MICHIGAN STATE UNIVERSITY

CE 831 RIGID PAVEMENT ANALYSIS AND DESIGN

RIGID PAVEMENT DESIGN PROJECT

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Submitted to: Dr. Buch

Spring Semester 2015

Contents

INTRODUCTION

There are several methods of designing jointed plain concrete pavements. These design methods depend on either empirical methods, mechanistic method or both. ASAHTO 93, PCA design method and AASHTO M-E PDG forms fundamental basis of designing jointed plain concrete pavements.

Every design methods have some advantageous; however, M-E PDG considers causes of stresses on the pavement in very detailed. In other words, AASHTO 93 and PCA design method is very limited to calculate stresses with respect to material and traffic consideration. In addition to that; they do not consider environmental effects on the stresses formed in the pavement. M-E PDG design method enables designer to design joint and consider shoulder consideration; however PCA design method only considers existence of joints and shoulder and there is no consideration of those for AASHTO 93. In addition to that, every design method takes traffic input differently; however, M-E PDG considers traffic in aspect of axle load spectra, vehicle class, monthly and hourly distribution. One of another significant difference of M-E PDG is material characterization. M-E PDG takes into account these layer properties during calculation of stresses.

The goal of the M-E PDG is to specify physical reasons of stresses why pavements fails and calibrate those causes with LTTP data. Mechanistic part of that design lies behind the causes of stresses; in other words, developed stresses due to traffic, material and climate whereas using LTTP data for calibration of M-E PDG is empirical part (Interactive, 2012).

The performance criteria of M-E PDG is transverse cracking, faulting and IRI. If predicted damage on the pavement at specified reliability standpoint is smaller than threshold values, the design is acceptable over design life.

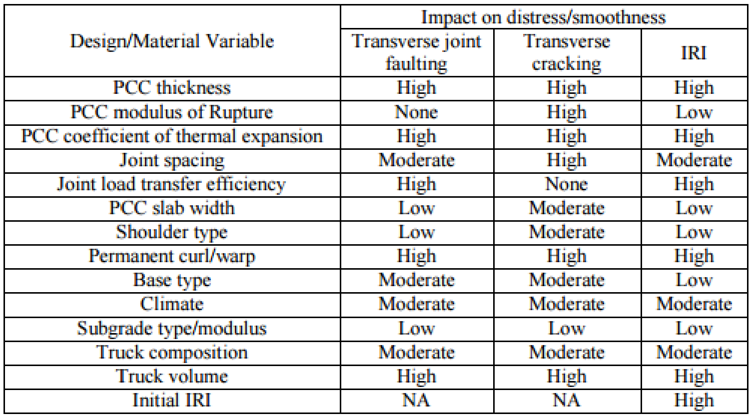
OBJECTIVE

In this report, 12 jointed plain concrete pavement sections which were constructed in Arizona in 1993 are going to be analyzed by using M-E PDG. Since information of JPCP sections are available, these sections are going to be designed according to M-E PDG input data and results are compared with the long term pavement performance (LTPP) data. At the end of comparison, these sections are tried to be calibrated by changing calibration coefficients lying behind the formulas calculating damaging.

TASK1. M-E PDG INPUT

Sensitivity analysis conducted by MSU research team (Buch, et al., 2013) indicates that there are some M-E PDG input values which play very significant role for performance measurements of M-E PDG (transverse cracking, faulting, IRI). These inputs and their significance on the performance can be shown as below table:

Table 1. Sensitivity of input parameters of M-E PDG (Buch, et al., 2013)



Design/Material Variable	Impact on distress/smoothness		
	Transverse joint faulting	Transverse cracking	IRI
PCC thickness	High	High	High
PCC modulus of Rupture	None	High	Low
PCC coefficient of thermal expansion	High	High	High
Joint spacing	Moderate	High	Moderate
Joint load transfer efficiency	High	None	High
PCC slab width	Low	Moderate	Low
Shoulder type	Low	Moderate	Low
Permanent curl/warp	High	High	High
Base type	Moderate	Moderate	Low
Climate	Moderate	Moderate	Moderate
Subgrade type/modulus	Low	Low	Low
Truck composition	Moderate	Moderate	Moderate
Truck volume	High	High	High
Initial IRI	NA	NA	High

For this project, some of the M-E PDG input data taken from LTPP is not provided. If these input data is not one of the design/material variable provided in table 1, level 3 (national default) data type is used. However, missing input parameter having great impact on performance, level 2 (regional default values) data type is used if it can be found. Also, note that first priority of selecting missing input parameters for one section is to look other sections M-E PDG input data whether it has the missing input parameter or not.

1.1. Inventory Input Data

In order to determine acceptance of design or rehabilitation with respect to transverse cracking, faulting and IRI, performance values are compared with threshold values. NCHRP 1-47 has determined threshold values for performance in different aspects and recommended performance threshold values are following for JPCP design:

Table 2. Recommended Performance Thresholds (Schwartz, Li, Kim, Ceylan, & Gopalakrishnan, 2011)

Slab Transverse Cracking	15%
Faulting	0.12 in

IRI	172 in/mile

For all sections, 15 ft joint spacing was used and 6 sections have 1.25 inch and other sections have 1.5 inch dowel diameter used (See Tables 6 and 7 in Appendix). In spite of the inequalities between PCC layer thicknesses, it can be said that PCC slab thickness of around 8 inch for 6 sections and around 11 inch for 6 sections was chosen.

Sections having unbound and lean concrete treated does not have sub-base whereas sections having HMA treated base do have unbound granular sub-base. Base thicknesses for sections having sub-base layer and no sub-base layer are about 4 inch and 6 inch.

1.2. Load and Traffic

Since sections are adjacent to each other, the traffic input is same for all sections. After construction, 2030 average daily truck traffic is counted at the first year (1993) and last count occurred at 9 years later (2002) and AADT was found as 10234. From these counts, annual growth factor can be calculated as:

$$\text{Annual Growth Factor} = (\frac{10234}{2030})^{1/(2002-1993)} = 1.2$$

For traffic volume adjustment factors and axle load distribution factors, data were directly taken from LTPP. For axle configuration and wheelbase data, national default values (level 3 data type) were used.

1.3. Material

1.3.1. PCC Layer Properties

Unit weight and poisson's ratio of the concrete used for PCC layer of sections is generally around 145 pcf and 0.15. Either 400 lb/yd^3 or 799 lb/yd^3 was used for cementitious material content and w/c ratio becomes 0.58 or 0.37 depending cementitious material content (See Table 8).

Since PCC coefficient of thermal expansion value has significant role on performance and IS not provided for all sections, PCC CTE value is taken as 8.1x10^{-6} for all sections that does not have PCC CTE value. Also, for section ID 222, unit weight and poisson's ratio are taken as 145 and 0.15 respectively by considering other sections value (See Table 8).

One of the important things is that for some of sections, the test date of 28 day PCC compressive strength test is not 28 day after construction. However, the actual 28 day strength value can also be found in LTTP data and these values are changed according to strength value of PCC measured 28 days after construction (See Table 8).

1.3.2. Base Layer Properties

Poisson's ratio and modulus of the sections are taken as level 3 data type because M-E PDG input states using AASHTO Ware Pavement ME default. For granular base, LL is selected as level 3 data type according to soil class. Plasticity index is taken as non-plastic (0 zero) for all sections. Sieve analysis of the section 213 and 216 are taken as the sieve analysis results of section 214 and 215 respectively. There is no information available for lean concrete treated base. The input data for those sections are level 3 data type (See Table 9).

1.3.3. Sub-base Layer Properties

Only four sections (221, 222, 223 and 224) have sub base layer. Since the material property input data for section 221 and 224 exists and are similar, average of these 2 section inputs are used for section 222 and 223. For poisson's ratio, K_0 and LL, AASHTO Ware Pavement ME default values are used as M-E PDG input report says (See Table 10). Asphalt grade of HMA is 4 which mean viscosity grade is AC-20.

1.3.4. Sub-grade Properties

The soil classes of sections which are not indicated are selected SM (poorly graded SAND with silt and gravel) soil type due to identification of subgrade material as silty sand with gravel in the inventory data and other missing data are presented as national default values according to soil class (See Table 11).

1.4. Environmental

The climate data of state of Arizona is taken from weather station of Phoenix, AZ – Phoenix Deer Valley Arpt. This station is nearest weather station found by using GPS data. However, the annual precipitation, temperature, freezing index and annual max-min humidity can be found in appendices section.

It should be noted that, during identifying missing data and determining a way for selecting those missing data, this general procedure is applied:

1. If one of the inputs is not available in LTTP M-E PDG input file, but it says "Use AASHTOWare Pavement ME default" for that input, default value (level 3 data type) is used.
2. If one of the missing data can be found in another section's LTTP, available data can be used under one consideration: to be sure that that parameter does not changes or keeps

very close for other sections. For instance, coefficient of thermal expansion of aggregates, there are only 2 sections having that property which are very close to each other and it can be assumed that that coefficient is available for all other sections due to the fact that project sections are adjacent to each other and the place of aggregate production should be same.

3. If missing parameter is not one of the significant input affecting performance (see table 1), level 3 (national value) data type is used. However, if it is important for performance, missing input value is going to be searched for that region by using internet or reading literature. (level 2 data type)

Also note that curling/warping stress is national default value used. If after implementation of inputs to M-E PDG, measured and predicted results are going to be so in consistent, curling/warping coefficient can be changed in order to catch LTTP data and make the M-E PDG data be ready for calibration.

TASK 2. M-E PDG RESULTS AND MEASUREMENTS

2.1. Developing input files:

In the second step of the project the inputs of M-E PDG should be imported to the software. M-E PDG software has three different sections. The first one is related to the general information e.g. design life and type of design, location of the project and analysis parameters such as failure limits and their corresponding reliabilities. The second section is dealing with traffic, climate and structure inputs. The last section demonstrates the outputs and results of the project.

Based on the provided inputs in the previous task a file should be made for each one of the sections. Since all of the twelve sections are continuously after each other, project information and some input data such as traffic and climate information are almost the same for all of the sections. Therefore, by importing these inputs in one file, and changing the structure inputs the simulation of all of the sections can be possible.

2.2. Quantifying the predicted performance:

After preparing the M-E PDG files for all of the sections, the next step is running the program and extracting the results. For this purpose a batch file is made including the twelve sections. The outputs of these files are stored in excel files, including input, reliability and distress summaries and detailed information about each one of the performances.

2.3. Comparing the predicted and observed performances:

For comparison of the predicted results with measured ones, some changes should be applied to the provided raw measured data. These changes will be explained in for each performance in the corresponding section:

2.3.1. Transverse cracking

For transverse cracking, the raw data is the number of count while M-E PDG output is percent slabs cracked. Therefore, the raw data should be converted to percent slabs cracked by the following formula:

$$\% \text{ Slab Cracked} = \frac{\text{Number of cracks}}{\left(\frac{\text{Project Length (miles)} \times 5280(\text{ft})}{\text{Joint Spacing (ft)}}\right)} \times 100$$

Since the length of each section is 0.1 mile and the joint spacing is 15 ft, the denominator is 35.2.

In the following the variations of measured and predicted values are illustrated in the pavement design life:

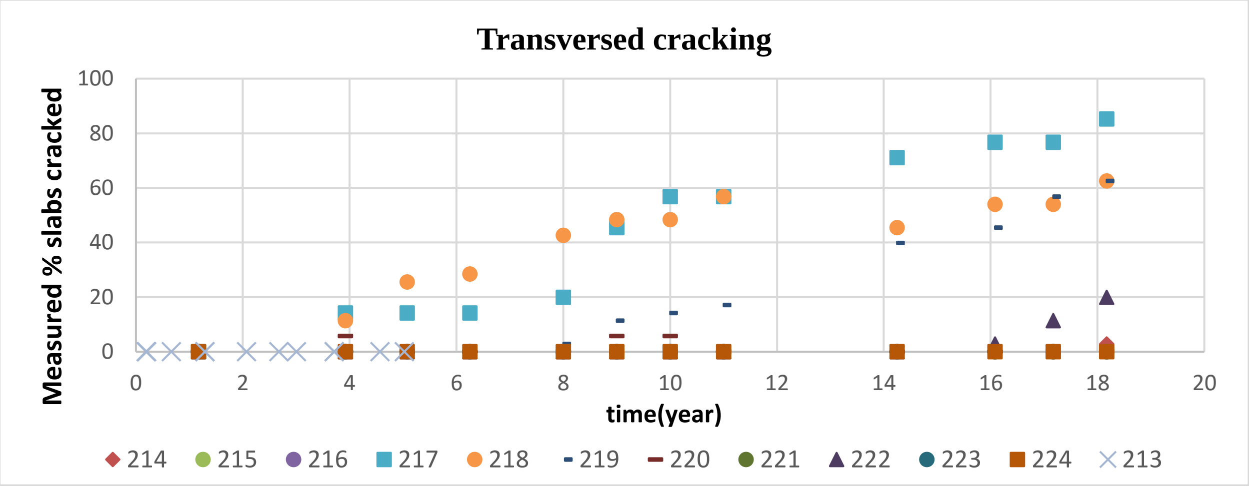


Figure 1. Raw data for measured percent slab cracked for all sections

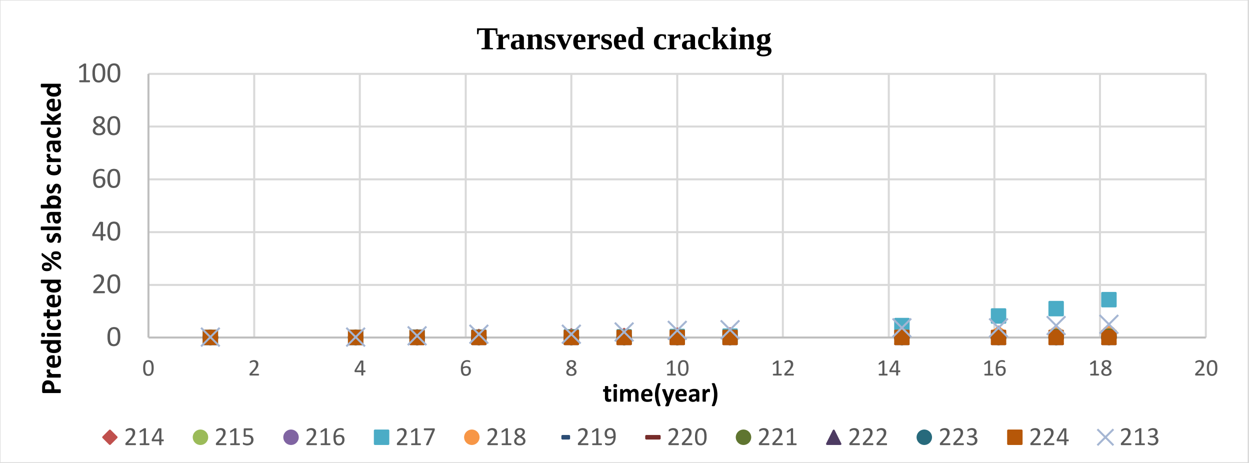


Figure 2. Raw data for predicted percent slab cracked for all sections

A comparison is done between measured and predicted transverse cracking:

