.trb.org/mepdg), July 2004.

Darter, M.I., L. Titus-Glover, H.L. Von Quintus. 2009. *Implementation of the Mechanistic-Empirical Pavement Design Guide in Utah: Validation, Calibration, and Development of the UDOT MEPDG User's Guide*. Research Report No. UT-09.11, Utah Department of Transportation, Salt Lake City.

Saito, M., and T.G. Jin. 2009. *Evaluating the Accuracy Level of Truck Traffic Data on State Highways*. Research Report No. UT-09.02. Utah Department of Transportation, Salt Lake City.

Seegmiller, L.W. 2006. "Utah Commercial Motor Vehicle Weigh-in-Motion Data Analysis and Calibration Methodology." Master's thesis, Department of Civil and Environmental Engineering, Brigham Young University.

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APPENDIX A. UTAH NEW HMA PAVEMENT DESIGN EXAMPLE

Reconstruction Project Design

This project is being designed as a reconstruction for a section of Utah State Route 36 from Mills Junction to I-80, Tooele County, Utah (west of Salt Lake City near the Great Salt Lake). The existing pavement will be removed and a new HMA structure constructed.

Design Life

The HMA pavement has a 20-year design life and the base will be constructed in the month of August 2010 (August 1st), the HMA in September 2010, and opened to traffic in October 2010 (October 1st).

Construction Requirements

Assuming a good quality of construction with stringent ride specifications, the pavement is expected to have an initial IRI of approximately 70 in/mile.

Analysis Parameters

The performance criteria were selected using Table 6 as a guide for a primary highway. At the end of the 20-year design life, the pavement will have no more than 20 percent alligator cracking at 90 percent reliability level and no more than 0.50 inch total rutting (mean of inner and outer wheelpath) at a reliability level of 90 percent. In addition, the smoothness should be maintained at an IRI of less than 169 in/mile at a reliability level of 90 percent. These criteria are all entered into the Performance Criteria window.

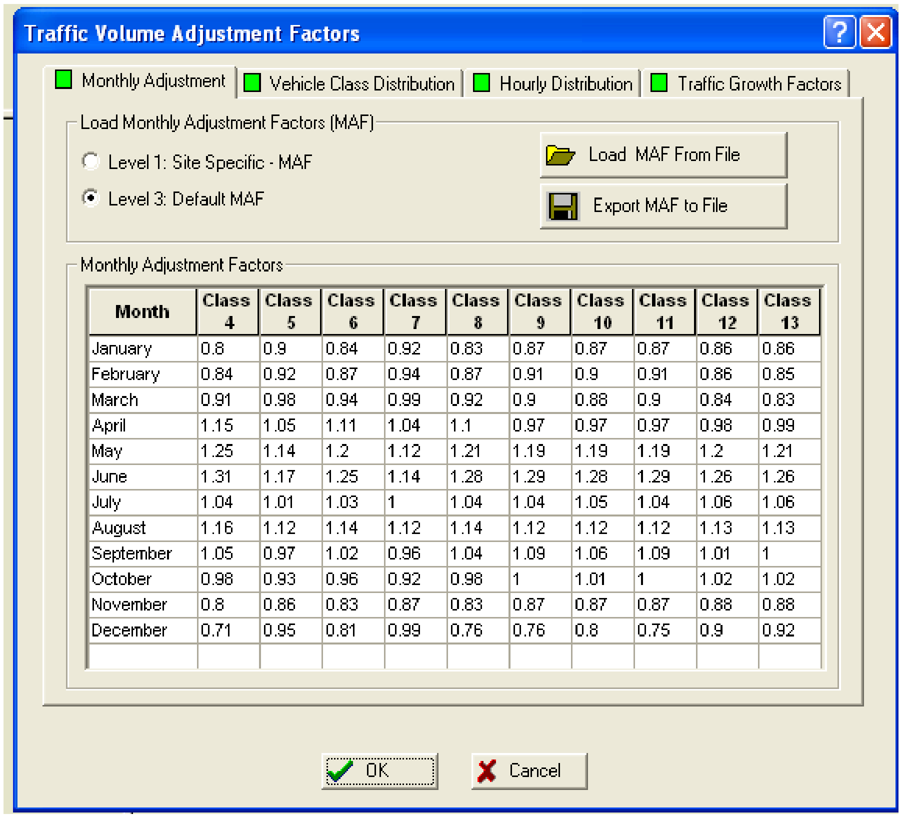
Traffic

WIM and ATR data were obtained for sites that were representative of the project site and used to develop project specific traffic inputs as follows:

- Volume adjustment factors. The initial two-way average annual daily truck traffic (AADTT) on this highway is estimated to be 2,000 trucks (Classes 4 through 13) during the first year of its service. This value will be adjusted using direction & lane adjustment factors. Specific inputs are as follows:
    - Initial two-way AADTT: 2,000
    - Directional distribution: 50 percent trucks in each direction.
    - Lane distribution: 90 percent trucks in outer design lane (2 lanes in design direction).

- Operational speed: 55 mph.

- Monthly volume adjustments are typically truck volume differences throughout the year. Monthly variations in truck traffic were measured and are included in the input screen shown in Figure A-1.



Month	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13
January	0.8	0.9	0.84	0.92	0.83	0.87	0.87	0.87	0.86	0.86
February	0.84	0.92	0.87	0.94	0.87	0.91	0.9	0.91	0.86	0.85
March	0.91	0.98	0.94	0.99	0.92	0.9	0.88	0.9	0.84	0.83
April	1.15	1.05	1.11	1.04	1.1	0.97	0.97	0.97	0.98	0.99
May	1.25	1.14	1.2	1.12	1.21	1.19	1.19	1.19	1.2	1.21
June	1.31	1.17	1.25	1.14	1.28	1.29	1.28	1.29	1.26	1.26
July	1.04	1.01	1.03	1	1.04	1.04	1.05	1.04	1.06	1.06
August	1.16	1.12	1.14	1.12	1.14	1.12	1.12	1.12	1.13	1.13
September	1.05	0.97	1.02	0.96	1.04	1.09	1.06	1.09	1.01	1
October	0.98	0.93	0.96	0.92	0.98	1	1.01	1	1.02	1.02
November	0.8	0.86	0.83	0.87	0.83	0.87	0.87	0.87	0.88	0.88
December	0.71	0.95	0.81	0.99	0.76	0.76	0.8	0.75	0.9	0.92

Figure A-1. Monthly adjustment factors for new HMA design example.

- Hourly truck distribution: The hourly truck distribution is only used for concrete pavements and not for asphalt pavements.

- Vehicle class distribution is the percent of each vehicle class in the traffic stream is an important input. Vehicle class distribution for this project was measured at an ATR site near the project. Specific inputs are shown in Figure A-2. This distribution is unusual in that the Class 5 single unit truck is the most common type of vehicle on this rural highway.

- Truck traffic growth is projected using a linear or compound model. Truck traffic has grown from 1 to over 10 percent on Utah highways over the years. For this project a compound growth rate of 2.8 % was determined after plotting past truck growth over time.

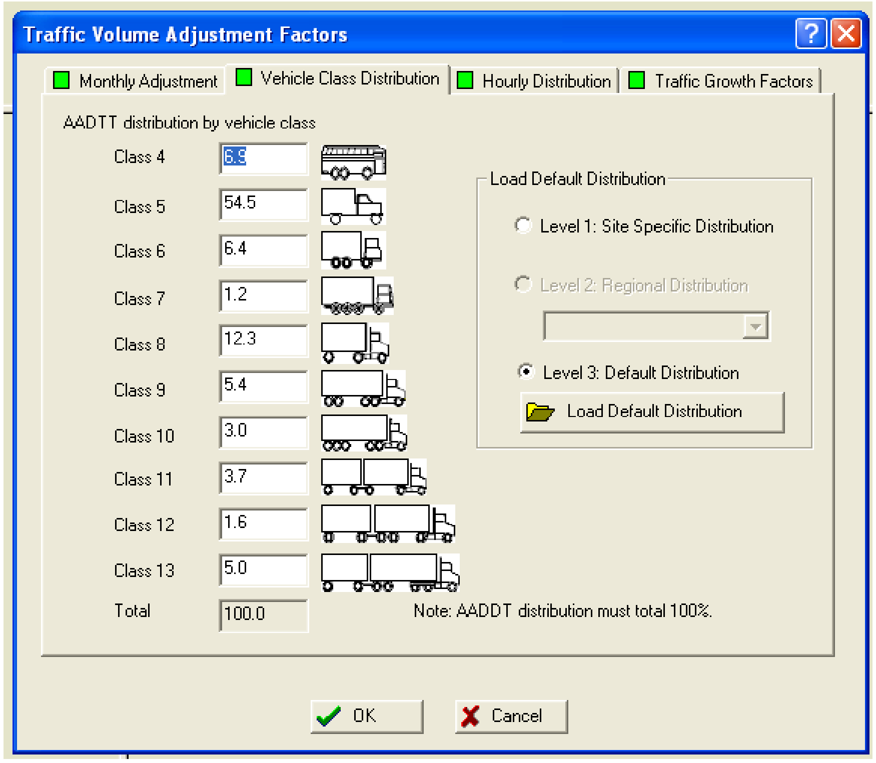


Figure A-2. Vehicle class distribution for new HMA design example.

- Axle load distribution. The axle load distribution is the most important traffic input. Damage is caused by the heavy single, tandem, tridem, and quad axle loads. The distributions were obtained from WIM equipment that is representative of this highway. A portion of the tandem axle distribution is shown in Figure A-3. The highest loads in these distributions appear to cause the majority of fatigue damage and permanent deformation to HMA pavement.

- General traffic inputs. These consist of lateral truck/wheel wander and number of axles per truck, axle configuration, and wheel base (see Figure A-4).
  - Lateral truck/wheel wander; three inputs are required here:
    - Mean wheel location (distance from outer edge of truck wheel to lane marking (paint stripe): 18-in (standard used in calibration)
    - Standard deviation of lateral truck wander: 10-in (standard used in calibration)
    - Design lane width: This distance is paint stripe to paint stripe. This is 12-ft.

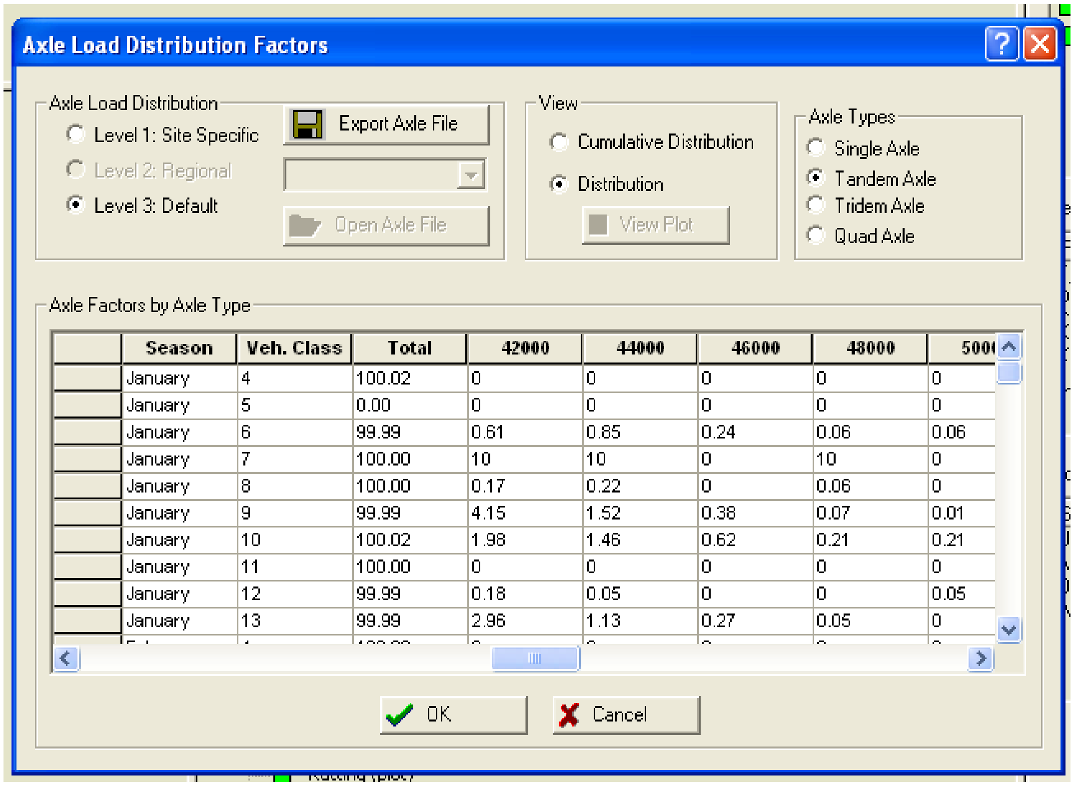


Figure A-3. Portion of tandem axle load distribution for new HMA design example.

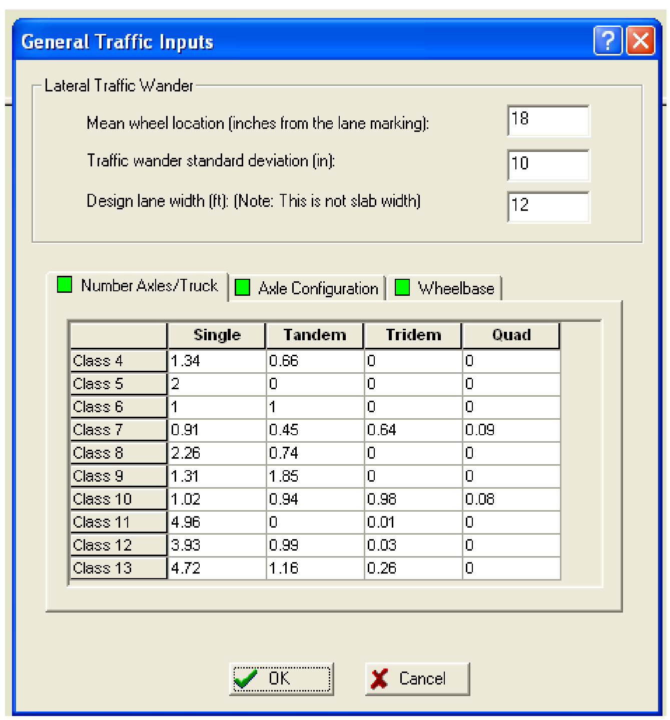


Figure A-4. Number of axles per truck for new HMA design example.

- Axles per truck: Mean number of axles per truck/vehicle class (see Figure A-4).

- Axle configuration: Axle width, spacing, and pressure (see Figure A-5).
  - Actual axle width (edge to edge of tire) outside dimensions: 8.5-ft, typical
  - Dual tire spacing: 12-in (typical used in calibration). Wide tires can only be considered in the Special Traffic Analysis routine in the MEPDG for HMA pavements.
  - Tire pressure: 120 psi, hot rolling pressure used in calibration.

