

CalME Help - v3.DD002

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1. About This Manual

This manual was last updated on 2/7/2023 to be consistent with *CalME* Version 3.D002. Some of the screenshots included in this manual may not have been updated. The *CalME* development team strives to keep this manual up to date but there is expected to be gaps between updates of the software and this manual.

We would appreciate it if you can notify us of any errors or inconsistencies related either to the software or this manual that you think needs to be corrected right away. You can use the issue tracking system to do that or send your comments directly to the Caltrans Office of Asphalt Pavements.

Here is a list of changes to this manual over time:

- 2/7/2023: added explanation on how project location entered in *CalBack* is used in *CalME* (see [here](#) and [here](#)), and a description of special counties such as Kern9 when [entering project locations](#)
- 1/18/2023: initial release for version 3.DD002

Printable Version

Click the following [link to open a PDF version](#) of this manual for viewing, printing and downloading.

2. Introduction To CalME

Historical Background on Mechanistic-Empirical Design in California and Calibration of CalME

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 began under the technical guidance of the Pavement Standards Team, with the Division of Design in the lead. One of the tasks was to develop and calibrate ME flexible pavement design models, which were used for the design of the first Long Life Asphalt project on I-710 in Long Beach, constructed in 2003.

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. Work on ME design for California pavements has continued under the direction of the Caltrans Office of Pavement, the successor the Pavement Standards Team.

The first step in a Mechanistic-Empirical (ME) pavement design or evaluation is to calculate pavement response - in terms of stresses, strains, and/or displacements - using a mathematical model. In the second step, the calculated response is used as a variable to predict structural damage (decrease in moduli and accumulation of permanent deformation). A third step then follows to estimate pavement distress based on the predicted damage. The first step is mechanistic, the second step has both mechanistic and empirical parts, while the third step is empirical. An introduction to M-E pavement design is included in [a later part of this manual](#).

The first step 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 and later correlate the damage to

pavement distress through empirical relationship. In other words, only if the calculated response is reasonably correct does it make sense to try to drive damage accumulation using the calculated 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 report titled "[Calibration of Incremental-Recursive Flexible Damage Models in CalME Using HVS Experiments](#)", and focus on calibration of the strain and stress responses, damage models, and initial calibration of fatigue and reflective cracking, and rutting. The CalME damage, fatigue cracking, and rutting models were subsequently calibrated in 2006 using the materials, deflection, and condition survey data from the FHWA 1995-1996 WesTrack closed circuit track accelerated pavement testing experiment. New damage models for full-depth recycling were included in *CalME* in 2020, and damage models for cement stabilized base and subgrade were updated. The CalME empirical models relating asphalt fatigue and reflective cracking to predicted damages in the asphalt layers were recalibrated in 2021 using thousands of miles of condition survey, as-built and traffic data from 1978 to 2018 in the Caltrans pavement management system (PMS).

Report links:

- [2004 HVS calibration report](#)
- [2006 WesTrack calibration report](#)
- [2021 Updates to CalME and Calibration of Cracking Models](#)

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 in 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 a web-based application with a user interface written in ASP.NET to access a new, modern and easy-to-maintain compute engine, which uses [Node.js](#) to provide various web services and C++ to run the actual simulations to optimize performance. *CalME* v3 were tested against v2 to make sure the results are the same before incorporating various improvements in the models.

CalME v3 uses the same traffic data used by Caltrans' pavement management system, [PaveM](#). This source of traffic data is more current than that used by v2 and it also uses traffic information from the [Performance Measurement System \(PeMS\)](#) in order to fine-tune traffic data. *CalME* v3 makes a suggestion on the traffic data (traffic volume and load spectrum) based on the location of the project on the highway system selected by the user. The user should compare this suggestion with the traffic data provided by the Caltrans traffic division. They should be close and the latter should be used, otherwise one should double-check if large discrepancy exists between the two.

CalME v3 also uses the same climate zone data used by [PaveM](#) and makes a suggestion for the best zone to use. Again, the user is able to select any climate zone.

CalME v3 also allows the import of backcalculation results generated by Caltrans' [CalBack](#) program via an export file. *CalME* v3 create a new project and a series of trials that represents the sections generated by *CalBack*.

3. CalME Change Management

CalME is expected to be updated from time to time. The following are some of the reasons that will trigger an update:

- To fix software bugs,
- To add new features: such as supporting new materials, new pavement structure types,
- To update models, either due to better calibration with updated PMS data, or due to improvements in the models

Each major *CalME* update requires a decision document that outlines the reason for the update, description of changes, and expected difference in design (if applicable).

A list of the major changes since the release of *CalME* v3 and the associated decision documents are shown in the following table:

Version	Release Date	Description
CalME-V3-DD001	3/3/2020	The <i>CalME</i> v3 version released in January 2019 used material percentile performance to account for between project variability as an interim solution for between projects variability while <i>CalME</i> was calibrated with field performance data from the PMS. <i>CalME</i> has been calibrated with field performance data. The materials and reliability factors have been updated to more explicitly account for the reliability.
CalME-V3-DD001.3	8/1/2020	This version was the last version before being upgraded to v3DD002. It included minor bug fixes on the user interface.

CaIME-V3-DD002	12/1/2022	This release includes addition of recycled materials in the standard library, updated damage models for cement stabilized material calibration for overlay designs. There are several user interface changes as well: • The enforcement of design rules are delayed until user simulation. • The ability to generate initial guess design is added for designs. This can now be done without running empirical. • In keeping with the cracking plot, the result plot shows for rutting in stead of average rut depth. • A bug/issue reporting system has been added. • This online help has been rewritten to match the new
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4. Getting Started

This section presents the typical steps for designing a flexible pavement using *CalME*, as well as some step-by-step examples. A list of training videos are also included.

4.1. Design Inputs

Inputs for Routine Designs

The inputs required to start a routine *CalME* pavement design are:

- Design life
- Traffic: load distribution (WIM station) and traffic volume in terms of TI (Traffic Index) or indirectly the number of equivalent single axle loads (ESALs)
- Climate zone
- Pavement structure
 - Number of layers
 - Layer type (e.g., HMA, AB, SG, etc.) and the specific layer material (e.g., *2020 Standard HMA Type A Mix with PG64-16 Binder and up to 15% RAP for non-PRS Projects, 2020 Standard AB-Class 2*)
 - Layer thickness
- Simulation parameters
 - Simulation type: deterministic or Monte Carlo
 - Reflection cracking parameters when applicable
 - Type of reflection cracking: AC on AC, or AC on cemented base

- For AC on AC, the extent of existing wheelpath cracking
- The cracked layer(s)
- For Monte Carlo simulations:
 - Number of simulations, the recommended value is 60

CalME has built-in tools to help select the traffic load distribution (i.e., load spectrum), TI and climate zone once the user enters the project location.

Note: the estimated traffic data provided by CalME is for the lane with maximum traffic, which is typically the outside lane (truck lane). The traffic input data should be replaced by recent traffic data provided by the Caltrans Office of Traffic Operations, if available.

CalME can suggest preliminary simple trial structures for given traffic and climate inputs when designing for new constructions. These guess structures are made up of HMA, AB and SG. Users can also choose to enter different starting structure layers with different thicknesses. The ability for CalME to suggest designs will grow as more pre-run cases are added to the database.

Once all the required inputs are set, the designer can run [ME simulations](#) (both [Deterministic and Monte Carlo](#)) to see how the design performs with respect to rutting and cracking over the [design life](#) of the structure. The deterministic simulation estimates median performance, while the Monte Carlo simulation estimates the distribution of performance and determines the desired quantile (5th percentile by default, corresponding to 95% design reliability). Changes are then made to the initial trial structure and the simulation is run again. This iterative process continues until the desired reliability is obtained that exceeds the minimum 95%.

Inputs for Non-Routine Designs

For non-routine designs such as projects using performance related specification (PRS) for construction, more options are available and can be accessed by granted users. The following is a partial list of the additional options:

- Construction specification type: PRS vs. non-PRS

- Additional materials in the Standard Material Library that
 - Represent individual materials from different contractors, districts, and suppliers;
 - Account for effects such as geogrid in unbound layer

4.2. Critical Concepts

The following is a list of concepts that are critical for using and understanding *CalME*:

- **Trial:** a collection of design inputs that represent a proposed pavement design for a given project segment
- **Project:** a collection of trials, a given project segment may have multiple trials
- **Simulation:** typically refers to the prediction of performance of a given trial.

There are two types of simulations: deterministic and Monte Carlo. Deterministic simulation is used to predict the median performance (i.e., with 50% reliability), while Monte Carlo simulation is used to predict the distribution of pavement performance, from which the design reliability is determined. The minimal design that has no less than 95% reliability is the optimal design. For convenience, the number of random samples used in Monte Carlo simulation is referred to as the "number of simulations".

4.3. Typical Design Process

The typical design process using *CalME* involves identifying design alternatives beforehand, using *CalME* to find the optimal design for each alternative, and review all the optimal designs for cost and sustainability.

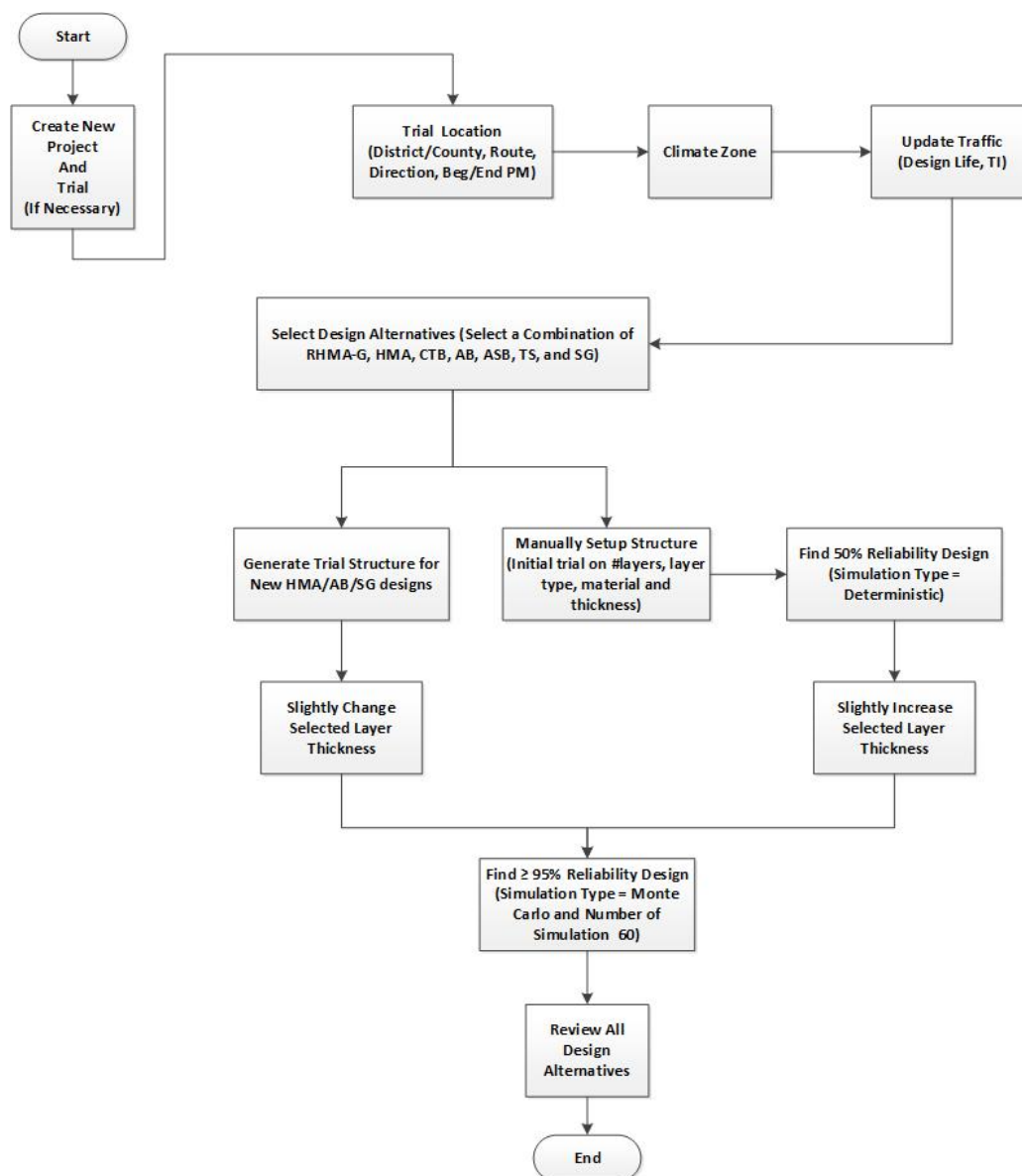
In addition, the process of evaluating designs for different segments of a project is the same as with other design methods, i.e., by evaluating the trade off between simplicity and cost.

The process for new construction designs is slightly different from the one for

rehabilitation projects. The design processes for new construction and rehabilitation are illustrated with flowcharts in the following subsections respectively.

4.3.1. New Constructions

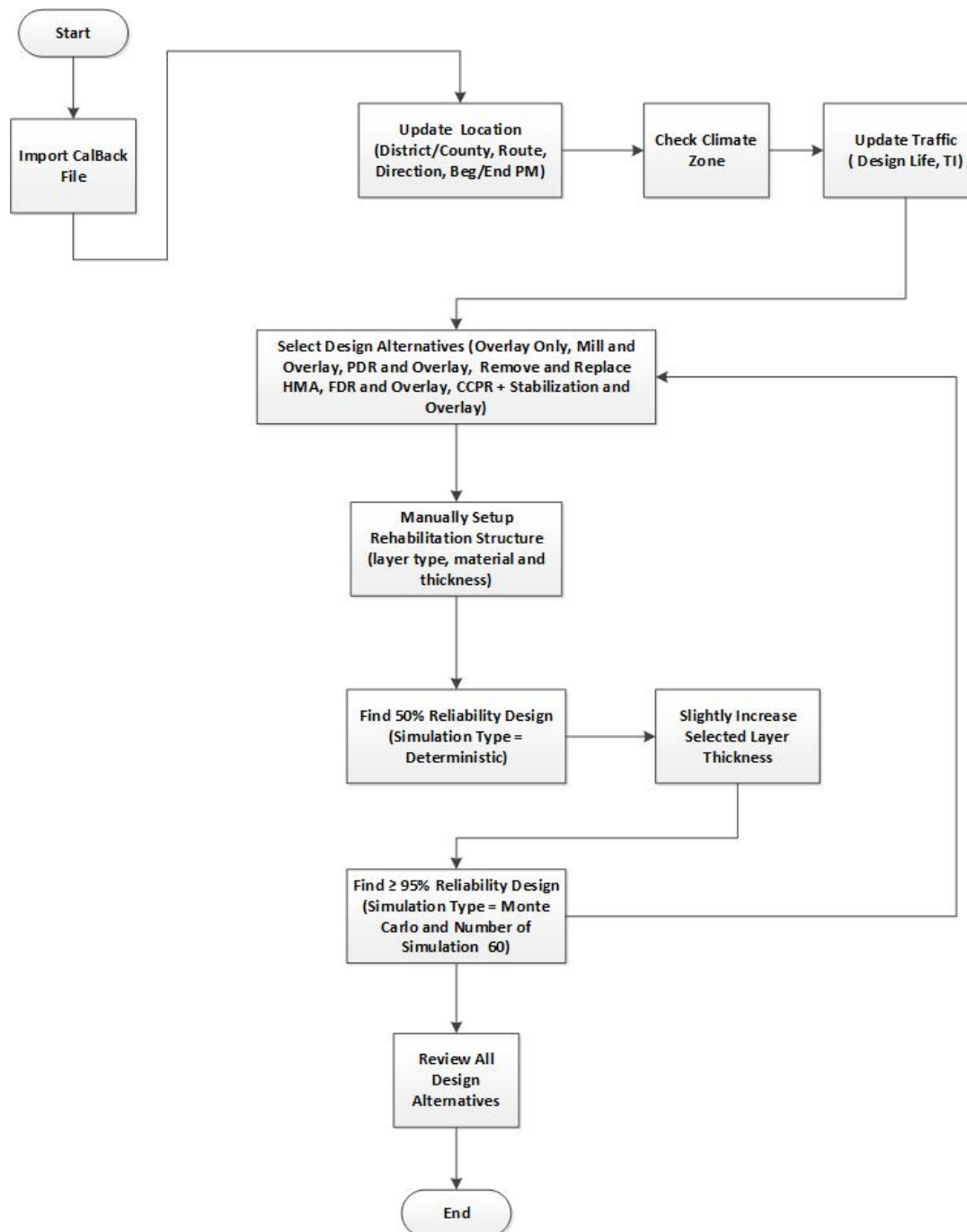
The flowchart shown below is a very high-level view of the design process for new construction and does not include the many administrative, engineering and policy related details that are associated with a pavement design.



Finding 50% and 95% reliability design both involves an iterative process in which a specific design is checked to see if it is optimal, which is defined as a design that is able to sustain the design traffic but any further reduction in any layer thickness will not sustain the design traffic. Example of this can be found in [New Construction Examples](#).

4.3.2. Rehabilitations

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



Examples of rehabilitation design can be found in [Rehabilitation Design Examples](#).

4.4. Design Examples and Case Studies

In this section, the typical *CalME* design process is illustrated through examples and case studies.

4.4.1. New Constructions

This section illustrates how to design a flexible pavement with a preliminary trial hot mix asphalt (HMA) thickness for the given subgrade type and TI. Table 1 lists the starting thicknesses for each subgrade type and a selection of TIs. Note that the table look up and interpolation or extrapolation (when necessary) has been programed into *CalME* for new pavements with HMA/AB/SG structure.

Table 1: Starting Point for Design of HMA Thicknesses (ft) with Minimum AB Thickness for
Different TIs and Subgrade Types (Passing 95% Reliability)

TI	Design Life (Years)	CH	CL	MH	ML	SC	SM	SP	SW	GC	GM	GP	GW
9	20	0.60	0.60	0.60	0.60	0.70	0.60	0.70	0.60	0.60	0.50	0.50	0.50
11	20	0.80	0.80	0.80	0.80	0.90	0.80	0.90	0.80	0.80	0.70	0.70	0.70
13	20	1.00	1.00	1.00	1.00	1.10	1.00	1.10	1.00	1.00	1.00	0.90	0.90
14	40	1.10	1.10	1.10	1.00	1.20	1.10	1.10	1.10	1.10	1.00	1.00	1.00
15	40	1.20	1.20	1.20	1.10	1.30	1.20	1.20	1.20	1.20	1.10	1.10	1.10
16	40	1.30	1.30	1.30	1.20	1.40	1.30	1.30	1.20	1.30	1.20	1.20	1.20
17	40	1.40	1.40	1.40	1.30	1.50	1.40	1.40	1.30	1.40	1.30	1.30	1.30
18	40	1.50	1.50	1.50	1.40	1.50	1.40	1.50	1.40	1.50	1.40	1.40	1.40
Min. AB Thickness (ft)		1.00	0.5	0.75	0.5	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35

This table was developed by finding the minimum HMA thickness in *CalME* required for a given TI and subgrade type. The actual design should be determined by additional *CalME* runs for the desired reliability. The structure of the pavement consisted of a subgrade, the minimum specified aggregate base thickness for the subgrade type, and the minimum thickness of HMA required to satisfy the design. The HMA mix used depends on the climate zone and will meet the requirement for binder PG grade listed in Table 632.1 of

the HDM. The AB used was the 2020 Standard AB Class 2. The other inputs used to generate the starting thicknesses are listed below in Table 2.

Table 2: Design Parameters

Parameter
Climate Zone
Load Distribution (V)
Growth Rate

These starting point designs can be further refined by increasing the AB layer above the minimum and then adjusting the HMA layer thickness. It is recommended that the user try other structure types, for example replacing a portion of the HMA with RHMA-G or polymer modified mix following Caltrans standard practices. These changes may reduce the overall AC thickness required.

4.4.1.1. Example N01: HMA/AB/SG

This example illustrates the design of a new flexible pavement for a TI that is not listed in [Table 1](#). The project location and design requirements are listed below:

- Project location: District 3, Yolo County, Route 5, Northbound, PM 10.0 to 11.0
- Design life: 20
- Design TI: 13.5
- Subgrade type: CL

The first design alternative to be evaluated is HMA/AB/SG.

Step 1: Define a Project and an Empty Trial

Navigate to the Projects page by clicking on the “Projects” tab at the top of the screen.

[Home](#)
[Instructions](#)
[Projects](#)
[Input](#)
[ME Design](#)
[Tools](#)
[Interpreting Results](#)
[?](#)
[About](#)
US SI
[Save To DB](#)
[Save To File](#)

Manage CalME Input Files and Database Projects (if logged in)

This page is used to manage CalME project data. Project data can be stored in **text files** (*.json-type files) on your local or network computer or in a **database** managed by UCPRC. File-based project data must first be uploaded to CalME in order to be used. Database-based project data is retrieved by selecting an existing project using the "Project" dropdown control below.

If you are storing CalME project data in the database, the UCPRC **recommends** that you save it locally as a file as a back-up to the data in the database.

Use the following controls to select and manage (Add/Delete/etc.) projects stored in the CalME database

Projects and Trials Stored in the Database

Loaded Project:

Loaded Trial:

Trial Title	Trial Description	
Workspace trial title-769	Workspace trial description	Delete

Use the following controls to select and load CalBack Export files stored locally on your computer. [Download CalBack.](#)

To upload a CalBack Export file (a *.json type file) and have CalME **generate** a master **Project** and a series of **Trials**, one for each section in the CalBack file, use the "Browse" button below to locate the file on your local system. Then use the "Upload" button to upload the file.

Choose File

Upload Status:

Use the following controls to select and load CalME input files stored locally on your computer

To load an existing CalME input file (a *.json-type file) into CalME, use the "Browse" button below to locate the file on your local system. Then use the "Upload" button to upload the input file.

☒ Create a New Project for the Uploaded File
 ☐ Add the Uploaded File To the Currently Loaded Project

Choose File

Upload Status:

Click the "Add Project" button to bring up the project definition screen and enter information as shown below. This screen also asks for the title of a first trial, which is given as "Flexible Pavement with a Starting Thickness" in this case. A "trial" represents a pavement design problem. A Project can have multiple Trials, corresponding to different segments within the project limit.

CalME: CALTRANS Mechanistic Empirical Tool

Add Project and its First Trial

Project Title

Description

Number (EA)

1st Trial Title

Description

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Click the “Save” button to return to the project page and it should look like below. As indicated in the screen shot, *CalME* has created a new Project along with an "Trial" using the names given in the dialog above.

CalME: CALTRANS Mechanistic-Empirical Tool

Home Instructions **Projects** Input ME Design Tools Interpreting Results ? About US UK Save To DB Save To File

Useful Links

- Caltrans
- UCPRC

Members role

Welcome JohnDoeDemo!

[Change your Password](#)

[Logout](#)

[Notice a bug? Submit an issue](#)

Manage CalME Input Files and Database Projects (if logged in)

This page is used to manage CalME project data. Project data can be stored in **text files** (*.json-type files) on your local or network computer or in a **database** managed by UCPRC. File-based project data must first be uploaded to CalME in order to be used. Database-based project data is retrieved by selecting an existing project using the "Project" dropdown control below.

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Use the following controls to select and manage (Add/Delete/etc.) projects stored in the CalME database

Projects and Trials Stored in the Database

Loaded Project: CalME Web Examples Edit Project Add Project Delete Project Save Project As

Loaded Trial: Flexible Pavement with a Starting Thickness Save Trial As

Trial Title	Trial Description	
Flexible Pavement with a Starting Thickness	HMA/AB/SG	Delete

Add Trial

Use the following controls to select and load CalBack Export files stored locally on your computer. [Download CalBack](#).

To upload a CalBack Export file (a *.json type file) and have CalME generate a master Project and a series of Trials, one for each section in the CalBack file, use the "Browse" button below to locate the file on your local system. Then use the "Upload" button to upload the file.

Choose File No file chosen Upload

Upload Status:

Use the following controls to select and load CalME input files stored locally on your computer

To load an existing CalME input file (a *.json-type file) into CalME, use the "Browse" button below to locate the file on your local system. Then use the "Upload" button to upload the input file.

☒ Create a New Project for the Uploaded File ☐ Add the Uploaded File To the Currently Loaded Project

Choose File No file chosen Upload

Upload Status:

Step 2: Define the Trial

At this point, the "trial" has not been defined. It only has a name and a description. To proceed with the design, one needs to input traffic, climate, structure, etc. (see [Design Inputs](#)).

To provide design inputs, click the "Input" tab item on top of the screen to navigate to the input page. CalME automatically enters a default project location, climate, traffic load distribution, growth rate, design life and traffic index (TI). While automatically setting these defaults were intended to make it easier to try the program, this information usually needs to be changed. After entering the correct project location, the screen will resemble the screenshot below:

CalME: CALTRANS Mechanistic-Empirical Tool

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[Save To File](#)

Useful Links

- Caltrans
- UCPRC

Members role

Welcome JohnDoeDemo!

[Change your Password](#)
[Logout](#)

[Notice a bug? Submit an issue](#)

Project ID

CalME Web Examples

Trial Title

Flexible Pavement with a Starting Thickness

Project Location

District

County

Route

Direction

PM Start

PM End

No. Lanes

3

Yolo

5

North

R

10,000

None

R

11,000

None

2

Project Length: 1,000 mi

Lane Miles: 2,000

Avg #lanes: 2.00

Traffic Count Information

Location

Location Description

AADT

AADTT

% Trucks

R9.411-R10.807

10,750

2,592

24.1

Climate

Climate Zone

Inland Valley

Suggested

Inland Valley

Design Lane Traffic Loads

Load Distribution (WIM Station)

Group1b

Suggested

Group1b

Growth Rate (From First Year)

4.8 %

First Year Axles / Design Lane

2,874,059

First Year Trucks / Design Lane

1,133,330

Design Life

20 yrs

Total ESALs

17,908,516

TI

12.7

Create a Trial Structure

(Using Design Life and TI)

Subgrade

Select

Generate

Error Message Summary

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS):

psi

TS->CSS

TS->LSS

CTB-Class B

Apply

Delete All

#	Old	Layer Type	Age (d)	Material	Thickness	Modulus-E	R-value	GF	Cost	Actions
No pavement layers										

Add Layer

Add 2 Layers

Add 3 Layers

Add 4 Layers

Add 5 Layers

Pavement structure must have at least two layers

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The traffic suggested by CalME for 20 year design life is 12.7 for this location. After changing this to the 13.5, and choose "CL" in the "Create a Trial Structure" box, then click on the Generate button, the input page looks like below:

Home Instructions Projects **Input** ME Design Tools Interpreting Results ? About US SI Save To DB Save To File

Project ID CalME Web Examples Trial Title Flexible Pavement with a Starting Thickness

Project Location

District: 3 County: Yolo Route: 5 Direction: North PM Start: R 10.000 None PM End: R 11.000 None No. Lanes: 2

Project Length: 1.000 mi Lane Miles: 2.000 Avg #lanes: 2.00

Traffic Count Information

Location: R9 411-R10.807 Location Description: AADT: 10,750 AADTT: 2,592 % Trucks: 24.1

Climate

Climate Zone: Inland Valley Suggested: Inland Valley

Design Lane Traffic Loads

Load Distribution (WIM Station): Group1b Suggested: Group1b

Growth Rate (From First Year): 4.8 %

First Year Axles / Design Lane: 4,843,894

First Year Trucks / Design Lane: 1,910,096

Design Life: 20 yrs Total ESALs: 30,182,727 TI: 13.5 (rounded)

Create a Trial Structure
(Using Design Life and TI)

Subgrade: CL Generate

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): psi TS->CSS TS->LSS CTB-Class B Apply Delete All

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft3)	Actions
1		HMA	90	2020 Standard HMA Type A Mix with PG 70-10 Binder and up to 15% RAP for non-PBS Projects	1.05	1,230.6	N/A	1.94	0.00	Edit Delete Insert
2		AB	N/A	2020 Standard AB-Class 2	0.50	45.0	78	1.10	0.00	Edit Delete Insert
3		Subgrade	N/A	2020 Standard CL	∞	9.9	16	N/A	0.00	Edit Delete Insert

Add Layer Add 2 Layers Add 3 Layers Add 4 Layers Add 5 Layers For CL Subgrade, AB- min is 0.50 or Equiv.

CalME uses the [Starting Point Table](#) to find a starting structure with necessary interpolation or extrapolation, and load it into the Pavement Structure window as the starting point as shown above.

Several notes:

- The aggregate base layer was set to the minimum specified thickness for this example. Increasing the AB layer will affect the required thickness of the surface HMA.
- CalME automatically picks the surface mix that meets the requirement on PG grade listed in Table 632.1 of the HDM. For High Desert and High Mountain, the HMA is divided into two layers by default because it is not recommended to use a mix with polymer modified binder for depths below 0.20 ft.
- The name of the materials also serve as links to the corresponding entries in the Standard Materials Library (SML), which provides the list of models as well as the model parameters for each material in the library.
- Use the "Edit" links in the "Pavement Structure" grid to change materials, thicknesses, or any other parameters as needed.
- The layer numbers can be used to navigate to a page to change some additional properties such as Poisson's ratio

- Use the "Delete" links in the "Pavement Structure" grid to delete layers
- Use the "Insert" links in the "Pavement Structure" grid to insert layers
- *CalME* will use the starting structure to replace any existing structure input, so make sure that is what you intended before hitting the "Generate" button.

Click the "Input" tab on top of the screen to navigate to the simulation parameters page, which is shown below:

Incremental-Recursive Parameters

Loaded Project: CalME Web Examples Loaded Trial: Flexible Pavement with a Starting Thickness

General

Starting Date: 6/16/2022 Simulation Duration: 20 yrs Vehicle Speed: 43.75 mph

Simulation Type

☐ Deterministic
☒ Monte-Carlo

Performance Criteria

Rutting: 0.4 in
Cracking: 5.0 %

Reflection Cracking

☒ None ☐ AC on AC ☐ AC on Cemented Base
Existing Cracking (%): > 35
Cracked layer(s) from: 0 to 0 <= Find Them

Spec. Type

☐ Non-PRS
☐ PRS

Monte Carlo Variability

No. of simulations: 60
☒ Construction variability

Construction Variability Table

Layer	CoV Thick	Sdf Modulus	
1	0.07	1.20	Edit
2	0.10	1.20	Edit
3	0.00	1.20	Edit

M&R Planning - This Feature is Coming Soon

Populate Grid With: 60 mm HMA Overlay Every 5 years

Year	Treatment
	No treatments

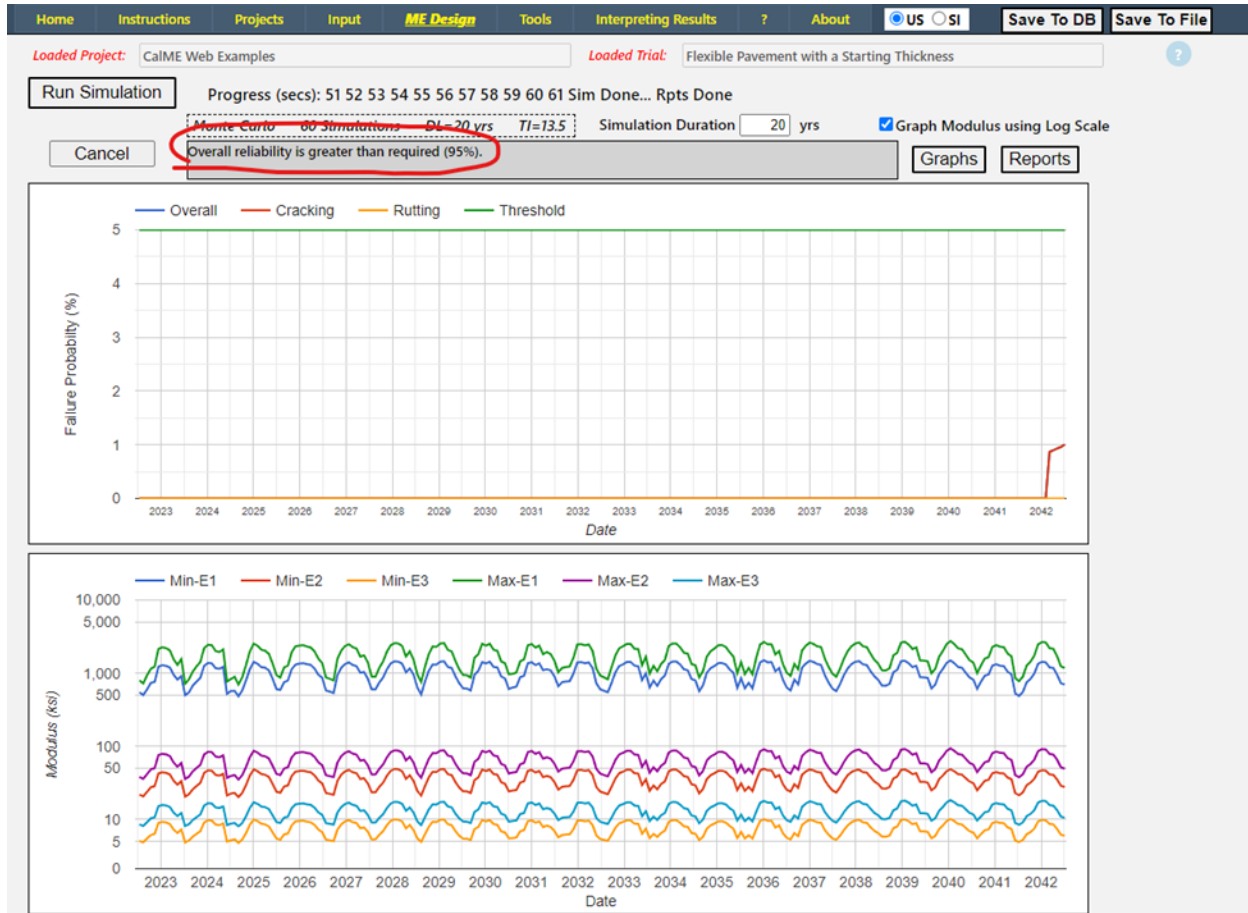
Add Treatment

Select the desired number of simulations for the Monte Carlo simulations. The default number is 60. You may use 20 simulations to expedite the process of finding the optimal design and then use 60 to confirm the final design. Select the construction variability option, which is enabled by default.

Step 3: Run *CalME* on the Selected Trial

Use the "ME Design" tab to navigate to the simulation window. Use the "Run Simulation" button at the upper left part of the screen to run *CalME*. The simulations will run in the background. The cracking/rutting chart and stiffness chart will update in real time as the simulations are running. The Layer Compression and Expected Life summaries will be

generated after the simulations are completed. The result is shown below:



As expected, the starting structure satisfies the design traffic. If this is not the case, minor adjustment may be needed. Scroll down the window to review the Layer Compression summary:



Use the scroll bar to right of the "Layer Compression" summary to scroll down to the "Expected Life" summary. The end of the Expected Life report lists the number of simulations that failed and the percent reliability. In general, designs should target a minimum of 95% reliability.



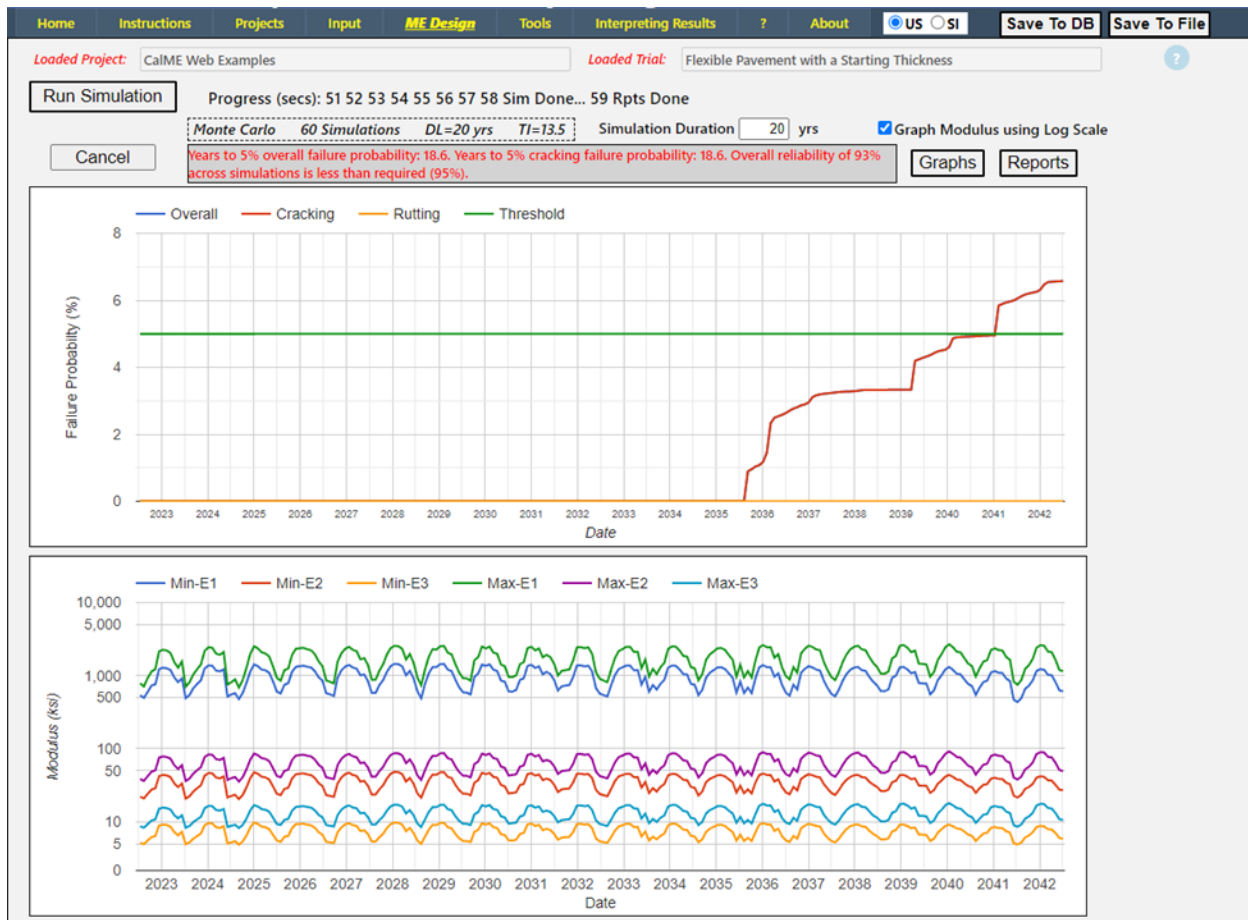
Keep scrolling down until the overall summary of Expected Life becomes visible:



This design achieved 98% reliability. To ensure that the pavement was not over-designed, iterative trials may be used to determine the minimum HMA thickness required to satisfy the 95 % reliability.

Step 4: Update the Structure and Run CalME

Return to the input screen and update the HMA thickness. For the next iteration, reduce the HMA thickness from 1.05 ft to 1.00 ft. Return to the simulation window and run the next trial. The results of the new trial are listed below.



The messaging area lists that the overall reliability of the structure is less than 95%. This design is projected to fail in year 18.6 due to cracking.

This confirms that 1.05 ft was the minimum required thickness to achieve 95% reliability.

It should be noted that Monte Carlo is probabilistic analysis, and may not return exactly the same reliability for every set of simulations run. One can use either deterministic analysis or Monte Carlo analysis with 10 to 40 simulations as the design is being refined. The final design must be done with Monte Carlo simulations. It is recommended that final design reliability be checked with Monte Carlo analysis using 60 simulations.

When the failure life is close to the design life (e.g., within 1 year), it is not uncommon for a 60-simulation Monte Carlo run to contradict a 20-simulation Monte Carlo run regarding whether a given design is sufficient.

Step 5: Generate a Report

Change the HMA layer thickness back to 1.05 ft and re-run the Monte Carlo simulation so that the results can be used to generate design report.

Use the “Reports” button to bring up the report window. Choose “Mechanistic Empirical” 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. See below for the report generated for this example:

CalME: CALTRANS Mechanistic-Empirical Structural Design Program for Flexible Pavements

Report: **Mechanistic-Empirical** **Generate** ☒ Include Problem Description in Output Reports **Download Report**

CalME v3.DD002.0 User: John Doe Report Time Stamp: Monday, January 02, 2023, 2:58 PM
 Project: CalME Web Examples
 Description: Demonstrate flexible pavement design with CalME
 Trial: Flexible Pavement with a Starting Thickness
 Description: HMA/AB/SG
 Output Time Stamp: Monday, January 02, 2023, 2:57 PM
 CalME engine: internal-calme-review-1459972082.us-west-1.elb.amazonaws.com:3302

Problem Description (User Input)

Project Location
 District 3, Yolo, Route 5, North, Start PM: R10.000, End PM: R11.000
 Project Length: 1.000 mi Lane Miles: 2.000 Avg #lanes: 2.00 Area (12 ft Lane Width): 126,720.00 ft**2

Pavement Structure
 When applicable, Unconfined Compressive Strength (UCS) for CSS or LTS: 300 psi

Layer	Material	Thick (ft)	Modulus (ksi)	Poisson	R	GF	Cost (\$/ft3)	Cost (\$)
1	2020 Standard HMA Type A Mix with PG 70-10 Binder and u	1.05	1230.6	0.35	N/A	1.91	0.00	0.00
2	2020 Standard AB-Class 2	0.50	45.0	0.35	78	1.10	0.00	0.00
3	2020 Standard CL	0.00	9.9	0.35	16	0.00	0.00	0.00
Project Cost:								0.00
Project Cost/Lane Mile:								0.00

Traffic Segment Counts
 PM Location: R9.411-R10.807
 AADT: 10750
 Total Trucks (AADTT): 2592

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Note that the report window does not close automatically. You may wish to close it once you are done downloading the report.

Step 6: Explore Alternatives

Given the weak subgrade (CL) encountered in this example, there may be ways to improve the support for the HMA layer and hence reduce its thickness and reduce the overall project cost. These alternatives are demonstrated in the examples included in the next subsections.

4.4.1.1.1. Example N01.1: Thicker AB

In this subsection, the alternative of increasing AB thickness is examined. Specifically, the AB thickness is increased from 0.50 ft to 1.0 ft.

To evaluate this option, create a new trial using the "Save Trial As" button to make a copy of the current trial and save it under "Example N01.1 Thicker AB" (see below):

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 ☐ SI
 [Save To DB](#)
[Save To File](#)

Manage CalME Input Files and Database Projects (if logged in)

This page is used to manage CalME project data. Project data can be stored in **text files** (*.json-type files) on your local or network computer or in a **database** managed by UCPRC. File-based project data must first be uploaded to CalME in order to be used. Database-based project data is retrieved by selecting an existing project using the "Project" dropdown control below.

If you are storing CalME project data in the database, the UCPRC **recommends** that you save it locally as a file as a back-up to the data in the database.

Use the following controls to select and manage (Add/Delete/etc.) projects stored in the CalME database

Projects and Trials Stored in the Database

Loaded Project: [Edit Project](#) [Add Project](#) [Delete Project](#) [Save Project As](#)

Loaded Trial: [Save Trial As](#)

Trial Title	Trial Description	
Example N01.1 Thicker AB	Increase AB from 0.50 to 1.0 ft	Delete
Example N01.2 Use RHMA-G Surface	With 0.20 to 0.50 ft of RHMA-G Surface	Delete
Example N01.2.1 Use RHMA-G and RAP25	Increase the stiffness of the overall HMA	Delete

[Add Trial](#)

Import From Users: [Import](#)

Use the following controls to select and load [CalBack Export files](#) stored locally on your computer. [Download CalBack.](#)

To upload a CalBack Export file (a *.json type file) and have CalME **generate** a master *Project* and a series of *Trials*, one for each section in the CalBack file, use the "Browse" button below to locate the file on your local system. Then use the "Upload" button to upload the file.

Choose File [Upload](#)

Upload Status:

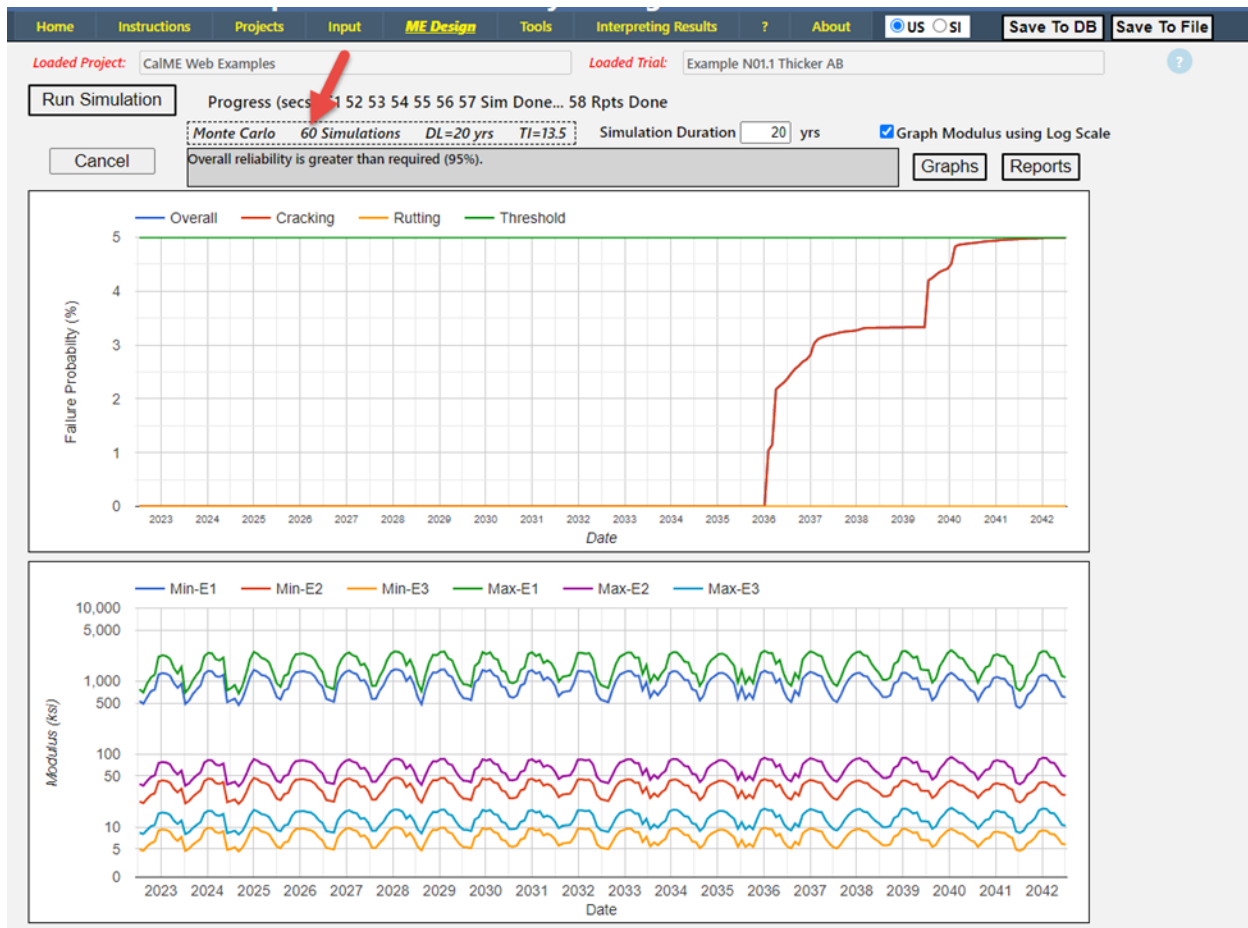
Use the following controls to select and load CalME input files stored locally on your computer

To load an existing CalME input file (a *.json-type file) into CalME, use the "Browse" button below to locate the file on your local system. Then use the "Upload" button to upload the input file.

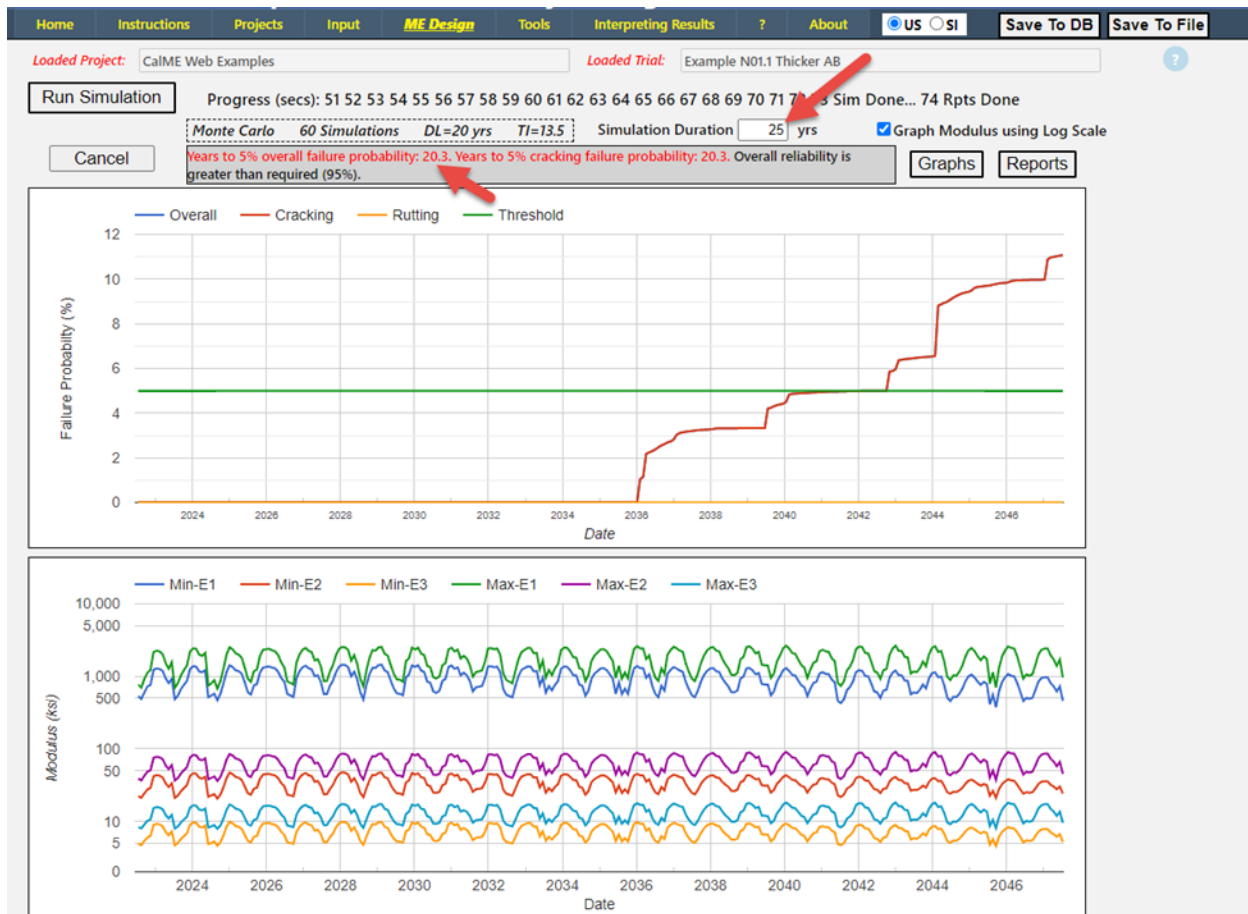
☒ Create a New Project for the Uploaded File
 ☐ Add the Uploaded File To the Currently Loaded Project

Choose File [Upload](#)

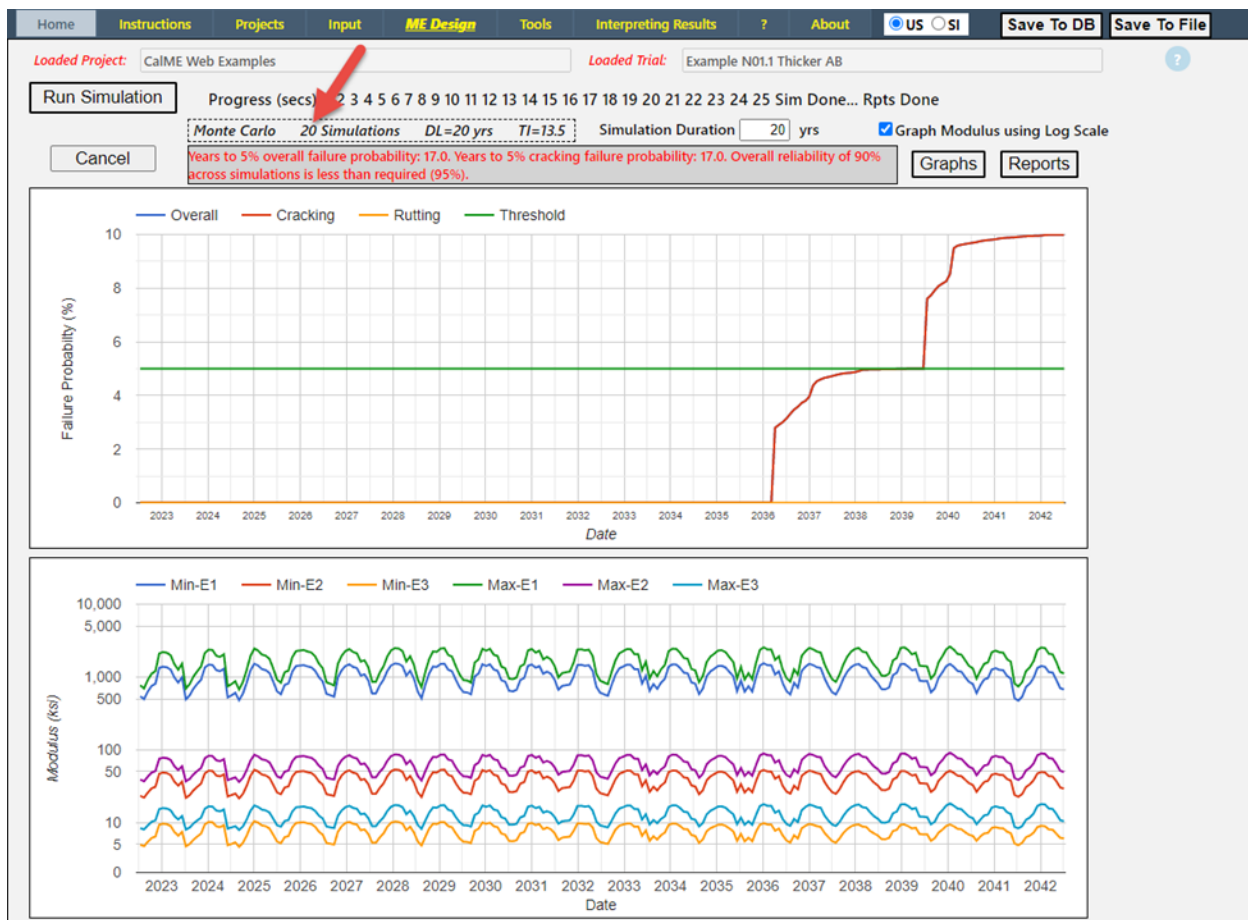
A 20-simulation Monte Carlo analysis indicates that the HMA thickness can be reduced from 1.00 ft to 0.95 ft. The new structure is shown below:



This confirms that a 0.50 ft increase in AB thickness can reduce the HMA thickness by 0.10 ft (from 1.05 ft to 0.95 ft). It also shows that the failure probability is very close to the 5% threshold. To find out exactly how long would it last, increase the simulation duration from 20 to 25 years and re-run the analysis. The results are shown below:



As shown in the screen shot, the time to failure is 20.3 years, which is very close to the design life. As pointed out in the last section, the 20-simulation run may provide different design conclusion. In fact, the 20-simulation Monte Carlo analysis indicates that the design will fail in 17.0 years (see below).



Given that the pavement is expected to barely last 20 years, it is probably better to use 1.0 ft HMA, which is 0.05 ft thicker than the minimum required value.

4.4.1.1.2. Example N01.2: Use RHMA-G surface

In this subsection, the alternative of introducing RHMA-G is examined. Specifically, an RHMA-G layer of between 0.20 and 0.50 ft is placed as the surface. The total asphalt concrete (AC) thickness required is expected to either be the same or reduced.

To evaluate this alternative, save the original trial under a new name "Example N01.2 Use RHMA-G Surface". Use the "Insert" link for layer 1 to add a layer on top of the HMA and pick "RHMA-G" from the "Layer Type" drop down list. There is only one RHMA-G mix available at this time.

The "Project Information" page for 0.50 ft RHMA-G + 0.50 ft HMA is shown below.

