IDAHO TRANSPORTATION DEPARTMENT

RESEARCH REPORT

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RP 268

Calibration of the AASHTOWare Pavement ME Design Software for PCC Pavements in Idaho

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Prepared for

Idaho Transportation Department

Research Program, Contracting Services

Highways Construction and Operations

August 2019

1. Report No. FHWA-ID-19-268	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Calibration of the AASHTOWare Pavement ME Design Software for PCC Pavements in Idaho		5. Report Date August 2019 6. Performing Organization Code 851944 (KLK585)
7. Author(s) Fouad Bayomy, Ahmed Muftah, Emad Kassem, Christopher Williams, Mumtahin Hasnat		8. Performing Organization Report No.
9. Performing Organization Name and Address National Institute for Advanced Transportation Technology University of Idaho 875 Perimeter Drive MS 0901 Moscow, ID 83844-0901		10. Work Unit No. (TRAIS) 11. Contract or Grant No. UI-17-04
12. Sponsoring Agency Name and Address Idaho Transportation Department (SPR) Division of Highways, Resource Center, Research Program PO Box 7129 Boise, ID 83707-7129		13. Type of Report and Period Covered Final Report 09/01/2017 - 8/31/2019 14. Sponsoring Agency Code RP 268
15. Supplementary Notes Project performed in cooperation with the Idaho Transportation Department and the U.S. Department of Transportation, Federal Highway Administration.		

16. Abstract

The performance prediction models incorporated in the AASHTOWare Pavement ME Design (PMED) software are calibrated using data obtained from the Long-Term Pavement Performance (LTPP) program. The nationally calibrated models are to be evaluated to determine whether they accurately predict field performance for local conditions. Otherwise, some pavements will be overdesigned and others under designed, turning to either excessive costs or premature failure. This study aims to evaluate and improve the accuracy of the prediction of the performance of rigid pavements in Idaho using the PMED software. The work done in this project is based on the PMED software version 2.5.3, which was the latest release by AASHTO at the time of this project. The calibration of the performance models of Portland Cement Concrete (PCC) pavements addressed in this study is performed for the transverse slab cracking, joint faulting and International roughness Index (IRI) models for the jointed plain concrete pavements (JPCP). Performance models of the continuous reinforced concrete pavements (CRCP) include Punchout and IRI. It was not possible to evaluate and calibrate the CRCP models due to lack of sites in Idaho. However, few LTPP sites in adjacent states were used to evaluate the CRCP models, but there was not sufficient data to conduct the calibration. For the JPCP calibration, a total of 40 PCC pavement sites were selected across the state of Idaho. These sites represent different climate zones, traffic levels, pavement structures, and materials. The required PMED inputs and the historical performance data for the selected sites were extracted from a variety of sources including project construction data, material testing records, and the ITD Transportation Asset Management System (TAMS). The accuracy of the nationally-calibrated PMED prediction models for Idaho conditions was statistically evaluated. The results showed a difference between the distress prediction and field observation. Therefore, calibrating the PMED models was recommended and the local calibration coefficients was developed. The calibrated models provide better accuracy with less bias and errors.

17. Key Words Mechanistic-empirical pavement design, rigid pavements, pavement performance, local calibration, cracking and faulting.	18. Distribution Statement Copies available online at: ITD Research Program Website		
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 122	22. Price

FHWA Form F 1700.7

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APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					LENGTH		
in	inches	25.4	millimeters	Mm	mm	millimeters	0.039	inches	in
ft	Feet	0.3048	meters	M	m	meters	3.28	feet	ft
yd	yards	0.914	meters	M	m	meters	1.09	yards	yd
mi	miles (statute)	1.61	kilometers	km	km	kilometers	0.621	Miles (statute)	mi
		AREA					AREA		
in^2	square inches	645.2	millimeters squared	cm^2	mm^2	millimeters squared	0.0016	square inches	in^2
ft^2	square feet	0.0929	meters squared	m^2	m^2	meters squared	10.764	square feet	ft^2
yd^2	square yards	0.836	meters squared	m^2	km^2	kilometers squared	0.39	square miles	mi^2
mi^2	square miles	2.59	kilometers squared	km^2	ha	hectares (10,000 m^2)	2.471	acres	ac
ac	Acres	0.4046	hectares	ha					
		MASS (weight)					MASS (weight)		
oz	ounces (avdp)	28.35	grams	g	g	grams	0.0353	ounces (avdp)	oz
lb	pounds (avdp)	0.454	kilograms	kg	kg	kilograms	2.205	pounds (avdp)	lb
T	short tons (2000 lb)	0.907	megagrams	mg	mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME					VOLUME		
fl oz	fluid ounces (US)	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces (US)	fl oz
gal	Gallons (liq)	3.785	liters	liters	liters	liters	0.264	Gallons (liq)	gal
ft^3	cubic feet	0.0283	meters cubed	m^3	m^3	meters cubed	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	meters cubed	m^3	m^3	meters cubed	1.308	cubic yards	yd^3
Note: Volumes greater than 1000 L shall be shown in m^3									
		TEMPERATURE (exact)					TEMPERATURE (exact)		
^oF	Fahrenheit temperature	5/9 (^oF-32)	Celsius temperature	^oC	^oC	Celsius temperature	9/5 ^oC+32	Fahrenheit temperature	^oF
		ILLUMINATION					ILLUMINATION		
fc	foot-candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-lamberts	3.426	candela/m^2	cd/cm^2	cd/cm^2	candela/m^2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS					FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N	N	newtons	0.225	pound-force	lbf
psi	pound-force per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	pound-force per square inch	psi

Acknowledgements

This project is funded by Idaho Transportation Department (ITD). It is performed in cooperation with ITD. The authors would like to acknowledge all members of the project Technical Advisory Committee (TAC) for their valuable feedback and cooperation with all project tasks. The authors also would like to thank many professionals at ITD, especially the District material engineers, for their support and technical assistance in providing project information and performance data for all project sites.

Dr. Chris Williams, head of the Dept. of Statistics at the University of Idaho, served as the statistical consultant and Dr. Linda Pierce, Principal at NCE, Inc., served as the external peer reviewer. She also contributed significantly to the technical editing of the report. The authors greatly appreciate their efforts and timely review.

At last, but not least, the authors thank all administrative staff of NIATT, CEE and OSP at the University of Idaho for their support all throughout the project tasks.

Technical Advisory Committee

Each research project is overseen by a technical advisory committee (TAC), which is led by an ITD project sponsor and project manager. The Technical Advisory Committee (TAC) is responsible for monitoring project progress, reviewing deliverables, ensuring that study objective are met, and facilitating implementation of research recommendations, as appropriate. ITD's Research Program Manager appreciates the work of the following TAC members in guiding this research study.

Project Sponsor – John Bilderback, P.E.

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List of Acronyms

AADTT	Annual Average Daily Truck Traffic
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Standard for Testing and Materials
CC	Cementitious materials content
CRCP	Continuously Reinforced Concrete Pavement
CTE	Coefficient of thermal expansion
E_c	PCC modulus of elasticity
EICM	Enhanced Integrated Climatic Model
ESAL	Equivalent Single Axle Load
f'_c	Compressive strength of PCC
f'_t	Split tensile strength of PCC
FD	Fatigue damage
HMA	Hot Mix Asphalt
IRI	International Roughness Index
ITD	Idaho Transportation Department
JPCP	Jointed Plain Concrete Pavement
LC	Local Calibration
LTPP	Long Term Pavement Performance
MAF	Monthly Adjustment Factor
ME	Mechanistic-empirical
MEPDG	Mechanistic-Empirical Pavement Design Guide
PMED	AASHTOWare Pavement ME Design
MMT	Mean monthly temperature
MR	Modulus of rupture of PCC
NCHRP	National Cooperative Highway Research Program
PCC	Portland Cement Concrete
PMED	AASHTOWare Pavement Mechanistic Empirical Design
Q	Heat capacity of PCC
RH	Relative humidity
RP	Research project
SCM	Supplementary cementitious materials
T_Z	PCC zero-stress temperature
w/cm	Water-to-cementitious materials ratio
ε_∞	Ultimate drying shrinkage
M	Poisson’s ratio of PCC

Executive Summary

Introduction

This report summarizes findings from research conducted for the Idaho Transportation Department (ITD). The research objective was to validate, and potentially calibrate the AASHTOWare Pavement ME Design™ (PMED) rigid pavement performance models to Idaho conditions.

Research Methodology

The AASHTOWare PMED software was developed for the design and analysis of new and rehabilitated pavements based on mechanistic-empirical principles. For the full implementation of the PMED software in Idaho, the University of Idaho in cooperation with ITD conducted several research projects over about ten years to enable the full implementation of the software for both flexible and rigid pavements. The PMED software incorporated pavement performance prediction models that are calibrated based on Long-Term Pavement Performance (LTPP) sites across North America. Hence, they may not necessarily reflected the road conditions in Idaho. For that, it is essential to evaluate the models and conduct local calibration if needed. In 2009, ITD started a major effort toward the implementation of the mechanistic-empirical design approach using the PMED software. The main focus of the implementation was to establish a comprehensive material, traffic, and climatic database for the Mechanistic-Empirical Pavement Design Guide (MEPDG) developed as part of the National Cooperative Highway Research Program Project 01-37A, *Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures*. The MEPDG rudimentary software has been updated and modified and is currently packaged as the AASHTOWare PMED. The research presented in this report is the last phase toward the successful implementation of the PMED based on Idaho conditions.

For the calibration of the Jointed Plain Concrete Pavements (JPCP) in Idaho, forty rigid pavement sections across the state were selected, representing different regions, traffic loads, and structures to evaluate the accuracy of the PMED prediction models to Idaho local conditions. The most recent PMED (v2.5.3), was utilized for this calibration. The calibration and validation of the performance models was conducted per the American Association of State Highway and Transportation Officials (AASHTO) *Guide for the Local Calibration of the Mechanistic-Empirical Pavement Guide* and the *Road Map for Implementing the AASHTO Pavement ME Design Software for the Idaho Transportation Department,* ITD project RP 211A. The statistical comparison between the predicted distress and the observed field measurements indicated the PMED rigid pavement performance models, using the national calibration coefficients, did not reflect Idaho conditions. Therefore, recalibration was recommended and local calibration coefficients were determined. The developed local calibration coefficients and other significant findings are presented in this study.

Key Findings

Performance models of the Jointed Plain Concrete Pavements (JPCP) were calibrated for the local Idaho conditions using PMED software version 2.5.3. The local calibration factors are presented in table 35. Calibration of the performance models of the Continuous Reinforced Concrete Pavements (CRCP) was not possible due to lack of sites and absence of sufficient performance data in Idaho. The following remarks are to be noted:

- The JPCP faulting model with the global calibration coefficients showed lower bias and the null hypothesis was accepted. However, further calibration was performed to improve the prediction accuracy compared to the measured field data. Minor change in the calibration factor C1 of the model was noted.
- The verification of the JPCP transverse cracking model with the global calibration coefficients showed significant amount of bias and Standard Error of Estimate (SEE). There was no clear trend whether the model is over or under predicting cracking. The locally calibrated model produced lower bias and SEE.
- The nationally calibrated JPCP International Roughness Index (IRI) model showed significant bias and local calibration improved the model accuracy.
- The performance prediction models for continuously reinforced concrete pavement (CRCP) were not possible to calibrate due to lack of sites in Idaho and insufficient data. The measured data points were not enough to validate the nationally calibrated models. Therefore, the national calibration coefficients was recommended until more data is available to perform calibration.

Recommendations

- The calibration of performance models is a continuous process. As performance models are revised and the PMED software upgraded, previous calibrations should be revisited and verified before new versions are adopted. As noted, the calibration completed in this research used PMED v2.5.3, which includes the North American Regional Reanalysis “NARR” climatic data for the rigid pavement analysis. A conversion to the Modern Era Retrospective-Analysis for Research and Applications (MERRA) climatic data system is anticipated and may result in significant changes in the prediction models. Therefore, the developed calibration coefficients determined in this study should be verified with future software updates.
- The developed performance databases should be populated with additional years of observations. This will facilitate future calibration especially with the upcoming release of the calibration tool to be released with PMED v2.6.0.
- The JPCP faulting and IRI performance models have reasonable agreement when comparing predicted to field observed results; however, the JPCP transverse cracking showed poor correlation

to observed field results. Thus, further validation for the transverse cracking model is recommended once additional field observed data is obtained.

- It is to be noted that the traffic database, developed under RP 193 research project, is outdated and should be updated with more recent data extracted from the WIM stations across the state. A new traffic database would be recommended for future calibration of the MPED software.

Future Calibration of the PMED

The key factor in any future calibration effort is the performance data over number of years at as many pavement sites as possible. In this study, performance data was accumulated for 40 sites of rigid PCC pavements. Furthermore, performance data was accumulated for close to 60 sites of flexible asphalt pavements under RP 235. In order not to repeat the effort spent in this study in gathering pavement information (construction, materials, traffic and performance data), we created a “Performance Database” for both flexible and rigid pavements using all sites employed in this project as well as those in RP 235. The performance database was included in the form of Excel Books. Furthermore, all PMED run files for all sites have been accumulated in the project folder. Hence, for future calibration, these files shall speed up the calibration process.

Suggested steps for future calibration:

- Update the performance database that are developed for both flexible and rigid pavements with future years’ performance data.
- Update the traffic database with more recent WIM data.
- Use the PMED files to re-run the files with updated performance data.
- If available use the new auto calibration tool in the PMED software (Calibrator)

Chapter 1
Introduction

Background

As part of the National Cooperative Highway Research Program (NCHRP) Project 01-37A, *Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures*, a mechanistic-empirical design procedure was developed for new and rehabilitated pavement structures along with rudimentary software. [2] Upon completion of the NCHRP project in 2004, the American Association of State Highway and Transportation Officials (AASHTO) released the *Guide for Mechanistic-Empirical Pavement Design of New and Rehabilitated Pavement Structures* (MEPDG) and shortly thereafter the complementary software, AASHTOWare Pavement ME Design™ (PMED).[3] The MEPDG has brought a radical change in the design of pavement structures; however, the PMED is an advanced and user friendly pavement design tool. The PMED follows the principles of engineering mechanics to calculate pavement responses (stresses, strains, and deflection), as well as the empirical distress transfer functions to convert pavement response to predicted pavement performance. Nationally calibrated distress and International Roughness Index (IRI) models were developed based on the data primarily contained within the national Long-Term Pavement Performance (LTPP) database. Prior to utilization of the PMED, each agency should evaluate and calibrate, if necessary, the nationally calibrated prediction models to local conditions.[4,Error! Reference source not found.,6,7] Like many State Highway Agencies (SHA), the Idaho T ransportation Department (ITD) is in the process of implementing the PMED for rigid pavements. This study included identifying other SHA activities and lessons learned, and development of a framework for conducting local calibration.

Research Problem Statement

The successful implementation of the PMED in Idaho requires the verification, and if needed, local calibration of the pavement performance models to Idaho conditions. In 2009, ITD initiated major efforts toward the implementation of the PMED. The implementation process started with the ITD research project RP 193 in which a comprehensive material, traffic, and climatic database for the flexible pavements was developed. In 2014, Applied Research Associates (ARA), Inc. completed the ITD project RP 211A and B and developed a roadmap for implementing PMED in Idaho and developed a software user's guide (for PMED v1.1). A key outcome from the roadmap was the need to develop local calibration factors for Idaho for both flexible and rigid pavements. The calibration process for flexible pavements has been completed under ITD project RP 235.

To proceed with the calibration process for rigid pavements, the research team needed to first develop a Portland cement concrete (PCC) material database, which was completed under ITD project RP253. At this time, the last phase of the PMED implementation is to calibrate the rigid pavement performance prediction models to reflect Idaho local conditions.

Research Objective and Project Tasks

The main objective of this project is to improve the accuracy of the PMED performance predictions for Idaho rigid pavements through local calibration. In order to achieve the project's main objective, the following tasks were conducted:

Task 1: Review of the distress prediction models for rigid pavements in the ME software

The PMED includes three main performance models for jointed plain concrete pavements (JPCP). These are transverse slab cracking, transverse joint faulting, and smoothness (as represented by the International Roughness Index [IRI]) models. Furthermore, the software includes an additional model for continuously reinforced concrete pavement (CRCP) punchouts. In this task, the team will review the PCC performance models in the latest version of the software, and identify the design input parameters required by these models. A summary of the review will be submitted at the end of the tasks 1 and 2 (Deliverable #1).

Task 2: Evaluate the inputs required for the design of new rigid pavement systems

The work in task one led to the identification of all required design inputs that need to be evaluated including materials, climate, traffic and pavement types doweled or undoweled. These parameters will be summarized and included in the review report submitted as part of Deliverable #1.

Task 3: Identify LTPP rigid pavement sites for calibration process

As per the AASHTO *Guide for the Local Calibration of the Mechanistic-Empirical Pavement Guide*[7], and the roadmap developed by ARA, we need to have at least 20 pavement segments to cover the different tiers of the sampling matrix. The matrix variables include type of joints (doweled or undoweled), truck traffic volume, and new as well as rehabilitated pavements. In addition, sites need to reflect the type of subgrade soil and base materials. The data required to be collected at these sites shall include as built design conditions, which are expected to be available from the ITD Phase Reports. Missing data may be completed by drilled cores or from historical files if available. To make sure all climatic regions are represented, the team will try to include, as a minimum, two sites from each geographical area. Full cooperation with state material/District engineers will be essential for this task.

Task 4: Develop a performance database required for the ME calibration

The key performance data shall be procured from Transportation Asset Management System (TAMS) database as well as video logs that are available at ITD. For LTPP sites, the data can be downloaded from the LTPP Infopave.fhwa.dot.gov website.

Upon the identification of the rigid pavements sections across the state (Task 3), the team procure all performance data from TAMS and develop the additional needed information from the video logs. The video logs will be essential to aid in transferring the descriptive and subjective performance information into performance indicators as defined in the PMED. For example, the PMED presents transverse slab cracking by percent of cracked slabs. But, TAMS provides this information as Low, medium and high severity levels. In this regard, the video logs will be necessary to obtain this type of information. All the collected information will be tabulated in a performance database (Microsoft Excel files). This will not only facilitate the calibration process, but will provide a wealth of information that could be used in the future when the calibration process is to be updated as recommended by the AASHTOWare developing team.

Task 5: Run the ME software

At a start, run the software using the nationally calibrated models, with the assembled database and compare the predicted performance (using the nationally calibrated factors) with Idaho's field measured performance. This will help assess the precision and bias in the design recommendations of the nationally calibrated performance models, and assess the need for the local calibration.

Task 6: Develop Idaho Calibration factors

This task will involve running the PMED for each selected pavement site with many trials. In each trial, the regional calibration factors will be changed to increase precision and minimize the bias between the predicted and the measured performance. This process will be done for all recruited pavement segments and for each distress model. Depending on how many sites are recruited, obtain performance data under Tasks 3 and 4, leaving a few sites for validation. In addition, utilize the Idaho LTPP sites to validate the calibration process. Other LTPP rigid pavement sites from adjacent states could also be used in the validation process. Depending on the total number of sites, the team may use the jackknifing method for validation. The jackknife estimator of a parameter is found by systematically leaving out each observation from a dataset and calculating the estimate and then finding the average of these calculations. Given a sample of size n, the jackknife estimate is found by aggregating the estimates of each n-1 sized sub-sample.

Upon completing the calibration for the distress models, the process will be repeated for the IRI model. That is because IRI model includes other predicted distress parameters (cracking and faulting). Hence, the distress models must be calibrated first.

Task 7: Develop implementation guidelines and training workshop for ITD engineers

This workshop will be developed in parallel with the preparation of the final report. The workshop is intended to have hands-on practice for ITD engineers. The workshop document will included a brief guide to enable the use of the PMED with the developed database and the regional calibration factors.

Task 8: Prepare final report

Draft Final Report will be developed and peer reviewed by a technical expert approved by ITD's Project Manager. A copy of the review comments and a summary of changes made to address the peer reviewer's comments will be submitted with the draft. The draft will also be reviewed by report editor prior to initial submission to ITD. The final report addressing ITD/FHWA review comments will be submitted at the conclusion of the project. The report will be consistent with ITD style requirements.

Report Organization

This report is organized in six chapters as described below:

Chapter 1 provides the introduction of this research project, presents the problem statement, research objectives, and project description.

Chapter 2 presents a literature review of the PMED distress prediction models for rigid pavements and summarizes PMED implementation processes for several State Highway Agencies (SHAs).

Chapter 3 presents the sensitivity of each input and evaluates its effect on performance prediction.

Chapter 4 presents the local calibration process, results, and analysis of the developed Idaho calibration factors.

Chapter 5 presents the validation process for local calibration.

Finally, **chapter 6** summarizes the key findings from this research and presents recommendations for ITD consideration.

Chapter 2
Review of Distress Prediction Models for Rigid Pavements

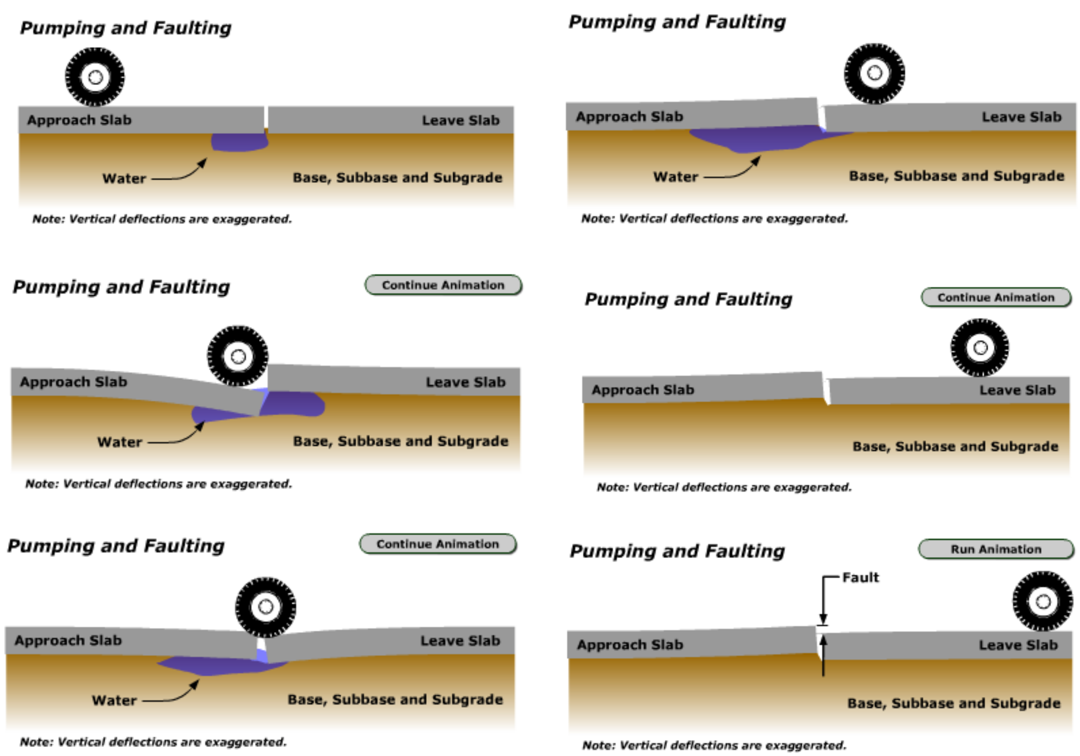
The literature review conducted as part of this study focused on the following three areas:

- Distress performance indicators for the PCC pavements including Joined Plain Concrete Pavements (JPCP) and Continuous Reinforced Concrete Pavements (CRCP).
- Performance prediction models included in the PMED.
- Implementation efforts by other state highway agencies.

Distress Performance Indicators

Mean Transverse in Joint Faulting in Joined Plain Concrete Pavements (JPCP)

Transverse joint faulting is one of three JPCP distress types predicted in the PMED. Faulting is the difference in elevation between adjacent slabs at a transverse joint or on either side of a transverse crack. Faulting occurs due to a combination of insufficient load transfer between adjacent slabs, moving heavy axle loads, and erodible base or subgrade material. Erosion occurs due to pumping action at the joint and is caused by the movement of fine material in the saturated base or subgrade. Pumping and faulting are further illustrated in Figure 1.[5,6,7]



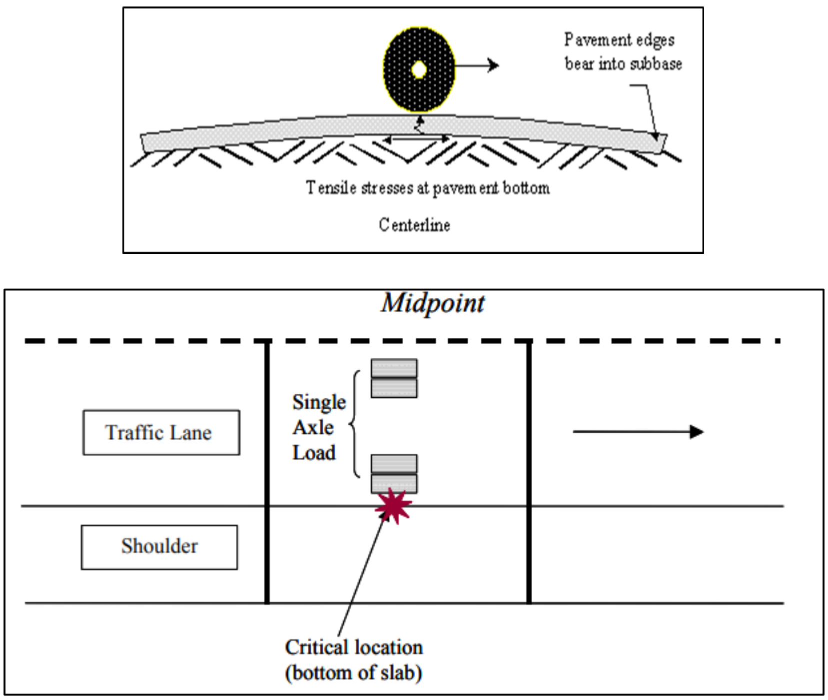
*Source: http://www.pavementinteractive.org/article/faulting/

Figure 1 Deflected Pavement Shape for Joint Faulting

Bottom-Up Transverse Cracking in Joined Plain Concrete Pavements (JPCP)

Transverse cracking can be triggered either at the bottom or top of the slab depending on the loading and climatic conditions. Since damage accumulation is different, the PMED computes bottom-up and top-down cracking separately.

For bottom-up cracking, a critical tensile bending stress takes place at the bottom of the slab when the truck axles are midway between the transverse joints and near the longitudinal joint edge (Figure 2). This stress progresses significantly when the top of the slab is warmer than the bottom, where the fatigue damage starts to accumulate more rapidly with repeated loadings of heavy axles under those conditions. This results in transverse cracks that propagate from the bottom of the slab to the surface of the pavement. The PMED calculates bottom-up transverse cracking as a percent of the total number of cracked slabs.

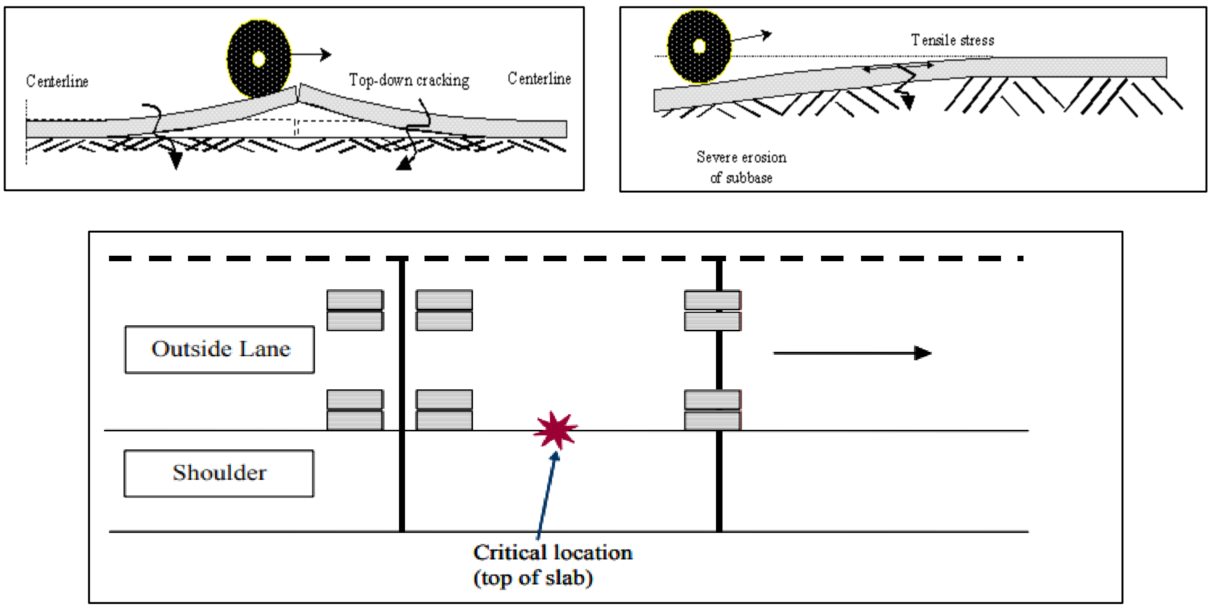


Source: *AASHTO Guide for Design of Pavement Structures* [7]

Figure 2 Critical Load and Structural Response Location for JPCP Bottom-up Transverse Cracking

Top-Down Transverse Cracking in Joined Plain Concrete Pavements (JPCP)

For top-down cracking, fatigue damage occurs at the top of the slab when it is exposed to repeated heavy truck loading with certain axle spacing as presented in Figures 3 and 4. The critical wheel loading occurs with the instantaneous application of two set of axles at opposite ends of a slab. With a high-negative temperature gradient (top of the slab is cooler than the bottom), a high tensile stress at the top of the slab starts to develop, and it becomes critical when a significant amount of curling is present. This will eventually trigger a transverse cracking at the surface and propagate downward to the bottom of the slab. This form of loading frequently shows up with the combination of steering and drive axles of truck tractors and other vehicles. Several trailers with reasonably short trailer-to-trailer axle spacing are other common causes of critical loadings for top-down cracking. Critical tensile stress can also occurs at the top of the slab when the subgrade is severely eroded. The loss of support at the transverse edge and with the application of heavy loads, top down cracking can occur. Top-down transverse cracking is predicted by PMED as a percent of the total number of cracked slabs.



