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Development of Caltrans Concrete Overlay on Asphalt Pavement Design Catalog Tables Using Pavement ME

Authors:
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Partnered Pavement Research Center (PPRC) Strategic Plan Element Number 3.53: Updated Caltrans Rigid Pavement Design Catalog Using Pavement ME (DRISI Task 3811)

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16. ABSTRACT

This report summarizes the work completed to develop the concrete overlay on asphalt (COA) tables of the new Caltrans *Highway Design Manual (HDM) Rigid Pavement Design Catalog*. The tables consider the different pavement structures that are candidates for rehabilitation with COA with short transverse joint spacing on the Caltrans road network. The tables were developed using *Pavement ME* (version 2.5.5) with the nationally calibrated COA cracking model. *Pavement ME* inputs were determined by considering the state's climate, traffic, materials, and construction practices. The design tables reflect the recommendations from previous Caltrans research about COA, including slab size, shoulder type, and load transfer efficiency. The *Pavement ME* inputs for developing the tables include a design life of 20 years, 10% target cracking, and 95% design reliability. The tables will be included in the printed version of the new *HDM Rigid Pavement Design Catalog*.

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rigid pavement, bonded concrete overlay of asphalt, whitetopping, pavement rehabilitation, Pavement ME

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7. PROPOSALS FOR IMPLEMENTATION

This report includes the proposed concrete overlay on asphalt design tables for the new *HDM Rigid Pavement Catalog*. The tables are directly implementable in the printed version of the new catalog.

8. RELATED DOCUMENTS

Mateos, A., and Harvey, J.T. 2020. *Development of Thin Bonded Concrete Overlay of Asphalt Design Method: Evaluation of Existing Mechanistic-Empirical Design Methods* (Technical Memorandum: UCPRC-TM-2019-01). Davis and Berkeley, CA: University of California Pavement Research Center.

Mateos, A., and Harvey, J.T. 2022. *Pavement ME Evaluation of the NCHRP 1-61 Concrete Overlay of Asphalt Sections with Half-Lane Width Slabs* (Research Report: UCPRC-RR-2022-01). Davis and Berkeley, CA: University of California Pavement Research Center.

9. LABORATORY ACCREDITATION

The UCPRC laboratory is accredited by AASHTO re:source for the tests listed in this report.

10. SIGNATURES

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

DISCLAIMER

ACKNOWLEDGMENTS

The development of the concrete overlay on asphalt (COA) design tables presented in this report follows validation of the *Pavement ME* COA cracking model. This validation was based on a sensitivity analysis and comparison of the model's predictions and cracking measured in 13 COA sections with short transverse joint spacing that were evaluated in NCHRP Project 1-61, "Evaluation of Bonded Concrete Overlays on Asphalt Pavements." The authors of this report would like to acknowledge and thank the NCHRP 1-61 research team—NCE and the University of Illinois Urbana-Champaign—and the National Cooperative Highway Research Program.

The UCPRC would like to thank the Caltrans Office of Concrete Pavement for direction and input on this project, particularly Deepak Maskey, who was the technical lead. The authors would also like to thank T. Joseph Holland for ongoing project management and Nick Burmas for ongoing program management. Finally, they want to thank the UCPRC publications team of David Spinner and Camille Fink.

PROJECT OBJECTIVES

The primary goal of Project 3.53 is to develop and implement a new Caltrans *Highway Design Manual (HDM) Rigid Pavement Design Catalog* using version 2.5.5 of *Pavement ME.* This catalog will consider climate, traffic, materials, design, and construction practices and standards applicable to the Caltrans road network. The new catalog will include jointed plain concrete pavements (JPCP), continuously reinforced concrete pavements (CRCP), and concrete overlay on asphalt (COA) pavements. The primary goal of Project 3.53 will be achieved by completing the following tasks:

- Task 1: Finalize JPCP design catalog tables.
- Task 2: Finalize COA design catalog tables.
- Task 3: Develop CRCP design catalog tables.
- Task 4: Implement design catalog tables in a web-based tool.

The goal of Task 2 is the development of the COA tables of the new *HDM Rigid Pavement Design Catalog*. This report summarizes the work conducted for Task 2.

LIST OF ABBREVIATIONS

AADTT	Average annual daily truck traffic
AASHTO	American Association of State Highway and Transportation Officials
AB	Aggregate base
ACI	American Concrete Institute
ATPB	Asphalt-treated permeable base
CIR	Cold in-place recycling
COA	Concrete overlay on asphalt
CRCP	Continuously reinforced concrete pavement
CTB	Cement-treated base
CTE	Coefficient of thermal expansion
EA	Emulsified asphalt
FA	Foamed asphalt
FDR	Full-depth recycling
HDM	Highway Design Manual
HMA	Hot mix asphalt
IRI	International Roughness Index
JPCP	Jointed plain concrete pavement
LCB	Lean concrete base
ME	Mechanistic-empirical
NCHRP	National Cooperative Highway Research Program
PDR	Partial-depth recycling
PG	Performance grade
PMS	Pavement management system
PPRC	Partnered Pavement Research Center
RHMA-G	Rubberized gap-graded hot mix asphalt
SE	Standard error
SJPCP	Short-jointed plain concrete pavement
SR	State Route
TI	Traffic Index
UCPRC	University of California Pavement Research Center
USCS	Unified Soil Classification System
WIM	Weigh in motion

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in.	inches	25.40	millimeters	mm
ft.	feet	0.3048	meters	m
yd.	yards	0.9144	meters	m
mi.	miles	1.609	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.09290	square meters	m^2
yd^2	square yards	0.8361	square meters	m^2
ac.	acres	0.4047	hectares	ha
mi^2	square miles	2.590	square kilometers	km^2
VOLUME				
fl. oz.	fluid ounces	29.57	milliliters	mL
gal.	gallons	3.785	liters	L
ft^3	cubic feet	0.02832	cubic meters	m^3
yd^3	cubic yards	0.7646	cubic meters	m^3
MASS				
oz.	ounces	28.35	grams	g
lb.	pounds	0.4536	kilograms	kg
T	short tons (2000 pounds)	0.9072	metric tons	t
TEMPERATURE (exact degrees)				
°F	Fahrenheit	(F-32)/1.8	Celsius	°C
FORCE and PRESSURE or STRESS				
lbf	pound-force	4.448	newtons	N
lbf/in^2	pound-force per square inch	6.895	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.03937	inches	in.
m	meters	3.281	feet	ft.
m	meters	1.094	yards	yd.
km	kilometers	0.6214	miles	mi.
AREA				
mm^2	square millimeters	0.001550	square inches	in^2
m^2	square meters	10.76	square feet	ft^2
m^2	square meters	1.196	square yards	yd^2
ha	hectares	2.471	acres	ac.
km^2	square kilometers	0.3861	square miles	mi^2
VOLUME				
mL	milliliters	0.03381	fluid ounces	fl. oz.
L	liters	0.2642	gallons	gal.
m^3	cubic meters	35.31	cubic feet	ft^3
m^3	cubic meters	1.308	cubic yards	yd^3
MASS				
g	grams	0.03527	ounces	oz.
kg	kilograms	2.205	pounds	lb.
t	metric tons	1.102	short tons (2000 pounds)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C + 32	Fahrenheit	°F
FORCE and PRESSURE or STRESS				
N	newtons	0.2248	pound-force	lbf
kPa	kilopascals	0.1450	pound-force per square inch	lbf/in^2

*SI is the abbreviation for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised April 2021)

1 INTRODUCTION

Concrete overlay on asphalt (COA), formerly known as thin whitetopping or thin bonded concrete overlay on asphalt, is a pavement rehabilitation technique that consists of the placement of a 4 to 7 in. thick concrete overlay on an existing flexible or composite pavement. This technique, an alternative to conventional asphalt and concrete overlay design and construction, has been used frequently on highways and conventional roads in several US states as well as in other countries, but its use in California has been very limited.

Under Partnered Pavement Research Center (PPRC) Project 4.58B, the COA technique was evaluated from 2014 to 2017 using accelerated loading applied by Heavy Vehicle Simulators. Overall, the outcome of the evaluation was highly positive. That research project's main conclusion was that a "well-designed and well-built 6×6 thin bonded concrete overlay placed on top of an asphalt base that is in fair to good condition can potentially provide 20 years of good serviceability on most of California's non-interstate roadways" *(1,2)*. Based on that evaluation, Caltrans decided to implement the technique in the field, and several Caltrans districts proceeded with COA pilot projects. District 11 implemented the COA technique in the rehabilitation of Interstate Route 8 in 2018, the first use of this technique on the Caltrans road network. District 3 also implemented the technique in the rehabilitation of State Route (SR) 113 in 2018 *(3)*. District 8 implemented the technique in the rehabilitation of SR 247 in 2019. In all cases, the COA slab size was half the lane width with about 6 ft. of transverse joint spacing.