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Project ID
CalME Web Examples
Trial Title
Example N01.2 Use RHMA-G Surface

Project Location
District
3
County
Yolo
Route
5
Direction
North
PM Start
R
10.000
None
PM End
R
11.000
None
No. Lanes
2
Project Length: 1.000 mi
Lane Miles: 2.000
Avg #lanes: 2.00

Traffic Count Information
Location
R9.411-R10.807
Location Description
AADT
10,750
AADTT
2,592
% Trucks
24.1

Climate
Climate Zone
Inland Valley
Suggested
Inland Valley

Design Lane Traffic Loads
Load Distribution (WIM Station)
Group1b
Suggested
Group1b
Growth Rate (From First Year)
4.8 %
First Year Axles / Design Lane
4,843,894
First Year Trucks / Design Lane
1,910,096
Design Life
20 yrs
Total ESALs
30,182,727
TI
13.5 (rounded)

Create a Trial Structure
(Using Design Life and TI)
Subgrade
CL
Generate

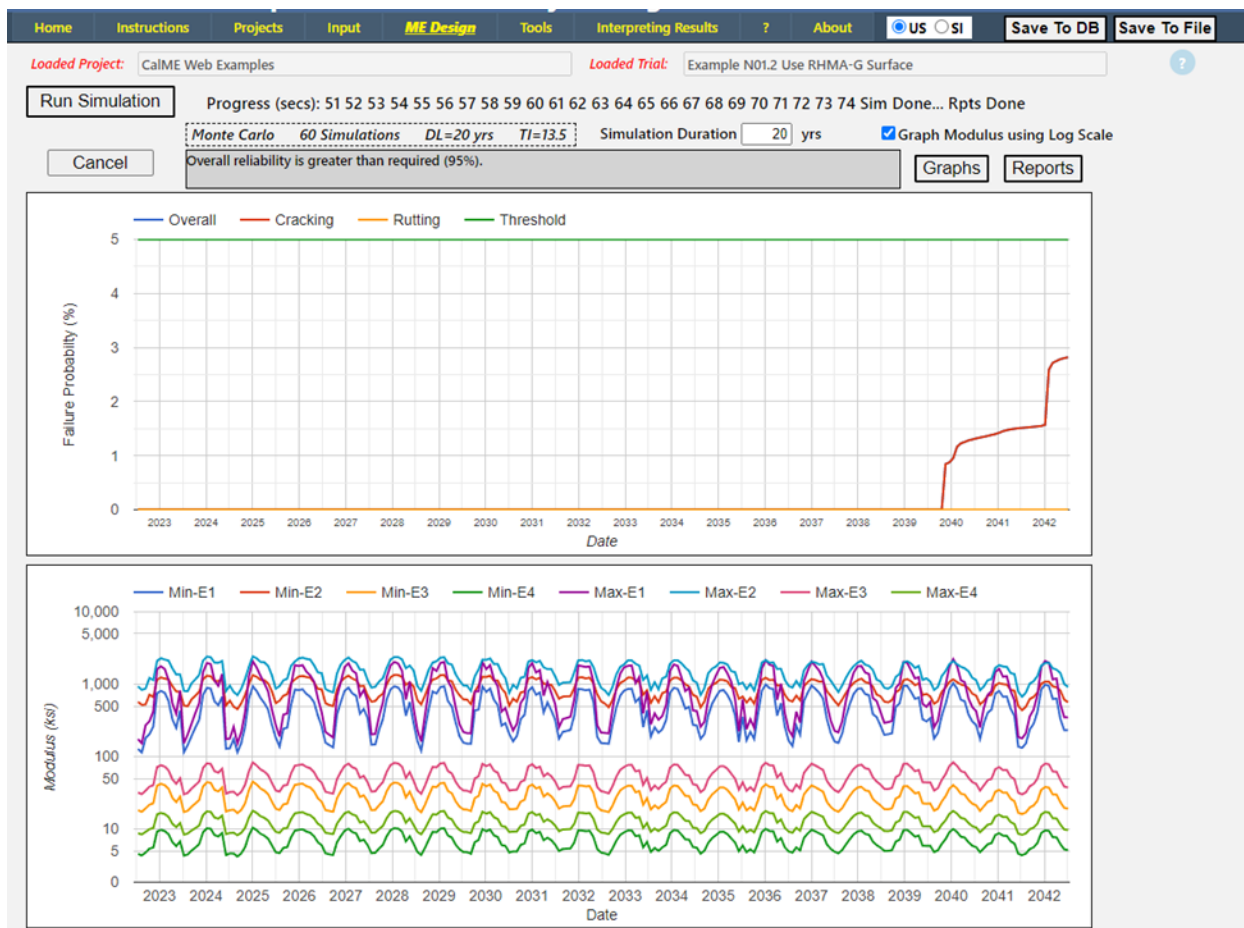
Error Message Summary

Pavement Structure
Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS):
psi
TS->CSS
TS->LSS
CTB-Class B
Apply
Delete All

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft3)	Actions
1		RHMA-G	90	2020 Standard RHMA-G with PG 64-16 base binder for non-PRS Projects	0.50	627.9	N/A	N/A	0.00	Edit Delete Insert
2		HMA	90	2020 Standard HMA Type A Mix with PG 70-10 Binder and up to 15% RAP for non-PRS Projects	0.50	1,230.6	N/A	1.54	0.00	Edit Delete Insert
3		AB	N/A	2020 Standard AB-Class 2	0.50	45.0	78	1.10	0.00	Edit Delete Insert
4		Subgrade	N/A	2020 Standard CL	∞	9.9	16	N/A	0.00	Edit Delete Insert

Add Layer
Add 2 Layers
Add 3 Layers
Add 4 Layers
Add 5 Layers
For CL Subgrade, AB-min is 0.50 or Equiv.

And the corresponding simulation results are shown below:



After running some Monte Carlo simulations, the required thickness combinations are determined and shown below in Table 1. As shown in the table, using 0.20 to 0.50 ft of RHMA-G reduces the combined thickness for asphalt bound layer by 0.05 ft. In other words, the HMA can be replaced with RHMA-G at roughly 1:1 ratio up to 0.50 ft.

Table 1: Required thickness combinations for the AC layers

Design #	RHMA-G Thickness (ft)	HMA Thickness (ft)	Total AC Thick (ft)
N01	0	1.0	1.05
N01.2.1	0.20	0.80	1.00
N01.2.2	0.30	0.70	1.00
N01.2.3	0.40	0.60	1.00
N01.2.4	0.50	0.50	1.00

4.4.1.1.3. Example N01.3: Use Soil Stabilization

In this subsection, the alternative of introducing lime stabilized subgrade (LSS) before placing aggregate base is examined. Specifically, an LSS layer of 1.0 ft thick is placed between AB and SG. The HMA thickness required is expected to be reduced.

The screen shot of the project input screen and the Monte Carlo simulation results are shown below. As shown in the screen shot, the UCS strength of the LSS layer is assumed to be 300 psi.

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Project ID CalME Web Examples Trial Title Example N01.3: Use Lime Stabilization

Project Location

District: 3 County: Yolo Route: 5 Direction: North PM Start: R 10,000 None PM End: R 11,000 None No. Lanes: 2

Project Length: 1.000 mi Lane Miles: 2.000 Avg #Lanes: 2.00

Traffic Count Information

Location: R9.411-R10.807 Location Description: AADT: 10,750 AADTT: 2,592 % Trucks: 24.1

Climate

Climate Zone: Inland Valley Suggested: Inland Valley

Design Lane Traffic Loads

Load Distribution (WIM Station): Group1b Suggested: Group1b

Growth Rate (From First Year): 4.8 %

First Year Axles / Design Lane: 4,843,894

First Year Trucks / Design Lane: 1,910,096

Design Life: 20 yrs Total ESALs: 30,182,727 TI: 13.5 (rounded)

Create a Trial Structure (Using Design Life and TI)

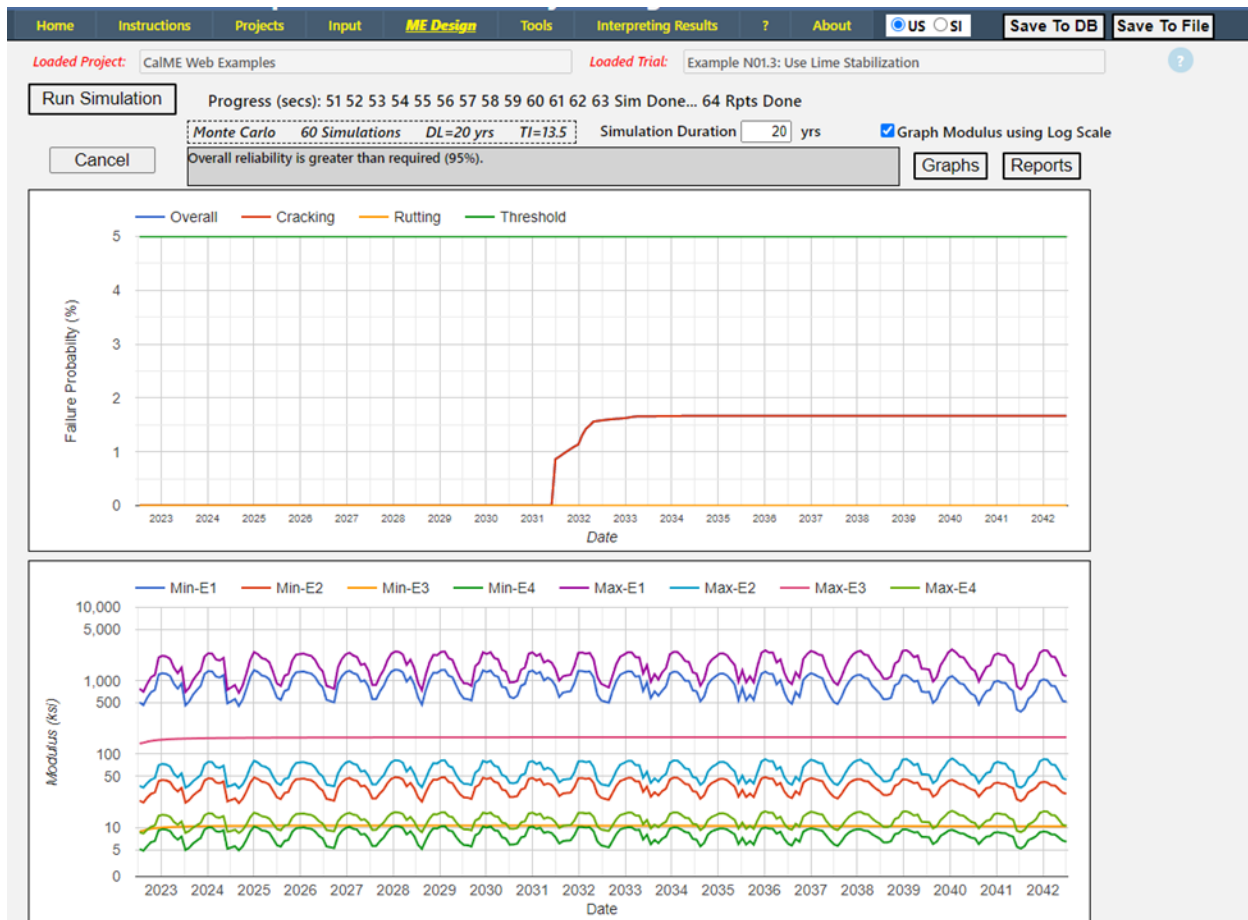
Subgrade: CL Generate

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): 300 psi TS->CSS TS->LSS CTB-Class B Apply Delete All

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft3)	Actions
1		HMA	90	2020 Standard HMA Type A Mix with PG 70-10 Binder and up to 15% RAP for non-PRS Projects	0.95	1,230.6	N/A	1.84	0.00	Edit Delete Insert
2		AB	N/A	2020 Standard AB-Class 2	0.50	45.0	78	1.10	0.00	Edit Delete Insert
3		TS	28	2020 Standard LSS (Needs UCS)	1.00	47.1	N/A	N/A	0.00	Edit Delete Insert
4		Subgrade	N/A	2020 Standard CL	∞	9.9	16	N/A	0.00	Edit Delete Insert

Add Layer Add 2 Layers Add 3 Layers Add 4 Layers Add 5 Layers For CL Subgrade, AB-min is 0.50 or Equiv.



As shown above, a 1.0 ft of LSS can reduce the HMA thickness required by 0.10 ft (from 1.05 ft to 0.95 ft) in this particular case.

4.4.1.1.4. Example N01.4: Use Aggregate Subbase

In this subsection, the alternative of introducing an aggregate subbase before placing aggregate base is examined. Specifically, an AS-Class 1 layer of 1.0 ft thick is placed between AB and SG. The HMA thickness required is expected to be reduced.

The screen shot of the pavement structure and the Monte Carlo simulation results are shown below.

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Project ID
CalME Web Examples
Trial Title
Example N01.4: Use Aggregate Subbase

Project Location

District
County
Route
Direction
PM Start
PM End
No. Lanes

3
Yolo
5
North
R
10.000
None
R
11.000
None
2

Project Length: 1.000 mi
Lane Miles: 2.000
Avg #Lanes: 2.00

Traffic Count Information

Location
Location Description
AADT
AADTT
% Trucks

R9.411-R10.807
None
10,750
2,592
24.1

Design Lane Traffic Loads

Load Distribution (WIM Station)
Growth Rate (From First Year)
First Year Axles / Design Lane
First Year Trucks / Design Lane

Group1b
4.8 %
4,843,894
1,910,096

Design Life
20 yrs
Total ESALs
30,182,727
TI
13.5 (rounded)

Climate

Climate Zone

Inland Valley

Create a Trial Structure
(Using Design Life and TI)

Subgrade
CL

Generate

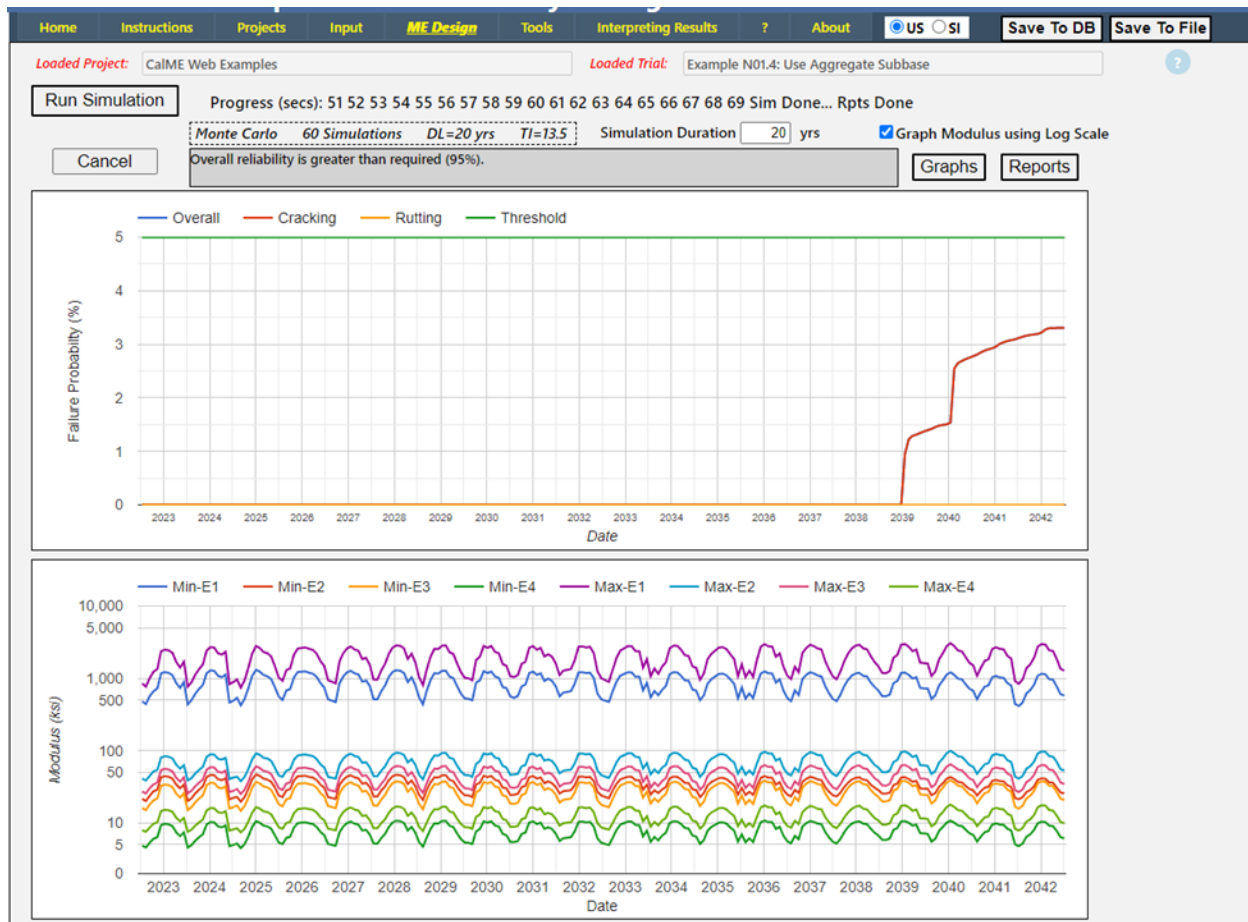
Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS):
psi
TS->CSS
TS->LSS
CTB-Class B
Apply
Delete All

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft3)	Actions
1		HMA	90	2020 Standard HMA Type A Mix with PG 70-10 Binder and up to 15% RAP for non-PRS Projects	0.95	1,230.6	N/A	1.91	0.00	Edit Delete Insert
2		AB	N/A	2020 Standard AB-Class 2	0.50	45.0	78	1.10	0.00	Edit Delete Insert
3		AS	N/A	2020 Standard AS-Class 1	1.00	35.0	60	1.00	0.00	Edit Delete Insert
4		Subgrade	N/A	2020 Standard CL	∞	9.9	16	N/A	0.00	Edit Delete Insert

Add Layer
Add 2 Layers
Add 3 Layers
Add 4 Layers
Add 5 Layers
For CL Subgrade, AB-min is 0.50 or Equiv.

Error Message Summary

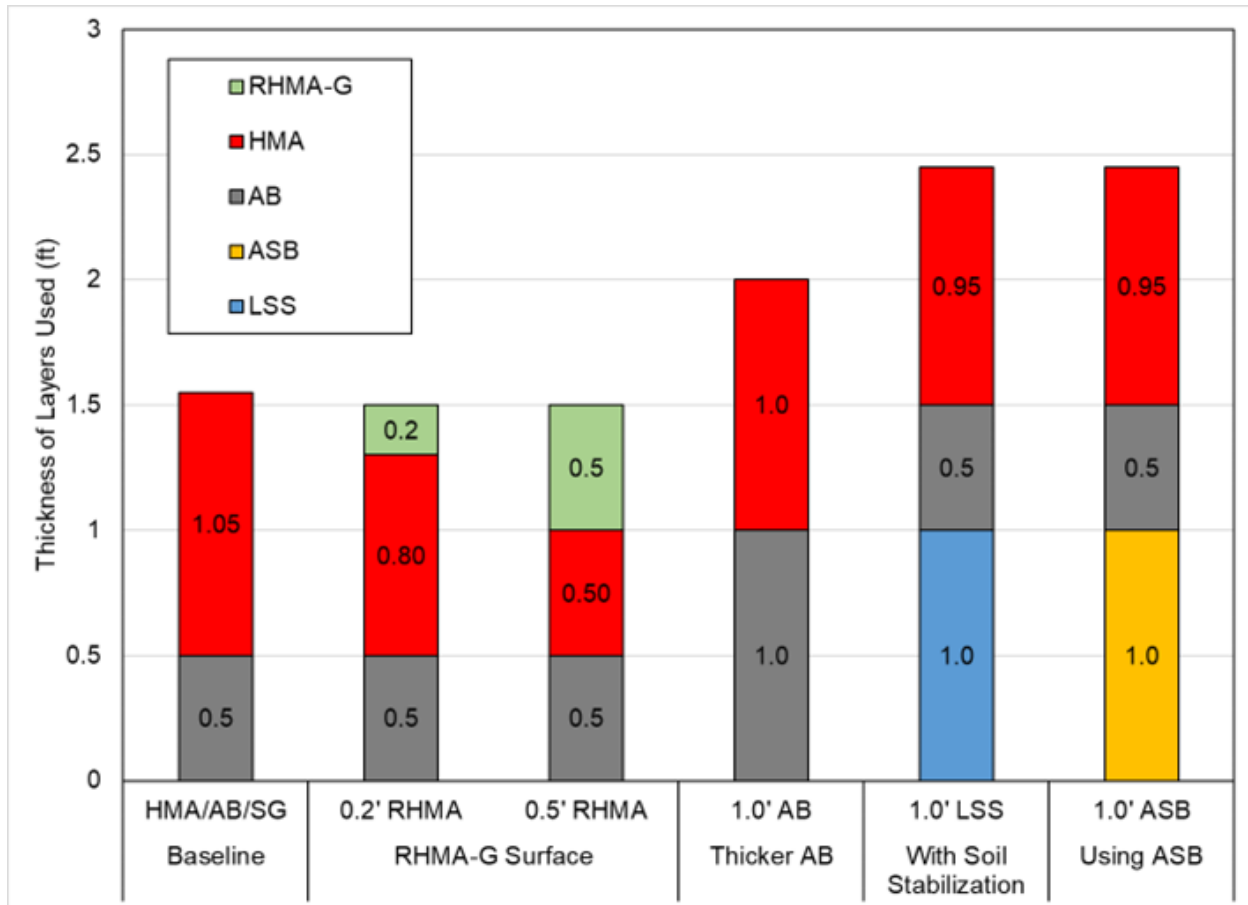


As shown above, a 0.95 ft of AS-Class 1 can reduce the HMA thickness required by 0.10 ft (from 1.05 ft to 0.95 ft).

4.4.1.1.5. N01 Design Summary

A comparison of the optimal designs for different alternatives is shown in the figure below. This is generated in *Excel* after collecting all optimal designs. These designs can then be further evaluated in LCCA for cost effectiveness and LCA for sustainability.

Note: *CalME* removes simulation results periodically. It is recommended that the simulation reports for the optimal designs be generated and downloaded. See Step 5 in [Example N01: HMA/AB/SG](#) for how to generate and download reports.



4.4.2. Rehabilitation Projects

In this section, examples are given for design of asphalt concrete overlays, one for an old flexible pavement and the other for an old composite pavement.

4.4.2.1. Example R01: Old Flexible Pavement

This example illustrates how to design for the rehabilitation of an existing flexible pavement. The project is located at:

- District 3, Sacramento County, Route I-5, North and South bound, PM 15.9 to 16.7

At this location, there are four mainlines in each direction. The two inside mainlines are flexible pavements, while the two outside lanes are composite pavements. The rehabilitation of the flexible mainlines are demonstrated in this section, while the rehabilitation of the composite mainlines are demonstrated in the [following section](#).

The following are the design requirements:

- Must maintain grade
- 20 year design TI of 12.5 with a growth rate of 2%, specified by the Caltrans Office of Traffic Operations

According to site investigation (core logs and DCP data) and as-built plans, the existing structure for the inside lanes can be simplified as:

- 0.1 ft of RHMA-O
- 0.65 ft of HMA
- 1.0 ft of aggregate base
- 1.0 ft of lime stabilized subgrade
- CL subgrade

There was no cracking observed on the surface of the two inside lanes.

It is important to note that the 0.1 ft RHMA-O layer is only a functional layer. As is typically the case, it was combined with the underlying HMA layer during backcalculation in *CalBack*. This layer needs to be discounted by removing it first in *CalME* when setting up the design structure.

The file exported from *CalBack* can be found [here](#), which includes backcalculation results for individual segments that are relatively uniform.

Step 1: Load CalBack file into CalME

Navigate to the Projects page by clicking on the “Projects” tab at the top of the screen. Click the “Choose File” button to select an exported *CalBack* file on the local computer’s file system. Select the “Upload” button to upload the selected files. When the file has uploaded, *CalME* will create a new project and a trial for each section in the *CalBack* File.

Note that the “Projects and Trials Stored in the Database” will be different from the screen shot below:

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[Projects](#)
[Input](#)
[ME Design](#)
[Tools](#)
[Interpreting Results](#)
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Manage CalME Input Files and Database Projects (if logged in)

This page is used to manage CalME project data. Project data can be stored in **text files** (*.json-type files) on your local or network computer or in a **database** managed by UCPRC. File-based project data must first be uploaded to CalME in order to be used. Database-based project data is retrieved by selecting an existing project using the "Project" dropdown control below.

If you are storing CalME project data in the database, the UCPRC **recommends** that you save it locally as a file as a back-up to the data in the database.

Use the following controls to select and manage (Add/Delete/etc.) projects stored in the CalME database

Projects and Trials Stored in the Database

Loaded Project: CalME Web Examples Edit Project Add Project Delete Project Save Project As

Loaded Trial: Example A1.1 Thicker AB Save Trial As

Trial Title	Trial Description	
Example A1.1 Thicker AB	Increase AB from 0.50 to 1.0 ft	Delete
Example A1.2 Use RHMA-G Surface	With 0.20 to 0.50 ft of RHMA-G Surface	Delete
Example A1.3 Use Lime Stabilization	LSS	Delete

Add Trial

Use the following controls to select and load CalBack Export files stored locally on your computer. [Download CalBack.](#)

To upload a CalBack Export file (a *.json type file) and have CalME **generate** a master **Project** and a series of **Trials**, one for each section in the CalBack file, use the "Browse" button below to locate the file on your local system. Then use the "Upload" button to upload the file.

Choose File I-5 Pocket to Florin Redesign_Export_202203211024.json Upload

Upload Status:

Use the following controls to select and load CalME input files stored locally on your computer

To load an existing CalME input file (a *.json-type file) into CalME, use the "Browse" button below to locate the file on your local system. Then use the "Upload" button to upload the input file.

☒ Create a New Project for the Uploaded File
 ☐ Add the Uploaded File To the Currently Loaded Project

Choose File No file chosen Upload

Upload Status:

The screen should look like the following once the upload is successfully completed.

NOTE: the project name is generated by CalME and will be different if the CalBack file has been imported by the same user before.

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Manage CalME Input Files and Database Projects (if logged in)

This page is used to manage CalME project data. Project data can be stored in **text files** ("json"-type files) on your local or network computer or in a **database** managed by UCPRC. File-based project data must first be uploaded to CalME in order to be used. Database-based project data is retrieved by selecting an existing project using the "Project" dropdown control below.

If you are storing CalME project data in the database, the UCPRC **recommends** that you save it locally as a back-up to the data in the database.

Use the following controls to select and manage (Add/Delete/etc.) projects stored in the CalME database

Projects and Trials Stored in the Database

Loaded Project: I-5 Pocket to Florin Redesign Edit Project Add Project Delete Project Save Project As

Loaded Trial: Section: SAC_05_NB_LANE_1_CENTER_STA_493_538.dat_sect_1 Save Trial As

Trial Title	Trial Description	
Section: SAC_05_NB_LANE_1_CENTER_STA_493_538.dat_sect_1	This is a trial generated from a section in a file exported from CalBack	Delete
Section: SAC_05_NB_LANE_1_CENTER_STA_493_538.dat_sect_2	This is a trial generated from a section in a file exported from CalBack	Delete
Section: SAC_05_NB_LANE_1_INSIDE_STA_493_538.dat_sect_1	This is a trial generated from a section in a file exported from CalBack	Delete

Add Trial

Use the following controls to select and load CalBack Export files stored locally on your computer. [Download CalBack.](#)

To upload a CalBack Export file (a *.json type file) and have CalME **generate** a master **Project** and a series of **Trials**, one for each section in the CalBack file, use the "Browse" button below to locate the file on your local system. Then use the "Upload" button to upload the file.

Choose File No file chosen Upload

Upload Status: File: "I-5 Pocket to Florin Redesign_Export_202203211024.json" successfully uploaded!

Use the following controls to select and load CalME input files stored locally on your computer

To load an existing CalME input file (a *.json-type file) into CalME, use the "Browse" button below to locate the file on your local system. Then use the "Upload" button to upload the input file.

☒ Create a New Project for the Uploaded File
 ☐ Add the Uploaded File To the Currently Loaded Project

Choose File No file chosen Upload

Upload Status:

Use the drop down list for "Loaded Trial" to see a list of loaded subsections:

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Manage *CalME* Input Files and Database Projects (if logged in)

This page is used to manage *CalME* project data. Project data can be stored in **text files** ("json"-type files) on your local or network computer or in a **database** managed by UCPRC. File-based project data must first be uploaded to *CalME* in order to be used. Database-based project data is retrieved by selecting an existing project using the "Project" dropdown control below.

If you are storing *CalME* project data in the database, the UCPRC **recommends** that you save it locally as a file as a back-up to the data in the database.

Use the following controls to select and manage (Add/Delete/etc.) projects stored in the *CalME* database

Projects and Trials Stored in the Database

Loaded Project: I-5 Pocket to Florin Redesign

[Edit Project](#)
[Add Project](#)
[Delete Project](#)
[Save Project As](#)

Loaded Trial: Section: SAC_05_NB_LANE_1_INSIDE_STA_493_538.dat_sect_1

[Save Trial As](#)

Trial Title	
Section: SAC_05_NB_LANE_1_CENTER_STA_493_538.dat_sect_1	
Section: SAC_05_NB_LANE_1_CENTER_STA_493_538.dat_sect_2	
Section: SAC_05_NB_LANE_1_INSIDE_STA_493_538.dat_sect_1	
Section: SAC_05_NB_LANE_1_INSIDE_STA_493_538.dat_sect_2	
Section: SAC_05_NB_LANE_2_INSIDE_STA_493+50_538+50.dat	
Section: SAC_05_NB_LANE_3_OUTSIDE_STA_493+50_538+50.dat	
Section: SAC_05_NB_LANE_4_OUTSIDE_STA_493_538.dat	
Section: SAC_05_SB_LANE_1_INSIDE_STA_540_495.dat_sect_1	
Section: SAC_05_SB_LANE_1_INSIDE_STA_540_495.dat_sect_2	
Section: SAC_05_SB_LANE_2_INSIDE_STA_539+50_494+50.dat_sect_1	
Section: SAC_05_SB_LANE_2_INSIDE_STA_539+50_494+50.dat_sect_2	
Section: SAC_05_SB_LANE_3_INSIDE_STA_540_495.dat	
Section: SAC_05_SB_LANE_3_OUTSIDE_STA_540_495.dat	
Section: SAC_05_SB_LANE_4_CENTER_STA_539+50_494+50.dat	
Section: SAC_05_SB_LANE_4_OUTSIDE_STA_539+50_494+50.dat_sect_1	
Section: SAC_05_SB_LANE_4_OUTSIDE_STA_539+50_494+50.dat_sect_2	
Section: SAC_05_SB_LANE_4_OUTSIDE_STA_539+50_494+50.dat_sect_3	

[Add Trial](#)

Use the following controls to select and load *CalME* input files stored locally on your computer

To upload a *CalBack* file, use the

Choose File No file chosen

[Upload](#)

Upload Status:

To load an existing *CalME* input file (a *.json-type file) into *CalME*, use the "Browse" button below to locate the file on your local system. Then use the "Upload" button to upload the input file.

☒ Create a New Project for the Uploaded File
 ☐ Add the Uploaded File To the Currently Loaded Project

Choose File No file chosen

[Upload](#)

Upload Status:

The section names indicate the direction, lane number, the lateral position (centerline, inside wheelpath, outside wheelpath), and the range of the pavement covered by the particular subsection. The suffix "sect_1", "sect_2", or "sect_3" was added by *CalBack* whenever the data was divided into two or more relatively uniform subsections.

As shown above, there are at least one backcalculation results for each of the eight lanes. For some lanes, e.g., SB Lane 4, there are backcalculation results for both centerline and one of the two wheelpaths. Rehabilitation designs should be conducted using data along wheelpaths because they typically endured more damage from truck traffic than centerlines. The centerline data, if available, should nevertheless be used to confirm that the rehabilitation design based on wheelpath data works for the centerline as well.

To start the design process, select the trial "Section: SAC_05_NB_LANE_1_INSIDE_STA_493_538.dat_sect_1" from the list. As the name suggests, it is for part of the Northbound lane 1 along centerline between Station 493 and 538. This section is one of the weakest segment for the inside lanes based on the

backcalculated layer stiffnesses.

Step 2: Fixing traffic and pre-rehabilitation structure inputs

Click the “Input” menu item on top of the screen to navigate to the “Project Information” menu, which is shown below:

The screenshot displays the CalME software interface with the following sections:

- Project Information:** Project ID: I-5 Pocket to Florin Redesign, Trial Title: Section: SAC_05_NB_LANE_1_INSIDE_STA_493_538.dat_sect_1. Project Location: District 3, County Sacramento, Route 5, Direction North, PM Start 15.900, PM End 16.800, No. Lanes 3. Project Length: 0.900 mi, Lane Miles: 2.700, Avg #lanes: 3.00.
- Traffic Count Information:** Location 16.147-16.700, Location Description, AADT 32,000, AADTT 4,177, % Trucks 13.1.
- Design Lane Traffic Loads:** Load Distribution (WIM Station) Group1b, Suggested Group1b, Growth Rate (From First Year) 5.0%, First Year Axles / Design Lane 4,326,926, First Year Trucks / Design Lane 1,706,240, Design Life 40 yrs, Total ESALs 73,481,980, TI 15.0.
- Climate:** Climate Zone Inland Valley, Suggested Inland Valley.
- Pavement Structure:** Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): 0 psi, TS->CSS, TS->LSS, CTB-Class B. Apply, Delete All.

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft3)	Actions
1	✓	HMA	90	2020 Standard Old HMA	0.76	1,175.0	N/A	1.65	0.00	Edit Delete Insert
2	✓	AB	N/A	2020 Standard AB-Class 2	1.02	98.1	N/A	1.10	0.00	Edit Delete Insert
3	✓	TS	28	2020 Standard LSS (Needs UCS)	1.02	256.2	N/A	N/A	0.00	Edit Delete Insert
4	✓	Subgrade	N/A	Change me	∞	28.3	49	N/A	0.00	Edit Delete Insert

Add Layer | Add 2 Layers | Add 3 Layers | Add 4 Layers | Add 5 Layers | Layer No. 4 has an unknown material: 'Change me'

CalME inputs the pavement structure that is recorded in the CalBack file. As indicated earlier, the RHMA-O layer was combined with the underlying HMA layer while conducting backcalculation.

Note 1: CalBack converts thickness into mm using 1 inch = 25.4 mm, while CalME converts mm into feet using 1 ft = 300 mm (i.e., 1 inch = 25 mm). As a result, a 1.0 ft AB in CalBack becomes 1.02 ft in CalME. Although it seems awkward, this inconsistency does not affect pavement design because both CalBack and CalME uses mm for layer thickness internally.

Note 2: CalME automatically sets the project location based on the data exported from CalBack, and sets the climate zone and provides an initial guess of the design traffic based on the project location. The county name is case insensitive and can be in either

the expanded or the abbreviated formats. The direction is also case insensitive and can be in either the expanded (North, South, East, and West) or the abbreviated formats (NB, SB, EB, or WB). For special counties please follow the rule explained [here](#).

In this case the project location was entered in *CalBack* and exported, which allows *CalME* to setup the project location automatically. If this is not the case you will need to enter the appropriate project location. *CalME* will automatically enter the climate, traffic load distribution, and the growth rate data.

Enter the subgrade type noted in the site investigation. The updated project input screen is shown below:

The screenshot displays the CalME software interface with the following sections:

- Project Location:** District: 3, County: Sacramento, Route: 5, Direction: North, PM Start: 15.900, PM End: 16.700, No. Lanes: 3. Project Length: 0.800 mi, Lane Miles: 2.400, Avg #lanes: 3.00.
- Traffic Count Information:** Location: 16.147-16.700, Location Description: , AADT: 32,000, AADTT: 4,177, % Trucks: 13.1.
- Design Lane Traffic Loads:** Load Distribution (WIM Station): Group1b, Suggested: Group1b, Growth Rate (From First Year): 5.0%, First Year Axles / Design Lane: 4,186,637, First Year Trucks / Design Lane: 1,650,920, Design Life: 20 yrs, Total ESALs: 26,513,875, TI: 13.3.
- Climate:** Climate Zone: Inland Valley, Suggested: Inland Valley.
- Create a Trial Structure:** Subgrade: CL, Generate button.
- Pavement Structure:** Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): 0 psi, TS->CSS, TS->LSS, CTB-Class B, Apply, Delete All.

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft3)	Actions
1	✓	HMA	90	2020 Standard Old HMA	0.76	1,175.0	N/A	1.75	0.00	Edit Delete Insert
2	✓	AB	N/A	2020 Standard AB-Class 2	1.02	98.1	N/A	1.10	0.00	Edit Delete Insert
3	✓	TS	28	2020 Standard LSS/Needs UCS	1.02	256.2	N/A	N/A	0.00	Edit Delete Insert
4	✓	Subgrade	N/A	2020 Standard CL	∞	28.3	49	N/A	0.00	Edit Delete Insert

As noted in [Design Inputs](#), the traffic inputs recommended by *CalME* based on project location is for the outside lane. Regardless of whether the design lane is the outside lane, these numbers need to be replaced with those provided by the Caltrans Office of Traffic Operations.

Overwrite the growth rate and TI with 2% and 12.5 respectively, and remove 0.10 ft from the old HMA layer that represents the RHMA-O layer. The screen shot should look like below:

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Project ID: I-5 Pocket to Florin Redesign Trial Title: Section: SAC_05_NB_LANE_1_INSIDE_STA_493_538.dat_sect_1

Project Location

District: 3 County: Sacramento Route: 5 Direction: North PM Start: 15.900 PM End: 16.700 No. Lanes: 3

Project Length: 0.800 mi Lane Miles: 2.400 Avg #lanes: 3.00

Traffic Count Information

Location: 16.147-16.700 Location Description: AADT: 32,000 AADTT: 4,177 % Trucks: 13.1

Design Lane Traffic Loads

Load Distribution (WIM Station): Group1b Suggested Group1b

Growth Rate (From First Year): 2.0 %

First Year Axles / Design Lane: 3,101,915

First Year Trucks / Design Lane: 1,223,180

Design Life: 20 yrs Total ESALs: 15,808,352 TI: 12.5 (rounded)

Climate

Climate Zone: Inland Valley Suggested Inland Valley

Create a Trial Structure
(Using Design Life and TI)

Subgrade: CL Generate

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): 0 psi TS->CSS TS->LSS CTB-Class B Apply Delete All

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft3)	Actions
1	☒	HMA	90	2020 Standard Old HMA	0.65	1,175.0	N/A	1.72	0.00	Edit Delete Insert
2	☒	AB	N/A	2020 Standard AB-Class 2	1.02	98.1	N/A	1.10	0.00	Edit Delete Insert
3	☒	TS	28	2020 Standard LSS (Needs UCS)	1.02	256.2	N/A	N/A	0.00	Edit Delete Insert
4	☒	Subgrade	N/A	2020 Standard CL	∞	28.3	49	N/A	0.00	Edit Delete Insert

Add Layer Add 2 Layers Add 3 Layers Add 4 Layers Add 5 Layers For CL Subgrade, AB-min is 0.50 or Equiv.

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Note: CalME rounds all layers to the nearest 0.05 ft when editing layer thicknesses. As a result the old HMA layer thickness becomes 0.65 ft rather than 0.66 ft.

To facilitate evaluation of multiple design alternatives, save this trial under a new name: "NBL1-495_538: Baseline":

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Project ID: I-5 Pocket to Florin Redesign Trial Title: **NBL1-493_538: Baseline**

Project Location

District: 3 County: Sacramento Route: 5 Direction: North PM Start: 15,900 PM End: 16,800 No. Lanes: 3

Project Length: 0.900 mi Lane Miles: 2.700 Avg #Lanes: 3.00

Traffic Count Information

Location: 16.147-16.700 Location Description: AADT: 32,000 AADTT: 4,177 % Trucks: 13.1

Climate

Climate Zone: Inland Valley Suggested: Inland Valley

Design Lane Traffic Loads

Load Distribution (WIM Station): Group1b Suggested: Group1b

Growth Rate (From First Year): 2.0 %

First Year Axles / Design Lane: 3,101,915

First Year Trucks / Design Lane: 1,223,180

Design Life: 20 yrs Total ESALs: 15,808,352 TI: 12.5 (rounded)

Create a Trial Structure
(Using Design Life and TI)

Subgrade: CL Generate

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): 0 psi TS->CSS TS->LSS CTB-Class B Apply Delete All

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft3)	Actions
1	☒	HMA	90	2020 Standard Old HMA	0.65	1,175.0	N/A	1.72	0.00	Edit Delete Insert
2	☒	AB	N/A	2020 Standard AB-Class 2	1.02	98.1	N/A	1.10	0.00	Edit Delete Insert
3	☒	TS	28	2020 Standard LSS (Needs UCS)	1.02	256.2	N/A	N/A	0.00	Edit Delete Insert
4	☒	Subgrade	N/A	2020 Standard CL	∞	28.3	49	N/A	0.00	Edit Delete Insert

Add Layer Add 2 Layers Add 3 Layers Add 4 Layers Add 5 Layers For CL Subgrade, AB-min is 0.50 or Equiv.

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4.4.2.1.1. Design Alternatives

The design alternatives under consideration for this project for the inside lanes are:

- Mill and overlay with the same thickness or remove HMA and replace.
- Full depth recycling with new overlay

4.4.2.1.2. Example R01.1: Mill and Overlay and Remove HMA and Replace

The first design alternative to try is mill and overlay with the same thickness. The question being answered is how much should be milled and in turn replaced. If milling and replacing all of the old HMA is not sufficient, part of the existing AB layer may also need to be replaced with new HMA.

For the given climate zone (Inland Valley), HDM requires to use mixes with PG70-10

binder for HMA, or PG64-16 or PG70-10 base binder for RHMA-G.

Note: the RHMA-G mix with PG70-10 base binder is currently not available from the *CalME* Standard Materials Library, it will be added to the library once enough data has been collected to properly characterize its performance.

Milling in *CalME* is simply achieved by reducing the thickness of the existing HMA layer. Deleting the existing HMA layer is equivalent to removing the whole existing HMA layer.

Option 1: Remove HMA and Replace

Given the relative thin existing HMA layer, the first option to try is to remove all the existing HMA and replace it with 0.2' of RHMA-G and 0.45' of HMA with PG70-10 binder. If this design is sufficient, then further explore the possibility of leaving some of the existing HMA in place.

To evaluate this design, save a copy of the trial named "NBL1-493_538: Baseline" as "NBL1-493_538: Mill and Overlay". Once the new trial is loaded, remove the existing HMA layer by using the "Delete" link. Add the RHMA-G and HMA layers to the pavement structure.

The project inputs and the simulation results are shown below. As one can see, the design is a valid option as it has higher than 95% reliability.

Note: The PG grade requirement specified in Table 632.1 in the HDM is meant for surface mix only. An HMA with PG64-16 base binder may also be used below 0.20 ft for Inland Valley.

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Project ID: I-5 Pocket to Florin Redesign
Trial Title: NBL1-493_538: Mill and Overlay

Project Location

District: 3
County: Sacramento
Route: 5
Direction: North
PM Start: None 15.900
PM End: None 16.800
No. Lanes: 3

Project Length: 0.900 mi
Lane Miles: 2.700
Avg #Lanes: 3.00

Traffic Count Information

Location: 16.147-16.700
Location Description:
AADT: 32,000
AADTT: 4,177
% Trucks: 13.1

Climate

Climate Zone: Inland Valley
Suggested: Inland Valley

Design Lane Traffic Loads

Load Distribution (WIM Station): Group1b
Suggested: Group1b
Growth Rate (From First Year): 2.0 %
First Year Axles / Design Lane: 3,101,915
First Year Trucks / Design Lane: 1,223,180

Design Life: 20 yrs
Total ESALs: 15,808,352
TI: 12.5 (rounded)

Create a Trial Structure
(Using Design Life and TI)
Subgrade: CL
Generate

Error Message Summary

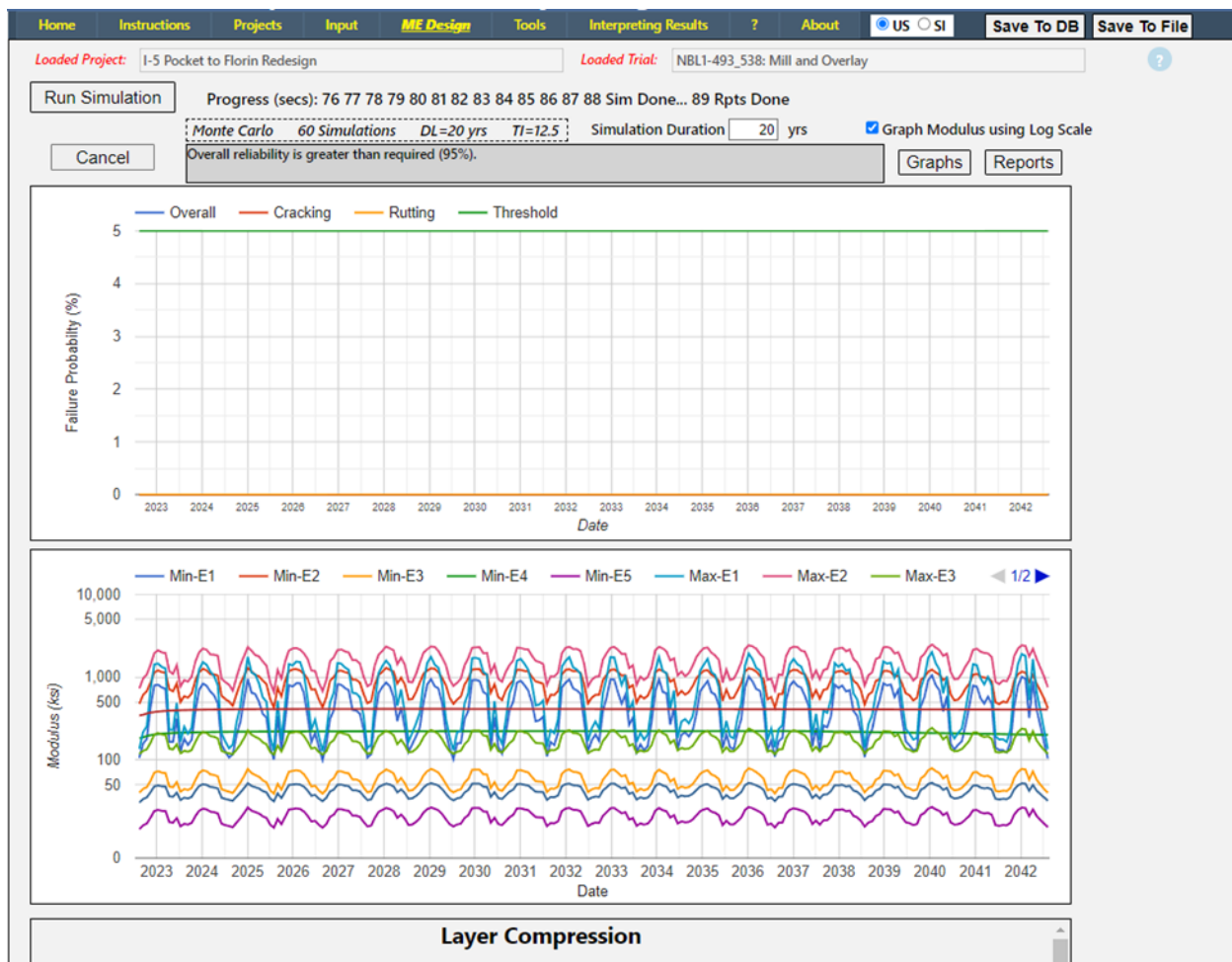
Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): 0 psi
TS->CSS
TS->LSS
CTB-Class B
Apply
Delete All

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft3)	Actions
1		RHMA-G	90	2020 Standard RHMA-G with PG 64-16 base binder for non-PRS Projects	0.20	627.9	N/A	N/A	0.00	Edit Delete Insert
2		HMA	90	2020 Standard HMA Type A Mix with PG 64-16 Binder and up to 15% RAP for non-PRS Projects	0.45	945.1	N/A	1.60	0.00	Edit Delete Insert
3		AB	N/A	2020 Standard AB-Class 2	1.02	98.1	N/A	1.10	0.00	Edit Delete Insert
4		TS	28	2020 Standard LSS (Needs UCS)	1.02	256.2	N/A	N/A	0.00	Edit Delete Insert
5		Subgrade	N/A	2020 Standard CL	∞	28.3	49	N/A	0.00	Edit Delete Insert

Add Layer
Add 2 Layers
Add 3 Layers
Add 4 Layers
Add 5 Layers
For CL Subgrade, AB-min is 0.50 or Equiv.

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Option 2: Keeping some existing HMA

Given that a complete removal of the existing HMA satisfy the design requirement, next step is to explore the option of keeping some existing HMA. A good option is to remove 0.4 ft of the existing HMA and replaced with 0.2' or RHMA-G and 0.2' of HMA. This leaves 0.25 ft of exiting HMA in place, which should provide sufficient cushion for typical construction variability in the existing HMA layer thickness.

Note that there is no need to activate reflective cracking for this design since there is no cracking observed on the existing pavement for the inside lanes.

To evaluate this option, save the previous trial under a new name "NBL1-493_538: Partial Removal".

The project inputs, simulation parameters, and simulation results are shown below, which indicated that this option is not viable as it fails in 8.4 years. The simulation results also suggests that the onset of surface cracking coincides with the significant drop in minimum stiffness of the existing HMA layer (the Min-E3 line).

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Project ID: I-5 Pocket to Florin Redesign
Trial Title: NBL1-493_538: Partial Removal

Project Location
District: 3
County: Sacramento
Route: 5
Direction: North
PM Start: 15,900
PM End: 16,800
No. Lanes: 3
Project Length: 0.900 mi
Lane Miles: 2.700
Avg #lanes: 3.00

Traffic Count Information
Location: 16.147-16.700
Location Description:
AADT: 32,000
AADTT: 4,177
% Trucks: 13.1

Climate
Climate Zone: Inland Valley
Suggested: Inland Valley

Design Lane Traffic Loads
Load Distribution (WIM Station): Group1b
Suggested: Group1b
Growth Rate (From First Year): 2.0 %
First Year Axles / Design Lane: 3,101,915
First Year Trucks / Design Lane: 1,223,180
Design Life: 20 yrs
Total ESALS: 15,808,352
TI: 12.5 (rounded)

Create a Trial Structure
 (Using Design Life and TI)
 Subgrade: CL

Generate

Error Message Summary

Pavement Structure
Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): 0 psi
TS->CSS
TS->LSS
CTB-Class B
Apply
Delete All

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft3)	Actions
1		RHMA-G	90	2020 Standard RHMA-G with PG 64-16 base binder for non-PRS Projects	0.20	627.9	N/A	N/A	0.00	Edit Delete Insert
2		HMA	90	2020 Standard HMA Type A Mix with PG 70-10 Binder and up to 15% RAP for non-PRS Projects	0.20	1,230.6	N/A	1.60	0.00	Edit Delete Insert
3		HMA	90	2020 Standard Old HMA	0.25	1,175.0	N/A	1.72	0.00	Edit Delete Insert
4		AB	N/A	2020 Standard AB-Class 2	1.02	98.1	N/A	1.10	0.00	Edit Delete Insert
5		TS	28	2020 Standard LSS (Needs UCS)	1.02	256.2	N/A	N/A	0.00	Edit Delete Insert

Add Layer
Add 2 Layers
Add 3 Layers
Add 4 Layers
Add 5 Layers
For CL Subgrade, AB-min is 0.50 or Equiv.

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Incremental-Recursive Parameters

Loaded Project: I-5 Pocket to Florin Redesign
Loaded Trial: NBL1-493_538: Partial Removal

General
Starting Date: 7/18/2022
Simulation Duration: 20 yrs
Vehicle Speed: 43.75 mph

Simulation Type
☐ Deterministic
☒ Monte-Carlo

Performance Criteria
Rutting: 0.4 in
Cracking: 5.0 %

Reflection Cracking
☒ None
☐ AC on AC
☐ AC on Cemented Base
Existing Cracking (%) > 35
Cracked layers(s) from 2 to 2 <= Find Them

Spec. Type
☐ Non-PRS
☐ PRS

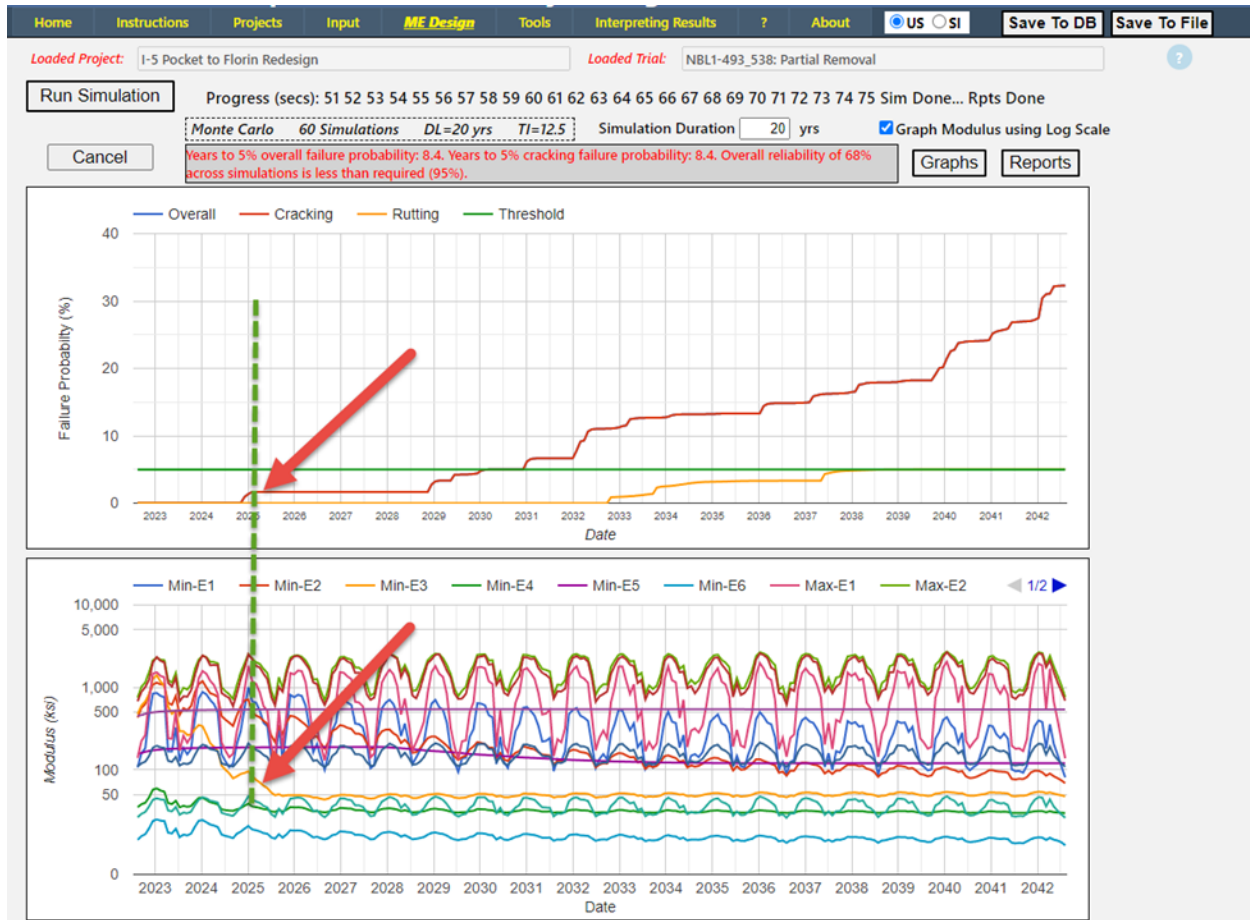
Monte Carlo Variability
No. of simulations: 60
☒ Construction variability
Construction Variability Table

Layer	CoV Thick	Sdf Modulus	
1	0.07	1.20	Edit
2	0.07	1.20	Edit
3	0.00	1.15	Edit
4	0.00	1.51	Edit
5	0.00	1.33	Edit

M&R Planning - This Feature is Coming Soon
Populate Grid With: 60 mm HMA Overlay Every 5 years

Year	Treatment
	No treatments

Add Treatment



4.4.2.1.3. Example R01.2: FDR and Overlay

The second design alternative to try is FDR and overlay. The FDR layer can be either FDR-FA or FDR-C depending on the characteristic of the underlying AB layer. Please refer to the ["Guide for Partial- and Full-Depth Pavement Recycling in California"](#).

