CalME Help - v3.1.0

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Introduction To *CalME* v3.1

More Coming Soon!

Printable Version of This Help System

Click the following link to open a PDF version of this help system for viewing, downloading and printing.

Historical Background on Mechanistic-Impirical Design in California

In 2005, the California Department of Transportation (Caltrans) approved an issue memo titled "Adoption of Mechanistic-Empirical (ME) Pavement Design Method," which calls for the adoption of ME pavement design methodology to replace existing pavement design methods that have been in place since the early 1960s.

The University of California Pavement Research Center (UCPRC) has been supporting the Caltrans effort to implement ME pavement design by working on a series of tasks since 2000. This work is under the technical guidance of the Pavement Standards Team, with the Division of Design in the lead. One of those tasks is to develop and calibrate ME flexible pavement design models.

The first step in creating a Mechanistic-Empirical (ME) pavement design or evaluation is to calculate pavement response - in terms of stresses, strains, and/or displacements - using a mathematical (or mechanistic) model. In the second step, the calculated response is used as a variable in empirical relationships to predict structural damage (decrease in moduli or cracking) and functional damage (rutting and roughness) to the pavement.

Both of these steps must be reasonably correct. If the calculated response bears little resemblance to the pavement's actual response, there is no point in trying to use the calculation to predict future damage to the pavement with the empirical relationship. In other words, only if the calculated response is reasonably correct does it make sense to try to relate the damage to the pavement response.

The validation and calibration of the models in *CalME* was first performed using performance data from Heavy Vehicle Simulator (HVS) tests completed by the UCPRC between 1995 and 2004. The results of that work are documented in a separate report titled "Calibration of Incremental-Recursive Flexible Damage Models in CalME Using HVS Experiments".

CalME Versions 1 and 2

The first version of *CalME*, v1, was released in 2011, and the second version, v2, was released in 2014; these were both desktop applications written Visual Basic. The desktop application was originally developed as a research tool that had a working user interface and workflow but it was very hard to maintain and enhance. The installation of the desktop application proved to be cumbersome to Caltrans since administrative privileges were required.

CalME Version 3!

***CalME* v3** is a complete rewrite of the desktop version of *CalME* (v2). CalME v3 is now a web-based application (using Microsoft's ASP.NET technology) that accesses the services of new, modern and easy-to-maintain ME compute engine written in C++ which is optimized for performance. *CalME* v3 has been tested against v2 and the results are the same.

CalME v3 uses the same traffic data used by Caltrans' pavement management system, PaveM. This source of traffic is more current than that used by v2 and it also uses traffic information from the PeMS system in order to fine-tune traffic. As a result, traffic is now a segment-based system, rather than a point-based system used by v2. Consequently, traffic data is automatically determined by *CalME* based on the location of the project on the highway system. This means that users no longer need to make a selection for the location of traffic count data, as was the case in v2. *CalME* v3 makes a suggestion on the most appropriate truck load distribution (WIMstation) to use. The user may select a different WIM if desired.

CalME v3 also uses the same Climate Zone data used by PaveM and also makes a suggestion for the best zone to use. Again, the user is able to select any zone.

CalME v3 has incorporates Caltrans' CalFP (new pavement design) and CalAC (rehab design) design procedures. The desktop versions of these applications will eventually be retired so *CalME* v3 will soon be the only way to run these applications, in addition to performing ME simulations.

CalME v3 also allows the import of Caltrans' *CalBack* data via a export file. *CalME* v3 create a new project and a series of trials that represents the sections generated by *CalBack*.

Technical Overview

ME design is an iterative process in which trial pavement designs are adjusted repeatedly either manually or automatically based on predicted performance until an optimal design is reached. A key component of any ME design system is a module that predicts the performance of a given pavement design. This module and the

pavement distresses included in it can vary from one ME design system to another, depending on the specific project. In *CalME*, the module's predicted distresses include fatigue cracking, reflective cracking, rutting, and smoothness. It is expected that in future versions of *CalME* additional pavement distresses will be added.

CalME uses an incremental-recursive performance prediction process. Figure 1 below shows a flowchart of this process and it illustrates both the "incremental" and the "recursive" parts of the module. Specifically, "incremental" refers to the part of the process where pavement performance is predicted for each time increment

and "recursive" refers to the part where the pavement condition is updated using the distress states (or levels) predicted for the preceding time increment before the incremental pavement distresses are predicted for the next time increment.

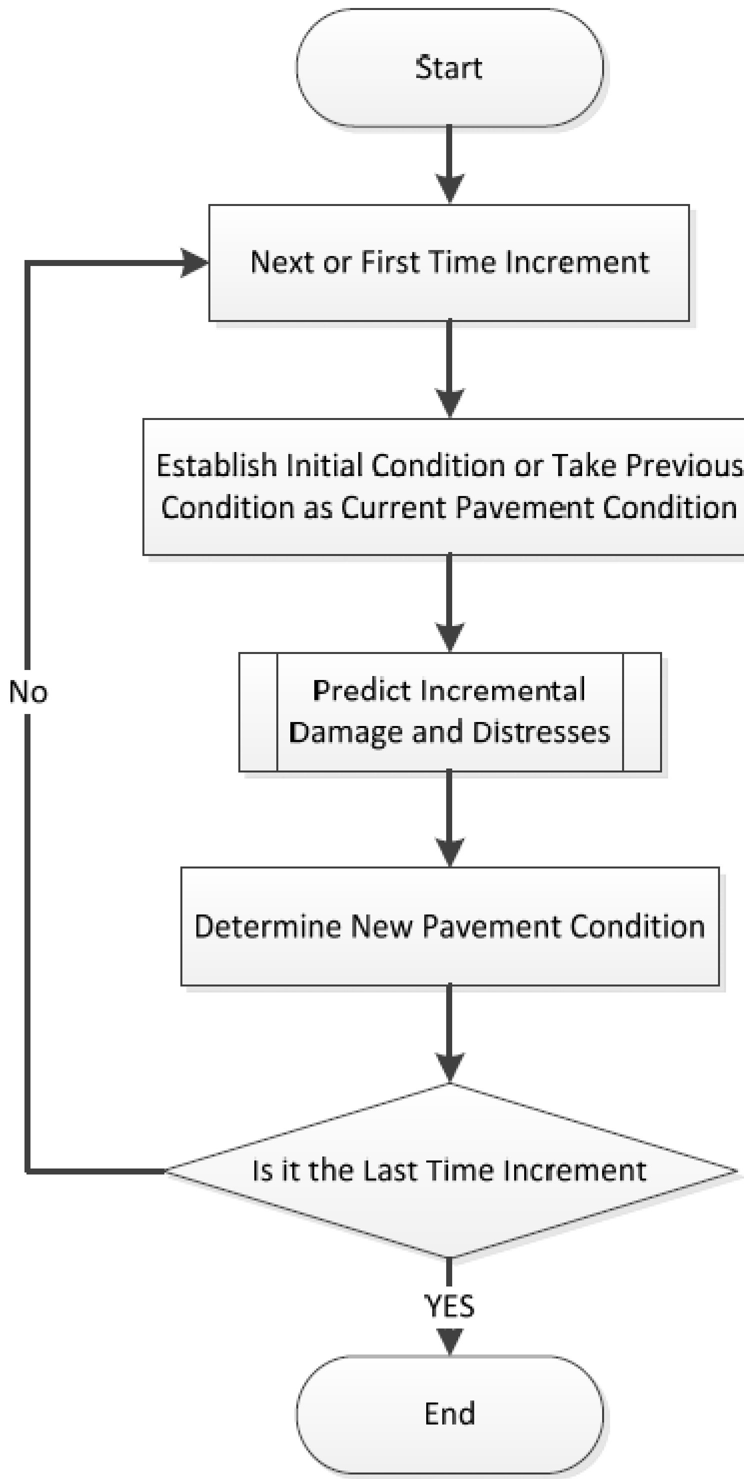


Figure 1 - Flowchart of the incremental-recursive performance prediction used in CalME

CalME uses Monte Carlo simulation for evaluating the statistical reliability of a given pavement design. Essentially, *CalME* generates a set of random pavement structures that together provide a representative sample of the as-built structures for a given pavement design. This accounts for the construction variability. In addition,
a designer can elect to include the uncertainties associated with predicting future climate conditions.

CalME then uses the process shown in Figure 1 above to predict the performance of each individual pavement structure with the corresponding climate condition and uses the performance statistics to determine the reliability of the given design.

Roles of Material Characterization in CalME

As shown in Figure 1, a key part of the incremental-recursive performance prediction process is the subprocess that predicts incremental damage and distresses. This subprocess is referred to as the incremental damage prediction process, which applies the environmental and traffic loading for the given time increment and predicts the incremental damage (loss of stiffness or permanent deformation) and resultant change in distresses in the pavement. This subprocess involves interaction between material characterization and the other components of the ME design, as illustrated in Figure 2.

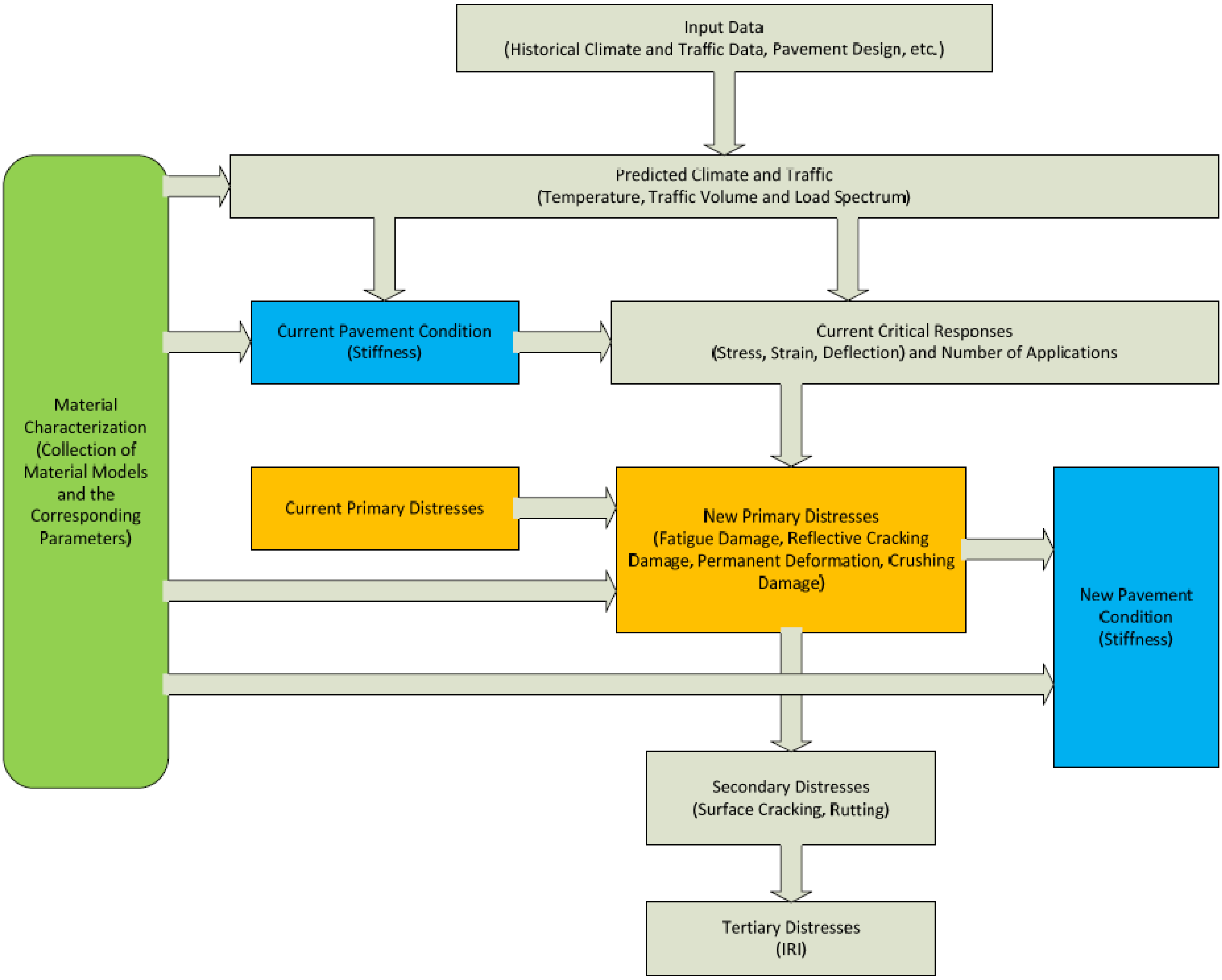


Figure 2 - Interaction between material characterization and other components of the incremental distress prediction process for CalME

As shown in Figure 2, there are three levels of damages or distresses predicted by *CalME*: primary, secondary, and tertiary. The primary distresses are damages such as fatigue damage, reflective cracking damage, and permanent deformation in each layer, which do not depend on other distresses. The secondary distresses are the ones that depend on primary distresses, while tertiary distresses are the ones that depend on primary and/or secondary distresses. For example, surface cracking is a result of fatigue damage and reflective cracking damage and therefore it is a secondary distress. Similarly, surface rutting is a function of layer permanent deformations and therefore it is also a secondary distress. In *CalME*, IRI is a function of surface rut variability and surface cracking, and therefore is a tertiary distress.

Figure 2 indicates that material characterization is not involved in the predictions of the secondary and tertiary distresses in *CalME*. Instead, these distresses can be determined based on a damage value alone, no matter what materials are used in the pavement. The role of material characterization is to provide models for predicting pavement conditions (temperature, moisture contents, etc.), critical primary responses (stress, strain, and/or deformation at critical locations in the pavement that are related to distress development), and the resulting primary distresses.

In *CalME*, pavement structures are simplified as multilayer elastic systems when calculating critical responses for predicting fatigue damage and permanent deformation. Accordingly, pavement responses only depend on layer stiffnesses since the Poisson's ratio of each material in the pavement structure is assumed to remain constant throughout the analysis life. In order to calculate the strain that drives reflective cracking damage in the new asphalt layer (e.g., overlay), joints and cracks in the underlying layer are introduced into the multilayer elastic system. The joint or crack characteristics such as spacing and opening width, however, are structural properties and not material properties.

Even without asphalt fatigue damage, which reduces stiffnesses, many important pavement materials do not have constant stiffnesses. For example, hot mix asphalt (HMA) stiffness depends on loading duration and HMA temperature. Similarly, subgrade stiffness typically demonstrates nonlinearity with respect to stress level, seasonal moisture content variation, and the freeze/thaw cycle. Fatigue damage and reflective cracking damage from traffic loading then add an additional element of change to the layer stiffness. Asphalt-bound material characterization describes how the stiffness of a material changes with loading duration and asphalt temperature as well as fatigue and reflection cracking damage.

Material properties also affect the prediction of environmental conditions for the pavement. Specifically, temperature profile in a pavement is affected by the thermal diffusivities of its layers. *CalME* does not account for effects of any climate conditions other than temperature profile on the asphalt-bound material.

There are three groups of functions that material characterizations in *CalME* can potentially provide:

1. Environmental models: models that affect pavement response to environmental conditions, e.g., a heat transfer model that is used to determine pavement temperature
2. Stiffness models: models for layer stiffness given all of the potential relevant factors such as loading duration, material temperature, loading stress, time of the year, age, fatigue damage, etc.
3. Physical evolution models: models for changing the physical conditions of a material. These are the models needed for updating primary distresses/damage given all potential critical primary responses (stress, strain, deflection), the corresponding number of traffic load applications, and the current damage. Examples of physical evolution models include an asphalt mix fatigue damage model and a cement-treated material curing model. Note that physical evolution can include both damage and stiffening (such as aging and curing).

In essence, material characterization involves selecting the appropriate set of material models and identifying the corresponding model parameters through laboratory and/or field testing. Different types of materials require different materials characterization parameters for each of the above three functional groups of models. Accordingly, types of materials in the *CalME* Standard Materials Library can be classified into functional groups, each with its own type of material models and therefore their own materials characterization needs. The material models selected for *CalME* for each of the functional groups are presented below along with the material classification.

Summary

Mechanistic-empirical (ME) design procedures need to provide pavement performance predictions regarding different distresses that are considered critical. Each critical distress requires a computational model to describe how the distress develops in each pavement layer under various loading conditions.

CalME has been developed by the UCPRC to enable Caltrans to design flexible pavements in California. The critical distresses in *CalME* include fatigue cracking, reflective cracking, surface rutting, and ride quality deterioration in terms of smoothness measured using the International Roughness Index (IRI).Future enhancement of *CalME* will consider other important distresses, such as thermal cracking, top-down cracking, etc.

Each of the computational models for the distresses included in *CalME* has a set of model parameters that need to be determined. In order to use a material as part of a pavement design in *CalME*, one first needs to characterize the material by providing parameters for the computational models that predict fatigue damage, reflective cracking damage, and permanent deformation under different traffic and environmental loadings.

A Standard Materials Library (SML) has been introduced into *CalME* to provide a list of predefined materials for use in pavement design. The SML is essentially a collection of materials that have been characterized through previous studies. Specifically, model parameters and the associated uncertainties when applicable have been determined for these materials. Each material in the library has been classified in one of three groups-asphaltic material, cement-treated material, and unbound material-based on the models needed for that material.

The *CalME* SML continues to grow. In terms of material characterization, most of the current effort has focused on asphaltic materials, which are defined as materials bounded by asphalt binder and that are typically used in surface layers. These materials must be strong enough to allow production of viable laboratory specimens because a series of lab tests will be conducted on them to determine the fatigue and permanent deformation resistance of each material.

On the other hand, most of the models for nonasphaltic materials use default model parameters and require no additional laboratory testing for them to be characterized. The only exception is the stiffness of a pavement layer. Typically, layer stiffnesses are estimated with falling weight deflectometer (FWD) tests and the resulting data are used to backcalculate layer stiffness and to provide an estimate of the variability of the stiffnesses for Monte Carlo simulation.

Getting Started

This section presents some the typical steps that are used in a new pavement design with links to help topics that will assist you in performing those steps in the *CalME* user interface (UI).

The flowchart shown below is a very high-level view of the design process and does not include the many administrative, engineering and policy related details that are associated with a pavement design.

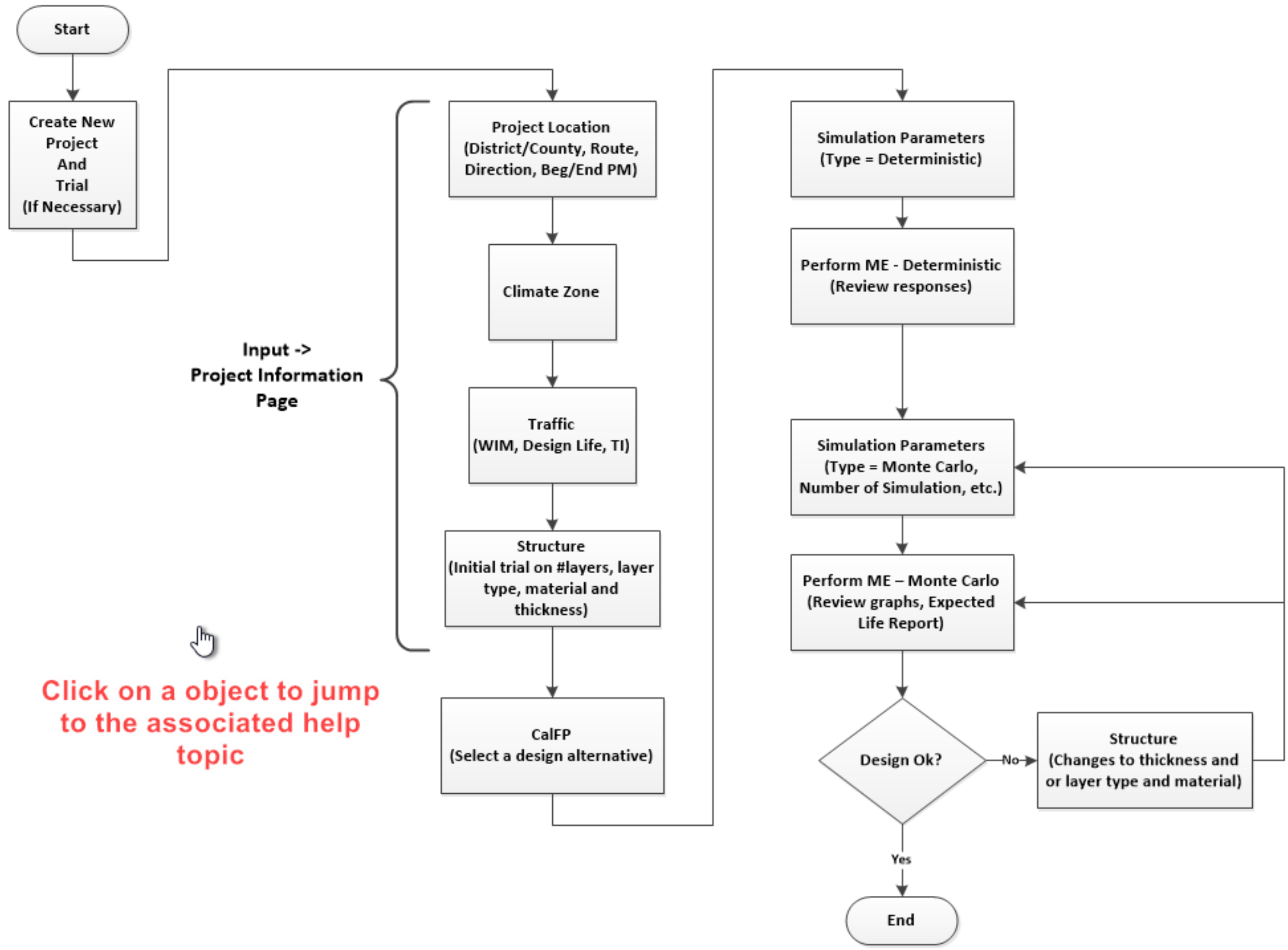
Design is an iterative process that must start somewhere, and in *CalME*, it starts with a traffic loads and a trial pavement structure, both defined on the Project Information page:

- TI (Traffic Index)
- Number of layers
- Layer type (e.g., HMA, AB, SG, etc.)
- Specific layer material (e.g., *HMA Type A (Mix 01) RAP00 PG 64-28 Blasted Granite*)
- Layer thickness (the initial thickness is not too important since CalFP-Web will determine thicknesses)

Once this has been defined, then CalFP-Web is used to determine a set of design alternatives (i.e., layer thicknesses) that meet the Caltrans R-value design criteria. After one of the design alternatives is selected, an ME simulation is performed (both a Deterministic and Monte Carlo) to see how it performs (i.e., are rutting and cracking Ok) over the design life of the structure. Changes are then made to the initial trial structure and the simulation is run again. This iterative process continues until the design criteria are satisfied.

CalFP-Web will determine R-value consistent thicknesses for a given pavement structure, but it will not determine alternative layer configurations. If you are unable to make your initial layer configuration work for your design constraints, then you will need to manually add or delete layers, change layer types or the specific layer materials.

Each step (process box) in the graphic below is a hot-link (hyperlink) to a section in this help system to show how to do the step in *CalME*. Simply click on a step to go to the appropriate help section.


Start
Create New Project And Trial (If Necessary)
Input -> Project Information Page
Project Location (District/County, Route, Direction, Beg/End PM)
Climate Zone
Traffic (WIM, Design Life, TI)
Structure (Initial trial on #layers, layer type, material and thickness)
CalFP (Select a design alternative)
Simulation Parameters (Type = Deterministic)
Perform ME - Deterministic (Review responses)
Simulation Parameters (Type = Monte Carlo, Number of Simulation, etc.)
Perform ME – Monte Carlo (Review graphs, Expected Life Report)
Design Ok?
No
Structure (Changes to thickness and or layer type and material)
Yes
End
Click on a object to jump to the associated help topic

Example Problems

Example 1

This section illustrates how to use *CalFP-Web* to find the designs for Example 1 listed in the Caltrans "Pavement Tech Notes: Flexible Pavement Design Examples - New Construction", which can be found at the here. Screen shots of the problem and solution are shown below.

FLEXIBLE PAVEMENT DESIGN EXAMPLES - NEW CONSTRUCTION

September 28, 2006

(1) Design Example 1 - Undrained Pavement structures Designed per California R-values of Underlying Layers (HMA/AB/AS or HMA/CTB-B/AS).

(a) Determine the total pavement structure GE, over the subgrade, using the standard design formula and the California R-value of the subgrade. For this example, assume a subgrade with a California R-value of 10. A TI of 12.5 is assigned based on the traffic forecasts for trucks. Thus, the total required GE is:

$GE_{Total} = 0.0032(TI)\ (100\text{-}R_{Subgrade})$; where R is the subgrade California R-value

$= 0.0032(12.5)\ (100\text{-}10) = 3.60$ ft.

(b) Determine the GE of the HMA surface layer using the standard formula. In this case, R is the California R-value of the Class-2 AB layer (see HDM Table 663.1B of the HDM for California R-values of various materials).

$GE_{HMA} = 0.0032(TI)\ (100\text{-}R)$; where R is the Class-2 AB California R-value

$GE_{HMA} = 0.0032\ (12.5)\ (100\text{-}78) = 0.88$ ft.

(c) Add the required 0.20 ft safety factor to the total GE of HMA:

Final $GE_{HMA} = GE_{HMA}$ + Safety Factor $= 0.88 + 0.20 = 1.08$ ft.

(d) Use HDM Table 633.1 of the HDM to determine the GE and thickness of the HMA surface layer:

With a TI of 12.5, the closest GE from HDM Table 633.1 is 1.09 ft for which the required HMA thickness is 0.65 ft.

(e) Although the calculated GE for the HMA is 1.09 ft, Table 633.1 of the HDM shows a GE of 1.09 as nearest to the calculated value. The value from Table 633.1 of the HDM will be used in subsequent calculations for the remaining layers.

(f) Determine the required GE of the combined HMA and AB layers using the standard design formula. In this case, R is the California R-value of the AS layer. For this example, assume a Class 2 AS, which has a specified minimum California R-value of 50 (see Table 663.1B of the HDM).

$GE_{HMA+AB} = 0.0032(TI)\ (100\text{-}R) = 0.0032(12.5)\ (100\text{-}50) = 2.00$ ft.

where R is the aggregate subbase California R-value

(g) Add the required 0.20 foot safety factor to this value to determine the GE of the combined HMA and AB.

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FLEXIBLE PAVEMENT DESIGN EXAMPLES – NEW CONSTRUCTION

September 28, 2006

$GE_{HMA+AB} = GE_{HMA+AB}$ + Safety Factor $= 2.00 + 0.20 = 2.20$ft.

(h) Subtract the GE of the HMA (Step d) from the combined GE of the HMA and AB to determine the required GE of the AB.

$GE_{AB} = GE_{HMA+AB} - GE_{HMA} = 2.20 - 1.09 = 1.11$ ft.

Table 633.1 of the HDM shows a value of 1.10 as the closest value to the calculated GE of 1.10 ft for the AB layer. The tabular value of 1.11 will be used in subsequent calculations for which the corresponding AB thickness is 1.00 ft.

Note

If CTB-B is used in lieu of AB, use HDM Table 633.1 of the HDM to determine actual thickness:

With a GE of 1.11 ft, HDM Table 633.1 shows CTB-B with a GE value of 1.14. This corresponds to a layer thickness of 0.95 foot of CTB-B.

(i) Subtract the GE of the HMA and AB layers, taken from HDM Table 663.1, from the GE of the total pavement structure (Step a) to determine the GE of the AS:

3.60 – 1.09(HMA) – 1.10(AB) = 1.41 ft (Round to 1.40)

Note

If CTB-B is used in lieu of AB, the GE of the AS will be:

3.60 – 1.09(HMA) – 1.14(CTB-B) = 1.37 ft (Round to 1.35)

Since AS has a G_f of 1.0, the actual thickness and the GE are equal.

(j) The structural layer thicknesses for the above example are:

Layer	Thickness (ft)
HMA	0.65
AB	0.95
AS	1.35

Note If CTB-B is used:

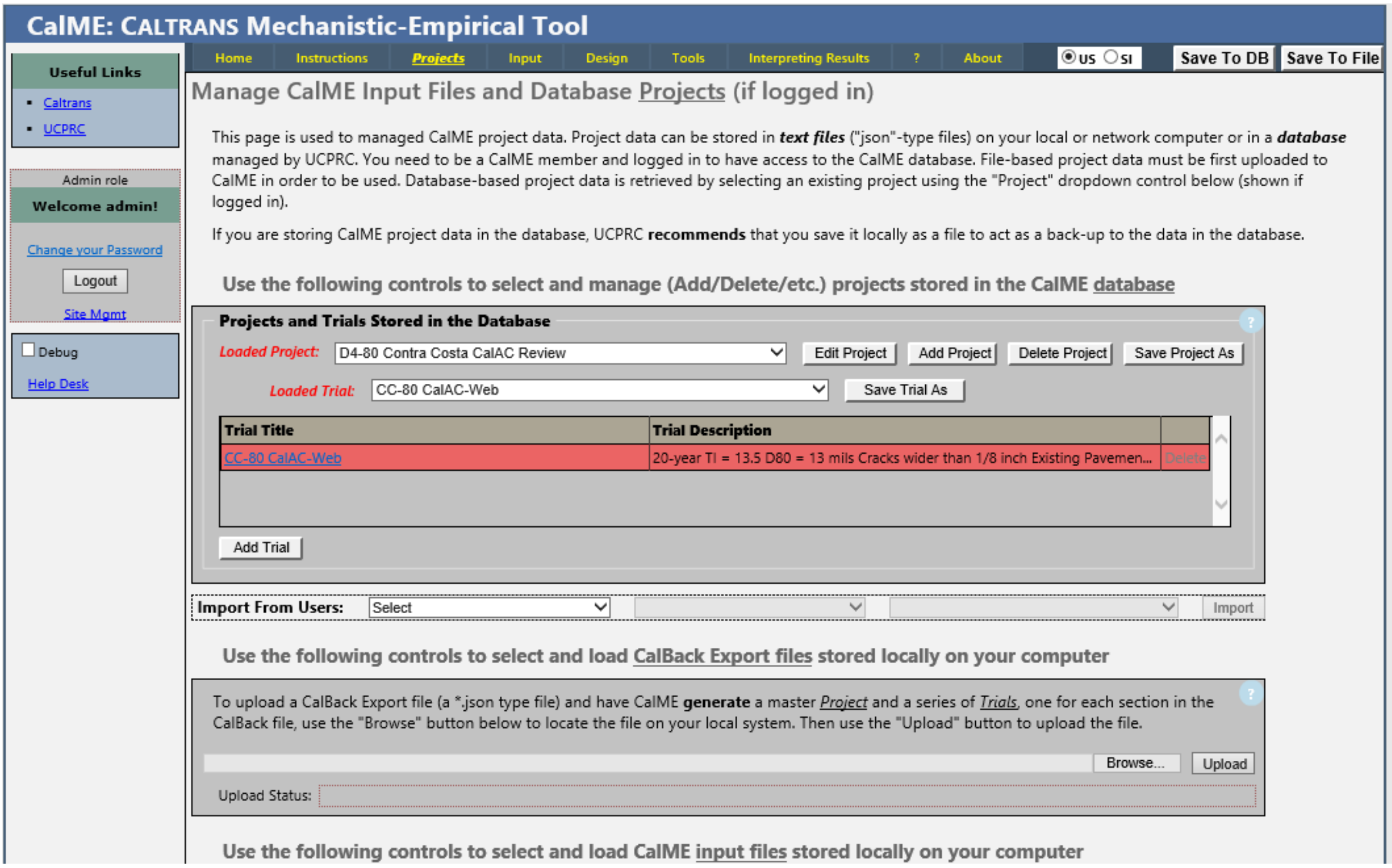
Layer	Thickness (ft)
HMA	0.65
CTB – B	1.00
AS	1.35

Step 0: Big Picture

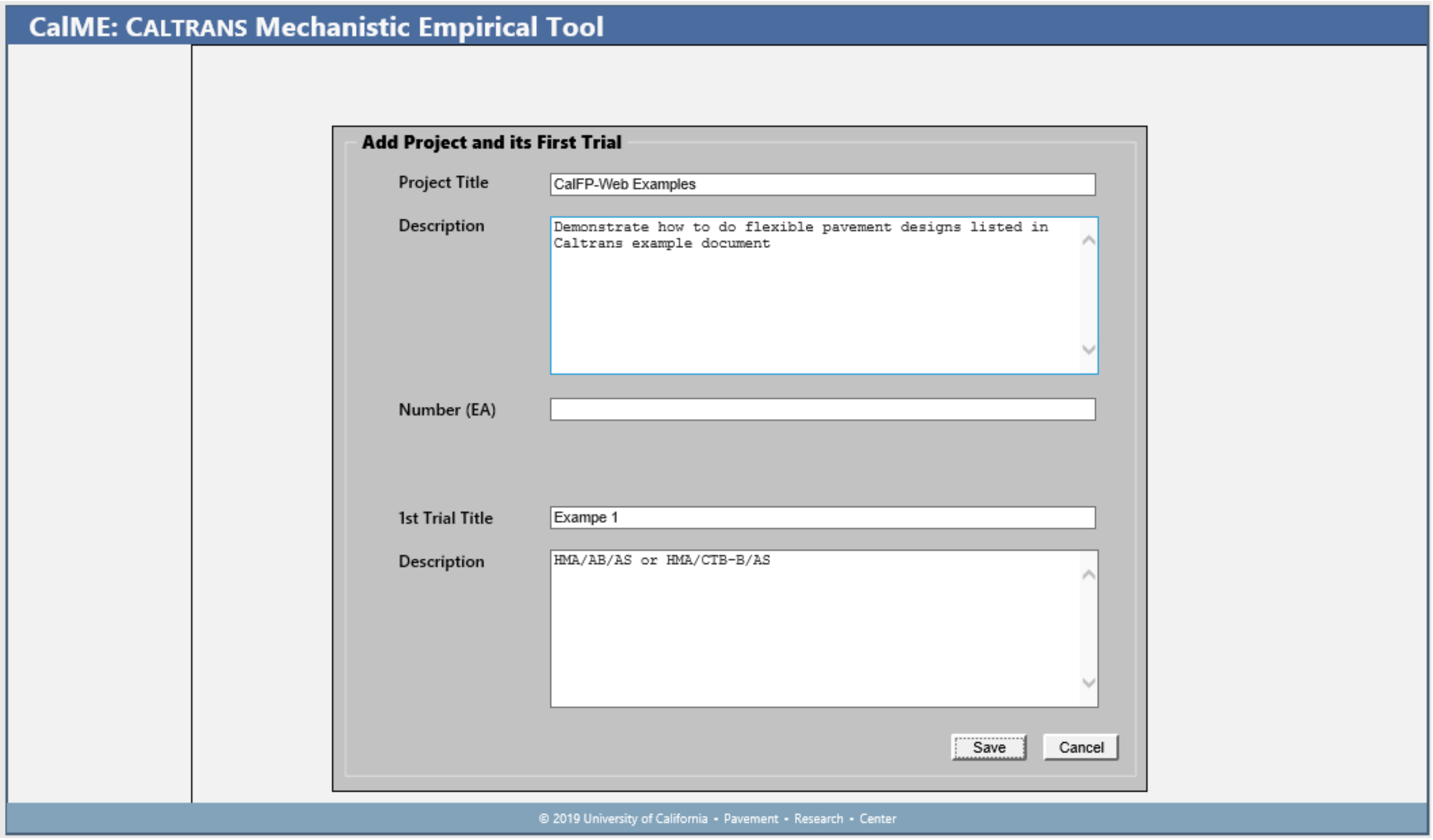
Note that currently *CalFP-Web* and *CalAC-Web* are hosted on the website for *CalME*, which is a software for structural design, rehabilitation, and maintenance of flexible pavements using mechanistic-empirical method. *CalME* is under active development by the University of California Pavement Research Center (UCPRC).

Step 1: Define a Project and an Empty Trial

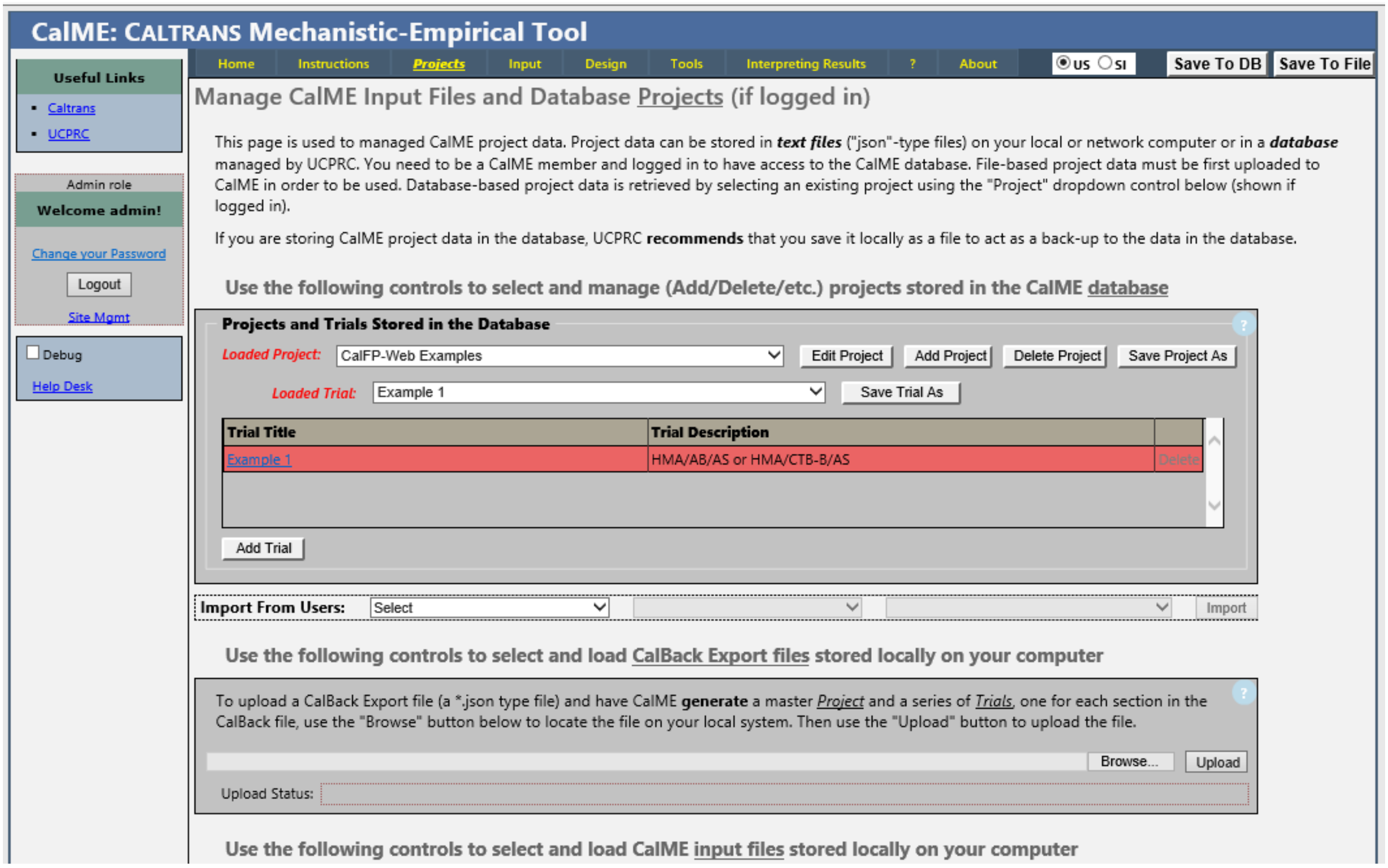
Navigate to the Projects tab by selecting the "Projects" menu at the top of the screen.



Click the "Add Project" button to bring up the project definition screen, and enter information as shown below (no need to use the exact words here). As one can see, this screen also asks for the title of a first trial, which is given as "Example 1" in this case. A "trial" represents a pavement design problem.



