Title

Rehabilitation Design for 02-PLU-36, PM 6.3/13.9 Using Caltrans ME Design Tools: Findings and Recommendations

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Publication Date

2009-08-01

August 2009
Technical Memorandum: UCPRC-TM-2008-01

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

PREPARED FOR:	**PREPARED BY:**
California Department of Transportation Division of Research and Innovation Office of Roadway Research, and Division of Pavement Engineering Office of Pavement Design	University of California Pavement Research Center UC Davis, UC Berkeley

DOCUMENT RETRIEVAL PAGE

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Prepared for:	**FHWA No.:**	**Date Work Submitted:**	**Report Date**:
Caltrans Division of Research and Innovation and Division of Design	CA101201C	January 27, 2010	August 2009

Strategic Plan No:	**Status:**	**Version No:**
3.4	Stage 6, final version	1

Abstract:
This technical memorandum presents the results of pavement evaluation and rehabilitation design of 02-PLU-36, PM 6.3/13.9. The pavement evaluation consists of deflection testing, coring, material sampling, backcalculation of stiffnesses, and condition assessment. Rehabilitation designs were developed using standard Caltrans methods. Alternative rehabilitation designs were developed using mechanistic-empirical software and models (*CalME*). Performance of all designs was assessed using mechanistic-empirical models. Suitable designs are recommended.

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

Proposals for implementation: Implement a plan for field evaluation of performance 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 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. 2009. University of California Pavement Research Center, Davis and Berkeley. UCPRC-TM-2008-02.
- *Rehabilitation Design for 06-KIN-198, PM 9.2/17.9 Using Caltrans ME Design Tools: Findings and Recommendations.* I. Guada, J. Signore, R. Wu, L. Popescu, and J.T. Harvey. 2010. University of California Pavement Research Center, Davis and Berkeley. UCPRC-TM-2008-03.

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DISCLAIMER

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ACKNOWLEDGMENTS

This work was funded and managed by the California Department of Transportation, Division of Research and Innovation, under the direction of Nick Burmas, Joe Holland, Michael Samadian, and Alfredo Rodriguez. The Pavement Standards Team technical leads were Bill Farnbach and Imad Basheer and the Caltrans Mechanistic-Empirical Design Technical Working Group, whose guidance is appreciated. The comments of District 2 Caltrans personnel and the coordination by Lance Brown are gratefully acknowledged.

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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 Chester, CA, designated 02-PLU-36, PM 9.3/13.9, and it outlines the procedures and findings of each step of the design and analysis, from presite 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. In 2010, District 2 engineering staff requested that additional designs be developed with an emphasis on full-depth recycling using cold-in-place foam. These designs have been incorporated into this memorandum.

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)

The map in Figure 1 shows where the three case study projects were located.

Figure 1: Map showing locations of three case studies.

PRESITE VISIT EVALUATION

Following project location identification by Caltrans, UCPRC staff contacted District 2 personnel to obtain existing information regarding as-builts, construction history, coring logs, distress surveys, deflection test results, and any other relevant information. This information was studied along with Caltrans pavement photologs to create a preliminary field testing plan that was later 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 made, and possible trenching locations were identified. District personnel established a traffic control plan for one day of field evaluation and testing. The field testing plan test plan was revised by UCPRC as requested by District 2 and sent back to all personnel involved.

SITE DESCRIPTION

The pavement for this case study is on State Route 36, near Chester, in Plumas County. Caltrans records show that the existing pavement structure was reconstructed in 1949 and has been overlaid with thin (0.10 ft) layers of HMA at various times. Construction records lacked the detail needed to determine the exact post mile limits of each overlay. The existing highway had extensive areas of cracking, providing a low level of service to highway users. The highway section chosen for the case study extended from Post Mile 6.3, at the junction of State

Route 89 near the northeast corner of Lake Almanor, to Post Mile 13.9, at the intersection with County Road A-13.

The section of highway was divided into three subsections based on as-builts and current condition, as follows:

- A section designated West that is flat at grade (elevation 4,515 ft [(1,375 m]) and that was subdivided into four parts:
    - West A: a two-lane rural section west of Chester
    - West B: a two-lane section in the town of Chester
    - West C: a four-lane section in the town of Chester
    - West D: a second two-lane section in the town of Chester
- A section designated Causeway that crosses an inlet of Lake Almanor and then climbs above the lake with an elevation gain of 380 ft (115 m) over 3.375 mi (5.4 km) at an average grade of 2.1 percent.
- A section designated East that is a combination of benched construction on the hillside and cut-and-fill sections.

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

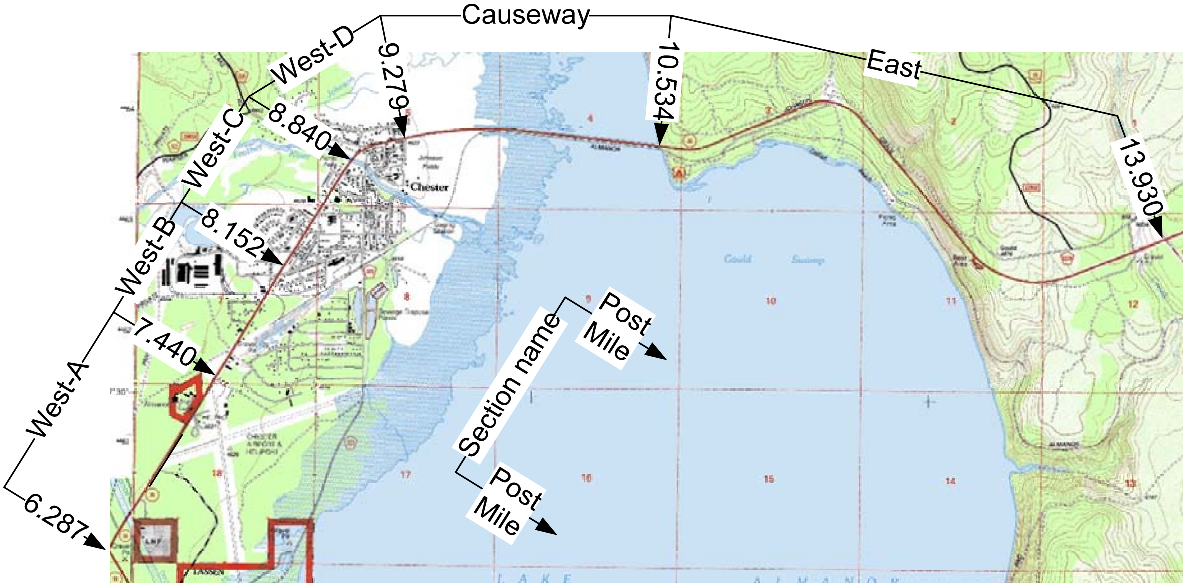


Figure 2: Map showing subsection locations.

Table 1: Subsection Locations and Lengths

Section	Post Mile	Field STA ft (m)	Section Length ft (m)	Landmark	Type	# Lanes
	6.287	0+00 (0)		Junction SR 36 & 89		
West A			6,091 (1,855)		Rural	2
	7.440	60+91 (1,855)		Plumas Co. Airport Rd		
West B			3,762 (1,146)		Town	2
	8.152	98+53 (3,001)		Collins Drive		
West C			3,635 (1,107)		Town	4
	8.840	134+88 (4,108)		N. Fork Feather River Bridge		
West D			2,318 (706)		Town	2
	9.279	158+06 (4,814)		West End causeway		
Causeway			6,629 (2,019)		Rural	2
	10.534	224+35 (6,833)		East End causeway		
East			17,940 (5,464)		Rural	2
	13.930	403+78 (12,298)		Junction SR 36 & County Rd. A-13		

FIELD INVESTIGATION—FINDINGS

On October 10, 2007, UCPRC and Caltrans personnel completed a one-day site investigation that included collection of FWD deflection data to determine the structural capacity of the existing pavement structure, coring at 18 locations to determine HMA layer thickness, and Dynamic Cone Penetrometer testing at 11 locations to examine the granular base thickness and estimated subgrade stiffness. Photographs of the pavement surface condition were also taken.

Pavement Condition

The pavement surface had extensive fatigue-type cracking in the wheelpaths and extensive transverse cracking across the roadway throughout the project length. The transverse cracking was likely thermal cracking, given the area’s climate conditions (High Mountain climate region). At numerous locations, transverse cracks progressed to a small area of fatigue-type cracking in the wheelpaths, and then changed to continuous wheelpath cracking. There were also extensive areas where one or both wheelpaths had been dug out and inlaid with new HMA material. The extracted cores showed that the cracking was either mostly surface-initiated or the result of debonding between the upper HMA layers. Representative photographs of the pavement are shown in Figure 3, Figure 4, and Figure 5.

It was concluded that thermal cracking was the predominant distress mechanism at work, as this process allows ingress of water which then softens the layers below the HMA layer and results in fatigue cracking of the HMA layer. The application of thin overlays does little to prevent reflective cracking due to cracks in the existing structure.

In addition to pavement condition, this rehabilitation also had to consider the finished grade height, particularly in downtown Chester where the rehabilitated roadway needed to match or nearly match grade. Since electrical and communication utilities were above ground, they posed no significant issues. Similarly, there were neither gas nor fiber optic utilities underground to affect the design. Lastly, water and sewer lines had been replaced recently and were about three feet below grade.

Figure 3: Two-lane section west of Chester adjacent to western part of Chester airport, approx. PM 6.9, WB.

Figure 4: Four-lane section in Chester, approx PM 8.4 (near Riverwood), EB.

Figure 5: Two-lane section over causeway, approx. PM 10.4, EB.

Pavement Coring

Results from the coring operations showed a consistent HMA layer with a thickness of 0.37 ft (115 mm) in sections West B, West C, and West D. Section West A had a thickness of 0.41 ft (125 mm) at STA 32+83 (1,000 m) and an average thickness of 0.69 ft (212 mm) at STA 42+68 ft (1,300 m) and 60+74 ft (1,850 m). The extent of the thicker section of HMA material in Section West A was unknown. (Note: A ground penetrating radar investigation would be able to show the extent of the thicker section of HMA and also the variability in the thickness of the HMA layer.) The thickness of the HMA layer on the Causeway section varied from 0.80 ft to 0.98 ft (245 mm to 300 mm), with an average thickness of 0.87 ft (265 mm) based on three cores. It was determined from five cores that the East section had an average thickness of 0.43 ft (130 mm) in the HMA layer and that this layer showed low variability. All of the cores from the East section showed a consistent pattern: an initial HMA layer (about 0.23 ft [70 mm]) and then a series of overlays approximately 0.08 ft (25 mm) thick. A diagram of the core thicknesses along the project is shown in Figure 6.

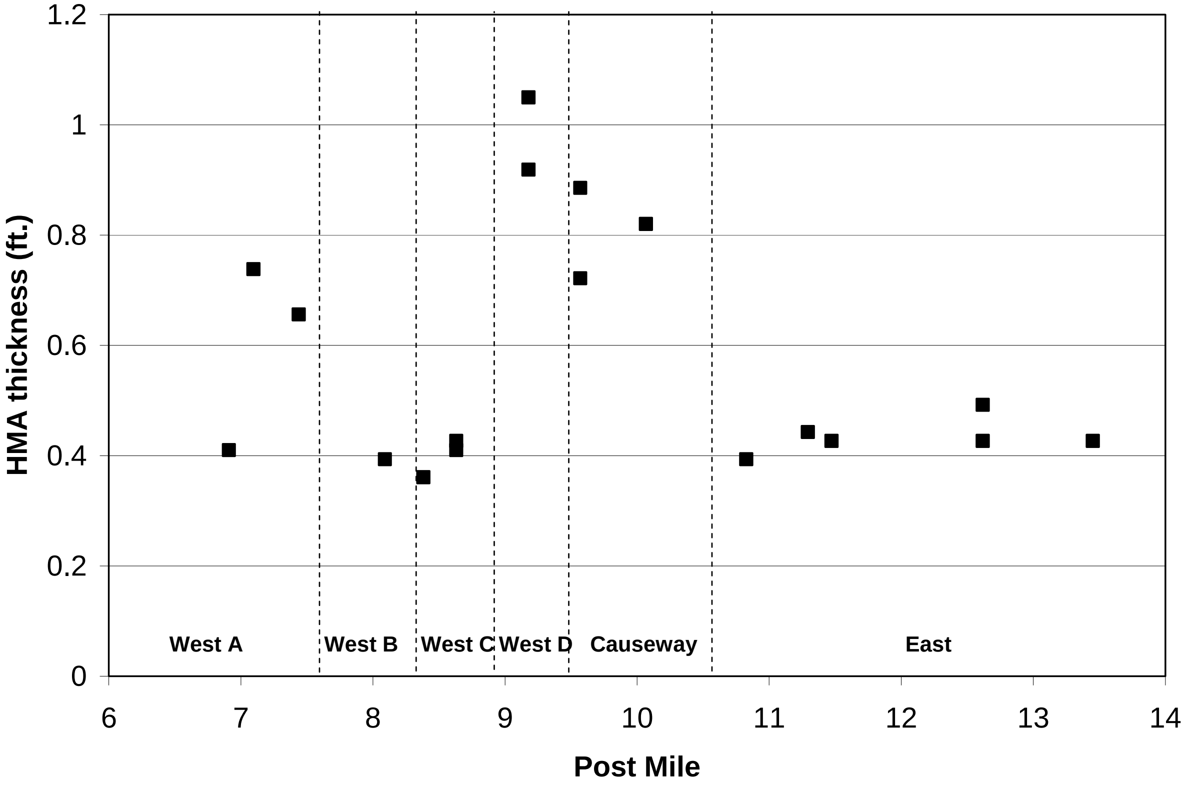


Figure 6: HMA core thicknesses by section and post mile (see Figure 2).

Pavement Section Details

Table 2 expands on Table 1 and shows the six pavement sections with their corresponding pavement layer thicknesses, 80th percentile deflection values, and backcalculated layer stiffnesses (moduli) from analysis using *CalBack.*

Table 2: Pavement Field Investigation Findings

Section	PM	Field Station ft (m)	Section Length ft (m)	Landmark	Type	No. lanes	Existing Section				80th % Defl. (mils)	Backcalc. Stiffness		
							HMA Thick. Range (ft) *(Cores)*	HMA Thick Typical for back calculation (ft)	AB Thick. (ft.) *(from DCP) UCS*	SG Soil		HMA psi (Mpa)	AB psi (MPa)	SG psi (MPa)
	6.287	0+00 (0)		Junction SR 36 & 89										
West A			6,091 (1,855)		Rural	2	0.35 to 0.75	0.4	0.65 to 1.0	SC/SM GC/GM	10.6	1,500,000 (10,350)	36,000 (250)	18,000 (125)
	7.44	60+91 (1,855)		Plumas Co Airport Rd					(GW)					
West B			3,762 (1,146)		Town	2	0.4	0.4	0.65 to 1.0	SC/SM GC/GM	13.9	1,750,000 (12070)	55,000 (380)	14,000 (95)
	8.152	98+53 (3,001)		Collins Drive					(GW)					
West C			3,635 (1,107)		Town	4	0.35 to 0.45	0.4	0.65 to 1.0	SC/SM GC/GM	16.6	1,100,000 (7600)	30000 (210)	14,000 (95)
	8.84	134+88 (4,108)		N Fork Feather River Bridge					(GW)					
West D			2,318 (706)		Town	2	0.9 to 1.05	0.95	0.65 to 1.0	SC/SM GC/GM	11.6	3,000,000 (20,700)	30,000 (210)	11,000 (75)
	9.279	158+06 (4,814)		West End causeway					(GW)					
Causeway			6,629 (2,019)		Rural	2	0.7 to 0.9	0.85	0.65 to 1.0		12.7	590,000 (4070)	20,000 (140)	15,000 (105)
	10.534	224+35 (6,833)		East End causeway					(GW)					
East			17,940 (5,464)		Rural	2	0.4 to 0.5	0.45	0.65 to 1.0	SC/SM GC/GM	15.2	1,400,000 (9650)	26,000 (180)	14,000 (95)
	13.93	403+78 (12,298)		Junction SR 36 & County Rd A-13					(GW)					

Deflection Data with Falling Weight Deflectometer (FWD)

The UCPRC Dynatest Falling Weight Deflectometer was used for deflection testing, and the resulting data was used for backcalculated estimations of layer stiffnesses with *CalBack*. At each testing (drop) location, two drops were made at three load levels (nominally 8,000 lb., 12,000 lb., and 20,000 lb.). In the West section, deflection testing was conducted in both directions from PM 6.3 to PM 9.3 with 330-ft (100-m) spacing, staggered in lanes in the opposite direction at 165 ft (50 m). In the Causeway and East sections, from PM 9.3 to PM 12.3, testing was generally in one direction with 250-ft (75-m) spacing although the direction changed at various points along the road due to traffic closures and time limitations. In the East section, from PM 12.3 to PM 13.9, testing was generally in one direction with 330-ft (100-m) spacing with the direction changing at various points along the road.