For an FDR design, the questions being answered include the thickness of the FDR and the thickness of the HMA on top. Optimizing two independent variables can be a little bit challenging.

The strategy used here is to fix the HMA thickness at the minimum and combine that with the minimal and maximal FDR thickness respectively. These two options should indicate what to change next.

FDR thickness has a minimum of 0.70 ft and a maximum of 1.50 ft.

Note: The maximum thickness of FDR that is practical for a given project may be less than the general maximum of 1.50 ft. In this project for example, there is 0.65 ft of existing HMA and 1.0 ft of AB. To make room for the new HMA in order to maintain grade, some existing HMA needs to be removed before the FDR construction. If the minimum combined AC thickness is 0.40 ft, then this reduces the available HMA for FDR from 0.65 ft to 0.25 ft. As a result, the maximum FDR thickness in this case is $0.25 + 1.0 = 1.25$ ft before considering the swell factor.

Option 1: Minimal HMA with minimal FDR-FA

The first option to try is with minimal HMA and minimal FDR-FA. Specifically, 0.2 ft of RHMA-G over 0.2 ft of HMA placed over 0.7 ft of FDR-FA. To maintain grade part of the existing HMA needs to be removed.

Note: one must consider the swell of FDR layer when determining the amount of existing HMA to be removed. In this particular option, using a swell factor of 1.07, a 0.7 ft of FDR-FA only needs 0.65 ft of raw material. The swell is 0.05 ft. Add this to the planned thickness of the new combined asphalt concrete layer (i.e., 0.40 ft), the total thickness that needs to be removed is 0.45 ft.

Since the excavation depth is 1.10 ft ($0.45 \text{ ft} + 0.65 \text{ ft}$), the remaining AB thickness is $0.65 + 1.0 - 1.10 = 0.55$ ft.

Save the baseline trial as a new trial named "NBL1-493_538: FDR-FA and Overlay". Setup the structure for this option as shown below. Note the reduction in AB thickness compared to the Mill and Overlay option.

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Project ID: I-5 Pocket to Florin Redesign Trial Title: NBL1-493_538: FDR-FA and Overlay

Project Location

District: 3 County: Sacramento Route: 5 Direction: North PM Start: 15.900 PM End: 16.800 No. Lanes: 3
 Project Length: 0.900 mi Lane Miles: 2.700 Avg #Lanes: 3.00

Traffic Count Information

Location: 16.147-16.700 Location Description: AADT: 32,000 AADTT: 4,177 % Trucks: 13.1

Climate

Climate Zone: Inland Valley Suggested: Inland Valley

Design Lane Traffic Loads

Load Distribution (WIM Station): Group1b Suggested: Group1b
 Growth Rate (From First Year): 2.0 %
 First Year Axles / Design Lane: 3,101,915
 First Year Trucks / Design Lane: 1,223,180

Design Life: 20 yrs Total ESALs: 15,808,352 TI: 12.5 (rounded)

Create a Trial Structure
 (Using Design Life and TI)
 Subgrade: CL Generate

Error Message Summary

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): 0 psi TS->CSS TS->LSS CTB-Class B Apply Delete All

		(ft)		UCS	(ksi)		(S/TCS)	
1	☐ RHMA-G	90	2020 Standard RHMA-G with PG 64-16 base binder for non-PRS Projects	0.20	627.9	N/A	N/A	0.00 Edit Delete Insert
2	☐ HMA	90	2020 Standard HMA Type A Mix with PG 70-10 Binder and up to 15% RAP for non-PRS Projects	0.20	1,230.6	N/A	1.60	0.00 Edit Delete Insert
3	☐ FDR	90	2020 Standard FDR-FA	0.70	435.1	N/A	N/A	0.00 Edit Delete Insert
4	☒ AB	N/A	2020 Standard AB-Class 2	0.55	98.1	N/A	1.10	0.00 Edit Delete Insert
5	☒ TS	28	2020 Standard LSS (Needs UCS)	1.02	256.2	N/A	N/A	0.00 Edit Delete Insert
6	☒ Subgrade	N/A	2020 Standard CL	∞	28.3	49	N/A	0.00 Edit Delete Insert

Add Layer Add 2 Layers Add 3 Layers Add 4 Layers Add 5 Layers For CL Subgrade, AB-min is 0.50 or Equiv.

The CalME simulation results is shown below, indicating that this option meets the design requirements. In fact, it will last more than 30 years before failing in cracking.



Since minimal HMA combined with minimal FDR-FA works, there is no need for further adjustment.

Option 2: Minimal HMA with minimal FDR-C

Option 2 is the same as Option 1 except the FDR-FA is replaced with FDR-C. To evaluate this option, save a copy of the trial for Option 1 with a new name "NBL1-493_538: FDR-C and Overlay". The updated structure in CalME and simulation results are shown below, which indicate that this option satisfy the design requirement as well.

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Project ID
I-5 Pocket to Florin Redesign
Trial Title
NBL1-493_538: FDR-C and Overlay

Project Location

District
County
Route
Direction
PM Start
PM End
No. Lanes

3
Sacramento
5
North
None
15.900
None
16.800
None
3

Project Length: 0.900 mi
Lane Miles: 2.700
Avg #lanes: 3.00

Traffic Count Information

Location
Location Description
AADT
AADTT
% Trucks

16.147-16.700
32,000
4,177
13.1

Climate

Climate Zone

Inland Valley
Suggested
Inland Valley

Design Lane Traffic Loads

Load Distribution (WIM Station)
Group1b
Suggested
Group1b

Growth Rate (From First Year)
2.0
%

First Year Axles / Design Lane
3,101,915

First Year Trucks / Design Lane
1,223,180

Design Life
20
yrs
Total ESALs
15,808,352
TI
12.5
(rounded)

Create a Trial Structure
(Using Design Life and TI)
Subgrade
CL
Generate

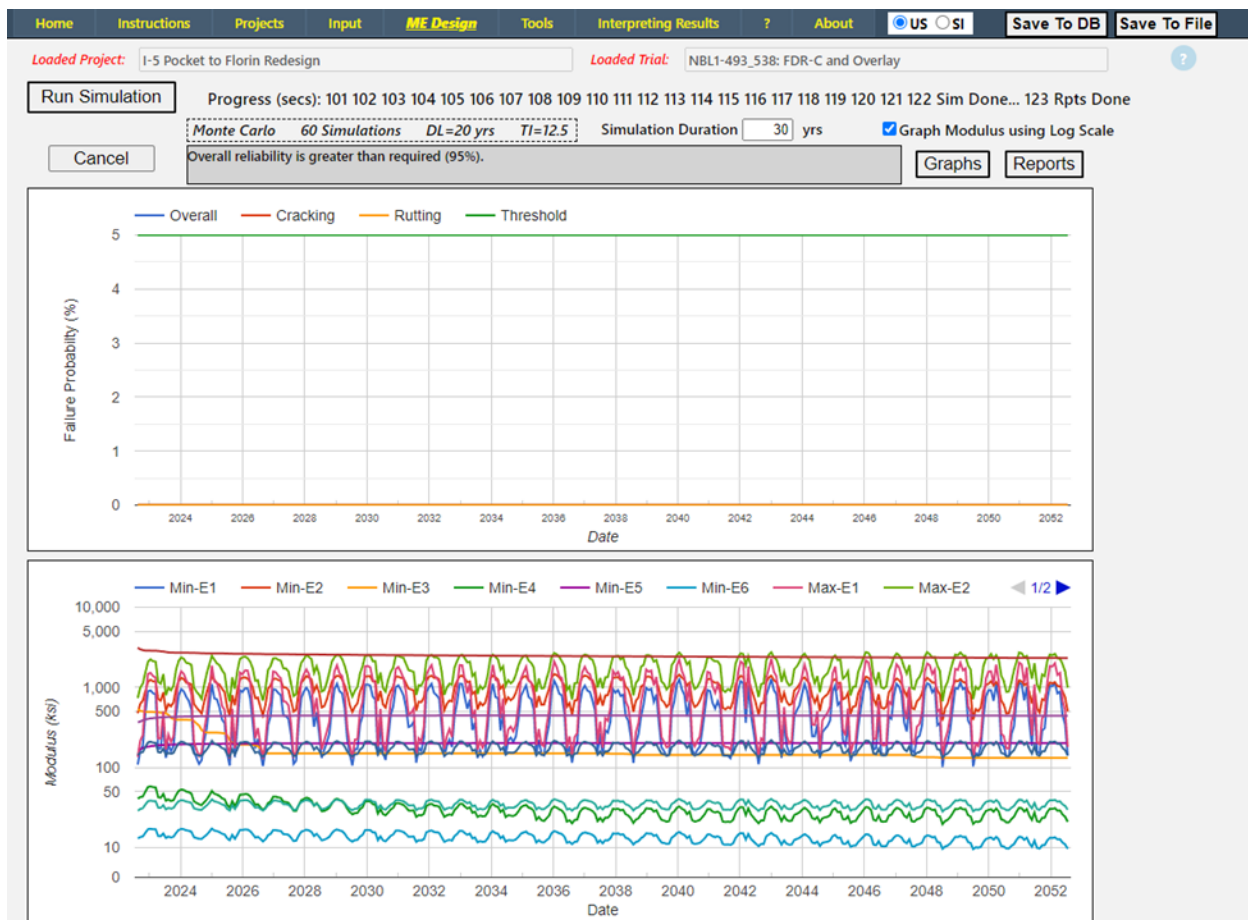
Error Message Summary

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS):
0
psi
TS->CSS
TS->LSS
CTB-Class B
Apply
Delete All

		(a)		UTG	(US)		(S/TS)	
1	☐	RHMA-G	90	2020 Standard RHMA-G with PG 64-16 base binder for non-PRS Projects	0.20	627.9	N/A	N/A
2	☐	HMA	90	2020 Standard HMA Type A Mix with PG 70-10 Binder and up to 15% RAP for non-PRS Projects	0.20	1,230.6	N/A	1.60
3	☐	FDR	N/A	2020 Standard FDR-C	0.70	1,450.4	N/A	1.70
4	☒	AB	N/A	2020 Standard AB-Class 2	0.55	98.1	N/A	1.10
5	☒	TS	28	2020 Standard LSS (Needs UCS)	1.02	256.2	N/A	N/A
6	☒	Subgrade	N/A	2020 Standard CL	∞	28.3	49	N/A

Add Layer
Add 2 Layers
Add 3 Layers
Add 4 Layers
Add 5 Layers
For CL Subgrade, AB-min is 0.50 or Equiv.

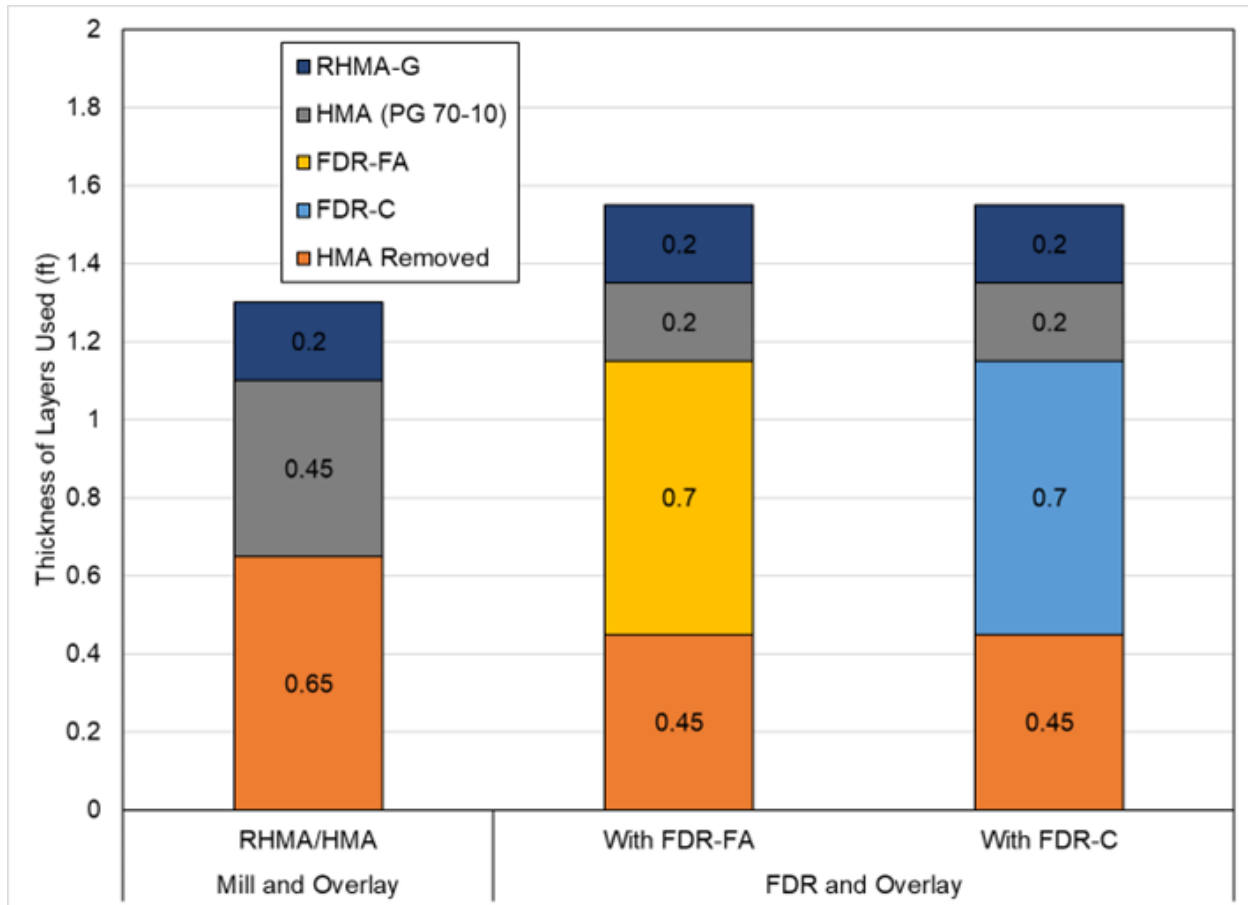


4.4.2.1.4. R01 Design Summary

A comparison of the optimal designs for different alternatives is shown in the figure below. These designs can then be further evaluated in LCCA for cost effectiveness and LCA for sustainability.

Note that this example only covers the design for one single segment within this project. As mentioned in [Typical Design Process](#), one needs to evaluate all segments within the project and decide whether to use a single design or multiple designs.

Note: *CalME* removes simulation results periodically. It is recommended to generate and download the simulation reports for the optimal designs. See Step 5 in [Example for New Pavement Design](#) for how to generate and download reports.



4.4.2.2. Example R02: Old Composite Pavement

This example illustrates how to design for the rehabilitation of an existing composite pavement resulted from a rigid pavement being overlaid with asphalt concrete.

The project is located at the same location as the one in [Example R01](#). As mentioned there, the outside lanes of the mainlines are composite pavements. The FWD backcalculation results for the outside lanes can be found in the same CalBack export file so it has been imported as well as part of [Example R01](#).

After reviewing the backcalculated stiffness of each individual segment in CalBack, the Southbound Lane 3 was found to be the weakest segment and is used in this example.

The following are the design requirements:

- Must maintain grade
- 20 year design TI of 15.0 with a growth rate of 2%, specified by the office of traffic operations (note that this is much higher than the inside lanes)

According to site investigation (core logs and DCP data) and as-built plans, the existing structure for the inside lanes can be simplified as:

- 0.1 ft of RHMA-O
- 0.65 ft of HMA
- 0.75 ft of PCC
- 0.42 ft of cement treated base
- 1.0 ft of lime stabilized subgrade
- CL subgrade

After updating project location and design traffic and removing the 0.1 ft of RHMA-O, save a copy of this trial under a new name: "SBL3_540-495: Baseline". The input page of the segment is shown below:

The screenshot shows the 'Input' tab of the Pavement Design software. The interface includes a top navigation bar with tabs: Home, Instructions, Projects, **Input**, ME Design, Tools, Interpreting Results, and About. The 'Project ID' is 'I-5 Pocket to Florin Redesign' and the 'Trial Title' is 'SBL3_540-495: Baseline'.

Project Location: District 3, County Sacramento, Route 5, Direction South. PM Start 15.900, PM End 16.800. No. Lanes 3. Project Length: 0.900 mi, Lane Miles: 2.700, Avg #lanes: 3.00.

Traffic Count Information: Location 16.147-16.700, Location Description, AADT 32,000, AADTT 4,177, % Trucks 13.1.

Climate: Climate Zone Inland Valley, Suggested Inland Valley.

Design Lane Traffic Loads: Load Distribution (WIM Station) Group1b, Suggested Group1b. Growth Rate (From First Year) 2.0%. First Year Axles / Design Lane 14,355,504. First Year Trucks / Design Lane 5,660,816. Design Life 20 yrs, Total ESALs 73,160,254, TI 15.0 (rounded).

Create a Trial Structure: Subgrade CL, Generate.

Pavement Structure: Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): 0 psi. Apply. Delete All.

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft3)	Actions
1	✓	HMA	90	2020 Standard Old HMA	0.65	1,241.9	N/A	1.57	0.00	Edit Delete Insert
2	✓	PCC	N/A	2020 Standard PCC for CSO ₁	0.76	2,172.0	N/A	N/A	0.00	Edit Delete Insert
3	✓	CTB-Class A	N/A	2020 Standard Old CTB	0.42	267.9	N/A	1.70	0.00	Edit Delete Insert
4	✓	TS	28	2020 Standard LSS (Needs UCS)	1.02	46.7	N/A	N/A	0.00	Edit Delete Insert
5	✓	Subgrade	N/A	2020 Standard CL	∞	25.5	44	N/A	0.00	Edit Delete Insert

Buttons: Add Layer, Add 2 Layers, Add 3 Layers, Add 4 Layers, Add 5 Layers. For CL Subgrade, AB-min is 0.50 or Equiv.

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4.4.2.2.1. Design Alternatives

Given the requirement to maintain grade, the design alternatives under consideration for this project for the inside lanes are:

1. Remove HMA and Replace: removal of all existing HMA and overlay with the same thickness
2. If alternative 1 is viable, further evaluate partial HMA removal and overlay

Note that the second alternative is only feasible if the first alternative is feasible.

Removing the PCC and replacing that with HMA is a costly option and will not be evaluated here. This is because the layers below the PCC is relative strong and there is no need to enhance them, hence no need to remove the PCC layer.

4.4.2.2.2. Example R02.1: Remove HMA and Replace

In this design alternative, all of the existing HMA will be removed and replaced with the same thickness of new asphalt concrete. The question to answer is whether this is a viable option.

Similar to the inside lanes, the first option to try is with 0.2 ft of RHMA-G and 0.45 ft of HMA, if it doesn't work then try to replace the surface with a mix with polymer modified binder:

- Option 1: 0.2 ft RHMA-G over 0.45 ft of HMA with PG70-10 binder
- Option 2: 0.2 ft of HMA with polymer modified binder over 0.45 ft of HMA with PG70-10 binder

Option 1: 0.2 ft RHMA-G over 0.45 ft of HMA with PG70-10 binder

To evaluate this option, save a copy of the baseline trial under a new name "SBL3_540-495: Remove HMA and Replace".

The project input, simulation parameters, and the simulation results are shown below. Note that in this case Layer 3 and Layer 4 are marked as cracked to account for reflection cracking, otherwise the compute engine will return an error.

As one can see, the design is sufficient.

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Project ID: I-5 Pocket to Florin Redesign Trial Title: SBL3_540-495: Remove HMA and Replace

Project Location

District: 3 County: Sacramento Route: 5 Direction: South PM Start: 15.900 PM End: 16.800 No. Lanes: 3
 Project Length: 0.900 mi Lane Miles: 2.700 Avg #Lanes: 3.00

Traffic Count Information

Location: 16.147-16.700 Location Description: AADT: 32,000 AADTT: 4,177 % Trucks: 13.1

Climate

Climate Zone: Inland Valley Suggested: Inland Valley

Design Lane Traffic Loads

Load Distribution (WIM Station): Group1b Suggested: Group1b
 Growth Rate (From First Year): 2.0 %
 First Year Axles / Design Lane: 14,355,504
 First Year Trucks / Design Lane: 5,660,816

Design Life: 20 yrs Total ESALS: 73,160,254 TI: 15.0 (rounded)

Create a Trial Structure
 (Using Design Life and TI)
 Subgrade: CL Generate

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): 0 psi TS->CSS TS->LSS CTB-Class B Apply Delete All

		(U)		UU	(US)		(S/TS)	
1	☐ RHMA-G	90	2020 Standard RHMA-G with PG 64-16 base binder for non-PRS Projects	0.20	627.9	N/A	N/A	0.00 Edit Delete Insert
2	☐ HMA	90	2020 Standard HMA Type A Mix with PG 70-10 Binder and up to 15% RAP for non-PRS Projects	0.45	1,230.6	N/A	1.46	0.00 Edit Delete Insert
3	☒ PCC	N/A	2020 Standard PCC for CSQI	0.76	2,172.0	N/A	N/A	0.00 Edit Delete Insert
4	☒ CTB-Class A	N/A	2020 Standard Old CTB	0.42	267.9	N/A	1.70	0.00 Edit Delete Insert
5	☒ TS	28	2020 Standard LSS (Needs UCS)	1.02	46.7	N/A	N/A	0.00 Edit Delete Insert
6	☒ Subgrade	N/A	2020 Standard CL	∞	25.5	44	N/A	0.00 Edit Delete Insert

Add Layer Add 2 Layers Add 3 Layers Add 4 Layers Add 5 Layers For CL Subgrade, AB-min is 0.50 or Equiv.

Home Instructions Projects **Input** ME Design Tools Interpreting Results ? About US SI Save To DB Save To File

Incremental-Recursive Parameters

Loaded Project: I-5 Pocket to Florin Redesign Loaded Trial: SBL3_540-495: Remove HMA and Replace

General

Starting Date: 7/18/2022 Simulation Duration: 30 yrs Vehicle Speed: 43.75 mph

Simulation Type

☐ Deterministic ☒ Monte-Carlo

Performance Criteria

Rutting: 0.4 in Cracking: 5.0 %

Reflection Cracking

☐ None ☐ AC on AC ☒ AC on Cemented Base
 Existing Cracking (%) > 35
 Cracked layer(s) from 3 to 4 <= Find Them

Spec. Type

☐ Non-PRS ☐ PRS

Monte Carlo Variability

No. of simulations: 60
☒ Construction variability

Construction Variability Table

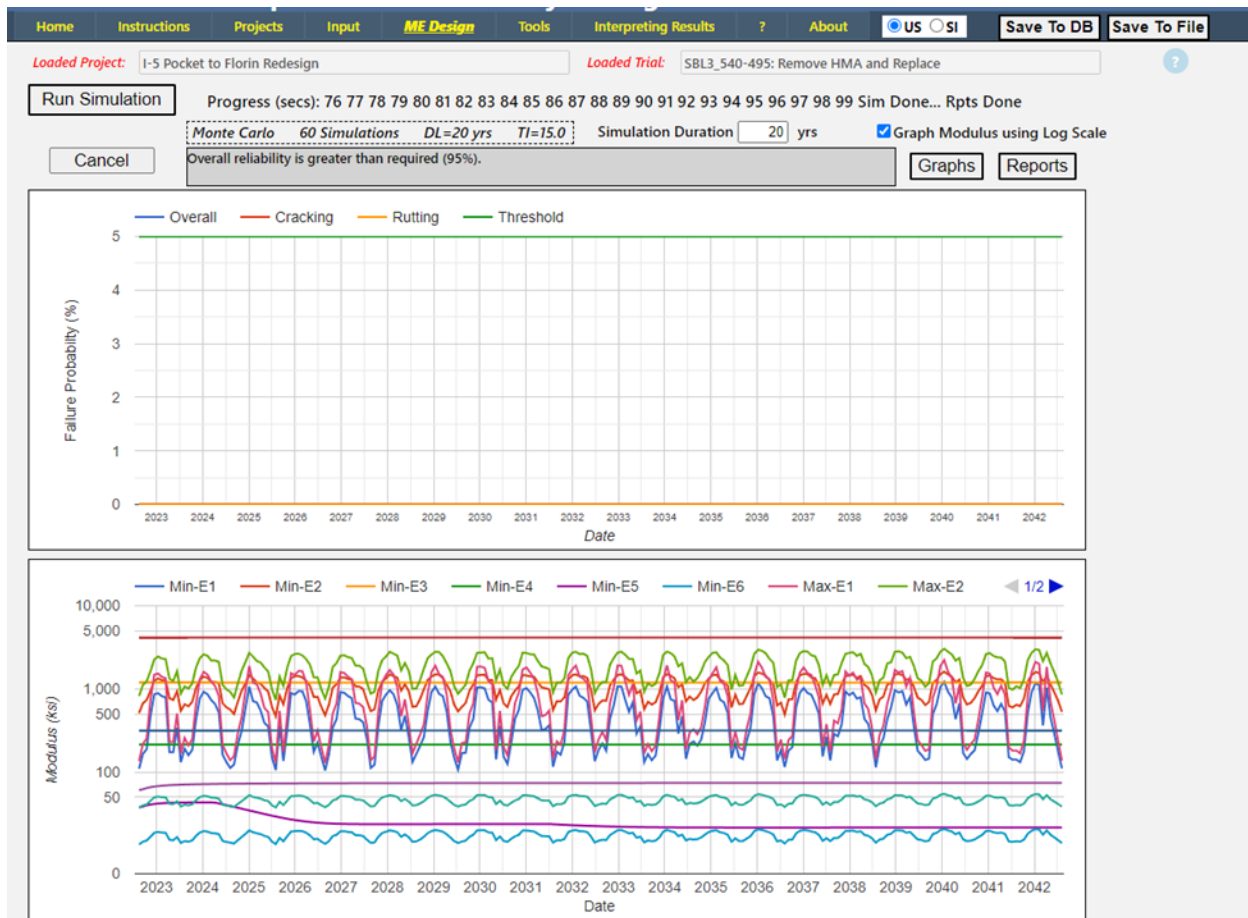
1	0.07	1.20	Edit
2	0.07	1.20	Edit
3	0.00	1.65	Edit
4	0.00	1.16	Edit
5	0.00	1.17	Edit
6	0.00	1.33	Edit

M&R Planning - This Feature is Coming Soon

Populate Grid With: 60 mm HMA Overlay Every 5 years

Year	Treatment
	No treatments

Add Treatment



Option 2: 0.2 ft of HMA with polymer modified binder over 0.45 ft of HMA with PG70-10 binder

To evaluate this option, replace the surface material with the mix with polymer modified binder using the "Edit" link for the RHMA-G layer. The project inputs and the simulation results are shown below. As show in the figure, this option satisfies the design requirement as well.

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US SI

Save To DBSave To File

Project ID

I-5 Pocket to Florin Redesign

Trial Title

SBL3_540-495: Remove HMA and Replace

Project Location

District

County

Route

Direction

PM Start

PM End

No. Lanes

3

Sacramento

5

South

None

15.900

None

None

16.800

None

3

Project Length: 0.900 mi

Lane Miles: 2.700

Avg #lanes: 3.00

Traffic Count Information

Location

Location Description

AADT

AADTT

% Trucks

16.147-16.700

32,000

4,177

13.1

Climate

Climate Zone

Suggested

Inland Valley

Inland Valley

Design Lane Traffic Loads

Load Distribution (WIM Station)

Growth Rate (From First Year)

First Year Axles / Design Lane

First Year Trucks / Design Lane

Group1b

2.0 %

14,355,504

5,660,816

Suggested

Group1b

Design Life

Total ESALs

TI

20 yrs

73,160,254

15.0 (rounded)

Create a Trial Structure

(Using Design Life and TI)

Subgrade

CL

Generate

Error Message Summary

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS):

0 psi

TS->CSS

TS->LSS

CTB-Class B

Apply

Delete All

		(d)		(ft)	(ksi)		(S/ft3)	
1	☐	HMA	90	2020 Standard HMA Type A Mix with PG 64-28M polymer modified binder for non-PRS Projects	0.20	572.0	N/A	1.46
2	☐	HMA	90	2020 Standard HMA Type A Mix with PG 70-10 Binder and up to 15% RAP for non-PRS Projects	0.45	1,230.6	N/A	1.46
3	☒	PCC	N/A	2020 Standard PCC for CSOL	0.76	2,172.0	N/A	0.00
4	☒	CTB-Class A	N/A	2020 Standard Old CTB	0.42	267.9	N/A	1.70
5	☒	TS	28	2020 Standard LSS (Needs UCS)	1.02	46.7	N/A	0.00
6	☒	Subgrade	N/A	2020 Standard CL	∞	25.5	44	0.00

Add Layer

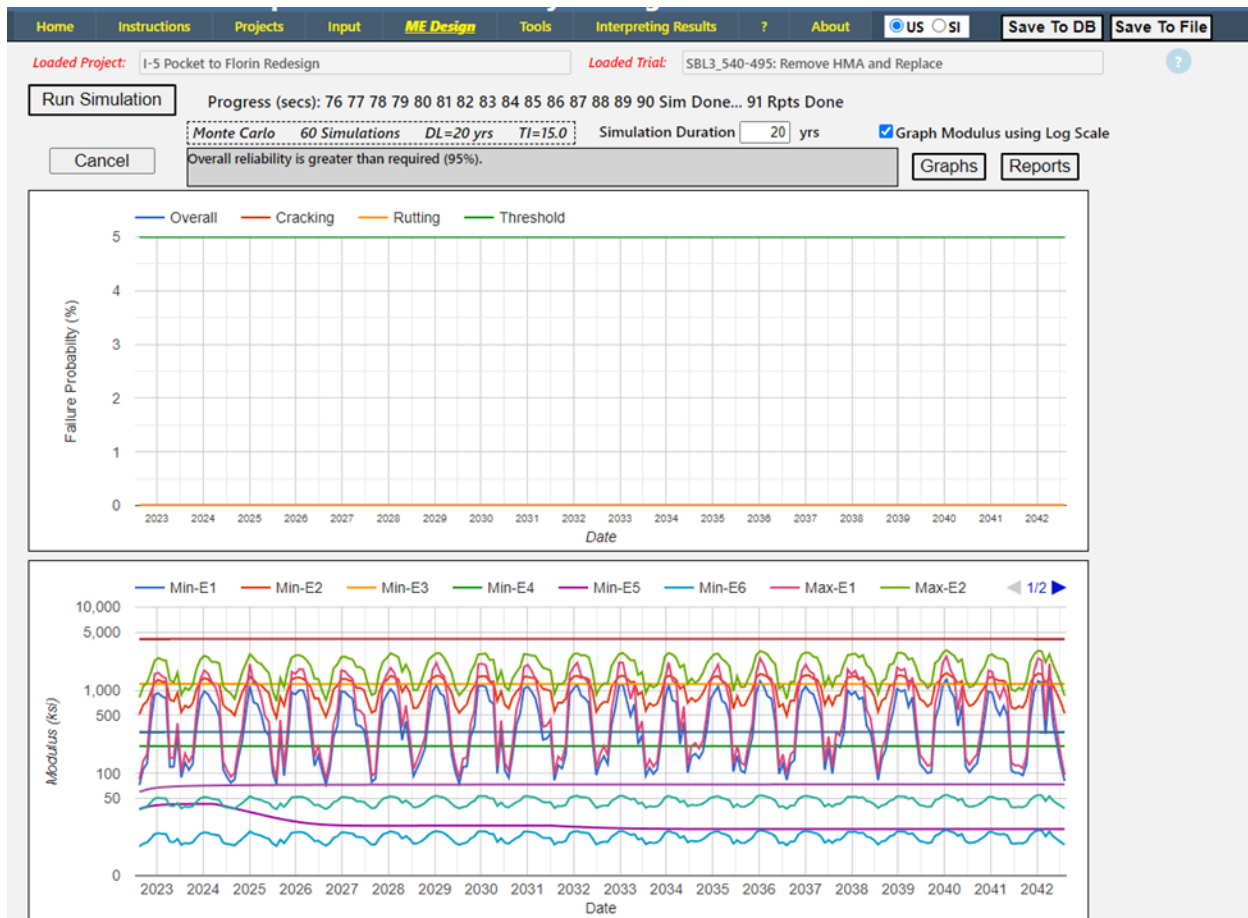
Add 2 Layers

Add 3 Layers

Add 4 Layers

Add 5 Layers

For CL Subgrade, AB-min is 0.50 or Equiv.



4.4.2.2.3. Example R02.2: Mill and Overlay

As shown in the previous subsection, removing all of the old HMA and replacing with new RHMA-G/HMA is more than sufficient. It may be feasible to only remove and replace a portion of the old HMA, which will be evaluated in this option.

To evaluate this option, save a copy of the "SBL3_540-495: Remove HMA and Replace" trial under a new name "SBL3_540-495: Partial Removal and Overlay".

Option 1: 0.2' RHMA-G over 0.25' of HMA with PG70-10 binder

It is recommended to keep a minimum of 0.2' of old HMA. The first structure to try for this option is the following:

- 0.2 ft RHMA-G with PG64-16 base binder

- 0.25 ft of HMA with PG70-10 binder
- 0.2 ft of old HMA

The project inputs, simulation parameters, and the simulation results are shown below.

Note: In this case Layer 3 to Layer 5 are marked as cracked to account for reflection cracking. The old HMA layer needs to be marked as cracked as well, and the type of reflection cracking is still "AC on Cemented Base" since there is cemented layer involved.

The results show that the design is not sufficient and lasts only 7.7 years before it fails in cracking.

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Project ID

I-5 Pocket to Florin Redesign

Trial Title

SBL3_540-495: Partial Removal and Overlay

Project Location

District

County

Route

Direction

PM Start

PM End

No. Lanes

3

Sacramento

5

South

None

15.900

None

16.800

None

3

Project Length: 0.900 mi

Lane Miles: 2.700

Avg #Lanes: 3.00

Traffic Count Information

Location

Location Description

AADT

AADTT

% Trucks

16.147-16.700

32,000

4,177

13.1

Climate

Climate Zone

Suggested

Inland Valley

Design Lane Traffic Loads

Load Distribution (WIM Station)

Growth Rate (From First Year)

First Year Axles / Design Lane

First Year Trucks / Design Lane

Group1b

2.0 %

14,355,504

5,660,816

Design Life

Total ESALs

TI

20 yrs

73,160,254

15.0 (rounded)

Create a Trial Structure

(Using Design Life and TI)

Subgrade

CL

Generate

Error Message Summary

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS):

0 psi

TS->CSS

TS->LSS

CTB-Class B

Apply

Delete All

1	☐	RHMA-G	90	2020 Standard RHMA-G with PG 64-16 base binder for non-PRS Projects	0.20	627.9	N/A	N/A	0.00	Edit Delete Insert
2	☐	HMA	90	2020 Standard HMA Type A Mix with PG 70-10 Binder and up to 15% RAP for non-PRS Projects	0.25	1,230.6	N/A	1.46	0.00	Edit Delete Insert
3	☒	HMA	90	2020 Standard Old HMA	0.20	1,241.9	N/A	1.46	0.00	Edit Delete Insert
4	☒	PCC	N/A	2020 Standard PCC for CSOL	0.76	2,172.0	N/A	N/A	0.00	Edit Delete Insert
5	☒	CTB-Class A	N/A	2020 Standard Old CTB	0.42	267.9	N/A	1.70	0.00	Edit Delete Insert
6	☒	TS	28	2020 Standard LSS (Needs UCS)	1.02	46.7	N/A	N/A	0.00	Edit Delete Insert
7	☒	Subgrade	N/A	2020 Standard CL	∞	25.5	44	N/A	0.00	Edit Delete Insert

Add Layer

Add 2 Layers

Add 3 Layers

Add 4 Layers

Add 5 Layers

For CL Subgrade, AB-min is 0.50 or Equiv.

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☒ US
 ☐ SI

[Save To DB](#)
[Save To File](#)

Incremental-Recursive Parameters ?

Loaded Project:
 Loaded Trial:

General ?

Starting Date
 Simulation Duration yrs
 Vehicle Speed mph

Simulation Type ?

☐ Deterministic
☒ Monte-Carlo

Performance Criteria ?

Rutting in
 Cracking %

Reflection Cracking ?

☐ None
 ☐ AC on AC
 ☒ AC on Cemented Base
 Existing Cracking (%) %
 Cracked layer(s) from to [<= Find Them](#)

Spec. Type ?

☐ Non-PRS
☐ PRS

Monte Carlo Variability ?

No. of simulations
☒ Construction variability
 Construction Variability Table

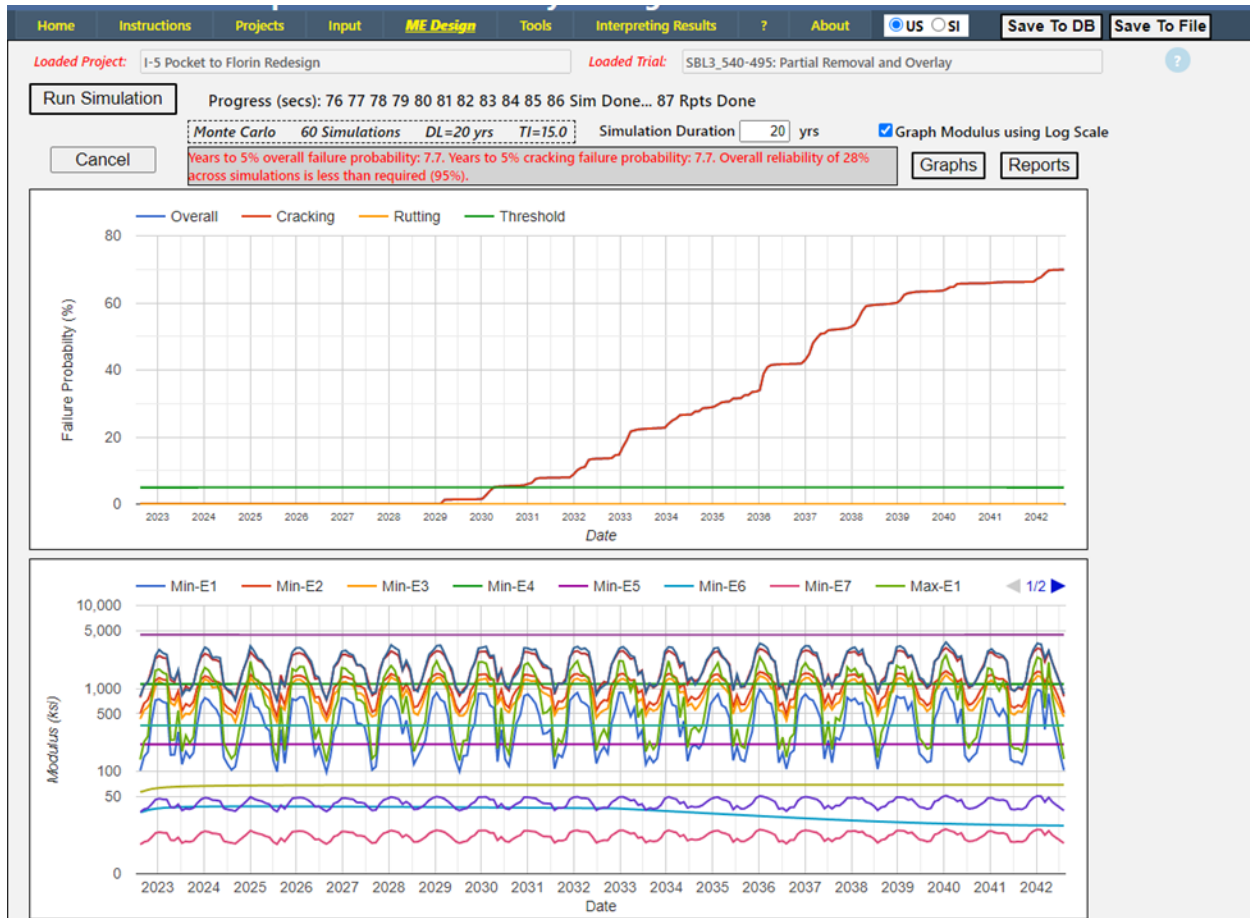
Layer	CoV Thick	Sdf Modulus	
1	0.07	1.20	Edit
2	0.07	1.20	Edit
3	0.00	1.42	Edit
4	0.00	1.65	Edit
5	0.00	1.16	Edit

M&R Planning - This Feature is Coming Soon ?

Populate Grid With:

Year	Treatment
	No treatments

[Add Treatment](#)



Option 2: 0.2' HMA with polymer modified binder over 0.25' of HMA with PG70-10 binder

This option is the same as above except the surface is replaced with an HMA with polymer modified binder. The project inputs, simulation parameters, and the simulation results are shown below.

As one can see, the design is not sufficient and lasts only 9.8 years before it fails in cracking.

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Incremental-Recursive Parameters ?

Loaded Project:

I-5 Pocket to Florin Redesign

Loaded Trial:

SBL3_540-495: Partial Removal and Overlay

General ?

Starting Date

7/18/2022

Simulation Duration

20 yrs

Vehicle Speed

43.75 mph

Simulation Type ?

☐ Deterministic
☒ Monte-Carlo

Performance Criteria ?

Rutting

0.4 in

Cracking

5.0 %

Reflection Cracking ?

☐ None
 ☐ AC on AC
 ☒ AC on Cemented Base
 Existing Cracking (%) > 35
 Cracked layers(s) from 3 to 5 <= Find Them

Spec. Type ?

☐ Non-PRS
☐ PRS

Monte Carlo Variability ?

No. of simulations

60

☒ Construction variability

Construction Variability Table

Layer	CoV Thick	Sdf Modulus	
1	0.07	1.20	Edit
2	0.07	1.20	Edit
3	0.00	1.42	Edit
4	0.00	1.65	Edit
5	0.00	1.16	Edit

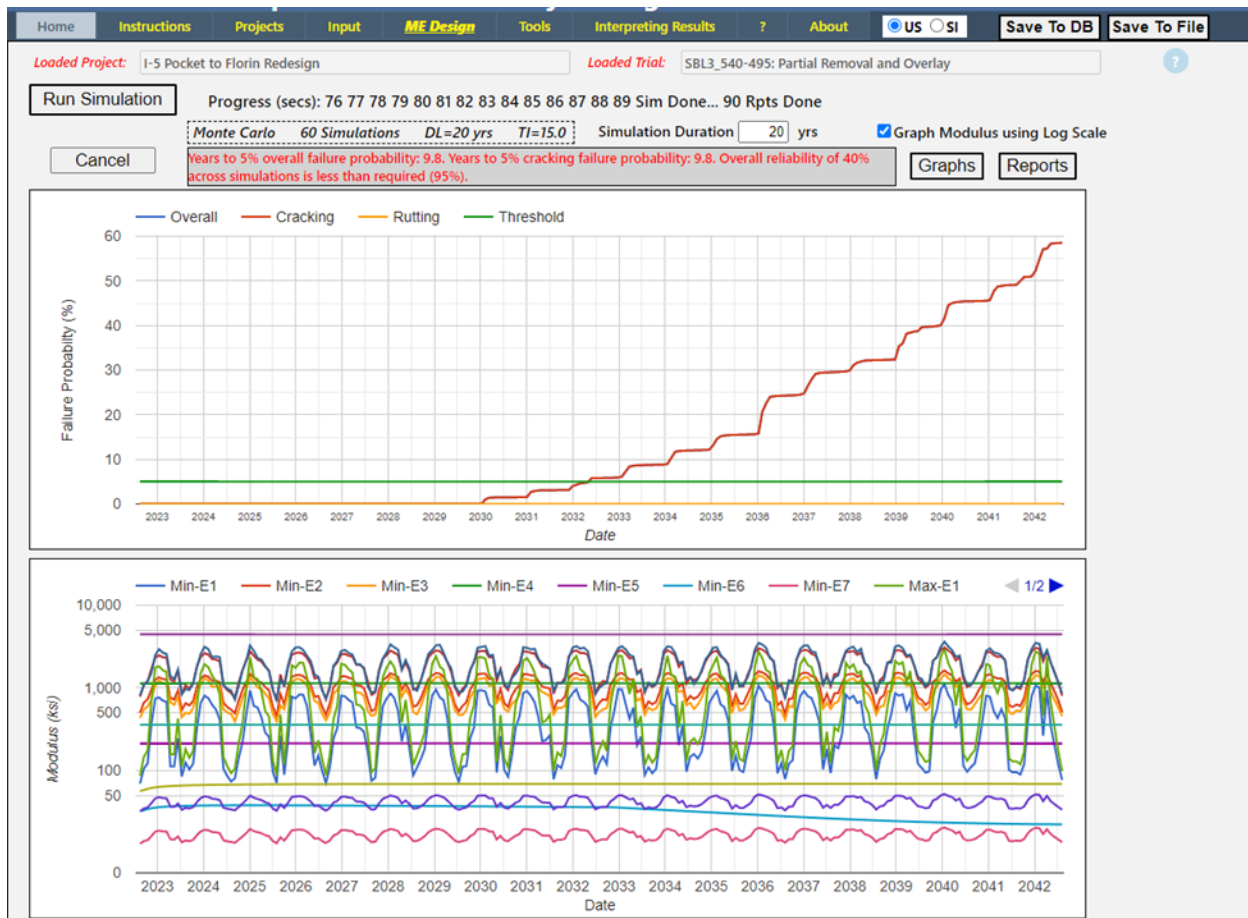
M&R Planning - This Feature is Coming Soon ?

Populate Grid With:

60 mm HMA Overlay Every 5 years

Year	Treatment
No treatments	

Add Treatment

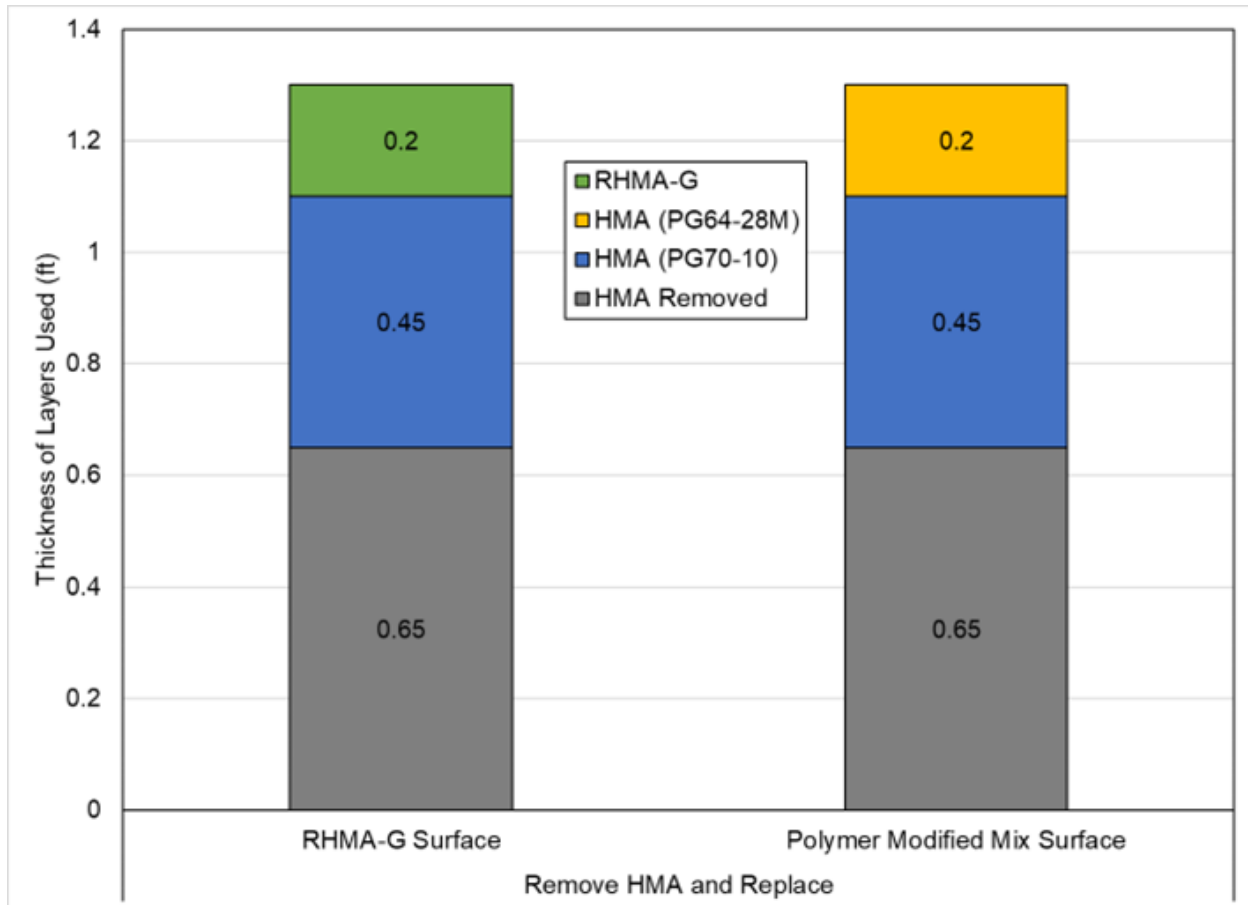


4.4.2.2.4. R02 Design Summary

A comparison of the optimal designs for different alternatives is shown in the figure below.

These alternatives need to be considered along with the alternatives for the inside lanes. It is probably easier for construction management if the thickness of the removed old HMA is the same for the inside lanes and the outside lanes.

In this case, the remove HMA and replace option is probably the best option for both the inside and outside lanes.



4.4.2.3. Example R03: Old Rigid Pavement

This section is under construction. If you have a rehabilitation project on rigid pavement and are willing to include it as an example here, please contact Caltrans Office of Asphalt Pavements.

4.4.3. Case Studies

In this section, case studies are presented to demonstrate the process of evaluating different structure alternatives using *CalME*. More case studies will be added here as more informative cases become available.

It is recommended to review the examples in the earlier sections if you are not familiar with the *CalME* user interface yet as there are no step-by-step instructions in this section.

4.4.3.1. CS-R01: Inyo 395 Rehabilitation Near Fish Springs

CalME can be used to identify design alternatives that are needed for life cycle cost assessment (LCCA) and life cycle assessment (LCA). Each design is based on the engineering inputs such as

the existing structure, design requirements (life, grade change allowed), environment, traffic, and maintainability.

The steps to using CalME include the following:

- Collect all relevant information about the project
 - Pavement structure information based on as-built designs, ground penetrating radar surveys, and dynamic cone penetrometer (DCP) testing, visual surveys, and forensic investigations.
 - Pavement layer conditions based on falling weight deflectometer (FWD) results, and DCP testing.
 - Material properties and material types from cores and soil sampling for material characterization.
 - Design requirements.
 - Design traffic.
- Develop alternatives for design strategies (lane replacement, straight overlay, mill and overlay, full depth recycling, partial depth recycling, etc.)
- Run CalME to determine the design structure meeting all requirements and traffic for each alternative

These designs can then be included in LCCA and LCA for economic and environmental review before making design recommendations.

This case study illustrates how the above process is applied to the rehabilitation of the southbound section of state highway 395 in Inyo County, between PM 91.6 and PM 99.03.

Several assumptions were made where information is missing to illustrate how available guidelines can be used to design possible structures that meet the design requirements.

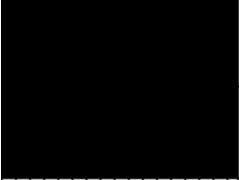
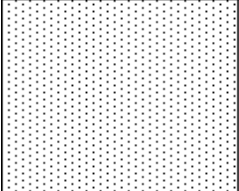
4.4.3.1.1. Design Inputs

The backcalculation results exported from CalBack can be found [here](#).

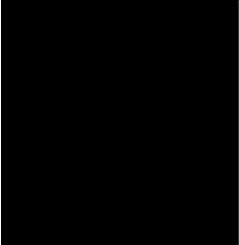
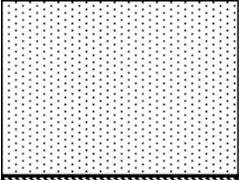
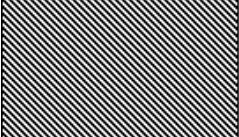
Structure Information

Layer Materials and Thicknesses

As-built plans for this section of highway are illustrated below.

	Layer: RHMA Thickness: 0.06 ft (18 mm)
	Layer: HMA Thickness: 0.55 ft (165 mm)
	Layer: Unbound Aggregate Base Thickness: 0.4 ft (120 mm)
	Layer: Subgrade Thickness: Semi infinite

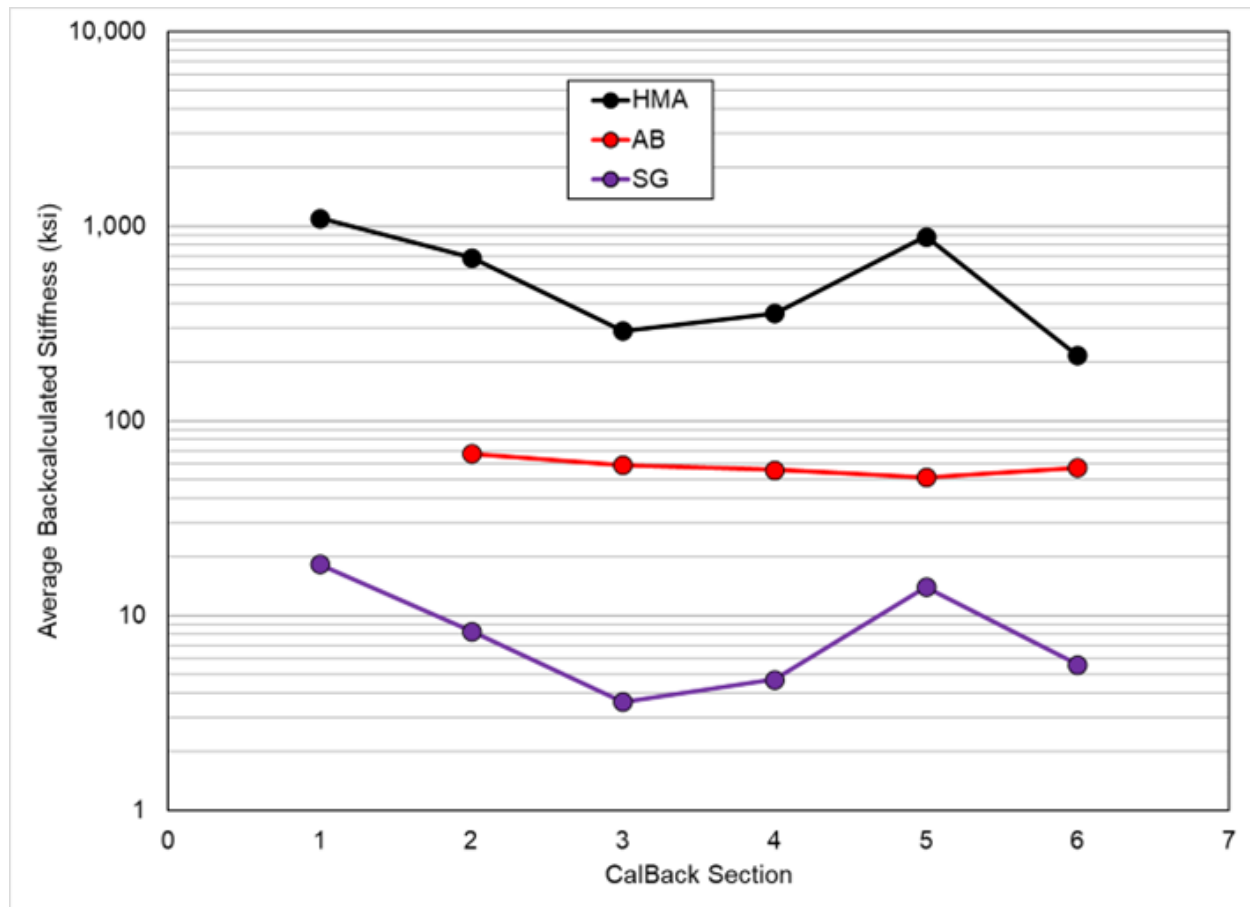
A site investigation was initiated because this is a rehabilitation project. The investigation consisted of FWD testing, coring, and soil sampling. The cores showed that the combined HMA layers (RHMA and HMA) thickness varied between 0.63 ft and 0.89 ft, with a median thickness of 0.7 ft. This provided the information needed to update the pavement structure as below:

	Layer: HMA Thickness: Varies between 0.63 and 0.89 ft (189 and 267 mm) Debonded at depths 0.25 to 0.3 ft (75 to 90 mm) over entire section
	Layer: Unbound Aggregate Base Thickness: 0.4 ft (120 mm)
	Layer: Subgrade Thickness: Semi infinite

Structure Conditions

The updated pavement structure together with the FWD deflection data was used in CalBack to backcalculate the layer stiffnesses and to divide the section of highway into uniform sections with similar stiffness values. CalBack determined there to be 6 different sections. The average

layer stiffnesses for the different sections are provided below:



The cores also showed that the HMA layer was debonded between 0.25 ft and 0.30 ft below the surface for the entire project.