Click the "Save" button to return to the project tab and it should look like this:

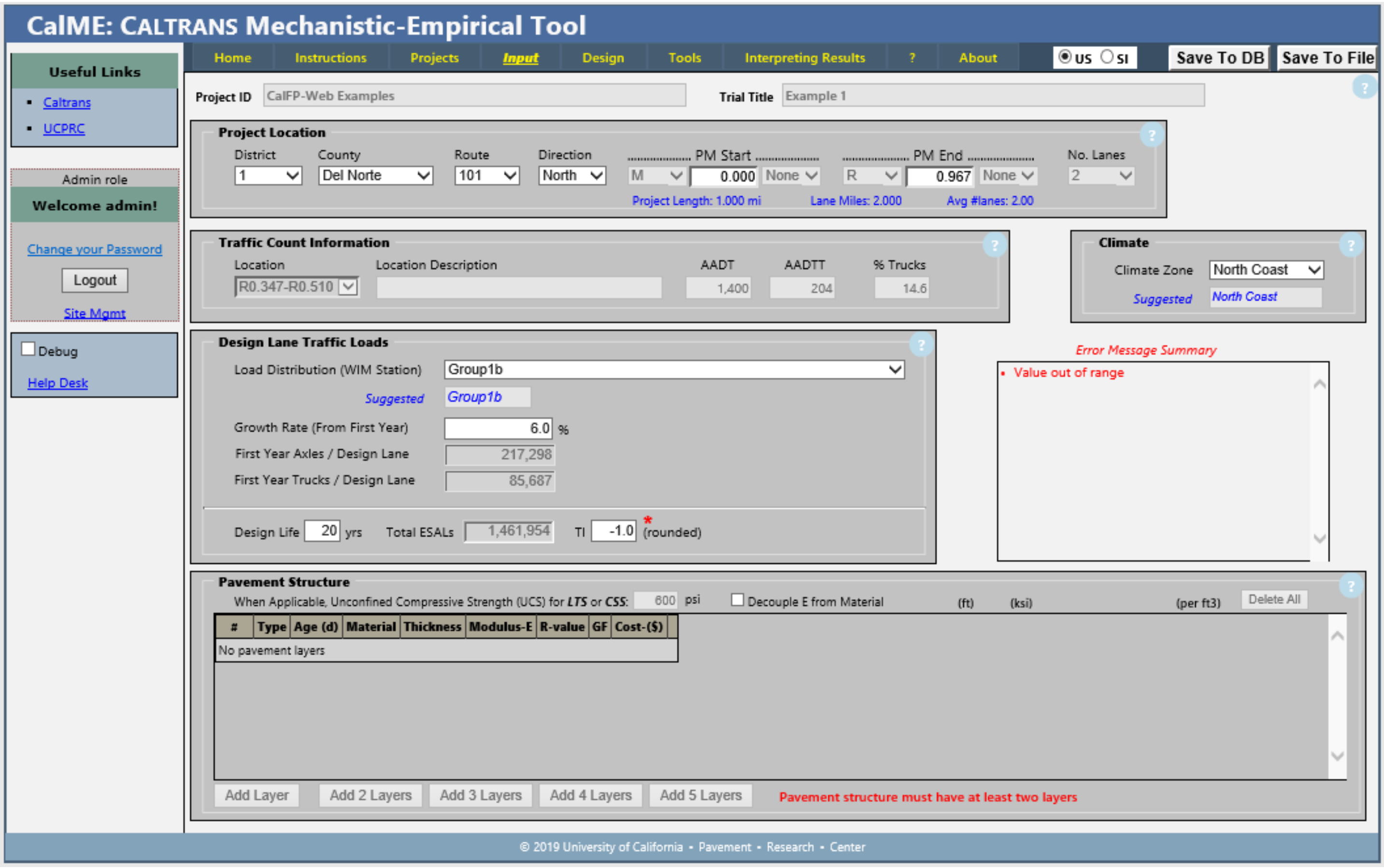


Step 2: Define the Trial

As mentioned above, a "trial" here represents a pavement design problem. For *CalFP-Web*, the information needed for a design include the following:

- Design TI for a 20 year design life
- Pavement structure, which includes
  - Subgrade type
  - Subbase type
  - Base type
  - Surface type

The above information are entered in the input screen. Click the "Input->ProjectInformation" menu item on top of the screen to navigate to the input screen, which is shown below:



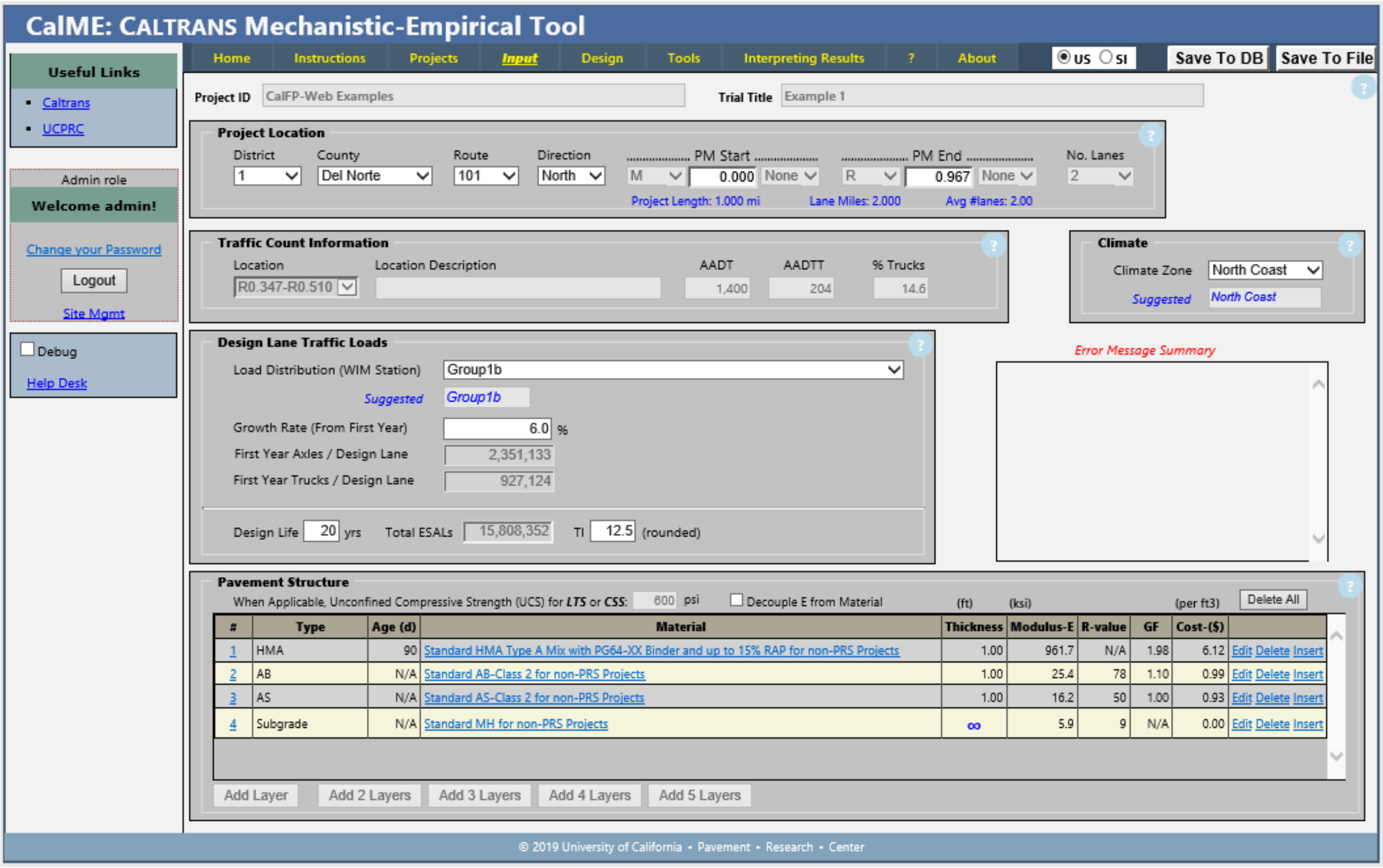
As one can tell, *CalME* automatically enters project location, climate, traffic load distribution, growth rate, etc. This information does NOT affect the design so it can be left unchanged. It is recommended however to enter the correct project location.

Keep in mind that *CalFP-Web* only does 20 year design, per HDM. For this particular example, the design TI for 20 years is 12.5, and the two trial structures under consideration are:

a HMA, AB-Class 2, AS-Class 2

b HMA, CTB-B, AS-Class 2

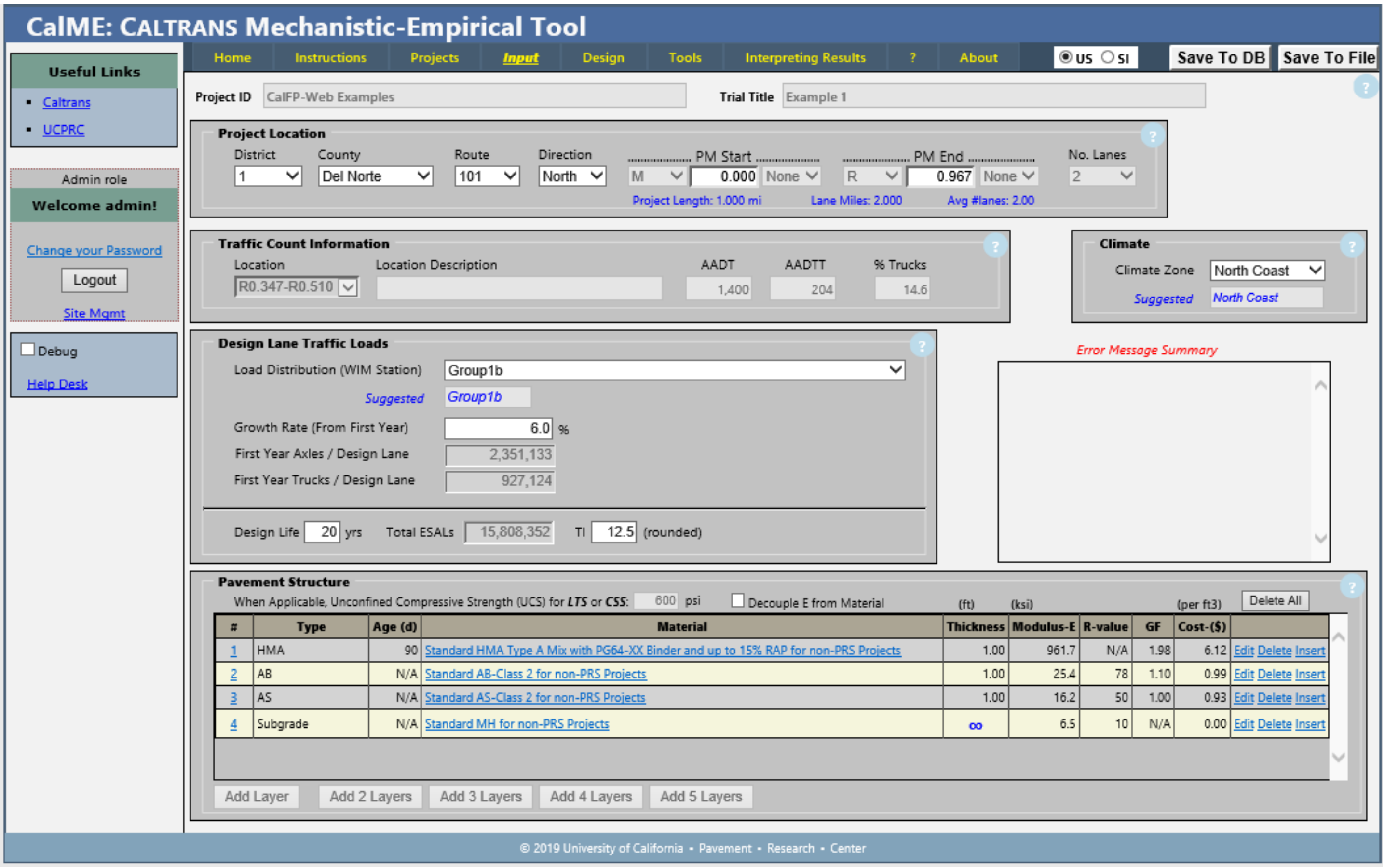
The subgrade R-value is 10. Consider option (a) in the current trial, and enter the TI, and structure in the input screen as shown below:



Several Notes:

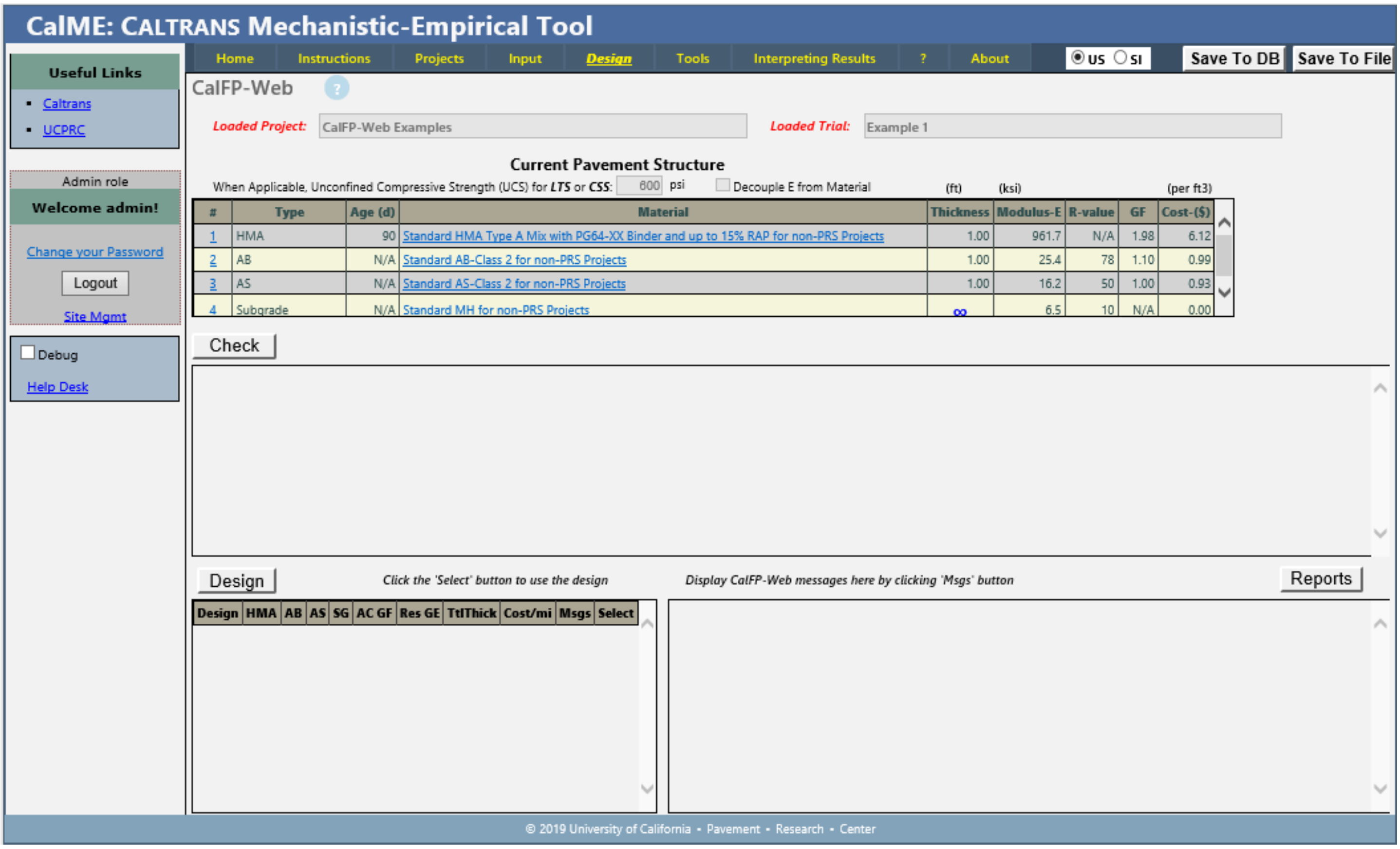
- All layers other than the subgrade has been set to 1.00 ft in thickness. This can be any positive number and does NOT affect the CalFP-Web result.
- There are multiple options for HMA layer, it is OK to pick any one from the list and it would NOT affect the CalFP-Web result.
- The subgrade R-value is 9 rather than 10. This needs to be modified.

Use the "Edit" link in the "Pavement Structure" grid for the subgrade layer to change the R-value to 10. The resulting input screen should look like the following:

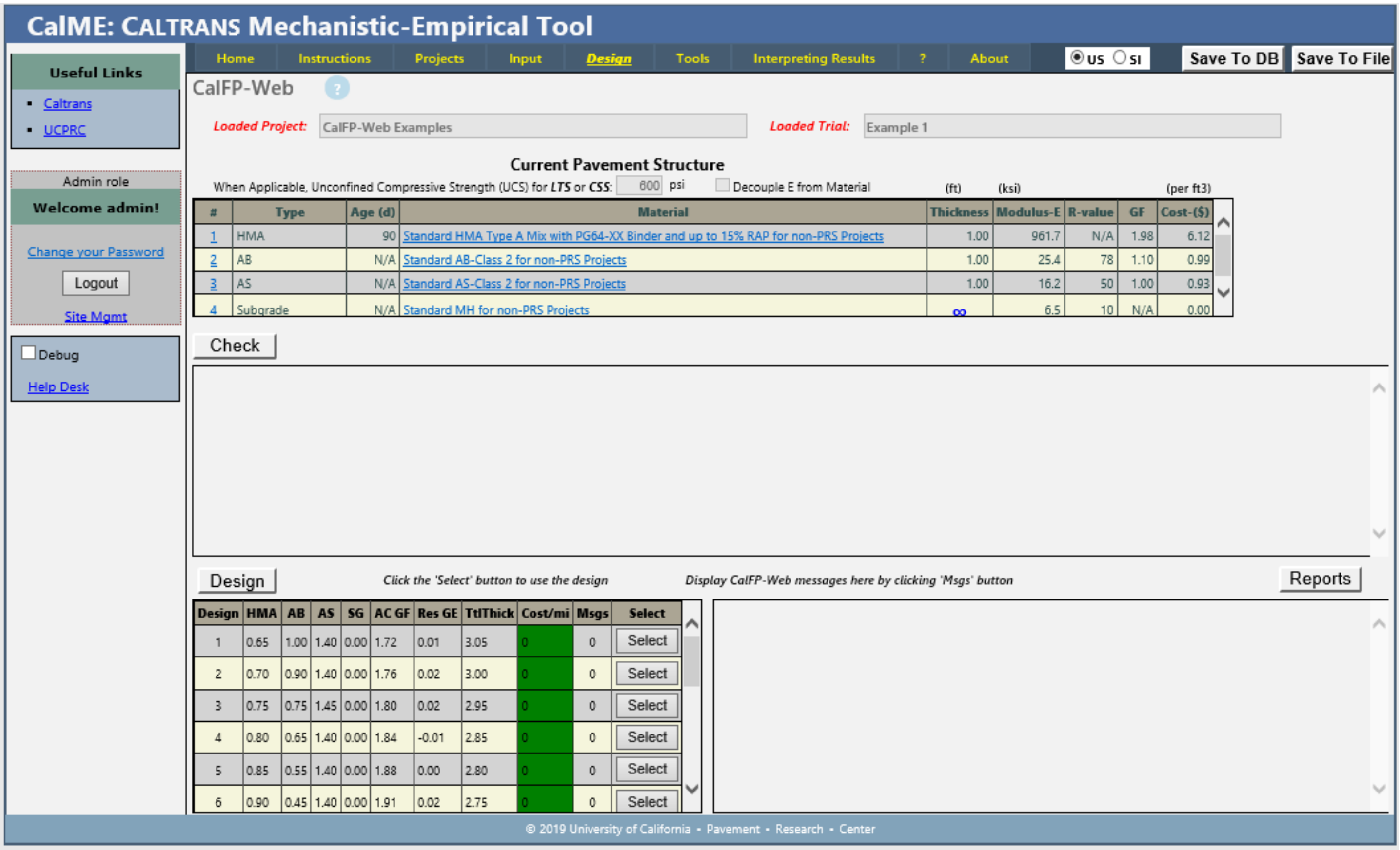


Step 3: Run CalFP-Web

Select "Design->CalFP-Web" to navigate to the CalFP-Web tab:



Use the "Design" button at the lower left part of the screen to run *CalFP-Web* design. The list of valid options are then used to populate the grid at the lower left part of the screen. The result should look like the following:



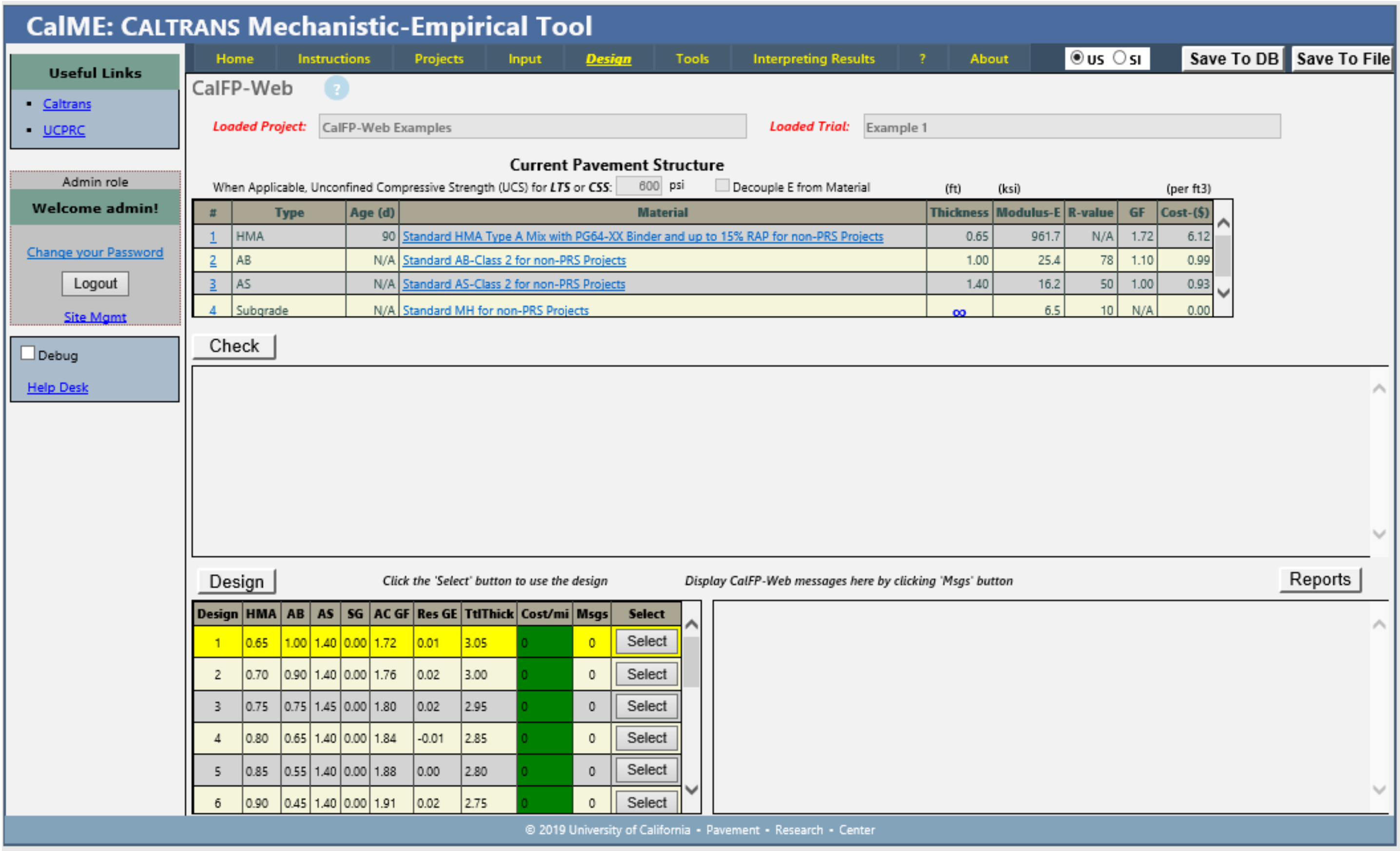
#	Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost-($) (per ft3)
1	HMA	90	Standard HMA Type A Mix with PG64-XX Binder and up to 15% RAP for non-PRS Projects	1.00	961.7	N/A	1.98	6.12
2	AB	N/A	Standard AB-Class 2 for non-PRS Projects	1.00	25.4	78	1.10	0.99
3	AS	N/A	Standard AS-Class 2 for non-PRS Projects	1.00	16.2	50	1.00	0.93
4	Subgrade	N/A	Standard MH for non-PRS Projects	∞	6.5	10	N/A	0.00

Design	HMA	AB	AS	SG	AC GF	Res GE	TtlThick	Cost/mi	Msgs	Select
1	0.65	1.00	1.40	0.00	1.72	0.01	3.05	0	0	Select
2	0.70	0.90	1.40	0.00	1.76	0.02	3.00	0	0	Select
3	0.75	0.75	1.45	0.00	1.80	0.02	2.95	0	0	Select
4	0.80	0.65	1.40	0.00	1.84	-0.01	2.85	0	0	Select
5	0.85	0.55	1.40	0.00	1.88	0.00	2.80	0	0	Select
6	0.90	0.45	1.40	0.00	1.91	0.02	2.75	0	0	Select

The first option on the list is the one with minimum HMA thickness. In this particular case it is 0.65 ft HMA/1.00 ft AB-Class 2/1.40 ft AS-Class 2. **This actually does NOT agree with the table shown in item (j) of the Caltrans example document. However, item (j) incorrectly summarizes the design. In fact, item (h) says the AB thickness is 1.0 ft, and item (i) says the AS thickness is 1.40 ft.**

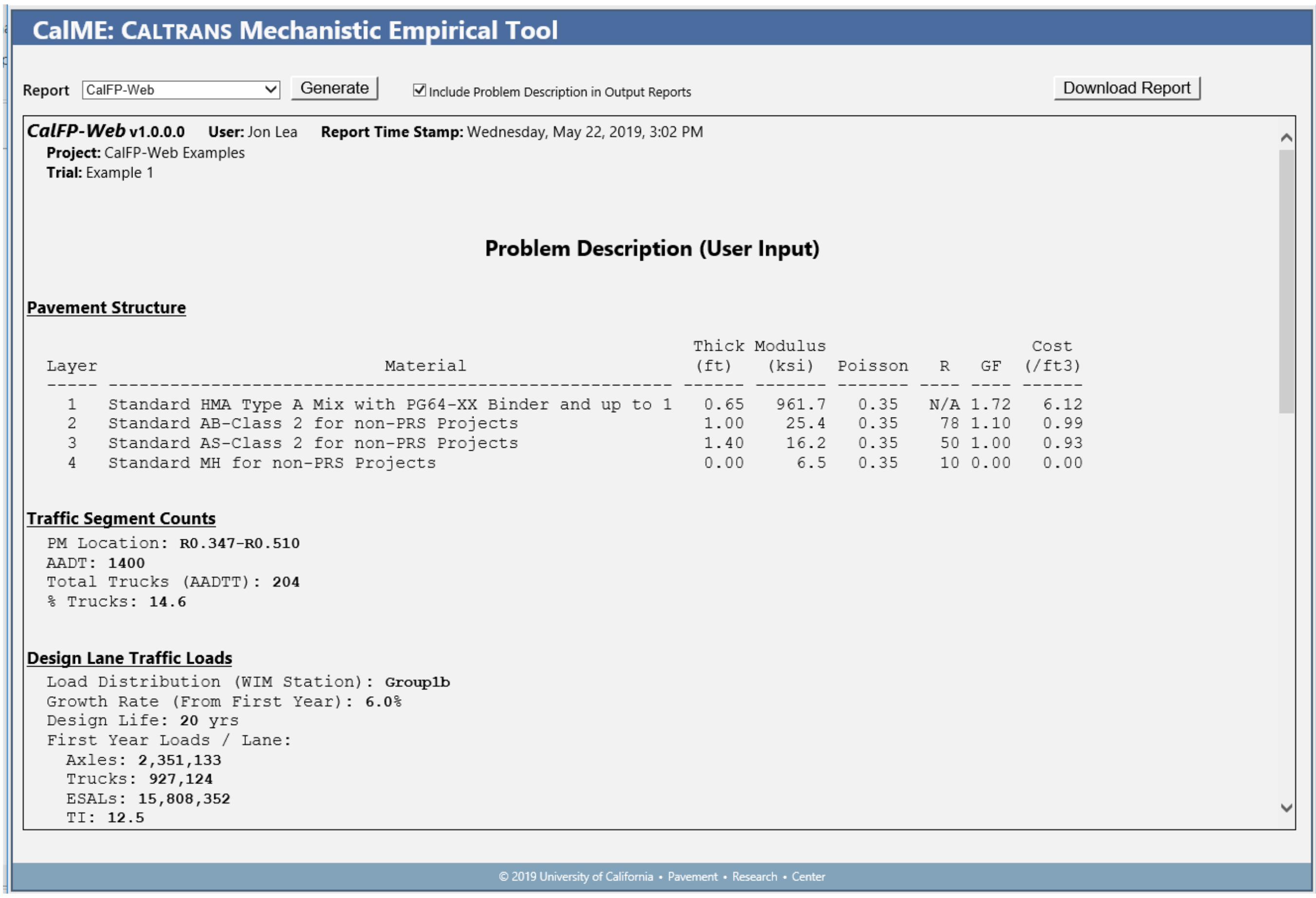
Step 4: Select a Design Option

Use the "Select" button in the grid to copy a particular design to the structure grid. The selected design will be highlighted in yellow.



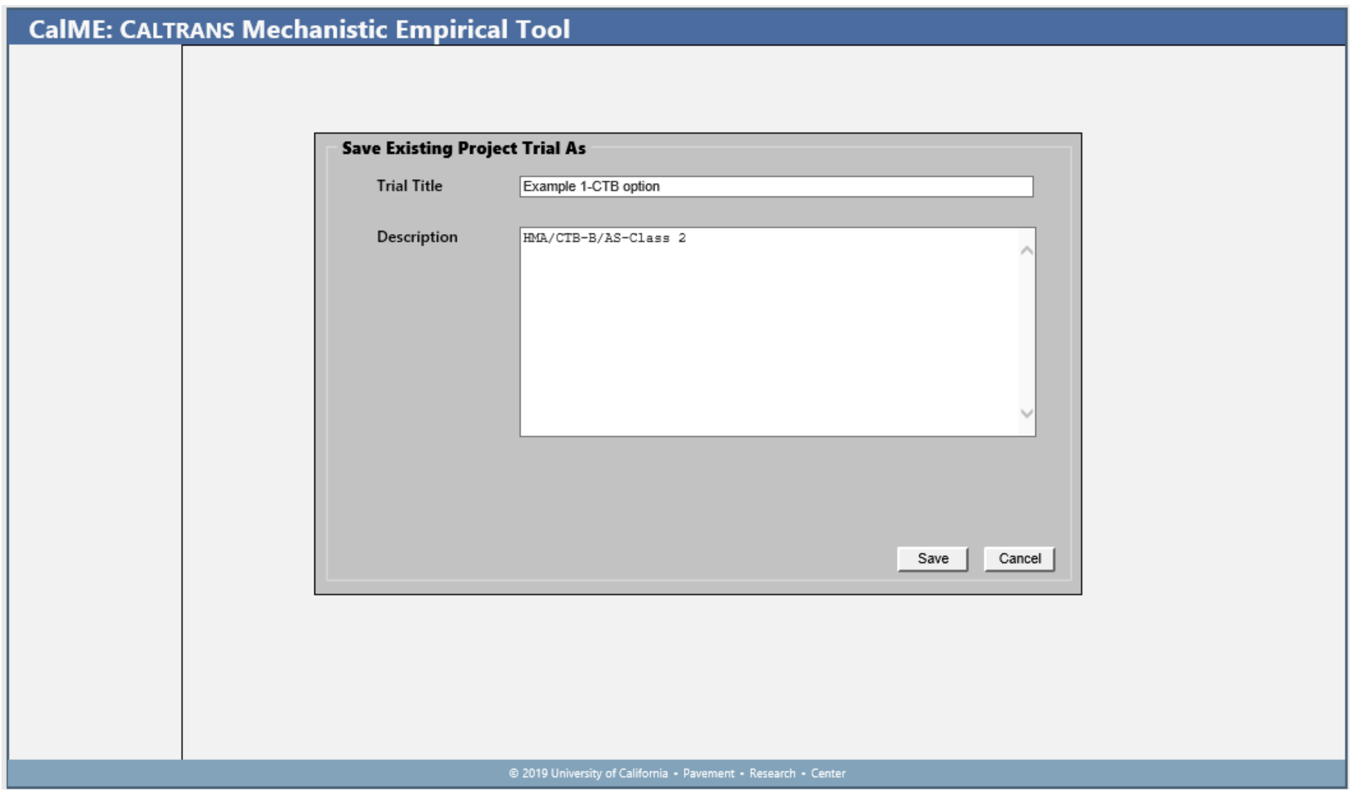
Step 5: Generate a Design Report

Use the "Reports" button to bring up the report window. Choose "CalFP-Web" from the list at the top left corner of the window. Use the "Generate" button to generate the report, and the "Download Report" button at the top right of the window to download a PDF copy of the report.

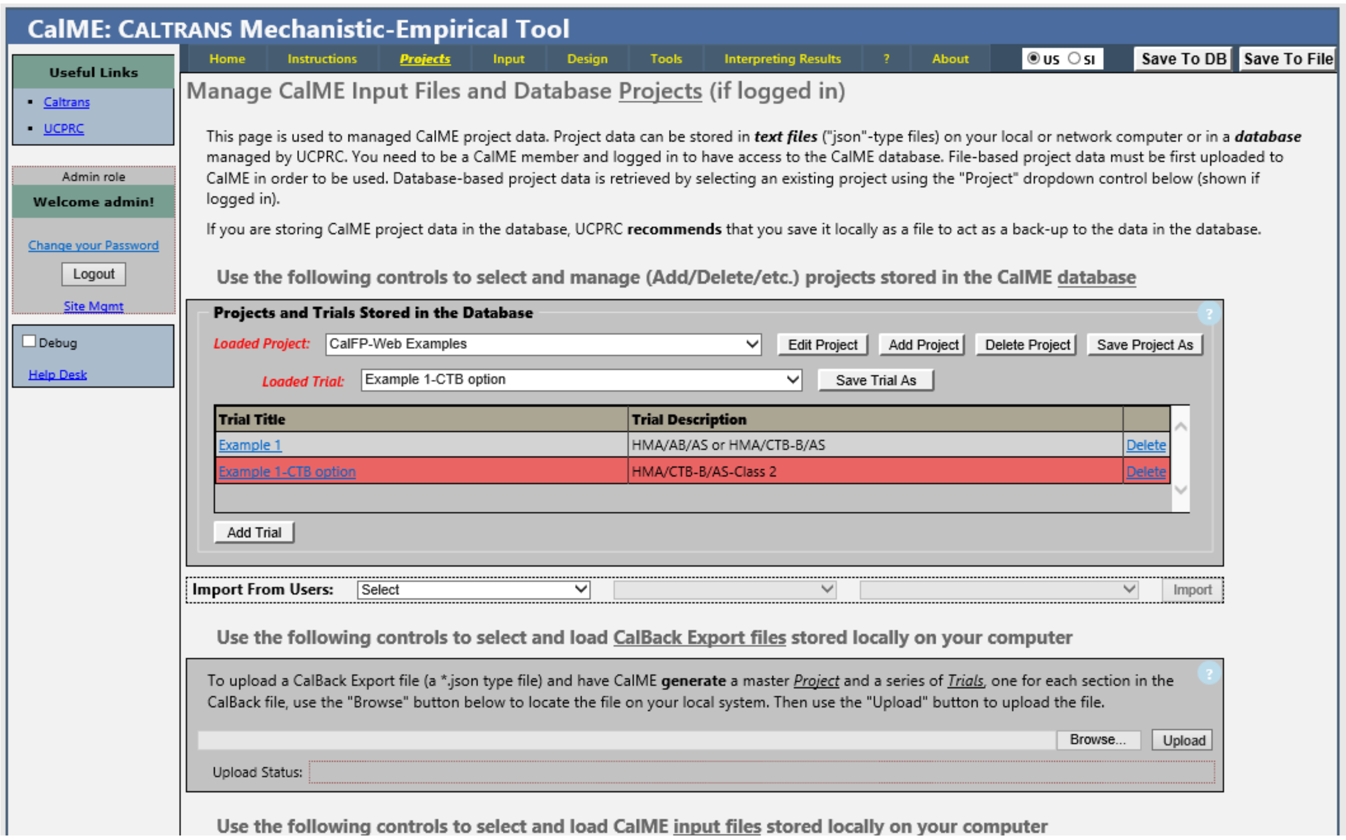


Step 6: Define a Second Trial

Close the report window. Go to the project tab, use the "Save Trial As" button to save the trial "Example 1" as "Example 1-CTB option". The screen shots are shown below.



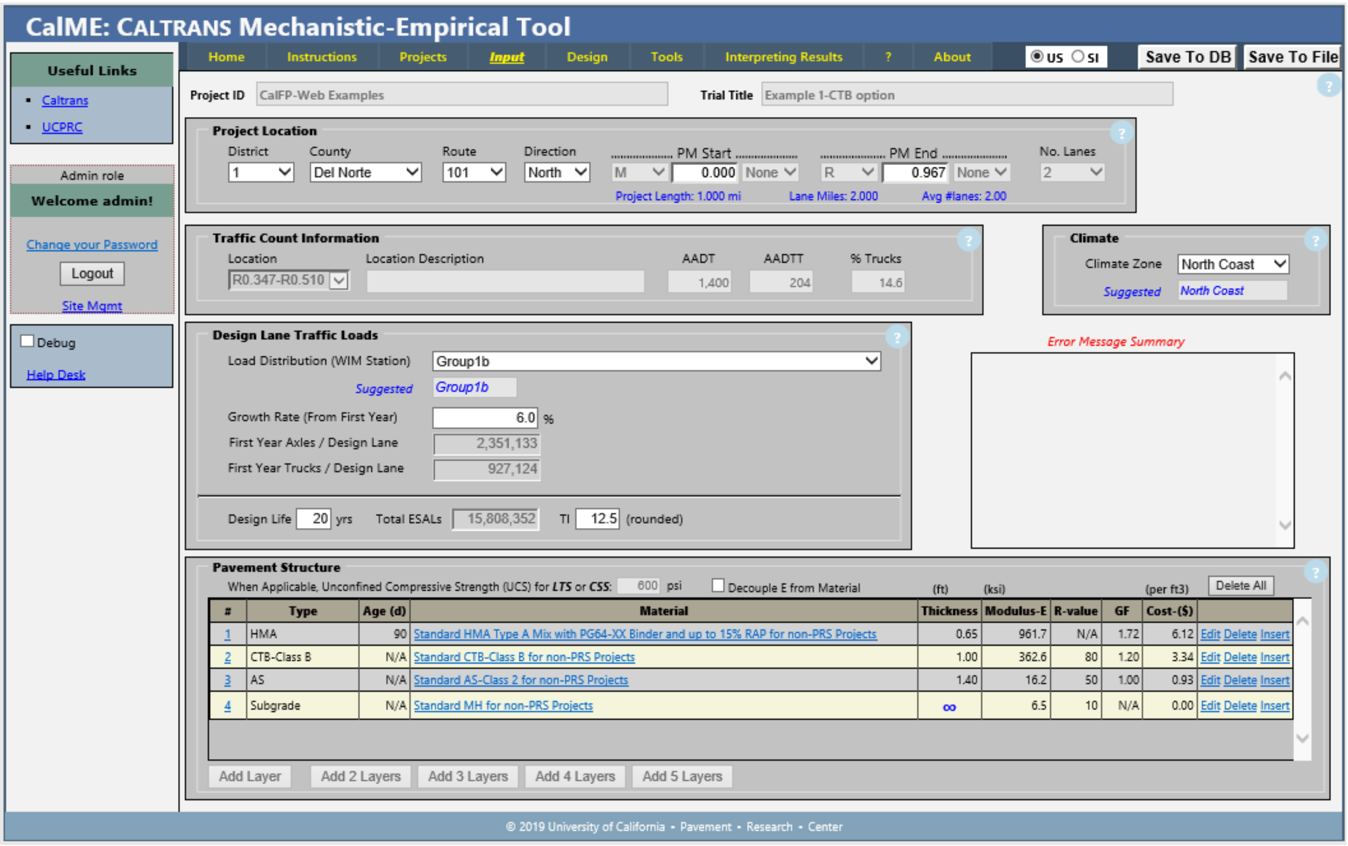
Selecting the Save button will take you back to the Projects page and it should look like what is shown below:



Note that the "Example 1-CTB option" is now shown in the "Loaded Trial" drop down list, and it is highlighted in the list of trials.

