Incorporation of Joint Faulting Model into BCOA-ME
MnDOT Contract No. 1003327 Work Order No. 4
-University of Pittsburgh-

Task 3 Memorandum

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Task 3 Memo: Implementation of improved faulting model into BCOA-ME procedure

Introduction

With the development of regression models to estimate climate-related inputs to BCOA-ME (including the Effective Equivalent Linear Temperature Gradient (EELTG), Effective HMA Modulus (EEHMA), Freezing Days, and days with significant precipitation), the BCOA-ME model could be extended across the contiguous United States. In particular, several representative locations within NRRA member states were included in developing the regression models. Therefore, the BCOA-ME model can now be used to model faulting in those states as well.

Under the present task, these regression models were incorporated into the faulting model framework and added to the BCOA-ME webtool. Under this framework, a location is specified in terms of its latitude, longitude, elevation, AMDAT Zone, and Sunshine Zone, which could be anywhere within the US. This information, together with traffic and material property inputs, is then used to design the thickness of the pavement based on fatigue cracking in the design life. This design thickness is then used by the faulting model to predict faulting at a chosen level of reliability. The webtool displays the faulting at the end of the month of September at each year of the analysis in the form of a bar chart. The model was developed in the C# programming language, with some changes made to the existing BCOA-ME webtool interface using ASP.NET.

Methodology

Once the updated faulting model with the climatic regression equations was incorporated into the BCOA-ME webtool, several checks were performed to confirm that the outputs were both reasonable as well as sensitive to the inputs to the extent that they are expected to be. After all validation checks were successfully performed, a sensitivity analysis was prepared to demonstrate its application in one city in each of the NRRA member states, as well as in Pittsburgh, PA. The selected cities and their geographic information are shown in Table 1.

Table 1: NRRA member-states and locations in the analysis matrix

NRRA State	Location	Latitude (°)	Longitude (°)	Elevation (ft)	AMDAT Zone	Sunshine Zone
California	Los Angeles	34.05	-118.25	305	5	2
Illinois	Champaign	40.12	-88.27	764	3	5
Iowa	Des Moines	41.58	-93.62	955	2	4
Michigan	Lansing	42.73	-84.51	860	2	6
Minnesota	Minneapolis	44.98	-93.27	830	1	5
Mississippi	Jackson	32.3	-90.18	279	5	4
Missouri	Columbia	38.95	-92.33	758	4	4
New York	Syracuse	43.03	-76.13	410	1	6
North Dakota	Bismarck	46.8	-100.78	1686	1	4
Wisconsin	Madison	43.07	-89.38	873	2	5
Pennsylvania **(reference)**	Pittsburgh	40.3	-80.14	1175	3	6

For each of these locations, three pavement structures were analyzed using the integrated BCOA-ME webtool. These structures are summarized in Table 2. These three structures were similar but with some key differences. Structure 2 is the same as Structure 1 except that the joint spacing increases from 6 ft to 10 ft. Structure 3 is also the same as Structure 1 except that the HMA thickness decreases from 7 in to 4 in. For Structures 1 and 3, the weighted average faulting for joint activation through the PCC only and through both PCC and HMA layers is presented, while for Structure 2, only the faulting for full-depth joint activation is presented. Furthermore, ESALs to failure are also presented, where failure is defined as a predicted faulting of 0.125 in at 85% reliability.

Table 2: Pavement structures in the analysis matrix

Property	**Structure 1**	**Structure 2**	**Structure 3**
Design Life (years)	20		
ESALs	13 million		
Trucks (%)	7		
HMA thickness (in)	**7**	**7**	**4**
k-value (psi/in)	250		
P200 of HMA	4		
P200 of subbase	50		
Binder content (%)	5		
Air voids in HMA (%)	3.5		
PCC flexural strength (psi)	650		
PCC elastic modulus (psi)	4,000,000		
CTE (10^{-6}°F^{-1})	5.0		
Cement content (lb/cyd)	500		
Joint spacing (ft)	**6**	**10**	**6**
Dowel bar diameter (in)	0		

Shoulder type	Not tied

Results

The development of faulting as a function of time for Structures 1, 2, and 3 for all the locations analyzed is shown in **Appendix A, B, and C** respectively, with the failure threshold also indicated on the same graphs. These are outputs from the BCOA-ME webtool. From this data, the ESALs at failure is obtained, which is shown in Figure 1. Both Structures 1 and 3 are 6 ft slabs, but the HMA layer is thicker in Structure 1. Consequently, the ESALs to failure are higher for Structure 1. Indeed, for North Dakota conditions, Structure 1 does not fail during the design life and hence no bar is shown for it on the graph.

Structure 2 has 10-ft slabs without dowels and failure occurs at about 4-5 million ESALs. In this case, dowels would be a good option to reduce faulting but they were not included in the design for this analysis so the sensitivity to faulting could be quantified.

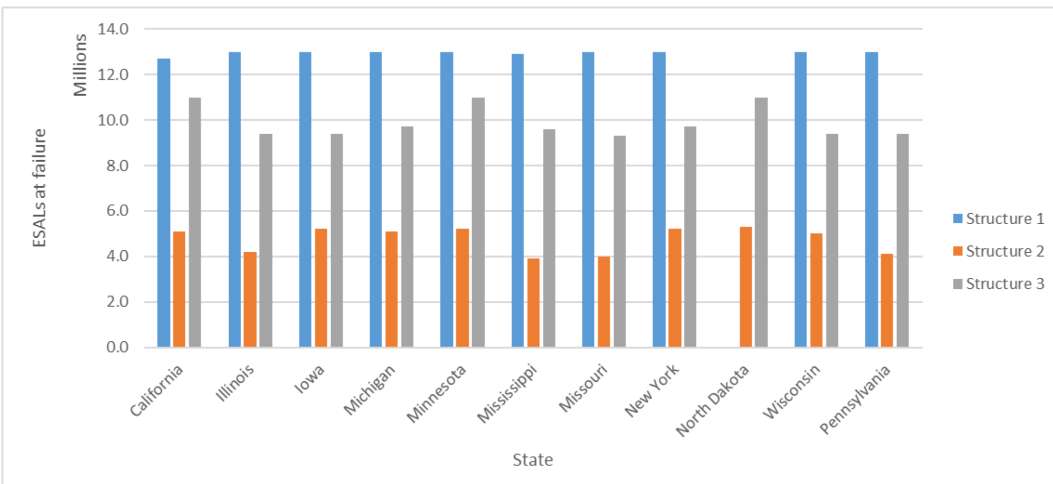


Figure 1: ESALs at failure for each structure and location (Structure 1 in North Dakota does not fail in the design life)

