Review of CalAC and CalME empirical overlay design

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1 Introduction

CalFP and CalAC are two computer programs developed by Caltrans to conduct empirical designs for flexible pavements following the Highway Design Manual (HDM). CalFP covers new flexible pavement designs while CalAC covers flexible pavement rehabilitation designs. More information about these programs can be found on Caltrans website (*1*). Both programs were designed to expire and stop working at the end of each year.

Due to the loss of source code, these programs can only be extended without any other updates. This makes it impossible for them to incorporate any revisions of HDM. In addition, these programs have become more and more difficult to maintain given the fast pace of change in computer software environment and the fact that they were originally developed under Windows XP.

To address the issues with CalAC and CalFP, Caltrans has decided to rewrite them. In addition, the new codes will be part of the California mechanistic-empirical (CalME) flexible pavement design software under development by the University of California Pavement Research Center (UCPRC) for Caltrans. It will help Caltrans' transition from empirical to ME method for flexible pavement design by having both design software available in one package.

CalME itself is being upgraded from a desktop application into a web application. Although an implementation of HDM empirical design procedures for both new and rehabilitation flexible pavements is included in the desktop version of CalME (a.k.a. CalME 2.0), they have yet to be evaluated by Caltrans.

The approach to rewrite CalAC and CalFP is to port the implementations in CalME 2.0 into the new web application (a.k.a. CalME 3.0). UCPRC will first compare its implementations with both CalAC/CalFP and current HDM and identify any inconsistencies. This will be followed by testing of some typical examples included in the tech notes published by Caltrans (*2, 3*). These are expected be accomplished by January 15th of 2019 and allow Caltrans to release the new implementation for public use.

It is recommended that CalAC and CalFP be extended till the end of 2019. This will allow a year of transition to remove as much bug in the new implementation as possible. During this transition period (i.e., year of 2019), it is recommended for Caltrans to require all empirical designs to be done using both CalFP/CalAC and the CalME 3.0.

This document is focused on the new implementation of CalAC. The new implementation of CalFP is discussed in a separate document.

2 Understanding CalAC

To use CalAC for overlay design, one needs to use the “Overlay” button on the main screen to do “Basic Overlay” design first and then use other buttons to show other options. The basic overlay design involves no milling but may include RHMA-G or SAMI.

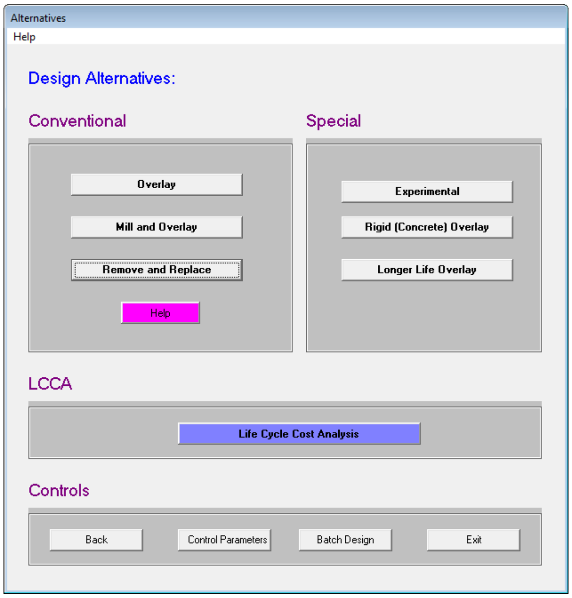


Figure 1. Main screen of CalAC

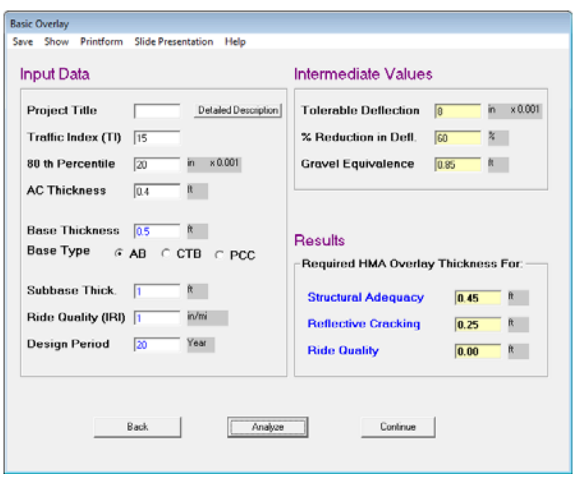


Figure 2. Basic overlay design

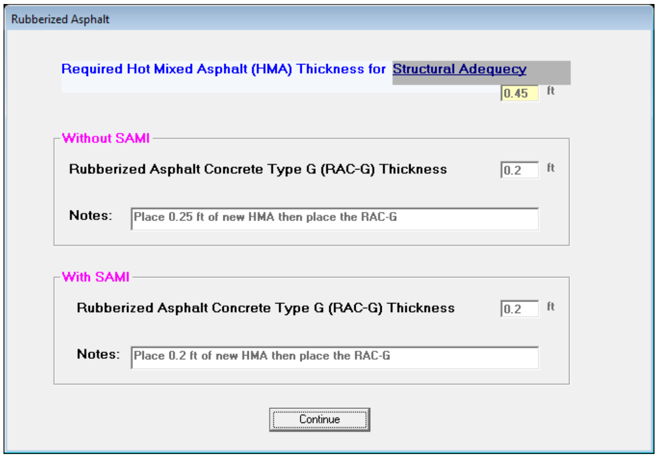


Figure 3. Options for including RHMA-G layer with or without SAMI (although not identified, it should mean SAMI-R here)