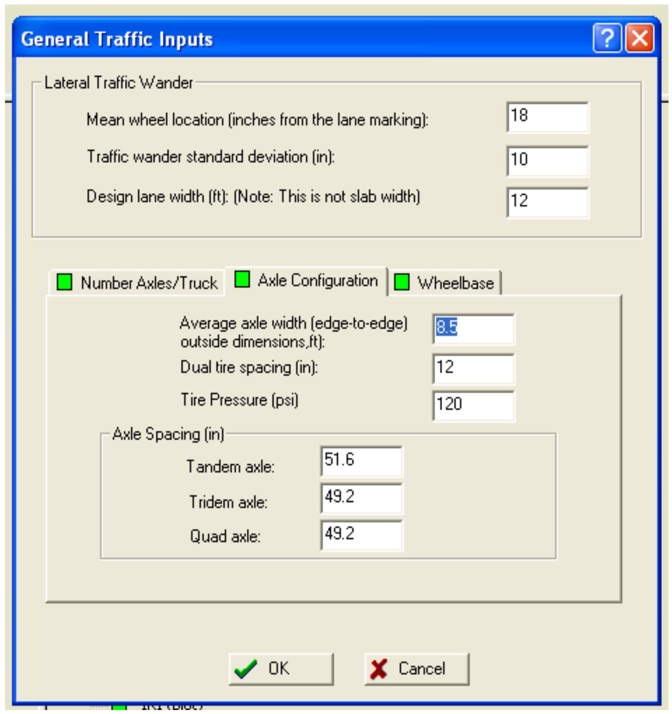


Figure A-5. Axle configuration for new HMA design example.

Climate Inputs

The project site is in the vicinity of Lake Point, Utah, close to the southern shore of the Great Salt Lake. The latitude and longitude of this site is as follows (obtain from various sources such as GPS units or Google Earth):

- Latitude: 40.41 degrees.minutes.
- Longitude: -112.16 degrees.minutes.

The designer enters the latitude and longitude and elevation into the MEPDG and uses the Interpolate Climate Data for Given Location button. The estimated depth of water table, in this case 25 ft, must also be entered before generating a climatic file for the project (see Figure A-6).

Note that the Utah Division of Water Rights has a well drilling database and geologic well logs available (http://www.waterrights.utah.gov/wellinfo/default.asp) which provide information on water depth or elevation observed in wells throughout the State. This resource, along with project geotechnical reports or the USDA-NRCS soil survey database, could also be used for estimating depth of water table for a pavement project site.

For this example, the closest weather station is at Salt Lake City International, 7 miles away and the next closest is 36 miles away as can be seen in the MEPDG screen (see Figure A-6). The question is: if there are multiple weather stations available, which should be selected for this design? In this case, the answer is obvious, the Salt Lake International Airport. It does not make any sense to combine other weather stations with this one. Thus, weather condition at Salt Lake International Airport was selected as appropriate climate for the project.

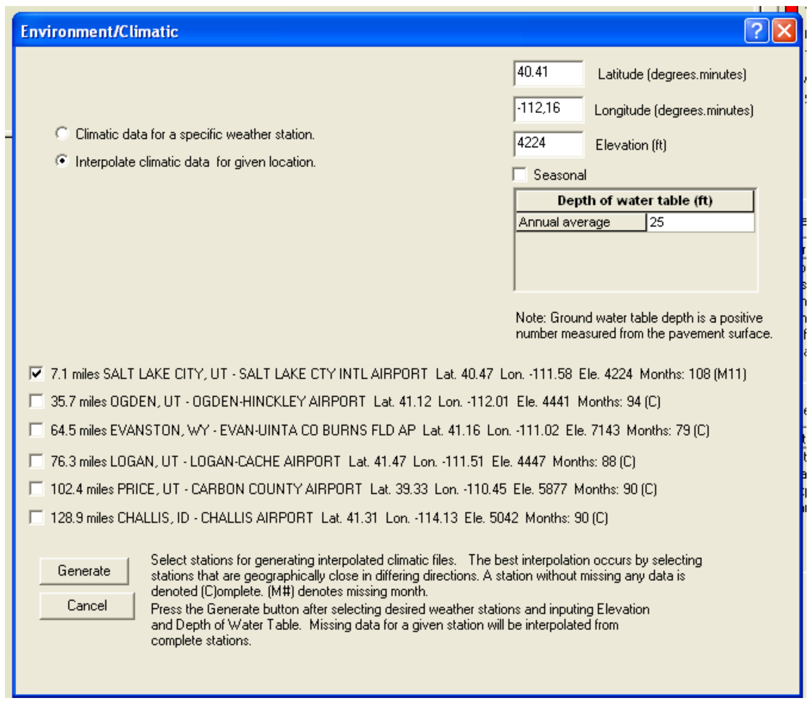


Figure A-6. Climate inputs for new HMA design example.

Note that the program also automatically creates a file called *climate.tmp* in the project directory. This is the file that the program reads hourly climatic information from during the analysis stage. This file contains the sunrise time, sunset time and radiation for each day of the design life period. In addition, for each 24-hour period in each day of the design life, the temperature, rainfall, air speed, sunshine, and depth of ground water table are also listed in the climate file.

By this stage, the user has completed the climatic inputs required by the program. The color-coded icons will have a green color for the traffic and climate and red icons for structure, indicating that the traffic and climate inputs are complete and structural inputs are yet to be addressed.

HMA Design Properties

The HMA dynamic modulus (E*) can be predicted by two different methods as shown on the input screen shown as Figure A-7. It is recommended to always use the NCHRP 1-37A Viscosity based model which was nationally calibrated.

The HMA Rutting Model Coefficients button should always be checked. The local calibration in Utah established that the rutting model was biased (over predicted) and new State calibration coefficients were established. These new values are entered into the Tools pull down bar as shown in Figures A-8 and A-9. Be sure to verify that the local calibration factors are used for each run by checking the MEPDG output Excel file "Inputs Summary" tab.

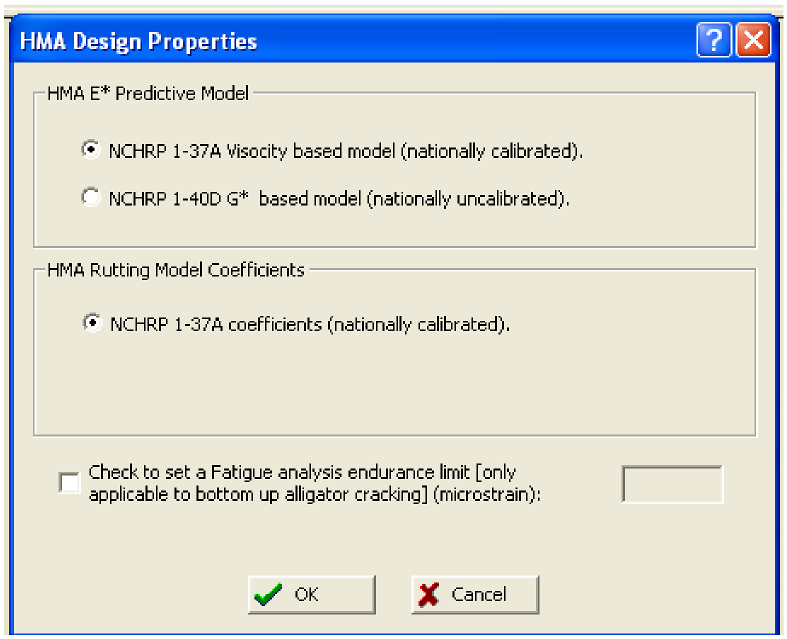


Figure A-7. Illustration of HMA design inputs.

There is also a box to check to set a fatigue analysis endurance limit for bottom up alligator cracking (see Figure A-7). This is intended for use for perpetual pavement design, but has never been calibrated. It is not recommended to use this approach. If a perpetual HMA pavement (or JPCP) is to be designed, the MEPDG can handle that very reasonably in the following way: structurally design the pavement for a long life, such as 50 years, for low fatigue damage criteria, such as 5 percent or less at a typically high level of reliability such as 90 percent or greater. The result will be a structurally adequate pavement whose surface can be renewed as needed.

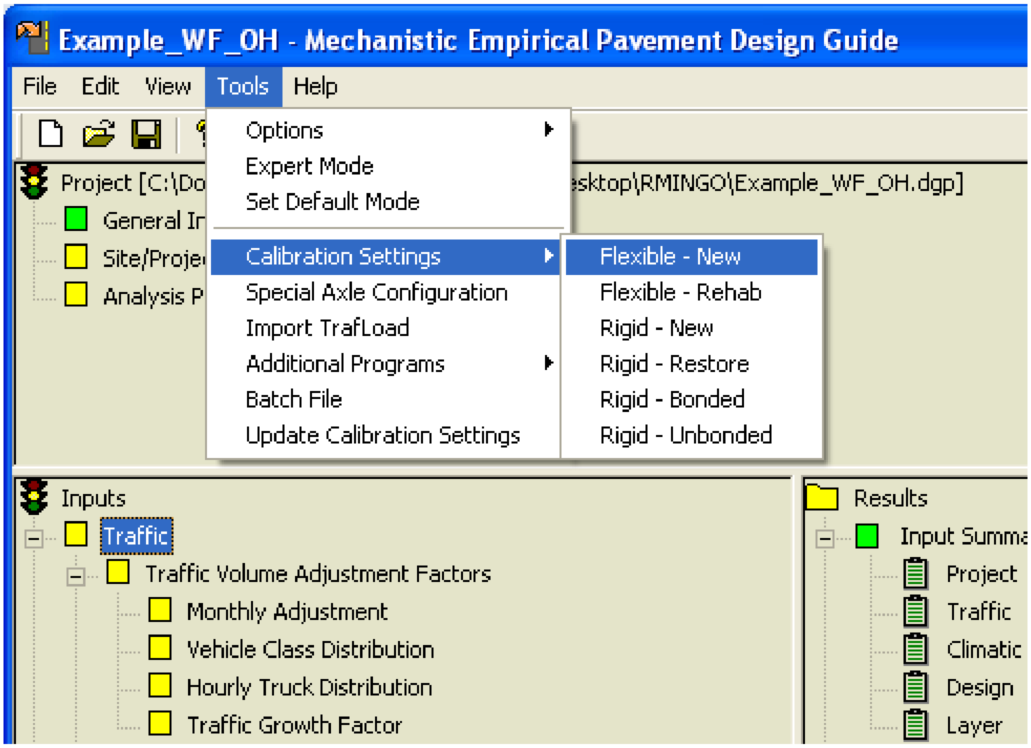


Figure A-8. Illustration of Utah tools tabs for providing local calibration factors.

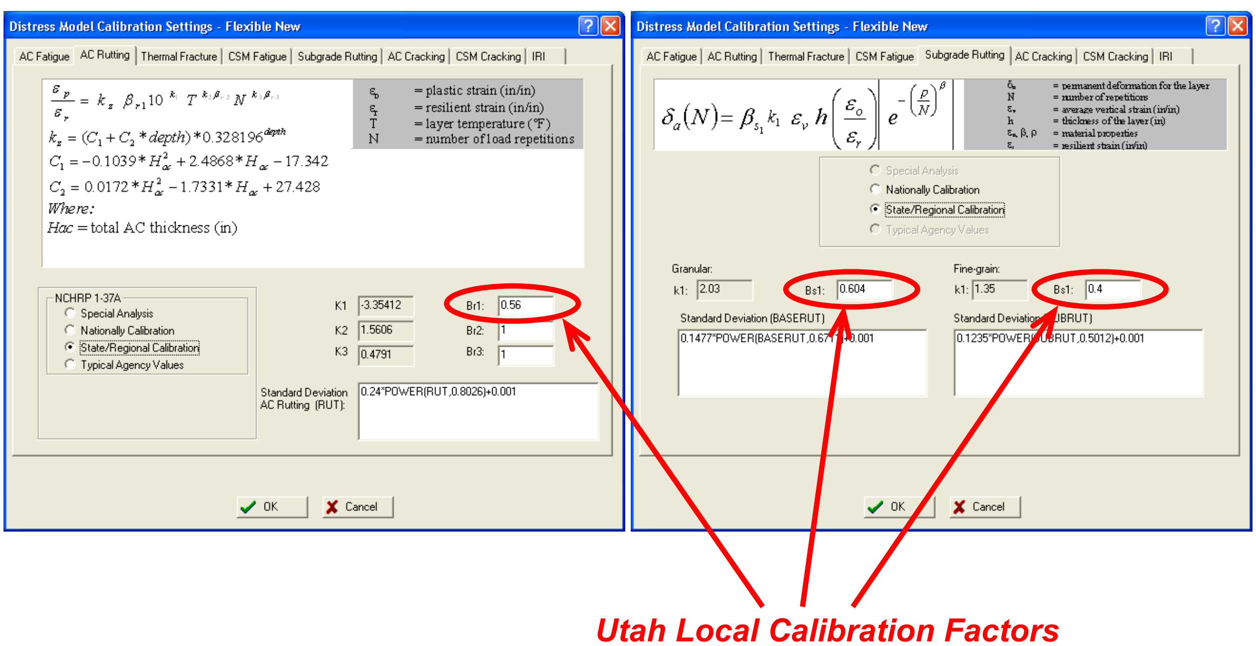


Figure A-9. Illustration of Utah rutting model local calibration factors in AC Rutting and Subgrade Rutting tabs (Br1=0.560 for HMA, Granular Bs1=0.604 for UTBC, and Fine-grain Bs1=0.400 for subgrade/embankment).

Structure and Layer Materials Definition

A set of structural and materials inputs are now selected forming the trial design that will be evaluated for its performance. The procedure is an iterative procedure and the user will have to develop a trial design and make several modifications to it, before a feasible and economic (or final) design is achieved. The trial design can be obtained using another design procedure (such as the AASHTO 1993) or an alternative of interest.

The thickness of HMA was varied from 6 to 9-in to obtain a design that passed all of the distress and IRI criteria. Note that the column labeled Interface has a 1, indicated full friction (see Figure A-10).

- 8-in HMA layer (total thickness of various sublayers).
- 4-in UTBC (unbound granular base course, A-1-a)
- 12-in GB (unbound granular borrow, A-1-a)
- Semi-infinite uncompacted (natural) subgrade layer (A-4 soil)

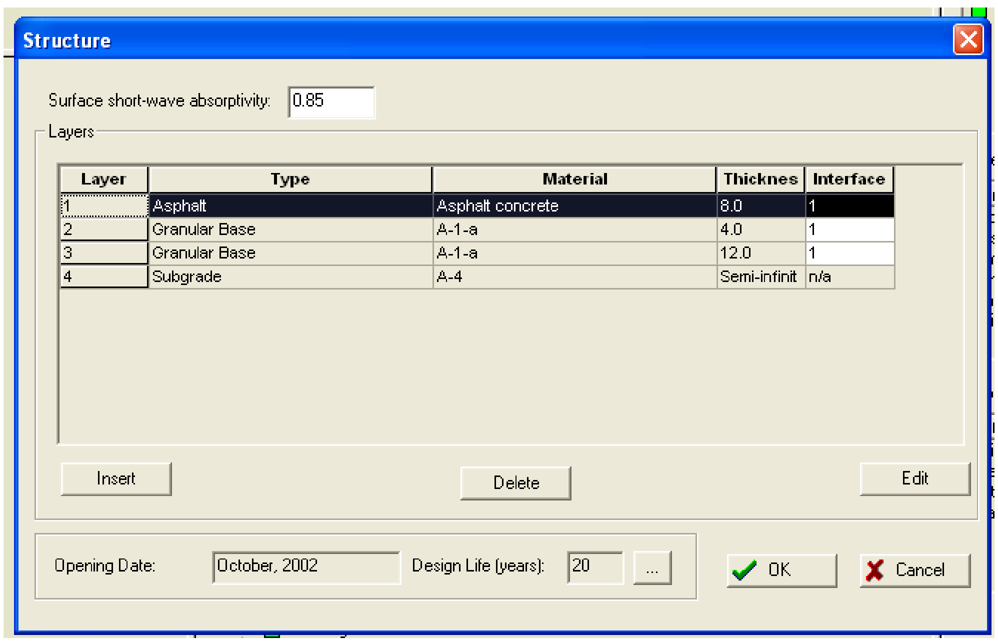


Figure A-10. Trial design structure definition for new HMA design example.