Source: AASHTO *Guide for the Local Calibration of the Mechanistic-Empirical Pavement Design Guide* [8]

Figure 3 Critical Load and Structural Response Location for JPCP Top-down Transverse Cracking

Source: FHWA Distress Identification Manual

Figure 4 Transverse cracking in JPCP

The PMED output is a combination of the slabs with bottom-up and top-down transverse cracks.[6,7]

Punchouts in Continuous Reinforced Concrete Pavements (CRCP)

Punchouts is a type of distress that appears between two closely spaced transverse cracks (Figure 5). The mechanism starts with micro cracks initiating at a transverse crack and propagating perpendicularly to an adjacent transverse cracks. Punchouts occur due to high-tensile stress at the top of the slab as truck axles pass near the longitudinal edge of the slab. This stress increases significantly when there is a loss of support along the edge of the slab or loss of load transfer across the transverse cracks. The prediction of punchouts involves several factors such as, erosion along the edge of the slab, loss of crack load transfer efficiency over the design life, effects of transitory and permanent moisture, and temperature gradients. The PMED punchout model includes only medium and high severity punchouts as defined in the LTPP *Distress Identification Manual*. The PMED predicts the number of punchouts per lane mile.[6,7,8]

Figure 5 Edge Punch-out in CRCP

Review of Performance Prediction Models in the PMED for Rigid Pavements

The following briefly describes the PMED rigid pavement performance prediction models.(6,8,12)

Transverse Slab Cracking Model for Jointed Plain Concrete Pavement (JPCP)

The PMED model for transverse cracking:

$$TCRACK = \left(CRK_{bottom-up} + CRK_{Top-down} - CRK_{bottom-up} \cdot CRK_{Top-down}\right) \cdot 100$$

$$Crack = \frac{100^{log(N_{allowable})}}{1 + \mathbf{C4} \cdot FD^{\mathbf{C5}}} = \frac{100^{\mathbf{C1}\left(\frac{MR}{\sigma}\right)^{\mathbf{C2}}}}{1 + \mathbf{C4} \cdot \left(\frac{N_{applied}}{N_{allowable}}\right)^{\mathbf{C5}}}$$

where:

$TCRACK$ = Total transverse cracking (percent, all severities);
$CRK_{Bottom\text{-}up}$ = Predicted amount of bottom-up transverse cracking;
$CRK_{Top\text{-}down}$ = Predicted amount of top-down transverse cracking;
CRK = predicted amount of bottom-up and top-down cracking (fraction);
DI_F = fatigue damage which is calculated by the following model.
C_1, C_2 = Calibration coefficient constants, default C_1 = 2.0, C_2 = 1.22
C_4, C_5 = Coefficients, default C_4 = 1.0, C_5 = -1.98
$N_{i,j,k,l,m,n}$ = Allowable number of load applications at condition i, j, k, l, m, n;
MR_i = PCC modulus of rupture at age i, psi
$\sigma_{i,k,l,m,n}$ = Applied stress at condition i, j, k, l, m, n;

Figure 6 JPCP Transverse Slab Cracking Equations

Joint Faulting Model for JPCP

Joint faulting is predicted using a monthly incremental approach in the PMED. Equation 3 through 6 presents the models used in PMED to predict joint faulting.

$$Fault_m = \sum_{i=1}^{m} \Delta Fault_i$$

$$\Delta Fault_i = (\mathbf{F3} + \mathbf{F4} \cdot FR^{0.25}) \cdot (FaultMax_{i-1} - Fault_{i-1})^2 DE_i$$

$$FaultMax_i = FaultMax_0 + \mathbf{F7} \sum_{k=1}^{i} DE_k \cdot \log(1 + \mathbf{F5} \cdot 5^{EROD})^{\mathbf{F6}}$$

$$FaultMax_0 = (\mathbf{F1} + \mathbf{F2} \cdot FR^{0.25})\delta_{curing} \left[\log(1 + \mathbf{F5} \cdot 5^{EROD}) \cdot Log(\frac{P_{200} \cdot WetDays}{P_s}\right]^{\mathbf{F6}}$$

where:

$Fault_m$ = Mean joint faulting at the end of month m, in;
$\Delta Fault_i$ = Incremental change (monthly) in joint faulting during month *i,* in;
$FAULTMAX_i$ = Maximum mean transverse joint faulting for month *i*, in;
$FAULTMAX_0$ = Initial maximum mean transverse joint faulting, in;
EROD = Base/ subbase erodibility factor;
DE_i = Differential density of energy of subgrade deformation accumulated during month,*i*;
$\delta_{curling}$ = Maximum mean monthly slab corner upward deflection PCC due to temperature curling and moisture warping;
P_s = Overburden on subgrade, lb;
P_{200} = Percent subgrade material passing #200 sieve;
WetDays = Average annual number of wet days (greater than 0.1 in. rainfall);
$F_{1,2,3,4,5,6,7}$ = National calibration constants, default **F1** = 1.29, **F2** = 1.1, **F3** = 0.001725, **F4** = 0.0008, **F5** = 250, **F6** = 0.4, **F7** = 1.2, C12 = C1 + C2 * $FR^{0.25}$, C34 = C3 + C4 * $FR^{0.25}$

FR = Base freezing index defined as percentage of time the tip base temperature is below freezing (32°F) temperature.

Figure 7 JPCP Joint Faulting Equations

International Roughness Index (IRI) Prediction Model for JPCP

The PMED estimates IRI based on the prediction of other distresses including site factor and spalling. Equation 7 is used to predict IRI in PMED.[6,7]

$$IRI = IRI_0 + \boldsymbol{R}1 \cdot Crack + \boldsymbol{R2} \cdot Spall + \boldsymbol{R3} \cdot Fault + \boldsymbol{R4} \cdot SiteFactor$$

Where:

IRI = Predicted IRI, in./mi,
IRI_o = Initial smoothness measured as IRI, in./mi,
CRK = Percent slabs with transverse cracks (all severities),
SPALL = Percentage of joints with spalling (medium and high severities),
TFAULT = Total joint faulting cumulated per mi, in., and
R1 = 0.8203, **R2** = 0.4417, **R3** = 0.4929, **R4** = 25.24
$SF = AGE\ (1 + 0.5556 * FI)\ (1+P_{200}) * 10^{-6}$
SF = site factor
AGE = Pavement age, year;
FI = Freezing index, °F-days, and
P_{200} = Percent subgrade material passing No. 200 sieve

$$SPALL = \left(\frac{AGE}{AGE+0.01}\right)\left(\frac{100}{1+1.005^{-12 * AGE + SCF}}\right)$$

where:

SPALL = Percentage joints spalled (medium-and high-severities),
AGE = Pavement age since construction, year, and
$SCF = -1400 + 350\ AC_{PCC}\ (0.5 + PREFORM) + 3.4\ f'c \cdot 0.4 - 0.2(FT_{cycles} \cdot AGE) + 43\ H_{PCC} - 536\ WC_{PCC}$
AC_{PCC} = PCC air content, %,
AGE = Time since construction, year,
PREFORM = 1 if preformed sealant is present; 0 if not,
f'c = PCC compressive strength, psi,
FT_{cycles} = Average annual number of freeze-thaw cycles,
H_{PCC} = PCC slab thickness, in., and
WC_{PCC} = PCC w/c ratio. (Inc., 2004)

Figure 8 JPCP IRI Equations

Punchout Model for Continuous Reinforced Concrete Pavement (CRCP)

Punchout prediction is a function of accumulated fatigue damage due to top-down stresses in the transverse direction and is determined using Equation 8.

$$PO = \frac{\boldsymbol{A_{PO}}}{1 + \boldsymbol{\alpha_{PO}} \cdot DI_{PO}^{\boldsymbol{\beta_{PO}}}}$$

where,

PO = Total predicted number of medium and high severity of Punchouts/mi,

DI_{PO} = Accumulated fatigue damage (due to slab bending in the transverse direction) at the end of y^{th} yr, and

$A_{PO}, \alpha_{PO}, \beta_{PO}$ = Calibration constants (195.789, 19.8947, -0.526316, respectively)

Figure 9 CRCP Punchout Equation

IRI Prediction Model for CRCP

Similar to JPCP, IRI prediction for CRCP is based on the initial roughness index, distresses associated to loading applications from traffic, and a site factor (Equation 9). This model was calibrated and validated using LTPP database that included a wide range of design features, traffic, material characteristics, and climatic conditions.[7]

$$IRI = IRI_I + C_1 \cdot PO + C_2 \cdot SF$$

where,

IRI_I = Initial IRI, in./mi,

PO = Number of medium and high severity of punchouts/mi,

C_1 = 3.15, C_2 = 28.35 and

$SF = AGE \cdot (1 + 0.5556 * FI) \cdot (1 + P_{200}) * 10^{-6}$

AGE = Pavement age, year;

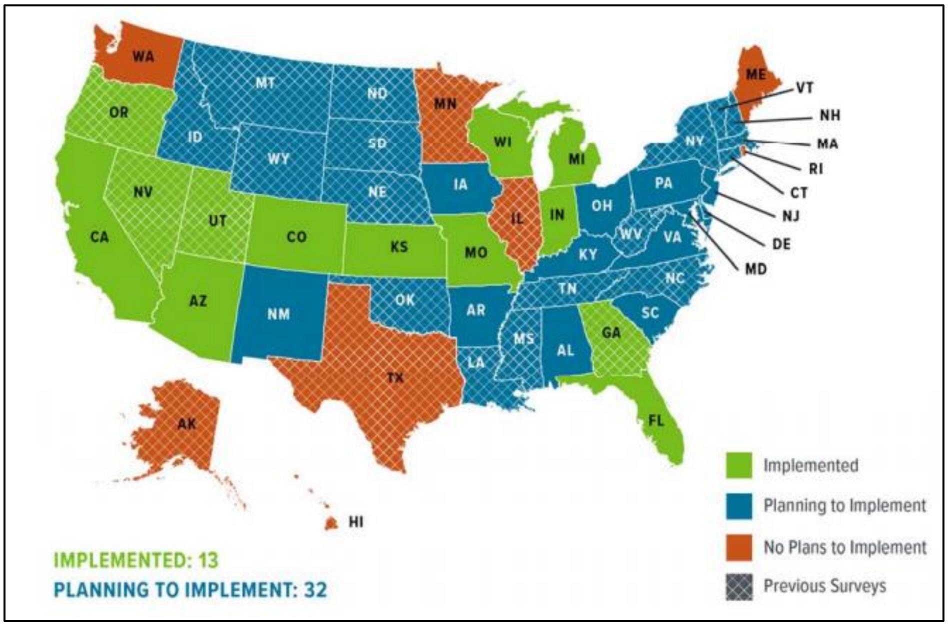
FI = Freezing index, °F-days, and

P_{200} = Percent subgrade material passing No. 200 sieve

Figure 10 CRCP IRI Prediction Equation

Review of State Highway Agency Implementation Efforts

A recent survey conducted of the AASHTO Pavement ME National User Group, shows that among 25 SHA, 9 SHAs have implemented the PMED, while 3 SHAs have no plans to the implement the PMED. The remaining SHAs are in the process or will be calibrating and implementing the PMED within the next five years.[10] Figure 11 presents the most recent status of PMED implementation in the U.S.



Source: FHWA *Technical Report: First Annual Meeting – Indianapolis* [10]

Figure 11 Summary of Agency MEPDG Implementation Status

The following provides a review of SHA PMED implementation efforts. The purpose of this review is to learn what activities need to be performed to overcome the challenges in the local calibration and successfully implement the PMED in Idaho.

Arizona

Arizona DOT's PMED implementation plan was completed in 2014. The study considered 48 JPCP sections and only 2 CRCP sections.[14] The project was designed to evaluate the nationally calibrated models to Arizona conditions, and if needed, local calibration. Researchers used 90 Percent of the selected projects for the calibration effort and the remaining 10 Percent were used in the validation process. The researchers verified all the distress models and IRI according to goodness of fit and bias. The results indicate under prediction of transverse cracking and yielded poor goodness of fit with bias. Figure 12 shows predicted vs. measured percent cracked slab using the nationally calibrated model.[14)]

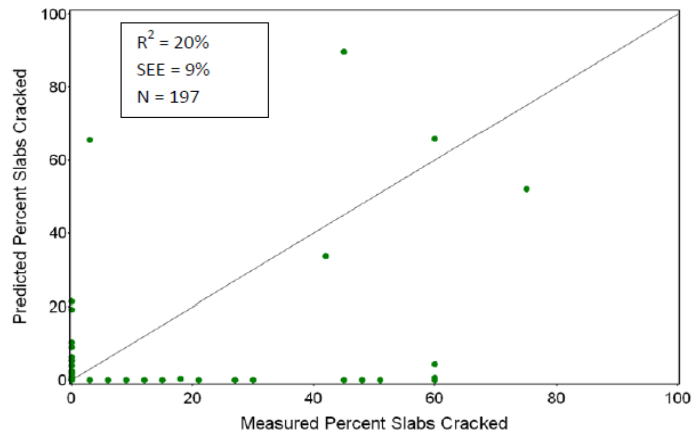


Figure 12 Predicted versus Measured JPCP Transverse Cracking using National Calibration Coefficients—Arizona

The transverse cracking prediction model for JPCP constructed over cement-treated base/lean concrete base was found to be unsuitable for Arizona due to the early loss of bond. As a result, the local calibration of transverse cracking model for JPCP sections placed above lean concrete base was modified for loss of friction to occur at age 0. Table 1 and Figure 13 represent the statistical results for the nationally calibrated JPCP transverse cracking model.

Table 1 Goodness of Fit and Bias Test Statistics for Nationally Calibrated JPCP Transverse Cracking Model—Arizona

Model Types	Model Coefficients	NCHRP 20-07 National Model (Using 100% of Projects)
PCC fatigue allowable N model	C1	2
PCC fatigue allowable N model	C2	1.22
PCC fatigue allowable N model	C4	0.19
JPCP transverse cracking model	C5	-2.067

Goodness of Fit: R2 = 72.8%, SEE = 7.25%, N = 198. **Bias Test:** H0: Slope = 1.0 (p-value = 0.8840) H0: Predicted and measured cracking from the same population (paired t test) (p-value = 0.0504)

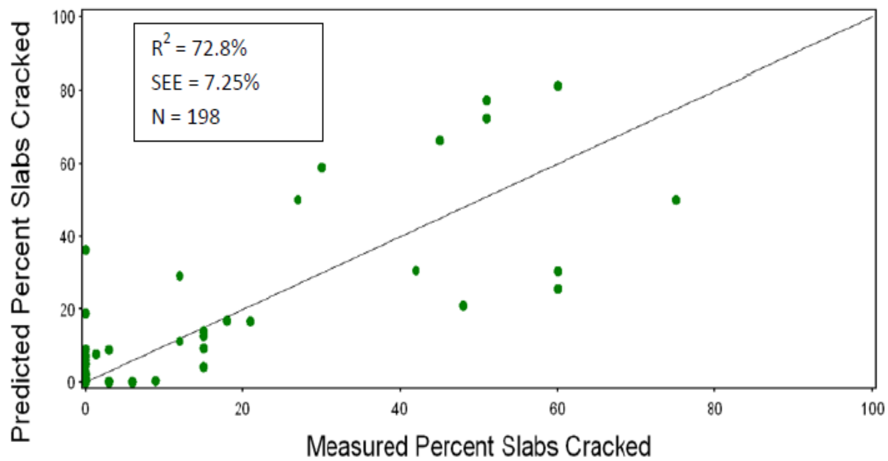


Figure 13 Predicted versus Measured JPCP Transverse Cracking (All Base Course Types)—Arizona

To verify the PMED joint faulting model, researchers determined the goodness of fit using all projects. Even though they found fair goodness of fit, the predictions of the model were biased; however, there were no obvious causes for this bias. The nationally calibrated IRI model over predicted smoothness; therefore, it was determined that local calibration was required. The local calibrated model showed better prediction with higher R^2 and lower bias. Table 2 summarize the local calibration coefficients for Arizona local condition.(14)

Table 2 Summary of the Local Calibration Coefficients—Arizona

Model Type	Model Coefficients	Nationally Calibration Coefficient	ADOT Local Calibration (using 100% of Projects)
PCC fatigue Model	C1	2	2*
PCC fatigue Model	C2	1.22	1.22*
JPCP transverse cracking model	C4	1	0.19
JPCP transverse cracking model	C5	-1.98	-2.067
Joint Faulting	C1	1.0184	0.0355
Joint Faulting	C2	0.91656	0.1147
Joint Faulting	C3	0.0021848	0.00436
Joint Faulting	C4	0.0008837	1.1E-07
Joint Faulting	C5	250	20000
Joint Faulting	C6	0.4	2.0389
Joint Faulting	C7	1.83312	0.1890
Joint Faulting	C8	400	400
IRI/Smoothness	J1 (CRK)	0.8203	0.60
IRI/Smoothness	J2 (SPALL)	0.4417	3.48
IRI/Smoothness	J3 (FLT)	1.4929	1.22
IRI/Smoothness	J4 (SF)	25.24	45.20

*Calibration factors could be modified but since this is based on substantial field testing data, changing these coefficients is not recommended.

For CRCP, researchers performed local calibration of the punchout and IRI models. They found the nationally calibrated prediction models provide reasonable results for Arizona-specific data inputs; therefore, local calibration was not required.

Table 3 summarizes the PMED nationally calibrated and Arizona local calibration results for both JPCP and CRCP.

Table 3 Comparison of National and Local Calibration Goodness of Fit Statistics—Arizona

Pavement Type	Distress/IRI Models	Nationally Calibrated Models R^2 (%)*	Nationally Calibrated Models SEE*	Locally Calibrated Models R^2 (%)	Locally Calibrated Models SEE
New JPCP	Transverse cracking	20	9%	78	6%
New JPCP	Transverse joint faulting	45	0.03 inch	52	0.03 inch
New JPCP	IRI	35	25 in/mi	81	10 in/mi
New CRCP	Punchouts	68%	5/mi	68%	5/mi
New CRCP	Slab/base friction	Established values	N/A	Established values	N/A

*National calibration coefficients using the Arizona database.

Colorado

Colorado DOT conducted a series of research projects to implement the PMED for use in daily pavement design, rehabilitation, evaluation, and forensic analysis practices.[15] The PMED calibration effort was completed in 2013 using projects from both the LTPP and Colorado DOT database. It should be noted this analysis was conducted using an early version of the PMED (formerly DARWin-ME).

The researchers found a limited presence of transverse cracking and joint faulting on Colorado JPCPs. Since most of the measured cracking and joint faulting values are approximately zero, traditional statistical analysis was not possible for verifying the PMED nationally calibrated prediction models to Colorado conditions. Therefore, a non-statistical analysis approach was used. After verification, the nationally calibrated coefficients for both models showed reasonable relation between predicted and measured values. The same trend was found in the JPCP smoothness prediction model. The evaluation using goodness of fit showed no significant difference between the measured and predicted values. For this reason, local calibration for Colorado conditions was not required.

Florida

Florida DOT conducted local calibration using an earlier version of the PMED (MEPDG v1.0).[16] The main objective, in addition to local calibration, was to develop a database and establish typical thickness design tables. Researchers, using the nationally calibrated models, found the PMED under predicts IRI and joint faulting; however, the transverse cracking was reasonably well predicted. A sensitivity analysis was conducted and revealed that C1 and C3 have a significant influence on transverse joint faulting and subsequently, IRI. Therefore, the calibration effort involved only adjusting these two factors. Table 4 summarizes the locally calibrated coefficients for joint faulting and IRI respectively.

Table 4 Comparison of National and Local Calibrated Model—Florida

Distress/Smoothness Model	Previous Calibration Coefficient	Calibrated Coefficient
Joint faulting (C1)	1.0184	2.00
IRI (C3)	1.4929	2.5

Iowa

In 2012, the Iowa DOT conducted a study to compare software versions (MEPDG v1.1 and PMED v1.1) to identify if there are any differences in magnitudes or trends of performance predictions. A total of 35 sections were selected, 70 Percent of these sections were utilized to identify the local calibration factors, and 30 Percent were withheld for validation. Calibration was conducted following the *Local Calibration Guide*.

The comparison results showed no significant difference in the JPCP transverse cracking and faulting predictions. However, there was a difference in the smoothness predictions. The researchers clarified the IRI models in both versions include an empirical relationship consisting of joint faulting, transverse cracking, and site conditions. Since joint faulting and transverse cracking predictions are comparable in both versions, the difference could be linked to the site conditions (e.g., number of freezing cycles and freezing index). Noting that the XML climate file in the PMED has extra hourly climate data points as compared to the climate data found in the MEPDG. Though, using the locally calibrated IRI model, the difference in IRI predictions is minimized by adjusting the coefficient associated with the site factor, reducing the national calibration factor from 25.24 to 1.17 for the local calibration factor. Table 5 summarizes the prediction comparison for the MEPDG and PMED.(17)

Table 5 MEPDG and PMED Comparison of JPCP Distress Prediction—Iowa

AADTT	Reliability (%)	Distress	National MEPDG 1.1	National PMED 1.1	Local MEPDG 1.1	Local PMED 1.1
1000	50	IRI (m/km)	1.48	1.06	1.03	1.01
1000	50	Transverse Cracking (% slabs)	0.0	0.0	0.0	0.0
1000	50	Faulting (mm)	0.03	0.02	0.61	0.64
1000	90	IRI (m/km)	2.09	1.49	1.40	1.36
1000	90	Tran. Cracking (% slabs)	4.5	4.5	3.8	3.8
1000	90	Faulting (mm)	0.53	0.51	1.50	1.53
5000	50	IRI (m/km)	1.53	1.12	1.10	1.08
5000	50	Tran. Cracking (% slabs)	0.7	0.7	0.1	0.1
5000	50	Faulting (mm)	0.15	0.14	5.11	5.16
5000	90	IRI (m/km)	2.18	1.59	1.51	1.47
5000	90	Tran. Cracking (% slabs)	6.6	6.6	4.6	4.6
5000	90	Faulting (mm)	0.81	0.76	6.86	6.91

The calibration results showed the models, using the national calibration factors, overestimate both transverse cracking and IRI. On the other hand, the nationally calibrated joint faulting model underestimated faulting as compared to field results. All models were locally calibrated. Table 6 provides a summary of the local calibration coefficients.

Table 6 Summary of Calibration Coefficients for JPCP Performance Predictions—Iowa

Distress	Factors	National	Local
Faulting	C1	1.0184	2.0427
Faulting	C2	0.91656	1.83839
Faulting	C3	0.0021848	0.0043822
Faulting	C4	0.0008837	0.001772563
Faulting	C5	250	250
Faulting	C6	0.4	0.8
Faulting	C7	1.83312	1.83312
Faulting	C8	400	400
Fatigue for Cracking	C1	2	2.17
Fatigue for Cracking	C2	1.22	1.32
Cracking	C4	1	1.08
Cracking	C5	-1.98	-1.81
IRI	C1	0.8203	0.04
IRI	C2	0.4417	0.02
IRI	C3	1.4929	0.07
IRI	C4	25.24	1.17

Kansas

Kansas DOT is also moving toward the implementation of the PMED. Local calibration for rigid pavements in Kansas was conducted in 2015.(18) In this study, PMED v1.3 was used. A total of 32 rigid pavement projects, representing different materials, traffic loading, and environmental conditions were included in this study. Projects were grouped according to the type of chemically stabilized base course. Various performance data were collected from KDOTs pavement management database (no forensic investigation to confirm input values was conducted). This study only considered joint faulting and IRI. The traditional splitting data method was used to determine local calibration coefficients. Researchers used JPCP sections with CTB (cement treated base) and DBWED (drainage base with edge drains) for local calibration and DCTB (drainable cement treated base) sections for validation of the locally calibrated model. The simulation runs revealed that the nationally calibrated models over predict joint faulting and under predict IRI. The developed local calibration factors significantly eliminated the bias and reduced the standard error of the estimate (SEE). The researchers noted that the joint faulting was not influenced by different types of base layer. Table 7 summarizes the local calibration coefficients.

Table 7 Summary of Local Calibrated Coefficients in the Traditional Splitting Data Method—Kansas

Source: Kansas DOT Final Report KS-14-17, April 2015. [18)]

Mean Transverse Joint Faulting Local Calibration Factors C3	Mean Transverse Joint Faulting Local Calibration Factors C6	Mean Transverse Joint Faulting Local Calibration Factors C7	IRI Model Local Calibration Factors J3	IRI Model Local Calibration Factors J4
0.00164	0.15	0.01	9.38	70

Louisiana

Local calibration for the Louisiana Department of Transportation and Development (DOTD) was important due to lack of LTPP sections in the national calibration effort. In total, 19 projects, consisting of PCC over unbound base and PCC over hot mix asphalt (HMA) pavement, were selected for evaluation of the PMED v1.3. [(19)] Projects included nine Interstate sections, eight U.S. highway sections, and two Louisiana highway sections. It was found that the PMED over predicted transverse cracking; however, underestimated joint faulting. The IRI prediction match well for PCC sections over unbound base, but not well for PCC sections over HMA pavement. Therefore, local calibration was needed.

The local calibration process mainly focused on adjusting C1 for transverse cracking and C6 for joint faulting. The locally calibrated models, using C1 = 2.6 and C6 = 1.2, showed better performance prediction for both types of pavements used in this research study. Additionally, researcher's compared PCC thickness as determined from the PMED and the AASHTO 1993 Guide. They found that the locally calibrated PMED results in thinner or equal PCC thickness as compared to 1993 Guide. However, the researchers noted that both longitudinal and corner cracking have been observed on some of the concrete pavement sections, although only transverse cracking was considered in the analysis (per software definition). To better match the load-related fatigue cracking for rigid pavement, future development of longitudinal cracking appears to be necessary.

Minnesota

Minnesota has adapted the PMED for the design of low-volume concrete pavements. The calibration was completed using MEPDG v0.910.[(20)] Low-volume PCC pavements in Minnesota are designed to carry average daily traffic from several hundred to nearly 35,000 vehicles per day. The pavement thicknesses vary from 6 to 9 inches, with a minimum compressive strength of 3,900 psi at 28 days. PCC joint spacing ranges from 10 to 27 feet, and both perpendicular and skewed transverse joints were used.

A total of 65 pavement sections located in Minnesota, Iowa, Wisconsin, and Illinois were used to perform local calibration. The results showed the faulting model produces satisfactory predictions. Conversely, the transverse cracking model did not provide accurate predictions, requiring local calibration. All roadway sections with 5-inch-thick PCC layer were excluded for the analyses since earlier versions (MEPDG v0.850 and later) were unable to analyze slab thickness less than 6 inches.

Comparison of several MEPDG versions was conducted. MEPDG v0.868 was observed to produce predicted cracking results close to the measured values. Table 8 summarizes predicted vs. measured faulting and cracking values for both MEPDG v0.850 and v0.868.[20]

Table 8 Summary of Predicted and Measured Faulting and Cracking—Minnesota

Cell No.	Project Name	Analysis Period, Years	Total Faulting (in.) Predicted by MEPDG 0.850	Total Faulting (in.) Predicted by MEPDG 0.868	Total measured Faulting (in.)	Total % of Cracked Slabs Predicted by MEPDG 0.850	Total % of Cracked Slabs Predicted by MEPDG 0.868	Total % of measured Cracked Slabs
36	IM36-1	10	0.001	0.002	0.02	56.6	1.4	0
36	IM36-2	10	0.004	0.002	0.04	78.5	10.9	0
37	IM37_1	10	0.036	0.027	0.02	5.2	0.1	0
37	IM37_2	10	0.042	0.031	0	22.5	1	0
38	IM38_1	10	0.001	0.001	0	51.8	14.6	0
38	IM38_2	10	0.001	0.001	0.01	81.3	65.5	0
39	IM39_1	10	0.002	0.001	0.04	67.3	38.8	0
39	IM39_2	10	0.002	0.001	0	87.7	82.4	0
40	IM40-6.3-1	10	0.064	0.03	0.05	54.3	16.2	0
40	IM40-6.3-2	10	0.074	0.037	0	82.7	68	0
40	IM40-7.6-1	10	0.044	0.021	0.05	8.9	0.4	0
40	IM40-7.6-2	10	0.052	0.026	0	31.1	7.3	0
52	IM52-1.0-1	5	0	0	0	0.1	0	0
52	IM52-1.0-2	5	0	0	0.01	0.3	0	0
52	IM52-1.25-1	5	0	0	0	0.1	0	0
52	IM52-1.25-2	5	0	0	0.01	0.3	0	0
53	IM53-1	5	0.004	0.004	0	0.1	0	0
53	IM53-2	5	0.005	0.005	0.03	0.5	0	0

Figures 14 and 15 represent measured vs. predicted cracking using the nationally calibrated model and the locally calibrated model, respectively. One of the main outputs of this study was developing a pavement design catalog prototype for the PCC low-volume roads in Minnesota. A threshold value of 30 Percent for transverse cracking and 0.25 inch for faulting was developed to represent the state's performance criteria at 50 Percent reliability level. Table 9 shows a comparison of national and local calibration coefficients.

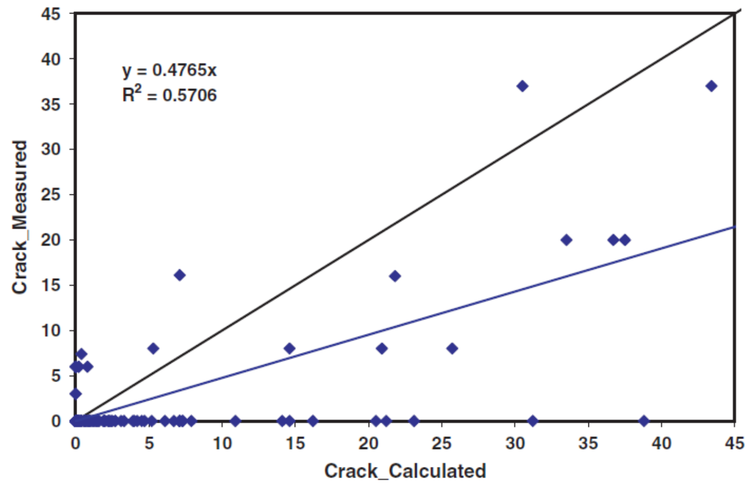


Figure 14 Measured versus Predicted Cracking using MEPDG National Model—Minnesota

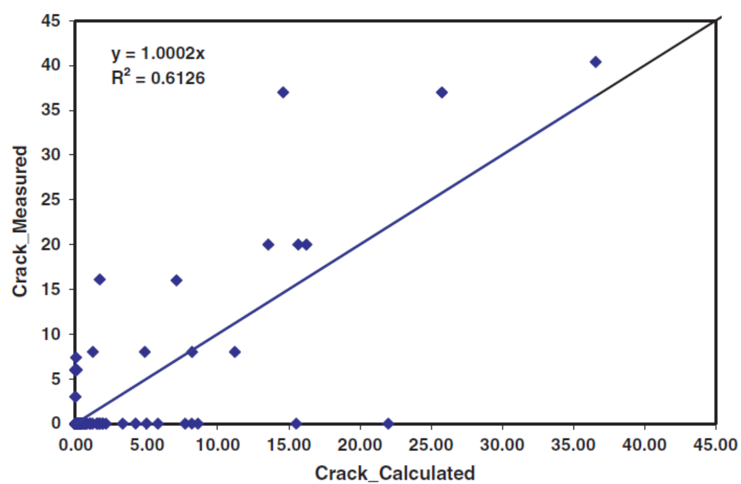


Figure 15 Measured vs. Predicted Cracking using Locally Calibrated Model—Minnesota

Table 9 Transverse Cracking Model National and Local Calibration Coefficients—Minnesota

Model	**C1**	**C2**	**R^2**	**Slope**
Original	1	-1.68	0.57	0.4765
Calibrated	1.9875	-2.145	0.61	1.0002

Ohio

The Ohio DOT conducted a study in 2009 to propose guidelines for MEPDG implementation. In this study, MEPDG v1.0 was used. Both the statistical and non-statistical approach were employed to check the adequacy of the distress/IRI prediction models.(21) The researchers determined local calibration was not required for the transverse cracking model. Although the joint faulting model provided reasonable prediction results, local calibrate was recommended due to the availability of additional database with higher joint faulting intensity. IRI model validation showed some bias; however, there was very good correlation between predicted and measured values with low SEE. Therefore, local calibration only included adjustment of the C1 and C4 coefficients. Upon completion of the analysis, researchers determined conducted changes did not result in major changes to R^2 or SEE.

