Local Calibration of Cracking Models in MEPDG for Ontario's Flexible Pavement

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Abstract

The AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG) introduces a pavement design method which uses both the mechanistic analyses and empirical models to predict pavement distresses and performance. Due to the significant differences between the global and the local conditions, the empirical distress models need to be calibrated for local environments and local design practices based on local pavement performance data. This paper focuses on the local calibration of the various cracking models (fatigue bottom-up, fatigue top-down and thermal longitudinal) in MEPDG for flexible pavements on Ontario's highways. First a local calibration database was developed based upon MTO's *Pavement Management System*. After this, simulations were run in the software and the predicted data is compared to the observed data. Significant difference is found in the comparisons which need to be minimized by calibrating the distress models. A new regression model is used to optimize the calibration parameters by minimizing the standard deviations of the residuals between the predicted and observed distresses. The challenges encountered and solutions developed during the local calibration are discussed.

1. Introduction

NCHRP Project 1-37A developed the Mechanistic-Empirical Pavement Design Guide (MEPDG) to bring the potential changes in the previous AASHTO method. The purpose of this guide is to develop a pavement design method which uses both mechanistic models (i.e. mechanistic theories) and the empirical approaches (i.e. experimental results). The MEPDG introduces elaborated M-E based design procedure of both flexible and rigid pavements for the evaluation of both existing and new pavements by adopting MEPDG software, AASHTOWare Pavement ME Design. From the name it is obvious that this guide combines the mechanistic analysis and empirical approaches to include the effects of traffic, climate and pavement conditions on the pavement performance.

Calibration is a process where biases are eliminated and residual errors between observed distress and the predicted distress are minimized. Globally calibrated distress prediction models (also known as transfer functions) are included in the software of MEPDG. These distress models are calibrated using the pavement sections located throughout North America using the Long Term Pavement Performance (LTPP) database. But the local conditions of climate, material properties, traffic, construction and maintenance activities may have important roles on the predicted performance models in MEPDG. So the local calibration is necessary before adopting the exercising of MEPDG for the local conditions.

Two types of cracking models are used in MEPDG: fatigue cracking models and transverse cracking models. Fatigue cracks are the results of repetitive traffic loading which causes high tensile strength. When the cracks initiate in the bottom of asphalt layer and propagate to the surface, these are called as bottom-up cracking (alligator cracking) and when the cracks initiate at top of asphalt layer and propagate to bottom, these are known as top-down cracking (longitudinal cracking). Top-down cracking is often initiated because of large shear strain at the edge of tire. Transverse cracking (thermal cracking) is a non-load related cracking process which generally appears perpendicular to the pavement centerline. These cracks occur due to asphalt hardening, seasonal and daily temperature differences, or exposure to constant cold weather. (NCHRP 2004)

Ontario's Ministry of Transportation (MTO) in Canada is considering adopting the MEPDG procedures for the upcoming pavement projects. Extensive researches were performed since 2009 to develop a local calibration database based on MTO's second generation pavement management system (MTO PMS-2) [Afzaal 2013]. The MEPDG default models were evaluated using this database and it is found that the local calibration is needed for Ontario's pavement [Jannat 2012]. This paper focused on the results of the most latest local calibration of the cracking models for Ontario's new and rehabilitated flexible pavements based on the cracking data from MTO PMS-2. In this study local calibration of cracking model of MEPDG is performed to predict the calibration coefficients in the transfer functions to eliminate the possible bias by reducing the sum of squared errors, the square of the difference between predicted and measured crack damage. Then the validation of the MEPDG cracking models is conducted to make sure that the calibrated models exhibits a strong and accurate predictions of pavement crack damage.

2. Literature Review

The *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures* is a crucial achievement of NCHRP project 1-37A in 2004[NCHRP]. NCHRP Project 1-40A (2006) is a comprehensive independent review of MEPDG and companion software Version 0.7 under NCHRP Project 1-37A (2004). This Project identified a number of problems which were necessary to solve. Then scores of changes to the MEPDG software were made under NCHRP Project 1-40D (NCHRP 2006) and the key findings of this project were summarized in *Research Results Digest 308* (NCHRP 2006). Addition of mixture-specific plastic deformation coefficients for individual HMA layers is one of the major findings. Some other changes are the inclusion of recalibration of distress transfer functions and correction of HMA transfer function. To solve other issues, NCHRP 9-30A project was launched and the changes in the material characterization were made. The final report of this project was released in 2012.