Maintenance history has also shown that this area was prone to alligator cracking in the wheelpaths, requiring excessive digouts along wheelpaths. The existing surface cracking exceeded 35% of the project area.

The site investigation further showed the following:

- Adequate drainage is present around the highway
- The distresses are bottom up in the AC layers in the wheelpaths.
- There are no fabric or geogrid present in the structure.
- The AB layer has permanent deformation in the wheelpaths.

Material Properties

This area has a history of low R values for the subgrade. The subgrade soil samples were tested for R-value and to classify the soil following the unified soil classification system (USCS). The R-value results and USCS classifications for each section are provided in Table 1. Note that there were no data for Sections 1 and 2.

Table 1: Subgrade Classification Results

<i>CalBack</i> Section	Subgrade	
	R value	USCS
3	5	SC
4	7	SC
5	22	SC
6	10	SC

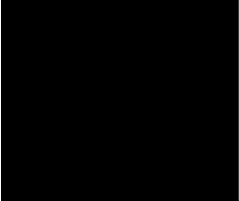
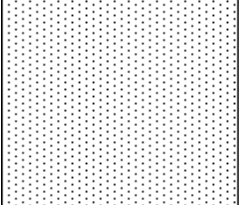
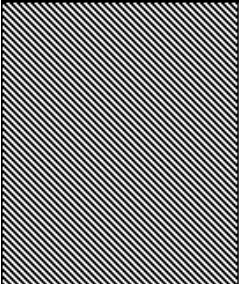
To determine the viability of full depth recycling (FDR), the "[Guide for Partial- and Full-Depth Pavement Recycling in California](#)" was followed for guidance.

The available material for FDR consists of approximately 0.65 ft of HMA and 0.4 ft of AB, for a 1.05 ft in total thickness. The cores were crushed and mixed with the AB material sampled from the site.

Since no blending tests were conducted for this project, it was assumed that the RAP and AB were blended at a ratio of 60 % RAP and 40% AB for each section. The blended material for sections 1 through 6 is assumed to meet the Class-2 AB specifications, with a USCS classification of GP, less than 15% passing #200, and a PI of less than 6. These numbers should be obtained from proper sampling and testing rather than being assumed in actual designs.

4.4.3.1.2. Alternatives Under Consideration

The structure and material properties are summarized in the following figure:

	Layer: HMA Thickness: Varies between 0.53 and 0.88 ft (159 and 264 mm) Debonded at depths 0.25 to 0.3 ft (75 to 90 mm) over entire section Stiffness: Varies between 217 and 1097 ksi (1496 and 7564 Mpa)
	Layer: Class 2 AB Thickness: 0.4 ft (120 mm) Stiffness: Varies between 51.4 and 68 ksi (354 and 469 MPa) USCS: GM
	Layer: Subgrade Thickness: Semi infinite Stiffness: Varies between 3.6 and 18.4 ksi (24.8 and 126.8 MPa) USCS: SC R-value: Varies between 5 and 22

Design considerations

The following design considerations were provided:

- The project has no grade restrictions, which allows the final grade to be raised.
- The design life is 40 years.
- The 40-year Traffic Index (TI) for this project is 12.

Strategies considered for this example

- Overlay Only: Overlay existing project with new HMA and HMA-PM (HMA Type A with polymer modified binder).
- Mill and Overlay: Mill off distressed AC and replace with new HMA and HMA-PM.
- Full Depth Recycling: Use the appropriate FDR recycling strategy to rehabilitate the highway, and to place HMA layer with an HMA-PM surface.
- Cold Central Plant Recycling (CCPR) with subgrade stabilization: Consider this option to address the weak subgrade and to recycle the existing RAP and AB materials in a cold central plant. Place an HMA layer (if required) on the CCPR with an HMA-PM surface.

The final decision should be based on a LCA and LCCA evaluation. The scope of this CalME example is to illustrate the process of using CalME and its related features to determine different appropriate structural designs for the traffic and environmental conditions.

4.4.3.1.3. Logistics and Overall Strategy

For this example, CalBack files were provided, which contained the pavement structure and the layer stiffnesses and variabilities. The first step is to upload the CalBack file into CalME. CalME generates a series of trials, one for each section as determined in CalBack. The project screen after importing the CalBack file is shown below:

The screenshot displays the CalME web application interface. At the top is a navigation bar with links: Home, Instructions, **Projects**, Input, ME Design, Tools, Interpreting Results, ?, and About. On the right of the navigation bar are radio buttons for 'US' (selected) and 'SI', and buttons for 'Save To DB' and 'Save To File'.

Below the navigation bar is the title 'Manage CalME Input Files and Database Projects (if logged in)'. A paragraph explains that project data can be stored in text files or a database managed by UCPRC. It states that file-based data must be uploaded to CalME, while database-based data is retrieved via a dropdown. A note recommends saving data locally as a backup.

The main section is titled 'Use the following controls to select and manage (Add/Delete/etc.) projects stored in the CalME database'. It contains a box titled 'Projects and Trials Stored in the Database'. Inside this box, there are dropdowns for 'Loaded Project' (showing '09-37910 Fish Springs SB 395 100.8-91.6-Raghu') and 'Loaded Trial' (showing 'Section: Fish Springs 395 sb 100.8-99.76_sect_1'). Buttons for 'Edit Project', 'Add Project', 'Delete Project', 'Save Project As', and 'Save Trial As' are present. Below these is a table with two columns: 'Trial Title' and 'Trial Description'. The table lists three trials generated from CalBack sections, each with a 'Delete' link. An 'Add Trial' button is at the bottom of the table.

Below the table is an 'Import From Users' section with a dropdown menu and an 'Import' button.

The next section is titled 'Use the following controls to select and load CalBack Export files stored locally on your computer. Download CalBack.' It contains a text box for file selection (showing 'No file chosen') and an 'Upload' button. Below this, the 'Upload Status' shows a red message: 'File: "CS-R01.IN395.json" successfully uploaded!'.

The final section is titled 'Use the following controls to select and load CalME input files stored locally on your computer'. It contains a text box for file selection (showing 'No file chosen') and an 'Upload' button. Below this, there are two radio buttons: 'Create a New Project for the Uploaded File' (selected) and 'Add the Uploaded File To the Currently Loaded Project'.

Trials from CalBack in CalME do not allow the user to change the layer stiffnesses. These trials contain the information about the existing structure as determined in CalBack. The user can change the structure within the rules set in CalME, by adding additional layers, reducing the existing layer thickness, or removing existing layers.

CalBack files do not contain any project location, climate, or design traffic information so these inputs need to be entered for each of the trial separately.

Calback does not have material type of the subgrade. It is necessary to select the correct material type for the subgrade (SC in this example).

Once all the missing information has been updated in the existing trials. Make a copy of this trial

for the first alternative design. This allows one to evaluate multiple alternatives with the same starting point.

Overall Strategy

In this example, the CalBack file contains six sections for the 7.43-mile long project. One should review the sections and find the weakest section and the strongest section. In case there is no clear way to determine the relative strength of different sections, one would have to design for all sections.

Whether to use a single design for all sections should depend on whether the difference in design thicknesses between the weakest section and the strongest section is large enough to justify the additional cost associated with multiple cross sections.

For this example, Section 3 has the weakest subgrade with a subgrade stiffness of 3.6 ksi. Accordingly, Section 3 will be used here to illustrate how the various design alternatives are determined. Note that one should also review the strongest section before deciding whether to use a single design throughout the project.

The existing structure for Section 3 is shown in the following figure.

	Layer: HMA Thickness: 0.65 ft (195 mm) Debonded at depths 0.25 to 0.3 ft (75 to 90 mm) over entire section Stiffness: 289 ksi (1993 MPa) Greater than 35% surface cracking
	Layer: Class 2 AB Thickness: 0.4 ft (120 mm) Stiffness: 59 ksi (407 MPa) USCS: GM
	Layer: Subgrade Thickness: Semi infinite Stiffness: 3.6 ksi (24.8 MPa) USCS: SC R-value: 5

After entering the project location and design traffic, the project input screen for Section 3 is shown below:

Home Instructions Projects **Input** ME Design Tools Interpreting Results ? About US SI Save To DB Save To File

Project ID 09-37910 Fish Springs SB 395 100.8-91.6-Raghu Trial Title Section: Fish Springs 395 sb 99.00-96.98_3

Project Location

District 9 County Inyo Route 395 Direction South PM Start 99.000 PM End 96.980 No. Lanes 2

Project Length: 2.020 mi Lane Miles: 4.040 Avg #Lanes: 2.00

Traffic Count Information

Location 97.462-98.542 Location Description AADT 2,975 AADTT 602 % Trucks 20.2

Climate

Climate Zone High Desert Suggested High Desert

Design Lane Traffic Loads

Load Distribution (WIM Station) Group1b Suggested Group1b

Growth Rate (From First Year) 5.6 %

First Year Axles / Design Lane 623,922

First Year Trucks / Design Lane 246,032

Design Life 40 yrs Total ESALs 11,217,739 TI 12.0 (rounded)

Create a Trial Structure
(Using Design Life and TI)

Subgrade SC Generate

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): psi TS->CSS TS->LSS CTB-Class B Apply Delete All

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft3)	Actions
1	✓	HMA	90	2020 Standard Qld HMA	0.65	289.0	N/A	1.75	0.00	Edit Delete Insert
2	✓	AB	N/A	2020 Standard AB-Class 2	0.41	59.4	N/A	1.10	0.00	Edit Delete Insert
3	✓	Subgrade	N/A	2020 Standard SC	∞	3.6	5	N/A	0.00	Edit Delete Insert

Add Layer Add 2 Layers Add 3 Layers Add 4 Layers Add 5 Layers For SC Subgrade, AB-min is 0.35 or Equiv.

Save a copy of this trial under a new name "Section 3: Baseline".

4.4.3.1.4.1. Overlay Only

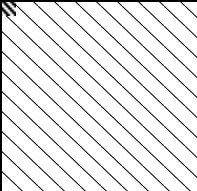
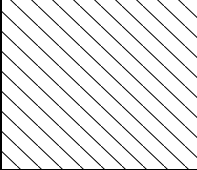
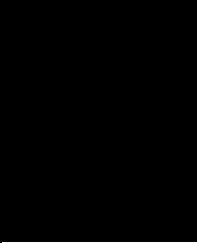
In this alternative, no milling is considered. The only design variable is the thickness of the overlay. Since the new overlay will be placed directly on the existing AC that is cracked, it is required to model the pavement with reflective cracking.

Note: Polymer modified mix is chosen instead of RHMA-G mix because the required RHMA-G with PG58-22 base binder for the High Desert climate of this project is relatively less common. Since RHMA-G with PG58-22 base binder is currently not available in CalME Standard Materials Library, please contact the headquarter if it is preferred to use RHMA-G in high desert and high mountain.

4.4.3.1.4.1.1. Three Layer System

The proposed design is provided in figure below. Three layers were added on top of the existing structure. A 0.2 ft rich bottom layer, an HMA layer with 25% RAP, and a final 0.20 ft HMA-PM surface course. The purpose of this design is to design the thickness of the HMA layer to carry the expected traffic.

Note: the reason for using the mix with up to 25% RAP as the intermediate layer is to take advantage of its high stiffness. Other options such as the mix with PG70-10 binder can provide similar benefit. Mix with softer binder may also be used, albeit with potentially thicker layer.

	Layer: HMA-PM Thickness: 0.2 ft (60 mm) Type: 2020 Std. HMA Type A with PG64-28M binder Stiffness: 627.9 ksi (4330 MPa)
	Layer: HMA Thickness: TBD Type: 2020 Std. HMA Type A with 25% RAP Stiffness: 1207.6 ksi (8326 MPa)
	Layer: Rich Bottom HMA Thickness: 0.2 ft (60 mm) Type: 2020 Std. Rich Bottom Mix Stiffness: 933.5 ksi (6436 MPa)
	Layer: HMA (Old) Thickness: 0.65 ft (195 mm) Debonded at depths 0.25 to 0.3 ft (75 to 90 mm) over entire section Stiffness: 289 ksi (1993 MPa) Greater than 35% surface cracking
	Layer: Class 2 AB Thickness: 0.4 ft (120 mm) Stiffness: 59 ksi (407 MPa) USCS: GM
	Layer: Subgrade Thickness: Semi infinite Stiffness: 3.6 ksi (24.8 MPa) USCS: SC R-value: 5

To evaluate this option, make a copy of the "Section 3: Baseline" trial under a new name "Section 3: Three-Layer Overlay". After adding the new layers, the project input screen is shown below:

Home Instructions Projects **Input** ME Design Tools Interpreting Results ? About US SI Save To DB Save To File

Project ID 09-37910 Fish Springs SB 395 100.8-91.6-Raghu Trial Title Section 3: Three Layer Overlay

Project Location

District 9 County Inyo Route 395 Direction South PM Start 99.000 PM End 96.980 No. Lanes 2

Project Length: 2.020 mi Lane Miles: 4.040 Avg #lanes: 2.00

Traffic Count Information

Location 97.462-98.542 Location Description AADT 2,975 AADTT 602 % Trucks 20.2

Design Lane Traffic Loads

Load Distribution (WIM Station) Group1b Suggested Group1b

Growth Rate (From First Year) 5.6 %

First Year Axles / Design Lane 623,922

First Year Trucks / Design Lane 246,032

Design Life 40 yrs Total ESALs 11,217,739 TI 12.0 (rounded)

Climate

Climate Zone High Desert Suggested High Desert

Create a Trial Structure
(Using Design Life and TI)

Subgrade SC Generate

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): psi TS->CSS TS->LSS CTB-Class B Apply Delete All

		(ft)		UCS	UCS		(S/TS)	
1	HMA	90	2020 Standard HMA Type A Mix with PG 64-28M polymer modified binder for non-PRS Projects	0.20	572.0	N/A	1.64	0.00 Edit Delete Insert
2	HMA	90	2020 Standard HMA Type A Mix with 25% RAP for non-PRS Projects	0.30	1,207.6	N/A	1.64	0.00 Edit Delete Insert
3	HMA	90	2020 Standard Rich Bottom Mix for non-PRS Projects	0.20	933.5	N/A	1.64	0.00 Edit Delete Insert
4	HMA	90	2020 Standard Old HMA	0.65	289.0	N/A	1.75	0.00 Edit Delete Insert
5	AB	N/A	2020 Standard AB-Class 2	0.41	59.4	N/A	1.10	0.00 Edit Delete Insert
6	Subgrade	N/A	2020 Standard SC	∞	3.6	5	N/A	0.00 Edit Delete Insert

Add Layer Add 2 Layers Add 3 Layers Add 4 Layers Add 5 Layers For SC Subgrade, AB-min is 0.35 or Equiv.

Note that the debonding within the old HMA layer can be accounted for in CalBack in two ways:

- Explicitly: by splitting the old HMA layer into two lifts and indicate that they are debonded;
- Implicitly: by treating the old HMA layer as a single layer, which should result in low back-calculated stiffness for the layer.

Judging the fact that there is only one layer for the old HMA, the debonding was accounted for implicitly in CalBack. This is confirmed by the relatively low stiffness imported from CalBack for the old HMA layer (see the screen shot above).

This design requires that reflective cracking be selected since the cracks in the existing HMA will not be removed. The simulation parameter screen is shown below:

Incremental-Recursive Parameters

Loaded Project: 09-37910 Fish Springs SB 395 100.8-91.6-Raghu Loaded Trial: Section 3: Three Layer Overlay

General

Starting Date: 1/3/2023 Simulation Duration: 40 yrs Vehicle Speed: 43.75 mph

Simulation Type

☐ Deterministic
☒ Monte-Carlo

Performance Criteria

Rutting: 0.4 in
Cracking: 5.0 %

Reflection Cracking

☐ None ☒ AC on AC ☐ AC on Cemented Base
Existing Cracking (%) > 35
Cracked layers(s) from 4 to 4 <= Find Them

Spec. Type

☐ Non-PRS
☐ PRS

Monte Carlo Variability

No. of simulations: 60
☒ Construction variability

Construction Variability Table

Layer	CoV Thick	Sdf Modulus	
1	0.07	1.20	Edit
2	0.07	1.20	Edit
3	0.07	1.20	Edit
4	0.00	1.27	Edit
5	0.00	1.84	Edit

M&R Planning - This Feature is Coming Soon

Populate Grid With: 60 mm HMA Overlay Every 5 years

Year	Treatment
	No treatments

Add Treatment

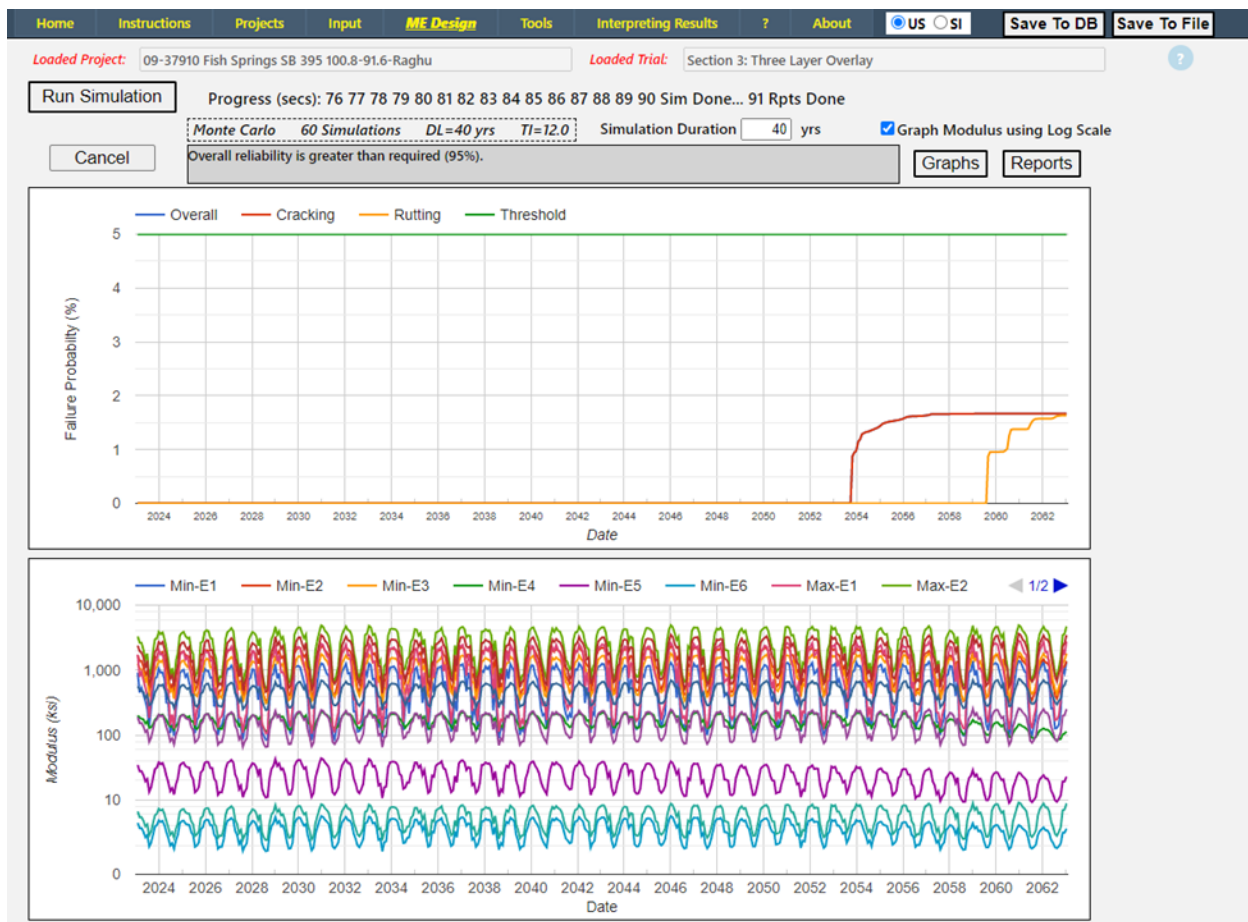
It is useful to enter a duration longer than the design life to determine how long this design will be able to carry the expected traffic if it does last longer than the design life.

For this example, three iterations were run to determine a suitable thickness of the intermediate HMA layer. To expedite the process, some preliminary Monte Carlo analysis were run with 20 simulations. The results are provided in Table 2. The results show that the thickness of the HMA layer should be at least 0.40' to carry the expected traffic over the design life. Cracking is more critical with 0.30' of intermediate layer, but both cracking and rutting are critical with thicker intermediate layer.

Table 2: Overlay CalME Results

Total AC Thickness (ft)	HMA Thickness for Layer 2 (ft)	Cracking Reliability (%)	Rutting Reliability (%)	Overall Reliability (%)	Number of Simulations in Monte Carlo Analysis	Years to failure (years)
0.70	0.30	90	100	90	20	33.2
0.75	0.35	95	100	95	20	>40
0.75	0.35	90	98	90	60	38.0
0.80	0.40	98	98	98	60	>40

The simulation results for the final design is shown below:



4.4.3.1.4.1.2. Two Layer System

The three layer system introduces an extra mix type so can potentially induce extra cost. The two layer overlay structure is the same as the three layer overlay except without the rich bottom layer.

Note: the rich bottom mix may offer other benefits that are not accounted for in CalME.

The update project input window is shown below with a 0.55 ft layer of HMA with up to 25% RAP.

Compared to the three layer plain overlay, the two layer system performance is practically the same.

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Project ID
09-37910 Fish Springs SB 395 100.8-91.6-Raghu
Trial Title
Section 3: Two Layer Overlay

Project Location
District
9
County
Inyo
Route
395
Direction
South
PM Start
None
99,000
None
PM End
None
96,980
None
No. Lanes
2
Project Length: 2.020 mi
Lane Miles: 4.040
Avg #lanes: 2.00

Traffic Count Information
Location
97.462-98.542
Location Description
AADT
2,975
AADTT
602
% Trucks
20.2

Climate
Climate Zone
High Desert
Suggested
High Desert

Design Lane Traffic Loads
Load Distribution (WIM Station)
Group1b
Suggested
Group1b
Growth Rate (From First Year)
5.6 %
First Year Axles / Design Lane
623,922
First Year Trucks / Design Lane
246,032
Design Life
40 yrs
Total ESALs
11,217,739
TI
12.0 (rounded)

Create a Trial Structure
(Using Design Life and TI)
Subgrade
SC
Generate

Error Message Summary

Pavement Structure
Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS):
psi
TS->CSS
TS->LSS
CTB-Class B
Apply
Delete All

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft3)	Actions
1		HMA	90	2020 Standard HMA Type A Mix with PG 64-28M polymer modified binder for non-PRS Projects	0.20	572.0	N/A	1.64	0.00	Edit Delete Insert
2		HMA	90	2020 Standard HMA Type A Mix with 25% RAP for non-PRS Projects	0.55	1,207.6	N/A	1.64	0.00	Edit Delete Insert
3		HMA	90	2020 Standard Old HMA	0.65	289.0	N/A	1.75	0.00	Edit Delete Insert
4		AB	N/A	2020 Standard AB-Class 2	0.41	59.4	N/A	1.10	0.00	Edit Delete Insert
5		Subgrade	N/A	2020 Standard SC	∞	3.6	5	N/A	0.00	Edit Delete Insert

Add Layer
Add 2 Layers
Add 3 Layers
Add 4 Layers
Add 5 Layers
For SC Subgrade, AB-min is 0.35 or Equiv.

The simulation parameters are shown below:

Home Instructions Projects **Input** ME Design Tools Interpreting Results ? About US SI Save To DB Save To File

Incremental-Recursive Parameters ?

Loaded Project: 09-37910 Fish Springs SB 395 100.8-91.6-Raghu Loaded Trial: Section 3: Two Layer Overlay

General ?

Starting Date 1/3/2023 Simulation Duration 40 yrs Vehicle Speed 43.75 mph

Simulation Type ?

☐ Deterministic
☒ Monte-Carlo

Performance Criteria ?

Rutting 0.4 in
Cracking 5.0 %

Reflection Cracking ?

☐ None ☒ AC on AC ☐ AC on Cemented Base
Existing Cracking (%) > 35
Cracked layer(s) from 3 to 3 <= Find Them

Spec. Type ?

☐ Non-PRS
☐ PRS

Monte Carlo Variability ?

No. of simulations 60
☒ Construction variability

Construction Variability Table

Layer	CoV Thick	Sdf Modulus	
1	0.07	1.20	Edit
2	0.07	1.20	Edit
3	0.00	1.27	Edit
4	0.00	1.84	Edit
5	0.00	1.13	Edit

M&R Planning - This Feature is Coming Soon ?

Populate Grid With: 60 mm HMA Overlay Every 5 years

Year	Treatment
	No treatments

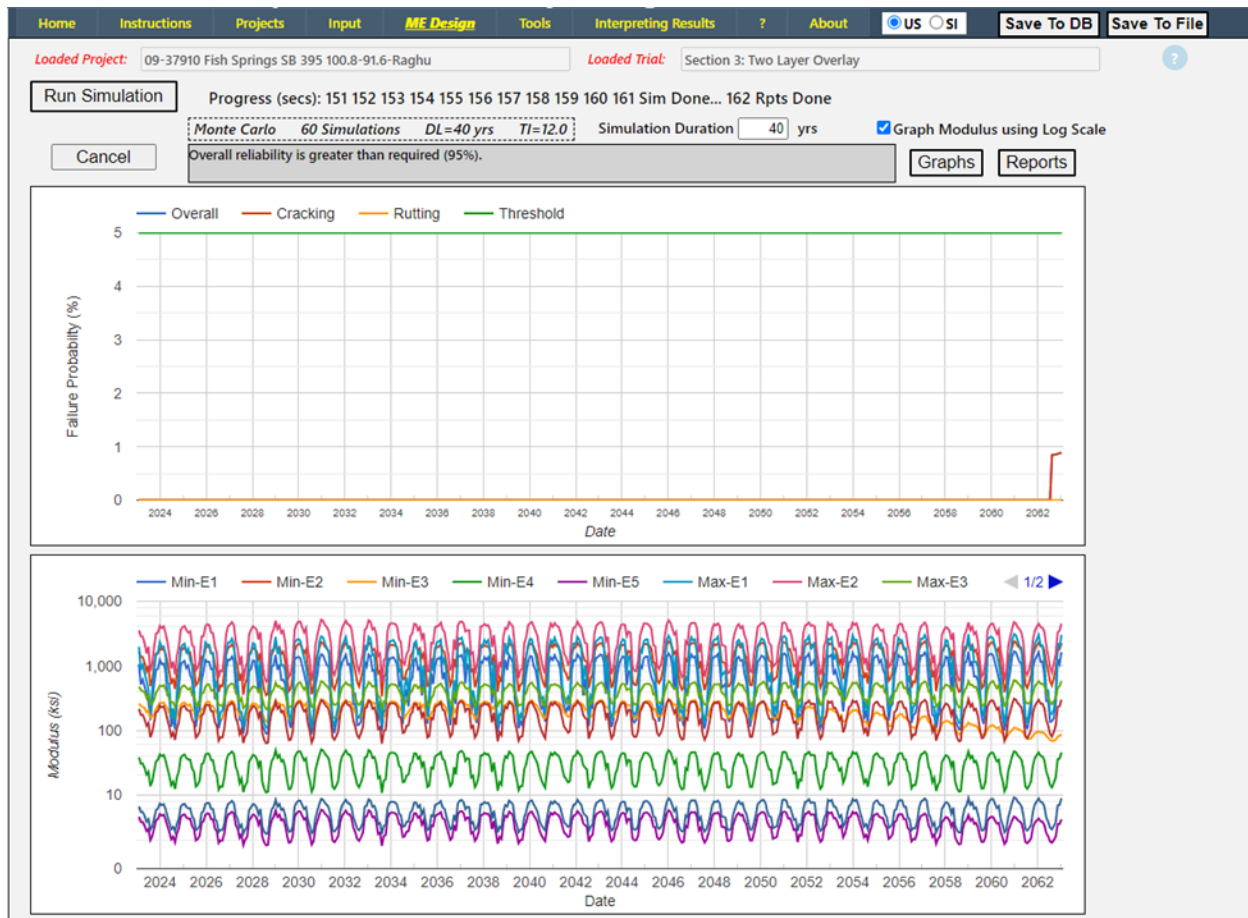
Add Treatment

Note that the cracked layers have to be changed to "from 3 to 3". Otherwise CalME will issue a warning and no analysis is allowed because Layer 4 is now the existing AB, which can not be served as the cracked layer.

Several iterations were tried before reaching the final design, which requires 0.65 ft for the second layer and a total thickness of 0.85 ft. In this case, using the rich bottom mix can reduce the total AC thickness required by 0.05 ft. The results of the CalME analyses are summarized below in Table 3. The simulation result of the final design is shown in the figure below.

Table 3: Two-Layer Plain Overlay CalME Results

Total AC Thickness (ft)	HMA Thickness for Layer 2 (ft)	Cracking Reliability (%)	Rutting Reliability (%)	Overall Reliability (%)	Number of Simulations in Monte Carlo Analysis	Years to failure (year)
0.75	0.55	82	97	82	60	32.3
0.80	0.60	93	98	93	60	39.8
0.85	0.65	98	100	98	60	>40

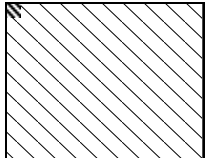
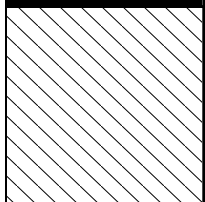
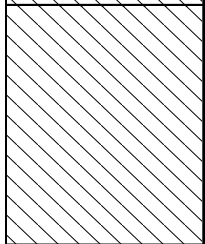


4.4.3.1.4.2. Remove HMA and Replace

One of the alternative is to mill off the old HMA to remove the possibility of reflective cracking. Since the cracks originated from bottom, all the old HMA should be milled off. A new two layer system will then be placed on top of the exposed AB layer.

To evaluate this option, load the baseline trial for Section 3 and saved a copy as "Section 3: Remove HMA and Replace".

The proposed design is shown in the figure below.

	Layer: HMA-PM Thickness: 0.2 ft (60 mm) Type: 2020 Std. HMA Type A with PG64-28M binder Stiffness: 627.9 ksi (4330 MPa)
	Layer: HMA Thickness: TBD Type: 2020 Std. HMA Type A with 25% RAP Stiffness: 1207.6 ksi (8326 Mpa)
	Layer: Class 2 AB Thickness: 0.4 ft (120 mm) Stiffness: 59 ksi (407 MPa) USCS: GM
	Layer: Subgrade Thickness: Semi infinite Stiffness: 3.6 ksi (24.8 MPa) USCS: SC R-value: 5

The project inputs are shown below with the layer 2 thickness set to 0.65 ft for one of the iterations tried.

Home Instructions Projects **Input** ME Design Tools Interpreting Results ? About US SI Save To DB Save To File

Project ID 09-37910 Fish Springs SB 395 100.8-91.6-Raghu Trial Title Section 3: Remove HMA and Replace

Project Location

District County Route Direction PM Start PM End No. Lanes

9 Inyo 395 South None 99.000 None 96.980 None 2

Project Length: 2.020 mi Lane Miles: 4.040 Avg #lanes: 2.00

Traffic Count Information

Location Location Description AADT AADTT % Trucks

97.462-98.542 2,975 602 20.2

Climate

Climate Zone High Desert

Suggested High Desert

Design Lane Traffic Loads

Load Distribution (WIM Station) Group1b

Suggested Group1b

Growth Rate (From First Year) 5.6 %

First Year Axles / Design Lane 623,922

First Year Trucks / Design Lane 246,032

Design Life 40 yrs Total ESALS 11,217,739 TI 12.0 (rounded)

Create a Trial Structure
(Using Design Life and TI)

Subgrade SC

Generate

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): psi TS->CSS TS->LSS CTB-Class B Apply Delete All

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft3)	Actions
1		HMA	90	2020 Standard HMA Type A Mix with PG 64-28M polymer modified binder for non-PRS Projects	0.20	572.0	N/A	1.64	0.00	Edit Delete Insert
2		HMA	90	2020 Standard HMA Type A Mix with 25% RAP for non-PRS Projects	0.65	1,207.6	N/A	1.64	0.00	Edit Delete Insert
3		AB	N/A	2020 Standard AB-Class 2	0.41	59.4	N/A	1.10	0.00	Edit Delete Insert
4		Subgrade	N/A	2020 Standard SC	∞	3.6	5	N/A	0.00	Edit Delete Insert

Add Layer Add 2 Layers Add 3 Layers Add 4 Layers Add 5 Layers For SC Subgrade, AB-min is 0.35 or Equiv.

The simulation parameters are shown below. Note that the reflection cracking option has been deactivated.

Several iterations were run to determine the minimum thickness of the HMA layer to carry the design traffic for the design life. The results are provided in Table 4. The results show that the thickness of the HMA should be at least 1.1 ft with a 0.20 ft HMA-PM overlay to carry the design traffic for 40 years.

Table 4: Mill and Overlay CalME Results

Total AC Thickness (ft)	HMA Layer 2 Thickness (ft)	Cracking Reliability (%)	Rutting Reliability (%)	Overall Reliability (%)	Number of Simulations in Monte Carlo Analysis	Years to failure (years)
0.85	0.65	50	0	0	20	2.6
1.2	1.0	100	85	85	20	29.7
1.3	1.1	100	95	95	20	>40
1.3	1.1	100	98	98	60	>40

The simulation result for the final design is shown in the following figure:

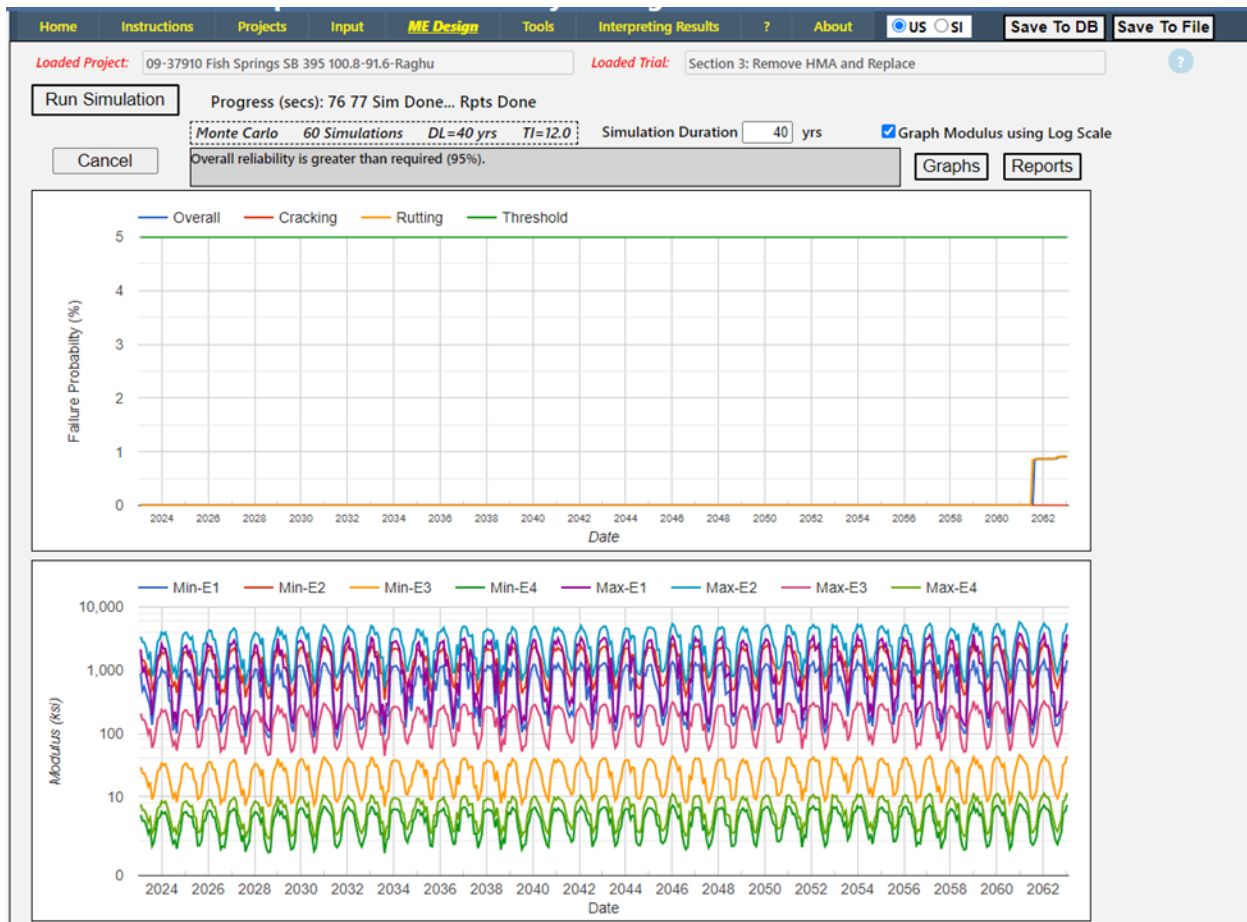


Table 4 suggests that the controlling failure mode is rutting. The layer compression summary is shown below, which suggests that the rutting mostly comes from the HMA-PM layer and the subgrade. Given the specific climate zone (High Desert), there is no other option for the surface mix. However, this suggests that strengthening the subgrade may be helpful.

Layer Compression		
Average of All Simulations For Last Time Step		
Layer	Avg Compression (in)	Percent of Total (%)
1	0.125	45.81
2	0.023	8.59
3	0.015	5.47
4	0.110	40.12
Total	0.273	100.00

4.4.3.1.4.3. FDR and Overlay

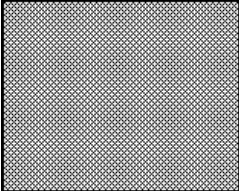
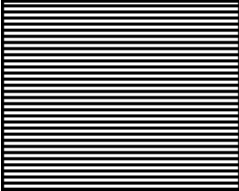
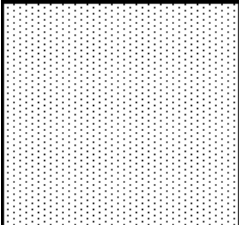
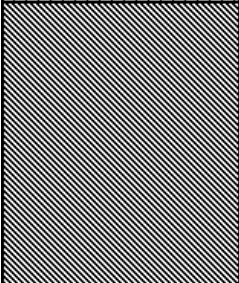
The original site investigation has shown that the cracks are predominantly bottom-up distresses. Following the recycling guide ([Guide for Partial- and Full-Depth Pavement Recycling in California](#)), PDR is not an option since the distresses are deeper than 0.4 ft.

With 0.65 ft of old HMA thickness and 0.4 ft of AB below, FDR is an appropriate option. In this example, section 3 had less than 15% passing the # 200, and the PI was less than 6. FDR-FA is thus an appropriate strategy. Given the low stiffness in the SC subgrade, a 0.35 ft of AB is kept in place to help achieve good compaction for the FDR layer. The maximum thickness for FDR is $0.70 \times 1.07 = 0.75$ ft if no fresh AB is added on top of the old HMA before FDR operation.

Two options are evaluated here, one with 0.75 ft of FDR which does not require importing fresh AB, and the other with 1.0 ft of FDR and requires importing 0.30 ft of new AB.

Note: FDR-FA itself can be placed directly over subgrade to provide a good construction platform for the upper layers.

The proposed design shown in the figure below. In this example, the goal is to design the thickness of the HMA layer. The structure will be capped with a 0.20 ft HMA-PM overlay.

	Layer: HMA-PM Thickness: 0.2 ft (60 mm) Type: 2020 Std. HMA Type A with PG68-28M binder Stiffness: 627.9 ksi (4330 MPa)
	Layer: HMA Thickness: TBD Type: 2020 Std. HMA Type A with 25% RAP Stiffness: 1207.6 ksi (8326 MPa)
	Layer: FDR-FA Thickness: 0.75 ft or 1.0 ft (225 mm or 300 mm) Type: 2020 Std. FDR-FA Stiffness: 435.1 ksi (3000 MPa)
	Layer: Class 2 AB Thickness: 0.35 ft (120 mm) Stiffness: 59 ksi (407 MPa) USCS: GM
	Layer: Subgrade Thickness: Semi infinite Stiffness: 3.6 ksi (24.8 MPa) USCS: SC R-value: 5

Load the "Section 3: Remove and Replace" trial and save a copy of it as "Section 3: FDR and Overlay". Change the AB thickness to 0.35 ft, and add the FDR and HMA layers. The project inputs are shown below:

The screenshot displays the CalME software interface with the following sections and inputs:

- Project Information:** Project ID: 09-37910 Fish Springs SB 395 100.8-91.6-Raghu; Trial Title: Section 3: FDR and Overlay.
- Project Location:** District: 9, County: Inyo, Route: 395, Direction: South, PM Start: 99.000, PM End: 96.980, No. Lanes: 2. Project Length: 2.020 mi, Lane Miles: 4.040, Avg #lanes: 2.00.
- Traffic Count Information:** Location: 97.462-98.542, Location Description: , AADT: 2,975, AADTT: 602, % Trucks: 20.2.
- Climate:** Climate Zone: High Desert, Suggested: High Desert.
- Design Lane Traffic Loads:** Load Distribution (WIM Station): Group1b, Growth Rate (From First Year): 5.6%, First Year Axles / Design Lane: 623,922, First Year Trucks / Design Lane: 246,032. Design Life: 40 yrs, Total ESALs: 11,217,739, TI: 12.0 (rounded).
- Create a Trial Structure:** Subgrade: SC, Generate button.
- Pavement Structure:** Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): psi, TS->CSS, TS->LSS, CTB-Class B. Table with 10 columns: #, Old, Layer Type, Age (d), Material, Thickness (ft), Modulus-E (ksi), R-value, GF, Cost (\$/ft3), Actions.

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft3)	Actions
1		HMA	90	2020 Standard HMA Type A Mix with PG 64-28M polymer modified binder for non-PRS Projects	0.20	572.0	N/A	1.64	0.00	Edit Delete Insert
2		HMA	90	2020 Standard HMA Type A Mix with 25% RAP for non-PRS Projects	0.50	1,207.6	N/A	1.64	0.00	Edit Delete Insert
3		FDR	90	2020 Standard FDR-FA	0.75	435.1	N/A	N/A	0.00	Edit Delete Insert
4		AB	N/A	2020 Standard AB-Class 2	0.35	59.4	N/A	1.10	0.00	Edit Delete Insert
5		Subgrade	N/A	2020 Standard SC	∞	3.6	5	N/A	0.00	Edit Delete Insert

Several iterations were run to determine the thicknesses the FDR and HMA layer to carry the design traffic for the design life. Designs were completed with FDR thicknesses of 0.75 ft and 1.0 ft to determine minimum thickness for the HMA layer. The results are summarized in Table 6. The results show that the minimum thickness of HMA reduces as the FDR layer thickness increases, requiring a minimum of 0.45 ft and 0.30 ft of HMA for FDR thicknesses of 0.75 ft and 1.0 ft respectively. The type of failure is predominantly rutting as a result of compression in the HMA-PM and subgrade.

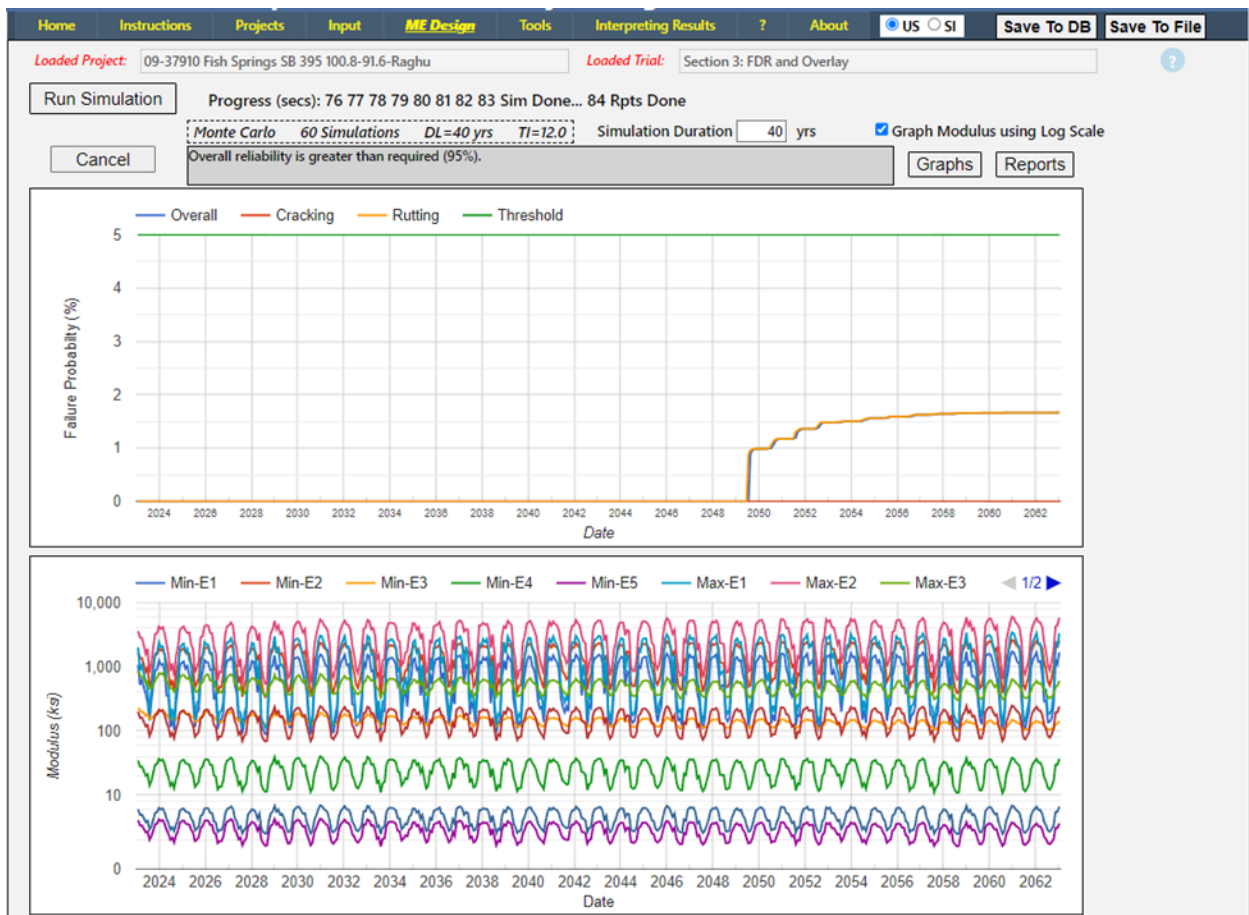
Table 6: CalME Results for FDR and Overlay Designs

Total AC Thickness (ft)	FDR Thickness (ft)	HMA Layer 2 Thickness (ft)	Cracking Reliability (%)	Rutting Reliability (%)	Overall Reliability (%)	Number of Simulations in Monte Carlo Analysis	Years to failure (years)
0.50	0.75	0.30	65	25	25	20	24.6

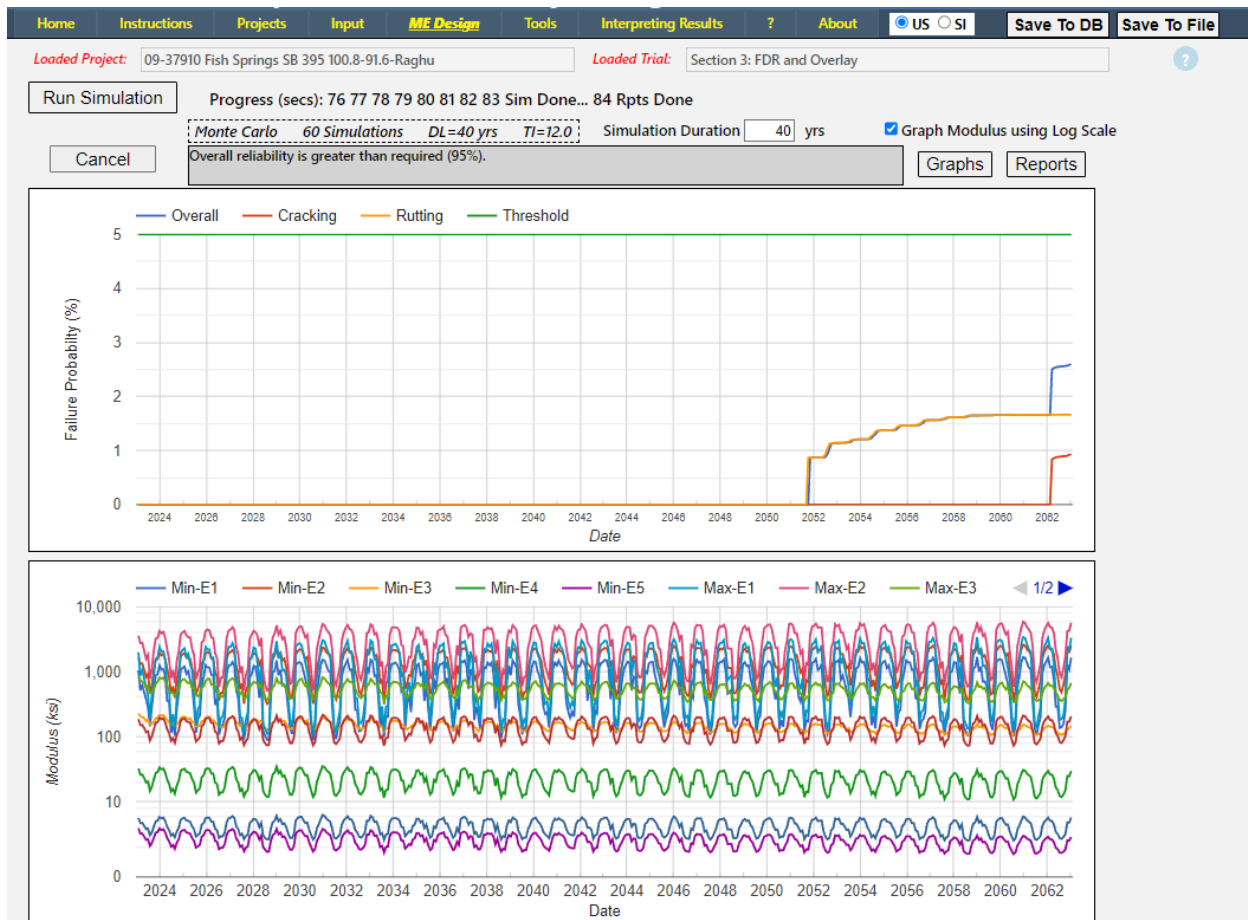
0.80	0.75	0.60	100	100	100	20	>40
0.65	0.75	0.45	100	100	100	20	>40
0.60	0.75	0.40	100	95	95	20	>40
0.60	0.75	0.40	100	93	93	60	36.6
0.65	0.75	0.45	100	98	98	60	>40
0.60	1.0	0.40	100	100	100	20	>40
0.40	1.0	0.20	70	90	65	20	29.3
0.50	1.0	0.30	100	100	100	20	>40
0.50	1.0	0.30	98	98	97	60	>40

*: shaded rows indicate optimal designs

The simulation results for 0.75 ft FDR option is shown below:



The simulation results for 1.0 ft FDR option is shown below:



4.4.3.1.4.4. CCPR with Subgrade Stabilization

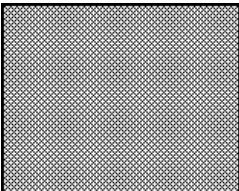
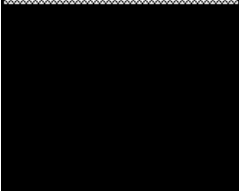
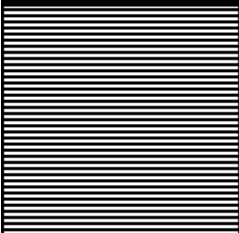
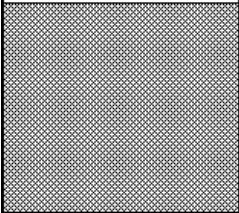
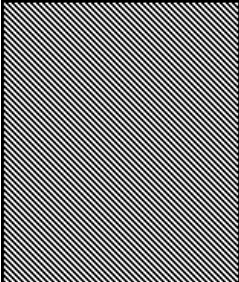
Given that the subgrade is rather weak, it is worthwhile to consider CCPR with subgrade stabilization. It is assumed that there is available site nearby where an CCPR plant can be set up. Since the percent passing the #200 is less than 15%, and the PI is less than 6, CCPR-FA or CCPR-EA are feasible recycling strategies.

For the subgrade, it is assumed that the PI is greater than 20 since the detailed USCS test results were not available for this analysis. For actual designs please obtain the actual test results and design accordingly.

Following the design guide, with a PI greater than 20, it is recommended to use a combination of lime and cement, first to modify the subgrade, then to stabilize the subgrade to provide a cement stabilized soil (CSS) layer with a target design strength of 300 psi.

The proposed design is shown in the figure below. In this example, the goal is to design the thickness of the HMA layer. Note that the CCPR layer is assumed to be 1.1 ft, which is the combined thickness of the existing HMA and AB multiply by a swell factor of 1.07. A minimum of 0.5 ft AB is typically required over the CSS layer to prevent shrinkage cracks in the CSS layer from reflecting to the upper layer. In this case the CCPR layer is believed to be able to stop the

reflection of shrinkage cracks so no new AB is needed above the CSS layer.

	Layer: HMA-PM Thickness: 0.2 ft (60 mm) Type: 2020 Std. HMA Type A with PG68-28M binder Stiffness: 627.9 ksi (4330 MPa)
	Layer: HMA Thickness: TBD Type: 2020 Std. HMA Type A with 25% RAP Stiffness: 1207.6 ksi (8326 MPa)
	Layer: CCPR-FA or CCPR-EA Thickness: 1.10 ft (330 mm) Type: 2020 Std. CCPR-FA or CCPR-EA Stiffness: 261.1 (1800 MPa)
	Layer: CSS Thickness: 1' (300 mm) Type: 2020 Std. CSS UCS: 300 psi (2.1 MPa)
	Layer: Subgrade Thickness: Semi infinite Stiffness: 3.6 ksi (24.8 MPa) USCS: SC R-value: 5

To evaluate this option, save a copy of the baseline trial for Section 3 as "Section 3: CCPR and CSS". After removing the existing HMA and AB layer, and adding the new layers, the project inputs are shown below:

Home Instructions Projects **Input** ME Design Tools Interpreting Results ? About US SI Save To DB Save To File

Project ID 09-37910 Fish Springs SB 395 100.8-91.6-Raghu Trial Title Section 3: CCPR and Overlay

Project Location

District County Route Direction PM Start PM End No. Lanes

9 Inyo 395 South None 99,000 None 96,980 None 2

Project Length: 2.020 mi Lane Miles: 4.040 Avg #Lanes: 2.00

Traffic Count Information

Location Location Description AADT AADTT % Trucks

97.462-98.542 2,975 602 20.2

Climate

Climate Zone High Desert

Suggested High Desert

Design Lane Traffic Loads

Load Distribution (WIM Station) Group1b

Suggested Group1b

Growth Rate (From First Year) 5.6 %

First Year Axles / Design Lane 623,922

First Year Trucks / Design Lane 246,032

Design Life 40 yrs Total ESALs 11,217,739 TI 12.0 (rounded)

Create a Trial Structure
(Using Design Life and TI)

Subgrade SC

Generate

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): 300 psi TS->CSS TS->LSS CTB-Class B Apply Delete All

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft ³)	Actions
1		HMA	90	2020 Standard HMA Type A Mix with PG 64-28M polymer modified binder for non-PRS Projects	0.20	572.0	N/A	1.64	0.00	Edit Delete Insert
2		HMA	90	2020 Standard HMA Type A Mix with 25% RAP for non-PRS Projects	0.20	1,207.6	N/A	1.64	0.00	Edit Delete Insert
3		CCPR	90	2020 Standard CCPR-EA or CCPR-FA	1.10	261.1	N/A	1.50	0.00	Edit Delete Insert
4		TS	28	2020 Standard CSS (Needs UCS)	1.00	119.9	N/A	N/A	0.00	Edit Delete Insert
5		Subgrade	N/A	2020 Standard SC	∞	3.6	5	N/A	0.00	Edit Delete Insert

Add Layer Add 2 Layers Add 3 Layers Add 4 Layers Add 5 Layers For SC Subgrade, AB-min is 0.35 or Equiv.