The current version of the Caltrans *Highway Design Manual (HDM)* Chapter 620, "Rigid Pavement," dated December 2020, includes a concrete pavement design catalog that considers jointed plain concrete pavement (JPCP) and continuously reinforced concrete pavement (CRCP) but not COA, since this type of pavement is relatively new for Caltrans. In order to include COA in the *HDM Rigid Pavement Design Catalog* (also referred to as the *HDM Design Catalog*), Caltrans tasked the University of California Pavement Research Center (UCPRC) with PPRC Project 4.67, "Development of Concrete Overlay on Asphalt Design Method" (2017–2020).

The first step of PPRC Project 4.67 was the evaluation of the existing mechanistic-empirical (ME) design procedures for COA, including *Pavement ME* and *BCOA-ME (4)*. This evaluation showed that *Pavement*

ME and *BCOA-ME* have some limitations, but they are based on sound ME principles *(5)*. These limitations include (1) the lack of models for concrete-asphalt debonding, transverse joint load transfer efficiency, faulting, and longitudinal smoothness and (2) the lack of calibration for California climate conditions, rapid strength concrete, and short construction windows most likely to occur in COA rehabilitation activity on the Caltrans road network. Caltrans's decision was to adopt *Pavement ME* for the development of the COA tables of the new *HDM Design Catalog*.

Pavement ME refers to COA with half-lane-width slabs and short transverse joint spacing as "short-jointed plain concrete pavement" (SJPCP). The reasonableness of the *Pavement ME* SJPCP cracking model was verified with a sensitivity analysis *(5)* and by comparing the model's predictions to the cracking measured in NCHRP Project 1-61 SJPCP sections *(6)*, both studies conducted as part of PPRC Project 4.67. NCHRP Project 1-61, "Evaluation of Bonded Concrete Overlays on Asphalt Pavements" (2018–2020), investigated factors that may impact COA performance based on the documented data and measured condition of 20 COA projects across the United States, 13 of them with short transverse joint spacing *(7)*.

The longitudinal cracking measured in the 13 COA sections with short transverse joint spacing from NCHRP Project 1-61 was compared to *Pavement ME* predictions *(6)*. When design values were adopted for the different input variables, the root mean square error (predicted versus measured) of *Pavement ME* predictions of longitudinal cracking was 2.4% for the set of 13 sections. This error reduced to 1.2% when constructed slab thickness measured with ground-penetrating radar was used instead of the design thickness, and *Pavement ME* predicted less than 5% longitudinal cracking in all 13 sections, which agrees with measured cracking.

The *Pavement ME* COA cracking model was introduced after version 2.3, released in 2016. The calibration of the model was based on empirical data from Minnesota, Illinois, and Colorado, which are states where COA performance data were readily available. NCHRP Project 1-61 has considerably expanded the range of climatic conditions for which reliable performance data are available by adding projects from Iowa, Kansas, and Pennsylvania (in addition to Minnesota, Illinois, and Colorado). Unfortunately, none of the climates of these states reflect the dry and warm conditions present in most of California. Consequently, the long-term performance of COA under the weather conditions of much of California still remains uncertain.

Due to the lack of empirical data for local calibration, Caltrans's decision was to move forward with the development of the COA tables of the new *HDM Design Catalog* by using the *Pavement ME* nationally calibrated cracking model. Subsequently, a number of meetings were held between the Caltrans Office of Concrete Pavements and UCPRC to define the COA tables factorial—the design variable levels, including slab thickness range, climatic regions, and subbase types—and the values for other relevant inputs to *Pavement ME*, such as concrete properties, reliability, and failure limit. The COA tables factorial and the values adopted for the different inputs to *Pavement ME* are presented and discussed in Chapter 2 of this report.

Once the COA tables factorial and *Pavement ME* inputs had been defined, *Pavement ME* was run for the factorial of scenarios and the outcome of the runs was used to generate the COA tables for the new *HDM Design Catalog*. The procedure that was used to analyze the *Pavement ME* output to produce the COA design tables is presented in Chapter 3, and the tables are included in Chapter 4.

1.1 Project Objective

The primary goal of Project 3.53 is to develop and implement a new Caltrans *HDM Design Catalog* using version 2.5.5 of *Pavement ME*. While Project 3.53 includes JPCP, CRCP, and COA, the work presented in this report focuses on COA. Specifically, the goal of this work is to develop the COA tables of the new *HDM Design Catalog*.

1.2 Scope

The design tables presented in this report focus on COA with half-lane-width slabs and short transverse joint spacing. Typical half-lane-width slabs are 5 to 8 ft. wide and are arranged with the longitudinal joints either between lanes or halfway between the left and right vehicle wheel paths. The typical transverse joint spacing of the half-lane-width slabs is 5 to 7 ft. While COA with full-lane-width slabs (e.g., 12×12 ft.) has been and continues to be built in some US states, including Iowa and Minnesota, its use is not recommended for California conditions, based on results from PPRC Project 4.58B *(1)*.

The design tables presented in this report are based on *Pavement ME* (version 2.5.5) calculations. This version was released in 2019, and it was the latest version available when the tables were generated. *Pavement ME* (version 2.6) was the latest one available in early 2021, when this report was written. The version discrepancy is not regarded as a problem since neither the COA cracking model nor the calibration coefficients have changed since the initial implementation of the COA design in *Pavement ME* in 2016.

The new *HDM Design Catalog* will be implemented with two different tools: a printed catalog and a web application. The printed version will resemble the current *HDM Design Catalog*. The COA design tables presented in Chapter 4 may be directly implemented in the printed version of the new catalog. The web version will include some features to aid the designer, including the automatic calculation of truck traffic based on project location.

2 PAVEMENT ME INPUTS FOR DEVELOPING THE DESIGN TABLES

2.1 Pavement ME Inputs

The inputs to the *Pavement ME* calculations are presented in Table 2.1 (user-defined variables) and Table 2.2 (fixed variables). Table 2.1 includes the variable options that the user of the new *HDM Design Catalog* (the designer) can choose from, shown in the column "variable levels." The combinations of all variable options shown in Table 2.1 constitute the cases that were run in *Pavement ME*. The outputs from these runs were used to develop the COA design tables presented in Chapter 4. Table 2.2 includes the fixed variables, which are constants with predefined values that the designer cannot change. These variables had the same value in all *Pavement ME* runs. The rationale for the selection of the different variables values is presented in Section 2.2.

Table 2.1: User-Defined Variables

Variable	Pavement ME Cracking Sensitivity	Variable Levels	Pavement ME Inputs	Comments
Slab thickness	High	0.35 to 0.60 ft.	0.35 to 0.60 ft. in 0.05 ft. increments (4.2 to 7.2 in. in 0.6 in. increments)	Slab thickness is not a user-defined variable but the output of the design catalog
Asphalt base type	Medium	<u>2 levels</u>: • HMA • CIR	<u>2 levels</u>: • Default asphalt concrete for the HMA • Default asphalt concrete with soft binder for the CIR	CIR is cold in-place recycling, either partial-depth recycling or full-depth recycling with asphalt emulsion or foamed asphalt plus cement stabilization
Asphalt base thickness	High	<u>3 levels</u>: • 0.25 ft. • 0.35-0.45 ft. • ≥0.45 ft.	<u>3 levels</u>: • 0.25 ft. (3.0 in.) • 0.35 ft. (4.2 in.) • 0.45 ft. (5.4 in.)	
Subbase type	Medium	<u>2 levels</u>: • AB, ATPB • CTB, LCB	<u>2 levels</u>: • AB, 0.58 ft. (7.0 in.) • CTB, 0.50 ft. (6.0 in.)	

