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Rehabilitation Design for 06-KIN-198, PM 9.2/17.9 Using Caltrans ME Design Tools: Findings and Recommendations

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Partnered Pavement Research Program (PPRC) Contract Strategic Plan Element 3.4:
Development of Improved Rehabilitation Design for Reflective Cracking

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Abstract:
This technical memorandum presents the results of pavement evaluation and rehabilitation design for 06-KIN-198, PM 9.2/17.9. The pavement evaluation consisted of deflection testing, coring, material sampling, backcalculation of stiffnesses using the software program *CalBack*, and condition assessment. Designs were prepared using current Caltrans methods and alternative rehabilitation designs were prepared using mechanistic-empirical software and models included in the software program *CalME*.

Keywords: Backcalculation, deflection, asphalt, aggregate base, rehabilitation

Proposals for implementation: Implement a plan for field evaluation of performance, including a control section, if one of the alternative mechanistic-empirical designs is constructed by Caltrans.

Related documents:

- *Calibration of CalME Models Using WesTrack Performance Data.* P. Ullidtz, J. Harvey, B.-W. Tsai, and C.L. Monismith. 2006. University of California Pavement Research Center, Davis and Berkeley. UCPRC-RR-2006-14.
- *Calibration of Incremental-Recursive Flexible Damage Models in* CalME *Using HVS Experiments.* P. Ullidtz, J.T. Harvey, B.-W. Tsai, and C.L. Monismith. 2006. University of California Pavement Research Center, Davis and Berkeley. UCPRC-RR-2005-06.
- CalBack: *New Backcalculation Software for Caltrans Mechanistic-Empirical Design.* Q. Lu, J. Signore, I. Basheer, K. Ghuzlan, and P. Ullditz. 2009. Journal of Transportation Engineering, ASCE.
- *Rehabilitation Design for 02-PLU-36, PM 6.3/13.9 Using Caltrans ME Design Tools: Findings and Recommendations.* J.M. Signore, B.D. Steven, J.T. Harvey, R. Wu, I.M. Guada, and L. Popescu. 2009. University of California Pavement Research Center, Davis and Berkeley. UCPRC-TM-2008-01.
- *Rehabilitation Design for 01-LAK-53, PM 3.1/6.9 Using Caltrans ME Design Tools: Findings and Recommendations.* L. Popescu, B. Steven, J. Signore, J. Harvey, R. Wu, and I. Guada. University of California Pavement Research Center, Davis and Berkeley. UCPRC-TM-2008-02.

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DISCLAIMER

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BACKGROUND AND OBJECTIVES

In 2008, the Caltrans Division of Pavement Management, Office of Pavement Engineering selected three pavement rehabilitation projects for use as case studies in rehabilitation design using Mechanistic-Empirical (ME) design procedures, with each case study's completion resulting in a technical memorandum that describes the work and analyses performed. This memorandum covers a site near Lemoore, CA, designated 06-KIN-198, PM 9.2/17.9, and it outlines the procedures and findings of each step of the design and analysis, from pre-site visit work to the site investigation to the rehabilitation design recommendations, based upon both current R-value and ME design procedures. The work was performed by the University of California Pavement Research Center (UCPRC) as part of Partnered Pavement Research Center Strategic Plan Element 3.4, in conjunction with Caltrans District and Headquarters staff.

The goal of the three case studies is to use current rehabilitation investigation techniques—including deflection testing, material sampling, and Dynamic Cone Penetrometer (DCP) testing—to provide inputs for two newly developed ME design and analysis software programs, *CalBack* and *CalME,* and associated testing and analysis procedures developed jointly by the UCPRC and Caltrans. Specifically, *CalBack* uses Falling Weight Deflectometer (FWD) data to backcalculate layer stiffnesses; *CalME* generates performance estimates of cracking and rutting based on ME damage models that integrate traffic, climate, layer type, and backcalculated stiffnesses. *CalME* can also produce designs using the Caltrans R-value and CT 356 procedures, which were performed as part of the work reported here for comparison purposes.

The objectives of each case study are:

1. To refine pre-field and in-field information gathering methods and office design and analysis techniques with the new software in order to identify changes needed for implementation by Caltrans.
2. To produce alternative designs for consideration by Caltrans.

Work conducted for each of these case studies consisted of a review of existing project documentation, field site and material evaluation, and development of new design and rehabilitation options.

Three pavements were used as case studies:

- 02-PLU-36, PM 6.3/13.9 (in and near Chester)
- 01-LAK-53, PM 3.1/7.4 (near Clearlake)
- 06-KIN-198, PM 9.2/17.9 (near Lemoore)

Figure 1: Map showing locations of three case studies.

PRESITE VISIT EVALUATION

Following site selection for this case study, UCPRC staff contacted District 6 personnel to obtain any existing information regarding the project, such as the construction history, as-builts, coring logs, deflection test results, and distress surveys. This information was studied along with the Caltrans pavement video log to create a preliminary field testing plan. This plan was sent to Albert Vasquez at Caltrans HQ and to appropriate District Design, Materials, and Maintenance staff. Following this, plans were made for a pretesting site visit with District personnel. During this visit, exact deflection testing limits were established, coring plans were confirmed, and trenching locations were identified. District personnel established a traffic control plan for two days of field evaluation and testing. The test plan was revised as requested and sent to all personnel involved.

SITE DESCRIPTION

The pavement selected for this case study is State Route 198 in Kings County from the junction of State Route 41 at Post Mile 9.2, west of Lemoore, to the intersection with 11th Avenue at Post Mile 17.9, in Hanford. The highway currently has areas of transverse cracking, continuous longitudinal cracks, and isolated areas of alligator cracking with some minor pumping that are often located at or near the embankments of bridge overcrossings between Lemoore and Hanford.

Caltrans records show that the existing pavement structure was originally constructed in 1963 and has since been overlaid with one or more thin (0.10 ft) layers of HMA at various locations along the section. The last major rehabilitation from PM 9.2 to PM 14.2 occurred in 1999, when 0.45 ft of HMA was placed after 0.10 ft of hot-mix asphalt (HMA) was cold planed. The last rehabilitation from PM 14.0 to PM 17.9 occurred in 1998, when 0.20 ft of HMA was placed on the existing structure in the eastbound direction and 0.35 ft of HMA was placed on the existing structure in the westbound direction.

The highway section was divided into four test sections, based on construction history, pavement structure, and current pavement condition, as follows (see Table 1, Description, for section location information):

- Section 1, PM 9.2 to 14.4
- Section 2, PM 14.4 to 15.1
- Section 3W (westbound), PM 15.1 to 17.9
- Section 3E (eastbound), PM 15.1 to 17.9

The boundary between Sections 1 and 2 was placed at PM 14.4, 0.1 mi west of the 14th Avenue ramps. *Note:* The Section 1 limit at PM 14.4 is based on deflection measurements taken as part of the preparation of this memo and actual conditions there might introduce some variability in boundary location. Recent construction work limits have been located west of PM 14.4, at PMs 14.0 and 14.2.

Section 3W (westbound) has core thicknesses and deflection responses similar to Section 1. Section 3E (eastbound) has core thicknesses and deflections similar to Section 2 and core thicknesses that differ from Section 3W by more than 0.1 ft (30 mm).

The post mile and length of each section and a map of the site are shown in Table 1 and Figure 2, respectively.

Table 1: Section Locations and Lengths

Section	Post Mile Start	Post Mile End	Section Length ft (m)	Description	Type
Section 1	9.2	14.4	27,456 (8,320)	Junction SR 41 to 14th Avenue ramps	Level, at grade
Section 2	14.4	15.1	3,696 (1,120)	14th Avenue—ramps and overcrossing	Embankment
Section 3E	15.1	17.9	1,4784 (4,480)	East of 14th Avenue ramps (Mussel Slough) to 11th Avenue undercrossing	Two (2) overcrossing embankment Sections
Section 3W	17.9	15.1	1,4784 (4,480)		

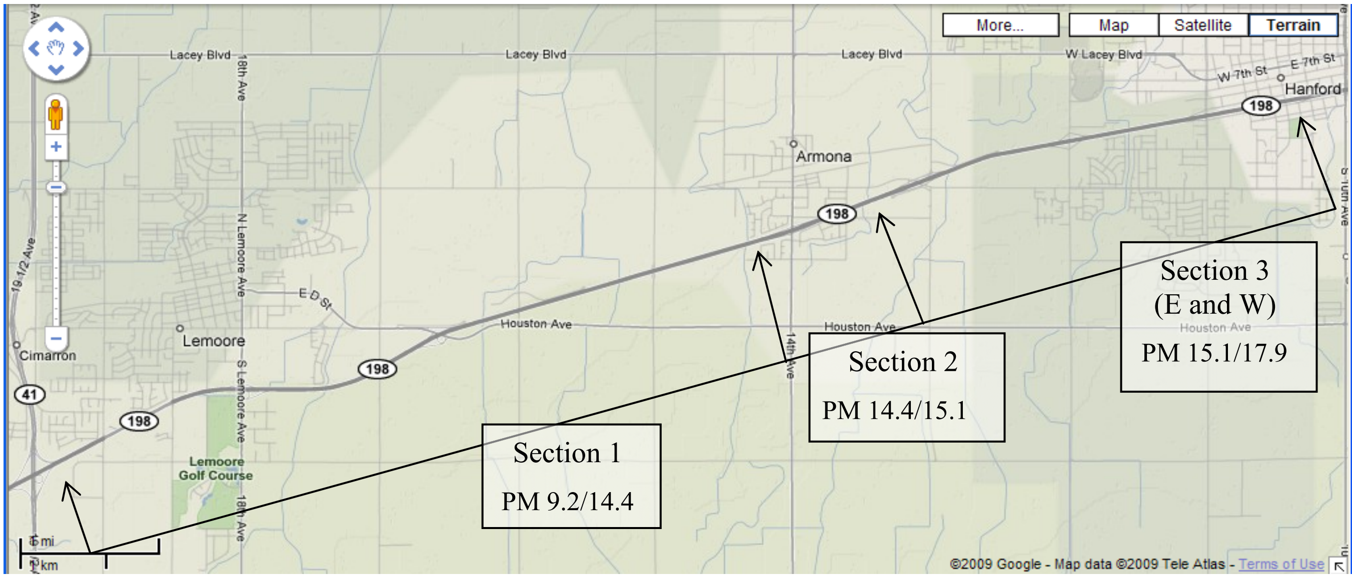


Figure 2: Map showing section locations.

FIELD INVESTIGATION—FINDINGS

On February 6 and 7, 2008, UCPRC and Caltrans personnel completed two days of site investigation that included FWD deflection testing for structural capacity of the existing pavement structure, coring at 19 locations for HMA layer thickness, and Dynamic Cone Penetrometer testing at 11 of the 19 core locations for granular base thickness and estimated subgrade stiffness. Some of the photographs taken showing the pavement surface condition appear in Figure 3, Figure 4, and Figure 5.

Pavement Condition

The pavement surface had longitudinal and transverse cracking throughout the project and severe fatigue cracking at isolated locations. Longitudinal cracking was primarily in the wheelpath, indicating that it was related to traffic loading. The source of the transverse cracking—whether it was due to reflection of existing transverse cracks through thin overlays or top-down transverse cracking related to aging and temperature changes—could not be determined.

The fine dust observed at some cracked locations suggests drainage-related pumping of the unbound base layers. This pavement has minimal drainage because it is predominantly at grade, has grass and other vegetation growing along its edge, and has been constructed above a native soil with low permeability. It is therefore suspected that after heavy rains the pavement base layers remain saturated at many locations, and this accelerates the mixing of fines into the base layers and pumping through to the surface.

Assuming the fine dust is a result of pumping, it can be deduced that some cracks must extend to the base interface, although some may have been surface-initiated or resulted from debonding of the upper HMA layers. Some cores showed cracks that reached the full core depth while others showed debonding between HMA layers (for a fuller discussion, see the next section, "Pavement Coring").

The fine dust might also be a product of cracking in the cement-treated base (CTB) of the original structure. The transverse cracking on the surface therefore might be a reflection of that transverse cracking, and it is possible that there was additional transverse cracking from aging, *thermal fatigue* (i.e., due to day-to-night temperature changes), and occasional below-freezing temperatures during Inland Valley climate region winters.

Regardless of the mechanism, the loss of fines from underlying layers likely had further reduced the pavement's structural support and accelerated fatigue damage. It is unlikely that application of thin unmodified overlays would prevent the relatively rapid reflection of cracks from those already existing in the pavement.

Figure 3: Alligator cracking in the wheelpath with transverse cracking, Section 3 near PM 15.2 EB.

Figure 4: Photo shows sealant over Alligator B cracking on an embankment, Section 2 near PM 14.7 EB.

Figure 5: Fines pumped through longitudinal cracking are visible, Section 3 near PM 15.1 WB.

Pavement Coring

Results from the UCPRC coring operations in the outside lane between PMs 13.6 and 16.0 showed HMA layers ranging between 0.55 and 0.76 ft (167 and 231 mm), with an average thickness of 0.66 ft (202 mm). Caltrans results from the year 2007 between PMs 9.9 and 17.4 in both lanes show a similar range of 0.57 to 0.80 ft (174 to 244 mm), which is consistent with the UCPRC-determined average, 0.67 ft (204 mm).

Evidence of debonding (delamination) between HMA layers was found at a depth of 0.20 to 0.40 ft (60 to 120 mm).

- Between PMs 9.2 and 14.0 (4.8 mi), 16 percent of the cores (4 out of 25) were found to be debonded between 0.20 and 0.30 ft (60 and 90 mm).
- Between PMs 14.0 and 17.9 (3.9 mi), 36 percent of the cores (8 out of 22) were found to be debonded between 0.20 and 0.40 ft (60 and 120 mm), and of these debonded cores 75 percent (6 out of 8) were debonded between 0.20 and 0.30 ft (60 and 90 mm).

The structural history as determined from the as-builts for the original structure from 1963 show that it was constructed with Class B CTB throughout its length and this is supported by visual evidence of cementation in cores taken between PMs 10 and 11.65, between PMs 15.13 and 16, and at PM 13.65. However, at other locations throughout the project—between PMs 11.65 and 13.5, PMs 13.65 and 15.0, and PMs 16.0 and 17.9—there was no visual evidence of cementation, which makes sense in that Class B CTB typically lacks sufficient cement to create a strongly cemented layer. The material found at these locations, 45 years after original construction, looked like coarse aggregate base.

The as-builts from the 1999 construction (EA 06-364804) indicate that the eastbound section between PMs 14.2 and 17.9 has a thinner HMA overlay (0.2 to 0.25 ft [60 to 75 mm]) than the westbound section (0.34 ft [105 mm]). The coring results show that between PMs 14.5 and 16.5, the average difference in HMA thickness between the two directions is 0.11 ft (33 mm). A diagram of the core thicknesses along the project is shown in Figure 6.

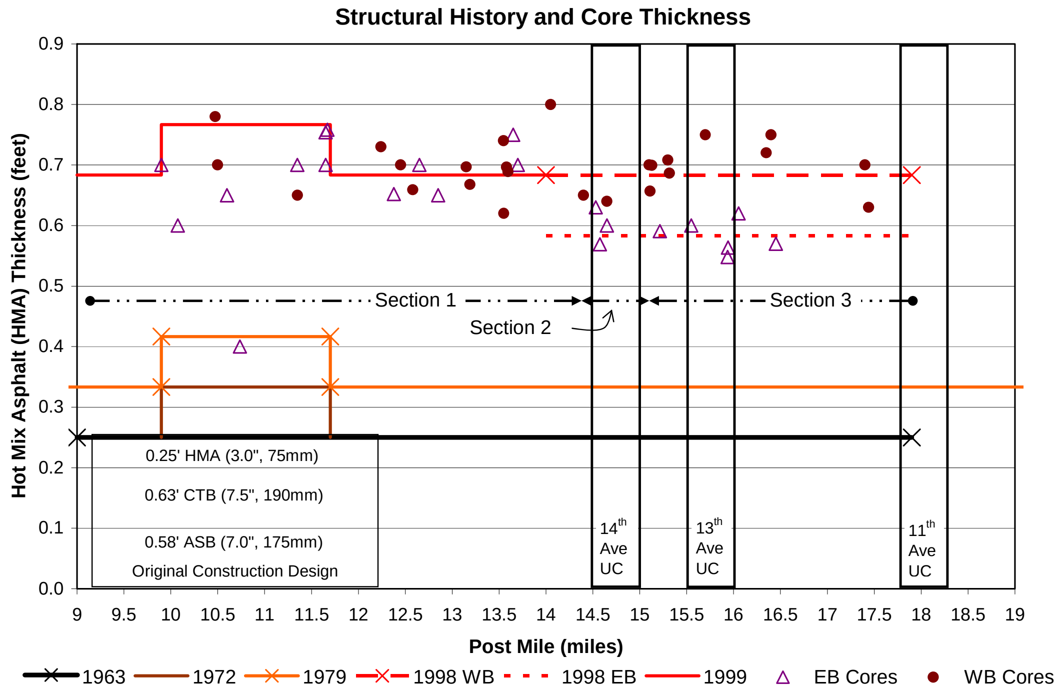


Figure 6: HMA core thicknesses by section and post mile (see Figure 2).

Deflection Data with Falling Weight Deflectometer (FWD)

The UCPRC Dynatest Heavy Weight Deflectometer was used for deflection testing. Three load levels (nominally 6,000 lb, 9,000 lb, and 12,000 lb, representing partially loaded, fully loaded, and overloaded trucks, respectively) with one drop per load level were made at each testing (drop) location. Deflection testing was conducted over six total miles in both directions: eastbound from PMs 11.7 to 13.5 and 14.5 to 16.0, and westbound from PMs 15.5 to 14.0 and 13.5 to 12.0. The distance interval varied along the testing sections due to time and space constraints. These data were used for backcalculation estimation of layer stiffnesses with *CalBack*. The FWD data from Drop 3 was used for backcalculation and is provided in Appendix Table A.3.

Dynamic Cone Penetrometer (DCP) Testing

The Dynamic Cone Penetrometer (DCP) was used to estimate base and subbase thickness, with the result based on the *penetration rate,* which is determined by measuring the depth of penetration every five blows. A high penetration rate indicates the presence of softer, weaker materials, while a lower penetration rate indicates that there are stiffer, stronger materials. Figure 7 shows the test results. Areas that had low penetration rates (less than 2 mm/blow) were assumed to be disintegrated CTB. Penetration rates between 2 and 3.5 were considered to be the design aggregate subbase (ASB), and rates greater than 3.5 were considered to represent subgrade, which was encountered between 2.5 and 2.8 ft (760 and 850 mm) below the road surface.

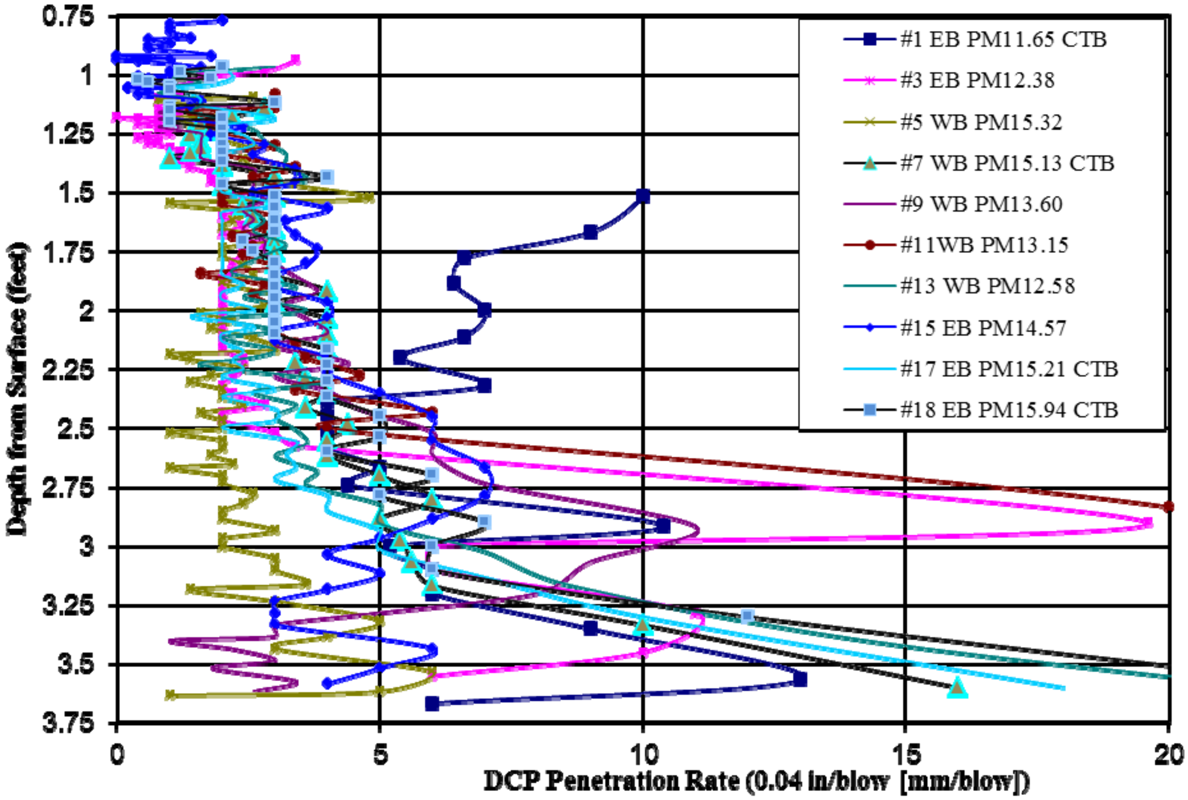


Figure 7: DCP locations and results.

Material Sampling for Laboratory Testing and Analysis

Soil samples were collected from several coring locations and from beneath a slab removed from PM 11.7 in the eastbound direction. By visual inspection, the materials appeared relatively consistent over the project length. A gradation analysis was performed on the subbase and subgrade obtained from beneath the slab, with the results in shown Table 2. Due to the large amount of sand in the subgrade, Atterberg limit testing was not performed. The aggregate subbase classifies as a poorly graded gravel with little to no fine aggregate (GP), and the subgrade as a silty-clayey sand with gravel (SC-SM).

Table 2: Gradation Analysis of Unbound Materials

	US	1"	¾"	½"	⅜"	#4	#8	# 16	# 30	# 50	# 100	# 200	
	mm	25	19	13	9.5	4.75	2.36	1.18	0.60	0.30	0.15	0.075	Soil Type
Subbase		100	96	59	41	20	13	10	8.7	6.9	5.1	3.7	GP, Poorly graded gravel w/ sand
Subgrade		100	99	92	87	77	70	65	56	35	23	15	SC-SM, Silty, clayey sand w/ gravel

Additional Information

Additional information collected included pavement profile grades and cross slopes, GPS latitude and longitude coordinates at the core locations, notes about whether the core was in or out of the wheelpath or was cracked, and the general topography (cut or fill).