Several iterations were run to determine the thicknesses the intermediate HMA layers to carry the design traffic for the design life. The results are provided in Table 6. The results show that the minimum required thickness of the intermediate HMA layer is 0.20 ft. The dominant failure in this design has changed from rutting in other alternatives to fatigue cracking in this case.

Table 6: CCPR and Subgrade Stabilization CalME Results

Total AC Thickness (ft)	CCPR Thickness (ft)	HMA Thickness (ft)	Cracking Reliability (%)	Rutting Reliability (%)	Overall Reliability (%)	Number of Simulations in Monte Carlo Analysis	Years to failure (years)
0.40	1.10	0.20	95	100	95	20	>40
0.40	1.10	0.20	97	100	97	60	>40

*: shaded row indicates the optimal design

4.4.3.1.5. CS-R01 Design Summary

The designs considered in this example illustrate several design options to rehabilitate a severely distressed section of IN395 with a weak subgrade. The design options ranged from strategies where none of the existing distresses are removed, to strategies that increasingly removed distresses to deeper depths while stabilizing underlying materials to create a stronger foundation. The total thickness of HMA (HMA-PM, intermediate HMA and rich-bottom HMA) are summarized in the figure below to illustrate the reduction in new HMA requirements for different

strategies to carry the design traffic, along with the new materials introduced. The design examples show the following:

- Using FDR or CCPR can significantly reduce the total HMA required. LCA and LCCA are required to evaluate the alternatives to rank them both in cost and sustainability respectively.
- Using CSS to stabilize the subgrade can change the failure mode from rutting to cracking

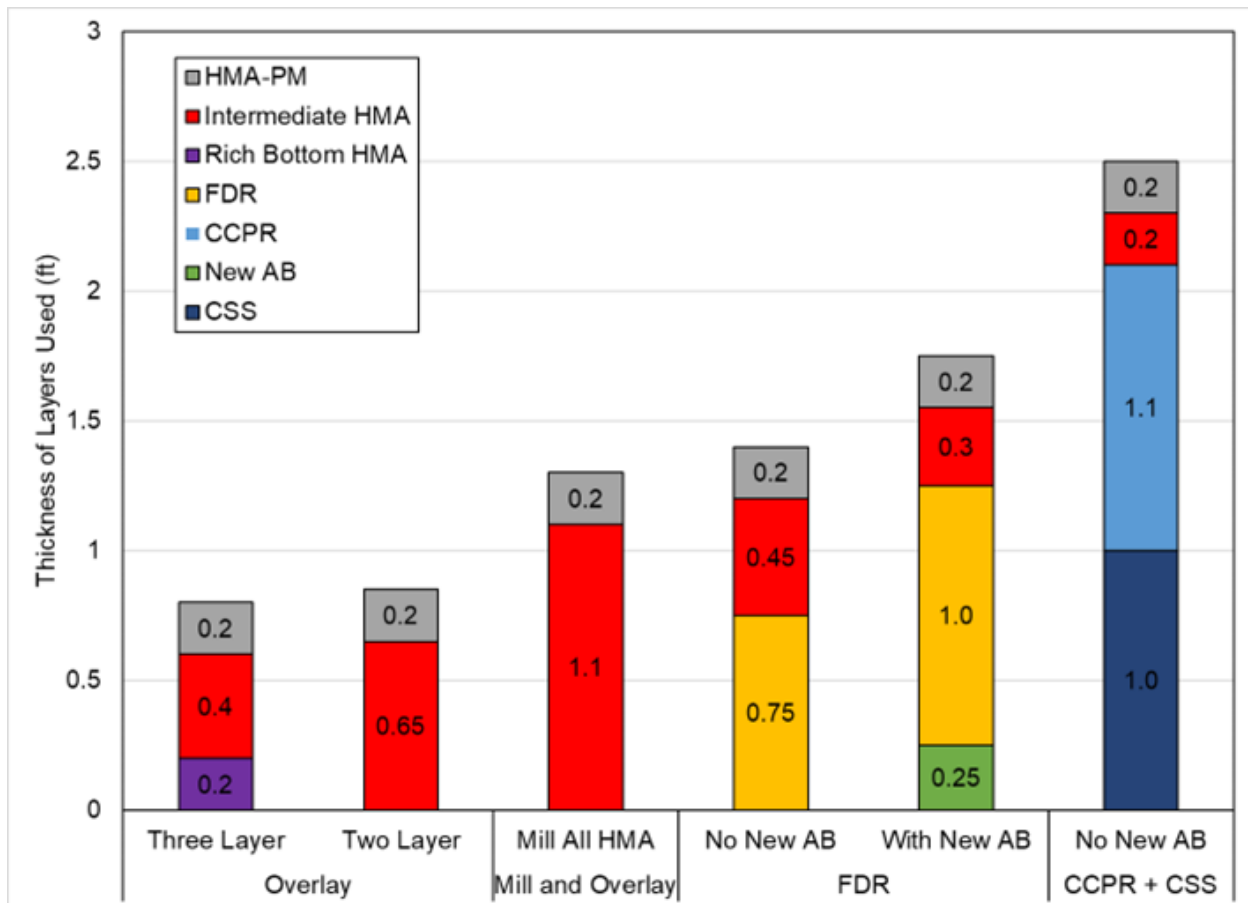


Figure 16: Thickness for layers used in each design alternative

4.5. Training Videos

The following is a list of training videos recorded from one of the *Ca/ME* training sessions.

Note that *Ca/ME* has undergone some changes both in user interface and actual design since the time of recording for these videos. Some inconsistencies between the video

and the current version of the software are expected.

Video ID	Description and Link
TA1	<i>CalME</i> Training Module A: Background to Mechanistic-E ME in Design, Reliability, and Calibration of
TA2	<i>CalME</i> Training Module A: Background to Mechanistic-E ME in Design, Reliability, and Calibration of
TB	<i>CalME</i> Training Module B : Site Investigation and Process
TC	<i>CalME</i> Training Module C : Hands-on Training for <i>CalME</i>

User Interface

This section was prepared based on version 3.DD002.

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

- In addition to links to Caltrans and UCPRC, link to the old version of CalME is provided here to allow smoother transition between versions.

1. Page tabs - you navigate between application pages by selecting a page tab
 - Home - the home page
 - Instructions - basic instructions on how to use *Ca/ME*, currently only provides links to this online help and some files used for *Ca/ME* training.
 - 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-Web and CalAC-Web.
 - Interpreting Results - this page is still under construction and will provide assistance in understanding the results generated by *Ca/ME*
 - About - a page that provides information about *Ca/ME*
3. Unit selection - *Ca/ME* 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 *Ca/ME* 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. *Ca/ME* 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 *Ca/ME*.
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

5.2.1. Manage DB Projects

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.

Projects and Trials Stored in the Database

Loaded Project: Long Life Project

Loaded Trial: Long Life Trial 1

Trial Title	Trial Description	
11	11	Delete
4	4	Delete
5	5	Delete

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:

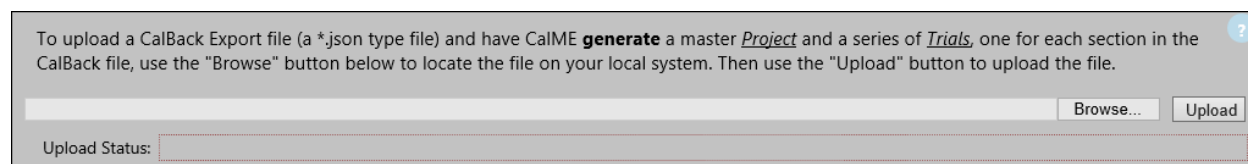
- Loaded Trial - used to select a trial contained in the selected *CalME* project
- Save Trial As - used to make a copy of the selected trial that will be added to the list of trials in the selected *CalME* project
- Trial Title hyperlink - used to edit atrial
- Delete button - used to delete a trial

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 screenshot shows a web-based interface for uploading a CalBack file. At the top, there is a text box with instructions: "To upload a CalBack Export file (a *.json type file) and have CalME **generate** a master *Project* and a series of *Trials*, one for each section in the CalBack file, use the "Browse" button below to locate the file on your local system. Then use the "Upload" button to upload the file." To the right of this text is a blue circle with a white question mark. Below the text is a file input field with a "Browse..." button to its right. Below the input field is an "Upload" button. At the bottom, there is a label "Upload Status:" followed by a red-outlined rectangular box.

If valid project location data (district, county, route, direction, and beginning and ending

postmiles) are entered in *CalBack*, *CalME* will automatically extract these data and setup the project location, traffic, and climate. See [here](#) for an example.

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).

5.2.3. 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 inputs for the selected trial to your local computer 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. 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 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.

To load an existing *CalME* input file (a *.json-type file) into *CalME*, use the "Browse" button below to locate the file on your local system. Then use the "Upload" button to upload the input file.

☒ Create a New Project for the Uploaded File
 ☐ Add the Uploaded File To the Currently Loaded Project

Upload Status:

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

- Radio buttons to select the destination project for the uploaded file data
 - Create a New Project for the Uploaded File - selecting this option will create a new Project for file data using the name of the project in the file. This is the default action.
 - Add the Uploaded File to the Currently Loaded Project - selecting this option will add the file data to the currently load project
- 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](#)

Project Location

District: 1 County: Del Norte Route: 101 Direction: North PM Start: 0.000 PM End: 0.967 No. Lanes: 2

Project Length: 1.000 mi Lane Miles: 2.000 Avg #lanes: 2.00

Traffic Count Information

Location: R0.347-R0.510 Location Description: AADT: 1,400 AADTT: 204 % Trucks: 14.6

Design Lane Traffic Loads

Load Distribution (WIM Station): Group1b Suggested: Group1b

Growth Rate (From First Year): 6.0 %

First Year Axles / Design Lane: 3,268,996

First Year Trucks / Design Lane: 1,289,066

Design Life: 20 yrs Total ESALs: 21,979,808 TI: 13.0 (rounded)

Climate

Climate Zone: North Coast Suggested: North Coast

Create a Trial Structure
(Using Design Life and TI)

Subgrade: CH Generate

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): psi TS->CSS TS->LSS CTB-Class B Apply Delete All

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft3)	Actions
1		RHMA-G	90	2020 Standard RHMA-G with PG 64-16 base binder for non-PRS Projects	0.20	627.9	N/A	N/A	0.00	Edit Delete Insert
2		FDR	90	2020 Standard FDR-FA	0.70	435.1	N/A	N/A	0.00	Edit Delete Insert
3		AB	N/A	2020 Standard AB-Class 2	0.85	45.0	78	1.10	0.00	Edit Delete Insert
4		Subgrade	N/A	2020 Standard CH	∞	4.4	6	N/A	0.00	Edit Delete Insert

Add Layer Add 2 Layers Add 3 Layers Add 4 Layers Add 5 Layers For CH Subgrade, AB-min is 1.00 or Equiv.

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

Project Location

District * County * Route * Direction *

PM Start * PM End *

Project Length: -1.000 Lane Miles: -1.000 Avg #lanes: 2

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.

Note: There are some special considerations when entering project location. A segment may be managed by the neighboring district that does not officially cover the county. For example, Route 14 in Kern county between PM 15.0 and 16.0 is managed by District 9 rather than District 6. In this case you will enter the project location using District 9, Kern9 County. Other special counties includes SM5 (San Mateo5), BUT2 (Butte2), LA12 (Los Angeles12), MPA6 (Mariposa6), SLO6 (San Luis Obispo6) and VEN5 (Ventura5).

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.

Project Location

District	County	Route	Direction	PM Start	PM End	No. Lanes
1	Del Norte	101	North	M 0.000 None	R 0.967 None	2

Project Length: 1.000 mi Lane Miles: 2.000 Avg #lanes: 2.00

Ca/ME will also assist with a manual PM specification, as illustrated below.

Project Location

District	County	Route	Direction	PM Start	PM End	No. Lanes
1	Del Norte	101	North	M 0.000 None	R 100.000 None *	2

Project Length: Lane Miles: Avg #lanes:

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.

Ca/ME 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 *Ca/ME* uses the latest official release of it.

Error Message Summary

- PM End value unknown

Ca/ME 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 *Ca/ME* 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)

Traffic Count Information				
Location	Location Description	AADT	AADTT	% Trucks
R0.347-R0.510		1,400	204	14.6

The second set of traffic controls, shown below, are used to specify traffic loads in the Design lane. *Ca/ME* 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 (WIM Station) - *Ca/ME* 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 *Ca/ME* populates. *Ca/ME* 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.

- Growth Rate (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.

Design Lane Traffic Loads

Load Distribution (WIM Station)

Group1b

Suggested Group1b

Growth Rate (From First Year)

6.0 %

First Year Axles / Design Lane

6,089,825

First Year Trucks / Design Lane

2,401,405

Design Life

20 yrs

Total ESALs

40,971,646

TI

14.0 (rounded)

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 will change First Year Axles / Design Lane, First Year Trucks / Design Lane and TI.

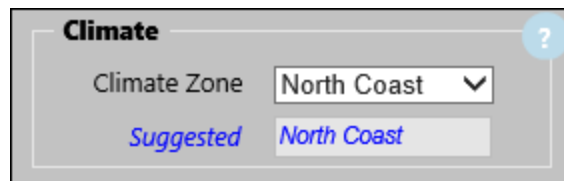
The question mark in the blue circle in the upper-right of the control group allows you to get help on the controls (this topic).

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 image shows a software control panel titled "Climate". It contains a dropdown menu labeled "Climate Zone" with "North Coast" selected. Below the dropdown, the word "Suggested" is written in blue, followed by a text box containing "North Coast". A blue circle with a white question mark is located in the top right corner of the panel.

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.

Ca/ME 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). You will be prompted for relevant rules when setting up the pavement structure. The rules prompted in red texts are mandatory and must be followed before one can start M-E simulations.

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): 500 psi ☐ TS->CSS ☐ TS->LSS ☐ CTB-Class B

#	Old	Layer Type	Age (d)	Material	Thickness	Modulus-E	R-value	GF	Cost	Actions
No pavement layers										

Pavement structure must have at least two layers

For new constructions, user can also use *Ca/ME* to provide a trial structure once the climate, design life, traffic volume (traffic index), and subgrade type has been defined (see below). The trial structure will be loaded into the Pavement Structure grid and ready for further refinement.

Home Instructions Projects **Input** ME Design Tools Interpreting Results ? About US SI Save To DB Save To File

Project ID: Workspace project title-769 Trial Title: Workspace trial title-769

Project Location

District: 1 County: Del Norte Route: 101 Direction: North PM Start: M 0.000 PM End: R 0.967 No. Lanes: 2

Project Length: 1.000 mi Lane Miles: 2.000 Avg #Lanes: 2.00

Traffic Count Information

Location: R0.347-R0.510 Location Description: AADT: 1,400 AADTT: 204 % Trucks: 14.6

Climate

Climate Zone: North Coast Suggested North Coast

Design Lane Traffic Loads

Load Distribution (WIM Station): Group1b Suggested Group1b

Growth Rate (From First Year): 6.0 %

First Year Axles / Design Lane: 3,268,996

First Year Trucks / Design Lane: 1,289,066

Design Life: 20 yrs Total ESALs: 21,979,808 TI: 13.0 (rounded)

Create a Trial Structure (Using Design Life and TI)

Subgrade: CH Generate

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): psi TS->CSS TS->LSS CTB-Class B Apply Delete All

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft3)	Actions
1		RHMA-G	90	2020 Standard RHMA-G with PG 64-16 base binder for non-PRS Projects	0.20	627.9	N/A	N/A	0.00	Edit Delete Insert
2		PDR	90	2020 Standard PDR-FA	0.70	435.1	N/A	N/A	0.00	Edit Delete Insert
3		AB	N/A	2020 Standard AB-Class 2	0.85	45.0	78	1.10	0.00	Edit Delete Insert
4		Subgrade	N/A	2020 Standard CH	∞	4.4	6	N/A	0.00	Edit Delete Insert

Add Layer Add 2 Layers Add 3 Layers Add 4 Layers Add 5 Layers For CH Subgrade, AB-min is 1.00 or Equiv.

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 and return to the read-only mode.

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.

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): 500 psi TS->CSS TS->LSS CTB-Class B Apply Delete All

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft ³)	Actions
1		HMA	90	2020 Standard HMA Type A Mix with polymer modified binder for non-PRS Proj	1.00	447.0	N/A	1.85	0.00	Save Cancel
2		AB	N/A	Change me	-1.00	0.0	N/A	N/A	0.00	Edit Delete Insert
3		Subgrade	N/A	Change me	∞	0.0	N/A	N/A	0.00	Edit Delete Insert

Add Layer Add 2 Layers Add 3 Layers Add 4 Layers Add 5 Layers HDM Min thick: 0.15

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.

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): 500 psi TS->CSS TS->LSS CTB-Class B Apply Delete All

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft ³)	Actions
1		HMA	90	2020 Standard HMA Type A Mix with polymer modified binder for non-PRS Projects	1.00	447.0	N/A	2.28	0.00	Edit Delete Insert
2		AB	N/A	Change me	-1.00	0.0	N/A	N/A	0.00	Edit Delete Insert
3		Subgrade	N/A	Change me	∞	0.0	N/A	N/A	0.00	Edit Delete Insert

Add Layer Add 2 Layers Add 3 Layers Add 4 Layers Add 5 Layers Layer No. 2 has an unknown material: 'Change me'

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.

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): 500 psi TS->CSS TS->LSS CTB-Class B Apply Delete All

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft ³)	Actions
1		HMA	90	2020 Standard HMA Type A Mix with polymer modified binder for non-PRS Projects	1.00	447.0	N/A	2.28	0.00	Edit Delete Insert
2		AB	N/A	2020 Standard AB-Class 2	1.00	45.0	78	1.10	0.00	Edit Delete Insert
3		Subgrade	N/A	2020 Standard CL	∞	9.9	16	N/A	0.00	Edit Delete Insert

Add Layer Add 2 Layers Add 3 Layers Add 4 Layers Add 5 Layers For CL Subgrade, AB-min is 0.50 or Equiv.

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, PDR, CCPR, PCC, LCB, CTB-Class A, CTB-Class B, AB, ATPB, AS, TS 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). For subgrade layers (SG), thickness is usually specified as "0.0", which tells *CalME* to treat the subgrade as semi-infinite. You can, however, supply a non-zero thickness value and *CalME* will treat the subgrade layer as bedrock (a layer with zero deflection). 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: $E \text{ (psi)} = R\text{-value} * 551 + 1117$. 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: $E \text{ (psi)} = R\text{-value} * 551 + 1117$.
- 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 controls for specifying a UCS to update the modulus for a stabilized layer and deleting all layers:

- If there is a stabilized layer present in the structure, the radio button for that layer type will become enabled. If there is more than one stabilized layer, then a second radio button will become enabled. You can specify a value for Unconfined Compressive Strength (UCS), select one of the enabled radio buttons and select the Apply button to update the modulus value for that layer.
- 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.

CalME: CALTRANS Mechanistic Empirical Tool

Edit Pavement Layer Material Properties

Loaded Project: 14 Loaded Trial: 14

Current Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): 450 psi ☐ TS->CSS ☐ TS->LSS ☒ CTB-Class B

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft3)
1	☐	HMA	90	2020 Standard HMA Type A Mix with polymer modified binder for non-PRS Projects	1.00	447.0	N/A	2.28	0.00
2	☐	CTB-Class B	0	2020 Standard CTB-Class B (Needs UCS)	1.00	1,209.2	N/A	N/A	0.00
3	☐	Subgrade	N/A	2020 Standard GW	∞	38.7	68	N/A	0.00

Layer 1: Material Type **HMA**: 2020 Standard HMA Type A Mix with polymer modified binder for non-PRS Projects

Initial Age: 90 days
Poisson's Ratio: 0.35
Reference Modulus: 447.0 ksi
Unit Cost: 0.00 \$/ft3

2020 Standard HMA Type A mix with polymer modified binder for projects not adopting performance related specifications

Save Cancel

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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](#)
- [Performance Criteria](#)
- [Reflection Cracking Parameters](#)
- [Specification Type](#)
- [Monte Carlo Variability](#)
- [Maintenance and Rehabilitation \(M & R\)](#)

Home Instructions Projects **Input** ME Design Tools Interpreting Results ? About US SI Save To DB Save To File

Incremental-Recursive Parameters ?

Loaded Project: 14 Loaded Trial: 14

General ?
 Starting Date 5/20/2019 Simulation Duration 20 yrs Vehicle Speed 43.75 mph

Simulation Type ?
 ☒ Deterministic
☐ Monte-Carlo

Performance Criteria ?
 Rutting 0.4 in
 Cracking 4.9 %

Reflection Cracking ?
 ☒ None ☐ AC on AC ☐ AC on Cemented Base
 Existing Cracking (%) > 35
 Cracked layer(s) from 0 to 0 <= Find Them

Spec. Type ?
 ☐ Non-PRS
☐ PRS

Monte Carlo Variability ?
 No. of simulations 10
☒ Construction variability
 Construction Variability Table

Layer	CoV Thick	Sdf Modulus	
1	0.07	1.20	Edit
2	0.10	1.20	Edit
3	0.00	1.20	Edit

M&R Planning - This Feature is Coming Soon ?
 Populate Grid With: 60 mm HMA Overlay Every 5 years
 Your Treatment
 No treatments
 Add Treatment

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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 ?
 Starting Date 1/24/2020 Simulation Duration 20 yrs Vehicle Speed 43.75 mph

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](#)

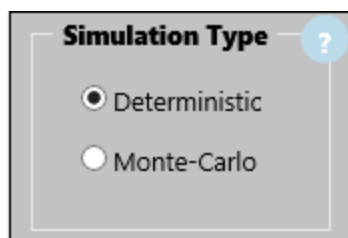
The question mark in the blue circle in the upper-right of the control group allows you to get help on the controls (this topic).

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) simulations to select from:

- Deterministic - a **single simulation** is performed on the design using the median inputs to estimate the median performance
- [Monte Carlo](#) - **multiple simulations** are performed in parallel on the design to estimate the distribution of its performance. Each simulation represents a likely as-built slice of the given design after accounting for the construction variability. The number of simulations is specified in the [Monte Carlo Variability](#) parameter section. For more details on the role of Monte Carlo simulations in *CalME* please go to [accounting for uncertainties](#).



In general, **Deterministic** simulations are performed to get close to the optimal design, and **Monte Carlo** simulations are performed to determine the optimal design, often after slightly thickening the structure. For details on how this process works see topic [Typical Design Process](#).

The default number of simulations for Monte Carlo runs is set at **60**, which is high enough to confirm whether a design to have minimum 95% reliability.

The amount of *CalME* runtime required to perform the Monte Carlo analysis is directly dependent on the number of simulations and the [simulation duration](#) (set to [Design Life](#) by default). Using a four-layer structure as an example, the following are runtimes are:

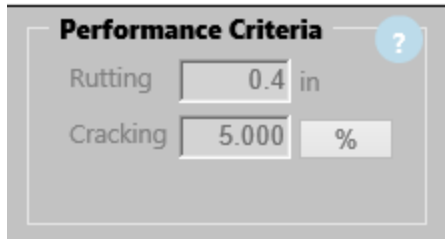
- | | | |
|---|----------------------------|-----|
| • Simulation duration = 20 yrs
seconds | Number of simulations = 10 | 19 |
| • Simulation duration = 20 yrs
seconds | Number of simulations = 60 | 64 |
| • Simulation duration = 40 yrs
seconds | Number of simulations = 60 | 121 |

This indicated that a 20 year design typically needs one minute to run, while a 40 year design needs two minutes.

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).

Performance Criteria

The following controls, located on the **Input -> Simulation Parameters Page**, are used to specify the [performance criteria](#) associated with the Mechanistic-Empirical simulation.



Performance Criteria ?

Rutting in

Cracking %

The performance criteria values are those that constitute failure for **rutting** and **cracking**. These criteria are used to determine the failure probability.

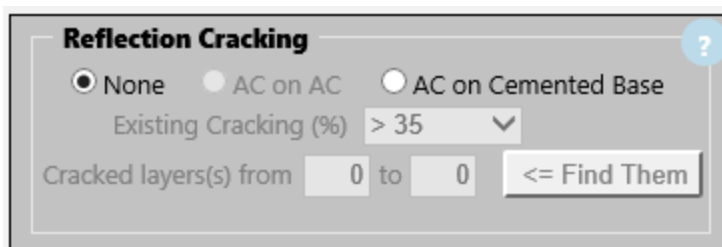
These controls are **readonly** for all *CalME* users other than those assigned to the Research Group. *CalME* users in the Research Group are permitted to change the Performance Criteria parameters.

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 Cemented Base - this radio button becomes enabled if there is HMA over a cemented base
- 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". There are five ranges of Existing Cracking:

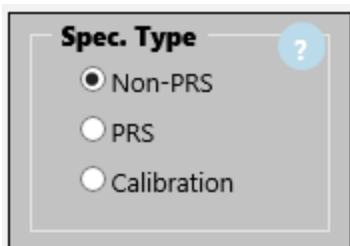
- 0 - 5
- 6 - 15
- 16 - 25
- 26 - 35
- >35
- Cracked layers(s) from - If the cracking is not reflecting from layer number 2 through an overlay, but from a deeper layer, the number of this layer must be entered in "Cracked layer" (if Cracked layer is 0 *CalME* assumes that cracks reflect from layer number 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).

Specification Type

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

Specification Type 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.



Specification Type:

- 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.

These controls are **readonly** for all *CalME* users other than those assigned to the Research Group. *CalME* users in the Research Group are permitted to change the Specification Type parameters.

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 modulus. The number of simulations is specified below. Monte Carlo takes into account within project construction variability.

Monte Carlo Variability ?

No. of simulations

☒ Construction variability

Construction Variability Table

Layer	CoV Thick	Sdf Modulus	
1	0.07	1.20	Edit
2	0.07	1.20	Edit
3	0.07	1.10	Edit
4	0.00	1.20	Edit

Monte Carlo Variability data items:

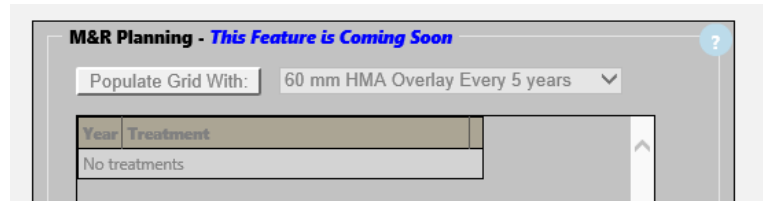
- No. of simulations - this sets the number of simulations to perform. The default is 60, which is high enough confirm whether a design can achieve a 95% or greater reliability.
- [Construction variability](#) - select this item to include construction variability. The default is to include construction 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

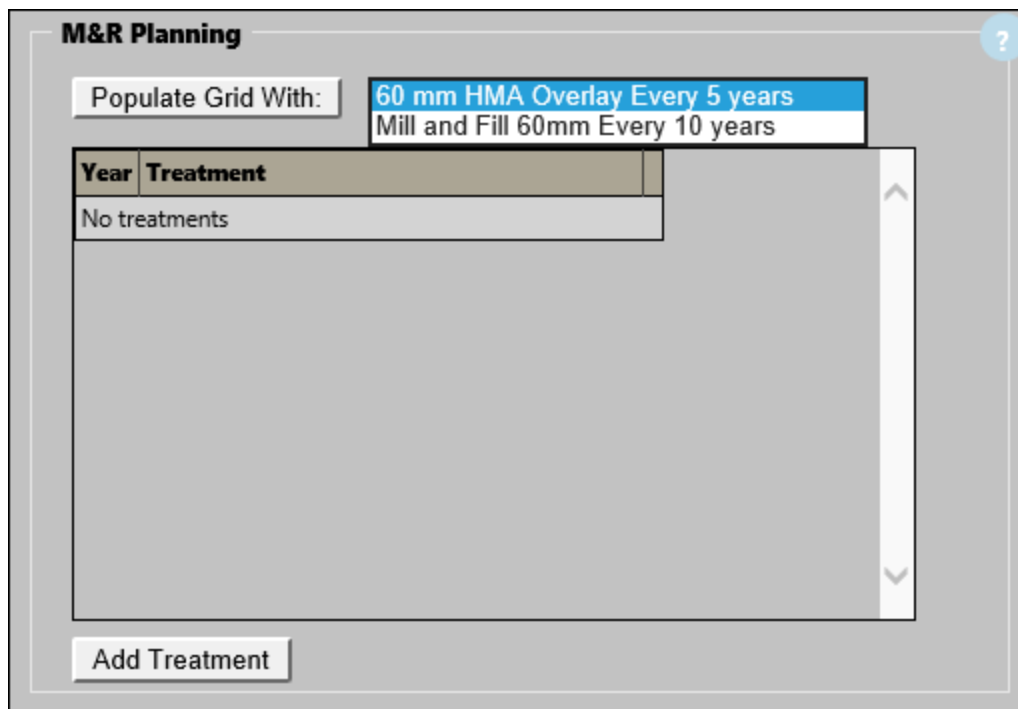
The following controls, located on the **Input -> Simulation Parameters Page**, are used to specify M&R details associated with the Mechanistic-Empirical simulation.

**** 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).

The screenshot shows the "M&R Planning" window. At the top, there is a "Populate Grid With:" dropdown menu set to "60 mm HMA Overlay Every 5 years". Below this is a table with three columns: "Year", "Treatment", and a column for actions. The table contains rows for the years 2024, 2029, 2034, 2039, 2044, 2049, and 2054. The "Treatment" column for all rows is "60 mm HMA Overlay". The action column for each row contains links: "Save Cancel" for 2024, and "Edit Delete Insert" for the other years. A dropdown menu is open for the 2024 row, showing options: "Select", "60 mm HMA Overlay", and "Mill and Fill 60mm". Below the table is an "Add Treatment" button.

Year	Treatment	
2024	Select 60 mm HMA Overlay Mill and Fill 60mm	Save Cancel
2029	60 mm HMA Overlay	Edit Delete Insert
2034	60 mm HMA Overlay	Edit Delete Insert
2039	60 mm HMA Overlay	Edit Delete Insert
2044	60 mm HMA Overlay	Edit Delete Insert
2049	60 mm HMA Overlay	Edit Delete Insert
2054	60 mm HMA Overlay	Edit Delete Insert

Add Treatment

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.

Edit Treatment

Name: 60 mm HMA Overlay

Material: AB-Class 2, HDM 2012

Thickness removed: 0.00 ft

Thickness added: 0.20 ft

Rut reduction: 0.4 in

CoV on thickness: 10 %

Save

Cancel

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.

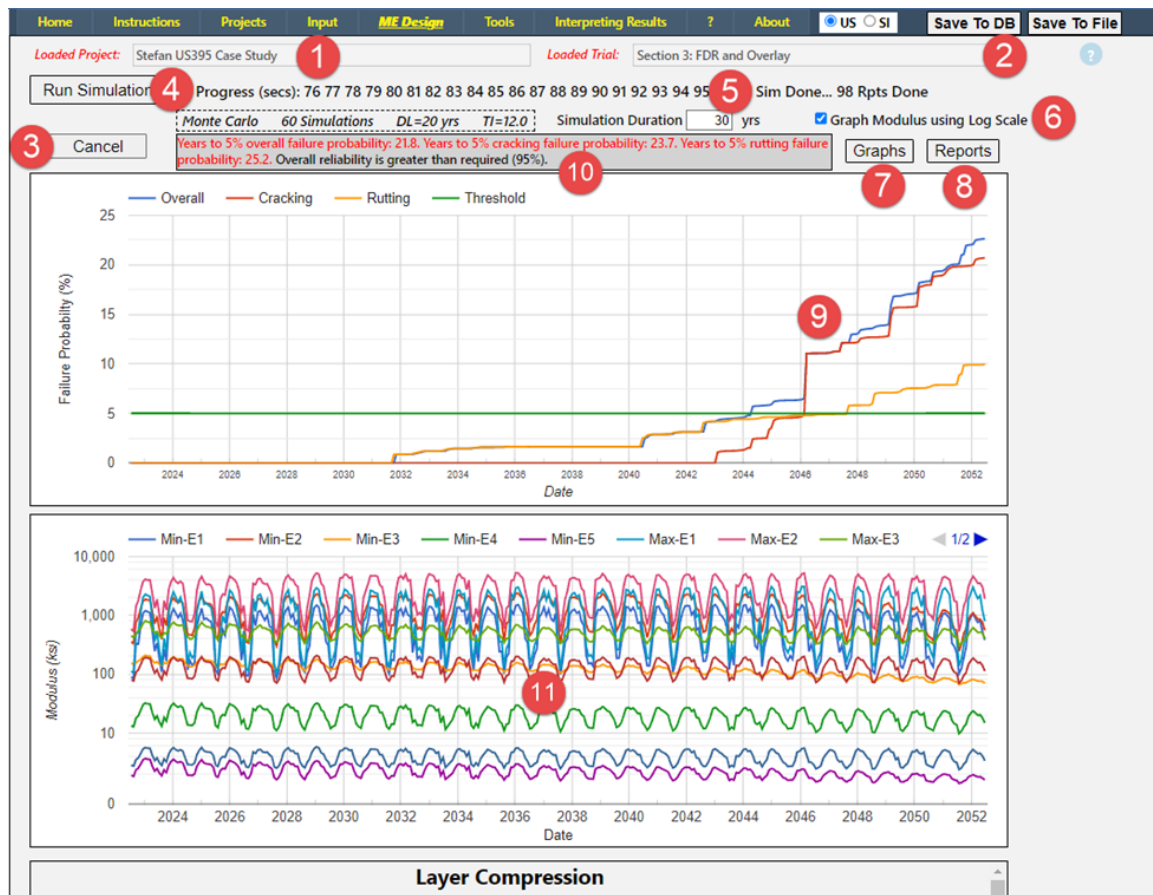
CalME can perform a **Deterministic** or **Monte Carlo** simulation depending on what is selected for [Simulation Type](#). The number of simulations performed in a Monte Carlo is set in the [Monte Carlo Variability](#) section.

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 respectively), buttons for starting the simulation ("Run Simulation") 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 (#10)
- Real-time graphing display for failure probabilities (overall, cracking, and rutting) and the 5% failure threshold (#9)
- Real-time graphing display for minimum and maximum for pavement layer moduli (#11)
- A scrollable text box control that displays pavement Layer Compression (#12), Expected Life (#13) report that also include a summary of the design reliabilities (#14) for cracking, rutting and overall respectively, once the simulation is complete. This section also includes a note (#15) on which server and port was used to run the *Ca/ME* engine.



Layer Compression		
Average of All Simulations For Last Time Step		
Layer	Avg Compression (in)	Percent of Total (%)
1	0.140	43.28
2	0.032	9.74
3	0.000	0.00
4	0.021	6.60
5	0.131	40.38

Expected Life			
Per simulation trial, year when probability exceeded performance criteria (or -- if never exceeded).			
Simulation#	Cracking	Rutting	Overall
1	--	--	--
2	--	--	--
3	--	--	--
4	--	--	--

58	--	--	--
59	--	--	--
60	--	--	--
No. Failed	0 of 60	2 of 60	2 of 60
No. Passed	60 of 60	58 of 60	58 of 60
Reliab. (%)	100	97	97

CalME engine: internal-calme-review-1459972082.us-west-1.elb.amazonaws.com:3302

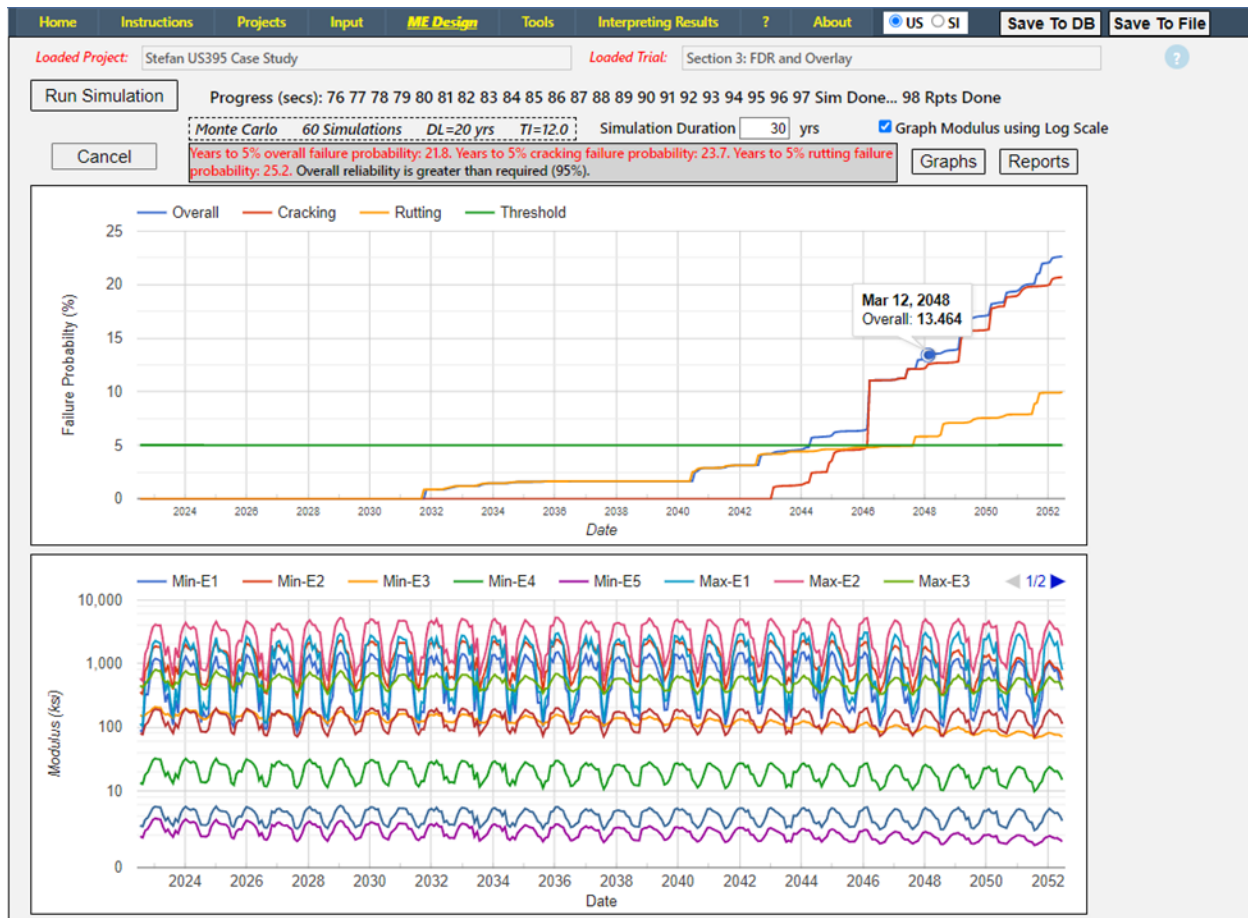
Section notes:

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 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 = 60) will take around 2 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. 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 failure probabilities of the surface, in real-time, as the simulation progresses. 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 hovering over it, as shown in the screenshot below.
10. This message area provides a summary of the simulation results including time to 5% overall failure, 5% cracking failure, or 5% rutting failure if any of them are shorter than the simulation duration. It also indicates whether the design satisfy the minimum 95% reliability. If the project inputs break any mandatory rules, there will be messaged listed in this area and the "Run Simulation" button will be disabled. In that case, one needs to review the error messages and address them before trying to run simulation again.
11. 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 hovering over it.
12. This section of the page presents the [Layer Compression](#) Report after the simulation is complete, including average layer compressions and percent contribution to total compression.
13. The [Expected Life](#) Report is presented after the Layer Compression Report, it lists the time to failure in rutting or cracking for each individual simulation

14. This section provides the tallies of simulations that failed or passed, and the design reliabilities based on cracking, rutting, and overall failure.
15. This message indicates which *CalME* engine was used to run the simulations.



Tools Page

Material Library

The Material Library page is accessed by selecting **Tools -> Material Library**.

The Material Library page allows you to see the equations and parameters for the various material models used in *CalME*. You select the Material Type (#1) and then a specific Material (#2) and *CalME* will list the applicable material models with their

parameters. Clicking on the double down arrow (#4) for one of the listed models will expand the view to show the details of the model. Clicking the up arrow will collapse the view for the model.

See the [Model Parameters](#) help topic for a discussion of the various material models used in *CalME*.

The screenshot shows the 'Material Library' window in CalME. At the top is a navigation bar with tabs: Home, Instructions, Projects, Input, ME Design, Tools, Interpreting Results, ?, and About. Below this is a 'Material Library Selection' section with two dropdown menus: 'Type' (set to 'HMA') and 'Material' (set to '2020 Standard HMA Type A Mix with 25% RAP for non-PRS Projects'). To the right of these is a text box describing the selected material. Below the selection section is a list of models, with 'Thermal Properties Model' and 'Damage Alpha Model' visible. The 'Damage Alpha Model' is expanded, showing its equation and a table of parameters. Red callout numbers 1 through 6 are placed over specific UI elements: 1 points to the 'Type' dropdown, 2 to the 'Material' dropdown, 3 to the material description text box, 4 to the expand/collapse arrow for the 'Damage Alpha Model', 5 to the model equation, and 6 to the parameter table.

Material Library Selection

Type: HMA Material: 2020 Standard HMA Type A Mix with 25% RAP for non-PRS Projects

2020 Standard HMA Type A mix with 25% RAP for projects not adopting performance related specifications

Thermal Properties Model

Damage Alpha Model

$$\omega = \left(\frac{MN}{MN_p} \right)^{\exp(\alpha)}, MN_p = A \cdot \left(\frac{\epsilon_{99.8}}{\epsilon_{ref}} \right)^{\beta} \cdot \left(\frac{E}{E_{ref}} \right)^{\gamma}$$

Parameter	Role	Type	Val1	Val2	Val3
A	P	lognormal_sdf	69.5	1.35	
SP	P		1		
α	P		0.010607		
β	P		-4.4636		
δ	P		0		
dN	I				
ε _{99.8}	I				
γ	P		-2.2318		
ω _{max}	P		0.9		
ω	O				

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Section notes:

1. Material Type selection dropdown control
2. Specific material selection dropdown control
3. Description of the selected material
4. Control to expand and collapse the pane that shows the details of a model
5. Model equation
6. Model parameters:
 - Parameter symbol
 - The role of the parameter
 - The type of the parameter
 - The value of the parameter

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.

The screenshot shows the CalFP-Web interface with the following components and callouts:

- 1**: Loaded Project: 14
- 2**: Loaded Trial: 14
- 3**: Current Pavement Structure table
- 4**: Check button
- 5**: Design button
- 6**: Design table
- 7**: Reports button

Current Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): psi ☐ TS->CSS ☐ TS->LSS ☐ CTB-Class B

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Use Min/Max	Min-Thick (ft)	Max-Thick (ft)	Modulus-E (ksi)	R-value	GF	Actions
1	☐	HMA	90	2020 Standard HMA Type A Mix with polymer modified binder for non-PRS Projects	0.40	☐	0.15	2.00	447.0	N/A	2.28	Edit
2	☐	Subgrade	N/A	2020 Standard GW	∞	☐ N/A	N/A	N/A	38.7	68	N/A	Edit

Results of the Caltrans Empirical Design Check Applied to the Current Structure

Minimum and Maximum Thickness Checks
No problems with minimum/maximum thickness checks;

Structural Adequacy Checks
Error: Gravel Equivalent Provided above Layer 2 (SG): 0.74 is less than required: 0.97;

Design Click the 'Select' button to use the design

Design	HMA	SG	AC	GF	Res	GE	TotThick	Cost/mi	Msgs	Select
1	0.55	0.00	1.86	-0.05	0.55	0	0	1	1	Select
2	0.60	0.00	1.92	0.08	0.60	0	0	1	1	Select
3	0.65	0.00	1.97	0.21	0.65	0	0	1	1	Select
4	0.70	0.00	2.02	0.34	0.70	0	0	1	1	Select
5	0.75	0.00	2.06	0.47	0.75	0	0	1	1	Select

Display CalFP-Web messages here by clicking 'Msgs' button

Reports

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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.

CalAC-Web

Home Instructions Projects Input ME Design **Tools** Interpreting Results ? About US SI Save To DB Save To File

Loaded Project: 14 Loaded Trial: 14

Current Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): psi TS->CSS TS->LSS CTB-Class B

#	Old	Layer Type	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft3)
1	☐	HMA	90	2020 Standard HMA Type A Mix with polymer modified binder for non-PRS Projects	0.40	447.0	N/A	2.28	0.00
2	☐	Subgrade	N/A	2020 Standard GW	∞	38.7	68	N/A	0.00

Current Pavement Condition

IRI 170 in/mi
D80 (80% of Surface Deflection) 10 mils
☐ Cracks wider than 1/8 inch
☐ PCC Layer was Cracked and Seated

Design Parameters

Depth of FDR 0 in
FDR-NS (PAB) Gravel Factor 0.000
FDR-FA (CFAC) Gravel Factor 0.000
FDR-PC Gravel Factor 0.000
UCS FDR-PC 0 psi

Design Life 20 yrs TI 9.4

Design Strategy

Design # 1 Overlay ST: 0.00; RC: 0.25; RQ: 0.25

#	Design Name	Mill	RHMA-G	CIPR	HRAC	RPI	GPI	HMA SG	FDR-PC	FDR-FA	PAB	AC GF	Res GE	Incr	Msgs
1.1	Plain HMA Overlay	0.00					0.25					0.00	0.00	0.25	0
1.2	HMA + RPI	0.00				0.00	0.25					0.00	0.00	0.25	1
1.3	HMA + GPI	0.00					0.25					0.00	0.00	0.25	1
1.4	RHMA-G	0.00	0.15				0.10					0.00	0.00	0.25	1

Display CalAC-Web messages below by clicking 'Msgs' button

Reports

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Section notes:

- Shows the currently loaded [CalME project](#)
- Shows the currently loaded [CalME trial](#) within the currently loaded project
- Shows the current structure, as specified on the [Project Information](#) page
- 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
- 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 recycling with Portland cement
 - FDR-FA - layer thickness for full depth recycling with foam asphalt
 - PAB - layer thickness for pulverized aggregate base, also know as full depth recycling 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.

CalME: CALTRANS Mechanistic Empirical Tool

Report Problem Description ☐ Include Problem Description in Output Reports

CalME v3.DD001.3 User: Mohammad Rahman Report Time Stamp: Wednesday, November 04, 2020, 8:05 PM
Project: CalFP-Web Example
Description: Workspace project description
Trial: Example 1
Description: Updating help file
Output Time Stamp: Wednesday, November 04, 2020, 6:32 PM

Problem Description (User Input)

Project Location
District 1, Del Norte, Route 101, North, Start PM: M0.000, End PM: R0.967
Project Length: 1.000 mi Lane Miles: 2.000 Avg #lanes: 2.00 Area (12 ft Lane Width): 126,720.00 ft**2

Pavement Structure

Layer	Material	Thick (ft)	Modulus (ksi)	Poisson	R	GF	Cost (\$/ft3)	Cost (\$)
1	2020 Standard HMA Type A Mix with FG64-XX Binder and up	1.00	945.1	0.35	N/A	0.00	6.12	775,526.40
2	2020 Standard AB-Class 2	1.00	45.0	0.35	78	1.10	0.99	125,452.80
3	2020 Standard AS-Class 2	1.00	29.9	0.35	50	1.00	0.93	117,849.60
4	2020 Standard MH	0.00	6.5	0.35	10	0.00	0.00	0.00
Project Cost:							1,018,828.80	
Project Cost/Lane Mile:							509,414.40	

Traffic Segment Counts
PM Location: R0.347-R0.510
AADT: 1400
Total Trucks (AADTT): 204
% Trucks: 14.6

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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.

CalME: CALTRANS Mechanistic Empirical Tool

Report: CalFP Generate ☐ Include Problem Description in Output Reports Download Report

CalME v3.0.0.0 User: Jon Lea Report Time Stamp: Thursday, March 21, 2019, 2:59 PM
 Project: Long Life Project
 Trial: 9
 Output Time Stamp: No Output

Results of the Caltrans Empirical Design Check Applied to the Current Structure

Minimum and Maximum Thickness Checks
 No problems with minimum/maximum thickness checks;

Structural Adequacy Checks
Error: Gravel Equivalent Provided above Layer 2 (AB): 0.65 is less than required: 1.04;
Error: Gravel Equivalent Provided above Layer 3 (SG): 1.09 is less than required: 3.23;

CalFP Design Alternatives

Design	HMA	AB	SG	AC GF	Res GE	AC Equiv	Cost/mi	MsgsText
1	0.65	1.90	0.00	1.75	0.00		0	Warning: Layer 2 (AB, 1.90 ft) layer may be thicker than allowed (1.05-ft)
2	0.70	1.80	0.00	1.79	0.01		0	Warning: Layer 2 (AB, 1.80 ft) layer may be thicker than allowed (1.05-ft)
3	0.75	1.70	0.00	1.84	0.02		0	Warning: Layer 2 (AB, 1.70 ft) layer may be thicker than allowed (1.05-ft)
4	0.80	1.60	0.00	1.88	0.04		0	Warning: Layer 2 (AB, 1.60 ft) layer may be thicker than allowed (1.05-ft)
5	0.85	1.50	0.00	1.91	0.05		0	Warning: Layer 2 (AB, 1.50 ft) layer may be thicker than allowed (1.05-ft)
6	0.90	1.35	0.00	1.95	0.02		0	Warning: Layer 2 (AB, 1.35 ft) layer may be thicker than allowed (1.05-ft)
7	0.95	1.25	0.00	1.99	0.04		0	Warning: Layer 2 (AB, 1.25 ft) layer may be thicker than allowed (1.05-ft)
8	1.00	1.10	0.00	2.02	0.01		0	Warning: Layer 2 (AB, 1.10 ft) layer may be thicker than allowed (1.05-ft)
9	1.05	1.00	0.00	2.05	0.03		0	

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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.

CalME: CALTRANS Mechanistic Empirical Tool

Report: CalAC Generate ☐ Include Problem Description in Output Reports Download Report

CalAC Report

Current Pavement Condition
IRI: 170 in/mi
D80: 10 mils
Cracks wider than 1/8 inch: False
PCC Layer was Cracked and Seated: False

Design Parameters
Depth of FDR: 0 in
FDR-NS (PAB) Gravel Factor: 0.000
FDR-FA (CFAC) Gravel Factor: 0.000
FDR-PC Gravel Factor: 0.000
UCS FDR-PC: 0 psi

Strategies with Their Desing Alternatives

Strategy Name: Overlay

Design Name	Mill	RHMA-G	CIPR	HRAC	RPI	GPI	HMA	AB	SG	FDR-PC	FDR-FA	PAB	AC GF	Res GE	Incr	Cost/mi
Plain HMA Overlay	0.00						0.25						0.00	0.00	0.25	0
HMA + RPI	0.00				0.00		0.25						0.00	0.00	0.25	0
HMA + GPI	0.00					0.00	0.25						0.00	0.00	0.25	0
RHMA-G	0.00	0.15					0.10						0.00	0.00	0.25	0

Strategy Name: Mill 0.05 ft and Overlay

Design Name	Mill	RHMA-G	CIPR	HRAC	RPI	GPI	HMA	AB	SG	FDR-PC	FDR-FA	PAB	AC GF	Res GE	Incr	Cost/mi
Mill and HMA	0.05						0.20						0.00	0.00	0.15	0

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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.

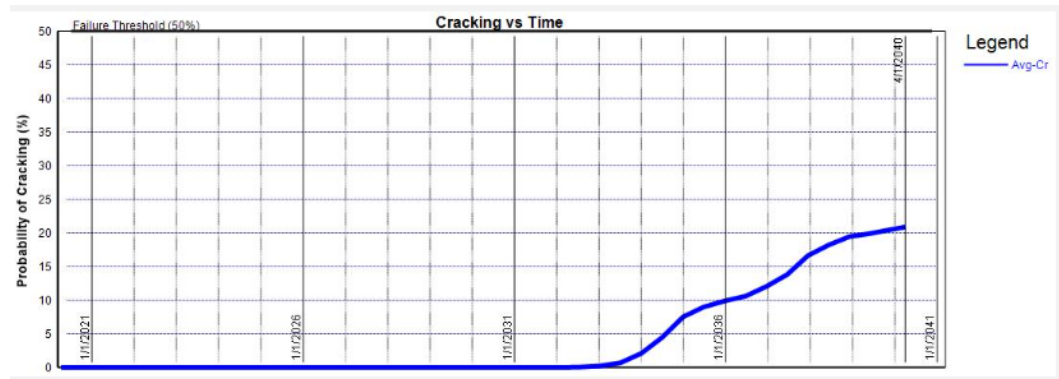
You can generate a PDF version of the report and download it to your local hard drive by selecting the "Download Report" button.

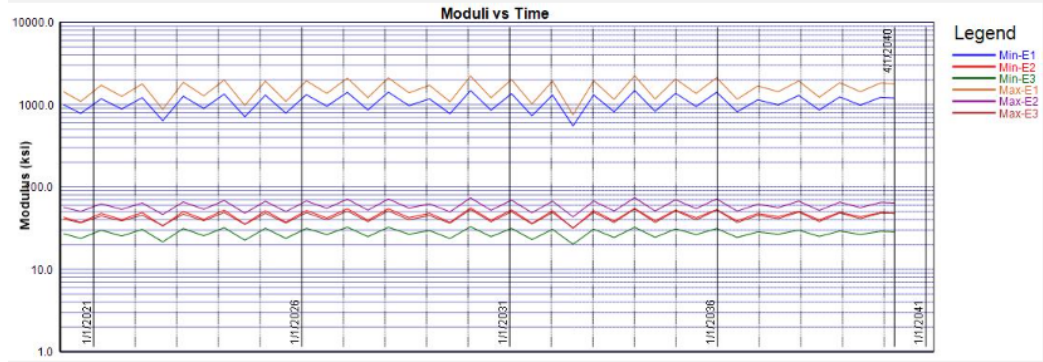
CalME: CALTRANS Mechanistic Empirical Tool

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





Layer Compression

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 -

CalME: CALTRANS Mechanistic Empirical Tool

Report

General Time Series

Generate

☐ Include Problem Description in Output Reports

Download Report

CalME v3.0.0.0

User: Jon Lea

Report Time Stamp: Thursday, March 21, 2019, 3:42 PM

Project: Long Life Project

Trial: 9

Output Time Stamp: No Output

Basic Time History Report

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

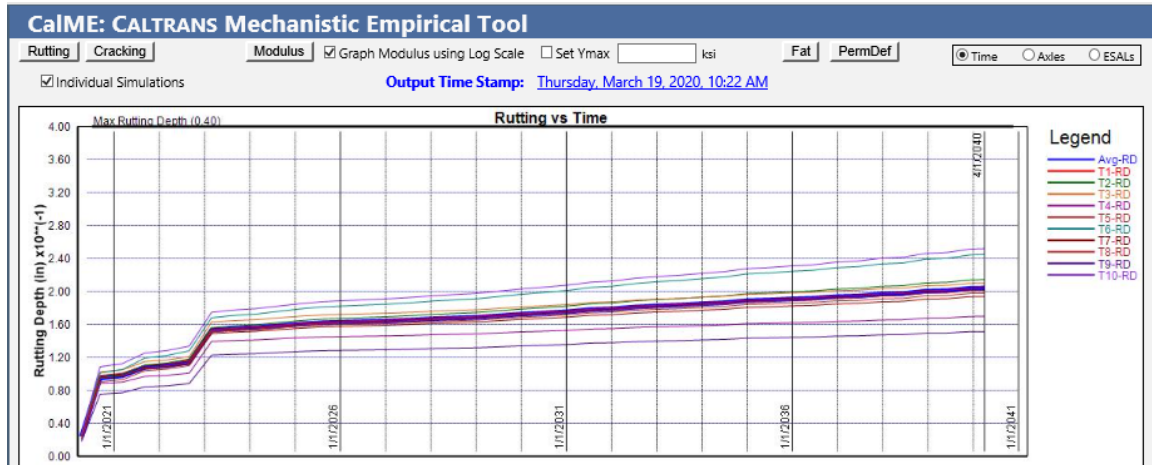
Graphs

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.