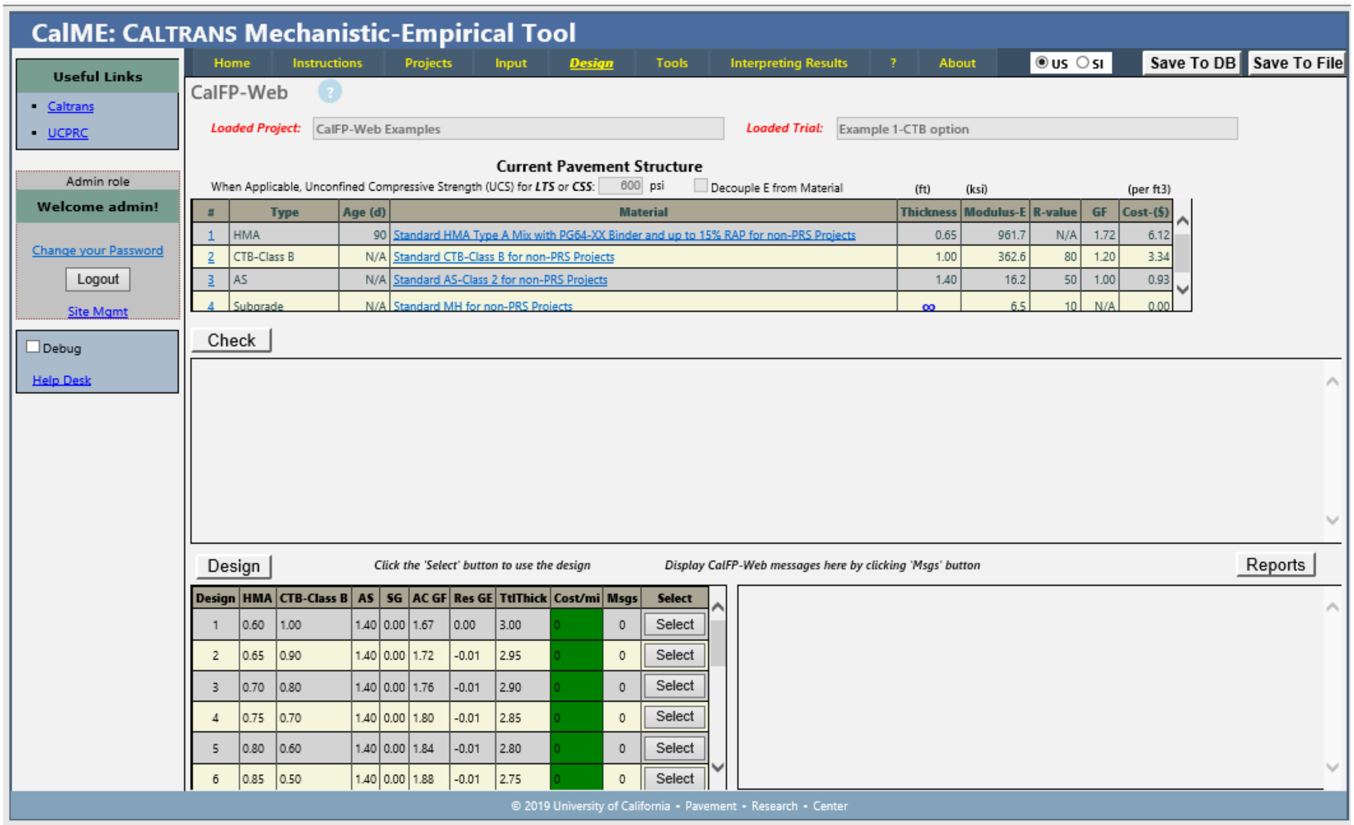
Step 7: Update the Structure

Update the structure (select Input->ProjectInformation) by changing the second layer to CTB-Class B. The resulting input tab should look like below:



Step 8: Run CalFP-Web for the CTB option

Same as in Step 3, run CalFP-Web to find a list of design options (see the screen shot below). The option with minimum thickness for HMA is: 0.6 ft HMA/1.0 ft CTB-Class B/1.40 ft AS-Class 2. Again this is inconsistent with the result in the Caltrans example. It was found that the Caltrans example did not properly account for the difference in R-value between AB-Class 2 and CTB-Class B.



The HMA thickness should be slightly less because of the higher Gf for the CTB-B (80 vs. 78).

$$GE_{required,HMA} = GE_{required,byCTB-B} + GE_{safety} = 0.0032(12.5)(100-80) + 0.20$$

$$GE_{required,HMA} = 0.80 + 0.20 = 1.00$$

At 0.60 ft, the GF for thenHMA layer is:

$$G_{f,HMA} = 7.00 \times \frac{0.60^{\frac{1}{3}}}{12.5^{\frac{1}{2}}} = 1.67$$

The total GE it provides is:

$$GE_{HMA@0.60ft} = 0.60 \times 1.67 = 1.00$$

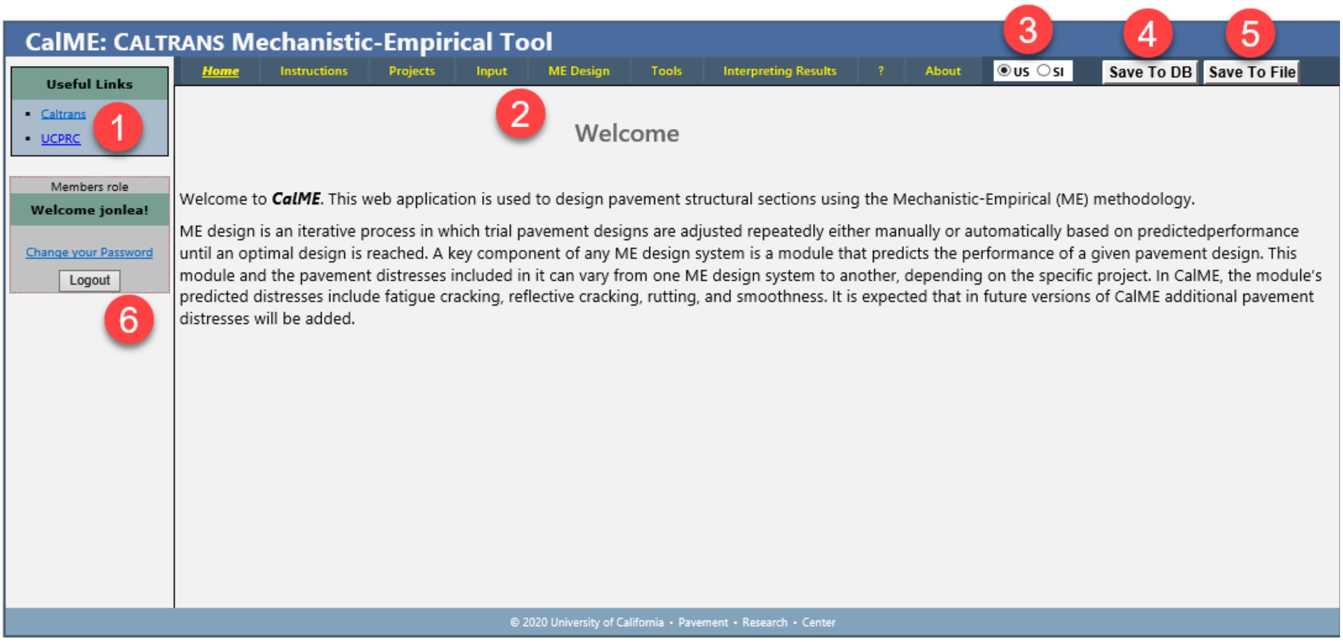
Based on the above calculations, only 0.60 ft of HMA is needed when CTB-B is used. As shown in the Item (d) of the example manual for Example #2, only 0.60 ft HMA is needed for a 12.5 TI and it provides GE of 0.98 ft according to Table 633.1. The example manual is providing an incorrect design.

User Interface

Global Controls

The home page for *CalME* is shown below. It consists of a left pane with Useful links and login controls, a series of page tabs, and some controls at the upper right and main pane that contains the content of each page as they are selected. The page tabs are disabled until you login.

These global controls are always available regardless of which page you are currently viewing.



Section notes:

1. Useful links
2. Page tabs - you navigate between application pages by selecting a page tab
    - Home - the home page
    - Instructions - basic instructions on how to use *CalME*
    - Projects - this page is where you select the current project and trial to use, add/delete projects and trials, etc.
    - Input - there are two pages (two menu items) associated with the Input tab: Project Information is where you define the pavement project, e.g., the location on a route, traffic loads, climate zone and pavement structure and Simulation Parameters is where you specify simulation parameters.
    - ME Design - this page is used to perform a Mechanistic-Empirical (ME) simulation
    - Tools - there are four pages (four menu items) associate with the Tools tab: Material

Library, Calculators, CalFP and CalAC.

- Interpreting Results - this page provides assistance in understanding the results generated by *CalME*
- About - a page that provides information about the status of *CalME*

3. Unit selection - *CalME* allows you to define your pavement project in either U.S. Customary or SI (metric) units. You can switch between the unit selection at any time and *CalME* will convert the data to the selected units. Reports and graphs will use the selected units also.
4. Save To DB - selecting this button will save the current data in the UI to the database. You will be asked to confirm this request. *CalME* will do an automatic save when you run a Mechanistic-Empirical (ME) simulation.
5. Save To File - selecting this button will generate a text version (in json format) of your data and allow you to download it to your local hard drive. You can later use the controls on the Projects page to upload this file into *CalME*.
6. Login controls - these controls allow you to:
    a. login/logout
    b. change your password
    c. get a temporary password if you have forgotten your current password

Projects Tab

Manage Database Projects and Trials

The following controls, located on the **Projects Page**, are used to select and manage *CalME* projects and project trials in the *CalME* database.

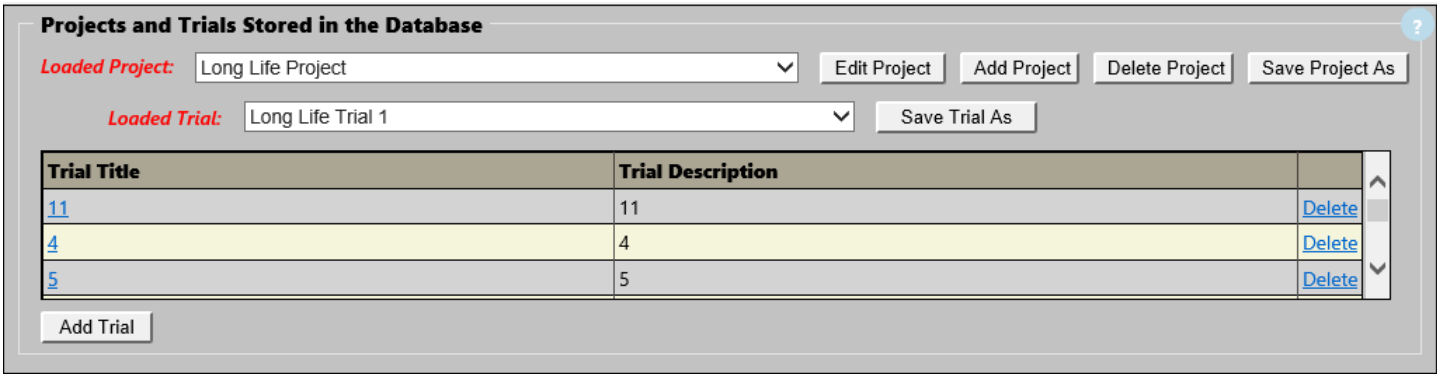
A *CalME* "project trial" or just trial, is a specification of a pavement project that can be used for an ME simulation. A *CalME* project trial contains data items such as:

- The start and end location of the pavement project on a route (begin and end postmiles)
- Traffic loading, e.g., truck load distribution group (WIM station)
- Climate zone
- Pavement structure, e.g., layer type, material, layer thickness, etc.
- Simulation parameters, e.g., simulation type, reflection cracking parameters, number of Monte Carlo simulations to perform, etc.

CalME collects any number of project trials into a a "project" for management purposes. In this way, you can have different configurations, e.g., a 2-layer system, a 3-layer system, different layer materials, etc., for a given roadway project, all collected into a single *CalME* project for easy management and logical organization.

CalME creates a default project with one default trial when you first login. You use the controls below to change the default project and trial names and add an appropriate description for both.

You can add any number of additional projects with any number of trials.



The following is a description of the project-related controls:

- Loaded Project dropdown - used to select a *CalME* project
- Edit Project button - used to edit the selected *CalME* project
- Add Project - used to add a new *CalME* project
- Delete Project - used to delete the selected *CalME* project (*CalME* prevents you from deleting all projects)
- Save Project As - used to make a copy of the selected *CalME* project, including all of its trials

The following is a description of the trial-related controls:

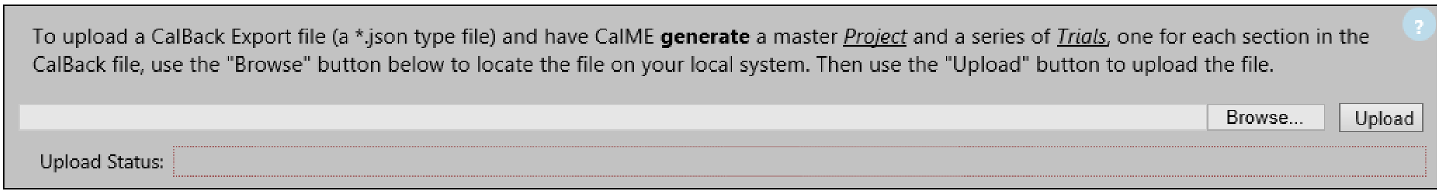
- Loaded Trial - used to select a trial contained in the selected *CalME* project
- Save Trial As - used to make a copy of the selected trial that will be added to the list of trials in the selected *CalME* project
- Trial Title hyperlink - used to edit atrial
- Delete button - used to delete a trial

The question mark in the blue circle in the upper-right of the control group allows you to get help on the controls (this topic).

Load a *CalBack* Exported File

The following controls, located on the **Projects Page**, are used to browse the local computer's file system to locate and select a file that has been exported out of *CalBack* for the purpose of importing into *CalME*.

When the *CalBack* file is uploaded, *CalME* will create a new project and a series of project trials, one for each of the sections contained in the exported *CalBack* file.



The following is a description of the *CalBack*-related controls:

- Browse button - used to locate and select a *CalBack* exported file on the local computer's file system
- Upload button - used to upload the file to *CalME*
- Upload Status area - used to show the status of the file upload process

The question mark in the blue circle in the upper-right of the control group allows you to get help on the controls (this topic).

Load a *CalME* Input File

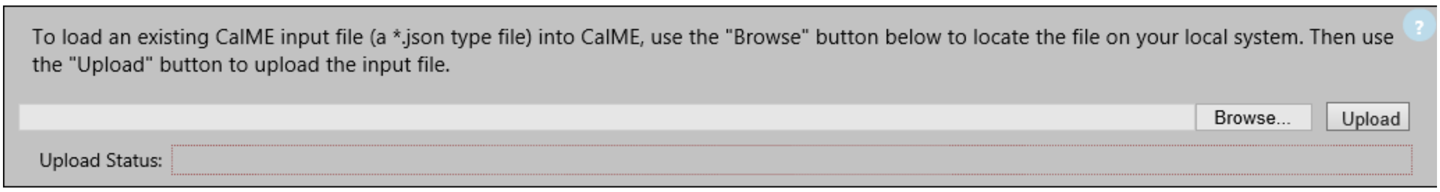
The following controls, located on the **Projects Page**, are used to browse the local computer's file system to locate and select a file that has been saved from within *CalME* and load it back into *CalME*.

One of the buttons in the upper-right of the *CalME* application window allows you to save a text-file version of the database data for the selected project trial to your local computer's file system to act as a backup to the data stored in the *CalME* database and for project documentation.

The "Save To File" button generates a json-formatted text file and allows you to download it to your local computer's file system. Once a *CalME* input file has been downloaded, you can use the controls described here to select it and upload it back into *CalME*.

This is activity is not done very often but can be useful for the following scenarios:

- Something has happened to the database version of the trial data e.g., it has become corrupt, the UCPRC database server had an issue, you made changes to the database version that you would like to revert back to an earlier version, etc. Again, this does not happen very often.
- A colleague has an example trial that you would like to use. In this case, your colleague would export the trial to a file, send it to you, and then you would be able to load it into your database and use it.



The following is a description of the *CalME* exported file related controls:

- Browse button - used to locate and select a *CalME* exported file on the local computer's file system
- Upload button - used to upload the file to *CalME*
- Upload Status area - used to show the status of the file upload process

The question mark in the blue circle in the upper-right of the control group allows you to get help on the controls (this topic).

Input Tab

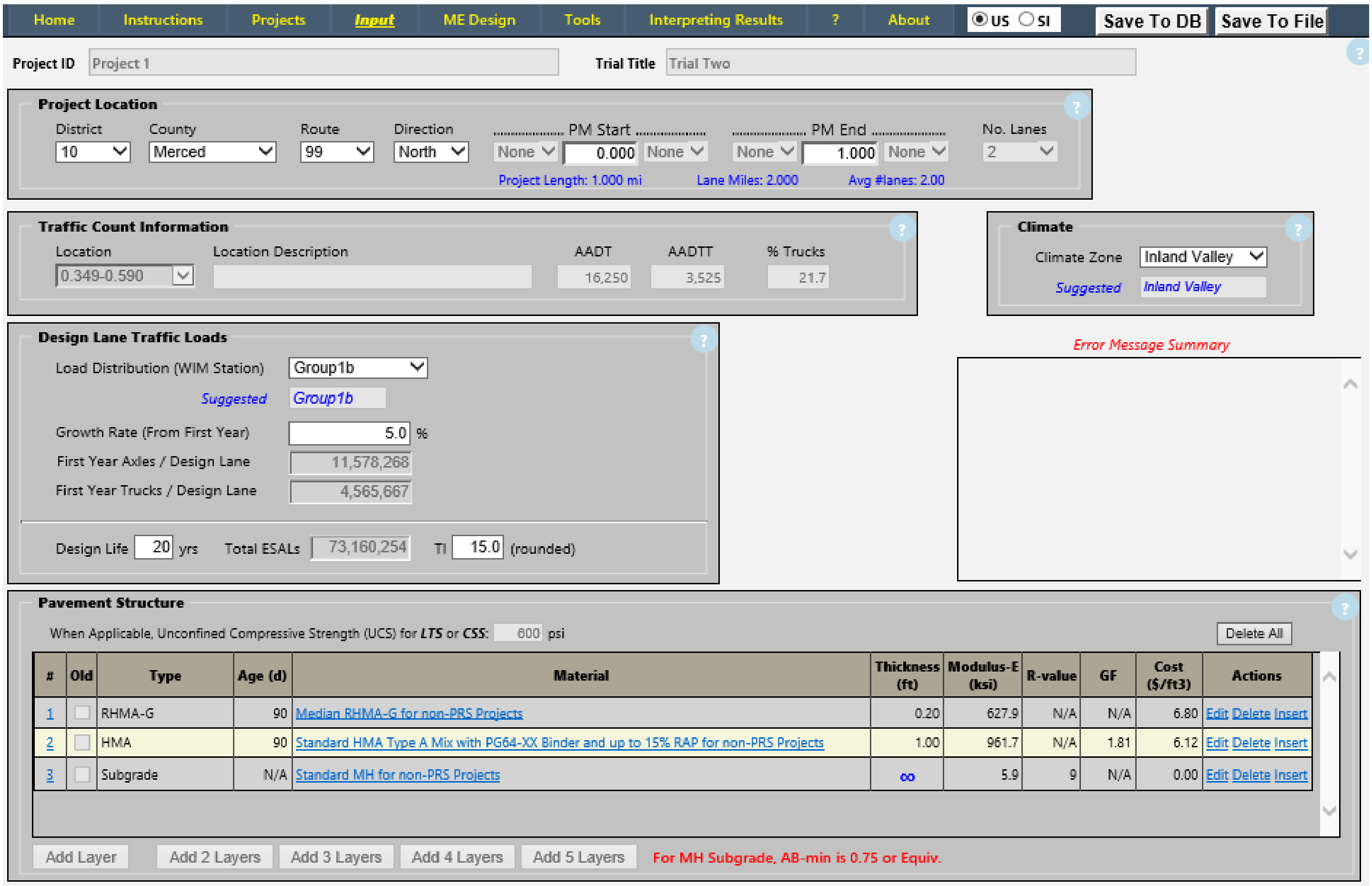
Project Information

Project Information Page

The following controls are located on the **Input -> Project Information Page.**

This page is used to specify:

- Location of the pavement project on a route
- Climate Zone
- Design lane traffic loads
- Pavement structure

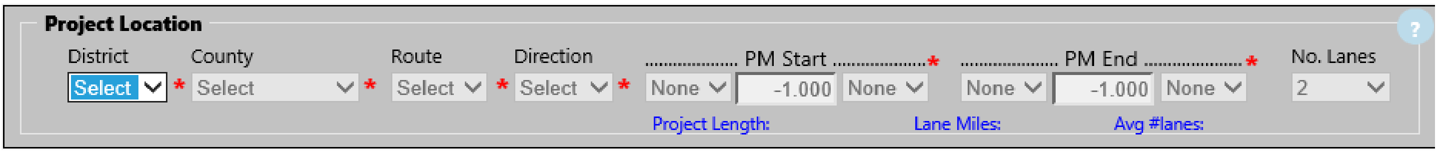


Location

The following controls, located on the **Input -> Project Information Page**, are used to specify the location of the pavement project on a route in California.

***CalME* uses the location of the project for the following**:

- obtaining the number of lanes of traffic in the direction of the route using the Caltrans Linear Reference System (LRS)
- obtaining traffic counts (AADT, AADTT) from the Caltrans traffic database
- determining an appropriate truck load distribution (WIM station)
- determining an appropriate climate zone from the Caltrans Climate Zone map



The red asterisks (*) indicate that a data item is required.

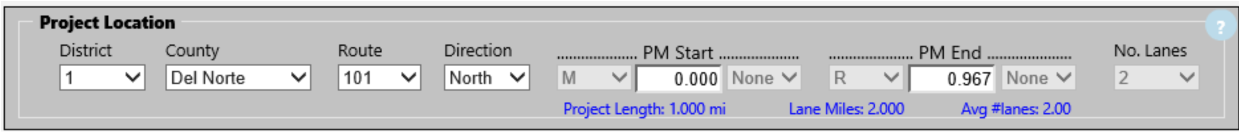
A pavement project is located on a route by the usual: **District-County-Route-Direction**, with **PM Start** and **PM End** of the start and ending of the pavement project. Postmiles (PM) are fully qualified with prefixes and suffixes. Details on postmiles can be found here.

CalME assists with the selection of the starting and ending PMs for a new project by assigning the project Start to be the PM of the beginning of the route and the project End to be the PM associated with a project length of 1.0 mile, after a selection for Direction is made. Shown below is what you will see when you select Route 101 North, in Del Norte county.

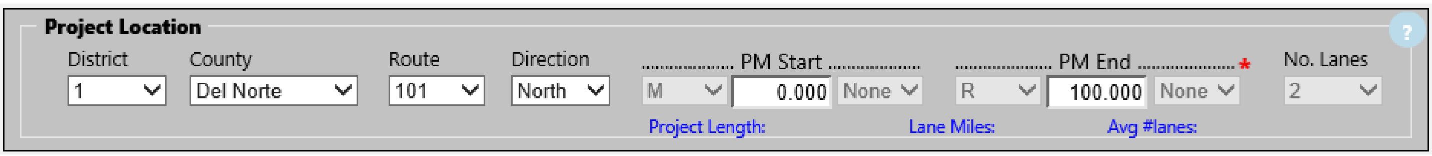
After you select North for Direction, CalME will generate a Start PM of "M0.000" and a End PM of "R0.967". These PM selections are for the start of Route 101 North in Del Norte county, and the PM associated with a project length of 1.0 miles. The blue text shown below the Start and End PMs shows the length of the project (1.0 miles), the lane miles (2.000) and the average number of lanes for the length of the project (2.00). CalME also assigns a value for the number of lanes (2) at the center point of the project.

You make changes to the default location for your specific project but generating a default project location gets you up-and-running quickly.

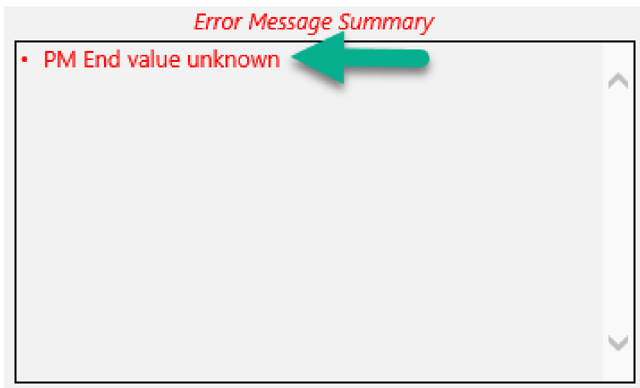
CalME automatically selects the PM prefix and PM suffix after you enter the value part of a PM.



CalME will also assist with a manual PM specification, as illustrated below.



If the PM value entered by the user (e.g., 100.000) is not valid, a message in the Error Message Summary text box will be generated.



CalME determines the validity of a PM, and the number of lanes for a project, by using the Caltrans Linear Reference System (LRS). The LRS is updated on a regular basis and *CalME* uses the latest official release of it.

CalME also makes suggestions for WIM Station and Climate Zone using Caltrans' LRS.

The question mark in the blue circle in the upper-right of the control group allows you to get help on the controls (this topic).

Traffic

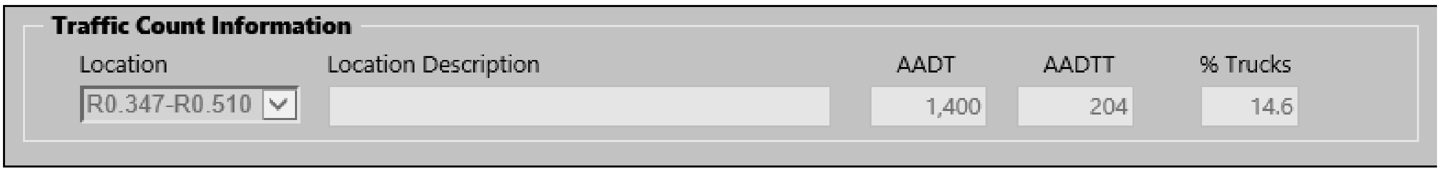
The following controls, located on the **Input -> Project Information Page**, are used to specify the traffic loadings for the pavement project.

The first set of controls, shown below, consists of several readonly fields that are used to report Caltrans traffic counts at the **center** point in the project limits. They are populated by *CalME* once the pavement project has been located on a route.

For example, if the pavement project is located in District 1, County of Del Norte, Route 101 North, PM Start of M0.000 and PM End of R1.000, the traffic counts reported in the Traffic Count Information set of controls will be based on the PM corresponding to: (State Odometer at the PM Start + State Odometer at PM End) / 2.0.

Traffic count data items:

- Location - the location of traffic counts comes from the PaveM traffic database. The PaveM database uses a processed version of the Caltrans traffic database and the PeMS database. The processing of these two databases results in one-way traffic counts, at a section level, not at a specific point. Section limits (or break points) are determined by a combination of the Caltrans Highway Log, the Caltrans Sequence Listing and with considerations of the specific locations of traffic counts. For the sample below, the traffic counts are for a section at "R0.347" to "R0.510".
- Location Description - a description of the location, if available, e.g., "0.1 mile before Bridge #23-127865"
- AADT - Average Annual Daily Traffic (one direction, all lanes)
- AADTT - Average Annual Daily Truck Traffic (one direction, all lanes)
- % Trucks - Percent Trucks (one direction, all lanes)



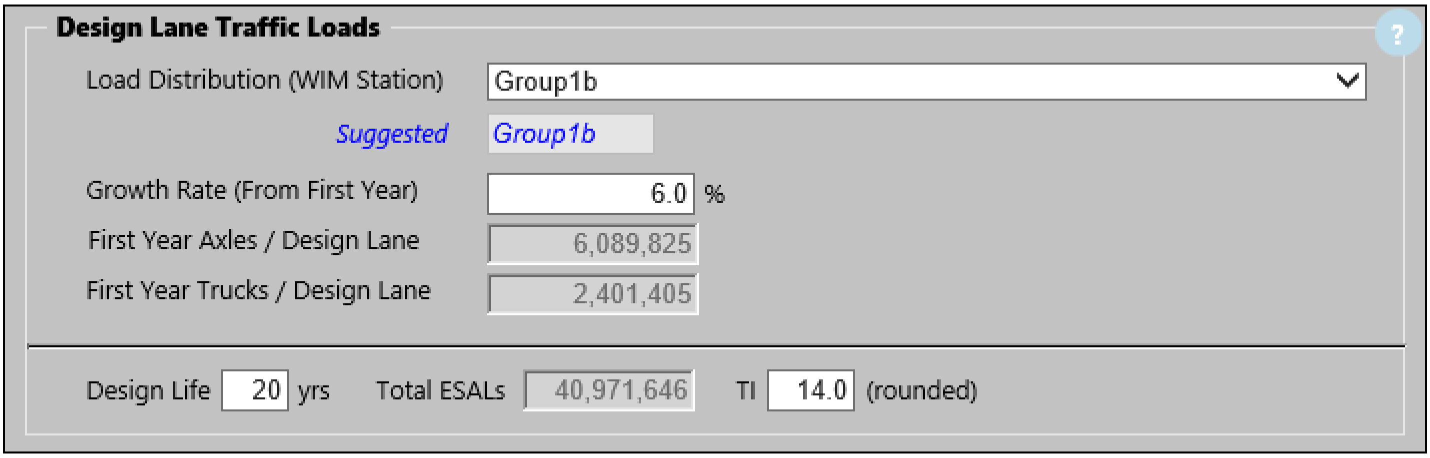
The second set of traffic controls, shown below, are used to specify traffic loads in the Design lane. *CalME* assumes that the Design lane is the outer-most lane since that lane has most of the truck traffic. Therefore, traffic count data is distributed across the lanes of traffic based on truck lane distribution rules.

Design Lane Traffic Loads data items:

- Load Distribution (WIMStation) - *CalME* populates this dropdown control with the Suggested value. You may select something other than the Suggested value.
- Suggested WIM Station - this is a readonly field that *CalME* populates. *CalME* determines the Suggested WIM group using the 9-to-5-axle truck ratio and the % trucks (determined earlier by the location of the project) to find the appropriate load distribution to use.
- GrowthRate (From First Year) - *CalME* populates this field with a value based on the selected WIM group. You may change this value. This value represents the growth in traffic from the start

date of the project *onward*. *CalME* applies a growth rate from the data of traffic observations to the *start* date of the project.

- First Year Axles / Design Lane - this is a readonly field that *CalME* populates with a value based on the selected WIM group.
- First Year Trucks / Design Lane - this is a readonly field that *CalME* populates with a value based on the selected WIM group.
- Design Life - *CalME* set a default value of 20 years. You may change this value. If you choose to design the pavement structure using either CalFP or CalAC, a Design Life of 20 years is required. You may specify any Design life for an ME design.
- Total ESALs - this is a readonly field that *CalME* populates with a value based on the selected WIM group.
- TI (Traffic Index) - *CalME* populates this field with a value based on the selected WIM group. You may change this value.



Making Changes to Growth Rate, Design Life and TI

Selecting a value for the WIM group sets the values for the other data items in the Design Lane Traffic Loads section. When you make a change to one of the editable fields, *CalME* will then recompute the other dependent values. For example, changing the TI will change: First Year Axles / Design Lane, First Year Trucks / Design Lane and Total ESALs; the WIM group and a Growth Rate are not modified. Also, changing the Growth Rate with change First Year Axles / Design Lane, First Year Trucks / Design Lane and TI.

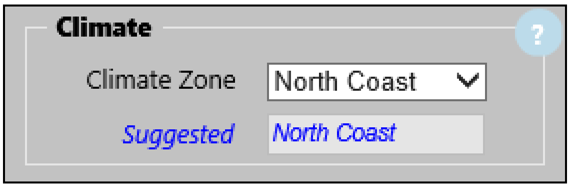
The question mark in the blue circle in the upper-right of the control group allows you to get help on the controls (this topic).

Climate Zone

The following controls, located on the **Input -> Project Information Page**, are used to specify the climate zone for the pavement project.

CalME suggests an appropriate climate zone based on the location of the center of the pavement project. You may select something other than the Suggested value. Currently, California is divided into nine climate zones and every state route has climate zone markers on it, by postmile.

The climate zone is used to obtain the seasonal and hourly variation of surface temperature for the pavement project. The surface temperature is used to find temperatures within the pavement structure using a 1D finite element analysis during the ME simulation.



The question mark in the blue circle in the upper-right of the control group allows you to get help on the controls (this topic).

Pavement Structure

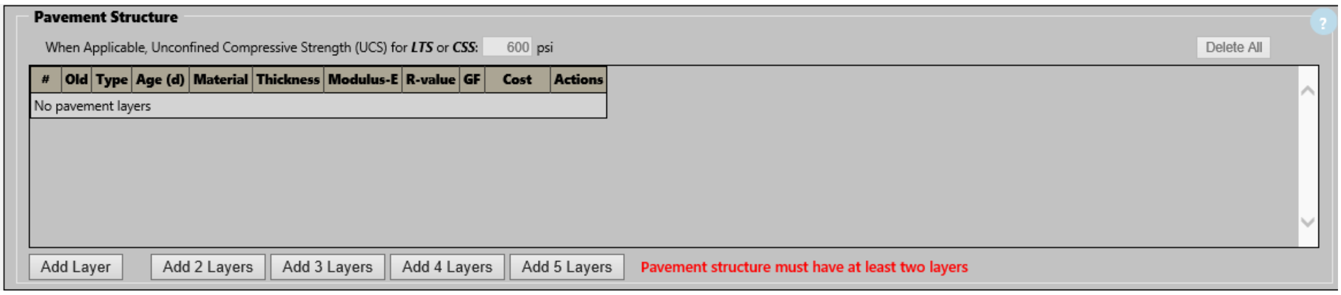
The following controls, located on the **Input -> Project Information Page**, are used to specify the structure for the pavement project.

The pavement structure is defined using a grid in which each row is one layer of the structure. You need to define at least two layers, but you may have as many layers as necessary.

You can add layers to the bottom of the current structure, insert before a layer and delete layers. You will be asked to confirm layer deletion.

There are four buttons at the bottom of the structure grid that allow you to add multiple layers at once and with layers of a specific type based on the number of layers. For example, selecting the "Add 3 Layers" button results in the following three-layer system: HMA, AB and SG. These buttons are only active if the current structure grid is empty.

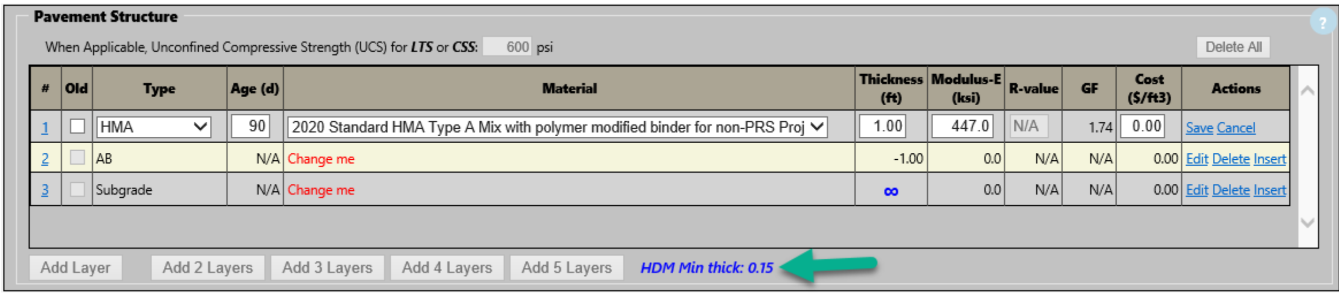
CalME has many "rules" to assist in constructing a valid structure, such as the topmost layer must be either HMA or RHMA, and the last layer must be SG (Subgrade).



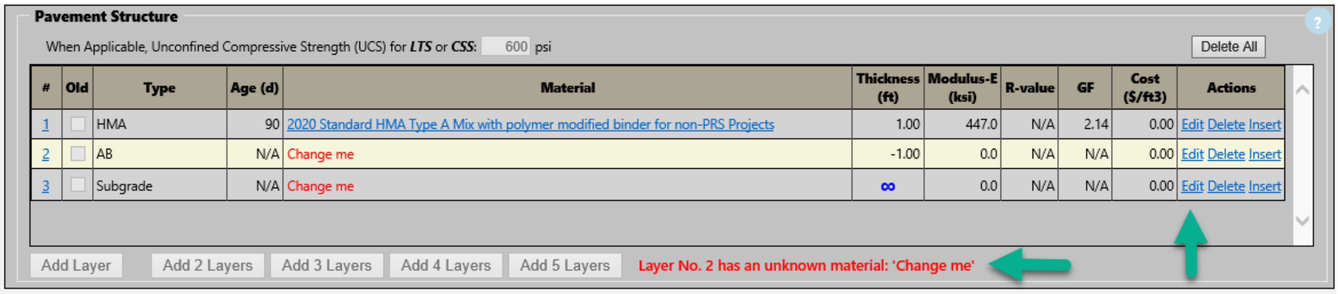
Rows (layers) are put into **Edit** mode by selecting the "Edit" button at the right of a row. Once in Edit mode, the list of buttons changes to "Save" and "Cancel". In edit mode, you can make changes to all fields that allow editing. You select the "Save" button to save your edits for the layer.

Shown below is how the Pavement Structure grid looks after selecting the Add 3 Layers button and selecting the Edit Button for the first layer (row) and entering a value of 1.0 ft for the layer thickness. All layers generated using one of the four layer generation buttons need to have a specific material selected since just the type of material (e.g., HMA) for each layer is generated by the layer generation buttons. The thickness for each layer is also required.

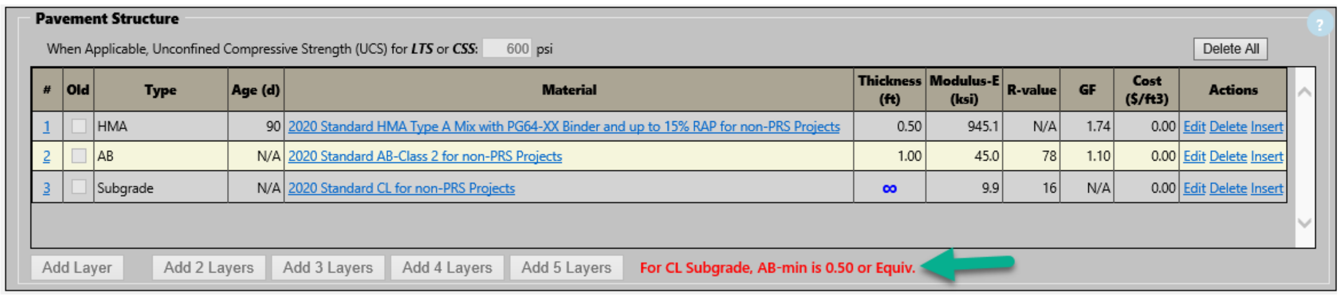
As shown below, *CalME* also checks the specified layer thickness against minimum and maximum values, as specified in Caltrans' Highway Design Manual (HDM), e.g., for HMA, the minimum thickness is 0.15 ft; there isn't a maximum value for HMA in the HDM.