Pavement Section Details

Table 3 expands on Table 1 and shows the four pavement sections with their corresponding pavement layer thicknesses, 80^{th} percentile deflection values, and backcalculated layer stiffness moduli from *CalBack* analyses. Backcalculated HMA stiffnesses were corrected to a common temperature of 68°F (20°C) using an HMA stiffness curve from a typical PG 64-10 binder.

Table 3: Pavement Details

Section	Section Boundaries			Existing Pavement Cross Section Used for *CalBack*						UCPRC Measurements			Backcalculated Stiffness[1]			
	PM[2]	Section Length ft (m)	Land-mark	HMA Max Thick ft (mm)	HMA Min Thick ft (mm)	HMA Avg Thick ft (mm)	CTB Avg Thick ft (mm)	ASB Avg Thick[3] ft (mm)	ASB & SG Soil Class.	Avg Defl mils (microns)	Avg Air Temp (F)	Condition Survey	HMA psi (MPa)	CTB psi (MPa)	ASB psi (MPa)	SG psi (MPa)
Sec 1	9.2	27,456 (8,320)	CA-41 Fresno	0.76 (231)	0.65 (198)	0.70 (212)	0.33 (102)	1.57 (480)	GP	10.2 (260.3)	17.4	Isolated alligator cracking. Continuous longitudinal cracks. Pumping.	1,151,454 (7,939)	548,968 (3,785)	28,137 (194)	10,588 (73)
	14.4		Ramps west of 14th Ave.						SC/ SM							
Sec 2	14.4	3,696 (1,120)	Ramps west of 14th Ave.	0.65 (198)	0.57 (173)	0.62 (188)	0.30 (90)	1.35 (410)	GP	18.4 (466.2)	24.2	Alligator cracking. Intermittent longitudinal cracking. Pumping.	588,708 (4,059)	362,449 (2,499)	21,901 (151)	9,282 (64)
	15.1		Ramps east of 14th Ave.						SC/ SM							
Sec 3E	15.1	14,784 (4,480)	14th Ave. EB on-ramp	0.60 (183)	0.55 (167)	0.57 (175)	0.28 (85)	1.80 (550)	GP	11.7 (296.3)	24.1	Isolated alligator cracking. Continuous longitudinal & transverse cracking.	904,020 (6,233)	700,967 (4,833)	35,534 (245)	11,168 (77)
	17.9		11th Ave. UC (UC 45-38)						SC/ SM							
Sec 3W	17.9	14,784 (4,480)	11th Ave. UC (UC 45-38)	0.75 (229)	0.66 (200)	0.70 (213)	0.28 (85)	1.80 (550)	GP	11.1 (282.0)	24.0	Isolated alligator cracking. Intermittent longitudinal & transverse cracking.	1,024,111 (7,061)	497,770 (3,432)	33,649 (232)	12,328 (85)
	15.1		14th Ave. WB off-ramp						SC/ SM							

[1] Backcalculated stiffnesses of HMA have been temperature corrected to 20°C.

[2] Subsection post mile limits extend beyond deflection testing limits. Thickness variation based on coring locations.

[3] Aggregate Subbase (ASB) layer thickness determined with Dynamic Cone Penetrometer (DCP).

DESIGN PROCEDURES AND REHABILITATION RECOMMENDATIONS

Procedure Overview and Design Inputs

The new mechanistic-empirical (ME) design method used in this project is a multistep process being developed by Caltrans in conjunction with the UCPRC (outlined below). The ME design method is incorporated in the newly developed software program *CalME (ver.1.02, 03-07-2011),* which is also capable of performing current Caltrans R-value and overlay thickness design calculations. The results from the field investigation provided input for the procedure.

The design inputs for *CalME* appear below:

- Materials
  - *Layer thickness (above subgrade).* Core thicknesses were used for the bound and surface layers. DCP tests were performed to determine base and subbase thicknesses. Available as-built information was reviewed.
  - *Material classification.* Visual assessments and sieve analyses were performed to classify the base (unbound) materials, which provide information regarding approximate stiffnesses. Atterberg limit tests were not run on the unbound materials sampled because of the significant amount of sand and lack of plasticity.
  - *Stiffness*. *CalBack* was used with layer thickness, material classification, and FWD (deflection) test results to determine layer stiffnesses.
  - *Resistance to permanent deformation and fatigue cracking.* Shear test and beam fatigue results were used from the statewide *CalME* Standard Materials Library for a crushed granite aggregate and PG 64-10 binder without polymer modification. The standard material PG grade was selected from the state climate region map. Shear and beam fatigue results from the *CalME* Standard Materials Library for a typical RHMA-G material were used for some design options. Shear and beam fatigue results from the existing pavement structure were used to estimate damage.
  - *Traffic.* Estimates of future traffic were made in terms of truck traffic. Kings 198 truck traffic volumes are approximately 50 percent greater at PM 17.9 than at PM 9.2. Annual averages of actual counts from 1992 to 2007 were used as the basis for estimating the Traffic Index (TI) for the Caltrans design methods. Inputs to *CalME* were the number of axles in the first year (1,558,282), the growth rate (0.56 percent), and the design period (20 years) based on the average traffic of both directions from 2000 to 2007. From these calculations, the 20-year TI is 13.5. Appropriate axle-load spectra were identified using the algorithm in *CalME*. The axle-load spectra used were for Group 1a described in the *CalME* documentation.

- Climate data for the Inland Valley region and pavement temperatures estimated in *CalME* for the site were used.
- Expected performance—A 20-year design was assumed with limiting failure criteria that correspond to approximately 5 percent cracking in the wheelpath and 0.5 in. (0.04 ft, 12.5 mm) wheelpath rutting.
  - Fatigue cracking: 0.15 ft/ft^2 (0.5 m/m^2)
  - Permanent vertical deformation (rutting) of the HMA: 0.5 in. (12.5 mm)

Preliminary Design Options: General

Preliminary design options were evaluated based on the design inputs and performance criteria. The designs were input into *CalME* and the performance predictions were compared with the predetermined failure criteria. A design was eliminated if it failed one or both of the design criteria for cracking or rutting. This iterative process was followed for all the rehabilitation design options. Ride quality criteria currently cannot be evaluated by *CalME* and were not addressed in the project.

Pulverization designs were not considered for this project, based upon the Caltrans *Flexible Pavement Rehabilitation Using Pulverization Guidelines (http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/PDF/pulverization-guide.pdf)* because of the inconsistent presence of intact cement-treated base (Class B, constructed in 1963) and because traffic considerations make this project unsuitable for pulverization. Given the extent of base layers weakened by disintegrated CTB and pumping, consideration should be given to the installation of lateral drains along the shoulder to alleviate pumping and extended periods of saturation following rainfall.

Only in Section 2 does the pavement exhibit advanced alligator cracking with 80th percentile deflections exceeding 0.015 in. This highly damaged section represents less than 10 percent of the project, 0.7 mi of an 8.7-mi project. However, some areas throughout the entire project will require a more timely condition assessment, and more rigorous oversight and observation to assess locations for additional distress mitigation, digouts, or complete replacement. Given these observations, two rehabilitation design strategies were considered:

- Caltrans reflective cracking overlay design
- Caltrans mill and fill design

As noted, this project was broken into four sections according to the existing pavement structures (shown below) and conditions: Section 1, Section 2, Section 3 East, and Section 3 West.

- Section 1: 0.70 ft HMA/0.35 ft CTB/1.57 ft ASB
- Section 2: 0.62 ft HMA/0.30 ft CTB/1.35 ft ASB
- Section 3 East: 0.57 ft HMA/0.30 ft CTB/1.80 ft ASB
- Section 3 West: 0.70 ft HMA/0.30 ft CTB/1.80 ft ASB

Design Alternatives for Each Section

Table 4 through Table 7 show the design options considered for Sections 1, 2, 3 East, and 3 West, respectively. The performance of all options was estimated with *CalME*. To produce performance estimates with reliability, thirty Monte Carlo simulations were run to produce a distribution of performance outcomes. The variability used for the Monte Carlo simulations for each section came from the imported distributions for layer stiffnesses from backcalculation using *CalBack* and the calculated distributions for layer thicknesses from coring by Caltrans and the UCPRC.

Estimated performance is shown at 20 years, with both 50 percent and 90 percent reliability. The average estimate of performance is equivalent to the estimate with 50 percent reliability. Ninety percent reliability was calculated using the average estimate of performance and the standard deviation, summing the average and 1.28 times the standard deviation. The design options were evaluated using the 90 percent reliability estimate of performance after 20 years, shown in the unshaded cells.

Table 4: Design Alternatives Developed with *CalME*—Kings County 198, Section 1, PM 9.2/14.4

Design Option		Design Structural Section Existing Section: 0.70 ft (215 mm) HMA 0.35 ft (105 mm) CTB 1.57 ft (480 mm) ASB ∞ SG	Grade Change ft (mm)	20-Year Performance (50 Percent & 90 Percent Reliability)			
				Rutting in. (mm)		Cracking ft/ft^2 (m/m^2)	
				50%	90%	50%	90%
1. Caltrans Reflective Cracking-based Overlay *Process: Overlay with* *(A) 0.10 ft of HMA* *(B) 0.15 ft of HMA* *(C) 0.10 ft of RHMA-G* *(D) 0.15 ft of RHMA-G* *Reflective cracking option in* CalME *used in all overlay scenarios.*	A	0.10 ft (30 mm) HMA overlay 0.70 ft (215 mm) existing HMA 0.35 ft (105 mm) existing CTB 1.57 ft (480 mm) existing ASB	+ 0.10 ft (30 mm)	0.13 (3)	0.20 (5)	0.01 (0.02)	0.53 (1.75)
	B	0.15 ft (45 mm) HMA overlay 0.70 ft (215 mm) existing HMA 0.35 ft (105 mm) existing CTB 1.57 ft (480 mm) existing ASB	+ 0.15 ft (45 mm)	0.16 (4)	0.21 (5)	0.00 (0.01)	0.02 (0.06)
	C	0.10 ft (30 mm) RHMA-G overlay 0.70 ft (215 mm) existing HMA 0.35 ft (105 mm) existing CTB 1.57 ft (480 mm) existing ASB	+ 0.10 ft (30 mm)	0.06 (2)	0.12 (3)	0.02 (0.05)	0.17 (0.56)
	D	0.15 ft (45 mm) RHMA-G overlay 0.70 ft (215 mm) existing HMA 0.35 ft (105 mm) existing CTB 1.57 ft (480 mm) existing ASB	+ 0.15 ft (45 mm)	0.06 (1)	0.09 (2)	0.01 (0.04)	0.03 (0.11)
2. Caltrans Mill and Fill Design *M: Mill depth, F: Fill depth, fill material(s)* *(A) M: 0.25 ft, F: 0.30 ft HMA* *(B) M: 0.25 ft, F: 0.10 ft HMA & 0.15 ft RHMA-G* *(C) M: 0.20 ft, F: 0.05 ft HMA & 0.15 ft RHMA-G* *(D) M: 0.20 ft, F: 0.05 ft HMA & 0.15 ft RHMA-G* ** Reflective cracking option is not used.* *Assumption: Milling 0.25 ft (75 mm) removes the delaminated layer.* *From coring: PM 9.2/14.0—4.8 miles 16 percent of cores debonded (4 of 25) between 0.2 and 0.3 ft depth.*	A*	0.30 ft (90 mm) HMA fill 0.45 ft (140 mm) existing HMA 0.35 ft (105 mm) existing CTB 1.57 ft (480 mm) existing ASB	+ 0.05 ft (15 mm)	0.25 (6)	0.34 (9)	0.0 (0.0)	0.01 (0.03)
	B*	0.15 ft (45 mm) RHMA-G fill 0.10 ft (30 mm) HMA fill 0.45 ft (140 mm) existing HMA 0.35 ft (105 mm) existing CTB 1.57 ft (480 mm) existing ASB	0.0 ft (0 mm)	0.12 (3)	0.17 (4)	0.0 (0.0)	0.00 (0.01)
	C	0.15 ft (45 mm) RHMA-G fill 0.05 ft (15 mm) HMA fill 0.50 ft (155 mm) existing HMA 0.35 ft (105 mm) existing CTB 1.57 ft (480 mm) existing ASB	0.0 ft (0 mm)	0.10 (2)	0.14 (4)	0.01 (0.03)	0.40 (1.32)
	D*	0.15 ft (45 mm) RHMA-G fill 0.05 ft (15 mm) HMA fill 0.50 ft (155 mm) existing HMA 0.35 ft (105 mm) existing CTB 1.57 ft (480 mm) existing ASB	0.0 ft (0 mm)	0.10 (2)	0.14 (4)	0.0 (0.0)	0.00 (0.01)

Table 5: Design Alternatives Developed with *CalME*—Kings County 198, Section 2, PM 14.4/15.1

Design Option		Design Structural Section Existing Section: 0.62 ft (190 mm) HMA 0.30 ft (90 mm) CTB 1.35 ft (410 mm) ASB ∞ SG	Grade Change ft (mm)	20-Year Performance (50 Percent & 90 Percent Reliability) Rutting in. (mm)		Cracking ft/ft^2 (m/m^2)	
				50%	**90%**	**50%**	**90%**
1. Caltrans Reflective Cracking-based Overlay *Process: Overlay with* *(A) 0.25 ft of HMA* *(B) 0.30 ft of HMA* *(C) 0.05 ft of HMA & 0.15 ft of RHMA-G* *Reflective cracking option in* CalME *used in all overlay scenarios.*	A	0.25 ft (75 mm) HMA overlay 0.62 ft (190 mm) existing HMA 0.30 ft (90 mm) existing CTB 1.35 ft (410 mm) existing ASB	+ 0.25 ft (75 mm)	0.22 (6)	0.27 (7)	0.00 (0.01)	0.17 (0.57)
	B	0.30 ft (90 mm) HMA overlay 0.62 ft (190 mm) existing HMA 0.30 ft (90 mm) existing CTB 1.35 ft (410 mm) existing ASB	+ 0.30 ft (90 mm)	0.24 (6)	0.29 (7)	0.00 (0.01)	0.02 (0.07)
	C	0.20 ft (60 mm) RHMA-G overlay 0.62 ft (190 mm) existing HMA 0.30 ft (90 mm) existing CTB 1.35 ft (410 mm) existing ASB	+ 0.20 ft (60 mm)	0.08 (2)	0.12 (3)	0.01 (0.04)	0.67 (2.2)
	D	0.15 ft (45 mm) RHMA-G overlay 0.05 ft (15 mm) HMA overlay 0.62 ft (190 mm) existing HMA 0.30 ft (90 mm) existing CTB 1.35 ft (410 mm) existing ASB	+ 0.20 ft (60 mm)	0.07 (2)	0.10 (3)	0.01 (0.03)	0.04 (0.14)
2. Caltrans Mill and Fill Design *M: Mill depth, F: Fill depth, fill materials* *(A) M: 0.08 ft, F: 0.10 ft HMA & 0.15 ft RHMA-G* *(B) M: 0.25 ft, F: 0.20 ft HMA & 0.15 ft RHMA-G* *(C) M: 0.25 ft, F: 0.25 ft HMA & 0.15 ft RHMA-G* ** Reflective cracking option is not used.* *Assumption: Milling 0.25 ft (75 mm) removes the delaminated layer.* *From coring: PM 14.0/17.9—3.9 miles* *36 percent (8 of 22) of cores debonded* *75 percent (6 of 8) of these cores debonded between 0.2 and 0.3 ft depth, 25 percent (2 of 8) deeper* *—0.40 ft depth at PM 14.05 WB* *—0.37 ft depth at PM 16.40 WB*	A	0.15 ft (45 mm) RHMA-G fill 0.10 ft (30 mm) HMA fill 0.54 ft (165 mm) existing HMA 0.30 ft (90 mm) existing CTB 1.35 ft (410 mm) existing ASB	+ 0.17 ft (50 mm)	0.13 (3)	0.16 (4)	0.01 (0.03)	0.05 (0.15)
	B*	0.15 ft (45 mm) RHMA-G fill 0.20 ft (60 mm) HMA fill 0.37 ft (115 mm) existing HMA 0.30 ft (90 mm) existing CTB 1.35 ft (410 mm) existing ASB	+ 0.10 ft (30 mm)	0.19 (5)	0.21 (6)	0.0 (0.0)	0.23 (0.74)
	C*	0.15 ft (45 mm) RHMA-G fill 0.25 ft (75 mm) HMA fill 0.37 ft (115 mm) existing HMA 0.30 ft (90 mm) existing CTB 1.35 ft (410 mm) existing ASB	+ 0.15 ft (45 mm)	0.18 (5)	0.22 (6)	0.0 (0.0)	0.0 (0.0)

Table 6: Design Alternatives Developed with *CalME*—Kings County 198, Section 3 East, PM 15.1/17.9

Design Option	Design Structural Section Existing Section: 0.57 ft (175 mm) HMA 0.30 ft (85 mm) CTB 1.80 ft (550 mm) ASB ∞ SG		Grade Change ft (mm)	20-Year Performance (50 Percent & 90 Percent Reliability)			
				Rutting in. (mm)		Cracking ft/ft^2 (m/m^2)	
				50%	90%	50%	90%
1. Caltrans Reflective Cracking-based Overlay *Process: Overlay with* *(A) 0.30 ft of HMA* *(B) 0.20 ft of RHMA-G* *(C) 0.05 ft of HMA & 0.15 ft of RHMA-G* *Reflective cracking option in* CalME *used in all overlay scenarios.*	A	0.30 ft (90 mm) HMA overlay 0.57 ft (175 mm) existing HMA 0.30 ft (85 mm) existing CTB 1.80 ft (550 mm) existing ASB	+ 0.30 ft (90 mm)	0.23 (6)	0.27 (7)	0.00 (0.01)	0.05 (0.17)
	B	0.20 ft (60 mm) RHMA-G overlay 0.57 ft (175 mm) existing HMA 0.30 ft (85 mm) existing CTB 1.80 ft (550 mm) existing ASB	+ 0.20 ft (60 mm)	0.07 (2)	0.10 (3)	0.02 (0.06)	0.13 (0.43)
	C	0.15 ft (45 mm) RHMA-G overlay 0.05 ft (15 mm) HMA overlay 0.57 ft (175 mm) existing HMA 0.30 ft (85 mm) existing CTB 1.80 ft (550 mm) existing ASB	+ 0.20 ft (60 mm)	0.09 (2)	0.11 (3)	0.01 (0.03)	0.04 (0.12)
2. Caltrans Mill and Fill Design *M: Mill depth, F: Fill depth, fill materials* *(A) M: 0.07 ft, F: 0.10 ft HMA & 0.15 ft RHMA-G* *(B) M: 0.25 ft, F: 0.25 ft HMA & 0.15 ft RHMA-G* *(C) M: 0.25 ft, F: 0.25 ft HMA & 0.15 ft RHMA-G* *(D) M: 0.25 ft, F: 0.20 ft HMA & 0.15 ft RHMA-G* ** Reflective cracking option is not used.* *Assumption: Milling 0.25 ft (75 mm) removes the delaminated layer.* *From coring: PM 14.0/17.9—3.9 miles* *36 percent (8 of 22)of cores debonded* *75 percent (6 of 8) of these cores debonded between 0.2 and 0.3 ft depth, 25 percent (2 of 8) deeper* *—0.40 ft depth at PM 14.05 WB* *—0.37 ft depth at PM 16.40 WB*	A	0.15 ft (45 mm) RHMA-G fill 0.10 ft (30 mm) HMA fill 0.50 ft (150 mm) existing HMA 0.30 ft (85 mm) existing CTB 1.80 ft (550 mm) existing ASB	+ 0.18 ft (50 mm)	0.12 (3)	0.14 (4)	0.01 (0.02)	0.03 (0.11)
	B	0.15 ft (45 mm) RHMA-G fill 0.25 ft (75 mm) HMA fill 0.32 ft (100 mm) existing HMA 0.30 ft (85 mm) existing CTB 1.80 ft (550 mm) existing ASB	+ 0.15 ft (45 mm)	0.17 (4)	0.19 (5)	0.00 (0.01)	0.03 (0.09)
	C*	0.15 ft (45 mm) RHMA-G fill 0.25 ft (75 mm) HMA fill 0.32 ft (100 mm) existing HMA 0.30 ft (85 mm) existing CTB 1.80 ft (550 mm) existing ASB	+ 0.15 ft (45 mm)	0.17 (4)	0.19 (5)	0.00 (0.00)	0.00 (0.00)
	D*	0.15 ft (45 mm) RHMA-G fill 0.20 ft (60 mm) HMA fill 0.32 ft (100 mm) existing HMA 0.30 ft (85 mm) existing CTB 1.80 ft (550 mm) existing ASB	+ 0.10 ft (30 mm)	0.17 (4)	0.21 (5)	0.00 (0.00)	0.01 (0.03)

Table 7: Design Alternatives Developed with *CalME*—Kings County 198, Section 3 West, PM 15.1/17.9

Design Option	Design Structural Section Existing Section: 0.70 ft (215 mm) HMA 0.30 ft (85 mm) CTB 1.80 ft (550 mm) ASB ∞ SG		Grade Change ft (mm)	20-Year Performance (50 Percent & 90 Percent Reliability) Rutting in. (mm)		Cracking ft/ft^2 (m/m^2)	
				50%	90%	50%	90%
1. Caltrans Reflective Cracking-based Overlay *Process: Overlay with* *(A) 0.10 ft of HMA* *(B) 0.10 ft of RHMA-G* *Reflective cracking option in* CalME *used in all overlay scenarios.*	A	0.10 ft (30 mm) HMA overlay 0.70 ft (215 mm) existing HMA 0.30 ft (85 mm) existing CTB 1.80 ft (550 mm) existing ASB	+ 0.10 ft (30 mm)	0.12 (3)	0.15 (4)	0.01 (0.02)	0.06 (0.20)
	B	0.10 ft (30 mm) RHMA-G overlay 0.70 ft (215 mm) existing HMA 0.30 ft (85 mm) existing CTB 1.80 ft (550 mm) existing ASB	+ 0.10 ft (30 mm)	0.05 (1)	0.07 (2)	0.01 (0.04)	0.04 (0.13)
2. Caltrans Mill and Fill Design *M: Mill depth, F: Fill depth, fill materials* *(A) M: 0.25 ft, F: 0.10 ft HMA & 0.15 ft RHMA-G* *(B) M: 0.25 ft, F: 0.10 ft HMA & 0.15 ft RHMA-G* *(C) M: 0.25 ft, F: 0.10 ft HMA & 0.10 ft RHMA-G* ** Reflective cracking option is not used.* *Assumption: Milling 0.25 ft (75 mm) removes the delaminated layer.* *From coring: PM 14.0/17.9—3.9 miles* *36 percent (8 of 22) of cores debonded* *75 percent (6 of 8) of these cores debonded between 0.2 and 0.3 ft depth, 25 percent (2 of 8) deeper* *—0.40 ft depth at PM 14.05 WB* *—0.37 ft depth at PM 16.40 WB*	A	0.15 ft (45 mm) RHMA-G fill 0.10 ft (30 mm) HMA fill 0.45 ft (140 mm) existing HMA 0.30 ft (85 mm) existing CTB 1.80 ft (550 mm) existing ASB	0.0 ft (0 mm)	0.12 (3)	0.14 (4)	0.01 (0.02)	0.03 (0.11)
	B*	0.15 ft (45 mm) RHMA-G fill 0.10 ft (30 mm) HMA fill 0.45 ft (140 mm) existing HMA 0.30 ft (85 mm) existing CTB 1.80 ft (550 mm) existing ASB	0.0 ft (0 mm)	0.12 (3)	0.14 (4)	0.0 (0.0)	0.0 (0.0)
	C*	0.10 ft (30 mm) RHMA-G fill 0.10 ft (30 mm) HMA fill 0.45 ft (140 mm) existing HMA 0.30 ft (85 mm) existing CTB 1.80 ft (550 mm) existing ASB	– 0.05 ft (15 mm)	0.13 (3)	0.16 (4)	0.0 (0.0)	0.03 (0.10)

SUMMARY

The summary presented here is based on the results of office and site investigations, analysis of materials with *CalBack*, and design with *CalME (ver.1.02, 03-07- 2011)* mechanistic-empirical methods, R-value method, and the Caltrans tolerable deflection–based method. In the rehabilitation, it is important to address the primary distresses exhibited on State Route 198, namely longitudinal, alligator, and transverse cracking.