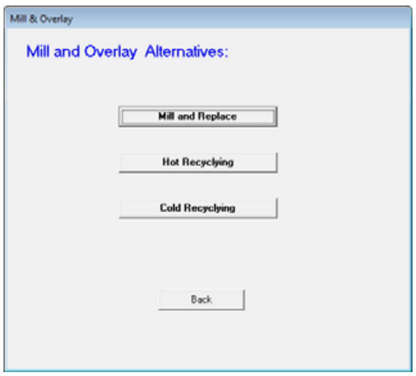


Figure 4. Mill and overlay screen

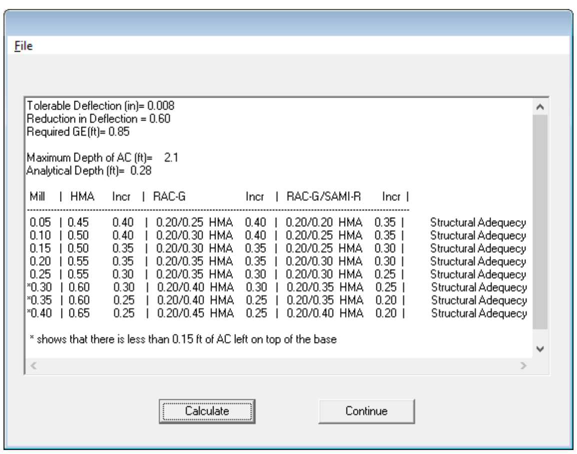


Figure 5. Mill and overlay options, including the use with RHMA-G with or without SAMI-R

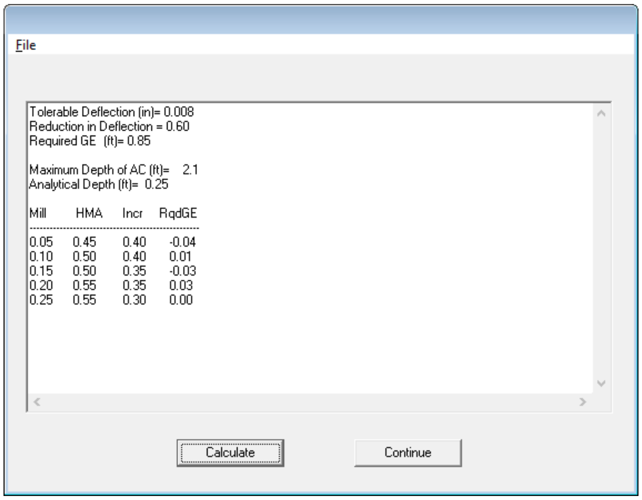


Figure 6. Mill and hot recycling options (not included in HDM anymore)

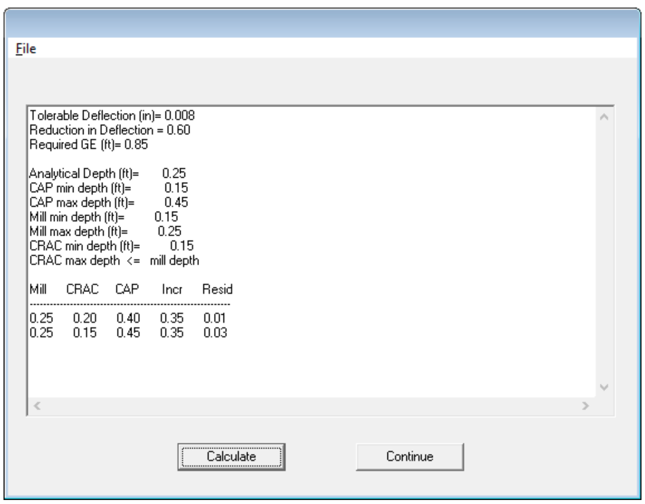


Figure 7. Mill and cold recycling options, options are controlled by the increase in grade (0.35 ft by default but allowed to be changed)

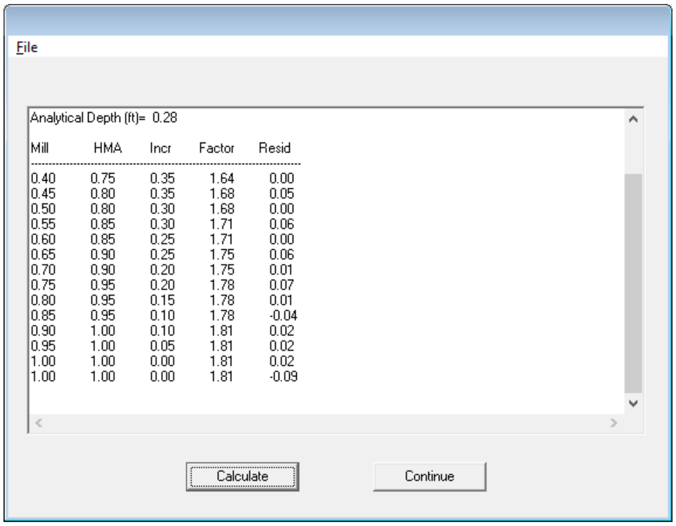


Figure 8. Remove and replace options, the results include milled depth, HMA overlay thickness, increase in grade, Gf of HMA, and residual GE (provided GE – needed GE)

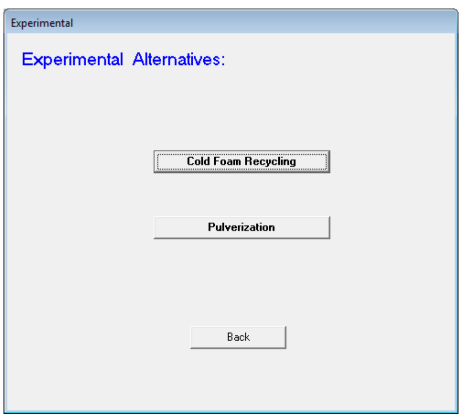


Figure 9. Experimental alternative selection screen

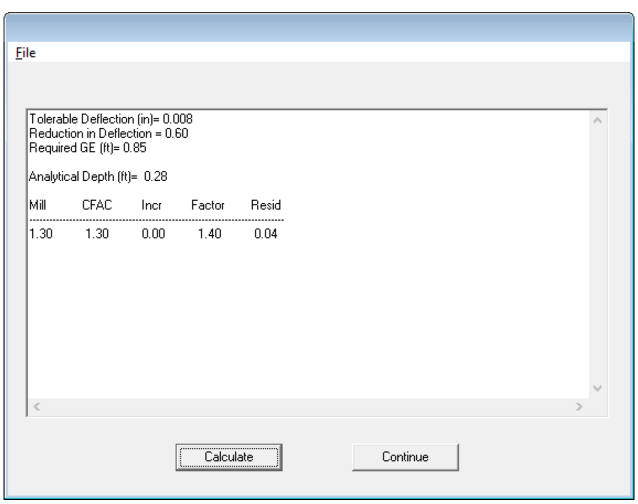


Figure 10. Cold foam recycling option, note that there is no HMA overlay included