Conclusion

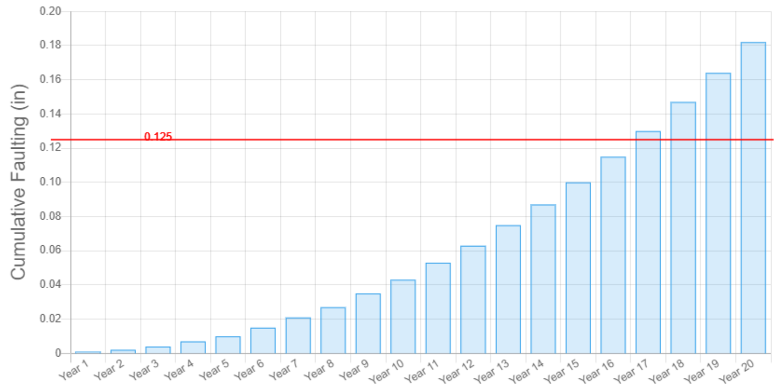
The updated faulting model, incorporating regression equations to model climatic inputs from across the contiguous US, was merged into the existing BCOA-ME web-based tool. The new tool designs the overlay thickness to achieve adequate fatigue performance over the design life and uses that thickness to report the cumulative faulting in each year. The tool was used to model faulting for three pavement structures across NRRA states (as well as in Pennsylvania for reference). The results were reasonable. The model can thus be used by practitioners in the contiguous US to develop their own BCOA designs.

Appendix A: Faulting development for Structure 1

California

Performance Analysis

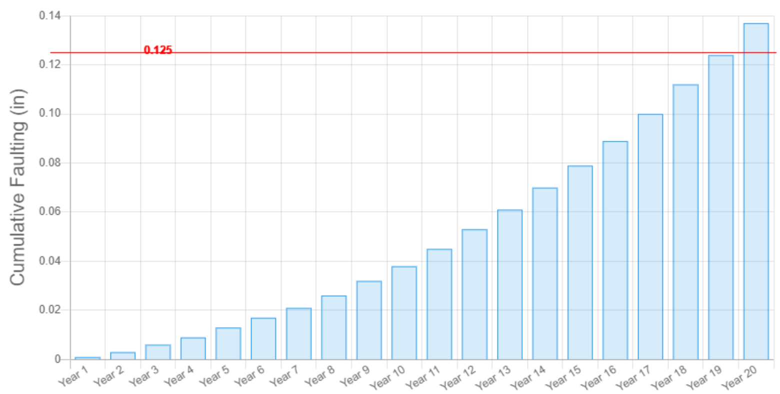
Calculated PCC Overlay Thickness (in)	3.52
Design PCC Overlay Thickness (in)	**3.5**
Is there potential for reflective cracking?	Yes
Predicted Faulting (in)	
	Solved.



Illinois

Performance Analysis

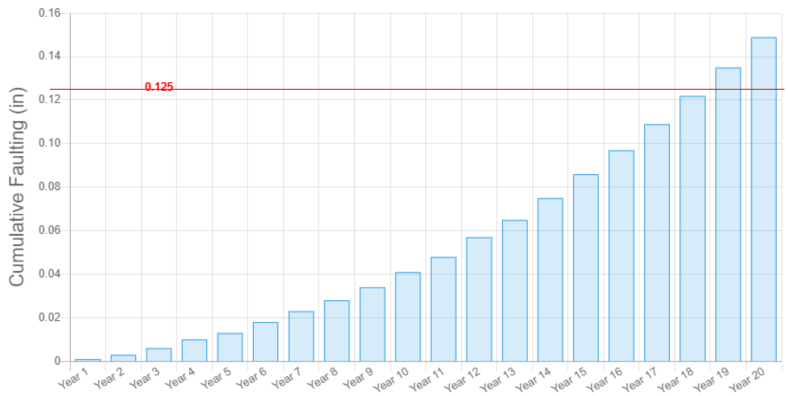
Calculated PCC Overlay Thickness (in)	4
Design PCC Overlay Thickness (in)	**4**
Is there potential for reflective cracking?	Yes
Predicted Faulting (in)	
	Solved.



Iowa

Performance Analysis

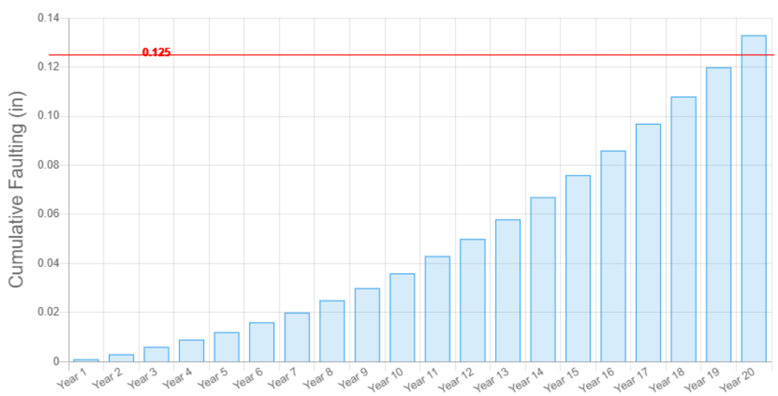
Calculated PCC Overlay Thickness (in)	3.64
Design PCC Overlay Thickness (in)	**4**
Is there potential for reflective cracking?	Yes
Predicted Faulting (in)	
	Solved.