Researchers also conducted a sensitivity analysis of the recalibrated JPCP models and found reasonable expectations within the results. It was also detected that joint spacing had significant influence on most of the distresses, where other parameters, such as concrete flexural strength, subgrade type, had moderate effects on the distresses prediction. It should be noted this study only included Ohio DOT LTPP Special Pavement Study projects, all of which had an average in-service age of 10 years, and do not fully represent all Ohio DOT concrete pavements or climatic conditions.

Oregon

Oregon DOT completed an MEPDG implementation study for both flexible and rigid pavements.(22,23) MEPDG (Darwin ME v1.1) was used in this calibration effort. For the PCC calibration, only four CRCP and no JPCP projects were selected. The simulation runs were conducted at 50 and 90 Percent reliability levels to demonstrate the effect of reliability. For three CRCP project, the punchout model under predicted the number of punchouts as compared to the field measured values at the same age, but over predicted the number of punchouts on the remaining sections. Although researchers were satisfied with the nationally calibrated models, they were unable to assess the accuracy of the nationally calibrated model due to the limited number of CRCP sections used in the analysis.

Utah

The study included the calibration of performance models for both flexible and rigid pavements.(24) Road sections' data was obtained from the Utah DOT pavement management system and LTPP projects in Utah. A total of 30 projects were selected covering new JPCP and rehabilitated JPCP. The project used both MEPDG v0.8 and MEPDG v1.0. The investigation showed the transverse slab cracking model to have good predictions with very adequate goodness of fit and no significant bias. Although most of the measured joint faulting data was close to zero, the statistical analysis showed good correlation between predicted and measured values with slightly higher SEE and no bias. The same results were found with the IRI prediction model; therefore, the MEPDG provided adequate prediction with no need for local calibration (Figure 16).

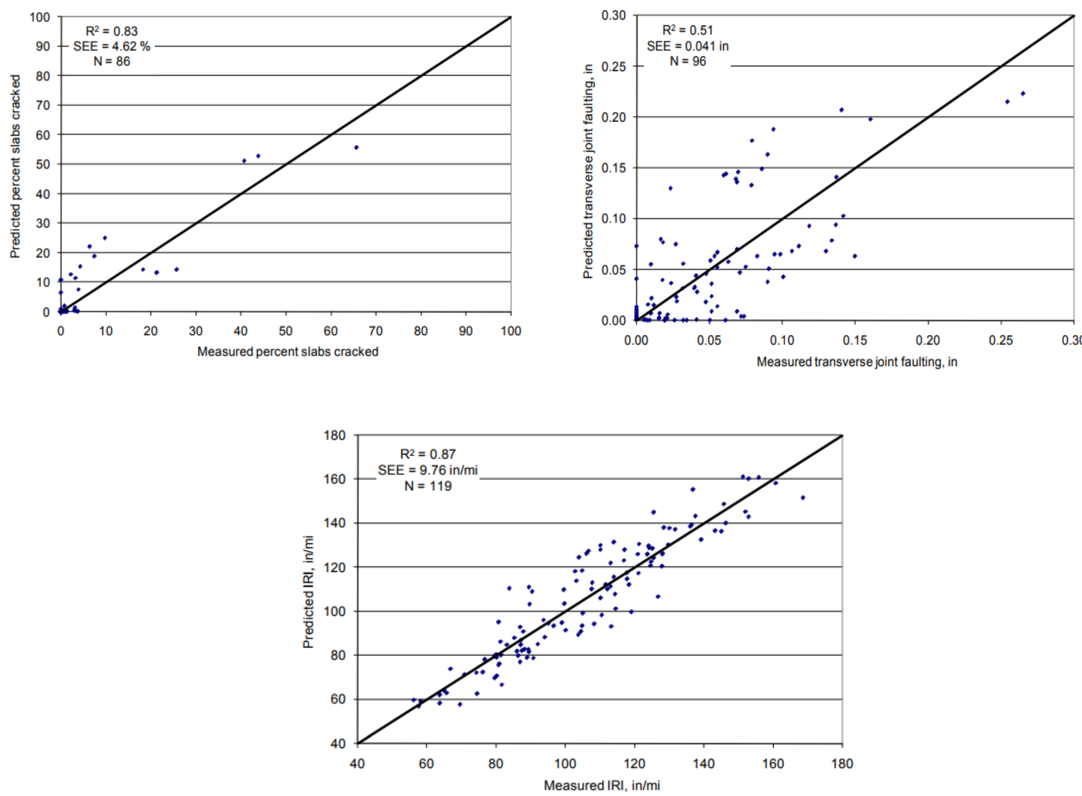


Figure 16 Plots of Measured vs. Predicted JPCP Transverse Cracking, Joint Faulting, and IRI—Utah

Virginia

The Virginia DOT also made an effort to locally calibrate the PMED.[25] PMED v1.3 was adopted for this research. Virginia DOT's pavement management database was the core source of field performance data. JPCP prediction models (transverse slab cracking and joint faulting) were not included due to limited project sites in Virginia. Only CRCP punchout and smoothness prediction models were considered in this study. The jackknife statistical approach was for the CRCP local calibration analysis. The results indicated the nationally calibrated model over predicted punchouts by 8 punchouts per mile. On the other hand, the nationally calibrated models under predicted IRI. The punchout local calibration coefficient removed the over prediction bias and lowered the SEE as compared to the nationally calibrated model. Although the locally calibrated CRCP IRI model showed less bias, it also resulted in significant increase in the SEE. Thus, researchers recommended using the nationally calibrated values. Given limited projects, the nationally calibrated models for JPCP transverse cracking and faulting were assessed to be acceptable.

Washington

Washington State DOT calibrated the PCC models using MEPDG v0.6 in 2005.[26] Data was extracted from the Washington State Pavement Management System (WSPMS), representing different regions statewide. The researchers indicated that almost 68 Percent of PCC pavements included in the study were in-service between 25 and 45 years, and the majority constructed without dowel bars. Since the WSPMS did not differentiate between longitudinal and transverse cracking, researchers faced challenges in comparing predicted to field cracking data. Based on a review of historical images, they found that longitudinal cracking was more prominent than transverse cracking. From this evaluation it was assumed that two-thirds of all cracks were longitudinal.

Figure 17 shows the calibration flow chart adopted during the calibration process. In generally, the calibration process indicated the nationally calibrated models over predict transverse cracking and under predict IRI. Joint fault prediction varied depending on climate condition and use of dowel bars. Table 10 shows local calibration factors for Washington State.[26]

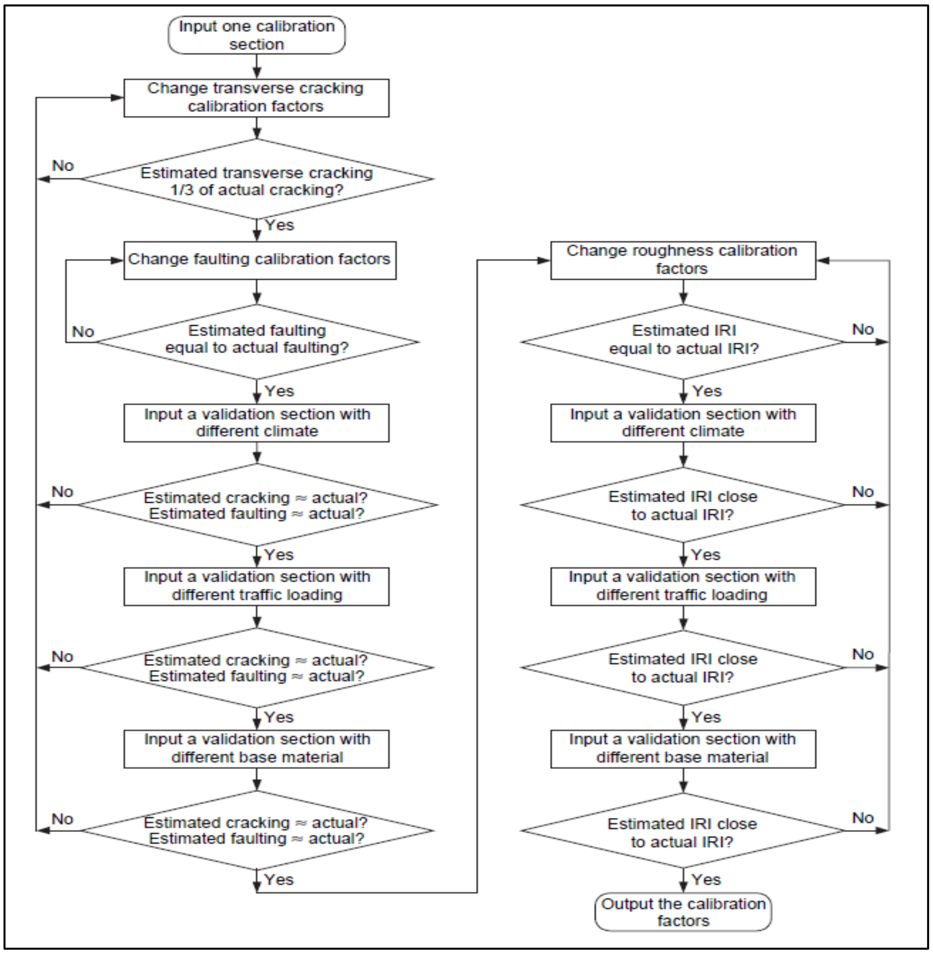


Figure 17 Calibration Flow Chart—Washington State

Table 10 Local Calibration Coefficients—Washington State

Calibration Factor	**Default for New Pavements**	**Undoweled**	**Undoweled-MP[a]**	**DBR[b,c]**
Cracking C_1	2	2.4	2.4	2.4
Cracking C_2	1.22	1.45	1.45	1.45
Cracking C_4	1	0.13855	0.13855	0.13855
Cracking C_5	-1.68	-2.115	-2.115	-2.115
Faulting C_1	1.29	0.4	0.4	0.934
Faulting C_2	1.1	0.341	0.341	0.6
Faulting C_3	0.001725	0.000535	0.000535	0.001725
Faulting C_4	0.0008	0.000248	0.000248	0.0004
Faulting C_5	250	77.5	77.5	250
Faulting C_6	0.4	0.0064	0.064	0.4
Faulting C_7	1.2	2.04	9.67	0.65
Faulting C_8	400	400	400	400
Roughness[d] C_1	0.8203	0.8203	0.8203	0.8203
Roughness[d] C_2	0.4417	0.4417	0.4417	0.4417
Roughness[d] C_3	1.4929	1.4929	1.4929	1.4929
Roughness[d] C_4	25.24	25.24	25.24	25.24

[a] Mountain pass climate
[b] Dowel bar retrofit
[c] DBR calibration factors are the same as default "restoration" values in NCHRP 1-37A software
[d] Roughness calibration factors are the same as the default values

In the state of Washington, studded tire wear plays significant role in pavement roughness and deterioration. Since the software doesn't account for the effect of studded tires on the IRI, the researchers were unable to calibrate the IRI model. This study concluded that due to above mentioned issues regarding to transverse and longitudinal cracking, the calibrated software can only predict joint faulting, but cannot predict cracking.

Wisconsin

At the time of this study, the Wisconsin DOT is in the process of implementing the PMED. The initial implementation plan was focused on using nine LTPP JPCP sites.[(27)]. MEPDG v1.0 was used in this study. The JPCP calibration effort only focused on transverse slab cracking. The comparison of field measured cracking verses predicted showed the necessity of local calibration. Researchers found that adjusting C1 in the fatigue model to a value between 1.45 to 2.80 and C5 for the cracking model to a value between -4.0 to -4.5 (depending on location), provided satisfying improvement in the accuracy of predictions. Table 11 summarizes calibration coefficients and MOR (Modulus of Rupture) and CTE (Coefficient of thermal expansion) for each of the nine LTPP locations.

Table 11 Calibrating Coefficients for JPCP Transverse Cracking Model—Wisconsin

Test Section	C1	C5	28-Day MOR psi	TP60 CTE με/F
STH 29, Chippewa Co	1.45	-4.5	651	5.9
STH 29a, Marathon Co	2.35	-4.5	454	6
STH 29b, Marathon Co	2.50	-4.0	619	5.5
USH 53, Trempealeau Co	1.90	-4.0	715	6.4
STH 16, Waukesha	2.70	-4.5	767	6.4
USH 18, Dane Co	1.98	-4.5	837	5.7
USH 45, Washington Co	2.80	-4.5	689	6.1
STH 26, Rock/Jefferson Co	2.77	-4.5	611	6.5
USH 151, Dodge Co	2.00	-4.5	733	6.5

SHAs ME Calibration Summary

The first version of the MEPDG was released in 2004, and several national level research studies were conducted after this release. Parallel to national level studies, many SHAs conducted studies to develop implementation plans and efforts to evaluate and calibrate the MEPDG/PMED to local conditions. Most of the local calibration effort was focused on flexible pavements, with limited studies for JPCP and CRCP. Additionally, the AASHTO *Local Calibration Guide* [8] provided useful support on how to conduct the calibration and validation of the performance models.

The main goal of this research is to determine the calibration coefficients for JPCP and CRCP prediction models for Idaho local conditions. Based on the literature review, many studies specified two primary issues that should be addressed for the successful implementation of the MEPDG, these include:

- Provide comprehensive and representative inputs when you have limited information about the selected projects.
- Collect and prepare field data in a format similar to the PMED output.

ITD’s current practice of maintaining records of construction history (as built structures) should be sufficient to provide traffic, layers’ thicknesses, and material properties inputs. Previous implementation efforts included several research projects to develop a comprehensive input database has already been established. In addition, a library for PCC material properties for typical mixes in Idaho has been recently completed. The PCC mix database, prepared under RP253 project, will play a vital rule in the success of calibration by providing sufficient information on mixes’ properties inputs. TAMS data and video log files collected over the past years will provide accurate and sufficient performance field measurements for comparison to PMED performance prediction results.

Based on the presented literature, notable findings include:

1. Many transportation agencies reported that locally calibrated MEPDG designs require less or equal PCC thickness as compared to the AASHTO 1993 Guide.

2. It is essential that measured performance data is accurately collected over time and consistent with PMED requirements.

3. Many SHAs use hierarchical input level 2 and 3 for traffic and material properties because they are the most economically and commonly available data.

4. Calibration coefficients C1 (transverse cracking model) and C6 (joint faulting model) have been found to be the most sensitive coefficients to the local calibration process.

5. Longitudinal cracking was found to be the predominant distress, rather than transverse cracking in several states. Therefore, researchers recommend development and inclusion of a longitudinal cracking model in the PMED.

6. States that allow the use of studded tires may underestimate IRI as a result of disregarding the effect of studded tire on ride quality of pavement.

7. Nationally calibrated models' prediction pattern is inconsistent among different SHAs, and there is no general outcome indicating the national calibration factors over or under estimate the predicted distresses. A summary of the prediction pattern and the developed local calibration coefficients for transverse slab cracking, joint faulting, IRI and punchouts are presented in Tables 12 and 13, respectively.

8. Sensitivity analysis illustrate the PMED performance models estimate reasonable prediction of joint faulting and IRI for JPCP pavements. The sensitivity levels varied based on each input. It was found that the mean joint faulting is extremely sensitive to most of the investigated inputs. IRI was found to be extremely sensitive to AADTT, CTE, and dowels diameter, and base type.

Table 12 Nationally Calibrated Prediction Pattern by SHA

SHA	JPCP Transverse Slab Cracking	JPCP Joint Faulting	JPCP IRI	CRCP Punchouts	CRCP IRI	Version Used
Arizona	Under	Over	Over	Well	Well	Darwin M-E v3.1
Colorado	Well*	Well*	Well*	X	X	MEPDG v1.0
Florida	Well	Under	Under	X	X	MEPDG v1.0
Iowa	Over	Under	Over	X	X	MEPDG v1.1
Kansas	N/A	Over	Under	X	X	PMED v1.3
Louisiana	Over	Under	Well	X	X	PMED v1.3
Minnesota	Over	Under	N/A	X	X	MEPDG v0.910
Ohio	Well*	Well	Some Bias	X	X	MEPDG v1.0
Oregon	X	X	X	Well**	Not Done	Darwin M-E v1.1
Utah	Well	Well*	Well	X	X	MEPDG v0.8 and MEPDG v1.0
Virginia	X	X	X	Over	Under	PMED v1.3
Washington	Over	Over	Under	X	X	MEPDG v1.0
Wisconsin	Over	Not Done	Not Done	X	X	MEPDG v1.0

Over= Over-prediction, Under=Under prediction, Well= well prediction.
* Measured values were almost zero.
** Researchers felt reasonable prediction though found both under and over prediction in different pavements.
X = either JPCP nor CRCP sections were not considered.
N/A = Not Available.

Table 13 Summary of SHA Local Calibration Coefficients

Factor	MEPDG	Darwin	AZ	CO	IA	LA	MO	OH	WA
Transverse Cracking C1	2	2	NNC	NNC	2.17	2.6	ONC	ONC	1.93
Transverse Cracking C2	1.22	1.22	NNC	NNC	1.32	ONC	ONC	ONC	1.177
Transverse Cracking C4	1	0.6	0.19	NNC	1.08	ONC	ONC	ONC	ONC
Transverse Cracking C5	-1.98	-2.05	-2.067	NNC	-1.81	ONC	ONC	ONC	ONC
Transverse Cracking Std. Dev.	SD1=5.3116	57.08	9.87						
Transverse Cracking Std. Dev.	SD2=0.3903	0.33	0.4012	NNC	ONC	ONC	ONC	ONC	ONC
Transverse Cracking Std. Dev.	SD3=2.99	1.5	0.5						
Faulting F1	1.0184	1.252632	0.0355	0.5104	2.0427	ONC	ONC	ONC	ONC
Faulting F2	0.91656	1.127369	0.1147	0.00838	1.83839	ONC	ONC	ONC	ONC
Faulting F3	0.0021848	0.002688	0.00436	0.00147	0.004382	ONC	ONC	ONC	ONC
Faulting F4	0.00088373	0.001087	1.10E-07	0.008345	0.001773	ONC	ONC	ONC	ONC
Faulting F5	250	250	20000	5999	ONC	ONC	ONC	ONC	ONC
Faulting F6	0.4	0.4	2.0389	0.8404	0.8	1.2	ONC	ONC	ONC
Faulting F7	1.83312	9.1	0.189	5.9293	ONC	ONC	ONC	ONC	ONC
Faulting F8	400	400	NNC	NNC	ONC	ONC	ONC	ONC	ONC
Faulting Std. Dev.	SD1=0.0097	0.00165	0.037	0.0831					
Faulting Std. Dev.	SD2=0.5178	0.3709	0.6532	0.3426	ONC	ONC	ONC	ONC	ONC
Faulting Std. Dev.	SD3=0.014	0.00231	0.001	0.00521					
IRI *R1*	0.8203	0.8203	0.6	NNC	0.04	ONC	0.82	0.82	ONC
IRI *R2*	0.4417	0.4417	3.48	NNC	0.02	ONC	1.17	3.7	ONC
IRI *R3*	1.4929	1.4929	1.22	NNC	0.07	ONC	1.43	1.711	ONC
IRI *R4*	25.24	25.24	45.2	NNC	1.17	ONC	66.8	5.703	ONC
IRI *Std. Dev.*	5.4	5.4	NNC	NNC	ONC	ONC	ONC	ONC	ONC

Note: ONC = the old national calibration coefficients developed with MEPDG release,
NNC = the new national calibration coefficients developed with Darwin release.

Chapter 3
Evaluation of Inputs Required for Rigid Pavements

PMED is a comprehensive tool that requires more than 100 inputs to complete a pavement design/analysis. For any design or analysis, four general categories of inputs are required: project inputs, climatic inputs, traffic inputs, and pavement structure inputs. The main purpose of project inputs is to define the emphasis of the project by providing information such as the type of design, construction and traffic opening dates, etc. as well as the design criteria (threshold values for distresses and roughness) with associated reliability level for each selected distress. The other general inputs describing traffic, climate, and structure deliver additional indispensable data to perform a reliable pavement structure design/analysis.

These inputs have major influence on the PMED distress/IRI predictions. Therefore, they should be selected very precisely using the highest possible hierarchical input level. This is because the hierarchical input level influences predicted distress/IRI SEE, which is a key component of determining the design reliability. Figure 18 shows the PMED v2.5.3 main screen for inputs, and Table 14 presents listing of these inputs parameters for rigid pavement design and analysis.

PCC material properties inputs can be obtained from an agency database, or can be estimated by correlations of simpler tests such as using compressive strength to estimate modulus of rupture. ITD developed its first concrete material database under RP253 as indicated earlier.[29] This database incorporated tests of ITD's Portland cement concrete (PCC) paving mixtures such as: compressive strength (f'c), modulus of elasticity (Ec), Poisson's ratio (μ), modulus of rupture (MR), splitting tensile strength (f't), coefficient of thermal expansion (CTE) and ultimate drying shrinkage (ε∞). The database was prepared in way that can provide the three hierarchical input levels as required by the software. Users have the choice to determine what level of data input is desired for each project. Figure 19 shows material properties for one of PCC mixes from District 2 as an example.

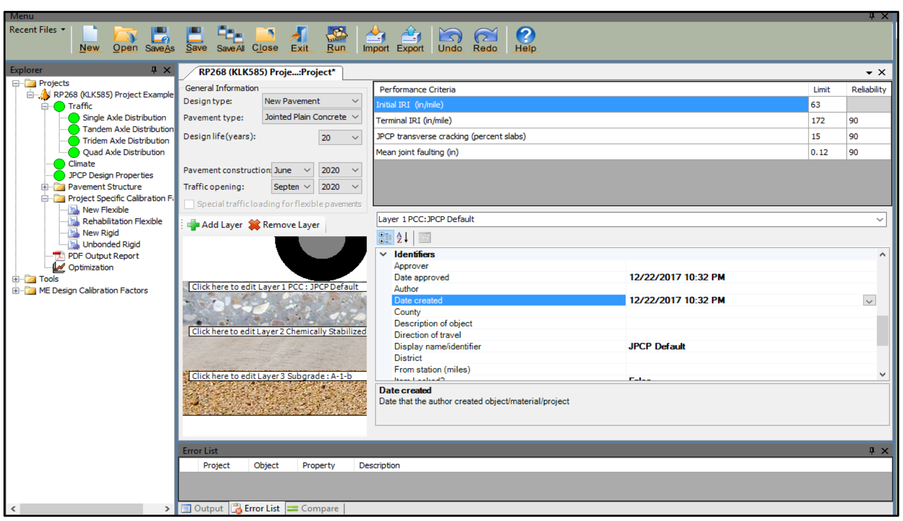
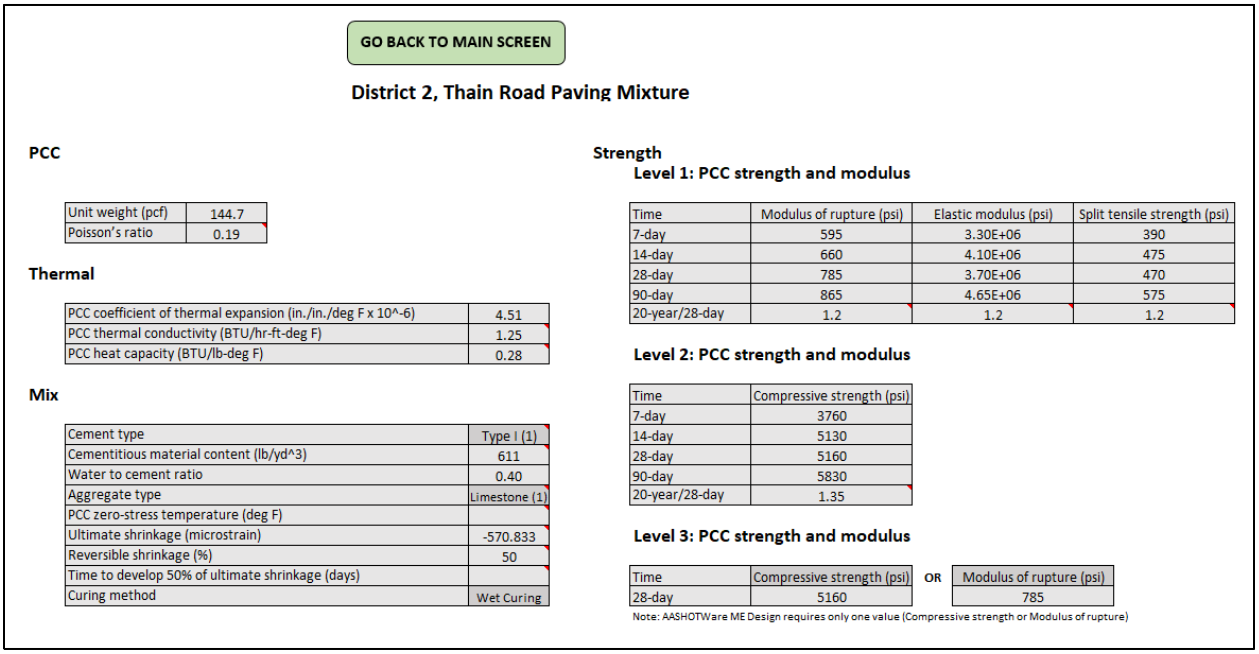


Figure 18 AASHTOWare Pavement ME Design Main Screen for Inputs

Table 14 Typical Input Levels Used in AASHTOWare Pavement ME Design Models

Source: AASHTO Mechanistic-Empirical Pavement Design Guide. A Manual of Practice [6]

Input Group	Input Parameter	Recalibration Input Level used (NCF)
Truck Traffic	Axle Load Distributions (Single, Tandem, Tridem, & Quad)	Level 1
Truck Traffic	Truck Volume Distribution	Level 1
Truck Traffic	Lane & Directional Truck Distribution	Level 1
Truck Traffic	Tire Pressure	Level 3
Truck Traffic	Axle Configuration, Tire Spacing	Level 3
Truck Traffic	Truck Wander	Level 3
Truck Traffic	Traffic Speed	Level 3
Climate	Temperature, Wind Speed, Cloud Cover, Precipitation, Relative Humidity	Level 1
Unbound Layers & Subgrade Properties	Resilient Modulus—All Unbound Layers	Level 1; Back calculation
Unbound Layers & Subgrade Properties	Classification and Volumetric Properties	Level 1
Unbound Layers & Subgrade Properties	Moisture-Density Relationships	Level 1
Unbound Layers & Subgrade Properties	Soil-Water Characteristic Relationships	Level 3
Unbound Layers & Subgrade Properties	Saturated Hydraulic Conductivity	Level 3
PCC Properties	PCC Elastic Modulus	Level 1
PCC Properties	PCC Flexural Strength	Level 1
PCC Properties	PCC Indirect Tensile Strength (CRCP Only)	Level 2
PCC Properties	PCC Coefficient of Thermal Expansion	Level 1
All Materials Except Bedrock	Unit Weight	Level 1
All Materials Except Bedrock	Poisson's Ratio	Level 1 & 3
All Materials Except Bedrock	Thermal Properties; Conductivity; Heat Capacity; Surface Absorptivity	Level 3
Existing Pavement (In Case of Overlay Design)	Condition of Existing Layers	Level 1 & 2



GO BACK TO MAIN SCREEN

District 2, Thain Road Paving Mixture

PCC

Unit weight (pcf)	144.7
Poisson's ratio	0.19

Thermal

PCC coefficient of thermal expansion (in./in./deg F x 10^-6)	4.51
PCC thermal conductivity (BTU/hr-ft-deg F)	1.25
PCC heat capacity (BTU/lb-deg F)	0.28

Mix

Cement type	Type I (1)
Cementitious material content (lb/yd^3)	611
Water to cement ratio	0.40
Aggregate type	Limestone (1)
PCC zero-stress temperature (deg F)	
Ultimate shrinkage (microstrain)	-570.833
Reversible shrinkage (%)	50
Time to develop 50% of ultimate shrinkage (days)	
Curing method	Wet Curing

Strength

Level 1: PCC strength and modulus

Time	Modulus of rupture (psi)	Elastic modulus (psi)	Split tensile strength (psi)
7-day	595	3.30E+06	390
14-day	660	4.10E+06	475
28-day	785	3.70E+06	470
90-day	865	4.65E+06	575
20-year/28-day	1.2	1.2	1.2

Level 2: PCC strength and modulus

Time	Compressive strength (psi)
7-day	3760
14-day	5130
28-day	5160
90-day	5830
20-year/28-day	1.35

Level 3: PCC strength and modulus

Time	Compressive strength (psi)	OR	Modulus of rupture (psi)
28-day	5160		785

Note: AASHOTWare ME Design requires only one value (Compressive strength or Modulus of rupture)

Figure 19 Example of PMED Inputs for District 2 Thain Road Mixture from PCC-database

Sensitivity Analysis of PMED Inputs

The research team of this study conducted a sensitivity analysis to evaluate the inputs required to run the PMED. It is important to identify which of these inputs have a greater effect on the predicted performance. Since, the greater the sensitivity of an input, the higher the hierarchical input level needed to obtain more reliable performance. This helps SHAs to decide where additional effort is demanded to provide the most important input variables.

The researchers used inputs (from rigid pavement database that was developed under RP 253 project) to develop new JPCP baseline designs representing typical Idaho site conditions.(29) Key inputs were varied separately using PMED v2.5.3. Details of the baseline designs for new JPCP is presented in Table 15.

Table 15 Mean (Baseline) and Range of Key Inputs Used for Sensitivity Analysis of New JPCP

Input Parameter	Lower End	Mean (Baseline)	Upper End
AADTT	1500	3000	6000
PCC Thickness, in	9.5	10.5	12
CTE, in/in/°F	3.75	4.5	5.25
Base type/thickness	No base	12-in DGAB	12-in /CTB
Dowel diameter, in	1	1.25	1.5
Joint spacing	12	15	17
Modulus of Rupture, psi	700	800	900
Shoulder type	HMA	Not tied (HMA)	Tied PCC

Results of the JPCP sensitivity analysis is presented and described below. The researchers plotted the predicted performance for each input to evaluate and assess their impact on: faulting, transverse cracking, and smoothness, respectively.

Truck Traffic Volume

The impact of traffic volume on PCC distress prediction is shown in Figures 20 through 22. Traffic volume has a very significant influence on both joint faulting and IRI smoothness. As traffic volume increases, the amount of faulting and IRI increase significantly. Traffic volume is one of the most sensitive inputs that has the highest impact on the distresses prediction. Regarding the transverse cracking, the traffic level did not affect the prediction of the cracking, and it remains consistent during the life period. The researchers consider that the increment of change in the transverse cracking is minimal within these traffic volumes.