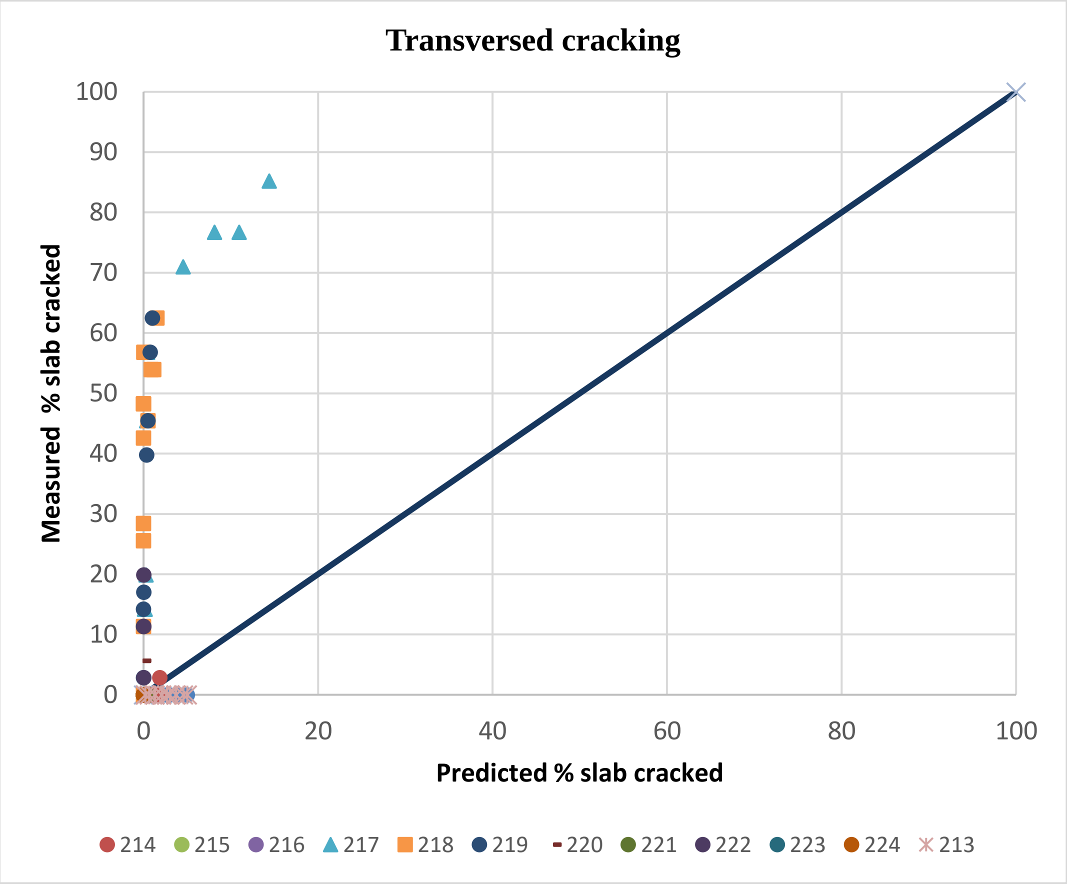


Figure 3. Comparison of measured and predicted % slabs cracked

As it can be seen with the original calibration setting of M-E PDG (C4=1 and C5=-1.98) the results of measured cracks are different from predicted ones in most of the sections. In some of them M-E PDG overestimated the cracking, mostly in granular based sections, and in others it underestimated the cracking, mostly in treated based sections. Since it is evident that bias and standard error of the results is outside the acceptable range, calibrations should be done to these coefficients to improve the pavement performance predictions.

2.3.2. Faulting:

For faulting, it can be seen that the measured values are fluctuating and they do not follow a specific trend. The raw data for section 0213 is shown in figure 4 as an example.

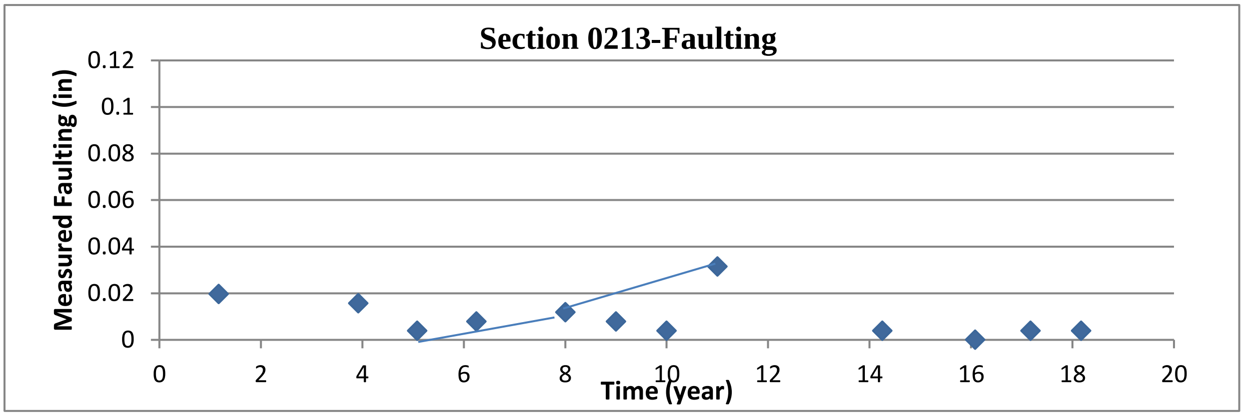


Figure 4. Raw data for measured faulting for section 0213

Since it is expected for faulting to increase by time, it is not possible and practical to consider all of these values. Therefore, only the values which follow an upward trend are selected. These chosen measurements are shown in the sample selection in figure 4 by a line. Moreover, the measured values are in mm which should be converted into inch, because M-E PDG results are reported in inch.

It is worth mentioning that the cause of these fluctuations can be due to inadequate measurements or rehabilitation of the pavement at different periods which decreased faulting at various times.

In the following the variations of the total and selected measured and predicted values are illustrated in the pavement design life:

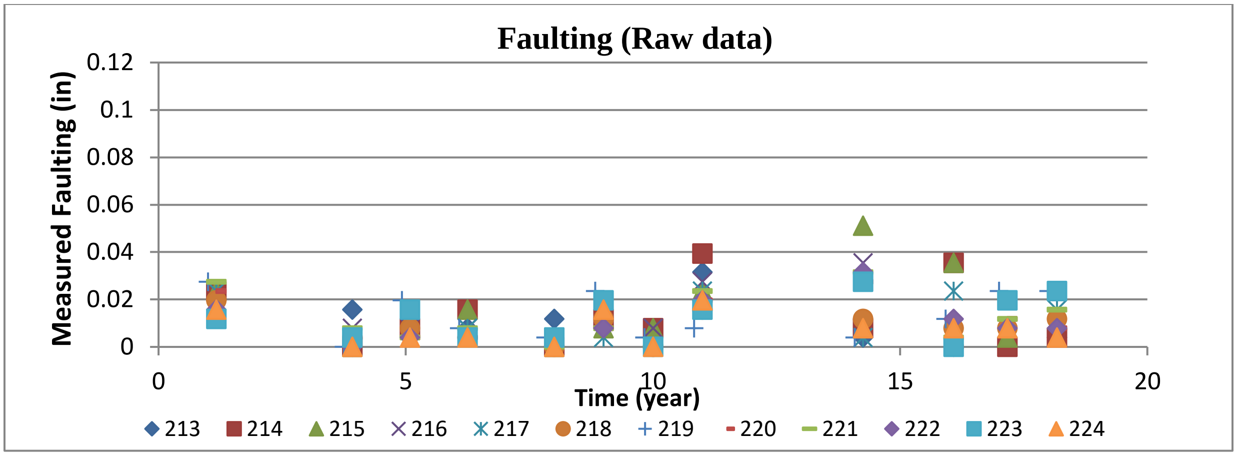


Figure 5. Total raw data for faulting measurements

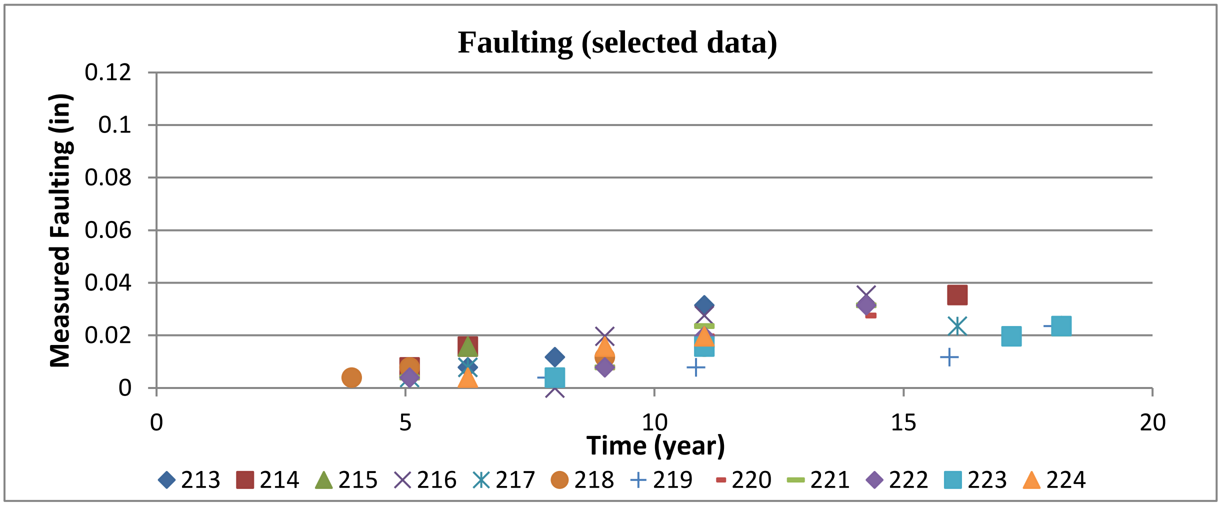


Figure 6. Selected data for faulting measurements

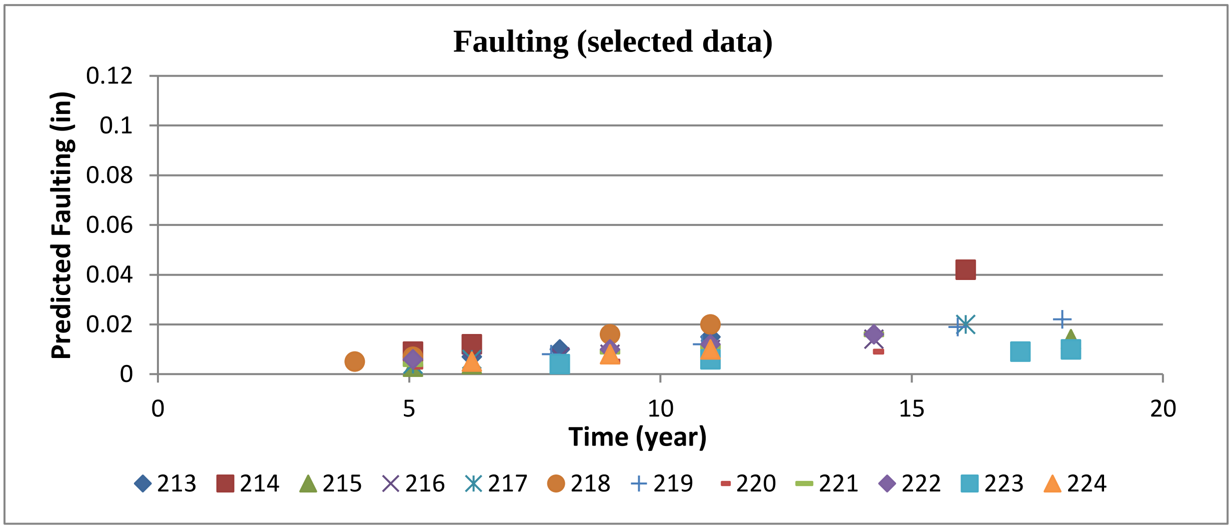


Figure 7. Selected data for faulting prediction

A comparison is done between measured and predicted faulting in figure 8.

As it can be seen with the original calibration coefficients of M-E PDG (C1=1.018) the bias and standard error of the results are not minimum. For improving the prediction of faulting performance calibrations should be done to C1 coefficient.

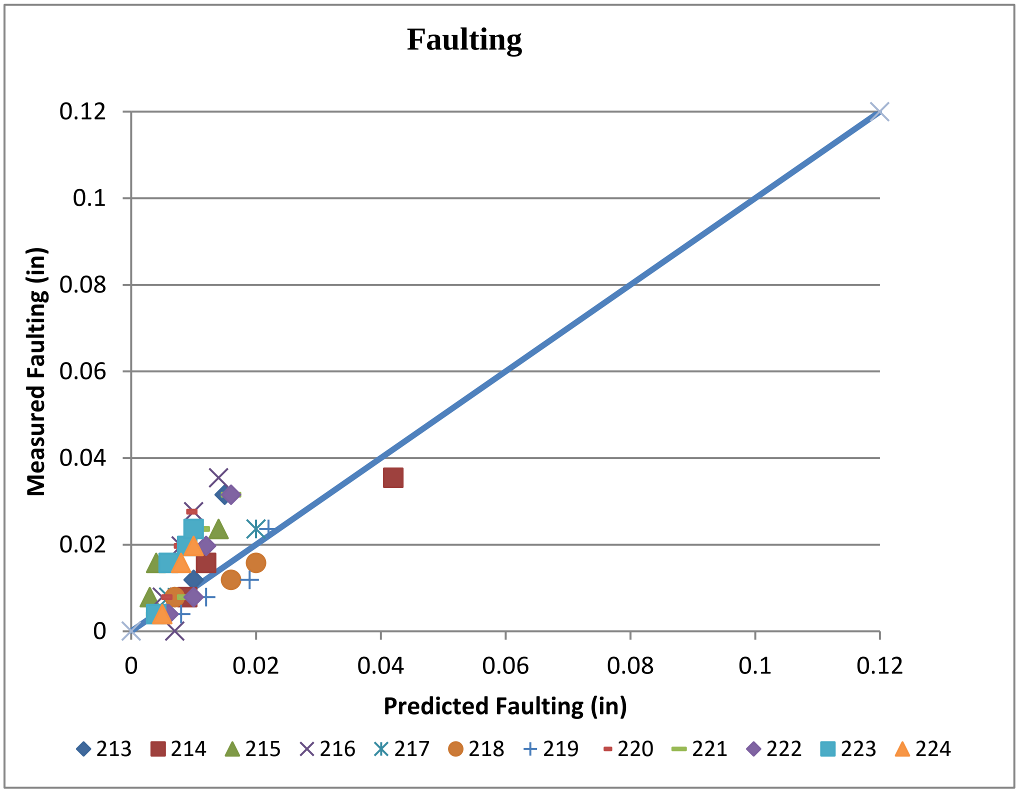


Figure 8. Comparison of measured and predicted faulting

2.3.3. IRI

The IRI data provided is in mm/km unit which needs to be converted to in/miles. Also similar to faulting, some fluctuations are evident in the measurements which are not consistent with the expected trend of IRI. Section 0213 is illustrated as an example in figure 9.

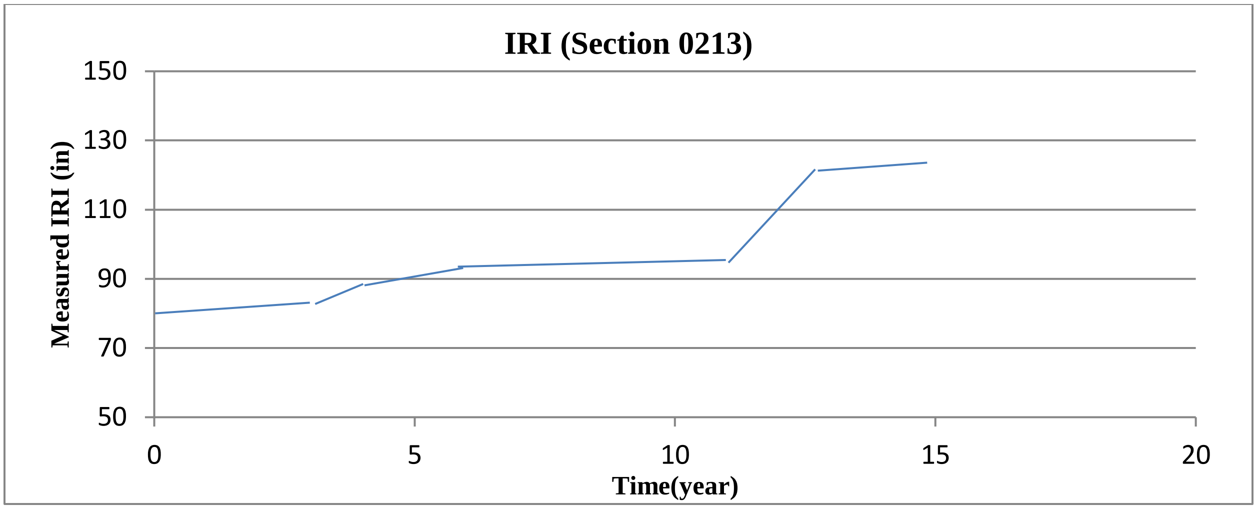


Figure 9. Raw data for IRI measurements for section 0213

Similar to faulting, only the measurements which are following an increasing trend are selected for comparison. These values are demonstrated as an example for section 0213 in Figure 9 with a line. These decreases can be due to the incorrect measurements or various rehabilitation of the pavement in its design life.