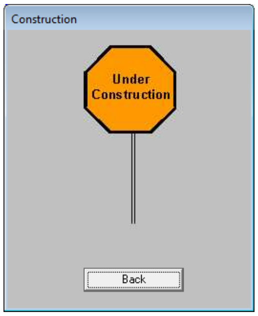


Figure 11. Pulverization options were still under construction

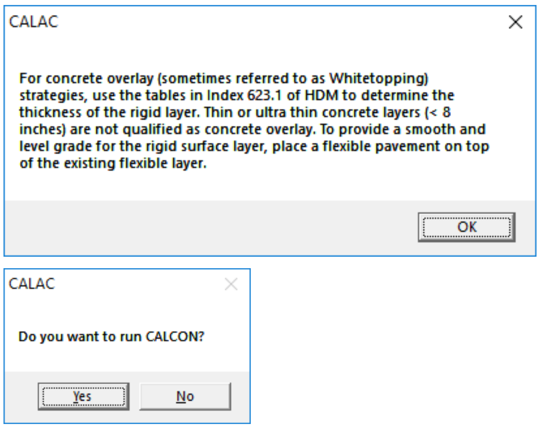


Figure 12. Recommendations for concrete overlay design

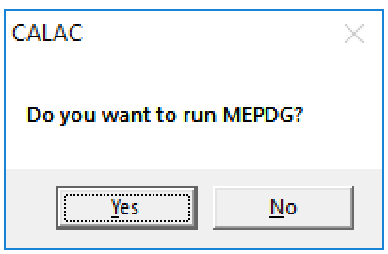


Figure 13. Recommendations for longer life overlay design

3 Review of CalAC and HDM

3.1 Basic overlay designs

3.1.1 TDS determination

TDS (Tolerable Deflection at the Surface) is obtained from Table 635.2A by knowing the existing total thickness of the flexible layer and TI. CalAC seems to use TDS values that are slightly different from those in Table 635.2A. The comparison is shown below and are believed to be due to rounding error.

Table 3.1. Comparison of TDS between CalAC and HDM for TI=15.0

Existing HMA thickness (ft)	Table 635.2A	CalAC
0.00	14	<Out of Range>
0.05	13	13
0.10	12	12
0.15	11	11
0.20	10	11
0.25	10	10
0.30	9	9
0.35	8	9

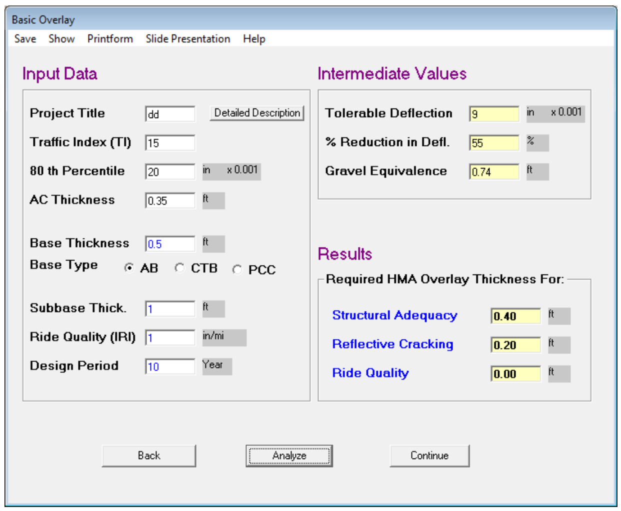


Figure 14. Screenshot indicating the TDS of 9 for TI=15 and 0.35 ft of existing HMA

3.1.2 Definition of "Treated" base

HDM defines base as "treated" when all of the followings are true:

- Base is either PCC, LCB or CTB-A
- Base thickness is equal or more than 0.35 ft
- D80 is less than 15 mil

CalAC uses this definition, but also consider any pavement with PCC base as treated regardless of the thickness and D80.

3.1.3 Reflective cracking requirements for treated base

When the base is treated per HDM definition (PCC/LCB/CTB-A, thickness >0.35 ft, and D80<15 mil), the minimum thickness requirements based on HDM and CalAC are slightly different as shown in the table below. HDM has been updated to increase the required overlay thickness for thick PCC that is not crack and seated before overlay, but CalAC has NOT been updated.

Table 3.2. Comparison of minimum thickness requirements for reflective cracking

	HDM 10-year design	CalAC 10-year design	HDM 20-year design	CalAC 20-year design
Thin PCC or thick PCC but Crack and Seated	Undefined	0.35-ft	0.45-ft	0.45-ft
Thick PCC, and no crack and seat	Undefined	0.45-ft	0.60-ft	0.55-ft

3.1.4 Reflective cracking retardation equivalencies between RHMA-G and HMA

HDM allows replacing HMA with thinner RHMA-G to address reflective cracking. The reflective cracking retardation equivalencies between RHMA-G and HMA is described in Table 635.2D. The table is however not well defined for the following reasons:

1. When the required HMA thickness is 0.35 ft, the two conditions for determining RHMA-G thickness are NOT complementary:
    - 0.15 if crack width<1/8 inch
    - 0.20 if crack width⩾1/8 inch or underlying material CTB, LCB, or rigid pavement
2. There is no option allowed for required HMA thickness of 0.40 ft.

For issue #1 listed above, it is understood as:

- 0.15 if crack width<1/8 inch
- 0.20 if crack width⩾1/8 inch
- 0.20 if underlying material CTB, LCB, or rigid pavement regardless of crack width

For issue #2 listed above, it is understood that 0.40 ft of HMA will require an undesirable combination of RHMA-G and HMA thickness combination and should be avoided.

3.2 Mill and Overlay Option

3.2.1 Maximum mill depth

The "Mill and Overlay" option is described in Index 635.2(5) of HDM, which states that:

> "Since existing pavement thicknesses will have slight variations throughout the project length, leave at least the bottom 0.15 foot of the existing surface course intact to ensure the milling machine does not loosen the base material or contaminate the recycled mix if used. If removal of the entire surface course layer and any portion of the base are required, use the procedure in Index 635.2(7)."

