Summary of SPTC Pooled-Fund Study for Sharing and Evaluation of *CalME* Flexible Pavement Design Software

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Abstract:
The California Department of Transportation (Caltrans) has funded the development of design models for flexible pavements and for overlays that have been incorporated in the software currently known as *CalME*. Under the direction of University of California Pavement Research Center (UCPRC) staff over a two-year period, personnel from the Washington State Department of Transportation (WSDOT), the Texas Department of Transportation (TxDOT), and the Minnesota Department of Transportation (MnDOT) participated in examining these models and identifying areas where they might be modified or enhanced. This project was funded by State Pavement Technology Consortium (California, Minnesota, Texas, and Washington) through a pooled-fund study. In-person training on *CalME* was provided by UCPRC at each of the participating state departments of transportation (DOTs). Case studies were conducted by UCPRC using data provided by the individual DOTs. Feedback was collected throughout the project and questionnaires were sent at its completion to collect final comments on *CalME*. This technical memorandum describes the researchers' efforts, including details of the evaluation and data collection procedures, other activities undertaken, and the case study using *CalME*. The participating states found many *CalME* features helpful and might adopt a selected set of models or approaches in their respective efforts to implement M-E design.

Keywords: CalME, Mechanistic-Empirical Design, State Pavement Technology Consortium

Proposals for implementation: None

Related documents:
- P. Ullidtz, J. Harvey, B.-W. Tsai, and C. Monismith. 2006. Research Report: *Calibration of CalME Models Using WesTrack Performance Data.* (UCPRC-RR-2006-14)
- P. Ullidtz, J. Harvey, B.-W. Tsai, and C. Monismith. 2006. Research report: *Calibration of Incremental-Recursive Flexible Damage Models in CalME Using HVS Experiments.* (UCPRC-RR-2005-06)
- B.-W. Tsai and R. Wu. 2009. Technical memorandum: *Mn/ROAD Case Study Using* CalBack *and* CalME (UCPRC-TM-2008-16) In progress.

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Department of Transportation, the Federal Highway Administration, the states of the State Pavement Technology Consortium (California, Minnesota, Texas, and Washington), or the California Department of Transportation. This report does not constitute a standard, specification, or regulation.

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1 BACKGROUND

The California Department of Transportation (Caltrans) has funded the development of design models for flexible pavements and for overlays that have been incorporated in the software currently known as *CalME*. Under the direction of University of California Pavement Research Center (UCPRC) staff over a two-year period, personnel from the Washington State Department of Transportation (WSDOT), the Texas Department of Transportation (TxDOT), and the Minnesota Department of Transportation (MnDOT) participated in examining these models and identifying areas where they might be modified or enhanced. This report describes the researchers' efforts.

This pooled-fund project had the following as its initial objectives:

- To provide code, software, and other information that the state transportation departments need to evaluate the models;
- To validate the models and further debug the demonstration software by using data from one or two state DOT projects to predict performance;
- To perform a limited amount of laboratory testing for materials characterization in order to operate the models if needed; and
- To document feedback on the models and software for future use by state DOTs as they move toward implementation of mechanistic-empirical design methods.

The following four incremental-recursive distress development models are the most important ones in the current version of *CalME:*

- Asphalt concrete fatigue
- Rutting of asphalt concrete
- Reflection cracking in asphalt concrete overlays
- Rutting of unbound layers

It is important to note that this project's emphasis was on the models, not on the software. This research provided a demonstration and additional validation of the draft software's alternative models for the distresses listed above. The research also provided access to the models' details and calibration data.

The current version of *CalME* includes data on materials, WIM, and climate for California, and the models included operate on materials properties, axle load spectra, and pavement temperatures. The software's first-version user interface also includes features for facilitating calibration (loading of HVS data, etc.), a function

which is not of use to potential pavement designers. Note that *CalME* has been under constant development during this pooled-fund evaluation project.

To date, the models in *CalME* have been calibrated with Heavy Vehicle Simulator (HVS) data, WesTrack data, selected NCAT data, and field data from California.

The current software also includes, as reference for designers, the Asphalt Institute method for new pavement designs and the empirical Caltrans R-value method for both new and rehabilitation pavement designs.

CalME also includes these major features, which are not included in the NCHRP 1-37A Mechanistic Empirical Pavement Design Guide:

- Use of an incremental-recursive damage calculation method that updates the properties of pavement layers to include damage after each set of loads;
- Use of laboratory permanent deformation test data for asphalt rutting calculation instead of mix stiffness alone;
- Consideration of thin overlays in asphalt rutting calculations;
- Inclusion of a mechanistic-empirical reflection cracking model for asphalt overlays;
- Use of Monte Carlo simulations to evaluate reliability of any given design;
- The ability to include M&R activities when predicting pavement performance; and
- Calibration with HVS test sections and WesTrack performance data, including deflections and backcalculated stiffnesses across the life of the pavement instead of just the end states of cracking and rutting.

2 WORK PERFORMED IN THE PROJECT

The following tasks were completed during this project:

- The project members participated in an initial webinar on *CalME* in September 2008. The webinar was attended by UCPRC and DOT personnel from the four member states, as well as consultants from MACTEC and Dynatest. UCPRC demonstrated the *CalME* software and gave introductions to the models implemented in it.
- The state DOTs evaluating *CalME* sent follow-up questions to UCPRC, which provided assistance and answers.
- UCPRC conducted in-person training sessions at Minnesota, Washington, and Texas DOT facilities.

- Analysis of example projects selected by WSDOT, MnDOT and TxDOT: UCPRC collected necessary data from the state DOTs, limited material testing was done on Mn/ROAD HMA, UCPRC then ran *CalME* and returned results to each state. See next section for more details.
- UCPRC collected final thoughts and feedback on *CalME*. Questionnaires were sent to the three state DOTs requesting feedback and comments on *CalME* and on plans for implementation of M-E design for flexible pavements.
- UCPRC was to deliver a summary report (this document) to the State Pavement Technology Consortium (SPTC).

The example projects analyzed and the other activities related to each state are summarized in Section 3, which is followed in Section 4 by feedback on *CalME*.

3 ACTIVITIES RELATED TO EACH STATE

As noted in Section 2, example projects for each participating state were analyzed. These projects were selected by each state and assumptions were made when needed data were unavailable. Note that no effort was made to match the *CalME* prediction with observed performance. In other words, these analyses were conducted with models calibrated for California and may not provide accurate predictions for cases from other states.

3.1 Washington State

Evaluation of *CalME* was conducted by the Washington State Department of Transportation (WSDOT). The WSDOT contact person on this project was Jianhua Li. An in-person training session was held at WSDOT headquarters in Olympia.

Three cases were sent to UCPRC for analysis, two of which were actual field projects at the following locations:

- Case 1: East Washington on SR-20 near Spokane
- Case 2: West Washington on SR-195 near Bellingham
- Case 3: A generic perpetual pavement design for 10 to 25 million ESALs for eastern Washington.

Cases 1 and 2: Knowns and Assumptions

The following were known for Case 1 and Case 2:

- Pavement structure (AC on AB)
- Materials: Binder grading (AR4000-W) and aggregate gradation
- Traffic: AADTT count and percentage by classification
- Climate: matches a similar California climate zone

- Performance history
    - Rutting
    - Longitudinal cracking (ft/mi.)
    - Alligator cracking (percentage of lane area)
    - Transverse cracking (ft/mi)
    - Climate: matches a similar California climate zone

The following were assumed for Case 1 and Case 2:

- Materials
    - HMA stiffness master curve determined based on binder grade and aggregate gradation following NCHRP 1-37A
    - Typical AB and SG stiffness for WSDOT, default stiffness variation
    - Shear and fatigue model parameters of HMA with similarly graded binder
- Traffic: assumed load spectrum
- Monte Carlo simulation: default variations for all quantities

The results for Case 1 and Case 2:

- Calculated rutting and cracking results matched the observed trend although the actual values were not the same

Case 3: Knowns and Assumptions

The following was known for Case 3, the 50-year perpetual pavement for eastern WA subjected to 10 to 25 MESAL:

- Pavement structure (AC on AB)
- Materials:
    - HMA master curve, shear and fatigue model parameters from UCPRC material library
    - Typical AB and SG stiffness for WSDOT, default stiffness variation
- Traffic: ESAL count
- Climate: Eastern WA, matches “Mountain, High Desert” in CA
- Expected Performance:
    - 10 mm of rut in 16 to 18 years
    - 10 percent wheelpath fatigue cracking in 16 to 18 years

The following were assumed for Case 3:

- Traffic: assumed load spectrum, and assumed 25 MESAL in 50 years
- Monte Carlo simulation: default variations for all quantities

The results after 17 years:

- Rutting: average 6.6 mm, stdev 1.8mm
- Cracking: average 0.1 percent, stdev 0.3 percent, less than 5 percent crack initiation

Detailed *CalME* inputs and outputs are listed in the Appendix. For WSDOT, the following general comments were made during the evaluation:

- WSDOT does not conduct fatigue and rutting tests on mixes, so it is difficult for the department to determine the mix model parameters required by *CalME;*
- WSDOT does not perform much new construction, and rehabilitation is much more important than new pavement design;
- WSDOT is moving towards Superpave mix design using PG grading, therefore the *CalME* standard PG grading material library would be helpful;
- *CalME*'s M&R function is very helpful for perpetual pavement design.

3.2 Minnesota

Evaluation of *CalME* was mostly done by the Minnesota Department of Transportation (MnDOT). Lev Khazanovich from the University of Minnesota also showed strong interest in implementing the models used in *CalME* in separate software. The contact person on this project for MnDOT was Shongtao Dai. An in-person training session was held at MnDOT headquarters on May 1, 2009.

Two mainline cells (Cell 3 and Cell 21) of flexible pavement from the Mn/ROAD project were selected because of material availability for laboratory testing and because of their contrasting fatigue cracking and rutting performance.

The inputs necessary to run *CalME* simulations were collected from the comprehensive Mn/ROAD database, and included data from falling weight deflectometer (FWD) testing and condition surveys, as well as measurements of pavement temperature and traffic loads and spectra. In addition, loose mix was obtained for laboratory testing to identify model parameters for *CalME* simulation.

CalME's companion backcalculation program, *CalBack* was used to backcalculate layer moduli from FWD data to evaluate the influence of freeze/thaw and seasonal changes of subgrade, the confining effect of aggregate base, and the hardening/aging effect of asphalt concrete. These effects were all captured by respective *CalME* models.

A unique climate zone was created using pavement temperatures from Mn/ROAD, and a customized WIM station was also created to represent the load spectrum on the mainline.

All data needed to run *CalME* was collected for the two Mn/ROAD cells so there was no need to make assumptions on *CalME* inputs, except for the variability for layer thickness and stiffness. The fatigue shift factor for HMA was taken as 1.0, indicating that one pass of truck traffic would have the same damaging effect as one repetition of bending strain of the same magnitude in a beam bending fatigue test. The rutting shift factor was assumed to be same as the one calibrated using WesTrack and HVS test data.

The simulation results indicated that the presumed bottom-up fatigue cracking results from *CalME* matched reasonably well with the recognized top-down cracking condition survey results for both cells (see Figure 3.1).

CalME was able to predict the rutting performance of Cell 3 appropriately; however, the rutting performance prediction of Cell 21 was completely inaccurate (see Figure 3.2). Over-asphalting during construction for Cell 21 might have contributed to the premature rutting failure, and this was not accounted for in material characterization.

Overall, the use of *CalBack* and *CalME* seems to be very promising as they were capable of predicting pavement performance in a rational way for these two Mn/ROAD sections. (For details of the analyses, see Reference *(1)*, which was presented in the poster session at TRB 2009 annual meeting.)