Material Sampling for Laboratory Testing and Analysis

Gradations were performed on sampled base and subgrade materials. The aggregate base material throughout the length of the project was well-graded gravel with sand (GW). The subgrade samples varied from silty clayey sand with gravel (SC/SM) to silty clayey gravel with sand (GC/GM). In the East section, the surface of the ground adjacent to the highway and the cut faces were rocky. Due to the highly granular nature of this subgrade material, Atterberg limit tests were not performed. A best estimate of Plasticity Index is 1 to 3.

Dynamic Cone Penetrometer (DCP) Testing

DCP testing and augering in core holes were used to estimate thicknesses of the base and subbase, and the stiffnesses of the base, subbase, and subgrade. Unlike the coring of HMA, the DCP yields inexact layer thickness measurements. In general, however, the greater the number of inches per blow with the DCP, the softer the material is understood to be and changes in the rate of travel per blow indicate potential changes in material. Figure 7 shows this project's results, which were highly variable due to the rocky nature of the base and subgrade. Vertical lines—for example, the blue and green ones—show constant depth per blow for up to two feet depth, indicating a relatively constant stiffness throughout. However, this contrasted with augering results that showed a transition to subgrade before that depth. The pink and purple lines show increased depth per blow at about 1 ft down, indicating the top of subgrade. These results are highly variable, but when viewed with augering material from core holes, engineering judgment led to an estimated average base thickness of 0.67 to 1.0 ft. Penetration depths substantially greater than 1 ft were possible in only three of the eleven tests due to the presence of stiff base material and/or large rocks (which impeded the penetrometer tip). The DCP results from STA 42+68 ft (1,300 m), Core 2 in Section West A, where the thicker layer of HMA (0.74 ft, 225 mm) was found, showed a weaker layer near the surface with a stronger layer at depth. In Section West D, at STA 152+67 ft, the soil was the project's weakest and showed uniform stiffness with depth. At STA 32+83 ft, 2-ft depth was attainable, but with a low blow count per inch rate. The remainder of the tests had to be terminated at depths less than 1 ft due to stiff base material.

Additional Information

Additional information was collected, including pavement profile (grades and cross slopes), GPS latitude and longitude for core location (in wheelpath/not in wheelpath), and general topography information (cut or fill).

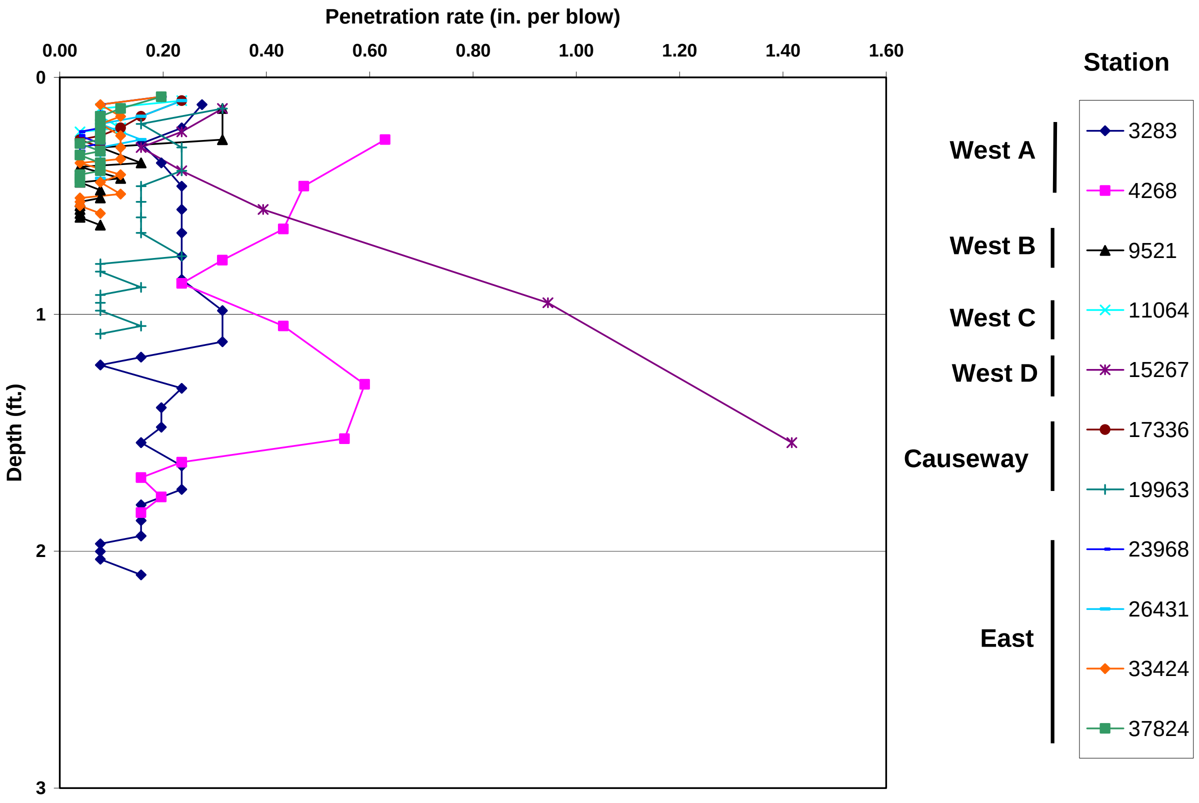


Figure 7: DCP locations and results.

DESIGN PROCEDURES AND REHABILITATION RECOMMENDATIONS

Procedure Overview and Design Inputs

The new 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*, which is also capable of performing current Caltrans R-value and overlay thickness design calculations. The results from the field investigation provided inputs for the design.

The design inputs for *CalME* appear below:

- Materials:
    - *Layer thickness.* 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. (For results, see Table 2.)
    - *Material classification.* Materials were classified by gradation, which provides information regarding approximate stiffnesses. (For results, see Table 2.)
    - *Stiffness. CalBack* was used with layer thickness, material classification, and FWD (deflection) test results to determine layer stiffnesses. (For results, see Table 2.)
    - *Resistance to permanent deformation and fatigue cracking.* This study used shear test and beam fatigue values contained in the *CalME* Standard Materials Library for a crushed granite aggregate from elsewhere in the state and a PG 64-28 binder without polymer modification. At the time of writing, the Standard Materials Library did not include fully characterized materials typical of those used in District 2. The standard material PG grade was selected from the Caltrans California Climate Regions map. Some design options included shear and beam fatigue results from the *CalME* Standard Materials Library for a typical rubberized hot-mix asphalt gap-graded (RHMA-G) material and a gap-graded modified binder (MB) mix from elsewhere in the state. The expected performance of actual District 2 materials may be better than those modeled in this document.
    - *Traffic.* Estimates of future traffic were made in terms of total traffic and truck traffic, with seasonal variations. Actual counts from 1998, 2004, and 2007 were used as the basis for computing the Traffic Index (TI) for the Caltrans design methods.
        - With 0 percent growth: TI=10.0
        - With 2 percent growth: TI=10.2
        - Caltrans Design TI=10.0

      For ME designs, *CalME* calculated traffic loading and axle-load spectra from the same traffic data using typical Weigh-In-Motion data applicable to this project. Inputs to *CalME* were the number of axles in the first year, the growth rate, and the design period.

- Climate
    - Data for the High Mountain Region and site pavement temperatures estimated in *CalME* were used.
- Performance
    - A 20-year design was assumed with two limiting failure criteria: fatigue cracking extent of 0.15 ft/ft^2 (0.5 m/m^2) Alligator A cracking and vertical compression of the HMA of 0.02 ft (8.0 mm, which corresponds to 0.04 ft [12.5 mm] total rutting).

Preliminary Design Options—General

Preliminary design options were reviewed in a scoping meeting with District 2. Based upon the design inputs and performance criteria, preliminary design options were evaluated. The designs were input into *CalME* and the performance predictions were compared against the predetermined failure criteria. If a design failed one or both of the design criteria—rutting or cracking—it was eliminated. This iterative process was followed for each of the rehabilitation design options.

The rehabilitation design strategies that were considered are listed below. (*Note: The pulverization designs were selected based on the design life and the criteria in the Caltrans* Flexible Pavement Rehabilitation Guidelines.)

- R-value with pulverization of existing pavement and overlay to create a pavement structure of pulverized aggregate base (PAB) and HMA overlay
- Caltrans deflection-based overlay - No structural overlay required -Mill and Fill Design
- *CalME* pulverize and overlay
- *CalME* pulverize with lime/cement and overlay
- *CalME* pulverize with lime/cement, remove, and overlay.

As noted earlier, this project was divided into six sections according to their pavement structure and alignment: West A, West B, West C, West D, Causeway, and East. For design purposes the six sections were grouped together based on the structural similarities of their existing structures as follows:

- West A, West B, West C—0.40 ft HMA/0.65 ft AB nominal
- West D, Causeway—0.8 to 1.0 ft HMA/0.65 ft AB nominal
- East—0.45 ft HMA/0.65 ft AB nominal (comparable in pavement structure to West A, West B, West C)

Design Alternatives for Sections West A, West B, West C, West D, Causeway, and East

Table 3 shows the design options considered for sections West A, West B, West C, and East. Table 4 shows the design options considered for sections West D and the Causeway.

Table 3: Design Alternatives Developed with *CalME*—West Sections A, B, C, and East

Design Option		**Design Structural Section Existing Section:** • **0.40 ft (120 mm) HMA** • **0.65 ft (200 mm) AB** • **SG**	**Grade Change ft (mm)**	**20-Year Performance (90% Reliability)**	
				Rutting mm in.	**Cracking m/m^2 ft/ft^2**
1. R-value with pulverization * *Process: Pulverize existing HMA plus 0.10 ft AB, add overlay.*		• 0.50 ft (150 mm) PG 64-28PM HMA overlay • 0.45 ft (140 mm) PAB, R = 1.2 • 0.60 ft (175 mm) existing AB • SG	+ 0.5 ft (150 mm)	8.1 0.32	0.05 0.02
2. Caltrans deflection-based overlay—No structural overlay required -Mill and Fill Design *Process: Mill 0.2 ft (A), 0.15 ft (B), overlay with PG 64-28PM (A) or RHMA-G (B).* *Perform reflective cracking mill and fill overlay design per Chapter 600 of Caltrans* Highway Design Manual *(20-year life).*	A	• 0.25 ft (75 mm) PG 64-28PM overlay • 0.40 ft (60 mm) existing HMA • 0.65 ft (200 mm) existing AB • SG	0.05 ft (15 mm)	19.2 0.75 (FAILS)	3.0 0.9 (FAILS)
	B	• 0.15 ft (45 mm) RHMA-G overlay • 0.25 ft (70 mm) existing HMA • 0.65 ft (200 mm) existing AB • SG	0 ft (0 mm)	13.7 0.54 (FAILS)	11.6 3.5 (FAILS)
3. *CalME* pulverize and overlay *Process: Pulverize existing HMA plus 0.10 ft AB, add overlay.*		• 0.40 ft (125 mm) PG 64-28PM overlay • 0.50 ft (145 mm) pulverized • 0.55 ft (175 mm) existing AB • SG	0.40 ft (125 mm)	9.1 0.36	0.77 0.26
4. *CalME* pulverize with lime/cement and overlay ** *Process: Pulverize with lime/cement existing HMA plus 0.10 ft AB, add overlay.*	A	• 0.40 ft (125 mm) PG 64-28PM overlay • 0.50 ft (145 mm) pulverized 3% lime • 0.55 ft (175 mm) existing AB • SG	0.40 ft (125 mm)	8.4 0.33	0.47 0.14
	B	• 0.40 ft (125 mm) PG 64-28PM overlay • 0.50 ft (145 mm) pulverized 2% cement • 0.55 ft (175 mm) existing AB • SG	0.40 ft (125 mm)	7.8 0.31	0.30 0.09

Design Option	**Design Structural Section Existing Section:** • **0.40 ft (120 mm) HMA** • **0.65 ft (200 mm) AB** • **SG**		**Grade Change ft (mm)**	**20-Year Performance (90% Reliability)**	
				Rutting mm in.	**Cracking m/m^2 ft/ft^2**
5. *CalME* pulverize with lime/cement, remove, and overlay *Process: Pulverize existing HMA plus 0.65 ft (200 mm) AB, remove 0.40 ft (120 mm) pulverized material, add overlay (maintain existing grade).*	A	• 0.50 ft (150 mm) PG 64-28PM overlay • 0.75 ft (225 mm) pulverized • 0.0 ft (0 mm) existing AB (or possibly more if AB > 200 mm) • SG	0	6.2 0.24	0.11 0.03
	B	• 0.40 ft (125 mm) PG 64-28PM overlay • 0.75 ft (225 mm) pulverized 3% lime • 0.0 ft (0 mm) existing AB (or possibly more if AB > 200 mm) • SG	0	6.3 0.25	0.9 0.27
	C	• 0.40 ft (125 mm) PG 64-28PM overlay • 0.75 ft (225 mm) pulverized 2% cement • 0.0 ft (0 mm) existing AB (or possibly more if AB > 200 mm) • SG	0	5.7 0.2	0.5 0.15
6. CalME full depth reclamation—foam and overlay *Process: Reclaim with FDR foam existing HMA plus 0.10 ft (30 mm) AB, add overlay.*		• 0.4 ft (125 mm) PG 64-28PM overlay • 0.5 ft (150 mm) FDR foam • 0.55 ft existing AB • SG	0.4 ft	6.1 0.23	0.13 0.04

* Caltrans design methods, but performance simulated with *CalME.*

** ASTM Standard Test Method for Determining Stabilization Ability of Lime (MDSAL) or British Standard Initial Consumption of Lime (Cement) test (ICL/ICC) should be performed on subgrade material to determine exact lime/cement percentage required to reach desired stiffness and strength.