CalAC allows milling options that leaves less than 0.15 ft of existing surface course, although it displays warning regarding this issue. This is probably NOT correct because Gf for HMA is different for “Mill and Overlay” and “Remove and Replace” options (i.e., Index 635.2(7)). Specifically, Gf for HMA is fixed at 1.9 but for the Mill and Overlay option but depends on TI and thickness for the Remove and Replace option. It is therefore decided to adhere to HDM in CalME.

3.2.2 Hot Recycling option for mill and overlay

This “Hot Recycling” option for mill and overlay is no longer included in HDM. CalAC still has it. However this option is exactly the same as mill and overlay with regular HMA since hot recycled HMA and regular HMA has the same gravel factor.

3.2.3 Cold in-place recycling option for mill and overlay

CalAC limits the CIPR option by fixing the grade increase. This is NOT included in HDM. The flexible pavement rehabilitation design examples (FPRDE, (*3*)) however shows that the use of CIPR should result in a grade reduction of at least 0.10 ft compared to the basic overlay option.

CalAC allows the CIPR thickness to be different from mill depth. FPRDE seems to suggest CIPR thickness should be the same as mill depth, which is consistent with typical construction practice.

CalME will include options present all the options satisfying the 0.10 ft grade reduction requirement.

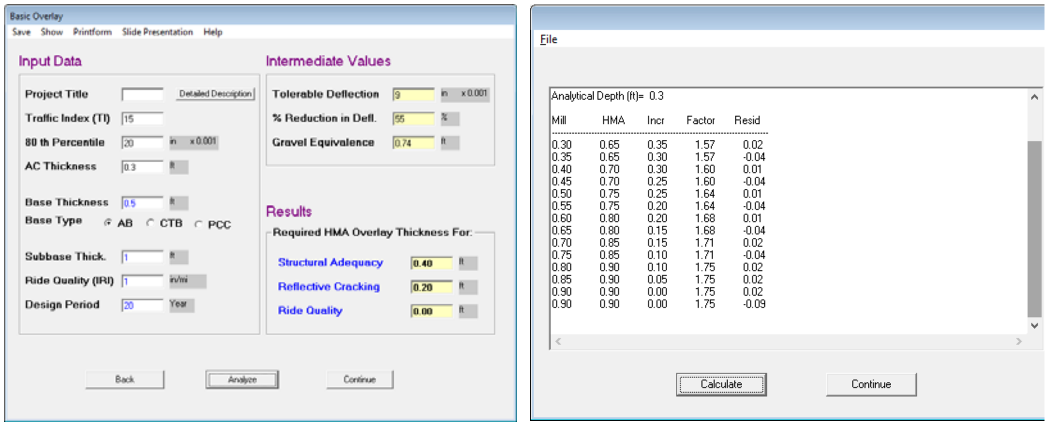
3.3 Remove and replace option

3.3.1 Maximum removal depth

For remove and replace option, HDM recommends a maximum partial removal depth of 1.0 ft. Beyond which the pavement should be design as new pavement. CalAC allows up to 1.05 ft, while in other cases only allows 0.75 ft. It is NOT clear what rule CalAC is applying regarding the maximum removal depth.

3.3.2 Accounting for lost GE due to removal of ASB

CalAC does NOT account for removed ASB in terms of lost GE (see Figure 15).



(a). Basic overlay design (b). Corresponding remove and replace option

Figure 15. No increase in HMA needed once the removal depth goes below AB

3.3.3 Accounting for lost GE due to removed CTB

Figure 16 shows the remove and replace options for a pavement with 0.30 ft HMA/0.50 ft CTB/1.0 ft ASB. The GE needed can be back-calculated as:

$$GE_{needed} = h_{HMA} * G_{f,HMA} - GE_{residual}$$

The correlation between GE needed and mill depth is shown in Figure 17, which indicated that for every foot of CTB milled, GE needed increases by 1.51 ft. This implies a Gf of 1.51 was used for the removed CTB. After accounting for rounding error, a value of 1.50 was likely to have been used as Gf for the removed CTB. This is roughly equal to the average of Gf for CTB-A (1.7) and CTB-B (1.2).