Michigan

Performance Analysis

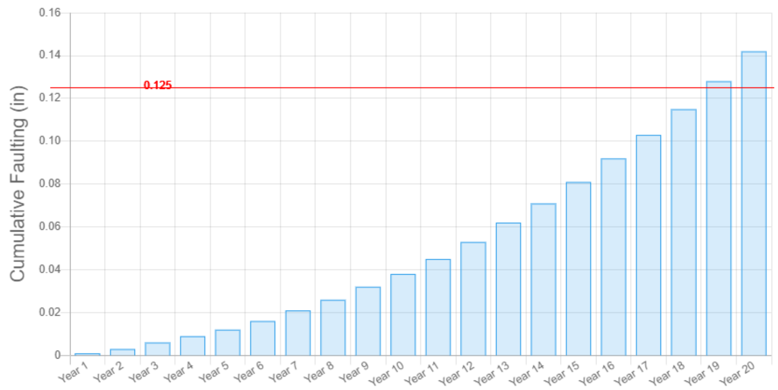
Calculated PCC Overlay Thickness (in)	3.73
Design PCC Overlay Thickness (in)	**4**
Is there potential for reflective cracking?	Yes
Predicted Faulting (in)	
	Solved.



Minnesota

Performance Analysis

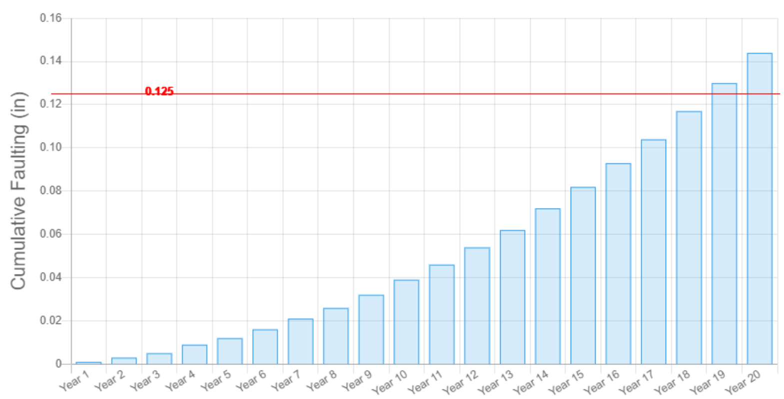
Calculated PCC Overlay Thickness (in)	4.02
Design PCC Overlay Thickness (in)	**4**
Is there potential for reflective cracking?	Yes
Predicted Faulting (in)	
	Solved.



Mississippi

Performance Analysis

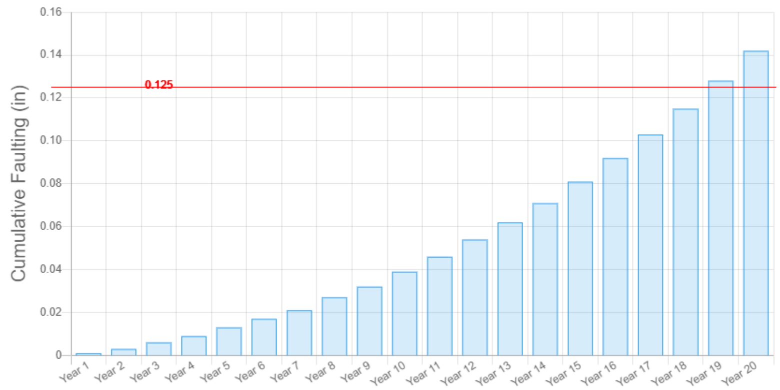
Calculated PCC Overlay Thickness (in)	3.66
Design PCC Overlay Thickness (in)	**4**
Is there potential for reflective cracking?	Yes
Predicted Faulting (in)	
	Solved.



Missouri

Performance Analysis

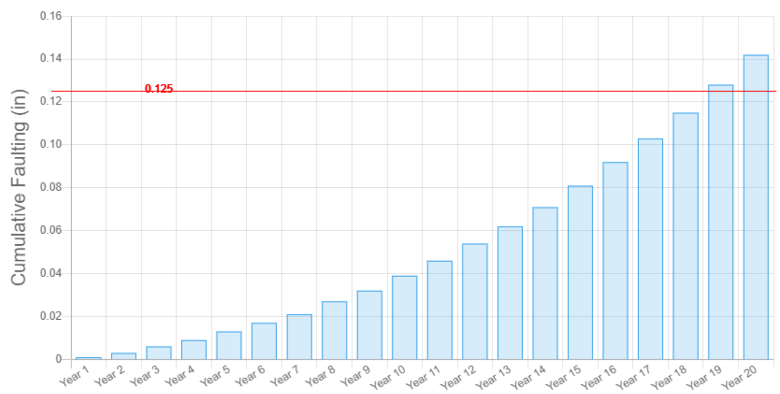
Calculated PCC Overlay Thickness (in)	3.92
Design PCC Overlay Thickness (in)	**4**
Is there potential for reflective cracking?	Yes
Predicted Faulting (in)	
	Solved.



New York

Performance Analysis

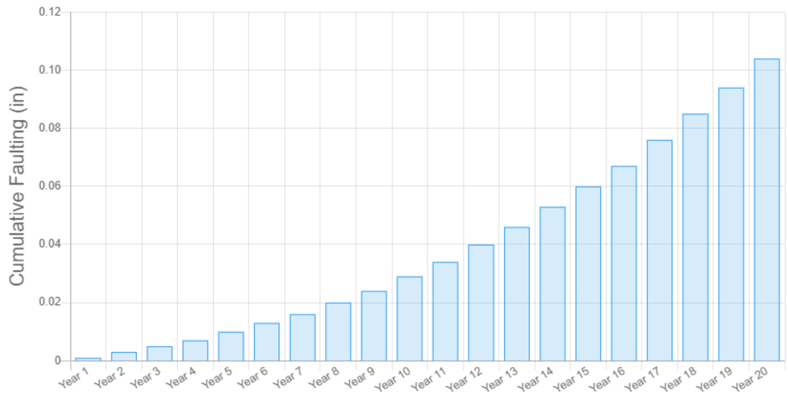
Calculated PCC Overlay Thickness (in)	3.92
Design PCC Overlay Thickness (in)	**4**
Is there potential for reflective cracking?	Yes
Predicted Faulting (in)	
	Solved.