Two general rehabilitation types were considered in the design alternatives: (1) overlay and (2) mill and fill. Each of these designs was evaluated with *CalME* for expected performance. Detailed economic analysis was not performed as part of this work, but relative cost rankings can be estimated from past experience. The design options are specific to certain sections of this project, based upon their existing structural section and potential grade constraints.

Design Option 1—Overlay

The Caltrans 356 design (Design 1 for all sections) indicates that in order to address the likely reflection of cracking a 0.10-ft to 0.30-ft (30 mm to 90 mm) overlay of HMA is required: 0.15 ft (45 mm) for Section 1, 0.30 ft (90 mm) for Section 2, 0.30 ft (90 mm) for Section 3E, and 0.10 ft (30 mm) for Section 3W. Using a rubber-modified mix may better address the reflective cracking and reduce the overlay thickness.

Use of a rubberized, gap-graded mix, RHMA-G, instead of HMA does not change the thickness for Section 1 (Option 1D in Table 4) or Section 3 West (Option 1B in Table 7). Overlaying Section 2 with 0.20 ft (60 mm) of RHMA-G would not satisfy the requirements (Option 1C in Table 5). Replacing the first 0.05 ft (15 mm) of the RHMA-G overlay with HMA overlay (Option 1D on Table 5) produced satisfactory results. For Section 3, overlaying with 0.20 ft (60 mm) of RHMA-G also produced satisfactory results (Option 1B in Table 6); however, replacing the first 0.05 ft (15 mm) of the RHMA-G overlay with HMA overlay (Option 1D in Table 6) produced results more similar to the other satisfactory results.

While it is understood that the use of modified binders will mitigate reflective cracking, the application of a stress-absorbing membrane interface (SAMI) is a cost-effective method to further reduce the likelihood of reflective cracking. Currently, however, *CalME* is unable to estimate the performance of fabrics, coatings, or thin surface treatments.

Similarly, *CalME* currently only considers reflective cracking due to traffic loading and not that attributable to temperature effects. Thermal cracking from low-temperature contraction and thermal fatigue from repeated daily temperature fluctuations may increase the amount of cracking over that estimated by *CalME*.

Design Option 2 – Mill and Fill

For the mill and fill–based design alternatives (Design 2 in Table 4 through Table 7), it is generally assumed that the milling depth of 0.25 ft (75 mm) would remove the existing cracked and delaminated HMA since 10 of the 12 delaminated cores debonded between a depth of 0.20 ft and 0.30 ft (60 mm and 90 mm). In addition to consideration of existing distresses, the rehabilitation must also take into account the finished grade elevation at three overcrossings along the section.

The current Caltrans *Highway Design Manual* requires a 16-ft vertical clearance; however, the California Log of Bridges *(www.dot.ca.gov/hq/structur/strmaint/brlog/logpdf/logd06.pdf)* specifies that the minimum allowed vertical clearances at 18th Avenue and Houston Avenue (in Section 1) are 15.4 ft (4.69 m) and 14.9 ft (4.54 m), respectively. The vertical clearance at 12th Avenue (in Section 3) is 16.7 ft (5.1 m). If the existing clearances need to be maintained, the current vertical clearances of these structures should be assessed.

The mill-and-fill options included the performance of two overlay materials, HMA and RHMA-G. Some design options included both materials because the constructed thickness of RHMA-G cannot exceed 0.2 ft (60 mm).

For Section 1, milling 0.25 ft (75 mm) and filling with 0.10 ft (30 mm) of HMA and 0.15 ft (45 mm) of RHMA-G (Option 2B in Table 4) shows that cracking is significantly reduced. If milling only 0.20 ft (60 mm) is sufficient to eliminate the poorly bonded interface (Option 2D in Table 4), the HMA thickness could be reduced by 0.05 ft (15 mm). These options do not change the final grade, which is important if the vertical clearances of the two bridges within Section 1 cannot be reduced.

CalME performance estimates show the importance of eliminating the possibility of reflective cracking in the rehabilitation. For Section 1, if 0.20 ft (60 mm) is milled, but the depth is insufficient to remove the poor bond and the reflective cracking is not eliminated (Option 2C in Table 4), the rehabilitation will fail. If milling 0.20 ft (60 mm) is sufficient to remove the poor bond and the reflective cracking is eliminated (Option 2D in Table 4), the rehabilitation will provide satisfactory performance.

During construction, it is suggested that inspectors be on hand to evaluate whether there are specific areas where deeper milling is required to eliminate locations where there is poorly bonded HMA. Because the goal of the mill-and-fill option is to mitigate reflective cracking, oversight and observation will be required to identify locations where the milling depth needs be increased to remove the poorly bonded interface.

For Sections 2 and 3 East, *CalME* indicates that more material should be filled than milled, adding 0.15 ft to the thickness of the HMA. In both sections, a milling of 0.08 ft (25 mm) (Option 2A in Table 6 and Table 7) followed by filling with HMA and RHMA satisfies the performance requirements; however, these options increase the grade as an overlay does. Milling 0.25 ft (75 mm) to remove the poorly bonded HMA area and filling with HMA—0.25 ft (75 mm) in Section 2 and 0.20 ft (60 mm) in Section 3 East—and 0.15 ft (45 mm) of RHMA (Option 2C in Table 5 and Option 2D in Table 6) raises the grade by 0.15 ft (45 mm) in Section 2 and 0.10 ft (30 mm) in Section 3 East. By eliminating the possibility of reflective cracking and adding structural thickness, the probability of cracking is very low.

For Section 3 West, milling and filling 0.25 ft (75 mm) well satisfies the cracking requirements (Option 2B in Table 7). Milling 0.25 ft (75 mm) and filling with 0.20 ft (60 mm) still provides adequate performance (Option 2C in Table 7).

Caution is to be exercised in considering these options—which are based on a site investigation performed in 2008—as they may be outdated. This is in keeping with the warning included in Section 635.1, Subsection 3 of *The Caltrans Highway Design Manual* that deflection data older than 18 months prior to the start of construction are considered unreliable in rehabilitation design.

FINAL DESIGN RECOMMENDATIONS

The final recommendation is to overlay Section 2 and Section 3 East with 0.05 ft (15 mm) of HMA, and then to overlay Sections 1, 2, 3 East, and 3 West (i.e., the entire project) with 0.15 ft (45 mm) of RHMA-G. The use of the rubberized stress-absorbing membrane interface (SAMI-R) is not accounted for in the analysis; however, SAMI-R would better mitigate cracking, the primary distress of this project. The recommendation for this project is based upon structural and geometric considerations. The final selection should be based on life-cycle cost analysis performed by the District.

This recommendation may be an overdesign for Section 3 West from PM 15.1 to 17.9, however. Although achieving a consistent thickness might simplify the project, an overlay of just 0.10 ft (30 mm) of RHMA-G—rather than the combined 0.20 ft (60 mm) mentioned above (0.05 ft [15 mm] of HMA and 0.15 ft [45 mm] of RHMA-G)—would provide satisfactory performance.

Recommendations for *CalME* and Mechanistic-Empirical Design Process

Based on this case study, there are three recommendations for *CalME* modeling of the mechanistic-empirical design process. First, it is recommended that a method for calculating cracking due to temperature changes be included in the program. A second recommendation is that *CalME* be revised to include models that account for the addition of fabrics, coatings, and thin surface treatments. A third recommendation is that the *CalME* Library of Standard Materials continue to be expanded so it includes rich bottom mixes for each of the four PG binder types currently in the library (data for fatigue and stiffness only) and further refinements on the import of new or unknown materials.

Recommendations for Further Monitoring and Analysis of Project

It is recommended that UCPRC staff be present during construction to take loose material samples, perform slab and/or core extractions, and make thickness measurements. The materials would be tested in the laboratory to develop in-situ material parameters for *CalME,* which would then be run again to validate or assess the initial analysis. Future performance monitoring of the project over the next five to ten years would add to performance modeling for *CalME*.

APPENDIX: 06-KIN-198 ME SUPPLEMENTARY DATA AND PROCEDURAL INFORMATION

This appendix contains detailed information on the ME design process from which the pavement designs in this report were developed. The information, which is outlined below, is not meant to be a "how-to guide" for ME, but to document the information derived during the field and office studies.

1. Benefits of Mechanistic-Empirical (ME) Design Using Caltrans New Design Tools *CalME* and *CalBack*
2. ME Procedure Overview
3. Traffic Data
4. Climate
5. Material Parameters
   a. Backcalculation with *CalBack*
   b. ME Analysis and Design with *CalME*

Benefits of Mechanistic-Empirical (ME) Design Using Caltrans New Design Tools *CalME* and *CalBack*

The following list shows the benefits to Caltrans of using the new ME design approach taken for this project.

General and Specific Benefits for the 06-KIN-198 Case Study

1. ME designs are based upon an analysis of three fundamental factors: material behavior, traffic loading, and climate. With ME, a library of statewide material, climate, and traffic data is accessible that allows the designer to tailor designs to very specific local needs. This information has been developed from rigorous laboratory testing, field testing, and analysis over the past decade.
   A. ME allows for design with specific binder and mix types. Both rutting and cracking levels can be reviewed during the design process, and tradeoffs can be made with regard to rutting and cracking performance. Test data for this project analysis included information for several RHMA-G and HMA mixes with PG 64-10 binder from the *CalME* Library of Standard Materials and project site data gathered from the 1963 construction and 1999 rehabilitation. Mixtures from the project site were obtained in February 2008.

      Rubberized mix performance for reflection cracking was assessed analytically rather than with generalized tables. A fatigue shift factor is required in *CalME* to calibrate the material properties. For the old in-situ HMA, the fatigue shift factor was determined using a backcast analysis that included condition survey and traffic data from 1999—a year in which a new overlay was placed—through 2007, in addition to fatigue material parameters determined from flexural bending beam tests.

B. ME uses detailed traffic information from WIM stations throughout the state. Axle counts and weights for each truck type are input into the design program. Typical axle-load spectra are used instead of ESALs.

C. ME uses climate data from weather stations throughout the state. In *CalME,* cracking and rutting performance are analyzed using detailed "Master Curves" of stiffness versus temperature for each binder and mix type produced in the state. For this project, the Inland Valley climate region was used for HMA performance calculations.

2. Three types of pavement designs can be produced and analyzed: traditional Caltrans designs (R-value and deflection based–overlay designs), Classical ME designs based upon Asphalt Institute performance curves, and newly developed Recursive ME designs that take into account decreased capabilities of HMA over time. ME analysis of Caltrans designs can be performed to show whether a particular Caltrans design is conservative or nonconservative.
3. The designer can preset failure criteria (cracking and rutting) and design life, and tailor the design to these factors. The level of reflection cracking and rutting is specified up front.
4. Deflection testing with the Falling Weight Deflectometer allowed the characterization of the existing base stiffness, base variability, subgrade stiffness, and subgrade variability to be taken into account in the design process. Specific designs were developed depending upon the existing structural section thickness and deflection performance.
5. "Reliability" of the design, meaning the probability of failure before the design life, can be considered, and higher reliabilities can be used for more critical projects. Variability in material/construction and traffic may be taken into account. The user can input the range of layer thicknesses and traffic levels expected in the project. Variability of stiffnesses backcalculated from FWD deflections for existing subgrade and aggregate base materials were included as part of the pavement design.
6. In *CalME,* the in-place cost of materials is included in the Materials Library. The cost of each design is calculated.
7. Users can rerun analyses with as-built information (thicknesses, stiffnesses) to estimate the expected life of the as-built pavement, if desired. This information can be used in the pavement management system to estimate when future maintenance may be needed compared with original design assumptions.
8. *CalME* and *CalBack* can output all design information to Microsoft *Excel* for further analysis.

ME Procedure Overview

ME design and analysis is a multistep process that uses detailed information about traffic loading, material performance, and climate. Many of the field data-gathering procedures are similar to what Caltrans performs currently. The major difference between traditional Caltrans design and new ME design is in how materials, climate, and traffic data can be uniquely analyzed for a given project. Generalized design tables based upon broad average behavior for generic materials are not used.

The process performed for 06-KIN-198 is summarized below:

An initial meeting was held with District 6 staff to discuss the project. As with standard Caltrans procedures, the design process began with analysis of structural section thicknesses (cores) and deflection measurements from Falling Weight Deflectometer (FWD) testing. The ME process then diverged from traditional methods. *CalBack* was used to estimate pavement layer stiffnesses through backcalculation. Using *CalBack,* the designer separated the project into distinct sections based upon layer thickness and estimated material stiffness. This offered more flexibility than sectioning by D_{80} deflection values alone. The designer now had detailed information on the performance of all layers within the pavement and could analyze designs for each specific section as needed.

CalME (ver. 1.02 [03-07-2011]) was used to perform deflection-based overlay designs and ME-based rehabilitation designs. The ME designs were either a Classical ME design based upon Asphalt Institute equations and/or an Incremental-Recursive method which took into account how pavement materials change in behavior (cracking, aging) over the lifetime of the project.

The *CalME* analysis process started with the importation of thicknesses, backcalculated stiffnesses, and standard deviation factors of backcalculated stiffnesses for each layer from *CalBack.* Variability of thickness was determined from field cores, and the coefficient of variation for each layer/section was manually entered into *CalME.* The two variability measures (stiffness and thickness) were used to describe the construction variability in the Incremental-Recursive method.

When values for thickness and stiffness variability are input into *CalME,* a single run determines one of many possible outcomes. *CalME* can also perform a Monte Carlo simulation of several runs to obtain a range of possible performance outcomes over the design life, including cumulative rutting and cracking after 20 years. The average and standard deviation of this distribution of estimates are used to determine the reliability of performance. To obtain the 90 percent reliability provided in this memo, the average value of 30 separate *CalME* runs at the end of the design life (Year 20) was added to 1.28 times the standard deviation.

Design options were developed based upon engineering judgment and evaluated with *CalME.* Structural sections were adjusted as necessary to make the most efficient designs that met the failure criteria specified (user chosen) within *CalME.*

Traffic Data

ME Weigh-in-Motion (WIM) data has been created from years of traffic counting at WIM stations distributed across the state. Traditional Caltrans designs used a Traffic Index (TI), based upon expected cumulative lifetime ESAL counts. ME WIM data consists of detailed vehicle counts by classification, axle counts, and axle-weight loading. ME takes this specific data and computes performance estimates based upon damage from the individual axle loads.

Traffic axle spectra for the ME designs for this project were based on detailed WIM data taken at stations that were either along or closest to the pavement section being designed. A *group factor* was needed to convert truck counts into equivalent axles, and the Group 1a factor determined for this site equals 3.898873213.

The number of traffic axles and the growth rate estimated for this project were based upon traffic counts from 1992 through 2007. Table A.1 shows the raw data of Caltrans estimates of vehicular traffic along this project. Table A.2 shows the calculated traffic by axle count and the estimated growth rate for 06-KIN-198. Figure A.1 shows a plot of the calculated traffic for 06-KIN-198. The 20-year TI used for this project is 13.5.

Table A.1: Traffic Log Data for 06-KIN-198

Year	AADT 1	AADT 2	AADTT 1	AADTT 2	AXLE2 1	AXLE2 2	AXLE3 1	AXLE3 2	AXLE4 1	AXLE4 2	AXLE OTHER 1	AXLE OTHER 2
1992	13100	13900	1074	1306	277	586	92	93	39	54	666	573
1993	13100	14000	1048	1260	272	567	95	88	31	51	650	554
1994	13500	14500	1080	1305	281	587	97	92	32	52	670	574
1995	13500	14500	1080	1305	281	587	97	92	32	52	670	574
1996	13600	15700	1088	1413	283	636	98	99	32	56	675	622
1997	13700	15900	1096	1431	285	644	99	100	32	57	680	630
1998	14000	17000	1120	1530	291	689	101	107	32	61	696	673
2000	14100	21100	1128	1899	474	855	102	133	56	76	496	836
2001	14200	24000	1136	2160	477	972	102	151	57	86	500	950
2002	17200	26000	1376	2340	578	1053	124	164	69	94	605	1030
2003	17700	27000	1416	2430	595	1094	127	170	71	97	623	1069
2004	20100	28500	1608	2565	675	1154	145	180	80	103	708	1129
2005	20100	27000	1608	2430	675	1094	145	170	80	97	708	1069
2006	20900	28500	1672	2565	702	1154	150	180	84	103	736	1129
2007	20900	28500	1672	2565	702	1154	150	180	84	103	736	1129

Table A.2: Traffic Calculations for 06-KIN-198

Year	AADT AVG	AADTT (PM 8.9)	Growth Rate	AADTT (PM 17.9)	Growth Rate	AADTT AVG	Growth Rate	
1992	13500	1074	0.976	1306	0.965	1190	0.970	
1993	13550	1048	1.031	1260	1.036	1154	1.033	
1994	14000	1080	1.000	1305	1.000	1193	1.000	
1995	14000	1080	1.007	1305	1.083	1193	1.049	
1996	14650	1088	1.007	1413	1.013	1251	1.010	
1997	14800	1096	1.022	1431	1.069	1264	1.049	
1998	15500	1120	1.007	1530	1.241	1325	1.142	
2000	17600	1128	1.007	1899	1.137	1514	1.089	
2001	19100	1136	1.211	2160	1.083	1648	1.127	
2002	21600	1376	1.029	2340	1.038	1858	1.035	
2003	22350	1416	1.136	2430	1.056	1923	1.085	
2004	24300	1608	1.000	2565	0.947	2087	0.968	
2005	23550	1608	1.040	2430	1.056	2019	1.049	
2006	24700	1672	1.000	2565	1.000	2119	1.000	
2007	24700	1672		2565		2119		
2008	*25815.8*	*1728*		*2698*		*2210*		
2009	*26981.9*	*1787*		*2837*		*2306*		
2010	*28200.8*	*1847*		*2984*		*2406*	*-- Too High!*	
2011	*29474.7*	*1910*		*3138*		*2510*		
	Average 2000-2007		1.060		1.0453879		**1.0505**	**Average 2000-2007**
	Average 1992-2007		1.034		1.0517188		1.043	Average 1992-2007
							1.0056	Average 2004-2007

2153844.8	1076922	BACKCASTING 1999 – 2003
3116564.3	**1558282**	**FORECASTING 2010 – 2030**
"2190"		

LOGARITHMIC GROWTH USING DATA 1992-2007		
69.38924407	SLOPE	
-225.9488393	YINT	
1.13E-226	10^yint	
2000	Year	2010
1279.8	AADTT	1809
1483402	Axles	2096816
3.898873213	Group 1a Factor	

K2, K5

Estimates	Axles in 1st Year	TI	Growth Rate	Axles over 20 Years	TI_{20}
CalME	1,182,557	9.2	5.05%	39,309,643	13.9
Author	1,558,282	9.5	0.56%	32,880,711	13.6

TI = 9 * (ESALs/1,000,000) ^ 0.119

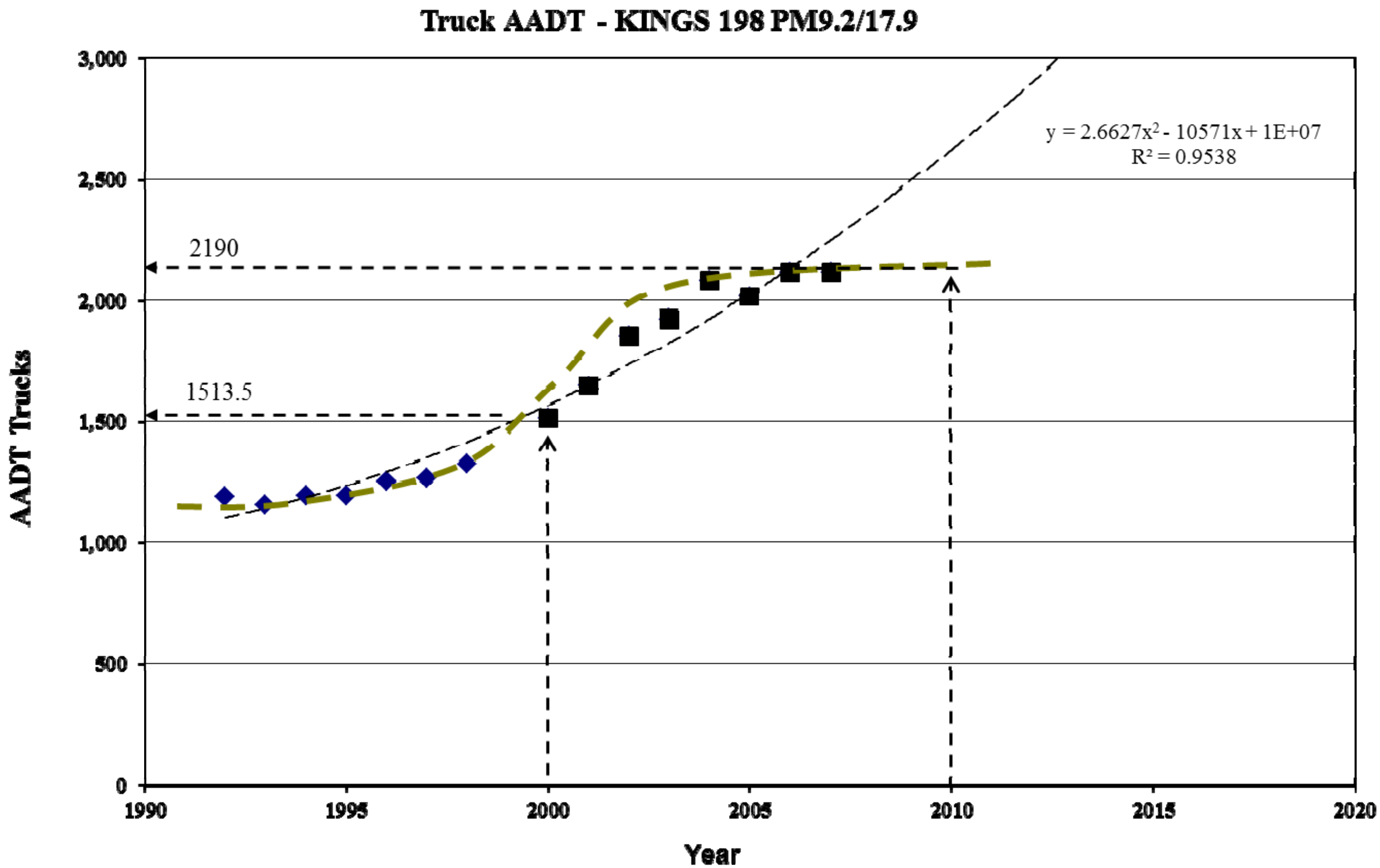


Figure A.1: Plot of truck traffic data for 06-KIN-198, showing AADT estimates for backcasting (1,513.5) and forecasting (2,190).

