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16. ABSTRACT

This project investigation has found that FDR-FA is a viable rehabilitation option for the Shasta 299 project between PM 51.8 and PM 60.0. The stiffness of the subgrade, determined from FWD testing was found to be adequate for FDR-FA projects. The thickness of the HMA, based on GPR and core measurements was found to be thicker than that typically appropriate for FDR-FA over approximately 60 percent of the project. Recycling more than 0.85 ft. of HMA will usually result in problems in achieving compaction throughout the recycled layer and consequently pre-milling of the excess material may be required. A life-cycle cost analysis indicated that the FDR-FA alternative designed using CalME (HMA thickness of 0.25 ft.) had the lowest life-cycle cost of the four alternatives assessed ($9.1m). The FDR FA alternative designed using the Caltrans R-value method (HMA thickness of 0.4 ft) had the highest life-cycle cost ($10.9m) compared to the other alternatives. The two mill-and-overlay options (mill 0.2 ft./overlay 0.4 ft. and mill 0.33 ft./overlay 0.3 ft.) had life-cycle costs of $10.6M and $10.2M, respectively

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Preliminary Project Study Report for Shasta 299, PM 51.8 – 60

following

Guidelines for Full Depth Reclamation with Foamed Asphalt

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Partnered Pavement Research Program (PPRC) Strategic Plan Element 3.8: Support for Field Projects Involving Recycling

PREPARED FOR:

California Department of Transportation
District 2 Maintenance Department and
Division of Research and Innovation
Office of Roadway Research

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DISCLAIMER STATEMENT

DISCLAIMER

The contents of this technical memorandum reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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PROJECT OBJECTIVES

The objective of this project is to provide assistance to the staff of Caltrans District 2 with determining whether full-depth reclamation using foamed asphalt and cement is an appropriate rehabilitation option for Shasta 299.

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CONVERSION FACTORS

SI* (MODERN METRIC) CONVERSION FACTORS				
Symbol	**Convert From**	**Convert To**	**Symbol**	**Conversion**
LENGTH				
mm	millimeters	inches	in	mm x 0.039
m	meters	feet	ft	m x 3.28
km	kilometers	mile	mile	km x 1.609
AREA				
mm^2	square millimeters	square inches	in^2	mm^2 x 0.0016
m^2	square meters	square feet	ft^2	m^2 x 10.764
VOLUME				
m^3	cubic meters	cubic feet	ft^3	m^3 x 35.314
kg/m^3	kilograms/cubic meter	pounds/cubic feet	lb/ft^3	kg/m^3 x 0.062
L	liters	gallons	gal	L x 0.264
L/m^2	liters/square meter	gallons/square yard	gal/yd^2	L/m^2 x 0.221
MASS				
kg	kilograms	pounds	lb	kg x 2.202
TEMPERATURE (exact degrees)				
C	Celsius	Fahrenheit	F	°C x 1.8 + 32
FORCE and PRESSURE or STRESS				
N	newtons	poundforce	lbf	N x 0.225
kPa	kilopascals	poundforce/square inch	lbf/in^2	kPa x 0.145
*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)				

1. PROJECT DETAILS

In July, 2010, the University of California Pavement Research Center (UCPRC) was requested by the District 2 Maintenance Engineer, Mr. Lance Brown, to assess the potential to use full depth reclamation with foamed asphalt (FDR-FA) along eight centerline miles of State Route 299 in Shasta County, east of Redding. FDR-FA was identified as a potentially appropriate rehabilitation option on this segment by the District 2 Maintenance Engineer in 2010, because of the ongoing need for repeated overlays and frequent digouts to repair extensive cracking. The preliminary site investigation was conducted between post mile 40 and post mile 60. The project length was later reduced by 12 miles to the segment between post mile 51.8 and post mile 60.0. Figure 1.1 shows a map of the project location. The work performed by the UCPRC was conducted as part of Partnered Pavement Research Center Strategic Plan Element 3.8 – Support for Field Projects Involving Recycling.

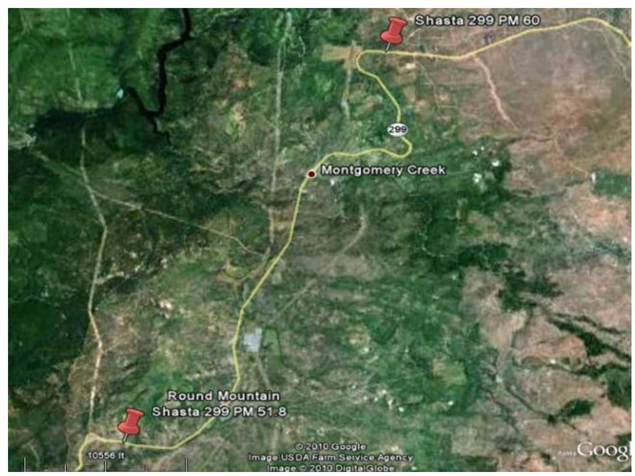


Figure 1.1: Maps showing the project location, east of Redding: Shasta 299.

The objectives of this project study are:

1. Determine the viability of FDR-FA following the draft guidelines for full-depth reclamation with foamed asphalt *(1)*, which requires consideration of:
   - Stiffness of the subgrade,
   - Condition and thickness of existing hot mix asphalt (HMA) and base/subbase layers, and
   - Whether there is bedrock near the surface that would interfere with construction equipment.
2. Produce preliminary pavement structural designs for overlay and FDR-FA for initial comparison of life cycle cost, following the Department's life cycle cost analysis (LCCA) Manual *(2)*.

The UCPRC performed the following tasks to complete the objectives:

- Visual assessment.
- Testing on-site on the existing pavement, including:

  - Measurement of deflections using a Falling Weight Deflectometer (FWD).
  - Estimation of pavement layer thicknesses using ground penetrating radar (GPR).
  - Estimation of bearing capacity of the base and subgrade and depth to bedrock using a Dynamic Cone Penetrometer (DCP).
  - Coring to verify GPR determined HMA thickness.
  - Excavation of test pits to sample base and subgrade materials for later laboratory testing and examination of the layer characteristics.
- Backcalculation of layer stiffnesses from deflection data using the *CalBack* program.
- Preparation of preliminary pavement designs following current Department methods, checked with a mechanistic-empirical analysis using the *CalME* program.
- Life-cycle cost analysis (LCCA) following Department procedures using the *RealCost* program.
- Draw conclusions regarding the viability of FDR-FA versus overlay based on comparison of the investigation results with the FDR-FA Guidelines and comparison of the life cycle cost of the different alternatives.

A flowchart for checking whether FDR-FA is an appropriate alternative is shown in Figure 1.2.

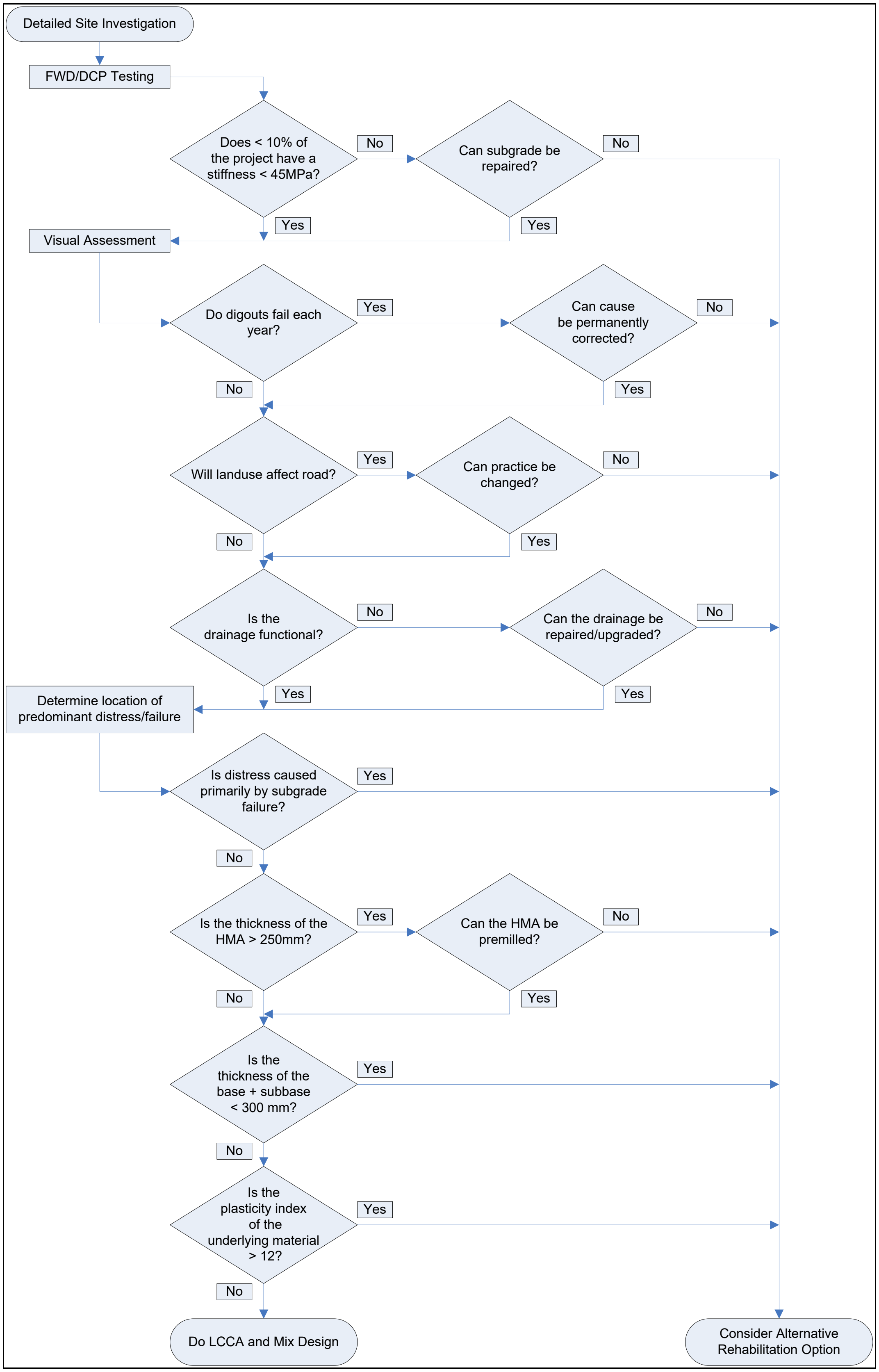


Figure 1.2: Flowchart for preliminary site investigation decision making.