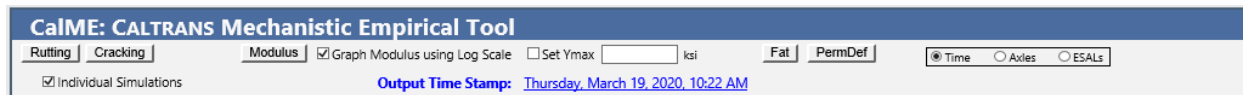


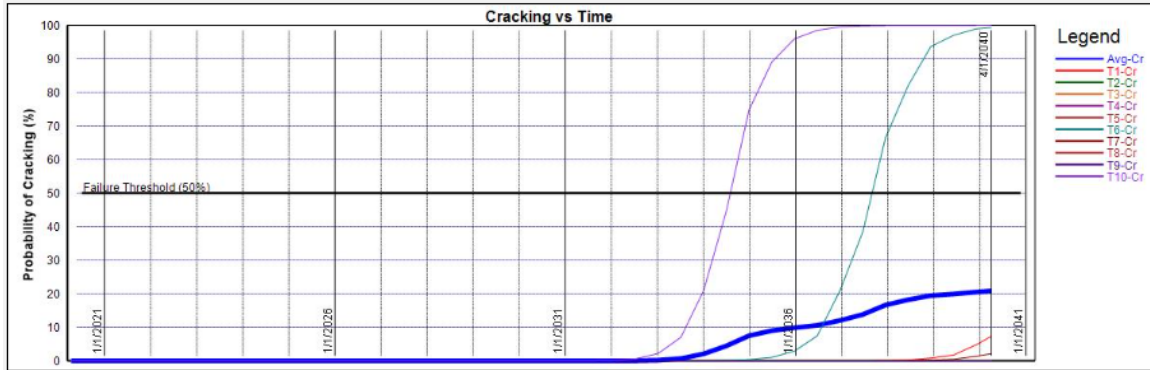
Cracking Graph

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.



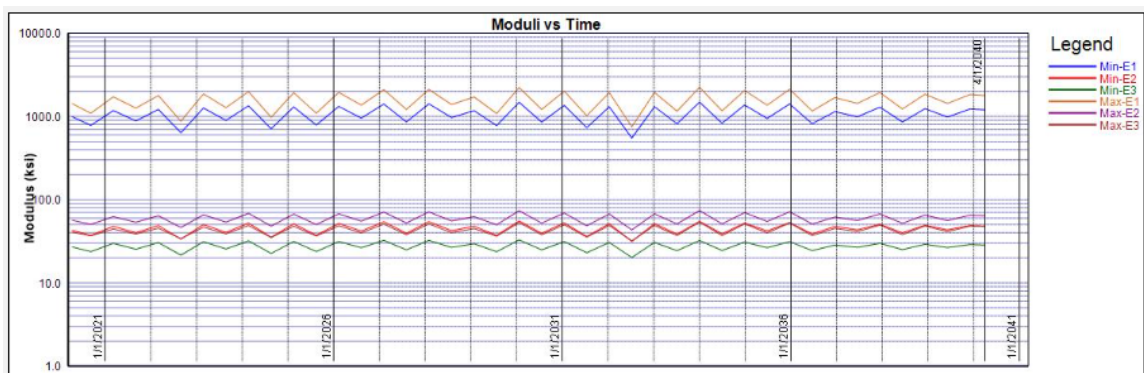
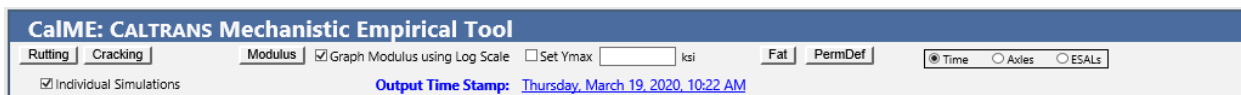


Modulus Graph

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](#).

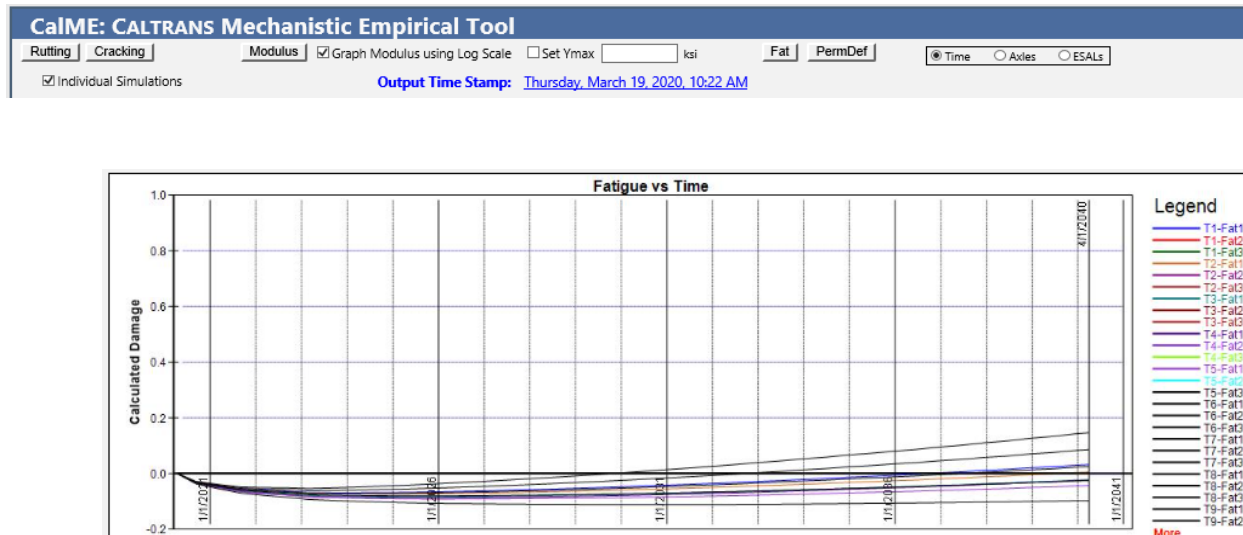


Fatigue Graph

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](#).

CalME: CALTRANS Mechanistic Empirical Tool

Rutting

Cracking

Modulus

☒ Graph Modulus using Log Scale

☐ Set Ymax

ksi

Fat

PermDef

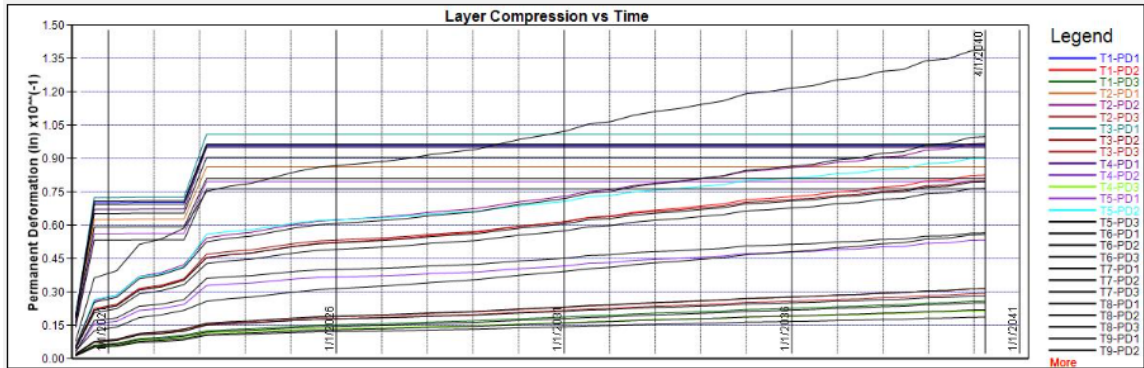
☒ Time

☐ Axles

☐ ESALs

☒ Individual Simulations

Output Time Stamp: Thursday, March 19, 2020, 10:22 AM



6. Introduction to Mechanistic-Empirical Pavement Design

In this section, a brief introduction to mechanistic-empirical (M-E) pavement design method is given.

6.1. Evolution of Pavement Design Methods

Pavement design methods that are currently available can be broadly divided into three groups:

Type	Approach	
Empirical	Use empirical equations or charts to correlate structure, material, traffic, and climate characteristics to pavement performance.	Caltrans R-value method Caltrans c
Classical Mechanistic-Empirical	Determining pavement responses due to loading through mathematical models and relating those responses to pavement performances	Shell p Asp AASHTO guide for
Mechanistic-Empirical	Same as classical mechanistic-empirical method, except each distress is explicitly accounted for and the empirical part for each distress requires local calibration	AASHTO Mechanistic E California Mechanis

Although one can argue that there is a fourth group called "Mechanistic" method, which goes a step further from the Mechanistic-Empirical method in terms of reducing the role of the empirical calibration. Specifically, the empirical data is only needed for validation because the mechanistic model is expected to capture all the behaviors affecting pavement performance. As of this writing, there is no mechanistic pavement design method that is used in routine design.

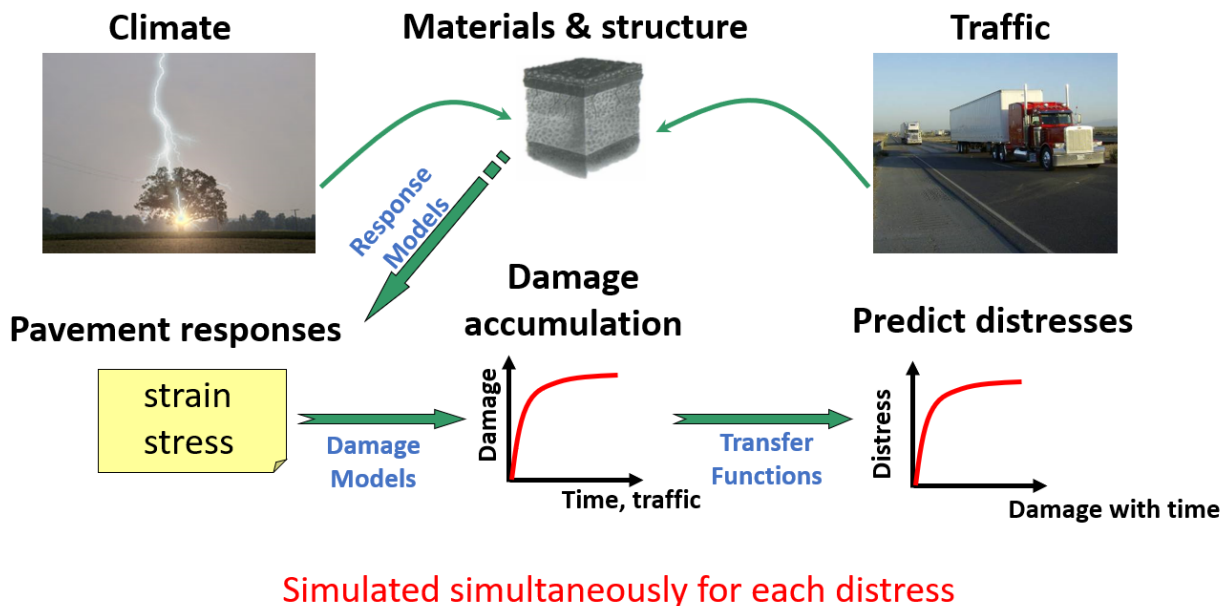
6.2. Components of Mechanistic-Empirical Design Method

The following figure illustrates the M-E simulation process, which essentially takes climate, material, structure, and traffic inputs and predicts the how various distresses accumulates over time.

The figure suggests several critical components of a mechanistic-empirical simulation process:

- Response models: predict pavement responses based on converts climate, material, structure and traffic inputs
- Damage models: predict damage accumulations based on pavement responses inputs
- Transfer functions: predicts pavement distress accumulations based on damage inputs

These components will be explained further in the following subsections.



Response models

Typically pavement responses are calculated using multilayer elastic theory (MET), which has been implemented into various computer programs. Finite element method may also be used to account for non-linearities such as joints, cracks, debonding, and frictional interfaces. To speed up the design process, finite element runs are typically conducted in advanced and regression models are in turn developed to perform the necessary interpolation or extrapolation.

This part of the M-E method is mechanistic.

6.4. Damage Models

Damage models predict damage accumulations based on pavement responses inputs. Typically this is achieved by providing estimate of the incremental damage caused by certain number of applications of a given critical pavement response. In addition, each damage model needs to specify how damages caused by various load levels are combined over time.

These damage models are typically developed based on laboratory test data. Damage can be broadly understood as physical changes, usually material degradation, in pavement layers caused by either traffic loading or environmental loading. Examples of damage observed in laboratory tests include stiffness reduction in beam fatigue tests (AASHTO T 321), or accumulation of permanent axial strain in repeated load tri-axial test using AMPT (AASHTO T 378).

Damage models need to be calibrated using data collected from well-controlled full scale pavement testings. Examples of these include but are not limited to various accelerated pavement testings. This calibration is necessary because there are significant differences in factors such as boundary condition, strain/stress state, and strain/stress path between laboratory tests and full scale pavement testing.

It is preferable that the data used to calibrate damage models come from small sections that are practically homogeneous in terms of material properties, layer thicknesses, trafficking history, and environment conditions. Any significant variations in these factors make it difficult to fully characterize the test section and account for the variabilities properly.

This part of the M-E method has both mechanistic (the damage model parameters determined using laboratory test data) and empirical (the calibration) parts.

6.5. Transfer Function

Transfer functions convert the predicted damages into the extent of observable pavement distresses. Typically each distress has its own set of corresponding damages. For example, surface cracking is typically correlated with bottom-up fatigue damage. Some M-E method also adds contribution to surface cracking from top-down fatigue cracking. Each distress has its own transfer function.

Transfer functions are typically developed through the field calibration process, in which correlation is established between predicted damages and the observed distress.

Transfer functions are the key components that bridge the relative simplicity of computer modeling with the complications and randomness of field performances. It is important to keep in mind that pavement performances are never really random. They seem

random because many of the factors affecting them can be random. For example, material deflections can happen randomly both within a project, and across different projects. The transfer functions should be formulated properly to account for this randomness.

This part of the M-E method is empirical.

6.6. ME Design Process

A key difference a user may notice when transitioning from empirical or classical ME design method to the new ME design method is that designing pavements using the new ME design method has changed from a non-iterative process into an iterative process in which trial designs are adjusted repeatedly, usually manually, until an optimal design is reached.

In other words, unlike empirical or classical ME design methods, the core output of the new ME methods is not layer thicknesses. Rather, the new ME methods outputs predicted pavement performances for a given set of layer thicknesses with respect to the individual distress mechanisms such as surface cracking and rutting.

It is nevertheless possible to build tools on top of the new ME design method to automatically find the layer thicknesses that satisfy the design requirements.

7. CalME Models and Procedures

This chapter explains how *CalME* works by describing the models and procedures used by *CalME* to predict pavement performance. The goal is to help users understand some of the key concepts in *CalME* and be able to make informed decisions when conducting a pavement design using *CalME*.

7.1. Technical Overview

CalME has been developed by Caltrans in collaboration with the [UCPRC](#) to enable Caltrans to design flexible pavements in California using a mechanistic-empirical method. *CalME* shares the general framework with other M-E design methods but differs from them in many important ways in the implementation. Below is a list of the key differences:

- *CalME* uses an [incremental-recursive](#) performance prediction process in which the predicted damages causes predicted pavement responses to increase over time. This allows the calibration of damage models using data from accelerated pavement testing, in which the pavement responses (such as deflections) increases as the test section is damaged by trafficking.
- *CalME* introduces the concepts of within-project variability and between-project variability to clearly distinguish and [account for uncertainties](#) from different sources. This allows for proper considerations of performance related construction specifications, which essentially is a way of reducing uncertainties in performance of as-built materials.
- *CalME* introduces a new framework for calibrations. The damage models are calibrated using well-controlled accelerated pavement testing data and the transfer functions are calibrated using field observations throughout the whole California highway network over time.
- *CalME* includes a standard materials library that allows addition of new materials whenever laboratory test data are available. This allows quick introduction of innovative materials.

Also, having its own M-E program allows the Caltrans/UCPRC team to optimize some of the key components to make the program run faster, which in turn make the design process much shorter. Here are some examples of these optimizations:

- A built-in temperature profile solver based on pre-calculated pavement surface temperature history.
- A built-in multi-layer elastic theory analysis program that is highly optimized to run millions of analyses on a structure that has layer stiffness changes but no layer thickness change.

With these optimizations, *Ca/ME* typically finishes estimation of the performance of a given design in about one minute.

The next subsections explain in more details the [incremental-recursive procedure](#), [how to account for uncertainties](#) and [how all the pieces fit together](#).

7.1.1. The Incremental Recursive Procedure

Ca/ME 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 damage and distress states (or levels) predicted for the preceding time increment before the incremental pavement distresses are predicted for the next time increment.

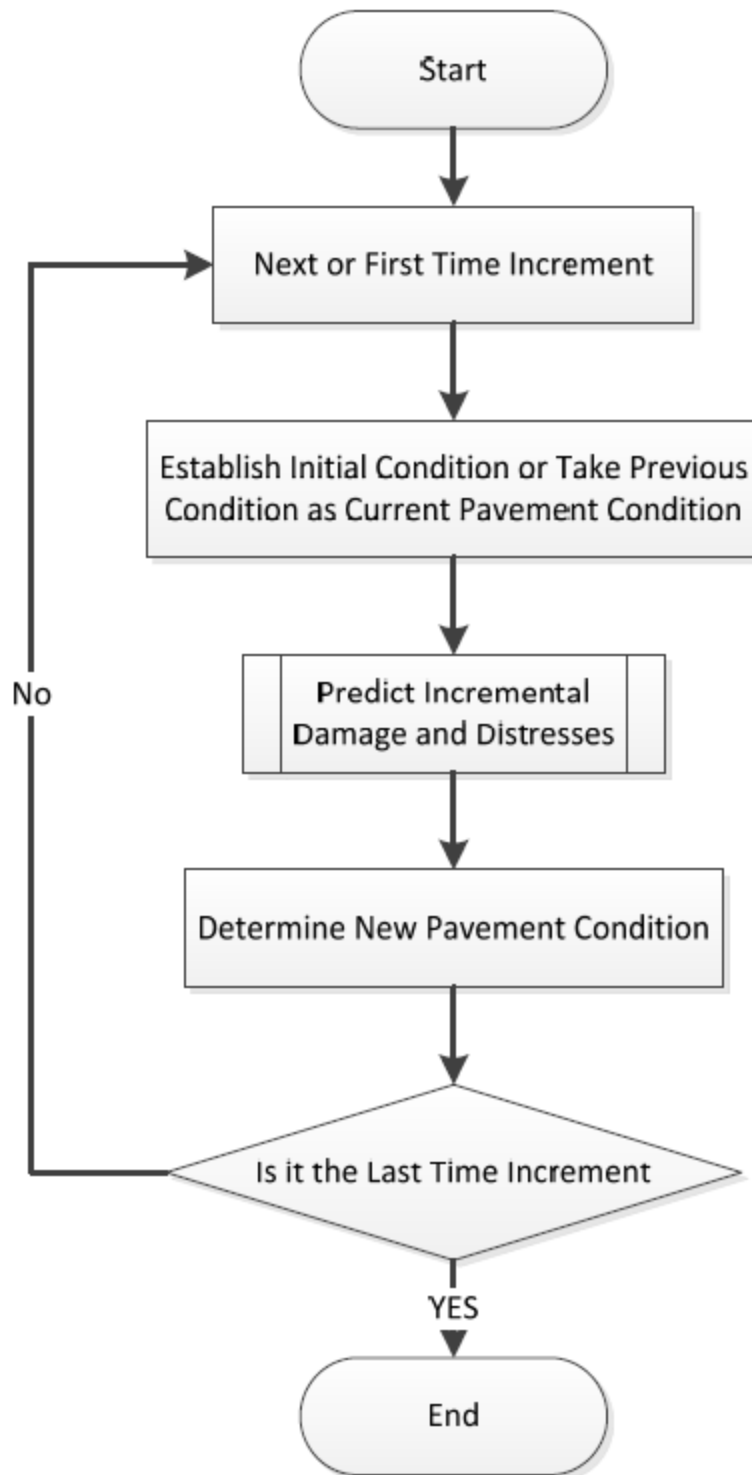


Figure 1 - flowchart of the incremental-recursive performance prediction used in *CalME*

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, as a function of time.

Although currently disabled, *Ca/ME* will also allow 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 duration of each increment is 30 days for pavement design. The program will select the day in the middle of each increment as the representative day 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). Both the time increment and the time periods can be customized for research and calibration. It is possible to use time increments from one hour and upwards. For calibration using HVS (heavy vehicle simulator) or track tests an increment of one hour is used.

At the beginning of the simulation, the program predicts the pavement temperature profile for every hour over the whole analysis period. These temperatures are then looked up as needed during the simulation.

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. 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 assumed 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.

Note that this incremental recursive procedure

7.1.2. Accounting for Uncertainties

In *CaME*, there are two sources of performance variability: within-project variability and between-project variability. Within project variability is the variability of the materials production and construction process within the project for a given contractor and material supplied. Differences in performance-related properties between materials produced by different suppliers are the primary source of between-project variability. Differences in median construction quality between different contractors would also contribute to between-project variability.

Within-Project Variability

Within-project variability comes from variations of the natural subgrade and the variability of materials production and construction using the given set of materials that a contractor brings to a single project. Within-project variability considers the rate of development of distress extent within a project as time and traffic progress. If there was no variability of materials properties in a project due to the natural subgrade and no variability in materials production and construction of the other layers, then theoretically the entire project would fail at exactly the same time. For example, the entire project would go from zero to 100 percent of the wheelpath cracked at the same time. Of course, this does not happen in practice. Within-project variability can be seen in the differences in time/traffic between the first part of a project that fails and the last part that fails.

Here is an example of within-project variability. Suppose there were two contractors, A and B, working with the same materials on the same project, as shown in Figure 1. If both have the same median construction quality but Contractor A's construction quality variability is higher than Contractor B's, then the project would reach a typical cracking failure extent threshold extent (such as 25 percent of the wheelpath cracked) earlier if Contractor A built the project than if Contractor B built it. In this case, the within-project variability of the subgrade is included in the within-project variability shown for both contractors.

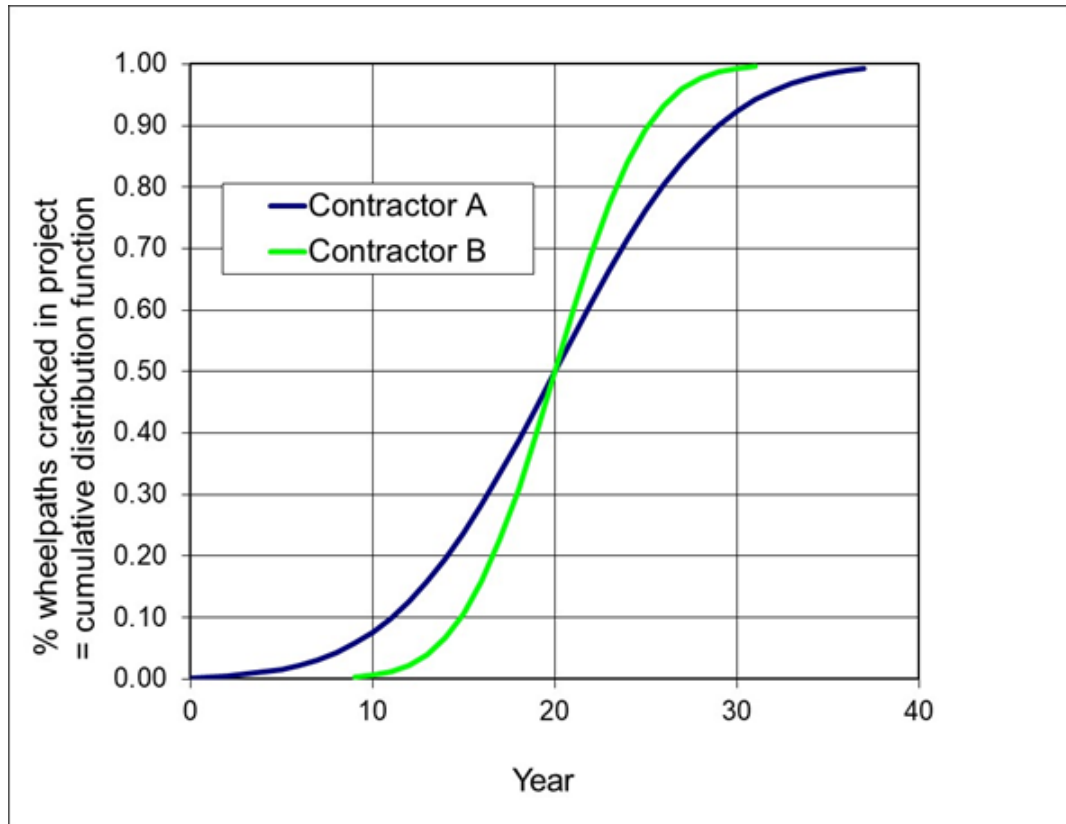


Figure 1: Two different within-project variabilities.

Between-Project Variability

Between-project variability addresses the uncertainty regarding the materials that a contractor would bring to a project in a low-bid environment, and to potential differences in median construction quality between contractors. Figure 2 shows a situation where Contractor A and Contractor B have the same within-project variability, but Contractor A brings an HMA material with a combination of stiffness and fatigue properties that results in less cracking than if Contractor B won the project.

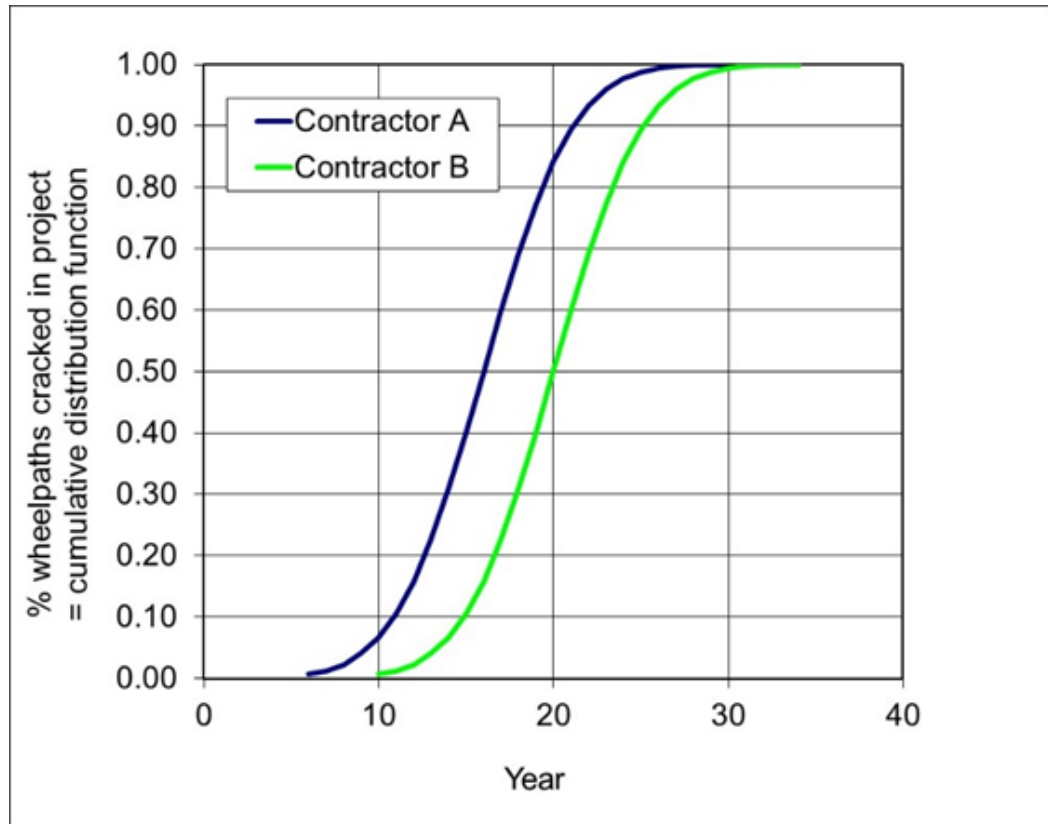


Figure 2: Between-project variability for two projects.

This can happen because typical construction specifications are method and volumetric based rather than performance based. The materials supplied by the two contractors both meet the method and volumetric requirements but can still have large difference in fatigue cracking performance.

Without performance-related specification (PRS), asphalt materials only need to pass performance-related binder specifications and volumetric mix design requirements that do not fully address mechanical performances such as fatigue and rutting characteristics. The stiffness, fatigue performance, and rutting performance-related properties are not well defined and are unknown to the designer.

Accounting for Within-Project Variabilities

CalME uses Monte Carlo simulation to account for the effects of within-project reliabilities 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. *CalME* then uses the [incremental-recursive procedure](#) to predict the performance of each individual pavement structure and uses the performance statistics to determine the reliability of the given design.

Construction Variabilities

To quantify construction variabilities, the following inputs of each layer are assumed to be random variables:

- Thicknesses: follows normal distribution
- Intact moduli: follows log-normal distribution
- Fatigue resistance: a critical fatigue model parameter is assumed to follow log-normal distribution
- Rutting resistance: a critical rutting model parameter is assumed to follow log-normal distribution

Monte Carlo simulations are run by taking random samples of these inputs. The statistical distribution of these variables depends on whether it is for an added layer (such as all of the layers in new constructions or the overlays in rehabilitation projects), or an existing layer (such as the old layers of rehabilitation projects). For an added layer, the built-in statistical distribution reflects the stated wide median construction practice and is [adjusted as part of the field calibration](#). For an existing layer, the statistical distribution reflects the in-situ condition determined through site investigation.

For log-normal distributions used in *CalME*, standard deviation factor (sdf) is used to quantify the variance of a random variable. Specifically, sdf is defined as 10 raised to the standard deviation of the logarithms of the moduli.

Note that for existing layers, the moduli and their sdf values are imported from *CalBack*, the software program developed by UCPRC for Caltrans to do layer moduli backcalculation using FWD. Since layer thicknesses are assumed to be constant during backcalculation, the resulting sdf on the moduli are, in reality, a function of both the thickness and the modulus variability. *CalME* adds the default variability of layer thicknesses on top of the imported variability of layer moduli, which leads to slightly more conservative designs for rehabilitation projects.

Although currently disabled, 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.

Accounting for Between-Project Variabilities

CalME uses a shift factor to account for the between-project variability in pavement performances for the same designs (same structure, same traffic, same climate) seen in the PMS calibration data. Specifically, the shift factor acts as a correction factor applied to the median pavement life for a given design to account for the difference in performance between low performing and median performing projects seen in the PMS data.

This shift factor has been determined to correspond to 95% design reliability. This means most (i.e., 95%) of the projects will be able to sustain the design life without

cracking or rutting failure.

A more detailed description of this process can be found [here](#).

The adoption of performance related specification (PRS) is likely to reduce the amount of between-project variability and *CalME* has built-in adjustments to account for that.

7.1.3. Put it All Together

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

The distresses predicted in *CalME* include surface cracking and surface rutting. Surface cracking can be attributed to [fatigue cracking](#) and, when applicable, [reflective cracking](#). Future enhancement of *CalME* will include other important distresses, such as thermal cracking, top-down cracking, etc.

As shown in the [incremental recursive procedure](#), 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 the resulting distresses. This subprocess involves interaction between various components of the ME design, as illustrated below.

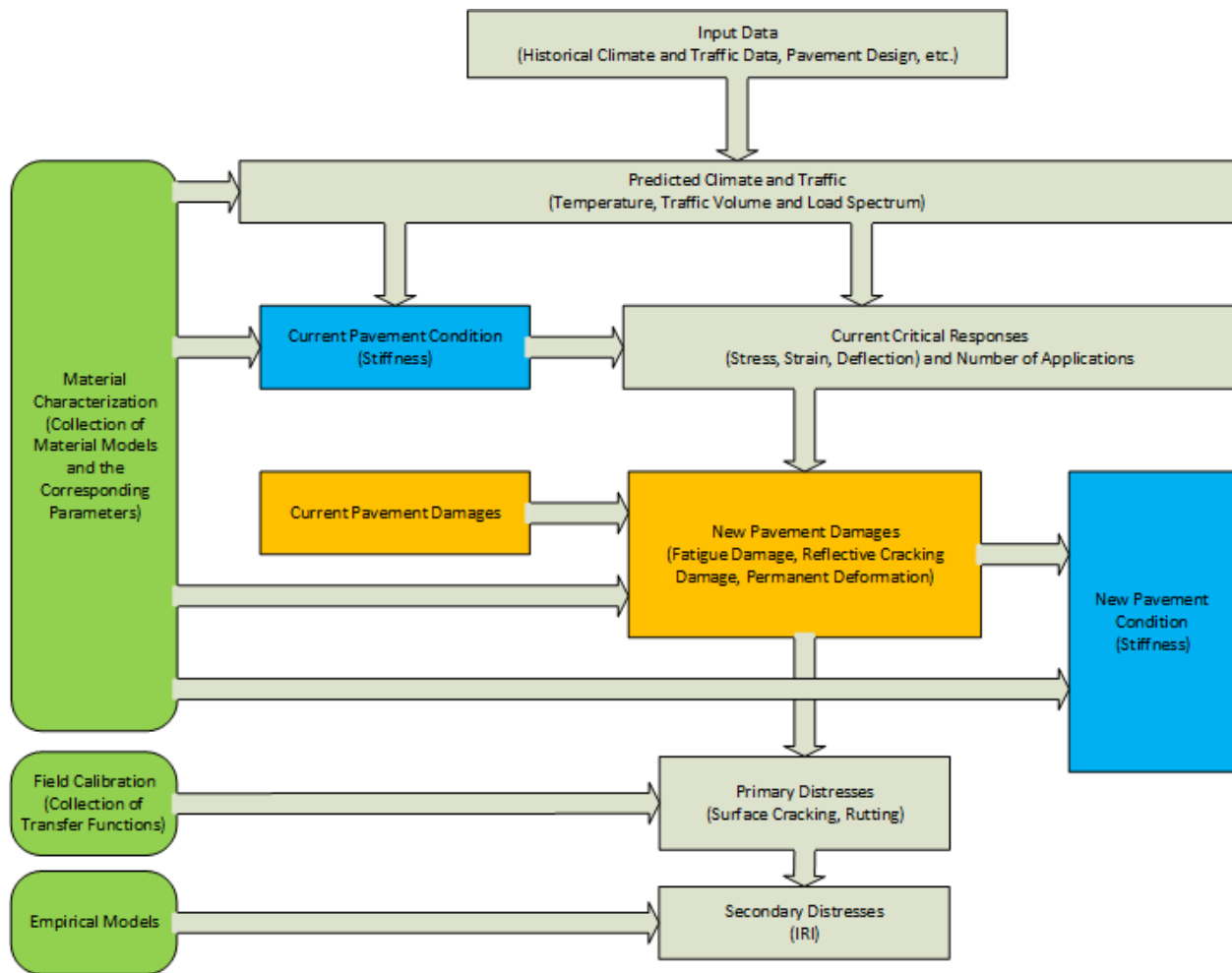


Figure 1 - Interaction between various models and other components of the incremental distress prediction process in CalME

Figure 1 indicates that material characterization is not involved in the predictions of the distresses in CalME. Instead, these distresses can be determined based on the predicted damage values without any material specific information. The role of material characterization is to provide models for predicting pavement conditions (temperature, moisture contents, etc.), critical pavement responses (stress, strain, and/or deformation

at critical locations in the pavement that are related to distress development), and ultimately the resulting damages.

There are two levels of distresses predicted by *CalME*: primary distresses and secondary distresses. The primary distresses are the ones that are directly related to various damages ([fatigue](#) damage, [reflective cracking](#) damage, and [permanent deformation](#)) in each layer and do not depend on other distresses. For example, surface cracking is a result of [fatigue](#) damage and [reflective cracking](#) damage and therefore it is a primary distress. Similarly, surface rutting is a function of layer [permanent deformations](#) and therefore it is also a primary distress. The secondary distresses are the ones that depend on primary distresses. For example, surface IRI depends on other distresses such as surface cracking and rutting and as a result is a secondary distress. Primary and secondary distresses are predicted using different sets of models.

Primary distresses are calculated from predicted pavement damages through the use of transfer functions, which are correlations/models determined through field calibration. The primary distresses are in turn used to calculate secondary distresses through empirical models.

7.2. Response Models

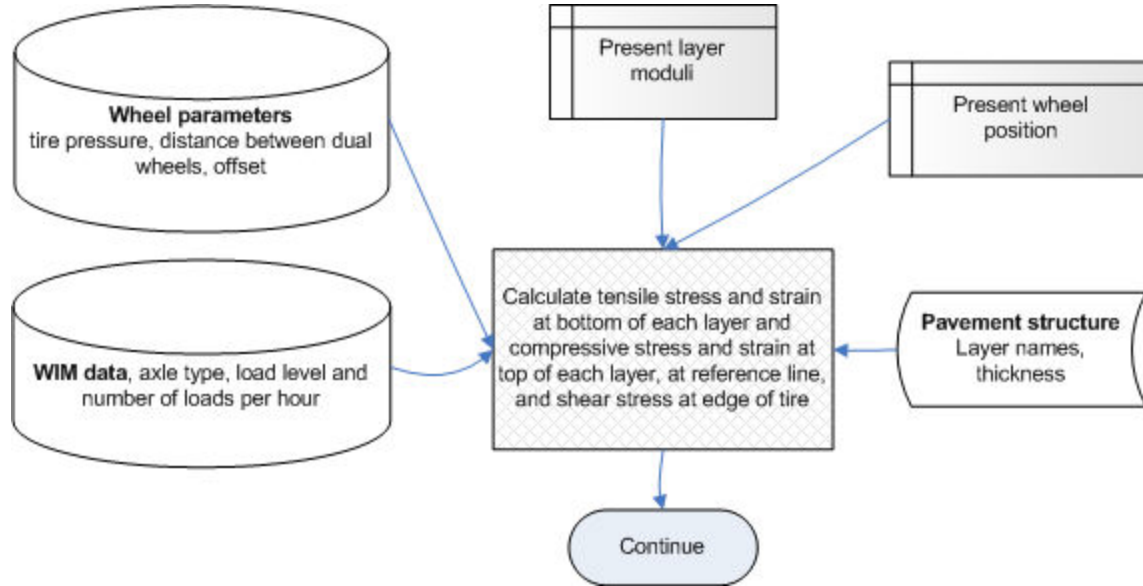
In *CalME*, [pavement structures](#) are simplified as multilayer elastic systems when calculating critical responses for predicting fatigue damage and permanent deformation. Accordingly, pavement responses only depend on layer stiffnesses since the Poisson's ratio of each material in the pavement structure is assumed to remain constant throughout the analysis life. Multilayer elastic theory cannot calculate the strain that drives reflective cracking damage in the new asphalt layer (e.g., overlay), due to cracks in underlying asphalt or stabilized layers, and joints and cracks in underlying concrete layers.

CalME uses Multilayer Elastic Theory to calculate pavement responses needed to drive fatigue cracking and surface rutting. The response model was implemented by Dr. Jeremy Lea, see www.openpave.org for details.

CalME uses the method developed by Wu (2005) to predict reflection cracking damage. In this method the tensile strain at the bottom of the overlay is estimated using a

regression equation developed based on thousands of finite element runs. The calculate critical tensile strains are then used to drive the accumulation of damage in asphalt overlays for reflective cracking prediction.

A flowchart for the response calculation used in *CalME* is shown below:



7.2.1. Critical Strain for Reflective Cracking

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:

$$\varepsilon = \alpha \times E_{an}^{\beta_1} \times E_{bn}^{\beta_2} \times (a_1 + b_1 \times \ln(LS_n)) \times \exp(b_2 \times H_{an}) \times (1 + b_3 \times H_{un}) \times (1 + b_4 \times E_{un}) \times \sigma_n$$

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

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

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:

$\alpha = 342650$, $\beta_1 = -0.73722$, $\beta_2 = -0.2645$, $\beta_3 = -1.16472$, $a_1 = 0.88432$,
 $b_1 = 0.15272$, $b_2 = -0.21632$, $b_3 = -0.061$, $b_4 = 0.018752$.

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](#).

One of the key input is the k-value of the layers below the PCC layer. It is determined by conducting a virtual plate test on top of the layer below the PCC layer with a standard load of 40 kN on a 375 mm radius plate. The deflection is calculated using multilayer elastic theory. The k-value is in turn calculated using the same equation as the one used for actual plate load test.

7.3. Damage Models

In *CalME*, damage models are needed for prediction of damages accumulations related to surface cracking and surface rutting. These models, along with environmental models for predicting pavement temperature profile, and stiffness models for predicting layer moduli, are attached to each layer based on its material type. For in-depth description of the material classifications and the models associated with each material type, refer to the [Standard Materials Library](#) in *CalME*.

Time hardening procedure

For the damage models used in the incremental-recursive process the parameters on the right hand side of the equations 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.

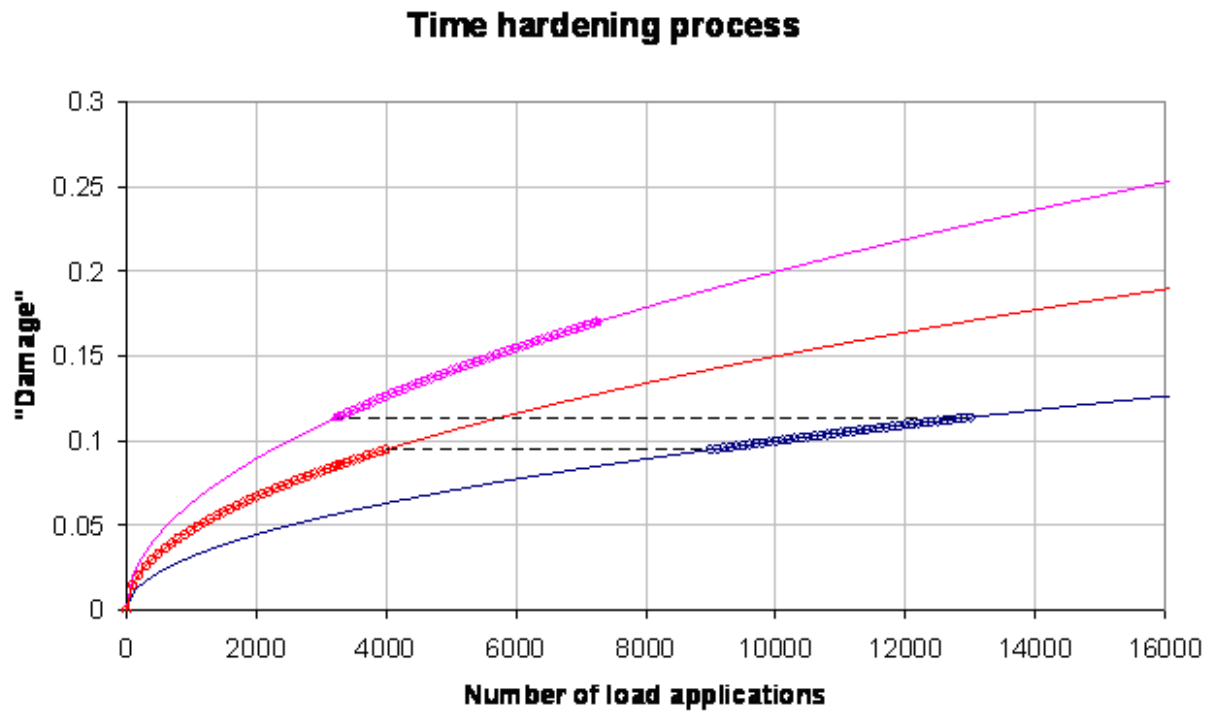
The method may be illustrated by an example using the equation for [permanent deformation of unbound](#) layers. If for example the permanent deformation of the subgrade was 2 mm at the start of the increment, the vertical strain calculated for the first wheel load at the first position was 800 microstrain, 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:

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

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:

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

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:



7.4. Transfer Functions

Two sets of transfer functions are needed in CalME: one for surface cracking and one for surface rutting. Each of these are described in more detail in the subsections.

7.4.1. Surface Cracking

Surface cracking in pavements can be caused by various reasons. In *CalME*, only fatigue cracking and reflective cracking are explicitly modeled, while all other types of cracking are accounted for through the field calibration process.

Fatigue Cracking

Once the fatigue damage is determined, the percent of wheelpath cracked, denoted as

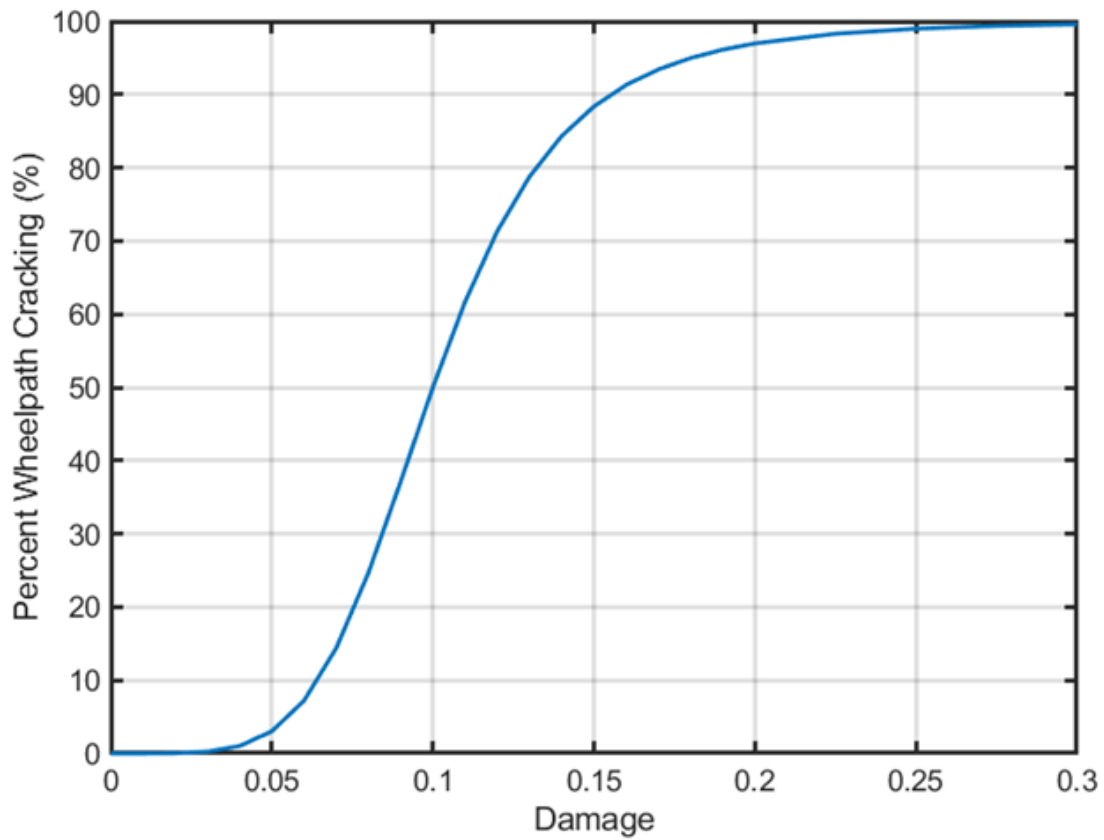
PWC, can be calculated using the following equation:

$$PWC = \frac{100}{1 + \left(\frac{\omega}{\omega_{50}} \right)^{\beta_{crk}}}$$

where ω_{50} is the critical damage corresponding to 50% of surface cracking, and β_{crk} is the shape parameter.

Both critical damage and shape parameter are determined through field calibration, and each may depend on additional factors such as pavement structure type, climate condition, HMA layer thickness. ω_{50} also represents the fatigue damage corresponding to 50 percent wheelpath cracking based on the form of the equation. The following figure illustrates the correlation between fatigue damage and percent wheelpath cracking. This equation is the transfer function for the fatigue cracking model used in *CalME*. Note that this equation is essentially a recast of one used in *CalME* v2.0.

Each of the asphaltic layer has a calculated fatigue damage. Only the one for the top layer is used to calculate fatigue cracking.



An example of the transfer function for fatigue damage, $\omega_{50} = 0.1$ and $\beta = -5.0$.

Reflective Cracking

Reflective cracking uses the same format of transfer function as the fatigue cracking, albeit with different sets of model parameters determined through field calibration.

Total Surface Cracking

The total surface cracking is determined by adding fatigue cracking and reflective cracking together, and cap it at 100%:

$$PWC_{total} = \min(100\%, PWC_{fatigue} + PWC_{RC})$$

where PWC_{total} is the total percent wheelpath with surface cracking,
 $PWC_{fatigue}$ is the percent wheelpath that has fatigue cracking, and
 PWC_{RC} is the percent wheelpath that has reflective cracking

Surface Rut

Once the layer compression of each layer is determined, the total permanent deformation DP , can be calculated as the sum of permanent deformation in each individual layer using the following equation:

$$DP = \sum_i d_{p,i}$$

where $d_{p,i}$ is the permanent deformation for layer i . The percent of wheelpath rutted, PWR , is then calculated using a transfer function similar to the one for cracking:

$$PWR = \frac{100}{1 + \left(\frac{DP}{DP_{50}} \right)^{\beta_{rut}}}$$

where DP_{50} is the critical permanent deformation correspond to 50% wheelpath having rutting failure, and

β_{rut} is the shape parameter.

Similar to fatigue cracking, both critical permanent deformation and shape parameter are determined through field calibration, and each may depend on additional factors such as pavement structure type, climate condition, HMA layer thickness.

7.5.1. Standard Materials Library

Each of the material models 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 models that predict different damages 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 database of materials that have been characterized through previous studies that sampled and tested materials from across the state. Specifically, model parameters and the associated uncertainties when applicable have been determined for these materials.

The *CalME* SML continues to grow. Additional materials are being added to the SML as more data become available.

Each material in the library has been classified in one of three groups: asphaltic material, non-asphaltic bound material, and unbound material-based on the models applicable for that material.

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 for a series of lab tests to determine the stiffness characteristics, and the fatigue and permanent deformation resistances of each material.

On the other hand, most of the models for non-asphaltic materials (both bound and unbound) 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 back-calculate layer stiffness and to provide an estimate of the within-project variability of the stiffnesses for Monte Carlo simulation.

Types of Material Models

The models needed for each material in *CalME* can be divided into the following three functional groups:

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 causing stiffness decreases and stiffnesses increases from mechanisms such as aging and curing.

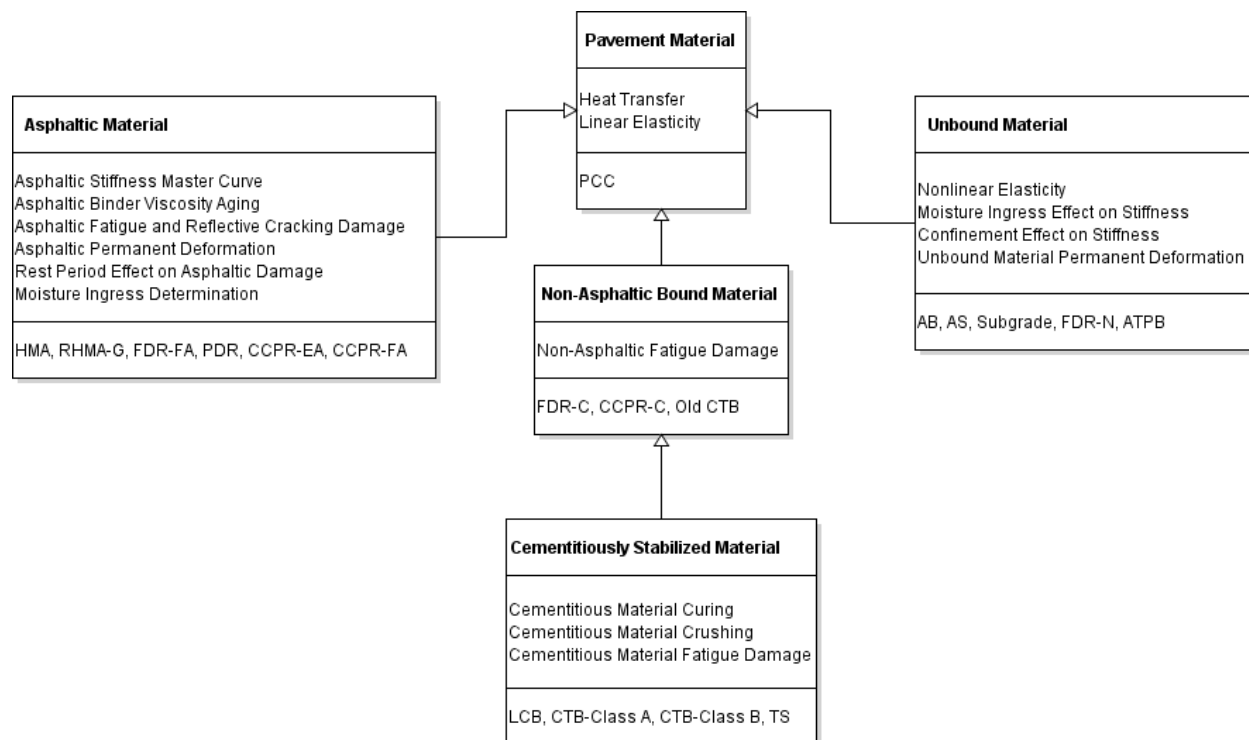
As one can see, *CalME* requires more than just damage models to work.

Material Characterization

Material characterization is the process of selecting the appropriate set of material models and identifying the corresponding model parameters through laboratory and/or field testing for a given material. Different types of materials require different materials characterization process for each of the above three functional groups of models. The material models selected for *CalME* for each of the functional groups are presented next along with the material classification.

7.5.1.1. Mateiral Models and Classification

There are different ways to classify different pavement materials. For *CalME*, materials are classified based on their mechanistic (stiffness and damage models) behaviors. Specifically, materials are classified by the sets of models needed to describe how they will perform in the M-E design process. The following figure shows the hierarchical classification of materials included in the Standard Materials Library in *CalME*.



(Note: each box contains the name of the material group followed by a list of models required for the material group, and a list of materials using the abbreviations of that appear in *CalME*. The arrows connecting different boxes indicate the “is a” relationship.)

The figure illustrates the hierarchy of materials in the Standard Materials Library arises out of the relations between different material classifications. For example, asphaltic material has an “is a” relationship with pavement material. In other words, asphalt material is a specialized type of pavement material. This implies that all models selected for pavement material (heat transfer and linear elasticity) are applicable to asphaltic material as well. In addition, asphaltic material has its own set of material models, including asphaltic stiffness master curve, asphaltic binder viscosity aging, etc. In *CalME*, asphaltic material has two stiffness models: the linear elasticity model inherited

from the generic pavement material, and the asphaltic stiffness master curve model that is specific to the asphaltic material. The asphaltic stiffness master curve accounts for the effects of loading time and temperature, and provides the Young's modulus needed for the linear elasticity model for use in the response models.

CalME includes three specialized groups of pavement materials: asphaltic material, non-asphaltic bound material, and unbound material. The non-asphaltic bound material can be further specialized into cementitiously stabilized material.

The ensuing subsections, which describe each type of material and the associated material models.

Generic Pavement Material

Every material used in *CalME* is a pavement material, which is defined by two models: heat transfer and linear elasticity. They do not undergo any change (such as fatigue damage and permanent deformation) in pavement design life.

Heat Transfer

A one-dimensional, coupled heat and moisture flow model called the Integrated Climatic Model (ICM) was developed in the late 1980s by Lytton et al. to simulate temporal variations in the temperature, moisture, and freeze/thaw conditions internal to the pavement and their impact on key pavement material properties (Lytton et al, 1993). This program is recognized as the most comprehensive model addressing the effects of climate on pavements.

The Enhanced Integrated Climatic Model (EICM) (Zapata and Houston, 2008) is an improved version of ICM that was developed for the Federal Highway Administration (FHWA) and adopted as the climatic model in the Mechanistic-Empirical Pavement Design Guide (MEPDG) software developed under National Cooperative Highway Research Program (NCHRP) Project 1-37A (ARA, 2004). EICM is intended to help predict or simulate the changes in behavior and characteristics of pavement and unbound materials in conjunction with varying environmental conditions over years of service.

EICM was found to be too slow and complex to be run within *CalME*. Instead, *CalME*

uses a simplified thermal model to predict a pavement's temperature profile during its service life. The model is based on surface temperatures generated by EICM and a constant deep soil temperature. Specifically, *Ca/ME* divides California into nine climate zones, each of which is represented by a "super weather station" that has thirty years (Ongel, 2004) of historical weather data ranging from 1961 to 1990 that can be used as inputs to EICM to calculate pavement surface temperatures over that same thirty-year period. *Ca/ME* assumes that pavement temperature at a depth of four meters remains constant and sets this value as the annual average surface temperature. *Ca/ME* then solves for pavement temperature profile by using a 1-D Finite Element formulation with a finite difference time step (Lea, 2012).

Ca/ME further assumes that pavement temperatures are cyclic and that the 30-year period is longer than the temperature cycle. Accordingly, *Ca/ME* uses the 30 years of historical temperature data to represent future pavement temperatures and repeats itself every thirty years. This is a simplification, and it is believed that the error introduced is minimal.