Table 4: West D and Causeway

Design Option	**Design Structural Section** **Existing Section:** • **0.90 ft (270 mm) HMA** • **0.65 ft (200 mm) AB** • **SG**		**Grade Change ft (mm)**	**20-Year Performance (90% Reliability)**	
				Rutting mm in.	**Cracking m/m^2 ft/ft^2**
7. R-value with pulverization * *Process: Pulverize existing HMA plus 0.10 ft AB, add overlay.*		• 0.50 ft(150 mm) HMA • 0.95 ft (295 mm) PAB, R = 1.2 • 0.55 ft (175 mm) existing AB • SG	+ 0.5 ft (150 mm)	7.4 0.3	0.03 0.01
8. Caltrans deflection-based overlay—No structural overlay required - Mill and Fill Design** *Process: Mill 0.45 ft (A and B), overlay with PG64-28 (A) or RHMA-G (B)* *Perform reflective cracking mill and fill overlay design per Chapter 600 of Caltrans* Highway Design Manual *(20 yr life).*	A	• 0.55 ft (170 mm) PG 64-28PM HMA overlay • 0.45 ft (135 mm) existing HMA • 0.65 ft (200 mm) existing AB • SG	0.2 ft (60 mm)	4.2 0.16	0 0
	B	• 0.15 ft (45 mm) RHMA-G overlay • 0.40 ft (125 mm) PG 64-28PM overlay • 0.45 ft (135 mm) existing HMA • 0.65 ft (200 mm) existing AB • SG	0.1 ft (35 mm)	4.6 0.18	0 0
9. *CalME* pulverize and overlay *Process: Pulverize existing HMA plus 0.10 ft AB, add overlay.*		• 0.40 ft (125 mm) PG 64-28PM overlay • 1.00 ft (295 mm) pulverized • 0.55 ft (175 mm) existing AB • SG	0.4 ft (125 mm)	8.3 0.33	0.67 0.20 (FAILS)
10. *CalME* pulverize with lime/cement and overlay *Process: Pulverize with lime/cement existing HMA plus 0.10 ft AB, add overlay.*	A	• 0.40 ft (125 mm) PG 64-28PM overlay • 1.00 ft (295 mm) pulverized 3% lime • 0.55 ft (175 mm) existing AB • SG	0.4 ft (125 mm)	7.5 0.30	0.36 0.11
	B	• 0.40 ft (125 mm) PG 64-28PM overlay • 1.00 ft (295 mm) pulverized 2% cement • 0.55 ft (175 mm) existing AB • SG	0.4 ft (125 mm)	6.9 0.27	0.20 0.06

Design Option	Design Structural Section Existing Section: • 0.90 ft (270 mm) HMA • 0.65 ft (200 mm) AB • SG		Grade Change ft (mm)	20-Year Performance (90% Reliability)	
				Rutting mm in.	Cracking m/m^2 ft/ft^2
11. *CalME* pulverize with lime/cement, remove, and overlay *** *Process: Pulverize existing HMA plus 0.65 ft (200mm) AB, remove 0.40 ft (120 mm) pulverized material, add overlay.*	A	• 0.40 ft (125 mm) PG 64-28PM overlay • 0.80 ft (250 mm) pulverized • 0.35 ft (100 mm) existing AB (or possibly more if AB > 200mm) • SG	0	8.6 0.34	0.70 0.21 (FAILS)
	B	• 0.40 ft (125 mm) PG 64-28PM overlay • 0.80 ft (250 mm) pulverized 3% lime • 0.35 ft (100 mm) existing AB (or possibly more if AB > 200 mm) • SG	0	7.8 0.31	0.39 0.12
	C	• 0.40 ft (125 mm) PG 64-28PM overlay • 0.80 ft (250 mm) pulverized 2% cement • 0.35 ft (100 mm) existing AB (or possibly more if AB > 200mm) • SG	0	7.2 0.28	0.23 0.07
12. CalME full-depth reclamation—foam and overlay *Process: Reclaim with FDR foam existing HMA plus 0.10 ft (30 mm) AB, add overlay.*		• 0.4 ft (125 mm) PG 64-28PM overlay • 1.0 ft (150 mm) FDR foam • 0.55 ft existing AB • SG	0.4 ft	4.2 0.17	0.0 0.0
13. CalME full-depth reclamation—foam and overlay *Process: Reclaim with FDR foam existing HMA plus 0.10 ft (30 mm) AB, remove 0.4 ft (120 mm) reclaimed material, add overlay.*		• 0.4 ft (125 mm) PG 64-28PM overlay • 0.6 ft (150 mm) FDR foam • 0.55 ft existing AB • SG	0.0 ft	5.2 0.21	0.25 0.01

* Caltrans design methods, but performance simulated with *CalME*.

** Delamination found to be present at 0.25 ft (several cores) and at approximately 0.6 ft (observed in one core only).

*** ASTM Standard Test Method for Determining Stabilization Ability of Lime (MDSAL) or British Standard Initial Consumption of Lime (Cement) test (ICL/ICC) should be performed on subgrade material to determine exact lime/cement percentage required to reach desired stiffness and strength.

FINAL DESIGN RECOMMENDATIONS

The design recommendations presented in this chapter are based on the results of the office and site investigations, analyses of materials with *CalBack*, and of designs using *CalME* Mechanistic-Empirical methods, the R-value method, and the Caltrans tolerable deflection-based method. *(Note:* In undertaking this rehabilitation project, the primary distresses exhibited on Route 36—extensive top-down and bottom-up fatigue, and thermal cracking—must be addressed.) The design alternatives include three general rehabilitation strategies: (1) *overlay,* (2) *pulverization and overlay,* and (3) *pulverization, remove material, and overlay;* and each design was evaluated with *CalME* for expected performance. A detailed life-cycle cost analysis of each was not performed as part of the work presented in this technical memorandum and needs to be performed by the District. Lastly, the design recommendations are specific to certain sections of this project, based on their existing structural section and potential grade constraints.

Recommended Design Alternative Strategies

Design 2 for all sections (the Caltrans 356 Design) indicates that no structural overlay is required. However, although thin blanket overlays may be insufficient to address the likely reflection of fatigue and thermal cracking into the overlay, this cracking can be minimized with proper binder selection. Regardless, this design is very unlikely to perform as well as the other designs because *CalME* currently only considers reflective cracking due to traffic loading and not that due to thermal expansion and contraction. For this reason the analysis does not show early failure for this design.

The *pulverization and overlay* alternatives—Designs 3, 4A, 4B, 9, 10A and 10B—show good rutting and cracking performance. The FDR foam and overlay alternatives—Designs 6 and 12—perform equally well. With removal of the existing cracked HMA through pulverization, reflective cracking was essentially eliminated. Each of these designs raise the existing grade 0.40 ft (125 mm), which can be problematic in the city of Chester (West B, West C, and West D).

The *pulverize, remove, and overlay* alternatives—Designs 5A, 5B, 5C, 11A, 11B, and 11C—perform well in terms of rutting and cracking performance and maintain the existing grade, which is important through Chester (West B, West C, and West D).

There is concern that use of 3 percent lime can cause excessive brittleness and shrinkage cracking. This value was selected based upon UCPRC studies of stabilized materials and is meant as a representative example to show how thinner HMA overlays may be placed over stiffer base layers. Engineering judgment is required regarding stabilization additive quantities and *a priori* testing is recommended.

Design Recommendations for Each Rehabilitation Section

Following are the recommendations of this project, based upon structural and geometric considerations. The District should base its final selection on the results of a life-cycle cost analysis.

West A: Designs 3, 4A, and 4B perform comparably, although cost will be higher with lime and/or cement. Designs 5A, 5B, and 5C are recommended, although their costs will be higher than Designs 3, 4A, and 4B due to removal. Design 6 will perform well if grade limitations are not an issue. Designs 2A and 2B fail in rutting.

West B, West C: Designs 5A, 5B, and 5C are recommended because of the need to maintain grade in this section. Designs 2A and 2B fail in rutting.

West D: Designs 11B, 11C, and 13 are recommended because of the need to maintain grade in this section. Design 8, which will raise the grade only 0.1 ft, may be used.

Causeway: If maintaining grade is not vital, Designs 10A, 10B, and 12 can be used and will perform comparably, although their costs will be higher with lime, cement, or foam. Designs 11B, 11C, and 13 are recommended although their costs will be higher than Designs 10A, 10B, and 12 due to removal. Design 8 may also be used.

East: If maintaining grade is not vital, Designs 3, 4A, 4B, and 6 will perform well, although the lime/cement/foam treatments will perform somewhat better—these carry higher costs, however. Designs 5A, 5B, and 5C are recommended although due to the removal step their costs will be higher than Designs 3, 4A, and 4B. Designs 2A and 2B fail in rutting.

OTHER RECOMMENDATIONS

Recommendations for *CalME* and Mechanistic Design Process

It is recommended that a method for calculating reflective cracking due to temperature changes be included in *CalME*. It is also recommended that the library of standard materials continue to be expanded to include rich bottom mixes for each of the four PG binder types currently in the library (fatigue and stiffness only) and further refinements on the pulverized asphalt binder (PAB) mix models.

Recommendations for Further Monitoring and Analysis of Project

It is recommended that UCPRC staff be present during construction to take loose material samples, to extract slabs and/or cores, and to measure thicknesses. 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*.

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

APPENDIX A: R-VALUE DESIGN CALCULATIONS AND PROCEDURES

R-Value with Pulverization: West A, B, C, and East (HMA + 0.08 ft AB)

- TI = 10
- R-value SG = 40
- GE total req = 0.975(TI)(100-R) = 1.9 ft
- PAB thickness 0.38 + 0.08 =.46 ft
- GE(PAB)=0.46 * 1.2 = 0.55 ft
- AB thickness .0.66-0.08 = 0.58 ft
- GE(AB) = 0.58 * 1.1 = 0.63 ft
- GE for HMA
- GE(HMA)=0.975(TI)(100-78) = 0.71 ft
    - Add 0.2 ft FoS = 0.9 ft
- GE(HMA) + GE(PAB) + GE(AB)
- 0.9 ft + 0.55 + 0.63 = 2.08 > 1.9 ft

Required Design

- 0.5 ft (150 mm) HMA
- 0.38 ft (140 mm) PAB
- 0.58 ft (175 mm) AB

R-Value with Pulverization: West D and Causeway

Pulverize existing HMA + 0.08 ft AB

- TI = 10
- R-value SG = 40
- GE total req = 0.975(TI)(100-R) = 1.9 ft
- PAB thickness 0.9 + 0.08 = 0.98 ft
- GE(PAB)=0.98 * 1.2 = 1.15 ft
- AB thickness 0.66 – 0.08 = 0.58 ft
- GE(AB) = 0.57 * 1.1 = 0.63 ft
- GE for HMA
- GE(HMA)=0.975(TI)(100-78) = 0.71 ft
    - Add 0.2 ft FoS = 0.9 ft
- GE(HMA)+GE(PAB)+GE(AB)
- 0.9 + 1.15 + 0.63 = 2.68 ft. > 1.9 ft

Required Design

- 0.5 ft (150 mm) HMA
- 1.0 ft (295 mm) PAB
- 0.58 ft (175 mm) AB

APPENDIX B: ME SUPPLEMENTARY DATA AND PROCEDURAL INFORMATION

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

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 these projects:

General and Specific Benefits for the 02-PLU-36 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. For this project, test data from both RHMA-G and PG 64-28 binder were used in the analysis. Rubberized mix performance for reflective cracking was assessed analytically rather than with generalized tables.
    B. ME can examine the impact of different additives to mixes, for example the use of lime or cement as a modifier to pulverized base material. For this project, the use of either lime or cement with the pulverized base was evaluated. The analyses included stiffnesses for the two types of stabilizer based on laboratory testing from previous projects.
    C. 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.

D. 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. Surface temperature data selected from the *Enhanced Integrated Climate Model* database (also referred to as the "climate region database") are used to calculate temperatures at different depths of the pavement structure. These calculated temperatures and load spectrum data read from the WIM database are the inputs needed in the *CalME* Incremental-Recursive analysis to calculate the elastic modulus changes from the Master Curves. For this project, the High Mountain 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 the 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 reflective cracking and rutting is specified up front.
4. Deflection testing with the Falling Weight Deflectometer allows 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 and can be updated by the designer. The cost of each design is calculated.
7. ME can reduce potential costs to Caltrans by producing efficient pavement structural sections and avoiding underdesigned sections. For this project, one design option is PG 64-28PM overlay over pulverized base. ME analysis shows that modifying the pulverized material with cement (stiffness increases from 45,000 psi to 75,000 psi) results in an overlay that is one inch (0.08 ft) thinner in West A, West B, and West C: 0.4 ft versus 0.5 ft for unmodified pulverized material. District 2 estimates that approximately $1,000,000 can be saved for every inch (0.08 ft) of reduced HMA thickness for every 100,000 yd^2 paved. These sections total approximately 65,000 yd^2, resulting in a saving of $650,000 for the District.

8. Users can rerun analysis 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.
9. *CalME* and *CalBack* can output all design information to *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 selected and analyzed for a given project. Generalized design tables based upon broad average behavior for generic materials are not used.

The process performed for 02-PLU-36 is summarized below.

An initial meeting was held with District 2 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/or 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 based on the Incremental-Recursive method which took into account how pavement materials change in behavior (cracking, aging) over the lifetime of a project.

The *CalME* analysis process started with importing 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.

Design options were developed based upon engineering judgment and District preferences, and were 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*. These threshold limits are based on a policy decision made by the Caltrans Office of Pavement Management.

Traffic Data

ME Weigh-in-Motion (WIM) data has been created from years of traffic counting from WIM stations distributed across the state. Traditional Caltrans designs used a Traffic Index, 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 on damage from the individual axle loads.

Traffic estimates for ME designs for this project were based on detailed WIM data taken from stations with truck traffic population characteristics similar to those of this project. The *CalME* software finds typical axle load spectra based on truck traffic count data identifying the different types of trucks.

Table 5 shows the raw data from a WIM station and Table 6 shows the calculated traffic by axle count for 02-PLU-36. Figure 8 shows a plot of the calculated traffic for 02-PLU-36. The 20-year TI for this project is 10.0.