(Notes: 300 mm = 12 in, 500 mm = 20 in, PI = plasticity index).

2. SITE INVESTIGATION RESULTS

2.1 Pavement Structure and Condition from Construction Records

State Route 299 in Shasta County is a two lane undivided highway. From construction records, the existing pavement structure has an HMA layer with total thickness typically between 0.6 ft and 0.75 ft (180 mm and 230 mm), with various overlay thicknesses on top of an original HMA layer of 0.33 ft to 0.42 ft (100 mm to 130 mm). The layers beneath consist of aggregate base or subbase materials. In some locations there is "road cake", consisting of oiled subgrade. Appendix A contains the recent construction history of the project.

Information from District 2 indicates that the typical subgrade R-value is 50, which equates to a material with few plastic fines.

2.2 Pavement and Drainage Condition from Visual Survey

Data from the 2006 Caltrans Pavement Condition Survey, the last year the project segment was surveyed, is summarized in Table 2.1.

Table 2.1: 2006 Pavement Condition Survey for Shasta 299

Survey Year	Begin pm	End pm	Direction	Length (Weighted avg)	IRI (inches/mile)	Alligator A (% of wheelpath)	Alligator B (% of wheelpath)
2006	51.8	60	Westbound	7.757	114	0.00	46.50
2006	51.8	60	Eastbound	7.757	113	5.52	34.53

A visual condition survey performed by the UCPRC in September, 2010 showed the following distresses:

- Wheelpath cracking (Alligator B) was seen in approximately 40 percent of the wheelpaths throughout the project except in areas of recent digouts (see Figure 2.1 and Figure 2.2).
- Edge cracking was seen at several locations, especially on fill.
- Transverse cracking and cracking between the wheelpaths (Alligator C) were seen over approximately 20 percent of the project length (see Figure 2.1).

- Asphalt patches and digouts were evident throughout the project limits (see Figure 2.2). Approximately 30 percent of the project length has digouts or patches.
- Rutting was observed in several short sections that appeared to have poor drainage. The rutting is likely to be occurring in the base or subgrade layers and not in the HMA.

All condition survey results indicate that the primary distress is cracking of the HMA.

Figure 2.1: Alligator B and C cracking and digouts.

Figure 2.2: Wheelpath cracking, patching, pumping.

2.3 Traffic and Climate Region

District 2 provided a 10 year Traffic Index of 9, and a 20 year Traffic Index of 10. The project is in the Low Mountain climate region.

2.4 Test Pits

Test pits were opened at post miles 41.70, 46.13, 52.60, and 56.53. The latter two (Test Pit 3 and Test Pit 4), were within the revised project scope. Figure 2.3 and Figure 2.4 show the pavement cross sections in Test Pit 3 and Test Pit 4, respectively.

Figure 2.3: Test Pit 3 cross section at PM 52.51 westbound.

Figure 2.4: Test Pit 4 cross section at PM 56.6 eastbound.

Pavement layer thicknesses and moisture contents from the test pits are shown in Table 2.2 and Table 2.3, respectively. The HMA thickness is not uniform across the lane in some locations. The subgrade moisture content at Test Pit 4 was higher than that at Test Pit 3. Test Pit 4 was near an area of seepage from a slope. Severe cracking in the pavement was noted in the vicinity of the seepage area.

Table 2.2: Layer Thickness Measured from Test Pits 3 and 4

Test Pit #	Layer	Average Thickness (ft [mm])	Combined Thickness (ft [mm])
3	Hot Mix Asphalt (HMA)	0.49 (150)	1.35 (410)
	Aggregate Base (AB)	0.85 (260)	
4	Hot Mix Asphalt (HMA)	0.82 (250) left face, 0.49 (150) right face	1.07 (325) left, 0.98 (300) right
	Aggregate Base (AB)	0.25 (75) left face, 0.49 (150) right face	

Table 2.3: Soil Moisture Content Determined using Samples taken from Test Pits 3 and 4.

Test Pit #	Layer	Moisture Contents (% of dry weight)
3	Aggregate Base (AB) Subgrade (SG) #1 Subgrade (SG) #2	4.9 11.9 10.0
4	Subgrade (SG)*	19.9

Samples of the subgrade were taken from the test pits. The material was characterized as non-plastic sandy gravel.

The aggregate base material from both test pits was non-plastic. Test Pit 3 had a thicker base than Test Pit 4. There were no signs of contamination of the base with subgrade materials.

Inspection of the HMA layers did not reveal the presence of rubber, fabrics, or other materials that may influence the recycling operation. The thickness of the hot-mix asphalt did not exceed 0.83 ft. (250 mm) in both test pits.

2.5 Layer Thickness from Ground Penetrating Radar and Coring

Ground penetrating radar data (GPR) from the Department's consultant collecting GPR data for the Pavement Management System were analyzed at the project level (every 16.5 inches [0.5 m]) by an independent consultant. Cores were taken at various locations along the project length in both directions to verify the GPR determined thicknesses. Cores were generally taken in the left and right wheelpaths and between the wheelpaths (center of lane) at each location. However, traffic control restrictions dictated that fewer cores were taken at some locations. The results were used to answer the following two questions:

1. Do the HMA thicknesses meet the optimal thicknesses for FDR-FA, which is between 0.83 ft. and 1.0 ft (255 mm and 305 mm)?
2. Is bedrock present at depths of less than 1.0 ft that might interfere with the recycling machines?

Coring locations for Eastbound and Westbound directions are shown in Appendix B. Core and GPR thicknesses are shown in Appendix C, along with layer thickness summaries for each subsection (identified by deflections in next part of this report) and the overlay project.

Regarding the first question, it was found that approximately 60 percent of the HMA thicknesses are greater than 0.83 ft, and approximately 30 percent of the HMA thicknesses are greater than 1.0 ft. The cumulative distribution plot of HMA thickness from the GPR is shown in Figure 2.5. Eastbound and Westbound thicknesses were generally similar.

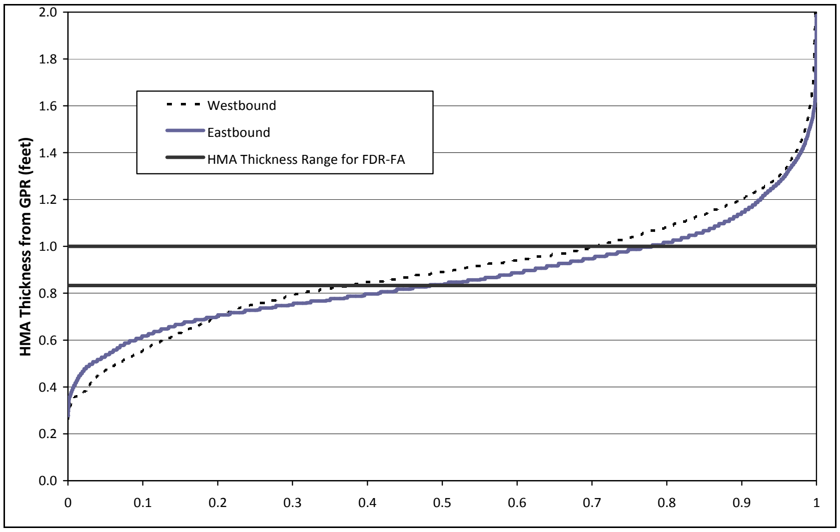


Figure 2.5: Cumulative distribution plot of HMA thickness from GPR.

Regarding the second question, the GPR analyst provided the following statement:

"*…our review of the low frequency GPR data did not reveal any evidence of bedrock in the data from PM 51.8 to PM 60.0. Note that the useful depth range of the low frequency antenna appears to be about 35 in. (2.9 ft [890 mm]), so bedrock below that depth may not be detectable.*"

2.6 FWD Analysis and Identification of Uniform Sections

The following questions were addressed through analysis of the FWD deflection data:

1. Is the stiffness of the subgrade greater than 45 MPa (6,530 psi), the minimum recommended stiffness for FDR-FA?
2. Does the project need to be divided into sub-sections to obtain relatively uniform conditions based on existing pavement structure and subgrade?

The deflection under the load plate was also analyzed for use with the Department's overlay design method. The stiffnesses of each layer were estimated by back-calculation for use in mechanistic-empirical analysis checks using the *CalBack* program.

The deflection modulus at 600 mm depth (1.97 ft) depth, (E_{def} (600 mm)), is the parameter used to evaluate subgrade stiffness to answer the first question. Values for E_{def} (600 mm) are shown in Appendix D. The results indicate that the calculated deflection moduli E_{def} (600 mm) are greater than 45 MPa (6,530 psi) throughout the project limit.

Stiffnesses were backcalculated for both directions of the entire project. An examination of the backcalculated stiffnesses (see Appendix D) indicates that the project can be divided into two subsections (A and B). Subsection A is from PM 50.8 to 56.6 and Sub-section B is from PM 56.6 to 60.0. Statistics and additional information regarding back-calculated stiffnesses are provided in Appendix D.

The 80th percentile deflections for the two sub-sections (A and B) are 9.4 mil (0.0094 in.) and 14.4 mil (0.0144 in.), respectively.

2.7 Dynamic Cone Penetrometer

DCP tests, conducted through the core holes described above, did not indicate the presence of weak subgrade or the presence of bedrock within the working depth of the recycling machines. Stony material was encountered in a number of the tests.