After saving the changes made to the first layer (row) using the Save Button in the Actions column, CalME will indicate that Layer 2 (and subsequently Layer 3) needs to have a specific material selected.



Shown below is how the grid looks after selecting a specific material for all three layers, along with specifying an acceptable layer thickness. At this point, CalME shows an informational message indicating the minimum thickness for the AB layer; this minimum is a function of the type (USC) of subgrade. In the example shown below, the subgrade is a type "CL", which has a minimum AB thickness of 0.50 ft.



Each **layer** has the following data items:

- Layer number - this is a link item that navigates to the *Edit Pavement Layer Material* page
- Type: this is the HDM type code for the layer material: HMA, RHMA-G, FDR-FA, FDR-NS, CIR, PCC, LCB, CTB-Class A, CTB-Class B, AB ATPB, CTPB, AS, LTS and SG (Subgrade)
- Old - a flag (checkbox) to indicate if a layer should be considered an existing layer, i.e., a layer that exists before any rehabilitation is done. When importing a *CalBack* file, all layers that are

generated during the import process are flagged as Old, and they cannot be changed from that state. Any layers added to the imported pavement structure can be selected as Old or New (unchecked); typically, added layers to a CalBack imported structure are not selected as Old since they are new layers added for a rehabilitation project.

- Age - the age at loading, in days
- Material - a specific material associated with the HDM type code
- Thickness - layer thickness (recall that *CalME* will check the specified thickness value against minimum and maximum limits). When a project is created from a *CalBack* import, thickness is set to the value contained in the import file.
- Modulus - this field gives the reference modulus for the material from the Material Library. You may change this value as necessary. When you change the modulus for a subgrade layer, the R-value is also changed using the equation: E (psi) = R-value * 551 + 1117. When a project is created from a *CalBack* import, the layer modulus is set to the average of the modulus points for a section defined in the import file.
- R-value - this field gives the Caltrans "R" value from the Material Library. You may change this value as necessary for subgrade layers. When you change the R-value for a subgrade layer, the modulus is also changed using the equation: E (psi) = R-value * 551 + 1117.
- GF (Gravel Factor) - this is a read-only field that gives the equivalent gravel factor for the material
- Cost ($) - This field gives the cost per volume from the Material Library. You may change this value as necessary.

The last column of the structure grid either contains three buttons (Edit, Delete, Insert) or two buttons (Save, Cancel), depending in the row is in **viewing** mode or **edit** mode:

- Edit - puts the row (layer) into Edit mode allowing you to make changes to the layer's properties
- Delete - deletes the row (layer); you will be asked to confirm this operation
- Insert - inserts a row above the row in which you selected the Insert
- Save - saves the changes to the row (layer)
- Cancel - puts the row back into viewing mode, basically canceling any changes

At the top of the structure grid are three controls:

- Unconfined Compressive Strength (UCS) for an LTS (or CSS) layer, if it has been used in the structure. Changing this value will also change the modulus for the LTS layer, using the following equation: Mr (ksi) = 0.124 * UCS (psi) + 9.98. Conversely, changing the modulus for an LTS layer will change the UCS using the same equation. See Table 666.1A in the HDM.
- Delete All - this button will delete all layers currently defined in the structure grid. You will be asked to confirm this operation.

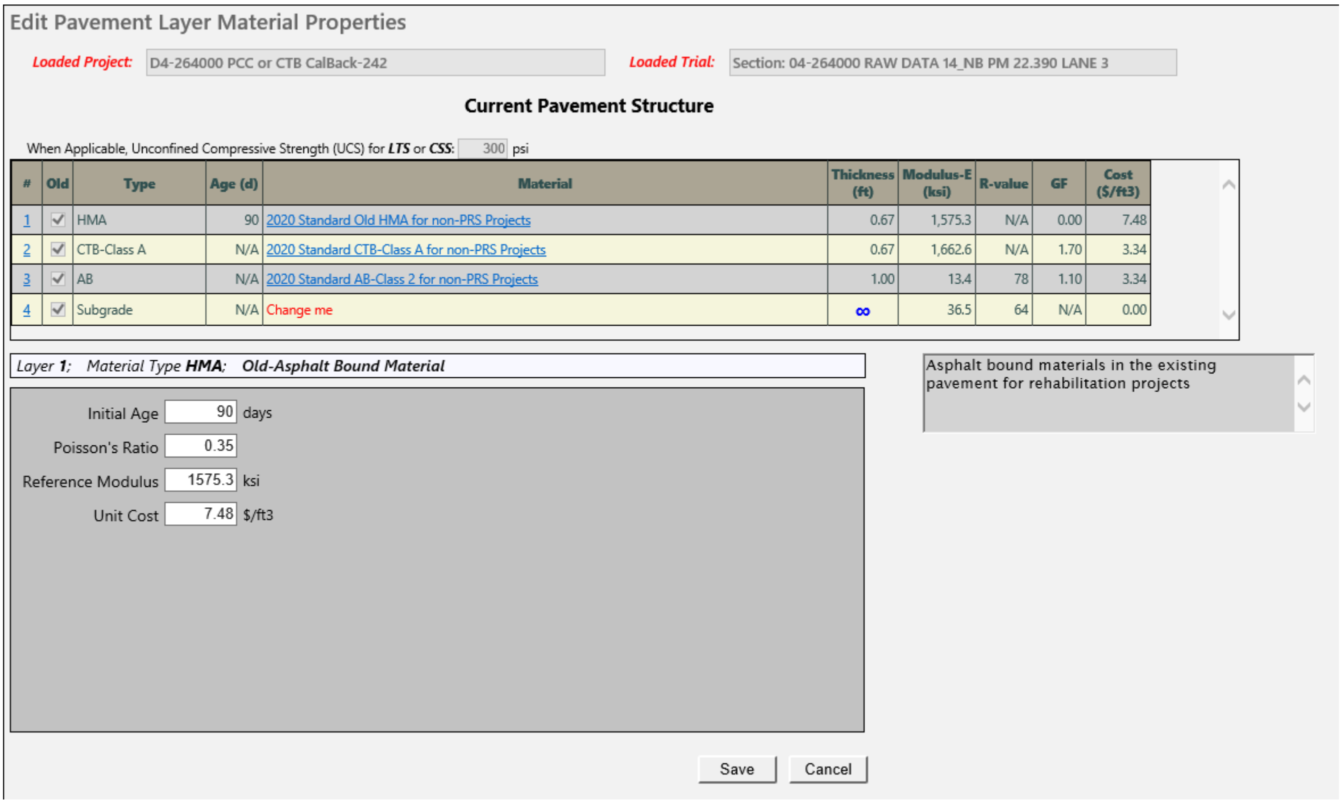
The question mark in the blue circle in the upper-right of the control group allows you to get help on the controls (this topic).

Edit Pavement Layer Material Properties

The following controls are available to edit layer material properties in a form-based approach instead of a grid-based approach.

This form is displayed when the layer number link button in the *pavement structure grid* is selected. The button controls in the grid are not available in this form but layer material data items maybe changed using field controls, as shown below.

In addition, some layer material items that are not available in the pavement structure grid, such as Poisson Ratio, are available on this form.


Edit Pavement Layer Material Properties

Loaded Project: D4-264000 PCC or CTB CalBack-242 Loaded Trial: Section: 04-264000 RAW DATA 14_NB PM 22.390 LANE 3

Current Pavement Structure

When Applicable, Unconfined Compressive Strength (UCS) for LTS or CSS: 300 psi

#	Old	Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost ($/ft3)
1	✓	HMA	90	2020 Standard Old HMA for non-PRS Projects	0.67	1,575.3	N/A	0.00	7.48
2	✓	CTB-Class A	N/A	2020 Standard CTB-Class A for non-PRS Projects	0.67	1,662.6	N/A	1.70	3.34
3	✓	AB	N/A	2020 Standard AB-Class 2 for non-PRS Projects	1.00	13.4	78	1.10	3.34
4	✓	Subgrade	N/A	Change me	∞	36.5	64	N/A	0.00

Layer 1; Material Type HMA; Old-Asphalt Bound Material

Asphalt bound materials in the existing pavement for rehabilitation projects

Initial Age 90 days

Poisson's Ratio 0.35

Reference Modulus 1575.3 ksi

Unit Cost 7.48 $/ft3

Save Cancel

Simulation Parameters

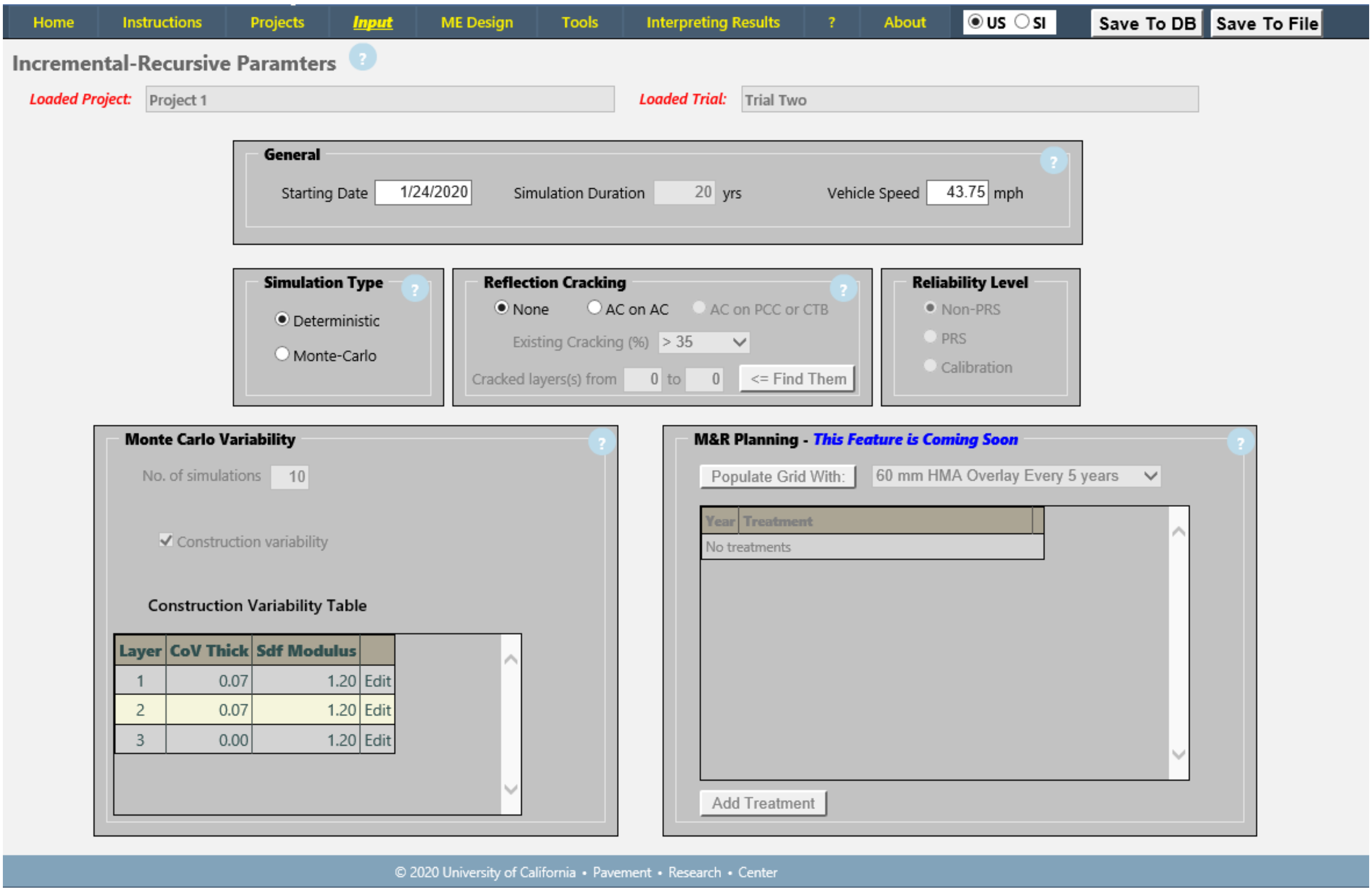
Simulation Parameters Page

The following controls are located on the **Input -> Simulation Parameters Page.**

This page is used to specify data items associated with a Mechanistic-Empirical simulation:

- General parameters
- Simulation Type
- Reflection Cracking Parameters

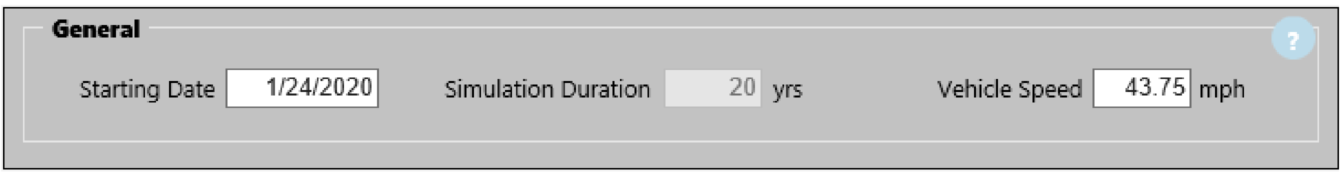
- Reliability Level
- Monte Carlo Variability
- Maintenance and Rehabilitation (M & R)



The question mark in the blue circle in the upper-right of the control group allows you to get help on the controls.

General

The following controls, located on the **Input -> Simulation Parameters Page**, are used to specify general parameters associated with the Mechanistic-Empirical simulation.



General simulation controls:

- Starting Date - the date when the road is opened to traffic is entered. This may be a planned date in the future or a historical date if the program is used for "back casting", where the past performance is simulated in order to test the validity of the prediction models for a rehabilitation design.
- Simulation Duration - this is a readonly field which shows the length of time (in years) for the simulation. This value is set on the *ME Design* Page. The default value for this is the *Design Life* set on the *Project Information* Page. The Simulation Duration is reset whenever you make a change to the Design Life.
- Vehicle Speed - the wheel speed is used in the asphalt temperature calculation

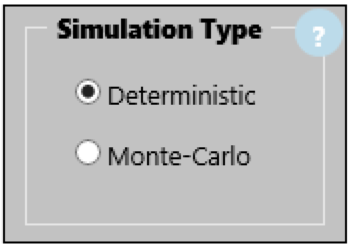
The question mark in the blue circle in the upper-right of the control group allows you to get help on the controls (this topic).

Simulation Type

The following controls, located on the **Input -> Simulation Parameters Page**, are used to specify the type of Mechanistic-Empirical simulation to perform for the pavement project.

CalME has two types of Mechanistic-Empirical (ME) to select from:

- Deterministic - a **single simulation** is performed on the pavement structure using the specified input values
- Monte Carlo - **many simulations** are performed on the pavement structure using random values from a distribution of values for several input data items, such as thickness and and modulus. The number of simulations is specified in the Monte Carlo Variability parameter section. Monte Carlo takes into account within project construction variability.



In general, a **Deterministic** simulation is performed first in order to understand the basic response of the pavement structure. Once that is done, then a **Monte Carlo** simulation is performed with the number of simulations set to give at least 95% reliability for rutting and cracking.

The default number of simulations is set at **10** but more are needed to obtain the 95% reliability level. In most cases, at least 50 simulations will be required for typical designs.

The amount of *CalME* runtime required to perform the Monte Carlo analysis is directly dependent on the number of simulations and the Design Life (and the load on the server). For a four-layer structure, some example runtimes are:

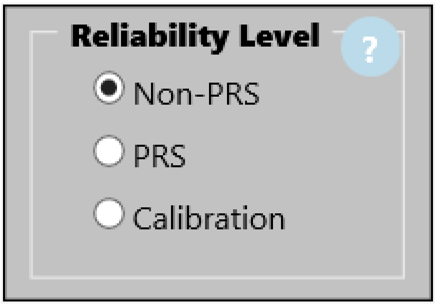
- Design Life = 20 yrs   Number of simulations = 10   30 seconds
- Design Life = 20 yrs   Number of simulations = 50   93 seconds
- Design Life = 40 yrs   Number of simulations = 50   168 seconds

The question mark in the blue circle in the upper-right of the control group allows you to get help on the controls (this topic).

Reliability Level

The following controls, located on the **Input -> Simulation Parameters Page**, are used to specify the Reliability Level associated with the Mechanistic-Empirical simulation.

Reliability Level is used to select the appropriate reliability that matches the uncertainties in pavement performance prediction for a given design. "PRS" is short for Performance Related Specifications.



Reliability Level:

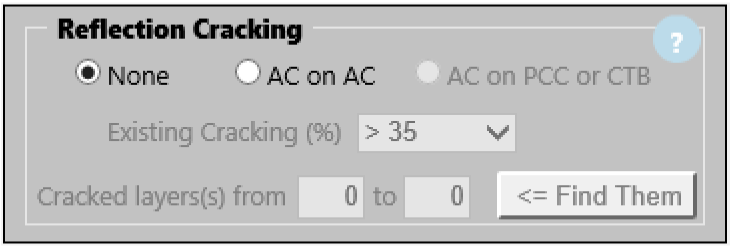
- Non-PRS - this level is used when the HMA materials follow the volumetric specification and there is no specific minimum performance requirements to meet
- PRS - this level is used when the HMA materials follow the performance related specifications. Each HMA material used in the design has a set of performance limits associated with it. The Job Mix Formula (JMF) submitted by the contractor will need to be verified to meet these performance limits as part of the approval process.
- Calibration - this level is used for calibrating performance models. Permission to use this level is granted, on a case-by-case basis, separately from the permission to run CalME.

The question mark in the blue circle in the upper-right of the control group allows you to get help on the controls (this topic).

Reflection Cracking Parameters

The following controls, located on the **Input -> Simulation Parameters Page**, are used to specify the reflection cracking parameters associated with the Mechanistic-Empirical simulation.

The reflection of cracks through overlying layers maybe included in the simulation by selecting the radio buttons shown below. The default is **None**. These radio buttons will be enabled if the structure has certain layer material types: HMA (or RHMA) over HMA and HMA over PCC or CTB, otherwise they will be disabled.



Reflection Cracking Controls:

- None - this is the default selection
- AC on AC - There needs to be multiple layers of HMA (AC) or RHMA over HMA for this control to be enabled.
- AC on PCC or CTB - this radio button becomes enabled if there is HMA over PCC or CTB.
- Existing Cracking - specifies the amount of existing wheel path cracking (longitudinal and transverse), in percent. This control becomes enabled when the Reflection Cracking is set to "AC on AC". The are five ranges of Existing Cracking:
  - 0 - 5
  - 6 - 15
  - 16 - 25
  - 26 - 35
  - >35
- Cracked layers(s) from - If the cracking is not reflecting from layer number 2 through an overlay, but from a deeper layer, the number of this layer must be entered in "Cracked layer" (if Cracked layer is 0 *CalME* assumes that cracks reflect from layer number 2).
- Find Them - this button assists in locating the layers for cracking

The question mark in the blue circle in the upper-right of the control group allows you to get help on the controls (this topic).

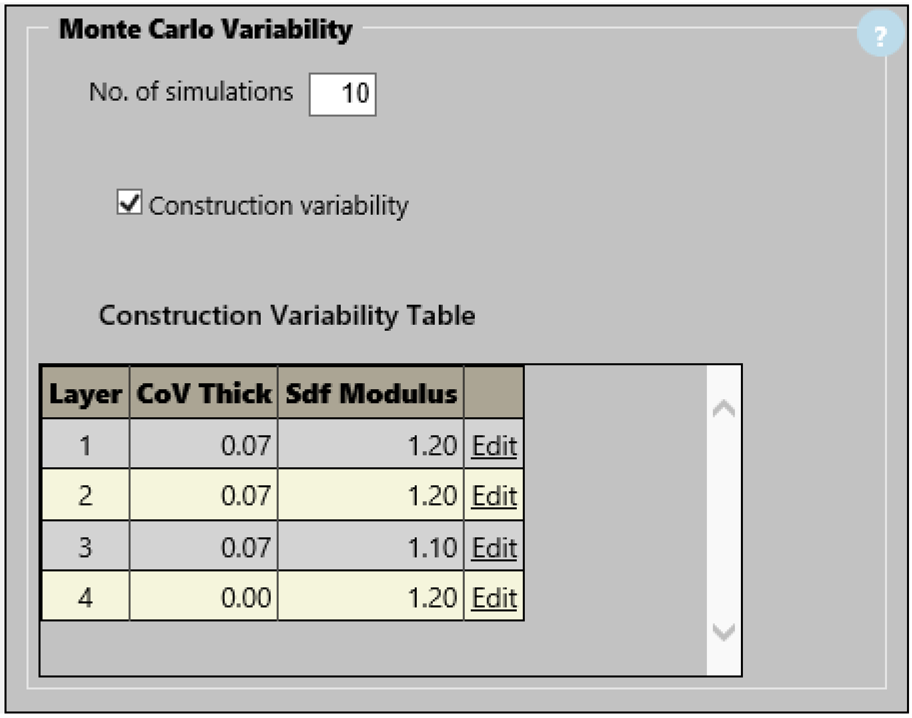
Monte Carlo Variability

The following controls, located on the **Input -> Simulation Parameters Page**, are used to specify Monte Carlo variability parameters associated with the Mechanistic-Empirical simulation.

Selecting **Monte Carlo** for the Simulation Type will enable the following set of controls.

In **Deterministic** mode, the values (for thickness and modulus) entered in the *Pavement Structure* grid will be used in the simulation. These values may either represent the values at a specific point or the mean values over a section of pavement. The simulation will predict the permanent deformation and the damage of each layer in the pavement, but the roughness cannot be calculated as this is a function of the variability.

In **Monte Carlo** mode, many simulations are performed on the pavement structure using random values from a distribution of values for several input data items, such as thickness and and modulus. The number of simulations is specified below. Monte Carlo takes into account within project construction variability.



Monte Carlo Variability data items:

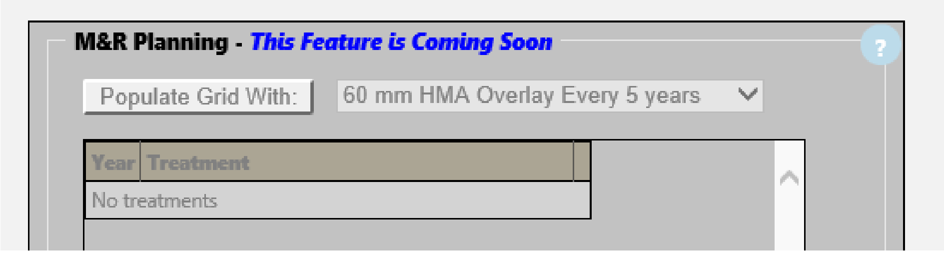
- No. of simulations - this sets the number of simulations to perform. The default is 10 but more are normally needed to achieve a 95% or greater reliability for rutting and cracking.
- Construction variability - select this item to include construction variability. The default is to include construction variability in the simulation.
- Layer variability parameters - the coefficient of variation for thickness (CoV Thick) and standard deviation for the modulus (Sdf Modulus) are shown for each layer from the Material Library. You may make changes to these values. When a project is created from a *CalBack* import, the "CoV Thick" is set to zero and the value for "Sdf Modulus" is computed from the modulus points for a section defined in the import file.

The question mark in the blue circle in the upper-right of the control group allows you to get help on the controls (this topic).

Maintenance and Rehabilitation (M&R) Planning

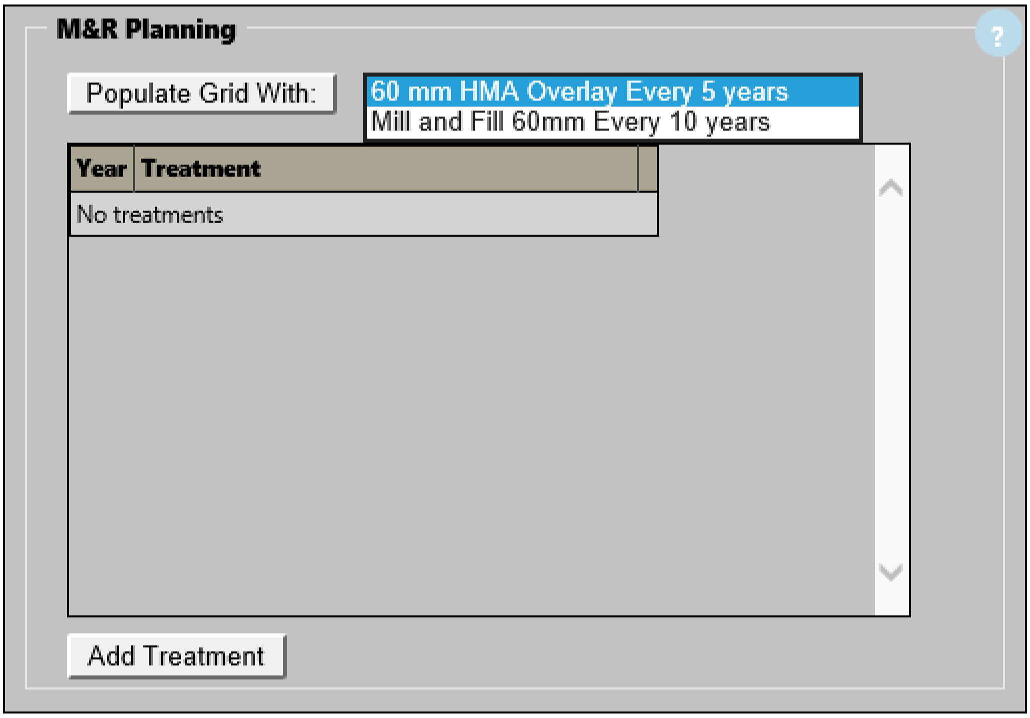
The following controls, located on the **Input -> Simulation Parameters Page**, are used to specify M&R details associated with the Mechanistic-Empirical simulation.

** This feature is currently under development so it is not enabled **.



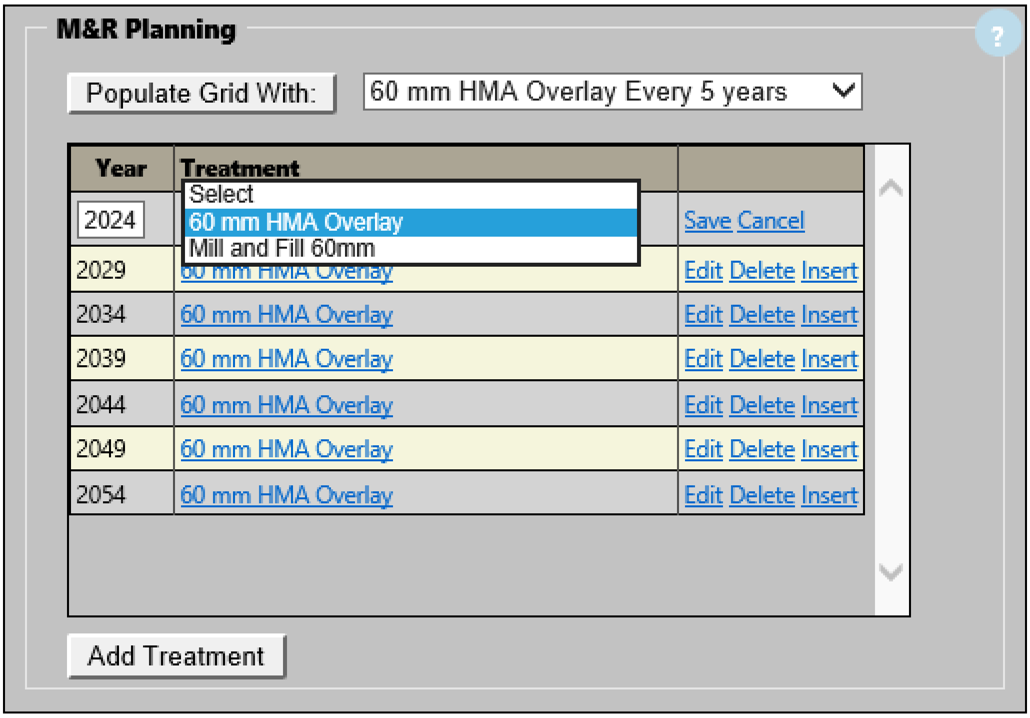
These controls allow you to specify a maintenance strategy that contains treatments to be applied at specific dates in the future. *CalME* has two strategies you can select from, as shown below:

- 60 mm HMA Overlay Every 5 years
- Mill and Fill 60 mm Every 10 years

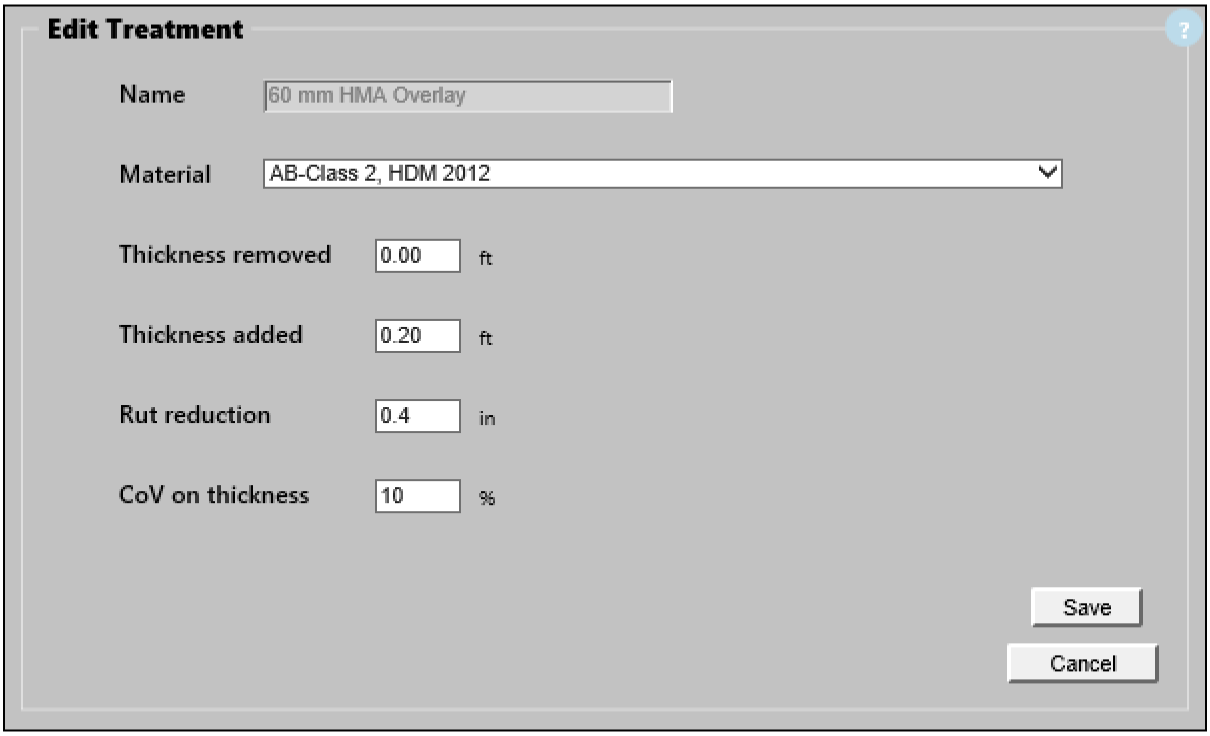


Selecting the "Populate Grid With:" will generate the selected strategy into the grid.

You can also build a specific strategy by selecting the "Add Treatment" button, entering the year for the treatment and selecting the kind of treatment. You can also delete a treatment by selecting the "Delete" button for the row (year) you want to delete. Selecting the "Edit" button allows you edit the data in the row (year).



Clicking on the treatment link will bring up the "Edit Treatment" form in which you can make changes to the treatment. This allows you to customize the built-in treatment details with your custom version for a specific year.



The question mark in the blue circle in the upper-right of the control group allows you to get help on the controls (this topic).

ME Design Page

Mechanistic-Empirical (ME)

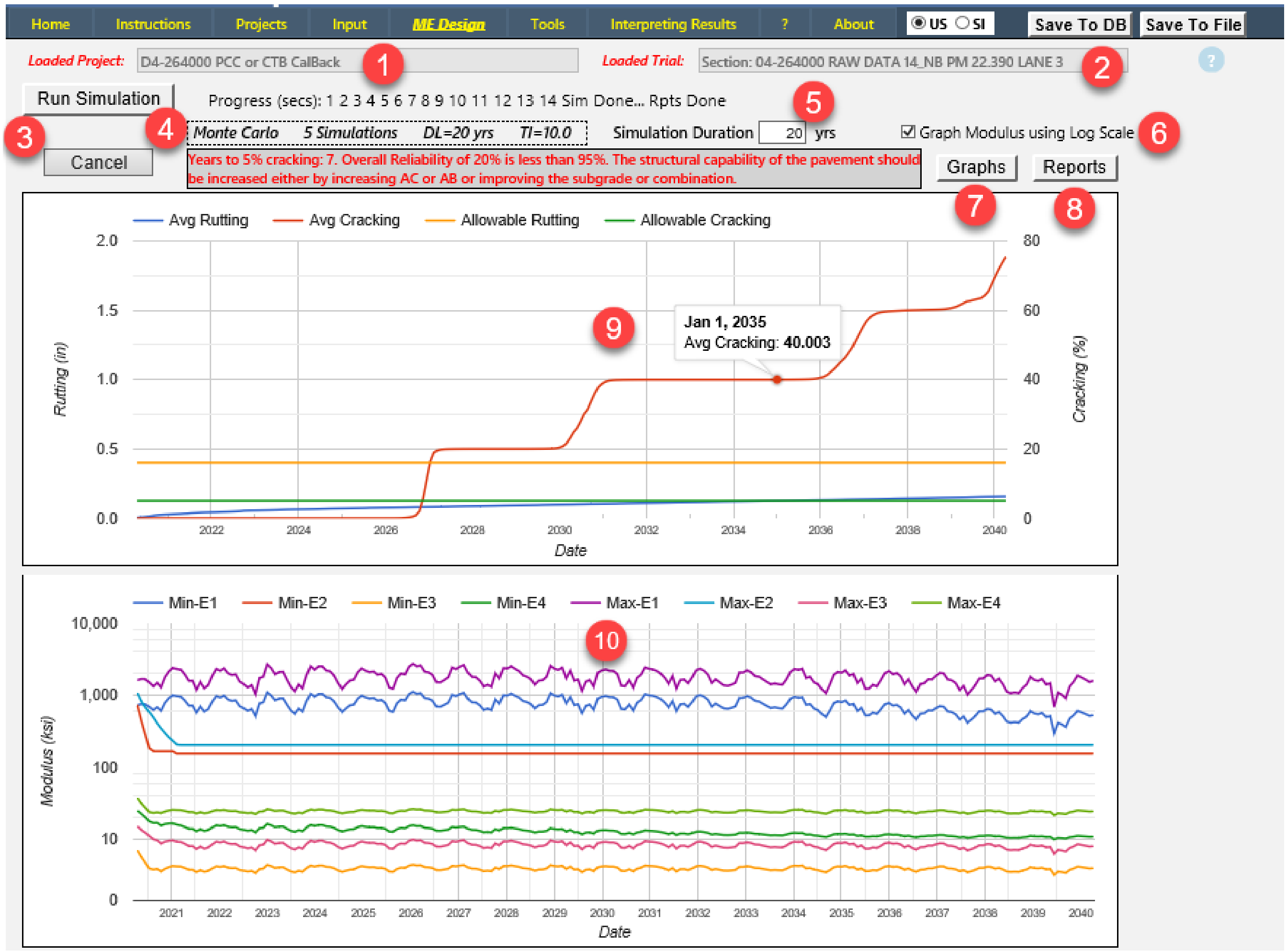
The following controls, located on the **Design -> Mechanistic Page**, are used to perform a Mechanistic-Empirical (ME) design check.

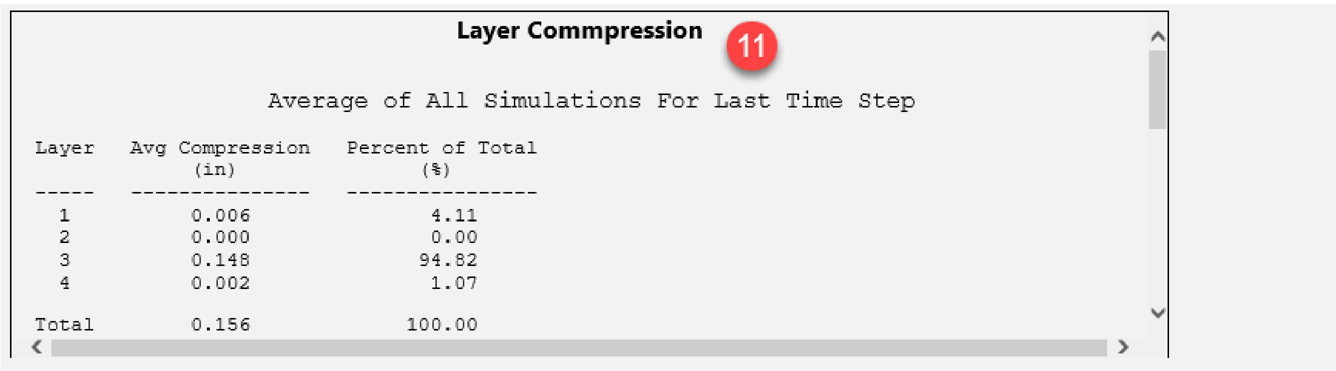
CalME can perform a **Deterministic** or **Monte Carlo** simulation depending on what is selected for Simulation Type. A Deterministic simulation performs a single simulation, using the properties defined on the *Project Information* page, while a Monte Carlo performs many simulations in which properties are randomly selected from a distribution of those properties. The number of simulations performed in a Monte Carlo is set in the Monte Carlo Variability section.

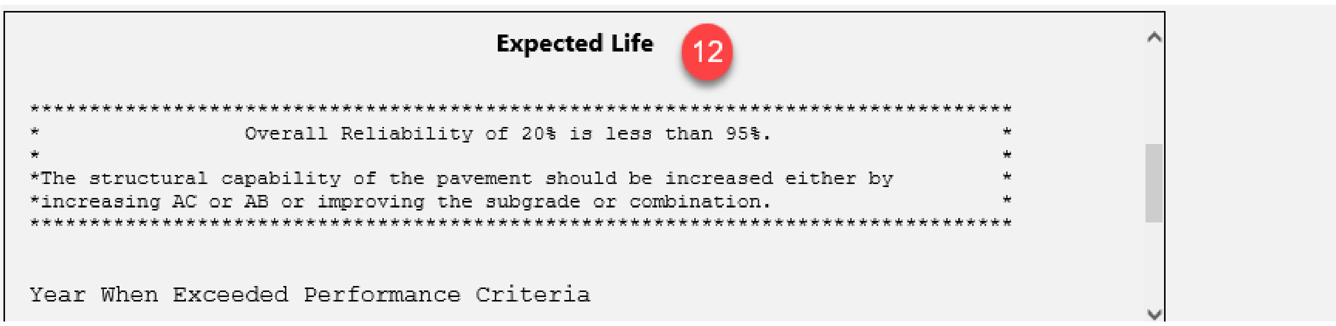
The length of time (in years) for the simulation(s) is initially set to the Design Life. You may change the simulation duration to be something other than the Design Life on this page (#5 below). Simulation Duration is reset to Design Life whenever it is changed. The start date for the simulation begins at what is set for Start Date.