North Dakota

Performance Analysis

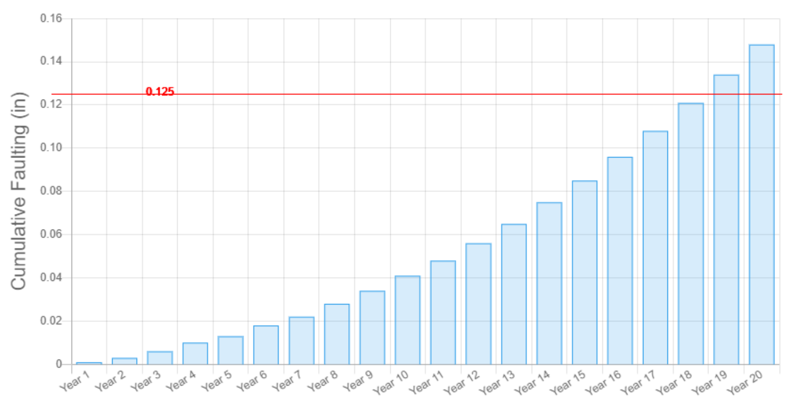
Calculated PCC Overlay Thickness (in)	4.16
Design PCC Overlay Thickness (in)	**4.5**
Is there potential for reflective cracking?	Yes
Predicted Faulting (in)	
	Solved.



Wisconsin

Performance Analysis

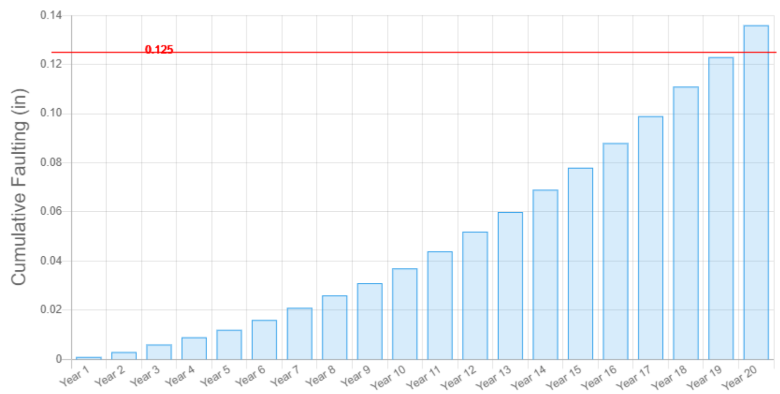
Calculated PCC Overlay Thickness (in)	3.74
Design PCC Overlay Thickness (in)	**4**
Is there potential for reflective cracking?	Yes
Predicted Faulting (in)	
	Solved.



Pennsylvania

Performance Analysis

Calculated PCC Overlay Thickness (in)	3.92
Design PCC Overlay Thickness (in)	**4**
Is there potential for reflective cracking?	Yes
Predicted Faulting (in)	
	Solved.



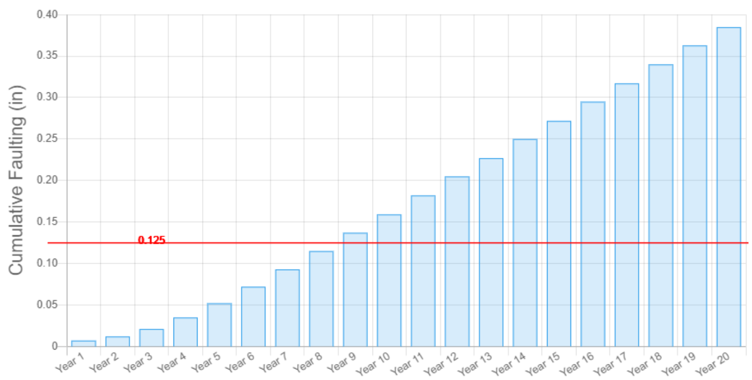
Appendix B: Faulting development for Structure 2

California

Performance Analysis

Calculated PCC Overlay Thickness (in)	<4.5
Design PCC Overlay Thickness (in)	**4.5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	

The calculated concrete thickness is less than the minimum recommended design thickness supported by this design methodology of 4.5 in. Thus, a 4.5 in. concrete overlay is recommended for such a joint spacing desgin. If a thinner design is desirable, small slabs (e.g. 6 ft x 6 ft) are recommended. Faulting is calculated assuming 4.5 in.

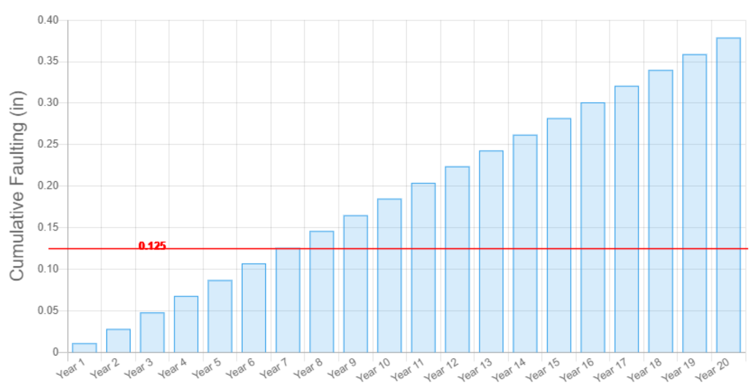


Illinois

Performance Analysis

Calculated PCC Overlay Thickness (in)	<4.5
Design PCC Overlay Thickness (in)	**4.5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	