Table 5: Raw WIM Data for 02-PLU-36

Year	Route	Dist	Cnty	PM	Leg	AADT Total	Total Trucks	Total Truck %	2 Axle Volume	2 Axle Percent	3 Axle Volume	3 Axle Percent	4 Axle Volume	4 Axle Percent	5 Axle Volume	5 Axle Percent	Description	Yr	Verify / Estimate
1998	36	2	PLU	6.287	A	3300	379	11.48	91	24.01	58	15.3	52	13.72	178	46.97	JCT. RTE. 89	98	V
	36	2	PLU	6.287	B	2050	313	15.27	63	20.22	39	12.53	64	20.44	147	46.81	JCT. RTE. 89	98	V
	36	2	PLU	8.08	O	3600	413	11.47	90	21.9	85	20.5	93	22.6	145	35	FARRAR DRIVE	95	V
	36	2	PLU	8.84	O	6000	486	8.1	104	21.5	109	22.4	103	21.2	170	34.9	FEATHER RIVER BRIDGE	95	E
	36	2	PLU	9.18	O	4800	528	11	116	22	113	21.4	113	21.4	186	35.2	CHESTER, MELISSA AVENUE	98	E
	36	2	PLU	13.93	A	2300	410	17.83	140	34.2	92	22.4	33	8.1	145	35.3	BIG SPRINGS ROAD	98	E
2004	36	2	PLU	6.287	A	3700	442	11.95	61	13.8	87	19.68	9	2.04	285	64.48	JCT. RTE. 89	4	V
	36	2	PLU	6.287	B	2150	289	13.44	37	12.8	55	19.03	10	3.46	187	64.71	JCT. RTE. 89	4	V
	36	2	PLU	8.08	O	3800	459	12.08	41	9	106	23	32	7	280	61	FARRAR DRIVE	4	E
	36	2	PLU	8.84	O	6300	488	7.74	59	12	137	28	49	10	244	50	FEATHER RIVER BRIDGE	4	E
	36	2	PLU	9.18	O	5100	479	9.4	58	12	134	28	48	10	240	50	CHESTER, MELISSA AVENUE	4	E
	36	2	PLU	13.93	A	2250	315	14	25	8	76	24	22	7	192	61	BIG SPRINGS ROAD	4	E
2007	36	2	PLU	6.287	A	3500	323	9.23	44	13.62	77	23.84	10	3.1	192	59.44	JCT. RTE. 89	7	V
	36	2	PLU	6.287	B	2350	254	10.81	48	18.9	63	24.8	8	3.15	135	53.15	JCT. RTE. 89	7	V
	36	2	PLU	8.08	O	3600	374	10.39	34	9	86	23	26	7	228	61	FARRAR DRIVE	7	E
	36	2	PLU	8.84	O	5900	393	6.66	47	12	110	28	39	10	197	50	FEATHER RIVER BRIDGE	7	E
	36	2	PLU	9.18	O	5100	407	7.98	49	12	114	28	41	10	204	50	CHESTER, MELISSA AVENUE	7	E
	36	2	PLU	13.93	A	2300	322	14	26	8	77	24	23	7	196	61	BIG SPRINGS ROAD	7	E

Table 6: Traffic Calculations for 02-PLU-36

	AADT	2 Axle	3 Axle	4 Axle	5 Axle	Total # axles	
1998	3300	91	58	52	178	1454	
2004	3700	61	87	9	285	1844	
2007	3500	44	77	10	192	1319	
Annual Change	66.7	-5.0	4.8	-7.2	17.8		65.0
	2.02%	-5.49%	8.33%	-13.78%	10.02%		4.47%
2008	3967	41	106	-20	356		2104
Intercept	-53728.6	10461.9	-4933.5	10086.4	-7555.2	8692.6	
Slope	28.6	-5.2	2.5	-5.0	3.9	-3.6	
RSQ	0.4	1.0	0.6	0.9	0.1	0.0	
1997	3328.6	96.5	59.0	53.8	195.0	1560.4	
2008	3642.9	39.4	86.5	-1.5	237.7	1521.1	
2009	3671.4	34.2	89.0	-6.5	241.6	1517.6	
2008	3650					1521	
				Axles / first year		555165	
				axles truck	1998	3.84	
				axles truck	2004	4.17	
				axles truck	2007	4.08	

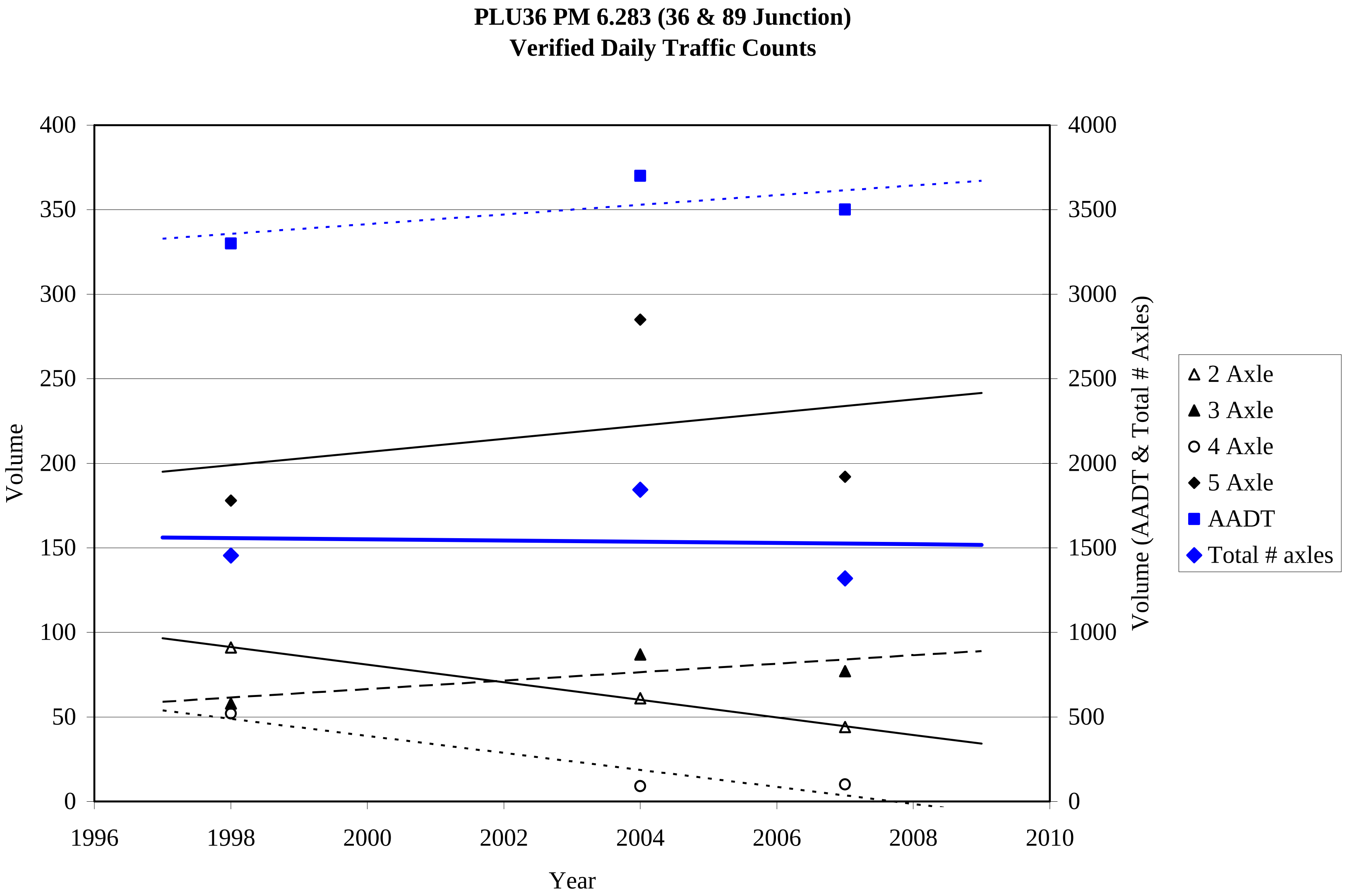


Figure 8: Plot of traffic data for 02-PLU-36.

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 9 below shows a portion of the Caltrans Pavement Climate Regions map. *CalME* contains a climate database to access hourly air temperatures and uses 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 files for further details about this topic.

The arrow points to the location of project 02-PLU-36, which was in the High Mountain climate region.

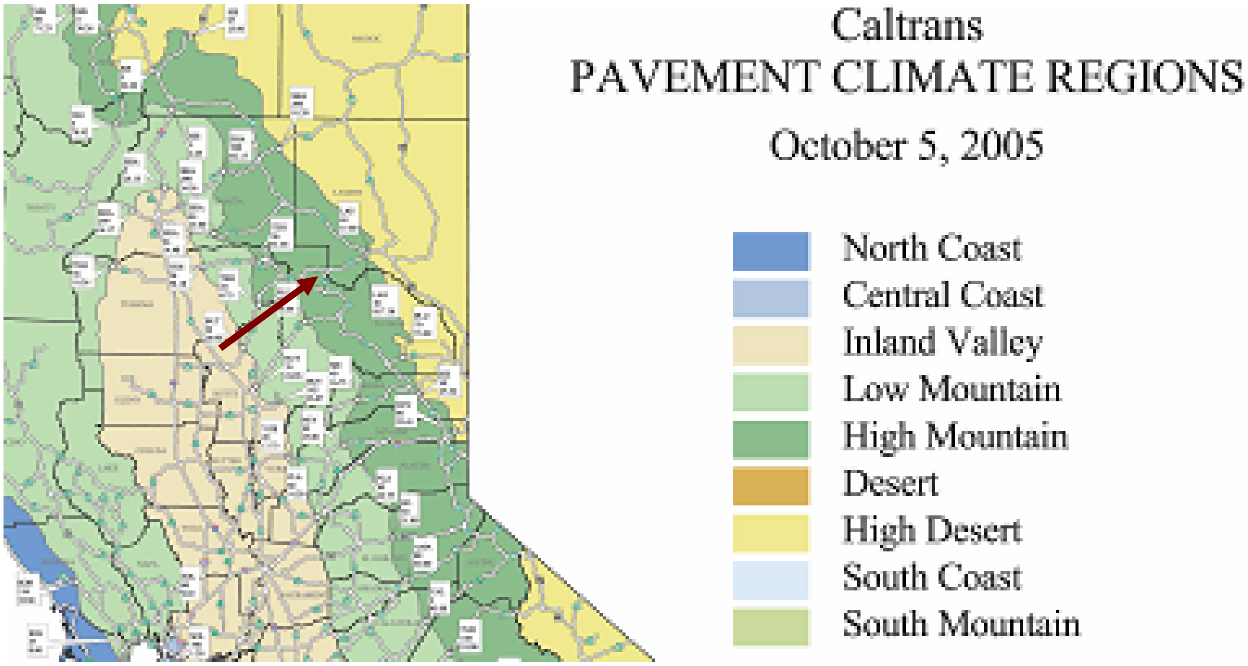


Figure 9: Caltrans pavement Climate Regions map.

Material Parameters

Backcalculation with CalBack

This project was broken up into six sections according to their pavement structure and alignment: West A, West B, West C, West D, Causeway, and East. Following FWD data analysis and for design purposes, the six sections were put together into three "design groups" according to their structural similarities as follows:

- West A, West B, West C—0.40 ft HMA / 0.65 ft AB nominal
- West D, Causeway—0.8 to 1.0 ft HMA / 0.65 ft AB nominal
- East—0.45 ft HMA / 0.65 ft AB nominal (similar in pavement structure to West A, West, B, and West C)

For reference, these are the post mile (PM) limits for each section:

- West A: 6.30 to 7.44
- West B: 7.44 to 8.15
- West C: 8.15 to 8.84
- West D: 8.84 to 9.28
- Causeway: 9.28 to 10.53
- East: 10.53 to 13.93

The backcalculation process began with the use of initial seed moduli from the Materials Library. From there, the *CalBac*k program's basin-fitting algorithm attempted to match the actual deflection values with deflections based on backcalculated moduli. When error levels reached sufficiently low levels, typically under 2 to 3 percent, the stiffness values presented were considered layer moduli.

Figure 10 shows the Falling Weight Deflectometer deflection data for inner sensor (D1) and HMA surface temperature versus post mile. Figure 11 shows the Falling Weight Deflectometer deflection data for the outer sensor (D8) and HMA surface temperature versus post mile. Deflection testing started in the morning at Section West A, and proceeded generally eastbound as indicated by increasing surface temperatures with post mile. Figure 12 shows the temperature-adjusted layer moduli from *CalBack* for the entire project. Reference stiffnesses for SC, SM, and Clay were comparable in this project since *CalME* did not contain sufficient calibrated soil materials at the time of analysis. Table 7 through Table 10 present the raw westbound and eastbound FWD data. Figure 13 shows the deflection bowl from Station 1850.

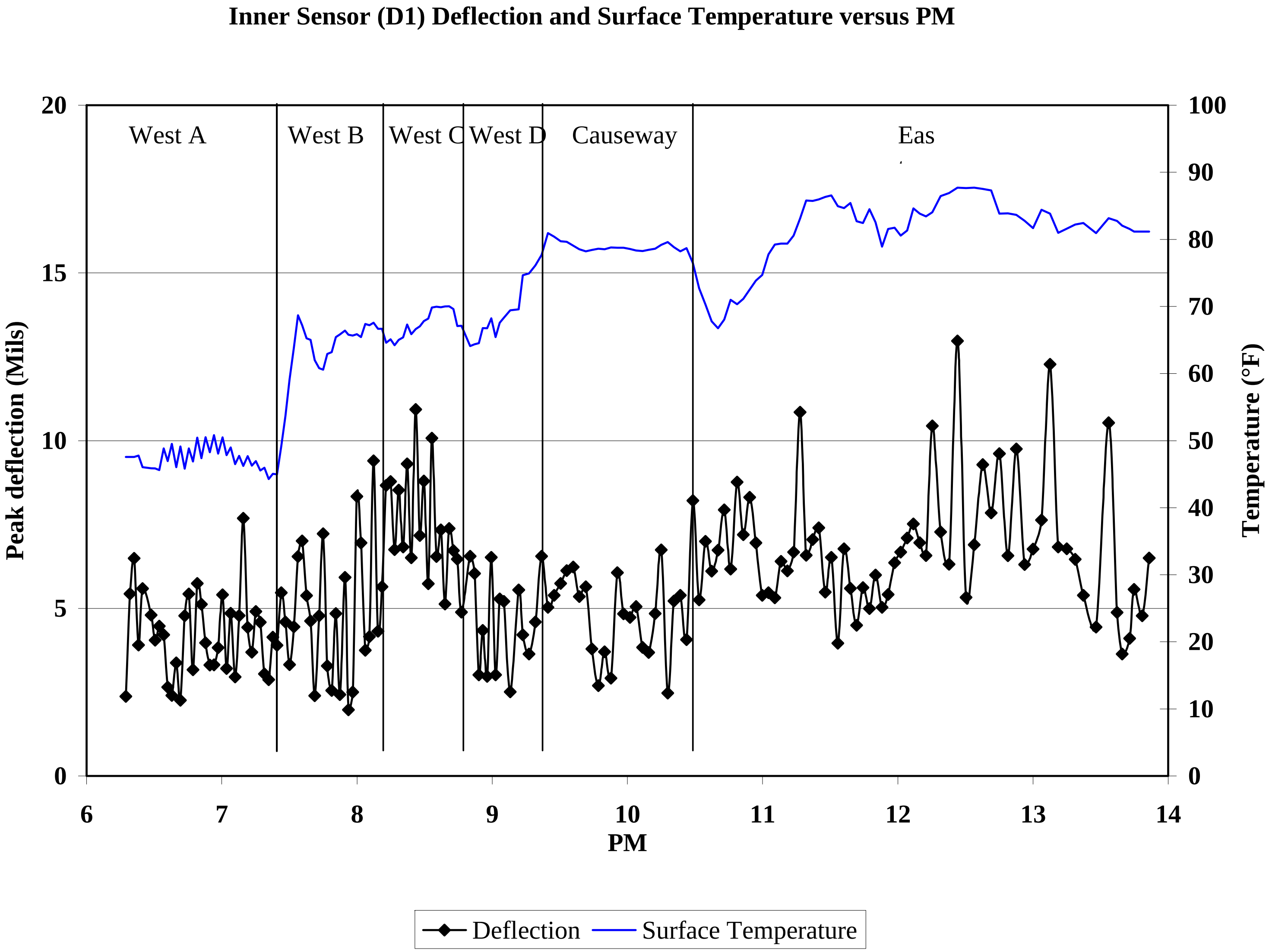


Figure 10: FWD inner sensor (D1) peak deflection and surface temperature versus post mile.