For MnDOT, the following general comments were made during the in-person training session:

- MnDOT wants to make sure *CalME* works, and understands how it works,
- Rehab design is more useful for MnDOT because it has its own design software for new flexible pavements.

3.3 Texas

Evaluation of *CalME* was done by the Texas Department of Transportation (TxDOT). The contact person on this project for TxDOT was Joe Leidy. An in-person training session was held at TxDOT headquarters in Austin on February 1, 2010.

TxDOT sent data for three perpetual pavements and one nonperpetual pavement to UCPRC for *CalME* analysis:

- SH-114 near Forth Worth, Superpave mixes, perpetual pavement
- SH-114 near Forth Worth, conventional mixes, perpetual pavement
- IH-35 near Cotulla, Superpave mixes, perpetual pavement
- US-83 near Uvalde, 20-year design with 3.7 million ESALs

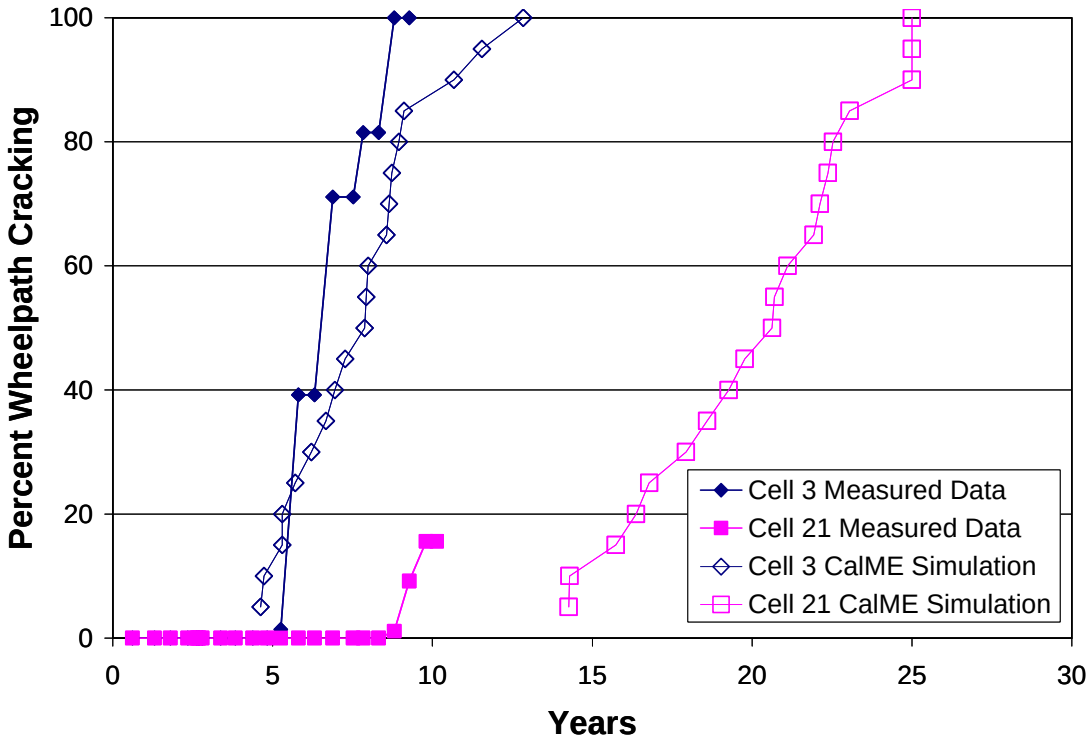


Figure 3.1: Comparison of *CalME*-predicted and Mn/ROAD measured surface cracking.

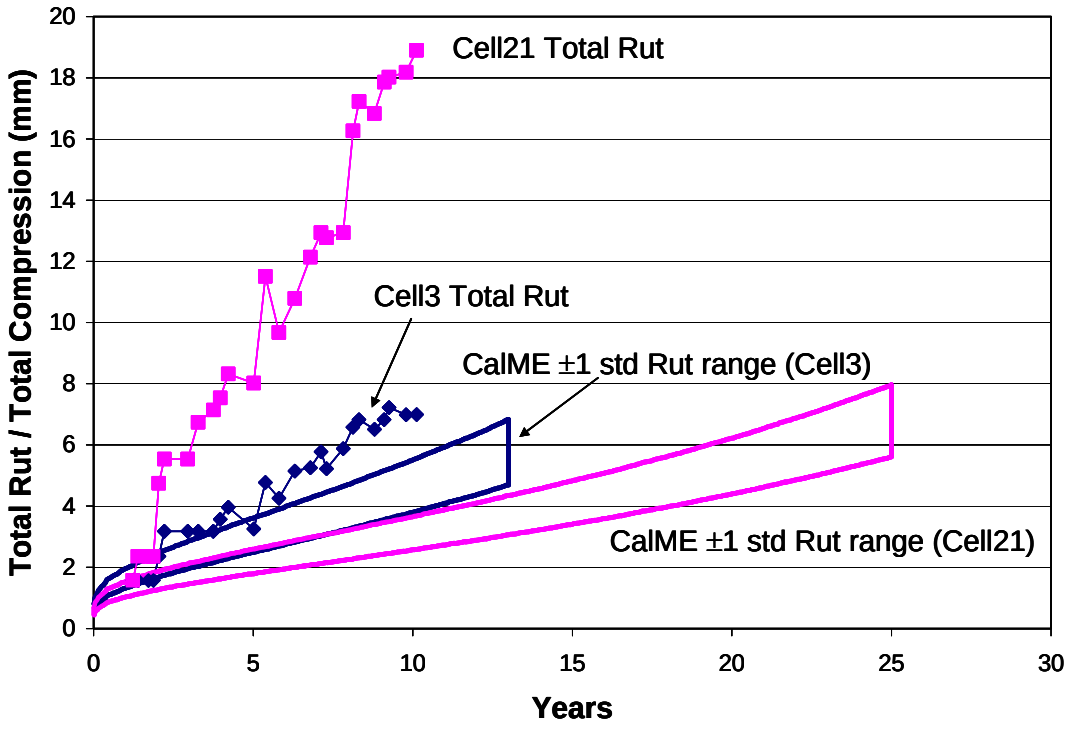


Figure 3.2: Comparison of *CalME*-predicted and Mn/ROAD-measured surface rut. Note that *CalME* predicts downward ruts (which is equal to total layer compressions), while measured values are total rut (i.e., the sum of hump and rut).

The following information was known for the TxDOT projects:

- Structure: layer thicknesses
- Materials:
    - Mix design (binder grade, binder viscosity, aggregate gradation, binder content)
    - For perpetual pavements, the following additional data was available:
        - Dynamic modulus at various temperatures and frequency
        - FWD data for backcalculation of supporting layer stiffnesses for perpetual pavements
- Traffic: Total ESAL counts in 20 years, and growth rate
- Climate: Custom *CalME* climate zone from EICM runs
- Performance: Three to five years of observations for perpetual pavements, and six years of observation for the US-83 nonperpetual pavement project

The following data was assumed:

- Traffic: A built-in *CalME* load spectrum was picked for each project based on similar neighborhoods
- Fatigue and rutting model parameters: Used parameters for calibrated WesTrack mixes

CalME predicted perpetual pavements to have 2 to 6 mm of rutting and no fatigue cracking after 40 years. In reality, no rutting and cracking were observed to date after three to five years of trafficking.

For the nonperpetual pavement, US-83, *CalME* predicted roughly 12 mm of rutting but no fatigue cracking. In reality, there was no cracking so far but 2 percent of the wheelpaths exhibited shallow rutting of about 12.5 mm (0.5 in.). *Note*: No specific calibration for TxDOT was performed.

TxDOT uses different test methods than Caltrans does for characterizing HMA materials, including triaxial dynamic modulus testing for stiffness master curves, fatigue testing with the overlay tester, and repeated permanent deformation testing using the simple performance tester. All these data can be used to identify *CalME* model parameters, albeit one would have to recalibrate *CalME* to link *CalME* predictions to actual field performance.

4 FEEDBACK AND COMMENTS ON *CALME*

During the in-person training sessions, staff from each state provided valuable comments and discussions on *CalME*. In addition, the UCPRC solicited feedback and comments via questionnaire as the project approached its end. The responses are summarized below.

On plans for implementation of M-E design for flexible pavements:

- Texas: Is developing a new M-E design guide.
- Washington: Is using AASHTO 1993 combined with an updated design table based on MEPDG and PMS performance data.
- Minnesota: Would like to implement MEPDG as it has both bituminous and concrete designs, but is also looking at other M-E design methods, such as *CalME*.

On the way CalME *helps in M-E design for flexible pavements (if applicable):*

- Texas: Is interested in some of the models (crushing model) and approaches (simplified traffic model) in *CalME*.
- Minnesota: Likes the overlay design part of *CalME* but needs more time to get familiar with it.

On what was particularly useful or interesting in the modeling/approach in CalME:

- Texas: The incremental-recursive approach; co-existence of empirical and M-E design; built-in climate data.
- Washington: Pavement performance estimation for each overlay cycle is of special interest.

On what was particularly useful or interesting in the modeling/approach in CalME:

- Texas: The incremental-recursive approach; co-existence of empirical and M-E design; built-in climate data.
- Washington: Pavement performance estimation for each overlay cycle was of special interest.

General comments:

- Texas: Very nice help menu/documentation.

5 SUMMARY AND RECOMMENDATIONS

During this pooled-fund project, State Pavement Technology Consortium (SPTC) member states (California, Minnesota, Texas, and Washington), participated in the evaluation of models in a mechanistic-empirical design software program called *CalME*, which was developed for the California Department of Transportation (Caltrans) by the University of California Pavement Research Center (UCPRC). A webinar and in-person training sessions were held to help engineers from each state learn the software and understand the models.

WSDOT and TxDOT provided UCPRC with typical design data for selected projects in each state for analysis with *CalME*. Assumptions were made on material properties and traffic load spectra in order to run *CalME*. With calibration factors developed based on HVS and WesTrack data, *CalME* predicted correct trends for both rutting and cracking. The actual values for predicted rutting and cracking were also fairly close to measured values.

MnDOT provided traffic, temperature, and structure data as well as chronicle FWD data on two mainline cells. In addition, loose mix was provided so that UCPRC could conduct all the necessary laboratory tests for characterizing the HMA layer. The predicted fatigue cracking matched that observed while the predicted rutting only matched that observed for one of the cells. Over-asphalting in the other cell was believed to be the reason for that discrepancy.

During this study, member states found many features of *CalME* helpful and might therefore adopt a selected set of models or approaches in their respective efforts on implementation of M-E design. At the same time, concerns were also raised about asphalt concrete characterization since UCPRC used model parameters based on tests that were not routinely run in other states. This, however, should not be an issue since *CalME* models are not tied to any specific type of test.

It was believed that evaluative effort by the state DOTs and UCPRC might have been limited by a lack of dedicated funding. It is recommended that additional funding be provided for each participant for similar projects in the future.

REFERENCE

1. Tsai, B.-W., R. Wu, and J. T. Harvey. 2009. *Mn/ROAD Case Study Using* CalBack *and* CalME. Poster session, 88th Annual Meeting of Transportation Research Board 2009. Washington, DC.