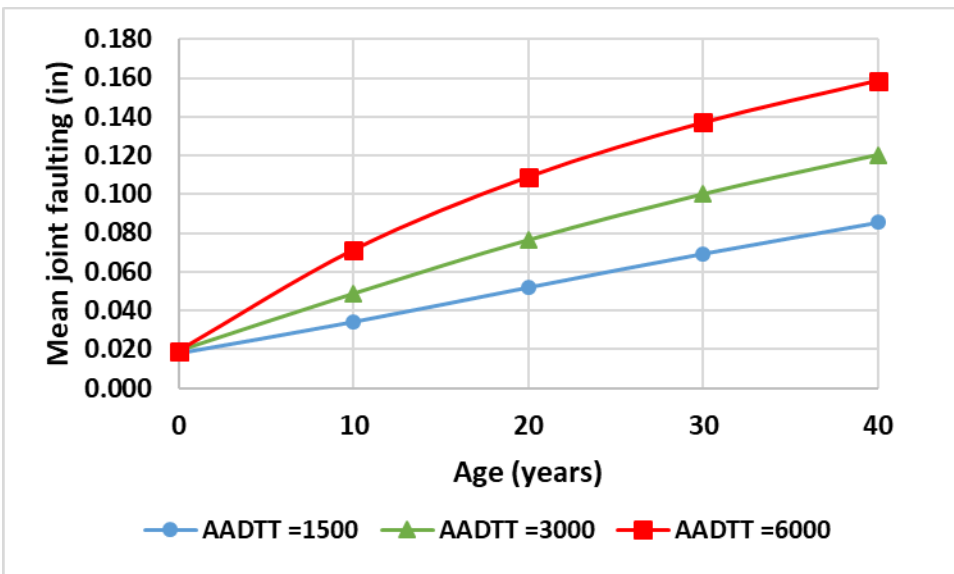


Figure 20 Effect of AADTT on JPCP Joint Faulting

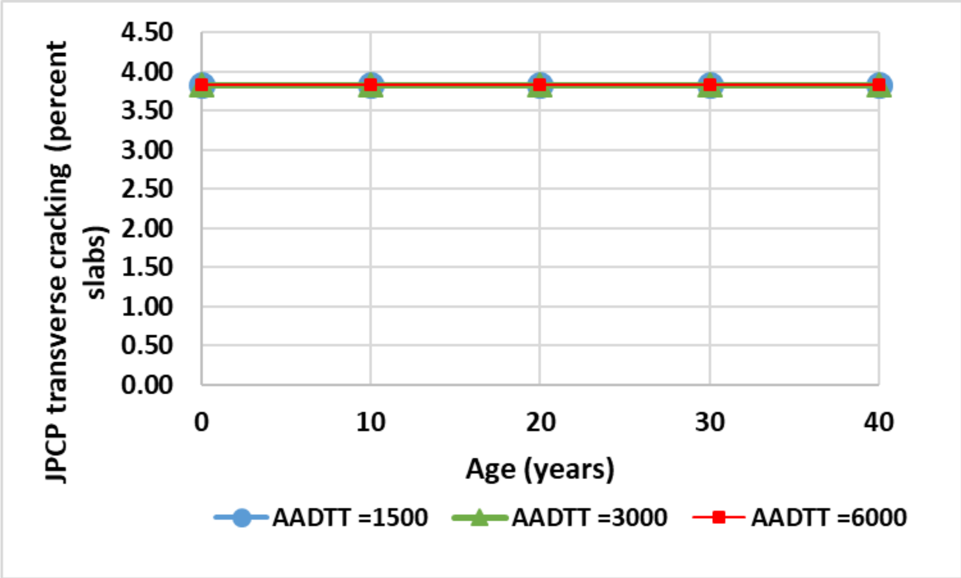


Figure 21 Effect of AADTT on JPCP Transverse Slab Cracking

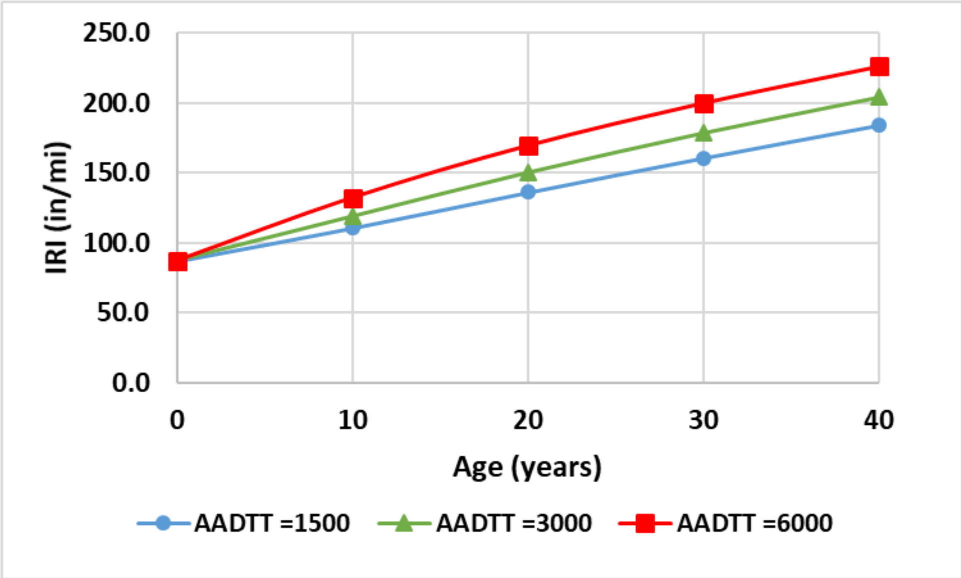


Figure 22 Effect of AADTT on JPCP IRI

PCC Thickness

Figures 23 to 25 illustrate the effect of increasing the PCC thickness on the predicted performance. Stresses, deflections and fatigue damage at the top and bottom of the slab are less in the thicker slabs. Accordingly, increased PCC slab thickness should result in less faulting, cracking, and IRI. However, the results indicated that faulting did not decrease significantly with the increase of the thickness. The same trend can be shown in the IRI, thickness effect on the smoothness was not significant. Increased thickness has no significant effect on transverse cracking in the first half of the life time. However, after that cracking starts propagating faster with lower thickness.

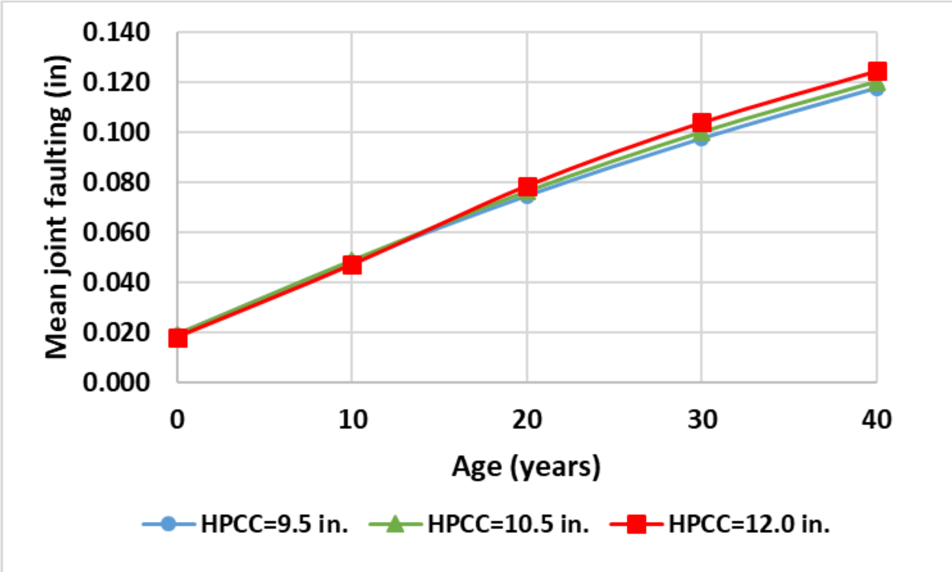


Figure 23 Effect of PCC Thickness on JPCP Joint Faulting

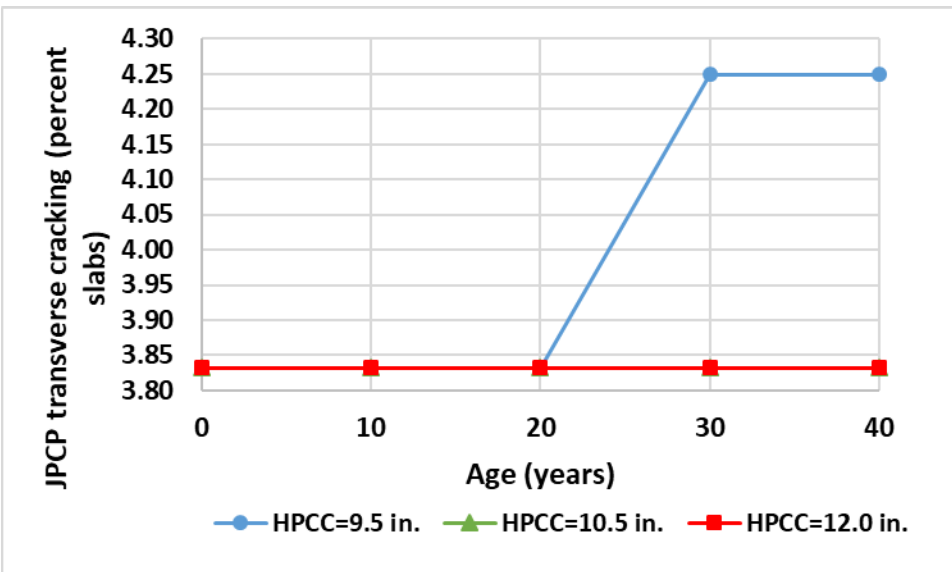


Figure 24 Effect of PCC Thickness on JPCP Transverse Slab Cracking

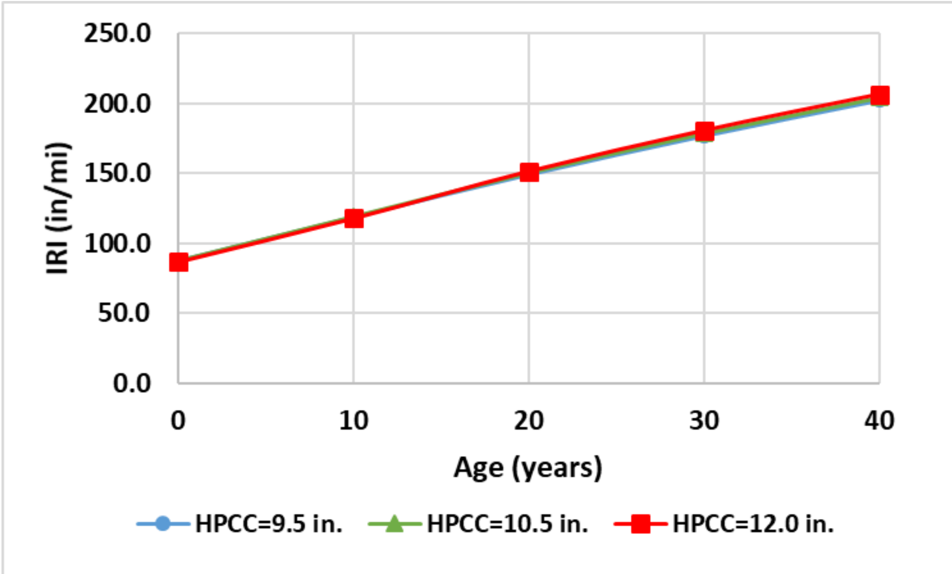


Figure 25 Effect of PCC Thickness on JPCP IRI

Coefficient of Thermal Expansion

The coefficient of thermal expansion (CTE) has significant impact on the slab curling due to temperature change. Figures 26 through 28 show the effect of CTE on predicted distress and IRI. The sensitivity analysis results show that the CTE effect on joint faulting was significant, and this was expected due to curling effect. Same results with the smoothness. IRI changed significantly with the CTE, but transverse slab carking remains almost the same regardless of what the CTE value was.

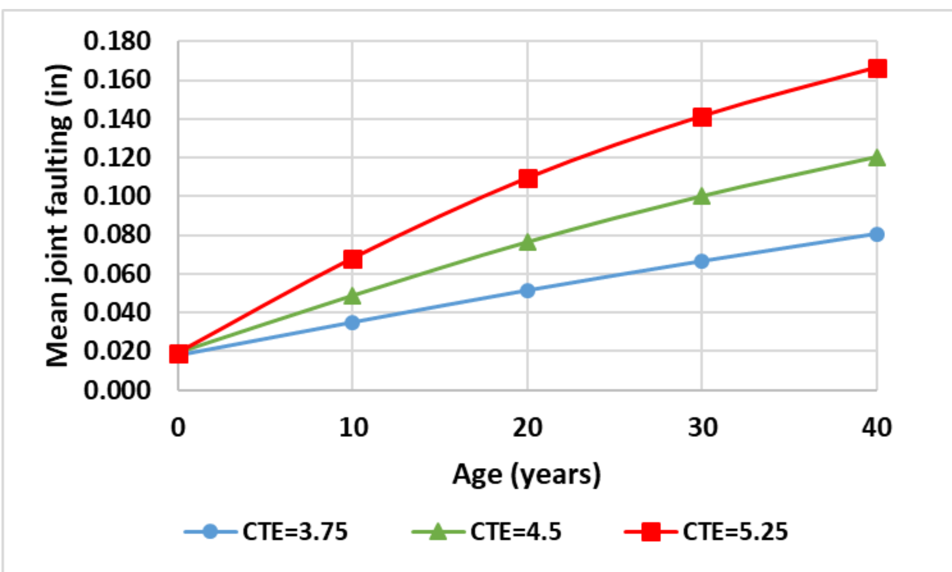


Figure 26 CTE on JPCP Joint Faulting

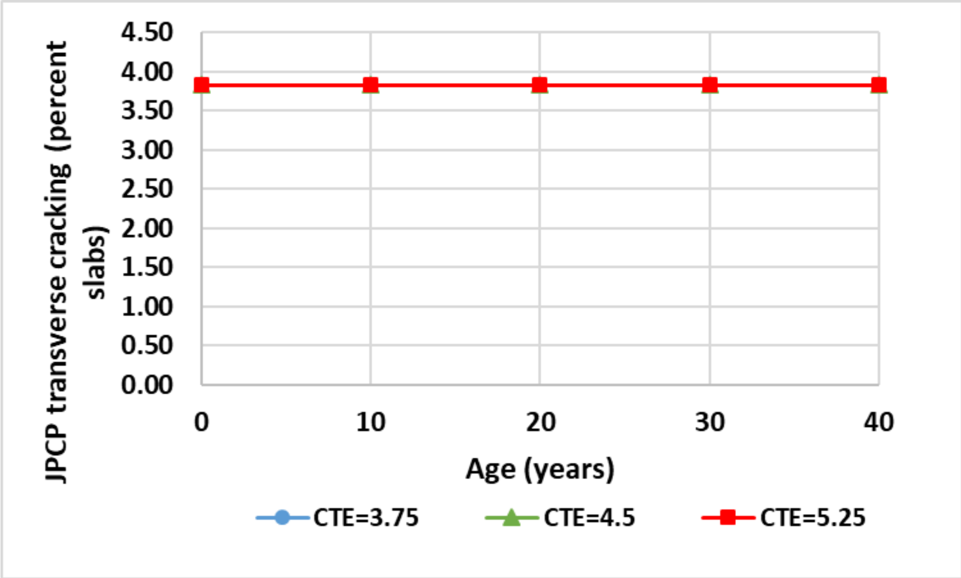


Figure 27 Effect of CTE on JPCP Transverse Slab Cracking

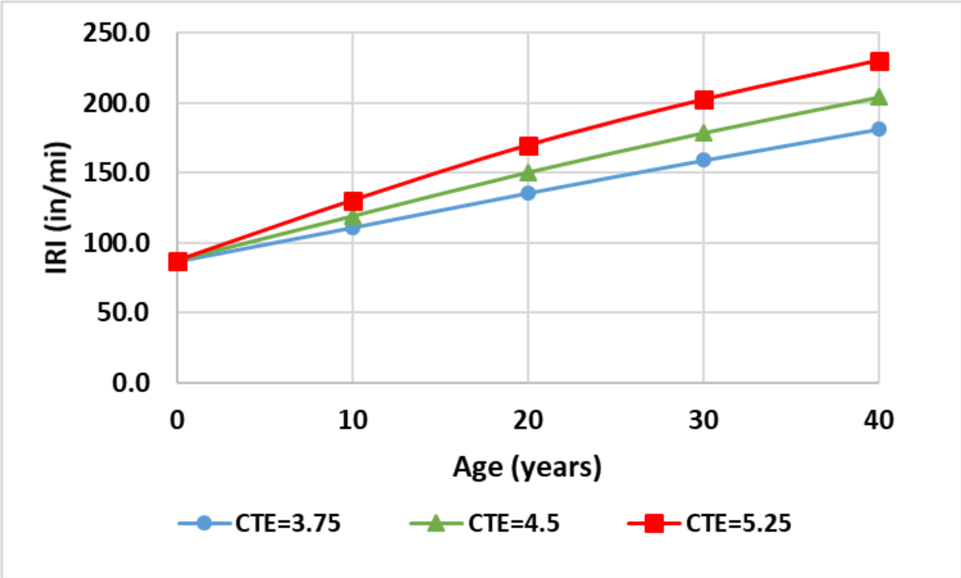


Figure 28 Effect of CTE on JPCP IRI

Dowel Diameter

Since, dowel diameter is correlated to the thickness, in this analysis, the diameter was increased with PCC thickness using the thickness divided by 8 ratio. Accordingly, a 10.5-inch slab would have a 1.25 inch dowel diameter. The influence of dowels dimeters on the performance is presented in Figures 29 to 31. The increase of the diameter reduced the faulting and IRI significantly, but does not have a significant impact of the transverse cracking. This behavior was predictable, similar to the thickness effect with distress development and future deterioration rates.

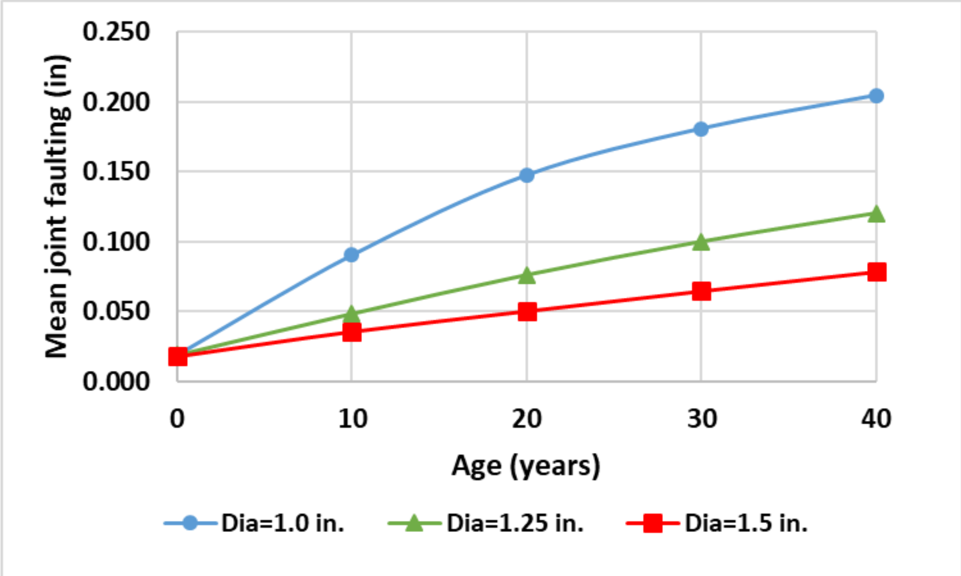


Figure 29 Effect of Dowel Diameter on JPCP Joint Faulting

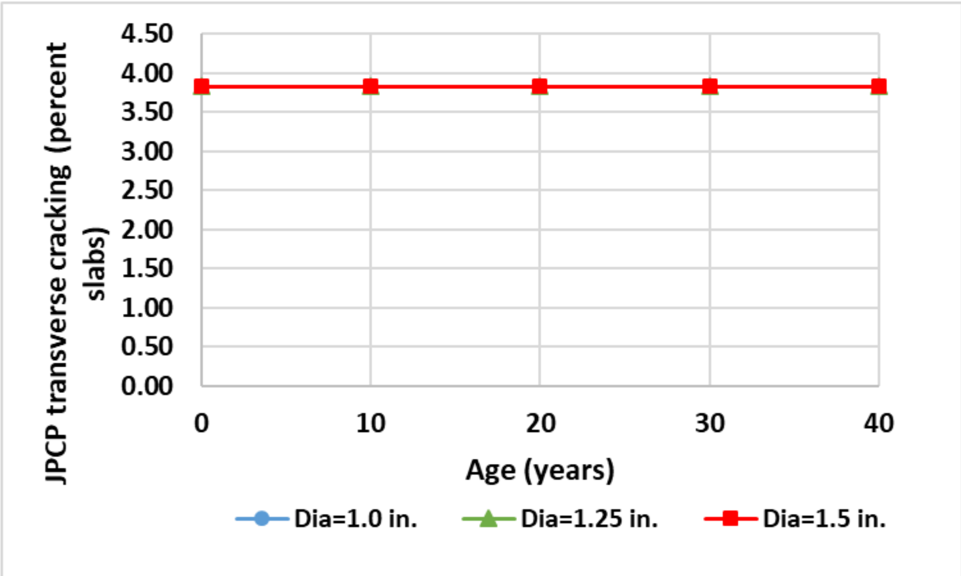


Figure 30 Effect of Dowel Diameter on JPCP Transverse Slab Cracking

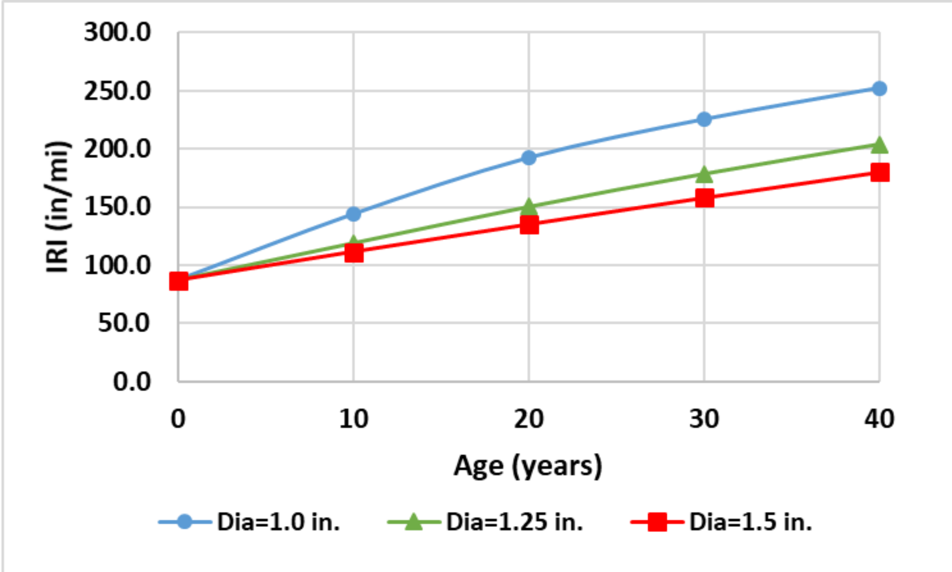


Figure 31 Effect of Dowel Diameter on JPCP IRI

Joint Spacing

Figures 32 through 34 show the effect of joint spacing on faulting, cracking, and IRI. The trends of predicted distress and IRI were as anticipated based on previous reviews. As the length of the slab increases, the predicted faulting and IRI increased. An increase in the joint slab spacing from 12 ft. to 17 ft. caused in an increase in the faulting by almost 80 Percent (Figure 32). IRI also increased, but the effect was less compared to faulting as shown by Figure 34. The impact on the transverse cracking was observed only at advanced life stage.

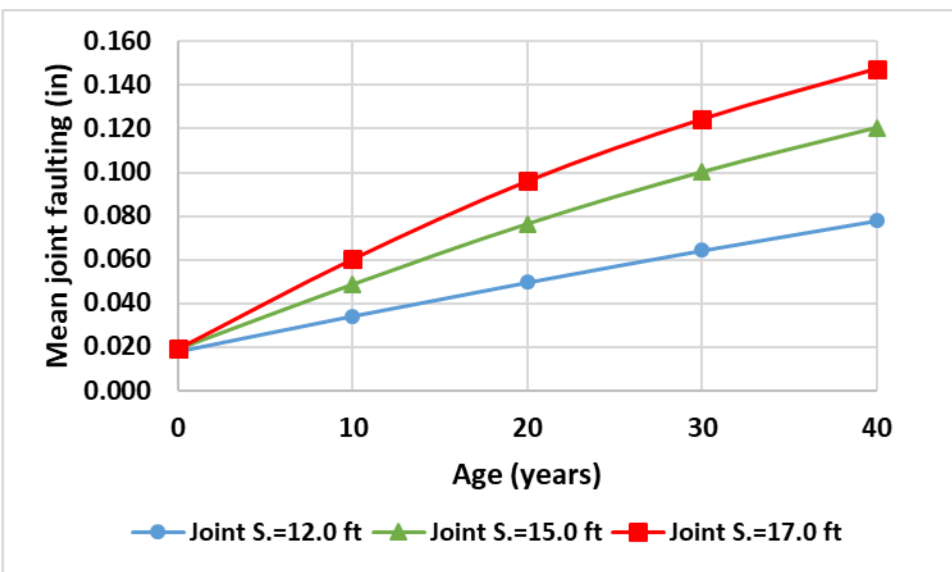


Figure 32 Effect of Joint Spacing on JPCP Joint Faulting

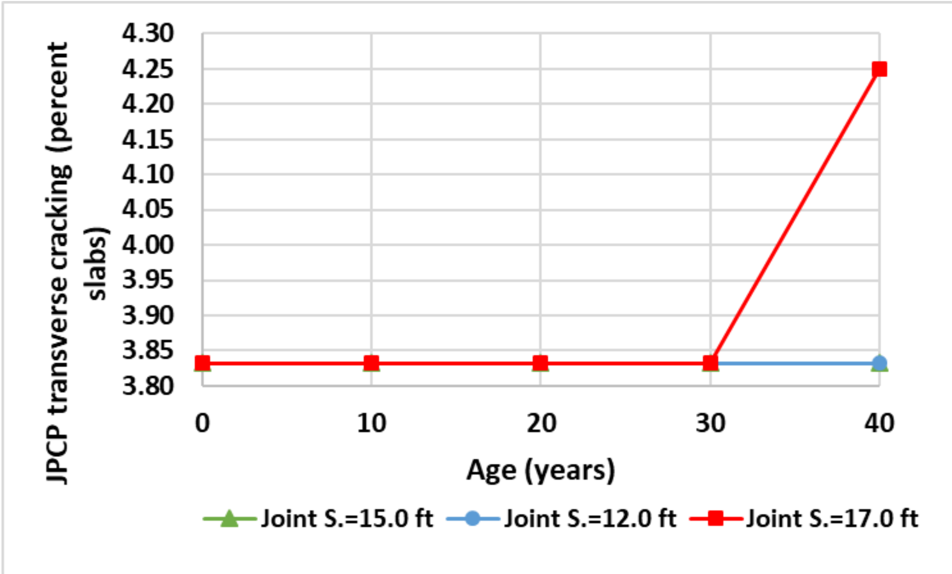


Figure 33 Effect of Joint Spacing on JPCP Transverse Slab Cracking

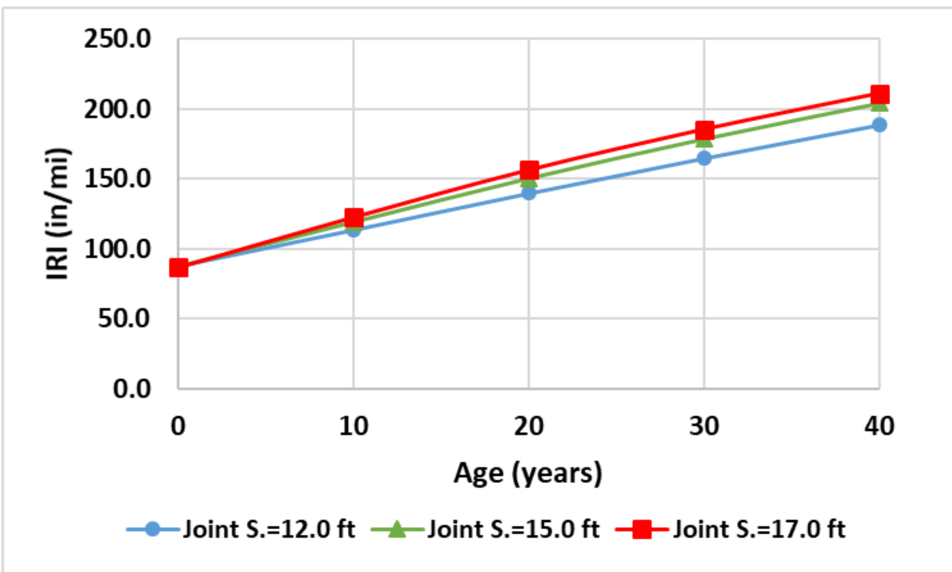


Figure 34 Effect of Joint Spacing on JPCP IRI

Base Type

Figures 35 through 37 present the impact of base type on predicted distress and IRI. The results show that there is a small effect on the faulting and IRI when non-stabilized base is added to the structure. However, significant improvement in the faulting and IRI performance is observed using chemically stabilized base, except for the cracking

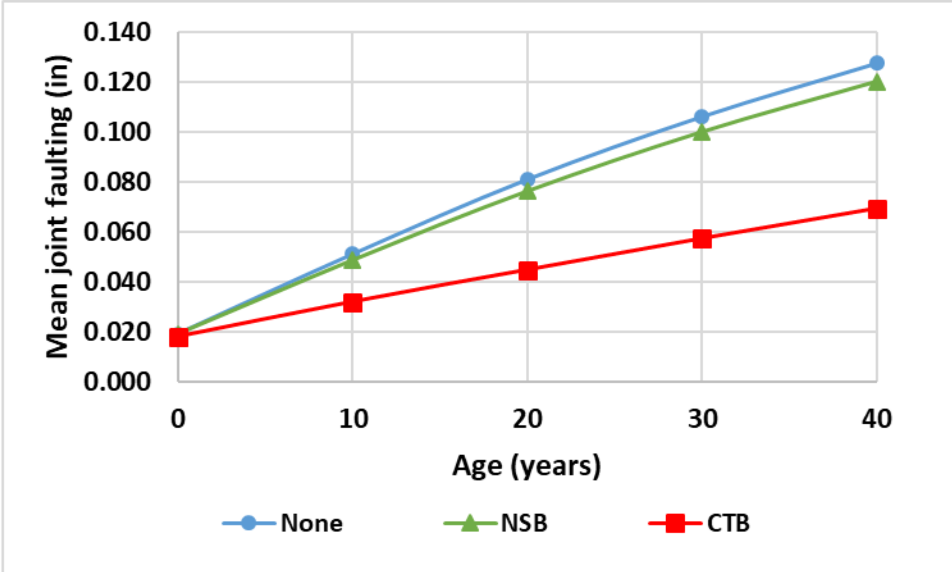


Figure 35 Effect of Base Type on JPCP Joint Faulting

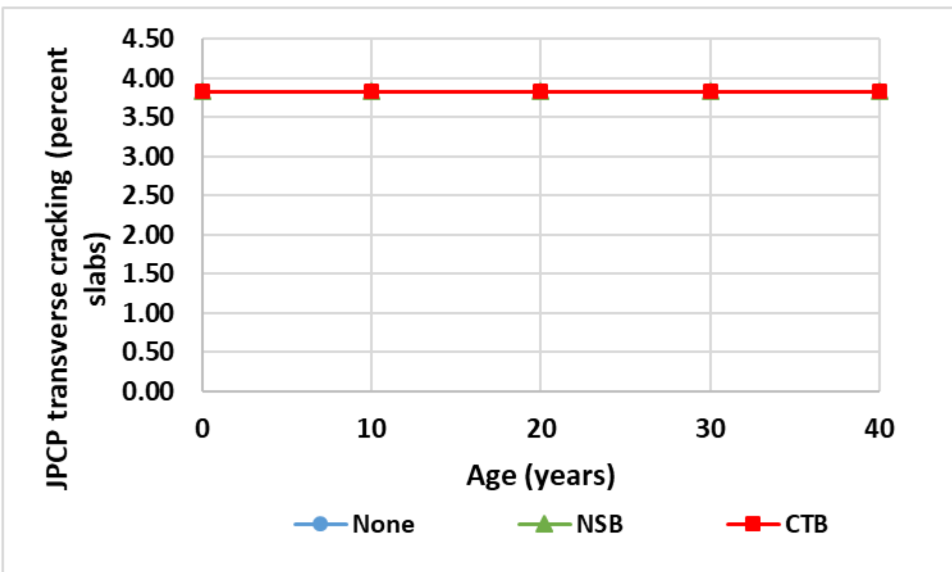


Figure 36 Effect of Base Type on JPCP Transverse Slab Cracking

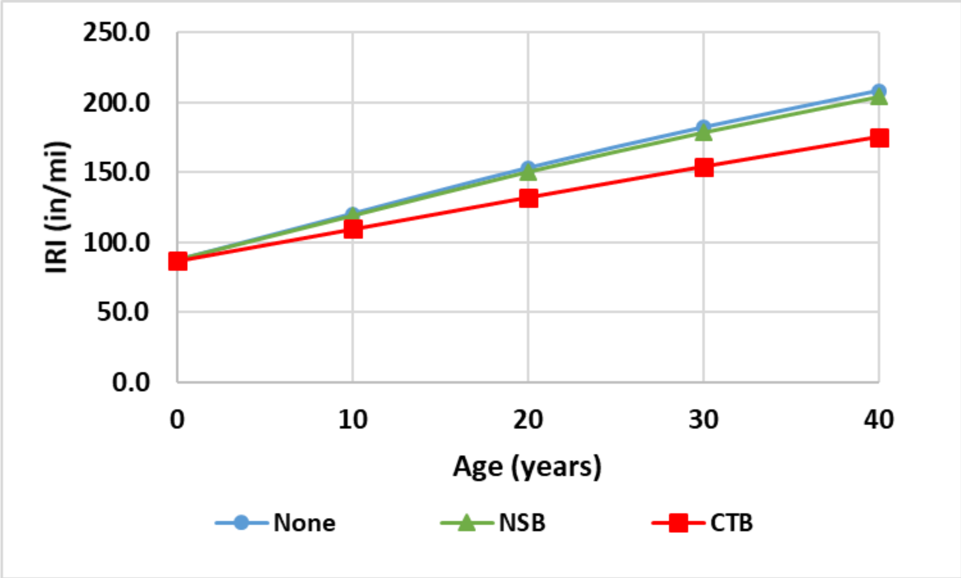


Figure 37 Effect of Base Type on JPCP IRI

Modulus of Rupture

Figures 38 through 40 demonstrate the influence of flexural strength (modulus of rupture) on predicted distress, cracking, and IRI. The researchers used a range of MR value from 700 psi to 900 psi. This choice is within the typical values that found in Idaho PCC database mixes. The sensitivity analysis indicated that the impact of MR value (within this range) had a very small effect on faulting and IRI, and no change in the cracking was observed. Table 16 summarizes the effect of all the previous inputs and categorizes them based on their effect on the performance to high, medium, and low.