In the following the variations of the total and selected measured and predicted values are illustrated in the pavement design life:

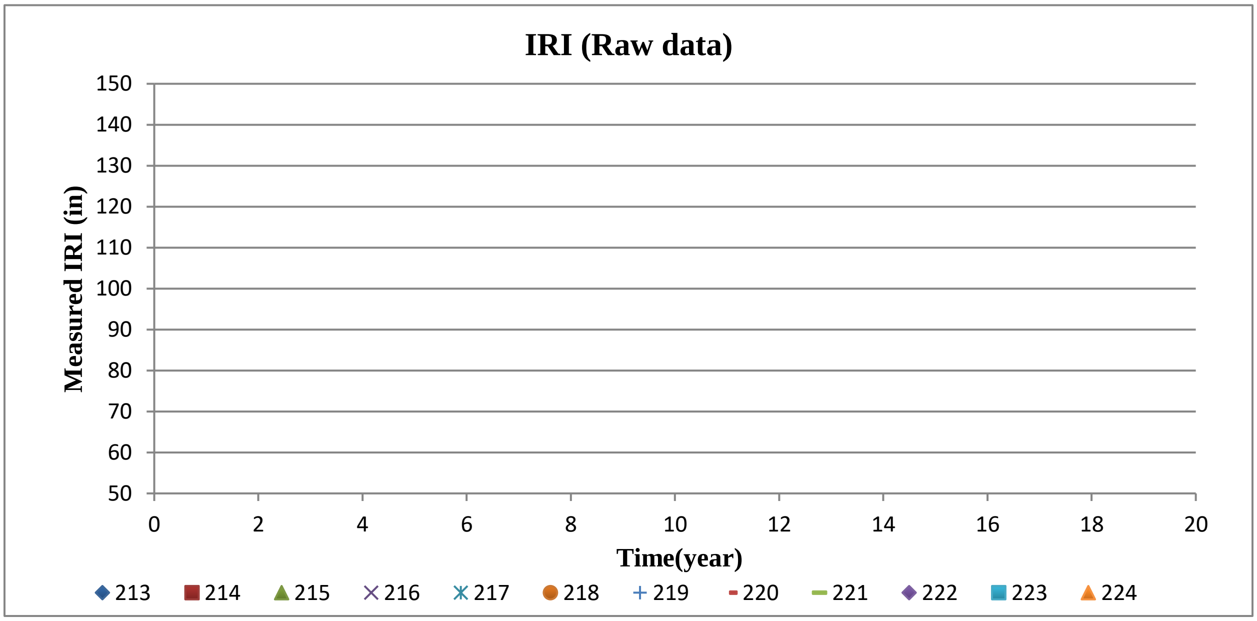


Figure 10. Raw data for IRI measurements for all of the sections

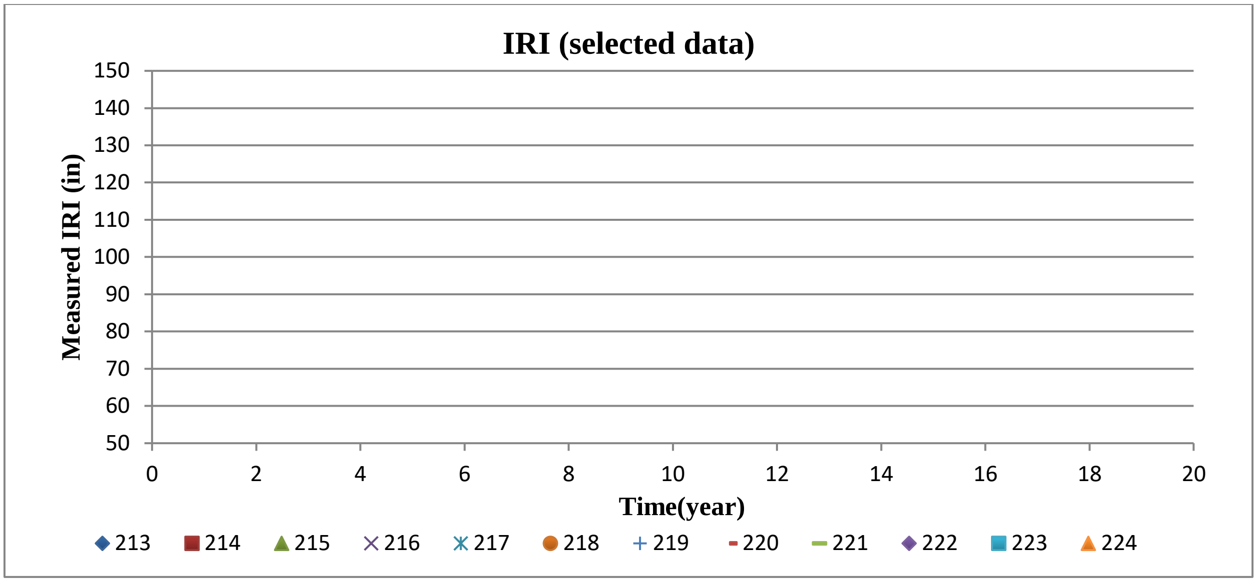


Figure 11. Selected data for IRI measurements for selected sections

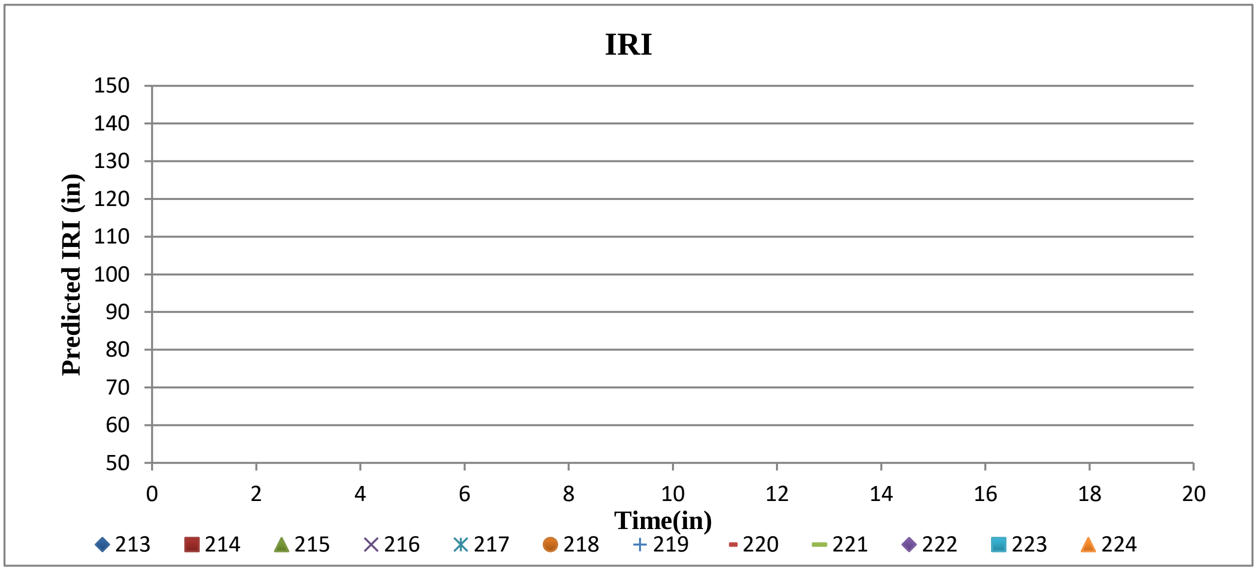


Figure 12. Selected data for IRI prediction for selected sections

A comparison is done between measured and predicted IRI:

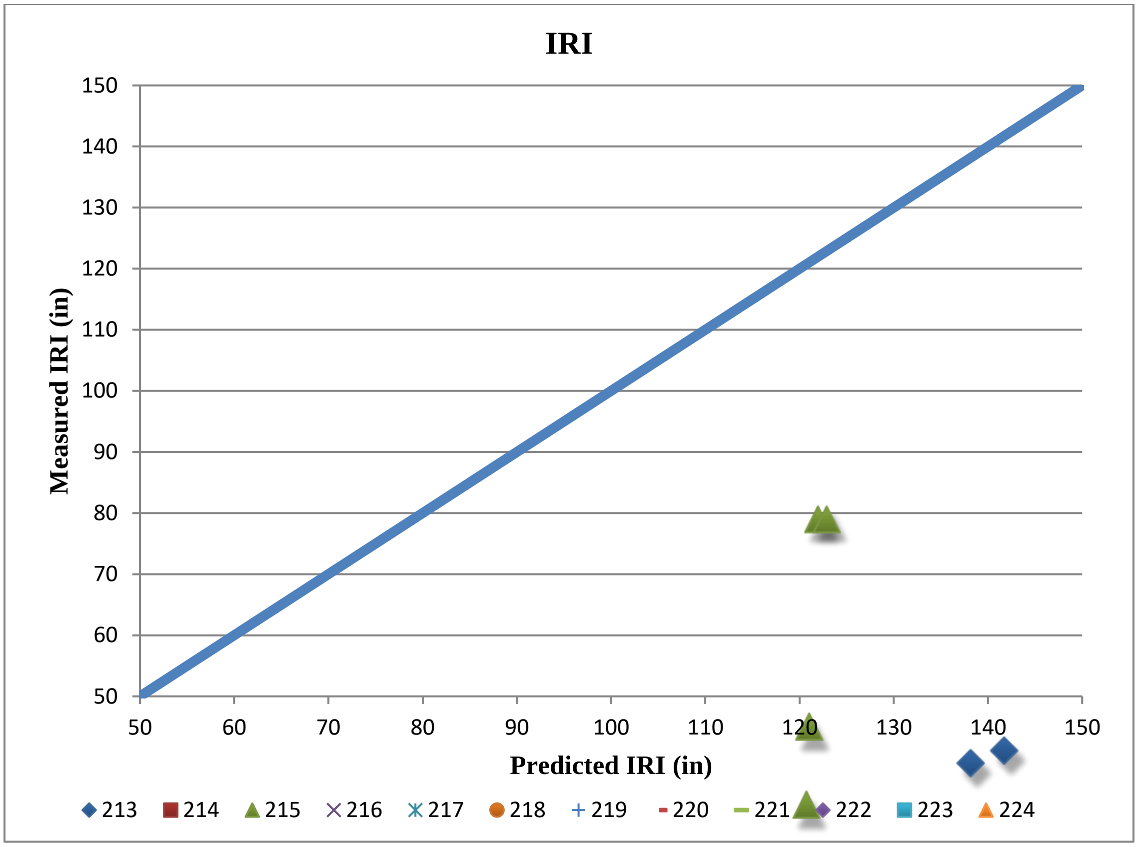


Figure 13. Comparison of measured and predicted IRI

As it can be seen, with the original calibration coefficients (C1=0.82, C2=0.44, C3=1.49 and C4=25.24) which are used by M-E PDG the variations of obtained predicted IRI in design life for most of the sections are smaller than the measured ones. The models are underestimating IRI, therefore, calibrations are required for these coefficients to improve these predictions.

In general, the measured and predicted performances are quite different. This can be due to the incorrect measurements, lack of input data and construction of the pavements.

TASK 3. CALIBRATION

When the model results are not adequate for prediction of the measured performances, local calibrations should be performed to improve the predicted performances. These calibrations can reflect the unique field conditions and design practices. Moreover they can confirm the capability of the model in prediction of pavement distress and smoothness with minimum bias and standard error.

For calibration of the performances, all of the sections should be considered simultaneously. By using statistical techniques the adequacy of each predicted performance can be evaluated. The success of these local calibrations are dependent on the dataset which is used. The size of the sampling and their accuracy can affect the confidence of the local calibration coefficients. In this project due to the limited number of sections, limited PCC designs (including only 8 and 11 inch slabs), calibrations can have some difficulties.

For validating the accuracy and precision of the calibration, mean bias and standard error of the predicted performances are computed and minimized. Bias is defined as the consistent under- or over-prediction of the performance. The standard error is the standard deviation of the sampling distribution divided by square root of the number of samples. The formula for both of these factors are shown below:

$$\text{Mean Bias} = \frac{Measured\ performance - Predicted\ Performance}{N}$$

$$\text{Standard error} = \frac{Standard\ deviation\ of\ Predicted\ Performance}{\sqrt{N}}$$

Due to the differences between measured and predicted values which were illustrated in the previous task, all of the performances require calibrations. These calibrations are explained here:

3.1. Transverse cracking:

Transverse cracking is a load related distress which is caused by repeated loading. Depending on the slab curling transverse cracking can occur starting at either the bottom or top of the slab. Every slab has the potential for either one of these cracking. This is the reason why the predicted bottom-up and top-down cracking are not particularly meaningful and instead a combination of them should be used, excluding the possibility of both occurring at the same time:

%Slab cracks= bottom-up cracking+ Top-down cracking - bottom-up cracking * Top-down cracking

The bottom-up and top-down cracking are obtained from the following formula:

$$CRK = \frac{100}{1 + C_4 (DI_F)^{C_5}}$$

For calibration of the results of M-E PDG the predicted top-down and bottom-up damages should be obtained from the software. By changing C_4 and C_5 coefficients the minimum mean bias and standard error should be found between predicted and measured values.

As it can be seen in figure 3 (predicted vs measured % slabs cracked) the differences between the crack measurements and predictions are too much. In some of the sections the measured values are zero and predicted values are non-zero and in some others vice versa. Due to the limited numbers of samples and limited designs (8 and 11 inch slabs) it is not possible to calibrate all of the sections together. Therefore the sections are divided based on the base type to granular base and treated base and the obtained results are demonstrated in figure 14 and 15 and table 3.