APPENDIX

Inputs and Results for *CalME* Analysis for WSDOT

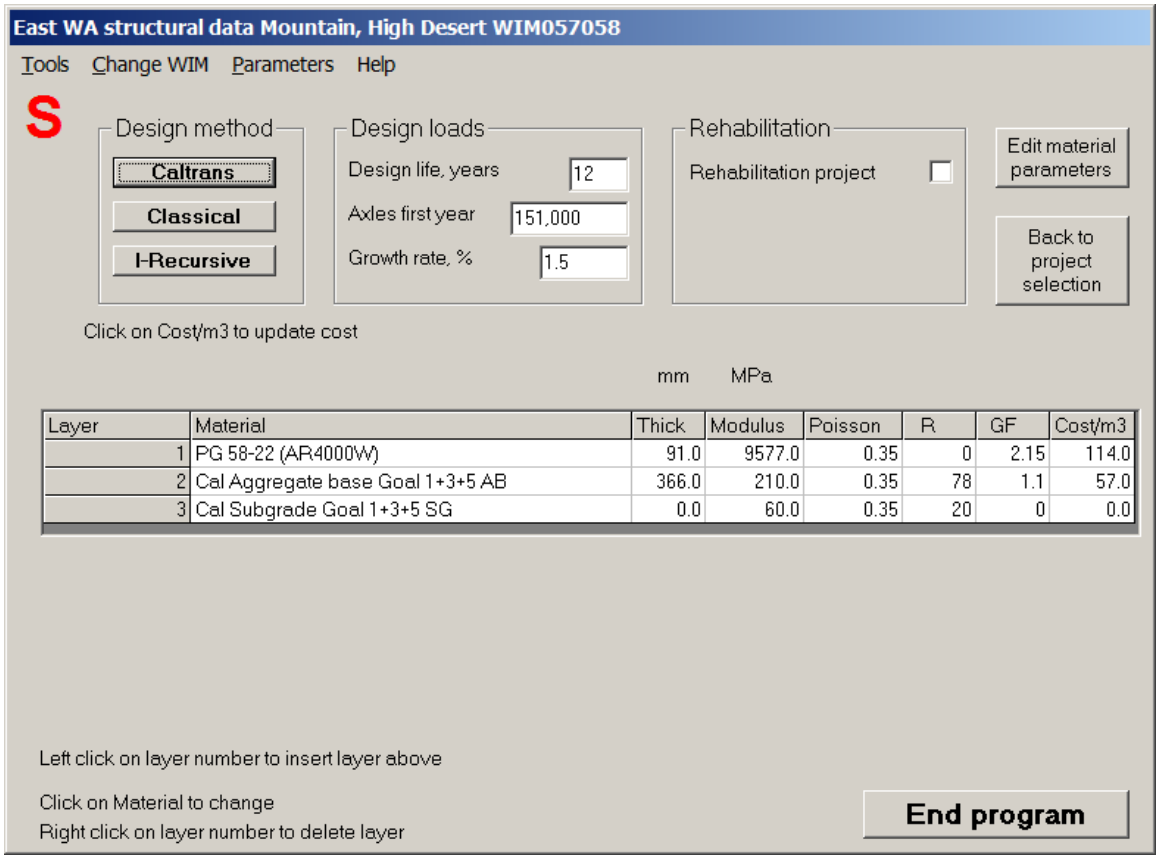


Figure A.1: Structure for Case 1, East WA project near Spokane.
Window caption indicates climate zone and representative WIM station used.

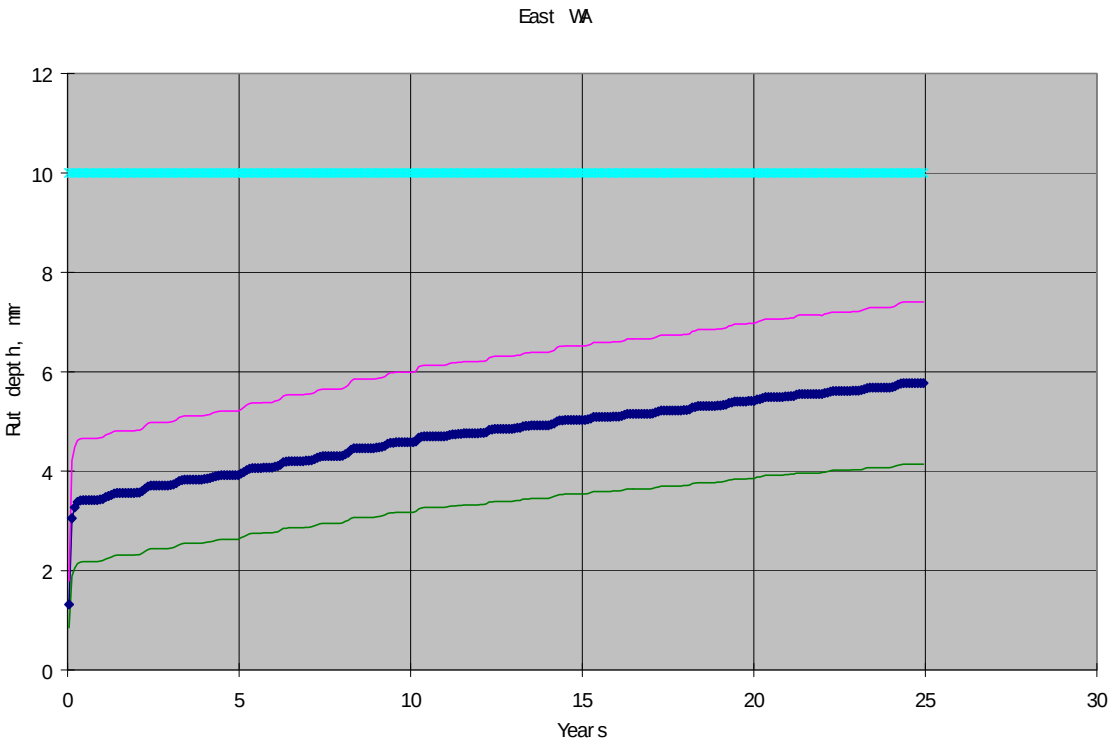


Figure A.2: Rutting performance for Case 1 predicted by *CalME*, mean and mean +/- 1 std.

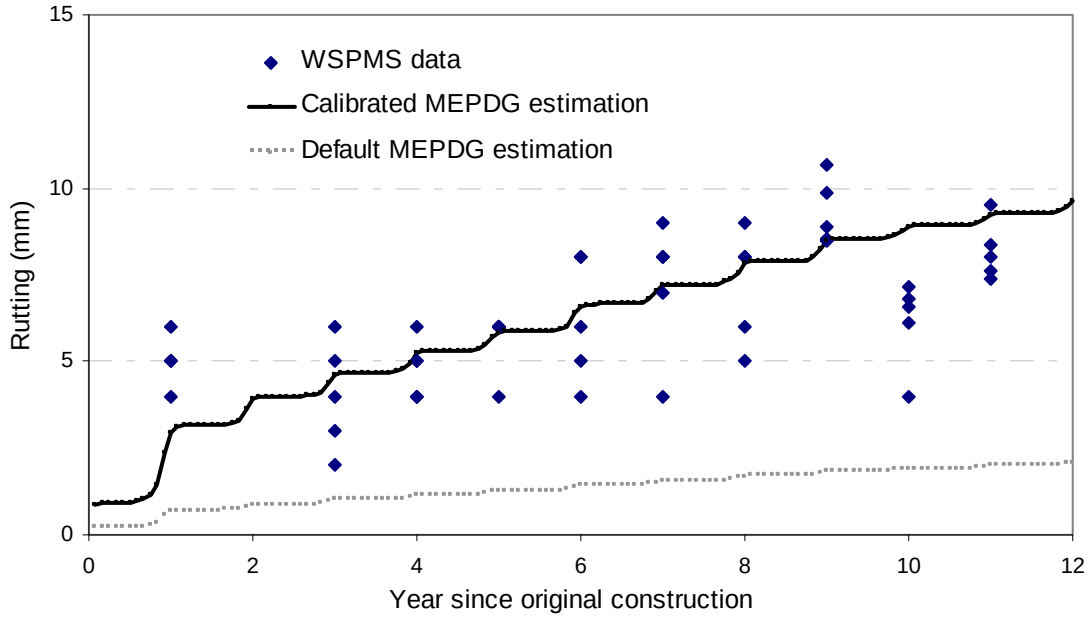


Figure A.3: Rutting performance data for Case 1 provided by WSDOT.

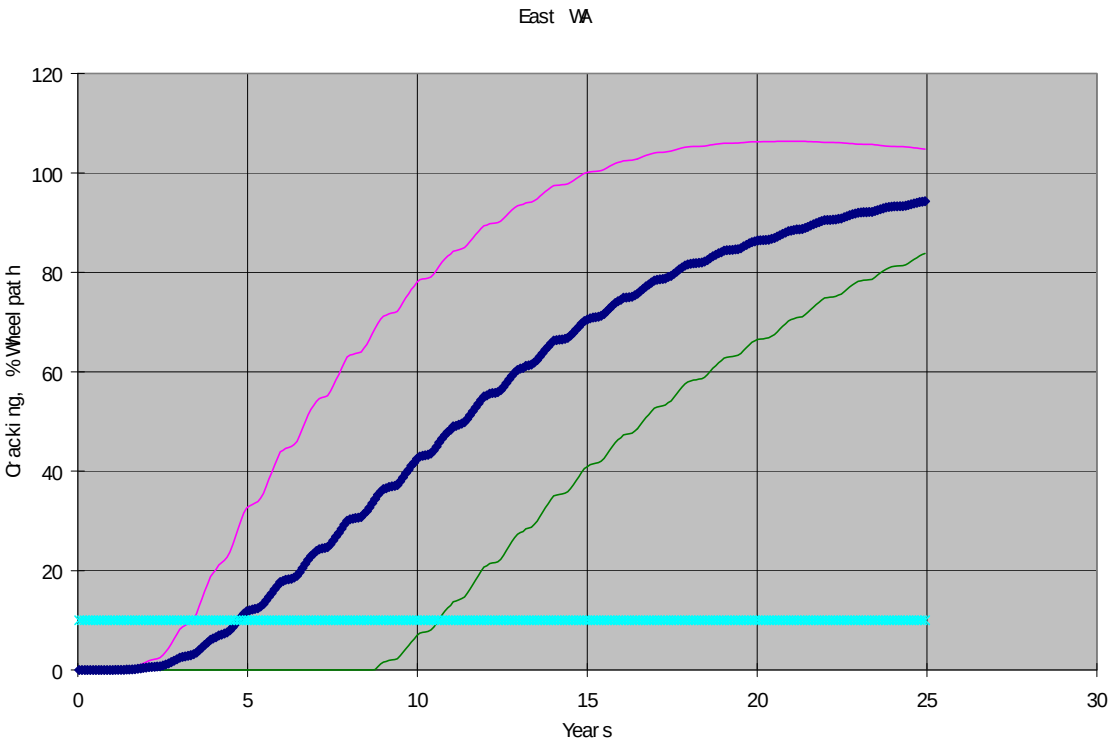


Figure A.4: Total surface fatigue cracking predicted by *CalME* for Case 1, mean and mean +/- 1 std.