Variable	Pavement ME Cracking Sensitivity	Variable Levels	Pavement ME Inputs	Comments
AADTT	High	7 levels (*): 50, 100, 200, 500, 1,000, 2,000, 4,000 per lane (*) Continuous variable in the web catalog	5,000	Concrete damage is linearly proportional to AADTT Truck traffic assumed to grow 3% annually, linear growth
Subgrade type	High	2 levels: • Type I • Type II and Type III without drainage issues	2 levels: • A3 soil (coarse grained) • A5 soil (fine grained)	Second group includes: • Any Type II subgrade • Only Type III subgrades without drainage issues
Climate	Medium	2 levels[1]: • Group I: CC, NC • Group II: SM, DE, HD, IV, LM, SC, HM	2 levels[1]: • CC • SM	

[1] Central Coast (CC), North Coast (NC), South Mountain (SM), Desert (DE), High Desert (HD), Inland Valley (IV), Low Mountain (LM), South Coast (SC), High Mountain (HM)

Table 2.2 : Fixed Variables

Variable	Pavement ME Sensitivity	Pavement ME Inputs	Comments
Concrete 28-day flexural strength	Medium	637 psi	637 psi flexural strength corresponds to 4,500 psi compressive strength using the ACI equation (see section 2.2.2.1)
Concrete CTE	Low	4.8 με/°F	
Concrete thermal properties	Low	• Albedo: 0.15 • Conductivity = 1.25 BTU/hr/ft/°F • Heat capacity: 0.28 BTU/lb/°F	*Pavement ME* defaults
Concrete composition and shrinkage	None	*Pavement ME* defaults	None of these inputs have any effect on *Pavement ME* predicted COA cracking
Slab size	Low	6×6 ft.	
Shoulder type	Low	Tied concrete	
Truck traffic characteristics	Low	WIM Spectra 5	WIM 5 is the spectra that produces the highest damage to COA
Load transfer efficiency	High	70%	
Permanent curl/warp	Low	-10°F	
Calibration coefficients	High	• C4 = 0.40 • C5 = -2.21	National calibration
Design life	High	20 years	
Target cracking	High	10% longitudinal cracking	
Target faulting	Not applicable	Not applicable	*Pavement ME* does not model faulting of COA
Target IRI	Not applicable	Not applicable	*Pavement ME* does not model IRI of COA
Design reliability	High	95%	
Provision for grinding	Low	0.03 ft. (0.36 in.)	

2.2 Justification of Pavement ME Inputs

2.2.1 User-Defined Variables

2.2.1.1 Slab Thickness

Variable levels: 0.35 to 0.60 ft.

Slab thickness is not a user-defined design variable but the output of the design catalog. Slab thickness values from 0.35 to 0.60 ft. in 0.05 ft. increments were used for the *Pavement ME* calculations that were conducted to develop the COA tables of the new *HDM Design Catalog*.

The minimum thickness, 0.35 ft. (4.2 in.), is the minimum value recommended for building COA with 6×6 ft. slabs *(8)*. Below 0.35 ft. slab thickness, the practice of COA recommends adopting 4×4 ft. panels *(8)*, the use of which on highways presents a number of limitations. The good performance of 4.5 in. thick (slightly over the minimum thickness) 6×6 ft. slabs was verified by means of full-scale testing with Heavy Vehicle Simulators in PPRC Project 4.58B *(1)*. The maximum thickness, 0.60 ft. (7.2 in.), is the lower limit of standard JPCP slab thickness. Above 0.60 ft. slab thickness, the standard JPCP design should be considered rather than COA design.

2.2.1.2 Asphalt Base Type

Variable levels:

- Hot mix asphalt (HMA)
- Cold in-place recycling (CIR), either partial-depth recycling (PDR) or full-depth recycling (FDR)

Two different asphalt base types are considered in the COA tables of the new *HDM Design Catalog*: (1) HMA and (2) CIR of the existing pavement with an asphalt recycling agent. HMA constitutes the traditional base of COA while the CIR alternative corresponds to a scenario where the asphalt pavement is in poor condition and, consequently, not directly suitable for COA rehabilitation. Instead, the asphalt pavement would be recycled with asphalt plus cement stabilization first and then overlaid with concrete.

The CIR alternatives include full-depth recycling with foamed asphalt (FDR-FA) and partial-depth recycling with emulsified or foamed asphalt (PDR-EA or PDR-FA). In the FDR-FA technique, the asphalt layers and part of the granular base are mixed and stabilized with foamed asphalt. There are limitations for use of FDR-FA based on the gradation and plasticity of the material to be stabilized (*10*). In the PDR technique, only the existing asphalt layers (typically, 3 to 5 in. depth) are recycled. Two approaches can be used for mixing the stabilizer with the recycled material: (1) mixing in place or (2) using a central plant set up on or close to the site. In the latter case, the technique is referred as cold central plant recycling. Treatment with emulsified or foamed asphalt typically introduces some portland cement or hydrated lime (up to a 2.5:1 residual-asphalt-to-cement ratio) to improve moisture resistance and initial stiffness of the recycled material.

Only CIR with asphalt stabilization (FDR-FA, PDR-EA, and PDR-FA) is included in the COA design tables. The use of a concrete overlay on FDR stabilized with only portland cement or hydrated lime (without asphalt) is beyond the scope of the COA design tables. This is because FDR stabilized with only portland cement or hydrated lime is not asphaltic material. Cement or hydrated lime stabilization alone (without asphalt) are not used for PDR.

The default material was selected in *Pavement ME* for modeling the HMA alternative. This default material had 7% air voids, 11.6% effective binder content by volume, and a continuous and relatively dense gradation typical of standard HMA. The performance grade (PG) of the asphalt binder was selected depending on the climate zone: PG 64-10 for Central Coast (CC) and PG 64-16 for South Mountain (SM), based on Caltrans specifications.

Based on *Pavement ME*, only the stiffness of the base material had an effect on the performance of the COA. Since *Pavement ME* does not consider the use of CIR for the COA base, the modeling of the CIR alternatives was conducted by selecting an HMA with a relatively soft binder (PG 64-40). Other than the binder type, the properties chosen for modeling CIR in *Pavement ME* were the same as the properties of the default HMA. The selection of the PG 64-40 binder was made so that the stiffness of the CIR (for the range of temperatures that the asphalt base experiences in COA) matches the stiffness selected for CIR with asphalt stabilization (FDR-FA, PDR-EA, and PDR-FA) in *CalME* (version 3). The stiffness parameters of CIR with asphalt stabilization (FDR-FA, PDR-EA, and PDR-FA) in *CalME* (version

3) are based on the dynamic modulus measured in the laboratory and structural evaluation of test and field sections *(11)*. It should be mentioned that *Pavement ME* does not allow level 1 inputs for the dynamic modulus of the COA base. Otherwise, the CIR dynamic modulus master curve would have been directly used for *Pavement ME* calculations.

Figure 2.1 includes the monthly comparison between the stiffness of HMA and CIR bases for the two climate regions considered in the COA design tables. As shown in the figure, the stiffness of the CIR with asphalt stabilization is 40% to 60% of the stiffness of the HMA.

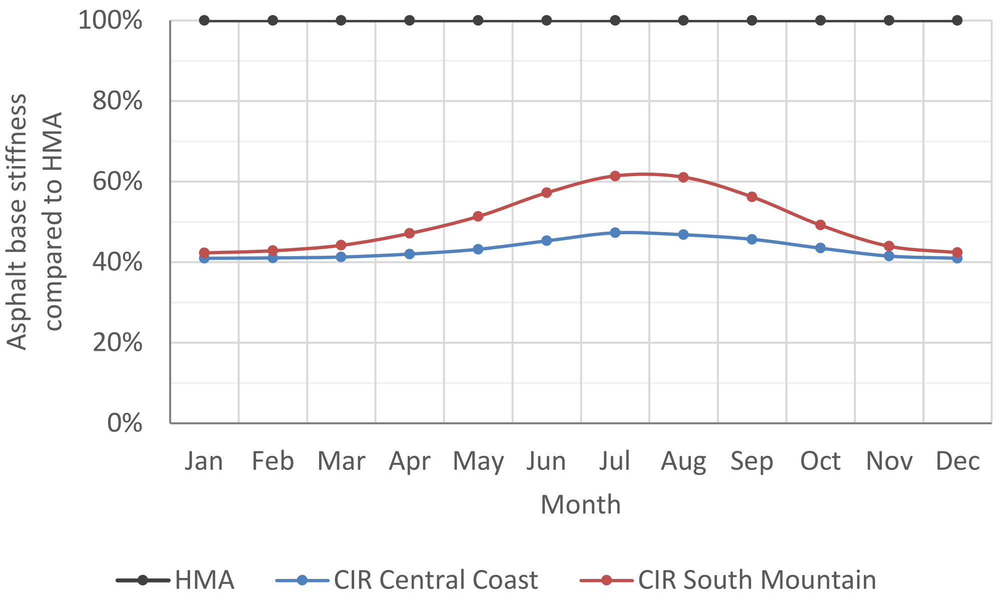

Figure 2.1: Comparison between the stiffness of HMA and CIR bases.

2.2.1.3 Asphalt Base Thickness

Variable levels:

- 0.25 ft.
- 0.35 to 0.45 ft.
- ≥0.45 ft.

The minimum thickness in the catalog, 0.25 ft. (3 in.), is the minimum value recommended by the practice of COA *(4,8)* and is the minimum asphalt thickness of the sections that were used for the *Pavement ME* national calibration *(9)*. This limit was also verified by means of full-scale testing with Heavy Vehicle Simulators in PPRC Project 4.58B *(1)*. The maximum thickness, 0.45 ft. (5.4 in.), is only applicable to the design process. In other words, if the thickness of asphalt is, for example, 0.6 ft., the design would be conducted assuming it is 0.45 ft. The reason is that some of the assumptions of the *Pavement ME* mechanistic model of the pavement (based on *Islab2000*) for thicker asphalt bases are too optimistic and result in an unrealistically high structural capacity of COA.