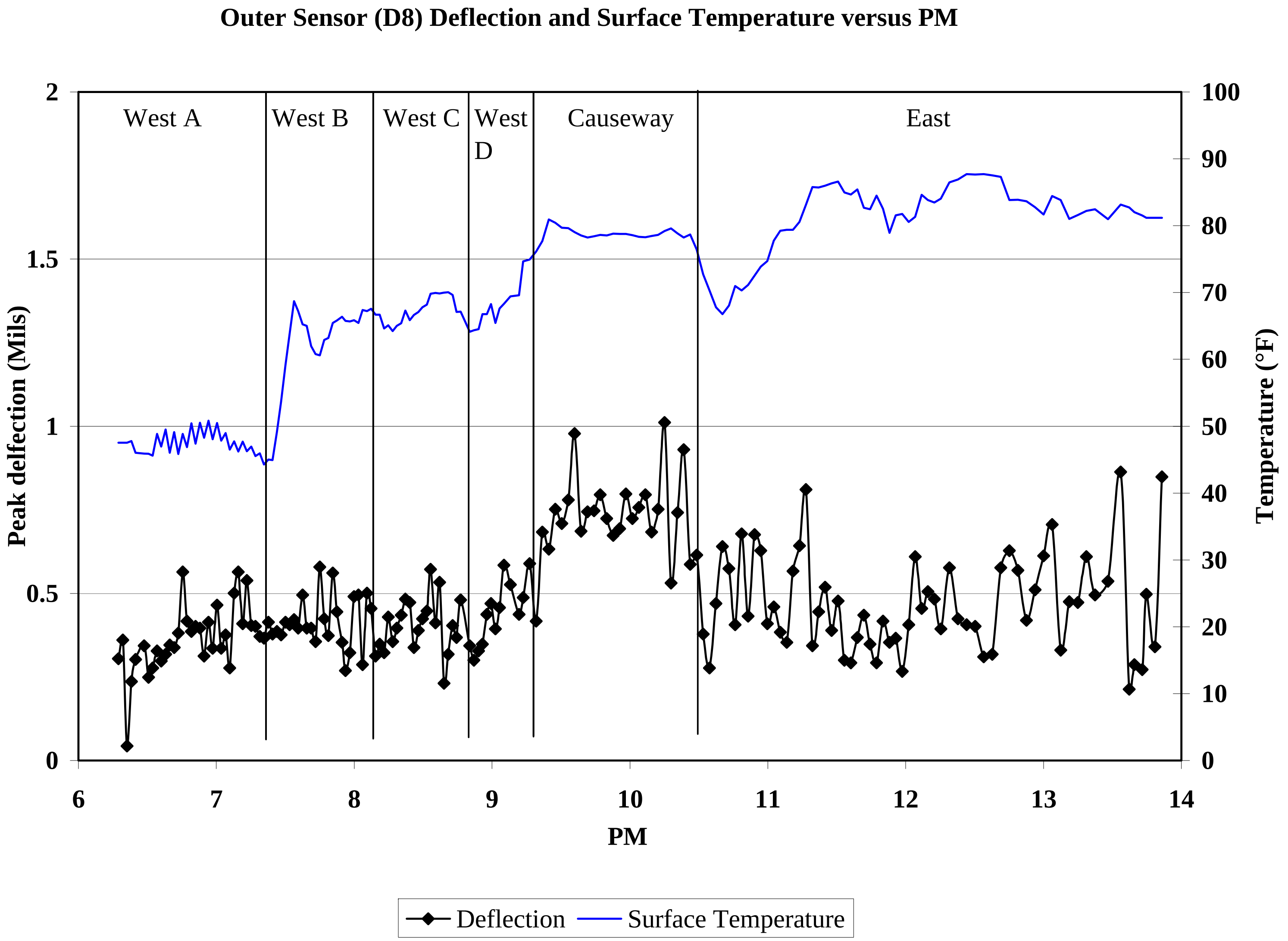


Figure 11: FWD outer sensor (D8) peak deflection and surface temperature versus post mile.

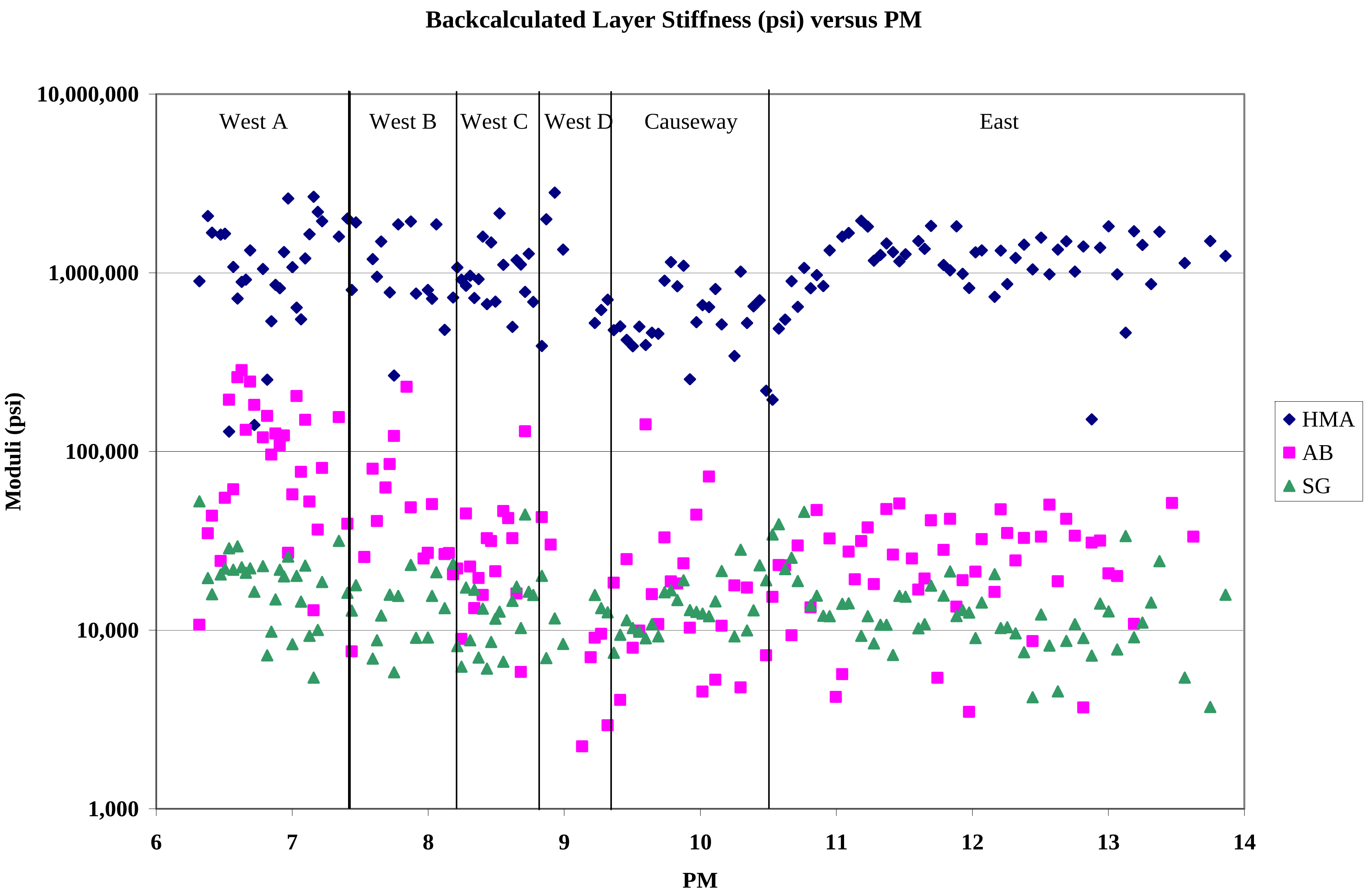


Figure 12: Backcalculated layer stiffness (temperature adjusted) versus post mile.

Table 7: Westbound Deflection Data, Part 1

Point	Drop	T F	DMI	Load	Time	Sl.po	D1	D2	D3	D4	D5	D6	D7	D8
1	6	46.9	1850	18122	932	CS	18.6	14.5	12.3	9.6	7.5	4.6	2.1	1.5
2	6	46.6	1750	16266	934	CS	16.2	14.2	12.9	10.9	9.1	6.1	2.7	1.7
3	6	46.9	1650	16726	936	CS	12.2	10.8	9.9	8.3	7	4.8	2.3	1.6
4	6	50.2	1550	16821	937	CS	18.8	15.5	13.7	10.8	8.5	5.2	2.2	1.6
5	6	50.2	1450	16567	940	CS	17	14.1	12.6	10.3	8.5	5.6	2.4	1.6
6	6	50.4	1350	16789	943	CS	18.5	15.8	14.2	12	10.2	7.2	3.3	2
7	6	52	1250	16821	945	CS	17.9	13.6	11.4	8.7	6.9	4.3	2	1.5
8	6	55.8	1150	16758	946	CS	20.1	16.5	14.6	11.9	9.8	6.5	2.8	1.8
9	6	55.9	1050	17012	948	CS	12.1	9.8	8.8	7.3	6.1	4.2	2.2	1.5
10	6	57.9	950	17503	950	CS	14.2	11.2	9.9	8	6.5	4.3	2	1.4
11	6	55.8	850	16726	951	CS	21.8	16.9	14.9	12.2	9.9	6.5	2.6	1.5
12	6	55.2	750	15980	953	CS	20.7	17.8	16.1	13.7	11.6	8.1	3.7	2.2
13	6	52.9	650	16440	955	CS	8.5	7.1	6.4	5.4	4.6	3.3	1.6	1.2
14	6	56.8	550	15996	957	CS	9.4	7.7	6.9	5.9	5.1	3.7	1.9	1.3
15	6	57.6	450	17250	958	CS	13.4	10.5	8.7	6.5	5.1	3.2	1.7	1.4
16	6	50.2	350	16948	1000	CS	12.7	9.6	8	5.9	4.4	2.6	1.3	1
17	6	57.7	150	17742	1002	CS	12.9	10.1	8.4	6.1	4.4	2.3	1	0.8
18	6	58.8	50	17440	1003	CS	15.9	12.7	10.4	7	4.7	2.5	1.6	1.4
19	6	69.1	2000	16726	1036	CS	16.2	13.8	12.3	10	8.1	5.4	2.4	1.6
20	6	70.3	2100	16297	1038	CS	24.3	19.6	16.9	13	9.8	5.6	2.2	1.6
21	6	56.7	2200	16424	1040	CS	17.1	14.3	11.8	10	7.6	4.6	2.1	1.5
22	6	67.8	2300	16377	1041	CS	17.8	13.7	11.5	8.6	6.7	4.2	2	1.5
23	6	64.9	2400	15694	1043	CS	12.6	10.7	9.7	8.2	7	5.1	2.7	1.8
24	6	71.1	2500	16583	1044	CS	18.6	17.8	16.7	14.4	12	7.2	3.4	2.3
25	6	66.6	2610	16409	1046	CS	21.5	16.8	14.2	10.9	8.6	5.2	2.2	1.5
26	6	58.3	2700	15536	1048	CS	9.8	8.5	7.7	6.4	5.4	3.7	2	1.4
27	6	68.5	2800	16139	1049	CS	24.7	19	15.7	11.3	8.4	4.7	2.5	1.9
28	6	64.8	2900	18948	1118	CS	13.7	12	10.6	8.5	6.9	4.7	2.6	1.8
29	6	67.1	3000	17503	1120	CS	14.8	12.2	10.6	7.7	6	3.5	1.7	1.3
30	6	63.1	3100	17424	1121	CS	28.3	22.1	18.6	11.8	8.9	5	1.9	1.5
31	6	57.7	3200	18027	1122	CS	22.4	17.6	14.5	10.1	7.5	4.5	2.3	1.5
32	6	66	3300	17726	1124	CS	21.9	15.8	13	9.5	7	4	2.1	1.6
33	6	66.7	3400	17472	1125	CS	21	19.1	16	12.3	9.4	5.6	2.7	1.9
34	6	62.2	3500	16710	1127	CS	25.9	22	18.9	14.4	10.8	6.1	2.6	1.6
35	6	69.3	3600	16900	1129	CS	19.6	16.3	13.9	10.6	8.2	5.1	2.5	1.6
36	6	69.1	3700	15869	1130	CS	22.4	18.2	15.7	12.2	9.6	5.9	2.7	1.7
37	6	70.3	3800	16932	1132	CS	16.9	12.5	10	7	5.1	2.8	1.3	0.9
38	6	71.1	3900	19122	1136	CS	20	14.5	11.5	7.7	5.4	3	1.9	1.4
39	6	68.4	3996	17884	1137	CS	14.8	11.7	10.2	8.2	6.7	4.7	2.4	1.7
40	6	57.7	4100	16821	1139	CS	21	15.1	12	7.3	5.6	3.6	1.8	1.3
41	6	55.9	4204	17884	1141	CS	10.4	9.3	8.5	7.3	6.3	4.1	1.9	1.1
42	6	69.1	4300	17027	1142	CS	11.2	10.6	9.7	8.4	7.3	5.3	2.5	1.6
43	6	68.9	4401	16948	1144	CS	11.2	10.2	9.5	8.3	7.1	5	2.1	1.3
44	6	56.7	4500	17250	1147	CS	19	17.2	15.9	13.7	11.7	8.2	3.7	2.3
45	6	79.9	4575	16202	1233	CS	9.5	8.8	8.2	7.4	6.6	5.3	3	1.9
46	6	72.7	4677	19519	1235	CS	19.3	17.2	15.6	13.1	10.9	7.1	3.3	1.8
47	6	74.5	4725	15456	1237	CS	16.2	14.5	13.5	11.9	10.5	7.8	3.7	2.1