This page has four sections of information:

- The top section - shows the *current project and trial* (#1 and #2), buttons for starting and canceling simulations (#3), progress on the simulation, summary data for the current project trial (#4), simulation duration (#5), selection of graph type for the layer moduli (6), navigation buttons for the *Graph* and *Report* pages (#7 and #8) and a messaging area
- Real-time graphing display for rutting (average of the simulations for a Monte Carlo) and cracking (average of the simulations for a Monte Carlo) curves, and allowable rutting and allowable cracking (#9) horizontal lines
- Real-time graphing display for minimum and maximum for pavement layer moduli (#10)
- A scrollable text box control that displays pavement Layer Compression (#11) and Expected Life (#12) reports, once the simulation is complete


Home
Instructions
Projects
Input
ME Design
Tools
Interpreting Results
?
About
US SI
Save To DB
Save To File
Loaded Project: D4-264000 PCC or CTB CalBack
1
Loaded Trial: Section: 04-264000 RAW DATA 14_NB PM 22.390 LANE 3
2
Run Simulation
Progress (secs): 1 2 3 4 5 6 7 8 9 10 11 12 13 14 Sim Done... Rpts Done
5
3
4
Monte Carlo 5 Simulations DL=20 yrs TI=10.0
Simulation Duration 20 yrs
Graph Modulus using Log Scale
6
Cancel
Years to 5% cracking: 7. Overall Reliability of 20% is less than 95%. The structural capability of the pavement should be increased either by increasing AC or AB or improving the subgrade or combination.
Graphs
Reports
7
8
Avg Rutting
Avg Cracking
Allowable Rutting
Allowable Cracking
Rutting (in)
Cracking (%)
9
Jan 1, 2035
Avg Cracking: 40.003
Date
Min-E1
Min-E2
Min-E3
Min-E4
Max-E1
Max-E2
Max-E3
Max-E4
10
Modulus (ksi)
Date


Layer Commpression
11
Average of All Simulations For Last Time Step
Layer Avg Compression Percent of Total
(in) (%)
1 0.006 4.11
2 0.000 0.00
3 0.148 94.82
4 0.002 1.07
Total 0.156 100.00


Expected Life
12
* Overall Reliability of 20% is less than 95%. *
*The structural capability of the pavement should be increased either by *
*increasing AC or AB or improving the subgrade or combination. *
Year When Exceeded Performance Criteria

Simulation#	Cracking	Rutting	Overall
1	19.8	>20.0	19.8
2	10.4	>20.0	10.4
3	>20.0	>20.0	
4	6.7	>20.0	6.7
5	16.5	>20.0	16.5
No. Failed	4 of 5	0 of 5	4 of 5
No. Passed	1 of 5	5 of 5	1 of 5
Reliab. (%)	20	100	20

Section notes:

1. Shows the currently loaded *CalME* *project*
2. Shows the currently loaded *CalME* *trial* within the currently loaded project
3. Selecting the "Run Simulation" button starts the simulation. Selecting "Cancel" will stop the simulation. The amount of clock time required for the simulation(s) depends on the Simulation Duration (#5) and the *Number of Simulations*. Typical design checks (Design Life = 40 years and Number of Simulation = 50) will take around 3 minutes. In addition, when there are many simulations (50+) the response curves shown in sections 9 and 10 will take around 30 seconds to begin showing progress. For a Deterministic simulation, the response curves begin almost immediately.
4. The progress of the simulation(s) is shown here by showing the number of seconds from the start of the simulation. "Sim Done" is shown when the simulation is complete, and "Rpts Done" will be shown after the reports have been generated and displayed. For a "large" simulation, the reports take around 5 - 6 seconds to be generated. Any messages generated during the simulation(s) will be shown in the grayed out messaging area. Several pertinent data items for the current project trial (type of simulation, number of simulations, Design Life and the TI) are also presented.
5. Simulation Duration - this data item defaults to the Design Life but may be changed to a value less than the Design Life or a value larger than the Design Life. It is reset back to the Design Life whenever the Design Life is changed.
6. A check box to select the graph type (arithmetic or logarithmic) for the real-time display of the layer moduli.
7. Button to navigate to the *Graph Page* after the simulation is complete.
8. Button to navigate to the *Report Page* after the simulation is complete.
9. This graphs shows the **rutting** and **cracking** of the surface, in real-time, as the simulation progresses. There are also horizontal lines for allowable rutting and allowable cracking. When performing a Monte Carlo simulation, rutting and cracking responses are presented as the average of all simulations. The responses for rutting and cracking for all simulations can be seen by going to the Graphs page by selecting the "Graphs" button shown at #7 above. You can see exact values for points on any curve by moving the mouse over it during the simulation or after, as shown in the Rutting and Cracking graph area (#9).
10. This graph show pavement layer moduli. For a Deterministic simulation there will be a single curve for each layer, while for a Monte Carlo simulation, there will be minimum and maximum curves for each layer (2 curves), as opposed to showing curves for every simulation. The layer number is appended to "Min-E" and "Max-E", e.g., Max-E1 is the maximum modulus (E) curve for Layer 1. The modulus curves for all simulations and for all layers can be seen by going to the Graphs page by selecting the "Graphs" button shown at #7 above. You can see exact values for points on any curve by moving the mouse over it during the simulation or after, as shown in the Rutting and Cracking graph area (#9).

11. This section of the page presents the Layer Compression Report after the simulation is complete.
12. The Expected Life Report is presented after the Layer Compression Report

The question mark in the blue circle in the upper-right of the control group allows you to get help on the controls (this topic).

Tools Page

Material Library

Coming Soon!

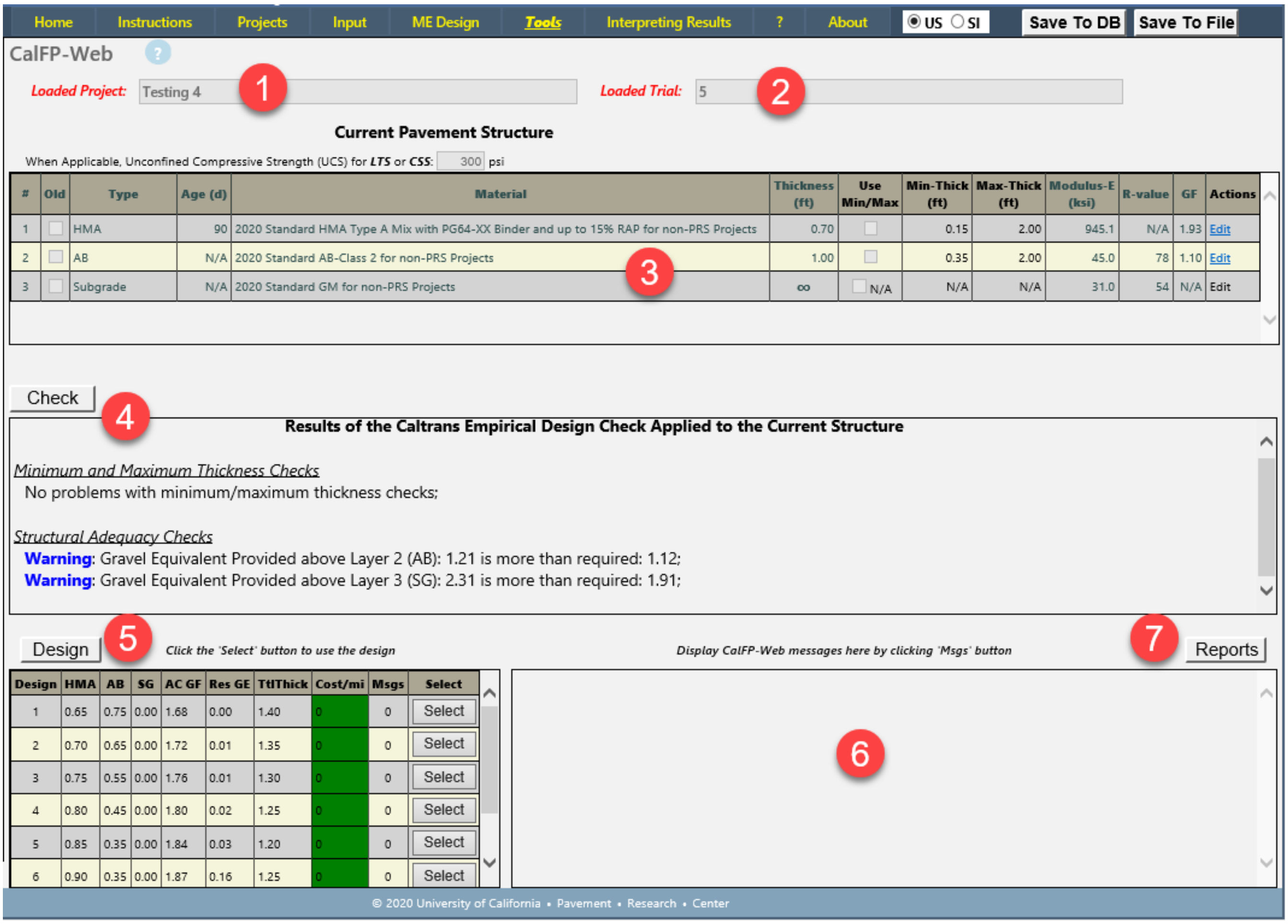
Calculators

Coming Soon!

CalFP-Web

The following controls, located on the **Tools -> CalFP-Web Page**, are used to perform a CalFP design.

CalFP-Web duplicates the behavior and results of the Caltrans desktop version of CalFP which implements the Caltrans R-value design method for new flexible designs. A CalFP design requires a Design Life of 20 years.



Section notes:

1. Shows the currently loaded *CalME* *project*
2. Shows the currently loaded *CalME* *trial* within the currently loaded project
3. Shows the current structure, as specified on the Project Information page
4. Selecting the "Check" button performs a Caltrans Empirical Design check on the **current** structure, as shown in section 3. There are **two** parts to the check: a **minimum/maximum** layer thickness check and a structural **adequacy** check. Any informational, warning and error messages will be shown here.
5. Selecting the "Design" button performs a CalFP design. The results of the design are shown in the grid: each row is a **design alternative**. The thicknesses of each layer in the defined structure are given, as well as additional data items:
   - AC GF - this is the AC gravel factor
   - RES GE - this is the residual gravel equivalent
   - AC Equiv - this the the AC equivalent
   - Cost/mi - this is the cost per mile
   - Msgs - this column will contain a button with a number indicating the number of messages associate with the design alternative. Clicking the button will display the messages in the pane to the right (section 6).
   - Select Button - selecting this button will replace the currently defined structure with the selected design alternative. The currently structure shown in section 3 will be updated with

the layer thicknesses for the selected design alternative.

6. Shows the messages associated with a design alternative when the "Msgs" button is selected, if any
7. Selecting this button will display the Reports page so that you can select to generate a CalFP report

A typical workflow scenario when performing a CalFP design might be:

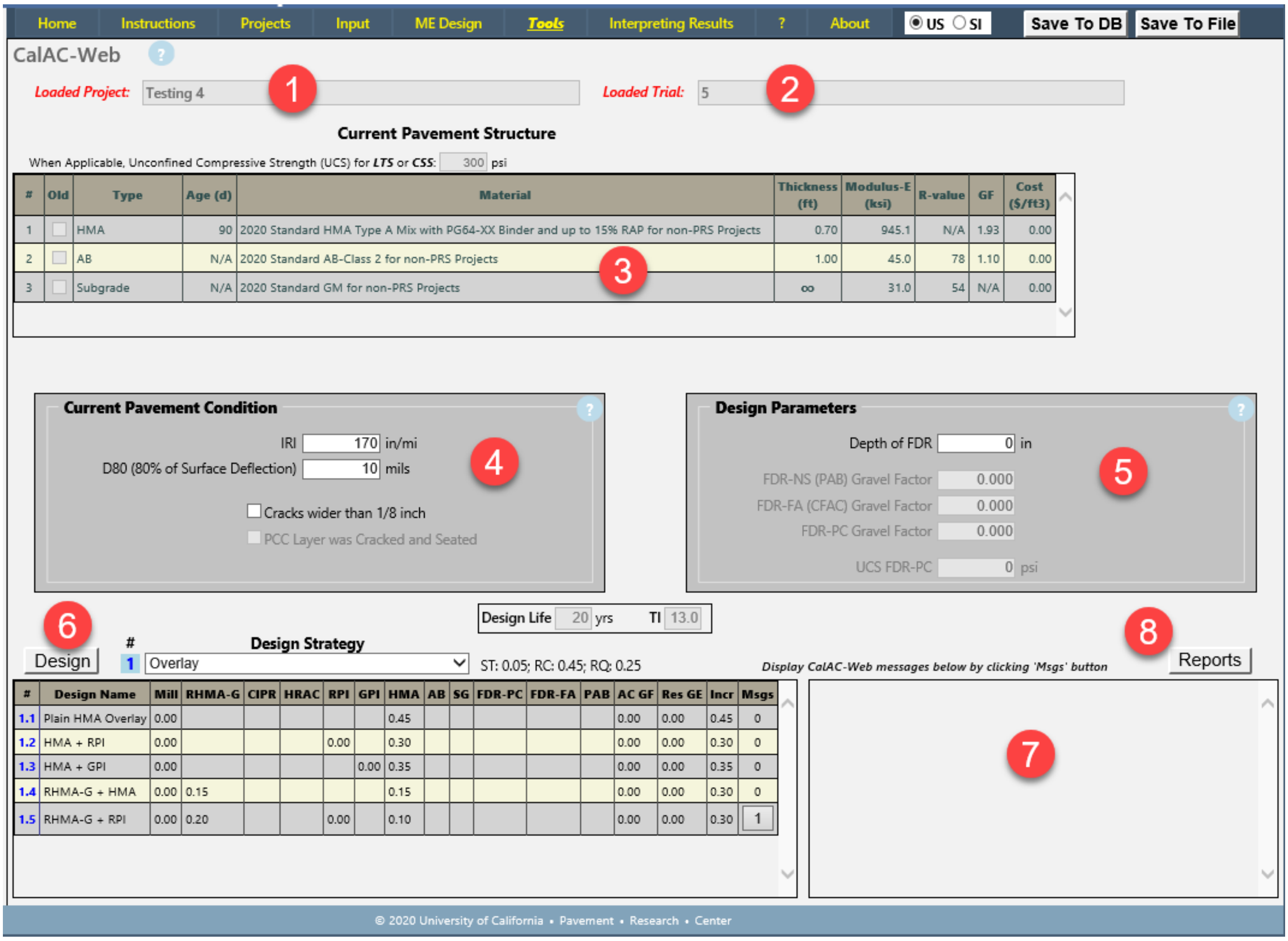
- Define the structure on the Project Information page
- Perform a CalFP design
- Select one of the design alternatives from the design alternative grid (section 5 above)
- Select the "Check" button - you should only see informational and warning messages; there should not be any error messages
- Perform a Mechanistic-Empirical simulation, first Deterministic and then Monte Carlo
- Generate a CalFP report and download it to your local hard drive

The question mark in the blue circle in the upper-right of the control group allows you to get help on the controls (this topic).

CalAC-Web

The following controls, located on the **Design -> CalAC-Web Page**, are used to perform a CalAC design.

CalAC-Web duplicates the behavior and results of the Caltrans desktop version of CalAC which implements the Caltrans R-value design method for rehabilitation projects. A CalAC design requires a Design Life of 20 years.



Section notes:

1. Shows the currently loaded *CalME* project
2. Shows the currently loaded *CalME* trial within the currently loaded project
3. Shows the current structure, as specified on the Project Information page
4. These controls allow you to define the current pavement condition
   - IRI - the current IRI
   - D80 (80% of Surface Deflection) - specify the D80 value, in mils
   - Cracks wider than 1/8 inch - select if the current pavement condition has cracks wider than 1/8 inch
   - PCC layer was Crack and Seated - select if this reflects the current condition
5. These controls allow you to define the parameters to be used for the CalAC design
   - Depth of FDR - specify the depth of the FDR, in inches
   - FDR-NS (PAB) Gravel Factor - specify this value
   - FDR-FA (CFAC) Gravel Factor - specify this value
   - FDR-PC Gravel Factor - specify this value
   - UCS FDR-PC - specify the Unconfined Compressive Strength for the FDR-PC, in psi

6. Selecting the "Design" button performs a CalAC design. The results of the design are shown in the grid for the selected **design strategy**: each row is a **design alternative**. The thicknesses of each layer in the defined structure are given, as well as additional data items:

    - Mill - thickness of old AC to be milled before overlay
    - CIPR - cold in-place recycling layer thickness
    - HRAC - hot recycled asphalt concrete thickness, also know as HIPR (hot in-place recycling)
    - RPI - whether Rubberized Pavement Interlayer is used, also known as SAMI-R (Rubberized Stress Absorbing Membrane Interlayer)
    - GPI - whether Geosynthetic Pavement Interlayer is used, also known as SAMI-F (Stress Absorbing Membrane Interlayer– Fabric)
    - FDR-PC - layer thickness for full depth reclamation with Portland cement
    - FDR-FA - layer thickness for full depth reclamation with foam asphalt
    - PAB - layer thickness for pulverized aggregate base, also know as full depth reclamation without stabilization
    - AC GF - this is the AC gravel factor
    - RES GE - this is the residual gravel equivalent
    - Incr - grade increase
    - Cost/mi - this is the cost per mile
    - Msgs - this column will contain a button with a number indicating the number of messages associate with the design alternative. Clicking the button will display the messages in the pane to the right (section 7).

7. Shows the messages associated with a design alternative when the "Msgs" button is selected, if any
8. Selecting this button will display the Reports page so that you can select to generate a CalAC report

The question mark in the blue circle in the upper-right of the control group allows you to get help on the controls (this topic).

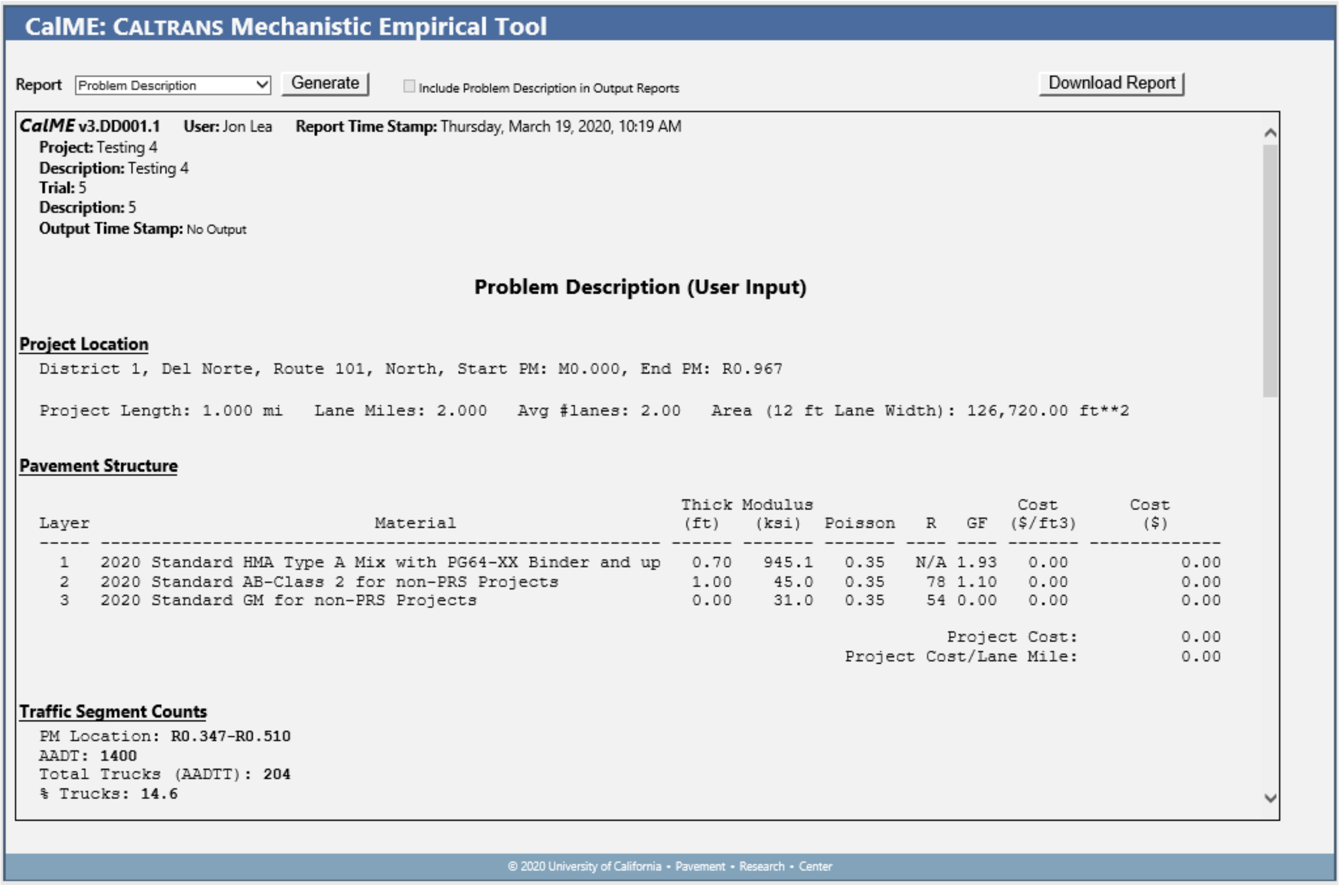
Reports

Problem Description Report

The Problem Description report is generated by going to the Reports page and selecting **Problem Description** and selecting the "Generate" button.

This report has a section for each input area, such as Location, Pavement Structure and Monte Carlo Variability.

You can generate a PDF version of the report and download it to your local hard drive by selecting the "Download Report" button.



CalFP Report

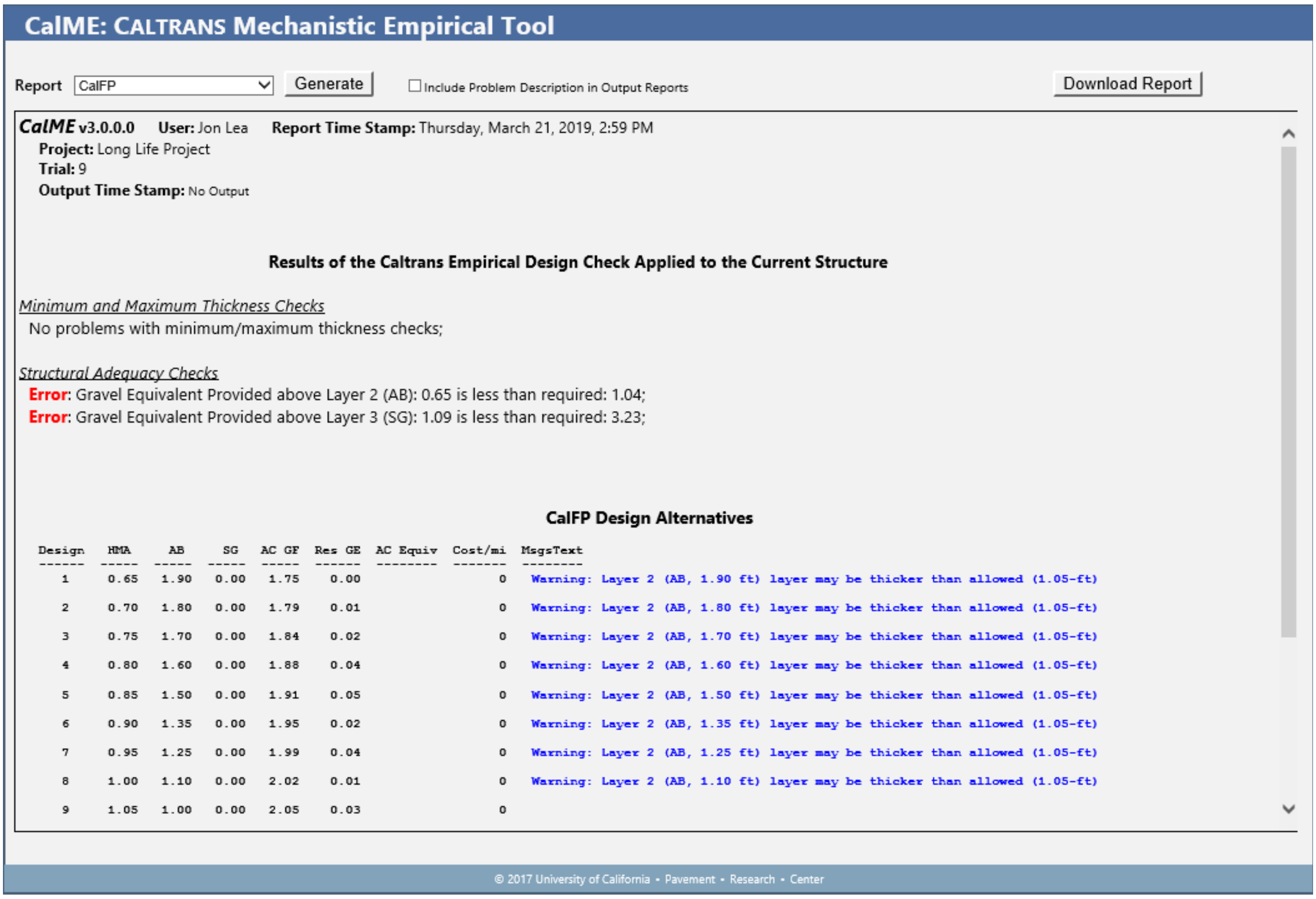
The CalFP report is generated by going to the Reports page and selecting **CalFP** and selecting the "Generate" button.

This report has two main sections:

- Results of the Caltrans Empirical Design Check Applied to the Current Structure (not to any of the CalFP design alternatives). This check is done for minimum and maximum layer thickness conformance and for structural adequacy.
- The CalFP computed design alternatives with their messages, if any.

The "Include Problem Description in Output Reports" is selected by default but is not done here in order to show the CalFP report.

You can generate a PDF version of the report and download it to your local hard drive by selecting the "Download Report" button.



CalAC Report

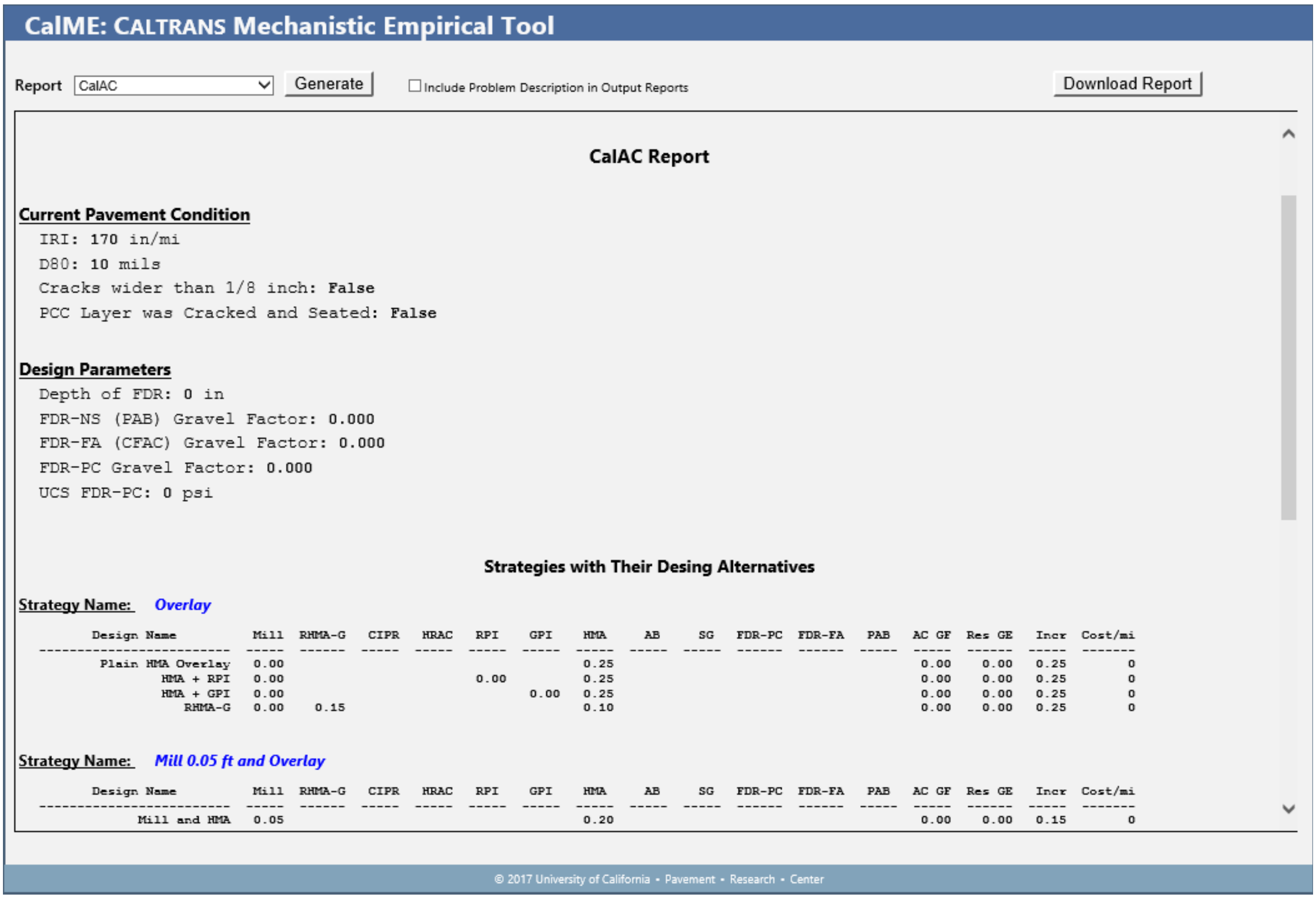
The CalAC report is generated by going to the Reports page and selecting **CalAC** and selecting the "Generate" button.

This report has two main sections:

- The data specified for the CalAC design:
  - Current Pavement Condition
  - Design parameters
- For each design strategy, the list of design alternatives

The "Include Problem Description in Output Reports" is selected by default but is not done here in order to show the CalAC report.

You can generate a PDF version of the report and download it to your local hard drive by selecting the "Download Report" button.



Mechanistic-Empirical (ME) Report

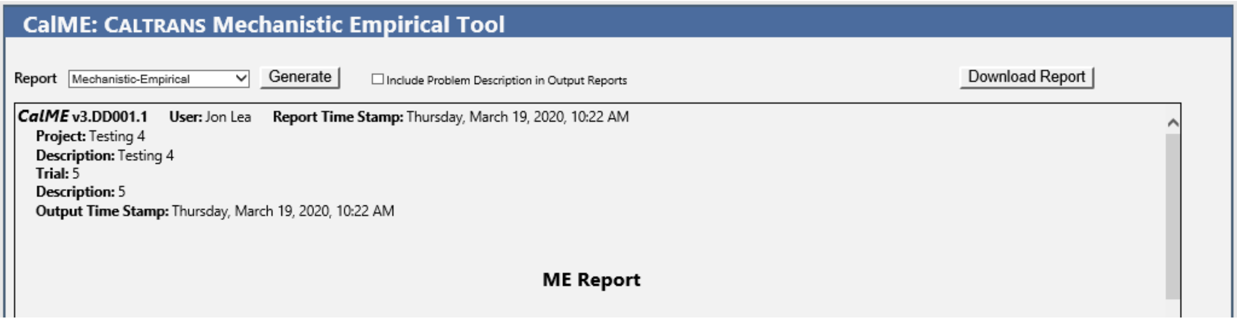
The ME report is generated by going to the Reports page and selecting **ME** and selecting the "Generate" button.

This report has two main sections:

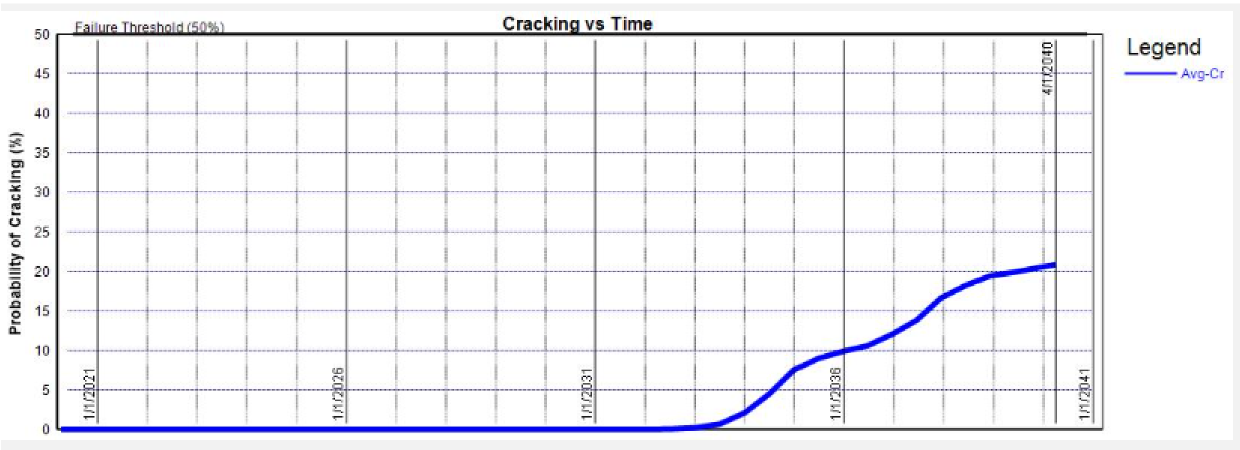
- A series of graphs:
  - Rutting vs Time
  - Cracking vs Time
  - Moduli vs Time
- A series of reports
  - Layer Compression table
  - Expected Life table

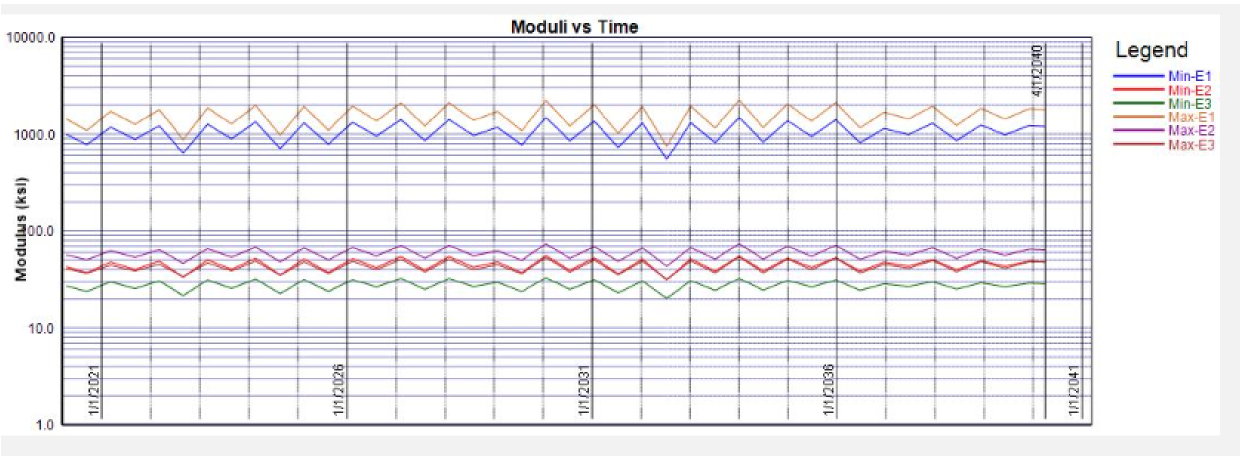
The "Include Problem Description in Output Reports" is not selected by default.

You can generate a PDF version of the report and download it to your local hard drive by selecting the "Download Report" button.


CalME: CALTRANS Mechanistic Empirical Tool
Report Mechanistic-Empirical
Generate
Include Problem Description in Output Reports
Download Report
CalME v3.DD001.1 User: Jon Lea Report Time Stamp: Thursday, March 19, 2020, 10:22 AM
Project: Testing 4
Description: Testing 4
Trial: 5
Description: 5
Output Time Stamp: Thursday, March 19, 2020, 10:22 AM
ME Report


Rutting vs Time
Max Rutting Depth (0.40)
Rutting Depth (in) x10**(-1)
4.00
3.60
3.20
2.80
2.40
2.00
1.60
1.20
0.80
0.40
0.00
1/1/2021
1/1/2026
1/1/2031
1/1/2036
4/1/2040
1/1/2041
Legend
Avg-RD


Cracking vs Time
Failure Threshold (50%)
Probability of Cracking (%)
50
45
40
35
30
25
20
15
10
5
0
1/1/2021
1/1/2026
1/1/2031
1/1/2036
4/1/2040
1/1/2041
Legend
Avg-Cr


Moduli vs Time
Modulus (ksi)
10000.0
1000.0
100.0
10.0
1.0
1/1/2021
1/1/2026
1/1/2031
1/1/2036
4/1/2040
1/1/2041
Legend
Min-E1
Min-E2
Min-E3
Max-E1
Max-E2
Max-E3

Layer Commpression

Average of All Simulations For Last Time Step

Layer	Avg Compression (in)	Percent of Total (%)
1	0.090	43.97
2	0.085	41.84
3	0.029	14.19
Total	0.204	100.00

Expected Life

```
*******************************************************************************
*               Overall Reliability of 80% is less than 95%.                  *
*                                                                             *
*The structural capability of the pavement should be increased either by      *
*increasing AC or AB or improving the subgrade or combination.                *
*******************************************************************************
```

Year When Exceeded Performance Criteria

Simulation#	Cracking	Rutting	Overall
1	>20.0	>20.0	
2	>20.0	>20.0	
3	>20.0	>20.0	
4	>20.0	>20.0	
5	>20.0	>20.0	
6	17.5	>20.0	17.5
7	>20.0	>20.0	
8	>20.0	>20.0	
9	>20.0	>20.0	
10	14.4	>20.0	14.4
No. Failed	2 of 10	0 of 10	2 of 10
No. Passed	8 of 10	10 of 10	8 of 10
Reliab. (%)	80	100	80

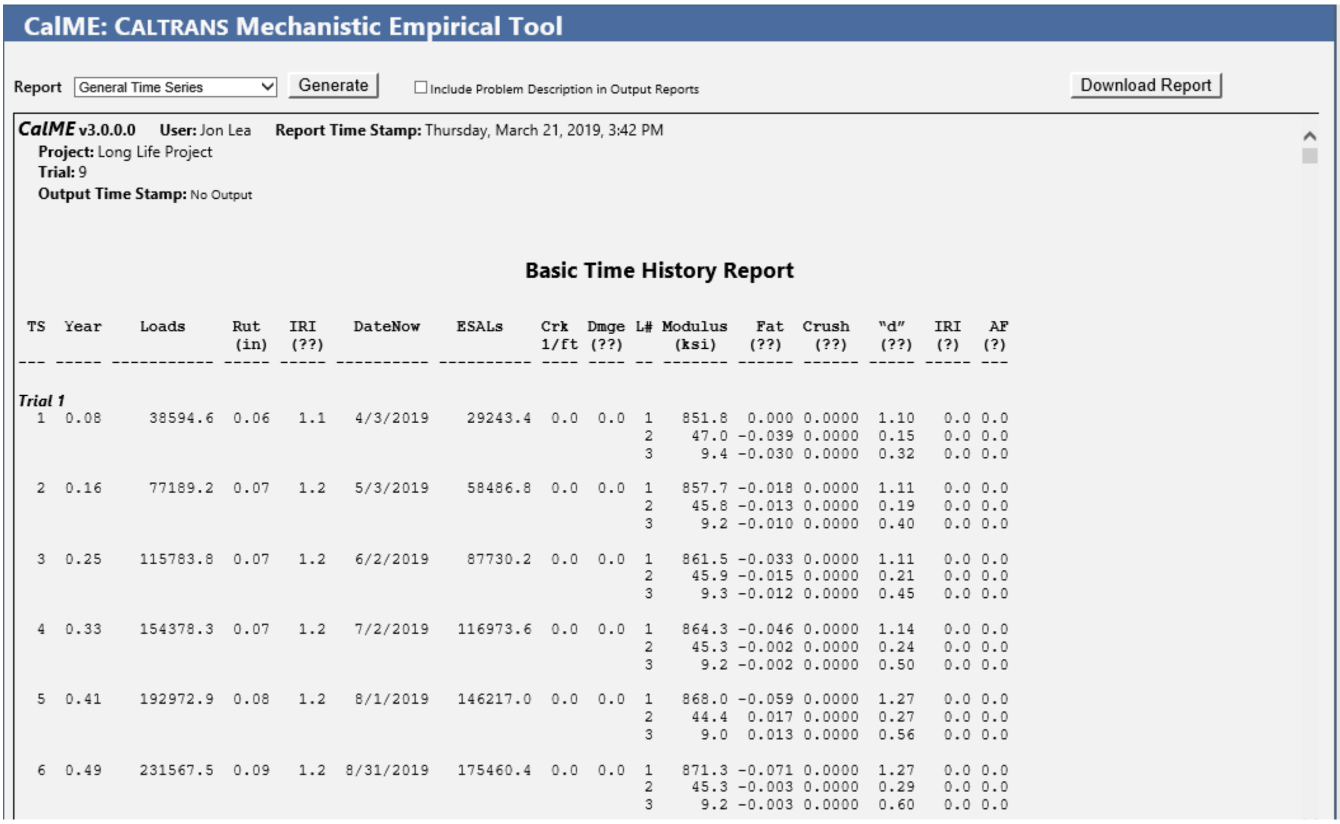
General Time Series Report

The General Time Series report is generated by going to the Reports page and selecting **General Time Series** and selecting the "Generate" button.