<u>Surface Shortwave Absorptivity HMA Surface</u>

Use the calibration standard of 0.85. This controls the flow of heat through the HMA. This value has been found to provide accurate temperature measurements through the HMA after it ages and the color turns gray.

Layer Materials Properties

HMA (Surface Layer)

Inputs required for the HMA layer is shown in the appropriate MEPDG input screens (see Figures A-11 through A-13). Note that the effective binder content is specifically for as-built volumetric conditions thus much higher than the gravimetric percentage normally used in practice. The air voids are in situ or as-built and are higher than the mix design air voids. Note that normally a thick layer will be divided into several layers and the MEPDG can handle this easily. For this example, only one HMA layer is included.

Base and Subbase (Granular Material) Layers

The untreated base course (UTBC) and granular borrow (GB) layers consist of unbound granular materials corresponding to an A-1-a AASHTO classification. Inputs for the UTBC layer are shown in Figure A-14. A CBR of 75 percent was used to estimate the resilient modulus. MEPDG defaults were used for the gradations.

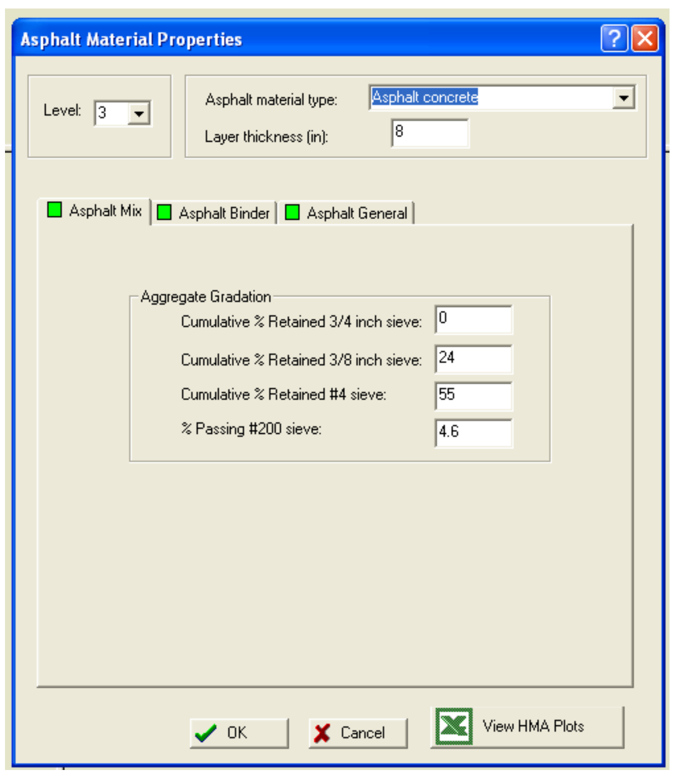


Figure A-11. HMA layer gradation for new HMA design example.

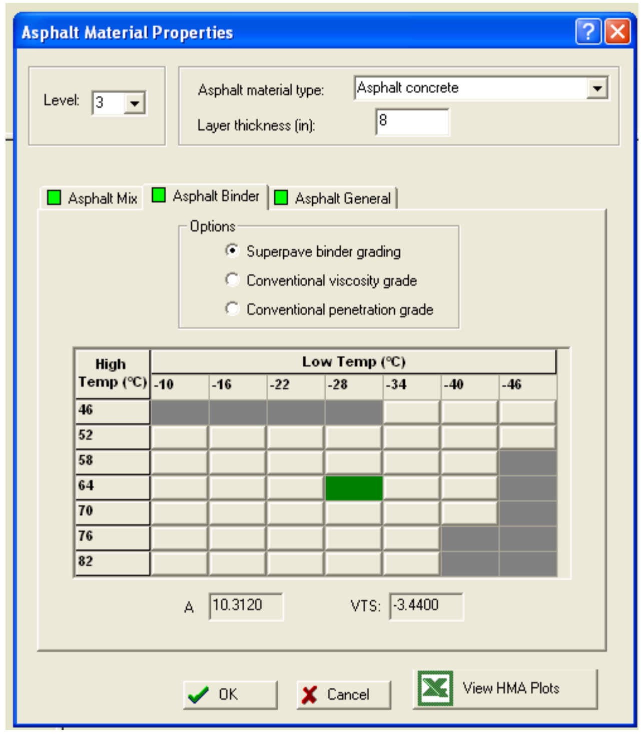


Figure A-12. HMA layer binder type selection for new HMA design example.

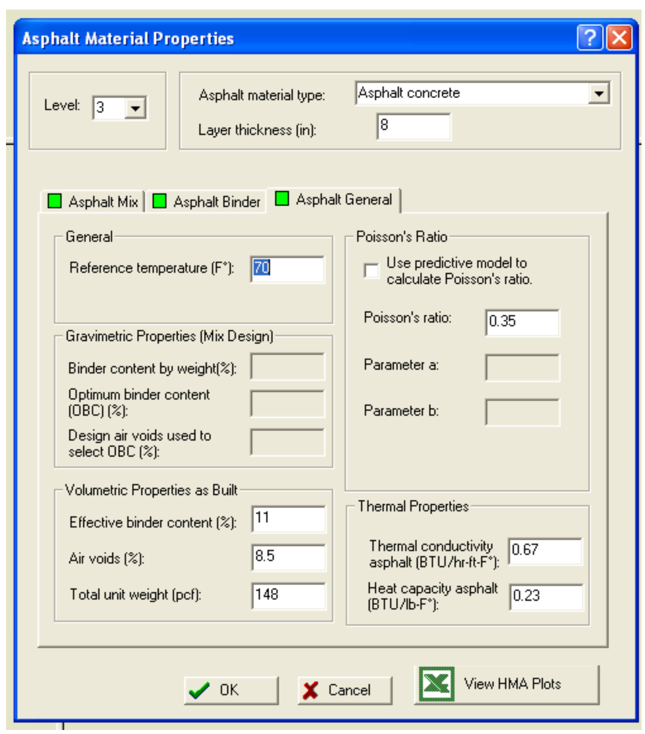


Figure A-13. HMA layer mix volumetric and temperature properties for new HMA design example.

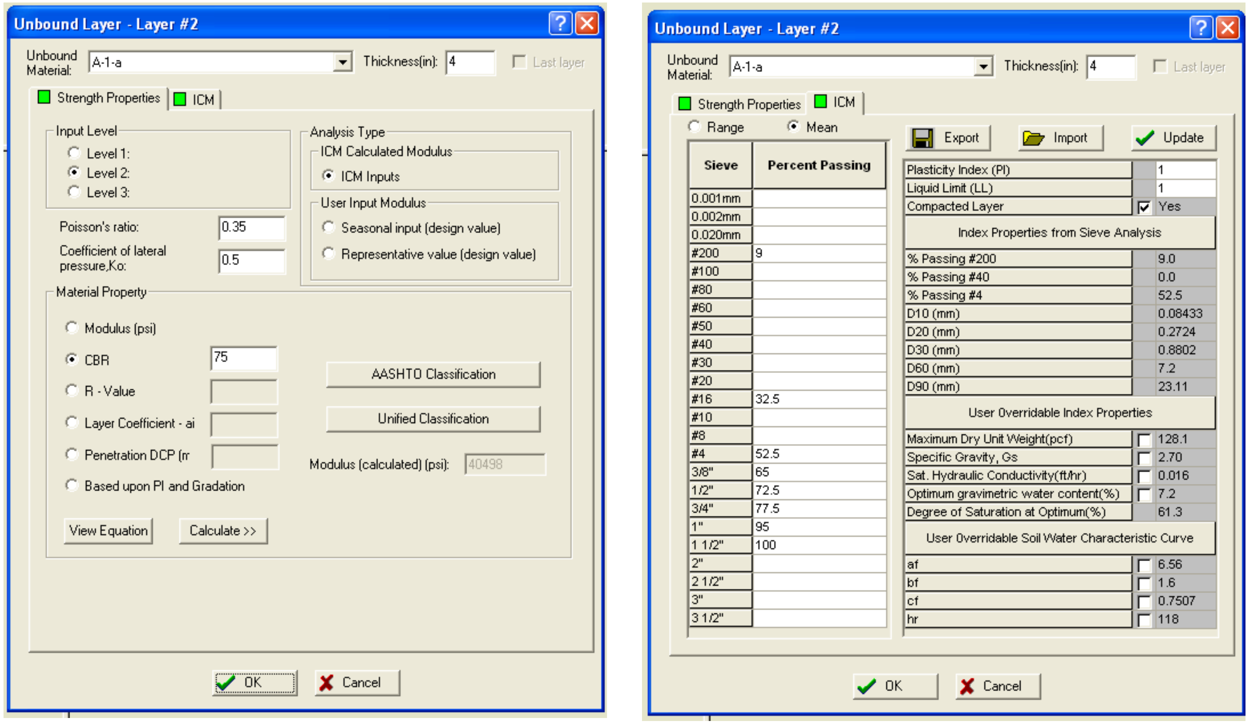


Figure A-14. UTBC properties for new HMA pavement design example.

Subgrade (Soil) Layer

The subgrade AASHTO classification and the laboratory resilient modulus (Mr) at optimum moisture content and density is the required input for the MEPDG. It is important to note that this input for Mr is at optimum moisture because the value is higher than what it would be wet of optimum which often occurs some time after placement and remains over its service life. In fact, the MEPDG moisture models (ICM) will usually show a decreased subgrade Mr after the first month or so in an area with higher precipitation and higher water table. Occasionally the opposite can occur with the Mr of the base/subbase or subgrade decreasing in moisture and increasing in Mr. The Mr is important because it is used to calculate the stresses and deflections with the elastic layered program. These are then used to compute fatigue damage and fatigue cracking and permanent deformation or rutting.

Information obtained from the county soil report (USDA-NRCS soil survey database) indicated an A-4 soil classification along much of this project. Inputs for the A-4 from the MEPDG defaults were used as shown in Figure A-15. The best way to estimate the subgrade Mr is to test with the FWD along the project. This was accomplished, the data examined and cleaned (outliers removed) and backcalculated modulus, Es, was computed using the AASHTO outer sensor (at 60 in) procedure.

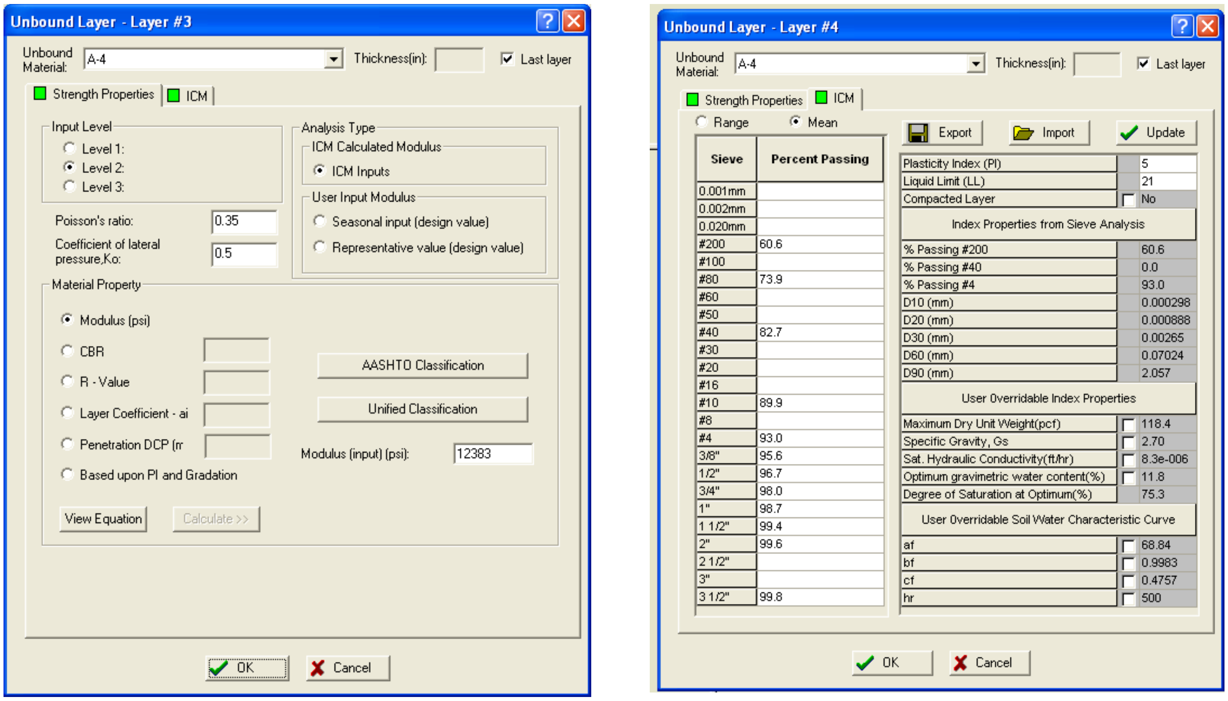


Figure A-15. Subgrade soil strength and other properties for new HMA design example.

Here is an example calculation of the subgrade elastic modulus for one point along the project:

$$Es = 0.24\ P\ /\ d\ S = 0.24 * 9850\ /\ 0.00175 * 60 = 22{,}514\ \text{psi}$$

Where: P = FWD load in lbs.
d = Deflection at spacing S from the loading plate, in
S = Spacing to outer sensor, in

This was a fine grained A-4 soil, and thus the adjustment factor to reduce this elastic modulus from a "field" to a "lab" Mr and then to a Mr at optimum moisture content is 0.55.

$$\text{Mr (lab value at optimum moisture)} = 0.55 * 22{,}514 = 12{,}383\ \text{psi}$$

Figure A-16 shows a plot of the Mr along the project. The mean Mr along the project was 12,383 psi and this will be used as the input to the MEPDG for this design. Note that if Level 3 default had been assumed, a value of 16,500 psi would have been obtained. This could make a difference in the design.

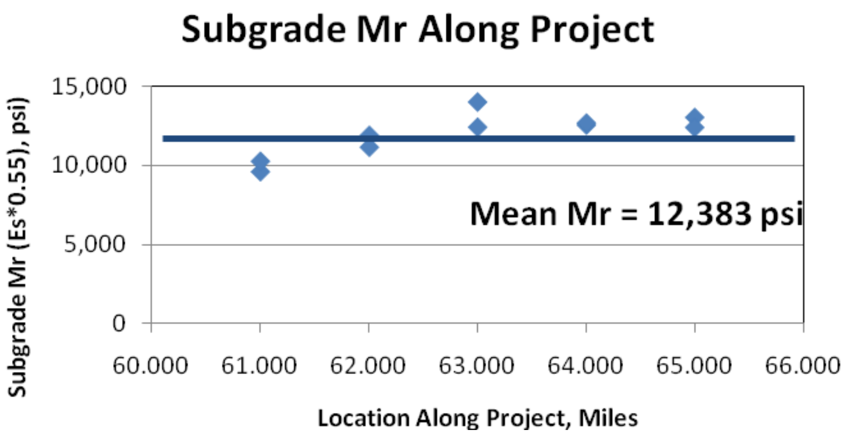
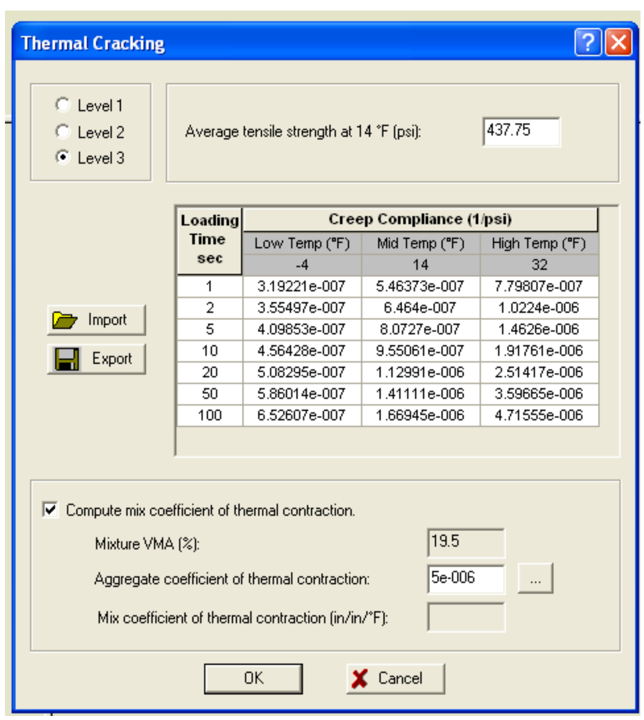


Figure A-16. Profile of subgrade Mr along the project as determined by backcalculation and then multiplying by the 0.55 (A-4 fine grained soil) to obtain the mean input for the MEPDG of 12,383 psi.