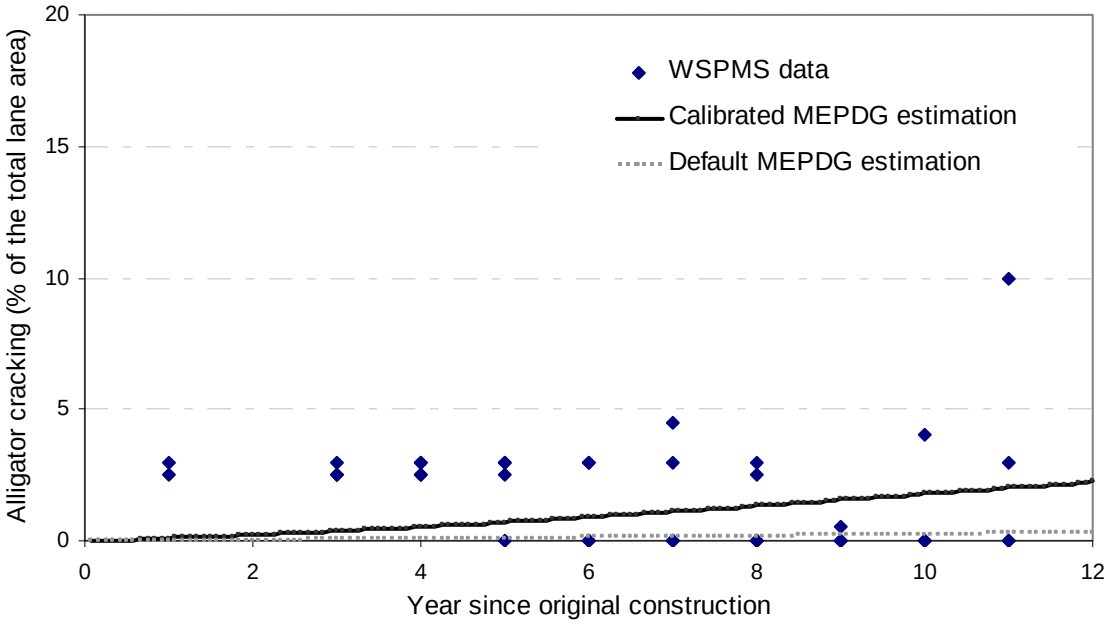


Figure A.5: Alligator cracking for Case 1 reported by WSDOT.

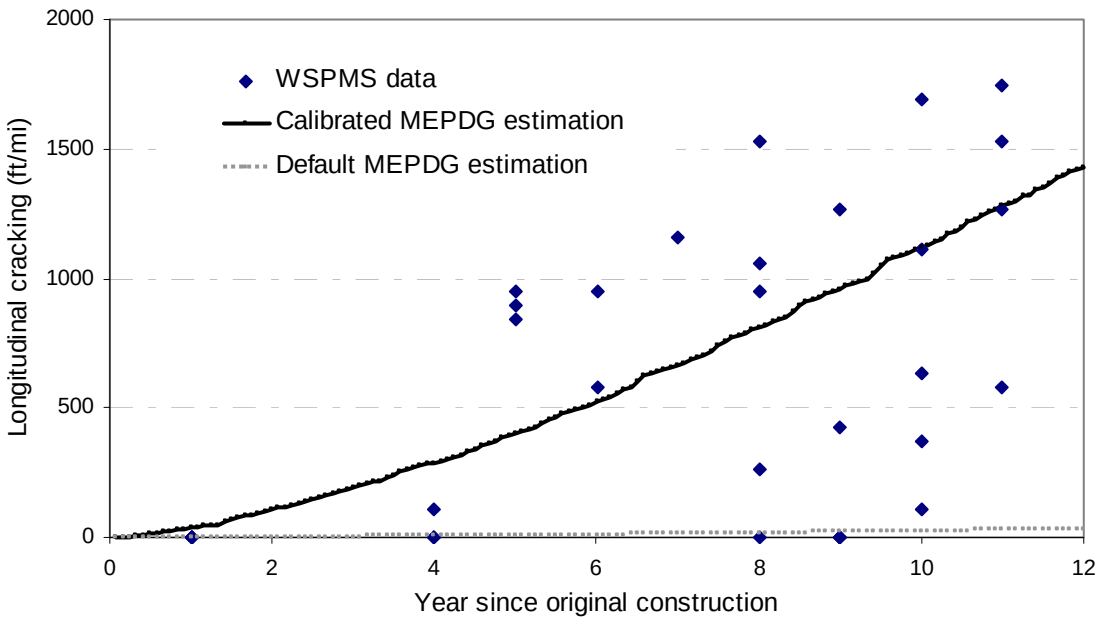


Figure A.6: Longitudinal cracking for Case 1 reported by WSDOT.

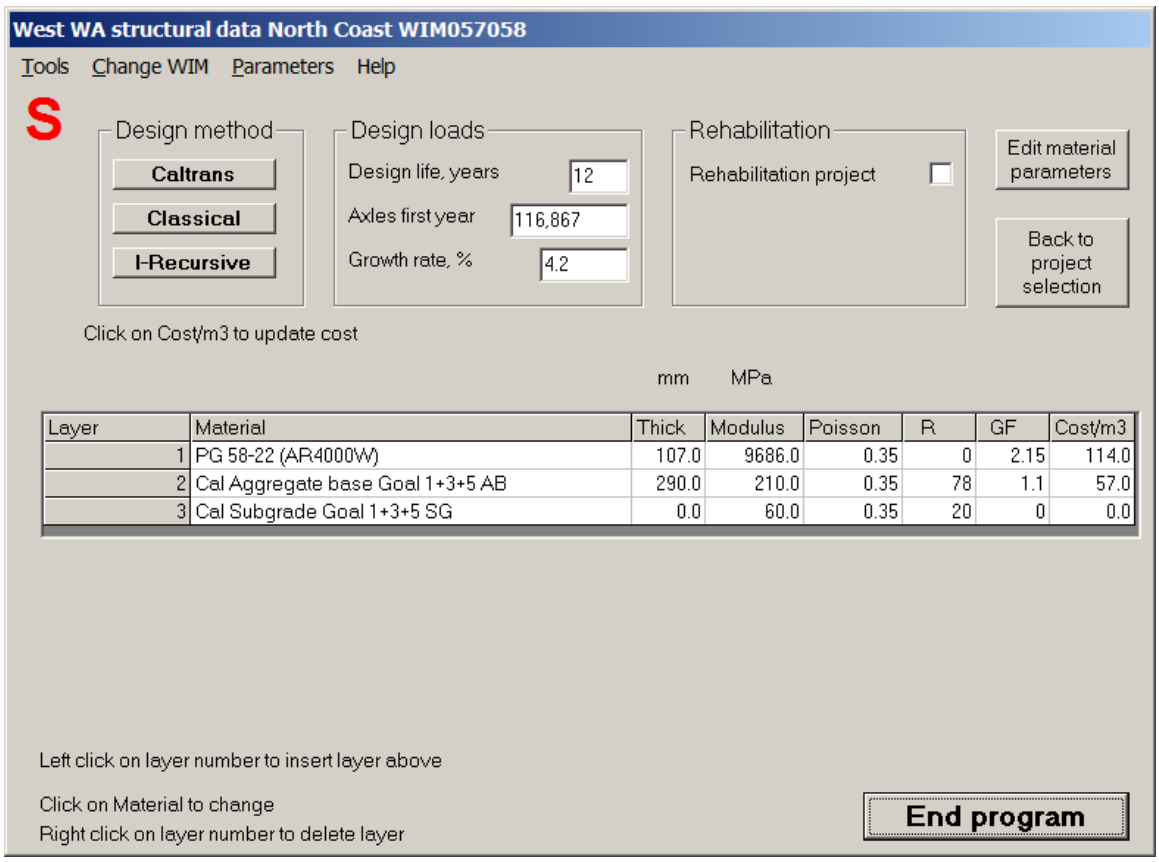


Figure A.7: Structure for Case 2, West WA project near Bellingham.
Window caption indicates climate zone and representative WIM station used.

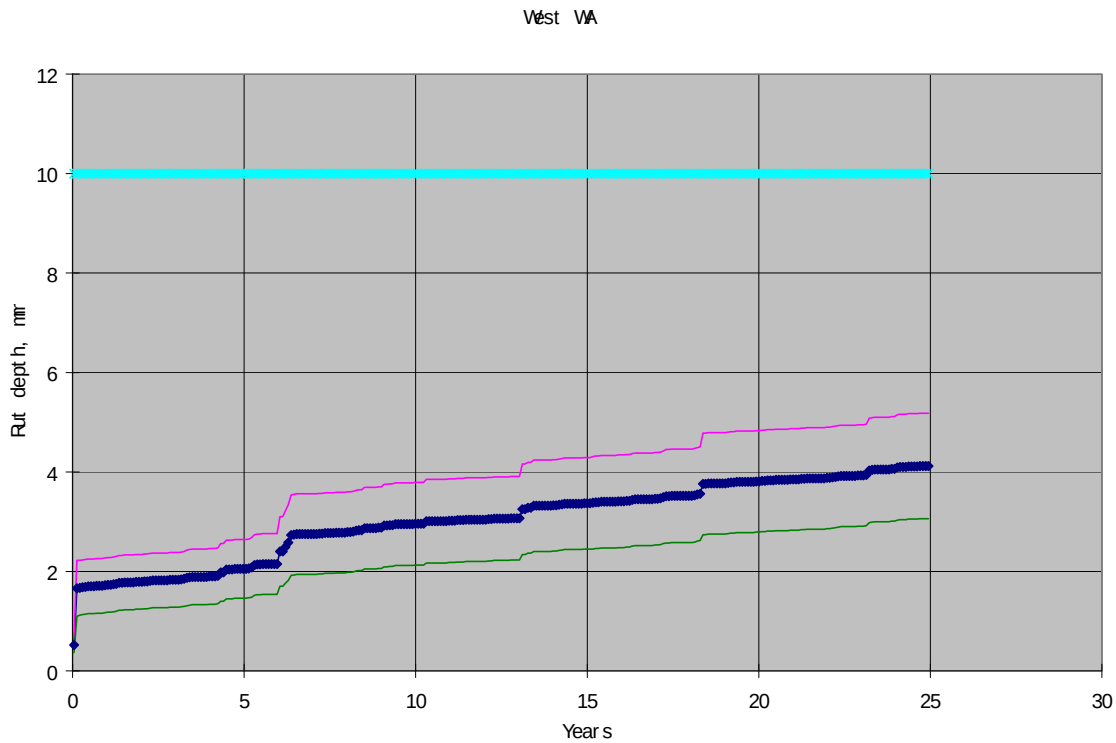


Figure A.8: Rutting performance for Case 2 predicted by *CalME*, mean and mean +/- 1 std.

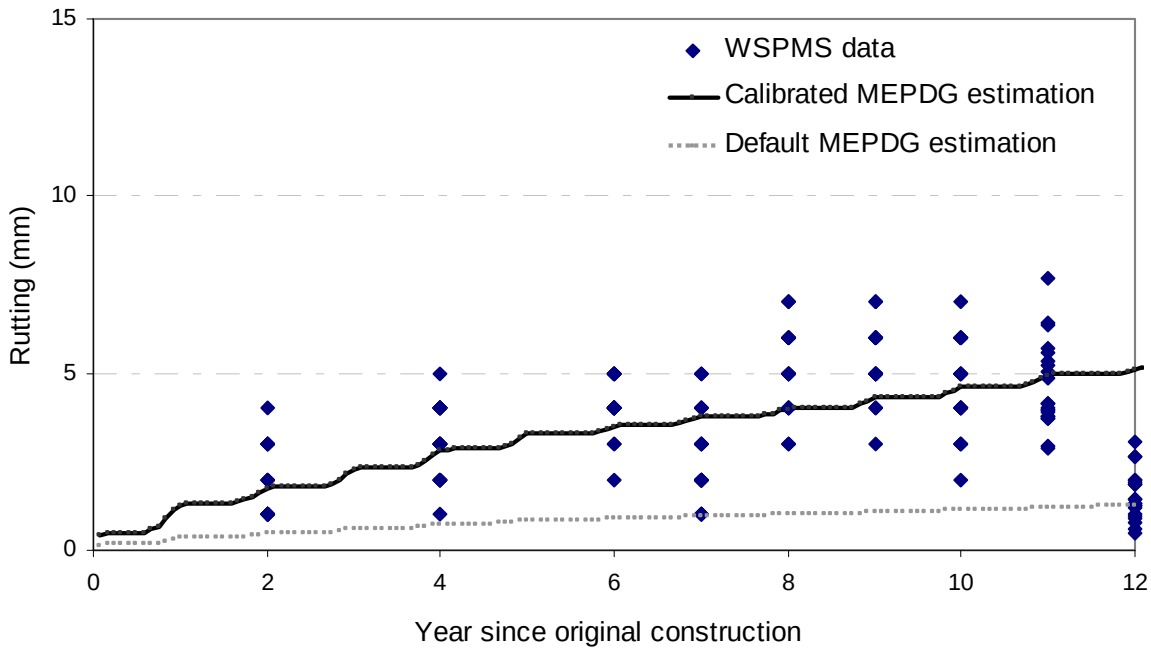


Figure A.9: Rutting performance for Case 2 reported by WSDOT.