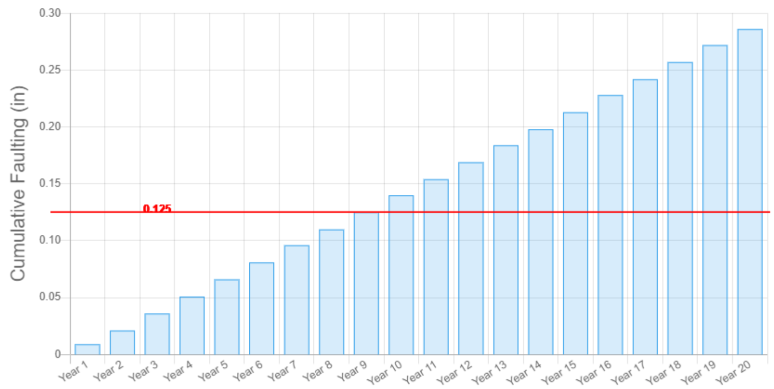
The calculated concrete thickness is less than the minimum recommended design thickness supported by this design methodology of 4.5 in. Thus, a 4.5 in. concrete overlay is recommended for such a joint spacing desgin. If a thinner design is desirable, small slabs (e.g. 6 ft x 6 ft) are recommended. Faulting is calculated assuming 4.5 in.



Iowa

Performance Analysis

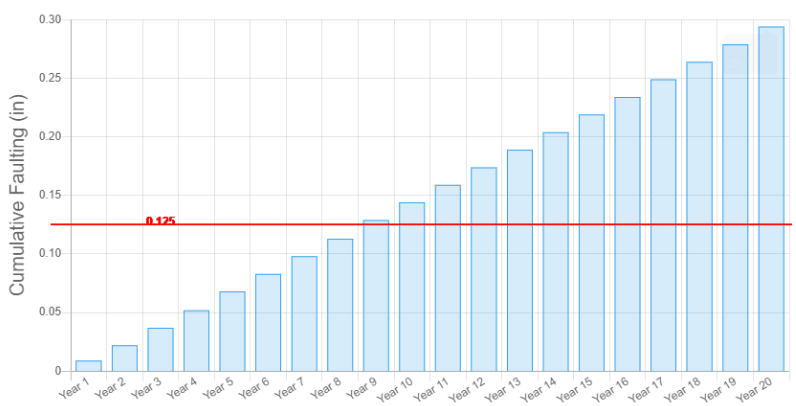
Calculated PCC Overlay Thickness (in)	4.77
Design PCC Overlay Thickness (in)	**5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	
	Solved.



Michigan

Performance Analysis

Calculated PCC Overlay Thickness (in)	4.77
Design PCC Overlay Thickness (in)	**5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	
	Solved.

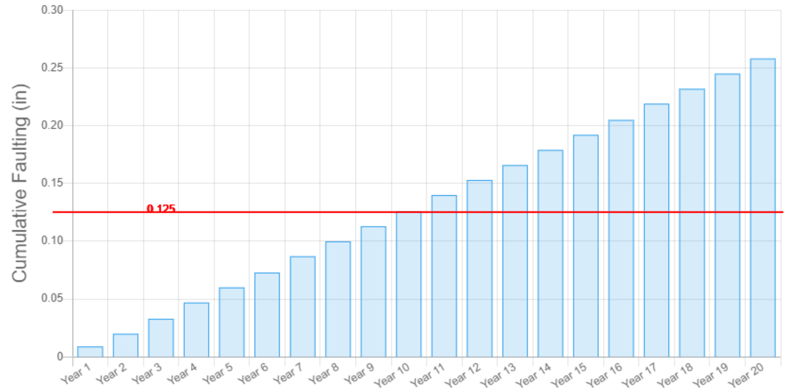


Minnesota

Performance Analysis

Calculated PCC Overlay Thickness (in)	5.3
Design PCC Overlay Thickness (in)	**5.5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	

Solved.

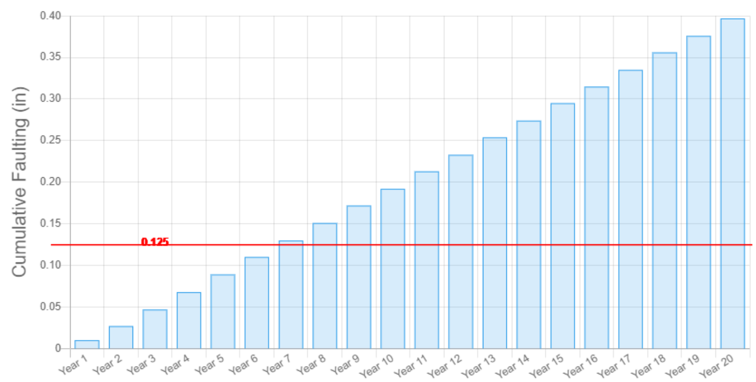


Mississippi

Performance Analysis

Calculated PCC Overlay Thickness (in)	<4.5
Design PCC Overlay Thickness (in)	**4.5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	

The calculated concrete thickness is less than the minimum recommended design thickness supported by this design methodology of 4.5 in. Thus, a 4.5 in. concrete overlay is recommended for such a joint spacing desgin. If a thinner design is desirable, small slabs (e.g. 6 ft x 6 ft) are recommended. Faulting is calculated assuming 4.5 in.