Climate

HMA rutting and cracking performance is highly dependent upon air and mix temperature over the pavement life. *CalME* designs take that into account by analyzing HMA performance using climatic conditions at the project site. Figure A.2 below shows the Caltrans Pavement Climate Regions map. The arrow points to the project location, which is situated in the Inland Valley climate region. *CalME* contains a climate database to access hourly air temperatures and uses the Bell's Equation to convert air temperature (based upon current and recent historical air temperatures) to HMA temperature at one-third depth. See the *CalME* help file for further details about this topic.

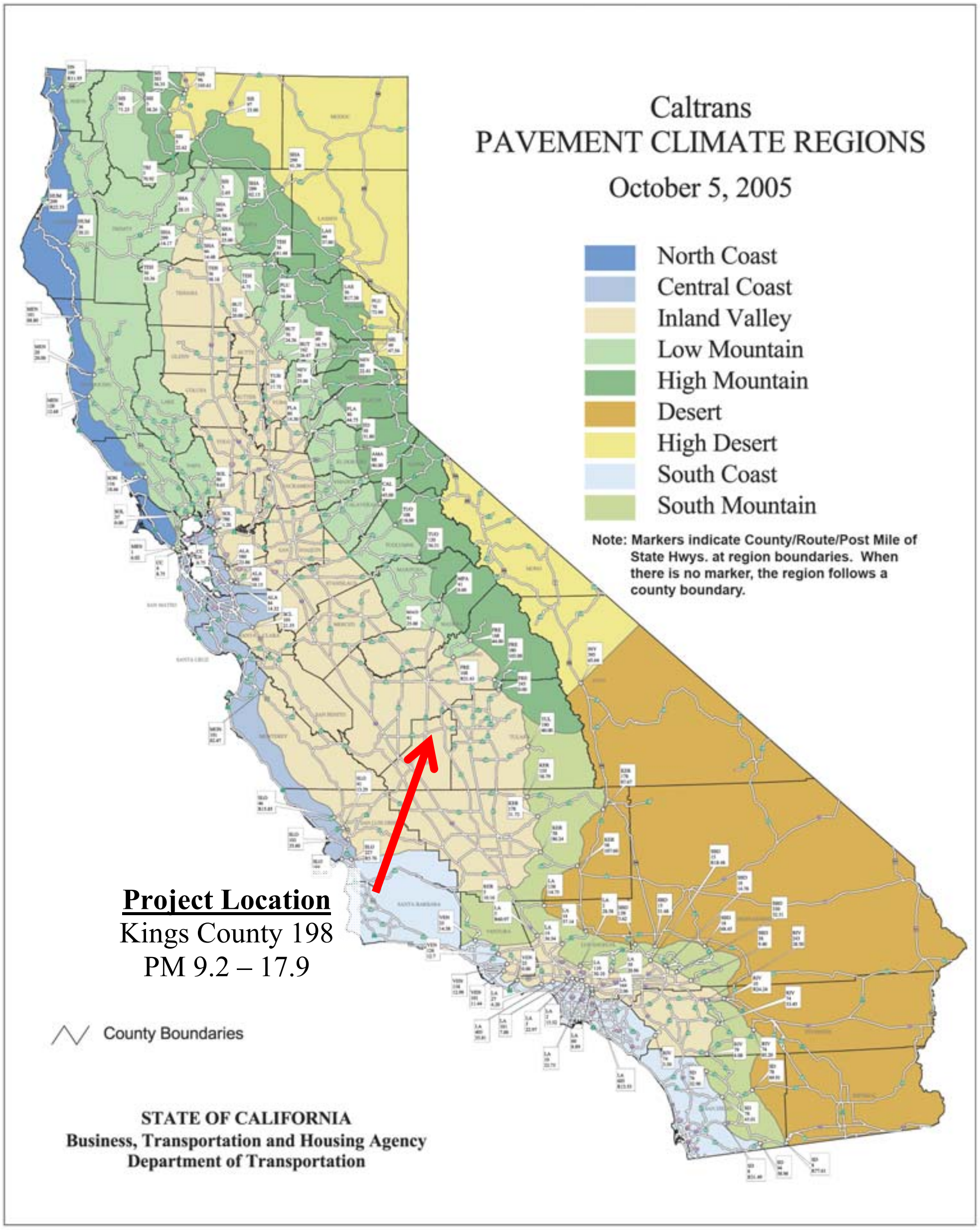


Figure A.2: Caltrans Pavement Climate Regions map.

Material Parameters

Backcalculation with CalBack

This project was broken up into sections according to their pavement structure and condition. Following FWD data analysis, four sections were created as follows: Section 1, Section 2, Section 3 East, and Section 3 West.

- Section 1: 0.70 ft HMA/ 0.35 ft CTB/ 1.57 ft ASB
- Section 2: 0.62 ft HMA/ 0.30 ft CTB/ 1.35 ft ASB
- Section 3 East: 0.57 ft HMA/ 0.30 ft CTB/ 1.80 ft ASB
- Section 3 West: 0.70 ft HMA/ 0.30 ft CTB/ 1.80 ft ASB

For reference, the PM limits for each section follow:

- Section 1: 9.2 – 14.4
- Section 2: 14.4 – 15.1
- Section 3: 15.1 – 17.9

To partition this project, FWD data was collected at individual point locations and deflection bowls for each point were backcalculated to produce estimated material moduli. From this, *CalBack* grouped areas where material moduli were relatively similar, producing the sections listed above. Once sectioned, the material moduli were averaged over the section length and ready for use in *CalME*.

- *FWD Data Collection at Point Locations*

Figure A.3 shows the Falling Weight Deflectometer deflection data for the surface sensor (D1) and subgrade sensor (D7) with HMA surface temperature versus post mile for the eastbound direction. Figure A.4 shows the same for the westbound direction. Deflection testing started in the morning at Section A North, and proceeded generally to the adjacent section as indicated by increasing surface temperatures with post mile.

- *CalBack Point-by-Point Backcalculation of Layer Moduli*

With deflections and material thicknesses loaded in *CalBack,* material moduli were adjusted to produce calculated deflection basins that best matched the measured deflection basins, as seen in Figure A.5. Using *CalBack's* basin-fitting algorithm, different combinations of material moduli were used to minimize the root mean error. This is an iterative process that began with initial seed values associated with selected material. When error levels were less than 2 or 3 percent, the layer moduli values were considered acceptable.

- *CalBack Layer Moduli for Sections*

Figure A.6 shows a screen shot of the Section 1 *CalBack* plot screen of temperature-adjusted moduli, a summary of the calculated moduli along a section. The title bar of the window in the screen shot shows the average moduli (in ksi) among the 178 points tested in Section 1 reported for the different layers; these match the ones reported in Table 2 (in psi) and those used in the *CalME*. Figure A.7 shows the temperature-adjusted layer moduli from *CalBack* for the entire project. Table A.3 contains the raw FWD data from the third drop in the sequence.

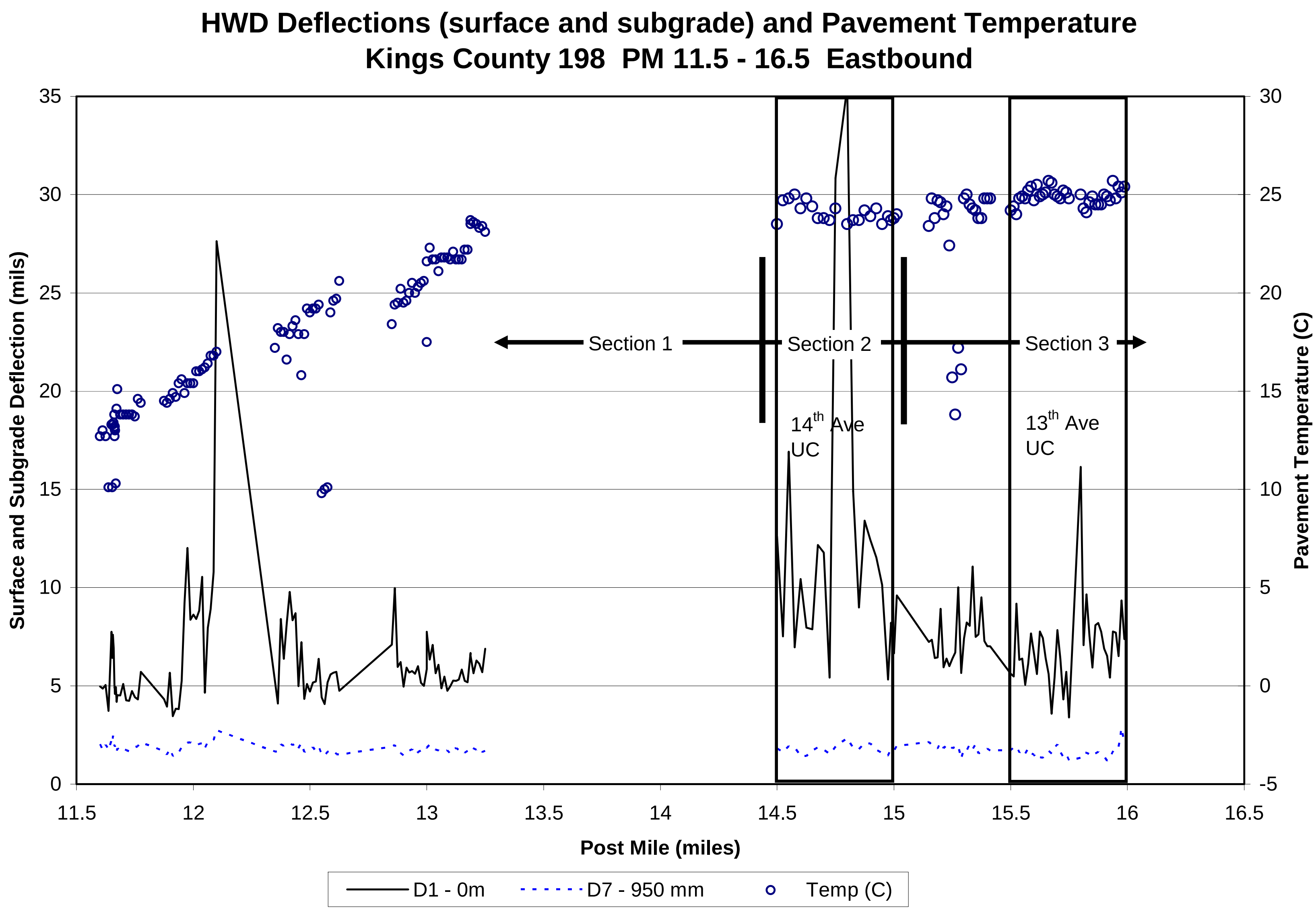


Figure A.3: FWD surface (D1) and subgrade (D7) deflections and surface temperature versus post mile, eastbound.

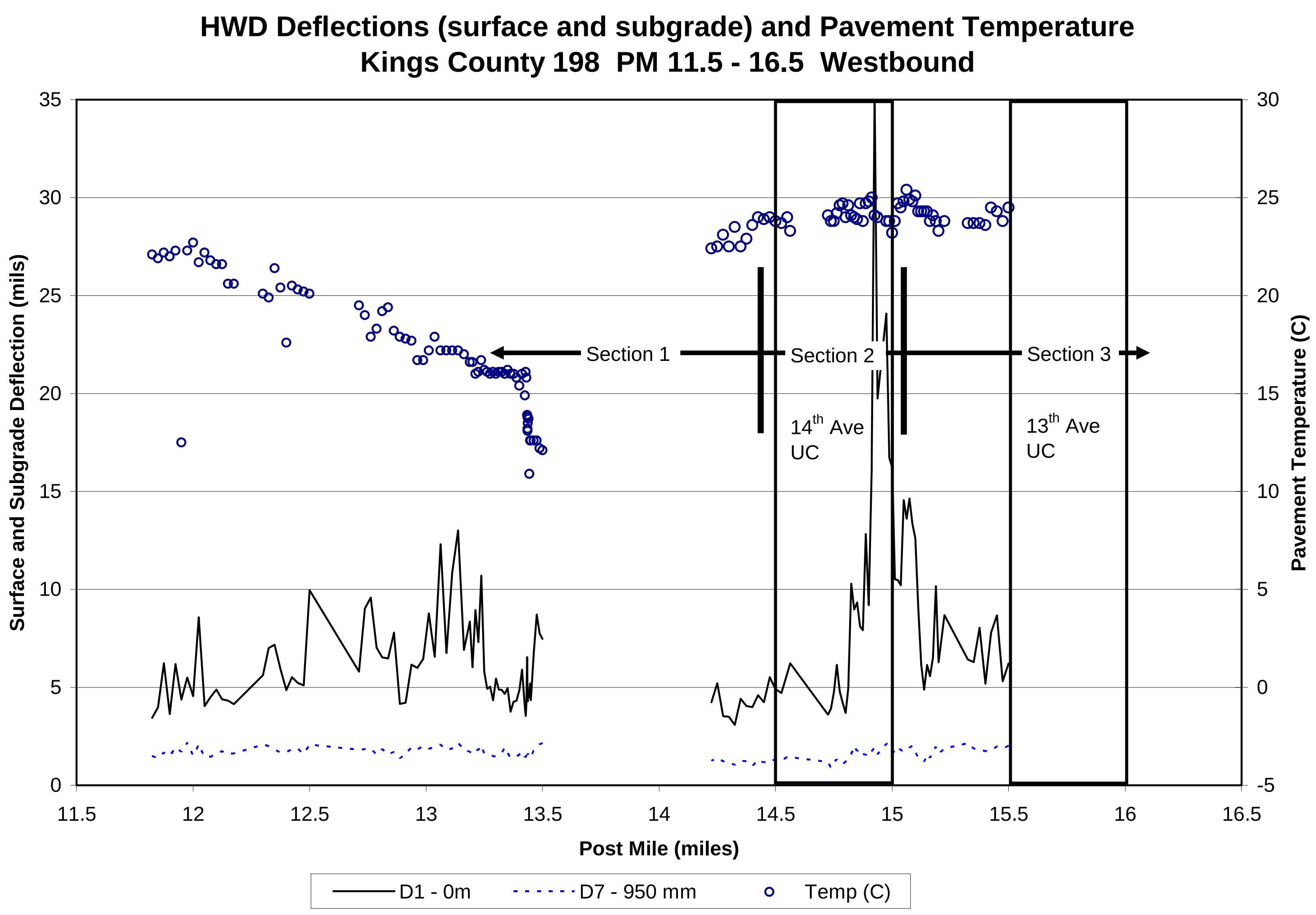


Figure A.4: FWD surface (D1) and subgrade (D7) deflections and surface temperature versus post mile, westbound.

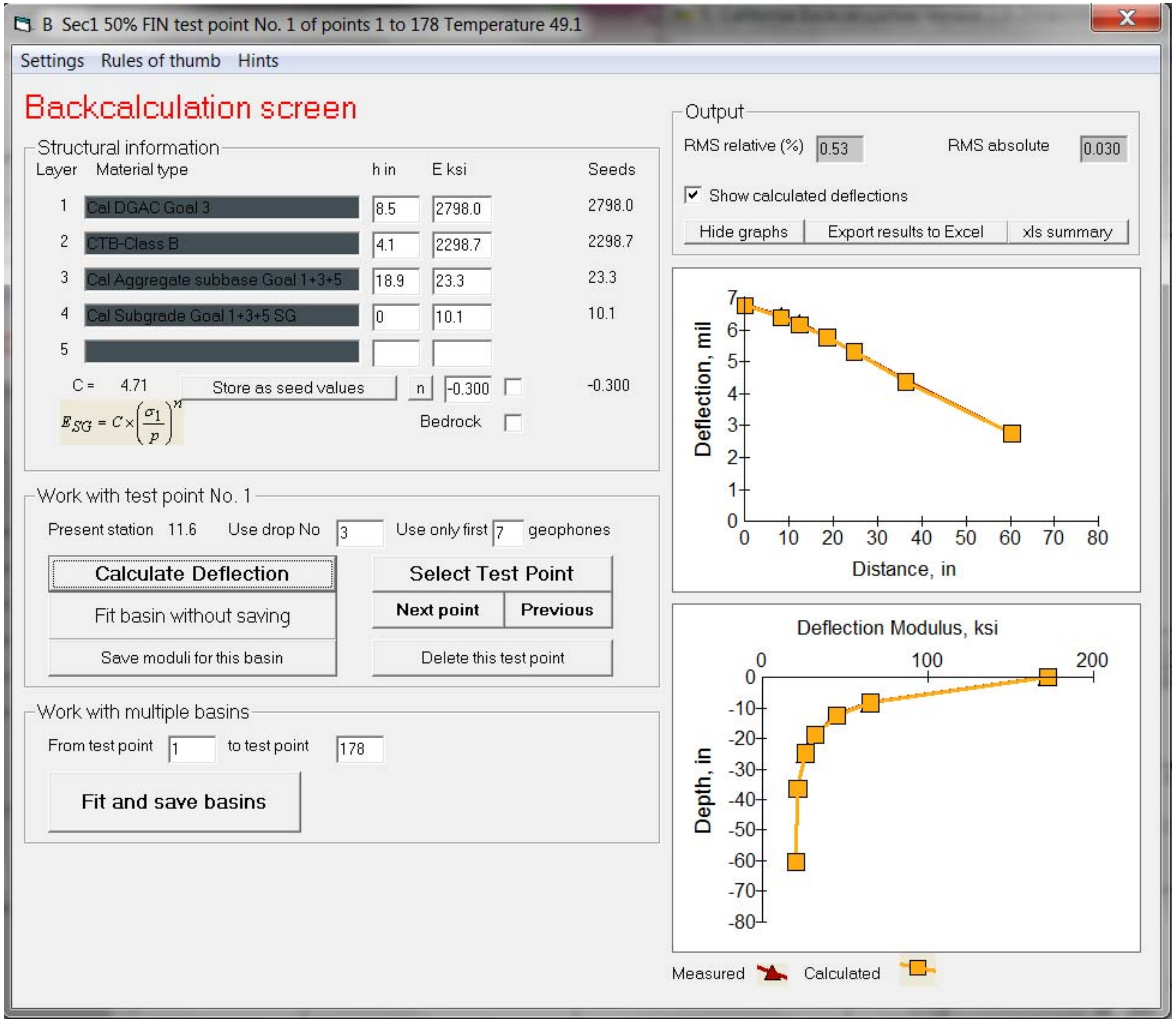


Figure A.5: Screen shot of *CalBack* backcalculation screen for Point 1 of Section 1.

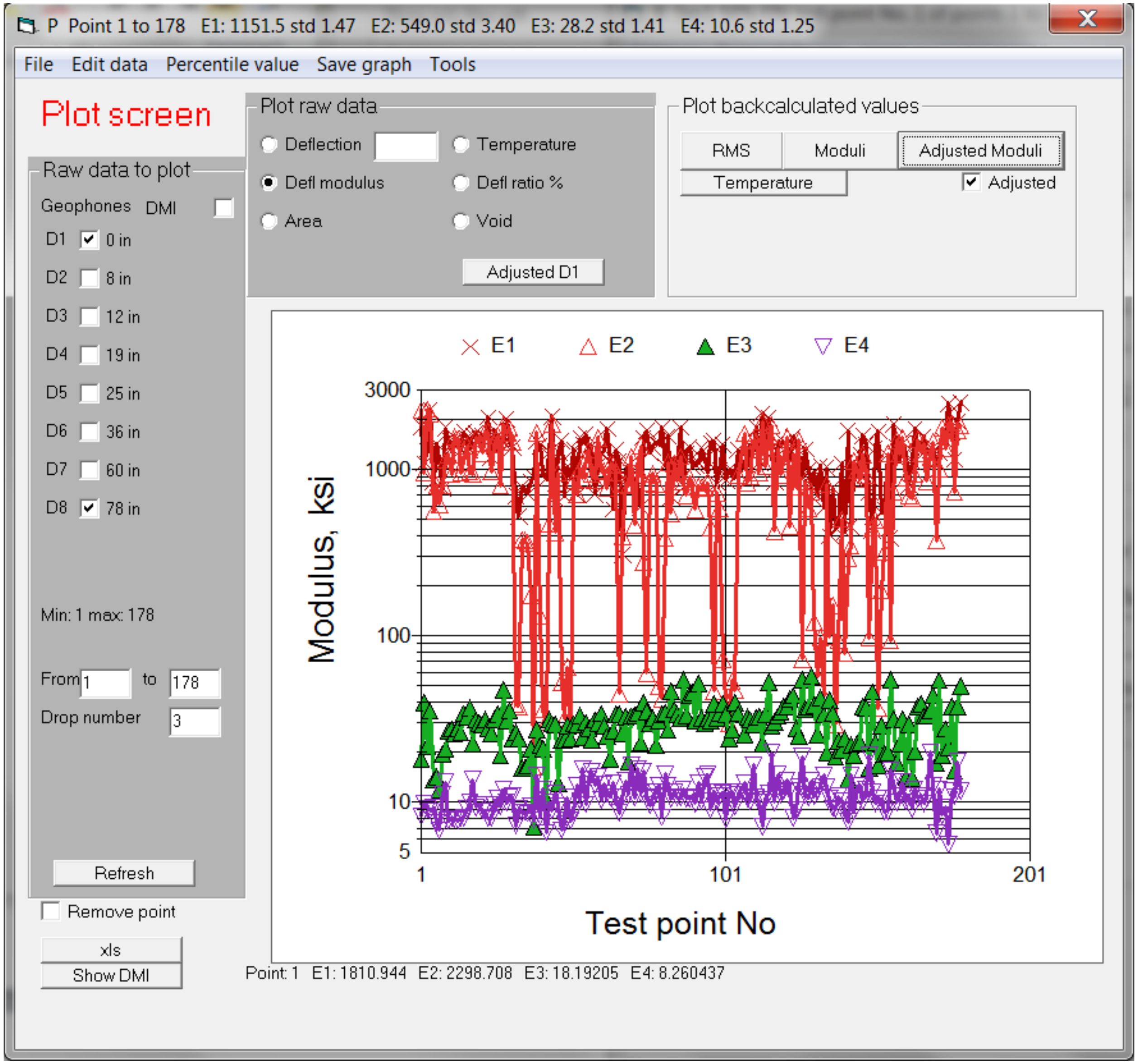


Figure A.6: Screen shot of Section 1 *CalBack* plot screen of temperature-adjusted moduli.