This report has presents results for every time step for all simulations:

- TS - the time step
- Year - the year from the start of the simulation
- Loads -
- Rut - surface rutting

- IRI- the IRI
- DateNow - the date at the time step
- ESALs - the ESALs at the time step
- Crk - the surface cracking
- Dmge -
- L# - the Layer number
- Modulus - the elastic modulus for the layer
- Fat - the fatigue damage for the layer
- Crush -
- d -
- IRI-
- AF -



TS	Year	Loads	Rut (in)	IRI (??)	DateNow	ESALs	Crk 1/ft	Dmge (??)	L#	Modulus (ksi)	Fat (??)	Crush (??)	"d" (??)	IRI (?)	AF (?)
Trial 1															
1	0.08	38594.6	0.06	1.1	4/3/2019	29243.4	0.0	0.0	1	851.8	0.000	0.0000	1.10	0.0	0.0
									2	47.0	-0.039	0.0000	0.15	0.0	0.0
									3	9.4	-0.030	0.0000	0.32	0.0	0.0
2	0.16	77189.2	0.07	1.2	5/3/2019	58486.8	0.0	0.0	1	857.7	-0.018	0.0000	1.11	0.0	0.0
									2	45.8	-0.013	0.0000	0.19	0.0	0.0
									3	9.2	-0.010	0.0000	0.40	0.0	0.0
3	0.25	115783.8	0.07	1.2	6/2/2019	87730.2	0.0	0.0	1	861.5	-0.033	0.0000	1.11	0.0	0.0
									2	45.9	-0.015	0.0000	0.21	0.0	0.0
									3	9.3	-0.012	0.0000	0.45	0.0	0.0
4	0.33	154378.3	0.07	1.2	7/2/2019	116973.6	0.0	0.0	1	864.3	-0.046	0.0000	1.14	0.0	0.0
									2	45.3	-0.002	0.0000	0.24	0.0	0.0
									3	9.2	-0.002	0.0000	0.50	0.0	0.0
5	0.41	192972.9	0.08	1.2	8/1/2019	146217.0	0.0	0.0	1	868.0	-0.059	0.0000	1.27	0.0	0.0
									2	44.4	0.017	0.0000	0.27	0.0	0.0
									3	9.0	0.013	0.0000	0.56	0.0	0.0
6	0.49	231567.5	0.09	1.2	8/31/2019	175460.4	0.0	0.0	1	871.3	-0.071	0.0000	1.27	0.0	0.0
									2	45.3	-0.003	0.0000	0.29	0.0	0.0
									3	9.2	-0.003	0.0000	0.60	0.0	0.0

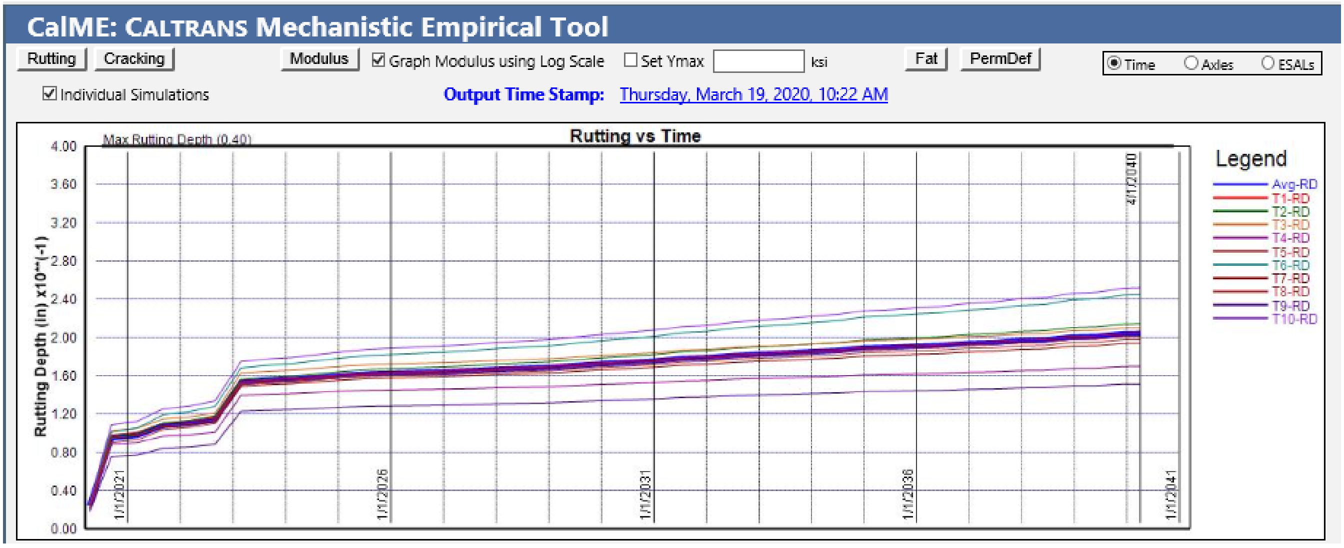
Graphs

Rutting Graph

The Rutting graph is generated by going to the Graphs page and selecting the "Rutting" button.

The rutting graph shows the surface rutting vs. Time for each simulation (if the "Individual Simulations" check box is selected) and also shows the average rutting of all simulations (the average is the curve shown in the real-time graph). You can also select to see the variation with Axles or ESALs using the radio buttons in the upper right of the page. The maximum allowed rutting depth is shown as a horizontal line at 0.40 inches.

The example below is for a Monte Carlo simulation type with 10 simulations.

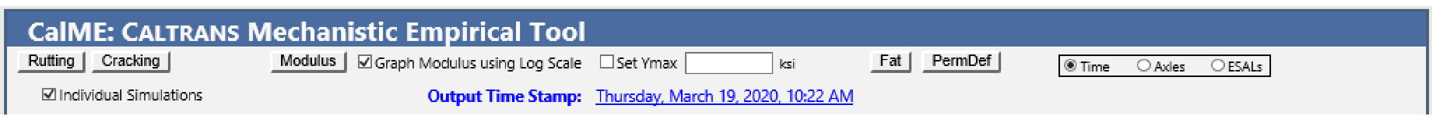


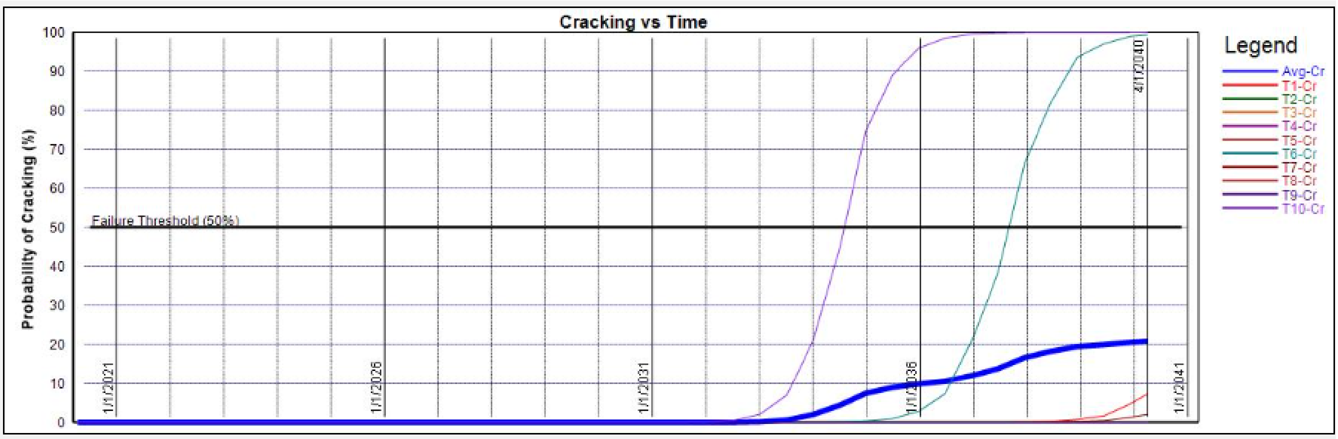
Cracking Graph

The Cracking graph is generated by going to the Graphs page and selecting the "Cracking" button.

The cracking graph shows the surface cracking vs. Time for each simulation (if the "Individual Simulations" check box is selected) and also shows the average cracking of all simulations (the average is the curve shown in the real-time graph). You can also select to see the variation with Axles or ESALs using the radio buttons in the upper right of the page. The maximum allowed cracking is shown as a horizontal line at 50%.

The example below is for a Monte Carlo simulation type with 10 simulations.



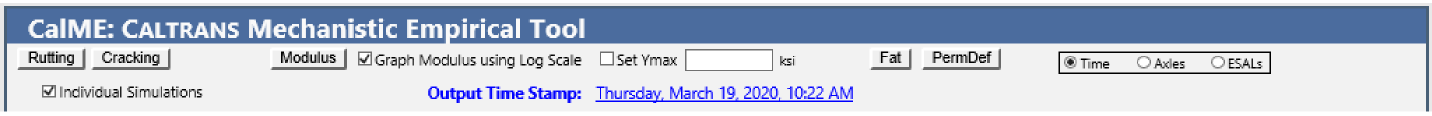


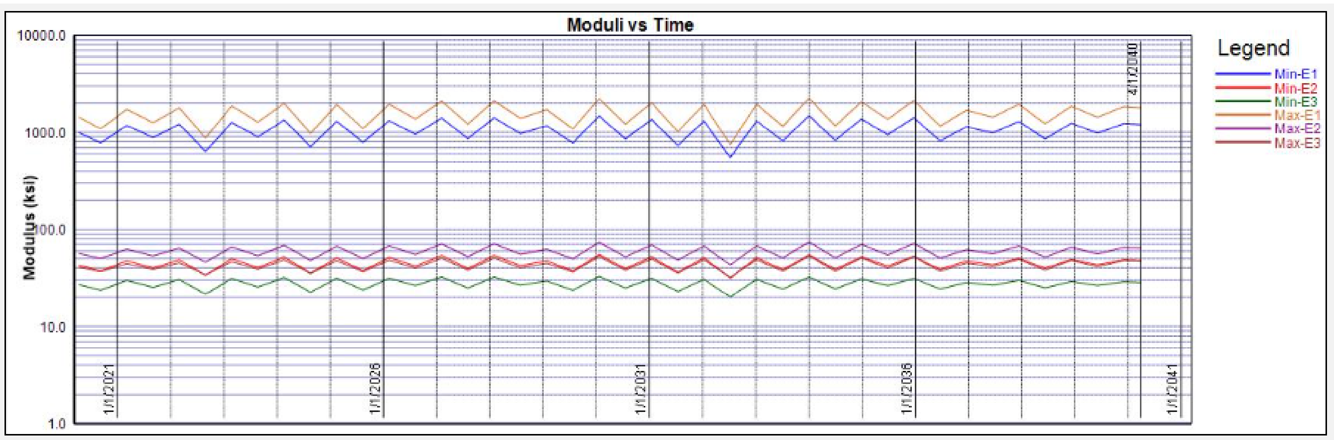
Modulus Graph

The Modulus graph is generated by going to the Graphs page and selecting the "Modulus" button.

The modulus graph shows the **layer** moduli vs. Time for each simulation. You can also select to see the variation with Axles or ESALs using the radio buttons in the upper right of the page. You can see the variation in modulus using Log scale or arithmetic (linear) scale. When viewing the variation in modulus in arithmetic scale, you can set the maximum value for the y-axis by selecting the "Set Ymax" check box and specifying a value in the text box and the selecting the Modulus button.

The example below is for a Monte Carlo simulation type with 10 simulations.



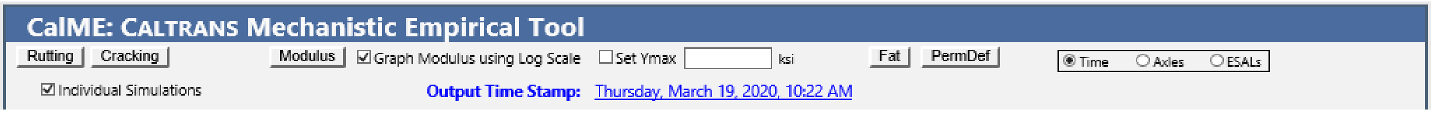


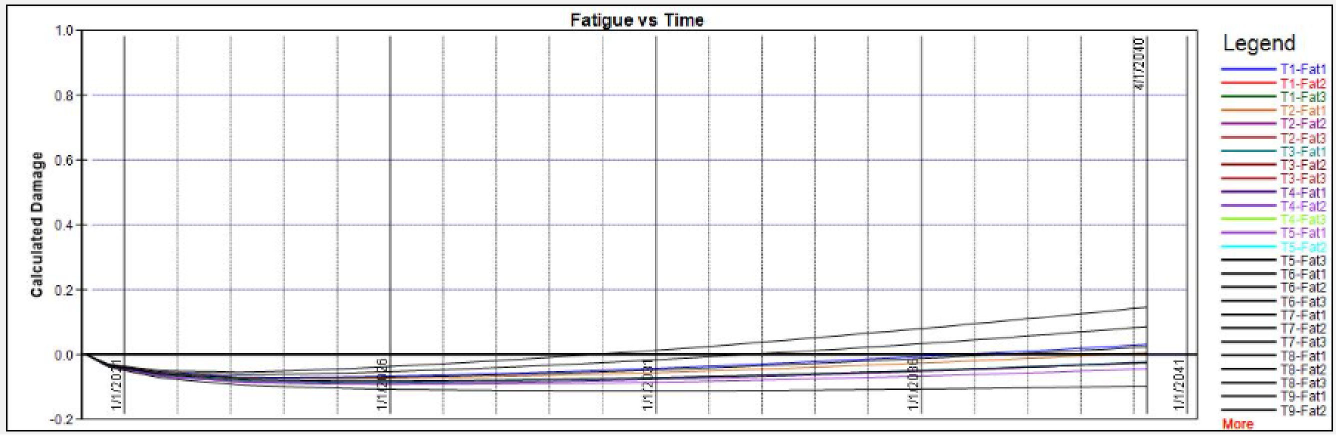
Fatigue Graph

The Fatigue graph is generated by going to the Graphs page and selecting the "Fat" button.

The Fatigue graph shows the **layer** fatigue damage vs. Time for each simulation. You can also select to see the variation with Axles or ESALs using the radio buttons in the upper right of the page.

The example below is for a Monte Carlo simulation type with 10 simulations.



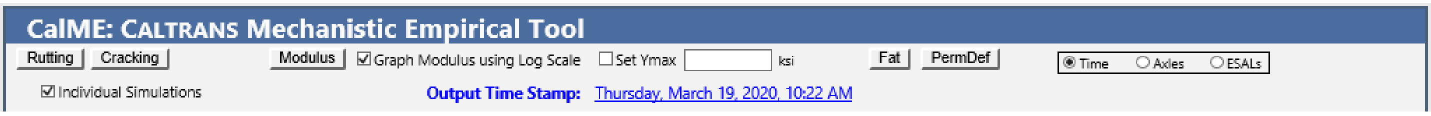


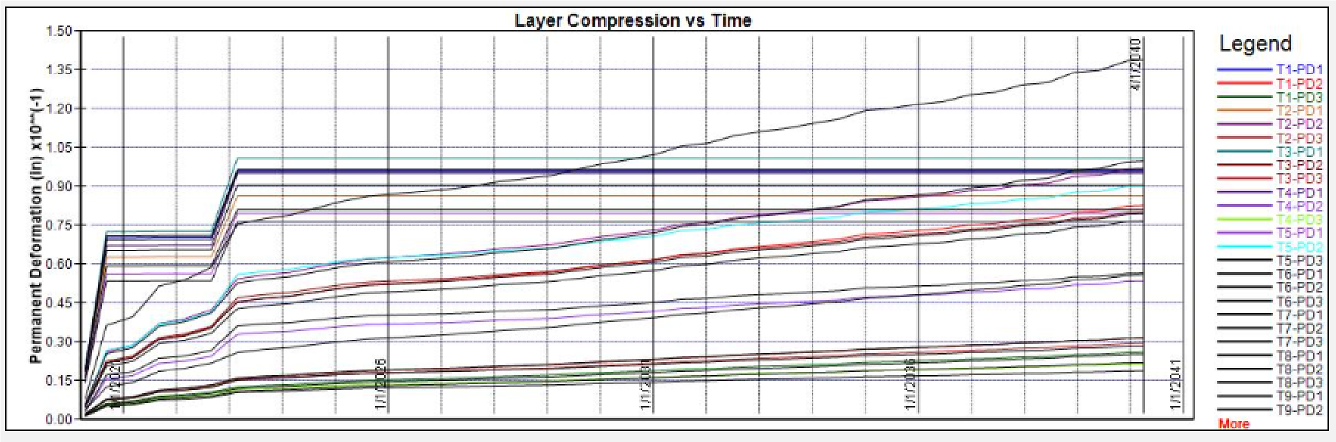
Permanent Deformation Graph

The Permanent Deformation graph is generated by going to the Graphs page and selecting the "PermDef" button.

The Permanent Deformation graph shows **layer** permanent deformation vs. Time for each simulation. You can also select to see the variation with Axles or ESALs using the radio buttons in the upper right of the page.

The example below is for a Monte Carlo simulation type with 10 simulations.




Layer Compression vs Time
Permanent Deformation (in) x10^(-1)
1.50
1.35
1.20
1.05
0.90
0.75
0.60
0.45
0.30
0.15
0.00
1/1/2021
1/1/2026
1/1/2031
1/1/2036
1/1/2041
4/1/2040
Legend
T1-PD1
T1-PD2
T1-PD3
T2-PD1
T2-PD2
T2-PD3
T3-PD1
T3-PD2
T3-PD3
T4-PD1
T4-PD2
T4-PD3
T5-PD1
T5-PD2
T5-PD3
T6-PD1
T6-PD2
T6-PD3
T7-PD1
T7-PD2
T7-PD3
T8-PD1
T8-PD2
T8-PD3
T9-PD1
T9-PD2
More

R-value design method

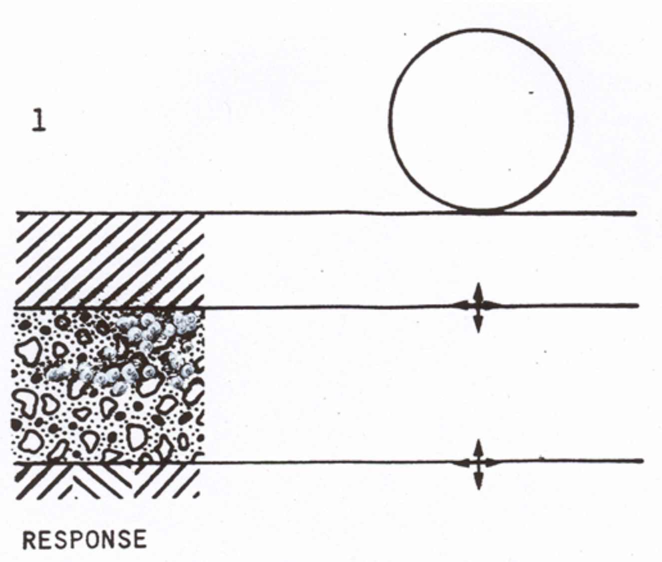
Caltrans presently (January 2011) makes use of the R-value method for design of new pavements.

Deflection reduction method

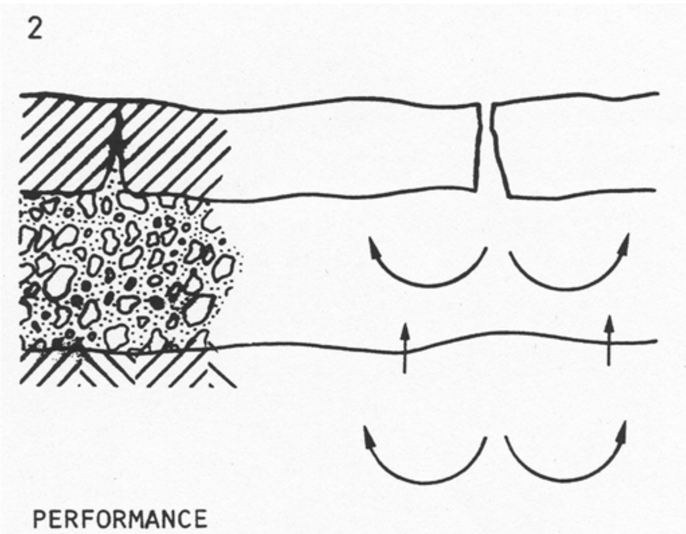
For rehabilitation design Caltrans presently (January 2011) makes use of the Deflection Reduction method, described in of the chapter 630 (topic 634) of the Caltrans Highway Design Manual.

Mechanistic-Empirical approach

The Mechanistic-Empirical approach to pavement design makes use of fundamental physical properties and a theoretical model to predict the stresses, strains and deflections, i.e. the pavement response, caused by a load on the pavement, as illustrated below. If the basic assumptions with respect to materials and boundary conditions are correct, this method is valid anywhere and may be used to correctly predict the response for any combination of loads, climatic effects and materials.



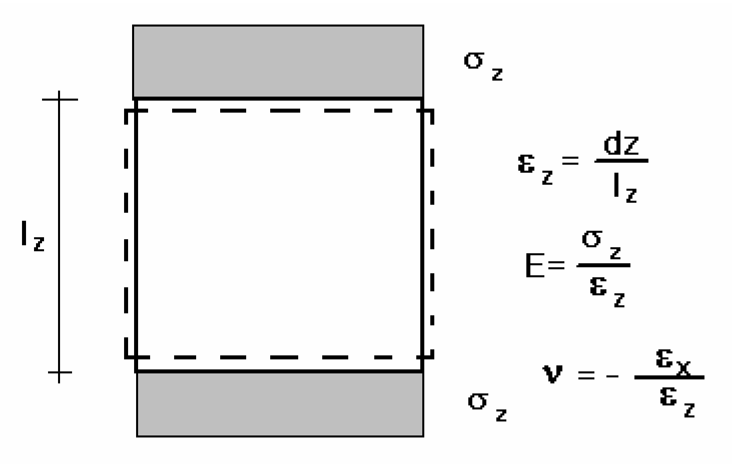
In the second part of the approach the pavement response is used with empirical relationships to predict the pavement performance:



In the Classical Mechanistic-Empirical method the pavement response is only calculated for the initial pavement condition and the empirical relations predict the number of loads to failure, through cracking, rutting or roughness. In the incremental-recursive approach the response is calculated for each increment and each load and the change in pavement condition is predicted (in terms of damage to pavement layers and permanent deformation in the layers) using the time hardening procedure. For the next increment the new pavement condition is used with the mechanistic model to predict the response. This also allows aging and hardening of pavement materials to be included.

Definition of elastic parameters

Subjecting a cube to a uniform stress in the direction z (vertical), σ_z, as shown in the figure below, will result in a change in length of the sides. When the deformations are very small compared to the dimensions of the cube the strains will be equal to the relative change of length.



Elastic parameters for uniaxial stress.

If the material is linear elastic, then the ratio of vertical stress, σ_z, to vertical strain, ε_z, will be a constant, the coefficient of elasticity or Young's modulus (*E*). This is known as Hooke's law. The ratio between the horizontal strain (ε_x or ε_y) and the vertical strain is also a constant. The ratio will be negative, and the positive value is known as Poisson's ratio (ν). A stress in one direction is seen to produce a strain proportional to $-\nu/E$ in a perpendicular direction.

A shear stress, $\tau_{xz} = \tau_{zx}$, will produce a shear strain, $\gamma_{xz} = \gamma_{zx}$. If the material is isotropic, the constant shear modulus, *G*, will be:

$$G = \frac{\tau_{xz}}{2\gamma_{xz}}$$

The shear strain does not affect the normal strains.

For three-dimensional loading of an isotropic material Hooke's law may be written by the above equation for *G* and by:

$$\varepsilon_x = \frac{\sigma_x}{E} + \frac{-\nu\sigma_y}{E} + \frac{-\nu\sigma_z}{E}$$

with rotation of the subscripts. For the general anisotropic case *E*, ν, and *G* should take the same subscript as the corresponding stress, and strain for ν.

Because few pavement materials are ideally elastic it is often useful to divide the stress into a hydrostatic and a deviatoric component.

$$\{\sigma\} = \begin{Bmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{xy} & \sigma_y & \tau_{yz} \\ \tau_{xz} & \tau_{yz} & \sigma_z \end{Bmatrix} = \{\sigma\} - p\{\delta\} + p\{\delta\} = \{s\} + p\{\delta\},$$

$$p = (\sigma_x + \sigma_y + \sigma_z)/3 = I_1(\sigma)/3 = (\sigma_1 + \sigma_2 + \sigma_3)/3,$$

$$\{\delta\} = \begin{Bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{Bmatrix},$$

$I_1(\sigma)$ is the first stress invariant (independent of the orientation of the co-ordinate system), p is the mean normal stress or the hydrostatic pressure, and {s} is the deviator stress tensor. The mean deviator stress is derived from the second deviator stress invariant:

$$q = \sqrt{3J_2(s)} = \sqrt{\left[(\sigma_x - \sigma_y)^2 + (\sigma_x - \sigma_z)^2 + (\sigma_y - \sigma_z)^2\right]/2 + \left[\tau_{xy}^2 + \tau_{xz}^2 + \tau_{yz}^2\right] \times 3} =$$
$$\sqrt{\left[(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2\right]/2} = \frac{3}{\sqrt{2}}\tau_{oct},$$

where τ_{oct} is the octahedral shear stress.

The strains used with p and q are the volumetric and deviator strain:

$$\varepsilon_v = (\varepsilon_x + \varepsilon_y + \varepsilon_z) = I_1(\varepsilon) = (\varepsilon_1 + \varepsilon_2 + \varepsilon_3),$$
$$\varepsilon_d = 2\sqrt{J_2(\varepsilon)/3} = \frac{\sqrt{2}}{3}\sqrt{(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_1 - \varepsilon_3)^2 + (\varepsilon_2 - \varepsilon_3)^2} = \sqrt{2}\gamma_{oct}$$

where γ_{oct} is the octahedral shear strain.

The ratio of hydrostatic stress to volumetric strain is called the bulk modulus, $K = p/\varepsilon_v$. The relationships between K, G, E and ν are:

$$K = \frac{p}{\varepsilon_v} = \frac{E}{3(1-2\nu)}, \quad G = \frac{q}{3\varepsilon_d} = \frac{E}{2(1+\nu)}, \quad E = \frac{9KG}{3K+G}, \; and \quad \nu = \frac{3K-2G}{6K+2G}$$

Response models

The user may select between two different response models: 1) Linear Elastic Theory (LET) as written by Dr. Jeremy Lea, see www.openpave.org for details and 2) a simplified approach based on Odemark's transformations and Boussinesq's equations.

It should be noticed that only LET has been used in the calibration studies.

Design temperature

For the Classical Mechanistic-Empirical design method only one temperature is used. This design temperature should be the temperature at which all of the loads during one year would cause the same damage as the loads do with the actual temperature variation over the year. This temperature is also called the "Damage Weighted Mean Annual Temperature" or DWMAT.

The DWMAT will vary with the thickness and stiffness of the pavement layers and with the design criteria used for the different materials. In practice it is seldom possible to determine a single DWMAT for a given pavement structure in a specific climate zone. The DWMAT with respect to rutting could be quite different from the DWMAT with respect to cracking, for example.

In CalME default DWMATs are imported from the "Climate zone" table of the database, but these values may be changed by the user.

Equivalent Standard Axle Load

The Classical Mechanistic-Empirical method makes use of an Equivalent Standard Axle Load (ESAL). This is a 40 kN dual wheel load with a tire pressure of 0.69 MPa and centre distance between the tires of 300 mm (although this may be changed in the table "Wheels" in the database).

The actual wheel load spectrum read from the WIM data is converted to ESALs using a power of 4.2 (this can be changed in the "Limits" table of the database).

The total number of ESALs during the design life is calculated from the number of axle passages during the first year and the growth rate in percent. If desired the number of ESALs may also be calculated from the TI, using the Caltrans design method.

Design criteria

The format of the default design criterion is:

$$Permissible\ response = CA \times MN^{c\alpha} \times \left(\frac{E}{E_{ref}} \right)^{c\beta}$$

where *MN* is the number of ESAL applications in millions,
E is the modulus of the material, and
CA, $c\alpha$, $c\beta$ and E_{ref} are constants.
The response may be either the vertical compressive strain or stress at the top of a layer or the maximum horizontal strain or stress at the bottom of a layer. In the database these are indicated by Type ev, zv, eh, and zh, respectively. The criteria may apply either to an asphalt material (AC) or to an unbound material (UB).

Name	Material	CA	$c\alpha$	E_{ref}	$c\beta$	Type
Kirk	AC	-195	-0.178	3000	0	eh
Ciannini & Camomilla	AC	-142	-0.234	3000	0	eh
South Africa gap graded	AC	-527	-0.137	3000	0	eh
South Africa continuous	AC	-279	-0.183	3000	0	eh
Nottingham hot rolled	AC	-209	-0.204	3000	0	eh
Nottingham DBM pen100	AC	-133	-0.285	3000	0	eh
Nottingham DBM pen200	AC	-94	-0.347	3000	0	eh
Shell 1978, 50%	AC	-538	-0.25	3000	0	eh
Shell 1978, 85%	AC	-403	-0.25	3000	0	eh
Shell 1978, 95%	AC	-344	-0.25	3000	0	eh
NCHRP 1-10b	AC	-240	-0.3039	3000	-0.26	eh
Corps of Engineers	AC	-214	-0.2	3000	-0.533	eh
Shell 1978, 50%	UB	885	-0.25	160	0	ev
Shell 1978, 85%	UB	664	-0.25	160	0	ev
Shell 1978, 95%	UB	567	-0.25	160	0	ev
Asphalt Institute	UB	482	-0.223	160	0	ev
Nottingham	UB	454	-0.28	160	0	ev
South Africa terminal psi=1.5	UB	1005	-0.1	160	0	ev
South Africa terminal psi=2.0	UB	728	-0.1	160	0	ev
South Africa terminal psi=2.5	UB	495	-0.088	160	0	ev
NAASRA	UB	1212	-0.141	160	0	ev
Kirk E<160 MPa, R=1.5	UB	0.145	-0.307	160	1.16	zv
Kirk E>160 MPa, R=1.5	UB	0.145	-0.307	160	1	zv
Asphalt Institute	AC	-240	-0.3039	3000	-0.26	eh
Ullidtz	AC	-246	-0.25	3000	-0.5	eh

The default criteria are the Asphalt Institutecriteria (highlighted in the table). For AC the default Asphalt Institutecriterion assumes a volume percent binder of 11 and an air voids percent of 5. The program has an option for modifying the Asphalt Institutecriterion to other values of volume percent binder and air voids percent.

The user may enter other design criteria (for example from the above table) using the "Edit materials parameters" on the Structure form or directly in the Materials or ProjectMaterials table in the DesignData*.mdb (fields starting by "C " as shown above). With the default value of pass/coverage ratio of 2 in the Classical method the value of CA in the table above must be multiplied by $2^{c\alpha}$.

Description of incremental recursive procedure

The incremental recursive procedure works in increments of time and uses the output from one increment, recursively, as input to the next increment. The procedure predicts the pavement conditions, in terms of layer moduli, crack propagation, permanent deformation and roughness (with Monte Carlo simulation), as a function of time, but it does not carry out an automatic design, where the needed layer thicknesses to achieve certain pavement conditions at the end of the design life, are determined. It may be used to check a design done using the Caltrans present methods or the Classical Mechanistic-Empirical method, and to modify that design if it is found to be unsatisfactory.

The method also allows the user to include one or more Maintenance & Rehabilitation actions, either at fixed points in time or triggered based on the predicted pavement condition.

The default duration of each increment is 30 days, but this may be changed by the user. The program will select the day in the middle of the first increment as being representative for the climatic conditions during that increment. The representative day is divided into periods. The default division is into 5 periods of 4, 4, 5, 5, and 6 hours, starting at 13 hours (1 pm), but this can be changed in the database table "Daily time periods" by the user. By doing this it is possible to use time increments form one hour and upwards. For calibration using HVS or track tests an increment of one hour is used.

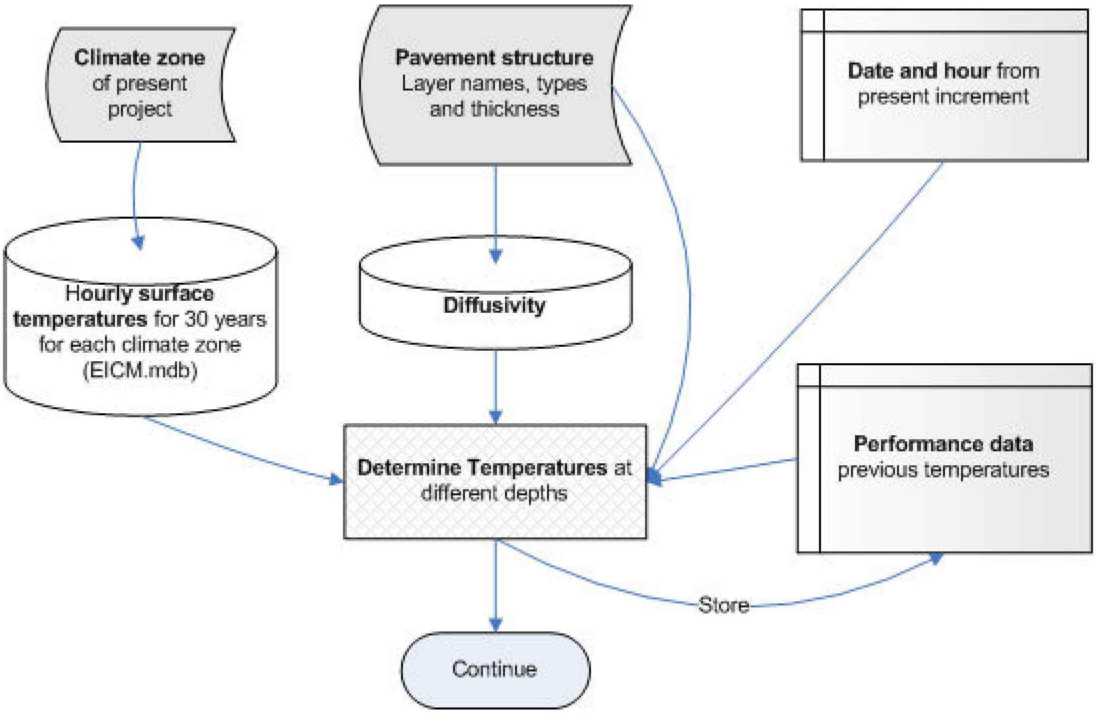
The temperatures at different depths of the pavement structure, over the simulation period, are first calculated. The temperature at the surface is read from the EICM database (with 30 years of data) and the temperatures at different depths are calculated using the surface temperature, a constant deep soil temperature and the previous temperatures. It is done using a 1-D Galerkin Finite Element formulation with a finite difference time step. Calculation over one year is used to initialize the system.

For the first period of the first time increment the program applies the load spectrum, read from the WIM data table, one load at a time. If the calculation considers wheel wander, the load is applied at the first lateral position. The temperature at one third depth of each asphalt layer is determined. The master curve for each asphalt material is used with this temperature and the loading time (depending on the vehicle speed and the depth in the structure) to determine the modulus of each asphalt layer. The modulus may also be influenced by existing damage to the layer and by aging/hardening. For the unbound materials the moduli are modified according to season and to the time elapsed after thawing (if relevant). The moduli of the unbound materials may also be influenced by the stiffness of the pavement layers above the material and by the load level.

For each load, at each load position, the critical stresses and strains in the materials are calculated at a reference line. As the default the reference line is assume to be at the center line of the single wheel and of one wheel in the dual wheel, but the wheels may be offset with respect to the reference line. For each layer the increase in damage and in permanent deformation is calculated using the time hardening procedure. For the next load or load position the new conditions of the pavement layers are used for determining the moduli and the increase in damage and permanent deformation.

When all load positions for all loads during the first period have been completed, the temperatures and moduli for next period are calculated and the loads of the period are applied, and so on until all periods of all increments in the desired analysis period have been completed.

Temperature flowchart



Time hardening procedure

For the damage models used in the incremental-recursive process the parameters on the right side of the equal-sign may change from increment to increment. In the model for fatigue damage of asphalt layers, for example, the strain, the modulus and the temperature may change from increment to increment. The first step in the process is, therefore, to calculate the "effective" number of load applications that would have been required, with the present parameters, to produce the condition at the beginning of the increment. In the second step the new condition, at the end of the increment, is calculated for the "effective" number of load applications plus the number of applications during the increment. This must be repeated for each load and load position during the increment.