The same asphalt base thickness limits apply to HMA and CIR.

2.2.1.4 Subbase Type

Variable levels:

- AB, ATPB
- CTB, LCB

Aggregate, cement-treated, lean concrete, and asphalt-treated permeable bases (AB, CTB, LCB, and ATPB, respectively) can be found in Caltrans road network asphalt pavements. For this reason, they are included as subbases (under the asphalt base) in the COA tables of the new *HDM Design Catalog*. AB and ATPB are grouped for design and modeled as AB in *Pavement ME*. Similarly, CTB and LCB are grouped and modeled as CTB.

AB was modeled as a non-stabilized base made of coarse-grained soil with AASHTO A-1-a default properties in *Pavement ME*, including a 40,000 psi reference resilient modulus. The AB stiffness was allowed to change based on temperature and moisture following the *Pavement ME* approach. An AB thickness of 0.58 ft. (7.0 in.) was chosen, which is the median value expected on the Caltrans road network based on as-built plans and the pavement management system (PMS) database.

CTB was modeled in *Pavement ME* as a chemically stabilized material with a 1 million psi resilient modulus and default values for the rest of material properties. A CTB thickness of 0.50 ft. (6.0 in.) was chosen, which is the median value expected on the Caltrans road network based on as-built plans and the PMS database.

2.2.1.5 AADTT

Variable levels: 50, 100, 200, 500, 1,000, 2,000, 4,000 per lane

The COA tables of the new *HDM Design Catalog* are based on average annual daily truck traffic (AADTT) rather than the Caltrans Traffic Index (TI). AADTT in the COA design tables is one-directional truck traffic per lane, the value that results after applying directional and lane distribution factors to the two-way AADTT.

The proposed AADTT range results, for 20 years of design life, is 0.1 to 12 million equivalent single-axle loads. This range corresponds to a TI range of 7 to 12. The minimum AADTT, 50, corresponds to secondary roads with very low traffic. The maximum AADTT, 4,000, is compatible with 0.60 ft. maximum slab thickness.

The adoption of AADTT levels is only applicable to the printed version of the new *HDM Design Catalog*, for practical reasons. Meanwhile, AADTT will be treated as a continuous variable in the web version. The user will introduce the exact project location, including lane number, and then the web tool will estimate AADTT based on Caltrans traffic database, first, and determine the slab thickness for the estimated AADTT, second.

Only one AADTT level has been modeled in *Pavement ME*: 5,000 per lane. Because concrete damage (ω) is linearly proportional to AADTT, the damage for the different AADTT levels was determined by linear proportion (e.g., $\omega(2000) = \omega(5000) \times 2000/5000$). *Pavement ME* uses ω to determine the percentage of slabs with cracking.

Truck traffic was assumed to grow 3% annually, with linear growth.

2.2.1.6 Subgrade Type

Variable levels:

- Type I
- Type II and Type III without drainage issues (note: this group includes any Type II subgrade but only the Type III subgrades that do not have drainage issues)

Two different subgrade types are considered in the COA tables of the new *HDM Design Catalog*: (1) Type I and (2) Type II and Type III without drainage issues. The subgrade type definition follows the indications included in Chapter 620 of the *HDM*. Type I includes subgrades made of coarse-grained soils that are primarily sand (S) and gravel (G), regardless of whether they are well or poorly graded (W, P) or have silt (M) or clay (C) in them (SC, SP, SM, SW, GC, GP, GM, and GW), based on the Unified Soil Classification System (USCS). Type II includes subgrades made of fine-grained soils with low (L) and high (H) plasticity (CL, MH, and ML). Finally, Type III includes subgrades made of fine-grained soil CH (clay with high plasticity). COA is not recommended for Type III subgrades with drainage issues. Type III subgrades stabilized with lime or cement are considered in the COA design tables as Type I subgrades.

The *HDM* classifies soils following the USCS while *Pavement ME* is based on the AASHTO soil classification system. There is not a one-to-one correspondence between the two systems. For developing the COA tables of the new *HDM Design Catalog*, the Type I subgrade was modeled as soil A3 (granular) in *Pavement ME*. The Type II and Type III (without drainage issues) subgrades were modeled as soil A5 (silt-clay).

The subgrade soil stiffness was allowed to change based on temperature and moisture following the *Pavement ME* approach.

2.2.1.7 Climate

Variable levels:

- Group I: Central Coast (CC), North Coast (NC)
- Group II: South Mountain (SM), Desert (DE), High Desert (HD), Inland Valley (IV), Low Mountain (LM), South Coast (SC), High Mountain (HM)

Caltrans considers nine climate regions for pavement design and management *(12)*. The climate regions are organized into two groups for COA design. Each group was modeled in *Pavement ME* by adopting the climate within the group that results in the highest level of cracking. Group I was modeled as CC (Central Coast), and the San Francisco 23234 climate station was specifically selected in *Pavement ME*. Group II was modeled as SM (South Mountain), and the Palm Springs 3104d climate station was specifically selected.

Based on *Pavement ME*, COA performed better in the Group I climate region than in the Group II climate region *(5)*.

The depth of the water table level was set to 10 ft., regardless of the climate region.

2.2.2 Fixed Variables

2.2.2.1 Concrete 28-Day Flexural Strength

Pavement ME input: 637 psi

The 637 psi flexural strength value corresponds to a compressive strength (*f'c*) of 4,500 psi, based on the American Concrete Institute (ACI) formula implemented in *Pavement ME* (*flexural strength* = 9.5 × *f'c*^0.5). The 4,500 psi value is the estimated statewide median 28-day compressive strength of the pavement concrete (the average is 4,540 psi). The estimation is based on the UCPRC database, which includes almost 100 projects. The compressive strength was measured on cores extracted from existing JPCP slabs and age-corrected by using the aging function implemented in *Pavement ME*.

The selected flexural strength value does not represent rapid strength concrete. Based on the rapid strength concrete mixes tested at the UCPRC, the 28-day flexural strength reaches values from 600 to 1,000 psi. The design opening time of these mixes varied from 4 hours to 24 hours. The large variation of opening time and 28-day flexural strength is due to the large variety of rapid strength mixes used in Caltrans concrete pavements—including cement contents up to 800 lb/cy; different cement types (Types I/II and III portland and calcium sulfoaluminate); and different admixtures.

2.2.2.2 Concrete CTE

Pavement ME input: 4.8 με/°F

The 4.8 με/°F value is the estimated statewide median coefficient of thermal expansion (CTE) of the pavement concrete (the average is 4.9 με/°F). The estimation is based on the UCPRC database, which includes over 100 projects. A minor portion of the database records were affected by the former AASHTO TP 60 error in 304 stainless steel CTE. The affected records were corrected, so the 4.8 με/°F median is compatible with the current AASHTO standard (T 336) for measuring concrete CTE.

2.2.2.3 Concrete Thermal Properties

Pavement ME input:

- Albedo: 0.15
- Conductivity = 1.25 BTU/hr/ft/°F
- Heat capacity: 0.28 BTU/lb/°F

Statewide information of pavement concrete thermal properties (albedo, conductivity, and heat capacity) is not available. Consequently, *Pavement ME* national defaults were used for these three variables: 0.15 albedo (surface shortwave absorptivity), 1.25 BTU/hr/ft/°F conductivity, and 0.28 BTU/lb/°F heat capacity.

2.2.2.4 Concrete Composition and Shrinkage

Pavement ME input: Pavement ME defaults

Concrete composition inputs in *Pavement ME* include cement type, cement content, water/cement ratio, and aggregate type. Drying shrinkage inputs include ultimate shrinkage strain, reversible shrinkage percentage, time to develop 50% ultimate shrinkage, and curing method. None of these variables have any effect on *Pavement ME* COA predicted cracking *(5)*.

2.2.2.5 Slab Size

Pavement ME input: 6×6 ft.

Based on full-scale testing with Heavy Vehicle Simulators at the UCPRC, it is recommended that COA transverse joint spacing not be larger than 6 ft. *(1)*. Slab width can be up to 8 ft. for the slab to fit the lane width and, if applicable, to provide a concrete shoulder 1 to 2 ft. wide. This configuration must be modeled as 6×6 ft. slabs in *Pavement ME* since the software can only model square slabs (it cannot model slabs that are 6 ft. long and 8 ft. wide). In any case, slab size has a minor effect on *Pavement ME* COA predicted cracking.

2.2.2.6 Shoulder Type

Pavement ME input: Tied concrete

Based on full-scale testing with Heavy Vehicle Simulators at the UCPRC, slab widening rather than tied concrete is recommended to build the concrete shoulder *(1)*. Nonetheless, *Pavement ME* cannot model widened slabs. *Pavement ME* can model either tied or untied concrete shoulders. The load transfer efficiency of the lane-shoulder longitudinal joint is set to 40% for tied concrete shoulders and to 20% for untied concrete shoulders. *Pavement ME* predicted COA cracking is always larger for tied than for untied concrete shoulders (note: this a paradoxical outcome that may lead designers to believe that COA performs better with untied shoulders). The COA design tables of the new *HDM Design Catalog* were developed by adopting the conservative assumption of tied concrete shoulders. In any case, the type of shoulder has a low effect on *Pavement ME* COA predicted cracking.