3. PRELIMINARY PAVEMENT DESIGNS

3.1 Introduction

Preliminary pavement designs for life-cycle cost analyses were performed to compare a conventional overlay with FDR-FA using Department methods. The calculation process was checked using the *CalAC* software for CTB Type-A materials, since *CalAC* does not include an FDR-FA option. These calculations were checked with the *CalME* software, which includes the Caltrans R-value and deflection reduction methods as an option. These designs were then analyzed for performance using the mechanistic-empirical program (ME) *CalME*. In addition, an ME design was performed which produced an alternative asphalt thickness for the FDR-FA option.

3.2 Caltrans R-Value Method for FDR-FA Option

A 20 year Caltrans R-Value design was performed with *CalME* based on a TI of 10 and subgrade R-value of 50. The recycling depth was assumed to be 0.83 ft (10 in.) and the full depth recycled (FDR) layer was taken as a treated base with gravel factor of 1.4. The detailed step by step calculations are listed in Appendix E. The minimum required HMA thickness is 0.40 ft.

3.3 Caltrans Deflection Reduction Method for Mill and Overlay Options

Mill and overlay designs were performed using both *CalME* and *CalAC* based on D80 determined by *CalBack* using FWD data. Details of the designs are listed in Appendix E.

Assuming each milling pass can remove approximately 0.17 ft (50 mm) of HMA, the 0.2 ft and 0.35 ft milling options were selected, corresponding to one and two passes of milling respectively. Both alternatives are governed by the reflective cracking requirement. The alternatives are:

1. Mill and Overlay Alternative 1: mill 0.20 ft, add 0.40 ft of HMA overlay

2. Mill and Overlay Alternative 2: mill 0.35 ft, add 0.30 ft of HMA overlay

3.4 Prediction of Pavement Performance for Design Options Using *CalME*

CalME software was used to predict performance for the FDR-FA and two mill and overlay designs. The results indicated that each of the three alternatives will not fail in 20 years by rutting, fatigue cracking or reflective cracking.

3.5 Prediction of Pavement Performances for Design Options Using *CalME*

The *CalME* software was used to check the overlay thickness for the FDR-FA design. The results indicated that a 0.25 ft (75 mm) overlay was sufficient to prevent cracking and rutting.

4. LIFE-CYCLE COST ANALYSIS SUMMARY

A preliminary life cycle cost analysis was performed on the designs listed in Table 4.1.

Table 4.1: Design Alternatives for LCCA Analysis

Parameter	Alternative			
	1	2	3	4
Name	M&O #1	M&O #2	FDR #1	FDR #2
Description	Mill and Overlay	Mill and Overlay	FDR	FDR
Design Method	Empirical	Empirical	Empirical	Incremental-Recursive
Premilling Depth (ft)	0.20	0.35	0.20*	0.20*
Overlay Thickness (ft)	0.40	0.30	0.40	0.25
* Pre-milling for FDR alternatives is assumed to be on 60% of the project where the existing HMA is thicker than 0.83 ft, with an average milling depth of 0.20 ft.				

The results of the LCCA are shown in Table 4.2. The values and assumptions for the LCCA are listed in Appendix F.

Table 4.2: LCCA Results Summary for Shasta 299 Options (note: the RealCost program uses inches for layer thickness)

Alternative No.	Unit	1	2	3a	4a	Notes
(Pre) Milling	Inch	2.4	4.1	2.5 (60%)	2.5 (60%)	
Pulverization	Inch			10.0	10.0	
HMA	Inch	4.7	3.5	4.7	3.0	
Design Life	Year	15	10	15	10	
Initial Const. Cost ($M)	$M	**7.7**	**6.6**	**7.9**	**5.5**	
Work-zone User Cost ($M)	$M	0.5	0.6	1.0	0.9	Initial Construction
Const. Duration	Month	**3**	**4**	**6**	**5**	Initial Construction
CAPM Cost (Discounted): Year 10	$M		1.7		1.7	1.2" Milling + 1.2" HMA
CAPM Cost (Discounted): Year 15	$M	2.2		2.2		2" Milling + 2" HMA
CAPM Cost (Discounted): Year 20	$M		1.1		1.1	1.2" Milling + 1.2" HMA
CAPM Cost (Discounted): Year 30	$M	0.8	0.8	0.8	0.8	1.2" Milling + 1.2" HMA
Total LCCA: 40 years	$M	**10.6**	**10.2**	**10.9**	**9.1**	

5. RECOMMENDATIONS

This project investigation has found that FDR-FA is a viable rehabilitation option for the Shasta 299 project between PM 51.8 and PM 60.0. The stiffness of the subgrade, determined from FWD testing was found to be adequate for FDR-FA projects. The thickness of the HMA, based on GPR and core measurements was found to be thicker than that typically appropriate for FDR-FA over approximately 60 percent of the project. Recycling more than 0.85 ft. of HMA will usually result in problems in achieving compaction throughout the recycled layer and consequently pre-milling of the excess material may be required. A life-cycle cost analysis indicated that the FDR-FA alternative designed using *CalME* (HMA thickness of 0.25 ft.) had the lowest life-cycle cost of the four alternatives assessed ($9.1m). The FDR-FA alternative designed empirically (HMA thickness of 0.4 ft) had the highest life-cycle cost ($10.9m) compared to the other alternatives. The two mill-and-overlay options (mill 0.2 ft./overlay 0.4 ft. and mill 0.33 ft./overlay 0.3 ft.) had life-cycle costs of $10.6M and $10.2M, respectively.

6. REFERENCES

1. JONES, D., Fu, P. and Harvey, J.T. 2008. **Full-Depth Pavement Reclamation with Foamed Asphalt in California: Guidelines for Project Selection, Design, and Construction.** Davis and Berkeley, CA.: University of California Pavement Research Center. (UCPRC-GL-2008-01).
2. **Life-Cycle Cost Analysis Procedures Manual.** 2007. Sacramento, CA: State of California, Department of Transportation, Pavement Standards Team & Division of Design.

APPENDIX A: RECENT CONSTRUCTION HISTORY

The roadway project work conducted between 1980 and 2009 on Shasta 299 between PM 40 and PM 60 is summarized in Table A.1 and Figure A.1 (note that dashed lines and color only are used to indicate overlapping project work [same year, same roadway section]).

Table A.1: Recent Construction History on Shasta 299

	Project Description	EA	PM - Begin	PM - End	Year
1	AC Surfacing	0E0404	41.1	41.3	2009
2	Placed AC (Type A) & AB	134954	56.5	57	1994
3	AC Surfacing	189104	45.6	50.9	1983
4	AC Overlay	212504	50.9	55.4	1984
5	Seal Coat	242504	40	45.8	1986
6	Seal Coat	242504	57.2	60	1986
7	Seal Coat	242504	40	60	1986
8	Seal Cracks	249304	55.4	60	1994
9	AC Overlay	249324	57	60	1994
10	AC Surfacing	2C9104	43	50	2007
11	AC Overlay	308504	40	60	1995
12	AC Overlay	340704	40	48.1	1998
13	Seal Cracks	341204	40	45	1998
14	Placed AC (Type A) & AB	3705U4	50.7	51.9	2007
15	Seal Coat	382304	44.9	48.9	2003
16	AC Surfacing	4C1904	40	41	2006
17	AC Overlay	277504	48.1	48.72	1999