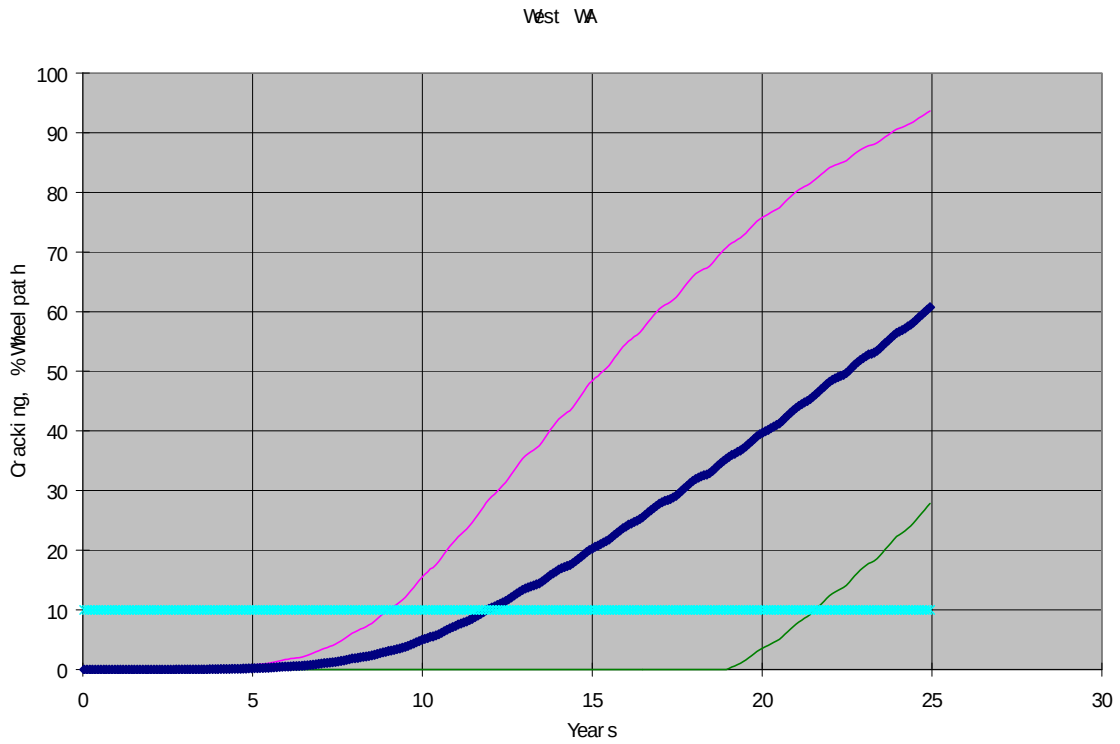


Figure A.10: Total surface fatigue cracking predicted by *CalME* for Case 2, mean and mean +/- 1 std.

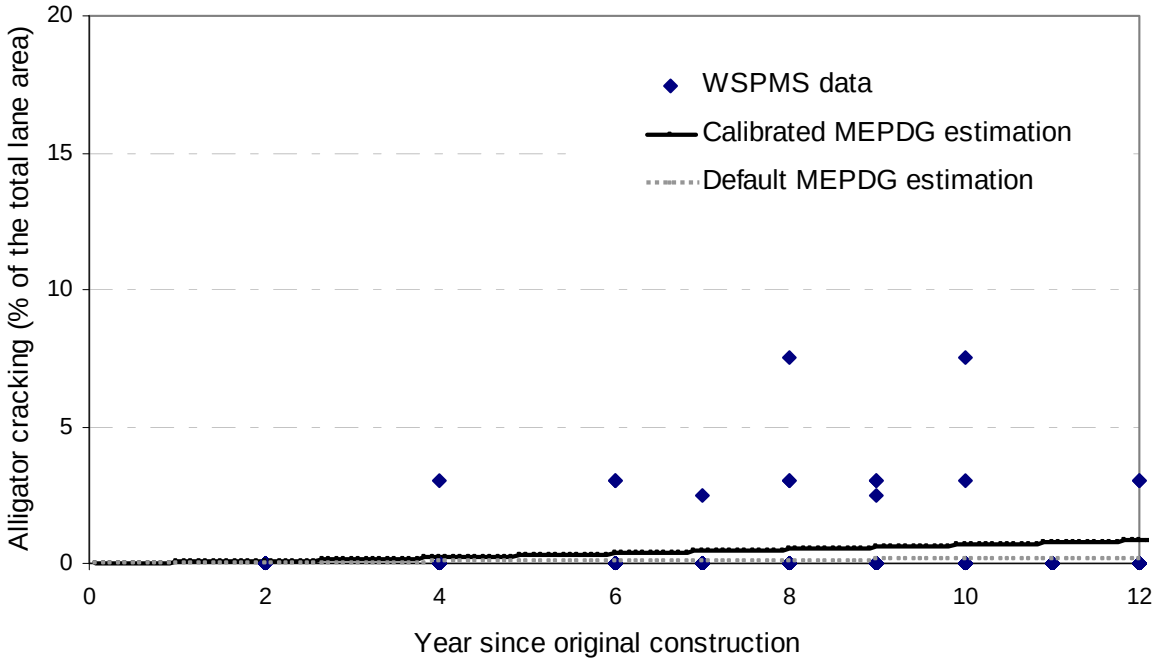


Figure A.11: Alligator cracking for Case 2 reported by WSDOT.

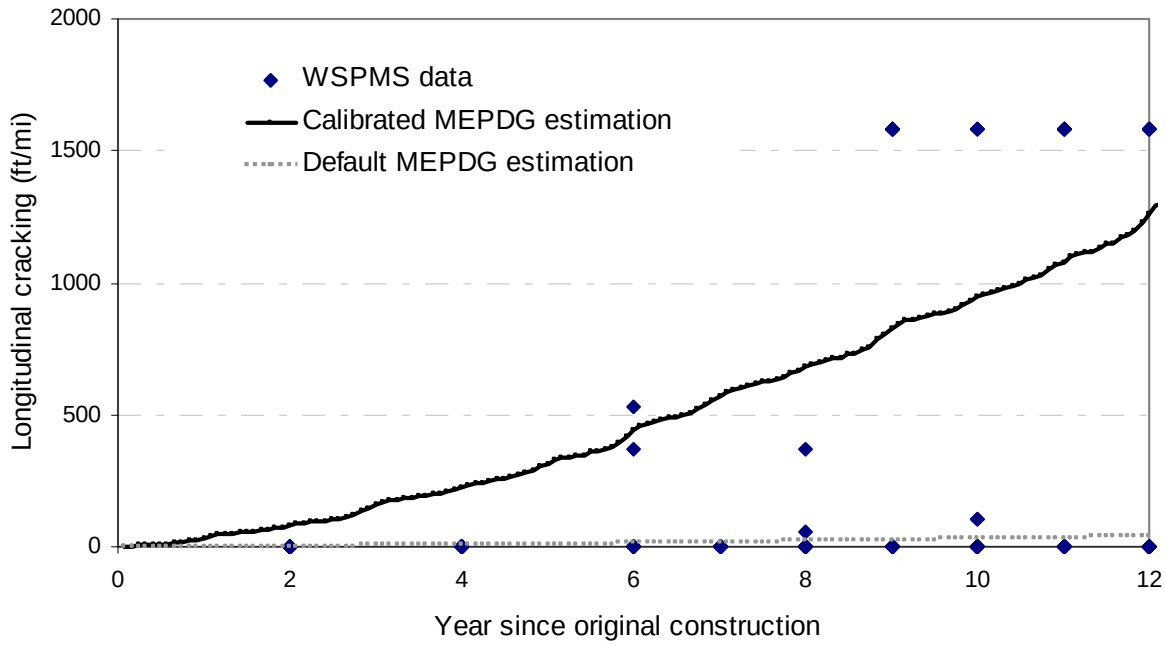


Figure A.12: Longitudinal cracking for Case 2 reported by WSDOT.

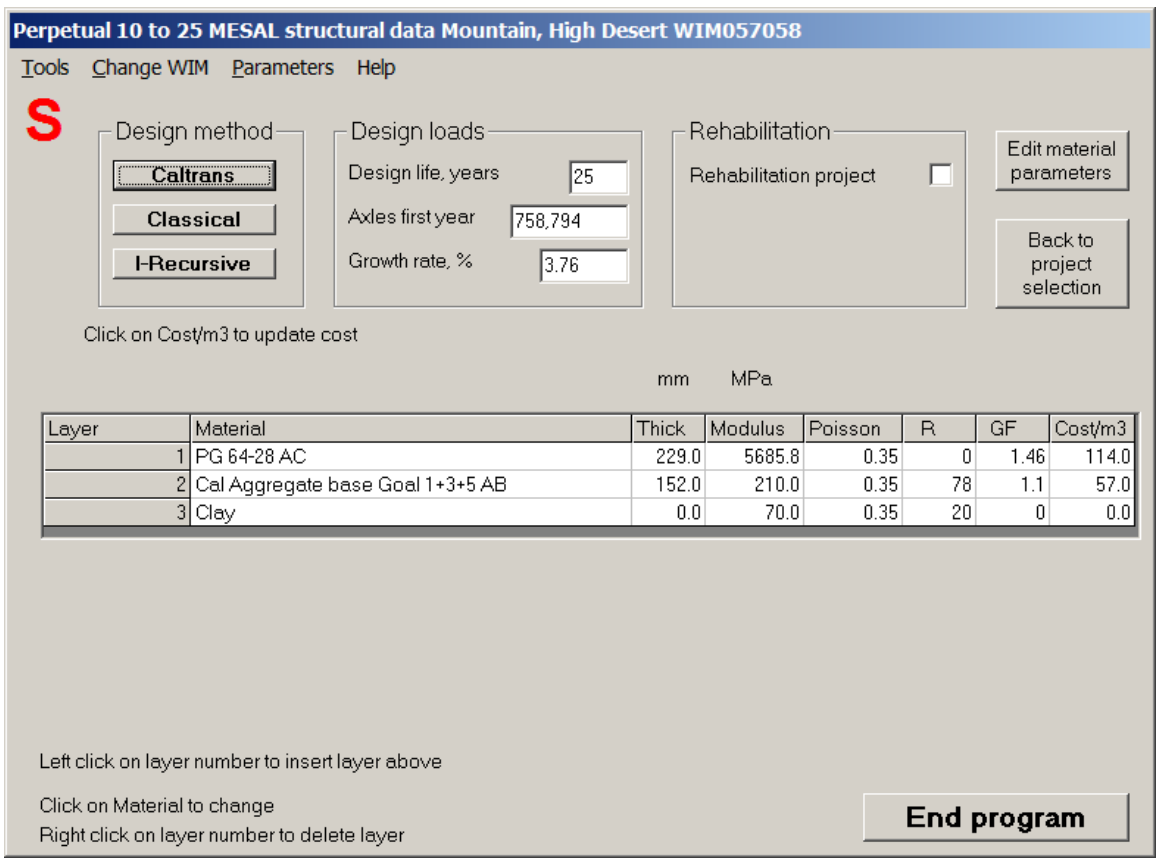


Figure A.13: Structure for Case 3, perpetual pavement for East WA subjected to 10 to 25 million ESALs in 50 years. Window caption indicates climate zone and representative WIM station used. In the analysis, 25 million ESALs were applied in 50 years.