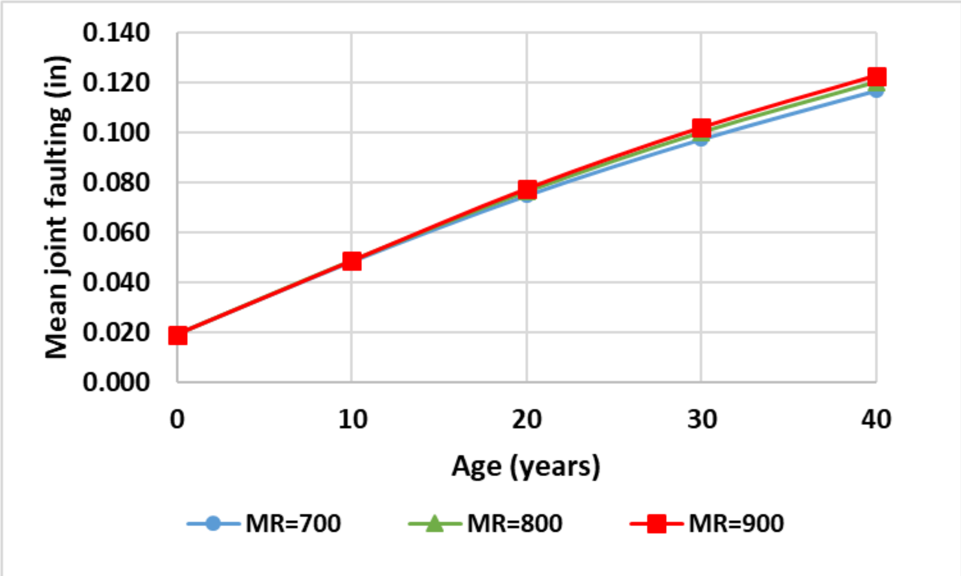


Figure 38 Effect of MR on JPCP Joint Faulting

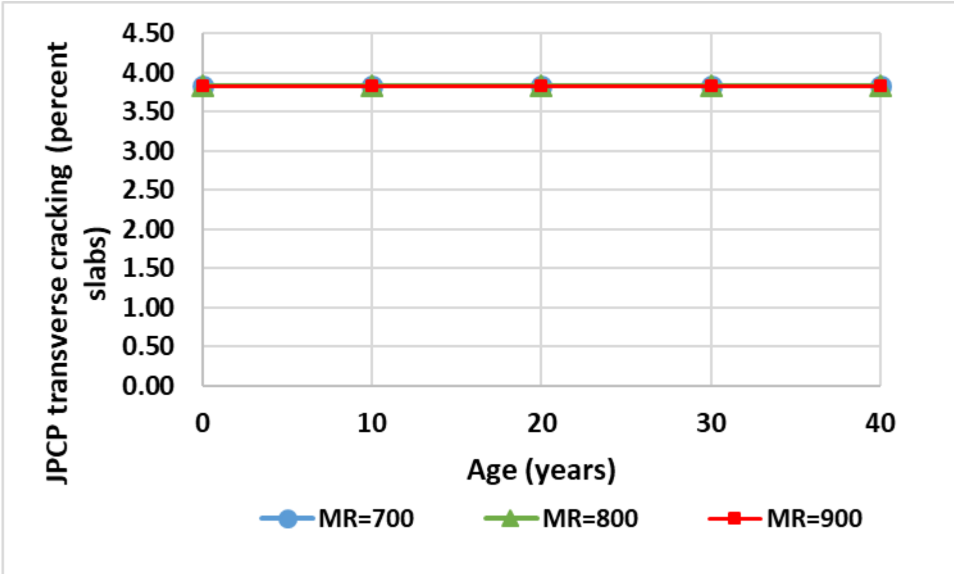


Figure 39 Effect of MR on JPCP Transverse Slab Cracking

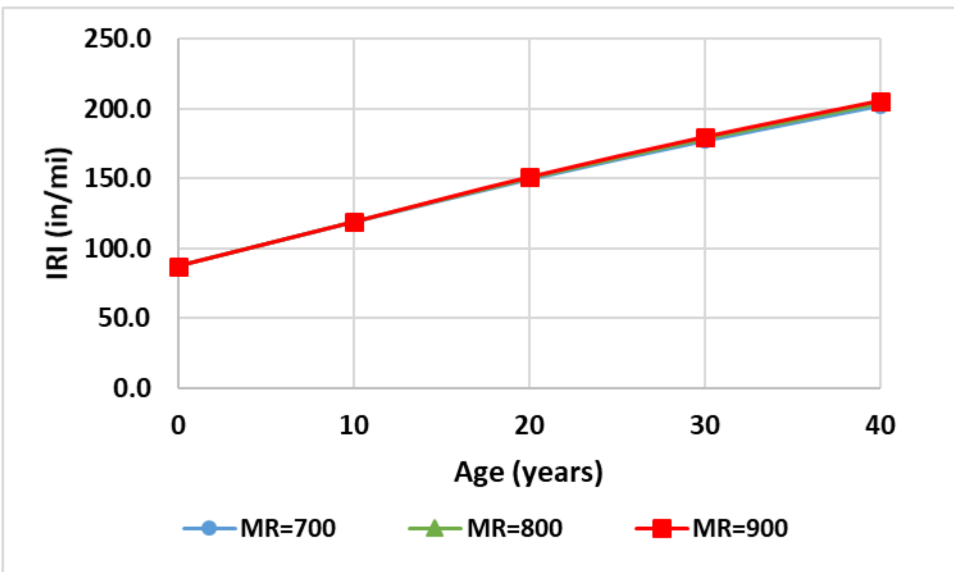


Figure 40 Effect of MR on JPCP IRI

Table 16 Summary of Sensitivity Analysis of New JPCP Results

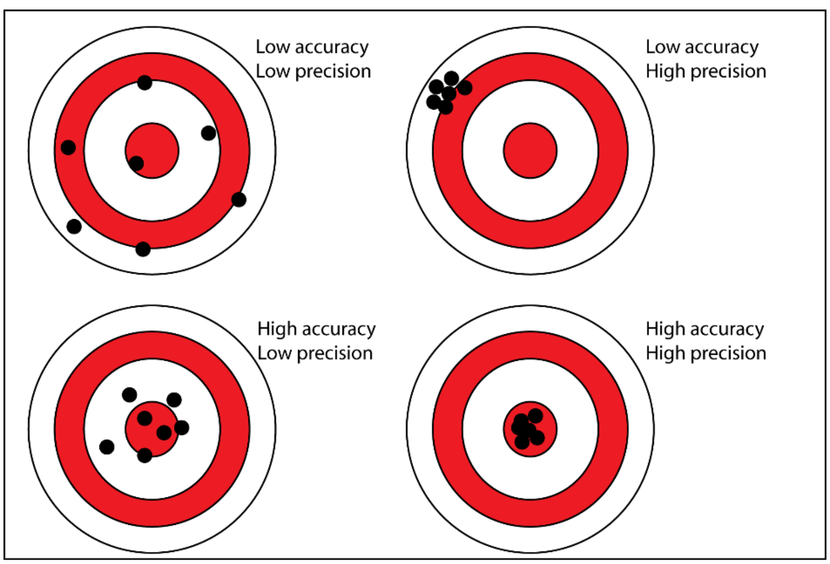
Input Parameter	Transverse Slab Cracking	Transverse Joint Faulting	IRI
Truck Traffic Volume	M	H	M
PCC Thickness	H	M	M
CTE	M	H	M
Dowels Diameter	L	H	M
Joint Spacing	H	M	M
Base Type	L	M	L
Modulus of Rupture	M	L	L

H = High, M = Moderate, L = None to Low.

Chapter 4
Development of Local Calibration Coefficients for Idaho

As previously discussed, the pavement performance prediction models in the PMED are nationally calibrated primarily using LTPP data. A comparison of field-measured and predicted distresses for some road sections in Idaho showed that the national calibration coefficients yielded biased and inaccurate performance predictions, particularly for transverse cracking. Therefore, to improve the PMED performance prediction, it is essential to calibrate to Idaho conditions. Well-calibrated performance models result in reliable pavement design and enable savings in construction and maintenance costs. This chapter presents the process of developing the local calibration coefficients for rigid pavement prediction models for Idaho.

Calibration, as defined in the AASHTO *MEPDG Manual of Practice*, means to reduce the total error between the measured and predicted distresses by varying the appropriate model coefficients. There are three important stages in the calibration process. The first stage is to implement verification runs on pavement sections using the national calibration factors. The second stage removes bias and decreases the SEE between the measured and predicted distresses. Once this is achieved and the SEE is within the adequate level set by the user, the third stage include validation of the calibrated prediction models. The validation process defines if the factors are appropriate and adequate for the construction, climate, materials, traffic, and other conditions.[3] Figure 41 illustrates the definitions of accuracy and precision, while Figure 42 illustrates the effects of bias and precision before and after local calibration.



Source: https://www.reddit.com/r/coolguides/comments [29]

Figure 41 Target Analogy for Precision and Accuracy

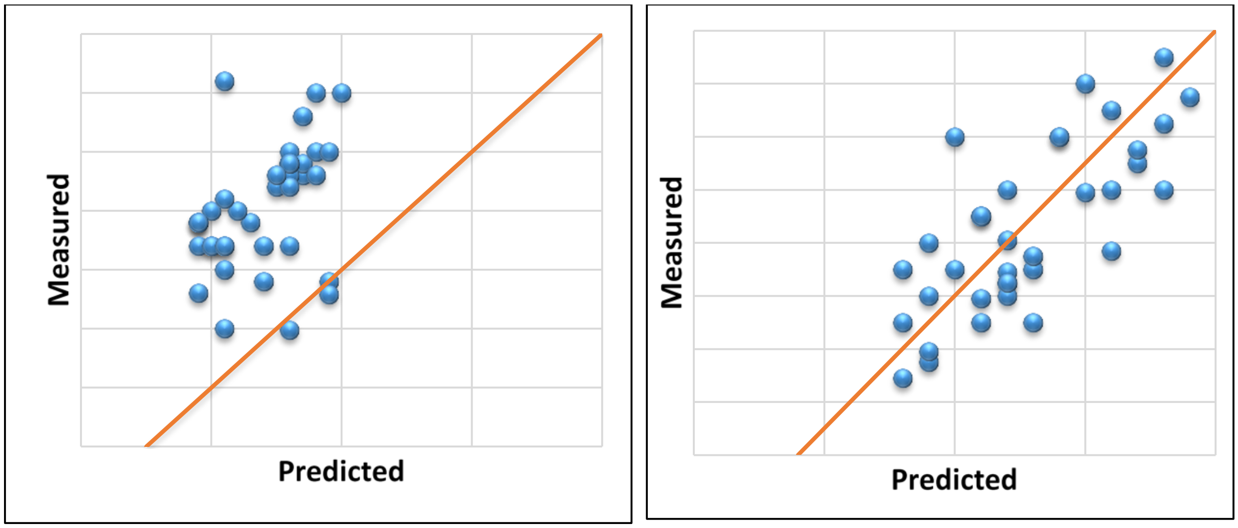


Figure 42 Improvement of Bias and Precision through Local Calibration

Framework for MEPDG Model Calibration and Validation

The AASHTO *Local Calibration Guide* (8) highly recommends each agency conduct an analysis on the results of the PMED to determine if the nationally calibrated models accurately predict field performance. The recommended local calibration steps include:(8)

Step 1 – Selected Hierarchical Input level

There are three levels of data input option available in the PMED. The hierarchical input levels are incorporated to provide the user with the highest flexibility for obtaining project design inputs based on its importance and economic consideration. Hierarchical levels include:

Level 1: this level of data input implies the highest knowledge of material characteristics and traffic condition. This level of input has the highest cost and data collection effort and is generally recommended for projects with the highest importance. This level may be used for forensic analysis of existing pavements.

Level 2: represent the intermediate level of data inputs. It is dependent on correlations or regression equations for inputs. Level 2 represent regional input data.

Level 3: This is the most uncertain data input level and is based on user defined default values. Default values are selected based on engineering experiences and national averages. This input level can be used for low risk, low volume roads when design inputs are not available.

Table 17 presents recommended hierarchical input levels and sensitivity on distress/smoothness prediction models for new JPCP.(12,**Error! Reference source not found.**)

Table 17 Recommended MEPDG Hierarchical Input Levels for New JPCP

Source: ITD Report RP 211A, Road Map for Implementing the AASHTO Pavement ME Design Software [4]

MEPDG Input Variable	**Sensitivity of Predicted Faulting**	**Sensitivity of Predicted Transverse Cracking**	**Sensitivity of Predicted IRI**	**Recommended Hierarchical Input Level**
PCC thickness	XX	XXX	XX	Level 1
PCC modulus of rupture and elasticity		XXX	X	Levels 2 and 3
PCC CTE	XXX	XXX	XXX	Level 1 and 2
Joint Spacing	XX	XXX	XX	Level 1
Lane to PCC shoulder long-term load transfer efficiency	XXX		XXX	Level 3
Edge Support	XX	XXX	XX	Level 1
Permanent curl/warp	XXX	XXX	XXX	Level 3
Base type	XXX	XXX	X	Level 1
Climate	XXX	XXX	XXX	Level 2
Subgrade type/modulus	X	XX	X	Level 1
Truck axle load distribution	X	XXX	X	Level 1
Truck volume	XXX	XXX	XXX	Level 1
Tire Pressure		X		Level 3
Truck lateral offset	XX	XXX	XX	Level 3
Truck wander		XX		Level 3
Initial IRI			XXX	Level 1 or 2

X = Small effect on distress/IRI; XX = Moderate effect on distress/IRI; XXX =Large effect on distress/IRI

It was observed that, all input data obtained for each project contains a mix of input levels. Figure 43 shows an example of typical input data collected from the ITD construction history and material records. Additional data is provided in Appendix B.

District 3_Project 1
Project Section: I-84 from Black Canyon Interchange to Sand Hollow Interchange
Mile post 12.6 to 17.61

DISTRICT 3 SELECTETED PAVEMENT SECTIONS

GO BACK TO MAIN SCREEN

Construction time	**1991**	
Coordinates	**43.833297**	**-116.762454**
Elevation	**2861 ft**	

Pefromance Measurment

IRI/Distresses	2012	2013	2014	2015
IRI (in/mile)	60.89	77.81	65.82	63.80
Faulting (in)	Seen or Not Colle	een or Not Colle	een or Not Colle	0.15
Transverse Cracking (%)	0.00	0.00	0.00	0.11

Structure

Layer #	Layer type	Thickness (in)	Property
1	PCC	9	Default_level3
2	Base	4.8	3/4" Agg. Base at 143 lbs/cf with 7
3	Subbase	4.8	Granular Borrow 2"
4	Subgrade	-	level 3

Traffic Data

ADT @ 1988	10120
ADT @ 1992	11380
Growth Factor (%)	3.11%
Trucks	
ADTT in 1992	2980
ADTT in 2012	5430
Growth Factor (%)	4.11%

Joint Design

Joint spacing	15 ft
Dowel dia.	1.25
Dowel length	18"& spacing 12"
Tie Bars	# 5 at 30" C. to C.

Figure 43 Example of Road Segment Input Data

Step 2 – Experimental Factorial and Matrix of Sampling Templates

Based on the *Local Calibration Guide* [7], the sampling template should be designed as a fractional factorial matrix as much as possible. The matrix must include more than a few pavement sections with different traffic loads, structures, subgrade types, and rehabilitation practices. Although not all cells in the matrix will likely be filled with full replicate roadway segments, the matrix should be balanced for specific design features or site conditions for each type of pavement and distress. The main objective of this step is to clarify the calibration of the PMED distress and IRI prediction models based on local conditions, materials, and policies. The local calibration sample for every distress simulation model would be designed to achieve three goals:

1. Determine local bias in the distress prediction models.
2. Define or find the cause of any bias that may be found through the local validation procedure.
3. Compute the local calibration coefficients for each distress and IRI prediction model.

Table 18 presents preliminary experimental sampling matrix for PCC pavements as recommend by RP 211 research project.

Table 18 Preliminary Experimental Sampling Matrix for PCC Pavements

JPCP Joints	Volume of Truck Traffic	Soil Type	New Design Unbound Base	New Design Stabilized Base	Rehabilitation PCC Over Flexible	Rehabilitation PCC Over Rigid	Rehabilitation CPR
With Dowels	Low	Coarse Grained					
With Dowels	Low	Low Plasticity					
With Dowels	Low	High Plasticity					
With Dowels	High	Coarse Grained					
With Dowels	High	Low Plasticity					
With Dowels	High	High Plasticity					
Without Dowels	Low	Coarse Grained					
Without Dowels	Low	Low Plasticity					
Without Dowels	Low	High Plasticity					

Step 3 – Minimum Sample Size Required for Validation and Local Calibration of Distress Prediction Model

The *Local Calibration Guide*[8] provides criteria for defining the minimum sample size for validation and local calibration of the PMED distress prediction models. The minimum required sample size, n, depends on design reliability level, confidence Interval, SEE of the nationally calibrated models, and performance indicator threshold values, as per equation in Figure (44).

$$n = \left(\frac{\frac{Z\alpha * \sigma}{2}}{E}\right)$$

where,
$Z_{\alpha/2}$ = 1.601 (for a 90 percent confidence level),
σ = performance indicator threshold (design criteria), and
E = tolerable bias at 90 percent reliability (1.601*SEE).

Figure 44 Equation of Minimum Sample Size, n

Table 19 represents an estimated minimum number of pavement projects required for the validation and local calibration as per Eq. 10 (Figure 44).[8]

Table 19 Estimated Number of Pavement Projects Required for the Validation and Local Calibration

Pavement Type	Performance Indicator	Performance Threshold (at 90% Reliability)	SEE	Minimum Number of Projects Required for Validation & Local Calibration as per Eq 10	Recommended Minimum Number of Projects Required for Idaho JPCP
New JPCP	Faulting	<0.15 in.	0.033 in.	21	21
New JPCP	Transverse cracking	< 10 percent slabs	4.52 percent	5	21
New JPCP	IRI	169 in/mi	17.1 in/mi	98	21

It is to be noted that, even though minimum number of projects required for IRI validation was 98, the controlling number here was 21. This does not mean that IRI was excluded in project selection because IRI equation depends on other pavement distress prediction's accuracy and site factors. Therefore, it is not necessary to validate the IRI model for a wide range of projects if other distress functions satisfy minimum project requirements and are deemed to be accurate and reasonable.[8]

Step 4 – Selection of Projects

In this step, the road sections with adequate construction history and performance data are recommended for the calibration process. These sections must have a minimum required data, include but not limited to:

- Project location (latitude and longitude).
- Construction year and month.
- As-built pavement structure (layer type and thickness of each layer).
- PCC/base/subbase/subgrade material properties required by the software.
- Traffic volume and axle load spectra data in the required PMED format.
- Performance data (mean joint faulting, transverse slab cracking, and IRI) at different points of time.
- Maintenance history.

Based on the research team's experience, level 1 data for in-service pavement sections in Idaho is difficult to obtain for most of the required inputs. Thus, level 2 and 3 input data will be used where level 1 data is unavailable. Results obtained from Project RP253 will play a vital role in the characterization of the material properties. Table 20 and Figure 44 present pavement sections selected for the calibration and the geological location of these sections, respectively.

Table 20 Identified Local PCC Sections in Idaho

District #	Construction Year	Route	Beg MP	End MP
D1	1991	I-90	58.5	62.25
D2	1924	US-95	0.06	0.11
D2	2011	SH008	2.77	3.27
D2	1976	US-95	251.075	261.588
D2	2004	US-12	2.197	2.62
D3	1981	I-84	26.35	28.3
D3	2011	I-84	36	38.7
D3	2009	I-84	41.3	43.8
D3	2004	I-84	49.15	49.73
D3	1996	I-84	49.73	50.21
D3	1972	I-84	58.8	59
D3	2001	I-84	70.1	82.3
D3	1996	I-84	90	94.6
D3	1983	I-84	94.3	103.5
D3	1994	I-84	103.5	109.1
D3	1995	I-84	114.5	121.2
D4	1979	I-84	120.66	127.945
D5	1972	I-15	30.87	36.207
D5	1960	I-86	14.808	25.98
D5	1985	US-91	80.15	81.02
D5	1986	US-91	78.81	79.66
LTPP_16_3023	1983	I-84 (ID)	15.1	
LTPP_49_3010	1978	I-15 (UT)	83.7	
LTPP_49_3011	1986	I-15 (UT)	221.2	
LTPP_49_7082	1990	I-15 (UT)	391.9	
LTPP_49_7085	1991	U.S. - 40 (UT)	12.6	
LTPP_49_7086	1991	SH – 154 (UT)	19	
LTPP_53_3013	1970	U.S. – 195 (WA)	91.6	
LTPP_53_3014	1986	U.S. – 395 (WA)	26.1	
LTPP_53_3019	1986	I-82 (WA)	115	
LTPP_53_3813	1966	SH-14 (WA)	11	
LTPP_53_7049	1981	I-82 (WA)	49	
LTPP_56_3027	1981	I-80 (WY)	103.2	
LTPP_32_3010	1982	I-80 (NV)	348.6	
LTPP_32_3013	1981	I-80 (NV)	401	

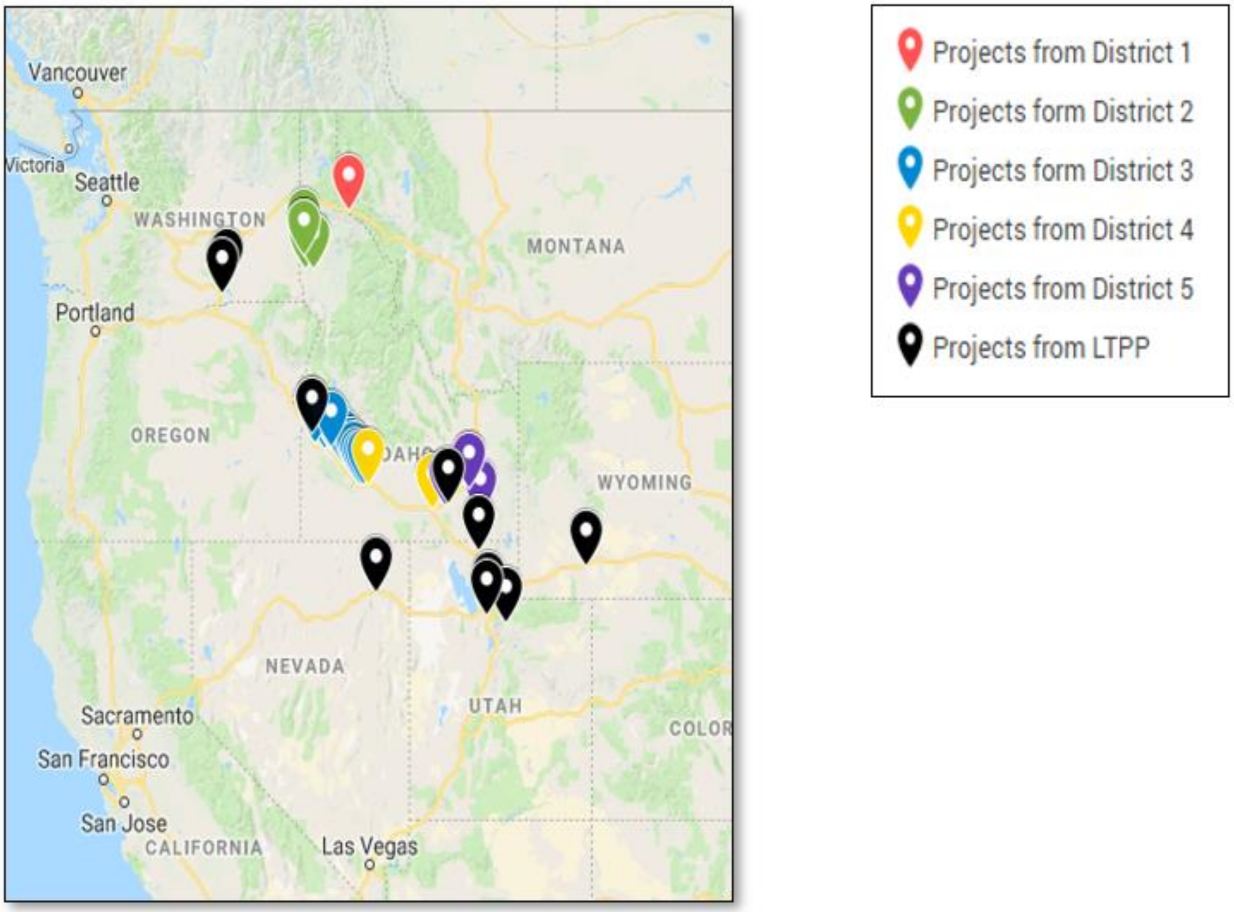


Figure 45 Selected Rigid Pavement Sections

Step 5 – Extraction and Evaluation of Distress and Project Data

Four activities are included in this step:

Extract and review distress/IRI data for each identified project: Distress data should be reviewed to confirm its quality and acceptance for the calibration process. If needed, the reported distress and smoothness data should be converted to match the PMED default reporting units.

Compare performance indicator magnitudes to the design threshold values: Comparison of the historical distress/IRI measurements from the selected projects to the design threshold values should be conducted to check whether the selected projects are appropriate for validation/calibration.

Evaluate the distress data to identify anomalies and outliers: Observe time series plot of distress/IRI vs. pavement age. Any anomalies can be identified by a sudden change in the data trend. A sudden low distress or smoothness after a growing trend might be caused by rehabilitation works or maintenance.

Determine MEPDG inputs: As indicated earlier, PMED requires comprehensive data inputs. All available inputs should be identified, and projects with outliers or anomalies, assimilation of data inputs should be removed and excluded.

After selecting the roadway segments, the next step is to collect all data and identify any missing information. The collected data can be divided into two main categories, input data (e.g., traffic, pavement structure, layer properties) and performance data.

Rigid pavement cracking reported by ITD includes transverse slab cracking, spalling, scaling, meandering cracks, faulting, and corner breaks. Each distress type includes three severity levels; low, medium, and high. However, the PMED only predicts transverse slab cracking (top down fatigue cracking) and joint faulting.

Step 6 – Field and Forensic Investigations

Field and forensic investigation is recommended to be conducted, as much possible, to collect additional data as needed on the selected pavement projects to fulfill the project database. If data inputs obtained from various databases seem reasonable, additional field and forensic investigations are not needed. Since, the research team has obtained the video log data for the selected road sections, there was sufficient data to observe crack propagation over the observed period. However, the research team also visited several sites to conduct forensic investigations. For example, the team captured the opportunity of having a US 95 site in Moscow (Jackson Street, in downtown Moscow, Idaho, which is a JPCP Pavement) to collect further distress information that were present. Site is located on US 95 between MP 345.051 and 345.637. The collected data ate presented in Tables 21 and 22.