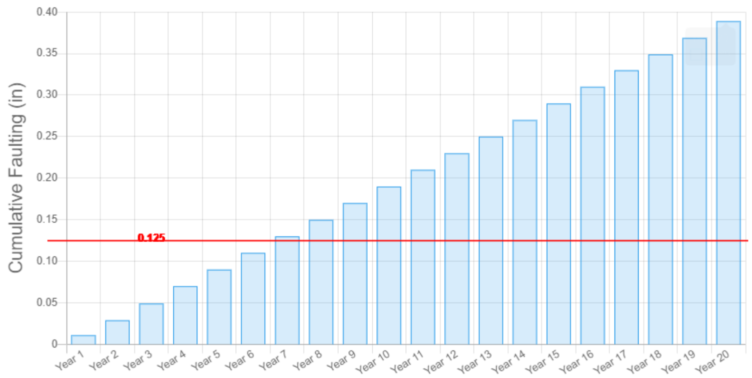


Missouri

Performance Analysis

Calculated PCC Overlay Thickness (in)	<4.5
Design PCC Overlay Thickness (in)	**4.5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	

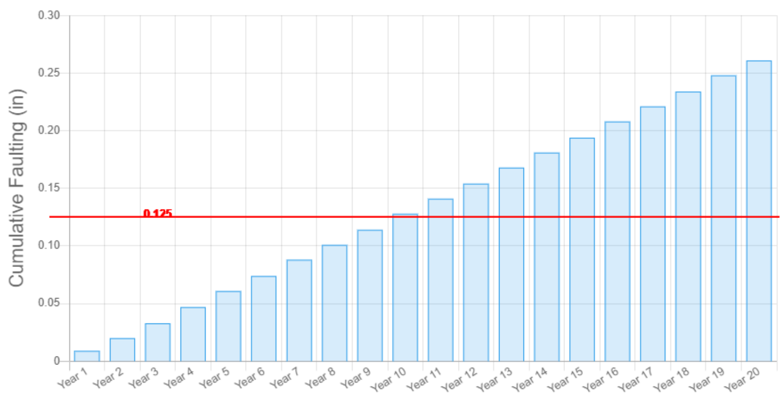
The calculated concrete thickness is less than the minimum recommended design thickness supported by this design methodology of 4.5 in. Thus, a 4.5 in. concrete overlay is recommended for such a joint spacing desgin. If a thinner design is desirable, small slabs (e.g. 6 ft x 6 ft) are recommended. Faulting is calculated assuming 4.5 in.



New York

Performance Analysis

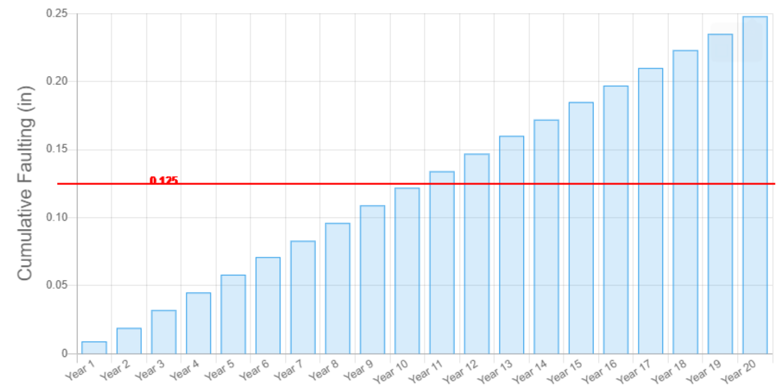
Calculated PCC Overlay Thickness (in)	5.33
Design PCC Overlay Thickness (in)	**5.5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	
	Solved.



North Dakota

Performance Analysis

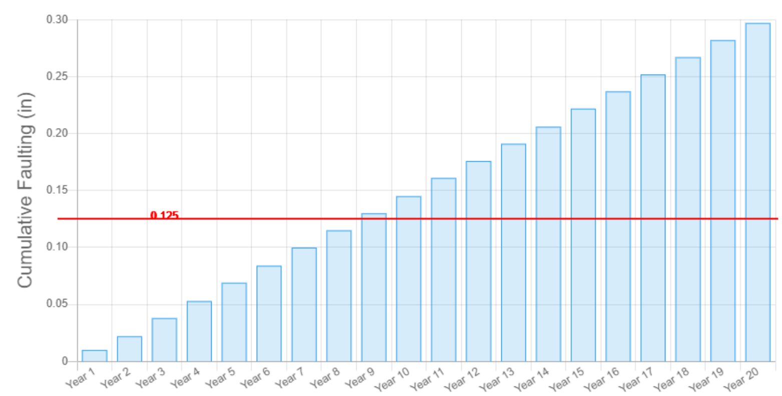
Calculated PCC Overlay Thickness (in)	5.38
Design PCC Overlay Thickness (in)	**5.5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	
	Solved.



Wisconsin

Performance Analysis

Calculated PCC Overlay Thickness (in)	4.78
Design PCC Overlay Thickness (in)	**5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	
	Solved.

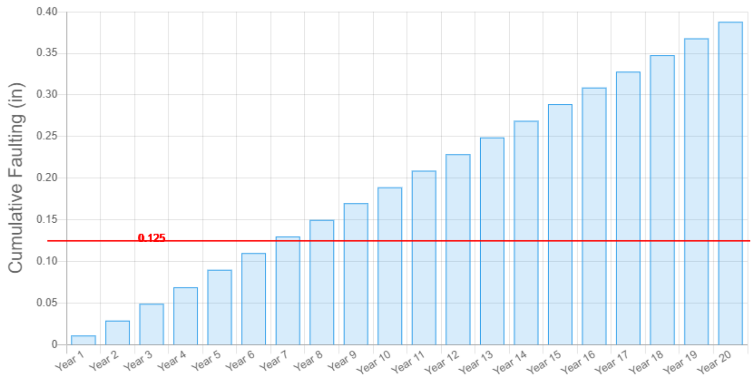


Pennsylvania

Performance Analysis

Calculated PCC Overlay Thickness (in)	<4.5
Design PCC Overlay Thickness (in)	**4.5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	

The calculated concrete thickness is less than the minimum recommended design thickness supported by this design methodology of 4.5 in. Thus, a 4.5 in. concrete overlay is recommended for such a joint spacing desgin. If a thinner design is desirable, small slabs (e.g. 6 ft x 6 ft) are recommended. Faulting is calculated assuming 4.5 in.