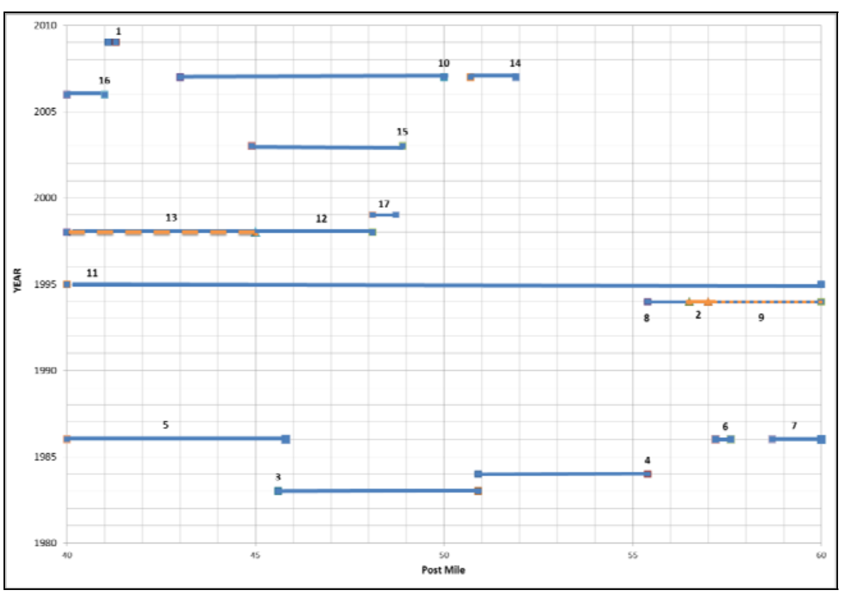
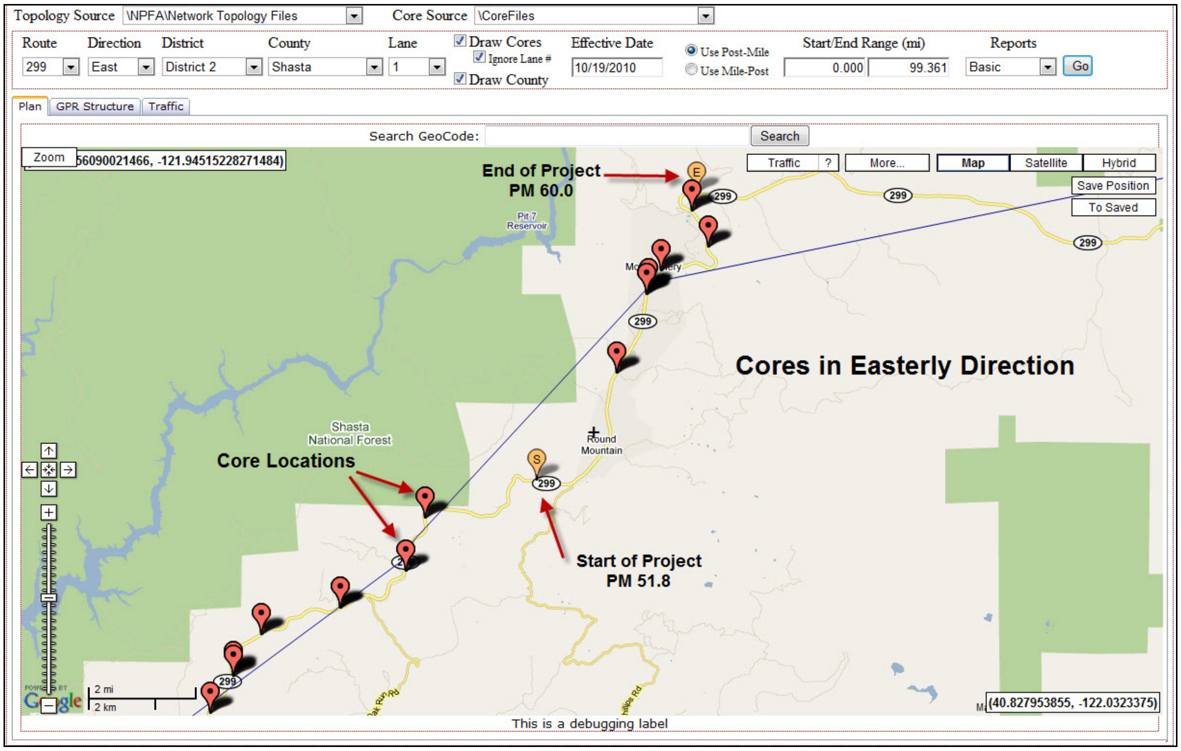
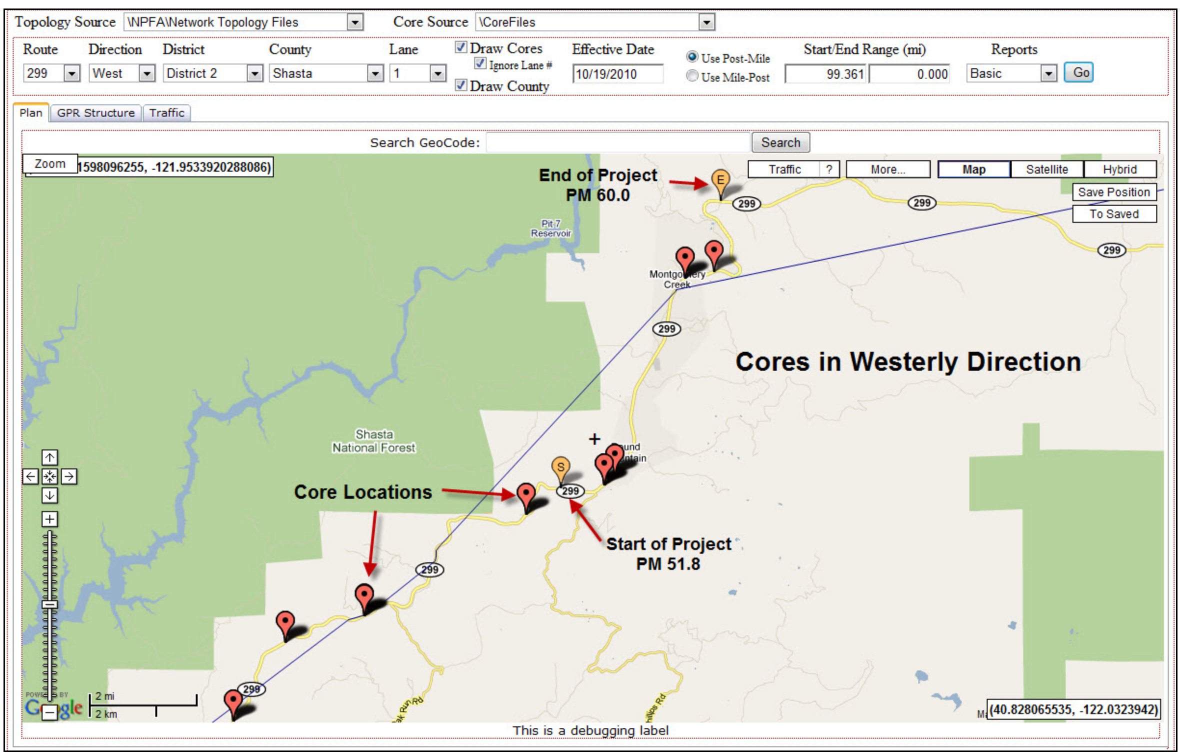


Figure A.1: Recent construction history on Shasta 299.

APPENDIX B: CORING LOCATIONS.





APPENDIX C: HMA THICKNESSES FROM GPR AND CORES

HMA thicknesses on the project are summarized in Table C.1 and Figure C.1 through C.5.

- Table C.1 provides a summary of HMA thicknesses determined from GPR data. The table includes an average of all measurements as well measurements for two sub sections (PM 51.8 to PM 56.6 and PM 56.6 to PM 60.0), which were delineated from the FWD data.
- Figure C.1 and Figure C.2 summarize the HMA thicknesses determined from core data from the eastbound and westbound directions, respectively. Typical FDR-FA thickness ranges are shown on the plots.
- Figure C.3 and Figure C.4 plot the core thicknesses on the GPR plots for comparative purposes for the eastbound and westbound directions, respectively. Typical FDR-FA thickness ranges are shown on the plots.
- Figure C.5 provides a view from the draft PMS GPR/Core Viewing tool. The plot shows pavement structure derived from GPR (Red and Green are asphalt layers, Blue is base thickness) and HMA cores (brown lines) for the eastbound direction for the project length.

Table C.1: HMA Thickness Summary from GPR (two subsections identified from deflection data)

Post Mile	Direction	Thickness					
		Average			Std. Deviation		
		ft.	in.	mm	ft.	in.	mm
51.8 to 60.0	Both Directions	0.88	10.6	268	0.23	2.8	72
51.8 to 56.6	Eastbound	0.85	10.2	259	0.25	3.0	75
	Westbound	0.84	10.1	256	0.28	3.3	85
	Both Directions	0.84	10.1	257	0.27	3.2	80
56.6 to 60.0	Eastbound	0.88	10.6	269	0.17	2.0	52
	Westbound	0.98	11.7	296	0.18	2.2	55
	Both Directions	0.93	11.1	282	0.18	2.2	55

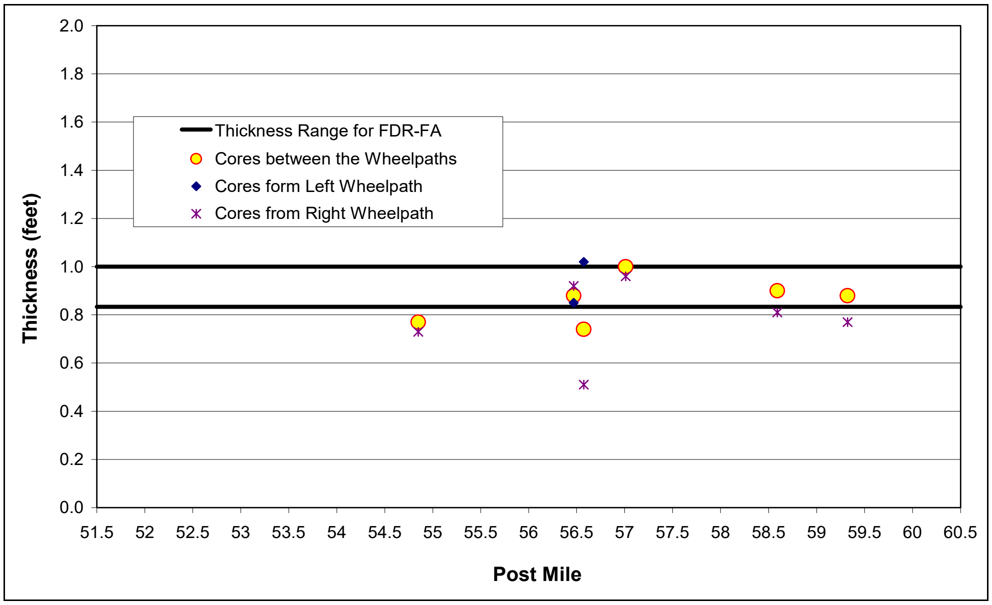


Figure C.1: HMA thickness summary from cores for eastbound lane.

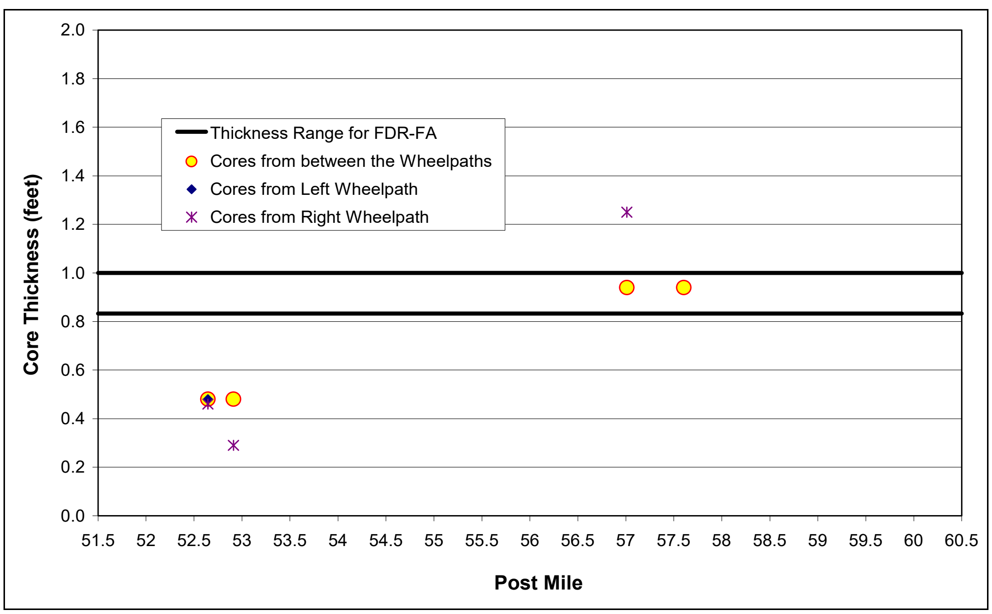


Figure C.2: HMA thickness summary from cores for westbound lane.