Table 8: Westbound Deflection Data, Part 2

48	6	64.2	4800	14330	1238	CS	13.8	12.2	11.4	10	8.9	6.7	3.6	2.3
49	6	82	4875	16758	1240	CS	16	13.1	11.8	10.1	8.7	6.3	3.1	2.1
50	6	81.3	4950	14615	1242	CS	21.5	18.8	17.1	14.5	12.3	8.7	4.3	2.6
51	6	78.6	5025	14647	1243	CS	17.4	15.2	13.8	11.8	10.1	7.1	3.6	2.4
52	6	82.2	5100	14695	1245	CS	19.3	16.3	14.6	12.3	10.4	7.3	3.8	2.8
53	6	80.4	5175	14837	1246	CS	20.1	17.9	16.4	14.2	12.1	8.5	3.9	2.7
54	6	79.5	5250	16155	1248	CS	19.7	17	15.2	12.8	10.8	7.6	4	3
55	6	77.7	5325	14457	1249	CS	22.3	19.7	18	15.5	13.4	9.7	5	3.4
56	6	78.3	5400	14774	1251	CS	17.9	16.7	13.6	11.3	9.4	6.5	3.4	2.5
57	6	79.3	5475	15012	1253	CS	19.9	16.6	15	12.7	10.8	7.6	3.6	2.5
58	6	77.9	5550	15742	1254	CS	13.3	11.8	11	9.9	8.8	6.8	4	2.8
59	6	77.9	5625	15393	1256	CS	9.6	8.6	8.2	7.6	7	5.8	3.9	2.7
60	6	78.6	5700	14822	1257	CS	13.4	11.8	11	9.6	8.5	6.4	3.6	2.6
61	6	79.3	5775	15234	1259	CS	10.7	9.7	9.1	8.2	7.3	5.5	3.1	2.2
62	6	79	5850	15869	1300	CS	20.3	15.9	13.5	11.1	9.3	6.4	3.4	2.5
63	6	79.2	5925	14346	1302	CS	16.7	14.5	13.1	11.2	9.7	7.1	3.9	2.7
64	6	77.7	6000	15060	1305	CS	16.2	14	12.6	10.8	9.4	7.2	3.9	2.8
65	6	78.6	6075	15409	1306	CS	17.1	15	13.6	11.7	9.9	7.2	4	2.8
66	6	78.4	6150	14901	1309	CS	13.7	12.2	11.3	10	8.8	6.7	3.9	2.6
67	6	77.7	6225	15234	1310	CS	13.3	11.3	9.9	8.2	7.1	5.3	3.2	2.4
68	6	78.8	6300	16869	1311	CS	17.2	15.9	15	13.5	12.1	6.9	4	2.8
69	6	78.6	6375	14647	1313	CS	23.7	20.4	18.9	16.5	14.3	10.2	5.7	3.8
70	6	79.5	6450	15298	1315	CS	8.9	7.4	6.8	5.9	5.2	4	2.5	1.9
71	6	81.3	6525	14837	1316	CS	17.1	15.1	13.8	12	10.3	7.2	3.4	2.6
72	6	79.7	6600	17884	1318	CS	18.5	16.1	14.7	12.7	11	8.1	4.5	3.1
73	6	75	6675	19090	1319	CS	12.8	11.3	10.3	8.8	7.6	5.5	3.1	2.1
74	6	75.6	6750	18789	1321	CS	22	18.9	16.3	12.4	9.7	5.9	3.1	2.4
75	6	81.9	6825	15536	1323	CS	16.6	12.3	9.9	7	5.1	3.2	1.9	1.6
76	6	70.2	6900	14949	1324	CS	23.8	17.3	14	9.5	6.3	3.3	1.7	1.2
77	6	61	6975	14980	1326	CS	20.7	15.9	13.1	9.5	7.1	4.3	2.6	2
78	6	63	7050	17837	1329	CS	21.9	17.8	15.2	11.5	8.8	5.4	2.9	2.4
79	6	63	7125	17456	1331	CS	25.6	20.7	17.5	12.8	9.5	5.5	2.9	2.3
80	6	76.6	7200	18249	1334	CS	20.7	16.5	13.8	10	7.1	3.8	2.5	2
81	6	86.2	10800	16028	1504	CS	21.5	17.8	15.1	11.4	8.7	5.5	2.9	2.3
82	6	83.1	10900	14885	1506	CS	25.3	20.4	17.7	13.9	10.9	6.9	3.5	2.7
83	6	82.4	11000	15361	1507	CS	37.4	29.9	23.1	15.2	10.5	4.8	2.8	1.9
84	6	83.8	11100	14901	1509	CS	23.2	18.7	15.9	12	9	5.2	2.4	1.9
85	6	83.7	11200	15663	1510	CS	22.8	18.6	15.7	11.7	8.5	4.9	2.3	2
86	6	72	11300	14774	1511	CS	22.4	18.1	15.4	11.7	9	5.5	3.3	2.5
87	6	86.2	11400	15520	1513	CS	18.7	15	12.8	9.9	7.9	5.2	2.9	2.5
88	6	85.5	11550	14520	1515	CS	16.6	14.6	12.9	10.6	7.3	5	2.7	2.1
89	6	84.9	11700	13806	1516	CS	37.2	31.3	27.4	21	15.6	10.4	4.8	3.2
90	6	76.3	11800	14473	1518	CS	18.1	15.6	13.7	11.1	8.9	5.7	2.8	2
91	6	82.9	11860	14806	1519	CS	13.2	11	9.7	7.7	6.1	3.7	1.7	1.2
92	6	84	11950	14742	1521	CS	14.6	11.8	10	7.6	5.6	2.9	1.3	1
93	6	82	12000	13679	1522	CS	21.1	18	16.1	13	10.5	6.6	2.7	2.1
94	6	82.4	12100	14377	1524	CS	17	13.7	11.9	9.2	7.1	4	1.7	1.4
95	6	74.5	12181	15567	1526	CS	21.9	18.7	16.2	13	10.7	7.6	4.7	3.6

Table 9: Eastbound Deflection Data, Part 1

Point	Drop	T F	DMI	Load	Time	Sl.pos	D1	D2	D3	D4	D5	D6	D7	D8
1	6	39.6	0	18630	840	CS	8.4	7.3	6.7	5.6	4.7	3.3	1.6	1.2
2	6	40.6	100	20503	843	CS	18.1	11.6	8.7	3.3	2.7	1.9	1.2	1
3	6	41	200	19852	844	CS	16.2	12.3	10.3	7.5	5.4	2.8	1.3	1.1
4	6	40.6	300	18646	852	CS	14.4	11.4	9.5	6.9	5.1	3	1.6	1.3
5	6	39.9	400	18329	854	CS	13.6	7.8	6.7	5.2	4.2	2.7	1.4	1.1
6	6	39.7	500	18710	856	CS	9.7	7.6	6.5	5.3	4.4	3.2	1.6	1.1
7	6	40.6	600	17789	858	CS	12.7	10.2	8.8	7.1	5.8	4	2	1.4
8	6	40.1	700	16948	859	CS	17.6	12.4	10.3	8	6.5	4.6	2.3	1.6
9	6	40.3	800	17123	901	CS	12.2	10	8.6	6.9	5.7	4	2.1	1.6
10	6	43	900	17075	903	CS	18.3	14.5	13	10.7	8.7	5.7	2.5	1.6
11	6	39.9	1000	16932	911	CS	12.3	9.5	8.2	6.5	5.1	3.3	1.6	1.2
12	6	44.6	1100	17202	913	CS	14	11.9	10.5	8.5	7	4.6	1.9	1.1
13	6	44.1	1200	17646	914	CS	11.9	9.5	8.3	6.9	5.7	4	2	1.3
14	6	42.8	1300	19566	916	CS	10.9	8.6	7.5	6.1	4.9	3.2	1.4	1
15	6	43.3	1400	17408	918	CS	25.9	22.3	19.6	15.5	12.3	7.5	2.7	2
16	6	44.4	1500	18519	920	CS	13.9	11.7	10.5	8.7	7.3	5.2	2.7	2
17	6	43.2	1600	16885	922	CS	17.1	14.5	12.9	10.6	8.7	5.6	2.4	1.8
18	6	43	1700	17535	924	CS	10.9	9	8.2	7	6	4.2	2	1.4
19	6	41.7	1800	17043	926	CS	14.4	12.1	10.6	8.5	6.8	4.4	2.1	1.6
20	6	46.6	1900	16615	928	CS	16.8	13.3	11.7	9.1	7.1	3.7	2.1	1.5
21	6	68	2750	15536	1052	CS	30.1	23.2	19.2	13.9	10.2	5.8	2.8	2
22	6	66.9	2650	16107	1053	CS	7.3	6.3	5.7	4.7	4	2.8	1.5	1
23	6	69.1	2550	15837	1055	CS	9.7	8.4	7.7	6.8	5.9	4.4	2.5	1.7
24	6	55.6	2450	14742	1057	CS	10.1	9.1	8.4	7.3	6.3	4.6	2.2	1.5
25	6	55.2	2350	15631	1058	CS	27.3	21.6	19.2	16	13.2	8.9	3.9	2.2
26	6	59.4	2250	15885	1100	CS	9.2	8.1	7.4	6.2	5.3	3.7	2	1.4
27	6	70.9	2150	16202	1101	CS	20	16.6	14.9	12.5	10.5	7.2	3.4	2.2
28	6	69.1	2050	16869	1103	CS	22.1	18.8	16.1	9.9	7.9	5.1	2.4	1.7
29	6	64	1950	17234	1106	CS	11.4	11.5	11.5	7.4	6.3	4.4	2.2	1.5
30	6	63.5	4450	16028	1151	CS	20.1	17.6	15.7	13	9.5	6.6	3.1	1.8
31	6	69.1	4350	16297	1153	CS	23.4	19.8	17.1	13.2	10.5	6.6	2.8	1.9
32	6	70.7	4250	17012	1154	CS	14.9	12.6	11	8.8	7.2	4.6	2	1.3
33	6	69.1	4150	16964	1156	CS	22.4	19.2	16.8	13.3	10.6	6.4	2.3	1.5
34	6	69.4	3945	16535	1158	CS	19.1	15.3	12.6	9	6.1	2.6	1.6	1.2
35	6	68.9	3849	17170	1159	CS	22.9	16.6	13.5	9.5	6.7	3.4	1.7	1.3
36	6	70.5	3750	17123	1201	CS	23.2	17.5	14.3	10.8	8.3	5.4	2.8	2.1
37	6	70.5	3644	16170	1202	CS	31.9	25.5	21.2	15.5	11.6	6.5	3	2.1
38	6	69.8	3548	17662	1204	CS	28.2	21.2	17.2	12.2	9	5	2.6	1.8
39	6	67.3	3450	16916	1206	CS	34.5	25.2	19.6	13.2	8.9	4.2	1.8	1.2
40	6	67.1	3350	15520	1207	CS	29.5	22.4	18.7	13.5	9.7	5.1	2.6	1.8
41	6	69.4	3250	16123	1209	CS	26.5	21.3	17.6	12.1	8.4	4.2	2	1.5
42	6	64.8	3150	16218	1210	CS	28.5	21.3	16.9	11.4	7.7	3.2	1.8	1.5
43	6	70.3	3050	16996	1212	CS	20	15.1	12.2	7.9	6	3.6	2	1.4

Table 10: Eastbound Deflection Data, Part 2

44	6	68	2950	16393	1214	CS	27.8	21.1	16.6	11.1	7.6	4.8	2.3	1.5
45	6	67.6	2850	15361	1216	CS	13.8	10.9	9.2	6.8	5.2	3.1	1.5	1.1
46	6	76.6	7276	19265	1346	CS	26.8	21.1	17.7	12.8	9.5	5.7	3.3	2.6
47	6	75.7	7350	19392	1347	CS	22.3	17.3	14	9.7	6.8	3.8	2.7	1.8
48	6	59.7	7425	18297	1349	CS	25.9	21.2	18.2	13.6	10.2	5.8	2.9	2.5
49	6	66.9	7500	17742	1351	CS	22	18.4	15.9	12.1	9.3	5.6	2.7	2.1
50	6	83.7	7575	15107	1352	CS	19.1	15.6	13.5	10.2	7.7	4.4	2	1.6
51	6	83.3	7650	15456	1354	CS	18.4	15	12.7	9.3	6.9	3.8	2.2	1.8
52	6	79.9	7725	15917	1356	CS	17.7	13.7	11.7	8.7	6.6	3.8	1.8	1.4
53	6	75	7800	17694	1357	CS	20.4	16.8	14.4	10.9	8.1	4.5	1.9	1.5
54	6	74.3	7875	18186	1359	CS	19.7	16.8	14.8	11.9	9.7	6.3	2.8	2
55	6	84.4	7950	14377	1400	CS	24.2	20.7	18.5	15.1	12.4	7.3	3.9	2.7
56	6	83.3	8025	15472	1402	CS	34.7	29.4	26.2	21	16.9	10.7	4.4	2.8
57	6	85.8	8100	15250	1403	CS	21.6	16.7	13.8	9.7	7	3.8	1.8	1.4
58	6	87.8	8175	15536	1405	CS	22.9	18.1	15.2	11.2	8.3	4.6	2.5	2.1
59	6	87.6	8250	15314	1406	CS	24.1	19.2	16.5	12.8	10	6.2	2.7	2.1
60	6	84	8325	15266	1408	CS	18	13.7	11.2	7.9	5.8	3.4	2	1.6
61	6	84.6	8400	15869	1409	CS	20.7	17.3	14.1	10.4	7.9	4.7	2.4	1.9
62	6	87.6	8475	15599	1411	CS	13.4	10.8	9.2	7.1	5.6	3.5	1.8	1.3
63	6	89.1	8550	17043	1412	CS	22.2	16.6	13.2	9.2	6.3	3.1	2.1	1.4
64	6	79.5	8625	15710	1414	CS	18.6	14	11.5	7.9	5.5	2.7	1.7	1.5
65	6	82.6	8700	14869	1416	CS	15.8	12.4	10.6	8.1	6.3	3.9	2.3	1.7
66	6	88.3	8775	17646	1417	CS	18.7	15.1	12.8	9.6	7.4	4.6	2.4	1.8
67	6	73.9	8850	15377	1419	CS	16.5	12.9	10.6	7.5	5.4	2.9	1.3	1.1
68	6	87.8	8925	14742	1420	CS	20.8	15.6	12.8	9	6.6	3.7	2.1	1.6
69	6	89.8	9000	14853	1421	CS	17.5	13.3	10.8	7.3	5	2.2	1.4	1.3
70	6	72.9	9075	15044	1423	CS	18.6	14	11.5	8.1	5.9	3.1	1.8	1.5
71	6	70.2	9150	14473	1424	CS	22.7	18	15.1	10.7	7.4	3.4	1.5	1.2
72	6	87.3	9225	14584	1426	CS	23	17.5	14.3	10.1	7.1	3.6	1.9	1.5
73	6	88.7	9300	16202	1427	CS	23.5	18.4	15.6	11.7	9.1	5.7	3.1	2.5
74	6	83.8	9375	14869	1429	CS	25.7	21.2	17.8	9.9	7.6	4.6	2.3	1.7
75	6	76.6	9450	16964	1430	CS	25.3	19.2	15.9	11.4	8.4	4.9	2.8	2.2
76	6	86.7	9525	15123	1432	CS	22.5	17.7	14.7	10.5	7.5	3.9	2.2	1.9
77	6	83.3	9600	15948	1445	CS	34.7	27.5	23.4	17.6	12	5.5	2.2	1.8
78	6	86.7	9700	14234	1447	CS	25.9	20.7	17.3	12.9	9.7	5.6	2.7	2.2
79	6	86.9	9800	14441	1448	CS	22.1	18	15.6	12	9.3	5.5	2.4	1.8
80	6	88.7	9900	13727	1450	CS	42.3	36	32.2	26.4	21.8	15.3	8.1	5.9
81	6	88.9	10000	14853	1451	CS	17.8	14	12.1	9.2	7.1	4.4	2.1	1.5
82	6	87.4	10100	15028	1453	CS	22.9	17.9	15.1	11	8.3	4.6	1.9	1.5
83	6	86.4	10200	14346	1454	CS	30.8	23.9	19.4	13.7	9.5	4.1	1.4	1.4
84	6	87.3	10300	16139	1456	CS	24.4	18.8	15.5	11.1	7.9	4.1	2.2	2
85	6	87.6	10400	14806	1457	CS	30.8	24.8	21.2	15.8	11.8	6.7	3.4	2.6
86	6	87.8	10500	14758	1459	CS	23.7	19.1	16.4	12.7	10	6.4	3.2	2.4
87	6	70.2	10600	16345	1500	CS	33.3	22.6	18.4	13.4	10.2	6.2	2.8	1.9
88	6	86.5	10700	14552	1502	CS	21.9	17.3	14.7	11	8.3	4.9	2.6	2.1