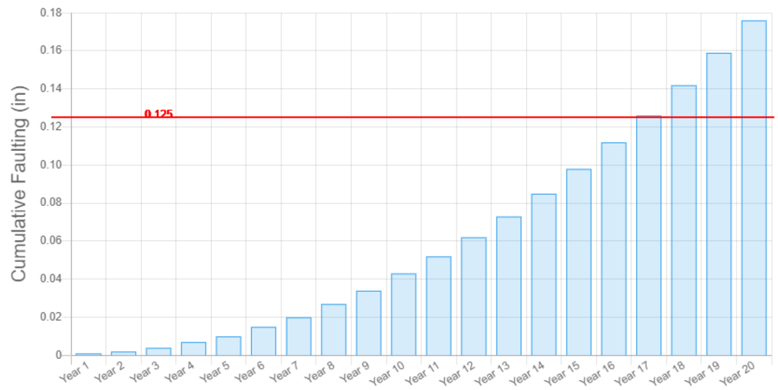


Appendix C: Faulting development for Structure 3

California

Performance Analysis

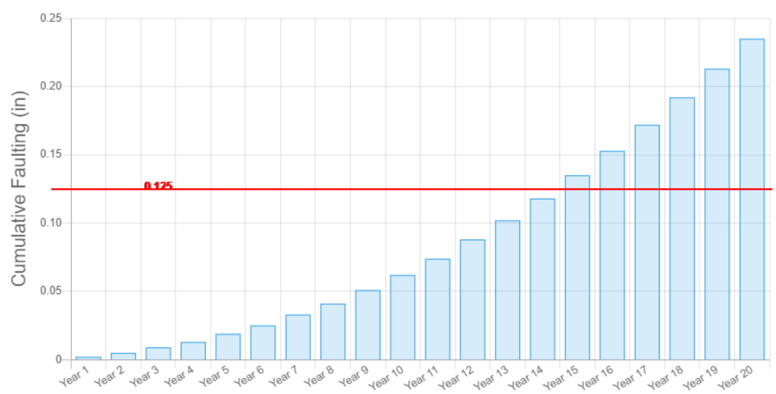
Calculated PCC Overlay Thickness (in)	4.43
Design PCC Overlay Thickness (in)	**4.5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	
	Solved.



Illinois

Performance Analysis

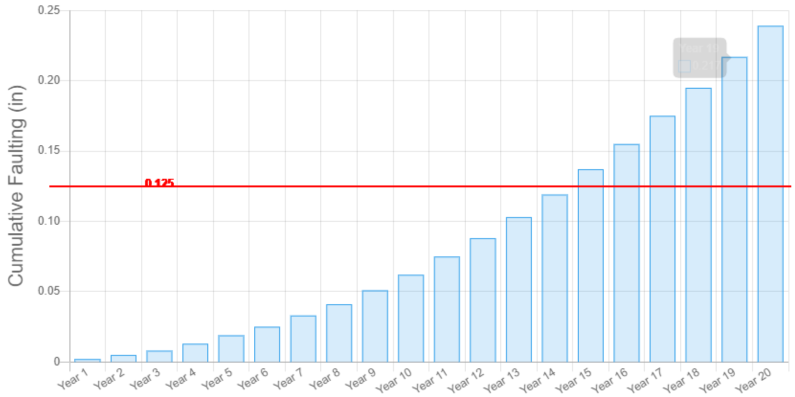
Calculated PCC Overlay Thickness (in)	4.61
Design PCC Overlay Thickness (in)	**4.5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	
	Solved.



Iowa

Performance Analysis

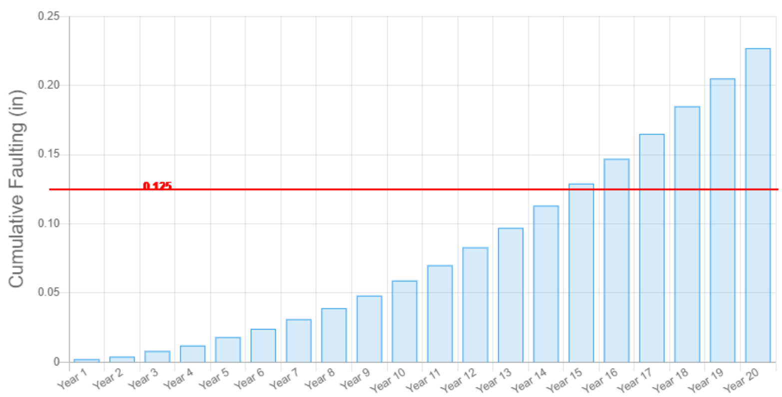
Calculated PCC Overlay Thickness (in)	4.56
Design PCC Overlay Thickness (in)	**4.5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	
	Solved.



Michigan

Performance Analysis

Calculated PCC Overlay Thickness (in)	4.59
Design PCC Overlay Thickness (in)	**4.5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	
	Solved.

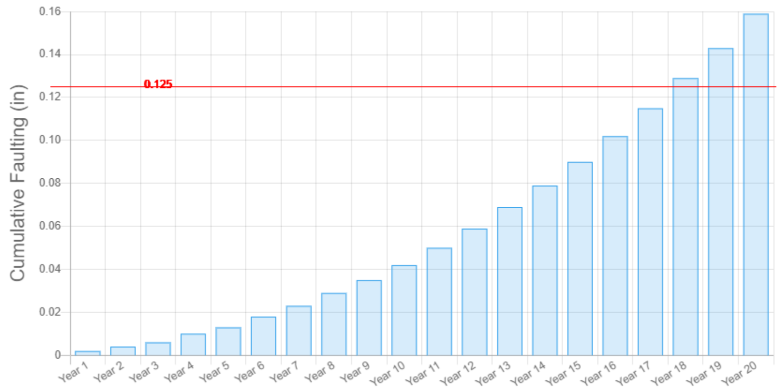


Minnesota

Performance Analysis

Calculated PCC Overlay Thickness (in)	4.75
Design PCC Overlay Thickness (in)	**5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	

Solved.