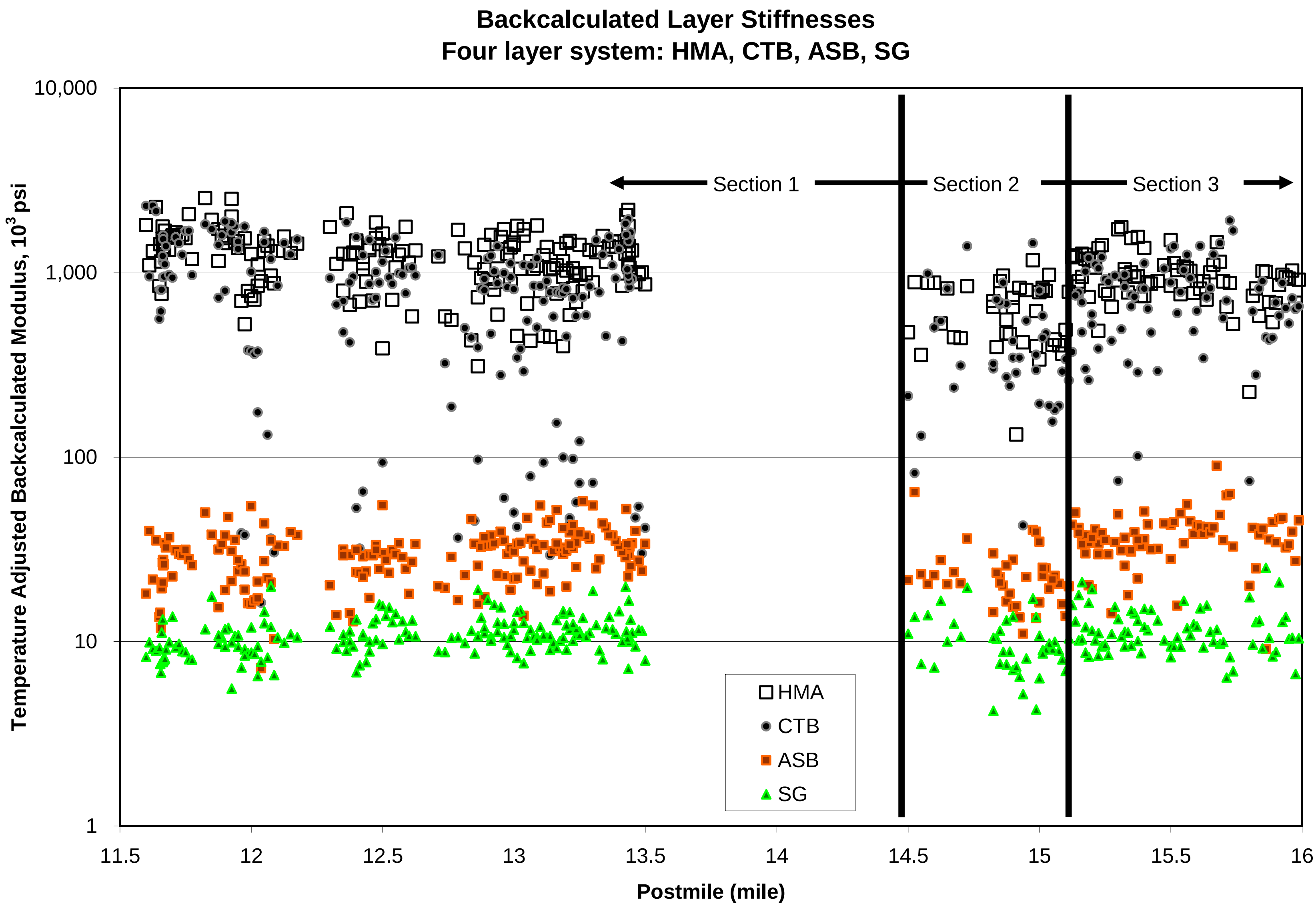


Figure A.7: Temperature-adjusted backcalculated layer stiffness versus post mile.

Table A.3: FWD Raw Data Used for 06-KIN-198 Analysis, Drop 3 Only

Point	Drop	Temp, C	DMI	Load	Time	D1	D2	D3	D4	D5	D6	D7	D8
Eastbound Post Mile 11.6 – 13.2													
1	3	12.7	0	54852	940	172.1	163.5	157.6	145.9	134.9	111.6	70.3	49.9
2	3	13	20	56902	941	171.9	155	145.8	130.4	118.1	94	60.4	44.4
3	3	12.7	40	57256	943	176.4	164.4	158	146.1	133.4	109.7	69.7	52.2
4	3	10.1	60	56973	944	132.4	124.9	120.2	111.8	104	88.8	61.3	47
5	3	13.3	80	55276	945	268.3	245	230.8	206.1	182.9	138.9	78.9	54.6
6	3	10.1	85	54994	946	229.8	217.2	206.7	187.9	168.8	132	78.7	54
7	3	13.3	90	53863	947	265	250.9	238.8	214.5	192.5	149.7	85.7	58.1
8	3	13.4	95	53438	948	243.2	220.7	209.2	187.4	167.7	131.1	79.9	56.7
9	3	13.8	100	54145	950	177.4	166.1	159.4	147.8	132.1	108.1	70.2	50.8
10	3	12.7	101	52944	951	171.5	160.6	154.2	141.7	129.4	106.4	69.8	50.1
11	3	13.1	102	53297	952	173.2	161.1	153.2	139.4	127.1	105	69.2	51.6
12	3	13.2	103	53368	953	161.6	150.9	145.2	134.3	124.5	104.8	70.2	52.1
13	3	13	104	53156	954	161.6	151.5	145.6	135.1	125.3	104.5	69.9	51.3
14	3	10.3	110	54145	955	175.1	162.3	155.5	141.5	128.8	105.2	69.9	51.5
15	3	14.1	115	51813	956	149.4	139.7	133.4	122.9	112.7	94.1	65	48.1
16	3	15.1	120	55630	959	158.2	146.4	139.6	129.6	116.9	96.5	64.1	46.9
17	3	13.8	140	56054	1000	157.8	144.4	136.5	123.3	111.4	89.9	59	44.5
18	3	13.8	160	54145	1002	179.4	166.9	159.2	143.8	129.9	103	65.5	46.9
19	3	13.8	180	56125	1003	150.9	140.8	134.5	123.2	113.2	94.2	61.8	44.3
20	3	13.8	200	54428	1004	148.8	138.3	131.5	119.5	111.3	89.1	58.3	43.3
21	3	13.8	220	55418	1005	165.1	153.4	146.2	133.4	121.4	98.9	64.3	47.4
22	3	13.7	240	56902	1006	155.2	144.4	138.5	128.7	118.4	99.2	67	48.6
23	3	14.6	260	54145	1007	152.8	145	139.2	128.6	119.7	100.2	68.1	49.1
24	3	14.4	280	56619	1009	201.7	186.6	177.8	161.9	146.2	118.7	76.3	53.8
25	3	14.5	440	56619	1014	152.1	143	136.1	124.2	113.7	92.6	59.5	42.5
26	3	14.4	460	54782	1015	137.4	127.3	122.2	111.3	102.6	84	54	38.7
27	3	14.6	480	54428	1016	200.1	186.9	176.9	159.5	140.6	108.5	62.7	44.3
28	3	14.9	500	55559	1017	120.3	109.9	104.2	95.8	88.3	72.8	48.9	37.1
29	3	14.7	520	56761	1018	141.1	132.7	126.5	117	107.3	87.7	55.9	41.7
30	3	15.4	540	56407	1019	135.4	125.4	120.3	111.7	101	84.7	55.2	41
31	3	15.6	560	54711	1020	184.9	172.6	164.2	149.6	135.3	106.5	64.7	47.2
32	3	14.9	580	55912	1021	318.2	279.3	255.4	217.9	184.1	131.5	69.1	46
33	3	15.4	600	55700	1022	399.6	347.2	310.5	257.1	215.1	141.4	75.6	45.6
34	3	15.4	620	55064	1023	288.5	262.6	245.1	213.7	186.2	136.9	73.8	45.8
35	3	15.4	640	56549	1027	295.5	264.7	246.9	214.5	185.4	134.2	71	46.8
36	3	16	660	53933	1028	290	261.8	241.9	208.9	180.1	130.8	67.6	45.6
37	3	16	680	55842	1030	302.1	270.7	249.3	214.9	185.5	135	71	47
38	3	16.1	700	56195	1031	357.4	330.2	297.9	252.5	192.3	139.2	71.6	47

Point	Drop	Temp, C	DMI	Load	Time	D1	D2	D3	D4	D5	D6	D7	D8
39	3	16.2	720	54357	1032	163	151.3	144.6	132.5	121.1	98.6	63	43.5
40	3	16.4	740	55700	1033	277.2	260.7	243	211.2	183.3	135.2	74.8	51.7
41	3	16.8	760	55771	1034	310.8	282.4	257.6	219.8	188.1	138.8	77.9	53.4
42	3	16.8	780	54216	1035	378	345.1	319.6	275.5	234.3	164.5	81.3	53.3
43	3	17	800	57185	1037	870.6	724.1	643.3	484.1	364.7	206	102	68.2
44	3	17.2	1200	57114	1050	183	164.4	155.2	138.3	124.1	97.6	57.7	42.9
45	3	18.2	1220	56831	1051	143.4	134.1	128.4	120.1	111.2	92.7	58.9	43.3
46	3	18	1240	57043	1052	289.6	259.3	236.6	201.2	173.3	127.3	70	48.9
47	3	18	1260	55983	1053	218.6	203.8	193.6	174.2	156.6	119.5	67.7	47
48	3	16.6	1280	56054	1055	281.3	255.6	239.1	208.5	181.4	132.7	72.8	50.6
49	3	17.9	1300	54852	1056	330.8	298.6	267.3	227.7	194	139.9	73.8	50.4
50	3	18.3	1320	56266	1057	285.7	261.4	236	195.8	165.9	119.9	69.9	49.5
51	3	18.6	1340	55135	1058	300.6	267.9	247.7	215.4	185.9	135.6	74.2	50.8
52	3	17.9	1360	54782	1059	178.3	164.2	155.7	140.4	127.5	103.1	66.9	47.6
53	3	15.8	1380	55630	1100	250.2	224.8	207.6	185	161.8	123.4	73.2	50.7
54	3	17.9	1400	54569	1101	153	140.6	133.9	120.9	109.4	87.8	57.4	44.1
55	3	19.2	1420	54852	1102	179.4	166.2	156.4	139.8	124.8	97	59.6	43.9
56	3	19	1440	54499	1103	165.1	152.3	145	131.1	118.7	95.4	60.8	43.7
57	3	19.2	1460	54216	1104	182.8	169.7	161	145.3	131.4	105	65.5	45.8
58	3	19.2	1480	56337	1105	183.6	168.2	158.7	142.2	126.2	98.4	58.7	41.3
59	3	19.4	1500	53933	1106	224	200.5	187.5	165.4	145.8	113	65.7	46.8
60	3	9.8	1520	51813	1107	155.3	143	135.1	122	110.5	87.9	54.4	38.8
61	3	10	1540	51954	1108	144.4	132.5	124.6	112	101.1	80.4	50.9	37.3
62	3	10.1	1560	52802	1109	180.9	167.6	157.5	140.5	124.9	97.5	57.6	41.8
63	3	19	1580	55559	1110	193.7	181	170.1	150.9	135.8	104.5	61.5	42.8
64	3	19.6	1600	54287	1112	198.9	182.6	171.9	153.7	137.3	106	61.5	43
65	3	19.7	1620	55206	1115	194.7	170.2	158.1	139.4	122.8	93.7	52.8	35.8
66	3	20.6	1640	54499	1116	166	152.2	143.1	128.6	114.9	88.3	53.4	38.9
67	3	18.4	2000	55418	1119	244.1	219.9	203.9	177.7	155.3	117.6	67.1	46.9
68	3	19.4	2020	57256	1120	341.9	283.8	258.6	219.2	185.3	131.5	69.7	49.9
69	3	19.5	2040	54640	1121	211.1	188.9	177.1	154.5	134.7	101.5	58.1	41.6
70	3	20.2	2060	55912	1122	216.9	196.1	182.8	161.2	141	106.3	56.6	39
71	3	19.5	2080	57185	1123	173.7	154.9	145.2	129.3	113.8	88.9	52.4	37.9
72	3	19.6	2100	57750	1125	206.8	185.7	170.3	148.4	130.5	99.5	59.2	40.9
73	3	20	2120	57962	1126	199.5	177.9	165.5	146.7	130.1	100.5	59.2	42
74	3	20.5	2140	58174	1131	201.3	178	167.8	149.5	134.3	106.2	62.2	43.2
75	3	20	2160	57326	1132	196.1	183.1	170.2	143.3	124.5	91.5	53.4	36.4
76	3	20.3	2180	54923	1133	212.4	191.8	179.2	157.1	137.8	103.1	59.1	42
77	3	20.5	2200	54852	1134	180.9	165.5	156	140.6	125.8	99.6	62.3	43.8
78	3	20.6	2220	54640	1136	175.5	160.9	152.1	137.5	122.5	96.6	60.2	40.9

Point	Drop	Temp, C	DMI	Load	Time	D1	D2	D3	D4	D5	D6	D7	D8
79	3	17.5	2240	57609	1200	204.1	187.8	176.2	157.5	139.7	107.2	62.2	44.6
80	3	21.6	2240	56478	1207	266.7	240.4	220.9	190.2	164.2	119.9	65.6	46.1
81	3	22.3	2260	54640	1208	221.9	204.8	193.4	172	153.9	119.1	71.8	49.9
82	3	21.7	2280	60366	1209	246.7	222.1	202.8	174.9	151.7	112.4	63.7	44.9
83	3	21.7	2300	56902	1210	196.2	180.3	169.4	151.1	134.3	102.9	60.3	44.7
84	3	21.1	2321	57326	1212	213.4	181.8	167.8	146.9	129	99.9	61.6	44.3
85	3	21.8	2340	59447	1213	174.8	157.1	148.2	133.1	120.2	95.9	59.1	43.1
86	3	21.8	2360	57680	1214	190.8	170.6	160.4	143.2	127.5	99.4	60	44.3
87	3	21.8	2380	56125	1216	166	154.8	147.4	134.3	122	98.6	61.3	43.3
88	3	21.7	2400	57468	1217	175.4	151.6	140.8	125.5	113	90	58.2	43
89	3	22.1	2420	57326	1218	185.8	168.2	157.3	140.7	125.2	97.5	61.7	46.3
90	3	21.7	2440	58316	1219	177.9	160.2	150.4	135.8	121	95.6	61.9	46.1
91	3	21.7	2460	57185	1221	183.9	163.1	151.2	135	120.5	95.2	60.1	43.8
92	3	21.7	2480	56619	1223	202.6	182.5	171.2	152.3	136.2	105.2	62.1	44.7
93	3	22.2	2500	62698	1225	185	162.6	151.2	133.4	117	91.5	59.5	42.2
94	3	22.2	2520	56690	1226	181.7	166	155.6	140.4	124.4	97.8	60.7	45
95	3	23.7	2540	57397	1229	231.6	208.1	194.4	171.7	152	115.6	67.1	48.3
96	3	23.5	2540	57326	1239	227.8	204.5	191.6	168.9	149.5	113.9	68.3	47.8
97	3	23.6	2560	57750	1241	199.8	182.9	171.1	153.4	136.7	106.7	65	48.3
98	3	23.5	2580	56266	1242	219.7	200.3	184.4	160.2	141.2	106	62.4	45
99	3	23.3	2600	56478	1242	211.9	186.2	174.4	153.9	137.3	107.4	64.6	47.2
100	3	23.4	2620	55700	1244	197.2	175.4	162.4	142.9	125.8	96.4	57.8	41
101	3	23.1	2640	56407	1245	240.1	215.6	198.5	170	144.5	105.9	62	43.4
Eastbound Post Mile 14.5 – 16.0													
102	3	23.5	0	59376	1201	401.1	344.4	303.6	242.9	196.3	130.3	62.9	41.6
103	3	24.7	40	59093	1203	254	222.4	194.2	159.1	136.3	103.3	57.1	37.5
104	3	24.8	80	59588	1204	552.9	464	399	308.3	242.1	151.6	69.1	49
105	3	25	120	58881	1205	239.8	214.7	200.6	175.9	155.5	118.5	65.7	43.1
106	3	24.3	160	57750	1206	352.6	315.8	284.5	234.8	195.5	128.9	53.1	36.6
107	3	24.8	200	60012	1207	270.9	227.9	203.9	170.1	142.6	99.5	51	32.8
108	3	24.4	240	56831	1208	277.3	247.1	228.4	200	172.8	125.3	63.8	42.4
109	3	23.8	280	60224	1209	405.2	341.9	298.6	241.7	199.3	136.8	68	43.7
110	3	23.8	320	57821	1210	389.8	336.6	296.4	243.2	200.4	135.7	64.9	42.4
111	3	23.7	360	59517	1211	191.4	168.5	156.3	140.7	122.8	95.2	56.3	39.2
112	3	24.3	400	55630	1212	978.4	812.5	715.8	560	406.8	181.3	71.2	49.3
113	3	23.5	480	57680	1214	1124.2	940.6	803.3	620.3	467	251.6	84.9	54.4
114	3	23.7	520	55064	1215	497.9	449.9	402.9	331.7	271.1	172.9	64.9	39.9
115	3	23.7	560	60295	1217	297.3	261.8	240.3	207	177.3	126.6	64.5	43.7
116	3	24.2	600	58174	1218	451.2	396.2	354.9	292.3	242.4	158.3	73.7	48.2
117	3	23.9	640	56478	1219	420.2	375.5	340.3	284.5	237.6	160.1	73.8	46.2

Point	Drop	Temp, C	DMI	Load	Time	D1	D2	D3	D4	D5	D6	D7	D8
118	3	24.3	680	57043	1220	391.6	349.6	318.9	268.8	225.6	151.8	64	39.7
119	3	23.5	720	57680	1222	337	298	269.7	226.3	189.4	126.5	56.5	35.6
120	3	23.9	760	56973	1223	183.1	164.9	154.6	135.8	118.7	89.8	51.7	36.5
121	3	23.7	780	59871	1225	276.1	232.7	206.8	173	148.3	108.4	61.7	42.9
122	3	23.8	800	59588	1226	229.3	202.3	185.7	162.1	142.1	106.6	60.5	42.6
123	3	24	820	55559	1227	327.6	292	269.5	228.8	194.8	136.1	68.9	45.9
124	3	23.4	1040	57962	1230	247.7	217.8	201.2	176.7	155.1	119.3	74.3	53
125	3	24.8	1060	57326	1231	253.2	224	206.3	179.2	156.4	117.1	69.8	51.4
126	3	23.8	1080	58881	1232	223.2	201.5	186.1	164.5	145.6	112.5	69.2	50.4
127	3	24.7	1100	59305	1233	222.5	200.1	185.8	162.3	142	106.3	61.2	49.1
128	3	24.6	1120	56973	1234	308.3	284.9	261.1	223.6	190.2	136.8	76.4	52.5
129	3	24	1140	56266	1235	206.3	184.7	172.4	153.2	135.8	105.5	65.4	47.1
130	3	24.4	1160	59588	1237	227.9	209.2	194.6	172	152.3	116.8	71.5	50.4
131	3	22.4	1180	58528	1238	206.3	187.8	175.4	155.9	139.3	109	66.8	47
132	3	15.7	1200	56337	1239	224.1	199.3	184.3	162	143.2	110.4	65	47.4
133	3	13.8	1220	55276	1240	236	210.1	194.7	170.6	150.5	113.8	66.4	44.9
134	3	17.2	1240	54852	1241	349.5	306.7	280.7	235.3	198.1	137.9	69.8	48.1
135	3	16.1	1260	52166	1242	202.3	179.6	164.1	141.1	120.8	88.2	48.4	33.7
136	3	24.8	1280	61214	1243	259.2	229.6	205.3	173.2	148.3	108.6	62	44.5
137	3	25	1300	58528	1244	282.3	255	235.3	203.9	172.4	118.8	62.6	45.7
138	3	24.5	1320	58599	1245	277.2	250.1	232.4	203.7	176.9	127.7	70.9	49
139	3	24.3	1340	59730	1246	375	328.3	293	242.2	200.9	135.1	65.9	44.4
140	3	24.2	1360	57962	1247	259.2	230.8	212.3	184.8	160.6	119.9	69.2	48.1
141	3	23.8	1380	58811	1248	259.3	225.1	203.8	173.4	145.8	103.3	53.5	37
142	3	23.8	1400	57892	1249	316.1	284.3	258	213.8	173.9	116.6	55.3	40.8
143	3	24.8	1420	58599	1250	249.7	216.9	199.3	173.5	151.3	111.2	59.2	40
144	3	24.8	1440	59305	1251	240	211.3	194	169.3	148.7	109.1	61.9	45.4
145	3	24.8	1460	57468	1252	238.2	203.7	185.8	159.4	137.1	101.9	59.8	41.2
146	3	24.2	1600	55912	1255	191.8	169.4	157.6	142.8	126	99.7	60.5	43.6
147	3	24.4	1620	55347	1256	188.9	170	158.7	143.2	129.3	104.2	65.6	46.7
148	3	24	1640	55135	1257	312.9	281.5	258.6	220.5	186.6	130.1	66.9	44.4
149	3	24.8	1660	55630	1258	218.2	187	171.5	149.3	131.3	101.4	59.1	41.4
150	3	24.9	1680	56054	1259	225.5	200.9	185.3	163.1	140.3	105.7	62	44.8
151	3	24.8	1700	57962	1301	180.2	158.3	147.1	131.3	117.2	91.6	56.8	41.6
152	3	25.2	1720	56831	1302	211.6	186.1	172.4	151.3	133.6	102.8	62.6	44.6
153	3	25.4	1740	56902	1303	261.9	220.9	197.6	165	138.8	98.5	56	39.1
154	3	24.7	1760	56619	1304	228.8	195.7	176.3	150	128.4	94.3	52.4	36.6
155	3	25.5	1780	56478	1305	195.4	170.9	157.5	136.4	118.5	85.8	45.2	32.3
156	3	24.9	1800	58104	1306	257.4	218.6	192.4	160.2	133.3	93.7	48.5	33.3
157	3	25	1820	58104	1307	248.2	212.7	191.5	160.6	134.9	94.9	50.1	33.3