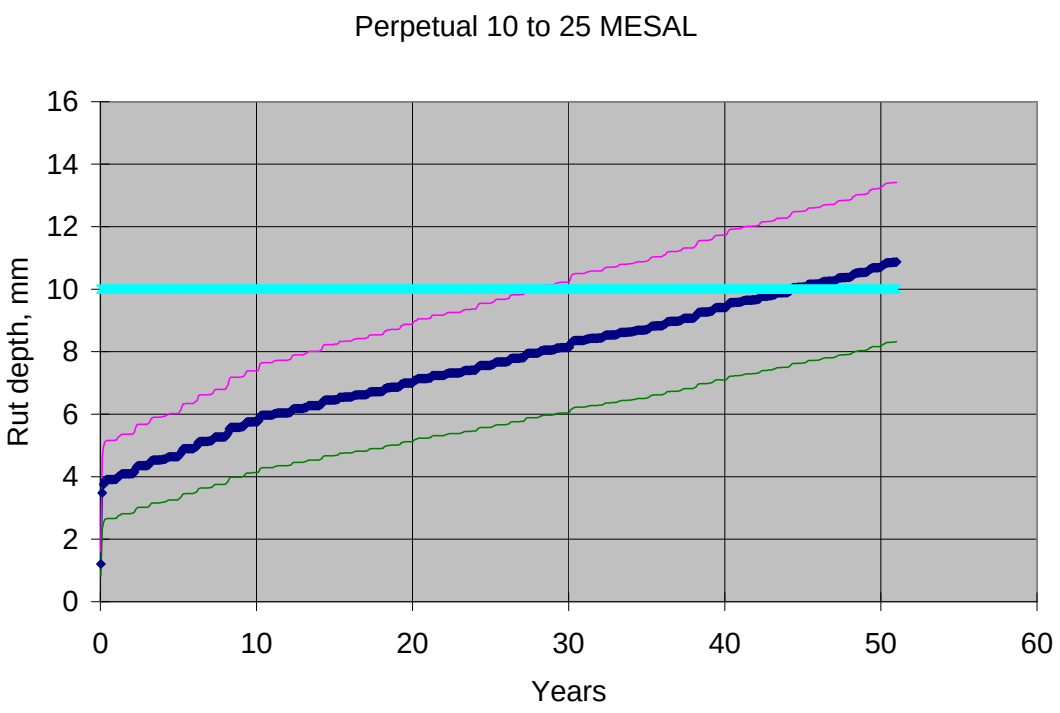


Figure A.14: Rutting performance predicted by *CalME* for Case 3, expected performance: 10 mm of rut in 16 to 18 years, mean and mean +/- 1 std.

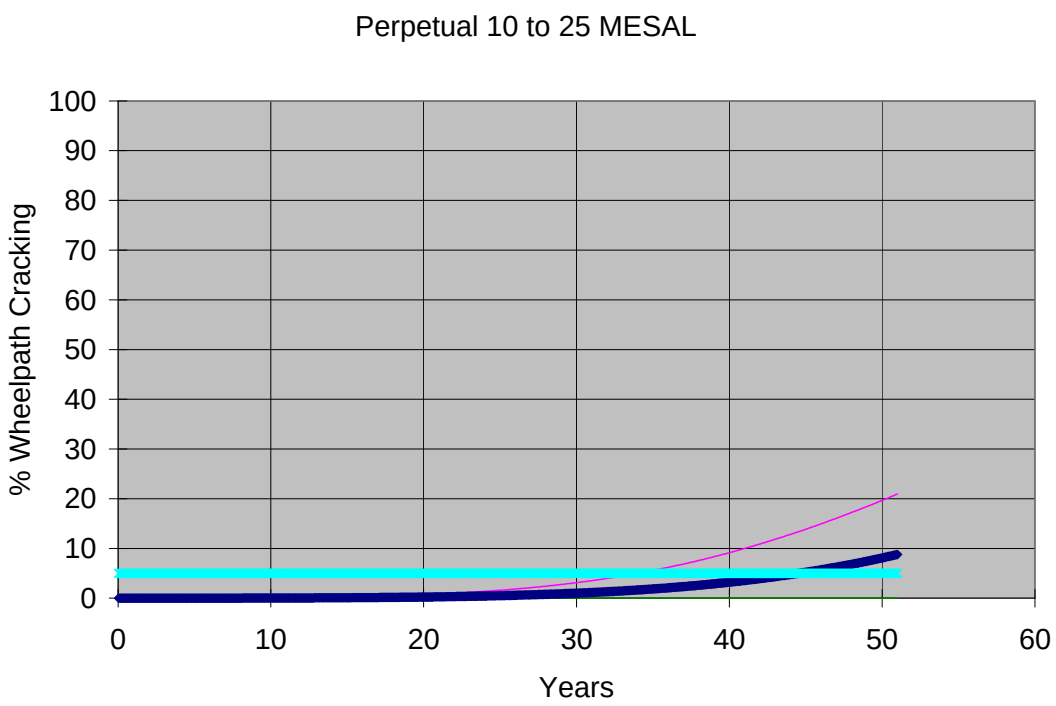
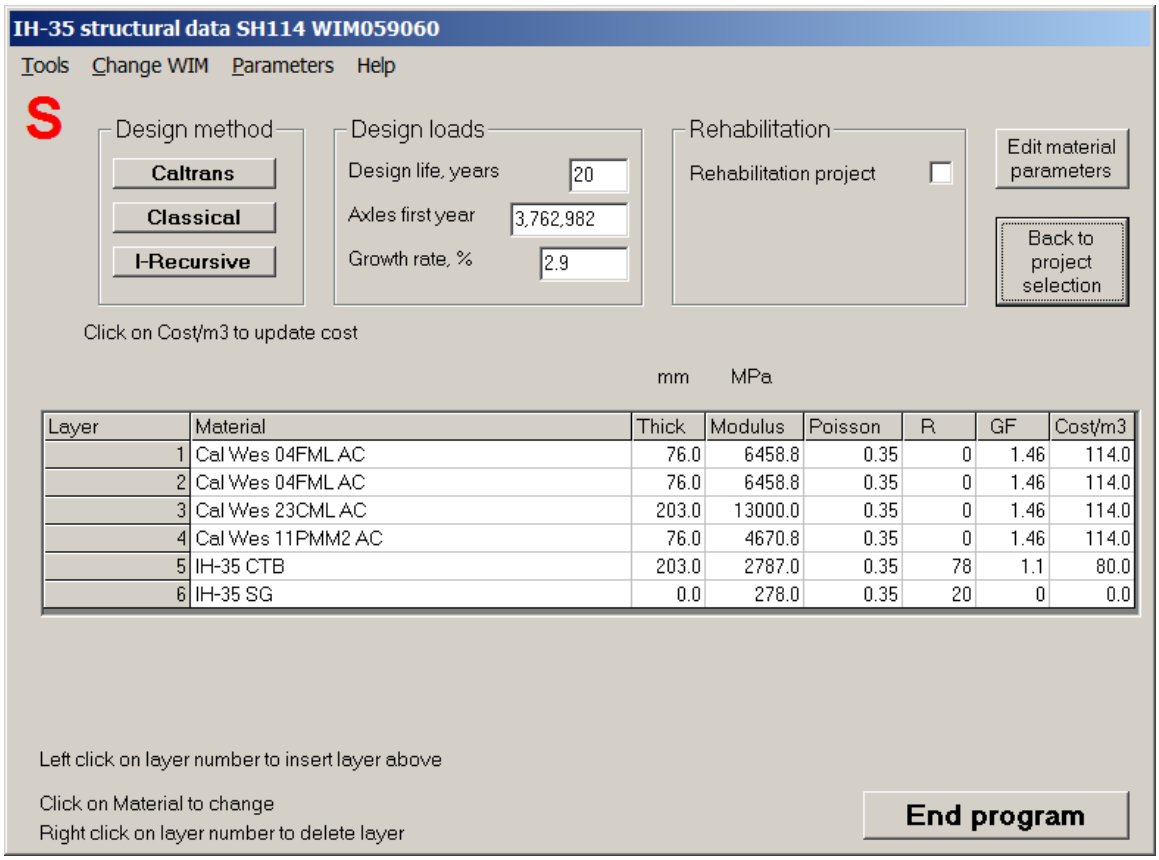


Figure A.15: Fatigue cracking performance predicted by *CalME* for Case 3, expected performance: 10 percent wheelpath fatigue cracking in 16 to 18 years, mean and mean +/- 1 std.

Inputs and Results for *CalME* Analysis for MnDOT

See Reference *(1)* for details.

Inputs and Results for *CalME* Analysis for TxDOT



Layer	Material	Thick	Modulus	Poisson	R	GF	Cost/m3
1	Cal Wes 04FML AC	76.0	6458.8	0.35	0	1.46	114.0
2	Cal Wes 04FML AC	76.0	6458.8	0.35	0	1.46	114.0
3	Cal Wes 23CML AC	203.0	13000.0	0.35	0	1.46	114.0
4	Cal Wes 11PMM2 AC	76.0	4670.8	0.35	0	1.46	114.0
5	IH-35 CTB	203.0	2787.0	0.35	78	1.1	80.0
6	IH-35 SG	0.0	278.0	0.35	20	0	0.0

Figure A.16: Structure for project on IH-35, perpetual pavement near Cotulla. Window caption indicates climate zone (SH114) and representative WIM station (WIM059060) used.