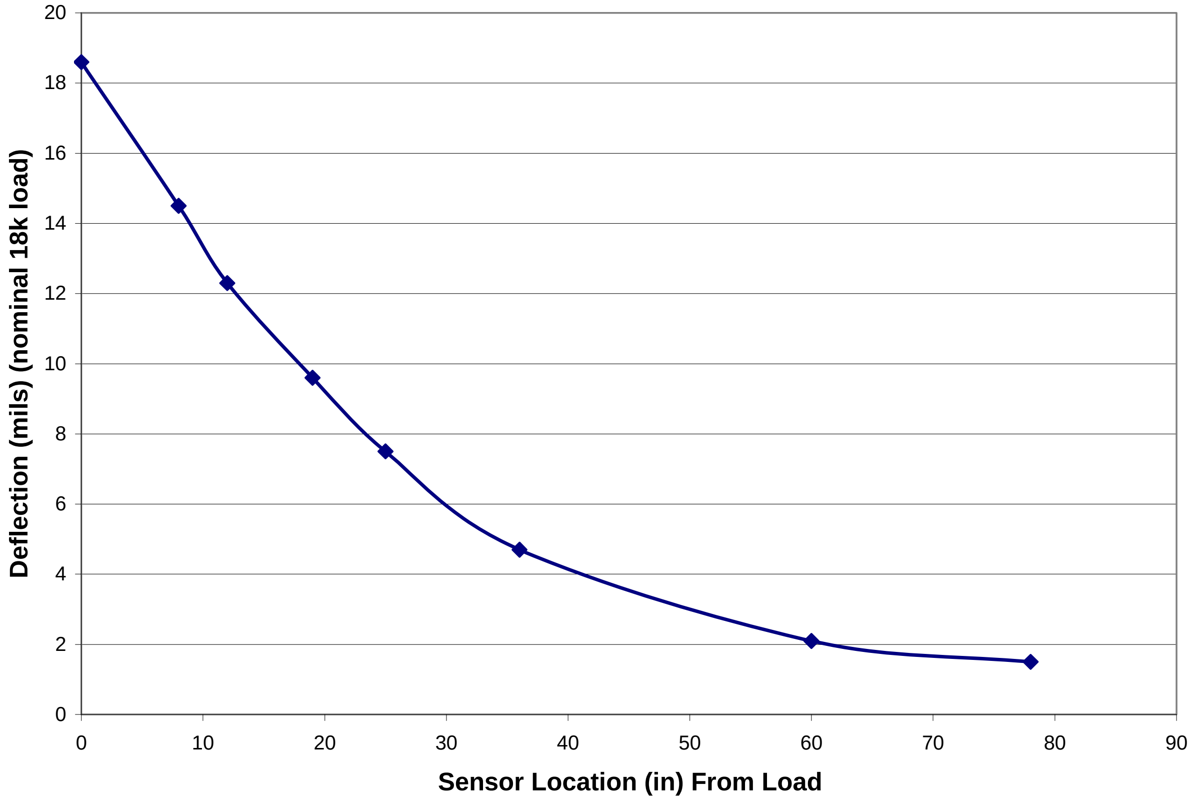


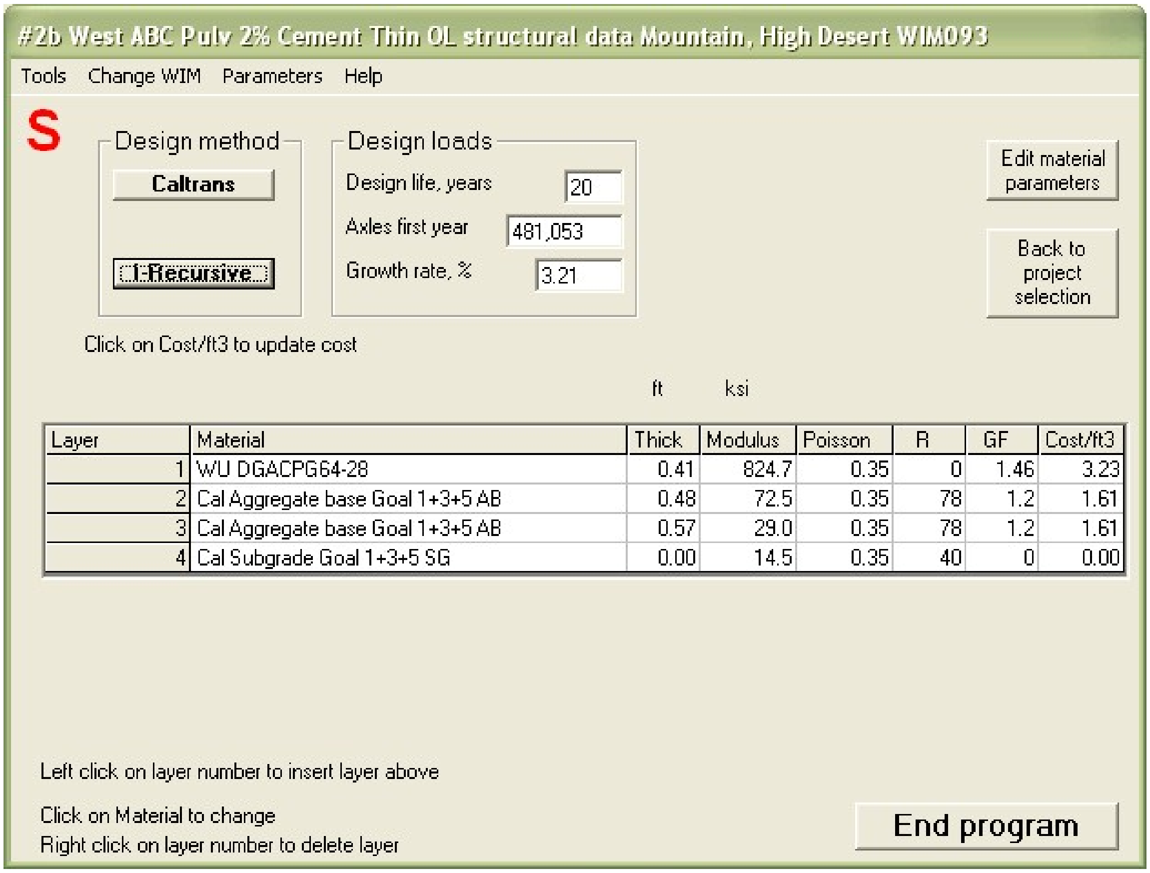
Figure 13: Typical deflection bowl from FWD testing.

ME Analysis and Design with CalME

Following *CalBack* analysis of the deflection and thickness data, *CalME* was run with the various design alternatives selected in conjunction with District 2 staff. Standard Caltrans designs were run. For ME-based designs, layer thicknesses were adjusted to produce the most efficient designs that still met the threshold criteria for HMA rutting (10 mm [3/8 in.]) and cracking (0.5 m/m^2 [0.15 ft/ft^2]) as predicted by *CalME*. Moduli for comparable materials were used in *CalME* analysis in this memorandum since cores and beams were not taken for laboratory testing, as was done in the 01-LAK-53 and 06-KIN-198 projects.

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 Monte Carlo runs at the end of the design life (Year 20) was added to 1.28 times the corresponding standard deviation. A value of 1.28 standard deviations above the mean is equal to the 90th percentile.

Presented below are input screens for Design Option 2B—2 percent cement, thin overlay. Figure 14 shows the data input screen for *CalME*, with material layers, thicknesses, and stiffnesses. Note the button “Edit Material Parameters,” which allows the user to very specifically tailor a given material behavior in *CalME*. Most of these parameters are preset for the user. Figure 15 presents the run options within *CalME* to analyze the pavement design. Figure 16 shows a rutting-versus-time plot for this design option. Note the progression in rut depth (blue/dark line) and the established limiting criteria (pink/light line). The pavement reaches the desired 20-year life. Figure 17 shows cracking-versus-age plot for this design option. Here, the pavement fails in cracking at about 20 years. Figure 18, Figure 19, and Figure 20 present the recursive material parameters for the surfacings used in this project, PG64-28, and existing RHMA-G and DGAC, respectively. These factors were generally left unchanged throughout the analysis procedure. Figure 21 shows the recursive material parameters for the aggregate base. These parameters were left unchanged throughout the analysis.



#2b West ABC Pulv 2% Cement Thin OL structural data Mountain, High Desert WIM093

Design life, years 20

Axles first year 481,053

Growth rate, % 3.21

Click on Cost/ft3 to update cost

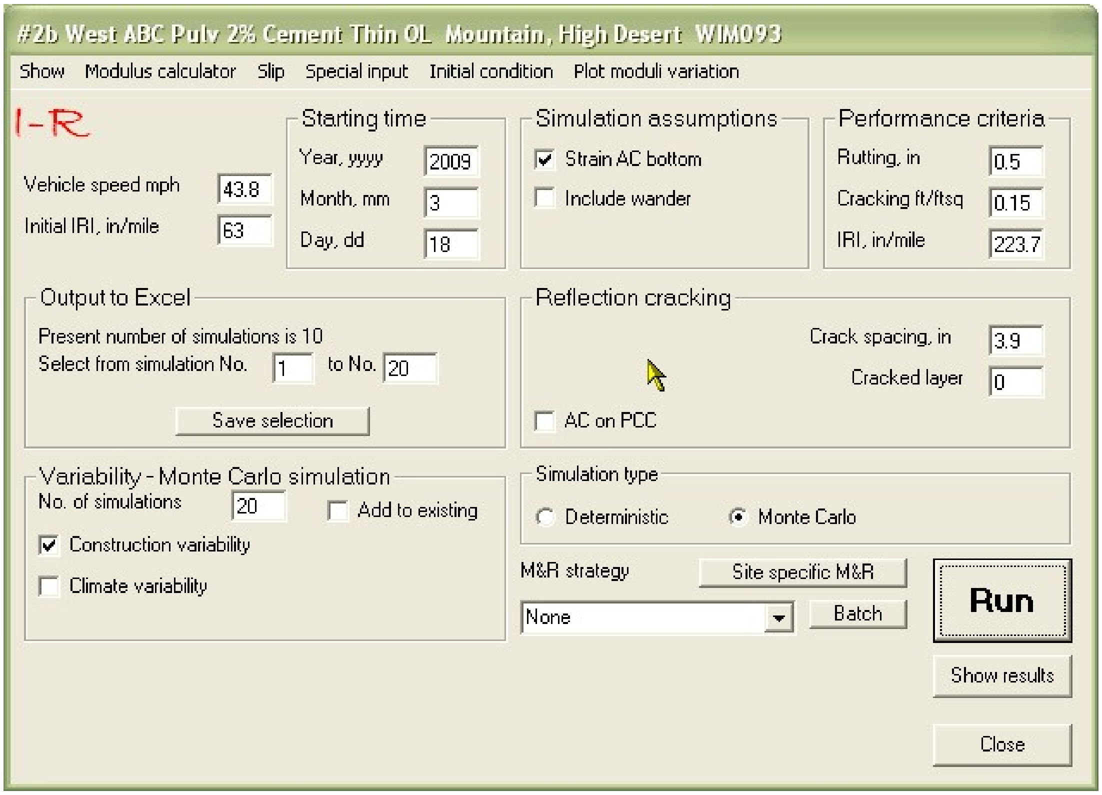
Layer	Material	Thick ft	Modulus ksi	Poisson	R	GF	Cost/ft3
1	WU DGACPG64-28	0.41	824.7	0.35	0	1.46	3.23
2	Cal Aggregate base Goal 1+3+5 AB	0.48	72.5	0.35	78	1.2	1.61
3	Cal Aggregate base Goal 1+3+5 AB	0.57	29.0	0.35	78	1.2	1.61
4	Cal Subgrade Goal 1+3+5 SG	0.00	14.5	0.35	40	0	0.00

Left click on layer number to insert layer above

Click on Material to change

Right click on layer number to delete layer

Figure 14: Structural input screen from *CalME* for Design 2B.



#2b West ABC Pulv 2% Cement Thin OL Mountain, High Desert WIM093

I-R

Vehicle speed mph: 43.8
Initial IRI, in/mile: 63

Starting time
Year, yyyy: 2009
Month, mm: 3
Day, dd: 18

Simulation assumptions
☑ Strain AC bottom
☐ Include wander

Performance criteria
Rutting, in: 0.5
Cracking ft/ftsq: 0.15
IRI, in/mile: 223.7

Output to Excel
Present number of simulations is 10
Select from simulation No. 1 to No. 20

Reflection cracking
Crack spacing, in: 3.9
Cracked layer: 0
☐ AC on PCC

Variability - Monte Carlo simulation
No. of simulations: 20
☐ Add to existing
☑ Construction variability
☐ Climate variability

Simulation type
○ Deterministic
● Monte Carlo

M&R strategy: None

Figure 15: *CalME* run options screen for Design 2B.

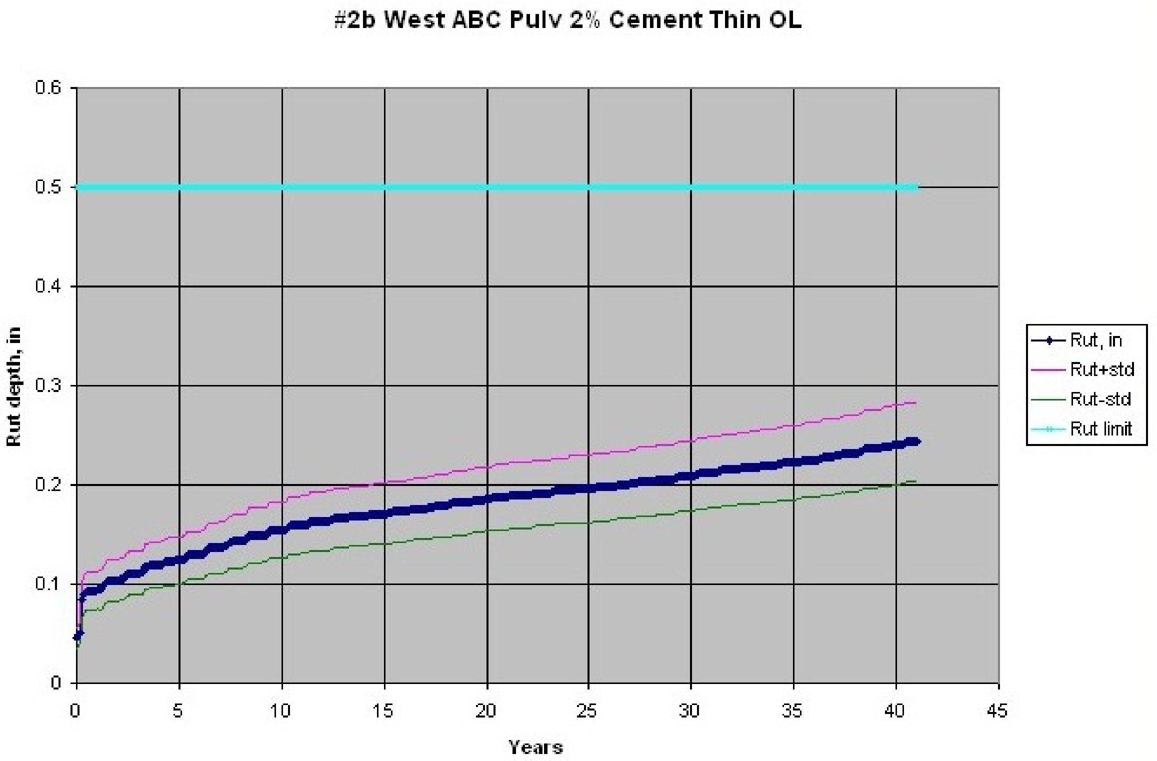


Figure 16: Rutting-versus-time plot from *CalME* for Design 2B.