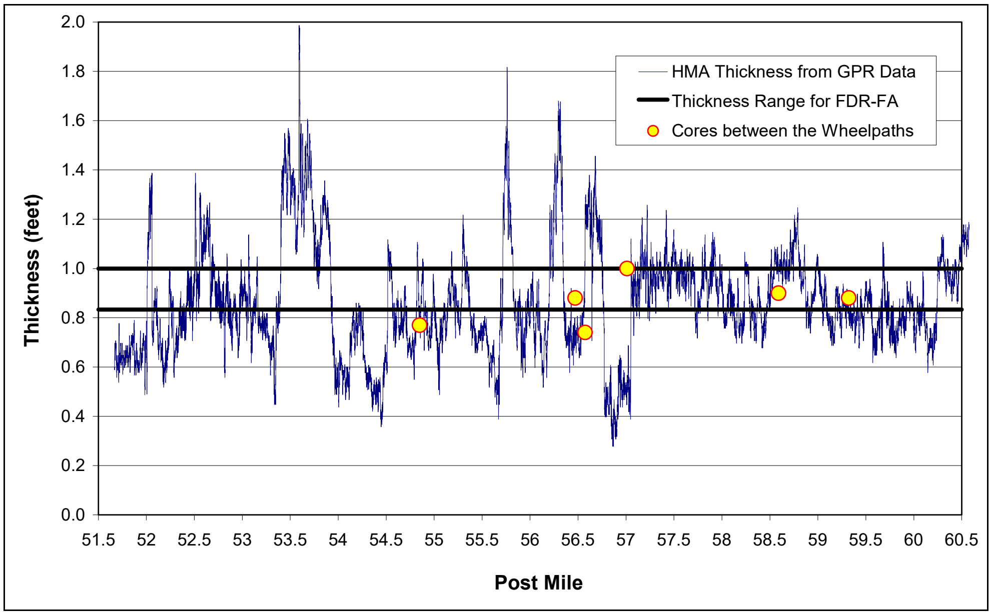


Figure C.3: Comparison of GPR and core thicknesses for eastbound lane.

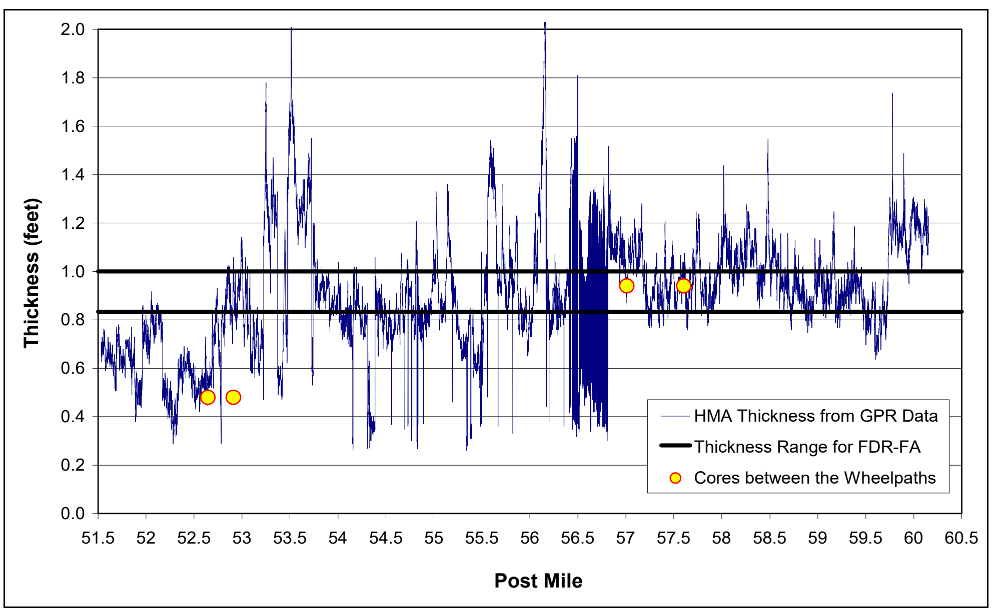


Figure C.4: Comparison of GPR and core thicknesses for westbound lane.

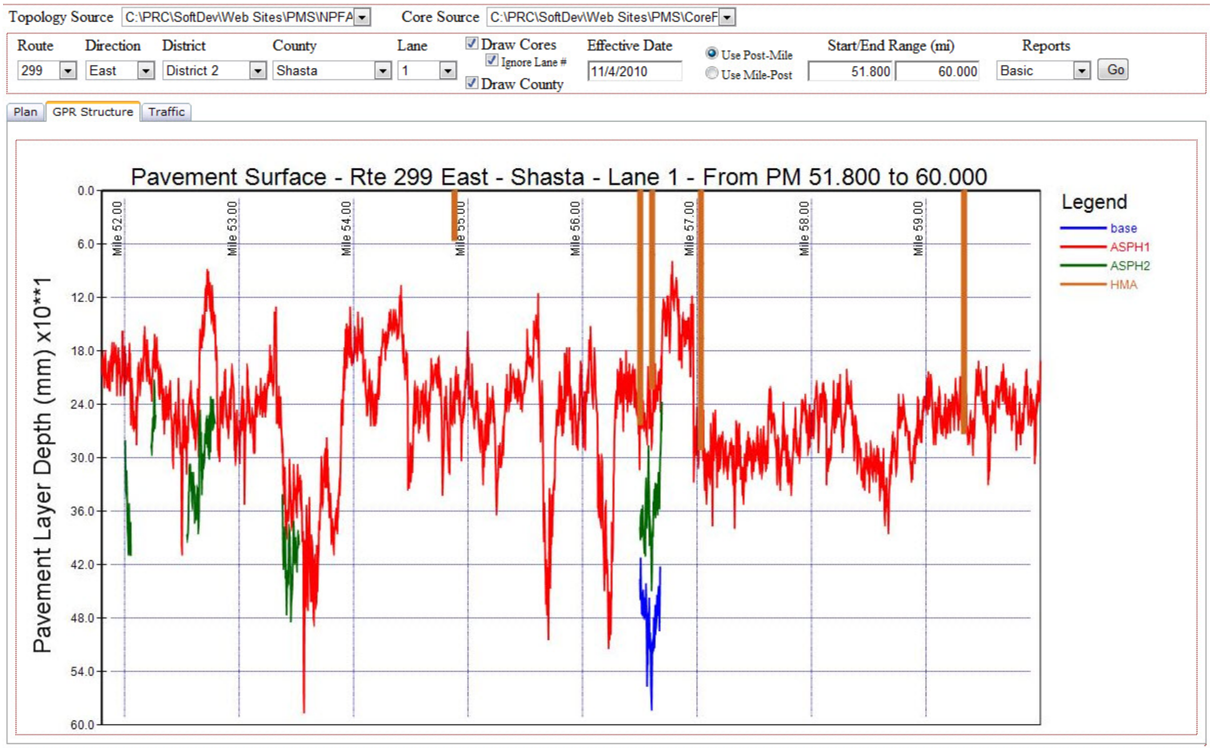


Figure C.5: Screenshot from PMS GPR/Core viewing tool.

(note that pavement layer depth is in centimeters [30 cm = 1 ft]).

APPENDIX D: FWD DATA ANALYSIS

D.1 Subgrade Stiffness (Deflection Modulus at 600 mm Depth)

The subgrade stiffness deflection modulus is undertaken to identify weak areas in the subgrade that will not provide adequate support for an FDR-FA base. A plot of the deflection moduli for the project is provided in Figure D.1. A deflection modulus below 6.5 ksi (45 MPa) would be a concern. The plot shows that the deflection moduli for the project are well above this limit. The statistics for the two segments are summarized in Table D.1.

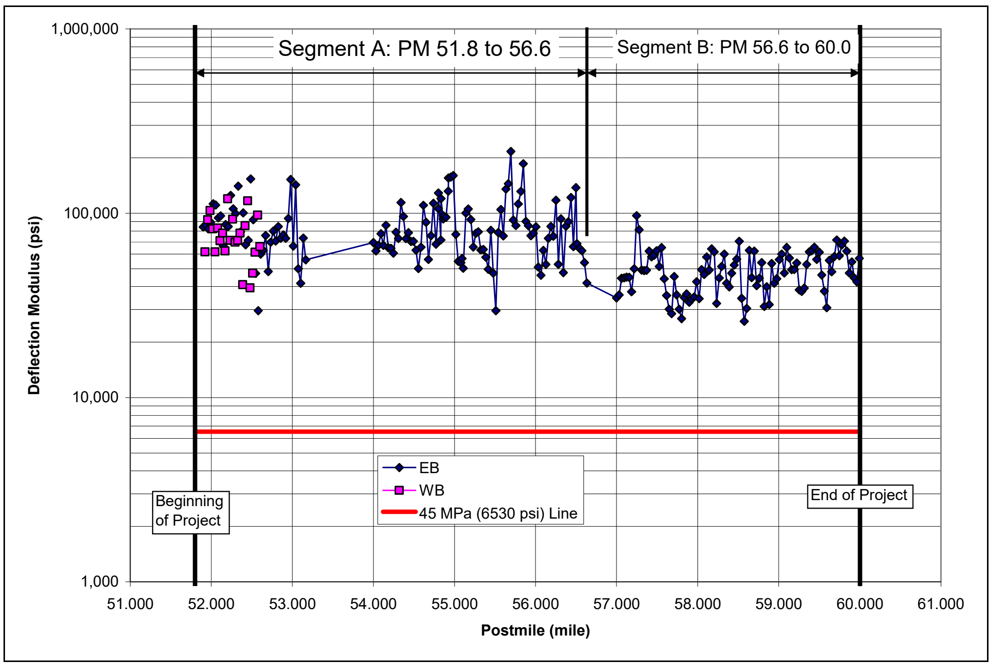


Figure D.1: Subgrade Deflection Modulus.