Two options are recommended to bring the design to the field: (1) widened exterior slabs (1 to 2 ft. wider to provide a concrete shoulder 1 to 2 ft. wide) or (2) an asphalt shoulder if the mill and fill construction approach is followed.

2.2.2.7 Truck Traffic Characteristics

Pavement ME input: WIM Spectra 5

Caltrans considers five different truck traffic groups for pavement design and management: WIM1, WIM2, WIM3, WIM4, and WIM5, where WIM stands for "weigh in motion." Each WIM spectra is defined by the truck class, axle type, axle weight, and hourly traffic distributions *(13)*. The five spectra represent truck traffic characteristics that exist on the Caltrans road network. Within *Pavement ME*, the WIM spectra can be regarded as the regional-level characterization of the truck traffic variables.

Only one WIM spectra was used for *Pavement ME* calculations since the WIM spectra has a minor effect on the COA cracking predicted with *Pavement ME*. Spectra 5 was selected since this was the spectra that resulted in the largest predicted cracking overall.

2.2.2.8 Load Transfer Efficiency

Pavement ME input: 70%

The national calibration of the *Pavement ME* COA cracking model assumed that the load transfer efficiency of the transverse joints is 80%. The same value is the current *Pavement ME* default. A slightly more conservative value of 70% was used for developing the COA tables of the new *HDM Design Catalog*. The more conservative value is based on initial results from the SR113 COA pilot project *(14)*.

2.2.2.9 Permanent Curl/Warp

Pavement ME input: -10°F

The -10°F value is the value assumed in the national calibration of the *Pavement ME* COA cracking model, and it is also the current *Pavement ME* default. This value is debatable since it was not specifically determined for COA but just copied from the JPCP cracking model. In any case, the permanent curl/warp has a minor effect on the COA cracking predicted with *Pavement ME*.

2.2.2.10 Calibration Coefficients

Pavement ME input:

- C4 = 0.40
- C5 = -2.21

C4 and C5 are the parameters of the empirical transfer function that relates mechanistically determined concrete damage to cracking, shown in Equation (2.1). The chosen values are the outcome of the national calibration of the *Pavement ME* COA cracking model and current *Pavement ME* defaults.

$$Cr = \frac{100}{1 + C4\,\omega^{C5}} \qquad \textbf{(2.1)}$$

where Cr is the percentage of slabs with cracking
ω is concrete damage

2.2.2.11 Design Life

Pavement ME input: 20 years

The 20-year period is the minimum design life that Caltrans considers for major roadway rehabilitation projects. It is also the most common design life in the standard practice of COA.

2.2.2.12 Target Cracking

Pavement ME input: 10% longitudinal cracking

The *Pavement ME* COA cracking model predicts mid-panel, bottom-up longitudinal cracking, which is the critical distress mechanism of this type of pavement. The 10% target for longitudinal cracking is the same as the percentage of cracked slabs adopted for the failure criterion in the JPCP tables of the new *HDM Design Catalog*. However, for JPCP, the cracking is transverse rather than longitudinal.

2.2.2.13 Target Faulting

Pavement ME input: Not applicable

The current version of *Pavement ME* (version 2.6) does not model faulting of COA. The same applies to *Pavement ME* (version 2.5.5), which was used for developing the new *HDM Design Catalog*.

2.2.2.14 Target IRI

Pavement ME input: Not applicable

Caltrans quantifies pavement longitudinal smoothness with the International Roughness Index (IRI). The current version of *Pavement ME* (version 2.6) does not model the longitudinal smoothness of COA. The same applies to *Pavement ME* (version 2.5.5), which was used for developing the new *HDM Design Catalog*.

2.2.2.15 Design Reliability

Pavement ME input: 95%

Pavement ME design reliability is based on the standard error of the cracking prediction model. This standard error can be determined with Equation (2.2), which is an output of the national calibration of the COA cracking model. The 95% reliability criterion is the same adopted for developing the JPCP and CRCP tables of the new *HDM Design Catalog.* This value for longitudinal cracking is expected to approximately correspond to the 95% within-project reliability level for wheelpath cracking used for asphalt-surfaced pavement design in *CalME*, though this has not yet been verified.

$$\mathrm{SE}\left(Cr\right) = 3.5522\,Cr^{0.4315} + 0.5 \tag{2.2}$$

where Cr is the percentage of slabs with cracking

2.2.2.16 Provision for Grinding

Pavement ME input: 0.03 ft. (0.36 in.)

The 0.03 ft. (0.36 in.) provision accounts for one grinding operation. The grinding operation may take place right after construction, with the goal of meeting strict Caltrans specifications, or after years in service. The provision is introduced in the COA design tables by increasing the slab thickness that results from *Pavement ME* calculations by 0.36 in.

3 PROCEDURE FOR ANALYSIS OF PAVEMENT ME OUTPUT

The user-defined variables allow the user of the new *HDM Design Catalog* to choose among different variable-specific options (Table 2.1). The user-defined variables are the following:

- Asphalt base type
- Asphalt base thickness
- Subbase type
- AADTT
- Subgrade type
- Climate

The goal of the *HDM Design Catalog* is to determine the slab thickness required for a given combination of user-defined variables. From the catalog operation perspective, the slab thickness is not a user-defined variable but the output of the design.

All combinations of user-defined variables and slab thickness values from 0.35 to 0.60 ft., in 0.05 ft. increments, were run in *Pavement ME*, with the only exception being AADTT, for which a single value was considered (5,000 trucks/lane). A total of 288 combinations resulted. From the catalog operation perspective, each of the 288 runs can be summarized by a single value: the concrete damage at the end of the 20-year design life. This variable is referred to as $\omega 5k$ (the "5k" refers to the 5,000 trucks/lane). The $\omega 5k$ variable can be used to determine the percentage of slab cracking at the end of the 20-year design life at a given reliability level, based on the empirical functions included previously in Sections 2.2.2.10 and 2.2.2.15. Consequently, the set of 288 $\omega 5k$ values can be used to determine the slab thickness required for any combination of user-defined variables, as explained in the following discussion.

For any combination of user-defined variables, the design slab thickness is the slab thickness value for which *Pavement ME* predicts 10% of slabs having longitudinal cracking at the end of the 20-year design life with 95% reliability. The following is an example of a combination of user-defined variables:

- Asphalt base type: HMA
- Asphalt base thickness: 0.35 ft. (4.2 in.)
- Subbase type: AB (aggregate base)
- AADTT: 2,000 trucks/lane
- Subgrade type: Type II (fine-grained soil)
- Climate: CC (Group I climate)

For any given combination of user-defined variables, the required slab thickness is determined as follows:

1. Read the damage at the end of the 20-year design life, *ω5k*, for the different slab thickness values from the *Pavement ME* runs database. The slab thickness values are 0.35 to 0.60 ft. in 0.05 ft. increments (4.2 to 7.2 in., in 0.6 in. increments).
2. Determine the damage at the end of the 20-year design life for the user-defined truck traffic for the different slab thickness values. This damage is referred as ω, and it is linearly proportional to AADTT: $\omega = \omega5\text{k} \times \text{AADTT}/5000$.
3. Determine slab cracking at the end of the 20-year design life at 95% reliability, based on ω, for the different slab thickness values, using equations (2.1) and (2.2).
4. Determine the slab thickness that corresponds to 10% slab cracking at the end of the 20-year design life by using linear interpolation in the log-cracking versus slab thickness space.
5. Add the 0.03 ft. (0.36 in.) provision for grinding.

The slab thickness determination for the previous example (0.35 ft. HMA, AB, 2,000 AADTT, Type II subgrade, and CC climate) is illustrated in Figure 3.1, except for step 5 (provision for grinding).