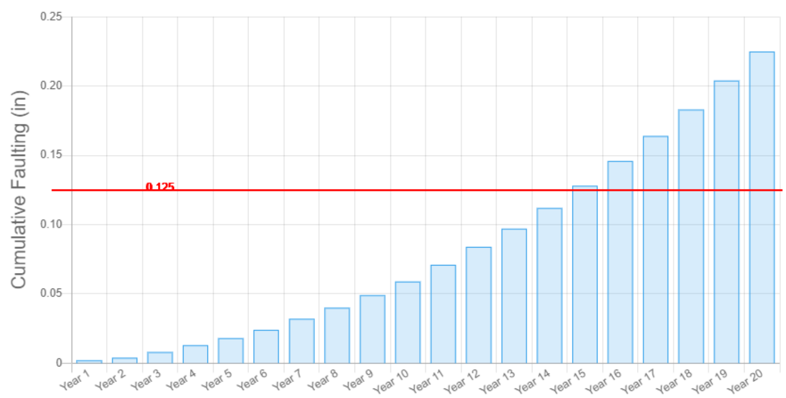


Mississippi

Performance Analysis

Calculated PCC Overlay Thickness (in)	4.48
Design PCC Overlay Thickness (in)	**4.5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	

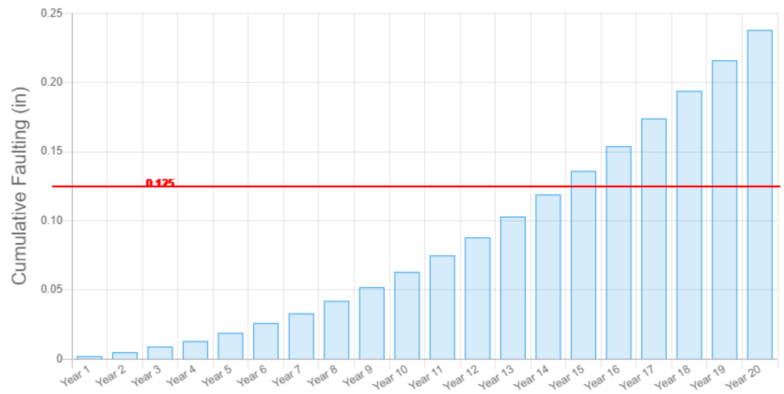
Solved.



Missouri

Performance Analysis

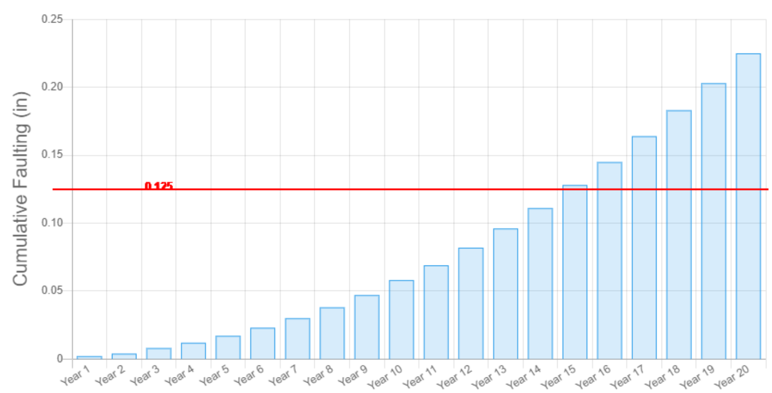
Calculated PCC Overlay Thickness (in)	4.52
Design PCC Overlay Thickness (in)	**4.5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	
	Solved.



New York

Performance Analysis

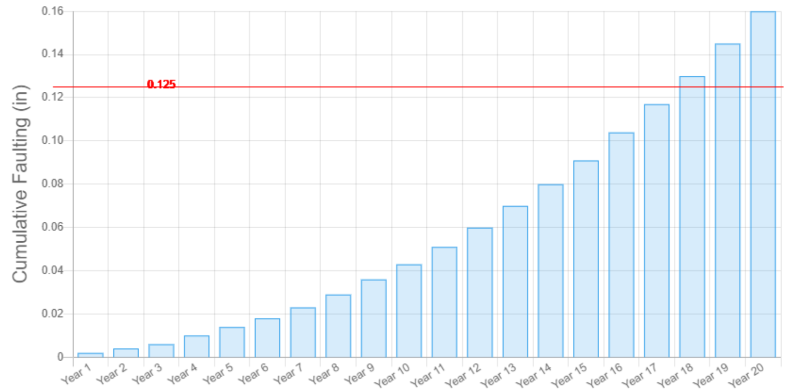
Calculated PCC Overlay Thickness (in)	4.61
Design PCC Overlay Thickness (in)	**4.5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	
	Solved.



North Dakota

Performance Analysis

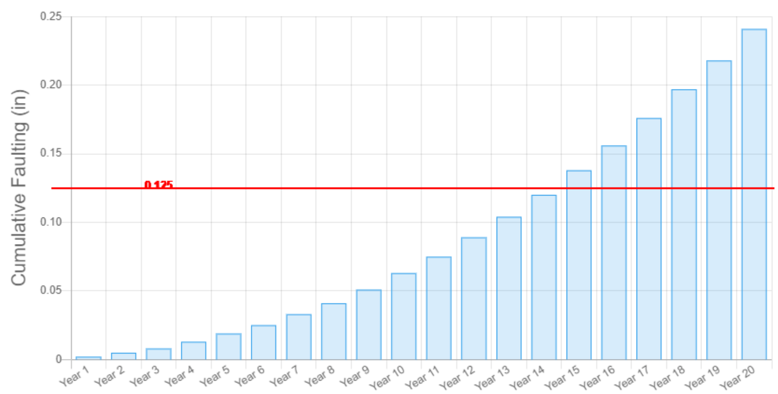
Calculated PCC Overlay Thickness (in)	4.81
Design PCC Overlay Thickness (in)	**5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	
	Solved.



Wisconsin

Performance Analysis

Calculated PCC Overlay Thickness (in)	4.6
Design PCC Overlay Thickness (in)	**4.5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	
	Solved.



Pennsylvania

Performance Analysis

Calculated PCC Overlay Thickness (in)	4.56
Design PCC Overlay Thickness (in)	**4.5**
Is there potential for reflective cracking?	No
Predicted Faulting (in)	
	Solved.