Point	Drop	Temp, C	DMI	Load	Time	D1	D2	D3	D4	D5	D6	D7	D8
158	3	25.1	1840	57538	1308	218.5	189.8	174.4	150.8	129.3	95.5	53.7	36.4
159	3	25.7	1860	57185	1309	195.9	173.9	161.8	143.8	127.5	100.2	58.2	41.6
160	3	25.6	1880	56125	1310	125	114.2	109.8	102.1	94.5	81.1	56.4	41.8
161	3	25	1900	56478	1311	187.5	168	157.2	142.3	129.4	104.5	66.5	48.4
162	3	24.9	1920	54923	1312	267.8	229.1	209.5	181.3	157.2	118.1	68.4	45.6
163	3	24.8	1940	55842	1313	222.4	188.9	171.1	149	130.8	101.5	58	37.4
164	3	25.2	1960	56619	1314	152.9	133.6	124.5	111.8	101.3	81.6	49.7	34.3
165	3	25.1	1980	55064	1315	195	167.8	154.9	139	125.5	96.8	54.1	35.3
166	3	24.8	2000	57962	1316	121.3	112.3	108.1	101.5	91	71.6	43.2	29
167	3	25	2080	57326	1318	523.1	377.8	301.8	211.7	160.4	97.7	49	32.9
168	3	24.3	2100	57043	1319	245.1	208.6	189	160.9	138.5	101.6	56.3	37.3
169	3	24.1	2120	56619	1320	326.9	284.1	250.6	203.7	168.1	114.7	58	37.9
170	3	24.6	2140	55559	1321	257.1	221.7	201.1	170.2	144.7	103.1	54.8	36.2
171	3	24.9	2160	55559	1322	203.1	178.5	163.3	140.5	121.8	90.2	49.3	31.5
172	3	24.5	2180	54852	1323	275	242.8	221.7	189.8	161.9	104.1	54.9	38.6
173	3	24.5	2200	55559	1324	283.2	237.5	213.6	178.9	150.7	109.3	59.9	41.5
174	3	24.5	2220	54711	1325	266.4	219.4	195.5	163.7	140.1	101.9	53.7	35.5
175	3	25	2240	54640	1326	237.8	203.7	184.5	156.9	135.1	96.8	50	32.3
176	3	24.9	2260	55771	1327	223.6	186.2	165.5	136.7	113.6	79.9	43.3	30.3
177	3	24.7	2280	55064	1328	186.3	159.9	145.8	125.3	110.3	79.4	43.7	30.8
178	3	25.7	2300	53438	1329	268.2	234.4	212.3	180.1	153.5	110.2	59.1	41.7
179	3	24.8	2320	53651	1329	265.9	231.4	210.1	179.3	152.7	112.3	65.1	46.7
180	3	25.4	2340	53792	1330	229.5	205.9	188.8	164.2	143.4	107.6	65.1	47.2
181	3	25.1	2360	55559	1331	314	276.7	254.3	224.1	197.3	149.4	85.8	61.5
182	3	25.4	2380	56973	1332	254.3	221	201.4	177.3	156.2	121.6	74.5	54.1
Westbound Post Mile 15.5 – 14.2													
183	3	24.5	0	56054	1325	215.6	201.7	191.8	173.4	155	121.2	71.6	49.8
184	3	23.8	40	57326	1326	185.1	165.8	154.9	139.7	126.4	103.5	65.8	47.1
185	3	24.3	80	58881	1328	298.5	264.8	240.2	203.6	174.3	128	70.4	45.6
186	3	24.5	120	56619	1329	267.7	230.2	209.7	180.6	156.5	116.4	64.4	43.4
187	3	23.6	160	57397	1330	182.3	162.9	151.1	134.1	119.6	94.8	60.4	43.4
188	3	23.7	200	57468	1331	277.8	245.2	220.7	186.5	158.9	116.1	64.5	46.2
189	3	23.7	240	57892	1332	221.5	203.7	189.2	166.6	146.1	111.4	65	46.3
190	3	23.7	280	58457	1333	223.4	198.6	185.6	167.2	151.2	121.6	75.6	53.8
191	3	23.8	441	56973	1335	294.1	248.2	224	189.8	162.6	119.8	64.2	45.7
192	3	23.3	480	56478	1336	218.5	192.7	175.5	151.8	131.6	99.4	58.1	42.2
193	3	23.8	500	55276	1337	355.8	321.1	286.9	243.2	208.3	147.8	72.4	45.8
194	3	24.1	520	55559	1338	227.6	204.4	190.8	168.6	149.1	113.5	64.4	44.4
195	3	23.8	540	56125	1339	194.7	174.4	159.7	136.2	118.6	86	51.4	37.9
196	3	24.3	560	57256	1340	210.3	184	167.4	146.1	126.7	94.8	54.4	38.7

Point	Drop	Temp, C	DMI	Load	Time	D1	D2	D3	D4	D5	D6	D7	D8
197	3	24.3	580	58104	1341	172.1	150.3	136.4	118.1	103.4	78.1	44.3	32
198	3	24.3	600	56761	1342	210.5	187.1	169.3	141.2	118.6	83	43.4	29.8
199	3	24.3	620	56973	1343	302.8	265.5	240.2	198.9	165.9	111.5	51.9	33.3
200	3	25.1	640	54852	1344	422.5	364.8	328.9	271.5	223	146.2	62.7	38.7
201	3	24.8	660	54994	1345	452.2	381.6	341.2	279.6	230.4	155	71.6	44.1
202	3	24.9	680	57185	1347	482.8	407.3	355.4	279.6	226.9	150.4	69.6	45.2
203	3	25.4	706	56619	1349	443.5	374.3	322.7	253.1	203.4	135.6	62.9	44.9
204	3	24.8	720	57750	1357	473.7	394.4	340.5	266.5	210.4	130.9	61.7	41.4
205	3	24.5	740	56619	1358	348.1	312	283.4	236.2	196.2	133	66.7	46.1
206	3	24.7	760	54287	1359	353.5	311.1	282.8	238.4	201.1	139.9	69.4	45.8
207	3	23.8	780	56690	1400	356	315.8	284.3	237.3	197.2	132.3	61.6	42.1
208	3	23.2	800	54145	1401	532.6	446.5	393.5	309.5	245	151	64.3	42
209	3	23.8	820	54428	1402	566.3	492.4	443.7	363.9	300.3	190.8	76.9	43.1
210	3	23.8	840	51883	1403	820.4	691.1	603.5	471.6	370.6	219.5	80.2	46.9
211	3	24	900	60295	1405	645.5	549.2	465.1	356.9	273.2	149.3	53	33.3
212	3	24.1	920	55488	1406	1096.9	919	802.7	605	454	222.7	72.6	96.7
213	3	25	940	56195	1407	526.9	393.2	350.4	283.6	231.1	149.2	65.8	43
214	3	24.8	960	57750	1418	307.4	261.7	234.2	193.3	159.6	109.9	53.7	35.4
215	3	24.7	980	55488	1419	424.7	359.7	316	251.7	203.7	130.6	56.9	36.7
216	3	23.8	1000	54994	1420	269.5	233.7	206.4	176.3	152.2	112	56.5	33.4
217	3	24.7	1020	55842	1421	283	256.1	237.3	207.2	180.4	133.3	66.5	42.2
218	3	23.9	1040	54499	1422	323.3	289.1	267.1	231.7	199	137.6	67.1	47.5
219	3	24	1060	54004	1423	311.3	267.7	246.4	211.7	184	137.2	73.1	50.9
220	3	24.1	1080	55347	1424	346.5	303.2	268.9	217.6	180.4	121.2	58.9	40.9
221	3	24.6	1100	55771	1425	178.1	155.1	144.3	129.7	116.1	91.5	53.9	37.2
222	3	24	1120	56337	1426	131.6	115.6	108.2	97.5	89.1	71.7	44.4	29.4
223	3	24.7	1140	57185	1427	148.8	124.3	113.2	98.7	87.2	67.5	40.3	27.8
224	3	24.6	1160	55206	1428	168	136.6	122.8	105.7	92.2	69.7	39.3	28.2
225	3	24.2	1180	54357	1429	213.1	178.7	160.3	136.4	116.7	86	47.4	32.2
226	3	23.8	1200	57114	1430	165.4	144.3	131.7	113.9	98.9	73.4	42.5	31
227	3	23.8	1220	56266	1431	138	112.2	100.8	85.5	74.3	55.6	33.8	24.6
228	3	24.1	1240	54499	1432	131.3	115.1	108.1	98	88.4	70.6	44.9	31.5
229	3	23.3	1500	52166	1434	215.9	188.1	170.1	142.8	118.3	88.4	49.6	35.3
230	3	24	1520	53721	1436	193.3	165.1	148.2	127.8	111.9	85.6	49.1	36
231	3	23.7	1560	51530	1437	167	149.9	138.5	120.7	105.6	79.2	45.6	33.5
232	3	23.8	1600	54075	1438	171.9	150.3	137.4	118.2	101.6	75.1	45.1	33.4
233	3	24	1640	51601	1439	197.8	178.3	164.8	142.2	123.5	89	48.1	32.7
234	3	23.9	1680	51530	1441	150.2	135.7	126.5	112.2	98.6	74.7	43.2	30
235	3	24	1720	52449	1442	163.9	149.6	142.2	125.6	110.8	83.7	47.1	35.8
236	3	23.6	1760	53368	1443	140.5	120	107.7	91.1	77.9	58.3	36	27.9

Point	Drop	Temp, C	DMI	Load	Time	D1	D2	D3	D4	D5	D6	D7	D8
237	3	22.9	1800	52732	1444	141.9	121.3	110.6	96.5	85.1	67.7	44.7	33.9
238	3	22.5	1840	51601	1445	153	131.9	119.9	102.4	89.6	68.4	44.3	34
239	3	23.5	1880	52025	1446	109.4	97.9	92.1	83.1	74.9	59.8	37.9	28.2
240	3	22.5	1920	53438	1448	124.4	110.6	103.9	92.4	82.6	64.8	42.4	29.7
241	3	23.1	1960	52378	1449	124.2	111.8	104.2	94.7	85.5	69.4	45.9	33.7
242	3	22.5	2000	53014	1450	183.1	160.5	146.3	125.3	108.3	81.8	50.3	38.4
243	3	22.4	2040	52661	1451	148.7	130.4	119.9	104.7	93.7	71.4	44.2	33.2
Westbound Post Mile 13.5 – 11.8													
244	3	12.1	0	55418	937	259.5	234.2	217	189.5	165.7	126.4	75.5	57
245	3	12.2	20	55206	939	268.8	245.6	227.6	198.7	171.8	127.1	73.3	53.7
246	3	12.6	40	56478	940	299.2	268.8	245.4	211.1	179.8	125.7	73.2	51
247	3	12.6	60	57185	941	235.4	207.9	191.7	167.9	146.2	109	64.4	47
248	3	12.6	80	56125	943	150.7	138.3	130.1	116.7	104.5	81.3	51.6	37.5
249	3	12.6	85	55912	945	182.2	173.1	164.2	149.8	132.2	92.1	55	38.3
250	3	10.9	90	54499	946	156	143.6	134.9	122.1	109.9	86.6	53.7	39.1
251	3	13.7	95	53651	948	171.4	154.1	144.2	127.8	113.5	88.2	53.8	41.5
252	3	13.5	100	54145	950	152.5	141.7	133.9	120.8	108.4	86	55	40.7
253	3	13.8	101	53792	951	151	140.7	133.2	120.6	108.9	86.7	55.2	42.2
254	3	13.2	102	62274	952	154	148.4	141	128.7	116.5	93.3	59.5	45.9
255	3	13.1	103	54923	953	176.2	161.2	153	138	126.2	99.4	63	46.1
256	3	13.8	104	54075	954	182.9	173	166.3	152	138.1	110	59.9	41.1
257	3	13.9	105	55559	956	232	242.6	245.6	172.4	143.6	96.8	56.3	38.9
258	3	15.8	110	54499	957	147.6	136.6	129.5	117.4	105.7	84.6	54.5	40.9
259	3	16.1	115	56054	1009	123.5	113.6	108.4	98.9	90.5	74.4	50.2	38.6
260	3	14.9	120	57680	1010	137.4	126.1	120.5	109.7	100.5	79.8	51.7	38.9
261	3	16	140	55983	1011	207.7	184.6	172.6	152.7	133.9	101.8	60.3	43.6
262	3	15.4	160	56902	1012	171	157	148.1	133.9	119.9	91.2	56.1	41.8
263	3	15.8	180	56195	1013	153	140.2	132.7	118.8	106.3	84	53.4	38.4
264	3	16	200	56125	1015	150.3	135.8	128.6	116.3	102.4	80.5	50.9	39.4
265	3	16	220	55630	1016	132.5	122.9	117.2	107.3	98.8	77.6	50.6	37.1
266	3	16.2	240	56973	1017	173.7	158.2	145.9	127.9	113.4	89.6	59	42.4
267	3	16	260	55064	1018	163.7	151.9	144.4	132.5	122	102.9	70.5	52.5
268	3	16.1	280	54923	1019	173.9	160.6	152.1	138	125.1	99.4	62.9	44.1
269	3	16.1	300	55983	1020	173.3	159.9	152.3	137.6	124.5	98.3	58.7	41
270	3	16	320	55064	1021	190.3	171.3	152.1	128	108.2	82.7	51.5	39.8
271	3	16.1	340	55276	1022	152.6	139.4	130.7	116.7	104.5	82.7	52.7	39.7
272	3	16	360	55488	1023	176.3	158.6	146.7	129.1	115	89.3	56.4	41.9
273	3	16.1	380	57043	1024	171.6	149.9	137.3	120.2	110.2	86.2	55.7	40.4
274	3	16.2	400	56266	1025	200.8	181.3	162	136.8	119.1	90.8	54.8	40.5
275	3	16.7	420	58245	1026	361.1	320.3	283.8	230.2	189.9	132.6	70.7	52.6

Point	Drop	Temp, C	DMI	Load	Time	D1	D2	D3	D4	D5	D6	D7	D8
276	3	16.1	440	58386	1027	249.1	224.5	202.5	169.8	145.5	113.4	63.9	46.6
277	3	16	460	56831	1028	302.4	265.2	230.8	193.6	162.6	114.3	64	46.9
278	3	16.6	480	54640	1029	206.8	185.8	174	156.3	136.7	99.9	56.9	40.7
279	3	16.6	500	55276	1030	286.6	234.7	205.5	169.1	145.3	109.2	61.3	43.8
280	3	17	540	55700	1032	236.4	211.2	187.8	157.6	146.8	109	64.3	47.1
281	3	17.2	580	54216	1033	427.5	367.6	328.1	267.8	215.3	146.7	73	51.3
282	3	17.2	620	55842	1034	366.7	314.5	280.8	229.3	189.1	129.7	69.4	48.9
283	3	17.2	660	55347	1035	239.3	218.8	205	181.2	158.2	118.4	65.6	45.6
284	3	17.2	700	55842	1036	414.7	357.4	317.2	258.9	213.7	144.7	75	55.3
285	3	17.9	740	52661	1038	228.7	216.1	206.3	184.2	163	124.7	70.4	48.7
286	3	17.2	780	54852	1039	298	254.3	228.5	192.5	165.5	119.9	67	48.2
287	3	16.7	820	54994	1040	225	206.8	195.8	175.7	157.9	122.6	70.4	50.2
288	3	16.7	860	55630	1042	208.3	188	177.6	158.9	141.8	109.7	64.4	45.7
289	3	17.7	900	54711	1043	216.9	200.1	188.6	168.5	149.7	116	70.3	52.5
290	3	17.8	940	54357	1044	150.3	138	130.9	119.7	107.8	87.2	57.1	42.1
291	3	17.9	980	54287	1045	144.2	131.5	123.9	111.8	98.2	77.4	48.8	36.6
292	3	18.2	1020	56054	1046	262.9	230.2	206.5	178.3	148	104	61.2	45.4
293	3	19.4	1060	56478	1047	225.3	183.4	166.7	142.3	123.8	92.7	55.5	41.1
294	3	19.2	1100	54357	1048	225.9	210.2	196.2	172.4	151.5	113.5	63.2	43
295	3	18.3	1140	53226	1049	244.8	225.1	210.3	184.6	152.6	108.2	57.7	41
296	3	17.9	1180	54923	1050	323.1	281.9	254.3	211.6	177.6	124.3	66.2	46.7
297	3	19	1220	53438	1052	314	277.6	254	214.5	183	127.7	65.1	45.9
298	3	19.5	1260	52732	1053	205.2	190.2	181.2	163.8	146.8	115	67	48
299	3	20.1	1600	60366	1102	330.9	269	232.1	187.9	165.3	121.6	73.9	45.7
300	3	20.2	1640	54569	1103	178.6	167.3	157.1	140	122.8	95.1	56.6	39.8
301	3	20.3	1680	54004	1104	181.6	170.2	161.5	147.3	134.2	107.4	65.5	45.3
302	3	20.5	1720	53792	1106	194	178.1	167.9	152.3	136.6	106.8	63.4	43.7
303	3	17.6	1760	54782	1107	170.1	157.9	149.7	136.4	123	97.5	59.2	42.8
304	3	20.4	1800	53792	1108	211	195.1	183.9	164.7	146.2	111.2	61.7	40.4
305	3	21.4	1840	54640	1109	250.9	223.2	207.6	181.6	159	117.1	64.2	43.5
306	3	19.9	1880	53863	1110	237	218	205.4	183.2	162.9	123.5	69.1	48.7
307	3	20.1	1920	53863	1111	196.6	183.9	175.5	159.1	144.4	116.8	73.1	53.4
308	3	20.6	2120	55135	1115	145.4	133	126.7	116	106.6	87.6	57.6	43.3
309	3	20.6	2160	54994	1117	151.4	137.7	129.5	117.4	106.9	87	55.4	41.3
310	3	21.6	2200	54711	1118	154.3	143.1	136.5	125.5	114.8	94.8	61.4	45.3
311	3	21.6	2240	55842	1119	172.8	157.4	148.2	132.7	119.3	93.6	58.9	42.9
312	3	21.8	2280	57114	1121	157.5	142.5	132.9	118.1	104.2	81.2	48.1	34.9
313	3	22.2	2320	57468	1122	140.8	126.7	119.9	108.9	98.8	80.4	51.5	39.1
314	3	21.7	2360	54357	1123	301.9	279.7	261.1	228.6	199	145.2	73.9	50.1
315	3	22.7	2400	58881	1125	159.2	142.8	132.9	118.5	107.2	86.7	54.9	41.9

Point	Drop	Temp, C	DMI	Load	Time	D1	D2	D3	D4	D5	D6	D7	D8
316	3	22.3	2440	54216	1126	195.9	184.4	177.4	163.9	149.5	121.3	74.4	52.5
317	3	12.5	2480	52095	1127	153.8	142.7	136.1	125.8	115.1	93.6	60	44.2
318	3	22.3	2520	56619	1128	220.9	210	200.9	184	165.8	126.5	69.9	47.3
319	3	22	2560	55488	1129	129	119.7	114.8	106.1	97.7	80.8	52.9	39.9
320	3	22.2	2600	54923	1131	219.8	200.8	188.9	168.1	148.3	111.2	60	40.5
321	3	21.9	2640	56973	1132	141.5	129.8	122.6	112.3	99.1	77.8	47	37.2
322	3	22.1	2680	55347	1133	121.1	112.9	107	98.9	91.2	75.6	51.1	38.1

ME Analysis and Design with CalME

Following *CalBack* analysis of the deflection and thickness data, *CalME (vers. 1.02 [03-07-2011])* was run with the various design alternatives. Standard Caltrans designs were run. For ME-based designs, layer thicknesses were adjusted to produce the most efficient designs that still met the limiting criteria for HMA rutting (0.04 ft, 0.5 in., 12 mm) and cracking (0.15 ft/ft^2, 0.5 m/m^2) as predicted by *CalME*. Important *CalME* screens are presented below.

Figure A.8 shows the window where structural section information can be input for *CalME* (indicated by the "S" in the figure). Material type, thickness, and moduli are the primary inputs. The figure also shows the incremental recursive screen (indicated by "I-R" in the figure) with simulation inputs, such as the parameters regarding reflective cracking and the construction variability of materials. When the construction variability box is checked in the I-R screen, the modulus variability (the moduli standard deviation factor indicated by "sdf Modulus") and the thickness variability (the coefficient of variation indicated by "CoV Thickness") can be seen for each layer.

Figure A.9 shows the cracking-versus-time plot for a 0.10 ft (30 mm) RHMA-G overlay on Section 1. Note the mean estimate, or 50 percent reliability, of crack progression (the thick line below 0.05 ft/ft^2) and the limiting criteria at 0.15 ft/ft^2. However, the *CalME* analysis shows that with 90 percent reliability, the 0.10 ft (30 mm) overlay cannot be expected to endure for the 20-year design life. The layer thicknesses were then adjusted upward and *CalME* was rerun until both the cracking and rutting criteria were met. In this case, the 0.15 ft (45 mm) thickness of RHMA-G provided good performance throughout the 20-year design life with 90 percent reliability. This is shown in the cracking-versus-time plot in Figure A.10.

Figure A.11 shows the rutting-versus-time plot for the same 0.15 ft (45 mm) RHMA-G overlay on Section 1. Note the progression in rut depth (the thick blue line at about 0.05 in.) and the established limiting criteria (the straight line at 0.5 in.). This pavement reaches the desired 20-year life for rutting.

The *CalME* structure screen has an “Edit Material Parameters” button (the dotted circle in Figure A.8), that allows users to specifically tailor a given material behavior in the program. These parameters are preset but can be adjusted. Figures A.12 through A.15 show the recursive material parameters for the existing materials used in this project: the existing 1963 DGAC, 1999 DGAC, cement-treated base, and aggregate subbase. Figures A.16 through A.19 show the modulus and recursive parameters for the HMA with PG 64-10 binder and RHMA-G from the Materials Library. These parameters were unchanged throughout the analysis.