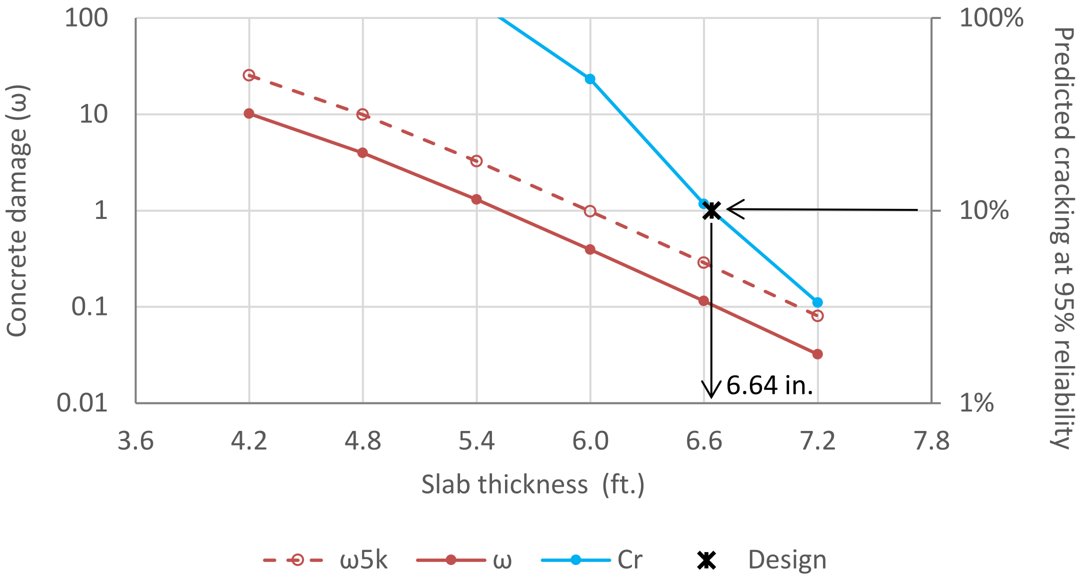

Figure 3.1: Illustration of approach for determining slab thickness.

4 COA DESIGN TABLES

The COA tables of the new *HDM Design Catalog* include the slab thickness required to meet 10% slab cracking at the end of the 20-year design life at 95% reliability, including provision for grinding of 0.03 ft. (0.36 in.). The following tables are presented in this chapter:

- Table 4.1: Type I subgrade and Group I climate
- Table 4.2: Type I subgrade and Group II climate
- Table 4.3: Type II subgrade and Group I climate
- Table 4.4: Type II subgrade and Group II climate

The subgrade types are defined as follows:

- Type I: Coarse-grained soils SC, SP, SM, SW, GC, GP, GM, and GW (USCS)
- Type II: Fine-grained soils CL, MH, and ML (USCS)

COA rehabilitation is allowed with Type III subgrades (CH) stabilized with lime or cement. These subgrades can be assimilated into Type I subgrades to determine the slab thickness.

COA rehabilitation is allowed with Type III subgrades (CH) without drainage issues. These subgrades can be assimilated into Type II subgrades to determine the slab thickness.

The climate groups are defined as follows:

- Group I: CC and NC
- Group II: SM, DE, HD, IV, LM, SC, and HM

Each COA design table contains the slab thickness for different combinations of asphalt base type, asphalt base thickness, and subbase type.

- Asphalt base type:
    - Hot mix asphalt (HMA)
    - Cold in-place recycling (CIR) with asphalt recycling agent

- Asphalt base thickness:
    - 0.25 ft. (3.0 in.); applicable if the base thickness is 0.25 to 0.35 ft.
    - 0.35 ft. (4.2 in.); applicable if the base thickness is 0.35 to 0.45 ft.
    - 0.45 ft. (5.4 in.); applicable if the base thickness is over 0.45 ft.
- Subbase type:
    - AB or ATPB (aggregate or asphalt-treated permeable base)
    - CTB or LCB (cement-treated or lean concrete base)

The CIR alternative includes full-depth recycling with foamed asphalt (FDR-FA) and partial-depth recycling with emulsified or foamed asphalt (PDR-EA or PDR-FA). The performance of COA with a CIR base has not been verified yet. Consequently, the implementation of this rehabilitation alternative should be closely monitored.

The asphalt base thickness is defined as follows:

- HMA alternative: The thickness of sound asphalt that remains after milling (if milling is conducted) plus any HMA or rubberized gap-graded hot mix asphalt (RHMA-G) overlay that may be added to improve the asphalt base structural capacity and/or surface condition.
- CIR alternative:
    - For FDR-FA: The thickness of the full-depth recycling.
    - For PDR-EA or PDR-FA: The thickness of sound asphalt that remains after milling plus the thickness of the partial-depth recycling.

The milling of the asphalt base is typically conducted for several reasons: removing surface-distressed asphalt, providing an even surface that helps achieve a uniform overlay thickness, and matching geometry requirements (e.g., bridge clearances).

The slab thickness in the tables is compatible with the following design features:

- Transverse joint spacing of 6 ft.
- Widened exterior slabs (1 to 2 ft. wider to provide a concrete shoulder 1 to 2 ft. wide) or an asphalt shoulder if the mill and fill construction approach is followed

- Maximum slab width of 8 ft.
- Undowelled transverse joints
- Tied and untied longitudinal joints

AADTT in the tables is the initial (year 1) average annual daily truck traffic per lane (the value that results after applying directional and lane distribution factors to the two-way AADTT).

The thickness in the tables is rounded to the nearest tenth of an inch and hundredth of a foot.

The “Not applicable” in the tables indicates that the required slab thickness is over 0.60 ft. (7.2 in.) and, consequently, standard JPCP rather than COA design should be considered.

Table 4.1: COA Design Table for Type I Subgrade (Coarse-Grained Soil) and Group I Climate (CC, NC)

AADTT (design lane)	**Subbase**	**HMA 0.25 ft. (3.0 in.)**	**HMA 0.35 ft. (4.2 in.)**	**HMA 0.45 ft. (5.4 in.)**	**CIR 0.25 ft. (3.0 in.)**	**CIR 0.35 ft. (4.2 in.)**	**CIR 0.45 ft. (5.4 in.)**
50	AB, ATPB	0.36 ft. (4.3 in.)	0.33 ft. (4.0 in.)	0.33 ft. (4.0 in.)	0.43 ft. (5.1 in.)	0.39 ft. (4.6 in.)	0.33 ft. (4.0 in.)
100	AB, ATPB	0.39 ft. (4.7 in.)	0.33 ft. (4.0 in.)	0.33 ft. (4.0 in.)	0.45 ft. (5.4 in.)	0.42 ft. (5.0 in.)	0.35 ft. (4.2 in.)
200	AB, ATPB	0.43 ft. (5.1 in.)	0.33 ft. (4.0 in.)	0.33 ft. (4.0 in.)	0.48 ft. (5.7 in.)	0.45 ft. (5.3 in.)	0.40 ft. (4.8 in.)
500	AB, ATPB	0.47 ft. (5.6 in.)	0.39 ft. (4.7 in.)	0.33 ft. (4.0 in.)	0.51 ft. (6.2 in.)	0.48 ft. (5.8 in.)	0.44 ft. (5.3 in.)
1,000	AB, ATPB	0.49 ft. (5.9 in.)	0.43 ft. (5.2 in.)	0.33 ft. (4.0 in.)	0.54 ft. (6.5 in.)	0.51 ft. (6.2 in.)	0.48 ft. (5.7 in.)
2,000	AB, ATPB	0.52 ft. (6.3 in.)	0.47 ft. (5.6 in.)	0.33 ft. (4.0 in.)	0.57 ft. (6.8 in.)	0.54 ft. (6.5 in.)	0.51 ft. (6.1 in.)
4,000	AB, ATPB	0.55 ft. (6.6 in.)	0.50 ft. (6.0 in.)	0.41 ft. (5.0 in.)	0.60 ft. (7.2 in.)	0.57 ft. (6.8 in.)	0.54 ft. (6.5 in.)
50	CTB, LCB	0.36 ft. (4.3 in.)	0.33 ft. (4.0 in.)	0.33 ft. (4.0 in.)	0.42 ft. (5.1 in.)	0.37 ft. (4.5 in.)	0.33 ft. (4.0 in.)
100	CTB, LCB	0.39 ft. (4.7 in.)	0.33 ft. (4.0 in.)	0.33 ft. (4.0 in.)	0.45 ft. (5.4 in.)	0.41 ft. (4.9 in.)	0.33 ft. (4.0 in.)
200	CTB, LCB	0.42 ft. (5.1 in.)	0.33 ft. (4.0 in.)	0.33 ft. (4.0 in.)	0.47 ft. (5.7 in.)	0.44 ft. (5.2 in.)	0.38 ft. (4.5 in.)
500	CTB, LCB	0.46 ft. (5.5 in.)	0.37 ft. (4.4 in.)	0.33 ft. (4.0 in.)	0.51 ft. (6.1 in.)	0.47 ft. (5.7 in.)	0.43 ft. (5.1 in.)
1,000	CTB, LCB	0.49 ft. (5.9 in.)	0.41 ft. (5.0 in.)	0.33 ft. (4.0 in.)	0.53 ft. (6.4 in.)	0.50 ft. (6.0 in.)	0.46 ft. (5.5 in.)
2,000	CTB, LCB	0.52 ft. (6.2 in.)	0.45 ft. (5.4 in.)	0.33 ft. (4.0 in.)	0.56 ft. (6.7 in.)	0.53 ft. (6.3 in.)	0.49 ft. (5.9 in.)
4,000	CTB, LCB	0.55 ft. (6.5 in.)	0.48 ft. (5.8 in.)	0.33 ft. (4.0 in.)	0.59 ft. (7.1 in.)	0.56 ft. (6.7 in.)	0.52 ft. (6.2 in.)