Table 21 Summary of Observed Distress at Jackson Street (US95), Moscow, Idaho

Crack Type of Distress (Cracking or Patching)	**Number of Distressed Slabs**	**Percent of Total Slabs**
Corner Cracking	12	7.2%
Diagonal Cracking	4	2.4%
Edge Cracking	4	2.4%
Longitudinal Cracking	30	18.1%
Transverse Cracking	52	31.3%
Patching	5	3.0%
Total Number of Slabs at the site is 166		

Table 22 Detailed Analysis of Transverse Cracking Evaluation at Jackson Street (US95), Moscow, Idaho

	Left Lane	**Middle Lane**	**Right Lane**	**Total**
Number of Slabs with Transverse Cracking	7	14	31	52
Percent of Slabs with Transverse Cracking *(Total No of slabs = 166)*	4.22%	8.43%	18.67%	31.3%

Step 7 – Assessment of Local Bias from Global Calibration Factors

Bias is defined as the consistent under or over prediction of distress/IRI. Statistical approaches are used to determine bias for the global calibration factors[8]. The hypothesis test with a significance level, α, of 0.05 or 5 percent will be assumed for all hypothesis testing of the data.

Hypothesis: determine whether the linear regression model developed using measured and PMED predicted distress/IRI has an intercept of zero. Using the results of the linear regression analysis, test the following null and alternative hypotheses to determine if the fitted linear regression model has an intercept of zero.

i. H_0: Model intercept = 0.

ii. H_A: Model intercept ≠ 0.

If the null hypothesis is accepted, local calibration is not required and the global calibration coefficients are robust and produce accurate predictions of pavement distress. Rejecting the null hypothesis (p-value < 0.05) implies the measured and predicted PMED distress/IRI are from different populations. This indicates that for the range of distress/IRI used in the analysis, the PMED results in biased predictions. When the null hypothesis is rejected, adjustments need to be made to the calibration coefficients due to the significant differences found between the predicted and measured performance. It will also be necessary to determine which calibration coefficients are causing these differences so appropriate adjustments can be made. The experimental plan and sampling matrix is developed around the hypothesis that there is no significant bias and no error between the measured and predicted performance.

Step 8 – Elimination of Local Bias

If the null hypothesis is rejected, the nationally calibrated coefficients need to be reviewed. The cause of the local bias should be identified, and it should be removed in this step. Elimination of bias should consider climate, traffic conditions, and material characteristics. Modifying calibration coefficients and reanalyzing the models can enhance predictions. Table 23 shows the recommended calibration coefficients to be modified to eliminate bias.[8]

Table 23 Recommendations for modifying MEPDG JPCP distress/IRI models global/local coefficients to eliminate bias

Distress	Eliminate Bias	Reduce SEE
JPCP Faulting	C_1	C_2, C_7
JPCP Transverse cracking	C_1, C_4	C_2, C_5
JPCP IRI	C_4	C_1
CRCP Punchouts	C_3	C_4, C_5
CRCP Punchouts fatigue	C_1	C_2
CRCP IRI	-	C_1, C_2

Step 9 – Assessment of SEE

Once bias has been eliminated, the SEE and the coefficient of determination (R^2) are calculated using the new calibration coefficients to assess the calibrated models goodness of fit. The calibrated model's SEE and R^2 are at that point compared to the PMED global calibration SEE and R^2. Diagnostic statistics and engineering judgment could be used to indicate the reasonableness of good of fit. Models exhibiting a poor R^2 (i.e., R^2 less than 50 percent) or excessive SEE are deemed as having a poor goodness of fit.

Step 10 – Reduction of SEE

If the user decides that the SEE is too large, resulting in overly conservative designs at higher reliability levels, revisions to the local calibration values of the transfer function may be needed. This step can be complicated and will probably require external revisions to the local calibration parameters or agency specific values to improve the prediction models' precision. The *Local Calibration Guide*(8) provides some general guidance for accomplishing this step.

Step 11 – Interpretation of Results

A limited sensitivity analysis of the locally calibrated models should be conducted to determine the reasonableness of predictions, and how predictions differ from the PMED nationally calibrated models. Based on the sensitivity analysis, the developed calibration factors can be accepted or adjustments can be made to the locally calibrated models as needed.

Calibration Coefficients of Joint Faulting Model for JPCP

Verification of the nationally calibrated faulting model showed the model produced satisfactory predictions, and the null hypothesis, no significant difference between the measured and predicted performance, was accepted and the national calibration coefficients can be adopted. However, since there was some bias, as shown in table 24, the researchers conducted several trials to reduce the bias further. According to the *Local Calibration Guide*(8), the C1 calibration factor can be adjusted to reduce both bias and SEE. After several trials, the final calibration results provided lower bias (near zero) and the SEE was also found to be reasonable, and lower than 0.1 inch. Figures 46 and 47 show the faulting data with the global and local calibration coefficients, respectively. The statistical summary of the data is presented in table 25.

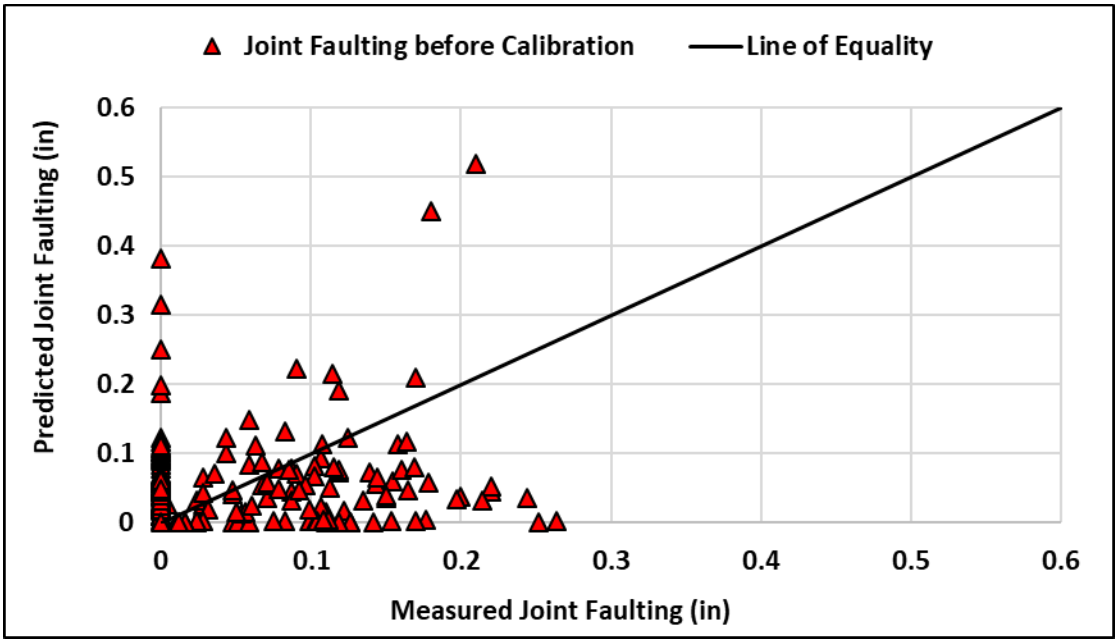


Figure 46 Measured vs. Predicted Joint Faulting Using National Calibration Coefficients

Table 24 National Calibration Coefficients for Joint Faulting

Performance Model Parameter	National Calibration Coefficients	N	Bias, $er_{(mean)}$	Standard Error, Se	Se/Sy	R^2, %	p-value (Paired t-test)
Faulting C1	0.595	178	-0.725	0.1	1.399	Poor	0.285
Faulting C2	1.636	178	-0.725	0.1	1.399	Poor	0.285
Faulting C3	0.00217	178	-0.725	0.1	1.399	Poor	0.285
Faulting C4	0.00444	178	-0.725	0.1	1.399	Poor	0.285
Faulting C5	250	178	-0.725	0.1	1.399	Poor	0.285
Faulting C6	0.47	178	-0.725	0.1	1.399	Poor	0.285
Faulting C7	7.3	178	-0.725	0.1	1.399	Poor	0.285
Faulting C8	400	178	-0.725	0.1	1.399	Poor	0.285

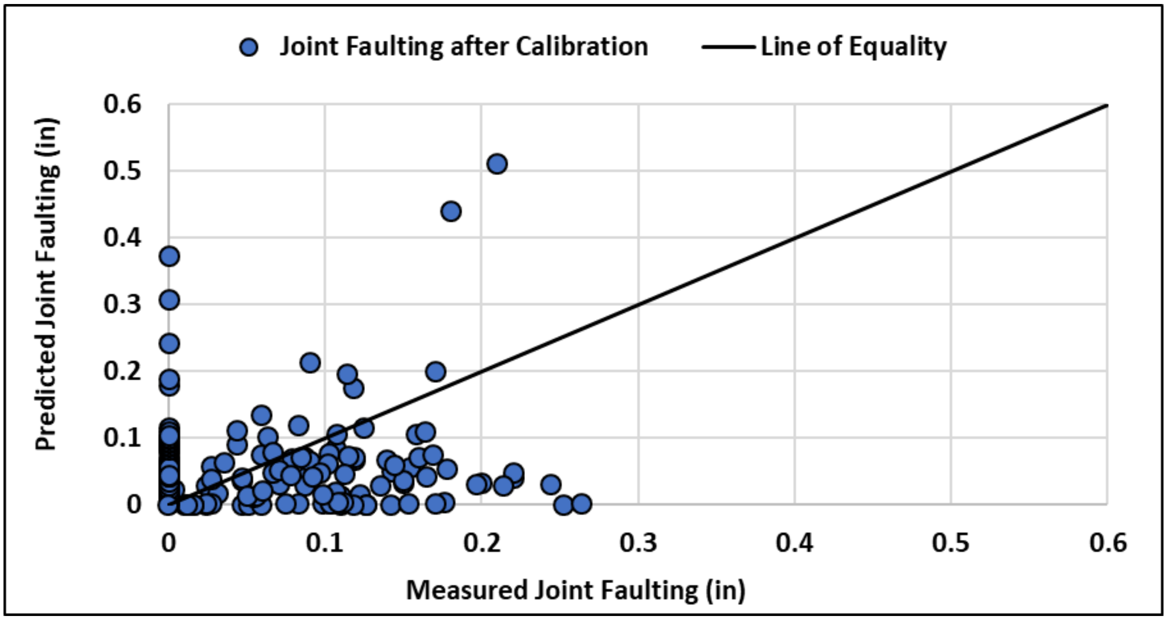


Figure 47 Measured vs. Predicted Joint Faulting Using Local Calibration Coefficients

Table 25 Local Calibration Coefficients for Joint Faulting

Performance Model Parameter	Local Calibration Coefficients	N	Bias, $er_{(mean)}$	Standard Error, Se	Se/Sy	R^2, %	p-value (Paired t-test)
Faulting C1	0.516	178	0.002	0.093	1.37	Poor	0.499
Faulting C2	1.636	178	0.002	0.093	1.37	Poor	0.499
Faulting C3	0.00217	178	0.002	0.093	1.37	Poor	0.499
Faulting C4	0.00444	178	0.002	0.093	1.37	Poor	0.499
Faulting C5	250	178	0.002	0.093	1.37	Poor	0.499
Faulting C6	0.47	178	0.002	0.093	1.37	Poor	0.499
Faulting C7	7.3	178	0.002	0.093	1.37	Poor	0.499
Faulting C8	400	178	0.002	0.093	1.37	Poor	0.499

Calibration Coefficients of Transverse Cracking Model for JPCP

The verification of the transverse cracking predictions using the global calibration coefficients was conducted. The statistical analysis revealed that the null hypothesis was rejected with significant bias and SEE. The model either over or under predicted cracking in Idaho, with no clear prediction trend. Therefore, local calibration was required. As per the *Local Calibration Guide*[8], adjusting C1 or C4 is recommended to reduce the bias. After several trials for different sets of C1, the optimized value provided lower bias. Although the SEE was found to be in the reasonable range, it was further minimized by adjusting the recommended calibration coefficients C2 and C5. However, during model validation the null hypothesis was not accepted due to poor correlation between measured and predicted cracking. The reason being is that most of the measured cracking values are approximately zero. This is similar to Colorado and Ohio state' studies.[15,21] Therefore, it was recommended to only reduce bias without going further to reduce the standard error (i.e., only C1 was optimized in this study). The resulting null hypothesis was accepted. The transverse cracking data before and after calibration is presented in Figures 48 and 49, respectively. The statistical summary results for the transverse cracking model before and after local calibration are shown in Table 26 and 27, respectively.

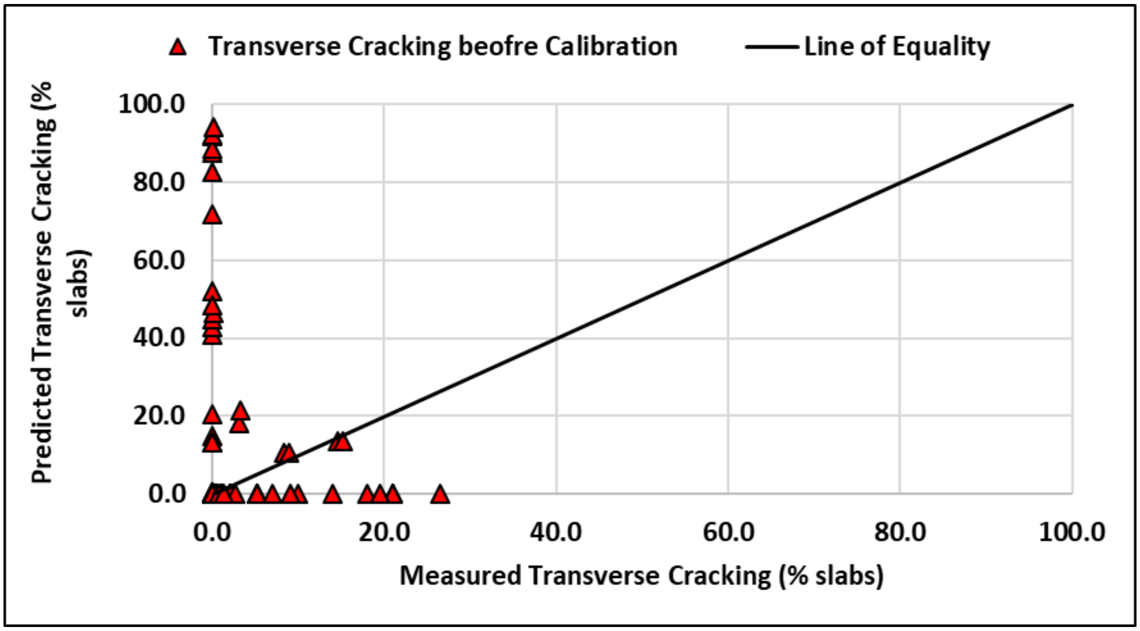


Figure 48 Measured vs. Predicted Transverse Cracking Using National Calibration Coefficients

Table 26 National Calibration Coefficients for Transverse Cracking

Performance Model Parameter	National Calibration Coefficients	N	Bias, $er_{(mean)}$	Standard Error, Se	Se/Sy	R^2, %	p-value (Paired t-test)
Transverse Cracking C1	2	196	-767.6	18.9	4.450	Poor	0.002
Transverse Cracking C2	1.22	196	-767.6	18.9	4.450	Poor	0.002
Transverse Cracking C4	0.52	196	-767.6	18.9	4.450	Poor	0.002
Transverse Cracking C5	-2.17	196	-767.6	18.9	4.450	Poor	0.002

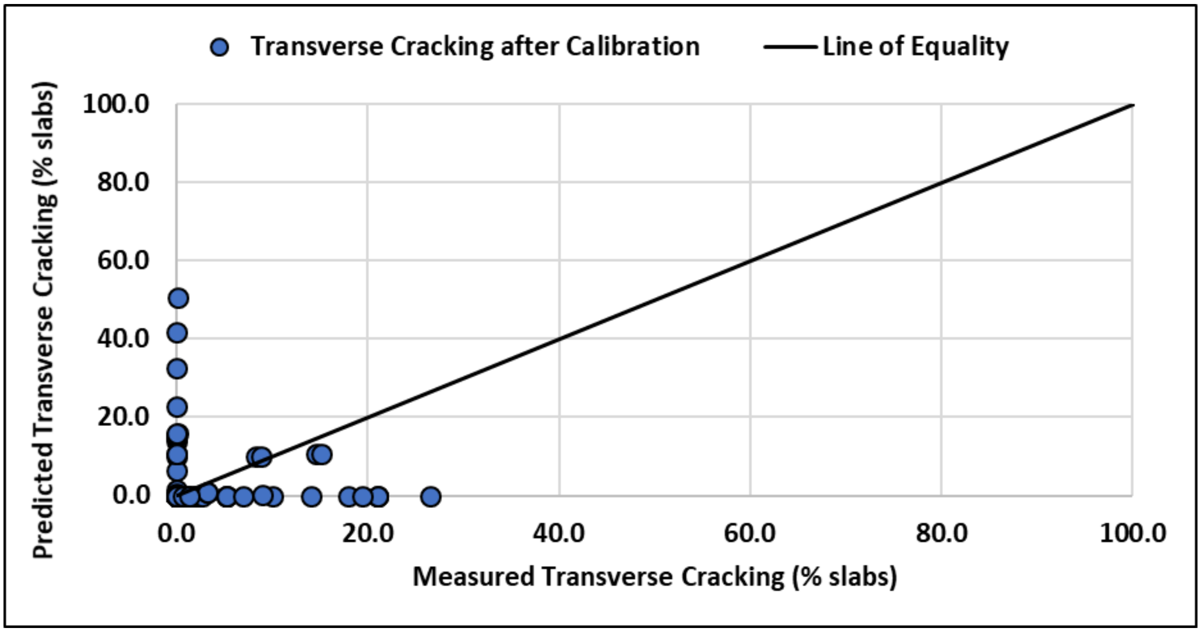


Figure 49 Measured vs. Predicted Transverse Cracking Using Local Calibration Coefficients

Table 27 Local Calibration Coefficients for Transverse Cracking

Performance Model Parameter	Local Calibration Coefficients	N	Bias, $er_{(mean)}$	Standard Error, Se	Se/Sy	R^2, %	p-value (Paired t-test)
Transverse Cracking C1	2.366	196	-69.02	7.6	1.8	Poor	0.258
Transverse Cracking C2	1.22	196	-69.02	7.6	1.8	Poor	0.258
Transverse Cracking C4	0.52	196	-69.02	7.6	1.8	Poor	0.258
Transverse Cracking C5	-2.17	196	-69.02	7.6	1.8	Poor	0.258

Calibration of Coefficients of International Roughness Index (IRI) Model for JPCP

The comparison of predicted and measured IRI with the global calibration coefficients showed significant bias and SEE. The p-value is lower than 0.05, which implies the null hypothesis should be rejected. Local calibration was attempted to reduce bias and SEE. The calibration coefficients J1 and J4 were adjusted. After several trials of adjusting J4, the bias was significantly reduced from -1404.41 to -0.37. Also, the adjusting J4 reduced the SEE. The null hypothesis was accepted. Figures 50 and 51 show the IRI data before and after the calibration. Tables 28 and 29 represent the summary of the statistics results for the verification of the IRI model.

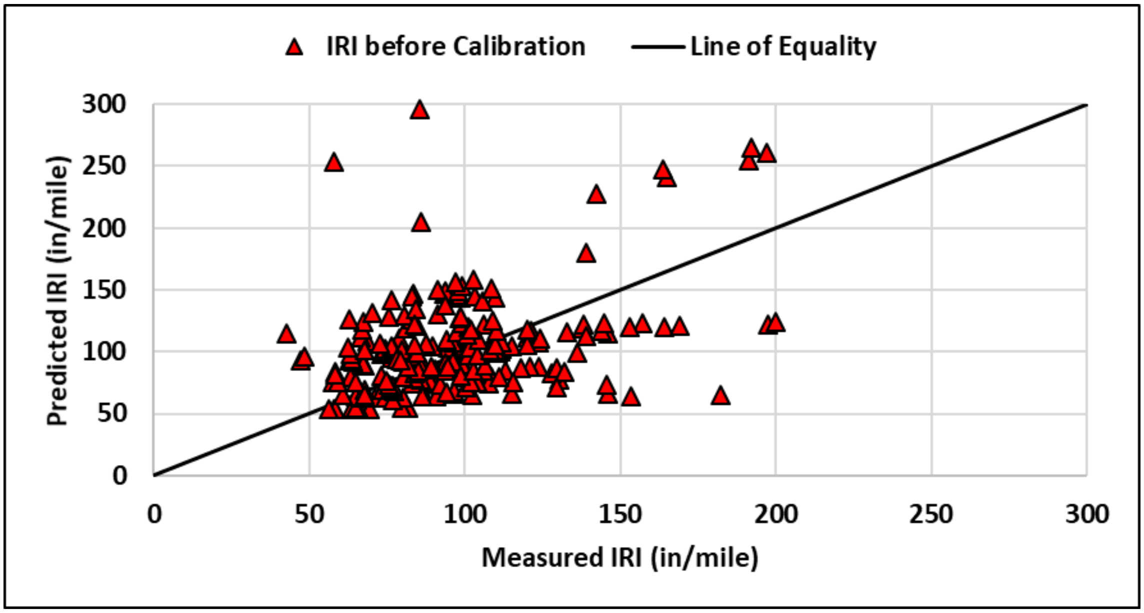


Figure 50 Measured vs. Predicted IRI Using National Calibration Coefficients

Table 28 National Calibration Coefficients for the IRI

Performance Model Parameter	National Calibration Coefficients	N	Bias, $er_{(mean)}$	Standard Error, Se	Se/Sy	R^2, %	p-value (Paired t-test)
IRI J1	0.8203	223	-1404.4	39.24	1.34	15	0.008
IRI J2	0.4417	223	-1404.4	39.24	1.34	15	0.008
IRI J3	1.4929	223	-1404.4	39.24	1.34	15	0.008
IRI J4	25.24	223	-1404.4	39.24	1.34	15	0.008

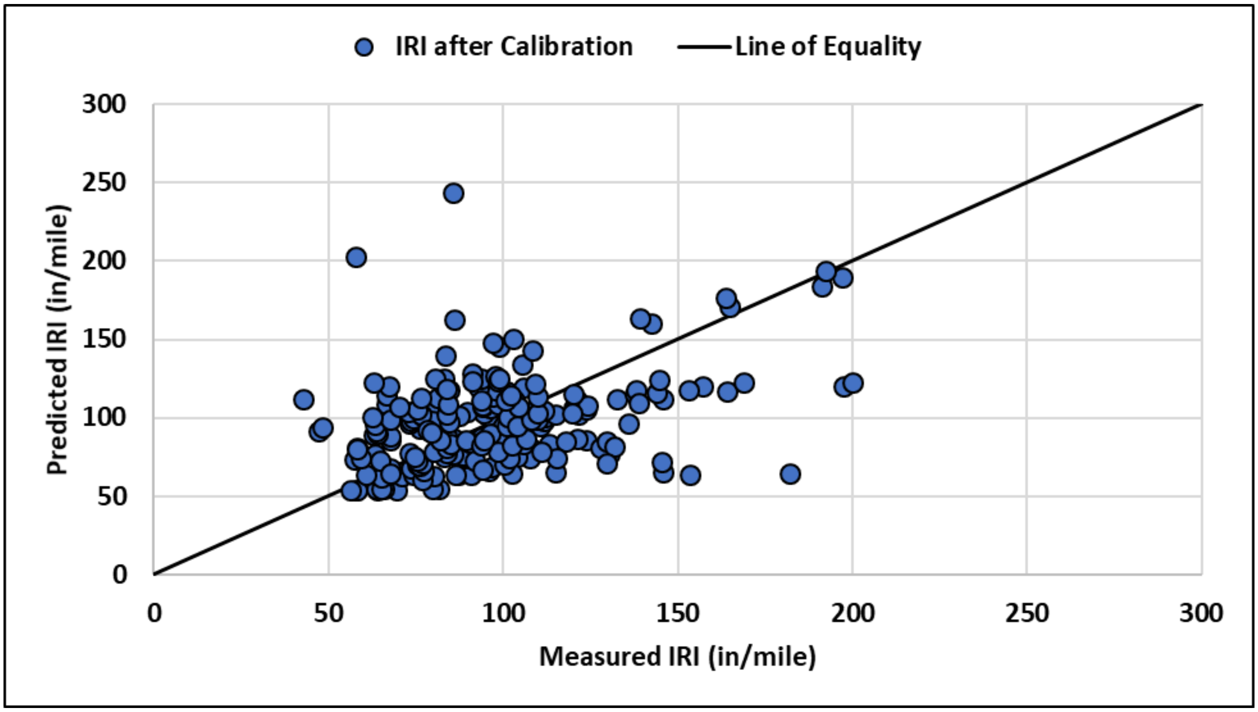


Figure 51 Measured vs. Predicted IRI Using Local Calibration Coefficients

Table 29 Local Calibration Coefficients for the IRI

Performance Model Parameter	Parameter	Local Calibration Coefficients	N	Bias, $er_{(mean)}$	Standard Error, Se	Se/Sy	R^2, %	p-value (Paired t-test)
IRI J1	J1	0.845	223	-0.37	31.89	1.1	15	0.5
IRI J2	J2	0.4417	223	-0.37	31.89	1.1	15	0.5
IRI J3	J3	1.4929	223	-0.37	31.89	1.1	15	0.5
IRI J4	J4	28.24	223	-0.37	31.89	1.1	15	0.5

Calibration Coefficients of Punchout Model for CRCP Pavements

The researchers attempted to locally calibrate the CRCP Punchout model to the Idaho local conditions. However, it was extremely difficult due to the scarcity of the data. Statewide, there is only one LTPP section with CRCP, and it is out of study. The researchers considered including three LTPP sections from Oregon, in that regard, four sections would be available for local calibration. The comparison of predicted and measured Punchout results using the national calibration coefficients are shown in Figure 52 and the statistical analysis are shown in Table 30. The results indicates the model over predicts Punchout and there is a significant difference between the measured and the predicted performance.

However, it is difficult to make a conclusion with such limited number of data points. Therefore, the researchers recommend using the national calibration coefficients.

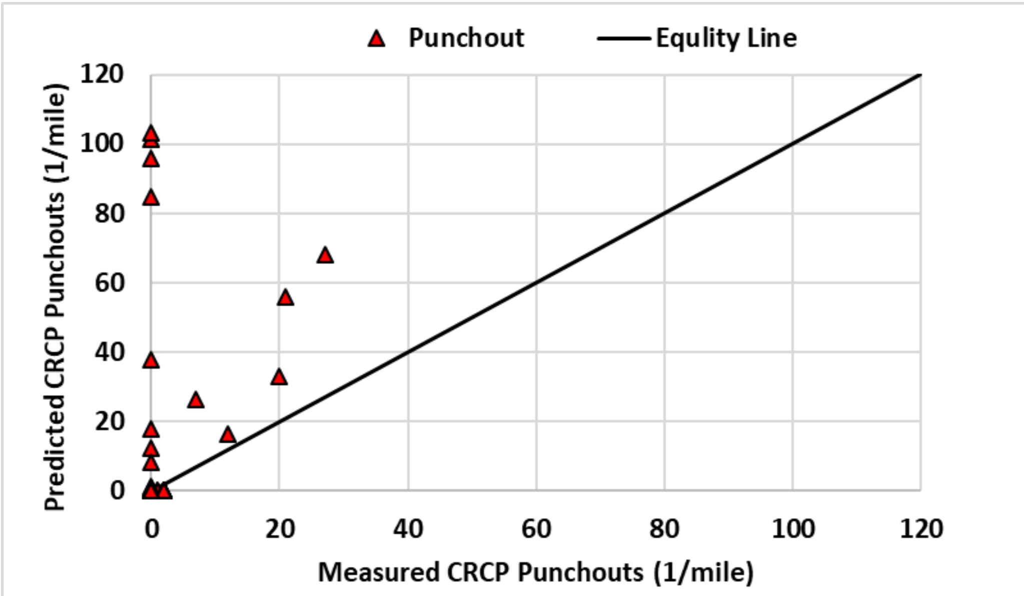


Figure 52 Measured vs. Predicted Punchout Using National Calibration Coefficients

Table 30 National Calibration Coefficients for Punchout

N	Bias (er)	Stand. Error (Se)	sy	Se/Sy	R2 (%)	Hypothesis (p_value)
34	-561.491	35.433	6.717	5.275	7.99%	0.00239

Calibration Coefficients of International Roughness Index (IRI) Model for CRCP

The comparison of predicted and measured IRI for the selected pavement sections using the national calibration coefficients is shown Figure 53. The statistical analysis, as shown in Table 31, indicates significant statistical difference. Since the IRI prediction is correlated to the Punchout, the IRI model can't be calibrated before the calibration of the Punchout model.

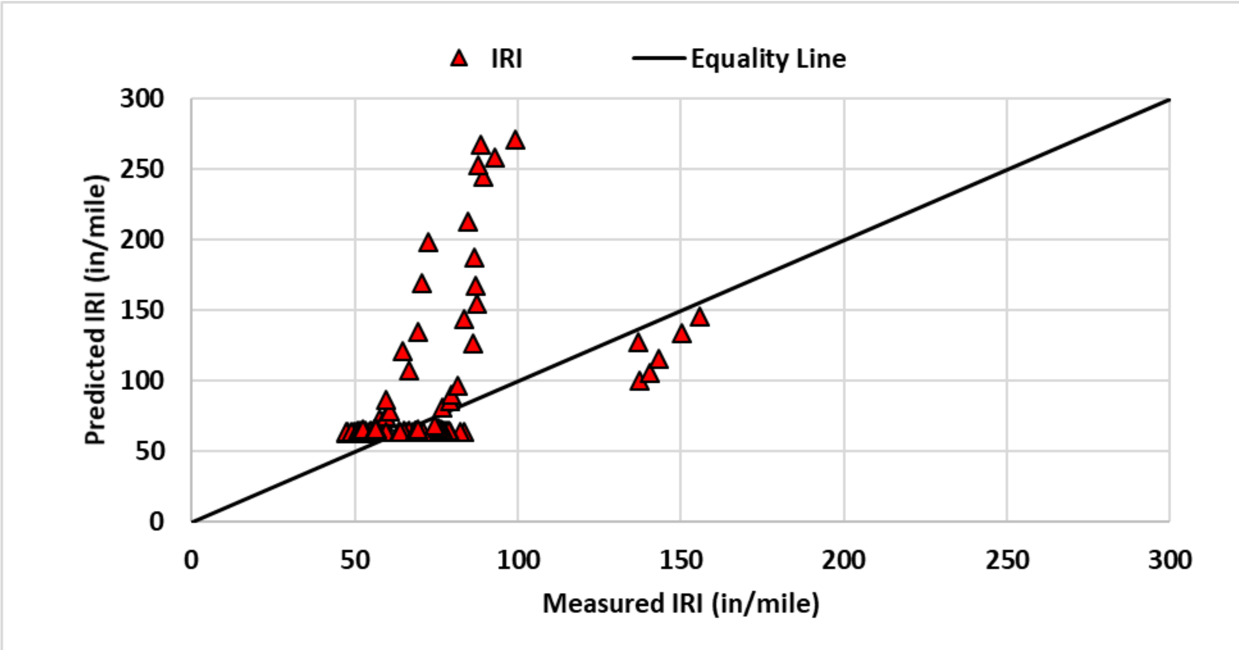


Figure 53 Measured vs. Predicted CRCP IRI Using National Calibration Coefficients

Table 31 Measured vs. Predicted IRI Using National Calibration Coefficients

N	Bias (er)	Stand. Error (Se)	sy	Se/Sy	R2 (%)	Hypothesis (p_value)
81	-1670.00	53.29	23.374	2.2797	19.4%	0.0002

Chapter 5
Validation of the Developed Calibration Coefficients

The objective of model validation is to demonstrate that the calibrated models produce robust and accurate pavement distress predictions for pavement segments exclude from model calibration. Validation typically requires an additional and independent set of in-service pavement performance data. Successful model validation requires that the bias and precision statistics of the model, when applied to the validation data set, are similar to those obtained from model calibration.