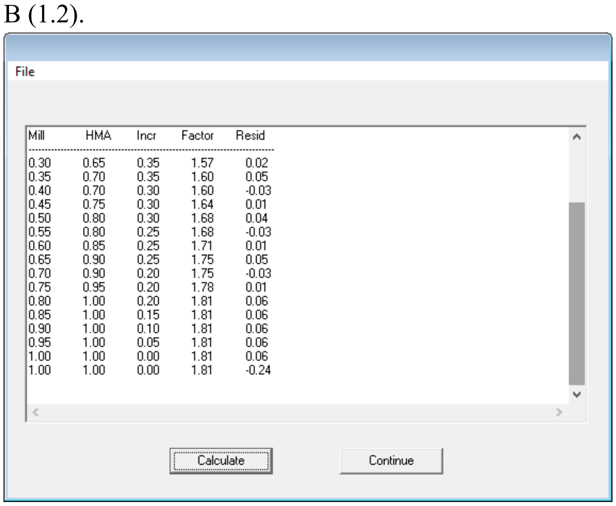


Figure 16. Remove and replace options for 0.30 ft HMA/0.50 ft CTB/1.0 ft ASB

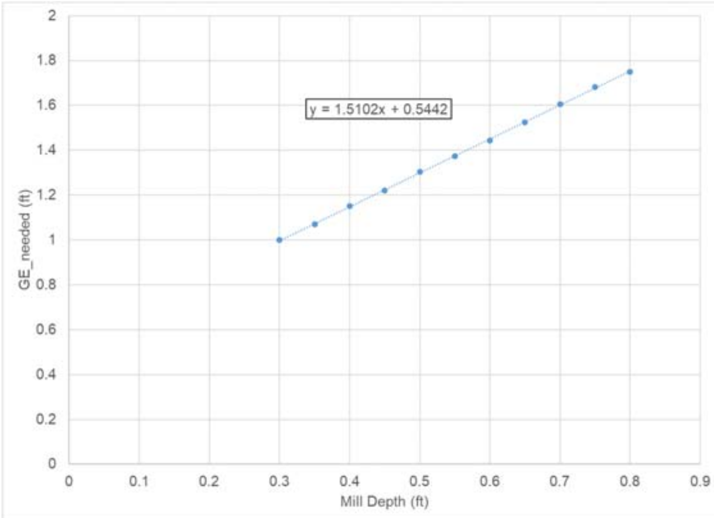


Figure 17. Increase of GE needed with mill depth

3.3.4 Accounting for lost GE due to removed PCC

Using the same approach shown in Section 3.3.3, the Gf for removed PCC layer can be back-calculated to be 1.49 (See Figure 18). After accounting for the rounding error, a value of 1.50 was likely used for Gf of removed PCC regardless of whether it was crack and seated.

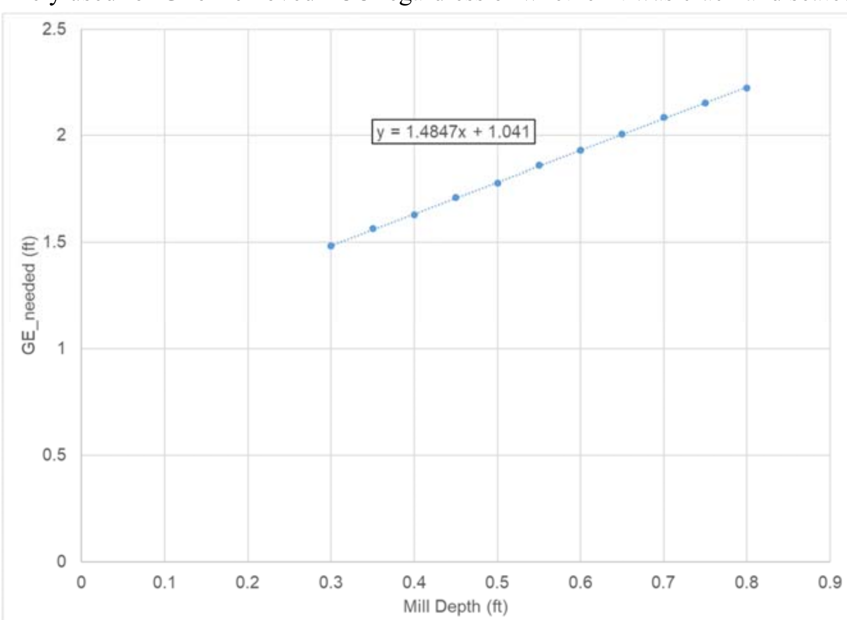


Figure 18. Correlation between GE needed and mill depth for 0.3 ft HMA/1.0 ft PCC (with and without crack and seat)

3.3.5 Accounting for lost GE due to removed AB

Using the same approach, it is believed that the Gf used for removed AB was 1.10, which is consistent with Table 633.1.

3.3.6 Use of alternative materials

HDM also allows the use of alternative materials (such as RHMA-G) for partial removal (i.e., not removing down to the subgrade leval). CalAC does NOT include such options.

3.4 Full depth reclamation rehabilitations

HDM has been updated to include options for FDR with foam asphalt stabilization (FDR-FA), FDR with cement stabilization (FDR-PC), and FDR without stabilization (FDR-NS, a.k.a. pulverization).

3.4.1 General

HDM provides example for FDR design with AB as the base. It is not clear how to deal with treated base in the existing pavement.

In general, "Full Depth Reclamation (FDR) transforms distressed existing asphalt into stabilized base to receive a new structural surface layer." (HDM). FDR is NOT recommended if the existing base if still strong.

CalME will do provide design for FDR that recycles CTB, and cracked LCB but will issue warning that the CTB and LCB should be in bad shape (such as low back-calculated stiffness from FWD testing data). CalME will also NOT provide FDR options when there is PCC in the old pavement.

HDM does not specify the residual Gf for treated base so a value of 1.2 will be used assuming they have been deteriorated into CTB-B.

3.4.2 Cold foam recycling (FDR-FA)

The FDR-FA design in CalAC does NOT seems to have been updated since last HDM revision. In particular there are several inconsistencies between them:

- CalAC does not account for the 7% swell in thickness for the FDR layer. As shown in the example below, the mill depth is the same as the FDR-FA (i.e., CFAC) thickness.
- Also, there is no HMA layer on top.
- The FDR-FA layer thickness seems too thick.

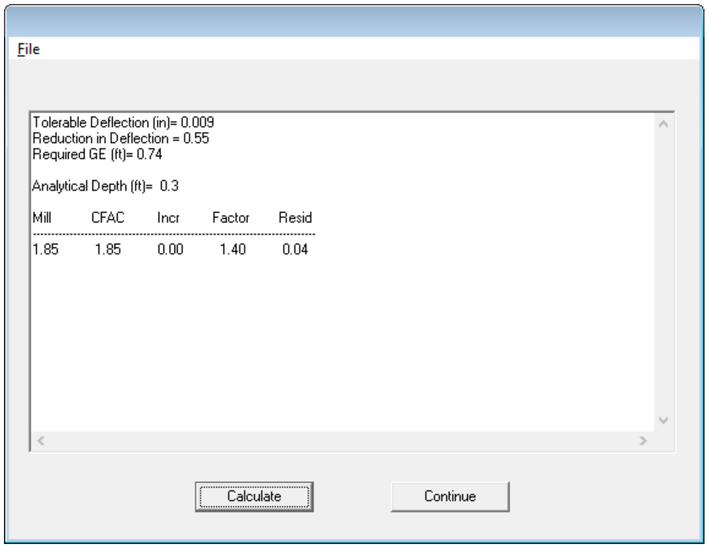


Figure 19. An example FDR-FA design for TI=15, 0.30 old HMA/0.50 AB/1.0 ASB, 20 years

3.4.3 FDR pulverization design

CalAC does NOT support FDR with pulverization option yet.

3.4.4 FDR with cement stabilization (FDR-PC)

CalAC does NOT support FDR with cement stabilization, which is not consistent with HDM.