Table D.1: Deflection Modulus (at 600 mm) Statistics for ach Subsection

Parameter	Segment A	Segment B
Boundaries	PM 50.8 to 56.6	PM 56.6 to 60.0
Average of E_{def} (600 mm) (ksi [MPa])	28 (193)	16 (112)
Standard deviation of E_{def} (600 mm) (ksi [MPa])	10 (69)	4 (29)
Coefficient of variation for E_{def} (600 mm)	0.35	0.26

D.2 Back-Calculated Pavement Stiffness

FWD deflection data were used to back-calculate layer stiffness using *CalBack* with the pavement structure listed in Table D.2. The results were adjusted for 20°C. A plot of the results for the project is shown in Figure D.2. Average values were calculated for each layer, assuming log-normal distribution for layer stiffness, and are summarized in Table D.3. Variation of layer thickness was determined by calculating standard deviation factors (SDF). The subsections differentiated using the deflection moduli were consistent with the subsections differentiated using *CalBack*.

Table D.2: Pavement Structure used during Layer Stiffness Backcalculation

Layer Number	Description	Lane	Postmile	Thickness			Notes
				ft.	in.	mm	
1	HMA	EB	51.8 – 60.0	0.83	10	250	-
		WB	51.8 – 53.7	0.67	8	200	-
			53.7 – 56.6	0.83	10	250	-
			56.6 – 60.0	1.0	12	300	-
2	AB	Both	51.8 – 60.0	0.83	10	250	-
3	SG	Both	51.8 – 60.0	Infinite			Nonlinear

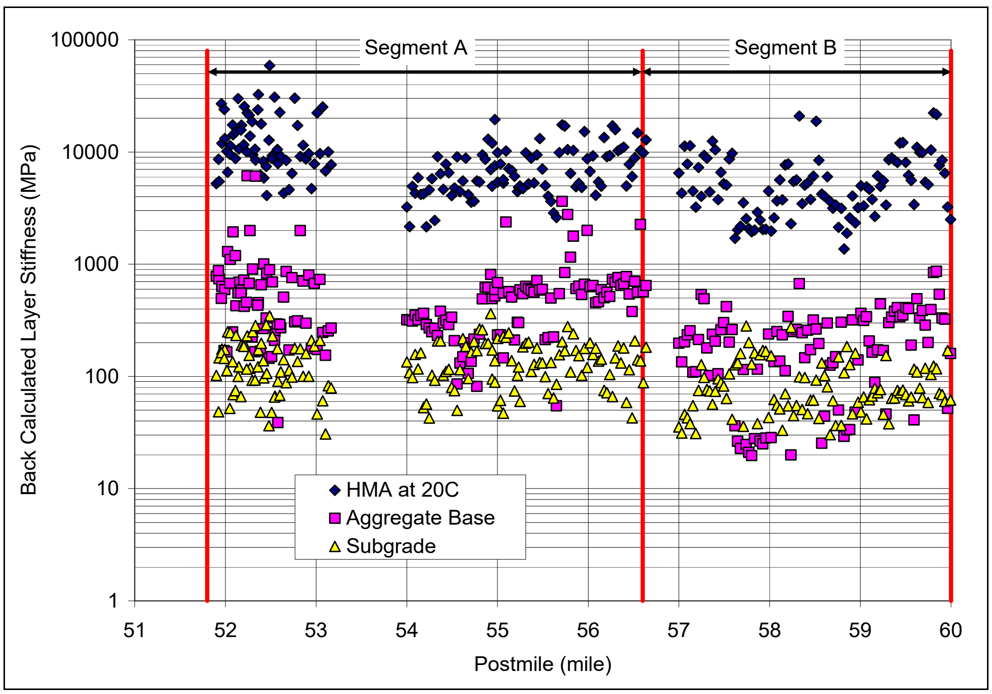


Figure D.2: Backcalculated layer stiffness and uniform subsection boundaries.

Table D.3: Summary of Backcalculated Layer Stiffnesses for each Subsection

Subsection	Layer	Layer stiffness		
		Average		SDF*
		ksi	MPa	
A	HMA	1220	8,411	1.28
	AB	66	453	1.31
	SG	18	124	1.66
B	HMA	730	5,029	1.25
	AB	23	159	1.31
	SG	11	76	1.68

* Standard deviation factor, calculated as 10 raised to the power of the standard deviation of the log of the layer stiffness

APPENDIX E: PRELIMINARY PAVEMENT DESIGN INFORMATION

E.1 Caltrans R-Value Design for FDR Alternative

A 20 year Caltrans R-Value design was performed based on a TI of 10.

The proposed structure is HMA over FDR-FA over Remaining Base Material over SG. The existing structure is:

- Average of 0.83 ft HMA.
- Average of 0.83 ft base material with R-Value of 60
- Subgrade with R-Value of 50

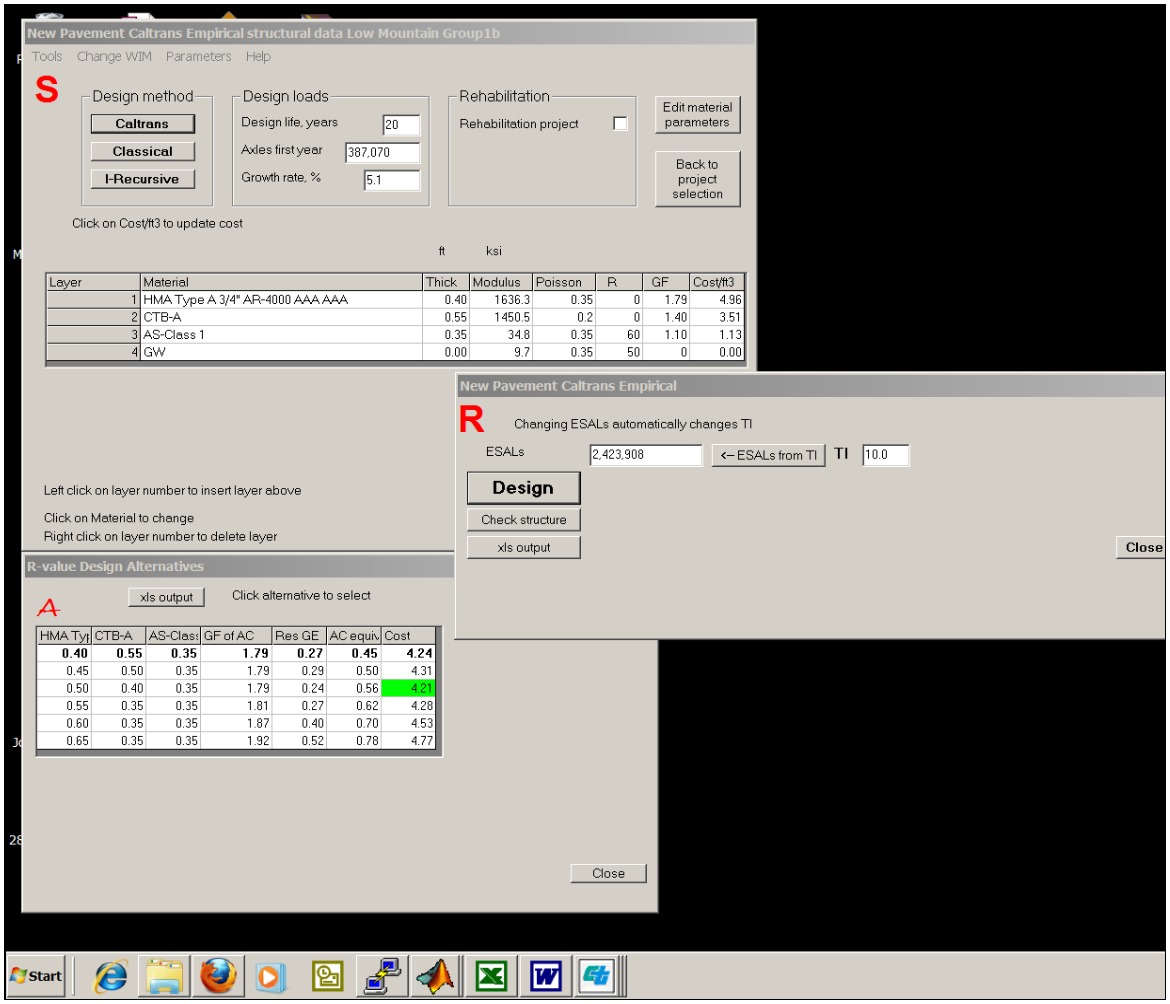
Table E.1. Structure used for R-Value Design

Layer Name	Structure Function	R-Value	Gravel Factor
HMA	AC Surface	N/A	Varies with thickness
FDR	Treated Base	N/A	1.4
Remaining base material	AS-Class 1	60	1.1
SG	Basement Soil	50	N/A

The following design procedure was followed:

1. Determine GE required over the basement soil: 0.0032*TI*(100-R) = 0.0032*10*(100-50) = <u>1.6 ft</u>
2. Determine GE required for the combined HMA and FDR using the standard formula and the R-Value of the AS: 0.0032*10*(100-60) = <u>1.28 ft</u>.
3. Determine GE required for HMA by multiplying the GE required for combined HMA and FDR layer by 0.4 and adding the safety factor: 1.28*0.4 + 0.2 = <u>0.712 ft</u>
4. Determine the actual thickness required for HMA: Gf = 1.79, thickness required is 0.712/1.79 = 0.398 ft, rounded to nearest 0.05 ft, which is 0.40 ft, since it is less than 0.50 ft the Gf used is valid.
5. Add the safety factor to the required GE of the combined HMA and FDR layer: 1.28 + 0.2 = <u>1.48 ft</u>
6. Subtract the actual GE provided by the HMA from the total GE required for HMA and FDR layers: 1.48 - 0.40*1.79 = <u>0.764 ft</u>
7. Determine the minimum thickness required for the FDR layer: 0.764/1.4 = 0.546 ft, rounded to <u>0.55 ft</u>. Note however, the actual thickness of FDR layer is <u>0.83 ft</u>
8. Determine remaining base layer thickness required to satisfy the total GE need: (1.6 - 0.40*1.79 - 0.83*1.4)/1.1 = <u>-0.25 ft</u>, (i.e. no additional base layer is required).
9. The proposed structural section is: <u>0.40 ft HMA</u>, <u>0.83 ft FDR</u>, on the remaining base layer.