Table 3. Results for transverse cracking calibration

	C4	**C5**	**Mean Bias**	**Standard error**
Granular base section	2	-3	0.0007	0.01775
Treated base sections	0.18	-0.977	-4.035	1.89

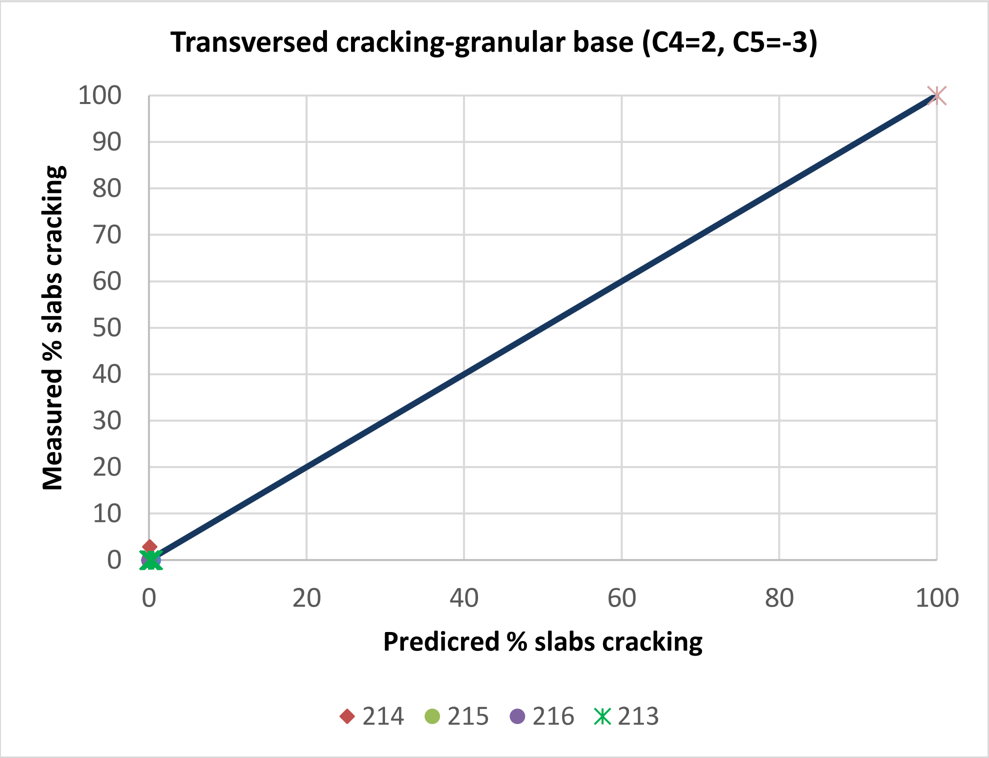


Figure 14. Comparison of measured and calibrated predicted transverse cracking for granular base sections

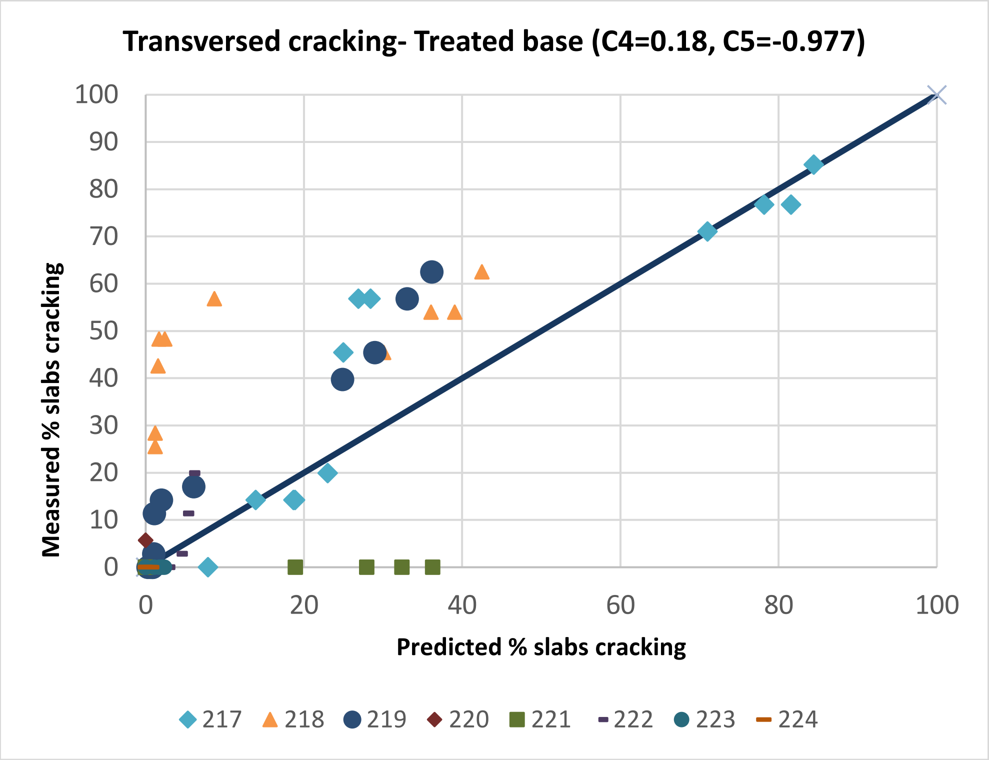


Figure 15. Comparison of measured and calibrated predicted transverse cracking for treated base sections

In these calibrations, the followings should be taken into account:

- C4 and C5 can change in range of [-10, 10].
- For granular base sections, most of the measured values are zero, therefore in calibration the selected C4 and C5 result in zero prediction and this is the reason why most of the point are in the origin. The selected coefficients are C4=2 and C5=-3.
- For the treated base sections the measured values are non-zero for sections 0217-0219 and 0222. On the other hand, since the predictions of M-E PDG are zero, their calibrations are not possible. This difference between the measured and predicted values demonstrates that the M-E PDG model is underestimating the distresses. Therefore, for obtaining similar results to the measured ones, it is required to change some of the parameters of the model which can be the reason for the measured cracking. In this project by changing elastic modulus of cement stabilized base (500,000, 2,000,000) and permanent warp/curling effective temperature difference (-10, -16), it is possible to obtain small but non-zero values for transverse cracking. After the calibration of the new predicted results, C4=0.18 and C5=-0.977 are selected.

- It can be seen that although the mean bias and standard errors should be less than 1, for treated base sections it is not possible to achieve better results. This is an indicator that the model is overestimating or underestimating the measured values and is not able to predict the transverse cracking properly. This is because of the limited number of sampling and design. Therefore, for obtaining better calibration coefficient more data is required.

3.2.Faulting

Faulting calibration for 12 sections of Arizona was conducted by changing C_1 calibration coefficient from the M-E PDG software. There are 3 different C_1 calibration coefficient used in order to calibrate faulting performance for those sections. These C_1 values are 2.0, 2.5 and 3.0 and corresponding predicted and measured faulting plots are like following:

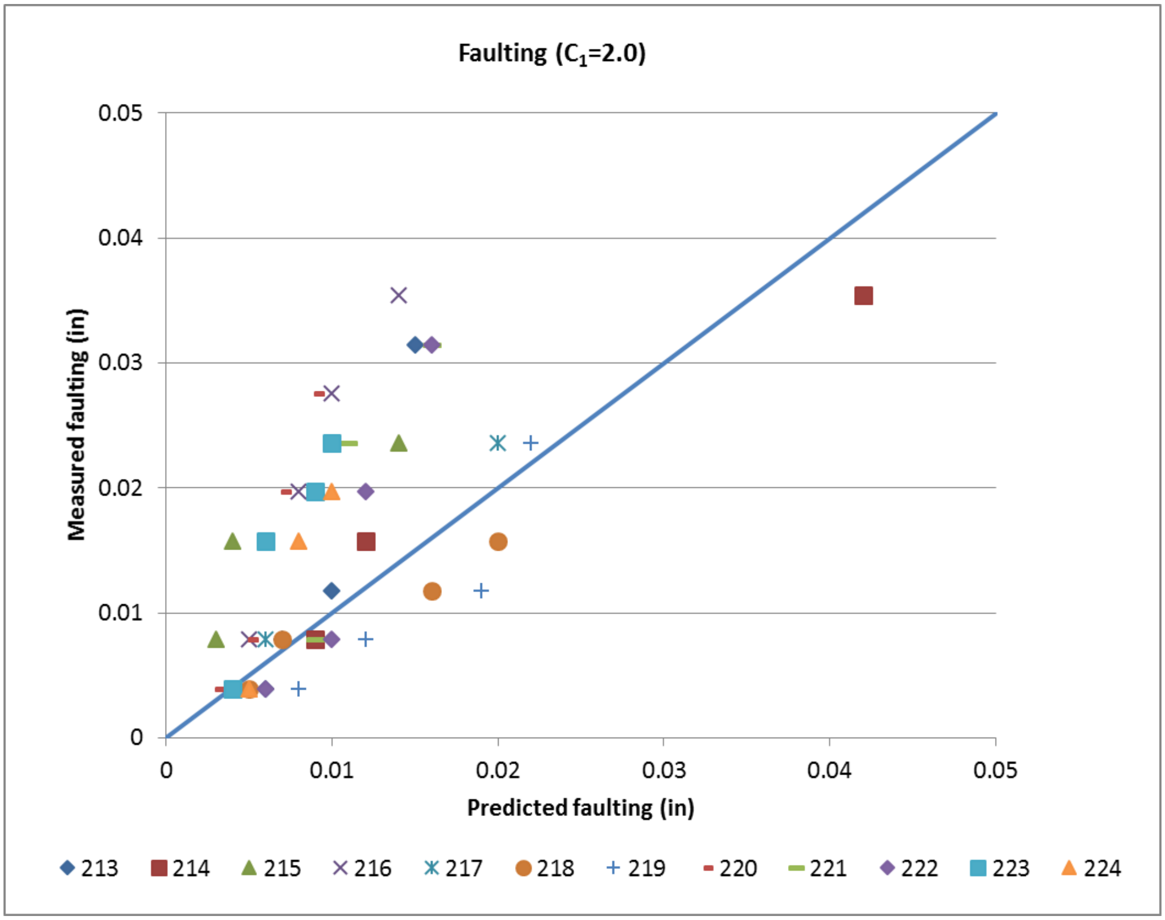


Figure 16: Faulting Calibration when C1 = 2.0

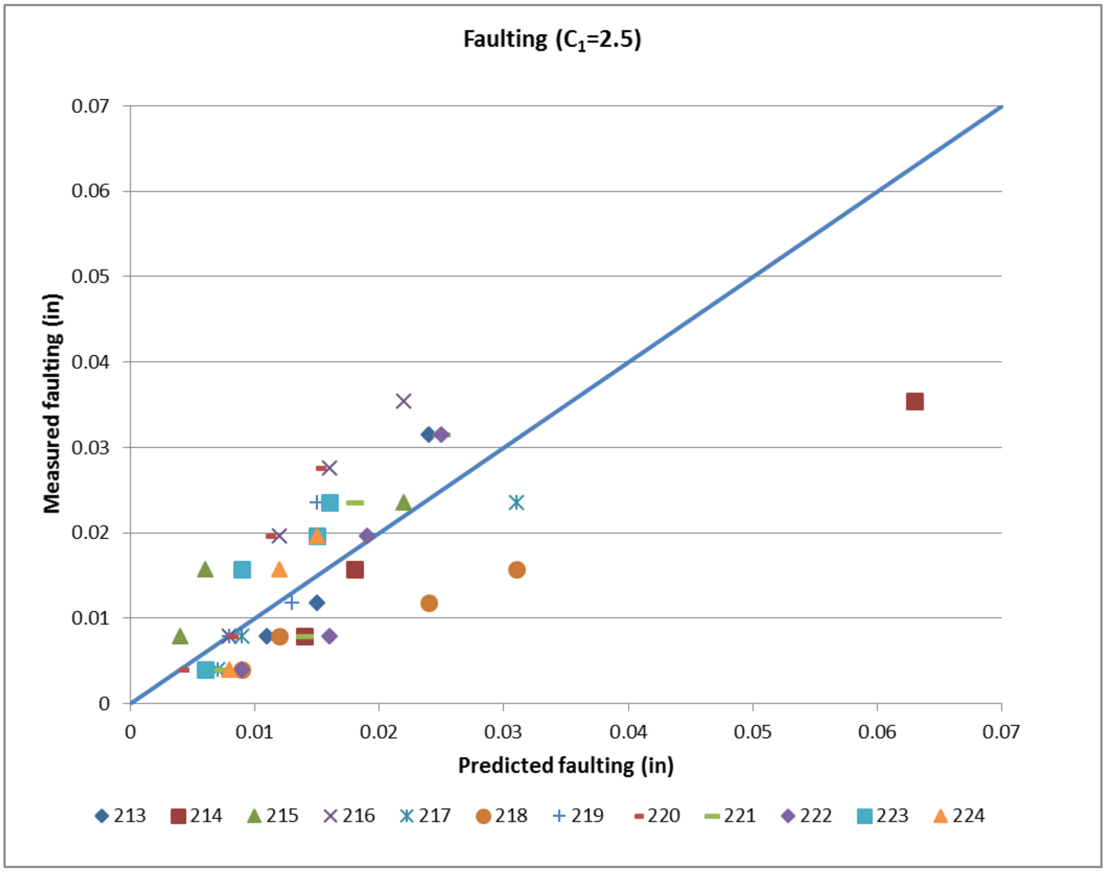


Figure 17: Faulting Calibration when C_1 = 2.5

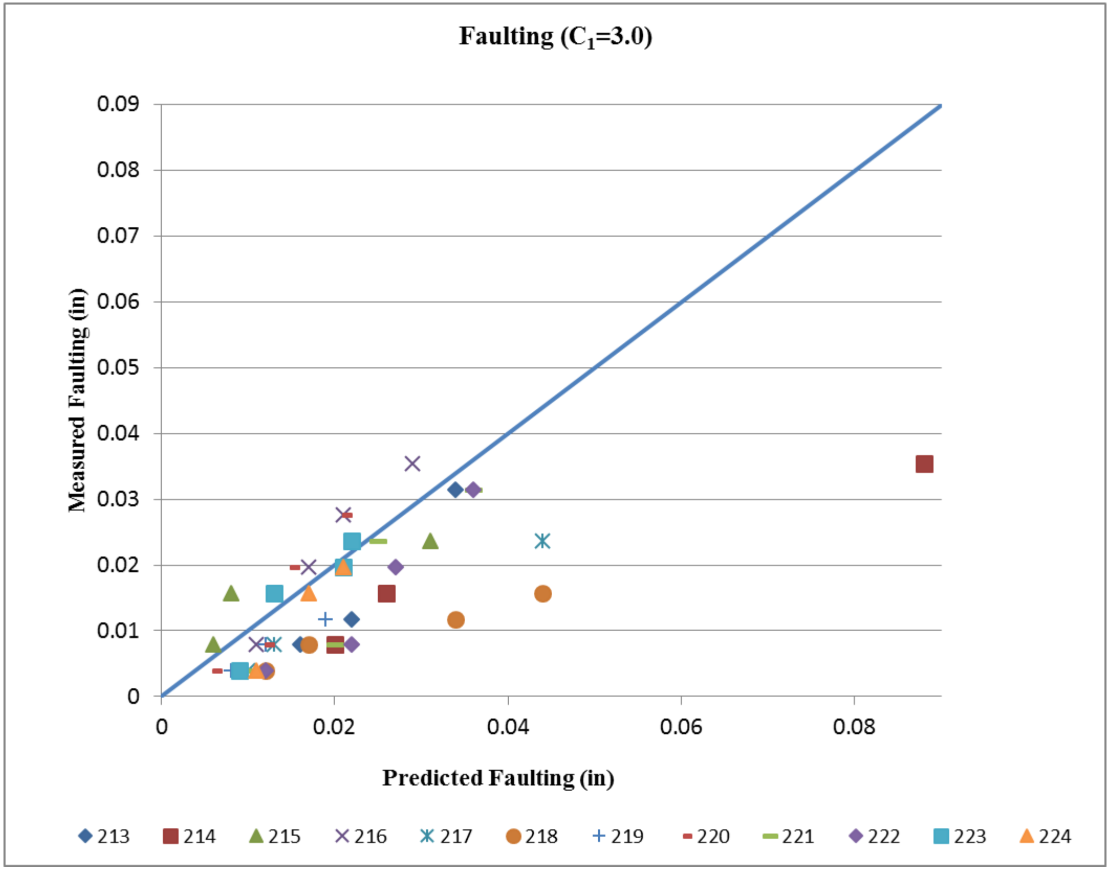


Figure 18: Faulting Calibration when C_1 = 3.0

Note that negative value of LTTP data was taken absolute value and some of the measured values from the field for faulting not showing increasing trend are disregarded during calibration of faulting. For instance, if faulting values are 0.019, 0.007, 0.027, 0.035 in inch for one section, 0.007 inch faulting is not taken into account.

From the plots and table below, it is clearly seen that when C_1 is equal to 2.5, bias and standard deviation for measured and predicted values are so small. Actually, all bias and standard deviation values are so small due to having almost no faulting distresses.