Thermal (Transverse) Cracking

Low temperature transverse cracking is predicted by the MEPDG using data shown in Figure A-17. For level 3, all of the inputs are estimated from various models.



Loading Time sec	Creep Compliance (1/psi)		
	Low Temp (°F) -4	Mid Temp (°F) 14	High Temp (°F) 32
1	3.19221e-007	5.46373e-007	7.79807e-007
2	3.55497e-007	6.464e-007	1.0224e-006
5	4.09853e-007	8.0727e-007	1.4626e-006
10	4.56428e-007	9.55061e-007	1.91761e-006
20	5.08295e-007	1.12991e-006	2.51417e-006
50	5.86014e-007	1.41111e-006	3.59665e-006
100	6.52607e-007	1.66945e-006	4.71555e-006

Figure A-17. HMA thermal cracking properties (creep compliance, indirect tensile strength, coefficient of thermal contraction) for new HMA design example.

As mentioned in the MEPDG design manual and the October 2009 UDOT MEPDG local calibration report, it is strongly recommended that the creep compliance test along with the indirect tensile strength be used for a specific HMA mixture. This is the only way to ensure accuracy in prediction of the amount of low temperature cracking in the MEPDG.

Run MEPDG to Predict Trial Design Performance over Design Period

After all design inputs are provided and all inputs are colored green (as shown below), the MEPDG software can begin the analysis process to predict the performance of the trial design over the 20-year design life of the pavement. Click on *Run Analysis*. The program runs the Traffic, Climate, Thermal Cracking, HMA Analysis, and Summary/IRI models and reports the analysis status on the upper right hand corner of the screen (see Figure A-18). At the end of the analysis, the program creates a summary file and other output files in the project directory, C:\DG2002\Projects\. The summary file is in a MS Excel format and is named after the input MEPDG filename. A description of the summary file content is presented later in this section.

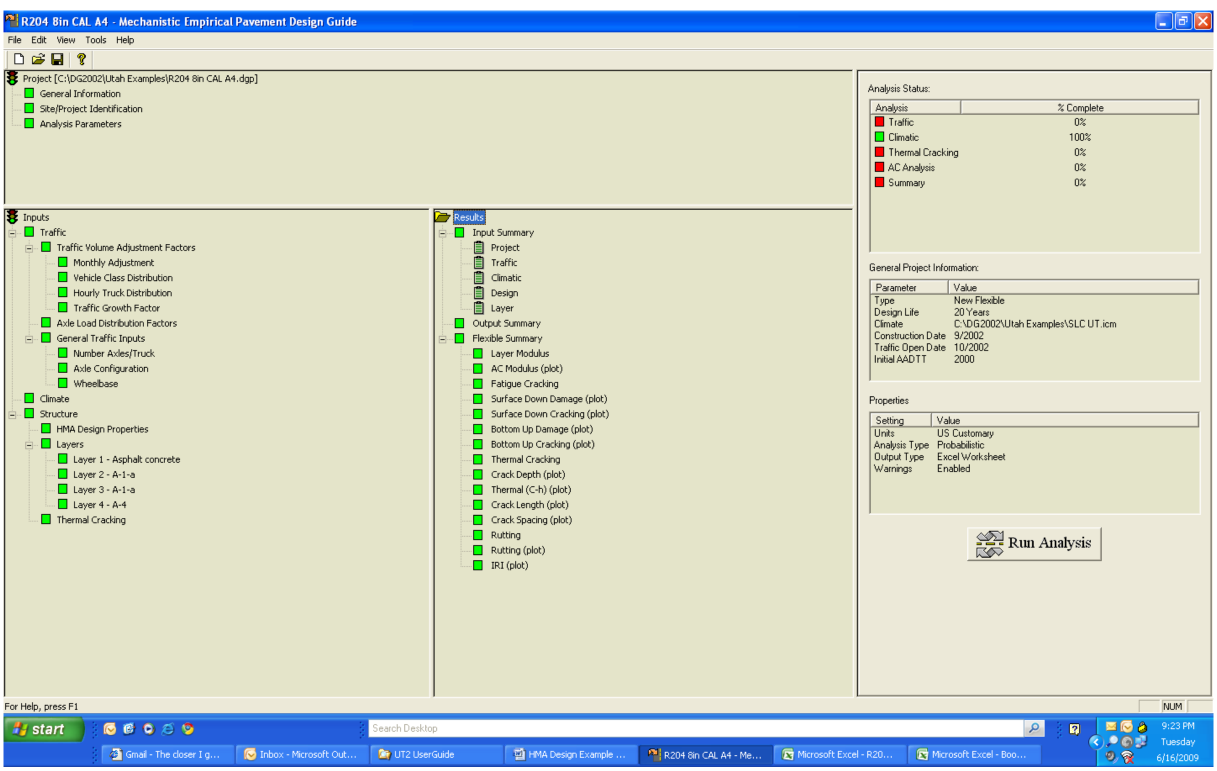


Figure A-18. MEPDG program layout screen after completing all inputs.

Modified Utah Rutting Calibration Factors

The rutting model coefficients were adjusted as noted in Figure A-9. Make sure that these locally established coefficients are input before making the run and check if they were used by checking the MEPDG output (under the Input Summary tab).

The summary file contains the following important tabs:

- **Input summary.** Should be reviewed carefully to ensure proper inputs have been entered.
- **Climate.** Identification of the weather station(s) used and climate summary data. Review carefully to ensure that the data looks reasonable and that major errors do not exist in the weather station data.
- **Reliability summary.** This gives an overall answer as to the adequacy of the design. Does the HMA pavement "Pass" all of the distress types and IRI criteria at the desired level of reliability? If not, prepare a new trial design and rerun.
- **Distress summary.** This table gives a nice summary by month of key modulus and distress and IRI outputs throughout the design period. Check carefully for reasonableness of each column.
- **Layers modulus.** Gives a detailed output of all modulus values for the HMA, base, subbase and subgrade. Review for reasonableness.
- **HMA modulus graph.** Shows HMA E* over time for each layer.
- **Fatigue cracking.** Detailed top down and bottom up fatigue damage.
- **Bottom up damage graph.** Plot of alligator cracking over time.
- **Thermal cracking length.** Plot of accumulating thermal cracking in ft/mile.
- **Transverse crack spacing.** Plot of decreasing thermal transverse crack spacing over time.
- **Total rutting.** Provides graph of total rutting mean and at reliability level plus permanent deformation of each layer in the pavement.
- **IRI.** Provides the mean 50 percentile and the Reliability curve for IRI over the design life.

The Distress Summary sheet in the output file provides a month by month overall summary of the HMA trial design for the project including critical material properties, traffic, and distress data. Detailed data for each distress type is provided on separate sheets as noted above. The distress summary sheet shown in Table A-1 indicates that this pavement carried 8.6 million heavy trucks in the design lane over the design period (the first month showed 26,197 trucks) and this provides an overall idea of the traffic loading on the pavement. During the first month of traffic, October, alligator cracking, transverse cracking, subtotal HMA Rutting, Total Rutting, and IRI are as shown in the table. They all increase over time and traffic as shown up to 20 years. All of these values look reasonable over the 20 year period.

Table A-1. Distress summary output worksheet for trial new HMA pavement design for the 8-in HMA trial design.

Predicted distress: Project Utah HMA Example 02

Pavement age			Alligator Cracking	Transverse Cracking	Subtotal AC Rutting	Total Rutting	IRI	Heavy Trucks
mo	yr	Month	(%)	(ft/mi)	(in)	(in)	(in/mi)	(cumulative)
1	0.08	October	0.0042	0	0.004	0.017	70.7	26197
2	0.17	November	0.0065	0	0.005	0.018	70.8	49566
3	0.25	December	0.0082	0	0.005	0.018	70.8	73599
4	0.33	January	0.01	0	0.005	0.019	70.8	97562
5	0.42	February	0.0119	0	0.005	0.019	70.9	122202
6	0.5	March	0.0149	0	0.005	0.02	70.9	148102
7	0.58	April	0.0189	0	0.006	0.021	71	176955
8	0.67	May	0.0258	0	0.01	0.027	71.3	209022
9	0.75	June	0.0378	0	0.021	0.039	71.8	242398
10	0.83	July	0.0512	0	0.033	0.053	72.4	270459
11	0.92	August	0.0656	0	0.04	0.061	72.8	301343
12	1	September	0.0748	0	0.042	0.062	72.9	328823
13	1.08	October	0.0811	0	0.042	0.063	72.9	355754
14	1.17	November	0.0838	0	0.042	0.063	73	379776
15	1.25	December	0.0855	0	0.042	0.063	73	404482
16	1.33	January	0.0871	0	0.042	0.063	73.1	429116
17	1.42	February	0.0889	0	0.042	0.063	73.1	454447
18	1.5	March	0.0913	0	0.042	0.063	73.2	481072
19	1.58	April	0.0977	0	0.042	0.064	73.3	510732
20	1.67	May	0.108	0	0.044	0.066	73.4	543697
21	1.75	June	0.124	0	0.05	0.072	73.7	578007
22	1.83	July	0.14	0	0.059	0.082	74.2	606855
23	1.92	August	0.156	0	0.065	0.088	74.5	638603
24	2	September	0.165	0	0.066	0.089	74.6	666852
Etc. over 20 years design life…								
239	19.9	August	2.48	0	0.228	0.261	110.8	8611580
240	20	September	2.5	0	0.229	0.262	111	8658020

- Alligator cracking: percent area of lane, all severities.
- Transverse cracking: ft/mile (divide by 12 to determine no. cracks/mile), all severities.
- AC rutting: mean total rutting, average of both wheel paths (wire line definition).
- IRI: mean of both wheelpaths.
- Heavy Trucks: design lane, Class 4 to 13, cumulative over time.

The Reliability Summary tab (see Table A-2) of the MEPDG output shows the information below. For the given trial design, the terminal IRI, HMA Bottom Up Cracking, HMA Thermal Fracture, and Permanent Deformation Total are each compared to their design criteria. UDOT only considers these performance criteria. For this project run of HMA of 8-in, all distress and IRI meet the design criteria at the level of design reliability.

Table A-2. Reliability Summary Tab new HMA pavement design.

Project: R204 8in Reliability Summary					
Performance Criteria	**Distress Target**	**Reliability Target**	**Distress Predicted**	**Reliability Predicted**	**Acceptable**
Terminal IRI (in/mi)	169	90	111	96.85	Pass
HMA Bottom Up Cracking (Alligator Cracking) (%):	20	90	2.5	96.83	Pass
HMA Thermal Fracture (Transverse Cracking) (ft/mi)	1267	90	1	99.999	Pass
Permanent Deformation (Total Pavement) (in)	0.50	90	0.26	99.9	Pass

Plots showing alligator cracking, rutting, and IRI are also given in the MEPDG output (see Figures A-19 through A-21). For cracking, rutting, and IRI, the top curve is distress or IRI predicted at the specified reliability level of 90 percent. The 50 percentile or mean model prediction is the curve directly under the top curve. Note that for rutting these two curves represents total rutting and not rutting in the individual pavement layers. .

As shown in Figures A-19 through A-21, the 90 percent reliability curve for rutting, alligator cracking, and IRI are all below the critical line indicating that all meet the selected performance criteria at this level of design reliability. This design adequately meets the design criteria.

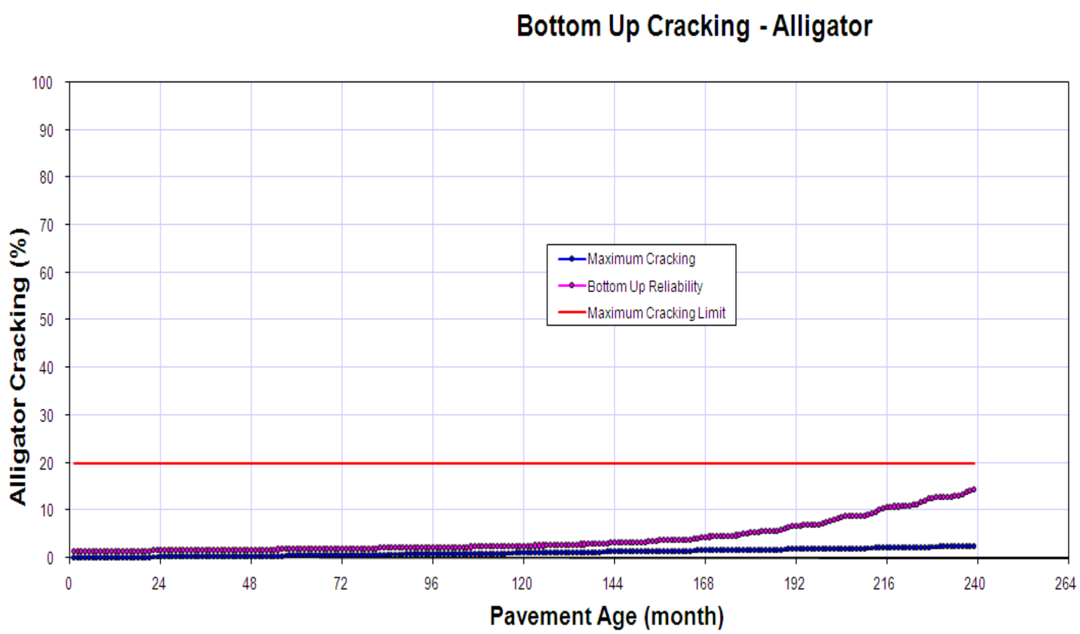


Figure A-19. Plot showing alligator cracking, percent lane area over time. The horizontal red line is the design criteria of 20 percent, the dark blue lower curve is mean 50 percent prediction, and the darker red curve is 90 percent reliability level.