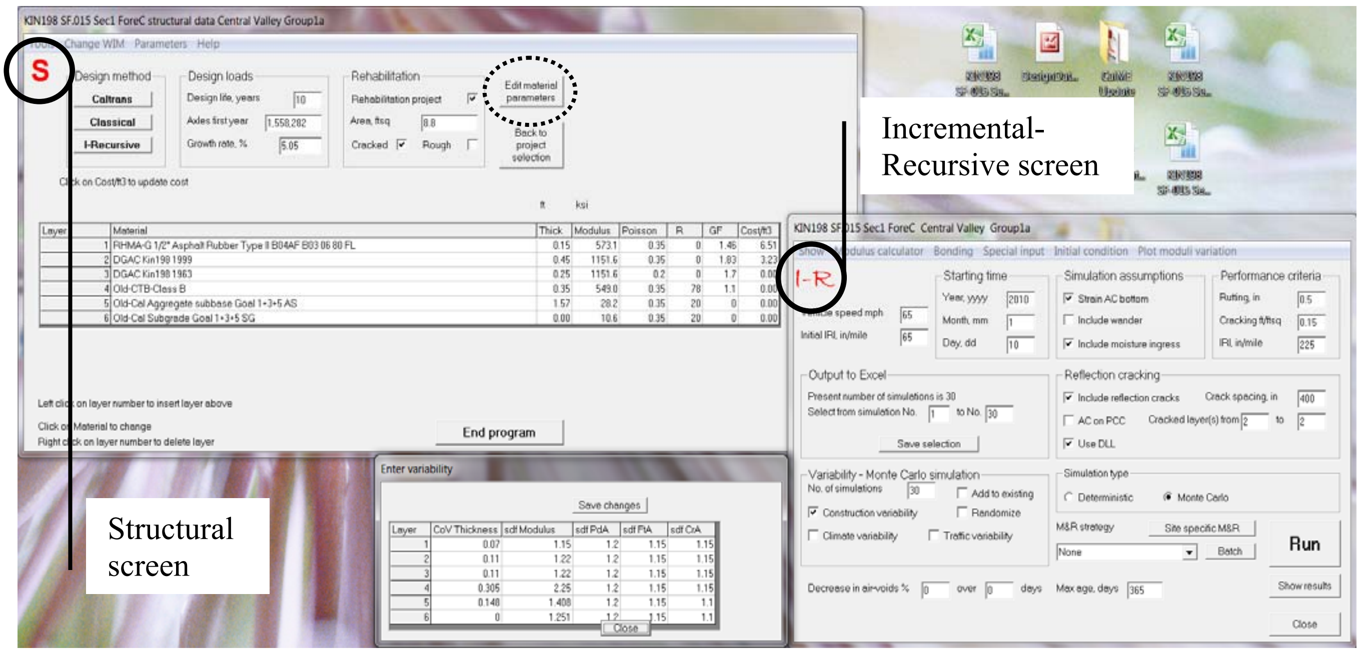


Figure A.8: Screen shot of Section 1 incremental-recursive design inputs for Monte Carlo variability simulation with 0.15 ft (45 mm) RHMA-G overlay.

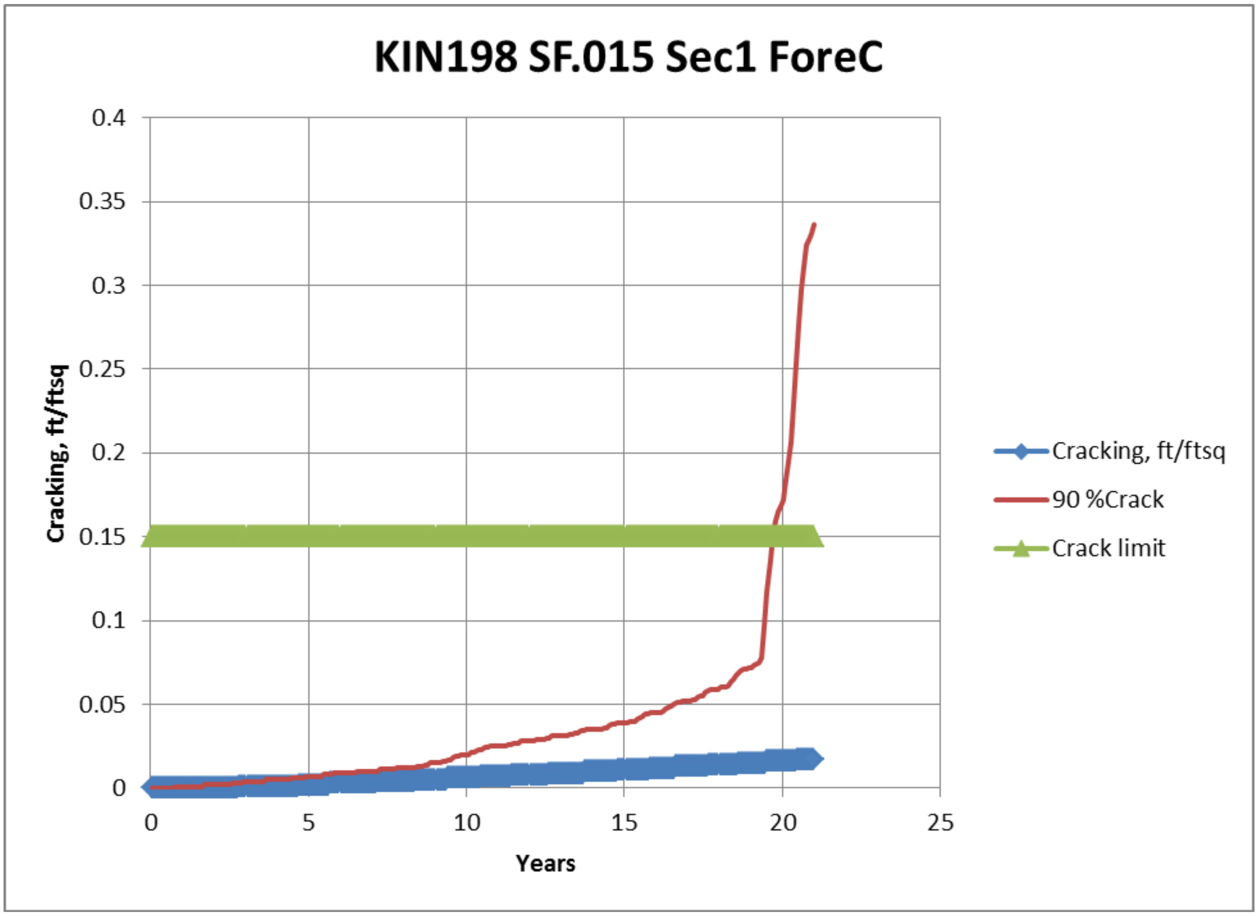


Figure A.9: Cracking-versus-time plot from *CalME* for a 0.10 ft (30 mm) RHMA-G overlay on Section 1. Note: The mean estimate of cracking after 20 years, with 50% reliability (0.02 ft/ft^2), is well below the failure criteria of 0.15 ft/ft^2. After 18 years, there is a 90% reliability of cracking not exceeding 0.08 ft/ft^2. But after 20 years, cracking exceeding 0.15 ft/ft^2 can be expected.

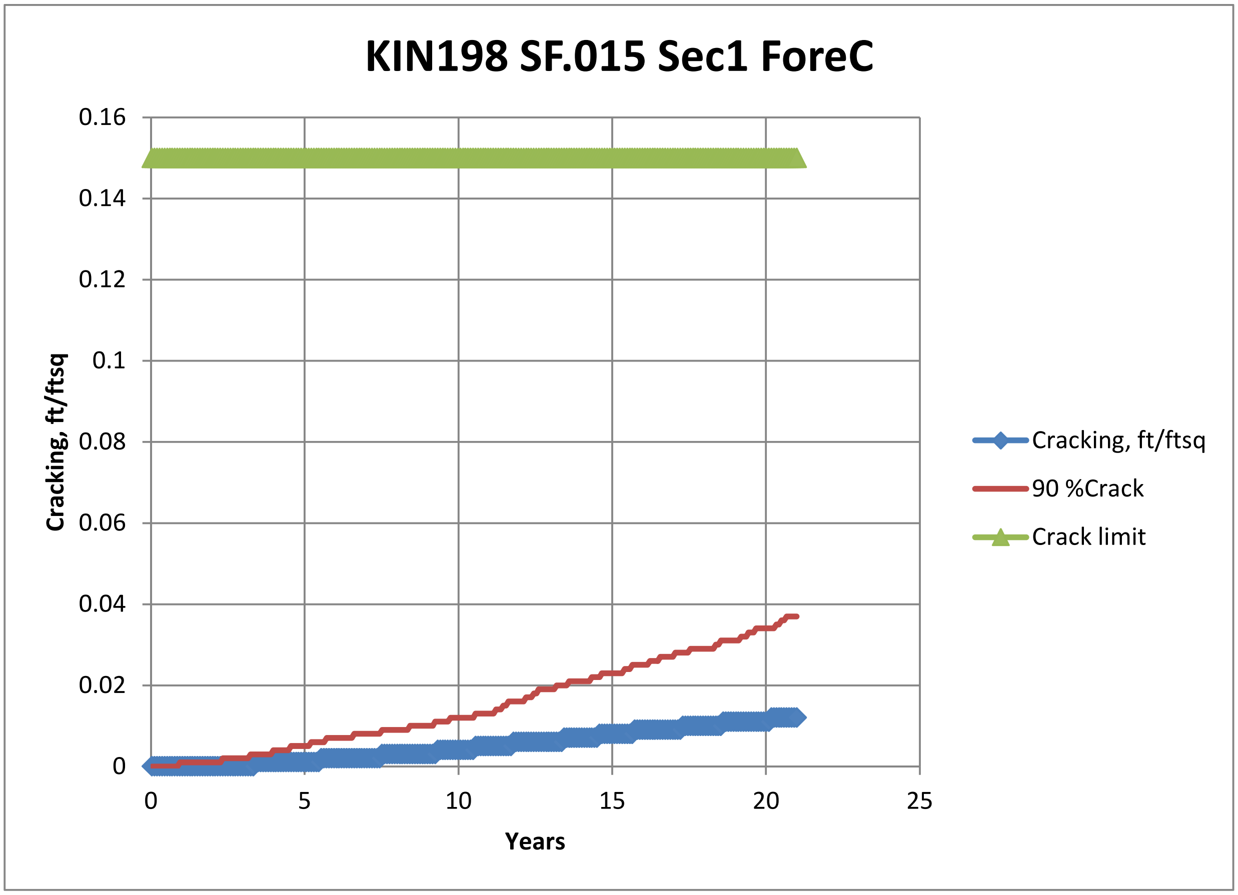


Figure A.10: Cracking-versus-time plot from *CalME* for a 0.15 ft (45 mm) RHMA-G overlay on Section 1. Note: The mean estimate of cracking after 20 years, with 50% reliability (0.01 ft/ft^2), is well below failure criteria of 0.15 ft/ft^2. Even after 20 years, there is a 90% reliability of cracking not exceeding 0.04 ft/ft^2.

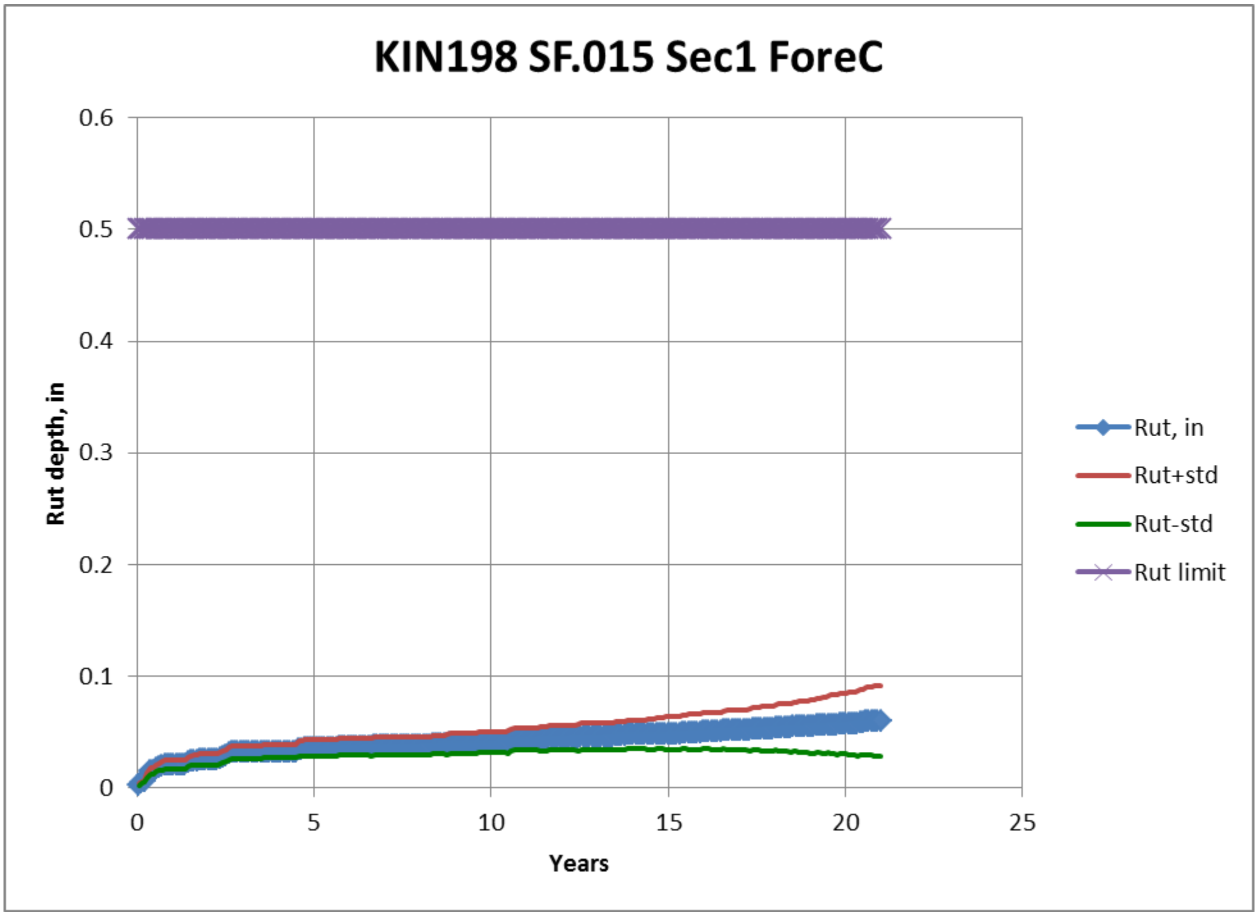


Figure A.11: Rutting-versus-time plot from *CalME* for a 0.15 ft (45 mm) RHMA-G overlay on Section 1. Note: The mean estimate of rutting after 20 years, with 50% reliability (0.06 in.), is well below the failure criteria of 0.5 in. The mean plus one standard deviation shows no more than 0.09 in. of rutting after 20 years with 68% reliability, and no more than 0.1 in. with 90% reliability.

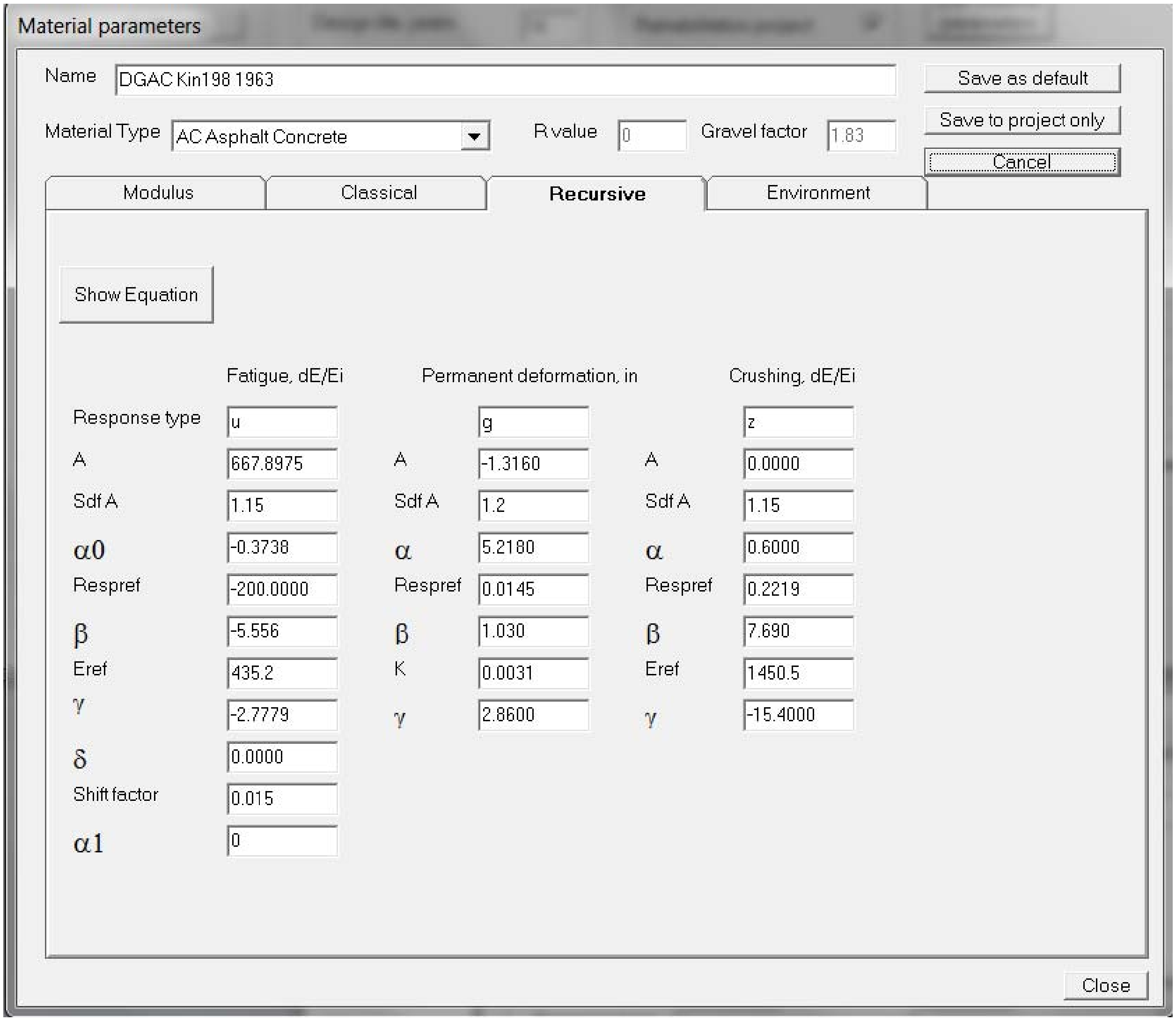


Figure A.12: Material parameter inputs for the DGAC from 1963 used in the *CalME* analysis.

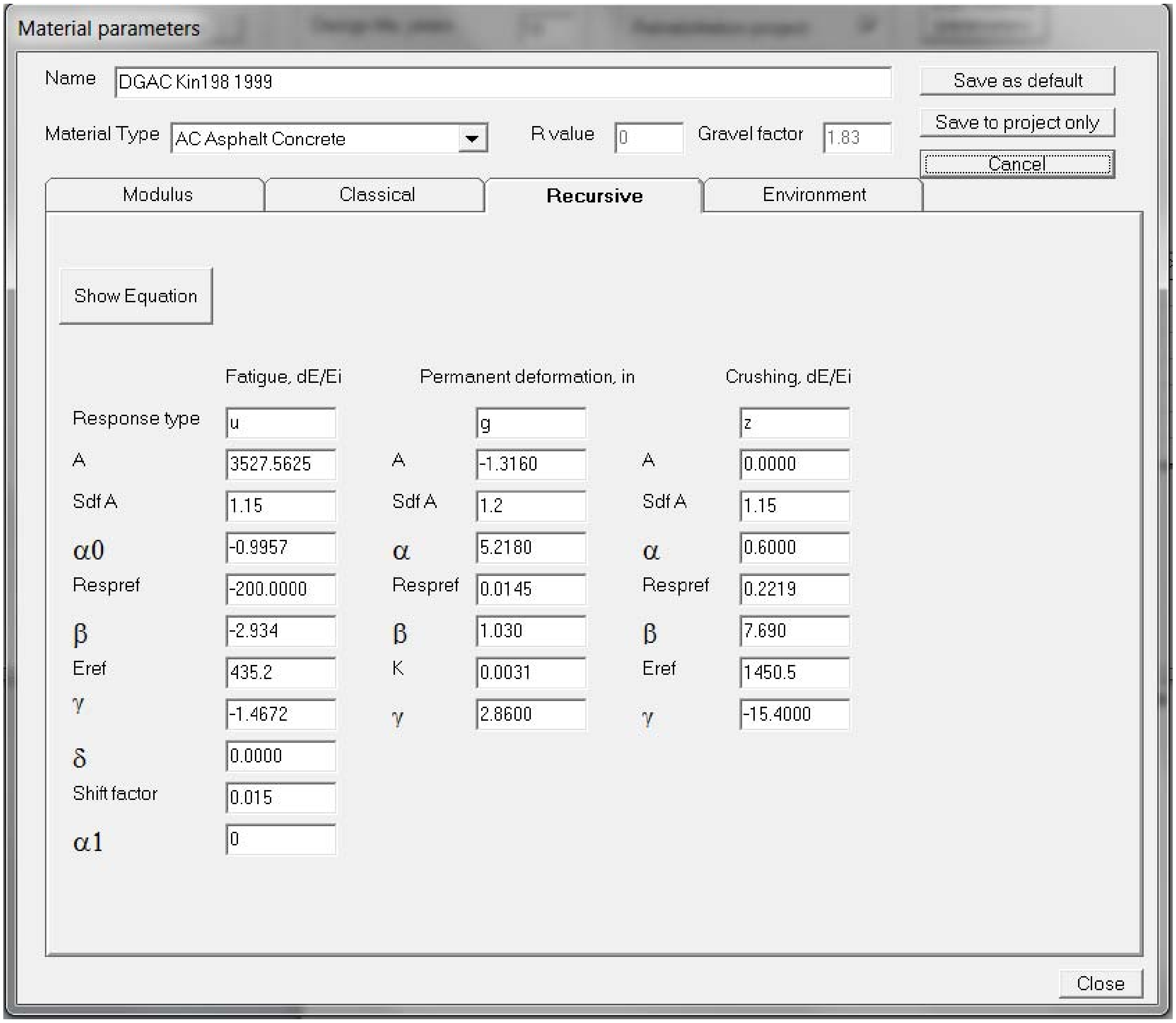


Figure A.13: Material parameter inputs for the DGAC from 1999 used in the *CalME* analysis.