The success of the validation process can be gauged based on the bias and SEE of the predicted values. A paired t-test is used to assess the bias for the validation data. A chi-square test is used to compare the SEE for the validation to the SEE for calibration. Both tests use a significance level of alpha = .05. The validation sample should be designed to statistically test the null hypothesis for each performance indicator. If either test rejects the null hypothesis, the soundness and completeness of the conceptual and the operational models must be re-evaluated. Further changes in the models require another round of calibration and validation to assure that the revised models are sufficiently accurate. The benefit of a stringent, independent test on the accuracy of the calibrated model far outweighs the increased costs associated with obtaining two independent data sets.

The split sample approach is typically used in the calibration and validation of statistical and simulation models. A typical split of a sample is 80/20 with 80 percent of the data used in calibration and 20 percent used for verification. It was observed that the local calibration considerably reduced the difference between the predicted and measured distresses/IRI.

Validation of Joint Faulting Model

To validate the local calibration coefficients of the joint faulting model, six independent sections were selected. The predicted joint faulting using the local calibration coefficients was comparable to the field-measured values. The comparison showed lower bias and SEE, and the null hypothesis was accepted. Therefore, the locally calibrated model was successfully validated. Figure 54 and Table 32 present the faulting data and the summary of the statistical results for the faulting model validation, respectively.

Validation of the Transverse Cracking Model

For the transverse cracking model, again due to the poor correlation between the predicted and measured values, it was difficult to validate the developed calibration factors. Most of the selected sections for validation have little to no observed cracking (Figure 55). Even though, the null hypothesis was accepted (Table 33), the researchers believe this to be an insufficient conclusion. Therefore, it is highly recommended additional data be obtained in the future to validate the model.

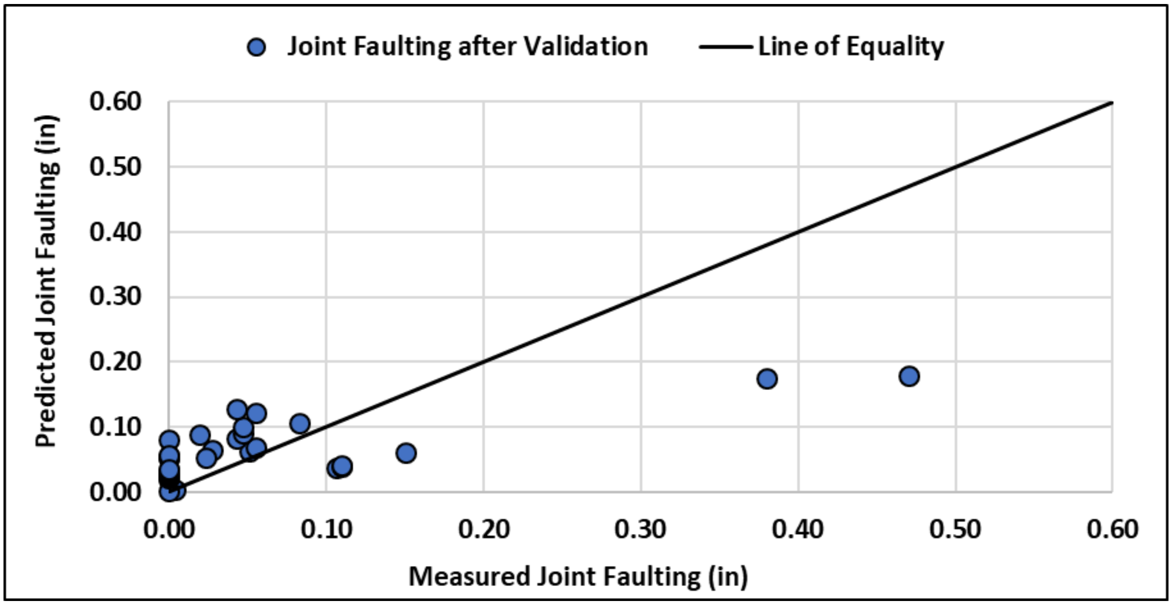


Figure 54 Measured vs. Predicted Joint Faulting Using Local Calibration Coefficients

Table 32 Statistical Summary of Joint Faulting Using Local Calibration Coefficients

N	Bias, $e_{r(mean)}$	Standard Error, Se	Se/Sy	R^2, %	p-value (Paired t-test)
33	-0.214	0.078	0.747	52.1	0.32

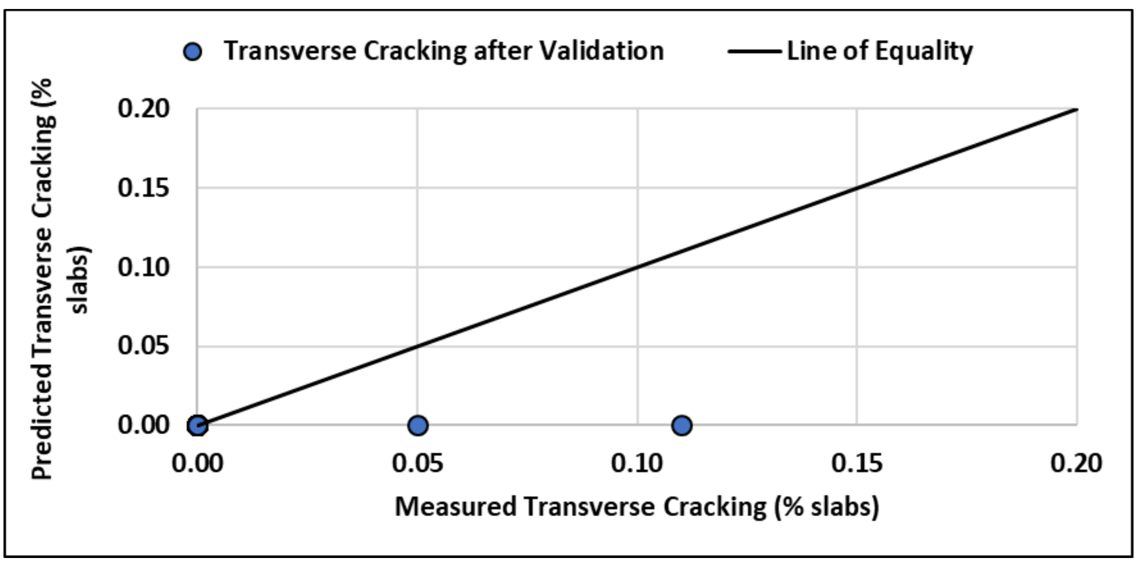


Figure 55 Measured vs. Predicted Transverse Cracking Using Local Calibration Coefficients

Table 33 Local Calibration Coefficients for Transverse Cracking

N	Bias, $e_{r(mean)}$	Standard Error, Se	Se/Sy	R^2, %	p-value (Paired t-test)
33	0.16	0.02	1.01	poor	0.095

Validation of the IRI Model

The locally calibrated IRI model was validated, and the null hypothesis was accepted with p-value of 0.485, which indicated lower bias. Figure 56 and Table 34 present the validation data and statistical summary of the IRI results, respectively.

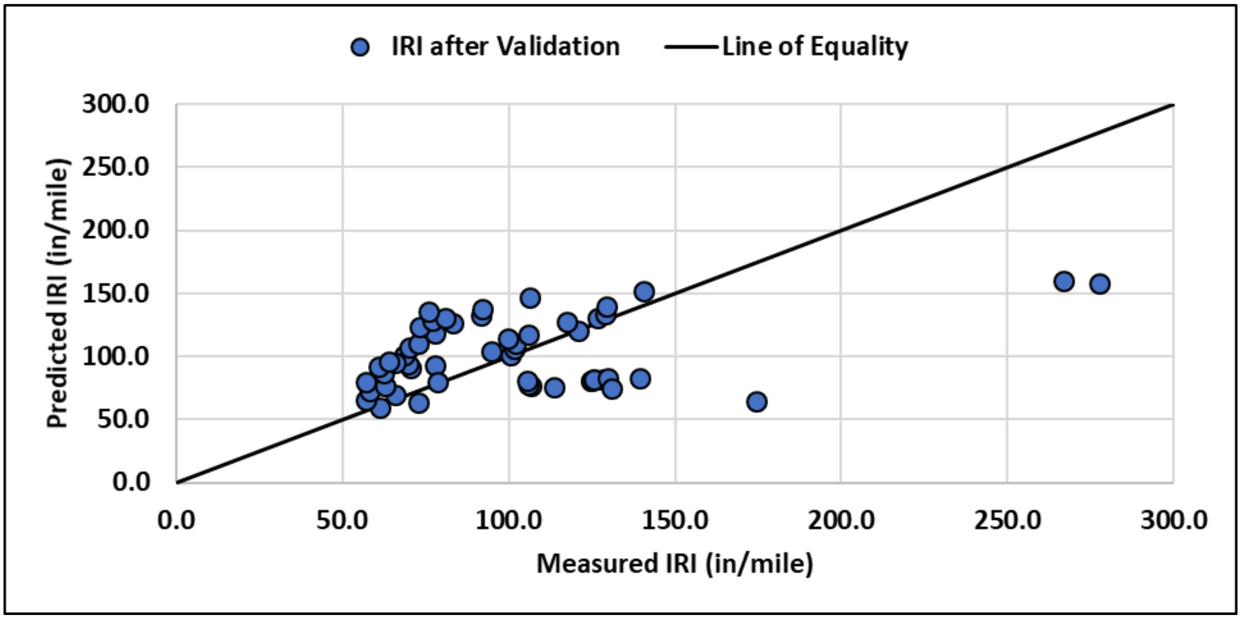


Figure 56 Measured vs. Predicted IRI Using Local Calibration Coefficients

Table 34 Local Calibration Coefficients for IRI

N	Bias, $e_{r(mean)}$	Standard Error, Se	Se/Sy	R^2, %	p-value (Paired t-test)
59	-11.55	41.04	0.940	15	0.485

Chapter 6
Summary, Conclusions and Recommendations

Summary

The main goal of this research project was to determine the calibration coefficients for the rigid pavement performance models in the AASHTOWare Pavement Mechanistic-Empirical Design (PMED) software to suite Idaho local conditions. The study focused on the Jointed Plane Concrete Pavements (JPCP) since they were the most common rigid concrete pavements in Idaho. It also considered few sites for Continuous Reinforced Concrete Pavements (CRCP) from the Long-Term Pavement Performance (LTPP) sites and from adjacent states.

Based on the literature review, many studies highlighted two main issues for successful implementation of the PMED. The first is to provide comprehensive, representative inputs if limited project information is available, and the second is the readiness of field-measured data in a format similar to the PMED outputs. ITD’s current practice of maintaining records of construction history (as built structures) was sufficient to provide traffic, layer thickness, and material property inputs. Previous ITD studies on implementation played a vital role in the success of this calibration by providing sufficient information for all PMED inputs. Performance data, that are stored in the ITD’s Transportation and Asset management System (TAMS) and video log files collected over the past years, provided sufficient field performance data to conduct the calibration effort.

Forty rigid pavement sections were selected for this study to calibrate and verify the accuracy of the PMED models prediction for Idaho local calibrations. The most recent version of the PMED (v2.5.3) was utilized for the calibration process. All the required inputs were collected, at different hierarchical levels, from the ITD engineers, and research projects RP 193, RP 211, and RP 253. Material inputs were extracted primarily from as-built structures and phase reports. Any missing inputs were considered following the Idaho PMED user guide (ITD Report RP 211B). The performance database for the rigid pavements were developed from TAMS and the LTPP database.

In this study, the JPCP prediction models were calibrated to improve prediction accuracy. The local calibration reduced bias and SEE, and the developed calibration coefficients were statistically accepted. Moreover, the traditional splitting approach was followed to validate the calibrated coefficients in Idaho. Table 35 represents the developed local calibration coefficients of Idaho.

Table 35 Idaho Local Calibration Coefficients for the JPCP Models for PMED v2.5.3

Calibration Coefficient	Global Calibration Coefficients	Local Calibration Coefficients
Faulting C1	0.595	0.516
Faulting C2	1.636	1.636
Faulting C3	0.00217	0.00217
Faulting C4	0.00444	0.00444
Faulting C5	250	250
Faulting C6	0.47	0.47
Faulting C7	7.3	7.3
Faulting C8	400	400
Transverse Cracking C1	2	2.366
Transverse Cracking C2	1.22	1.22
Transverse Cracking C4	0.52	0.52
Transverse Cracking C5	-2.17	-2.17
IRI J1	0.8203	0.845
IRI J2	0.4417	0.4417
IRI J3	1.4929	1.4929
IRI J4	25.24	28.24

Conclusions

Performance models of the JPCP were calibrated for the local Idaho conditions using PMED software version 2.5.3. The local calibration factors are presented in Table 35. Calibration of the performance models of the Continuous Reinforced Concrete Pavements (CRCP) was not possible due to lack of sites and absence of sufficient performance data in Idaho. The fowling remarks are to be noted:

- The JPCP faulting model with the global calibration coefficients showed lower bias and the null hypothesis was accepted. However, further calibration was performed to improve the prediction accuracy compared to the measured field data. Minor change in the calibration factor C1 of the model was noted.

- The verification of the JPCP transverse cracking model with the global calibration coefficients showed significant amount of bias and standard error of estimates (SEE). There was no clear trend whether the model over or under predicts cracking. The locally calibrated model produced lower bias and SEE.

- The IRI for JPCP showed significant bias and the null hypothesis was rejected. The local calibration was conducted and the results showed no significant difference.

- The CRCP models were not possible to calibrate due to the lack of sufficient performance data. More data is required to perform future calibration.

Recommendations

- The calibration of the performance models is a continuous process. As the PMED software gets updated, it will depend on the level and type of update whether re-calibration would be needed. For instance, when a new top-down cracking model for asphalt pavement is implemented in the software, re-calibration of the model becomes necessary. Furthermore, the calibration process in this study was conducted using the PMED v2.5.3, which includes the “NAAR” climatic data. It is expected to include the “MERRA” climatic data system in future software updates. This may result in significant changes in models’ prediction. Therefore, calibration coefficients determined in this study might not be applicable, and further verification will be required.
- To facilitate future recalibration, all performance data for the sites considered in this study were recorded and documented in a “Performance Database”, which is provided as an Excel file. The performance data gathered so far includes 4 years of data at the most. Therefore, it recommended that performance data to be collected by ITD in future years at all sites considered in this study, be added to the database to extend the time series of all performance indicators. This will facilitate future calibration, especially with the upcoming calibration tool (“calibrator”) available in PMED v2.6.0.
- The JPCP faulting and IRI performance models’ prediction compare well with field-measured data. However the JPCP transverse cracking showed poor correlation. Therefore, further calibration is recommended once additional data and observations are acquired.
- The current traffic database should be refined with more recent data from the WIM stations across the state. This will provide more accurate measurements of traffic counts and classifications.

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Appendix A – Example of Input and Output of Pavement ME Design Software

Design Inputs

Design Life: 23 years
Design Type: CRCP

Existing construction: -
Pavement construction: September, 1972
Traffic opening: November, 1972

Climate Data Sources (Lat/Lon): 43.565, -116.22

Design Structure

Layer type	Material Type	Thickness (in)
PCC	CRCP Default	8.3
Cement_Base	Cement stabilized	4.0
NonStabilized	Crushed gravel	6.6
Subgrade	A-4	Semi-infinite

Steel Reinforcemment:	
Steel (%)	0.61
Bar diameter (in)	0.75
Steel depth (inch)	3.50

Traffic

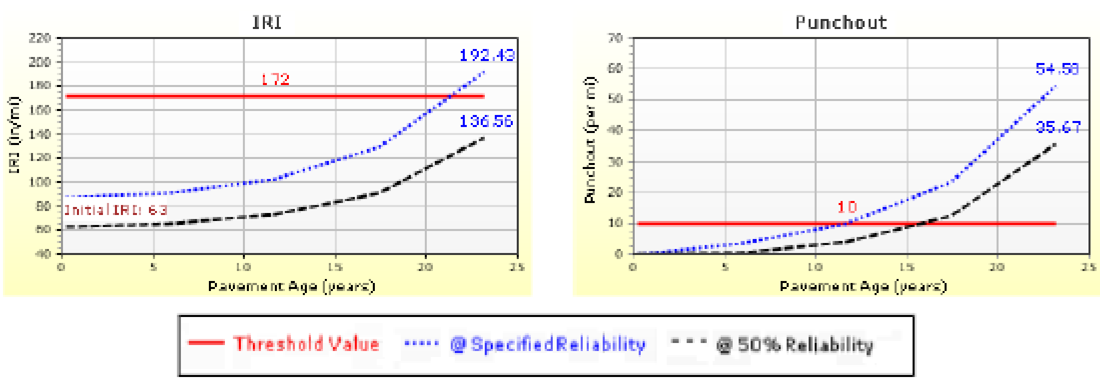
Age (year)	Heavy Trucks (cumulative)
1972 (initial)	1,018
1983 (11 years)	2,337,930
1995 (23 years)	5,385,550

Design Outputs

Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in/mile)	172.00	192.43	90.00	79.19	Fail
CRCP punchouts (1/mile)	10.00	54.58	90.00	4.10	Fail

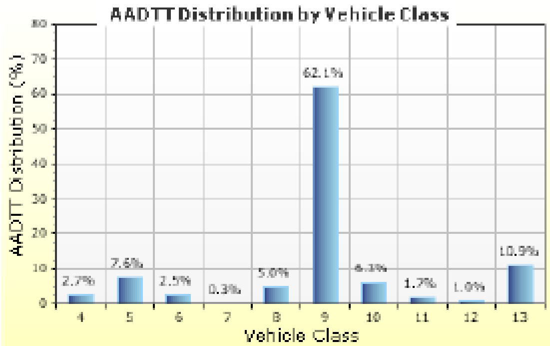
Distress Charts

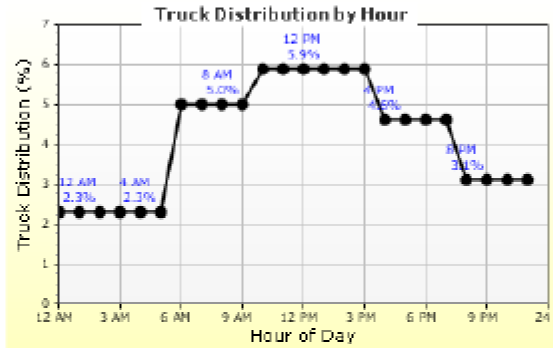


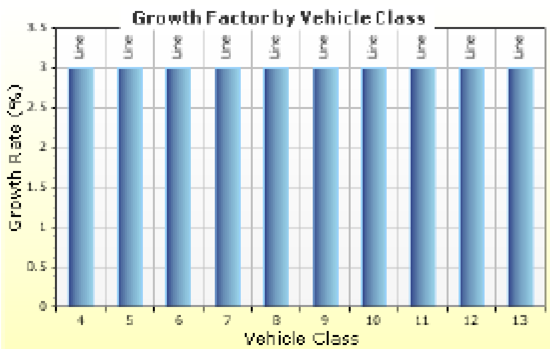
Traffic Inputs

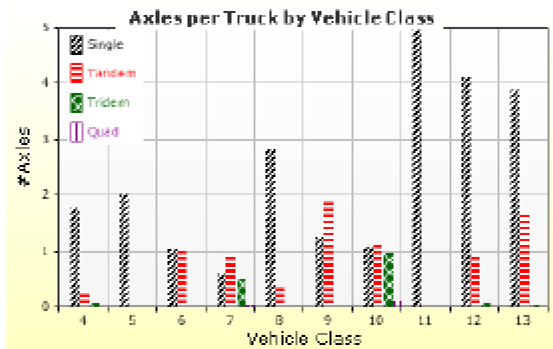
Graphical Representation of Traffic Inputs

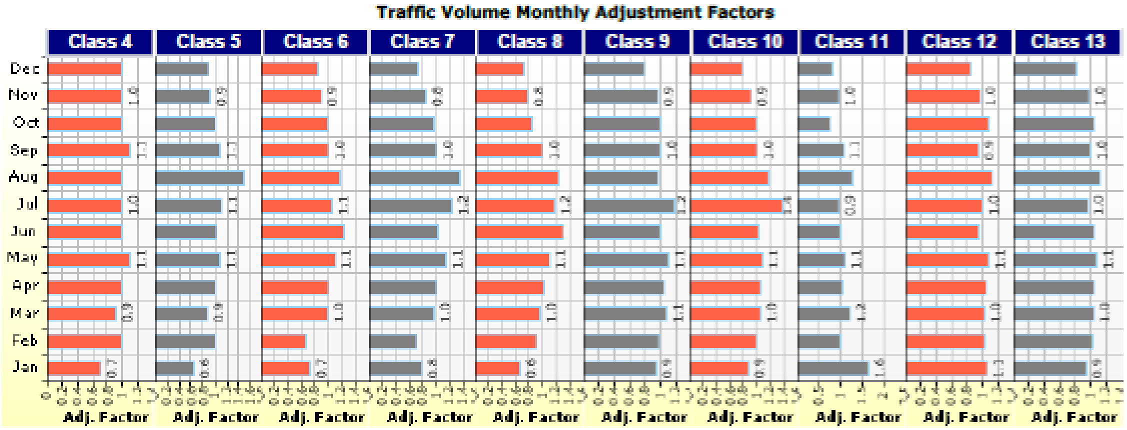
Initial two-way AADTT:	1,018	Percent of trucks in design direction (%):	50.0
Number of lanes in design direction:	2	Percent of trucks in design lane (%):	95.0
		Operational speed (mph)	60.0











Tabular Representation of Traffic Inputs

Volume Monthly Adjustment Factors

Level 3: Default MAF

Month	Vehicle Class									
	4	5	6	7	8	9	10	11	12	13
January	0.7	0.6	0.7	0.8	0.6	0.9	0.9	1.6	1.1	0.9
February	1.0	1.0	0.7	0.7	0.9	1.0	1.0	1.0	1.0	1.0
March	0.9	0.9	1.0	1.0	1.0	1.1	1.0	1.2	1.0	1.0
April	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.0	1.0	1.0
May	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
June	1.0	1.0	1.2	1.0	1.3	1.0	1.0	1.0	0.9	1.0
July	1.0	1.1	1.1	1.2	1.2	1.2	1.4	0.9	1.0	1.0
August	1.0	1.5	1.2	1.4	1.2	1.0	1.2	1.3	1.1	1.1
September	1.1	1.1	1.0	1.0	1.0	1.0	1.0	1.1	0.9	1.0
October	1.0	1.0	1.0	1.0	0.8	1.0	1.0	0.7	1.1	1.0
November	1.0	0.9	0.9	0.8	0.8	0.9	0.9	1.0	1.0	1.0
December	1.0	0.9	0.8	0.7	0.7	0.8	0.8	0.8	0.8	0.8

Distributions by Vehicle Class

Vehicle Class	AADTT Distribution (%) (Level 3)	Growth Factor	
		Rate (%)	Function
Class 4	2.7%	3%	Linear
Class 5	7.6%	3%	Linear
Class 6	2.5%	3%	Linear
Class 7	0.3%	3%	Linear
Class 8	5%	3%	Linear
Class 9	62.1%	3%	Linear
Class 10	6.3%	3%	Linear
Class 11	1.7%	3%	Linear
Class 12	1%	3%	Linear
Class 13	10.9%	3%	Linear

Truck Distribution by Hour

Hour	Distribution (%)	Hour	Distribution (%)
12 AM	2.3%	12 PM	5.9%
1 AM	2.3%	1 PM	5.9%
2 AM	2.3%	2 PM	5.9%
3 AM	2.3%	3 PM	5.9%
4 AM	2.3%	4 PM	4.6%
5 AM	2.3%	5 PM	4.6%
6 AM	5%	6 PM	4.6%
7 AM	5%	7 PM	4.6%
8 AM	5%	8 PM	3.1%
9 AM	5%	9 PM	3.1%
10 AM	5.9%	10 PM	3.1%
11 AM	5.9%	11 PM	3.1%
		Total	100%

Axle Configuration

Traffic Wander	
Mean wheel location (in)	18.0
Traffic wander standard deviation (in)	10.0
Design lane width (ft)	12.0

Axle Configuration	
Average axle width (ft)	8.5
Dual tire spacing (in)	12.0
Tire pressure (psi)	120.0

Average Axle Spacing	
Tandem axle spacing (in)	51.6
Tridem axle spacing (in)	49.2
Quad axle spacing (in)	49.2

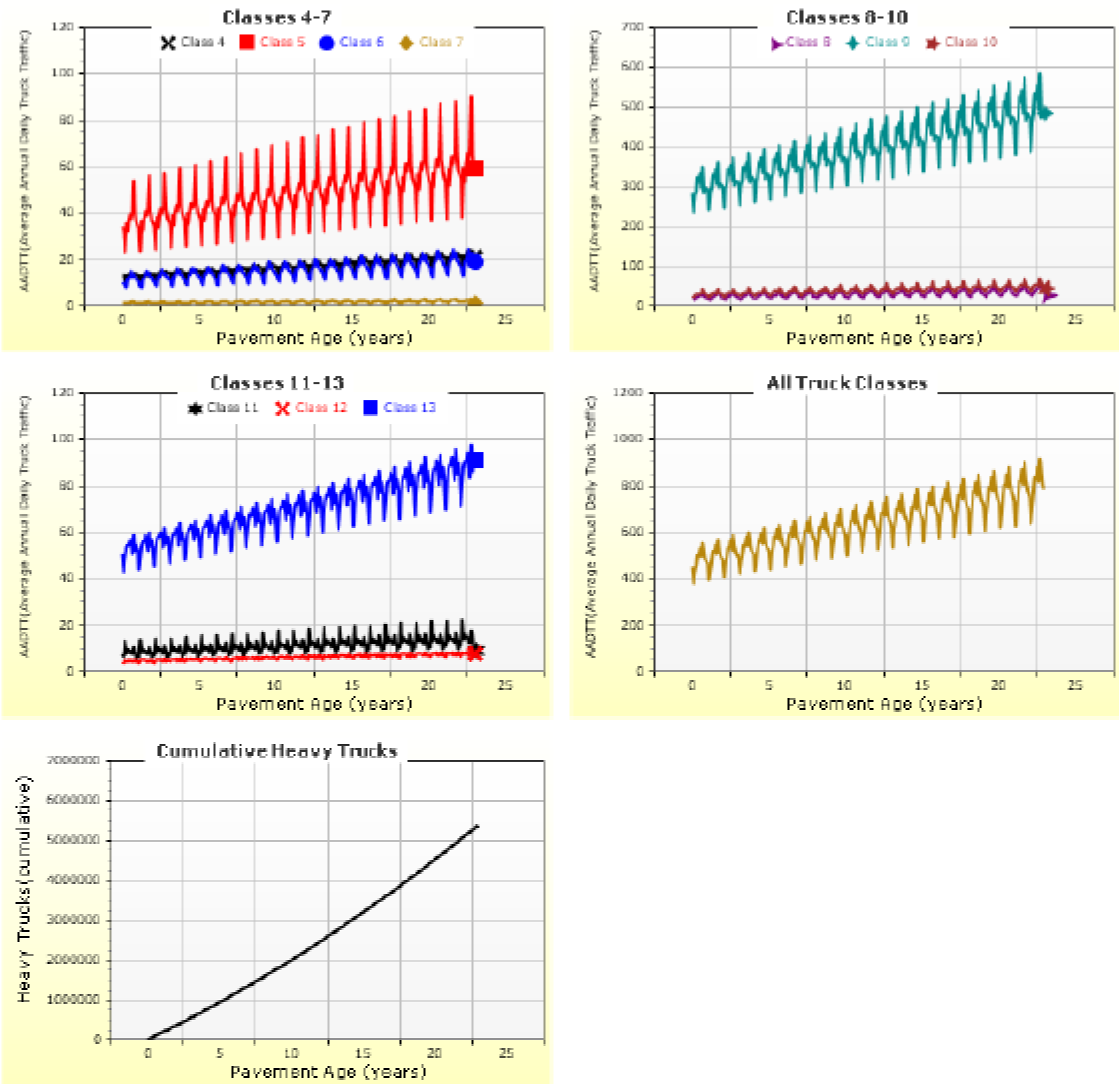
Wheelbase			
Value Type / Axle Type	Short	Medium	Long
Average spacing of axles (ft)	12.0	15.0	18.0
Percent of Trucks (%)	17.0	22.0	61.0

Number of Axles per Truck

Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.768333336	0.281666664	0.079999998	0
Class 5	2	0	0	0
Class 6	1.008333325	0.991666675	0	0
Class 7	0.583333328	0.911666662	0.513333331	0.039999999
Class 8	2.808333317	0.353333329	0	0
Class 9	1.233333349	1.879999995	0	0
Class 10	1.075000008	1.104999999	0.985000004	0.099999999
Class 11	4.998333295	0	0	0
Class 12	4.095000029	0.901666661	0.068333333	0
Class 13	3.86833334	1.613333344	0.046666666	0

AADTT (Average Annual Daily Truck Traffic) Growth

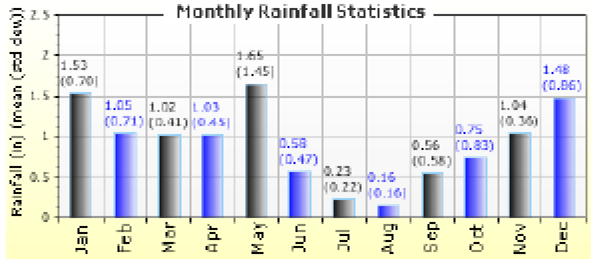
* Traffic cap is not enforced



Climate Inputs

Climate Data Sources:

Climate Station Cities:	Location (lat lon elevation(ft))
BOISE, ID	43.56500 -116.22000 2814