3.5 Concrete overlay on existing flexible pavement

CalAC redirect user to use Index 623.1 for designing concrete overlay on existing flexible pavement (i.e., whitetopping).

4 Comparison of CalME and CalAC for empirical overlay design

These examples are selected from the Caltrans flexible pavement rehabilitation design examples (*2*). The examples are numbered exactly the same as the Caltrans document. Note that Examples #1 and #2 are related to determination of D80 only so are not included in this section.

4.1 *Example 3: HMA Overlay #1*

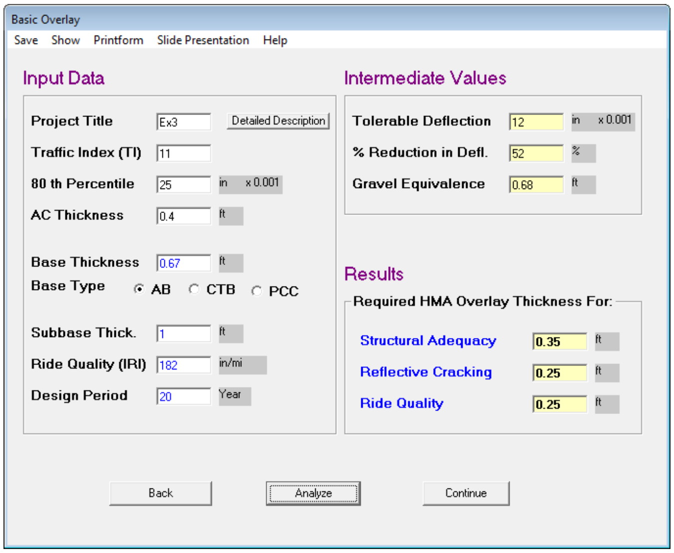


Figure 20. CalAC screen shot for Example 3

Table 4.1. Design thickness requirements from different methods for Example 3

	Caltrans Example	CalAC	CalME
Structural Adequacy	0.35	0.35	0.35
Reflective Cracking	0.25	0.25	0.25
Ride Quality	0.25	0.25	0.25
		Same	Same

4.2 *Example 4: HMA Overlay #2*

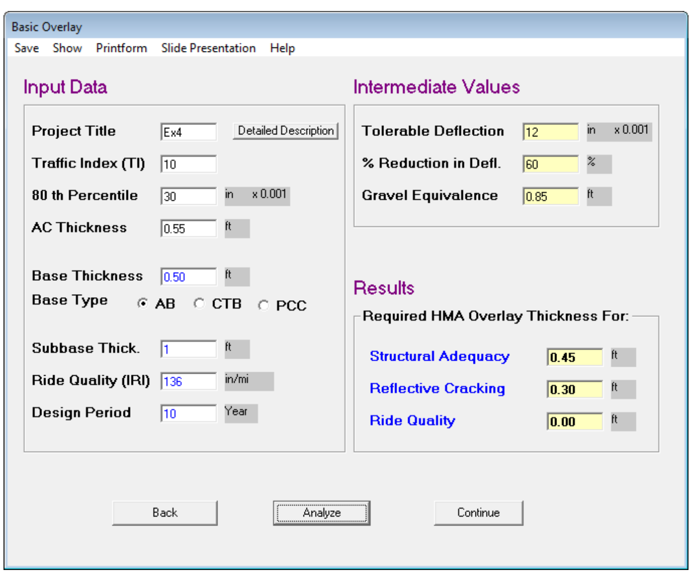


Figure 21. CalAC screen shot for Example 4

Table 4.2. Design thickness requirements from different methods for Example 4

	Caltrans Example	CalAC	CalME
Structural Adequacy	0.45	0.45	0.45
Reflective Cracking	0.30	0.30	0.30
Ride Quality	0.00	0.00	0.00
		same	same

4.3 *Example 5: Mill and Overlay*

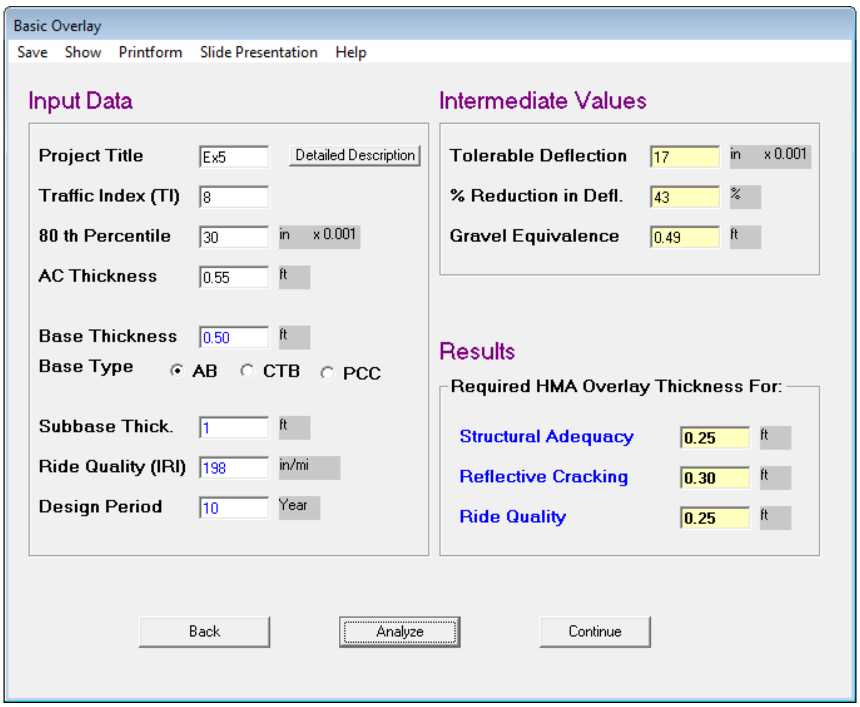


Figure 22. CalAC screen shot for Example 5

Table 4.3. Design thickness requirements from different methods for Example 5

	Caltrans Example	CalAC	CalME
Structural Adequacy	0.25	0.25	0.25
Reflective Cracking	0.30	0.30	0.30
Ride Quality	0.25	0.25	0.25
		same	same

The design example tried different mill depth to find one that satisfy the 0.10 ft minimum grade reduction requirement (compared to basic overlay). The recommendation is mill 0.30 ft /0.30 ft CIPR / 0.20 ft HMA as cap. CalAC on the other hand, presents many more options (see Figure 23).