Solving for pavement temperature profile with known top (surface) and bottom (i.e., 4 meter depth) temperature history is essentially a heat transfer problem, which is governed by the following partial differential equation (in 1D) called Fourier's Law of conduction:

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial z^2}$$

where: T is temperature that varies with time t and depth z
 α is the thermal diffusivity

Ca/ME starts with an initial uniform temperature profile using the average annual surface temperature as the fixed value. It solves the above heat conduction equation hour by hour. It uses a year of simulation to stabilize the solution and remove the effect of the assumed initial temperature profile. The only model parameter required here is α , i.e., the thermal diffusivity of the material in each layer.

Lytton, R.L., D.E. Pufahl, C.H. Michalak, H.S. Liang, and B.J. Dempsey. *An Integrated Model of the Climatic Effects on Pavements*, Report No.: FHWA-RD-90-033. 1993. Prepared by U.S. Department of Transportation, Federal Highway Administration: McLean, VA.

Zapata, C.E., W.N. Houston, and National Cooperative Highway Research Program. *Calibration and Validation of the Enhanced Integrated Climatic Model for Pavement Design*, Report No.: NCHRP Report 602. 2008. Prepared by Transportation Research Board of the National Academies: Washington, DC.

ARA Inc., *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures*, ERES Consultants Division, ARA Inc. 2004. Prepared by the National Cooperative Highway Research Program, Transportation Research Board, National Research Council.

Ongel, A., and J.T. Harvey. *Analysis of 30 Years of Pavement Temperatures using the Enhanced*

Integrated Climate Model (EICM). Report No.: UCPRC-RR-2004/05. 2004. Prepared by Pavement Research Center, Institute of Transportation Studies, University of California Berkeley, University of California Davis.

Lea, J.D., and J. Harvey, editors. *Simplified Thermal Modeling Approach Used in CalME*. In *Proceedings of the Transportation Research Board 91st Annual Meeting*. 2012.

Linear Elasticity

In *CalME*, pavement structures are simplified as multilayer elastic systems. All materials are assumed to be linear elastic when calculating the critical responses of the pavement. This is true even for rate-dependent materials such as asphaltic materials and stress-dependent materials such as unbound materials. This is possible because all of the models in *CalME* that affects layer stiffness are non-iterative. In other words, if layer stiffness is affected by certain factor, that factor cannot in turn be affected by the same layer stiffness.

To characterize a linear elastic material in *CalME*, the user needs to provide the layer stiffness and Poisson's ratio. Stiffness refers to the apparent Young's modulus of a material under a given loading condition, such as loading rate, temperature, age, confinement, or stress state.

For in-service pavements, the layer moduli are determined from backcalculation using FWD data.

Even though it can significantly affect the calculated pavement responses, Poisson's ratio is fixed for each material type during model calibration. As a result, Poisson's ratio is fixed for each material type for design too.

The only material that is classified as generic pavement material is portland cement concrete (PCC).

Asphaltic Materials

Asphaltic materials are the ones that has asphaltic binders that make the material viscoelastic, which means the stiffness depends on loading time and temperature.

Asphaltic materials are subjected to the following damage mechanisms under repeated traffic loads:

- Fatigue damage due the gradual breakage of asphaltic bonds, and
- Permanent deformation due to shear flow of the material

Asphaltic Stiffness Master Curve

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

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

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:

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

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

The viscosity is found from:

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

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 = 1000 cPoise = 10 Stoke (St)).

For asphaltic 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 [200 + z]/speed.

Examples of the viscosity parameters are shown below, given for temperature in °R ($A^{\circ}K = A^{\circ}R + VTS \times \log(9/5)$). 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				

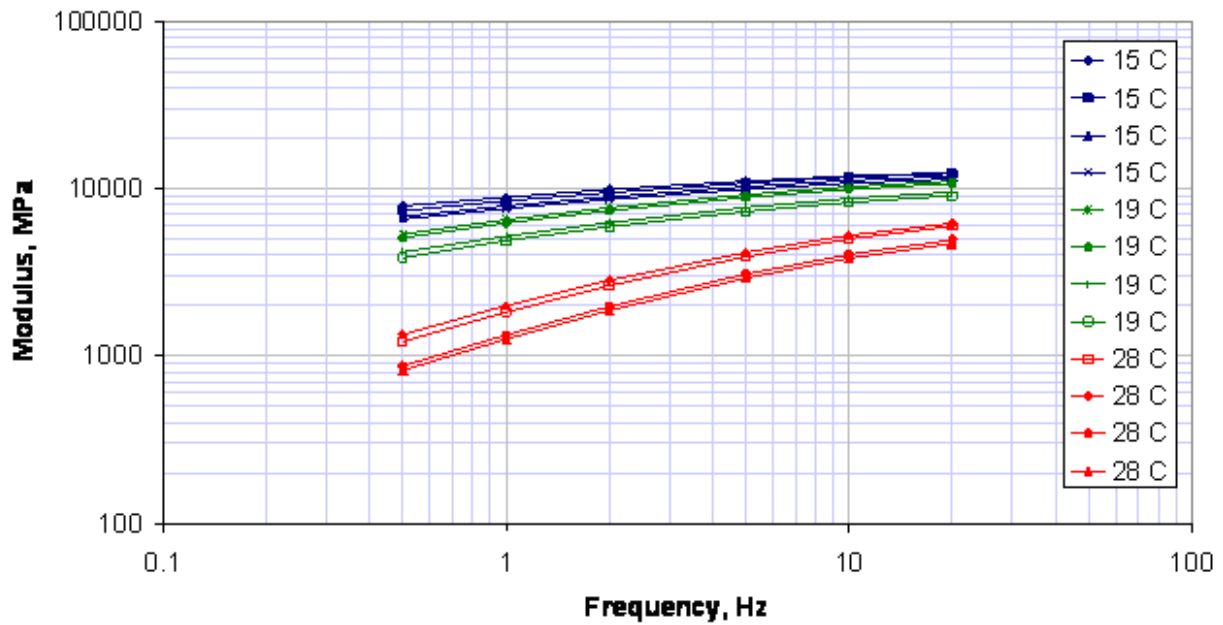
Grade	A	VTS
AC-2.5	11.5167	-3.8900
AC-5	11.2614	-3.7914
AC-10	11.0134	-3.6954
AC-20	10.7709	-3.6017
AC-30	10.6316	-3.5480
AC-40	10.5338	-3.5104

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.

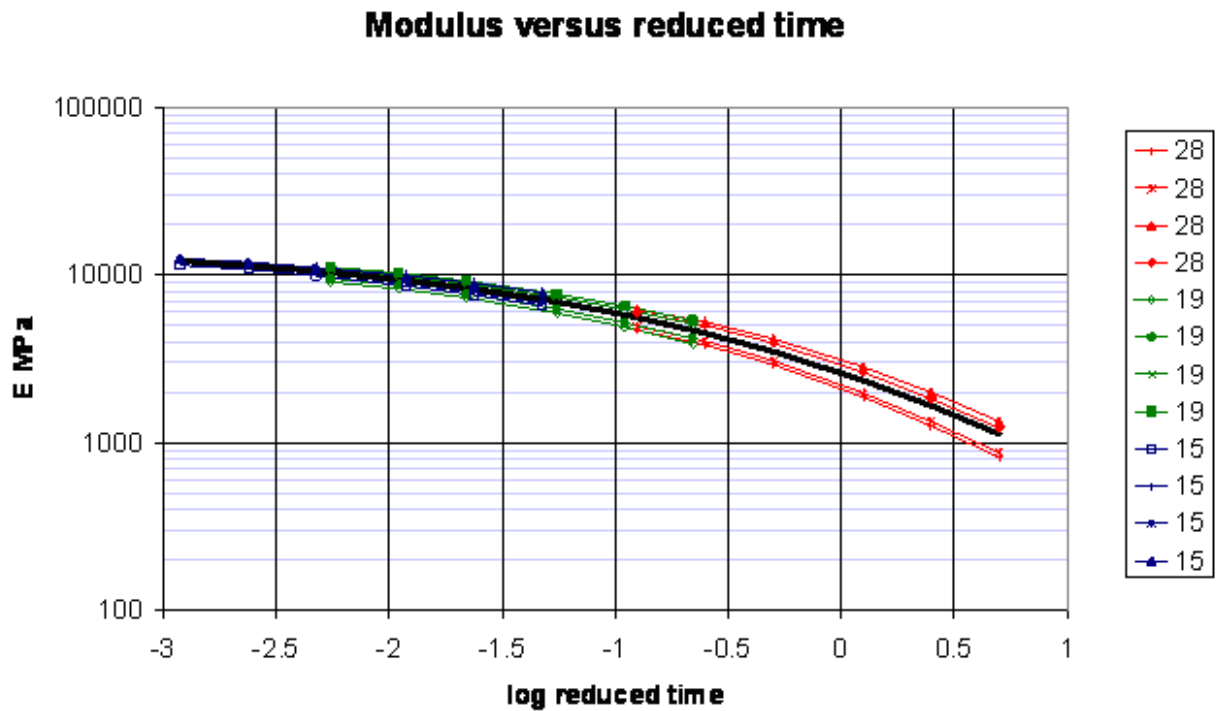
The figure below shows the results of frequency sweep tests done at three different temperatures (15, 19 and 28 oC)

Modulus versus frequency at different temperatures



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 minimizing 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.

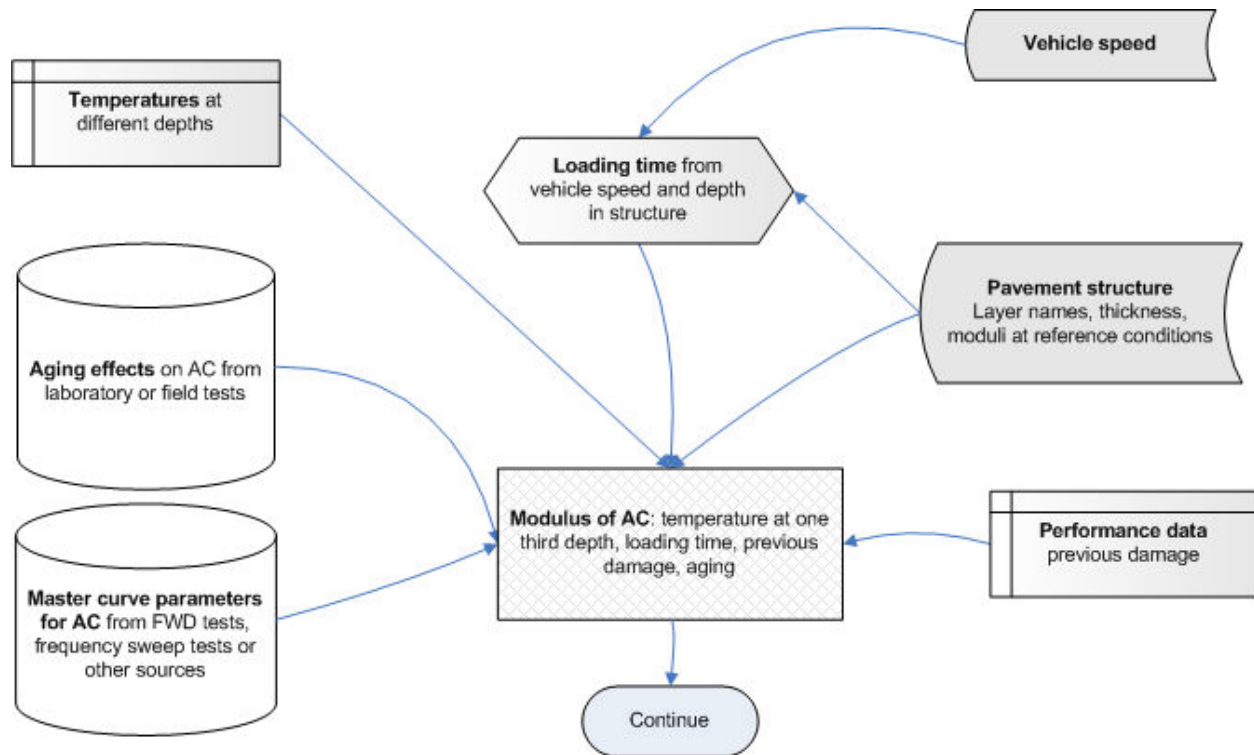


The master curve equation for this case was:

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

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 200 MPa, corresponding to the modulus of the aggregate alone, is recommended even though it may not fit the softer part of the laboratory data as well.

Flowchart for Determining Asphaltic Material Modulus



Asphaltic Binder Viscosity Aging

Hardening of the asphaltic materials may be caused by a reduction in air void contents caused by post-construction compaction and/or by aging (oxidation) of the binder. In *CalME* the following model is used to describe the binder aging through increase in viscosity:

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

where ΔA is the increase in the [viscosity constant](#),

time is age of the material in months,

T is the pavement temperature in degree Celsius at 1/3 depth of the pavement layer,

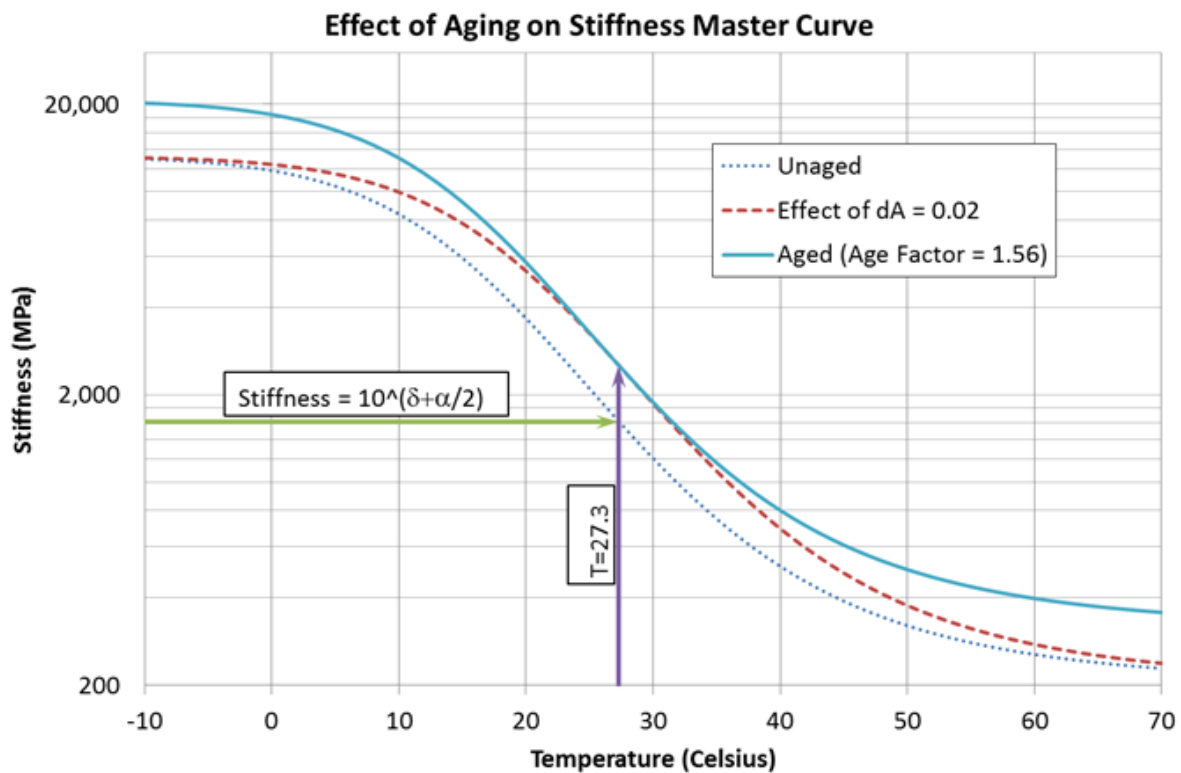
A = 0.7 and B = 0.007 are constants, and

All logs are base 10.

This model is derived from the work by Houston et al. (2007) with some additional assumptions. The model parameter A depends on the A-VTS relationship of the binder, but the variations are very small and an average value of 0.7 may be used for most

binders. The model parameter B can be adjusted to account for different types of material. The default values shown above were determined based on preliminary field data collected in California.

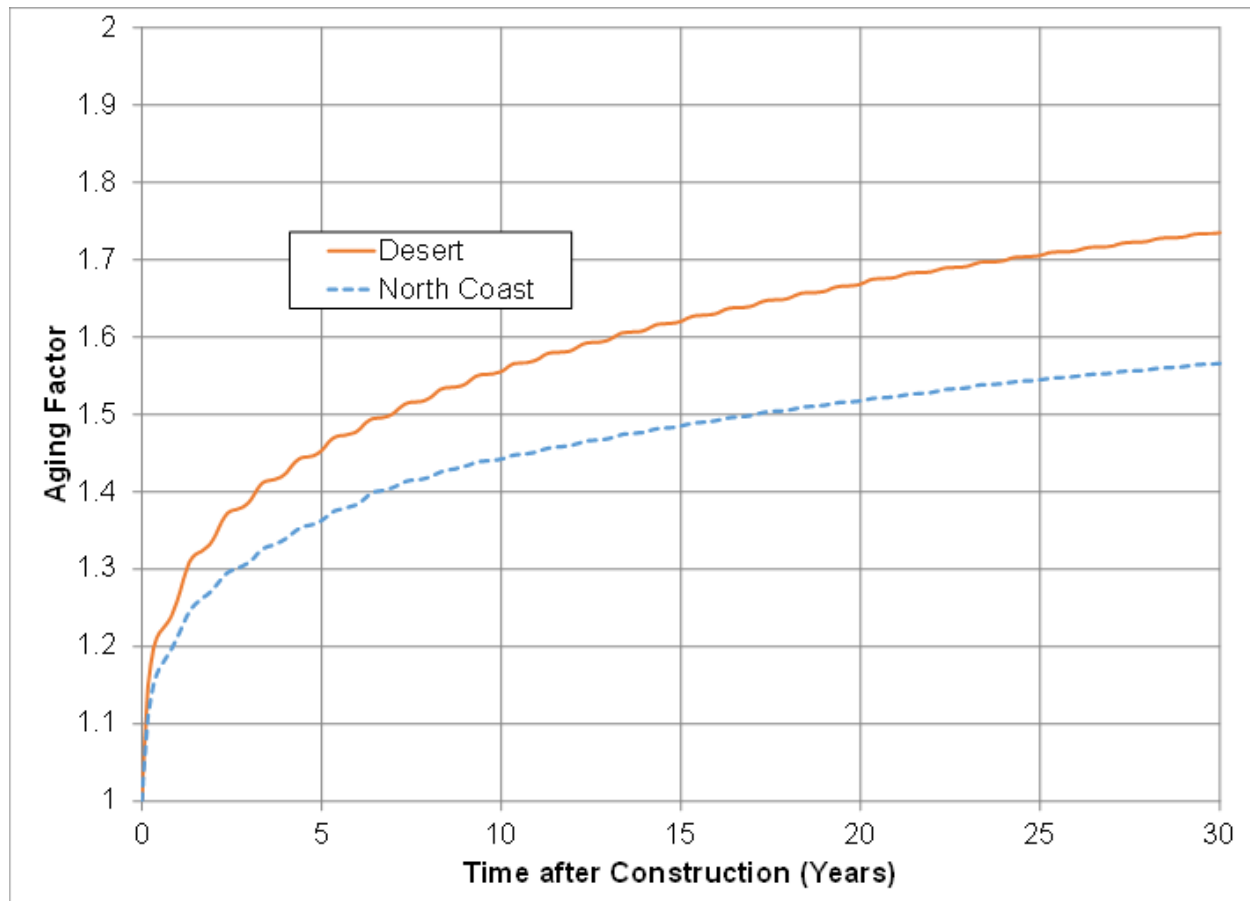
Just increasing the viscosity will make the master curve shift to the right, which implies that there will be no hardening effect at high or low temperatures. To allow the hardening effect at both high and low temperatures, an aging factor has been introduced and it is defined as the ratio of the modulus of hardened material to the modulus of the original material. The aging factor is determined by evaluating the effect of a viscosity increase due to aging for the temperature corresponding to a modulus of the original material of $10^{\delta+\alpha/2}$ under 10 Hz loading frequency. The aging factor is then used to increase the modulus at all temperatures. In essence, applying a uniform aging factor for all temperatures is equivalent to increasing δ . An example of how the aging factor is determined along with the unaged and aged stiffness master curves are shown below. Note that the aging factors are different for different materials even if ΔA is the same because the aging factor depends on the parameters of the stiffness master curve model itself.



Demonstration of the effect of increase in A (i.e., ΔA) and the corresponding unaged and aged stiffness master curves, $\beta = 0.7482$, $\delta = 2.3010$, $\gamma = 0.8718$ and $\alpha = 1.8195$, loading frequency = 10Hz.

As an example to demonstrate how they change with time and climate, aging factors

have been calculated for an HMA layer in a flexible pavement in the North Coast and Desert climate zones respectively over a thirty-year period. The structure has 150 mm HMA over 300 mm AB-Class 2 followed by subgrade with CL soil. The changes of aging factors over time are shown below, which indicates that the HMA layer stiffness will increase by approximately 50 to 70 percent over 30 years due to aging depending on the climate zone the pavement is in.



Aging factor calculated for a typical flexible pavement in the North Coast and Desert climate zones respectively.

Aging may be limited by a maximum age in days, beyond which no more aging takes place. This is set to 10 years or 3650 days in *CalME*.

Houston, W.N., M. W. Mirza, C. E. Zapata, and S. Raghavendra. National Cooperative Highway Research Program. *Research Results Digest 324: Simulating the Effects of Hot Mix Asphalt Aging for Performance Testing and Pavement Structural Design*. 2007. Available from: onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rrd_324.pdf. (Accessed Jan. 17, 2017)

Asphaltic Fatigue and Reflective Cracking Damage

Asphaltic materials are subjected to fatigue damage and reflective cracking damage. The model for calculating both damages are the same except the critical strains are determined using different [response models](#).

Fatigue and reflective cracking damage changes the stiffness master curve independently. The damaged stiffness master curve has the following format:

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

where the damage, ω , is calculated from the following equation following the [time hardening procedure](#):

$$\omega = \left(\frac{MN}{SF \times MN_p} \right)^{\alpha_f}$$

where: MN is the number of load applications in millions,
 MN_p is the allowable number of load repetitions in millions,
 α_f is a material-dependent model parameter, and
 SF is the shift factor used to account for difference between laboratory and in-situ conditions.

The shift factor is determined from the difference between laboratory fatigue tests and full scale testing (HVS and track tests).

Damage as a function of number of loads, strain, temperature, and modulus. MN_p is calculated in turn using the following equation:

$$MN_p = A \times \left(\frac{\varepsilon}{\varepsilon_{ref}} \right)^{\beta} \times \left(\frac{E}{E_{ref}} \right)^{\beta/2}$$

where: ε = the critical strain, negative for tensile,

ε_{ref} = -200 microstrain is the reference bending tensile strain,

E is the damage stiffness,

E_{ref} = 3,000 MPa (435 ksi) is the reference stiffness, and

A and β are material constants.

The critical strain for fatigue damage is the longitudinal bending strain at the bottom of the combined asphaltic layer in microstrain under the center of one of the tire for fatigue damage. The critical strain for reflective cracking damage is the average first principle strain (in tension) along the vertical direction for the area within 0.4" (10 mm) of the

crack/joint tip.

The parameters of the damage function are determined from four-point, constant strain bending tests in the laboratory.

The intact modulus, E_i , corresponds to a damage, ω , of 0 and the minimum modulus, $E_{min}=10^5$, to a damage of 1.

The master curve for damaged asphalt leads to:

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

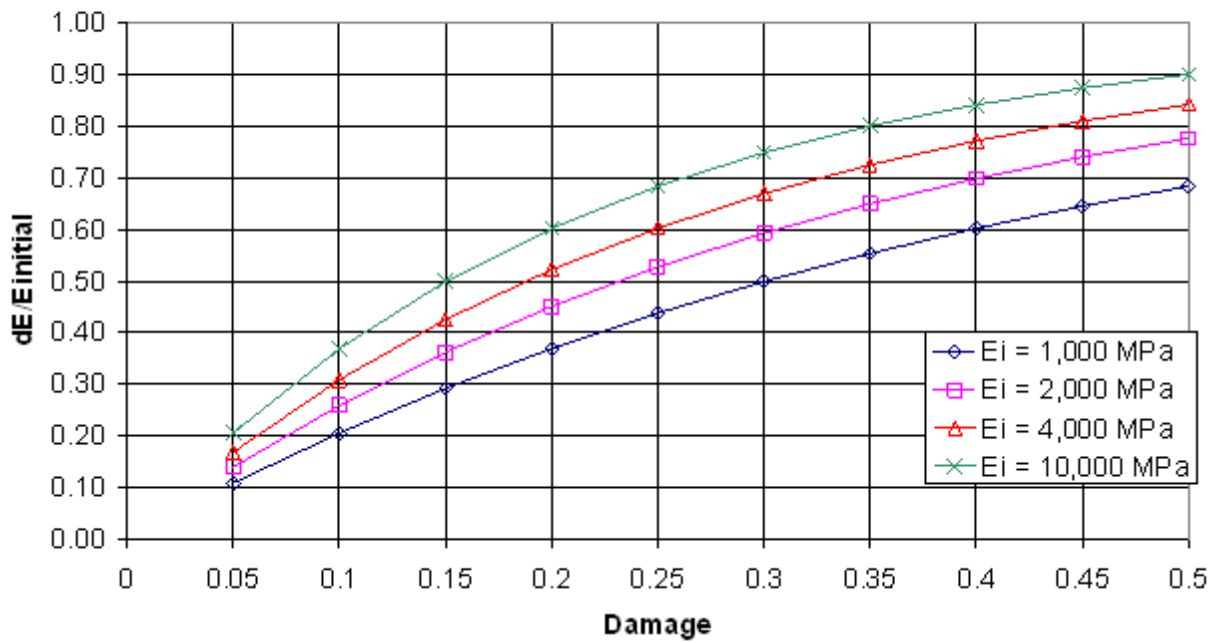
$$\frac{E}{E_i} = \left(\frac{E_{min}}{E_i} \right)^\omega, \text{ or}$$

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

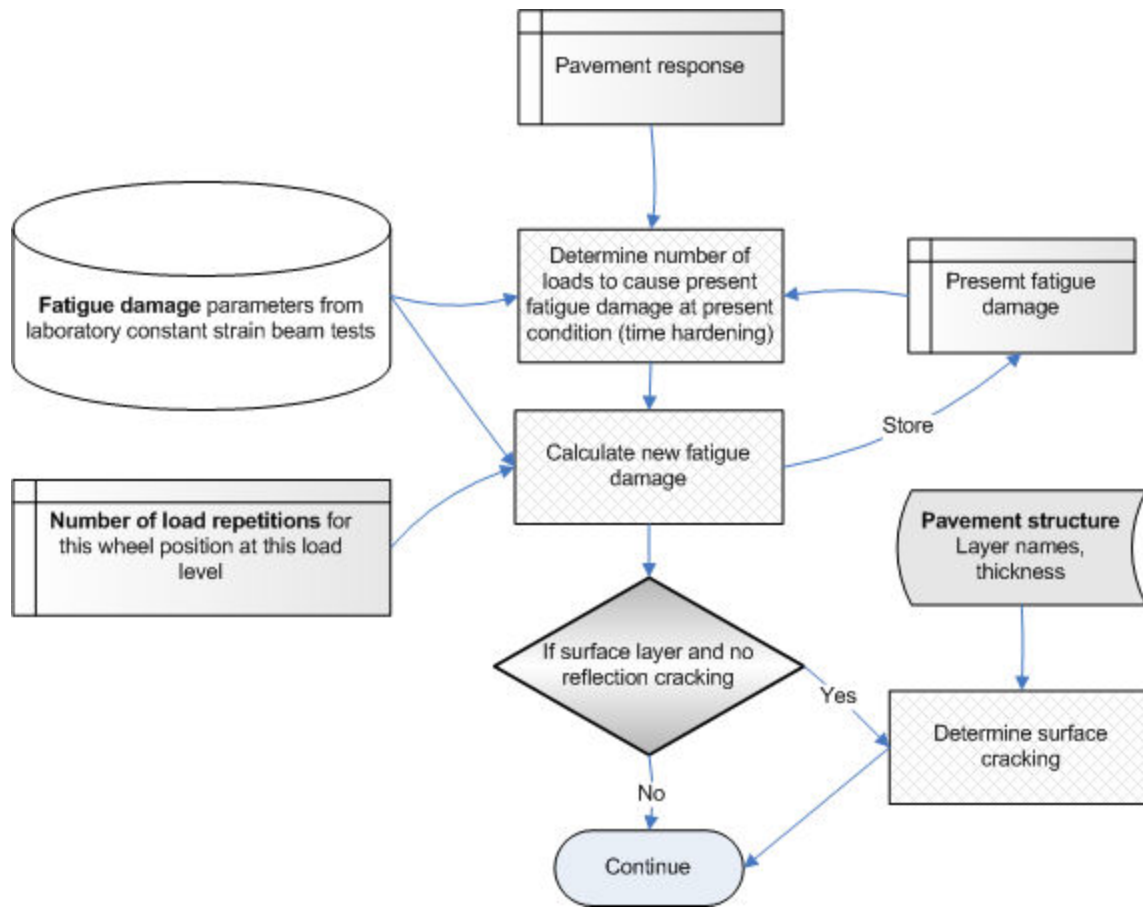
where .SR is the residual stiffness ratio.

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.

Decrease in modulus as function of damage



Flowchart for fatigue damage



Rest Period Effect on Asphaltic Damage

The effect of rest periods on asphaltic damage (fatigue or reflective cracking) is accounted by multiplying the shift factor SF in the damage equation with the following correction factor:

$$C_{rp} = 1 + \left(\frac{RP}{RP_{ref}} \times \left(\frac{\eta(T_{ref})}{\eta(T)} \right)^{aT} \right)^{\varphi}$$

where RP is the rest period,

T_{ref} and aT are [master curve](#) parameters,

$\eta(t)$ is the viscosity at a temperature of T , and

$\eta(T_{ref})$ is the viscosity at reference temperature T_{ref} , and

RP_{ref} and φ are constants.

The default values of RP_{ref} and φ are 10 sec and 0.4, respectively. The rest period is calculated as the interval between trucks (not axles) by evenly distributing the trucks over time.

7.5.1.3.3.3. Effect of Thermal Strain

Another potential reason for the difference between the beam fatigue tests and in-situ pavements is that daily and seasonal temperature changes cause changes to the asphalt materials that affect the fatigue properties. Cooling of an asphalt beam will cause the beam to contract, but in the pavement layer the material is restrained from contracting. In a linear elastic material this constraint would cause a semi-static tensile stress in the material.

For fatigue of metals several methods are used to add the effects of static and dynamic tensile stresses. The dynamic stress is normally sinusoidal, with an amplitude of σ_a , on which a static stress of σ_m is superimposed.

Goodman's method of adding dynamic and static stresses states that failure is reached when:

$$\frac{\sigma_a}{S_N} + \frac{\sigma_m}{S_u} = 1$$

where: σ_a is the amplitude of the dynamic stress,
 σ_m is the static stress,
 S_N is the fatigue stress for N load applications, and
 S_u is the static strength.

If the fatigue equation for purely dynamic loading is used, the effect of the static stress may be considered by multiplying the amplitude of the dynamic stress by a factor f :

$$f = \frac{S_u}{S_u - \sigma_m}$$

For asphalt it appears that strain is more important than stress. For metals stress and strain are practically proportional, but for a viscoelastic material such as asphalt concrete that is not the case. The coefficient of thermal contraction (CTC) for asphalt depends on the temperature and range from 3 to 30 microstrain/°C for -20 to 55°C (Islam, 2015). Cooling an asphalt beam by 10°C would cause it to contract by as much as 300 microstrain. To bring it back to the original length that strain must be imposed on the material. This will create a stress that relaxes over time, but the strain will remain.

When an asphalt pavement cools down it will contract in the vertical direction but not in the horizontal direction (at least not longitudinally). This will not create a measurable strain in the material, but on the level of the grain size it will. A strain will develop in the binder film when the grain contracts. The condition of the material will be the same as in a beam that is cooled and then strained to gain its original length. It makes sense, therefore, to consider a strain caused by temperature changes, although it would not be possible to

measure such a strain in the material.

One possible way of including this strain would be to use the method given above, but with the static (temperature-induced) strain added to the dynamic (load-induced) strain. This would require a calculation of the static strain, and to do this the temperature at which the static strain is zero must be known. It is uncertain whether this temperature is constant during the year since it could be changing as a result of permanent deformation in the material, so it would be interesting to measure the contraction or expansion on cores or slabs cut from asphalt layers at different times and temperatures. The Goodman method would also require a maximum permissible static strain (or minimum temperature), which could possibly be related to the low temperature grade for PG grade materials.

An option for including temperature strains using the Goodman method has been added to *CalME*. This option is only activated for the thermal reflective cracking strains, i.e., the strain in the overlay caused by contraction of the underlying cracked layers. The temperature when thermal strain becomes zero ($T_{\varepsilon=0}$) is set to 20°C. The temperature corresponding to maximum allowable temperature strain ($T_{\min}$)

$$\frac{1}{f} = \frac{S_u - \sigma_m}{S_u} = 1 - \frac{\sigma_m}{S_u} = 1 - \frac{\varepsilon_{\text{thermal-RC}}}{(T_{\min} - T_{\varepsilon=0}) \times CTC}$$

where $\varepsilon_{\text{thermal-RC}}$ is the thermal strain in the HMA layer caused by contraction of the underlying cracked layer,

and CTC is the coefficient of thermal contraction of the HMA layer

The following equation is used to calculate $\varepsilon_{\text{thermal-RC}}$:

$$\varepsilon_{\text{thermal-RC}} = C_{RC} \cdot (T_{\text{cracked}} - T_{\varepsilon=0}) \times CTC_{\text{cracked}}$$

where C_{RC} is the coefficient of reflective cracking strain transfer

T_{cracked} is the temperature of the underlying cracked layer, and

CTC_{cracked} is the coefficient of thermal contraction of the underlying cracked layer

C_{RC} depends on whether it is an AC on AC overlay or an AC on PCC overlay. C_{RC} is set to 1.20 for AC on AC overlays and 5.4 for AC on PCC overlays in *CalME*. The reason an old cracked AC layer transfers much less of its thermal strain to the AC overlay than an old cracked PCC layer is because of its lower stiffness (relative to the AC overlay) and its much higher creeping capability. The reason C_{RC} is greater than 1.0 is because of the strain concentration caused by the existence of cracks or joints.

Note that the calculation of thermal reflective cracking strain still has a lot of open questions. The way it

is handled in *CalME* will most likely be further refined and improved in the future.

Islam, R., Asce, S.M., Tarefder, R.A., and Asce, M. 2015. "Coefficients of Thermal Contraction and Expansion of Asphalt Concrete in the Laboratory." *Journal of Materials in Civil Engineering* 27 (11): 04015020. [https://doi.org/10.1061/\(ASCE\)MT.1943-5533.0001277](https://doi.org/10.1061/(ASCE)MT.1943-5533.0001277).

Asphaltic Permanent Deformation

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 gamma function:

$$\gamma^i = A \cdot \exp\left(\alpha \times \left[1 - \exp\left(-\ln(N)/\gamma\right) \times \left(1 + \ln(N)/\gamma\right)\right]\right) \times \gamma^e$$

where γ_e is the elastic shear strain,

N is the number of load repetitions, and

A , α , and γ are constants determined from the RSST-CH.

The rut depth is calculated for the upper 100 mm of the AC layers. The elastic shear strain 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, $\gamma_e = \varepsilon_{xz}$, is calculated from:

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

where τ is the shear stress,

E_i is the modulus of layer i , and

ν_i is Poisson's ratio for layer i .

x is in transverse direction, while z is in vertical direction. Please notice that the xz shear strain is used, not the angular (or engineering) shear strain which is twice this value. The permanent shear strain of each layer is calculated from the gamma function, and the permanent deformation is determined from:

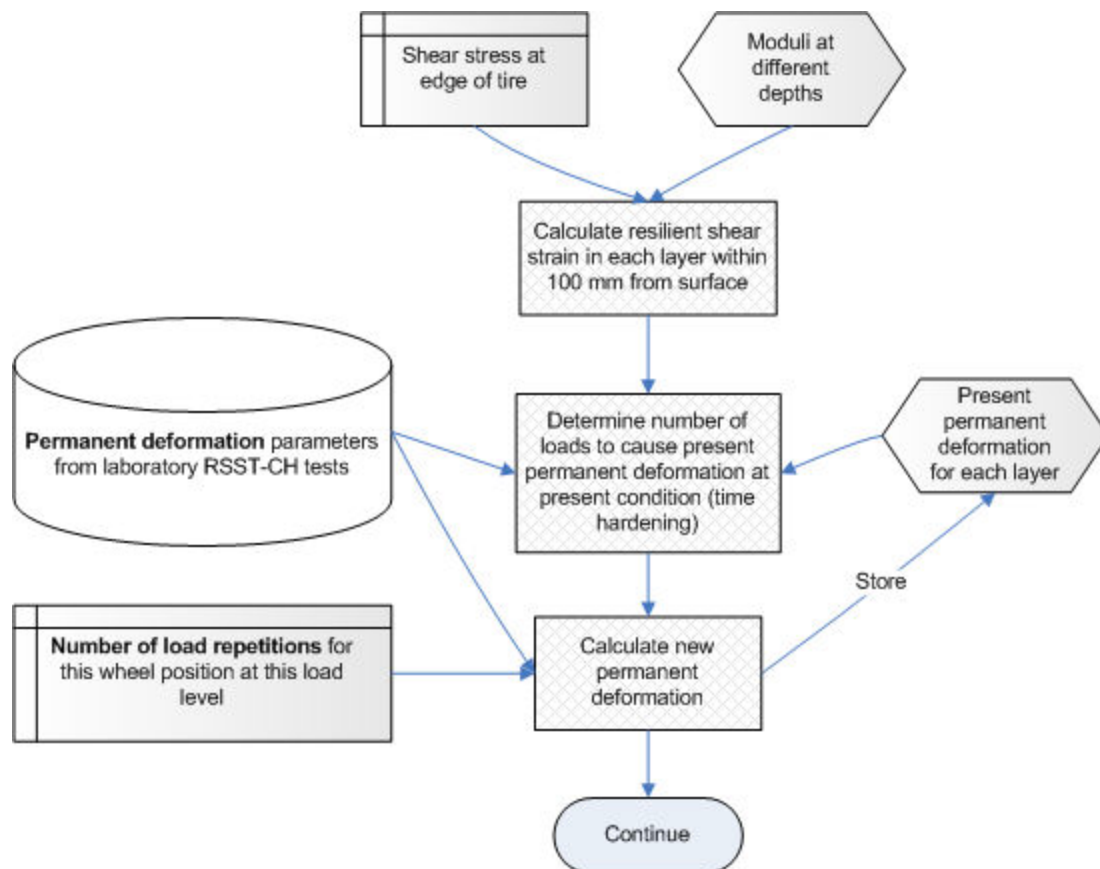
$$d_{pi} = K \times h_i \times \gamma_i^i$$

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.

Deacon, J.A., J.T. Harvey, I. Guada, L. Popescu, and C.L. Monismith, *Analytically Based Approach to Rutting Prediction*. Transportation Research Record, 2002(1806): p. 9-18.

Flowchart for permanent deformation of asphalt



Moisture Ingress Determination

When intact, asphaltic materials together act as a moisture barrier to stop surface

run-off from infiltrating directly through them into the unbound layers below. As fatigue damage accumulates in the asphaltic layers, cracking develops and the moisture barrier starts to break.

As the modulus of the asphalt decreases due to micro- and macro-cracking, the material may become permeable.

Ca/ME determines whether the moisture can ingress through an individual asphaltic layer by comparing its fatigue damage against a preset threshold. Specifically, residual [stiffness ratio](#) of the layer material is used to indicate the extent of fatigue damage. The moisture ingress flag for an asphaltic layer is set when its residual stiffness ratio drops below the threshold (default value is 0.70).

List of Asphaltic Materials

Asphaltic materials include the following types:

- HMA,
- RHMA-G,
- FDR-FA: full depth recycled material with foam asphalt
- PDR: partial depth recycled materials, using either engineering emulsion (EA) or foam asphalt (FA), either produced in-place (PDR), or through cold central plant (PDR/CCPR)
- CCPR-EA and CCPR-FA: cold central plant recycled materials using either engineering emulsion or foam asphalt

Although they are not quite as well bounded as typical HMA, FDR-FA, PDR/CCPR-FA, and PDR/CCPR-EA materials are strongly enough that viable beams (AASHTO T 321) and cores (AASHTO T 320) can be produced and tested in the laboratory. These materials may therefore be characterized the same way as HMA.

PDR-EA was characterized using AASHTO T 321 and T 320 using specimens cut from slabs taken from California highway. CCPR-EA is essentially the same as PDR-EA in *Ca/ME* until additional data become available.

FDR-FA was characterized using a combination of lab testing and field testing. In particular, the stiffness master curve was developed based on AASHTO T 321 frequency sweep using beams cut from an accelerated pavement testing (APT) track. The fatigue damage model was developed based on APT data. The permanent deformation model was assumed to be the same as a RHMA-G mix.

PDR-FA and CCPR-FA are assumed to be the same as PDR-EA (not FDR-FA) until more data become available.

It is possible in the future to use lower variability of CCPR materials compared to PDR materials, once more data become available.

Non-Asphaltic Bound Materials

Non-asphaltic bound materials are materials bound by non-asphaltic binders. Their stiffnesses are not sensitive to loading time and loading temperature.

These materials may be subjected to fatigue damage.

Non-Asphaltic Fatigue Damage

A damage function similar to the one used for fatigue damage of asphaltic materials may be used for generic non-asphaltic bound materials. It is based on the maximum tensile strain at the bottom of the layer. The fatigue damage is calculated using the following equation and the [time hardening procedure](#):

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

where MN is the number of load repetitions in millions,
 ε is the horizontal tensile strain at the bottom of the layer in the longitudinal direction,
 ε_{ref} is the reference strain,
 E is the modulus of the material (adjusted for climate and damage),
 E_{ref} is the reference modulus, and
 A , α , β and γ are constants.

The modulus of the layer is reduced by multiplying the intact modulus by $(1 - \omega)$, where ω is the fatigue damage. To avoid unreasonably low stiffness, the damage ω must be no more than ω_{max} which is set to 0.9 by default:

$$\omega \leq \omega_{max}$$

List of Generic Non-Asphaltic Bound Materials

Generic non-Asphaltic bound materials include the following:

- FDR-C: full depth recycled material with cement,
- CCPR-C: cold central plant recycled material with cement, and
- Old CTB: old cement treated base, regardless of whether it was constructed as CTB-Class A or CTB-Class B.

Consideration for FDR-C and CCPR-C

Although FDR-C is a cementitiously stabilized material, it is modeled as generic non-asphaltic bound material because accelerated pavement testing data using HVS (heavy vehicle simulator) is available for identifying parameters for the non-asphaltic fatigue damage model.

CCPR-C is treated the same way as FDR-C due to their similar composition. Potentially CCPR-C can lead to better pavement performance due to better quality control. These benefits will be implemented into *CalME* when more data become available.

Consideration for Old CTB

Note that fatigue damage in Old CTB is by default deactivated by setting the maximum allowable fatigue damage to be 0.

Cementitiously Stabilized Materials

Cementitiously stabilized materials (CSM) includes lean concrete base, cement stabilized aggregate, and soil stabilized with cement, lime, fly ash, or combinations thereof in the subgrade, sub-base, and base layers of pavement structures.

CSM are special kind of non-asphalt bound materials. These materials undergo curing, bottom up fatigue damage, and top down crushing damage. The models for CSM are taken from the paper by Li et al (2019). The cementitious material fatigue damage model replaces the non-asphaltic fatigue damage model.

These materials tend to be stable and do not experience permanent deformation.

Li, X., Wang, J., Wen, H., and Muhunthan, B. 2019. "Field Calibration of Fatigue Models of Cementitiously Stabilized Pavement Materials for Use in the Mechanistic-Empirical Pavement Design Guide." *Infrastructure Transportation Research Record* 2673 (2): 427–35.
<https://doi.org/10.1177/0361198118821924>.

Cementitious Material Curing

Curing in cement-stabilized materials only depends on time. At any given time of the service life, the material strength is increased from the 28-day value by a ratio determined by the following equation:

$$c_{strength} = p_1 \left(1 - \frac{1}{1 + \frac{t - t_0}{p_2}} \right)$$

where $c_{strength}$ is the curing factor for strength
 p_1 and p_2 are model parameters,
 t is the current time in months, and
 t_0 is the initial time at which the strength (either UCS or MOR) was determined.

This factor is used to calculate current UCS (unconfined compressive strength) or MOR (modulus of rupture):

$$UCS = UCS_{28} \cdot c_{strength}$$

$$MOR = MOR_{28} \cdot c_{strength}$$

where UCS_{28} is the 28-day UCS and MOR_{28} is the 28-day MOR. Although not used in *CalME*, the layer stiffness of cement-stabilized material can be correlated to UCS through the following equation:

$$E_f = 15229 \times UCS^{0.35}$$

where E_f is the flexural stiffness. Accordingly, the curing factor for stiffness can be determined using the following equation:

$$c_{stiffness} = c_{strength}^{0.35}$$

Cementitious Material Fatigue Damage

Bottom-up fatigue damage in cementitiously stabilized materials is driven by the tensile stress at the bottom of the layer. The model for fatigue life is:

$$\log_{10}(N_{ft}) = k_1 \cdot \left(\frac{k_3 - \frac{\sigma_t}{MOR}}{k_2} \right)$$

where N_{ft} is the fatigue life, k_1 , k_2 and k_3 are model parameters, σ_t is the tensile stress in the transverse direction, and MOR is the current modulus of rupture after accounting for curing. Once the fatigue life is determined for each axle load, the fatigue damage is accumulated following Miner's Law:

$$\omega_{ft} = \sum_i \frac{N_i}{N_{fti}}$$

where ω_{ft} is the fatigue damage, N_i is the number of passes for the i^{th} axle load, and N_{fti} is the crushing life corresponding the i^{th} axle load. The stiffness is then reduced by the following ratio:

$$SR_{fatigue} = 1 - \frac{m_2}{\ln(UCS_{28,psi})} \cdot \left(\frac{1}{2} - \frac{1}{1 + \exp[\sinh(n_2 \cdot \omega_{ft})]} \right)$$

where $SR_{fatigue}$ is the stiffness ratio due to fatigue damage, m_2 and n_2 are model parameters that depend on the material type, $UCS_{28,psi}$ is the 28-day UCS in psi, and ω_{ft} is the crushing damage. Damage is updated after every set of loads following the incremental-recursive procedure in *CalME*.

Cementitious Material Crushing

The top-down crushing damage in cementitiously stabilized materials is driven by vertical compressive stress. The model for the crushing life is:

$$\log_{10}(N_{fc}) = k_4 \cdot \log_{10} \frac{\rho}{wc_{opt}} \cdot \left(1 - \frac{\sigma_c}{k_5 \cdot UCS} \right)$$

where N_{fc} is the crushing life,

k_4 and k_5 are model parameters that depend on the material type,
 ρ is the maximum dry density of the material in lbs/ft^3 ,
 wC_{opt} is the optimum moisture content in percent,
 σ_c is the vertical compressive stress at the top of the layer, and
 UCS is the current unconfined compressive stress after accounting for curing.

Once the crushing life is determined for each axle load, the crushing damage ω_c is accumulated the same way as cementitious fatigue damage, following Miner's Law, but damage is updated after every set of loads following the incremental-recursive procedure in *CalME*. The stiffness is then reduced by a ratio SR_{curing} , which is determined using the same equation as cementitious fatigue damage.

Combining All Damages

At any given time during the service life, the curing factors are first determined based on the current time. The stiffness is updated using the following equation:

$$E = E_{28} \cdot c_{stiffness} \cdot SR_{fatigue} \cdot SR_{crushing}$$

In the meantime, both UCS and MOR are updated following the [curing model](#) respectively. The vertical stress needed to drive crushing damage and the tensile stress needed to drive fatigue damage are then calculated for each axle load. The fatigue life and crushing life are then calculated using the updated UCS and MOR.

List of Cementitiously Stabilized Materials

Asphaltic materials include the following types:

- LCB: lean concrete base, including regular LCB and rapid set LCB (LCBRS).
- CTB-Class A,

- CTB-Class B, and
- Treated Soil: including lime stabilized soil (LSS) and cement stabilized soil (CSS)

7.5.1.4.3.6. Strength and Stiffness of Cementitiously Stabilized Materials

For cementitiously stabilized materials (CSM), the fatigue and crushing damage models both require strength as input. The 28-day strengths and stiffnesses for the CSMs are listed in the following table. The unconfined compressive strength (UCS) is the main input, from which both the initial (28-day) stiffness and MOR are estimated. The equations for estimating stiffness from UCS depend on the material type, while the following equation (Wen et al, 2013) is used to estimate MOR from UCS for all materials (

$$MOR_{psi} = 47.45 \times \ln(UCS_{psi}) - 205$$

Material Type	28-day UCS (psi/MPa)	28-day MOR (psi/MPa)	28-day Stiffness (ksi/MPa)	
LCB	700/4.83	106/0.73	1,508/10,398	1.33 Stan $E_{tan} = 57 \times \sqrt{UCS}$
LCBRS (Rapid set LCB)	Same as LCB			
CTB-Class A	Same as LCB			
CTB-Class B	User input, default 400/2.76	Estimated from 28-day UCS, default 79/0.55	Estimated from 28-day UCS, default 1,140/7,860	Stiffness equation
LSS	User input, default 300/2.07	Estimated from 28-day UCS, default 66/0.45	Estimated from 28-day UCS, default 47/326	$E_{tan} = 0.128 \times 1000 \times UCS$
CSS	User input, default 300/2.07	Estimated from 28-day UCS, default 66/0.45	Estimated from 28-day UCS, default 360/2,484	$E_{tan} = 1.2 \times UCS$

Unbound Materials

Unbound materials includes granular base, subbase, and subgrade, as well as materials

that have similar behaviors.

Confinement Effect on Stiffness

It was found that the stiffness 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 function is defined to calculate the effect of confinement:

$$f_{confinement}(S_n) = 1 - \left(1 - \frac{S_n^3}{S_{ref}^3}\right) \times SF$$

where S_n is the bending stiffness for layer n ,
and S_{ref} and SF are constants.

If all layers above layer n are still fully bonded, the bending stiffness for layer n is calculated from:

$$S_n = \sum_{i=1}^{n-1} h_i \times \sqrt[3]{E_i}$$

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

$$S_n = \left(\sum_{i=1}^{n-1} h_i^3 \times E_i \right)^{1/3}$$

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

Unbound layer stiffness is affected by the confinement effect through the following equation:

$$E = E_{ini} \times \frac{f_{confinement}(S_n)}{f_{confinement}(S_{n,ini})}$$

where E_{ini} is the initial layer stiffness,
 $S_{n,ini}$ is the initial bending stiffness for layer n

This equation implies that the unbound layer stiffness is only affected by the change in the stiffnesses of the layers above but not their absolute values.

Nonlinear Elasticity

In addition to confinement effect, the unbound layers for some of the Heavy Vehicle Simulator (HVS) tests also showed typical non-linearity, with the stiffness 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:

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

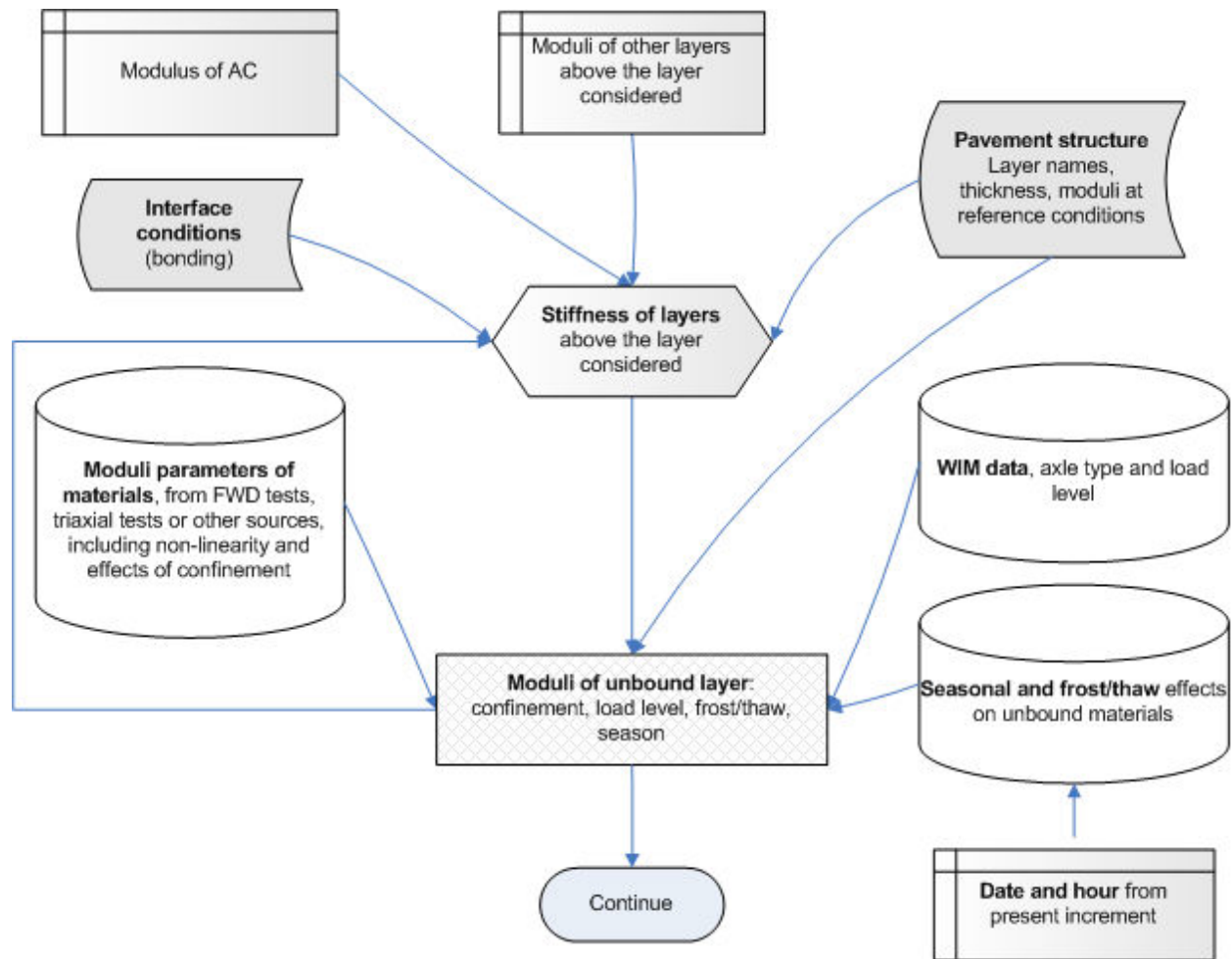
Modulus of unbound material as a function of [hub](#) load.

where E_P is the stiffness at [hub](#) load P in kN,
 $E_{40 \text{ kN}}$ is the stiffness at a [hub](#) load of 40 kN, and
 α is a constant (positive for granular materials and negative for cohesive).

Effects of seasonal variations on unbound material stiffness is currently disabled based on recent research that finds no such effect in unbound layers in California highway (Curran, 2018).

Curran, H., J. T. Harvey and R. Wu (2018). *Guidance for Selection of Unbound Pavement Layer Seasonal Stiffnesses* University of California Pavement Research Center UC Davis, UC Berkeley.

Flowchart for modulus of unbound materials



Moisture Ingress Effect on Stiffness

For a given unbound layer, the moisture barrier becomes broken when all of the asphaltic materials above have reach certain threshold of damage. Details on how *CalME* determines moisture ingress can be found [here](#).

If the stiffness of the asphalt layers all have decreased to a certain fraction of the initial stiffness, the stiffness of the unbound layer may be divided by a value. By default, this value is 1.20 for aggregate base and 2.0 for subgrade.

Permanent deformation of unbound

layers

Permanent deformation, d_p , of the unbound materials is based on the vertical resilient strain at the top of the layer, ε_{zt} , and on the stiffness of the material, E :

$$d_p = A \times MN^\alpha \times \left(\frac{\varepsilon_{zt}}{\varepsilon_{ref}} \right)^\beta \times \left(\frac{E}{E_{ref}} \right)^\gamma$$

where MN is the number of load applications in millions,
 A , α , β , γ , ε_{ref} and E_{ref} are constants.