Table 4. Bias and Standard Deviation Values for Different C1 Values

C_1 **Coefficient**	**Bias**	**Standard Deviation**
$\mathbf{C_1 = 2.0}$	6.5×10^{-3}	1×10^{-3}
$\mathbf{C_1 = 2.5}$	5.9×10^{-3}	$2 .2 \times 10^{-4}$
$\mathbf{C_1 = 3.0}$	7.9×10^{-3}	2.1×10^{-3}

In order to get rid of inconsistencies of measurements from the field, some measured data breaking the increasing trend for each section have to be disregarded. Comparisons and calibrations for were done by considering measured field data which is not disregarded and corresponding M-E PDG performance prediction.

Although the study of calibration for faulting was conducted, it may not be so significant to calibrate in terms of faulting due to lower distresses. In detailed, in spite of upper limit value of faulting identified by NCHRP being 0.12 inch, measured and M-E PDG performance before calibration is 0.035 and 0.049 inch, respectively. Therefore, measured and predicted values are so small comparing threshold value. The reasons behind this fact can be summarized as follows:

- Joint and dowel design is so enough that differential energy due to deflection of loaded and unloaded slab becomes so low.
- Since it can be seen from climate data, the climate of Arizona; in other words, annual average temperatures, is not so tough to get higher freezing index.
- In terms of erodibility of base layer of sections, sections having treated base layer has smaller M-E PDG predictions and also measurements than sections having granular base due to the fact that treated base may have higher modulus to resist deformation.

3 different calibration study was conducted for faulting. Each time only C1 calibration coefficients was changed in order to calibrate faulting and although mean and standard error values are so small for all calibration coefficient trials due to low distresses, when C1 is equal to 2.5, bias and standard error are the smallest value.

3.3.IRI

IRI calibration for 12 JPCP sections of Arizona was conducted by using initial IRI, calibrated faulting and transverse cracking, spalling and site factor. Except initial IRI, all parameters which form IRI are related to one calibration coefficient (C1, C2, C3 and C4).

$$IRI = IRI_I + C1\ x\ CRK + C2\ x\ SPALL + C3\ x\ TFAULT + C4\ x\ SF$$

Spalling data was taken from M-E PDG results. Site Factor was calculated from the **formula()** below. Since, freezing index is zero for all sections, site factor only depends on age of the pavement percent subgrade material passing No. 200 sieve.

$$SF = AGE(1 + 0.5556xFI)(1 + P_{200})x10^{-6}$$

Due to the fact that the calibration process of transverse cracking are studied according to base type and transverse cracking affects calculation of IRI, calibration of IRI also takes place in 2 parts: sections having granular base and sections having treated base.

During study of calibration of IRI, some measurements IRI from field making the tendency irregular over years are disregarded. For instance, , if measured IRI values are 1.022, 1.215, 1.235, 1.233 and 1.322 in inch/mile respectively for one section, 1.233 inch/mile is not taken into account.

Granular Base Sections

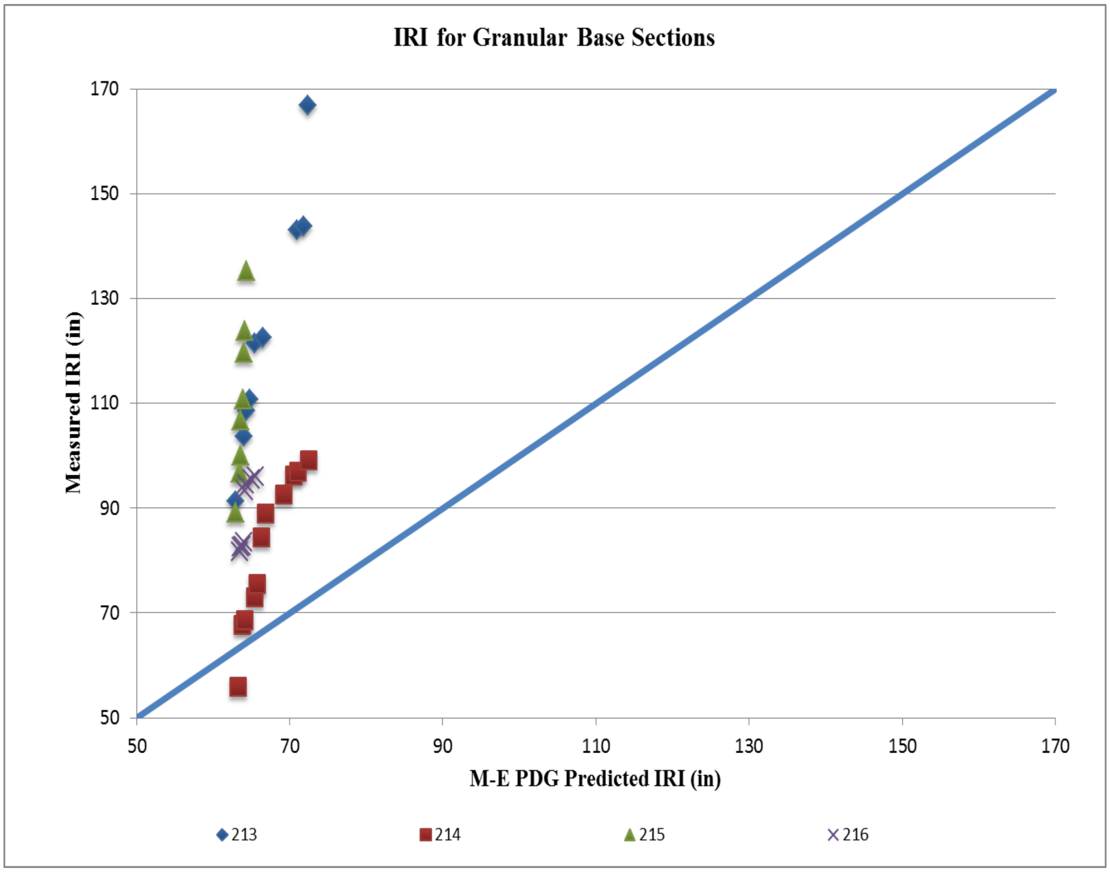


Figure 19: Comparison between measured and predicted IRI before Calibration for granular base sections

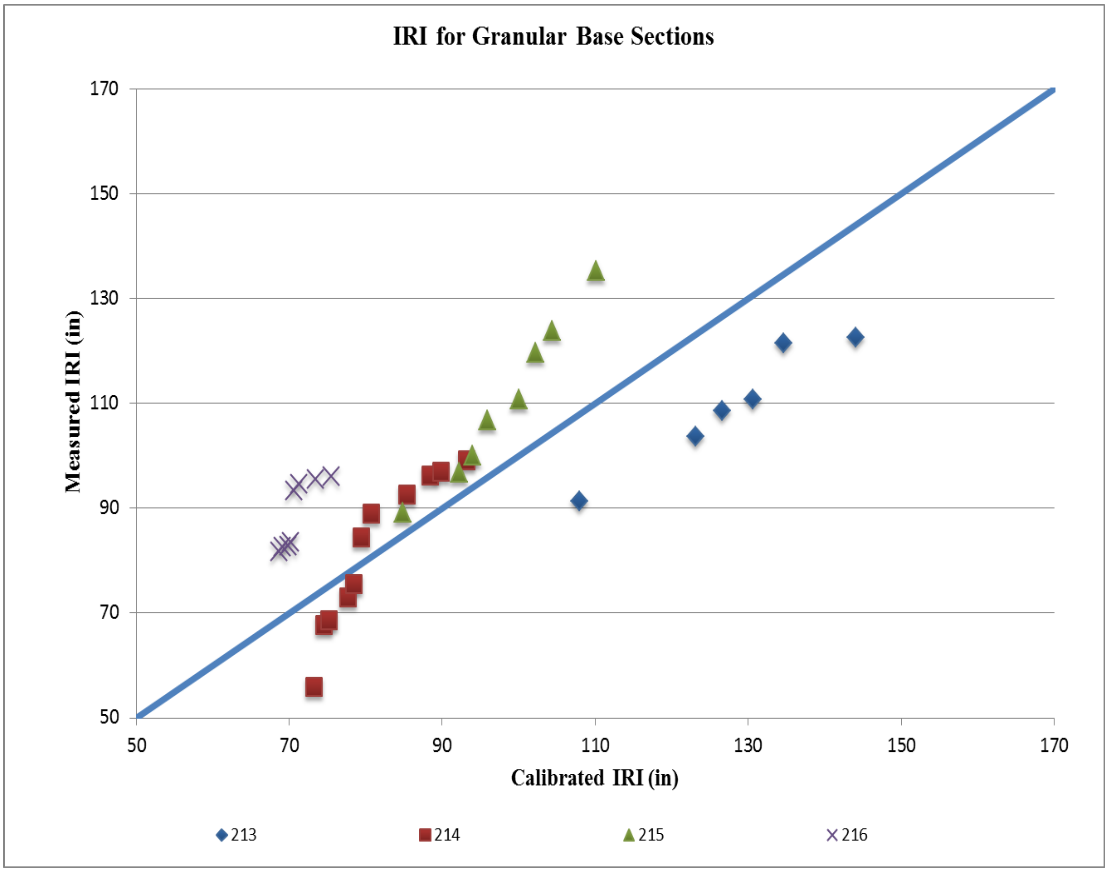


Figure 20: Comparison between measured and predicted IRI before Calibration for granular base sections

Table 5. Bias & Standard Error for Calibrated and Initial Calibration Coefficients

Calibrated Part		**M-E PDG Predicted Part**	
Mean Bias	**Standard Error**	**Mean Bias**	**Standard Error**
0.00E+00	5.85	-3.44E+01	0.48
C1	1.02	**C1**	0.82
C2	54.02	**C2**	0.44
C3	1.49	**C3**	1.49
C4	90.00	**C4**	25.24

Calibration coefficients were found as above table. C2 coefficient should be less than 10 but it is out of range. If C2 is kept below 10 and calibration was conducted with respect to C1, C3 and C4, mean bias was obtained as -26.57 which is very close to mean bias obtained from comparison between M-E PDG prediction and field measurement.

Treated Base Sections

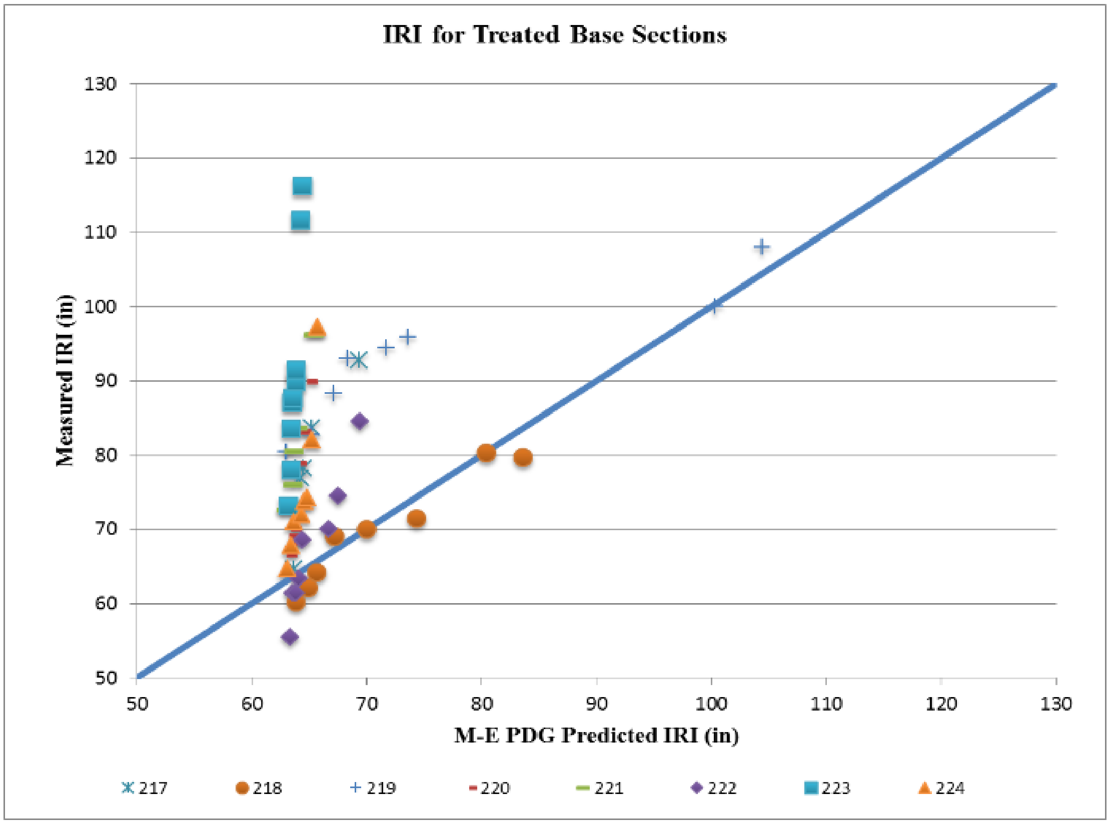


Figure 21: Comparison between measured and predicted IRI before Calibration for treated base sections

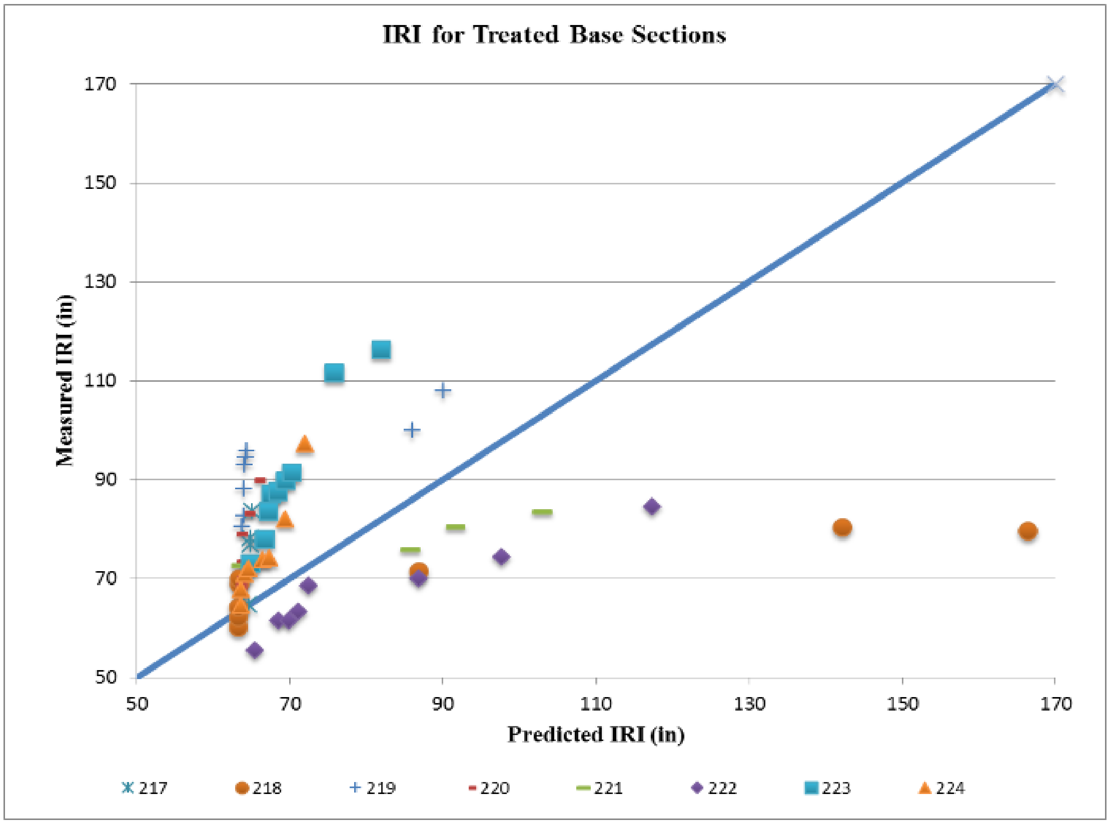


Figure 22: Comparison between measured and predicted IRI after Calibration for treated base sections

Table 6. Bias & Standard Error for Calibrated and Initial Calibration Coefficients

Calibrated Part		**M-E PDG Predicted Part**	
Mean Bias	**Standard Error**	**Mean Bias**	**Standard Error**
4.82E-16	3.28	-4.81E+00	1.00
C1	6.85	**C1**	0.82
C2	1.45	**C2**	0.44
C3	0.02	**C3**	1.49
C4	25.00	**C4**	25.24

Like granular base sections, after calibration process of IRI for treated base sections, C2 was larger than upper limit recommended value. However, if a condition was put for C2 which is less than 10, calibration coefficients became as above table.