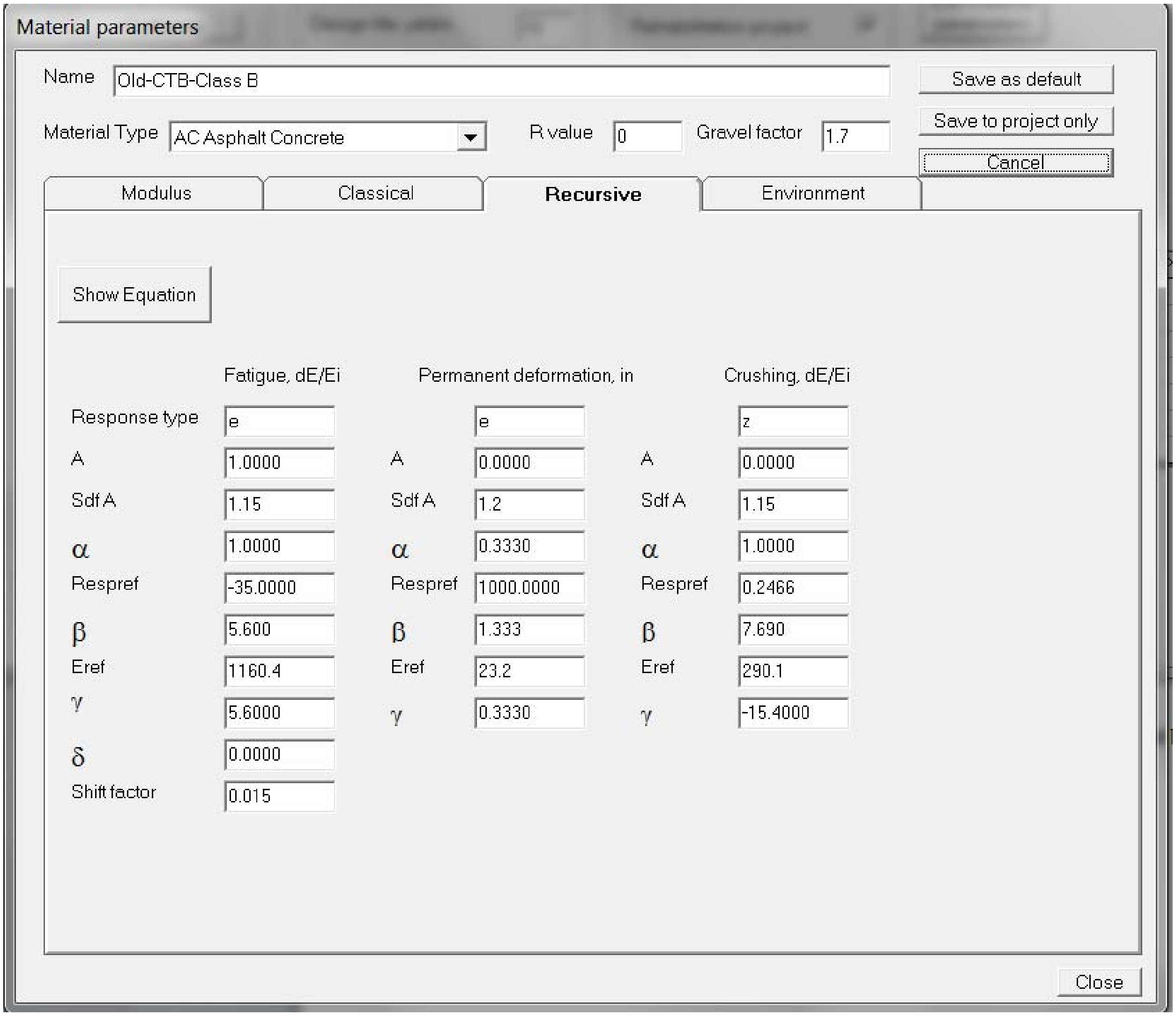


Figure A.14: Material parameter inputs for the cement-treated base used in the *CalME* analysis.

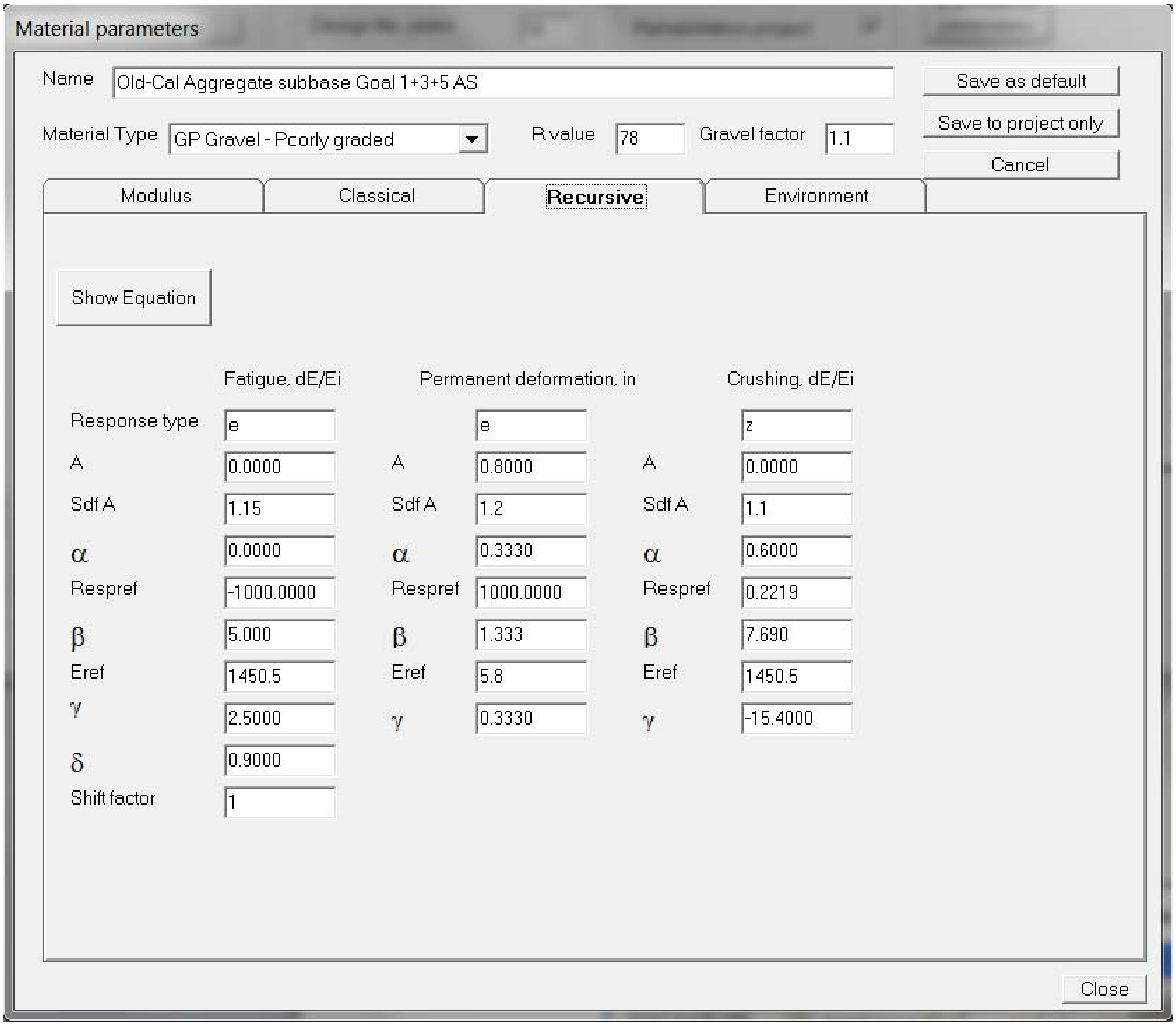
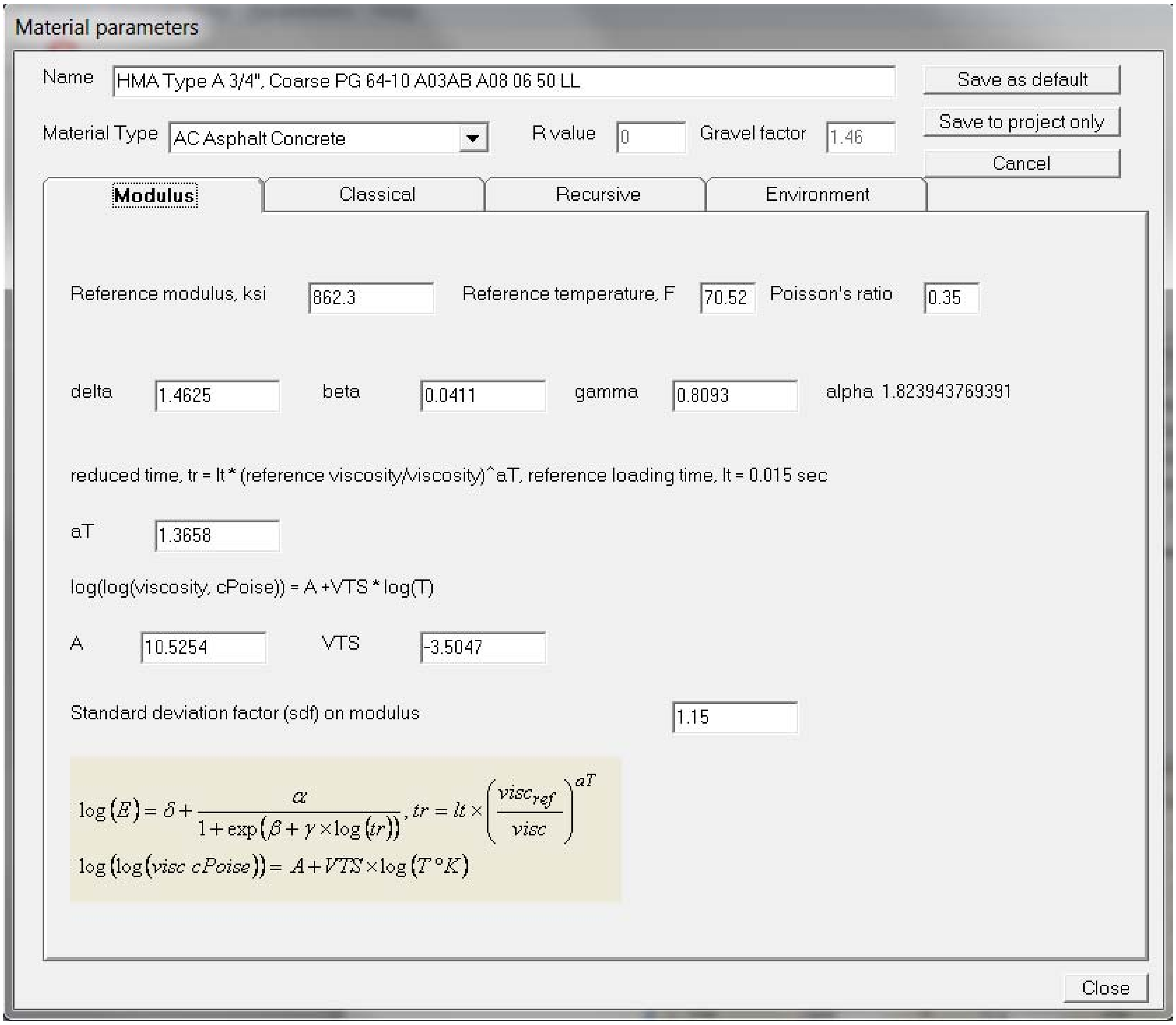


Figure A.15: Material parameter inputs for the calibrated aggregate subbase used in the *CalME* analysis.



$$\log(E) = \delta + \frac{\alpha}{1+\exp(\beta+\gamma\times\log(tr))}, tr = lt \times \left(\frac{visc_{ref}}{visc}\right)^{aT}$$

$$\log(\log(visc\ cPoise)) = A + VTS \times \log(T\,°K)$$

Figure A.16: Material parameter modulus inputs for the PG 64-10 HMA used in the *CalME* analysis.

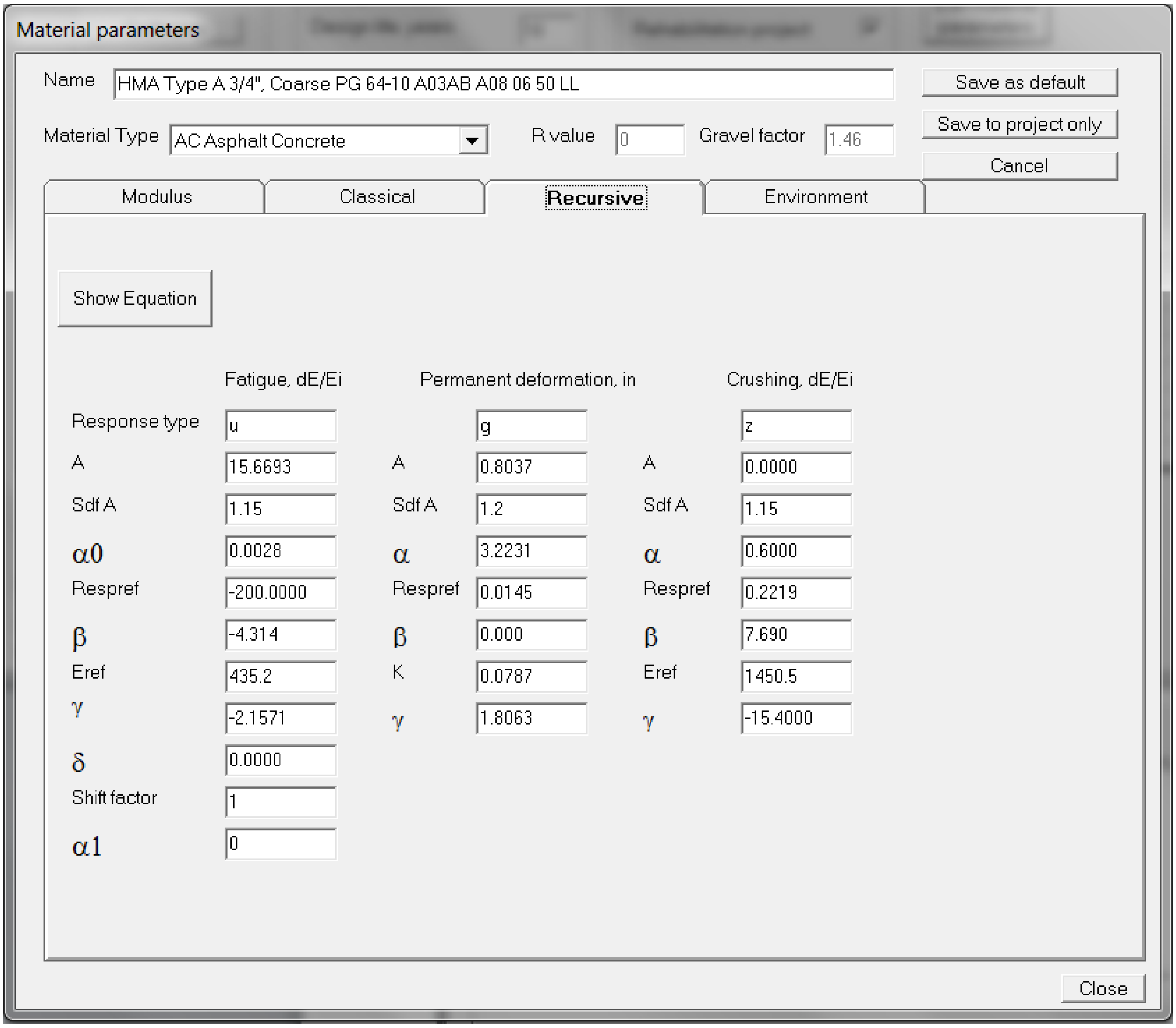


Figure A.17: Material parameter recursive inputs for the PG 64-10 HMA used in the *CalME* analysis.

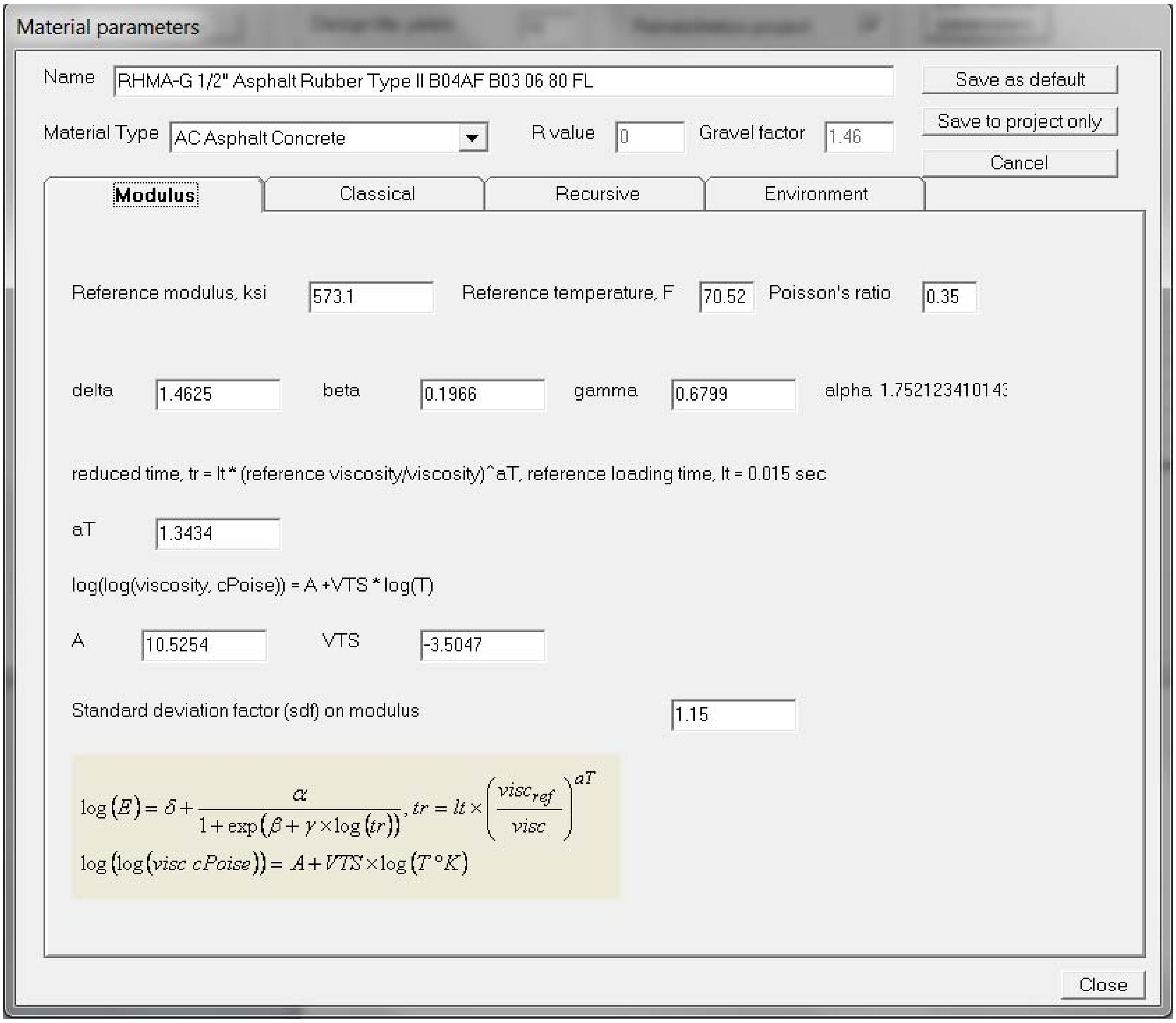


Figure A.18: Material parameter modulus inputs for the RHMA-G used in the *CalME* analysis.

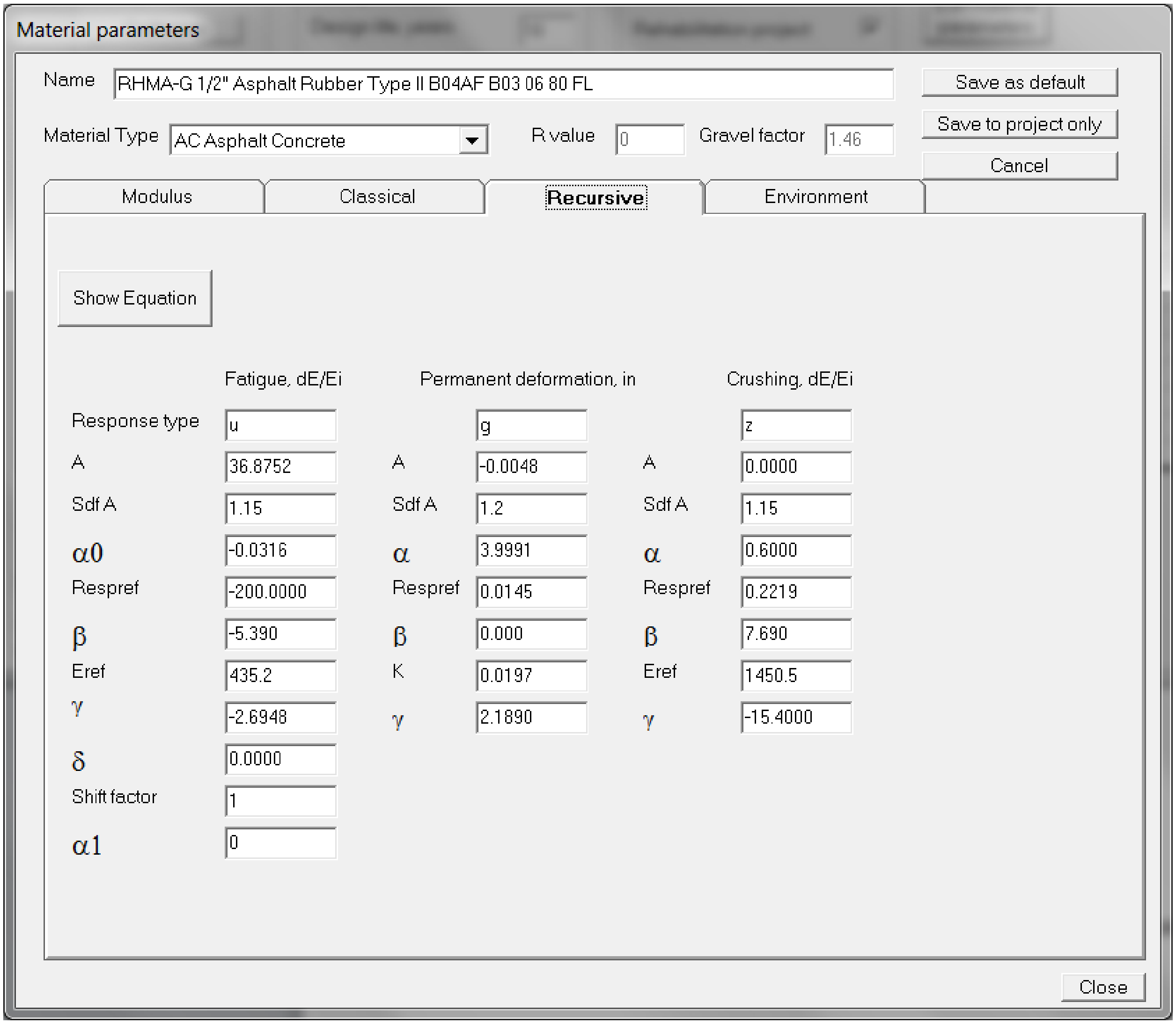


Figure A.19: Material parameter recursive inputs for the RHMA-G used in the *CalME* analysis.