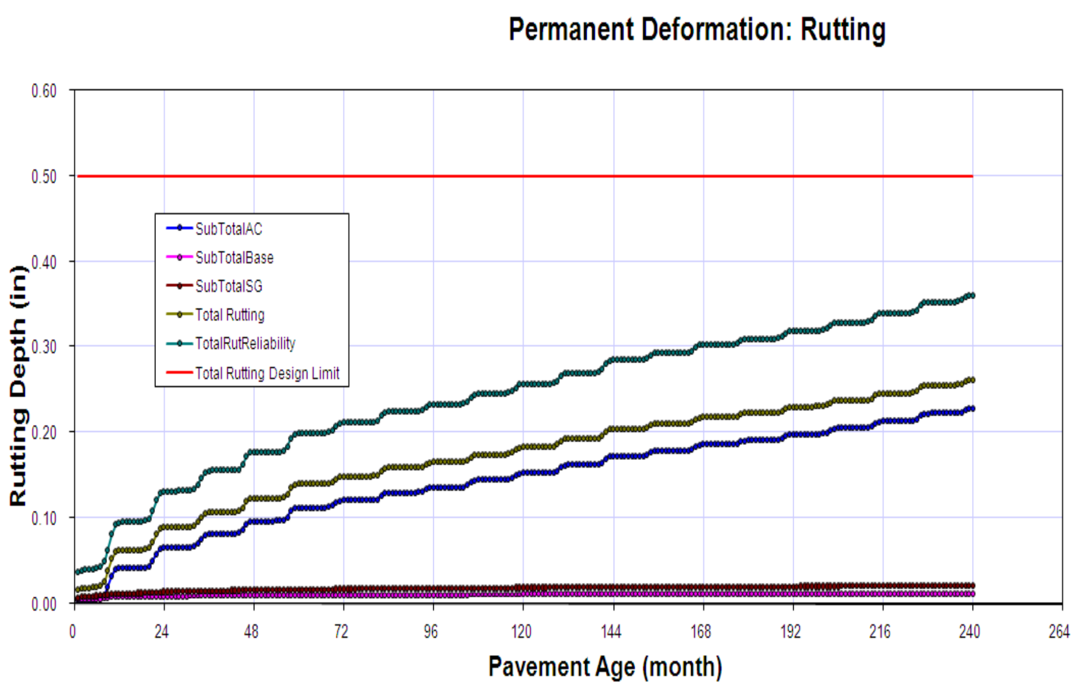


Figure A-20. Permanent deformation or rutting over time. The horizontal red line is the design criteria of 0.50-in, top curve is the 90 percent reliability level, second curve down is mean 50 percent total rutting prediction, third curve down is the HMA rutting, and lower two curves are unbound base/subbase and subgrade.

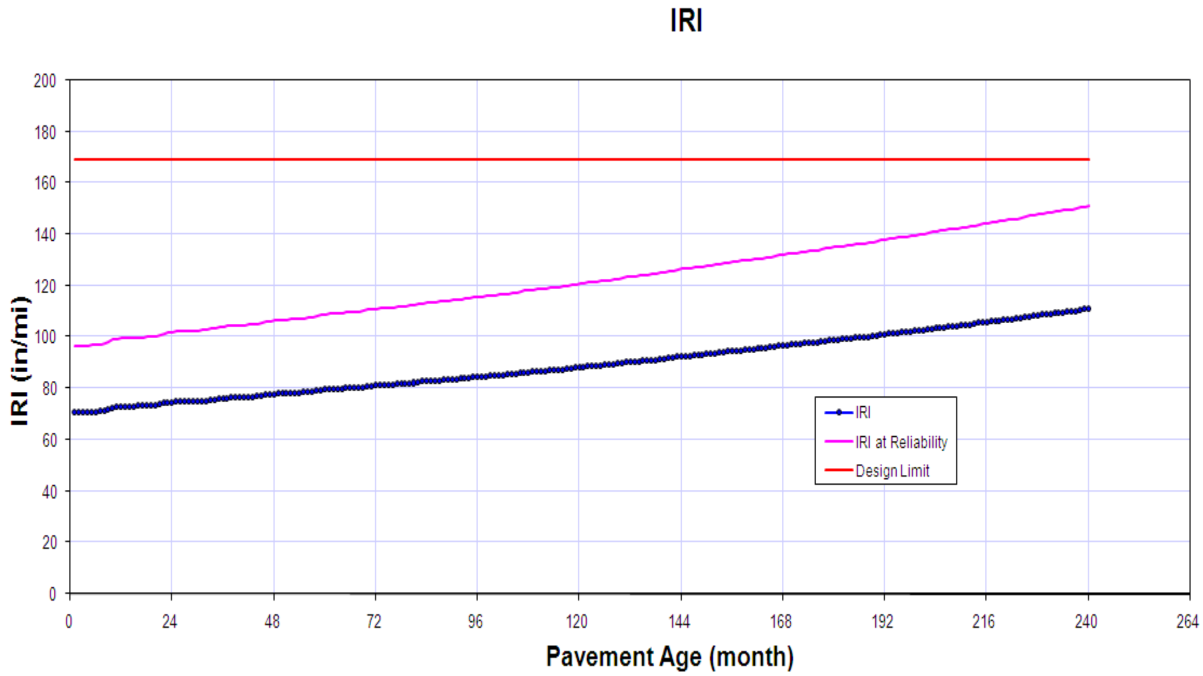


Figure A-21. Plot showing predicted IRI over the design life of the 8-in HMA pavement. The design criterion of 169 in/miles is met by the top curve at 90 percent reliability. Note that top curve is the 90 percentile and the lowest curve is the mean 50 percentile prediction curve.

Modify Trial Design

The designer usually has to try several trial designs to arrive at an acceptable or optimal design. For this design, trial HMA thickness values of 6, 7, 8, and 9-in were run. These trial designs showed the following results.

- 6-in HMA: Failed fatigue alligator cracking, barely passed other criteria.
- 7-in HMA: Failed fatigue alligator cracking.
- 8-in HMA: Passed all criteria.
- 9-in HMA: Passed all criteria, overdesign.

Through the modification of layer thickness and material properties various other alternative designs can be evaluated. Once a design passes all of the criteria it can be considered a feasible alternative that can be subjected to a cost analysis and compared to other alternatives.

APPENDIX B. UTAH NEW JPCP DESIGN EXAMPLE

Reconstruction Project Design

This project is being designed as a reconstruction for a section of Interstate 15 in Juab County, Utah. The existing pavement will be removed and a new JPCP structure constructed.

Design Life

The jointed plain concrete pavement (JPCP) has a 30-year design life and will be constructed in the month of May 2010 (May 1st) to be opened to traffic in June 2010 (June 1st).

Construction Requirements

Assuming a good quality of construction with stringent ride specifications, the pavement is expected to have an initial IRI of approximately 70 in/mile.

Analysis Parameters

It is expected that at the end of the 30-year design life, the pavement will have no more than 10 percent slabs with transverse cracking and no more than 0.12 inch faulting both distresses at a reliability level of 95 percent. In addition, the smoothness should be maintained at an IRI of less than 169 in/mi at a reliability level of 95 percent. These criteria are all entered into the Performance Criteria window of the MEPDG software.

Traffic

There exists a WIM site near this project so Level 1 traffic inputs were readily available.

<u>Truck Volume and Axle Volume Estimates</u>

- **Volume Adjustment Factors.** The initial two-way average annual daily truck traffic (AADTT) on this highway is estimated to be 3,000 trucks (Classes 4 through 13) during the first year of its service. This value will be adjusted through several volume adjustment factors. These include:
    - **Directional distribution:** 50 percent trucks in each direction.
    - **Lane distribution:** 90 percent trucks in outer design lane.
    - **Monthly volume adjustments:** There are typically truck volume differences throughout the year. Monthly variations in truck traffic are summarized below. These slight variations typically do not typically have a significant effect on pavement performance, except for unusual

situations of recreational highways and farm to market roads. Values used are shown below and were obtained from the nearby WIM site (see Figure B-1).

- **Hourly truck distribution:** Truck volume varies over a 24-hour period. The following values were used in the analysis. This affects PCC pavement performance (see Figure B-2).

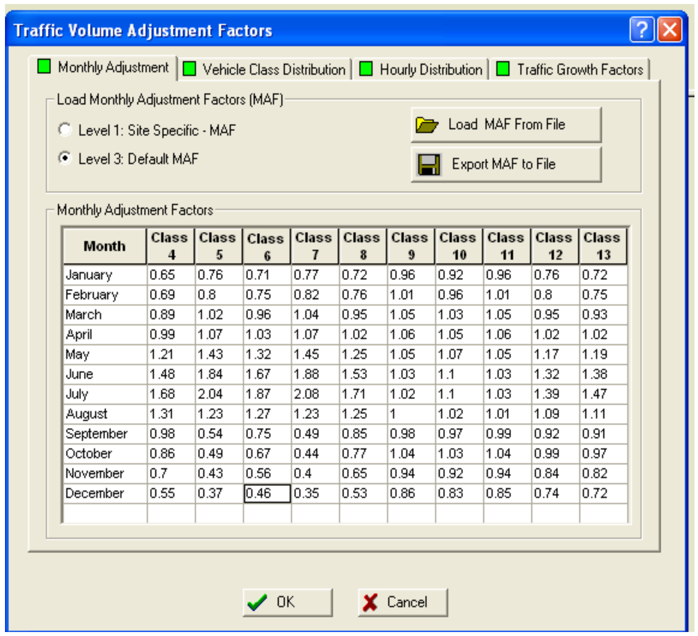


Figure B-1. Monthly adjustment factors for new JPCP trial design.

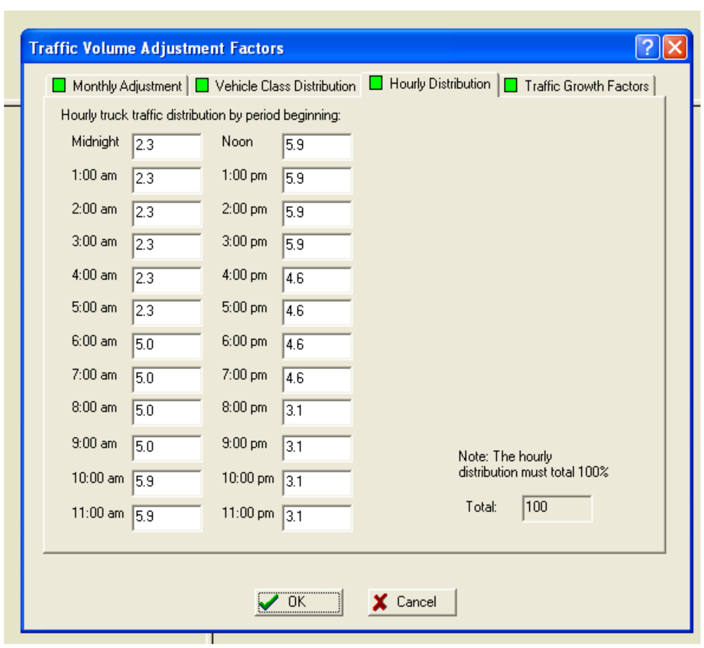


Figure B-2. Hourly distribution factors for new JPCP trial design.

- **Vehicle class distribution:** The percent of each vehicle class in the traffic stream is an important input. These are shown in Figure B-3 for this project as measured at the WIM site near the project. The Class 9 truck is the most common type of vehicle on this rural highway.
- **Truck traffic growth:** Truck traffic has grown from 1 to over 10 percent on Utah highways over the years. For this project a linear growth rate of 4.0 % was determined after plotting past truck growth over time.
- **Axle load distribution.** The axle load distribution is the most important traffic input. Damage is caused by the heavy single, tandem, tridem, and quad axle loads. The distributions used were those of the national defaults (derived from LTPP) provided with the Design Guide software for each vehicle class, axle type, load category, and months of the year (see Figure B-4). The WIM measured values were close to the national defaults. The highest loads in these distributions appear to cause the majority of fatigue damage to JPCP.

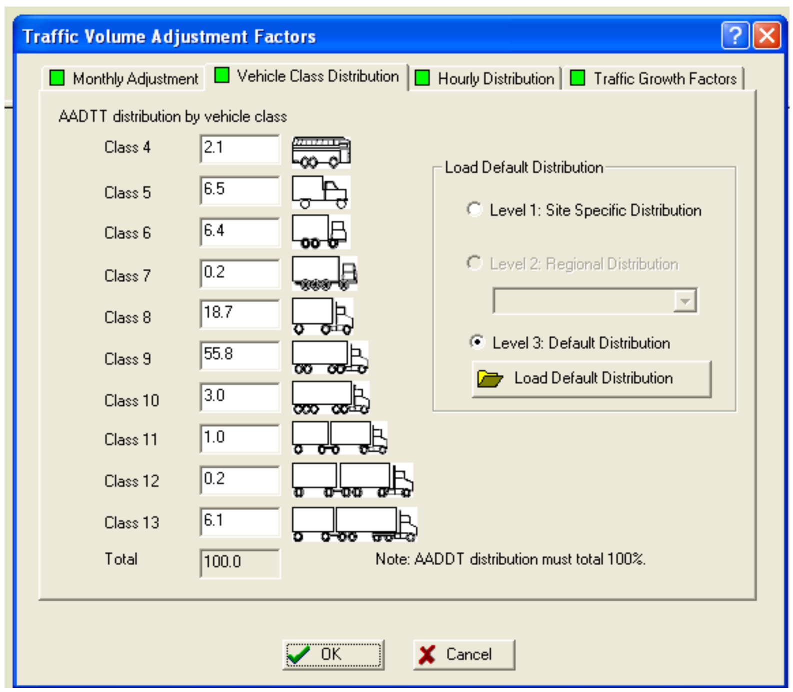


Figure B-3. Vehicle class distribution factors for new JPCP trial design.

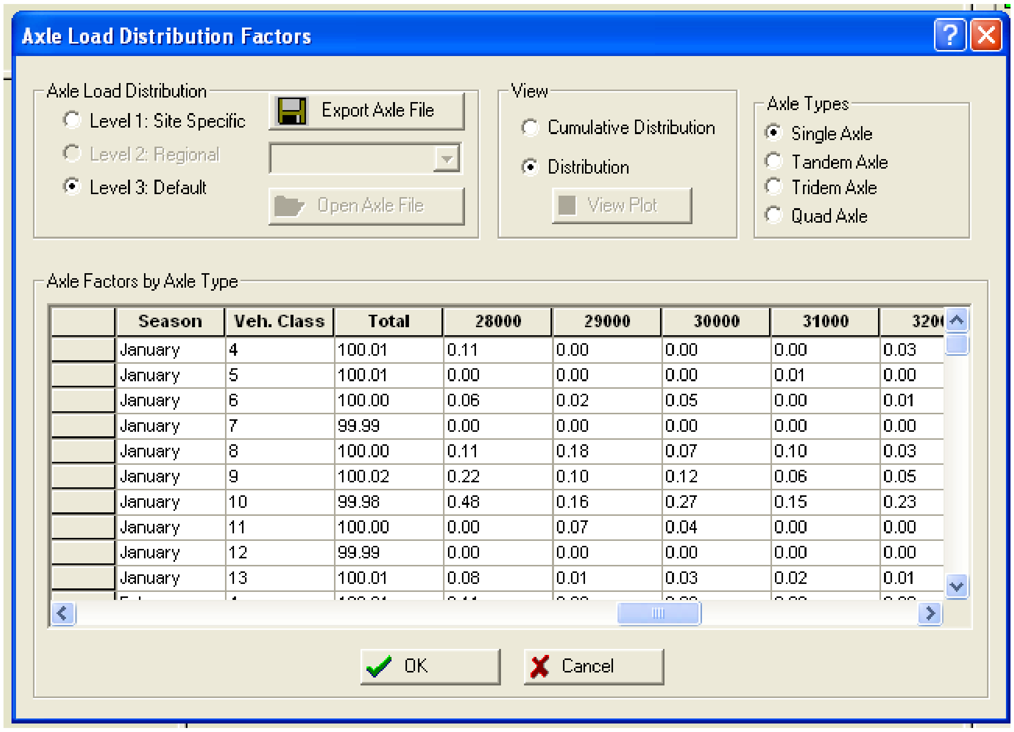
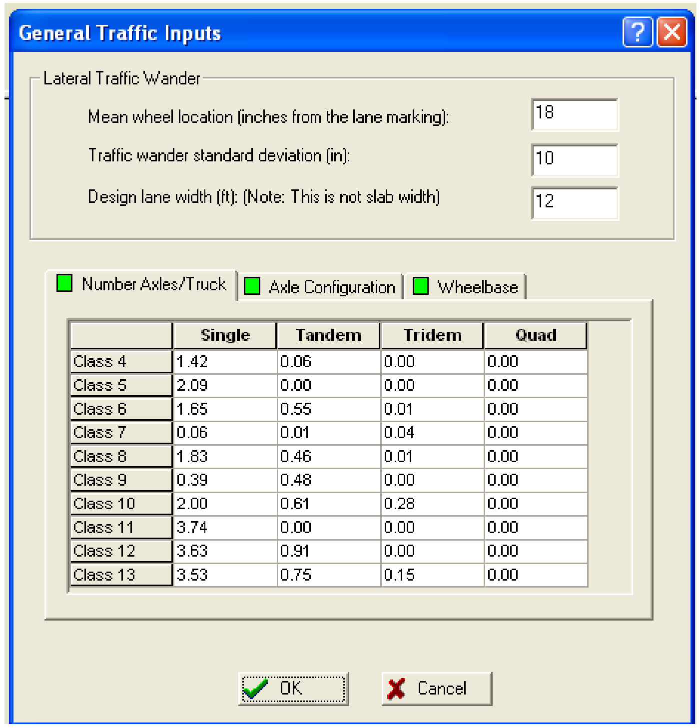


Figure B-4. Partial axle load distribution for single axles for new JPCP trial design.