Table 4.2: COA Design Table for Type I Subgrade (Coarse-Grained Soil) and Group II Climate (SM, DE, HD, IV, LM, SC, HM)

AADTT (design lane)	Subbase	HMA 0.25 ft. (3.0 in.)	HMA 0.35 ft. (4.2 in.)	HMA 0.45 ft. (5.4 in.)	CIR 0.25 ft. (3.0 in.)	CIR 0.35 ft. (4.2 in.)	CIR 0.45 ft. (5.4 in.)
50	AB, ATPB	0.42 ft. (5.0 in.)	0.38 ft. (4.6 in.)	0.35 ft. (4.2 in.)	0.44 ft. (5.3 in.)	0.42 ft. (5.1 in.)	0.39 ft. (4.7 in.)
100	AB, ATPB	0.44 ft. (5.3 in.)	0.41 ft. (5.0 in.)	0.36 ft. (4.4 in.)	0.47 ft. (5.6 in.)	0.45 ft. (5.4 in.)	0.42 ft. (5.1 in.)
200	AB, ATPB	0.47 ft. (5.6 in.)	0.44 ft. (5.3 in.)	0.40 ft. (4.8 in.)	0.49 ft. (5.9 in.)	0.47 ft. (5.7 in.)	0.45 ft. (5.4 in.)
500	AB, ATPB	0.51 ft. (6.1 in.)	0.48 ft. (5.8 in.)	0.45 ft. (5.3 in.)	0.53 ft. (6.3 in.)	0.51 ft. (6.1 in.)	0.49 ft. (5.9 in.)
1,000	AB, ATPB	0.53 ft. (6.4 in.)	0.51 ft. (6.1 in.)	0.48 ft. (5.7 in.)	0.55 ft. (6.7 in.)	0.54 ft. (6.5 in.)	0.52 ft. (6.2 in.)
2,000	AB, ATPB	0.56 ft. (6.7 in.)	0.54 ft. (6.5 in.)	0.51 ft. (6.1 in.)	0.58 ft. (7.0 in.)	0.57 ft. (6.8 in.)	0.55 ft. (6.6 in.)
4,000	AB, ATPB	0.59 ft. (7.1 in.)	0.57 ft. (6.8 in.)	0.54 ft. (6.5 in.)	Not applicable	0.60 ft. (7.2 in.)	0.58 ft. (6.9 in.)
50	CTB, LCB	0.41 ft. (4.9 in.)	0.36 ft. (4.4 in.)	0.33 ft. (4.0 in.)	0.44 ft. (5.3 in.)	0.41 ft. (5.0 in.)	0.38 ft. (4.5 in.)
100	CTB, LCB	0.44 ft. (5.2 in.)	0.40 ft. (4.8 in.)	0.33 ft. (4.0 in.)	0.46 ft. (5.6 in.)	0.44 ft. (5.3 in.)	0.41 ft. (4.9 in.)
200	CTB, LCB	0.46 ft. (5.6 in.)	0.43 ft. (5.1 in.)	0.37 ft. (4.5 in.)	0.49 ft. (5.9 in.)	0.47 ft. (5.6 in.)	0.44 ft. (5.3 in.)
500	CTB, LCB	0.50 ft. (6.0 in.)	0.46 ft. (5.6 in.)	0.42 ft. (5.1 in.)	0.52 ft. (6.3 in.)	0.50 ft. (6.0 in.)	0.48 ft. (5.7 in.)
1,000	CTB, LCB	0.53 ft. (6.3 in.)	0.49 ft. (5.9 in.)	0.45 ft. (5.4 in.)	0.55 ft. (6.6 in.)	0.53 ft. (6.3 in.)	0.51 ft. (6.1 in.)
2,000	CTB, LCB	0.55 ft. (6.7 in.)	0.52 ft. (6.3 in.)	0.49 ft. (5.8 in.)	0.58 ft. (6.9 in.)	0.56 ft. (6.7 in.)	0.53 ft. (6.4 in.)
4,000	CTB, LCB	0.58 ft. (7.0 in.)	0.55 ft. (6.6 in.)	0.52 ft. (6.2 in.)	Not applicable	0.59 ft. (7.0 in.)	0.56 ft. (6.7 in.)

Table 4.3: COA Design Table for Type II Subgrade (Fine-Grained Soil) and Group I Climate (CC, NC)

AADTT (design lane)	Subbase	HMA 0.25 ft. (3.0 in.)	HMA 0.35 ft. (4.2 in.)	HMA 0.45 ft. (5.4 in.)	CIR 0.25 ft. (3.0 in.)	CIR 0.35 ft. (4.2 in.)	CIR 0.45 ft. (5.4 in.)
50	AB, ATPB	0.50 ft. (6.0 in.)	0.44 ft. (5.2 in.)	0.33 ft. (4.0 in.)	0.54 ft. (6.5 in.)	0.51 ft. (6.2 in.)	0.48 ft. (5.7 in.)
100	AB, ATPB	0.52 ft. (6.3 in.)	0.47 ft. (5.6 in.)	0.33 ft. (4.0 in.)	0.57 ft. (6.8 in.)	0.54 ft. (6.5 in.)	0.51 ft. (6.1 in.)
200	AB, ATPB	0.55 ft. (6.6 in.)	0.50 ft. (6.0 in.)	0.41 ft. (5.0 in.)	0.59 ft. (7.1 in.)	0.56 ft. (6.8 in.)	0.53 ft. (6.4 in.)
500	AB, ATPB	0.58 ft. (7.0 in.)	0.53 ft. (6.4 in.)	0.47 ft. (5.6 in.)	Not applicable	0.60 ft. (7.2 in.)	0.57 ft. (6.8 in.)
1,000	AB, ATPB	Not applicable	0.56 ft. (6.8 in.)	0.50 ft. (6.0 in.)	Not applicable	Not applicable	0.60 ft. (7.1 in.)
2,000	AB, ATPB	Not applicable	0.59 ft. (7.1 in.)	0.53 ft. (6.4 in.)	Not applicable	Not applicable	Not applicable
4,000	AB, ATPB	Not applicable	Not applicable	0.57 ft. (6.8 in.)	Not applicable	Not applicable	Not applicable
50	CTB, LCB	0.48 ft. (5.7 in.)	0.40 ft. (4.8 in.)	0.33 ft. (4.0 in.)	0.52 ft. (6.3 in.)	0.48 ft. (5.8 in.)	0.44 ft. (5.2 in.)
100	CTB, LCB	0.50 ft. (6.0 in.)	0.43 ft. (5.2 in.)	0.33 ft. (4.0 in.)	0.55 ft. (6.6 in.)	0.51 ft. (6.1 in.)	0.47 ft. (5.6 in.)
200	CTB, LCB	0.53 ft. (6.3 in.)	0.46 ft. (5.6 in.)	0.33 ft. (4.0 in.)	0.57 ft. (6.8 in.)	0.54 ft. (6.4 in.)	0.50 ft. (6.0 in.)
500	CTB, LCB	0.56 ft. (6.7 in.)	0.50 ft. (6.1 in.)	0.41 ft. (4.9 in.)	Not applicable	0.57 ft. (6.9 in.)	0.53 ft. (6.4 in.)
1,000	CTB, LCB	0.59 ft. (7.1 in.)	0.53 ft. (6.4 in.)	0.45 ft. (5.4 in.)	Not applicable	0.60 ft. (7.2 in.)	0.56 ft. (6.8 in.)
2,000	CTB, LCB	Not applicable	0.56 ft. (6.7 in.)	0.49 ft. (5.9 in.)	Not applicable	Not applicable	0.59 ft. (7.1 in.)
4,000	CTB, LCB	Not applicable	0.59 ft. (7.1 in.)	0.53 ft. (6.3 in.)	Not applicable	Not applicable	Not applicable

Table 4.4: COA Design Table for Type II Subgrade (Fine-Grained Soil) and Group II Climate (SM, DE, HD, IV, LM, SC, HM)