CalME and *CalFP* were used to check the R-value design. An FDR-FA option is currently not available in either software package; however, a CTB-A layer was used as an alternative (Figure E.1 and Figure E.2). The same required HMA thickness to that of the R-Value design described above was obtained from both analyses.



Layer	Material	Thick (ft)	Modulus (ksi)	Poisson	R	GF	Cost/ft3
1	HMA Type A 3/4" AR-4000 AAA AAA	0.40	1636.3	0.35	0	1.79	4.96
2	CTB-A	0.55	1450.5	0.2	0	1.40	3.51
3	AS-Class 1	0.35	34.8	0.35	60	1.10	1.13
4	GW	0.00	9.7	0.35	50	0	0.00

HMA Typ	CTB-A	AS-Class	GF of AC	Res GE	AC equiv	Cost
0.40	**0.55**	**0.35**	**1.79**	**0.27**	**0.45**	**4.24**
0.45	0.50	0.35	1.79	0.29	0.50	4.31
0.50	0.40	0.35	1.79	0.24	0.56	4.21
0.55	0.35	0.35	1.81	0.27	0.62	4.28
0.60	0.35	0.35	1.87	0.40	0.70	4.53
0.65	0.35	0.35	1.92	0.52	0.78	4.77

Figure E.1: Screen shot of R-Value design using *CalME*

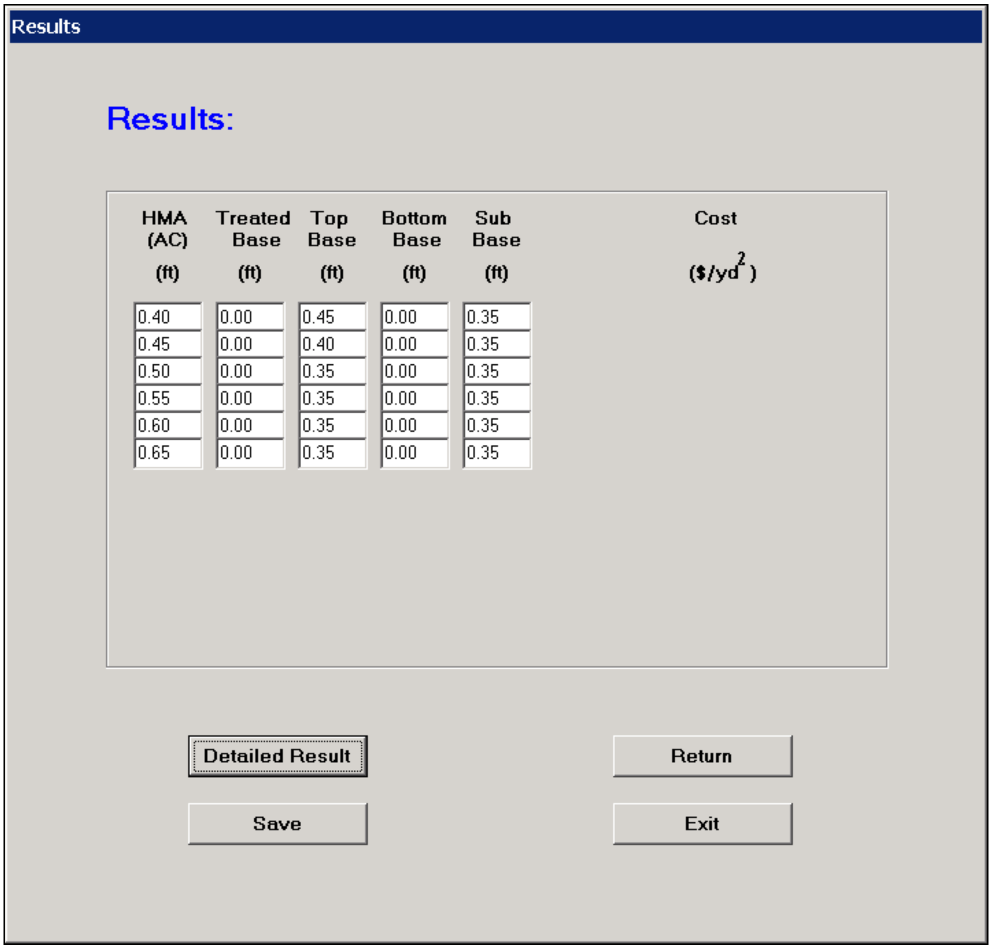


Figure E.2: Design alternatives for FDR option from *CalFP*.

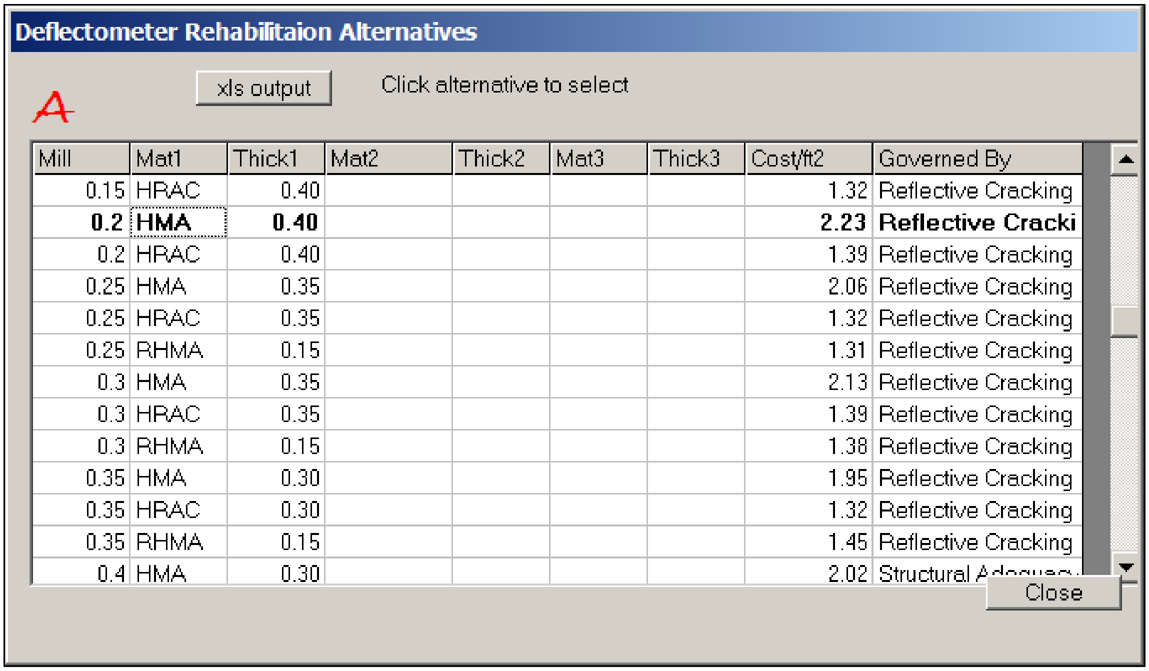
(Note: FDR is represented by a CTB-A layer. The required thickness of the CTB layer is not correct, but the required HMA thickness is correct).

E.2: Caltrans Empirical Design for Mill and Overlay Options

Caltrans mill and overlay design was performed using *CalME* and checked with *CalAC*. The 80th percentile of measured surface deflections (i.e., D80) were calculated from FWD data using *CalBack*. The project was initially divided into two segments (A and B) based on the surface deflection modulus data. The D80 values are:

- Segment A: 9.4 mil (0.0094 in.)
- Segment B: 14.4 mil (0.0144 in.)

The resulting designs were, however, exactly the same for both segments. The alternatives are listed in Figure E.3 through Figure E.5.