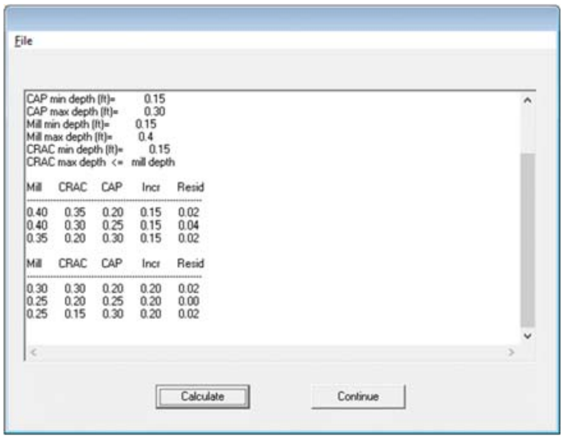


Figure 23. Mill and overlay with CIPR option from CalAC

4.4 Example 6: Mill and Overlay Below the Analytical Depth

This example demonstrates how to solve the designs for hot recycling. Since hot recycling layer is used as a the overlay surface and has a Gf of 1.9, this option is exactly the same as regular mill and overlay (i.e., without recycling).

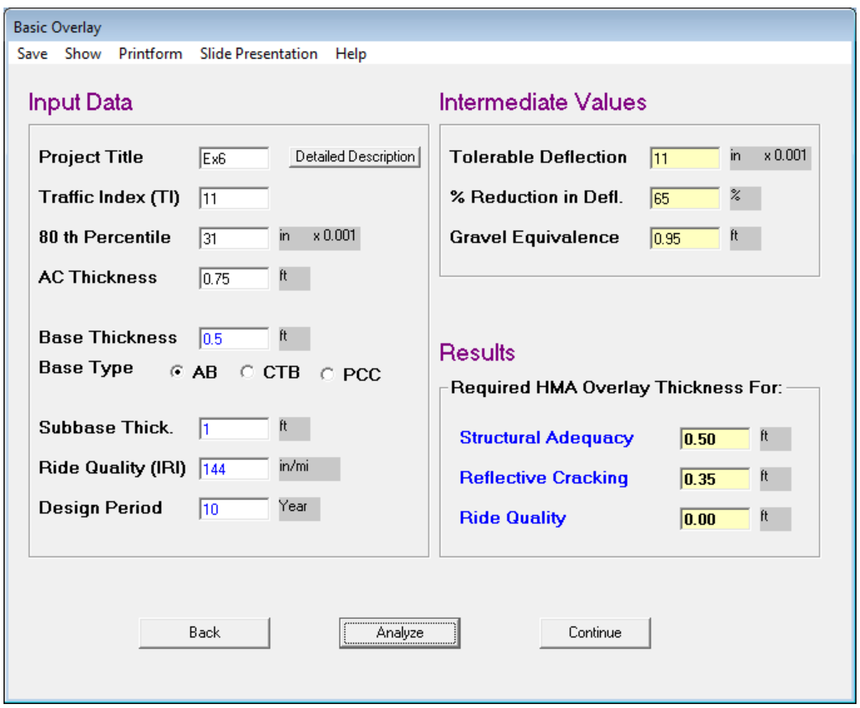


Figure 24. CalAC screen shot for Example 6

Table 4.4. Design thickness requirements from different methods for Example 6

	Caltrans Example	CalAC	CalME
Structural Adequacy	0.50	0.50	0.50
Reflective Cracking	0.35	0.35	0.35
Ride Quality	0.00	0.00	0.00

		same	same

The design options provided by CalAC are listed in Figure 25. The comparison among the three are shown in Table 4.5.

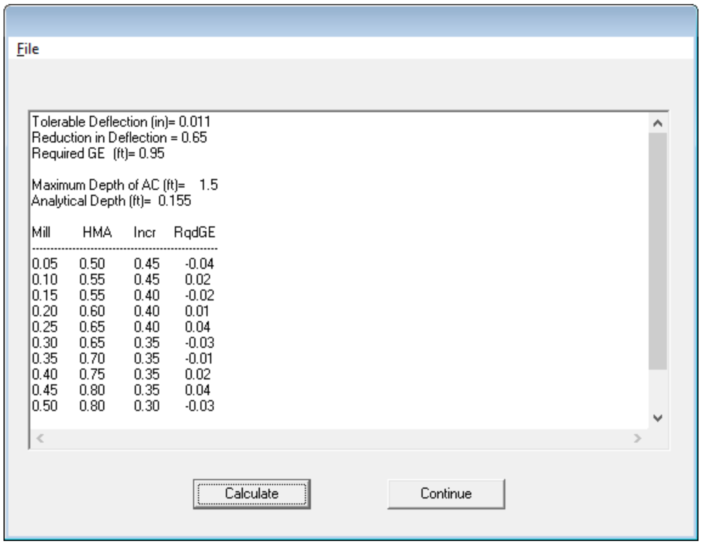


Figure 25. Hot recycling options from CalAC for Example 6

As shown in the table, the only difference is for the 0.05 ft milling option. Based on Figure 25, the GE needed is 1.9*0.50-(-0.04) = 0.99 ft, which correspond to the 1.0 ft needed for 67% PRD after account for the rounding error. The HMA thickness needed is then 1.0/1.9 = 0.526 ft so should be rounded to 0.55 ft rather than 0.50 ft.