<u>General Traffic Inputs</u>

These consist of lateral truck/wheel wander, number of axles per truck, axle configuration, and wheel base.

- **Lateral truck/wheel wander:** Three inputs are required here as shown in Figure B-5.
    - Mean wheel location (distance from outer edge of truck wheel to lane marking (paint stripe): 18-in (standard used in calibration)
    - Standard deviation of lateral truck wander: 10-in (standard used in calibration)
    - Design lane width: This distance is paint stripe to paint stripe. It is not slab width as measured from longitudinal joint to longitudinal joint. This is 12-ft.
- **Axles per truck:** Mean number of axles per vehicle/truck class (see Figure B-5).
- **Axle configuration:** Axle width, spacing, and tire pressure are required as shown in Figure B-6.
    - Actual axle width (edge to edge of tire) outside dimensions: 8.5-ft, typical
    - Dual tire spacing: 12-in (typical used in calibration).
    - Tire pressure: 120 psi, hot rolling pressure used in calibration.



	Single	Tandem	Tridem	Quad
Class 4	1.42	0.06	0.00	0.00
Class 5	2.09	0.00	0.00	0.00
Class 6	1.65	0.55	0.01	0.00
Class 7	0.06	0.01	0.04	0.00
Class 8	1.83	0.46	0.01	0.00
Class 9	0.39	0.48	0.00	0.00
Class 10	2.00	0.61	0.28	0.00
Class 11	3.74	0.00	0.00	0.00
Class 12	3.63	0.91	0.00	0.00
Class 13	3.53	0.75	0.15	0.00

Figure B-5. Number of axles per truck for new JPCP trial design.

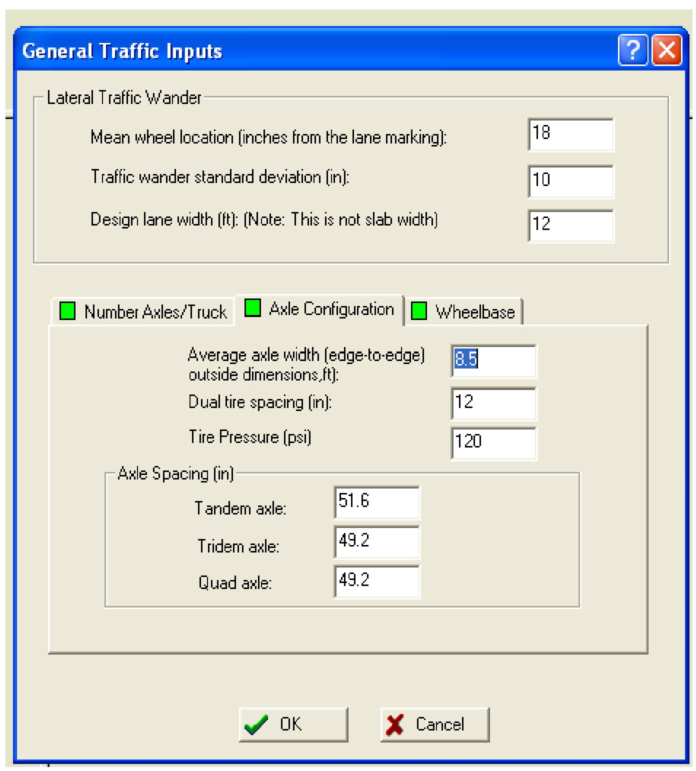


Figure B-6. Axle configuration for new JPCP design example.

- **Wheel base:** This dimension refers to the distance from the steering axle and the next axle of the truck tractor and ranges from less than 12 to more than 20 ft. Three typical spacing have been used: short (11 to 13.5-ft), medium (13.5 to 16.5-ft, and long (16.5 to 20-ft) (see Figure B-7). These data were measured for limited Utah traffic conditions. Wheel base distribution affects top down cracking of JPCP.

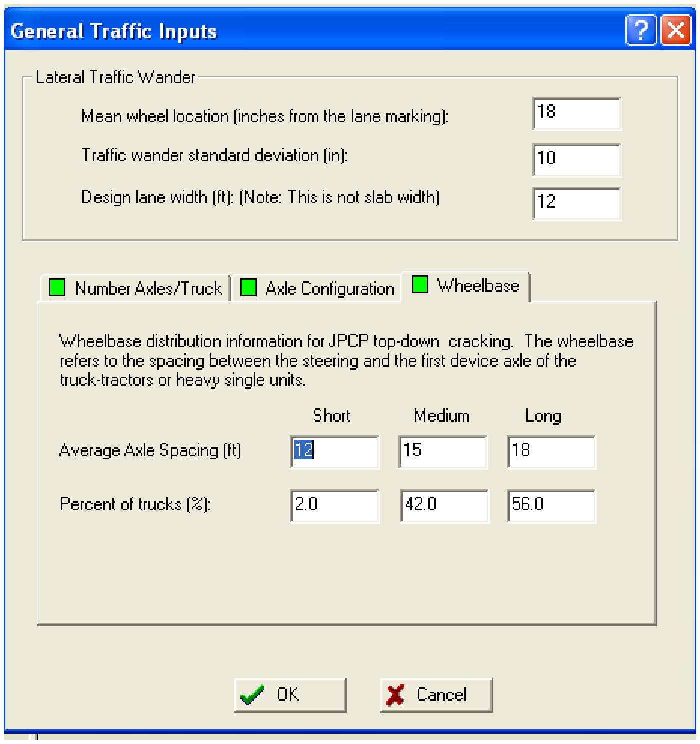


Figure B-7. Wheelbase dimensions for new JPCP design example.

Climate Inputs

The project site is in the vicinity of Nephi, Utah. The latitude and longitude of this site is as follows (obtain from various sources such as GPS units or Google Earth):

- Latitude: 39.40 degrees.minutes.
- Longitude: -111.51 degrees.minutes.

The designer enters the latitude and longitude and elevation into the MEPDG and uses the Interpolate Climate Data for Given Location button. The estimated depth of water table must also be entered before generating a climatic file for the project (see Figure B-8).

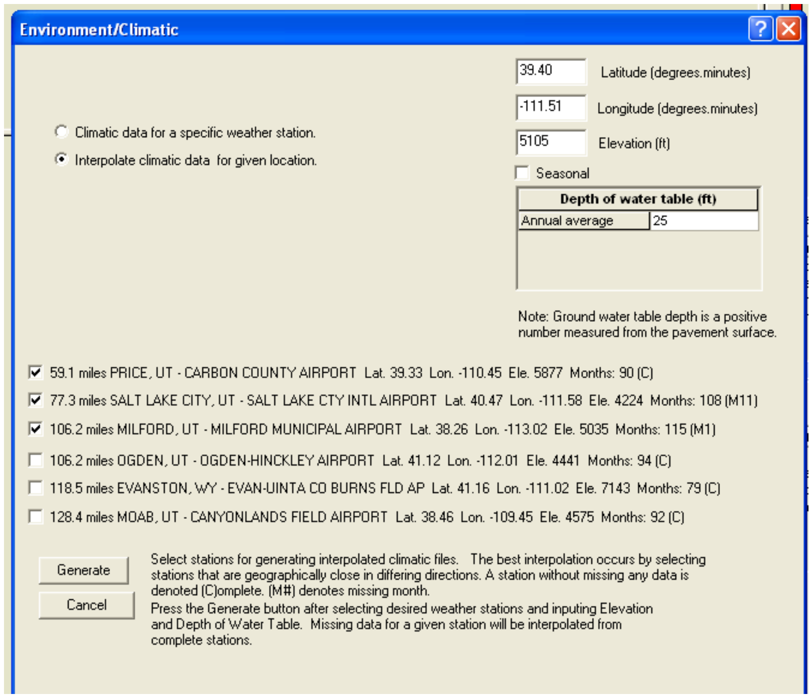


Figure B-8. Climate inputs for new JPCP design example.

Checking in the MEPDG weather station database, the closest weather stations are shown in Figure B-8 and are many miles from the project site. The question is: what one or multiple weather stations should be selected for the design? In this case, three stations were selected and a virtual weather station generated: Price, Salt Lake City, and Milford as the most representative. A name is given to this virtual weather station similar to the project name. Note that the program also automatically creates a file called *climate.tmp* in the project directory. This is the file that the program reads hourly climatic information during the analysis stage. This file contains the sunrise time, sunset time and radiation for each day of the design life period. In addition, for each 24-hour period in each day of the design life, the temperature, rainfall, air speed, sunshine, and depth of ground water table are also listed in the climate file.

By this stage, the user has completed the climatic inputs required by the program. The color-coded icons will have a green color for the traffic and climate and red icons for structure, indicating that the traffic and climate inputs are complete and structural inputs are yet to be addressed.

The design could be run with each individual station, two virtual stations, or three virtual stations to see if a significant difference is obtained in the design thickness. This was done and the results show that while the individual distress predictions change somewhat between different weather stations and virtual stations, the overall design thickness and other features did not change significantly. Of course, this may not occur in all cases and it may be wise to check different stations to see if they make a difference.

Structure and Layer Material Definition

A set of structural and materials inputs are now selected forming the trial design that will be evaluated for its performance. The procedure is an iterative procedure and the user will have to develop a trial design and make several modifications to it, before a feasible and economic (or final) design is achieved. The trial design can be obtained using another design procedure (such as the AASHTO 1993) or an alternative of interest. For this example, the following trial design structure and layer material types were selected:

- 12.0-in JPCP layer, 12-ft wide, 15-ft transverse perpendicular joint spacing.
- 6-in unbound granular base course.
- 6-in unbound granular subbase course.
- Semi-infinite uncompacted (natural) subgrade layer.

The JPCP slabs in the trial design will have a transverse joint spacing of 15 feet and 1.5-in diameter dowels (selected as approximately slab thickness divided by 8, or 12/8 = 1.5-in) across the transverse joints spaced at 12-in. The joints will have a liquid sealant. The shoulders will be tied concrete and will be placed separately, thus giving an estimated long term joint load transfer efficiency of 50 percent.

Design Features

The following design features inputs are required (see also Figure B-9):

- Slab thickness: 12-in trial
- Permanent curl/warp effective temperature difference (degrees F): -10 degrees F. This was established during national calibration and worked well for the Utah local calibration.
- Joint spacing: 15-ft perpendicular (UDOT standard)
- Sealant type: liquid
- Dowel diameter: 1.5-in trial
- Dowel spacing: 12-in

- Edge support, tied PCC shoulder long term joint load transfer efficiency: 50 percent, since PCC shoulder will be placed separately
- Base Erodibility: 4, fairly erodible unbound granular
- PCC base interface friction: full friction over design life, or 360 months (30 years)

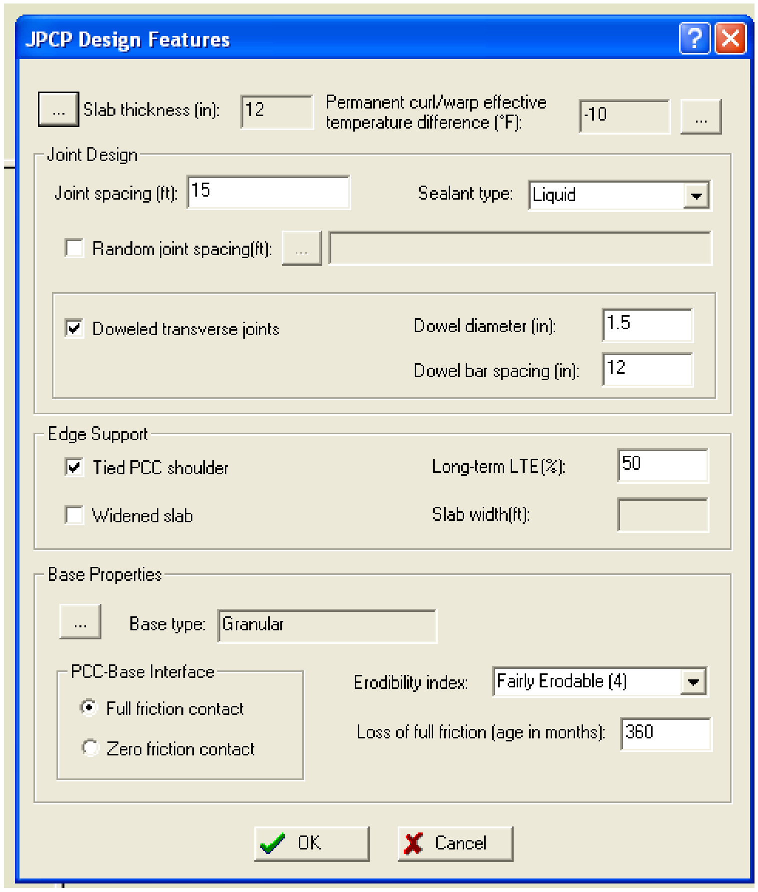


Figure B-9. Design features inputs for new JPCP design example.

Pavement Layers Material Properties

PCC (Surface Layer)

Inputs for the General and Thermal, Mix, and Strength Properties of the PCC slab are presented in Figures B-10 through B-12. For Surface Shortwave Absorptivity PCC Surface, the calibration standard of 0.85 was used. This controls the flow of heat through the slab. This value has been found to provide accurate temperature measurements through the slab as the white slabs change into gray with aging.