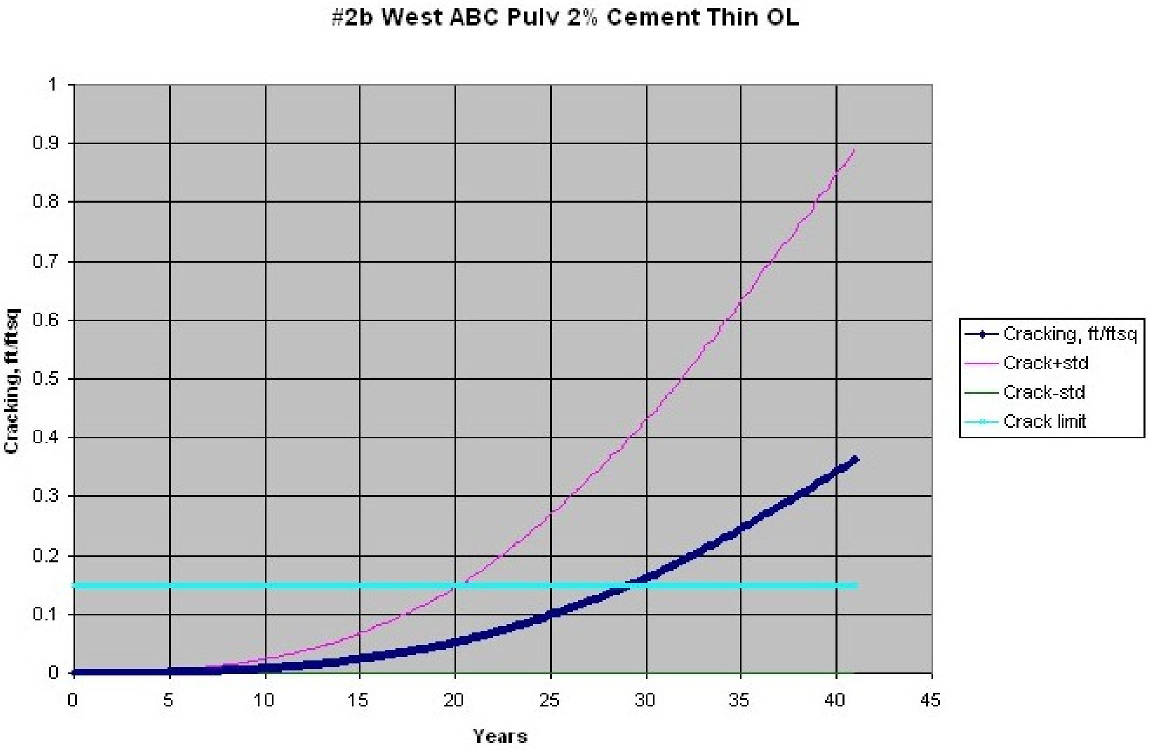
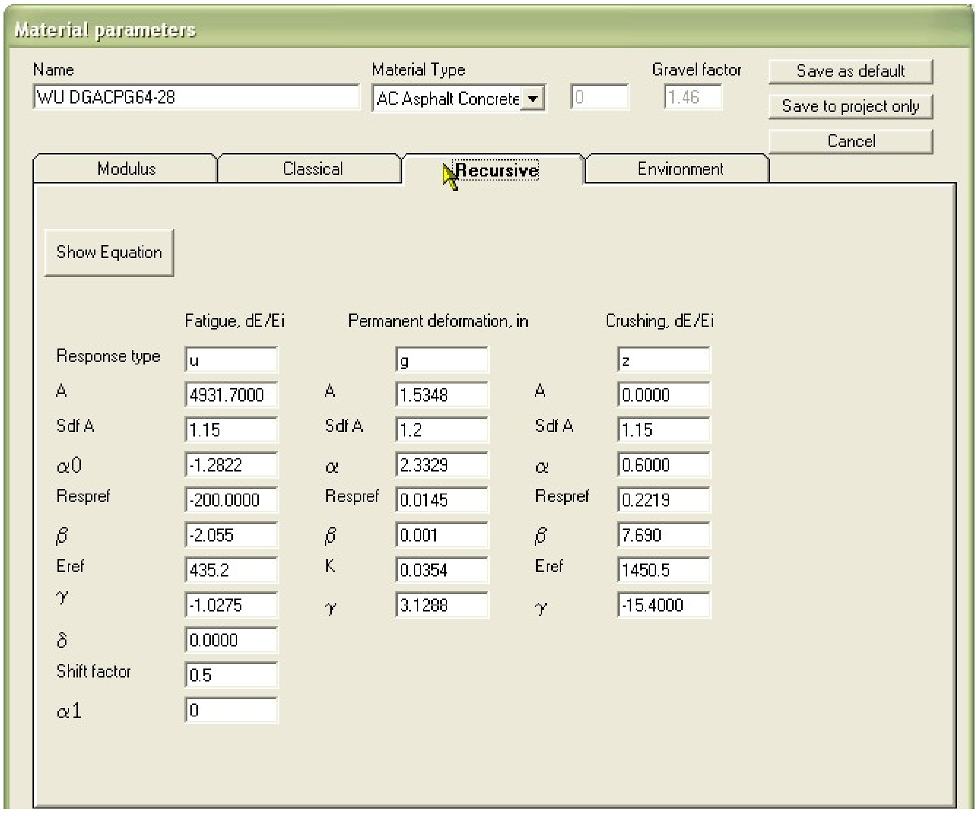


Figure 17: Cracking-versus-time plot from *CalME* for Design 2B.



Name: WU DGACPG64-28

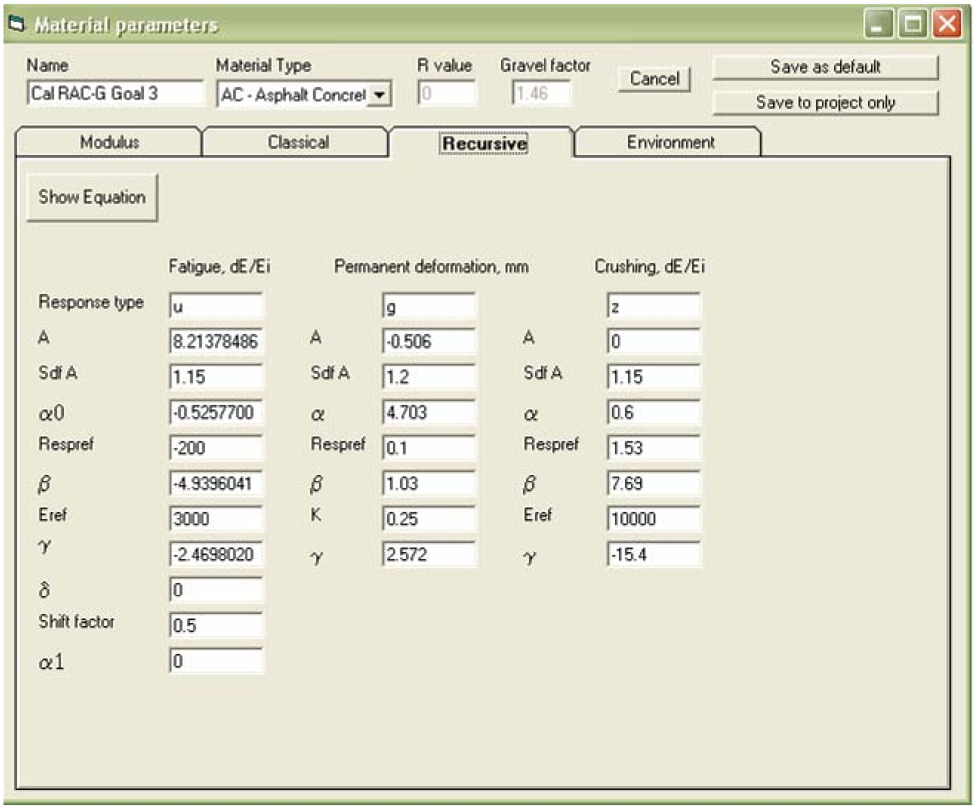
Material Type: AC Asphalt Concrete

0

Gravel factor: 1.46

	Fatigue, dE/Ei		Permanent deformation, in		Crushing, dE/Ei
Response type	u		g		z
A	4931.7000	A	1.5348	A	0.0000
Sdf A	1.15	Sdf A	1.2	Sdf A	1.15
$\alpha 0$	-1.2822	α	2.3329	α	0.6000
Respref	-200.0000	Respref	0.0145	Respref	0.2219
β	-2.055	β	0.001	β	7.690
Eref	435.2	K	0.0354	Eref	1450.5
γ	-1.0275	γ	3.1288	γ	-15.4000
δ	0.0000				
Shift factor	0.5				
$\alpha 1$	0				

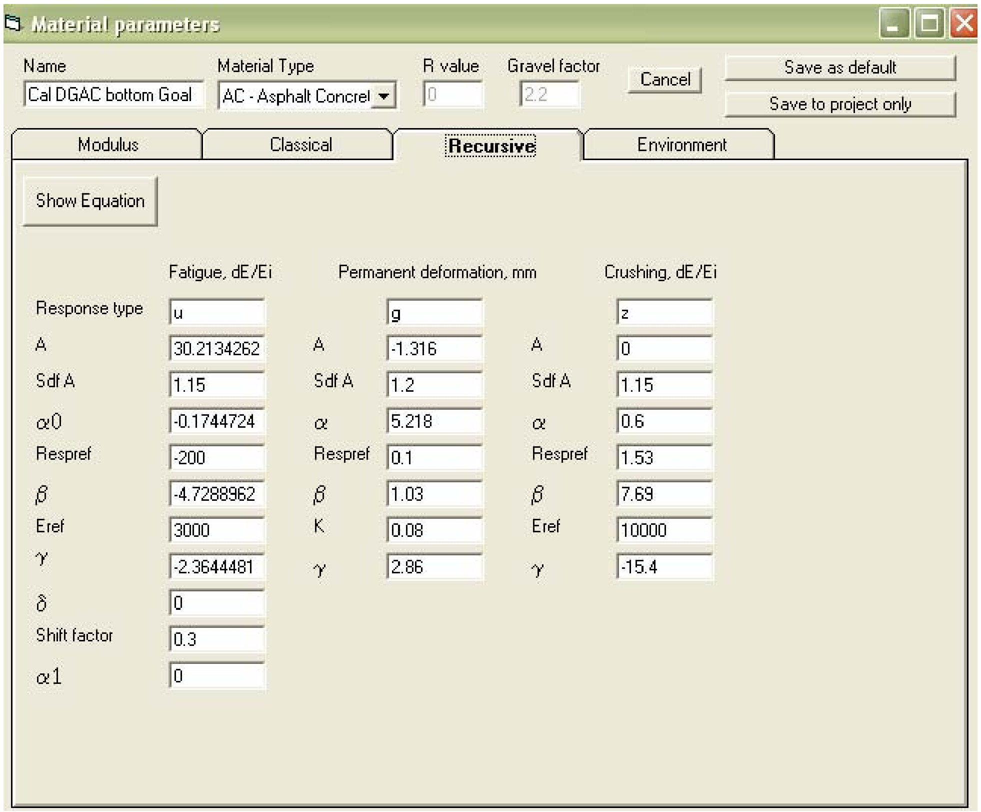
Figure 18: Material parameter inputs for PG 64-28 HMA used in *CalME* analysis.



Name: Cal RAC-G Goal 3
Material Type: AC - Asphalt Concrel
R value: 0
Gravel factor: 1.46

	Fatigue, dE/Ei		Permanent deformation, mm		Crushing, dE/Ei
Response type	u		g		z
A	8.21378486	A	-0.506	A	0
Sdf A	1.15	Sdf A	1.2	Sdf A	1.15
$\alpha 0$	-0.5257700	α	4.703	α	0.6
Respref	-200	Respref	0.1	Respref	1.53
β	-4.9396041	β	1.03	β	7.69
Eref	3000	K	0.25	Eref	10000
γ	-2.4698020	γ	2.572	γ	-15.4
δ	0				
Shift factor	0.5				
$\alpha 1$	0				

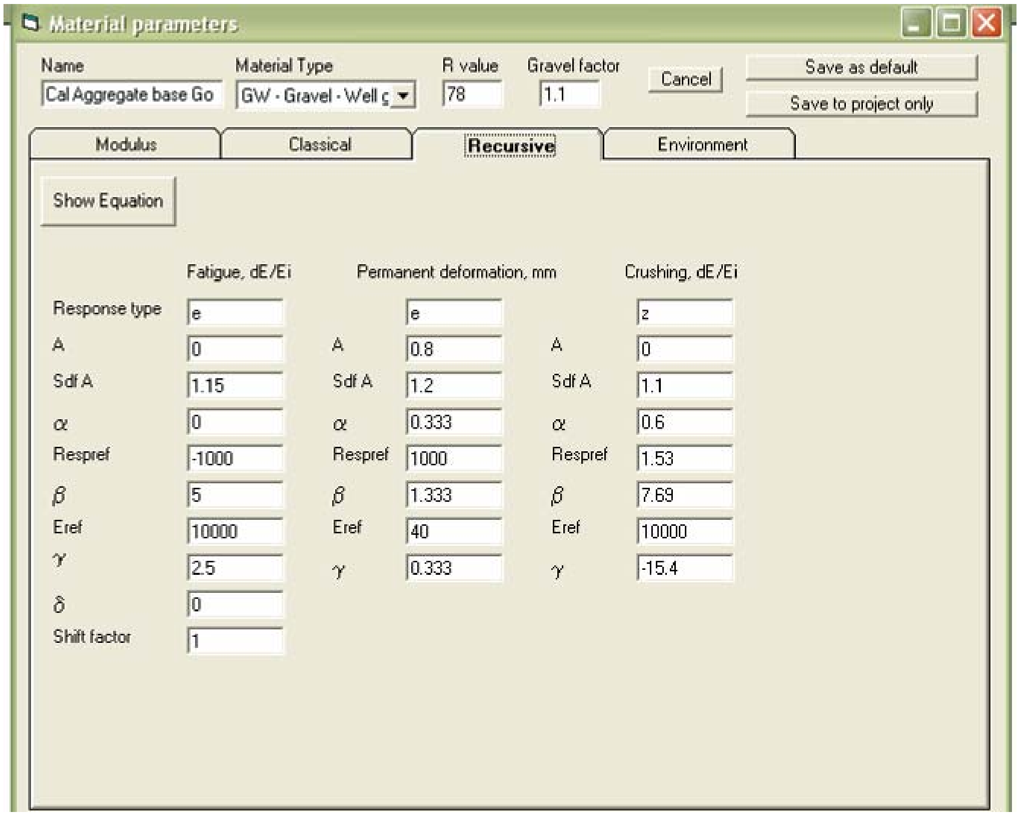
Figure 19: Material parameter inputs for existing RHMA-G used in *CalME* analysis.



Name: Cal DGAC bottom Goal
Material Type: AC - Asphalt Concrel
R value: 0
Gravel factor: 2.2

	Fatigue, dE/Ei		Permanent deformation, mm		Crushing, dE/Ei
Response type	u		g		z
A	30.2134262	A	-1.316	A	0
Sdf A	1.15	Sdf A	1.2	Sdf A	1.15
$\alpha 0$	-0.1744724	α	5.218	α	0.6
Respref	-200	Respref	0.1	Respref	1.53
β	-4.7288962	β	1.03	β	7.69
Eref	3000	K	0.08	Eref	10000
γ	-2.3644481	γ	2.86	γ	-15.4
δ	0				
Shift factor	0.3				
$\alpha 1$	0				

Figure 20: Material parameter inputs for existing DGAC used in *CalME* analysis.



Name: Cal Aggregate base Go
Material Type: GW - Gravel - Well g
R value: 78
Gravel factor: 1.1

	Fatigue, dE/Ei	Permanent deformation, mm	Crushing, dE/Ei
Response type	e	e	z
A	0	0.8	0
Sdf A	1.15	1.2	1.1
α	0	0.333	0.6
Respref	-1000	1000	1.53
β	5	1.333	7.69
Eref	10000	40	10000
γ	2.5	0.333	-15.4
δ	0		
Shift factor	1		

Figure 21: Material parameter inputs for calibrated aggregate base used in *CalME* analysis.