Table 4.5. Hot recycled surface layer thicknesses (ft) from different methods for Example 6

Mill Depth (ft)	Caltrans Example	CalAC	CalME (Mill and Overlay)
0.05		0.50	0.55
0.10		0.55	0.55
0.15	0.55	0.55	0.55
0.20		0.60	0.60
0.25	0.65	0.65	0.65
0.30	0.65	0.65	0.65
0.35		0.70	0.70
0.40		0.75	0.75
0.45		0.80	0.80
0.50		0.80	0.80
0.55		0.85	0.85
0.60		0.90	0.90

4.5 *Example 7: Remove and Replace (Partial Depth)*

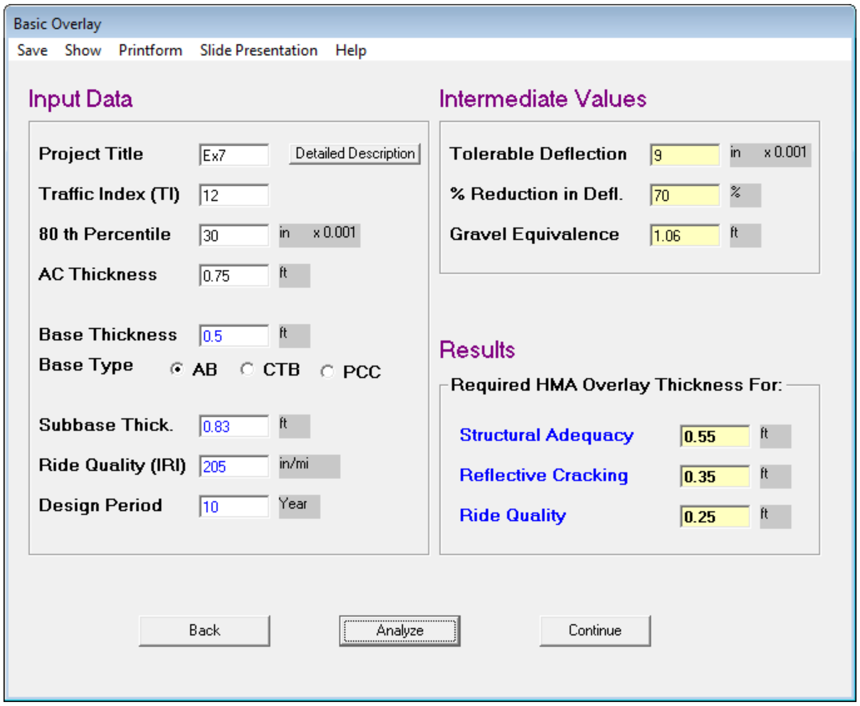


Figure 26. CalAC screen shot for Example 7

Table 4.6. Design thickness requirements from different methods for Example 7

	Caltrans Example	CalAC	CalME
Structural Adequacy	0.50	0.55	0.55
Reflective Cracking	0.35	0.35	0.35
Ride Quality		0.25	0.25
		same	same

The design options provided by CalAC are listed in Figure 25. The comparison among the three are shown in Table 4.5.

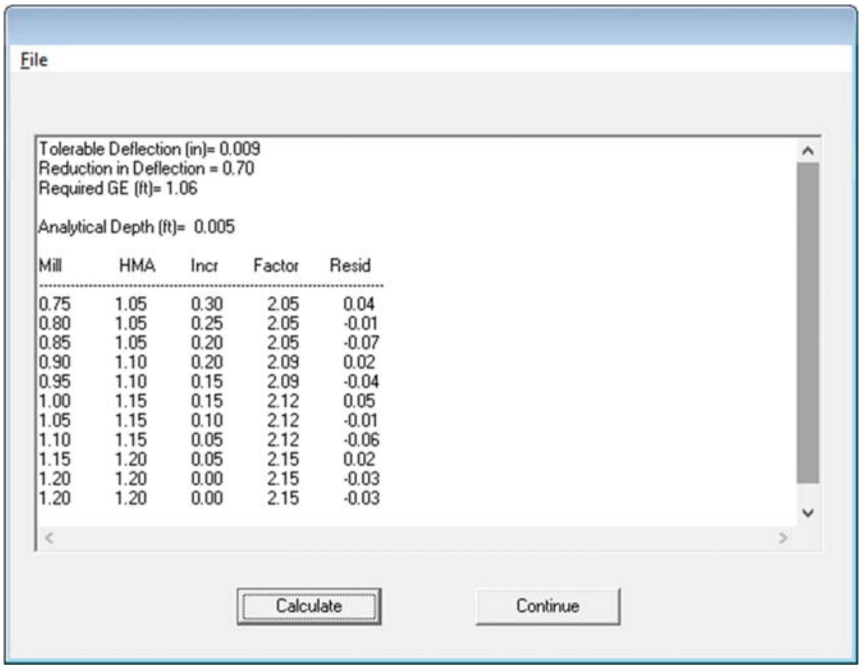


Figure 27. Partial remove and replace options from CalAC for Example 7

Table 4.7. Overlay thicknesses (ft) from different methods for Example 7

Mill Depth (ft)	Caltrans Example	CalAC	CalME
0.75	1.03 (written as 1.3 due to typo)	1.05	1.05
0.80		1.05	1.10
0.85		1.05	1.10
0.90		1.10	1.10
0.95		1.10	1.15
1.00		1.15	1.15
1.05		1.15	
1.10		1.15	
1.15		1.20	
1.20		1.20	

As shown in Table 4.7, there are some slight difference between CalAC and CalME. This is likely due to the error in analytical depth calculation for CalAC. In particular, the analytical depth should be zero in this case, but CalAC arrives at 0.005 as shown in Figure 27. Higher analytical depth means less overall GE required for the removed existing HMA layer because the GE needed to replace the removed HMA down to analytical depth is fixed by the 70% PRD.

5 Summary and recommendations

After reviewing them, it is found that there are some minor inconsistencies between CalAC and HDM. There are design options available in HDM but not available in CalAC and vice versa. These issues have been listed in Section 3. It is recommended for Caltrans to review these issues and provide necessary decisions so that the new CalAC implementation in CalME 3.0 reflected the most current design procedure.

6 References

1. Caltrans. *Pavement Software*. Available from: http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/Software.html.
2. California Department of Transportation. *Flexible pavement rehabilitation design examples*. 2006; Available from: http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/PDF/Flex_Rehab_Examples_final.pdf.
3. California Department of Transportation. *Flexible pavement design examples - new construction*. 2006; Available from: http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/PDF/FlexPvmt_Design_Ex_english.pdf.