The range of M-E PDG prediction and measurements from the field are 63 to 113.6 and 55.56 to 166.6 and also, most of the prediction and corresponding measurement value are not matched. Therefore, IRI calibration is needed to be done for 12 JPCP sections.

Since IRI calculation was affected by cracking and faulting, calibration of transverse cracking and faulting should be done firstly. From the transverse cracking calibration, C4 and C5 calibration coefficients change with base type; that’s why, calibration coefficients for IRI also changes with base type: granular base and treated base.

Before going into detail for section calibration coefficients, it should be mentioned that each calibration coefficient is related to one property. C1, C2, C3 and C4 make the effect of transverse cracking, spalling, faulting and site factor, respectively, to change. Unlike transverse cracking and faulting calculation, IRI is not calculated mechanistically by M-E PDG. Therefore, IRI is the weakest part of the M-E PDG.

By looking faulting calibration results for granular base, it can be seen that C2 coefficient exceeds its limit of 10. During calibration work, it had seen that C2 calibration coefficient was great effect on calibration. However, C2 is related with spalling and spalling performance is an empirical model according to collected data from NCHRP 1-19, FHWA RPPR, and FHWA PRS projects. C1 is not effective for this situation because calibrated almost all of the transverse cracking for granular base is zero. C3 has also insignificant due to low calibrated faulting data. Due to the fact that, freezing index for all sections is zero and freezing index is one of the important input value of site factor, C4 is not effective during calibration of IRI. Therefore, C2 has great effect on calibration and it makes the trend change obviously. However, C2 exceeds its limit; that’s why, it can be said that IRI calibration for 4 granular JPCP section cannot made. If more section having granular base were available, calibration could be made; however, those 4 section which is available are not enough to calibrate coefficients.

For sections having treated base, due to the existence of measured and predicted transverse crack, effect of C1 coefficient on IRI calibration is not insignificant. Tough C2 coefficient has still great impact on calibration, all coefficients are within their limits due to transverse cracking occurred and predicted from M-E PDG. Like granular base sections, freezing index of sections is zero and does not affect to site factor. Only subgrade material passing through No. 200 sieve affects the site factor and that impact is so small to consider. In addition to that, due to the measured and predicted M-E PDG faulting being almost zero, C3 has no significant role in IRI calibration. Both C1 and C2 is decisive parameters for calibration of IRI.

APPENDIX

- **M-E PDG INPUT**
    - **Inventory Data**

Table 7. Joint Spacing and Dowel Diameters

Section ID	**213**	**214**	**217**	**218**	**221**	**222**
Joint Spacing(ft)	15					
Dowel Diameter (in)	1.25					

Section ID	**215**	**216**	**219**	**220**	**223**	**224**
Joint Spacing(ft)	15					
Dowel Diameter (in)	1.5					

Table 8. Inventory Input Data 2

Section ID	**Subgrade Material**	**Sub-base Material / Thickness (in)**	**Base Material / Thickness (in)**		**JPCP Layer Thickness (in)**
213	Coarse-Grained Soil: Silty Sand with Gravel	No sub-base	Unbound (granular base): Crushed Gravel	5.8	7.9
214				6.1	8.3
215				6.3	11
216				6.3	11.2
217			Bound (treated base): Lean Concrete	6.1	8.1
218				6.2	8.3

219				6.2	10.8
220				6.2	11.2
221	Unbound (granular base): Crushed Gravel	4.2	Bound (treated base): Open Graded, Hot Laid, Central Plant Mix	4.2	8.1
222		4.3		3.9	8.6
223		3.5		4.1	11.1
224		3.8		4.4	10.6

- ### Material

Table 9: PCC Layer Material Properties

		PCC Layer Properties					
-	**Section ID**	**Unit weight (pcf)**	**Poisson's Ratio**	**Coefficient of thermal expansion (/ F° x 10^{-6})**	**Cementitious material content (lb/yd^3)**	**Water / Cement Ratio**	**28 – day PCC compressive strength (psi)**
	213	143	0.15	-	400	0.58	6500
	214	145	0.2	-	799	0.37	6490
	215	143	0.14	8.1	400	0.58	4628
	216	145	0.17	8.0	799	0.37	6883
	217	146	0.18	-	400	0.58	4287

218	145	0.18	-	799	0.37	7147
219	144	0.14	-	400	0.58	4475
220	145	0.20	-	799	0.37	7215
221	144	0.16	-	400	0.58	5420
222	-	-	-	799	0.37	6975
223	145	0.15	-	400	0.58	5257
224	146	0.16	-	799	0.37	7010

Table 10: Base Layer Material Properties

Base Layer Properties

Section ID	**Type**	**Poisson's ratio**	**Coefficient of lateral pressure (K_0)**	**LL**	**PI**	**Sieve Analysis**								
						#200	**#80**	**#40**	**#10**	**#4**	**3/8**	**¾**	**1**	**2**
213	**Granular Base**	-	-	-	-	-	-	-	-	-	-	-	-	-
214		-	-	-	NP	6.3	11	20	38	44	55	90	100	100

215		-	-	-	NP	8	14	26	48	54	64	94	100	100
216		-	-	-	-	-	-	-	-	-	-	-	-	-
217	**Treated Base (Lean Concrete)**	NOT AVAILABLE												
218														
219														
220														

		Asphalt Grade	**Asphalt Content (%)**	**Bulk Specific Gravity**	**Max. Specific Gravity**
221	**Treated Base (HMA)**	4	2.5	2.284	-
222		-	1.8	2.248	2.606
223		4	2.4	2.27	2.604
224		4	2.7	-	-

Table 11: Sub-base Layer Material Properties

Sub-Base Layer Properties

Section ID	Type	Poisson's ratio	Coefficient of lateral pressure (K_0)	LL	PI	Sieve Analysis								
						#200	#80	#40	#10	#4	3/8	¾	1	2
221	Granular Base	-	-	-	NP	7.4	12	22	44	50	61	92	100	100
222		-	-	-	-	-	-	-	-	-	-	-	-	-
223		-	-	-	-	-	-	-	-	-	-	-	-	-
224		-	-	-	NP	6.9	12	21	40	46	57	91	100	100

Table 12:Sub-grade Layer Material Properties

Sub-grade Layer Properties

Section ID	Soil Class	Poisson's ratio	Coefficient of lateral pressure (K_0)	LL	PI	Sieve Analysis								
						#200	#80	#40	#10	#4	3/8	¾	1	2
213	A-2-4	-	-	-	NP	24.8	35	50	76	85	92	97	98	100
214	-	-	-	-	-	-	-	-	-	-	-	-	-	-
215	-	-	-	-	-	-	-	-	-	-	-	-	-	-
216	A-2-4	-	-	22	3	25.6	35	49	75	83	93	99	100	100
217	A-2-4	-	-	-	NP	22.5	36	56	84	89	94	99	100	100
218	-	-	-	28	NP	18.5	26	33	54	67	82	97	98	100

219	**-**	-	-	-	NP	33.3	53	68	89	94	98	100	100	100
220	**A-1-b**	-	-	28	6	20.9	31	47	76	83	90	97	99	100
221	**-**	-	-	-	-	-	-	-	-	-	-	-	-	-
222	**A-2-6**	-	-	31	11	21.7	31	45	71	81	89	95	98	100
223	**A-2-4**	-	-	-	NP	21.1	34	53	82	88	93	97	99	100
224	**-**	-	-	31	7	40.9	52	61	83	89	94	98	100	100

- **Environmental**

Table 13: Climate Data

Time (Year)	**Climate (Virtual Weather Station (VWS) Data)**			
	Annual Average Precipitation (mm)	**Annual Average Temperature (^{0}C)**	**Annual Average Freeze Index (^{0}C $^)$days)**	**Annual Average Humidity Min-Max (%)**
1993	375.7	22.1	0	22-57
1994	198.1	22.4	0	22-56
1995	183.1	22.8	0	22-57
1996	134.3	23.3	0	18-49
1997	151.1	23.1	0	
1998	302.7	21.4	0	24-61
1999	152.2	22.1	0	19-50
2000	212.8	22.7	0	20-52
2001	157.6	22.5	0	22-55
2002	94.7	22.2	0	16-43
2003	226.7	23	0	18-49
2004	228.8	23.1	0	19-50
2005	234.9	23	0	20-52
2006	149.8	23.1	0	16-45
2007	154.1	23.5	0	16-46
2008	229.9	23.2	0	17-51
2009	111.4	23.6	0	15-45
2010	251.7	23.1	0	18-51
2011	113.6	22.9	0	

2012	102.8	23.7	0	
2013				

Table 14. Transverse cracking calibration for granular based sections

		C4	**2**	**C5**	**-3**					
	Year	**Bottom up Damage**	**Top-down Damage**	**MEPDG fatigue cracking**	**Total damage calc. (bottom-up)**	**Total damage calc. (top-down)**	**Total fatigue cracking calculated**	**Measured from Field (count)**	**Measured from Field (%)**	**Bias**
213	**1.17**	0.0421	0.0098	0.2000	0.0000	0.0000	0.0038	0.0000	0.0000	0.0038
	3.92	0.0415	0.0081	2.0000	0.0000	0.0000	0.0036	0.0000	0.0000	0.0036
	5.08	0.0780	0.0150	3.0000	0.0002	0.0000	0.0239	0.0000	0.0000	0.0239
	6.25	0.1100	0.0200	4.3000	0.0007	0.0000	0.0669	0.0000	0.0000	0.0669
	8	0.1100	0.0200	6.7000	0.0007	0.0000	0.0669	0.0000	0.0000	0.0669
	9	0.1400	0.0260	8.1000	0.0014	0.0000	0.1379	0.0000	0.0000	0.1379
	10	0.1600	0.0290	9.7000	0.0020	0.0000	0.2056	0.0000	0.0000	0.2056
	11	0.1700	0.0310	11.3000	0.0025	0.0000	0.2465	0.0000	0.0000	0.2465
	14.25	0.1900	0.0330	14.4000	0.0034	0.0000	0.3436	0.0000	0.0000	0.3436
	16.08	0.2100	0.0460	16.1000	0.0034	0.0000	0.3436	0.0000	0.0000	0.3436
	17.17	0.2200	0.0520	17.1000	0.0046	0.0000	0.4658	0.0000	0.0000	0.4658
	18.17	0.2200	0.0520	18.0000	0.0053	0.0001	0.5366	0.0000	0.0000	0.5366
214	**1.17**	0.0122	0.0077	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001
	3.92	0.0370	0.0219	0.2000	0.0000	0.0000	0.0031	0.0000	0.0000	0.0031
	5.08	0.0448	0.0261	0.3000	0.0000	0.0000	0.0054	0.0000	0.0000	0.0054
	6.25	0.0544	0.0303	0.4000	0.0001	0.0000	0.0094	0.0000	0.0000	0.0094
	8	0.0667	0.0375	0.6000	0.0001	0.0000	0.0175	0.0000	0.0000	0.0175
	9	0.0739	0.0411	0.8000	0.0002	0.0000	0.0236	0.0000	0.0000	0.0236
	10	0.0810	0.0447	0.9000	0.0003	0.0000	0.0310	0.0000	0.0000	0.0310
	11	0.0881	0.0483	1.1000	0.0003	0.0001	0.0398	0.0000	0.0000	0.0398
	14.25	0.0974	0.0636	1.4000	0.0005	0.0001	0.0590	0.0000	0.0000	0.0590
	16.08	0.1009	0.0732	1.6000	0.0005	0.0002	0.0709	0.0000	0.0000	0.0709
	17.17	0.1032	0.0784	1.7000	0.0005	0.0002	0.0790	0.0000	0.0000	0.0790
	18.17	0.1053	0.0834	1.9000	0.0006	0.0003	0.0873	1.0000	2.8409	-2.7536
215	**1.17**	0.0001	0.0030	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	3.92	0.0004	0.0082	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	5.08	0.0004	0.0097	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	6.25	0.0005	0.0111	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001
	8	0.0006	0.0136	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001
	9	0.0007	0.0148	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0002
	10	0.0008	0.0161	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0002
	11	0.0008	0.0173	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000	0.0003
	14.25	0.0009	0.0218	0.1000	0.0000	0.0000	0.0005	0.0000	0.0000	0.0005
	16.08	0.0009	0.0246	0.1000	0.0000	0.0000	0.0007	0.0000	0.0000	0.0007
	17.17	0.0009	0.0261	0.1000	0.0000	0.0000	0.0009	0.0000	0.0000	0.0009
	18.17	0.0009	0.0275	0.1000	0.0000	0.0000	0.0010	0.0000	0.0000	0.0010

216	**1.17**	0.0000	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	3.92	0.0000	0.0010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	5.08	0.0000	0.0012	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	6.25	0.0000	0.0013	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	8	0.0000	0.0016	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	9	0.0000	0.0017	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	10	0.0000	0.0018	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	11	0.0000	0.0020	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	14.25	0.0000	0.0025	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	16.08	0.0000	0.0028	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	17.17	0.0000	0.0030	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	18.17	0.0000	0.0031	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 15. Transverse cracking calibration for treated based sections

		C4	**0.1827188**	**C5**	**-0.9775**					
	Year	**Bottom up Damage**	**Top-down Damage**	**MEPDG fatigue cracking**	**Total damage calc. (bottom-up)**	**Total damage calc. (top-down)**	**Total fatigue cracking calculated**	**Measured from Field (count)**	**Measured from Field (%)**	**bias**
217	**1.17**	0.014	0.000	0.000	0.078	0.001	7.892	0.000	0.000	7.892
	3.92	0.027	0.000	0.000	0.138	0.001	13.887	5.000	14.205	-0.318
	5.08	0.039	0.000	0.000	0.185	0.002	18.683	5.000	14.205	4.478
	6.25	0.039	0.000	0.000	0.187	0.002	18.873	5.000	14.205	4.669
	8	0.051	0.000	0.000	0.228	0.003	23.018	7.000	19.886	3.132
	9	0.056	0.001	0.000	0.247	0.003	24.986	16.000	45.455	-20.469
	10	0.062	0.001	0.000	0.267	0.003	26.899	20.000	56.818	-29.919
	11	0.068	0.001	0.000	0.282	0.003	28.423	20.000	56.818	-28.396
	14.25	0.141	0.160	1.500	0.446	0.477	71.023	25.000	71.023	0.000
	16.08	0.170	0.235	3.900	0.492	0.570	78.174	27.000	76.705	1.469
	17.17	0.195	0.280	5.700	0.525	0.612	81.578	27.000	76.705	4.873
	18.17	0.218	0.333	7.800	0.553	0.651	84.420	30.000	85.227	-0.807
218	**1.17**	0.001	0.000	0.000	0.004	0.001	0.516	0.000	0.000	0.516
	3.92	0.001	0.000	0.000	0.008	0.001	0.825	4.000	11.364	-10.538
	5.08	0.002	0.000	0.000	0.011	0.001	1.194	9.000	25.568	-24.374
	6.25	0.002	0.000	0.000	0.011	0.001	1.194	10.000	28.409	-27.215
	8	0.002	0.000	0.000	0.014	0.002	1.557	15.000	42.614	-41.056
	9	0.002	0.000	0.000	0.015	0.002	1.676	17.000	48.295	-46.619
	10	0.003	0.001	0.000	0.017	0.008	2.406	17.000	48.295	-45.889
	11	0.003	0.013	0.000	0.017	0.071	8.670	20.000	56.818	-48.148
	14.25	0.003	0.069	0.000	0.020	0.286	30.089	16.000	45.455	-15.366
	16.08	0.003	0.092	0.000	0.021	0.347	36.050	19.000	53.977	-17.927