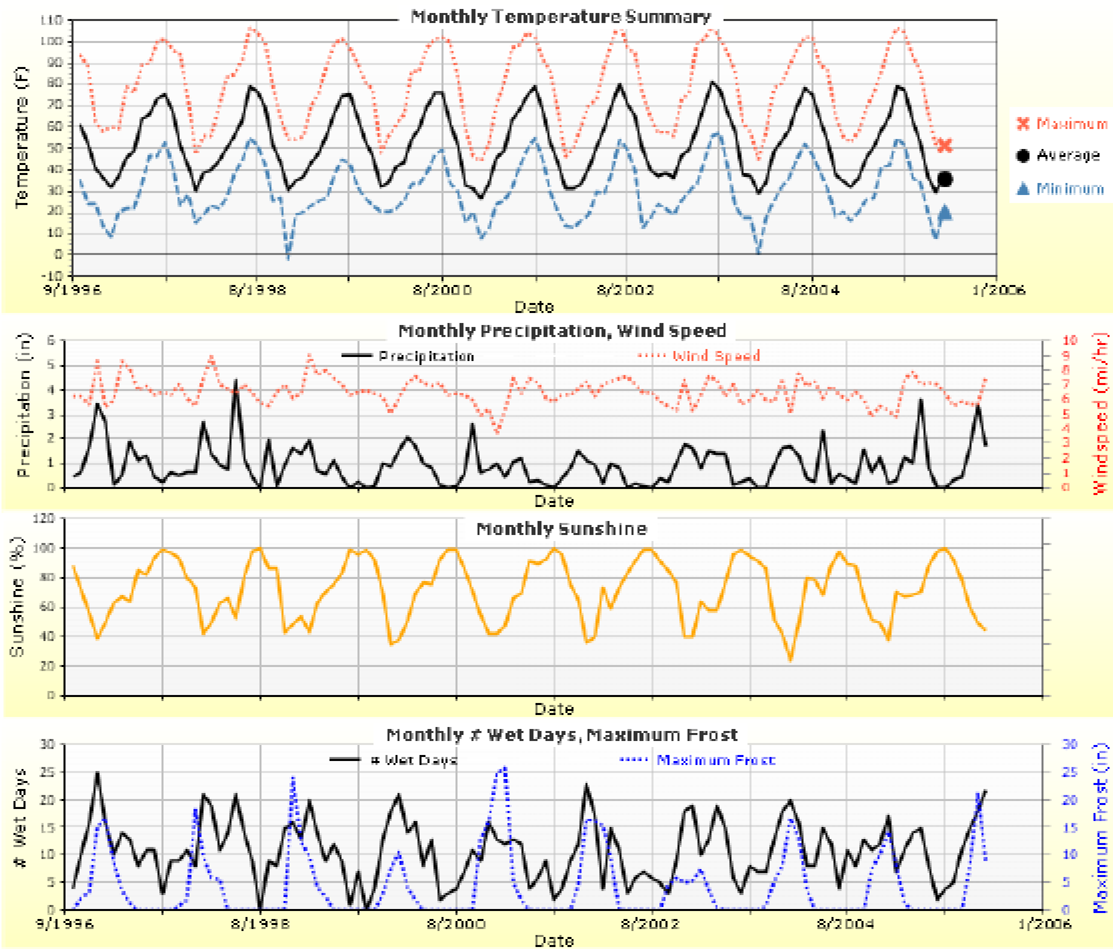


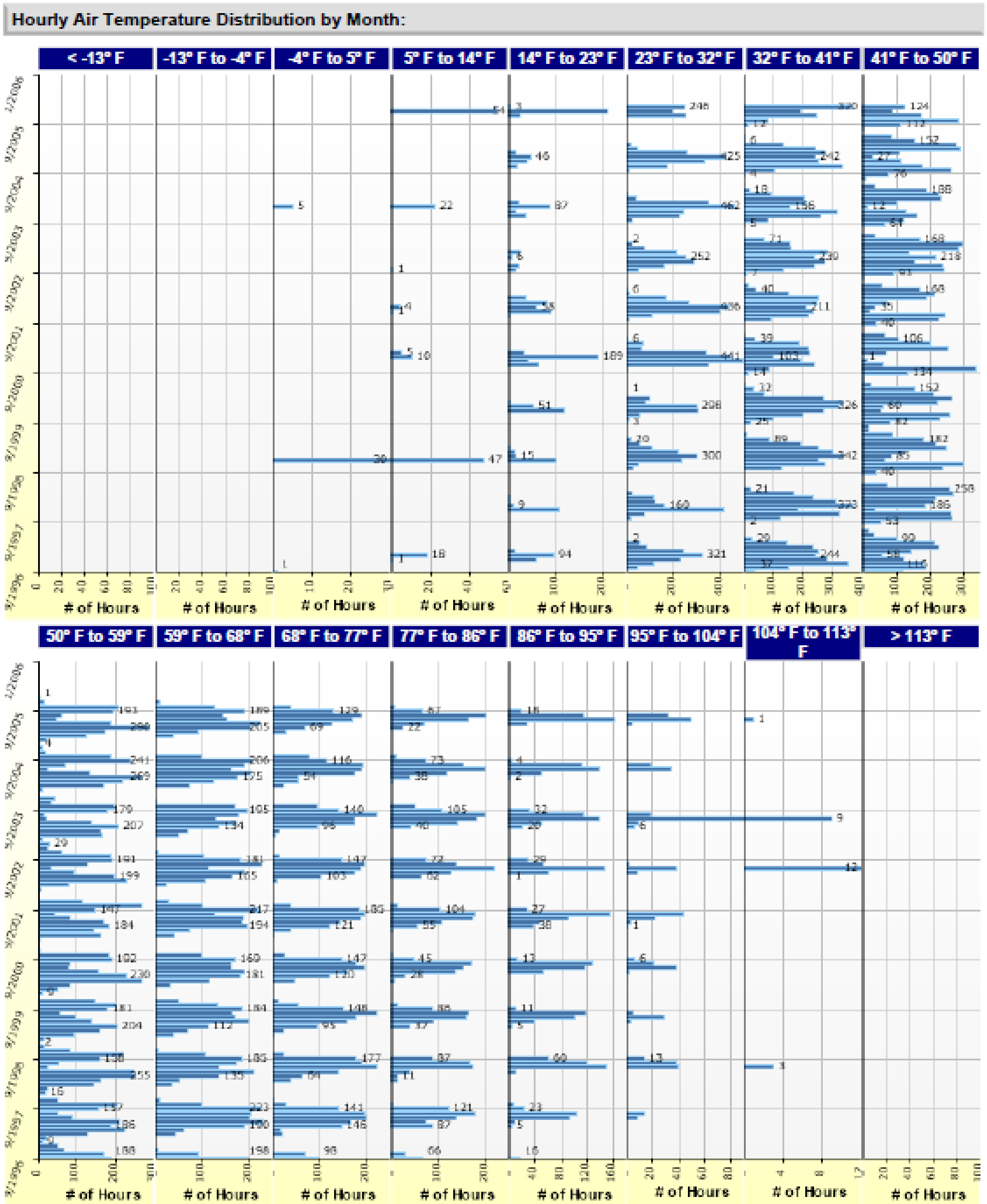
Annual Statistics:

Mean annual air temperature (ºF)	52.97
Mean annual precipitation (in)	11.07
Freezing index (ºF - days)	175.37
Average annual number of freeze/thaw cycles:	75.32

Water table depth (ft)	2.00

Monthly Climate Summary:




Hourly Air Temperature Distribution by Month:
< -13° F
-13° F to -4° F
-4° F to 5° F
5° F to 14° F
14° F to 23° F
23° F to 32° F
32° F to 41° F
41° F to 50° F
50° F to 59° F
59° F to 68° F
68° F to 77° F
77° F to 86° F
86° F to 95° F
95° F to 104° F
104° F to 113° F
> 113° F
# of Hours

Design Properties

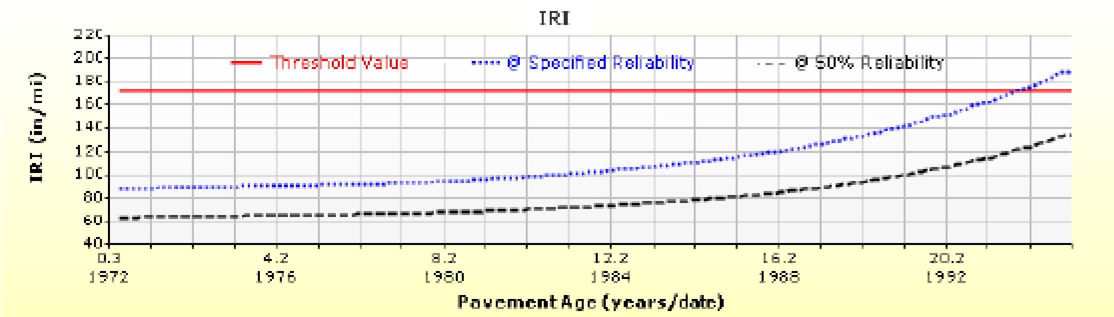
CRCP Design Properties

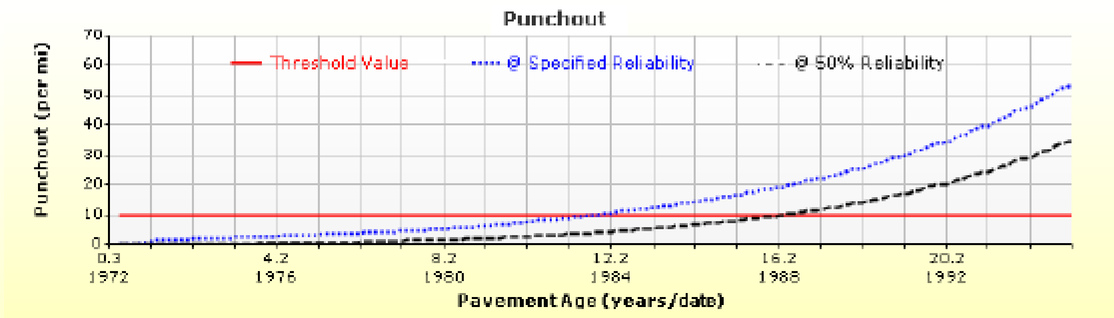
Structure - ICM Properties	
PCC surface shortwave absorptivity	0.85

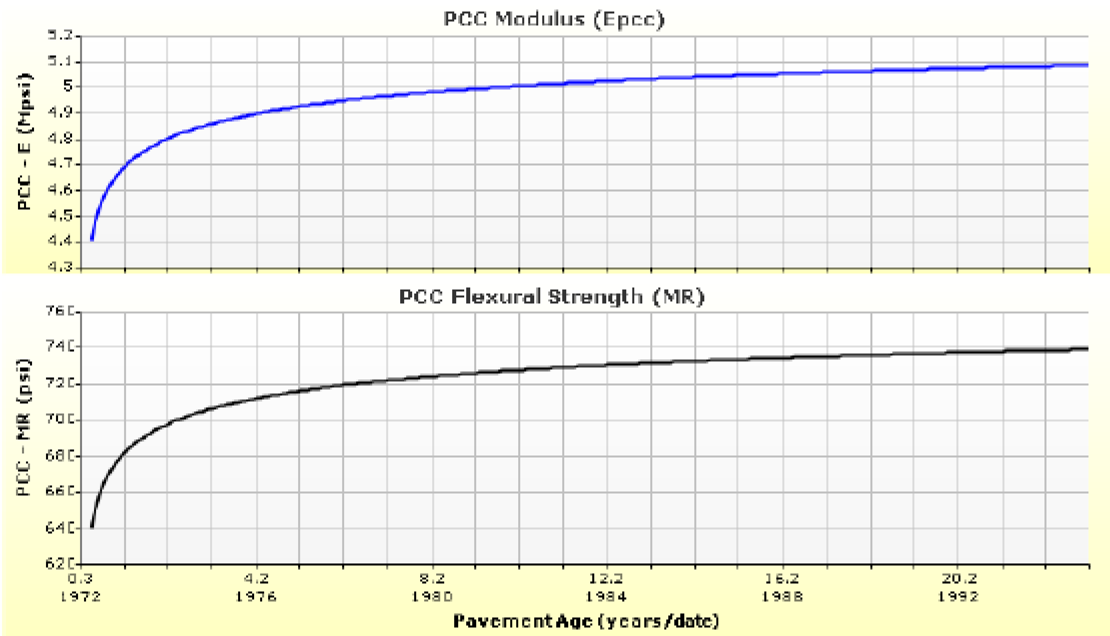
Crack Spacing	
Is crack spacing computed using prediction model?	True
Crack spacing (in)	42

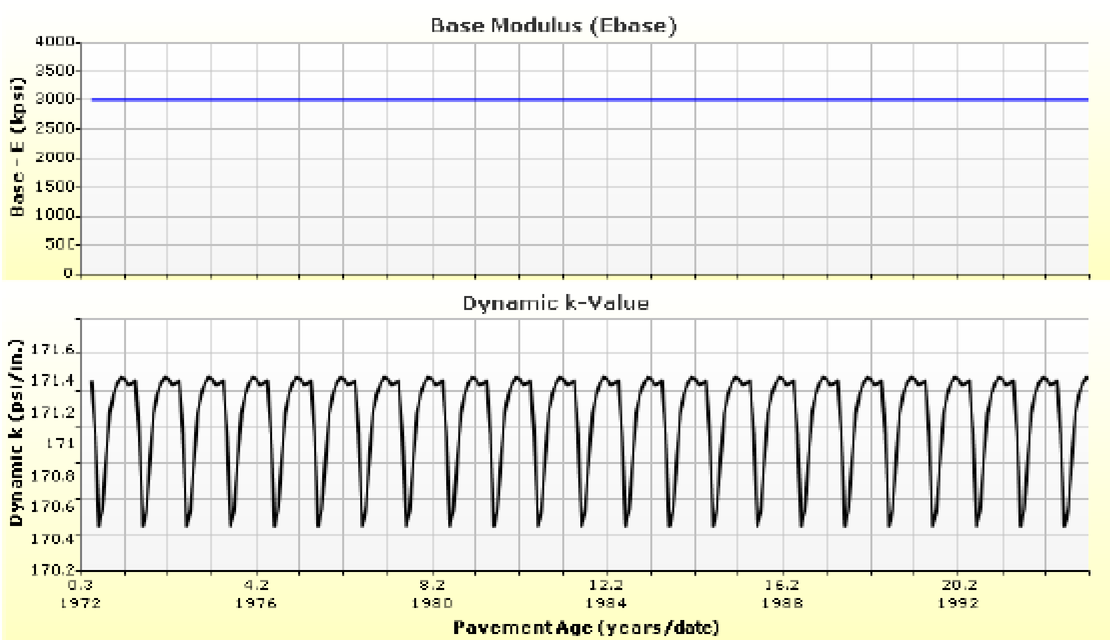
Shoulder type	Asphalt (2)
Permanent curl/warp effective temperature difference (°F)	-10.00
Steel (%)	0.61
Bar diameter (in)	0.75
Steel depth (inch)	3.50
Base/slab friction coefficient	8.90

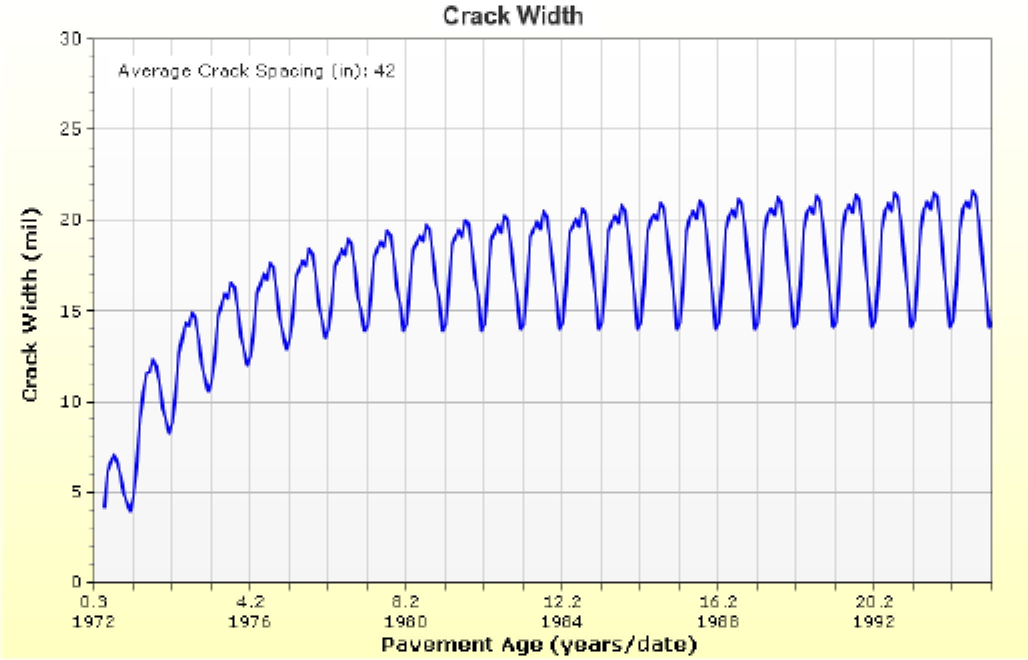
Analysis Output Charts

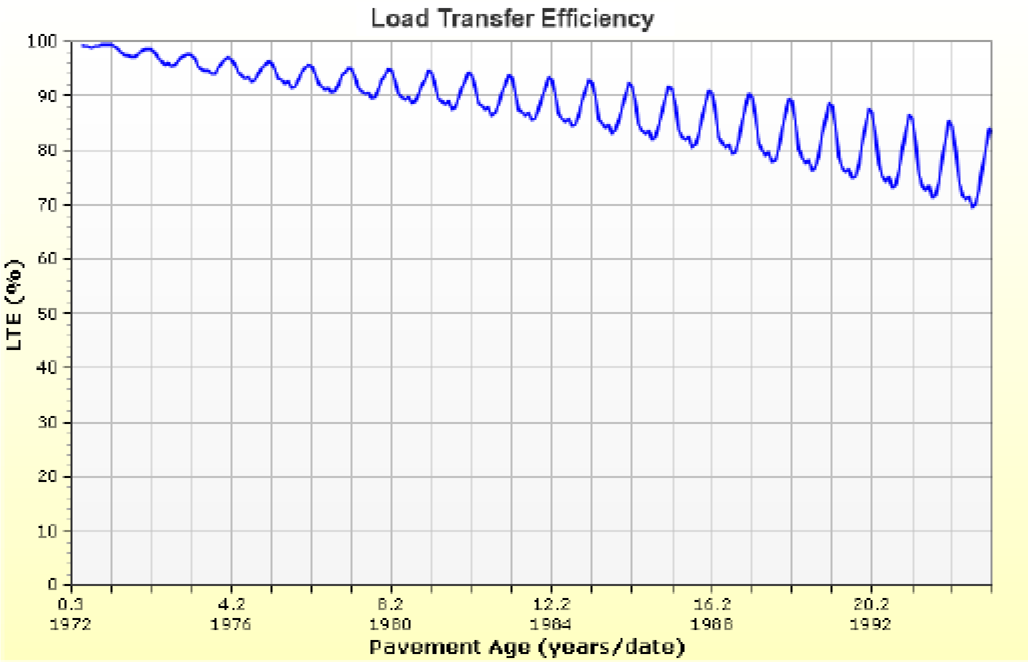





PCC Modulus (Epcc)
PCC - E (Mpsi)
PCC Flexural Strength (MR)
PCC - MR (psi)
Pavement Age (years/date)


Base Modulus (Ebase)
Base - E (kpsi)
Dynamic k-Value
Dynamic k (psi/in.)
Pavement Age (years/date)


Crack Width
Average Crack Spacing (in): 42
Crack Width (mil)
30
25
20
15
10
5
0
0.3 1972
4.2 1976
8.2 1980
12.2 1984
16.2 1988
20.2 1992
Pavement Age (years/date)


Load Transfer Efficiency
LTE (%)
100
90
80
70
60
50
40
30
20
10
0
0.3 1972
4.2 1976
8.2 1980
12.2 1984
16.2 1988
20.2 1992
Pavement Age (years/date)

Layer Information

Layer 1 PCC : CRCP Default

PCC	
Thickness (in)	8.3
Unit weight (pcf)	150.0
Poisson's ratio	0.2

Thermal	
PCC coefficient of thermal expansion (in/in/°F x 10^-6)	4.9
PCC thermal conductivity (BTU/hr-ft-°F)	1.25
PCC heat capacity (BTU/lb-°F)	0.28

Mix		
Cement type		Type I (1)
Cementitious material content (lb/yd^3)		600
Water to cement ratio		0.42
Aggregate type		Limestone (1)
PCC zero-stress temperature (°F)	Calculated Internally?	True
	User Value	-
	Calculated Value	
Ultimate shrinkage (microstrain)	Calculated Internally?	True
	User Value	-
	Calculated Value	654.2
Reversible shrinkage (%)		50
Time to develop 50% of ultimate shrinkage (days)		35
Curing method		Curing Compound

PCC strength and modulus (Input Level: 3)

28-Day PCC compressive strength (psi)	4130.0
28-Day PCC elastic modulus (psi)	4200000.0

Identifiers

Field	Value
Display name/identifier	CRCP Default
Description of object	
Author	
Date Created	5/29/2018 11:54:19 AM
Approver	
Date approved	5/29/2018 11:54:19 AM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 1	
User defined field 2	
User defined field 3	
Revision Number	0

Layer 2 Chemically Stabilized : Cement stabilized

Chemically Stabilized	
Layer thickness (in)	4
Poisson's ratio	0.2
Unit weight (pcf)	150

Strength	
Elastic/resilient modulus (psi)	3018848.3

Thermal	
Heat capacity (BTU/lb-ºF).	0.28
Thermal conductivity (BTU/hr-ft-ºF)	1.25

Identifiers

Field	Value
Display name/identifier	Cement stabilized
Description of object	Default material
Author	AASHTO
Date Created	1/1/2011 12:00:00 AM
Approver	
Date approved	1/1/2011 12:00:00 AM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 1	
User defined field 2	
User defined field 3	
Revision Number	0

Layer 3 Non-stabilized Base : Crushed gravel

Unbound	
Layer thickness (in)	6.6
Poisson's ratio	0.35
Coefficient of lateral earth pressure (k0)	0.5

Modulus (Input Level: 3)

Analysis Type:	Modify input values by temperature/moisture
Method:	Resilient Modulus (psi)

Resilient Modulus (psi)
25000.0

Use Correction factor for NDT modulus?	-
NDT Correction Factor:	-

Identifiers

Field	Value
Display name/identifier	Crushed gravel
Description of object	Default material
Author	AASHTO
Date Created	1/1/2011 12:00:00 AM
Approver	
Date approved	1/1/2011 12:00:00 AM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 1	
User defined field 2	
User defined field 3	
Revision Number	0

Sieve

Liquid Limit	6.0
Plasticity Index	1.0
Is layer compacted?	False

	Is User Defined?	Value
Maximum dry unit weight (pcf)	False	127.2
Saturated hydraulic conductivity (ft/hr)	False	5.054e-02
Specific gravity of solids	False	2.7
Water Content (%)	False	7.4

User-defined Soil Water Characteristic Curve (SWCC)	
Is User Defined?	False
af	7.2555
bf	1.3328
cf	0.8242
hr	117.4000

Sieve Size	% Passing
0.001mm	
0.002mm	
0.020mm	
#200	8.7
#100	
#80	12.9
#60	
#50	
#40	20.0
#30	
#20	
#16	
#10	33.8
#8	
#4	44.7
3/8-in.	57.2
1/2-in.	63.1
3/4-in.	72.7
1-in.	78.8
1 1/2-in.	85.8
2-in.	91.6
2 1/2-in.	
3-in.	
3 1/2-in.	97.6

Layer 4 Subgrade : A-4

Unbound	
Layer thickness (in)	Semi-infinite
Poisson's ratio	0.35
Coefficient of lateral earth pressure (k0)	0.5

Modulus (Input Level: 3)

Analysis Type:	Modify input values by temperature/moisture
Method:	Resilient Modulus (psi)

Resilient Modulus (psi)
15000.0

Use Correction factor for NDT modulus?	-
NDT Correction Factor:	-

Identifiers

Field	**Value**
Display name/identifier	A-4
Description of object	Default material
Author	AASHTO
Date Created	1/1/2011 12:00:00 AM
Approver	
Date approved	1/1/2011 12:00:00 AM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 1	
User defined field 2	
User defined field 3	
Revision Number	0

Sieve

Liquid Limit	21.0
Plasticity Index	5.0
Is layer compacted?	False

	Is User Defined?	**Value**
Maximum dry unit weight (pcf)	False	118.4
Saturated hydraulic conductivity (ft/hr)	False	8.325e-06
Specific gravity of solids	False	2.7
Water Content (%)	False	11.8

User-defined Soil Water Characteristic Curve (SWCC)	
Is User Defined?	False
af	68.8377
bf	0.9983
cf	0.4757
hr	500.0000

Sieve Size	**% Passing**
0.001mm	
0.002mm	
0.020mm	
#200	60.6
#100	
#80	73.9
#60	
#50	
#40	82.7
#30	
#20	
#16	
#10	89.9
#8	
#4	93.0
3/8-in.	95.6
1/2-in.	96.7
3/4-in.	98.0
1-in.	98.7
1 1/2-in.	99.4
2-in.	99.6
2 1/2-in.	
3-in.	
3 1/2-in.	99.8

Calibration Coefficients

Punchouts

$$\log(N) = C_1 \left(\frac{MR}{\sigma} \right)^{C_2}$$

$$P.O. = \frac{C_3}{1 + C_4 Damage^{C_5}}$$

$$cw = C_6 (cw_i)$$

Crack Width	Fatigue
C6: 1	C1: 2
	C2: 1.22

Punchout
C3: 107.73
C4: 2.475
C5: -0.785

PCC Reliability PO Standard Deviation
2.208 * Pow(PO,0.5316)

IRI-crcp

C1 - Punchout

C2 - Site Factor

C1: 3.15	C2: 28.35
Reliability Standard Deviation	
5.4	

Appendix B – Performance Database

(e-file)

Calibration of the AASHTOWare Pavement ME Design Performance Models for Rigid Pavments in Idaho

ITD Research Project RP268 - University of Idaho NIATT Project KLK585

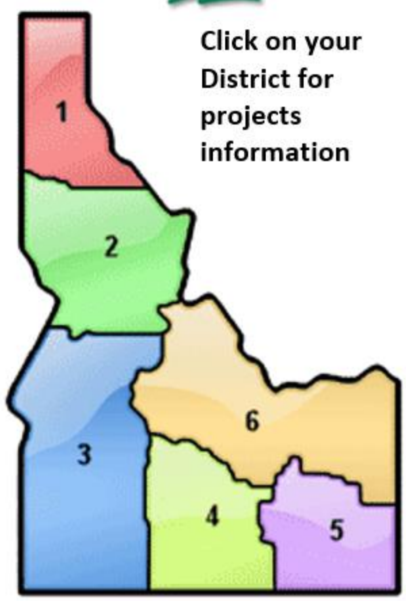
Perfomance Database Version 1.1

Developed by:

Fouad Bayomy (PI)
Emad Kassem
Ahmed Muftah
Mumtahin Hasnat

NIATT

Click on your District for projects information



District 1 Selected Projects

Section #	Route	Beg. MP	End MP	Location
D1-1	I-90	58.5	62.25	Mullan to Montana SL
D1-2				

GO BACK TO MAIN SCREEN

District 1_Project 1
Project Section: I-90, Mullan to Montana SL
Mile post 58.5 to 62.25
key 12967 & 12293

DISTRICT 1 SELECTETED PAVEMENT SECTIONS

GO BACK TO MAIN SCREEN

Construction time	Jun-13	
Traffic Opening	Sep-13	
Coordinates	47.4693662	-115.76226
Elevation	4970 ft	

Pefromance Measurment

IRI/Distresses	2013	2014	2016	2017
IRI (in/mile)	175.13	153.51	182.08	145.79
Faulting (in)	Seen or Not Colle	Seen or Not Colle	0.263	0.176
Transverse Cracking (%)	0	0	0.598	1.246

Structure

Layer #	Layer type	Thickness (in)	Property
1	JPCP	12	Use the PCC database from D1
2	Plant mix	1.8	ATPLC_SP5_PG64-28
3	Aggregate Base	12	Rock Cap, R= 80
4	Subgrade	-	A-1-b, MR = 25000

Traffic Data

AADTT	6000
Growth Factor (%)	3.11%
D	60/40
V	70 mph

Joint Design

Joint spacing	15 ft
Dowel dia.	1.25"
Dowel length	10" (9" required + 1" additonal for chain wear and grinding)
Slab Width	13 ft (W)

PCC Mix Properties

PCC

Unit weight (pcf)	142.0
Poisson's ratio	default

Thermal

Coefficient of thermal expansion (in./in./deg F x 10^-6)	3.75
PCC thermal conductivity (BTU/hr-ft-deg F)	1.25
PCC heat capacity (BTU/lb-deg F)	0.28

Mix

Cement type	Type I/II
Cementitious material content (lb/yd^3)	688
Water to cement ratio	0.40
Aggregate type	Limestone (1)
PCC zero-stress temperature (deg F)	Derived
Ultimate shrinkage (microstrain)	-315
Reversible shrinkage (%)	50
Time to 50% of ultimate shrinkage (days)	33

District 2 Selected Projects

Section #	Route	Beg. MP	End MP	Location
D2-1	US-95	0.06	0.11	Jackson Street Moscow
D2-2	US-95	345.48	346.12	Segment code (001540)
D2-3	US-95	345.05	345.44	Washington Street, 8th to 1st, Moscow
D2-4	SH008	2.77	3.27	White Pl to S Fk Palouse River Br
D2-5	US-95	251.075	261.588	South of Cottonwood to Ferdin
D2-6	US-12	2.197	2.62	Clearwater River Bridge to Rose Garden

GO BACK TO MAIN SCREEN

District 3 Selected Projects

Section #	Route	Beg. MP	End MP	Location
D3-1	I-84	12.6	17.61	Black Canyon Interchange to Sand Hollow
D3-2	I-84	26.35	28.3	10th Ave IC to Franklin Rd IC, Caldwell
D3-3	I-84	36	38.7	Franklin Blvd to 11th Ave, Nampa
D3-4	I-84	41.3	43.8	Ten Mile Rd to Meridian IC
D3-5	I-84	49.15	49.73	WYE IC Stage 1 & Franklin IC Etc.
D3-6	I-84	49.73	50.21	Cole-Overland
D3-7	I-84	50.2	54.9	Cole to Broadway
D3-8	I-84	58.8	59	Gowen IC to Eisenman IC
D3-9	I-84	70.1	82.3	Regina to Cleft
D3-10	I-84	90	94.6	Sebree to Fairfield
D3-11	I-84	94.3	103.5	Mountain Home to Hammett
D3-12	I-84	103.5	109.1	MP 103.5 to West Hammett I.C
D3-13	I-84	109.1	114.5	MP 109.1 to E. Hammett I.C
D3-14	I-84	114.5	121.2	MP 114 to D3 Border
D3-15	I-184	0	3.62	Flying Wye to Main St.
D3-16	US-20	24.8	25.3	-
D3-17	US-20	47.25	48.36	-

GO BACK TO MAIN SCREEN

District 4 Selected Projects

Section #	Route	Beg. MP	End MP	Location
D4-1	I-84	215.94	222	Declo IC to Salt Lake IC
D4-2	I-84	120.66	127.945	East to West of snake river Bridge

GO BACK TO MAIN SCREEN

District 5 Selected Projects

Section #	Route	Beg. MP	End MP	Location
D5-1	I-15	30.870	36.207	Downey Rd Overpass to Exit 36
D5-2	I-86	14.808	25.980	Yale RD overpass to Raft River
D5-3	US-91	80.15	81.02	Burnside to Highway Ave
D5-4	US-91	78.81	79.66	Flandro To Poleline

GO BACK TO MAIN SCREEN

District 6 Selected Projects

NO SECTIONS WERE SELECTED FROM DISTRICT 6

GO BACK TO MAIN SCREEN