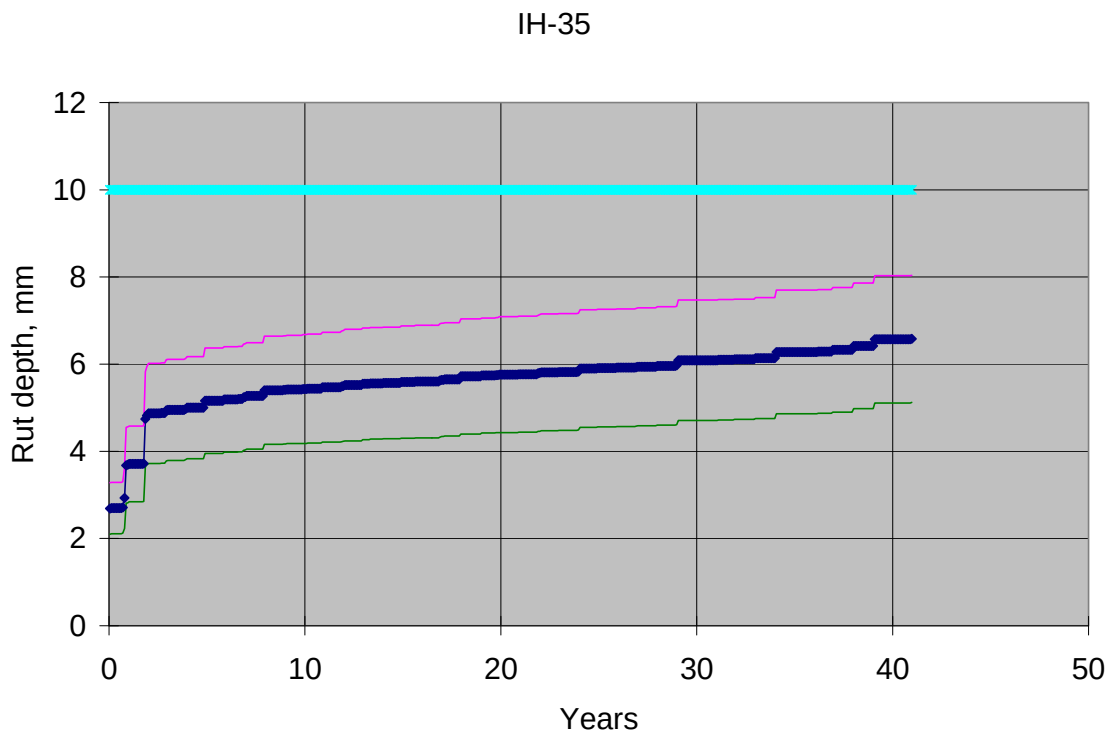
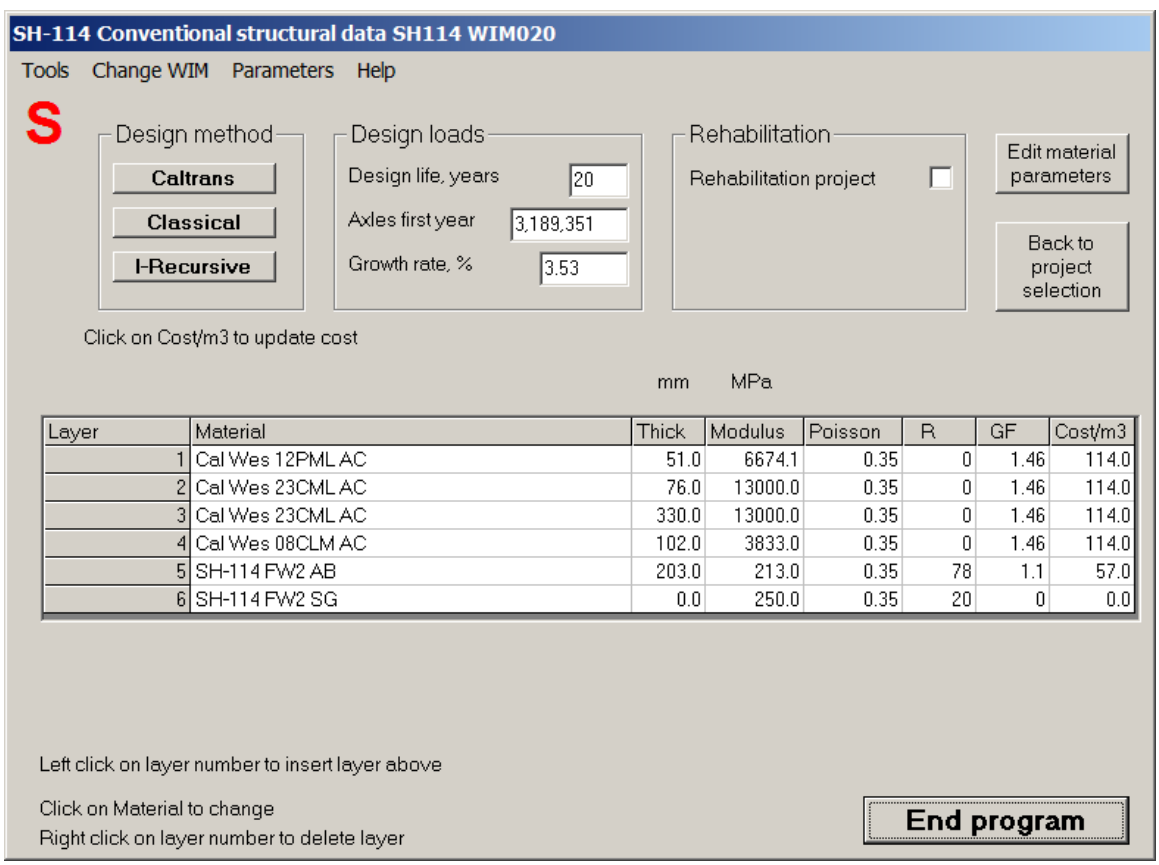


Figure A.17: Predicted mean and mean +/- 1 standard deviation rutting for IH-35 project; *CalME* predicted no cracking after 40 years.



Layer	Material	Thick	Modulus	Poisson	R	GF	Cost/m3
1	Cal Wes 12PML AC	51.0	6674.1	0.35	0	1.46	114.0
2	Cal Wes 23CML AC	76.0	13000.0	0.35	0	1.46	114.0
3	Cal Wes 23CML AC	330.0	13000.0	0.35	0	1.46	114.0
4	Cal Wes 08CLM AC	102.0	3833.0	0.35	0	1.46	114.0
5	SH-114 FW2 AB	203.0	213.0	0.35	78	1.1	57.0
6	SH-114 FW2 SG	0.0	250.0	0.35	20	0	0.0

Figure A.18: Structure for project on SH-114, perpetual pavement near Forth Worth using conventional mixes. Window caption indicates climate zone (SH114) and representative WIM station (WIM020) used.

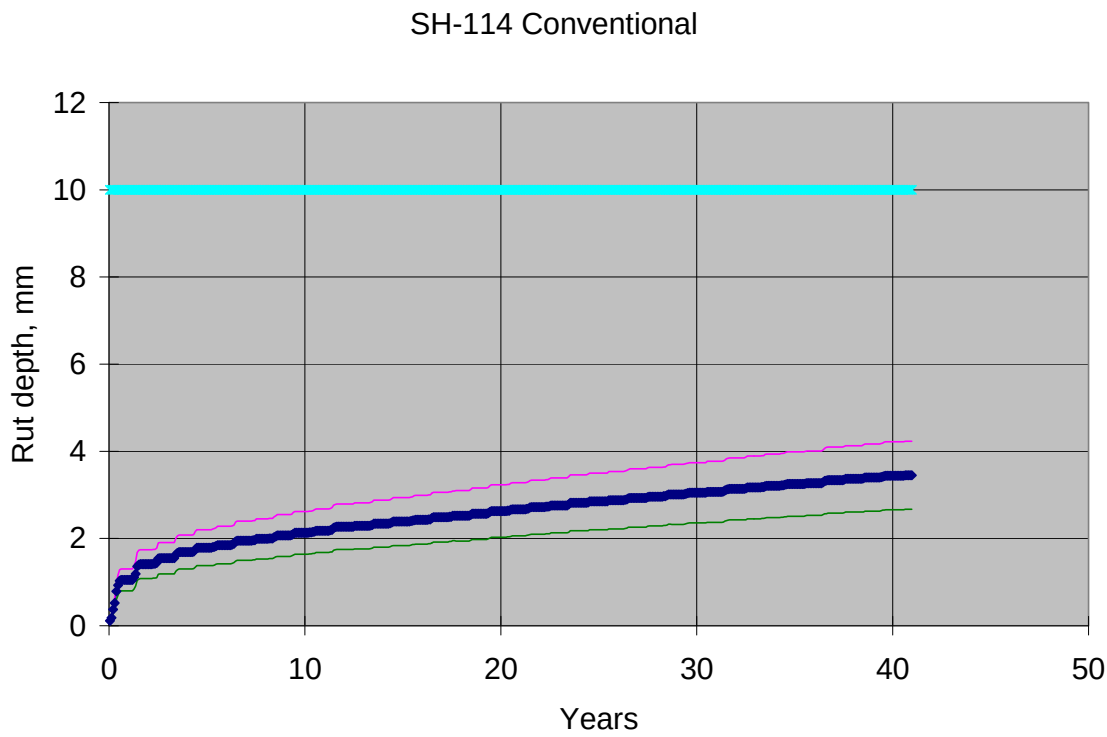


Figure A.19: Predicted mean and mean +/- 1 standard deviation rutting for SH-114 project with conventional mix; *CalME* predicted no cracking after 40 years.

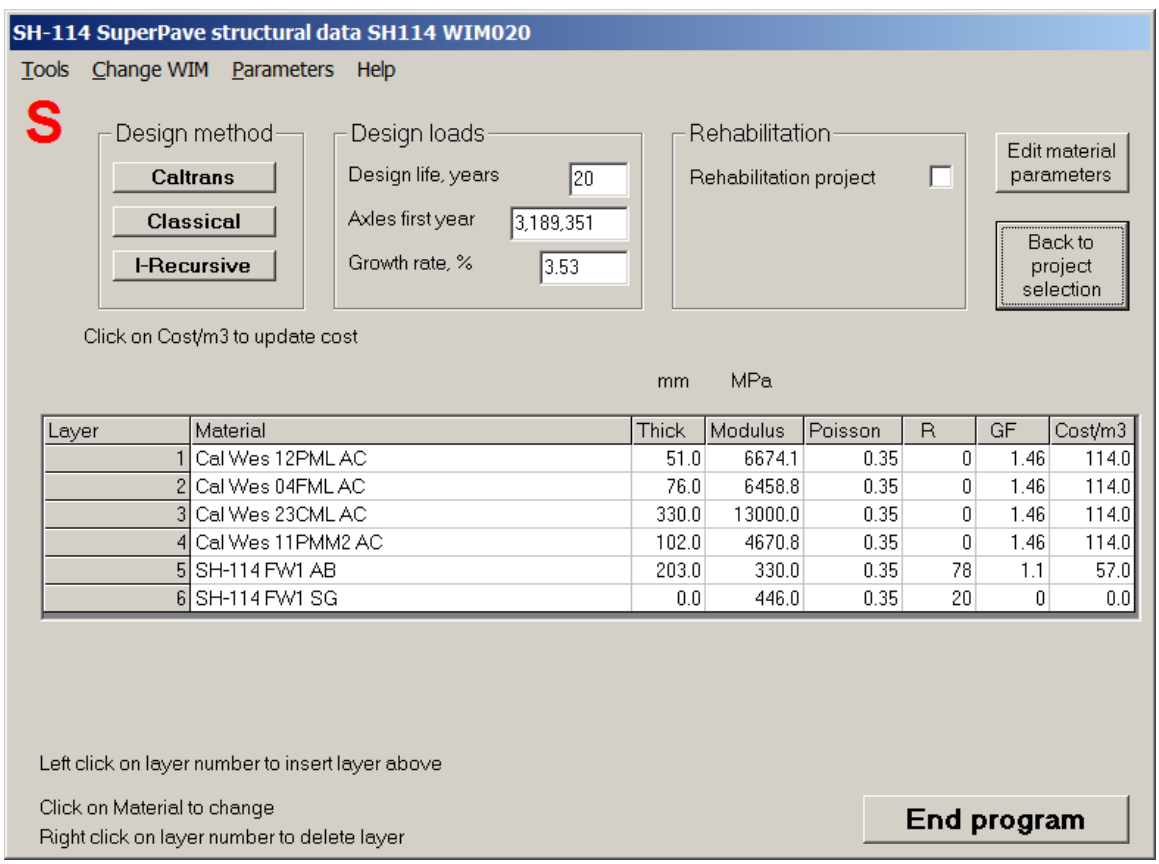


Figure A.20. Structure for project on SH-114, perpetual pavement near Forth Worth using Superpave mixes. Window caption indicates climate zone (SH114) and representative WIM station (WIM020) used.