	17.17	0.004	0.105	0.000	0.022	0.377	39.043	19.000	53.977	-14.935
	18.17	0.004	0.122	0.000	0.022	0.412	42.502	22.000	62.500	-19.998
219	**1.17**	0.000	0.000	0.000	0.000	0.003	0.260	0.000	0.000	0.260
	3.92	0.000	0.001	0.000	0.000	0.006	0.574	0.000	0.000	0.574
	5.08	0.000	0.001	0.000	0.001	0.008	0.825	0.000	0.000	0.825
	6.25	0.000	0.001	0.000	0.001	0.008	0.825	0.000	0.000	0.825
	8	0.000	0.002	0.000	0.001	0.009	1.008	1.000	2.841	-1.833
	9	0.000	0.002	0.000	0.001	0.010	1.069	4.000	11.364	-10.295
	10	0.000	0.003	0.000	0.001	0.019	1.962	5.000	14.205	-12.243
	11	0.000	0.011	0.000	0.001	0.060	6.050	6.000	17.045	-10.995
	14.25	0.000	0.057	0.000	0.001	0.248	24.858	14.000	39.773	-14.915
	16.08	0.000	0.070	0.000	0.001	0.289	28.963	16.000	45.455	-16.492
	17.17	0.000	0.085	0.000	0.001	0.330	33.011	20.000	56.818	-23.807
	18.17	0.000	0.098	0.000	0.001	0.361	36.129	22.000	62.500	-26.371
220	**1.17**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	3.92	0.000	0.000	0.000	0.000	0.000	0.000	2.000	5.682	-5.682
	5.08	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6.25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	9	0.000	0.000	0.000	0.000	0.000	0.000	2.000	5.682	-5.682
	10	0.000	0.000	0.000	0.000	0.000	0.000	2.000	5.682	-5.682
	11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	14.25	0.000	0.000	0.000	0.000	0.001	0.132	0.000	0.000	0.132
	16.08	0.000	0.000	0.000	0.000	0.002	0.197	0.000	0.000	0.197
	17.17	0.000	0.000	0.000	0.000	0.003	0.260	0.000	0.000	0.260
	18.17	0.000	0.001	0.000	0.000	0.003	0.324	0.000	0.000	0.324
221	**1.17**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	3.92	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	5.08	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6.25	0.000	0.000	0.000	0.001	0.000	0.067	0.000	0.000	0.067
	8	0.000	0.000	0.000	0.001	0.000	0.067	0.000	0.000	0.067
	9	0.000	0.000	0.000	0.001	0.000	0.067	0.000	0.000	0.067
	10	0.000	0.000	0.000	0.001	0.000	0.067	0.000	0.000	0.067
	11	0.000	0.000	0.000	0.001	0.000	0.067	0.000	0.000	0.067
	14.25	0.027	0.010	0.100	0.140	0.057	18.911	0.000	0.000	18.911
	16.08	0.045	0.017	0.200	0.208	0.090	27.925	0.000	0.000	27.925
	17.17	0.055	0.020	0.400	0.243	0.107	32.372	0.000	0.000	32.372
	18.17	0.065	0.023	0.500	0.274	0.122	36.272	0.000	0.000	36.272
222	**1.17**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	3.92	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

	5.08	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6.25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	14.25	0.001	0.003	0.000	0.009	0.016	2.468	0.000	0.000	2.468
	16.08	0.002	0.004	0.000	0.014	0.026	4.035	1.000	2.841	1.194
	17.17	0.003	0.005	0.000	0.017	0.032	4.826	4.000	11.364	-6.537
	18.17	0.003	0.006	0.000	0.020	0.037	5.605	7.000	19.886	-14.282
223	**1.17**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	3.92	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	5.08	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6.25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	14.25	0.000	0.002	0.000	0.000	0.011	1.063	0.000	0.000	1.063
	16.08	0.000	0.003	0.000	0.000	0.017	1.719	0.000	0.000	1.719
	17.17	0.000	0.003	0.000	0.000	0.021	2.071	0.000	0.000	2.071
	18.17	0.000	0.004	0.000	0.000	0.024	2.362	0.000	0.000	2.362
224	**1.17**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	3.92	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	5.08	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	6.25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	14.25	0.000	0.001	0.000	0.000	0.003	0.324	0.000	0.000	0.324
	16.08	0.000	0.001	0.000	0.000	0.006	0.574	0.000	0.000	0.574
	17.17	0.000	0.001	0.000	0.000	0.006	0.635	0.000	0.000	0.635
	18.17	0.000	0.001	0.000	0.000	0.008	0.758	0.000	0.000	0.758

Table 16. Faulting calibration for C=2

		C=1.018		C=2.0		
	Year	**Calculated Faulting by MEPDG**	**Measured Faulting (in)**	**Calculated Faulting by MEPDG**	**Measured Faulting (in)**	**Bias**
213	**5.08**	0.006	0.004	0.006	0.004	2.06E-03
	6.25	0.007	0.008	0.007	0.008	8.74E-04
	8	0.010	0.012	0.010	0.012	1.81E-03
	11	0.015	0.031	0.015	0.031	1.65E-02
214	**5.08**	0.009	0.008	0.009	0.008	1.13E-03
	6.25	0.012	0.016	0.012	0.016	3.75E-03
	16.08	0.042	0.035	0.042	0.035	6.57E-03
215	**5.08**	0.003	0.008	0.003	0.008	4.87E-03
	6.25	0.004	0.016	0.004	0.016	1.17E-02
	18.17	0.014	0.024	0.014	0.024	9.62E-03
216	**6.25**	0.005	0.008	0.005	0.008	2.87E-03
	9	0.008	0.020	0.008	0.020	1.17E-02
	11	0.010	0.028	0.010	0.028	1.76E-02
	14.25	0.014	0.035	0.014	0.035	2.14E-02
217	**5.08**	0.004	0.004	0.004	0.004	6.30E-05
	6.25	0.006	0.008	0.006	0.008	1.87E-03
	16.08	0.020	0.024	0.020	0.024	3.62E-03
218	**3.92**	0.005	0.004	0.005	0.004	1.06E-03
	5.08	0.007	0.008	0.007	0.008	8.74E-04
	9	0.016	0.012	0.016	0.012	4.19E-03
	11	0.020	0.016	0.020	0.016	4.25E-03
219	**7.83**	0.008	0.004	0.008	0.004	4.06E-03
	10.83	0.012	0.008	0.012	0.008	4.13E-03
	15.92	0.019	0.012	0.019	0.012	7.19E-03
	18	0.022	0.024	0.022	0.024	1.62E-03
220	**5.08**	0.003	0.004	0.003	0.004	9.37E-04
	9	0.005	0.008	0.005	0.008	2.87E-03
	11	0.007	0.020	0.007	0.020	1.27E-02
	14.25	0.009	0.028	0.009	0.028	1.86E-02
221	**5.08**	0.004	0.004	0.004	0.004	6.30E-05
	9	0.009	0.008	0.009	0.008	1.13E-03
	11	0.011	0.024	0.011	0.024	1.26E-02
	14.25	0.016	0.031	0.016	0.031	1.55E-02
222	**5.08**	0.006	0.004	0.006	0.004	2.06E-03
	9	0.010	0.008	0.010	0.008	2.13E-03
	11	0.012	0.020	0.012	0.020	7.69E-03

	14.25	0.016	0.031	0.016	0.031	1.55E-02
223	**8**	0.004	0.004	0.004	0.004	6.30E-05
	11	0.006	0.016	0.006	0.016	9.75E-03
	17.17	0.009	0.020	0.009	0.020	1.07E-02
	18.17	0.010	0.024	0.010	0.024	1.36E-02
224	**6.25**	0.005	0.004	0.005	0.004	1.06E-03
	9	0.008	0.016	0.008	0.016	7.75E-03
	11	0.010	0.020	0.010	0.020	9.69E-03

Table 17. Faulting calibration for C=2.5

		C=1.018		**C=2.5**		
	Year	**Calculated Faulting by MEPDG**	**Measured Faulting (in)**	**Calculated Faulting by MEPDG**	**Measured Faulting (in)**	**Bias**
213	**5.08**	0.009	0.004	0.009	0.004	5.06E-03
	6.25	0.011	0.008	0.011	0.008	3.13E-03
	8	0.015	0.012	0.015	0.012	3.19E-03
	11	0.024	0.031	0.024	0.031	7.50E-03
214	**5.08**	0.014	0.008	0.014	0.008	6.13E-03
	6.25	0.018	0.016	0.018	0.016	2.25E-03
	16.08	0.063	0.035	0.063	0.035	2.76E-02
215	**5.08**	0.004	0.008	0.004	0.008	3.87E-03
	6.25	0.006	0.016	0.006	0.016	9.75E-03
	18.17	0.022	0.024	0.022	0.024	1.62E-03
216	**6.25**	0.008	0.008	0.008	0.008	1.26E-04
	9	0.012	0.020	0.012	0.020	7.69E-03
	11	0.016	0.028	0.016	0.028	1.16E-02
	14.25	0.022	0.035	0.022	0.035	1.34E-02
217	**5.08**	0.007	0.004	0.007	0.004	3.06E-03
	6.25	0.009	0.008	0.009	0.008	1.13E-03
	16.08	0.031	0.024	0.031	0.024	7.38E-03
218	**3.92**	0.009	0.004	0.009	0.004	5.06E-03
	5.08	0.012	0.008	0.012	0.008	4.13E-03
	9	0.024	0.012	0.024	0.012	1.22E-02
	11	0.031	0.016	0.031	0.016	1.53E-02
219	**7.83**	0.006	0.004	0.006	0.004	2.06E-03
	10.83	0.008	0.008	0.008	0.008	1.26E-04
	15.92	0.013	0.012	0.013	0.012	1.19E-03
	18	0.015	0.024	0.015	0.024	8.62E-03
220	**5.08**	0.004	0.004	0.004	0.004	6.30E-05

	9	0.008	0.008	0.008	0.008	1.26E-04
	11	0.011	0.020	0.011	0.020	8.69E-03
	14.25	0.015	0.028	0.015	0.028	1.26E-02
221	**5.08**	0.007	0.004	0.007	0.004	3.06E-03
	9	0.014	0.008	0.014	0.008	6.13E-03
	11	0.018	0.024	0.018	0.024	5.62E-03
	14.25	0.025	0.031	0.025	0.031	6.50E-03
222	**5.08**	0.009	0.004	0.009	0.004	5.06E-03
	9	0.016	0.008	0.016	0.008	8.13E-03
	11	0.019	0.020	0.019	0.020	6.85E-04
	14.25	0.025	0.031	0.025	0.031	6.50E-03
223	**8**	0.006	0.004	0.006	0.004	2.06E-03
	11	0.009	0.016	0.009	0.016	6.75E-03
	17.17	0.015	0.020	0.015	0.020	4.69E-03
	18.17	0.016	0.024	0.016	0.024	7.62E-03
224	**6.25**	0.008	0.004	0.008	0.004	4.06E-03
	9	0.012	0.016	0.012	0.016	3.75E-03
	11	0.015	0.020	0.015	0.020	4.69E-03

Table 18. Faulting calibration for C=3

		C=1.018		**C=3.0**		
	Year	**Calculated Faulting by MEPDG**	**Measured Faulting (in)**	**Calculated Faulting by MEPDG**	**Measured Faulting (in)**	**bias**
213	**5.08**	0.012	0.004	0.012	0.004	8.06E-03
	6.25	0.016	0.008	0.016	0.008	8.13E-03
	8	0.022	0.012	0.022	0.012	1.02E-02
	11	0.034	0.031	0.034	0.031	2.50E-03
214	**5.08**	0.020	0.008	0.020	0.008	1.21E-02
	6.25	0.026	0.016	0.026	0.016	1.03E-02
	16.08	0.088	0.035	0.088	0.035	5.26E-02
215	**5.08**	0.006	0.008	0.006	0.008	1.87E-03
	6.25	0.008	0.016	0.008	0.016	7.75E-03
	18.17	0.031	0.024	0.031	0.024	7.38E-03
216	**6.25**	0.011	0.008	0.011	0.008	3.13E-03
	9	0.017	0.020	0.017	0.020	2.69E-03
	11	0.021	0.028	0.021	0.028	6.56E-03
	14.25	0.029	0.035	0.029	0.035	6.43E-03
217	**5.08**	0.010	0.004	0.010	0.004	6.06E-03
	6.25	0.013	0.008	0.013	0.008	5.13E-03

	16.08	0.044	0.024	0.044	0.024	2.04E-02
218	**3.92**	0.012	0.004	0.012	0.004	8.06E-03
	5.08	0.017	0.008	0.017	0.008	9.13E-03
	9	0.034	0.012	0.034	0.012	2.22E-02
	11	0.044	0.016	0.044	0.016	2.83E-02
219	**7.83**	0.008	0.004	0.008	0.004	4.06E-03
	10.83	0.012	0.008	0.012	0.008	4.13E-03
	15.92	0.019	0.012	0.019	0.012	7.19E-03
	18	0.022	0.024	0.022	0.024	1.62E-03
220	**5.08**	0.006	0.004	0.006	0.004	2.06E-03
	9	0.012	0.008	0.012	0.008	4.13E-03
	11	0.015	0.020	0.015	0.020	4.69E-03
	14.25	0.021	0.028	0.021	0.028	6.56E-03
221	**5.08**	0.010	0.004	0.010	0.004	6.06E-03
	9	0.020	0.008	0.020	0.008	1.21E-02
	11	0.025	0.024	0.025	0.024	1.38E-03
	14.25	0.036	0.031	0.036	0.031	4.50E-03
222	**5.08**	0.012	0.004	0.012	0.004	8.06E-03
	9	0.022	0.008	0.022	0.008	1.41E-02
	11	0.027	0.020	0.027	0.020	7.31E-03
	14.25	0.036	0.031	0.036	0.031	4.50E-03
223	**8**	0.009	0.004	0.009	0.004	5.06E-03
	11	0.013	0.016	0.013	0.016	2.75E-03
	17.17	0.021	0.020	0.021	0.020	1.31E-03
	18.17	0.022	0.024	0.022	0.024	1.62E-03
224	**6.25**	0.011	0.004	0.011	0.004	7.06E-03
	9	0.017	0.016	0.017	0.016	1.25E-03
	11	0.021	0.020	0.021	0.020	1.31E-03