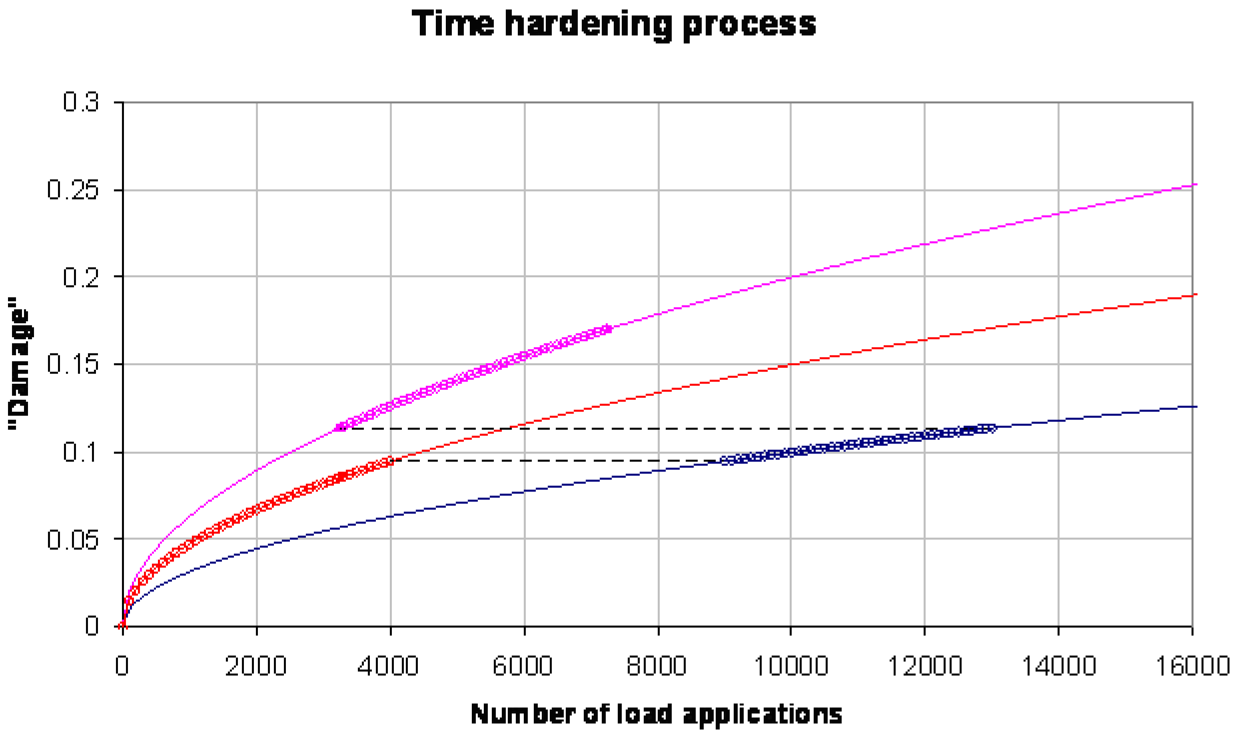
The method may be illustrated by an example using the equation for permanent deformation of unbound layers. If for example the permanent deformation of the subgrade was 2 mm at the start of the increment, the vertical strain calculated for the first wheel load at the first position was 800 µstrain, and the modulus of the subgrade was 60 MPa. Then the effective number of load applications at the start of the increment (in millions) may be found from:

$$MN_{eff} = \left[\frac{2}{A \times \left(\frac{800}{\mu\varepsilon_{ref}} \right)^{\beta} \times \left(\frac{60}{E_{ref}} \right)^{\gamma}} \right]^{1/\alpha}$$

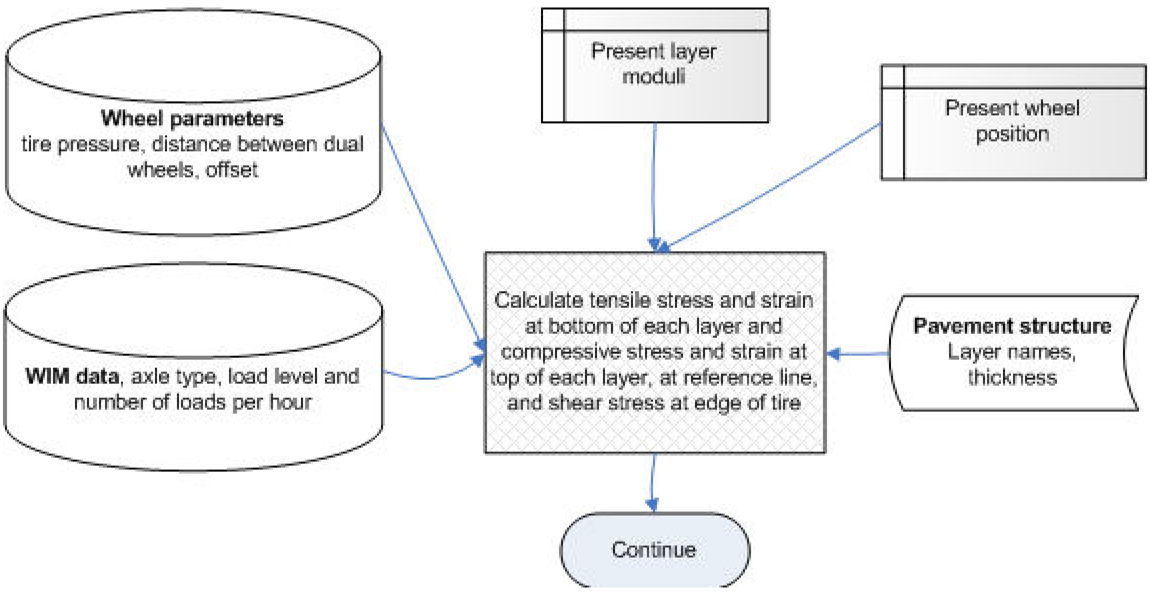
If the number of repetitions, in millions, of this load, at this position, is dMN during the increment, then the permanent deformation after these loads have been applied would be:

$$dp,mm = A \times \left(MN_{eff} + dMN\right)^{\alpha} \times \left(\frac{800}{\mu\varepsilon_{ref}}\right)^{\beta} \times \left(\frac{60}{E_{ref}}\right)^{\gamma}$$

The process must be repeated recursively, using the output from each calculation as input to the next, for all loads at each position, before proceeding to the next time increment. The process is also illustrated in the figure below:

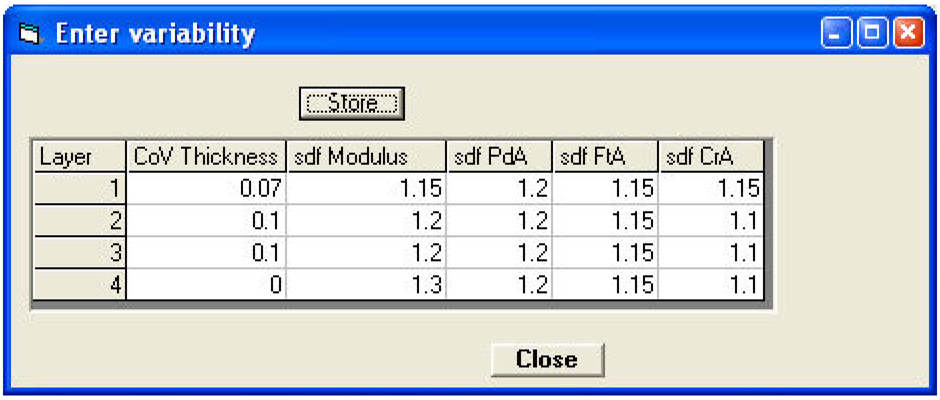


Response flowchart



Variability

It is possible to consider within section construction variability through a Monte Carlo simulation, and it is necessary to do this in order to calculate roughness. Checking the "Construction variability" checkbox opens a table for input of the variability.



Layer	CoV Thickness	sdf Modulus	sdf PdA	sdf FtA	sdf CrA
1	0.07	1.15	1.2	1.15	1.15
2	0.1	1.2	1.2	1.15	1.1
3	0.1	1.2	1.2	1.15	1.1
4	0	1.3	1.2	1.15	1.1

For each simulation the program will select a random value from the distribution of each of the variable parameters.

For thickness the Coefficient of Variation (CoV) is entered. If a layer consists of several lifts the CoV on the total layer thickness will be the CoV on the individual lifts divided by the square root of the number of lifts.

The distribution of layer moduli is assumed to be log-normal. The standard deviation factor (sdf) is 10 raised to the standard deviation of the logarithms of the moduli. If the moduli were imported from a CalBack database the sdf of the moduli are also imported. It should be recalled that the layer thicknesses are assumed to be constant during backcalculation, so that the resulting sdf on the moduli are, in reality, a function of both the thickness and the modulus variability. If the CoV of the thickness is known (or estimated) the actual sdf on the modulus may be estimated from the following equation (where s is for standard deviation):

$$(s\log(E))^2 = (s\log(E_{FWD}))^2 - \left(\frac{3}{\ln(10)}\right)^2 \times (\text{cov}\,h)^2$$

where the standard deviation factor of E is sdfE = 10slog(E).

The first parameters in the relationships for permanent deformation, fatigue, and crushing are also assumed to be log-normally distributed. The default values are based on the variability of some laboratory tests.

It is also possible to include variability on the climate. In this case start of the simulation will be selected randomly from the 30 years of temperature data and the day used during each increment will also be selected randomly. For simulating a specific section of pavement the climate variability should not be included, as the climate will be the same for all points of the pavement. Finally traffic variability may be included, but this is for experimental reasons only and it is not recommended that this facility be used for design at the present time.

Master curve

For asphalt bound materials the modulus is determined from a model of the format used in MEPDG:

$$\log(E) = \delta + \frac{\alpha}{1 + \exp(\beta + \gamma \log(tr))}$$

Equation: MEPDG Asphalt modulus versus reduced time (master curve).

where *E* is the modulus in MPa,
tr is reduced time in sec,
α, *β*, *γ*, and *δ* are constants, and
logarithms are to base 10.

Reduced time is found from:

$$tr = lt \times \left(\frac{visc_{ref}}{visc} \right)^{aT}$$

Equation: Reduced time as function of loading time and viscosity of binder.

where *lt* is the loading time (in sec)
$visc_{ref}$ is the binder viscosity at the reference temperature,
visc is the binder viscosity at the present temperature, and
aT is a constant.

The viscosity is found from:

$$\log(\log(visc\ cPoise)) = A + VTS \times \log(T_K)$$

Equation: Binder viscosity, cPoise, as a function of temperature.

where T_K is the temperature (in °K), and
A and *VTS* are constants.

To get the loglog linear relationship of the equation the viscosity must be given in cPoise. The SI unit for viscosity is Pa•sec (= 10 Poise = 10 Stoke (St)).

For asphalt materials the temperature is calculated at a depth one third into the material and the loading time is calculated as 200 mm plus the depth one third into the material, divided by the wheel speed in mm/sec ([200 + z]/speed).

Examples of the viscosity parameters are shown below, given for temperature in ºR (*A* ºK = *A* ºR + *VTS*×log(9/5)). A given mix modulus versus temperature relationship can, however, be fitted quite well with a number of different viscosity versus temperature relationships.

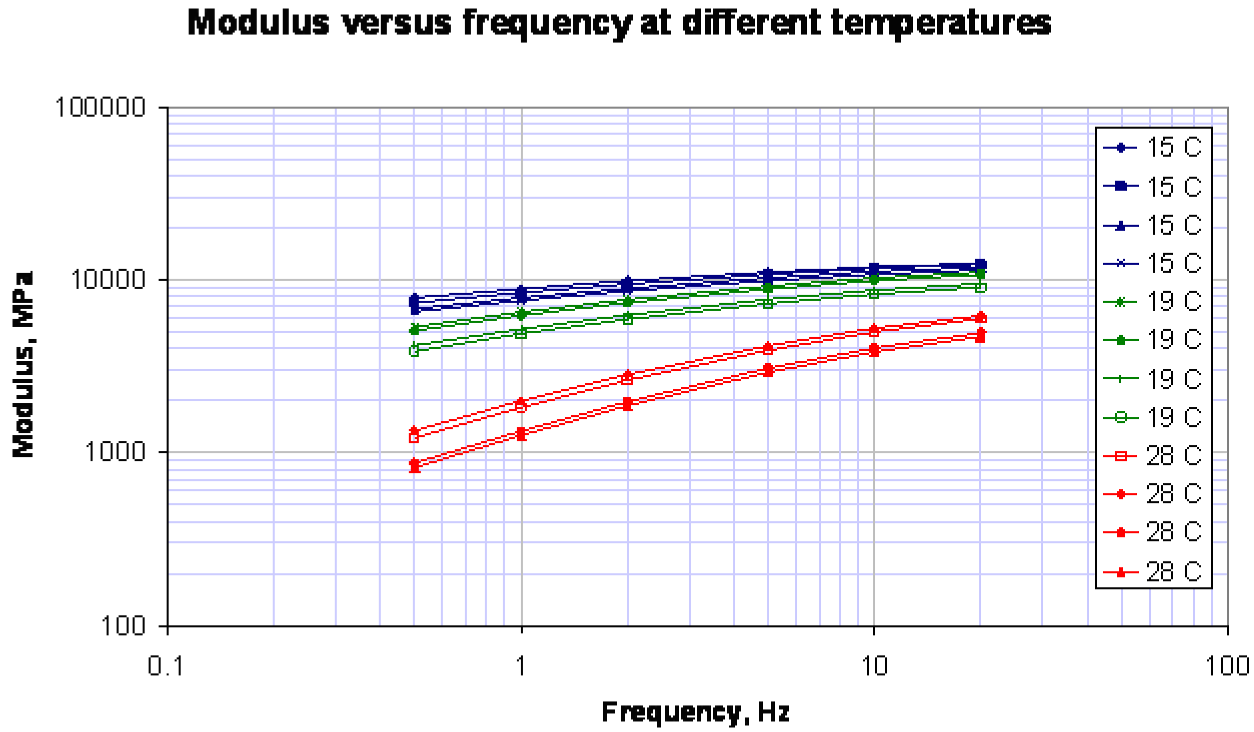
High Temp Grade	Low Temperature Grade													
	-10		-16		-22		-28		-34		-40		-46	
	VTS	A	VTS	A	VTS	A	VTS	A	VTS	A	VTS	A	VTS	A
46									-3.901	11.504	-3.393	10.101	-2.905	8.755
52	-4.570	13.386	-4.541	13.305	-4.342	12.755	-4.012	11.840	-3.602	10.707	-3.164	9.496	-2.736	8.310
58	-4.172	12.316	-4.147	12.248	-3.981	11.787	-3.701	11.010	-3.350	10.035	-2.968	8.976		
64	-3.842	11.432	-3.822	11.375	-3.680	10.980	-3.440	10.312	-3.134	9.461	-2.798	8.524		
70	-3.566	10.690	-3.548	10.641	-3.426	10.299	-3.217	9.715	-2.948	8.965	-2.648	8.129		
76	-3.331	10.059	-3.315	10.015	-3.208	9.715	-3.024	9.200	-2.785	8.532				
82	-3.128	9.514	-3.114	9.475	-3.019	9.209	-2.856	8.750	-2.642	8.151				

Grade	*A*	*VTS*
AC-2.5	11.5167	-3.8900
AC-5	11.2614	-3.7914
AC-10	11.0134	-3.6954
AC-20	10.7709	-3.6017
AC-30	10.6316	-3.5480
AC-40	10.5338	-3.5104

Grade	*A*	*VTS*
40-50	10.5254	-3.5047
60-70	10.6508	-3.5537
85-100	11.8232	-3.6210
120-150	11.0897	-3.7252
200-300	11.8107	-4.0068

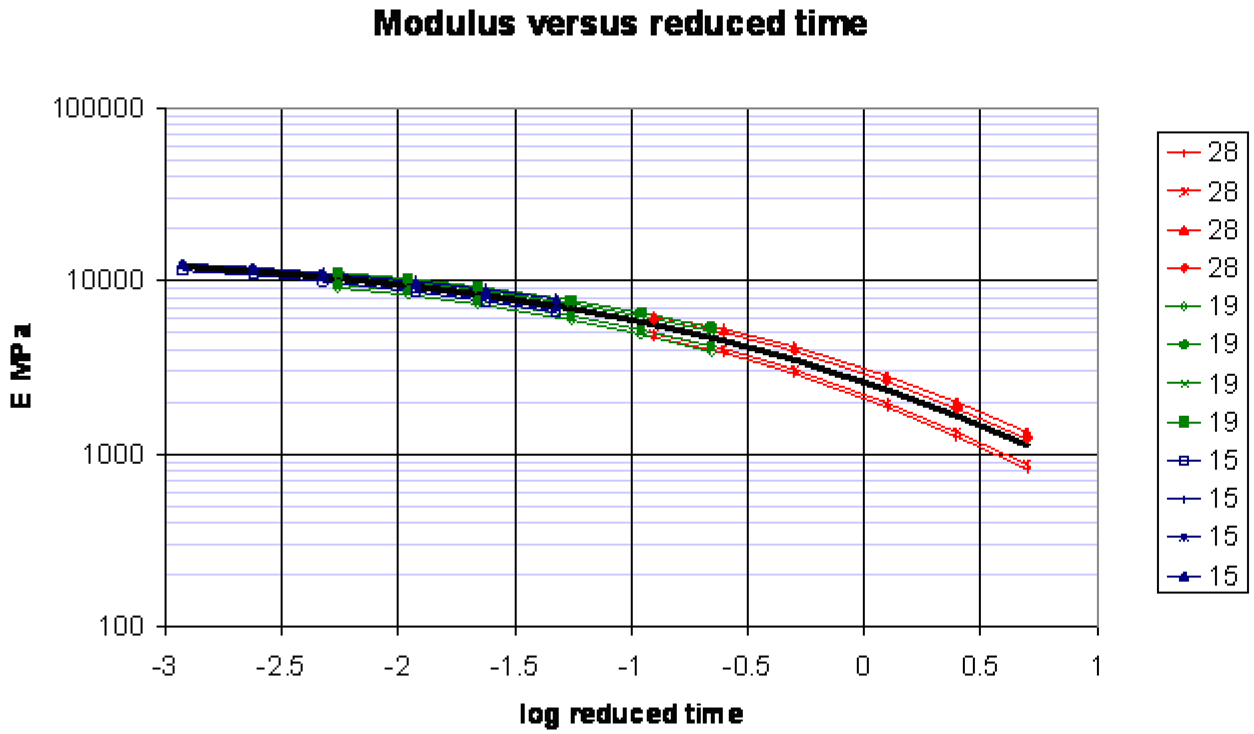
Viscosity susceptibility parameters recommended by MEPDG for PG, viscosity and penetration grades.

The figure below shows the results of frequency sweep tests done at three different temperatures (15, 19 and 28 oC)



It was assumed that the binder viscosity could be described by A = 9.6307 and VTS = -3.5047 (temperatures in degree Kelvin). The master curve is not sensitive to the selection of binder parameters and almost any of the combinations given in the tables above could have been used.

The measured moduli were fitted to the master curve equation using Solver in an Excel spreadsheet and minimising the Root Mean Square (RMS) difference between the measured values and the values calculated from the master curve equation. In the following figure the measured moduli are plotted against reduced time. The heavy black line is the master curve equation.

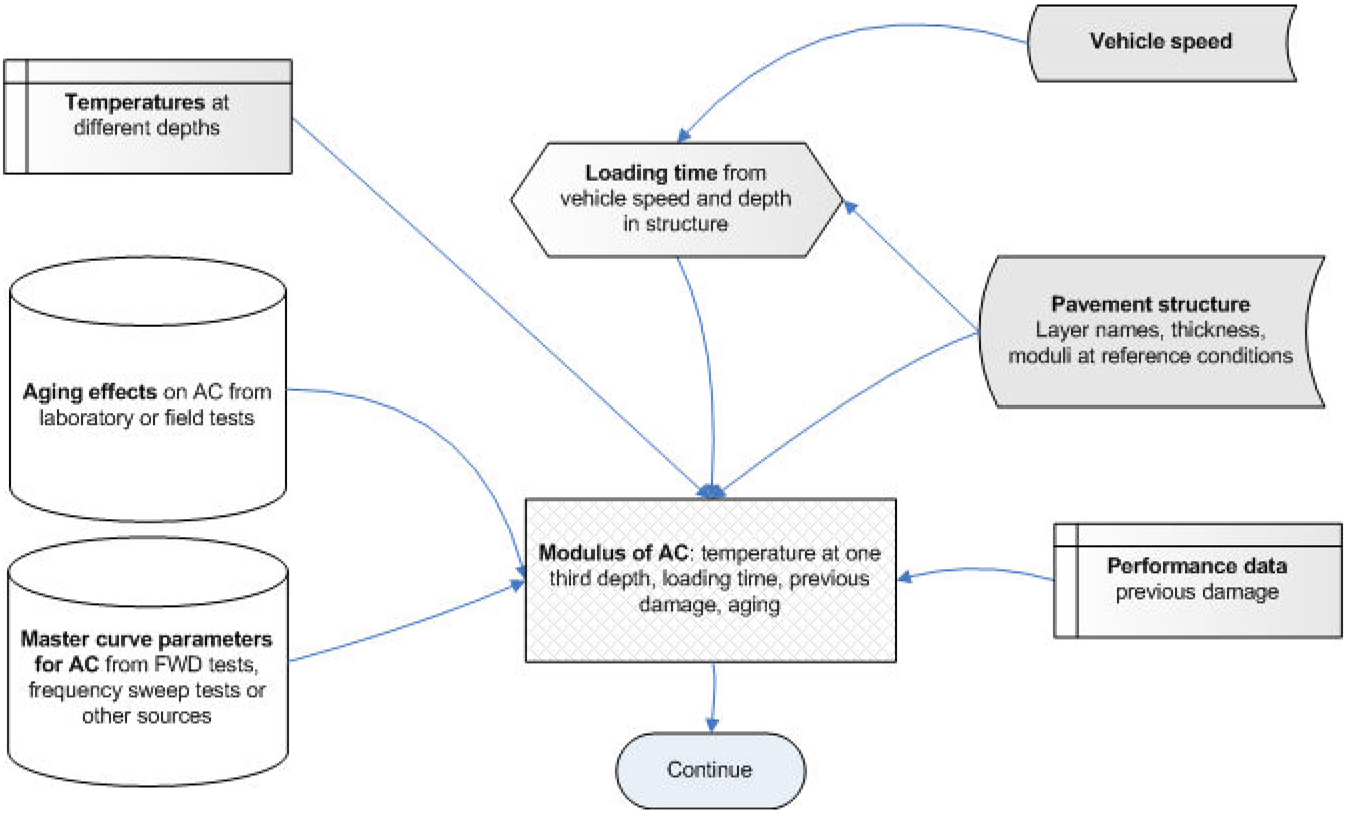


The master curve equation for this case was:

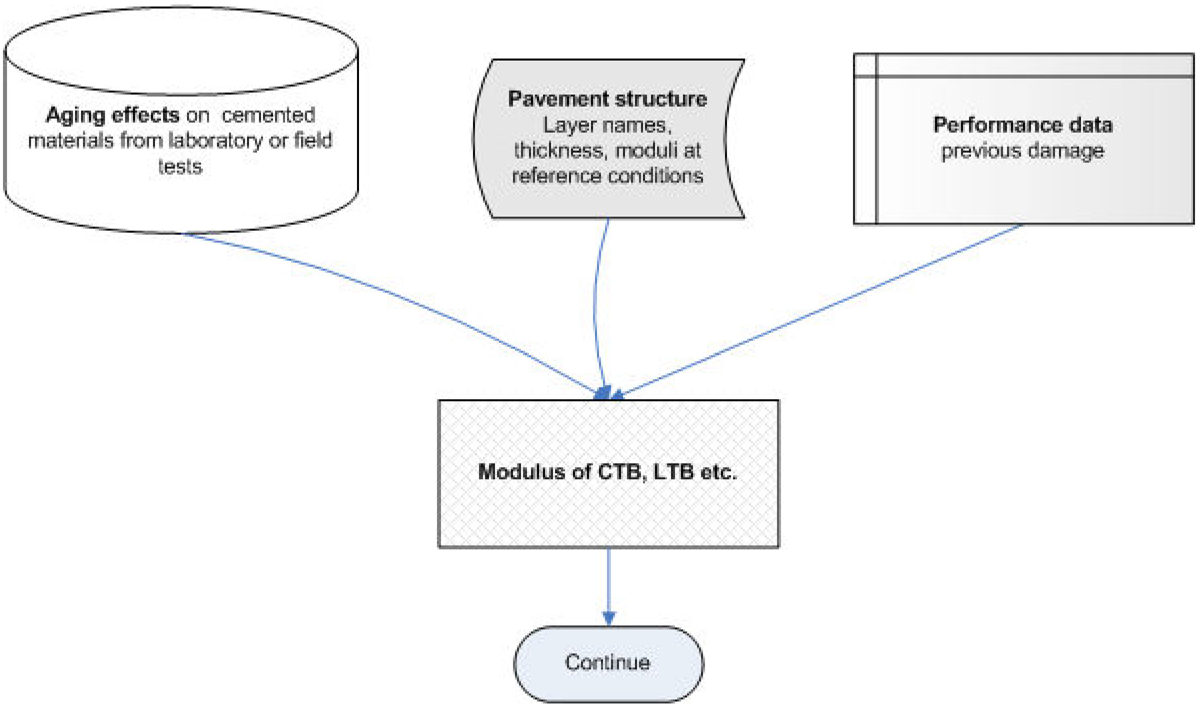
$$\log(E) = 0 + \frac{4.1998}{1+\exp(-1.4732+0.7088\times\log(tr))}, \quad tr = lt \times \left(\frac{v_{ref}}{v}\right)^{13709}$$

In this case the minimum modulus was assumed to be 1 MPa in order to fit the measured moduli. For use with CalME a minimum modulus of 100 to 200 MPa, corresponding to the modulus of the aggregate alone, is recommended even though it may not fit the laboratory data as well.

Flowchart for determining asphalt modulus



Flowchart for determining modulus of cemented materials



Alternative formats of master curve

The MEPDG master curve for asphalt materials may also be written on a simpler format as:

$$\log(E) = \delta + \frac{\alpha}{1 + \left({}^{tr}\!/_{tr_{ref}} \right)^{\gamma'}} \; where$$

$$\gamma' = {}^{\gamma}\!/_{\ln(10)} \; and \; tr_{ref} = \exp\left(- {}^{\beta}\!/_{\gamma} \times \ln(10) \right)$$

Alternative format of master curve.

With this format *tr*$_{ref}$ may be used to shift the master curve left or right and *γ'* may be used to change the slope of the curve. For *tr* = *tr*$_{ref}$ one has log(*E*) = *δ* + *α*/2.
The master curve may also be written on the format:

$$\log(E) = \delta + \frac{\alpha}{1 + \left({}^{lt}\!/_{tr_{ref}} \right)^{\gamma'} \times \exp\left(\eta \times \left(1 - \left({}^{T_K}\!/_{T_{Kref}} \right)^{VTS} \right) \right)},$$

$$\eta = \ln(10) \times \gamma' \times aT \times 10^{A} \times T_{Kref}^{VTS}$$

Second alternative format of master curve.

Where *A*, *VTS* and *T*$_K$ are defined in the equation for binder viscosity, and *T*$_{Kref}$ is the reference temperature in °K.

Hardening/aging

Hardening of the asphalt mix may be caused by a reduction in air voids content caused by post compaction and/or by aging (oxidation) of the binder. In *CalME* the following model is used

$$\Delta A = B \times \frac{\log(time + 1)}{1 - A \times \log\left({}^{T}\!/_{10\,°C} \right)}$$

where ΔA is the increase in the viscosity constant A at the temperature where log(E) = δ + α/2 on the original master curve,
time is in months,
T is the temperature, and
A and B are constants.
The relative increase in modulus at this temperature is applied at all temperatures.

In the Custom version a simpler model is also available:

$$E(d1) = E(d0) \times \frac{AgeA \times \ln(d1) + AgeB}{AgeA \times \ln(d0) + AgeB}$$

where *E*(*d1*) is the modulus after *d1* days,
d0 is the initial age, and
AgeA and *AgeB* are constants (*AgeB* may be fixed to 1).

E(d0) is the modulus at the initial age of a layer and is the value given in the grid of the Structure form. The initial age, *d0*, may be input via the menu point "Initial condition" on the Incremental Recursive form.

When importing FWD data from CalBack, the user is asked to input the age at the time of the FWD test, for any material that may show aging (*B* or *AgeA* <> 0). If a material shows aging, but does not have an input for initial age, the user is asked to input the initial age when starting a simulation.

Hardening may be limited by a maximum age in days, beyond which no more hardening takes place. This is done on the IncrementalRecursive form in the box "Max age, days".

Unbound materials

During calibration of the *CalME* models it was found that the moduli of unbound materials could vary with the stiffness of the asphalt layers. This could happen both when the variation in stiffness was due to temperature variations and when it was due to fatigue damage to the asphalt. For the granular layers the change in stiffness was the opposite of what would be expected due to the non-linearity of the material. To describe this stiffness variation of the unbound layers the following relationship is used:

$$E_n = E_{nref} \times \left(1 - \left(1 - S / S_{ref}\right) \times Stiffness\ factor\right), with$$

$$S = \left(\sum_{1}^{n-1} h_i \times \sqrt[3]{E_i} \right)^3$$

Equation: Modulus of unbound material as a function of confinement or bending stiffness.

where h_i is the thickness of layer *i*,

E_{nref} is the modulus of layer *n* at a bending stiffness $S = S_{ref}$,

and S_{ref} and *Stiffness factor* are constants.

If full slip has developed between two or more layers their combined stiffness is found from:

$$S = \sum_{1}^{n-1} h_i^3 \times E_i$$

For partial slip between layers a linear interpolation is done between full and no slip.

The unbound layers for some of the Heavy Vehicle Simulator (HVS) tests also showed typical non-linearity, with the modulus of granular layers increasing with increasing bulk stress and the modulus of cohesive materials decreasing with increasing deviator stress. Because of the variation in modulus given by the equation for confinement (bending stiffness) these non-linearities had to be treated as functions of the wheel load rather than as functions of the stress condition:

$$E_P = \left(\frac{P}{40\ kN} \right)^{\alpha} \times E_{40\ kN}$$

Modulus of unbound material as a function of wheel load.

where E_P is the modulus at wheel load *P* in kN,

E_{40} kN is the modulus at a wheel load of 40 kN, and

α is a constant (positive for granular materials and negative for cohesive).

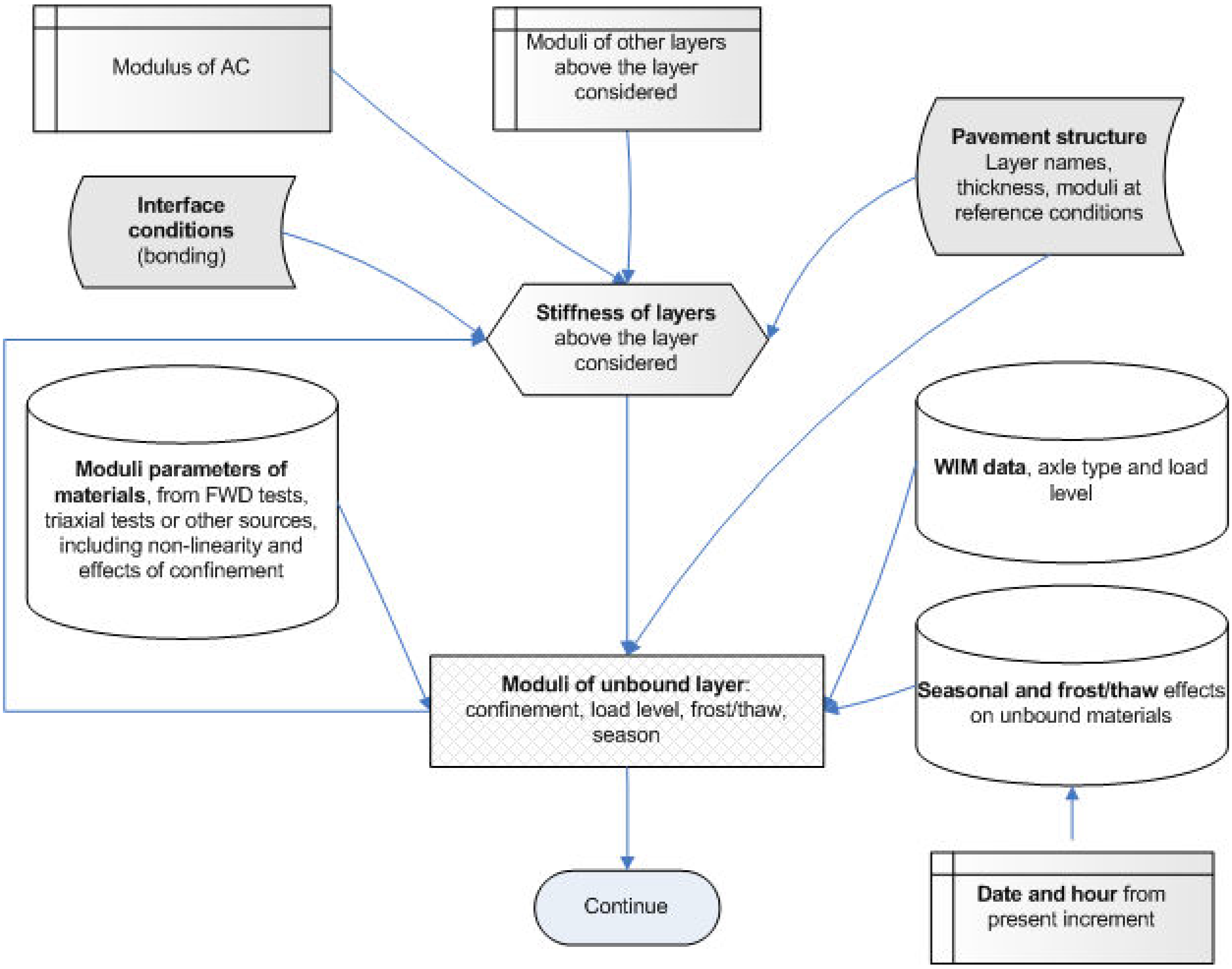
If a constant tire radius is used in the response calculations (to speed up the calculations) the moduli are only adjusted to the standard wheel loads (20 kN for single wheels and 40 kN for dual wheels).

The modulus may also be affected by moisture ingress. As the modulus of the asphalt decreases due to micro- and macro-cracking, the material may become permeable. If the moduli of the asphalt layers all have decreased to a certain fraction of the initial modulus, given as an input value, the modulus of the unbound layer may be divided by a value, also given as an input for the unbound material (see Incremental Recursive form, Custom.

For effects of seasonal variations see Seasonal effects on unbound materials.

For AC on PCC the k-value of the layers below the PCC layer is determined from the surface deflection under a standard load of 40 kN. The deflection is calculated using elastic layer theory and the k-value, that will produce the same deflection, is determined through iteration, using Westergaard's equation.

Flowchart for modulus of unbound materials



Asphalt fatigue damage

The model for damaged asphalt has the format:

$$\log(E) = \delta + \frac{\alpha \times (1-\omega)}{1+\exp(\beta + \gamma \log(tr))}$$

Equation: Modulus of damaged asphalt.

where the damage, ω, is calculated from:

$$\omega = \left(\frac{MN}{MN_p}\right)^{\alpha}, \alpha = \exp\left(\alpha_0 + \alpha_1 \times \frac{t}{1°C}\right)$$

$$MN_p = A \times \left(\frac{\mu\varepsilon}{\mu\varepsilon_r}\right)^{\beta} \times \left(\frac{E}{E_r}\right)^{\gamma} \times \left(\frac{E_i}{E_r}\right)^{\delta}$$

Damage as a function of number of loads, strain, temperature, and modulus.

where *MN* is the number of load applications in millions,
$\mu\varepsilon$ is the strain,
E is the (damaged) modulus,
E_i is the intact modulus,
t is temperature, and
A, α_0, α_1, β, γ, δ, $\mu\varepsilon_r$, and E_r are constants.

The intact modulus, E_i, corresponds to a damage, ω, of 0 and the minimum modulus, E_{min}=10$_\delta$, to a damage of 1. The parameters of the damage function are determined from four-point, constant strain bending tests in the laboratory.

The master curve for damaged asphalt leads to:

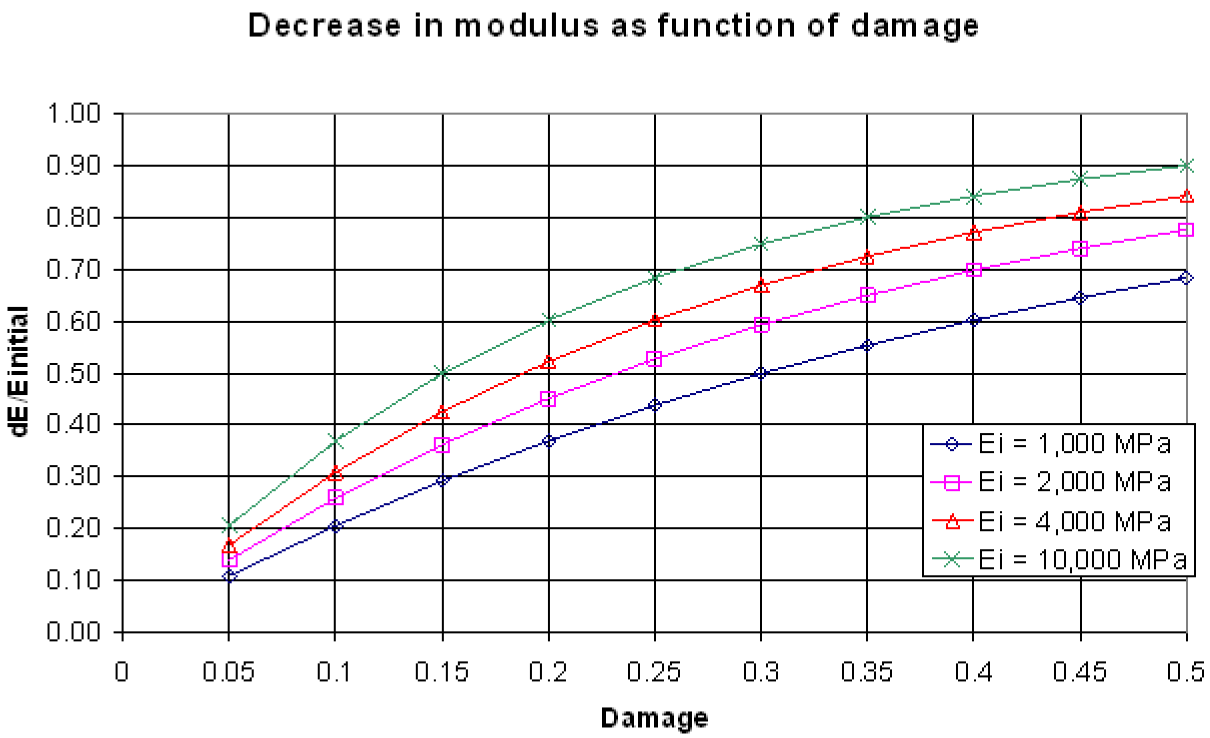
$$\log(E) - \delta = (\log(E_i) - \delta) \times (1 - \omega), or$$

$$\frac{E}{E_i} = \left(\frac{E_{\min}}{E_i}\right)^{\omega}, or$$

$$\omega = \frac{\log\left(E / E_i\right)}{\log\left(E_{\min} / E_i\right)} = \frac{\ln(SR)}{\ln\left(E_{\min} / E_i\right)}$$

Relations between moduli, stiffness reduction and damage.

It should be noticed that the relative decrease in modulus will depend on the minimum modulus, E_{min}, and on the initial modulus, E_i, which again is a function of temperature and loading time. Some examples are shown in the figure below, for E_{min} = 100 MPa and different values of E_i. A decrease in modulus by 50% would correspond to a damage between 0.15 and 0.30, depending on the initial modulus.