List of Unbound Materials

Unbound materials include the following types:

- AB: aggregate base,
- AS: aggregate subbase,
- Subgrade
- FDR-N: full depth recycled material with no stabilization
- ATPB: asphalt treated permeable base

Consideration for FDR-N

The UCPRC has conducted extensive research on FDR-N (also known as pulverized) material (Jeon, 2009). Comprehensive laboratory and field tests of the pulverized materials were conducted and the results were compared with those of typical aggregate materials. It was concluded that the pulverized material is stiffer than typical aggregate base material and the permanent deformation resistance of the pulverized material was worse than that of the typical aggregate base material in California at low stress levels but better at higher stress levels. *CalME* simulations suggested that the difference in accumulated permanent deformation in the aggregate base layer after 20 years of trafficking were minimal between the pavements using pulverized material and the ones using typical aggregate material.

It was decided to consider FDR-N material as typical aggregate base, i.e., AB-Class 2.

Consideration for ATPB

Caltrans has only one generic classification for asphalt-treated permeable base (ATPB) (Section 29, Caltrans Standard Specifications). It is produced the same way as hot mix asphalt except with lower binder content that has a default value of 2.5 percent by weight

of aggregate. It has historically been used almost exclusively as a 75 mm (0.25 ft) thick drainage layer directly below the dense-graded asphalt concrete layers.

Research (Bejarano et al., 2004) has shown that ATPB layer is prone to stripping in accelerated pavement testing. ATPB layer stiffness was found to decrease from around 1,500 MPa before HVS trafficking to between 200 and 400 MPa after HVS trafficking. This significant reduction in the stiffness of the ATPB was due to stripping resulting from loading and the intrusion of fines from the aggregate base, regardless of the presence of water. Caltrans and UCPRC researchers have noted that ATPB has about a 50 percent chance of stripping in the field within 10 years of construction.

It was decided to use ATPB in its stripped condition. Specifically, ATPB is treated as an unbound material with stiffness similar to a Class 2 aggregate base.

Bejarano, M.O., J.T. Harvey, A. Ali, M. Russo, D. Mahama, D. Hung, and P. Preedonant. *Performance of Drained and Undrained Flexible Pavement Structures under Wet Conditions Test Data from Accelerated Pavement Test Section 543-Drained*. 2004. Prepared by University of California Pavement Research Center, Institute of Transportation Studies, University of California, Berkeley

Jeon, E.J., PhD Thesis. *Comprehensive Performance Evaluation of In-place Recycled Hot Mix Asphalt as Unbound Granular Material*. University of California, Davis, 2009

Model Parameters

Model parameters for each of the material included in the Standard Materials Library can be found through the [CalME user interface](#).

Consideration for Climate in CalME

Pavement behaviors are affected by climate conditions such as temperature, solar radiation, precipitation/moisture, water table, and freezing/thawing. Currently *CalME* only accounts for the effects of pavement temperature. This is believed to be sufficient for the majority of conditions in California. Note that any factors not explicitly considered in *CalME* is accounted for through the field calibration process.

For pavement design, the California highway network is divided into 9 climate zones. Pavements in each climate zone are subjected to the same climate condition.

Temperature

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 the full 30 years is used to initialize the system.

Surface temperatures have been pre-calculated for each hour of a 30 year period for all climate zones and different pavement structures in California. The values are stored in a database. Calculation over 30 years is used to initialize the system. More details of the model for temperature calculation can be found in the subsection on [Heat Transfer](#).

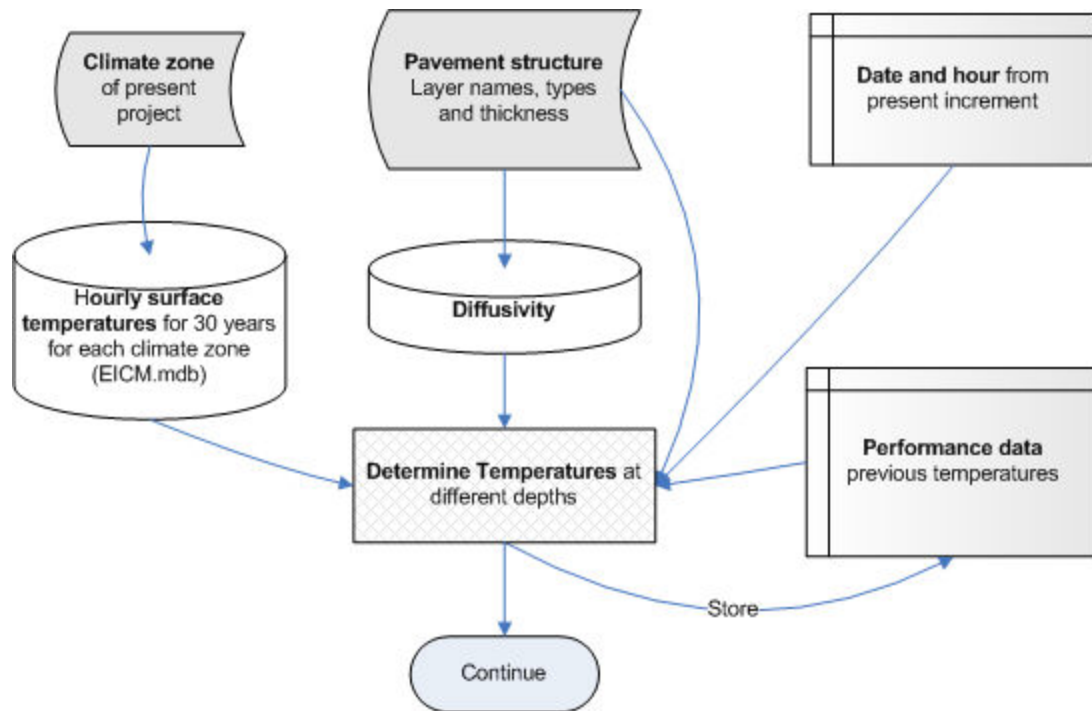
If the temperature database is not available, *CalME* can calculate the temperature from the yearly mean, yearly range and daily range temperatures using the following equations:

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

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

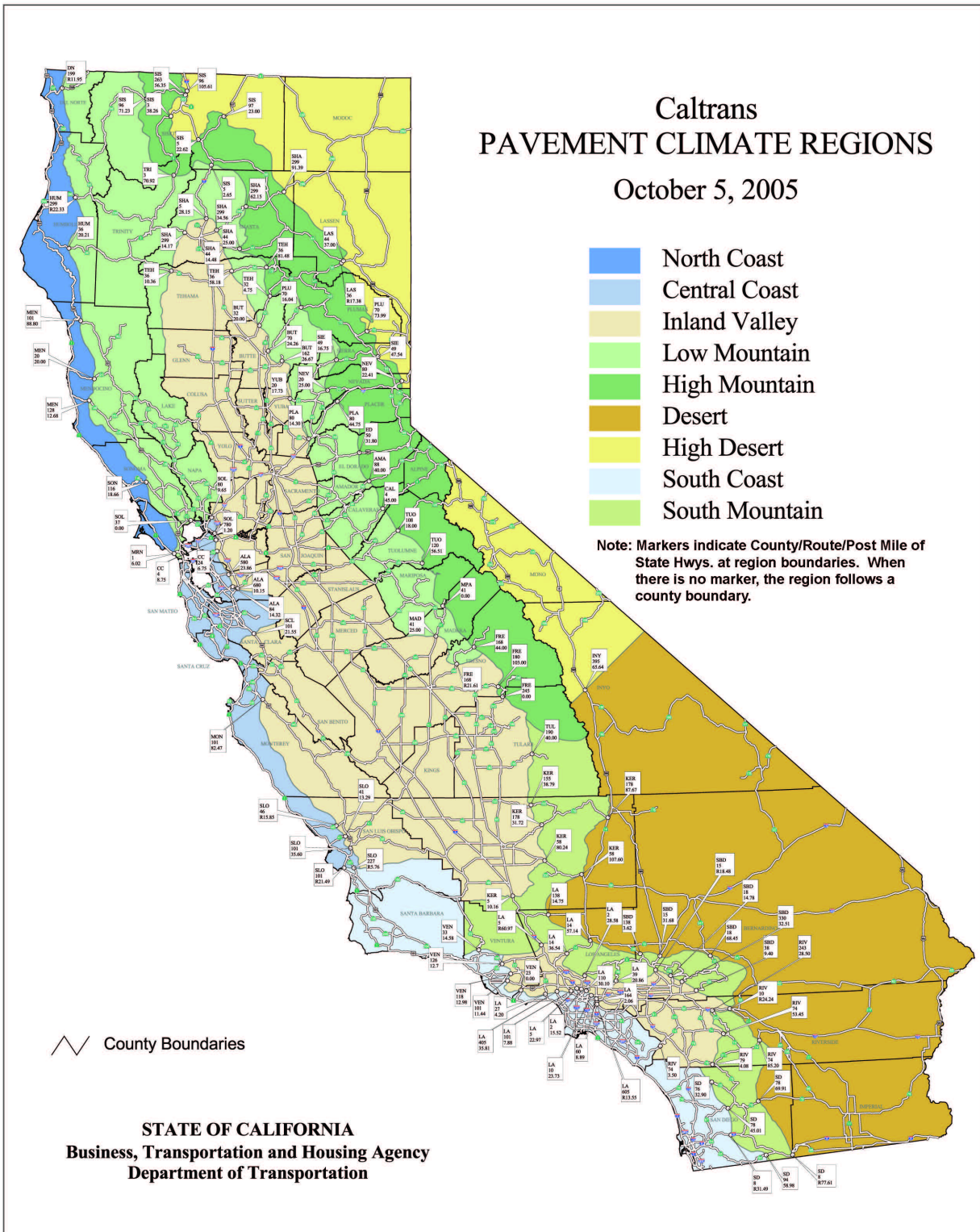
where tYearMean is the mean yearly surface temperature, degree Celsius,
 YearRange is the yearly range in surface temperature, degree Celsius,
 DayRange is the daily range in surface temperature, degree Celsius,
 z is the depth in mm, and
 h is the hour counted from the start of the year.

Temperature flowchart



Caltrans Pavement Climate Zones

Caltrans pavement network is divided into 9 climate regions (referred to as climate zones in *CalME*) using the following map (adopted from the [Caltrans climate website](#)). *CalME* has built-in support to lookup the climate zone using project post mile.



General Approach for Traffic Input

Similar to other M-E design procedures, traffic inputs are defined by specifying the traffic volume and the load spectrum for trucks in *CalME*. Passenger cars are ignored in pavement structure designs because they are much lighter and as a result cause much less damage to pavements structures compared to trucks.

Traffic volume in *CalME* is specified by entering the design traffic index (TI), which is correlated to the number of Equivalent Standard Axle Load (ESAL) through the following equation (adapted from Caltrans Highway Design Manual):

$$TI = 9.0 \times \left(\frac{ESAL}{10^6} \right)^{0.119}$$

The conversion of truck traffic to ESAL count follows the standard equations. *CalME* uses a power of 4.2 following Caltrans practice.

Load spectrum refers to the distribution of truck traffic over time and load level. A load spectrum provides all the details needed for spreading the traffic volume into traffic loads needed for calculating pavement responses and in turn predicting the traffic induced pavement damages. The combination of traffic volume and load spectrum fully specifies the mixture of traffic loads to be applied on a pavement structure for any given time period. In order to calculate pavement response, one needs to know the tire layout, tire pressure, load direction, and load amplitude. In order to predict damage, one needs to also know the number of applications of each traffic load.

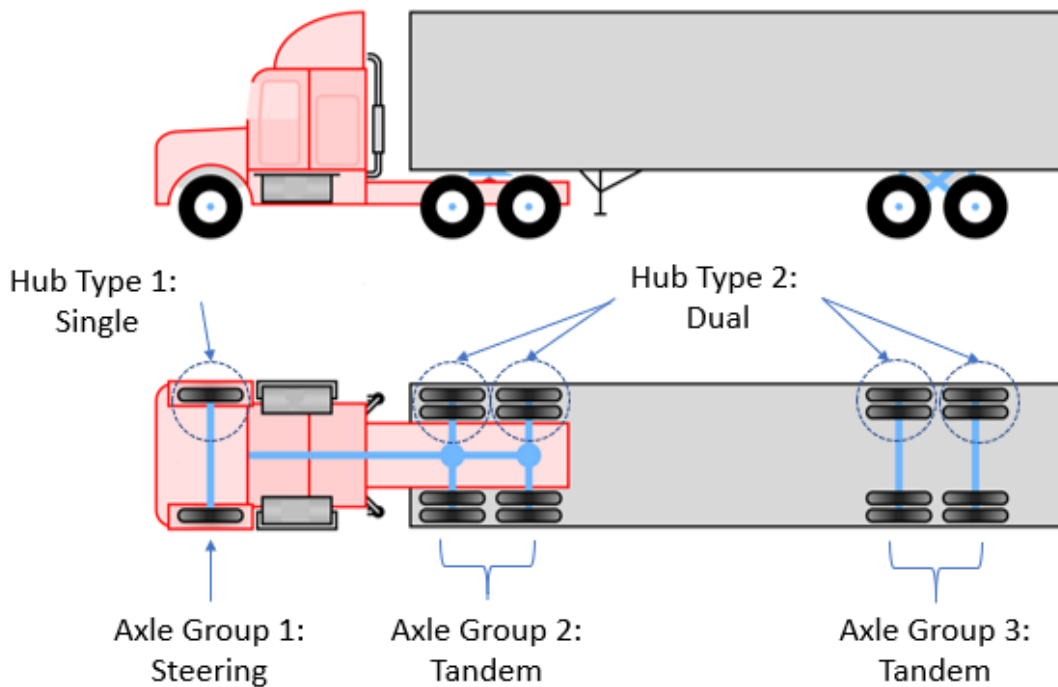
It takes a large set of numbers to fully define a load spectrum, even after accounting for the cyclic patterns of truck traffic. To make it easy, *CalME* has a set of pre-defined load spectra for designers to choose from. These spectra were developed after reviewing data from hundreds of weight-in-motion (WIM) stations installed in California highway ([Truck Traffic Analysis using Weigh-In-Motion \(WIM\) Data in California](#)).

Load Spectrum

In *CalME*, truck passages are converted into passages of four **axle groups**: steering, single, tandem and tridem. Each axle group is made up of one or more **axles**. The steering and single axle groups each has one axle, the tandem axle group has two axles, while the tridem axle group has three axles. Each axle is made of a **shaft** with a **hub** attached to each of the two ends. The steering axle group uses **single hubs** (i.e., each hub has only one wheel), while all other axle groups uses **dual hubs** (i.e., each hub has

two wheels).

As an example, one passage of an 18-wheeler is converted into one passage of steering axle group, and two passage of tandem axle group. This is illustrated below. As shown in the figure, the truck passage used in this example is further converted into the passages of one single hub and four dual hubs.



**One passage of this truck
= one passage of steering axle group, and two passages of tandem axle group
= one passage of single hub, and four passages of dual hub**

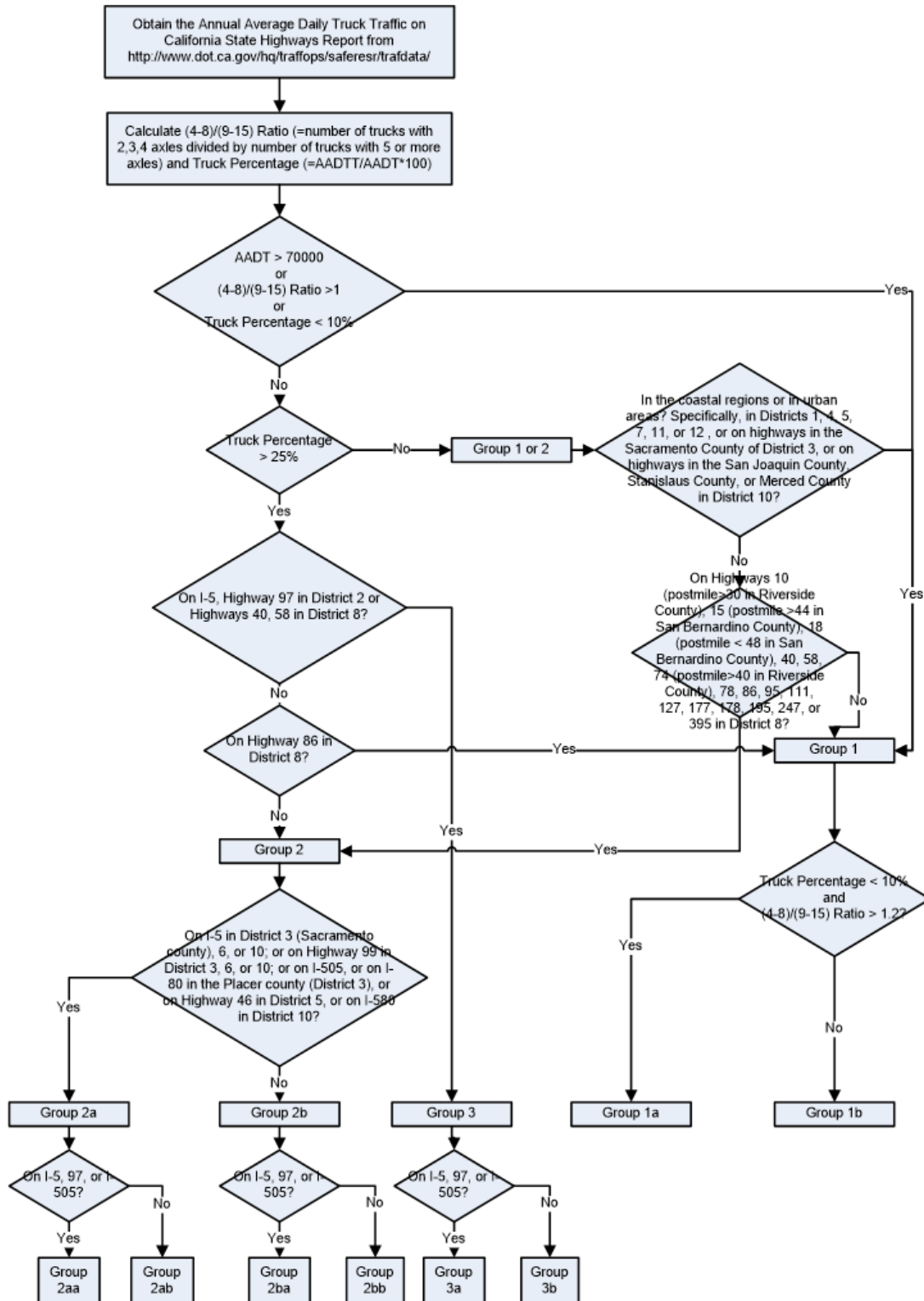
Truck schematic adapted from Wikipedia,
https://en.wikipedia.org/wiki/File:Conventional_18-wheeler_truck_diagram.svg

In *CaIME*, truck traffic is distributed into the four axle groups, the 24 hourly periods for each day, and various group load brackets. An example of how the load spectrum is defined is shown below for Group1. As shown in the example, 0.528462% of the daily traffic comes in the form of 50kN steering axle group. Note that the load shown below is for the whole axle group. A group load of 80 kN for a tandem axle corresponds to a 20 kN load for each of the four dual hubs in the axle group.

	A	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	
1	Spectrum Name	Axle Group	Group Load (kN)	Hour 1	Hour 2	Hour 3	Hour 4	Hour 5	Hour 6	Hour 7	Hour 8	Hour 9	Hour 10	Hour 11	Hour 12	Hour 13	Hour 14
2	Group1	Steering	10	0.012506	0.009765	0.009225	0.011739	0.026485	0.063056	0.102319	0.11012	0.122724	0.131679	0.133962	0.137456	0.137932	0.1
3	Group1	Steering	20	0.034286	0.027617	0.026834	0.032747	0.06666	0.151668	0.252061	0.292251	0.336011	0.356957	0.364484	0.376391	0.376663	0.3
4	Group1	Steering	30	0.079377	0.07746	0.083248	0.102889	0.15885	0.251211	0.365072	0.418826	0.48883	0.523154	0.531841	0.537599	0.525988	0.5
5	Group1	Steering	40	0.186377	0.180446	0.189963	0.231324	0.32947	0.456559	0.591582	0.638784	0.717769	0.793464	0.814036	0.817369	0.792011	0.7
6	Group1	Steering	50	0.146543	0.137777	0.141153	0.168735	0.230899	0.304232	0.36164	0.382926	0.436711	0.502892	0.528462	0.53375	0.519176	0.4
7	Group1	Steering	60	0.027094	0.024931	0.02486	0.029641	0.041534	0.057911	0.070807	0.077823	0.089385	0.102763	0.107815	0.110076	0.108177	0.1
8	Group1	Steering	70	0.001807	0.001687	0.001948	0.002845	0.006033	0.012308	0.017225	0.01917	0.020859	0.023344	0.023679	0.022886	0.021101	0.0
9	Group1	Steering	80	0.000719	0.000751	0.001053	0.001757	0.003517	0.007385	0.012418	0.013743	0.013292	0.0145	0.014528	0.01336	0.012255	0.0
10	Group1	Steering	90	0.000318	0.000377	0.000494	0.000817	0.001308	0.003016	0.005443	0.005835	0.005422	0.005767	0.005653	0.005333	0.004952	0.0
11	Group1	Steering	100	7.62E-05	0.000113	0.000136	0.00016	0.000259	0.000658	0.001098	0.001094	0.001031	0.00105	0.001078	0.001089	0.001065	0.0
12	Group1	Steering	110	1.56E-05	2.50E-05	2.98E-05	3.28E-05	7.05E-05	0.000162	0.000272	0.000224	0.000221	0.000213	0.000236	0.000258	0.000263	0.0
13	Group1	Steering	120	5.32E-06	5.41E-06	5.65E-06	9.77E-06	2.26E-05	6.58E-05	0.000106	7.81E-05	7.26E-05	8.06E-05	8.16E-05	8.84E-05	0.000102	8.4
14	Group1	Steering	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	Group1	Single	10	0.03773	0.037303	0.041479	0.052523	0.078038	0.122289	0.157604	0.176148	0.209637	0.242974	0.257911	0.257098	0.243666	0.2
28	Group1	Single	20	0.06698	0.063453	0.069394	0.08731	0.133912	0.221378	0.30871	0.337063	0.388447	0.421836	0.429809	0.435156	0.425897	0
29	Group1	Single	30	0.06718	0.06269	0.066225	0.081849	0.125377	0.20931	0.298736	0.321555	0.377502	0.409532	0.416767	0.423815	0.423219	0.4
30	Group1	Single	40	0.067003	0.061942	0.062567	0.075016	0.108124	0.162923	0.218201	0.240502	0.282015	0.304637	0.311479	0.316443	0.313614	0.3
31	Group1	Single	50	0.065329	0.061429	0.062464	0.072816	0.101573	0.137472	0.173742	0.188195	0.204673	0.216664	0.220534	0.217455	0.210012	0.2
32	Group1	Single	60	0.062699	0.060569	0.062737	0.074677	0.106823	0.142557	0.173836	0.182756	0.185185	0.187518	0.183998	0.176853	0.166662	0.1
33	Group1	Single	70	0.058419	0.057381	0.060186	0.075597	0.116984	0.162783	0.196667	0.208605	0.213322	0.219436	0.21736	0.214155	0.202184	0.1
34	Group1	Single	80	0.040258	0.038685	0.039922	0.050611	0.082055	0.118678	0.142991	0.151878	0.159527	0.171101	0.173086	0.175408	0.168738	0.1
35	Group1	Single	90	0.013477	0.012519	0.012764	0.016266	0.026254	0.039462	0.047351	0.051135	0.053778	0.059065	0.060982	0.062933	0.062853	0.0
36	Group1	Single	100	0.001927	0.001692	0.001726	0.00237	0.004146	0.006695	0.008145	0.00854	0.008831	0.009692	0.010374	0.010635	0.010787	0.0
37	Group1	Single	110	0.000289	0.00028	0.000304	0.000496	0.000985	0.001605	0.001785	0.001765	0.001813	0.002223	0.002353	0.002386	0.002342	0.0
38	Group1	Single	120	9.19E-05	9.00E-05	8.65E-05	0.000189	0.000354	0.000566	0.000573	0.000495	0.000583	0.000772	0.000896	0.00083	0.00078	0
39	Group1	Single	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52	Group1	Tandem	20	0.021452	0.020147	0.019573	0.022752	0.030837	0.045633	0.068428	0.081633	0.099644	0.113512	0.119823	0.121353	0.118061	0.1
53	Group1	Tandem	40	0.07692	0.072962	0.074215	0.087946	0.119635	0.168355	0.258724	0.301719	0.361985	0.427405	0.453169	0.461975	0.447028	0.4
54	Group1	Tandem	60	0.100872	0.096557	0.099848	0.119091	0.16234	0.220341	0.297948	0.331755	0.402148	0.480608	0.519712	0.531035	0.513924	0
55	Group1	Tandem	80	0.085257	0.08151	0.084497	0.099811	0.132424	0.172593	0.207813	0.218344	0.249223	0.287224	0.302681	0.309371	0.300884	0
56	Group1	Tandem	100	0.073429	0.070843	0.073864	0.087874	0.118218	0.148863	0.167057	0.167625	0.18486	0.203594	0.207925	0.210017	0.202774	0.1
57	Group1	Tandem	120	0.085927	0.082271	0.087775	0.105475	0.142557	0.177199	0.192843	0.191902	0.208174	0.227446	0.231654	0.230229	0.223928	0.2
58	Group1	Tandem	140	0.090858	0.08697	0.090314	0.107348	0.143633	0.180194	0.200771	0.204432	0.222223	0.247319	0.258202	0.260794	0.25547	0.2
59	Group1	Tandem	160	0.09092	0.08922	0.09098	0.106155	0.143474	0.17799	0.197455	0.197077	0.20655	0.230311	0.237095	0.231535	0.220111	0.1

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](#)). It was found that there is very little seasonal variation. It was therefore decided to use the same load spectrum for every day throughout the year.

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 growth rate.

Conversion from TI to Axle Group Count

For a given load spectrum, the ratio between the number of axle groups applied and the resulting ESALs is a constant. This allows one to convert design TI into the number of axle groups to be applied during the design life of a pavement (i.e., the design axle group count).

Daily Axle Group Count

The design axle group count is distributed into each year following a linear growth pattern. The yearly axle group count is then evenly distributed into each month of the year (i.e., there is no traffic growth within each year). The monthly axle group count is then evenly distributed into each day. The daily axle group count is distributed into each hour following the load spectrum.

Truck Count

For a given load spectrum, the ratio between the number of axle groups applied and the number of trucks applied (i.e., truck count) is assumed to be a constant. This ratio is referred to as axle groups per truck (AGPT). *CalME* uses AGPT to show the truck traffic volume once the axle group count has been determined using TI and load spectrum.

Note: Both AGPT and load spectrum depend on truck composition (i.e., the proportions of trucks in different classifications). In addition, load spectrum depends on the distribution of axle loads. Theoretically it is possible to have two locations that have similar load spectra but significantly different AGPT, or vice versa. Therefore it is

necessary to keep in mind that the truck count shown in *CalME* is a rough estimate and may not be accurate.

List of Load Spectra

The following table is a list of pre-defined load spectra in *CalME* and the main characteristics. As the number in the table indicates, the higher the group # for a load spectrum, the heavier the truck traffic.

Spectrum Name	Axle Groups per Truck	ESAL per Axle Group
Group1	2.77	0.24
Group1a	2.87	0.26
Group1b	2.54	0.21
Group2	3.01	0.36
Group2a	3.04	0.36
Group2aa	3.12	0.37
Group2ab	2.94	0.34
Group2b	2.97	0.36
Group2ba	3.00	0.35
Group2bb	2.97	0.36
Group3	2.96	0.47
Group3a	3.09	0.46
Group3b	3.12	0.49

Other Assumptions and Limitations

Traffic loads in *CalME* are applied by simplifying the tire contact areas into circular shape. The distance between tires in dual hubs is 1 ft (300 mm) on center.

Currently *CalME* suggests a load spectrum for a given project location. The suggestion is meant for the truck lanes. For designing non-truck lanes, such as Lane #1 of a four lane (one direction) highway, the designer may need to choose a load spectrum that is lighter than the one suggested by *CalME*.

According to [Truck Traffic Analysis using Weigh-In-Motion \(WIM\) Data in California](#), truck speeds typically fall within the range of 50 to 75 mph (80 to 120 km/h). Vehicle speeds are assume to be constant in *CalME* with a default value of 44 mph (70 km/h), which typically leads to slightly shorter predicted life than a speed of 50 mph (80 km/h).

7.6. Field Calibration

The UCPRC developed a new approach for field calibration that takes advantage of Caltrans investments in its pavement management system databases for as-builts and its many years of condition survey data. The UCPRC improved the usefulness of that data extensively for performance modeling for the PMS through quality checking and by matching as-built records to condition time histories. More than 10 years of extensive review of the data had produced a very large database for development of empirical-mechanistic performance models for the Caltrans pavement management system. This database was available for *CalME* calibration, as well as for calibration of the Pavement ME program from AASHTO, which is used for design of jointed plain concrete pavement.

The new field calibration approach has been explained in Wu et al. (2022), and in more details in Wu et al. (2021).

Note that this approach is very different from traditional methods which use small numbers of field sections from which materials may or may not have been sampled. This is made possible by the availability of both the extensive PMS data collected by Caltrans and the comprehensive historical material testing database accumulated by the UCPRC.

Wu, R., Harvey, J., Lea, J., Jones, D., Louw, S., Mateos, A., Hernandez-Fernandez, N., Shrestha, R., and Holland, J. 2022. "Calibration of a Mechanistic-Empirical Cracking Model Using Network-Level Field Data:" *Transportation Research Record: Journal of the Transportation Research Board*, May, 036119812210915. <https://doi.org/10.1177/03611981221091561>

Wu, R., Harvey, J., Lea, J., Mateos, A., Yang, S., and Hernandez, N. 2021. *Updates to CalME and Calibration of Cracking Models*. <https://escholarship.org/uc/item/460234g0>.

7.6.1. Calibration Approach

The conventional approach to calibrating an ME method, which has been used since calibration of the Shell Method and Asphalt Institute Method in the 1970s and early 1980s, through calibration of the Mechanistic-Empirical Pavement Design Guide (ARA, 2004) consists of the following:

- Identify short sections of pavement
 - Preferably most of the pavements have some failure on them, otherwise the time to failure would be uncertain because it hasn't occurred yet.
 - The sections need to have a construction time history.
- Collect the materials properties on the test sections.
- Backcast the traffic and materials properties to the time of construction.
- Simulate the performance using measured materials properties using Miner's Law, which has the following issues:

- o The response engine calculating critical stresses, strains, and deformations is unverified.
 - o The damage evolution and predicted state of damage on the section is also unverifiable because use of Miner's Law forces the shape of the damage evolution curve.
 - o Only the end state of distress is used for calibration.
- Find calibration coefficients for the calculated damage-to-distress transfer function to minimize the errors between observed and measured distress.
- Use the variability around the minimized error transfer function for reliability.

The conventional approach has several limitations:

- It requires expensive and time-consuming sampling and testing of materials properties for each section, resulting in a small number of sections being available for calibration.
- It ignores the fact that a design-bid-build (low-bid) designer does not know the performance-related properties of the materials the contractor will bring to the job; this results in a blurred understanding of the sources of variability and their consideration in the design reliability approach.

The new calibration approach developed by the UCPRC to calibrate *CalME* aims to improve calibration and the reliability approach used in ME design by doing the following:

- Use all the good quality distress performance data and as-built data in the Caltrans PMS databases collected since 1978 and quality checked over the last 10 years; this provides orders of magnitude more performance data for calibration, with the data organized by project.
- Use median properties to match median performance, and use the variability of observed median performance to determine between-project variability, after using *CalME* to account for the effects of climate, pavement cross section, and traffic.
 - o The weighted average performance of a set of mixes from the UCPRC databases was used to represent the time periods present in the cracking and rutting performance data since 1978.
- Backcalculate within-project variability by matching the shape of observed performance time history.

It was assumed that calibration using the very large amounts of data available in the PMS performance data and representative mix data for that time period would provide a more comprehensive calibration than just using detailed sampling and testing of materials from a few projects. Once the calibration is completed, comparisons with sections with detailed sampling and testing can provide additional validation.

The new approach also explicitly separates within-project and between-project variability in the calibration, and in the design method. This allows for use of appropriately different between-project reliability factors for PRS and non-PRS projects. The need for explicit consideration of between-project reliability and the inherent problem of calibrating using measured materials properties in a design-bid-build approach is expressed in the following excerpt from the MEPDG report:

From MEPDG report Section 3.3.2 OVERVIEW OF FLEXIBLE PAVEMENT DESIGN PROCESS

3.3.2.1 Design Inputs Trial Design Inputs and Site Conditions

A major difficulty in obtaining adequate design inputs is that the desired project specific information is not generally available at the design stage and must often be estimated several years in advance of construction. The actual materials used in a project may not 3.3.4 even be known until a few weeks before construction begins. The designer should obtain as much data as possible on in-situ material properties, traffic, and other inputs for use in design to obtain a realistic design. The designers should also conduct a sensitivity analysis to identify key factors that affect pavement performance. Based on sensitivity analysis results, provisions could be made in the contract documents for stringent control of the quality of key material properties (e.g., asphalt concrete stiffness), or the design could be modified to make the pavement performance less sensitive to the input in question. (ARA, 2004)

The inclusion of between-project reliability in *CalME* v3.0 overcomes the need for the sensitivity analysis in the project design process called for in the MEPDG report to assess the range of potential materials that might be delivered to the project- which depends on who wins the design-bid-build contract.

ARA Inc., *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures*, ERES Consultants Division, ARA Inc. 2004. Prepared by the National Cooperative Highway Research Program, Transportation Research Board, National Research Council.

What to Calibrate

The following is the list of quantities to be determined as part of the field calibration process:

- Transfer function parameters: such as critical damage ω_{50} and shape parameter β_{crk} for [fatigue cracking transfer function](#)
- The [coefficient of variance of selected random inputs](#) needed to reflect the amount of within project variabilities in typical projects
- The [performance multiplier](#) for the selected design reliability level to account for between project variabilities.

More detailed explanation of the calibration of each of the following subsections using cracking model calibration as an example.

7.6.3. Calibration of Transfer Function

There are two parameters in the fatigue cracking transfer function: the critical damage ω_{50} and shape parameter β_{crk} . Each needs to be determined as part of the field calibration process.

Calibration of Critical Damage ω_{50}

To understand how to determine ω_{50} , imagine dividing a project into 100 individual segments. Each segment has a set of M-E inputs that are uniform within itself. There is one segment that has the median M-E inputs and refer to it as the median segment. The median segment will have the median performance among all segments, because fatigue cracking performance is a monotonic function of M-E inputs such as thickness, fatigue cracking resistance, etc. This is referred to as the monotonic property and is true for most M-E systems.

An example of the performance of the individual segments as well as the overall median and average performance is shown in Figure 1.

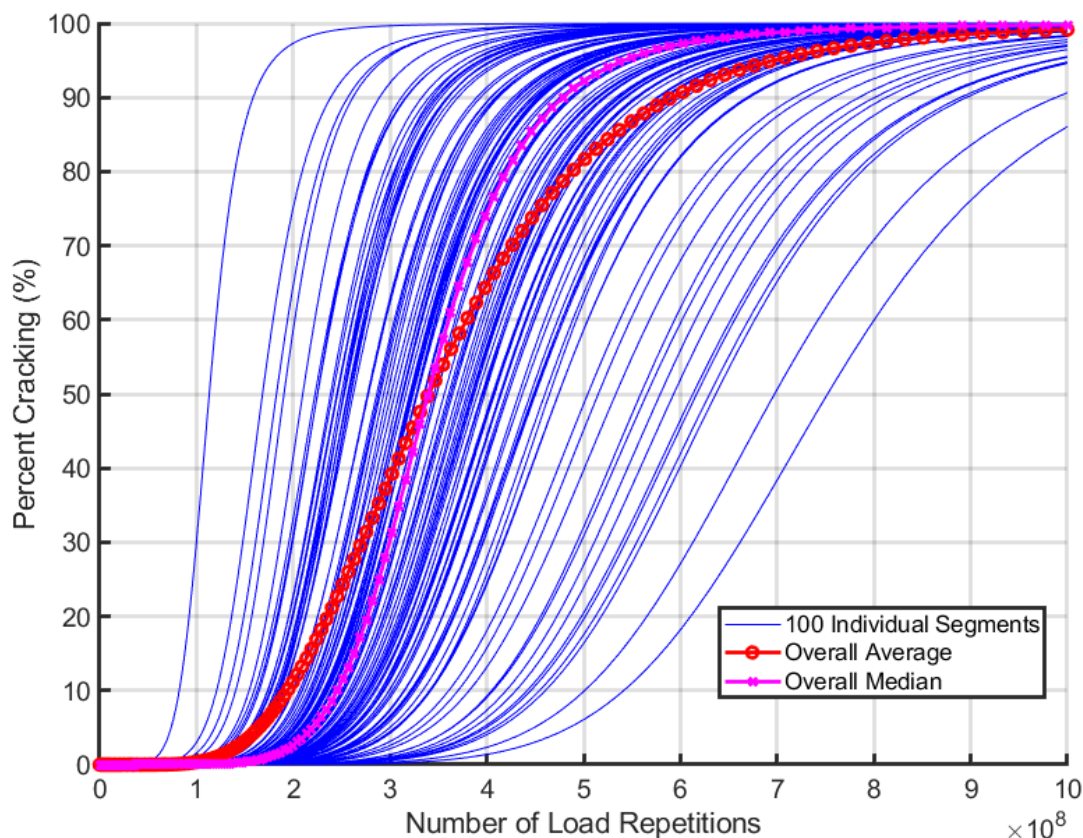


Figure 1: Cracking histories for individual segments and the project overall average and median

The overall average shown in Figure 1 is the performance data typically collected in pavement condition surveys. Figure 1 indicates that the shape of the cracking history curve for individual segments is very different from the shape of the overall average

curve: the overall average curve is much flatter than the curves for individual segments.

Figure 1 shows a striking feature: the overall average and overall median reach 50% simultaneously, which is not a coincidence and is the result of the monotonic property.

This feature can be used to determine ω_{50} . Specifically, we can find the median M-E inputs and use them to define the median segment. The damage in the median segment will reach ω_{50} when the project reaches 50% cracking.

This concept can be extended to whole highway network. The difference is that the median segment becomes a median project within a given type of pavement and given design and traffic level, and potentially other sensitive M-E variables.

Note that there is no need to know what exact material is used in which specific project. It is however required that one knows enough about the performance of historical materials so that the median project can be determined.

Calibration of the Shape Parameter β_{crk}

The effect of WPV on the expected pavement performance is illustrated in Figure 2 as an example, which shows five projects with different M-E inputs in terms of fatigue parameter A and HMA stiffness E. The five projects have the same mean/median inputs but different WPV. While all going through the same N_{50} (number of load repetitions to 50% cracking), the overall average cracking curves change shape with the amount of WPV. The higher the WPV, indicated by the larger values for standard deviation, the more spread out the pavement performance is, as indicated by the flatter slope of the middle portion of the overall average cracking curves. In other words, the steepest slope of the mid-portion of the observed overall average cracking curves provides an upper bound estimate of the shaper parameter β of the transfer function (since the share parameter is always negative, the lower the value the steeper the slope).

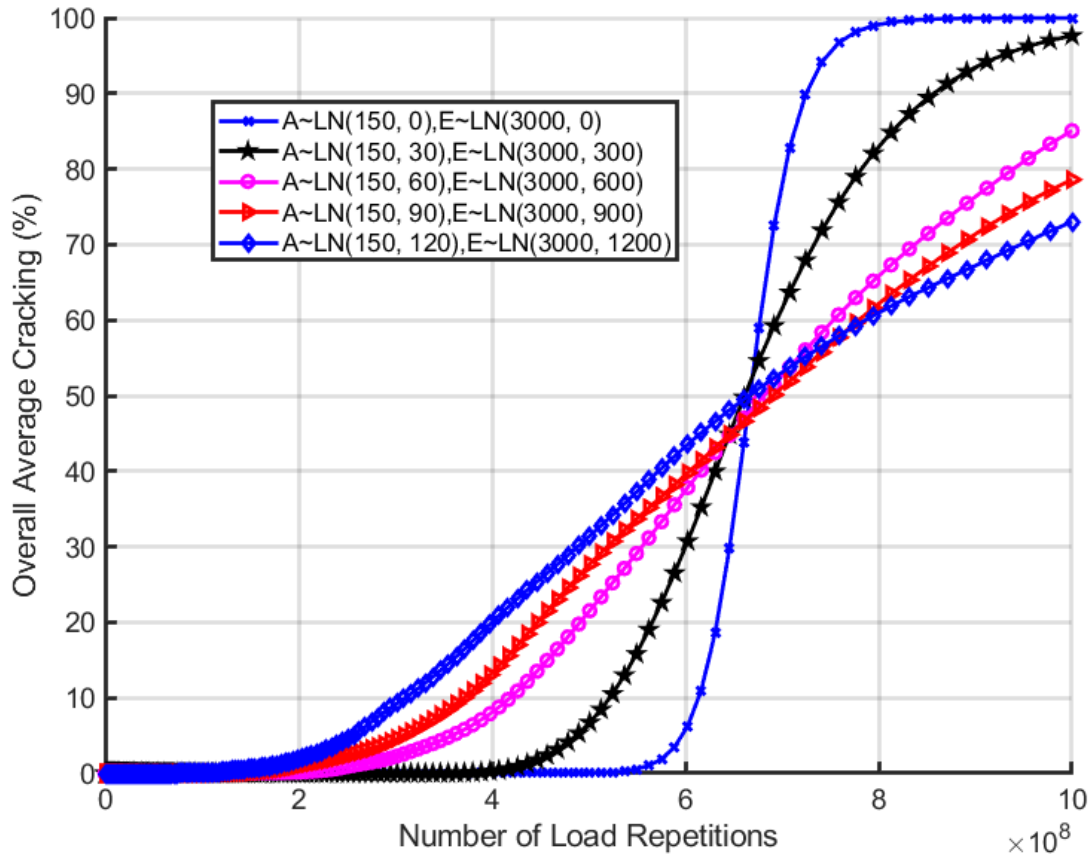


Figure 2: Effect of within project variability on observed cracking histories (LN(u,s) indicates log-normal distribution with mean u and standard deviation s) (fatigue parameter A and HMA stiffness E are two critical M-E inputs)

An example of the cumulative distribution functions of the shape parameters is shown in Figure 3 for the sub-network of new flexible pavements with aggregate base (AB). According to this figure, the upper bound of shape parameter β_{crk} is between -20 and -30. A value of -30 was chosen in CalME for this sub-network.

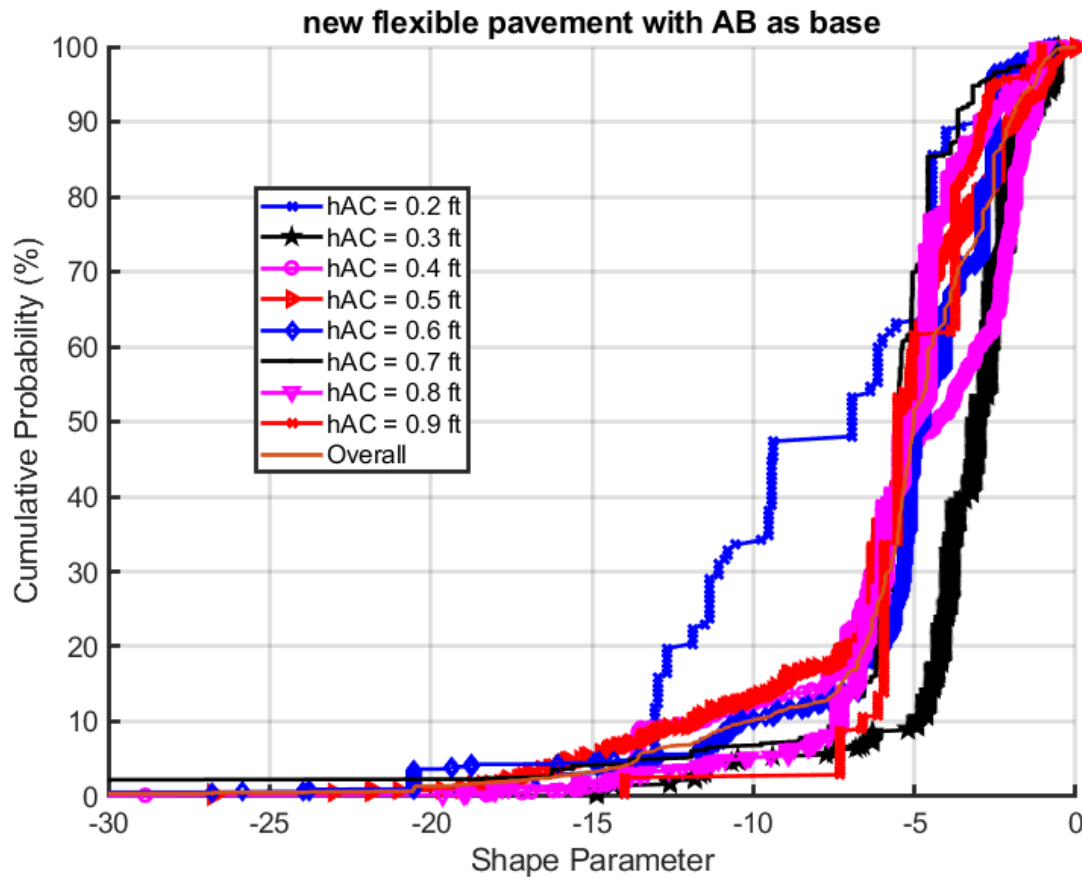


Figure 3: Cumulative distribution functions of shape parameters for the sub-network of new flexible pavements with aggregate base (hAC is the combined thickness of AC layers)

7.6.4. Calibration of Within Project Variabilities

As [discussed earlier](#), WPV is tied to the rate of distress development for a given project: the higher the WPV, the more slower the distress progresses, indicating the wider range of project performance. The rate of distress development can be determined from observed performance history.

On the other hand, WPV can be expressed in terms of coefficients of variances for the selected set of random inputs. As [discussed before](#), the following sets of variables for each layer are assumed to be random and follow certain statistical distributions:

- Thicknesses
- Moduli
- Fatigue resistances
- Rutting resistances

These variables are selected because their variances are found to have large effects on the range of simulated project performance. *CalME* uses Monte Carlo simulation to

estimate the corresponding distribution of project performance, from which a performance history can be predicted. A predicted rate of distress development can in-turn be determined.

The way to account for WPV then lies in choosing the right coefficient of variances for the selected random inputs so that the predicted and observed rate of distress development matches. Note that resulting distributions for each of these random inputs should be similar but not the same as the actual industry practices. This is because the selected set of random variables is only a subset of all of the potential random factors affecting pavement performances.

As shown in Figure 3 under subsection [Calibration of Transfer Function](#), the median value of the observed shape parameter $\beta_{observed}$ is about -5.0. The next step was to evaluate whether the use of the estimated median distributions of important mechanistic variables would result in the observed within-project variability (WPV) (i.e., the same result as using a fixed $\beta_{observed}$ of about -5.0.

The typical variance of total asphalt layer thickness came from data collected from cores and ground-penetrating radar stored in the Caltrans *iGPR* tool. Fourteen different projects built between 2000 and 2010 were analyzed, totaling 33 miles total length of paving. The conclusion was that the thickness variability found in the these projects matched those identified from the literature when developing *CalME* v2.0.

The typical variance of HMA stiffness and the fatigue damage equation parameter A was determined for each mix type and PG grade from laboratory flexural fatigue testing of 35 total HMA and RHMA G mixes.

A batch of Monte Carlo simulations was run with different combinations of asphalt layer thickness, stiffness, and fatigue parameter variabilities close to the values estimated as described above to evaluate whether the resulting equivalent shape factors were similar to the median observed shape parameter. Three combinations were found to result in observed shape parameters that are close to -5.0, as can be seen in Table 1. Based on these results, the first set was selected for use in the calibration WPV because these values are closest to those observed in the evaluation of thickness and asphalt properties described above.

Table 1: Variabilities of Asphalt Concrete Layer Properties and the Resulting Shape Parameter

No.	Thickness COV	Stiffness SDF*	SDF* for Fatigue Pa
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1	0.07	1.20	1.35
2	0.10	1.20	1.05
3	0.10	1.20	1.25

*: SDF of a variable x is defined as the $e^{cov(\ln(x))}$

7.6.5. Calibration of Between Project Variability

Between project variability (BPV) is tied to the range of performances of similar projects within the network: the higher the BPV, the wider the range. Specifically, the median service life t_{mp} , defined as the time when 50% of the project fails, can be determined for each project in the network based on the observed performance history. An empirical cumulative distribution function (CDF) for t_{mp} can in-turn be developed. The empirical CDF can then be used to determine various quantiles for the median service life.

One way of quantifying BPV is to use the ratio between different quantiles, in particular, the following ratio is used in *CalME*:

$$z_p = \frac{q_{1-p}}{q_{50\%}}$$

where q_x is the x -th quantile,

$q_{50\%}$ is the 50% quantile (i.e., the median), and

z_p is the performance multiplier for reliability level of p (in percent)

The performance multiplier can be determined for various reliability levels. For example, a performance multiplier for 95% reliability level is:

$$z_{95\%} = \frac{q_{5\%}}{q_{50\%}}$$

This multiplier can be used to convert a prediction median performance into a performance with 95% reliability. For example, if the predicted median cracking life of a pavement is 30 years, and $z_{95\%}$ is 0.10, the design life corresponding to 95% reliability is $0.10 * 30 = 3.0$ years.

The way to account for BPV then lies in determining the empirical CDF for the median service life from network level performance data, and find the performance multiplier for the desired design reliability level. Figure 1 shows the empirical CDF of the performance normalized by the time to median performance (i.e., $q_{50\%}$) for the sub-network of new flexible pavement with aggregate base. According to the figure, $z_{95\%}$ is determined to be 0.10.

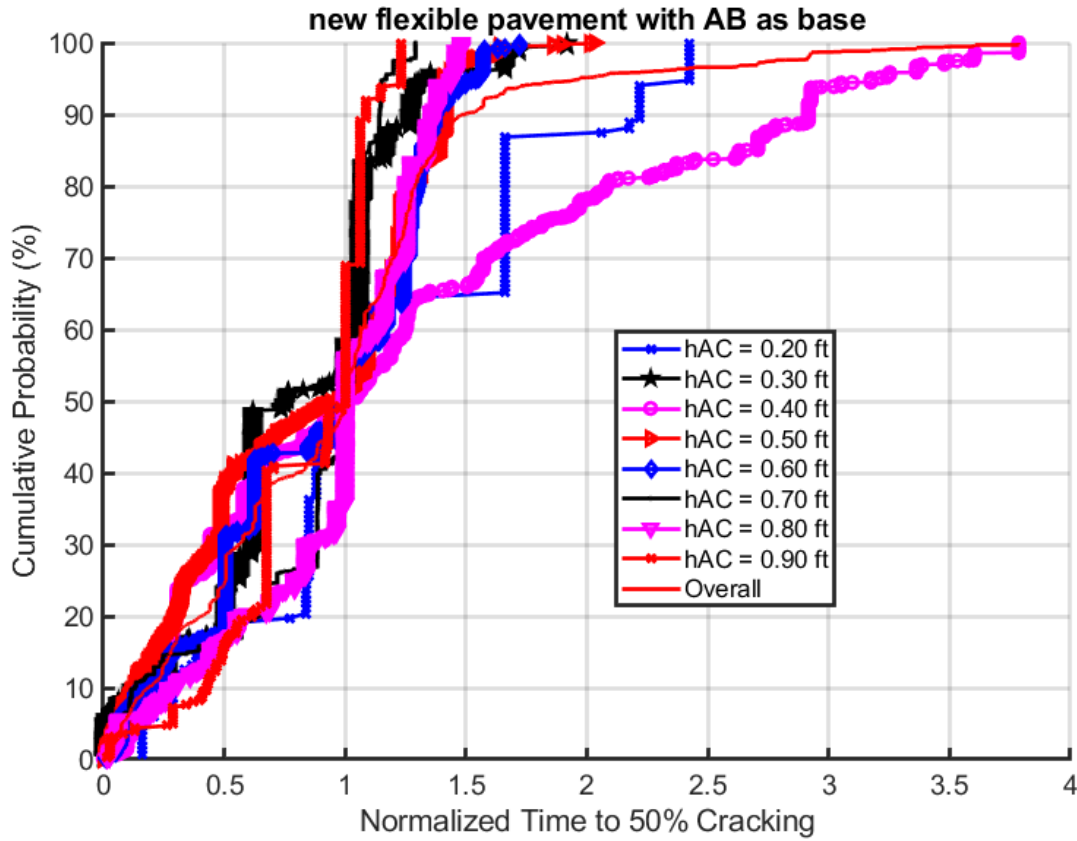


Figure 1: Distribution of relative performance factor for each asphalt concrete surface thickness for the sub-network of new flexible pavements with aggregate base (hAC is the combined thickness of the AC layers)

7.6.6. Summary of Cracking Calibration

The transfer function is in essence an empirical correlation between the fatigue or reflective cracking damage predicted by the ME models and the probability of surface cracking. To ensure the high accuracy of such empirical correlations, it is necessary to divide a highway network into sub-networks in which the pavement structures are similar and, in turn, have similar failure mechanisms.

The list of sub-networks for the field calibration is shown in the table below. As shown in the table, the division is mostly based on the structure type.

No.	Structure Group	Structure Type
1.1	New flexible pavement	With aggregate base
1.2	New flexible pavement	With cement base (cement-treated base concrete base)
2.1	Rehabilitation with new HMA	New HMA over old flexible pavement

2.2	Rehabilitation with new HMA	New HMA over old rigid pavement
3.1	Rehabilitation with partial-depth in-place recycled layer	With engineering emulsion as the stabilizing agent
4.1	Rehabilitation with full-depth in-place recycled layer	With foam asphalt as the stabilizing agent
4.2	Rehabilitation with full-depth in-place recycled layer	With cement as the stabilizing agent

Before the performance data extracted from the Caltrans pavement management system (PMS) software program Pavem can be used for the field calibration, the pavements the data covers must be divided into short lane-by-lane segments with uniform construction histories, traffic, and climate. This results in approximately uniform explanatory variables for the associated performance time histories. Each of these segments with its associated performance time history will serve as a basic unit for field calibration and are hereafter referred to as “virtual projects.” Note that multiple virtual projects can occupy the same space but they must be from different time periods. A brief summary of the amount of data available for each of the sub-networks is listed in the following table.

Sub-network Abbreviation	Total Number of Virtual Projects	Total Lane Miles of Virtual Projects	Observation Period
N-AB	8,350	1,063	1978-2014
N-CB	1,366	161	1978-2014
R-FP	253,841	34,702	1978-2014
R-RP	7,877	1,401	1978-2014
R-PDR-EA	6,717	892	1978-2018
R-FDR-FA	1,431	174	1978-2018
R-FDR-C	19	6	1978-2020

A summary of the field calibration results is listed in the following table.

Sub-network Abbreviation	Critical Damage ω_{50}	Shape Parameter β_{crk}	Performance Modification Factor 95% Reliability
N-AB	0.06	-30.0	0.10

N-CB	$0.0007 \cdot e^{0.0188 \cdot hAC_{mm}}$ minimum 0.01, maximum 0.10	-90.0	0.23
R-FP	0.11	-90.0	0.20
R-RP	0.03	-90.0	0.20
R-PDR-EA	0.03	-30.0	0.10
R-FDR-FA	0.06	-30.0	0.32
R-FDR-C	0.03	-90.0	0.20

Note that these calibration factors are periodically updated when new data become available and new rounds of calibration are conducted. Some of the subnetworks (such as R-FDR-C) has very little available data so the calibration needs to be checked for reasonableness and adjusted accordingly.

Acronyms

AC - Asphalt Concrete

CIPR - cold in-place recycling

CoV - Coefficient of Variation

CSM - Cementitiously Stabilized Material

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 recycling with foam asphalt

FDR-PC - full depth recycling 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 (10^{mean of logarithms})

MEPDG - Mechanistic Empirical Pavement Design Guide

NMAS - Nominal Maximum Aggregate Size

PAB - pulverized aggregate base, also know as full depth recycling without stabilization

PM - Caltrans postmile, e.g., 1.000, R12.456R

PRS - performance related specification

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