Table 19: IRI calibration for granular based sections

	C1 = 1.024		C2 = 54.02		C3 =1.493		C4 = 90								
	year	MEPDG Result	Measured IRI (m/km)	Measured IRI (in/mile)	Initial IRI	FI	P200	Side Factor	Total damage calc. (bottom-up)	Total damage calc. (top-down)	Total damage calculated	Faulting	Spalling	Calculated IRI (calibration)	error
						SIDE FACTOR		CALIBRATED VALUES							
213	0.08	63	1.442	91.37	63	0	24.8	2.06E-06	6.25E-11	4.00E-12	6.65E-09	0	0.83	108.01	16.65
	3.08	64	1.636	103.66	63	0	24.8	7.95E-05	6.28E-04	6.66E-06	6.34E-02	0.001	1.11	123.14	19.49
	4	64.4	1.712	108.47	63	0	24.8	1.03E-04	1.33E-03	1.31E-05	1.34E-01	0.001	1.18	126.63	18.16
	5	64.8	1.748	110.75	63	0	24.8	1.29E-04	2.41E-03	2.26E-05	2.43E-01	0.002	1.25	130.66	19.91
	5.92	65.4	1.916	121.40	63	0	24.8	1.53E-04	3.92E-03	3.47E-05	3.95E-01	0.002	1.32	134.61	13.21
	7.92	66.5	1.935	122.60	63	0	24.8	2.04E-04	8.51E-03	7.07E-05	8.58E-01	0.003	1.48	144.09	21.48
	14.75	71	2.257	143.00	63	0	24.8	3.81E-04	3.18E-02	4.98E-04	3.22E+00	0.007	2.22	186.43	43.43
	16.08	71.8	2.269	143.76	63	0	24.8	4.15E-04	3.50E-02	6.58E-04	3.56E+00	0.008	2.40	196.57	52.80
	17	72.4	2.632	166.76	63	0	24.8	4.39E-04	3.82E-02	8.17E-04	3.90E+00	0.009	2.54	204.09	37.33
214	1.25	63.3	0.883	55.95	63	0	25.4	3.30E-05	1.52E-06	2.56E-07	1.78E-04	0.003	0.19	73.29	17.34
	3.08	63.8	1.068	67.67	63	0	25.4	8.13E-05	1.26E-05	2.77E-06	1.53E-03	0.008	0.21	74.55	6.88
	4	64.2	1.084	68.68	63	0	25.4	1.06E-04	2.55E-05	5.25E-06	3.08E-03	0.01	0.23	75.22	6.53
	7	65.4	1.152	72.99	63	0	25.4	1.85E-04	1.05E-04	1.93E-05	1.25E-02	0.021	0.27	77.67	4.68
	7.92	65.8	1.191	75.46	63	0	25.4	2.09E-04	1.48E-04	2.62E-05	1.75E-02	0.024	0.29	78.51	3.04
	8.83	66.3	1.333	84.46	63	0	25.4	2.33E-04	2.01E-04	3.45E-05	2.35E-02	0.028	0.30	79.39	-5.07
	10.17	66.9	1.404	88.96	63	0	25.4	2.68E-04	2.71E-04	4.50E-05	3.16E-02	0.034	0.33	80.77	-8.18
	14	69.2	1.461	92.57	63	0	25.4	3.70E-04	4.52E-04	1.26E-04	5.77E-02	0.052	0.41	85.40	-7.17
	16.08	70.5	1.518	96.18	63	0	25.4	4.25E-04	5.13E-04	1.96E-04	7.09E-02	0.063	0.47	88.39	-7.79
	17	71.1	1.529	96.88	63	0	25.4	4.49E-04	5.46E-04	2.39E-04	7.85E-02	0.068	0.49	89.83	-7.05
	19	72.5	1.565	99.16	63	0	25.4	5.02E-04	6.16E-04	3.43E-04	9.58E-02	0.079	0.56	93.25	-5.91

215	0.08	63	1.408	89.21	63	0	25.4	2.11E-06	0.00E+00	5.00E-13	5.00E-11	0	0.41	84.91	-4.30
	3.08	63.5	1.528	96.81	63	0	25.4	8.13E-05	1.35E-11	1.50E-07	1.50E-05	0.003	0.54	92.28	-4.54
	4	63.6	1.579	100.05	63	0	25.4	1.06E-04	3.20E-11	2.76E-07	2.76E-05	0.003	0.57	93.95	-6.10
	5	63.6	1.684	106.70	63	0	25.4	1.32E-04	3.20E-11	4.56E-07	4.56E-05	0.004	0.61	95.88	-10.82
	7	63.9	1.749	110.82	63	0	25.4	1.85E-04	1.08E-10	9.30E-07	9.31E-05	0.007	0.69	100.08	-10.74
	7.92	64	1.888	119.62	63	0	25.4	2.09E-04	1.08E-10	1.26E-06	1.26E-04	0.008	0.72	102.17	-17.45
	8.83	64.1	1.955	123.87	63	0	25.4	2.33E-04	1.71E-10	1.62E-06	1.62E-04	0.009	0.77	104.38	-19.49
	11	64.4	2.134	135.21	63	0	25.4	2.90E-04	2.56E-10	2.59E-06	2.59E-04	0.012	0.87	110.10	-25.11
216	4	63.5	1.289	81.67	63	0	25.6	1.06E-04	0.00E+00	5.00E-10	5.00E-08	0.005	0.11	68.73	-12.94
	5	63.6	1.305	82.68	63	0	25.6	1.33E-04	0.00E+00	8.64E-10	8.64E-08	0.006	0.11	69.09	-13.59
	7	63.8	1.307	82.81	63	0	25.6	1.86E-04	0.00E+00	1.37E-09	1.37E-07	0.009	0.13	69.88	-12.93
	7.92	64	1.319	83.57	63	0	25.6	2.11E-04	0.00E+00	2.05E-09	2.05E-07	0.011	0.13	70.27	-13.30
	8.83	64.1	1.474	93.39	63	0	25.6	2.35E-04	0.00E+00	2.46E-09	2.46E-07	0.012	0.14	70.69	-22.71
	10.17	64.3	1.494	94.66	63	0	25.6	2.71E-04	0.00E+00	3.43E-09	3.43E-07	0.014	0.15	71.33	-23.33
	14	65	1.506	95.42	63	0	25.6	3.72E-04	0.00E+00	7.81E-09	7.81E-07	0.021	0.19	73.50	-21.92
	17	65.6	1.516	96.05	63	0	25.6	4.52E-04	0.00E+00	1.35E-08	1.35E-06	0.027	0.23	75.57	-20.48

Table 20: IRI calibration for treated based sections

	C1 = 6.84		C2 = 1.45		C3 =0.02		C4 = 25								
	year	**MEPDG Result**	**Measured IRI (m/km)**	**Measured IRI (in/mile)**	**Initial IRI**	**FI**	**P200**	**Side Factor**	**Total damage calc. (bottom-up)**	**Total damage calc. (top-down)**	**Total damage calculated**	**Faulting**	**Spalling**	**Calculated IRI (calibration)**	**error**
						SIDE FACTOR		**CALIBRATED VALUES**							
217	1.25	63.7	1.022	64.75	63	0	22.5	2.94E-05	0.00E+00	0.00E+00	0.00E+00	0.001	1.08	64.58	-0.18
	3.08	64.2	1.215	76.98	63	0	22.5	7.24E-05	0.00E+00	0.00E+00	0.00E+00	0.001	1.21	64.77	-12.22
	4	64.5	1.235	78.25	63	0	22.5	9.40E-05	0.00E+00	0.00E+00	0.00E+00	0.002	1.28	64.87	-13.38
	5.92	65.2	1.322	83.76	63	0	22.5	1.39E-04	0.00E+00	0.00E+00	0.00E+00	0.003	1.44	65.10	-18.66
	12.67	69.3	1.465	92.82	63	0	22.5	2.98E-04	2.53E-01	1.22E-01	3.44E+01	0.007	2.15	301.57	208.75
218	1.25	63.8	0.951	60.26	63	0	18.5	2.44E-05	0.00E+00	0.00E+00	0.00E+00	0.001	0.15	63.22	2.96
	3.08	64.9	0.982	62.22	63	0	18.5	6.01E-05	0.00E+00	0.00E+00	0.00E+00	0.004	0.17	63.24	1.02
	4	65.6	1.015	64.31	63	0	18.5	7.80E-05	0.00E+00	0.00E+00	0.00E+00	0.005	0.18	63.26	-1.05
	5.92	67.2	1.09	69.06	63	0	18.5	1.15E-04	0.00E+00	0.00E+00	0.00E+00	0.008	0.20	63.29	-5.77
	8.83	70	1.106	70.08	63	0	18.5	1.72E-04	0.00E+00	0.00E+00	0.00E+00	0.013	0.24	63.35	-6.73
	12.67	74.3	1.129	71.53	63	0	18.5	2.47E-04	1.60E-02	1.84E-02	3.41E+00	0.021	0.30	86.77	15.24
	17	80.4	1.269	80.40	63	0	18.5	3.32E-04	5.83E-02	5.99E-02	1.15E+01	0.031	0.39	142.07	61.66
	19	83.6	1.258	79.71	63	0	18.5	3.71E-04	7.78E-02	7.83E-02	1.50E+01	0.036	0.44	166.32	86.62
219	0.08	63	1.271	80.53	63	0	33.3	2.74E-06	0.00E+00	0.00E+00	0.00E+00	0	0.46	63.67	-16.86
	3.08	65.2	1.306	82.75	63	0	33.3	1.06E-04	0.00E+00	0.00E+00	0.00E+00	0.004	0.61	63.90	-18.85
	5	67.1	1.394	88.32	63	0	33.3	1.72E-04	0.00E+00	0.00E+00	0.00E+00	0.007	0.69	64.01	-24.32
	5.92	68.3	1.469	93.08	63	0	33.3	2.03E-04	0.00E+00	0.00E+00	0.00E+00	0.01	0.73	64.07	-29.01
	7.92	71.7	1.492	94.53	63	0	33.3	2.72E-04	0.00E+00	0.00E+00	0.00E+00	0.016	0.82	64.20	-30.33
	8.83	73.6	1.514	95.93	63	0	33.3	3.03E-04	0.00E+00	0.00E+00	0.00E+00	0.02	0.87	64.27	-31.66
	16.08	100.3	1.58	100.11	63	0	33.3	5.52E-04	2.60E-03	2.82E-02	3.07E+00	0.07	1.34	86.00	-14.11
	17	104.4	1.706	108.09	63	0	33.3	5.83E-04	3.24E-03	3.33E-02	3.64E+00	0.077	1.41	90.00	-18.09

220	1.25	63.1	1.051	66.59	63	0	20.9	2.74E-05	0.00E+00	0.00E+00	0.00E+00	0.001	0.08	63.11	-3.48
	3.08	63.3	1.078	68.30	63	0	20.9	6.75E-05	0.00E+00	0.00E+00	0.00E+00	0.002	0.09	63.13	-5.17
	4	63.3	1.091	69.13	63	0	20.9	8.76E-05	0.00E+00	0.00E+00	0.00E+00	0.003	0.09	63.14	-5.99
	5.92	63.5	1.106	70.08	63	0	20.9	1.30E-04	0.00E+00	0.00E+00	0.00E+00	0.005	0.10	63.15	-6.92
	8.83	63.7	1.157	73.31	63	0	20.9	1.93E-04	0.00E+00	0.00E+00	0.00E+00	0.008	0.12	63.18	-10.12
	10.17	63.9	1.246	78.95	63	0	20.9	2.23E-04	0.00E+00	0.00E+00	0.00E+00	0.009	0.13	63.20	-15.75
	14	64.3	1.312	83.13	63	0	20.9	3.07E-04	0.00E+00	1.32E-03	1.32E-01	0.014	0.17	64.16	-18.97
	19	64.9	1.419	89.91	63	0	20.9	4.16E-04	0.00E+00	3.24E-03	3.24E-01	0.021	0.23	65.56	-24.35
221	0.08	63	1.146	72.61	63	0	25.4	2.11E-06	0.00E+00	0.00E+00	0.00E+00	0	0.41	63.60	-9.01
	3.08	63.6	1.199	75.97	63	0	25.4	8.13E-05	2.76E-02	4.49E-03	3.20E+00	0.001	0.55	85.71	9.74
	4	63.7	1.27	80.47	63	0	25.4	1.06E-04	3.55E-02	5.12E-03	4.05E+00	0.001	0.58	91.55	11.09
	5.92	64	1.319	83.57	63	0	25.4	1.56E-04	4.98E-02	7.58E-03	5.70E+00	0.001	0.65	102.96	19.39
	12.67	65.4	1.519	96.24	63	0	25.4	3.34E-04	1.10E-01	5.25E-02	1.56E+01	0.003	0.98	171.41	75.16
222	1.25	63.3	0.877	55.57	63	0	21.7	2.84E-05	1.97E-03	1.32E-03	3.29E-01	0	0.15	65.47	9.90
	3.08	63.6	0.97	61.46	63	0	21.7	6.99E-05	4.49E-03	3.24E-03	7.72E-01	0.001	0.17	68.53	7.07
	4	63.8	0.971	61.52	63	0	21.7	9.08E-05	5.12E-03	4.49E-03	9.58E-01	0.002	0.18	69.82	8.30
	5	64.1	1	63.36	63	0	21.7	1.14E-04	6.35E-03	5.12E-03	1.14E+00	0.002	0.19	71.11	7.75
	5.92	64.4	1.083	68.62	63	0	21.7	1.34E-04	7.58E-03	5.74E-03	1.33E+00	0.002	0.20	72.38	3.76
	12.67	66.7	1.105	70.01	63	0	21.7	2.88E-04	1.42E-02	2.01E-02	3.41E+00	0.007	0.30	86.76	16.75
	14.75	67.5	1.176	74.51	63	0	21.7	3.35E-04	1.66E-02	3.39E-02	4.99E+00	0.008	0.34	97.66	23.15
	19	69.4	1.335	84.59	63	0	21.7	4.31E-04	2.07E-02	5.88E-02	7.83E+00	0.012	0.44	117.25	32.67
223	1.25	63.2	1.156	73.24	63	0	21.1	2.76E-05	0.00E+00	1.97E-03	1.97E-01	0	0.34	64.84	-8.40
	3.08	63.4	1.232	78.06	63	0	21.1	6.81E-05	0.00E+00	4.49E-03	4.49E-01	0	0.38	66.63	-11.43
	4	63.4	1.32	83.64	63	0	21.1	8.84E-05	0.00E+00	5.12E-03	5.12E-01	0.001	0.40	67.09	-16.55
	5	63.5	1.376	87.18	63	0	21.1	1.11E-04	0.00E+00	5.74E-03	5.74E-01	0.001	0.43	67.55	-19.63
	5.92	63.6	1.385	87.75	63	0	21.1	1.31E-04	0.00E+00	6.97E-03	6.97E-01	0.001	0.45	68.43	-19.32
	7.92	63.8	1.42	89.97	63	0	21.1	1.75E-04	0.00E+00	8.20E-03	8.20E-01	0.001	0.51	69.36	-20.61
	8.83	63.8	1.444	91.49	63	0	21.1	1.95E-04	0.00E+00	9.42E-03	9.42E-01	0.001	0.54	70.23	-21.26
	12.67	64.2	1.764	111.77	63	0	21.1	2.80E-04	0.00E+00	1.72E-02	1.72E+00	0.002	0.68	75.76	-36.01

	14.75	64.4	1.836	116.33	63	0	21.1	3.26E-04	0.00E+00	2.59E-02	2.59E+00	0.002	0.77	81.87	-34.46
224	1.25	63.1	1.021	64.69	63	0	40.9	5.24E-05	0.00E+00	6.73E-04	6.73E-02	0	0.10	63.60	-1.09
	3.08	63.4	1.071	67.86	63	0	40.9	1.29E-04	0.00E+00	6.73E-04	6.73E-02	0.001	0.11	63.62	-4.24
	5.92	63.7	1.121	71.03	63	0	40.9	2.48E-04	0.00E+00	1.32E-03	1.32E-01	0.001	0.13	64.10	-6.93
	11	64.3	1.137	72.04	63	0	40.9	4.61E-04	0.00E+00	1.97E-03	1.97E-01	0.002	0.17	64.61	-7.43
	12.67	64.6	1.166	73.88	63	0	40.9	5.31E-04	0.00E+00	4.49E-03	4.49E-01	0.003	0.19	66.37	-7.51
	14	64.8	1.172	74.26	63	0	40.9	5.87E-04	0.00E+00	5.74E-03	5.74E-01	0.003	0.21	67.24	-7.01
	16.08	65.2	1.296	82.11	63	0	40.9	6.74E-04	0.00E+00	8.81E-03	8.81E-01	0.004	0.24	69.39	-12.73
	19	65.7	1.536	97.32	63	0	40.9	7.96E-04	0.00E+00	1.24E-02	1.24E+00	0.005	0.28	71.94	-25.38