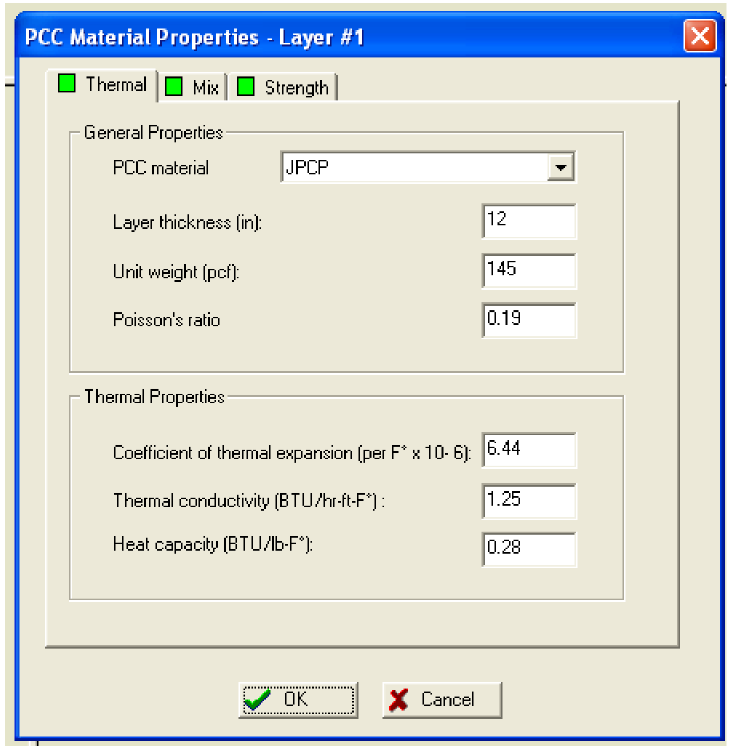


Figure B-10. PCC general and thermal properties inputs for new JPCP design example.

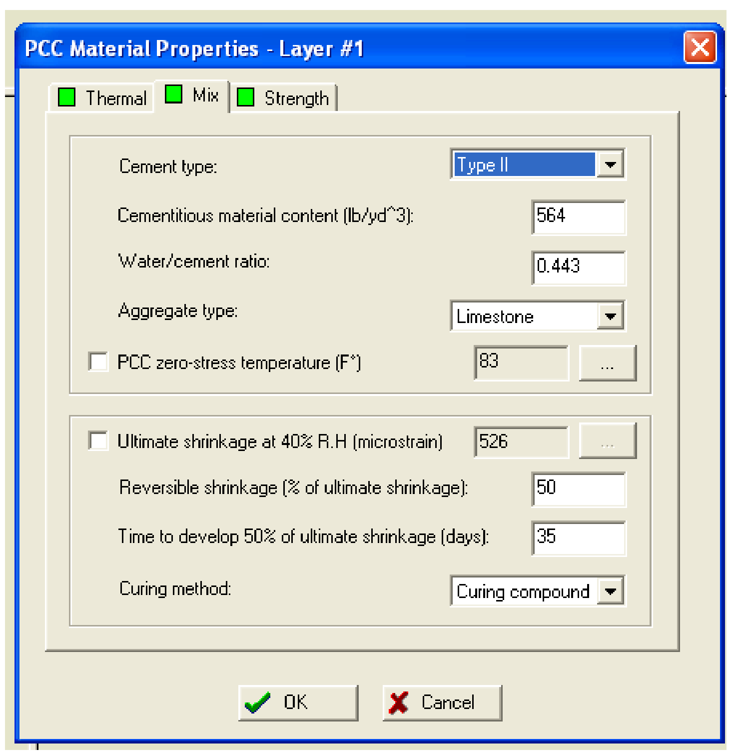


Figure B-11. PCC mix properties inputs for new JPCP design example.

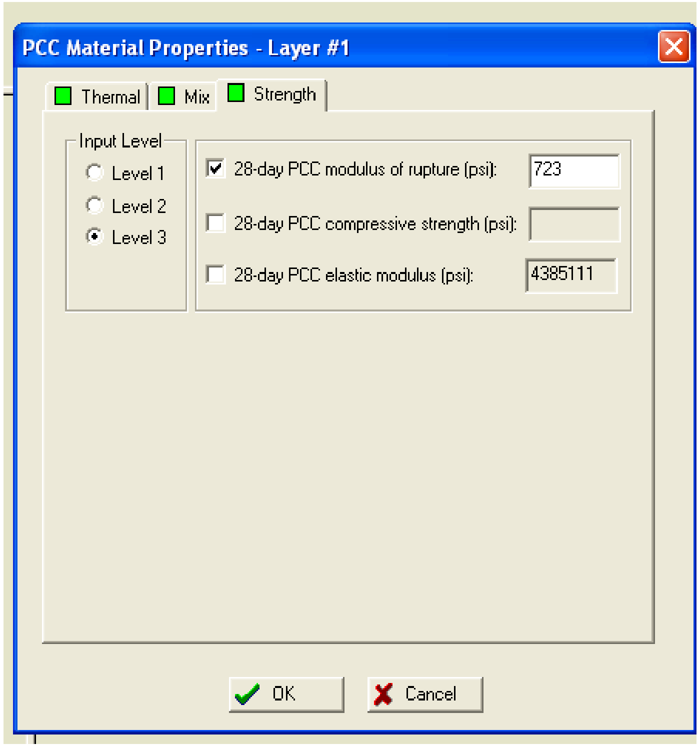


Figure B-12. PCC strength properties inputs for new JPCP design example.

Inputs for concrete strength and modulus are critical. These values must be selected as means and not specification limits. The variation of strength and modulus is included in the design reliability considered through the model error residuals. Strength should not be reduced below the mean regularly achieved in the field. A mean 28-day modulus of rupture of 723 psi is used as recommended for Level 3.

<u>Base and Subbase Layers</u>

The base and subbase layers consist of unbound granular materials corresponding to an A-1-a AASHTO classification. Inputs for the base layer are given in Figure B-13.

<u>Subgrade Soil Layer</u>

The subgrade AASHTO classification and the laboratory resilient modulus (Mr) at optimum moisture content is the required input for the MEPDG. This input along with the moduli of each layer is used in the program to backcalculate a subgrade k-value for each month. This modulus is used to calculate the stresses and deflections, incremental fatigue damage, and incremental cracking and joint faulting.

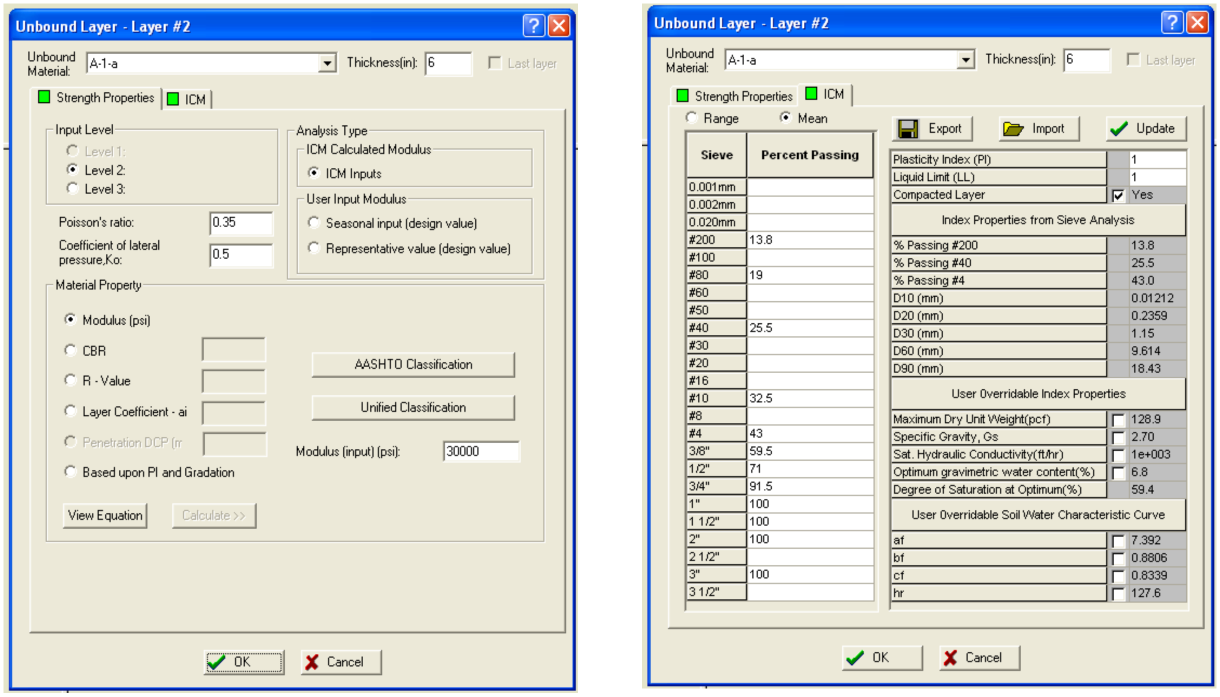


Figure B-13. Granular base strength and other properties for new JPCP design example.

Information obtained from the county soil report (USDA-NRCS soil survey database) indicated an A-4 soil classification along much of this project. Data from the suggested gradation and dry unit weight was entered into the MEPDG window as shown in Figure B-15.

For this design, an FWD was used to obtain a deflection profile along a portion of the project at center slab. The loading was 9,000 lbs. and a deflection basin was measured. The in situ dynamic k-value was backcalculated and then used to obtain a better estimate of the proper subgrade input Mr. For this section, the mean backcalculated dynamic k-value was 238 psi/in using data from 1993 to 1997 as shown in Figure B-14.

The plot in Figure B-14 shows considerable scatter of results about the mean but that is typical of deflection and backcalculated moduli values along a project.

The proper input subgrade Mr at optimum moisture content (required input for the MEPDG) that gives this subgrade in situ k-value (238 psi/in) was approximately 15,000 psi. This was obtained using the MEPDG program over a range of values of resilient moduli until the backcalculated (in situ) k-value was obtained for the months of deflection testing, which is shown later in the MEPDG output. Thus, if the subgrade Mr at optimum moisture content of 15,000 psi is input, the program outputs a k-value of approximately 205 to 212 psi/in, which is close to the mean value obtained from backcalculation. Subgrade strength and other properties inputs are presented in Figure

B-15. If a Level 3 approach to determining the subgrade resilient modulus was used, the default design Mr is 16,500 psi, compared to 15,000 psi. This small difference in Mr input would not affect design.

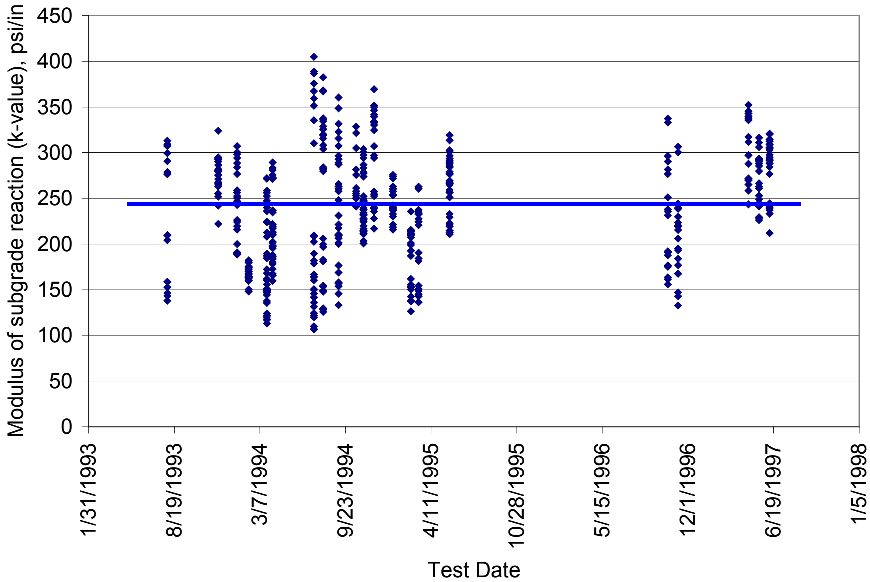


Figure B-14. Backcalculated dynamic k-value using data from FWD center slab loading.

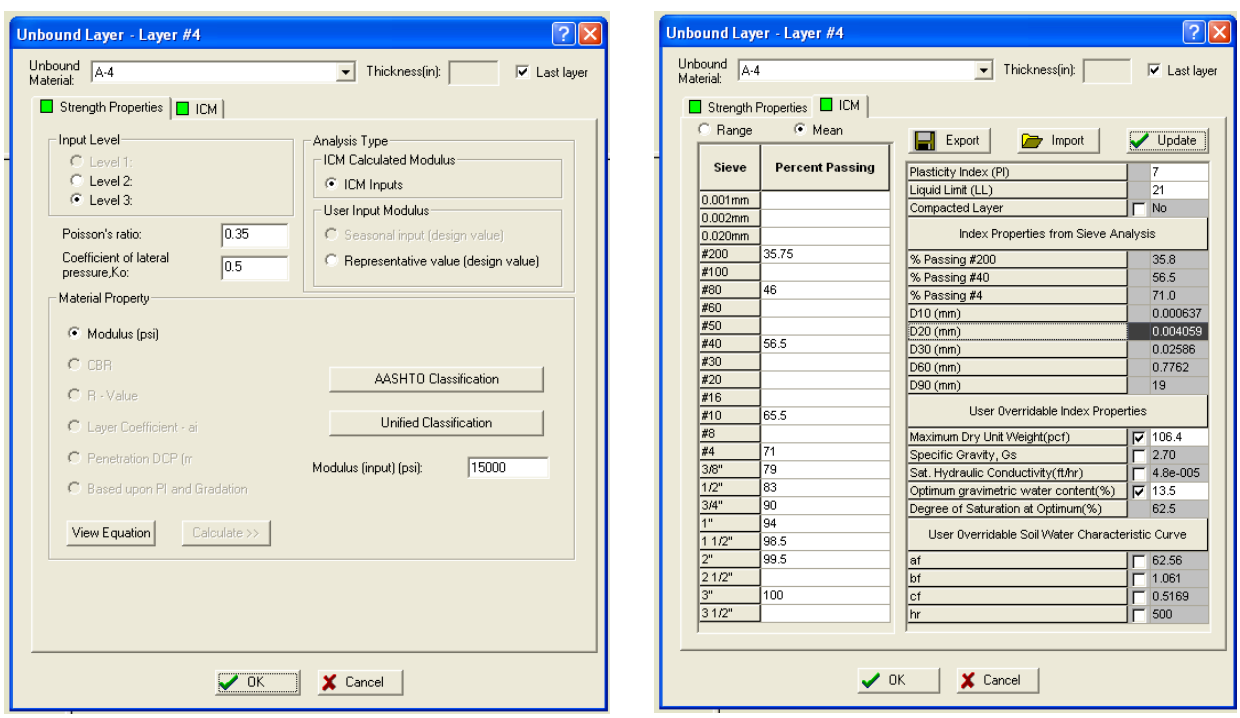


Figure B-15. Subgrade A-4 soil strength and other properties for new JPCP design example.

Run MEPDG to Predict Performance Over Design Period

After all design inputs are provided and all inputs are colored green (as shown in Figure B-16), the MEPDG software can begin the analysis process to predict the performance of the trial design over the 30-year design life of the pavement. Click on *Run Analysis*. The program runs the Traffic, Climate, Modulus, faulting JPCP, Cracking JPCP, and Summary and IRI modules and reports the analysis status on the upper right hand corner of the screen.

At the end of the analysis, the program creates a summary file and other output files in the project directory, C:\DG2002\Projects. The summary file is in a MS Excel format and is named after the MEPDG input file name. The summary file contains an input summary sheet, climate, reliability, distress, faulting, cracking summary sheets in a table format, and the predicted faulting, transverse joint LTE, cumulative top and bottom damage, cracking, and IRI in a graphical format.