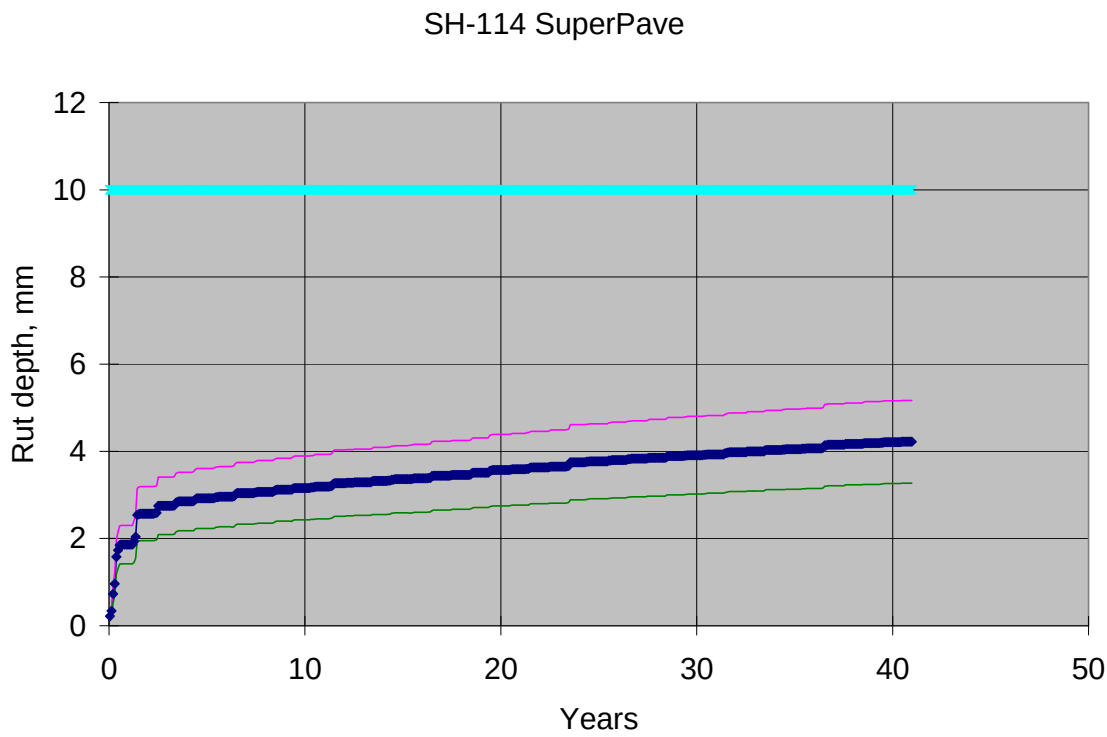


Figure A.21: Predicted mean and mean +/- 1 standard deviation rutting for SH-114 project with Superpave mix; *CalME* predicted no cracking after 40 years.

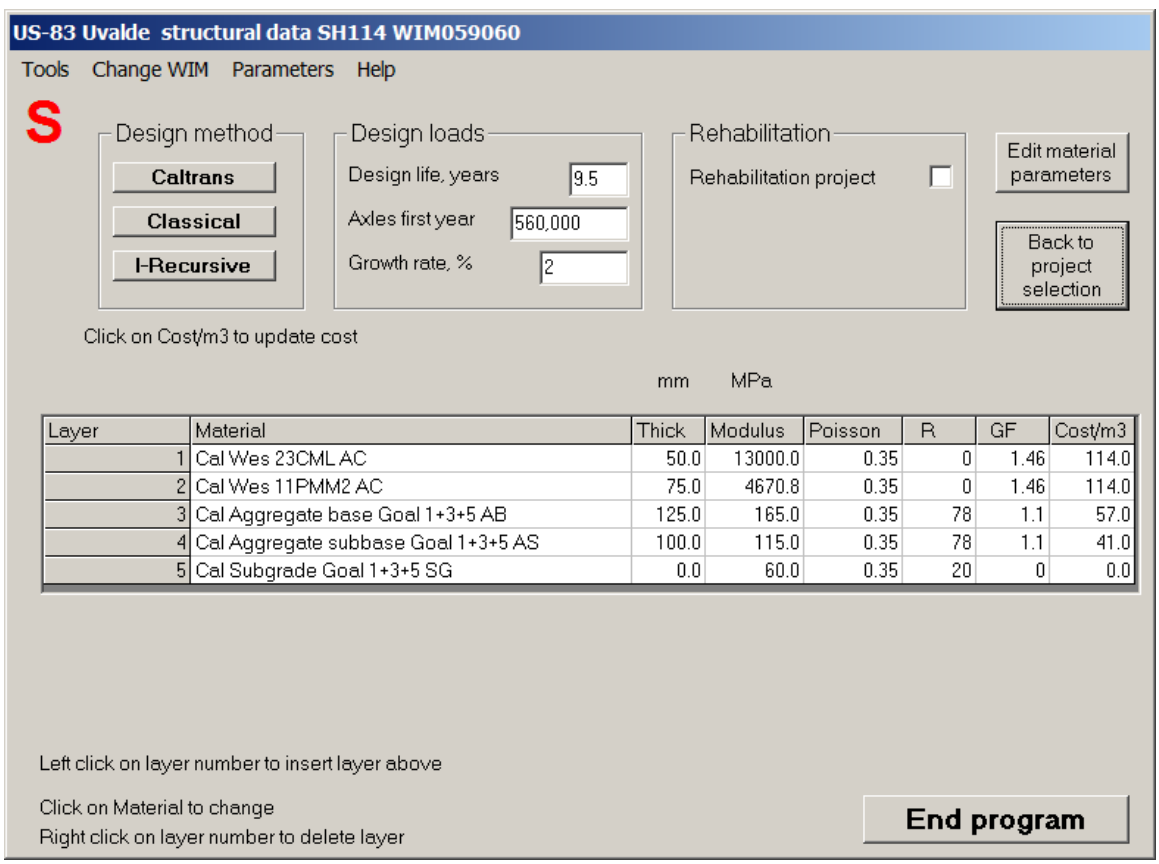


Figure A.22: Structure for project on US-83, 20-year design near Uvalde. Window caption indicates climate zone (SH114) and representative WIM station (WIM09060) used.

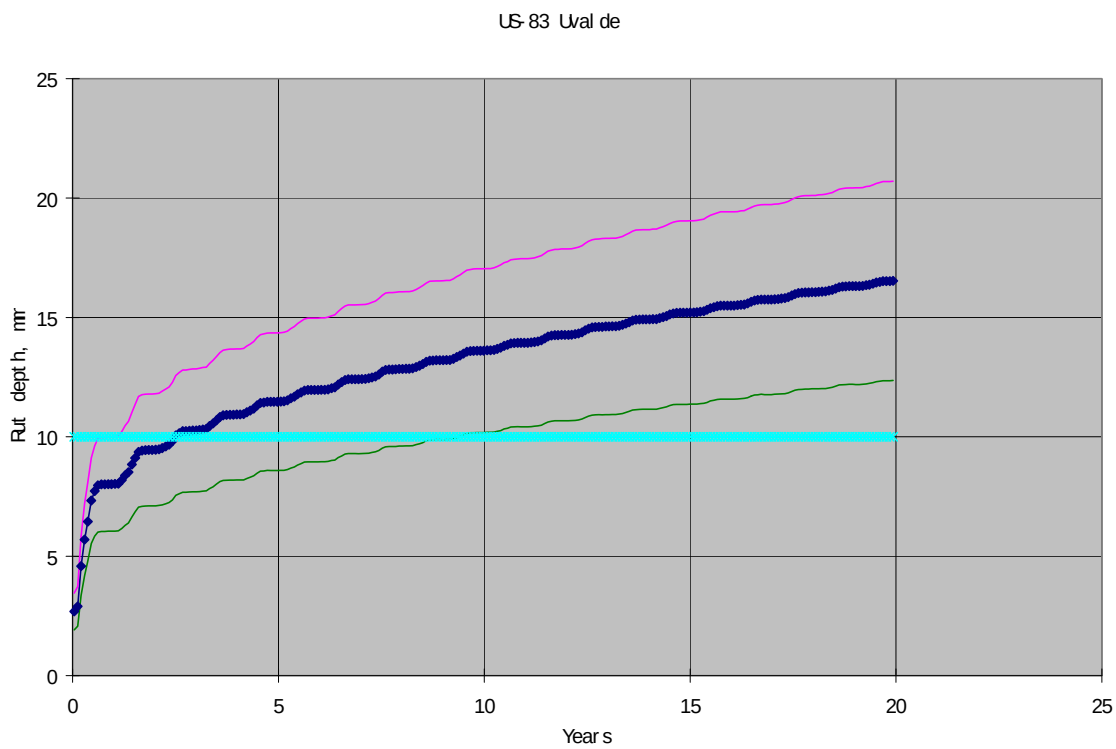


Figure A.23: Predicted mean and mean +/- 1 standard deviation rutting for US-83 project; about 12.5-mm of rut observed after 6 years of service for 2 percent of the wheelpath.

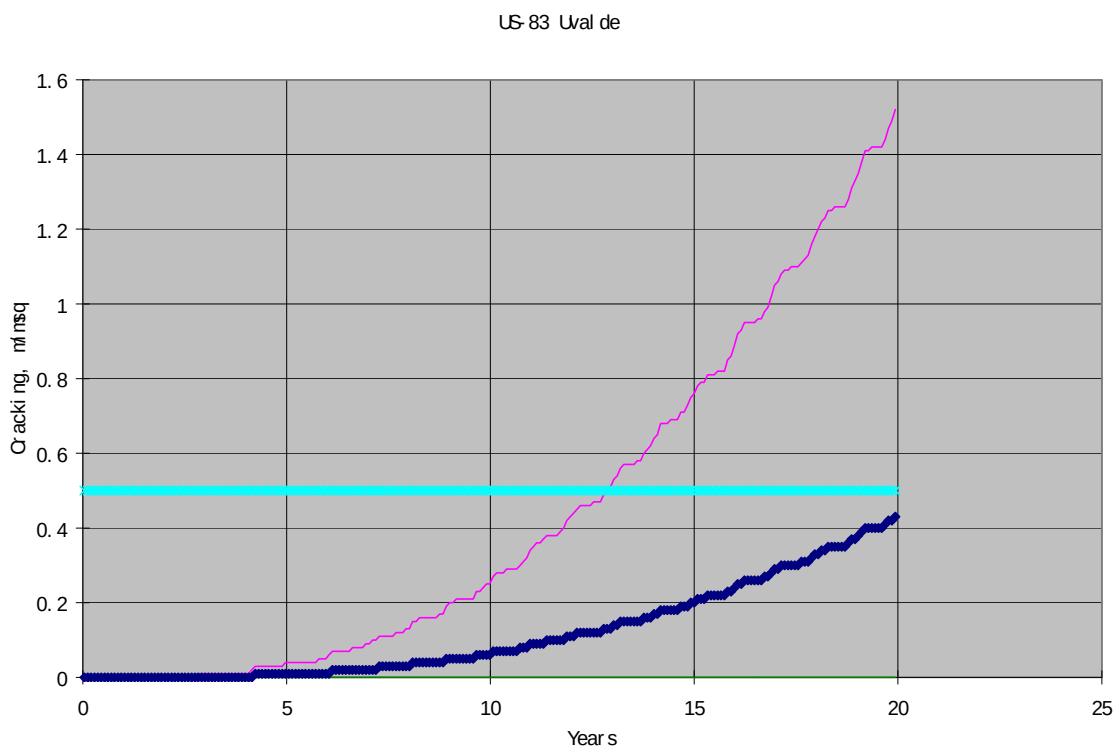


Figure A.24: Predicted mean and mean +/- 1 standard deviation fatigue cracking for US-83 project; no cracking has been observed yet after 6 years of service.