To predict in-situ damage from the laboratory test results, a shift factor, *SF*, is introduced:

$$\varpi = \left(\frac{MN}{SF \times MN_p} \right)^{\alpha}$$

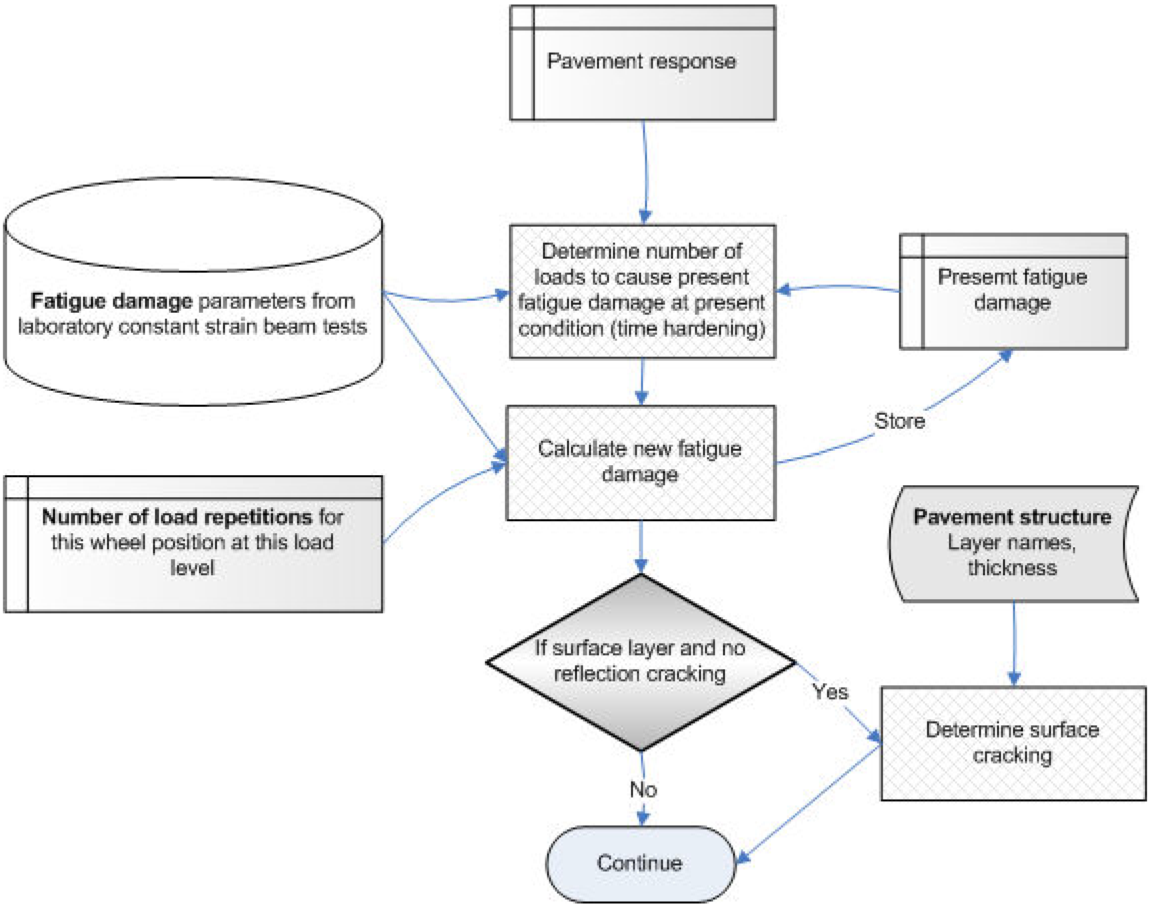
The shift factor is determined from the difference between laboratory fatigue tests and full scale testing (HVS and track tests), *SFF*, and the effects of rest periods:

$$SF = \left\{ 1 + \left[\frac{Rp}{Rp_{ref}} \times \left(\frac{\eta(t_{ref})}{\eta(t)} \right)^{aT} \right]^{\varphi} \right\} \times SFF$$

where *Rp* is the rest period,
tref and *aT* are master curve parameters,
$\eta(t)$ is the viscosity at a temperature of *t*, and
Rpref and φ are constants.

The default values of *Rpref* and φ are 10 sec and 0.4, respectively.

Flowchart for fatigue damage



Damage to cemented materials

A damage function similar to the one used for fatigue damage of asphalt materials may be used for other cemented materials. It may be based on either the maximum tensile strain or stress at the bottom of the layer. The modulus of the layer is reduced by multiplying the intact modulus by (1 - ω), where ω is the damage.

$$Damage = A \times MN^{\alpha} \times \left(\frac{resp}{resp_{ref}}\right)^{\beta} \times \left(\frac{E}{E_{ref}}\right)^{\gamma}$$

where *MN* is the number of load repetitions in millions,

resp is the response (horizontal tensile stress or strain at the bottom of the layer),

$resp_{ref}$ is a reference response (can be related to strength),

E is the modulus of the material (adjusted for climate and damage),

E_{ref} is a reference modulus, and

A, α, β and γ are constants.

Crushing of lightly cemented materials

Lightly cemented materials may crush from the top due to excessive compressive stresses or strains. The damage due to crushing is calculated from:

$$Damage = A \times MN^{\alpha} \times \left(\frac{resp}{resp_{ref}}\right)^{\beta} \times \left(\frac{E}{E_{ref}}\right)^{\gamma}$$

where *MN* is the number of load repetitions in millions,

resp is the response (vertical stress or strain on top of layer),

$resp_{ref}$ is a reference response (can be related to strength),

E is the modulus of the material (adjusted for climate and damage),

E_{ref} is a reference modulus, and

A, α, β and γ are constants.

Reflection cracking

Reflection cracking damage is calculated using the method developed by Wu (2005). In this method the tensile strain at the bottom of the overlay is estimated using a regression equation. The calculated tensile strain at the bottom of the overlay is used with the fatigue equation described in Asphalt fatigue damage to calculate damage in the asphalt layers.

AC on AC

The regression equation for tensile strain at the bottom of an AC overlay on a cracked AC pavement is based on a large number of finite element calculations, and assumes a dual wheel on a single axle:

$$\varepsilon = \alpha \times E_{an}^{\beta 1} \times E_{bn}^{\beta 2} \times \left(a1 + b1 \times \ln\left(LS_n\right)\right) \times \exp\left(b2 \times H_{an}\right) \times \left(1 + b3 \times H_{un}\right) \times \left(1 + b4 \times E_{un}\right) \times \sigma_n$$

$$E_{an} = E_a / E_s,\ E_{bn} = E_b / E_s,\ E_{un} = E_u / E_s,\ \sigma_n = \sigma_o / E_s,$$

$$LS_n = LS / a,\ H_{an} = H_a / a,\ H_{un} = H_u / a$$

where E_a is the modulus of the overlay,

H_a is the thickness of the overlay,

E_u is the modulus of the underlayer,

H_u is the thickness of the underlayer,

E_b is the modulus of the base/sub-base,

E_s is the modulus of the subgrade,

LS is the crack spacing,

σ_o is the tire pressure, and

a is the radius of the loaded area for one wheel.

The following constants were used:

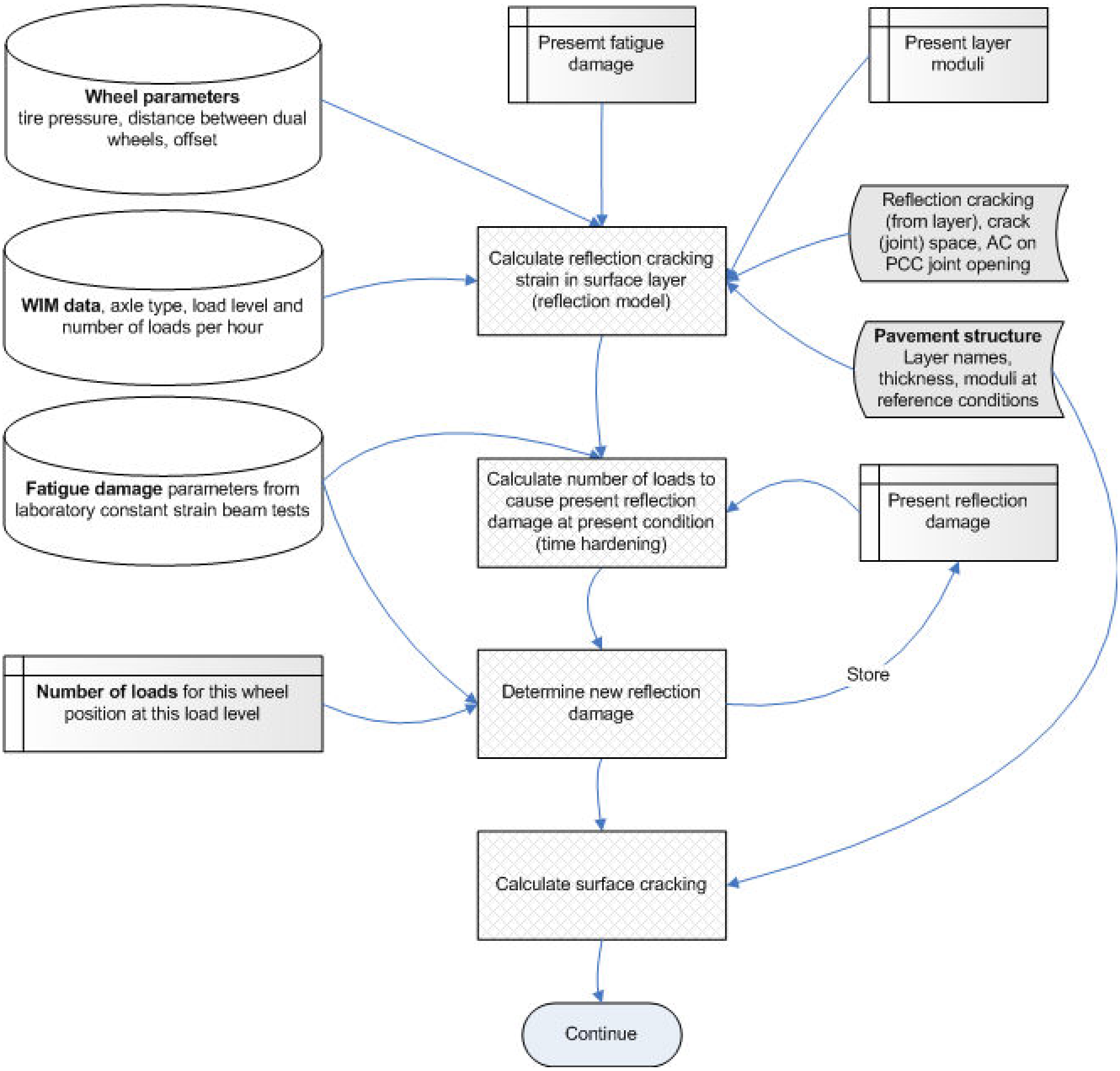
α = 342650, β1 = -0.73722, β2 = -0.2645, β3 = -1.16472, a1 = 0.88432,

b1 = 0.15272, b2 = -0.21632, b3 = -0.061, b4 = 0.018752.

AC on PCC

Reflection of cracking through an AC layer on a PCC support was also determined through a large number of finite element calculations. The equations and parameters used for AC on PCC are given in AC on PCC Strain Calculator.xls.

Reflection cracking flowchart



Visual cracking

The damage to the surface layer at crack initiation is determined from:

$$\omega_{initiation} = \frac{1}{1+\left(\frac{h_{AC}}{h_{ref}}\right)^{a}}$$

where $\omega_{initiation}$ is the damage at crack initiation,

h_{AC} is the combined thickness of the asphalt layers, and

a and h_{ref} are constants (-2 and 250 mm as default for new pavements).

Inversely,the time of crack initiation may be determined from the damage to the surfacing layer.

The amount of cracking, Cr in percent or length/area, is determined from:

$$Cr = \frac{Cr_{max} \times \left(\omega_{initiation}^{\alpha} - 1\right)}{\omega_{initiation}^{\alpha} - Cr_{max}/Cr_i + \left(Cr_{max}/Cr_i - 1\right) \times \omega^{\alpha}}$$

where ω is the damage to the surfacing layer,

Cr_i is the cracking corresponding to crack initiation,

Cr_{max} is the maximum cracking, and

α is a constant (α = -8 as default for new pavements and -3.5 for reflection cracking).

The amount of cracking at crack initiation must be assumed (in calibration studies values of 5% or 0.5 m/m^2 have been used).

The parameters are set in the "Crack_damage" table of the database.

Permanent deformation of asphalt

A shear-based approach for predicting rutting of the asphalt layer is used. The method was developed by Deacon et al. (2002). Rutting in the asphalt is assumed to be controlled by shear deformation. The permanent, or inelastic, shear strain, γ_i, is determined as a function of the shear stress,τ , the elastic shear strain, γ_e, and the number of load repetitions, from Repeated Simple Shear Tests at Constant Height (RSST-CH) in the laboratory. The laboratory test data are fitted either using a power function:

$$\gamma_i = A \times MN^{\alpha} \times \exp\left(\frac{\beta \times \tau}{\tau_r}\right) \times \gamma_e^{\delta}$$

or by using a gamma function:

$$\gamma_i = \exp\left(A + \alpha \times \left[1 - \exp\left(-\ln(N)/\gamma\right) \times \left(1 + \ln(N)/\gamma\right)\right]\right) \times \exp\left(\beta \times \tau/\tau_{ref}\right) \times \gamma_e^{\delta}$$

where γ_e is the elastic shear strain,

τ is the shear stress,
N is the number of load repetitions,
MN is the number of load repetitions in millions,
τ_{ref} is a reference shear stress (0.1 MPa ≈ atmospheric pressure), and
A, *α*, *β*, *γ*, and δ are constants determined from the RSST-CH.

The rut depth is calculated for the upper 100 mm of the AC layers. The shear stress is calculated at a depth of 50 mm beneath the edge of the tire. For each of the layers within 100 mm from the surface the elastic shear strain, $\gamma_e = \gamma_{xz}$, is calculated from:

$$\gamma_e = \frac{\tau}{E_i / (1+\nu_i)}$$

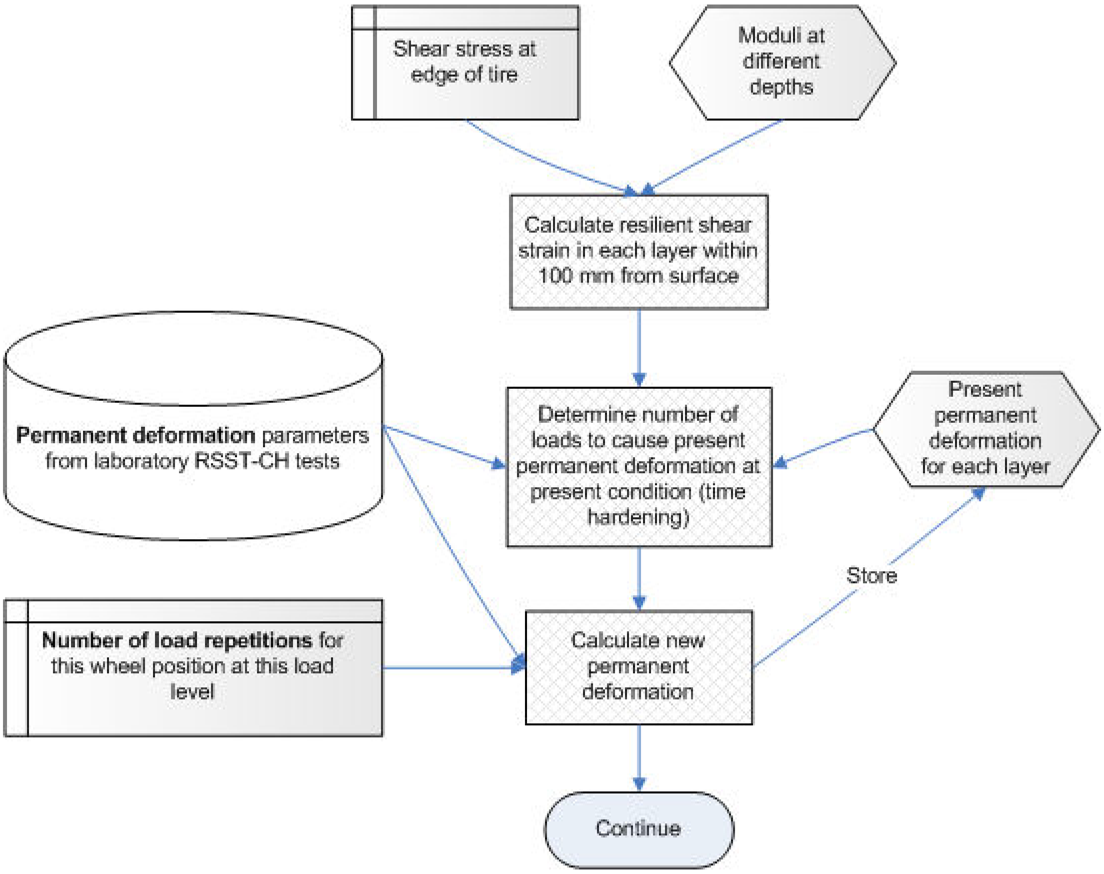
where E_i is the modulus of layer *i*, and
ν_i is Poisson's ratio for layer *i*.
Please notice that the xz shear strain is used, not the angular shear strain which is twice this value. The permanent shear strain of each layer is calculated from the power function or the gamma function, and the permanent deformation is determined from:

$$dp_i = K \times h_i \times \gamma_i$$

where h_i is the thickness of layer *i* (above a depth of 100 mm), and
K is a calibration constant.

The total rut depth (down rut) in the AC is the sum of the permanent deformation of the layers within the top 100 mm of the AC.

Flowchart for permanent deformation of asphalt



Permanent deformation of unbound layers

Permanent deformation, *dp*, of the unbound materials is based on the vertical resilient strain at the top of the layer, $\mu\varepsilon$, and on the modulus of the material, *E*:

$$dp,\ mm = A \times MN^{\alpha} \times \left(\frac{\mu\varepsilon}{\mu\varepsilon_{ref}}\right)^{\beta} \times \left(\frac{E}{E_{ref}}\right)^{\gamma}$$

where *MN* is the number of load applications in millions,
A, α, β, γ, $\mu\varepsilon_{ref}$ and E_{ref} are constants.

Roughness

Roughness can be predicted from the distribution of permanent deformation using the approach described below:

The standard deviation of the rut depth (permanent deformation at the surface), σ, may be found from:

$$\sigma = \sqrt{\frac{1}{N-1} \times \sum (rd_i - \mu)^2}$$

where rd_i is the rut depth at point *i*,

N is the number of points, and
μ is the average rut depth.

The autocorrelation coefficient, *ρ*, is the correlation coefficient of consecutive points at constant distances. It may be calculated from:

$$\rho = \frac{1}{N-1} \times \sum \left[\left(\frac{rd_i - \mu}{\sigma} \right) \times \left(\frac{rd_{i+1} - \mu}{\sigma} \right) \right] = \frac{1}{(N-1) \times \sigma^2} \sum \left[(rd_i - \mu) \times (rd_{i+1} - \mu) \right]$$

Slope Variance (*SV*) was used at the AASHO Road Test to describe roughness. The slope is measured, in mm/m, over a distance of 300 mm. The Slope Variance may be calculated from:

$$SV = \frac{1}{N-2} \times \sum \left[\frac{(rd_{i+1} - rd_i)}{0.3} \right]^2$$
$$= \frac{1}{0.3^2 \times (N-2)} \sum \left[(rd_{i+1} - \mu)^2 + (rd_i - \mu)^2 - 2 \times (rd_{i+1} - \mu) \times (rd_i - \mu) \right]$$
$$\cong \frac{2 \times \sigma^2}{0.09} \times (1 - \rho)$$

This means that the roughness, in terms of slope variance, is determined by the standard deviation of the rut depth and the autocorrelation coefficient for a distance of 300 mm.

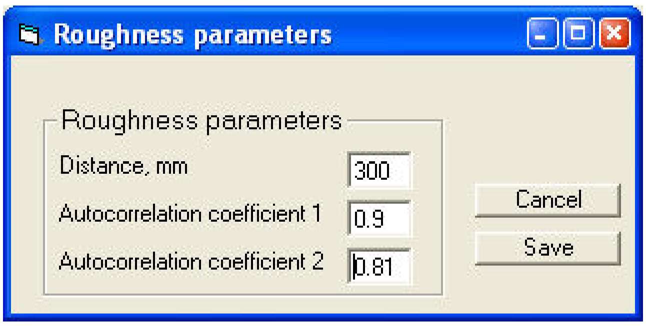
A longitudinal surface profile that has a standard deviation of σ and an autocorrelation coefficient of ρ can be generated through a first order autoregressive process:

$$rd_{i+1} = \varphi \times rd_i + a_t,\ \varphi = \rho,\ \sigma_x = \sigma \times \left(1 - \rho^2\right)$$

where *xt* is the elevation at point *t* and *at* is a normally distributed random variable with mean value 0 and a standard deviation of σx.
With CalME it is possible to use a second order autoregressive process:

$$rd_{i+2} = \varphi_1 \times rd_{i+1} + \varphi_2 \times rd_i + a_t,$$
$$\varphi_1 = \frac{\rho_1 \times (1 - \rho_2)}{1 - \rho_1^2},\ \varphi_2 = \frac{\rho_2 - \rho_1^2}{1 - \rho_1^2},$$
$$\rho_x = \sigma \times (1 - \rho_1 \times \varphi_1 - \rho_2 \times \varphi_2)$$

The parameters are entered in the form below, through the menu points "Special input" and "Change Roughness Parameters":



The second autocorrelation coefficient ρ_2 should be less than or equal to the square of the first autocorrelation coefficient (if equal the process reverts to a first order autoregressive process).

The standard deviation, σ, is calculated from the variation in predicted rut depth and a longitudinal surface profile is generated using the distance and autocorrelation coefficients. The "Golden Car" (Sayers & Karamihas, 1998) is used to calculate the IRIvalues from this profile.

When variability is considered the IRIvalue will also be reported in the output, as shown in Example_2.xls.

Temperature

Surface temperatures have been precalculated for each hour of a 30 year period, using the Enhanced Integrated Climate Model (EICM), for a number of climate zones and different pavement structures in California. The values are stored in the database EICM.mdb. The temperatures at different depths are calculated using the surface temperature, a constant deep soil temperature and the previous temperatures. It is done using a 1-D Galerkin Finite Element formulation with a finite difference time step. Calculation over one year is used to initialize the system.

If the temperature database is not available, CalME will calculate the temperature from:

$$t_1 = tYearMean + YearRange/2*(1-z/1000)*\sin(\pi*h/4380 - \pi/2 - \pi/12)$$

$$t = t_1 + DayRange/2*(0.11*(z/100)^2 - 0.66*z/100 + 1)*\sin(\pi*h/12 - \pi/2 - 3\pi/12)$$

where tYearMean is the mean yearly surface temperature, ^oC,
YearRange is the yearly range in surface temperature, ^oC,
DayRange is the daily range in surface temperature, ^oC,
z is the depth in mm, and
h is the hour counted from the start of the year.

The yearly mean, yearly range and daily range temperatures are stored in the "Climate zone" table.

Seasonal effects on unbound materials

Two types of seasonal effects on unbound materials may be considered. One is a sinusoidal variation with time during the year given as:

$$E = Emean * (1 + ERange/2*\sin(2\pi(Day - MaxDay)/365 + \pi/2))$$

where Emean is the modulus given in the structuraldata form,
ERange is the relative range in modulus during the year,
Day is the day number counted from the start of the year, and
MaxDay is the day with maximum modulus.

The values are stored in the table "Moisture factors".

The other variation is for thawing of a material. If a material has been frozen and then thaws, the modulus is multiplied by a factor, R:

$$R = 1 - (1 - Ro) * \exp(A * \text{days since frost})$$

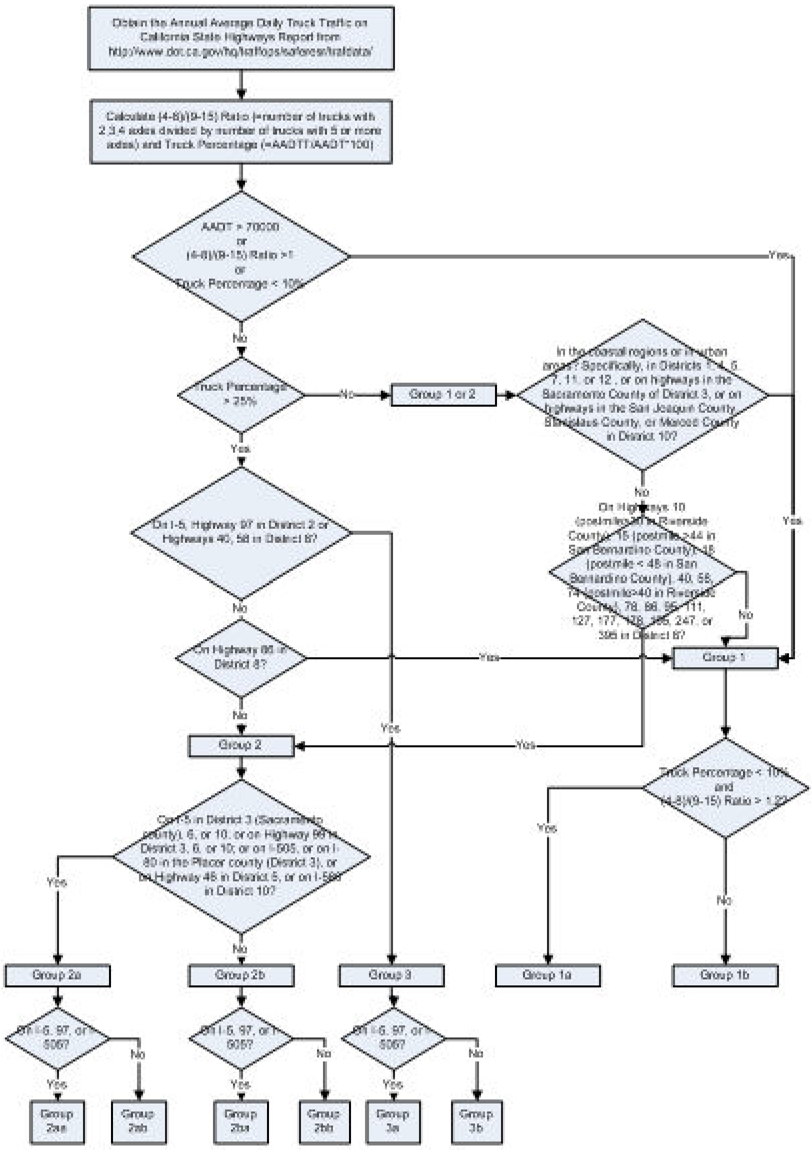
where Ro is the maximum frost reduction, and
A is the recovery rate.

These values are also stored in the table "Moisture factors".

Traffic

The traffic loads are distributed on four axle types: steering (with a single wheel), single, tandem and tridem (all with dual wheels). For each time period and each lateral position (if wander is considered) the critical stresses and strains are evaluated for each load level for each of the axle types.

The load distributions are derived from Weigh-In-Motion (WIM) stations at more than 100 locations in California (Truck Traffic Analysis using Weigh-In-Motion (WIM) Data in California). An analysis of the load distribution data (Grouping of WIM Sites Based on Axle Load Spectra) showed that the load distributions fall into eight groups. The decision tree used to determine the group is shown below and in "corrected_flowchart".



The averaged traffic inputs from all WIM sites in each group were used as the traffic characteristics of the regions covered by the group. For CalME, the number of axles per truck and the hourly axle load spectra are averaged for each group. Other traffic inputs, including the number of axles per lane per year and growth rate are calculated for each highway section from the Caltrans annual AADTT report

http://www.dot.ca.gov/hq/traffops/saferesr/trafdata/

which is stored in the table "CaltransAADTT". The present number of axles in the design lane is calculated from the year of estimation in the table, using a linear growthrate.

Calibration studies

Parameters for the different models used in the incremental recursive design method have been determined through calibration studies, primarily using the California Heavy Vehicle Simulators (HVSs) (Ullidtz et al. 2007) but also some test track data (Ullidtz et al., 2008). Calibration of model parameters is an ongoing activity. The following papers on calibration are available: HVS calibration TRB 2008 and APT2008, WesTrack calibration AAPT 2008 and APT2008, Reflection cracking 6th-RILEM 2008 and APT2008,

The calibrations are normally done in two steps. First the pavement response calculated during the *CalME* simulation is compared to the measured response. The pavement response is used to predict the performance, in terms of permanent deformation and damage. It is essential that the calculated response is not too different from the actual, measured response, otherwise the calibration effort is without any value. The calibration studies till now have made use of resilient deflections measured using a Road Surface Deflectometer (RSD, similar to a Benkelman beam), Multi Depth Deflectometers (MDDs, which records both resilient and permanent deflections at several depths in the pavement structure) and/or a Falling Weight Deflectometer (FWD). Getting the pavement response correct involves the models for predicting the moduli of the materials and how they change with climate, damage and aging.

Once the *CalME* simulation can predict the pavement response for the whole duration of the experiment, then the models for permanent deformation can be calibrated.

Initial model parameters are derived from laboratory tests or from in situ tests such as FWD or Dynamic Cone Penetrometer (DCP). Damage function parameters are determined from laboratory fatigue testing (four-point bending, constant strain) and RSST-CH.

Materials that have been used in calibration studies are preceded by "Cal " in the Materials table of the database.

Master curve parameters

The master curve parameters may be determined from frequency sweep tests on beams or shear tests, using the Repeated Simple Shear Tests at Constant Height (RRST-CH), from initial values during fatigue tests or RSST-CH tests to determine permanent deformation parameters, or from FWD tests.

Parameters determined from a number of calibration studies are shown in Master curve.xls

The parameters in the spreadsheet are from the equations below:

$$\log(E) = \delta + \frac{\alpha}{1+\exp(\beta+\gamma\log(tr))}$$

$$tr = lt \times \left(\frac{visc_{ref}}{visc}\right)^{aT}$$

$$\log(\log(visc\,cPoise)) = A + VTS*\log(t_K)$$

Fatigue damage parameters

The fatigue damage parameters may be determined from four point, constant strain fatigue tests.

Parameters determined from a number of calibration studies are shown in an Excel spreadsheet called FatigueDamageParameters.xls

The parameters in the spreadsheet are from the equations below:

$$\omega = \left(\frac{MN}{MN_p}\right)^{\alpha}, \alpha = \exp\left(\alpha_0 + \alpha_1 \times \frac{t}{1°C}\right)$$

$$MN_p = A \times \left(\frac{\mu\varepsilon}{\mu\varepsilon_r}\right)^{\beta} \times \left(\frac{E}{E_r}\right)^{\gamma} \times \left(\frac{E_i}{E_r}\right)^{\delta E_i}, or$$

$$MN_p = A \times \left(\frac{\mu\varepsilon}{\mu\varepsilon_r}\right)^{\beta} \times \left(\frac{E}{E_r}\right)^{\gamma} \times \exp\left(\delta_T \times \frac{t}{1°C}\right)$$

The last format for MN_p was used for some early calibration of HVS tests, and is not presently supported by CalME.

Permanent deformation parameters for asphalt

The permanent deformation parameters for asphalt are determined from the Repeated Simple Shear Test at Constant Height (RRST-CH) in the laboratory.

Parameters determined from a number of calibration studies are shown in an Excel spreadsheet called ACPermanentDeformations.

The parameters in the spreadsheet are from the equations below:

$$\gamma_i = A \times MN^{\alpha} \times \exp\left(\frac{\beta \times \tau}{\tau_r}\right) \times \gamma_e^{\delta}$$

$$\gamma_i = \exp\left(A + \alpha \times \left[1 - \exp\left(-\ln(N)/\gamma\right) \times \left(1 + \ln(N)/\gamma\right)\right]\right) \times \exp\left(\beta \times \tau / \tau_{ref}\right) \times \gamma_e^{\delta}$$

For a number of materials in the spreadsheet the value of β was not determined from RSST-CH testing, as all testing was at a shear stress of approximately 70 kPa. Instead an assumed value (from previous experiments) of 1.03 was used. From those RSST-CH tests where β was determined it appears that the assumed value of 1.03 was too high. The values determined for DGAC range from 0.15 to 0.52. For modified binders the value was close to 0 (zero). For the materials with β equal to 1.03 it may be necessary to adjust the relationship to a lower β value before it is used in CalME.

The permanent deformation, in mm, is calculated from the permanent shear strain through:

$$dp_i = K \times h_i \times \gamma_i$$

where *K* is a calibration factor, determined through full scale testing.

Hardening/aging parameters

For the WesTrack experiment the effect of hardening/aging were estimated from indirect tensile tests done before and after the experiment, adjusted for moduli backcalculated from FWD tests. The value of A was fixed at 0.7 and the value of B is given for each section in the table below. The mean value of B was 0.022 with a coefficient of variation of 0.44. The default value is 0.007.

$$\Delta A = B \times \frac{\log(time + 1)}{1 - A \times \log\left(\frac{T}{10\,°C}\right)}$$

Section	B
01FMM1	0.0264
02FLM	0.0169
03FLH1	0.0446
04FML	0.0266
05CMM1	0.0150
06CMH	0.0314
07CHM	0.0174
08CLM	0.0058
09PHL2	0.0150
10PLH	0.0159
11PMM2	0.0178
12PML	0.0158
13PHM	0.0178
14FHM	0.0272
15FMM2	0.0240
16FLH2	0.0357
17FMH	0.0364
18FHL	0.0099
19PMM1	0.0211
20PMH	0.0328
21PHL1	0.0315
22PLM	0.0233
23CML	0.0091
24CMM2	0.0104
25CHL	0.0291
26CLH	0.0170

Moduli of unbound materials

The parameters describing the moduli of unbound materials as a function of the bending stiffness of the materials above the layer, and as a function of the load level, are given in the spreadsheet ModuliUnboundMaterial.xls.

The parameters in the spreadsheet are those defined by the equations:

$$E_n = E_{nref} \times \left(1 - \left(1 - S / S_{ref}\right) \times Stiffness\ factor\right), with$$

$$S = \left(\sum_{1}^{n-1} h_i \times \sqrt[3]{E_i} \right)^3$$

$$E_P = \left(\frac{P}{40\ kN} \right)^{\alpha} \times E_{40\ kN}$$

In addition the spreadsheet may be used to evaluate the influence of the seasonal changes, given by:

E = Emean * (1 + ERange/2*sin(2π(Day – MaxDay)/365 + π/2))

and the influence of frost/thaw:

R = 1 - (1 - Ro) * exp(A * days since frost)

Stabilized material parameters

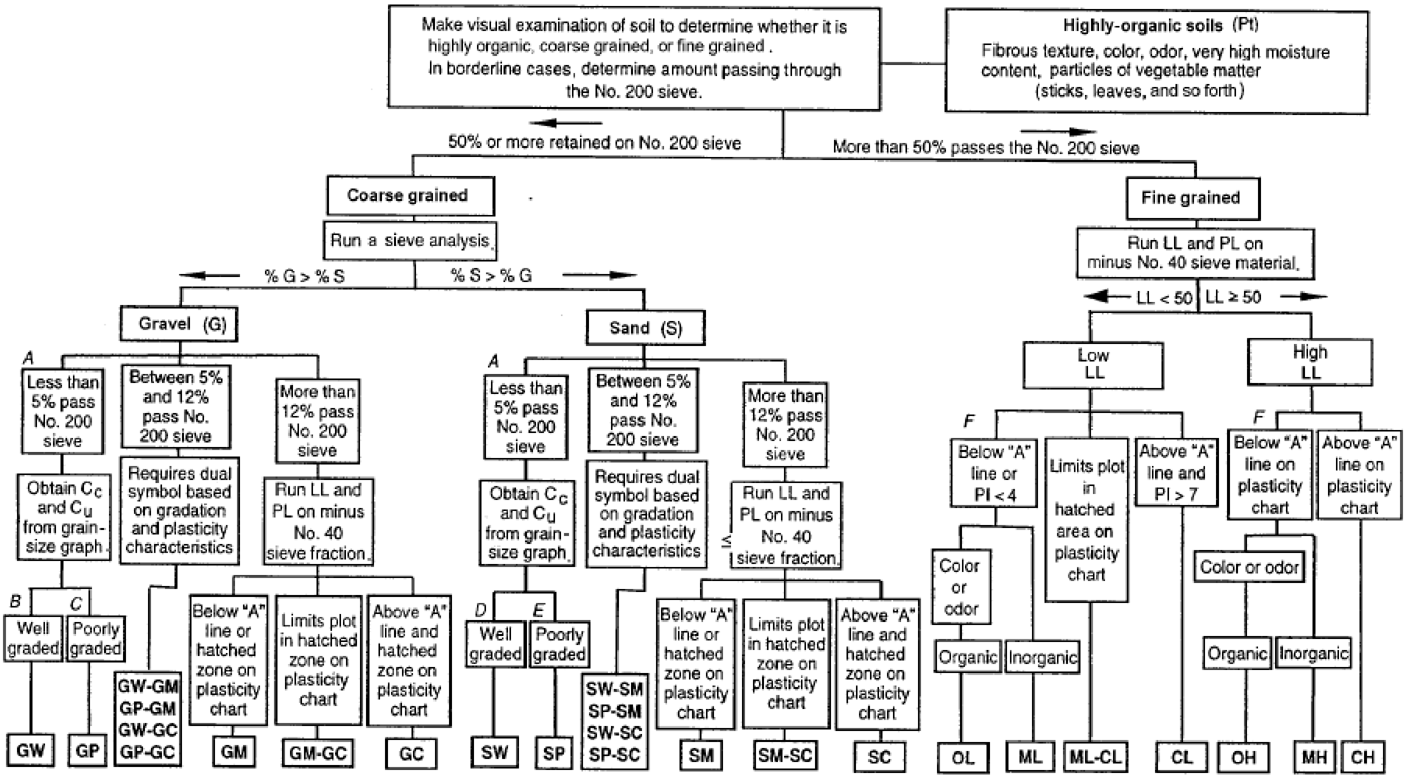
Very little information is presently available on stabilized materials. In the HVS test done on Goal 9 (MBroad) the aggregate base consisted of recycled crushed concrete. This material was self-cementing, with a modulus increasing to more than 1000 MPa with time. During HVS loading the material degraded again, mostly from the top according to DCP measurements. To simulate this material a crushing model was developed for CalME. The parameters are given in the spreadsheet: StabilizedParameters.xls

AC specifications

The specifcations for the AC materials that are presently available in the database are given in ACSpecifications.xls

Unbound specifications

Unified Soil Classification System



A If fines interfere with free-draining properties, use a double symbol such as GW-GM.
B For well-graded gravel, the C_u must be > 4 and the C_c must be ≥ 1 and ≤ 3.
C For poorly graded gravel, the C_u must be ≤ 4 and/or the C_c is < 1 or > 3.
D For well graded sand, the C_u must be > 6 and the C_c must be ≥ 1 and ≤ 3.
E For poorly graded sand, the C_u must be ≤ 6 and/or the C_c is < 1 or > 3.
F In cases where organic material can't be determined by color or odor, a LL and PL test must be conducted on a sample of natural moisture content and a sample that has been oven-dried. Organic soils will show a radical drop in plasticity for the oven-dried sample compared to the retained-moisture sample. Inorganic soils generally fall within ± 1 or 2 percent of each other.

The format for the specification of unbound materials is given in UnboundSpecifications.xls, but no standard materials have been entered at the present time (January 2011).

Stabilized specifications

No stabilized materials have been used in calibration experiments, except for the self-cementing granular base material at MB road which showed some of the characteristics of stabilized materials but which is not typical of these types of materials (January 2011).

Acronyms

AC - Asphalt Concrete

CIPR - cold in-place recycling
CoV - Coefficient of Variation

D80 - 80th percentile deflection under the California Deflectometer
DCP - Dynamic Cone Penetrometer
DGAC - Dense Graded Asphalt Concrete
DWMAT - Damage Weighted Mean Annual Temperature

EICM - Enhanced Integrated Climate Model
ESAL - Equivalent Standard Axle Load

FDR-FA - full depth reclamation with foam asphalt
FDR-PC - full depth reclamation with Portland cement
FWD - Falling Weight Deflectometer

GPI - Geosynthetic Pavement Interlayer,also known as SAMI-F (Stress Absorbing Membrane Interlayer – Fabric)

HMA - Hot Mix Asphalt
HRAC - hot recycled asphalt concrete, also know as HIPR (hot in-place recycling)
HVS - Heavy Vehicle Simulator

Incr - grade increase
IRI- International Roughness Index

MDD - Multi Depth Deflectometer
ME - Mechanistic-empirical
mean of logarithmic normal distribution is the geometric mean (10mean of logarithms)
MEPDG - Mechanistic Empirical Pavement Design Guide

NMAS - Nominal Maximum Aggregate Size

PAB - pulverized aggregate base, also know as full depth reclamation without stabilzation
PM - Caltrans postmile, e.g., 1.000, R12.456R

RES GE - residual gravel equivalent
RMS - Root Mean Square
RPI - Rubberized Pavement Interlayer,also known as SAMI-R (Rubberized Stress Absorbing Membrane Interlayer)

sdf -standard deviation factor or geometric standard deviation (10standard deviation of the logarithms)

TI-Traffic Index

UCPRC - University of California Pavement Research Center
USCS - Unified Soil Classification System

WIM - Weigh In Motion

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