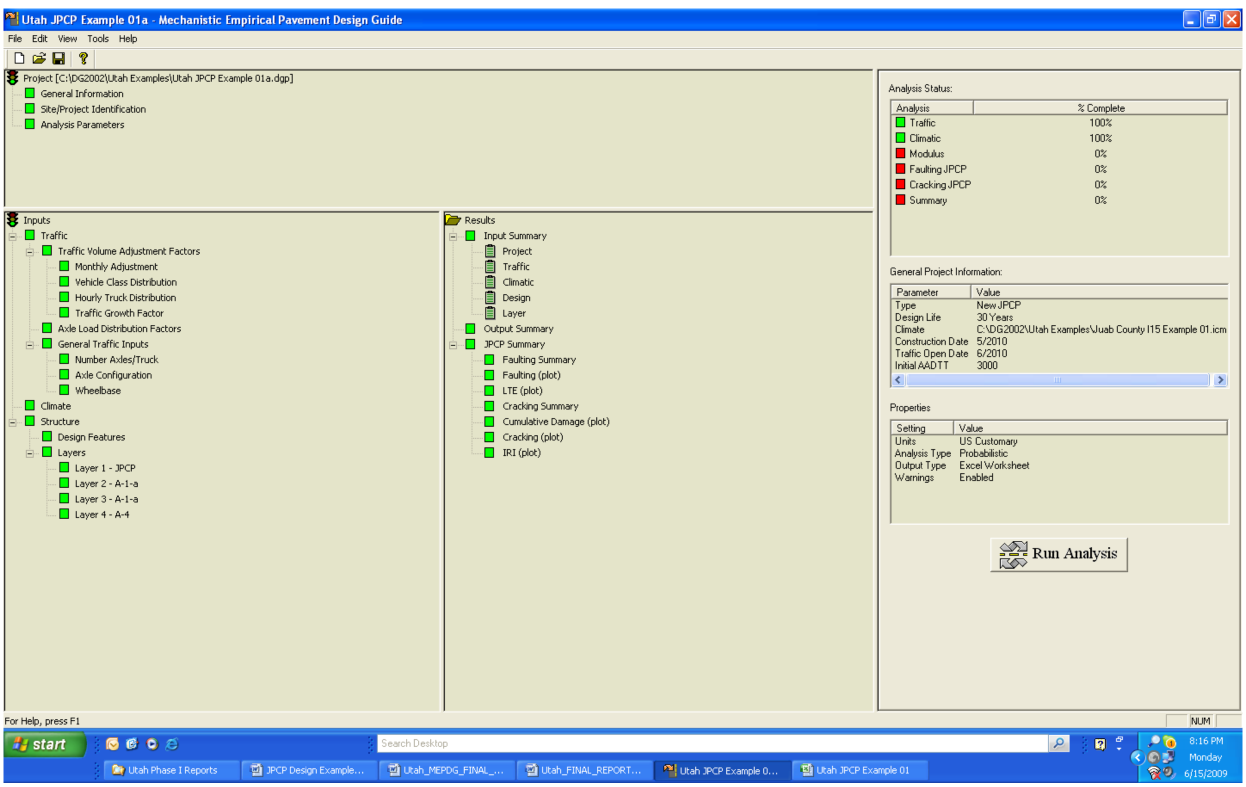


Figure B-16. MEPDG program layout screen after completing all inputs.

The MEPDG Output Summary file contains the following important tabs:

- **Input summary.** Should be reviewed carefully to ensure proper inputs have been entered.
- **Climate.** Identification of the weather station(s) used and climate summary data. Review carefully to ensure that the data looks reasonable and that major error do not exist in the weather station data.
- **Reliability summary.** This gives an overall answer as to the adequacy of the design. Does the JPCP "Pass" all of the distress types and IRI criteria at the desired level of reliability? If not, prepare a new trial design and rerun.
- **Distress summary.** This table gives a nice summary by month of key modulus and distress and IRI outputs throughout the design period. Check carefully for reasonableness of each column.
- **Faulting summary.** Gives a detailed output of modulus and other parameters and faulting predictions. Review for reasonableness.
- **Faulting graph.** Shows graph of transverse joint faulting prediction.
- **LTE:** Joint Load Transfer Efficiency, in percent, over design life.
- **Cracking summary.** Modulus values, detailed top down and bottom up fatigue transverse cracking damage, and cracking predictions.
- **Cumulative damage.** Top down and bottom up fatigue damage. Identifies where fatigue cracking is initiating.
- **Cracking graph.** Plot of transverse fatigue cracking over time.
- **IRI.** Provides the mean 50 percentile and the Reliability curve for IRI over the design life.

The Distress Summary sheet in the output file provides a month by month overall summary of the JPCP trial design for the project including critical material properties, traffic, and distress data. Detailed data for each distress type is provided on separate sheets. The distress summary sheet shown in Table B-1 indicates that this pavement carried 20.77 million heavy trucks in the design lane over the design period (the first month showed 45,740 trucks) and this provides an overall idea of the traffic loading on the pavement. During the first month of traffic, June, the modulus of elasticity of the PCC slab was 4.48 million psi, the resilient modulus of the unbound granular base was 32,650 psi, the dynamic FWD backcalculated k-value was 212 psi/in, faulting and cracking was zero and the initial IRI was 70 in/mile. All of these values look reasonable this month and over the 30 year period.

Table B-1. Distress summary sheet for new JPCP trial design.

Predicted distress: Project Utah JPCP Example 01

Pavement age		Month	Epcc Mpsi	Ebase ksi	Dyn. k psi/in	Faulting in	Percent slabs cracked	IRI in/mile	Heavy Trucks (cumulative)	IRI at specified reliability
Mo.	Yr.									
1	0.1	June	4.48	32.65	212	0	0	70	45740	106
2	0.2	July	4.6	34.49	212	0	0	70.1	93821	106.5
3	0.3	August	4.68	34.85	212	0	0	70.2	133763	106.5
4	0.3	September	4.73	34.87	212	0	0	70.2	166884	106.7
5	0.4	October	4.76	34.88	212	0	0	70.3	200503	106.8
6	0.5	November	4.8	34.45	211	0	0	70.3	230236	106.8
7	0.6	December	4.82	32.13	210	0	0	70.4	256663	107
8	0.7	January	4.85	25.48	206	0	0	70.4	288184	107.1
9	0.8	February	4.87	23.01	204	0	0	70.5	321351	107.2
10	0.8	March	4.88	21.86	205	0.001	0	70.5	358318	107.3
11	0.9	April	4.9	25.73	207	0.001	0	70.6	396559	107.5
12	1	May	4.91	29.63	210	0.001	0	70.6	438304	107.5
13	1.1	June	4.93	32.65	212	0.001	0	70.7	485874	107.7
14	1.2	July	4.94	34.49	212	0.001	0	70.7	535878	107.8
15	1.3	August	4.95	34.85	212	0.001	0	70.8	577417	108
16	1.3	September	4.96	34.87	212	0.001	0	70.8	611863	108
17	1.4	October	4.97	34.88	212	0.001	0	70.9	646827	108.2
18	1.5	November	4.98	34.45	211	0.001	0	70.9	677750	108.2
19	1.6	December	4.99	32.13	210	0.001	0	71	705234	108.4
20	1.7	January	5	25.48	206	0.001	0	71	738015	108.4
21	1.8	February	5	23.01	204	0.001	0	71.1	772509	108.6
22	1.8	March	5.01	21.86	205	0.001	0	71.1	810955	108.6
23	1.9	April	5.02	25.73	207	0.001	0	71.2	850725	108.8
24	2	May	5.02	29.63	210	0.001	0	71.2	894140	108.8
Etc. over 30 year design life										
354	30	November	5.3	34.45	211	0.034	0.3	108.2	20326200	168.1
355	30	December	5.3	32.13	210	0.034	0.3	108.5	20383300	168.5
356	30	January	5.3	25.48	206	0.034	0.3	108.6	20451400	168.7
357	30	February	5.3	23.01	204	0.034	0.3	108.9	20523000	169
358	30	March	5.3	21.86	205	0.034	0.3	109.1	20602800	169.4
359	30	April	5.3	25.73	207	0.034	0.3	109.4	20685400	169.8
360	30	May	5.3	29.63	210	0.034	0.3	109.6	20775600	170.1

- Epcc: modulus of elasticity of concrete slab, millions psi
- Ebase: modulus of base course, ksi
- Dynamic k-value: subgrade dynamic k-value (from FWD loading)
- Faulting: mean joint faulting, in
- Percent slabs cracked: transverse cracking, percent slabs
- IRI: measured in both wheel paths, in/mile
- Heavy trucks: number in design lane

The Reliability Summary tab of the MEPDG output shows the information presented in Table B-2. For the given trial design, the transverse cracking and joint faulting over the design life as predicted by the MEPDG software at the mean and at the selected reliability level pass the criteria. The reliability of these is both above 95 percent specified. The IRI technically fails but comes very close to the criteria. Plots showing faulting, cracking, and IRI are also given in the MEPDG output and are shown in Figures B-17 through B-19. The blue (bottom) curve is the 50 percentile or mean model prediction. The top curve is distress or IRI predicted at the specified reliability level of 95 percent. The red line is the design criteria at the specified reliability level of 95 percent. Faulting and cracking 95 percent reliability curves are far below the critical line and the IRI just passes through it within the last year of the design period. Practically, this design could be considered as Passed.

Table B-2. Reliability summary for new JPCP trial design.

Project: Utah JPCP Example 01 Reliability Summary					
Performance Criteria	**Distress Target**	**Reliability Target**	**Distress Predicted**	**Reliability Predicted**	**Acceptable**
Terminal IRI (in/mi)	169	95	109.6	94.68	Fail
Transverse Cracking (% slabs cracked)	10	95	0.3	98.94	Pass
Mean Joint Faulting (in)	0.12	95	0.034	99.8	Pass

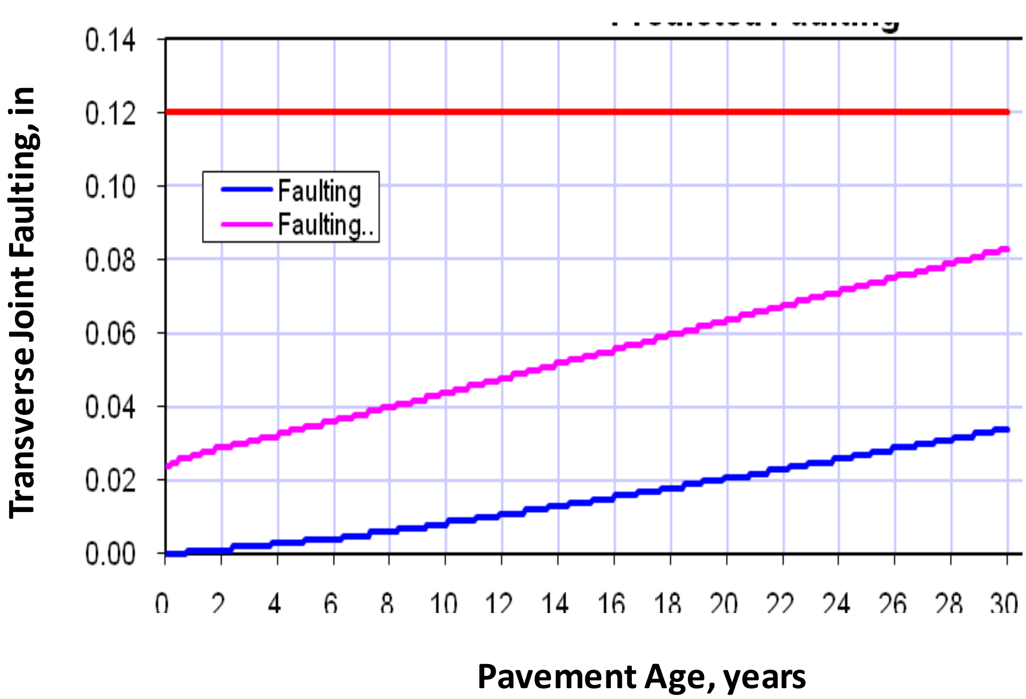


Figure B-17. Plot of predicted faulting versus pavement age.

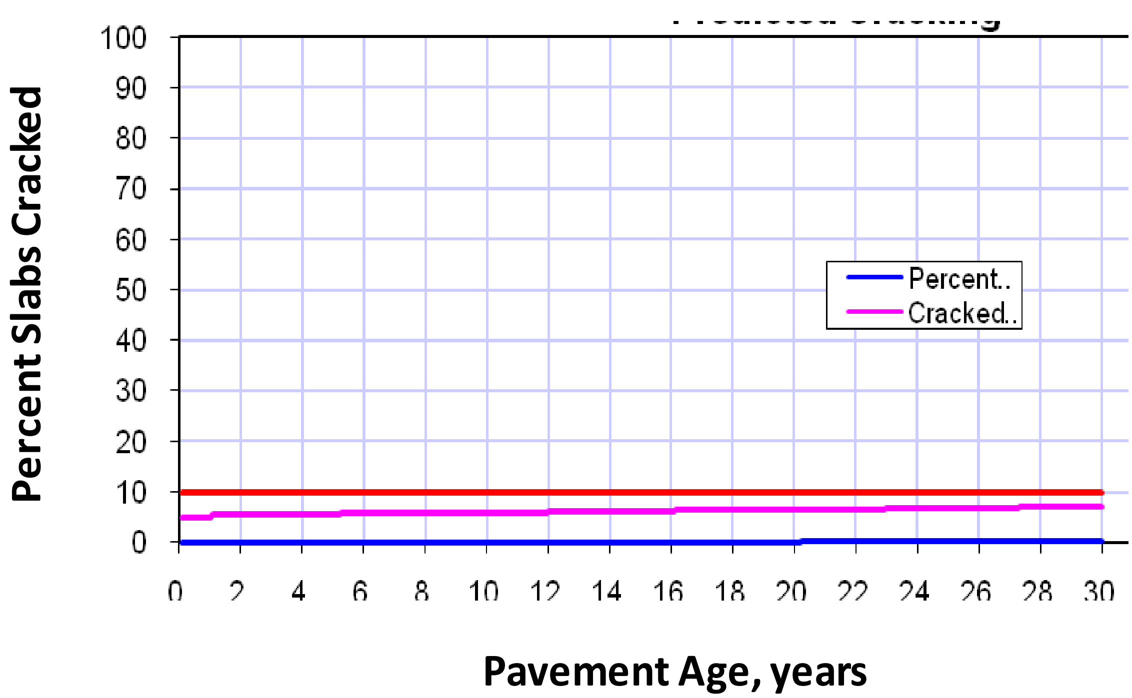


Figure B-18. Plot of predicted transverse cracking versus pavement age.

Figure B-19. Plot of predicted IRI versus pavement age.

Modify Trial Design

The user may have to modify the trial design if any of the performance criteria are not met. For this design, they are all met or close enough as in the case of IRI. However, if for example, cracking did not pass the criteria at the desired reliability level, the following actions could have been taken in a revised trial design:

- Increase slab thickness.
- Decrease joint spacing.
- Provide a stabilized base course.
- Provide a tied concrete shoulder, or wider slab (13-ft).

If joint faulting did not pass the criteria at the desired reliability level, the following actions could have been taken in a revised trial design:

- Increase the diameter of the dowel bar across the transverse joint.
- Provide a stabilized base course.

If IRI did not pass the criteria at the desired reliability level, the following actions could have been taken in a revised trial design:

- Take actions to reduce slab cracking and joint faulting.
- Reduce the initial IRI (as constructed IRI) by adjusting smoothness specifications.

Once a design passes all of the criteria it can be considered a feasible alternative that can be subjected to a cost analysis and compared to other alternatives.

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