AADTT (design lane)	Subbase	HMA 0.25 ft. (3.0 in.)	HMA 0.35 ft. (4.2 in.)	HMA 0.45 ft. (5.4 in.)	CIR 0.25 ft. (3.0 in.)	CIR 0.35 ft. (4.2 in.)	CIR 0.45 ft. (5.4 in.)
50	AB, ATPB	0.52 ft. (6.3 in.)	0.50 ft. (6.0 in.)	0.46 ft. (5.6 in.)	0.55 ft. (6.6 in.)	0.53 ft. (6.3 in.)	0.51 ft. (6.1 in.)
100	AB, ATPB	0.55 ft. (6.6 in.)	0.52 ft. (6.3 in.)	0.49 ft. (5.9 in.)	0.57 ft. (6.8 in.)	0.55 ft. (6.6 in.)	0.53 ft. (6.4 in.)
200	AB, ATPB	0.57 ft. (6.9 in.)	0.55 ft. (6.6 in.)	0.52 ft. (6.3 in.)	0.60 ft. (7.1 in.)	0.58 ft. (6.9 in.)	0.56 ft. (6.7 in.)
500	AB, ATPB	Not applicable	0.59 ft. (7.0 in.)	0.56 ft. (6.7 in.)	Not applicable	Not applicable	0.59 ft. (7.1 in.)
1,000	AB, ATPB	Not applicable	Not applicable	0.59 ft. (7.0 in.)	Not applicable	Not applicable	Not applicable
2,000	AB, ATPB	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
4,000	AB, ATPB	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
50	CTB, LCB	0.50 ft. (6.0 in.)	0.47 ft. (5.6 in.)	0.42 ft. (5.1 in.)	0.53 ft. (6.3 in.)	0.50 ft. (6.0 in.)	0.47 ft. (5.7 in.)
100	CTB, LCB	0.53 ft. (6.3 in.)	0.49 ft. (5.9 in.)	0.45 ft. (5.4 in.)	0.55 ft. (6.6 in.)	0.53 ft. (6.3 in.)	0.50 ft. (6.0 in.)
200	CTB, LCB	0.55 ft. (6.6 in.)	0.52 ft. (6.3 in.)	0.48 ft. (5.8 in.)	0.58 ft. (6.9 in.)	0.55 ft. (6.6 in.)	0.53 ft. (6.3 in.)
500	CTB, LCB	0.59 ft. (7.1 in.)	0.56 ft. (6.7 in.)	0.52 ft. (6.3 in.)	Not applicable	0.59 ft. (7.1 in.)	0.57 ft. (6.8 in.)
1,000	CTB, LCB	Not applicable	0.58 ft. (7.0 in.)	0.55 ft. (6.6 in.)	Not applicable	Not applicable	0.59 ft. (7.1 in.)
2,000	CTB, LCB	Not applicable	Not applicable	0.58 ft. (7.0 in.)	Not applicable	Not applicable	Not applicable
4,000	CTB, LCB	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable

5 SUMMARY AND RECOMMENDATIONS

5.1 Summary

This report summarizes the work conducted to develop the COA tables of the new *HDM Design Catalog*. The tables consider the different pavement structures that are more likely candidates for rehabilitation with COA with short transverse joint spacing on the Caltrans road network. The tables were developed using *Pavement ME* (version 2.5.5) with the nationally calibrated COA cracking model introduced in 2016. *Pavement ME* inputs were determined by considering the state's climate, traffic, materials, and construction practices.

The design tables reflect the recommendations from previous Caltrans research about COA, including slab size, shoulder type, and load transfer efficiency.

The chosen values for design life (20 years), target cracking (10%), and design reliability (95%) are compatible with Caltrans pavement practices.

The COA design tables, presented in Chapter 4, may be directly implemented in the printed version of the new *HDM Design Catalog*.

5.2 Recommendations

The COA design tables do not consider faulting and longitudinal smoothness. Further research and collection of empirical data for the Caltrans road network's climate, materials, and construction practices are recommended so that faulting and longitudinal smoothness can be considered in future updates of the COA design tables.

The COA design tables introduce a rehabilitation alternative based on CIR with asphalt plus cement stabilization, but the performance of this alternative practice has not yet been verified. Consequently, the implementation of this rehabilitation alternative should be closely monitored.

The *Pavement ME* COA cracking model was calibrated based on empirical data from sections in Minnesota, Illinois, and Colorado, which are states with climate conditions that do not represent the dry and warm weather present in most of California. Further, the sections used for the calibration may not represent the rapid strength concrete used and the short construction windows most likely to occur with COA rehabilitation activity on the Caltrans road network. Consequently, performance monitoring of Caltrans COA pilots is recommended.

REFERENCES

1. Mateos, A., Harvey, J.T., Paniagua, F., Paniagua, J. and Wu, R. 2019. *Development of Improved Guidelines and Designs for Thin Whitetopping: Summary, Conclusions, and Recommendations* (Summary Report: UCPRC-SR-2018-01). Davis and Berkeley, CA: University of California Pavement Research Center. escholarship.org/uc/item/5g04q2mb.

2. Mateos, A., Harvey, J.T., Paniagua, F., Paniagua, J. and Wu, R. 2019. "Accelerated Testing of Full-Scale Thin Bonded Concrete Overlay of Asphalt." *Transportation Research Record* 2673, no. 2: 404-414. journals.sagepub.com/doi/10.1177/0361198119825645.

3. Mateos, A., Harvey, J.T., Millan, M.A., Wu, R., Paniagua, F., Cisneros, J., and Paniagua, J. 2020. *Concrete Overlay on Asphalt Pilot Project at Woodland SR 113: Construction* (Research Report: UCPRC-RR-2020-01). Davis and Berkeley, CA: University of California Pavement Research Center. escholarship.org/uc/item/86f4f3sr.

4. Li, Z., Dufalla, N., Mu, F., and Vandenbossche, J.M. 2013. *Bonded Concrete Overlay of Asphalt Pavements Mechanistic-Empirical Design Guide (BCOA-ME): Theory Manual* (FHWA Pooled Fund Project: TPF-5-165). Pittsburgh, PA: University of Pittsburgh,. engineeringx.pitt.edu/uploadedFiles/_Content/Sub_Sites/Faculty_Subsites/Vandenbossche/Documents/BCOA%20ME%20Theory%20Manual.pdf.

5. Mateos, A., and Harvey, J.T. 2020. *Development of Thin Bonded Concrete Overlay of Asphalt Design Method: Evaluation of Existing Mechanistic-Empirical Design Methods* (Technical Memorandum: UCPRC-TM-2019-01). Davis and Berkeley, CA: University of California Pavement Research Center. escholarship.org/uc/item/43r2938w.

6. Mateos, A., and Harvey J.T. 2020. *Pavement ME Evaluation of the NCHRP 1-61 Concrete Overlay on Asphalt Sections with Half-Lane Width Slabs* (Research Report: UCPRC-RR-2022-01). Davis and Berkeley, CA: University of California Pavement Research Center. escholarship.org/uc/item/3z31q57r.

7. Pierce, L., Stolte, S., Weitzel, N., Medina, J., Van Dam, T., Senn, K., Roesler, J., Scott, G., Sen, S., Jadallah, A., Maser, K., Carmichael, A., Smith, K., and Smith, K. 2020. *Evaluation of Bonded Concrete Overlays on Asphalt Pavements* (Final Report NCHRP Project No. 01-61). Washington, DC: National Cooperative Highway Research Program.

8. Harrington, D., and Fick, G. 2014. *Guide to Concrete Overlays: Sustainable Solutions for Resurfacing and Rehabilitating Existing Pavements*, Third Edition. Ames, IA: National Concrete Pavement Technology Center.

9. Bhattacharya, B., Gotlif, A., and Darter, M. 2017. "Implementation of the Thin Bonded Concrete Overlay of Existing Asphalt Pavement Design Procedure in the AASHTOWare Pavement ME Design Software." *Transportation Research Record* 2641, no. 1: 12–20. journals.sagepub.com/doi/abs/10.3141/2641-02.

10. Jones, D., S. Louw, and J. Harvey. 2021. *Guide for Partial- and Full-Depth Pavement Recycling in California* (Guidelines: UCPRC-GL-2020-01) Davis and Berkeley, CA: University of California Pavement Research Center. escholarship.org/uc/item/54z679x4.

11. Wu, R., J. Harvey, J. Lea, A. Mateos, S. Yang, and N. Hernandez. 2021. *Updates to CalME and Calibration of Cracking Models* (Research Report: UCPRC-RR-2021-01). Davis and Berkeley, CA: University of California Pavement Research Center. escholarship.org/uc/item/460234g0.

12. California Department of Transportation. Pavement Climate Regions. n.d. "Caltrans Pavement Climate Regions Map." Accessed January 16, 2021. dot.ca.gov/programs/maintenance/pavement/concrete-pavement-and-pavement-foundations/climate.

13. Kim, C., Lea, J., Kannekanti, V., and Harvey, J.T. Forthcoming. *Updating Weigh-in-Motion (WIM) Spectra in PaveM*. Davis and Berkeley, CA: University of California Pavement Research Center.

14. Mateos, A., Harvey, J.T., Millan, Paniagua, F., and Yang, S. Forthcoming. *Concrete Overlay on Asphalt Pilot Project at Woodland SR 113: Initial Performance*. Davis and Berkeley, CA: University of California Pavement Research Center.