Mill	Mat1	Thick1	Mat2	Thick2	Mat3	Thick3	Cost/ft2	Governed By
0.15	HRAC	0.40					1.32	Reflective Cracking
0.2	**HMA**	**0.40**					**2.23**	**Reflective Cracki**
0.2	HRAC	0.40					1.39	Reflective Cracking
0.25	HMA	0.35					2.06	Reflective Cracking
0.25	HRAC	0.35					1.32	Reflective Cracking
0.25	RHMA	0.15					1.31	Reflective Cracking
0.3	HMA	0.35					2.13	Reflective Cracking
0.3	HRAC	0.35					1.39	Reflective Cracking
0.3	RHMA	0.15					1.38	Reflective Cracking
0.35	HMA	0.30					1.95	Reflective Cracking
0.35	HRAC	0.30					1.32	Reflective Cracking
0.35	RHMA	0.15					1.45	Reflective Cracking
0.4	HMA	0.30					2.02	Structural Adequacy

Figure E.3: Partial list of alternatives for mill and overlay option from *CalME.*

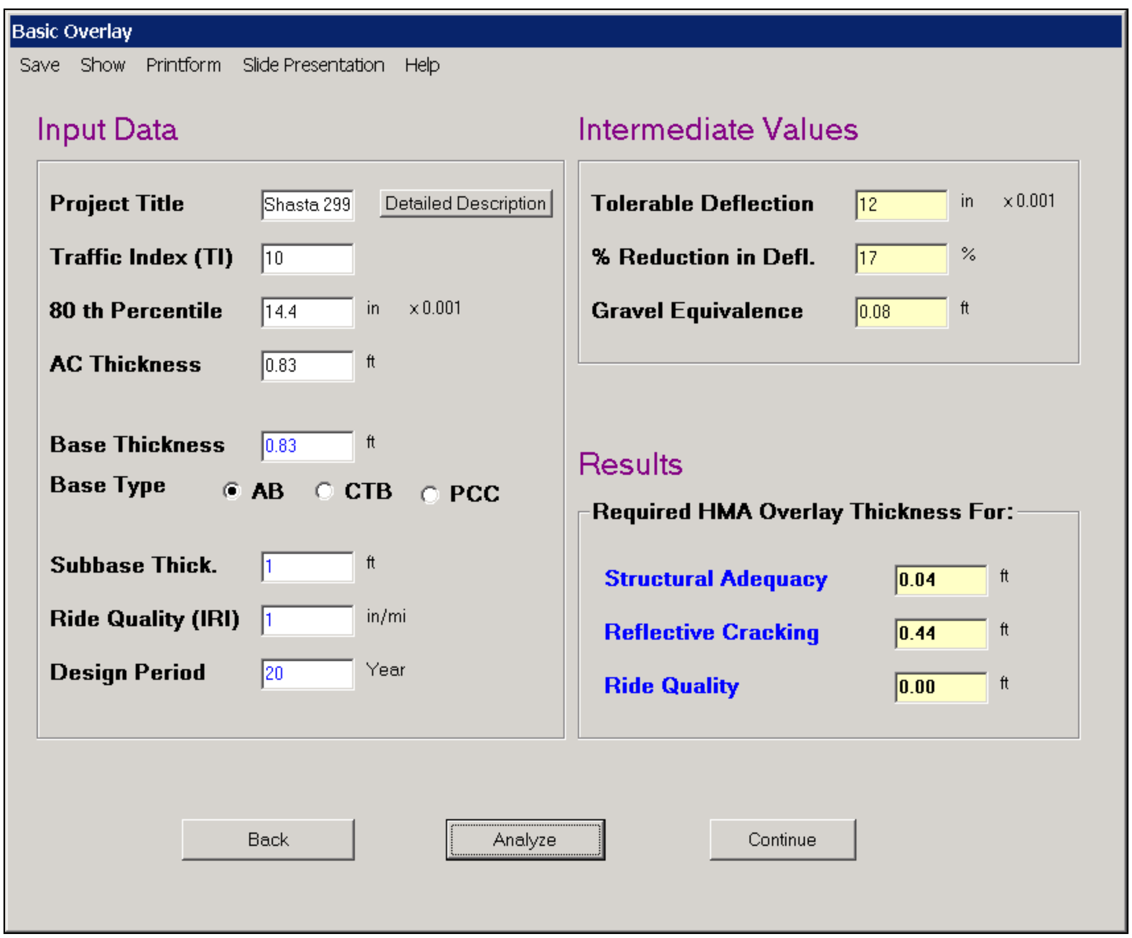


Figure E.4: Input screen for *CalAC* (changing subbase thickness to 0 ft did not change the result).

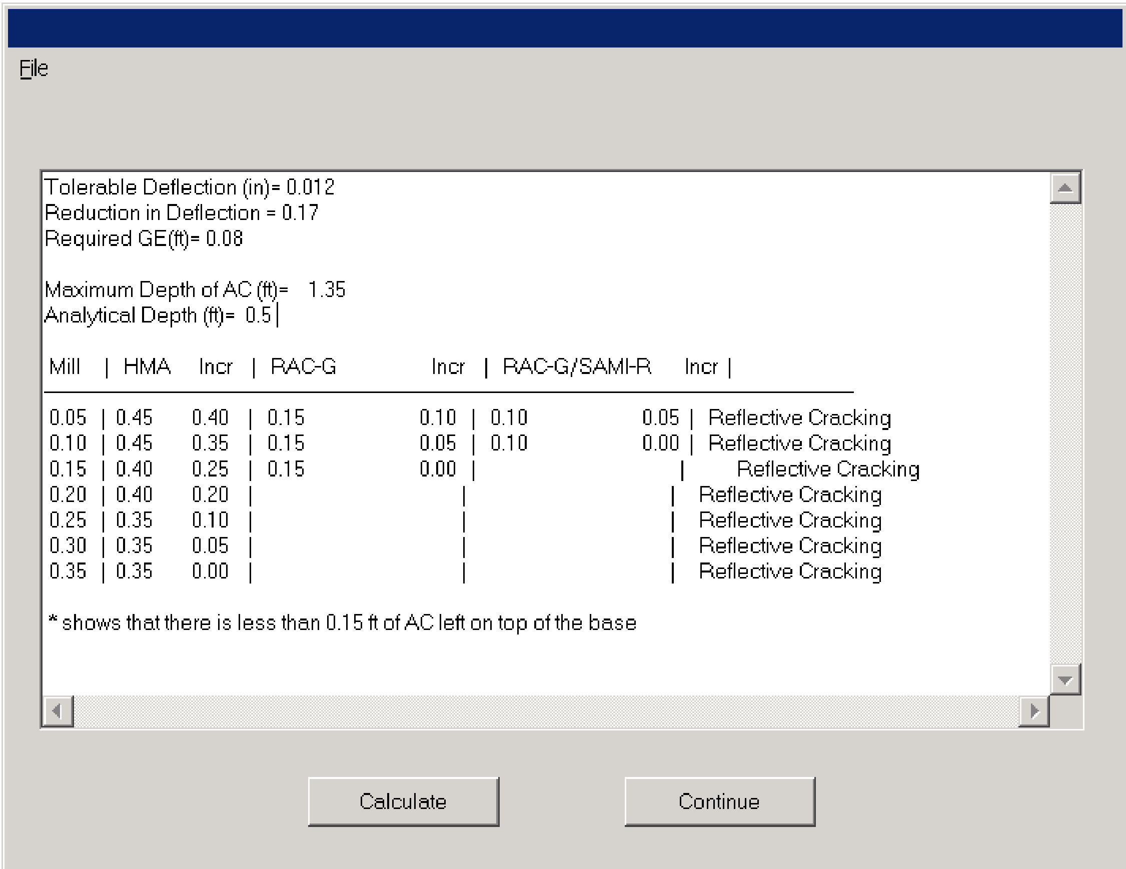


Figure E.5: List of design options based on *CalAC*.

The required overlay thickness, governed by reflective cracking, was calculated for the alternative design options chosen (i.e., milling 0.20 and 0.35 ft respectively). The results are summarized in Table E.2.

Table E.2: Calculation of Overlay Thickness Required to Prevent Reflective Cracking

Parameter	Option 1	Option 2
Mill Depth (ft)	0.20	0.35
Existing HMA thickness (ft)	0.83	0.83
Remaining HMA thickness (ft)	0.63	0.48
Overlay Thickness Required for 10 year design (ft)	0.5*0.63 = 0.315	0.5*0.48 = 0.24
Adjust for 20 year design by multiply by 1.25	0.315*1.25 = 0.39	0.30
Rounded off to nearest 0.05 ft	0.40	0.30

APPENDIX F: ASSUMPTIONS AND VALUES USED FOR LCCA

1. Project boundary = PM 53 – 60 (Shasta)
2. Scope = 8 miles; 30' width (2 lanes x 12' + 3' median + 3' shoulder)
3. Compared 4 design alternatives: two 2 milling and HMA overlay and two pulverization and HMA overlay
4. Used the Caltrans LCCA procedure
   A. The analysis period = 35 years
   B. Discount rate = 4%
   C. The CA4PRS LCC function was used to the NPV calculation, which adopts the same procedure in Realcost (note: time was not enough to run the Realcost software).
   D. The future M&R sequnsing was based on: LCCA manual HMA Low Moutain region (M&R Table F-4), combining with ME expected design-life, and some engineering assumption.
5. Cost estimate was based on the typical Caltrans procedure
   A. Pavement unit prices were based on the Caltrans bid database (District 2, 2002-2010, the awarded lowest bid, using minimum quantity filter). For example, HMA = $100 per Tonn (SI).
   B. http://sv08data.dot.ca.gov/contractcost/
   C. Some items such as pulverization and foamed asphalt prices were referred from other sources, when the data is not available. Unit price for different milling depth was adjusted slightly, proportional to the milling depth.
   D. The multiplier of 2 was used to cover non-pavement (including traffic) costs and indirect costs for the initial construction and future M&R
6. Construction duration was estimated, using the CA4PRS schedule estimate procedure (note: time was not enough to run the CA4PRS software).
7. Workzone traffic delay was based on demand-capacity model.
   A. Typical AADT was assumed to be 4,000 on average, base on the Caltrans 2008 truck database (http://traffic-counts.dot.ca.gov/): PM 27.23 (AADT=9,400) and PM 60.05 (AADT=3,400).
   B. Maximum peak-hour traffic volume per direction was less than 150 cars / hour, generated from the Caltrans two-peaks rural weekday traffic pattern.
   C. Truck percentage = 10%
   D. The capacity of workzone with one-way traffic control per direction was estimated to be about 400 car per hour. No major queue delay was expected.
   E. Assumed that on average all traffic (24 hours) experience about 10 minute additional travel time through the workzone with the one-way traffic control (pilot cars).
   F. Time value for RUC: passenger car = $11.51 per hour; commercial truck = 27.83 per hour.