In the global calibration, a large number of experimental data were collected to select the most appropriate transfer functions and therefore to establish the basic parameters of the transfer functions. Then, a set of global calibration parameters are added to the basic models. Finally the predicted data obtained from the global calibration models are compared to the global calibration dataset (LTPP database). NCHRP 1-37A used 82 pavement sections from 24 different states for the global calibration of the fatigue cracking models and 42 pavement sections (22 sections from the LTPP database, 14 sections from the Canadian C-SHRP program, one section from Peoria, IL, and 5 sections from MnROAD cells from the Minnesota DOT) for the global calibration of the thermal cracking models [NCHRP 2004]. In the local calibration process, same steps are followed for local conditions.

Many state or regional agencies have started local calibration for the local conditions throughout the North America. Kang and Adams (2007) have calibrated the fatigue damage model in flexible pavement and identified two calibration factors for Midwest Region (Michigan, Ohio and Wisconsin). Database from these three DOT's were collected and the calibration were done. The pavement performance data from Michigan and Ohio shows irregular trends. So, Wisconsin's data was used for calibration. After calibration values were determined with Wisconsin's data, the field data from Ohio and Michigan were compared to the prediction models using (1) default calibration values in the MEPDG and (2) calibration values for Wisconsin data.

Muthadi (2007) and Jadoun (2011) have completed complete their research works on local calibration of MEPGD for North Carolina separately. Both have calibrated the model for the alligator cracking and permanent deformation. In Muthadi's research work, fifty three (53) pavement sections were selected from which thirty (30) sections were from LTPP database and twenty three (23) sections are from the NCDOT. In Jadoun's research work, Material properties and fatigue characterization were developed for all 12 asphalt mix that is used commonly in North Carolina before local calibration. His study also followed a conversion model developed by

Corley-Lay et al. (2010) to convert the alligator cracking ratings to equivalent LTPP ratings. LTPP distress models were compared to the NCDOT models for 23 LTPP pavement sections in North Carolina and significant differences were found. So the models were recalibrated for the alligator cracking.

Li et al. (2009) developed procedures to calibrate the MEPDG performance models for flexible pavement for Washington State. Fatigue damage, longitudinal cracking, alligator cracking, and rutting models were considered. Data from the Washington State Pavement Management System (WSPMS) was used.

Souliman et al. (2010) calibrated the MEPDG performance prediction models for alligator cracking, longitudinal cracking, rutting and IRI for Arizona. Thirty nine (39) pavement sections from LTPP database were used in this study.

Momin (2011) calibrated the MEPDG performance prediction models for alligator cracking, longitudinal cracking, rutting and IRI for North Eastern United States. LTPP database has been used in this study. For longitudinal fatigue cracking, the maximum length of linear cracking which can occur in two wheel paths has been considered as: “1856” instead of “1000”.

Hall et al. (2011) have completed the calibration of the MEPDG for flexible pavement design in Arkansas by using LTPP and PMS database. They have calibrated the alligator cracking models. Defaults values of some calibration parameters were used due to lack of data. The coefficients were optimized by using the solver function in Microsoft Excel. This paper recommends establishing more additional sites and robust data collections for the full implementation of MEPDG in Arkansas. This paper also emphasize on collecting the data for transverse cracking.

Williams and Shaidur (2013) calibrated fatigue prediction models for rehabilitated pavements for Oregon. Both alligator and longitudinal cracking models were calibrated and the coefficients were optimized by using the solver function in Microsoft Excel. Then after analysing the comparison between the results before and after the calibration process, significant differences were found and both cracking models were improved by local calibration.

Tarefder et al. (2013) calibrated the distress models of rutting, alligator cracking, longitudinal cracking and IRI for New Mexico. Total twenty-four (24) pavement sections of New Mexico and both LTPP and NMDOT database were used for the calibration.

The literature review shows that the calibration data were used in three ways: (i) combination of LTPP database and PMS data, (ii) combination of LTPP database and road test sections and (iii)

PMS database. In this research, PMS data from MTO were used for the calibration process. The literatures show two types of calibration process: (i) clustering process or the Level 3 calibration and (ii) section-by-section calibration process or Level-1 calibration (Jannat et. al 2014).

3. Local Calibration Process

3.1. Motivation

In MEPDG, LTPP database was used for the global calibration of the distress models. Since the transfer functions used in the calibration process is purely empirical, hence to adopt the MEPDG locally, local calibration is needed. Because, local conditions i.e. the climate, traffic conditions, materials, construction and maintenance process should be taken in the considerations as these are used as the input parameter in the calibration process. Therefore, the local transportation agency of a state or province should go under the local calibration process to use the MEPDG for pavement design.

3.2. Methodology of Local Calibration

A Guide for the Local Calibration of MEPDG was published by AASHTO in 2010 which includes a step-by-step process of local calibration. The main goal of the local calibration is to eliminate the bias and reduce the standard errors of the predicted model. In this research, following steps are followed: (i) development of database of pavement, (ii) MEPDG evaluation, (iii) Using of regression process in local calibration and (iv) validation.

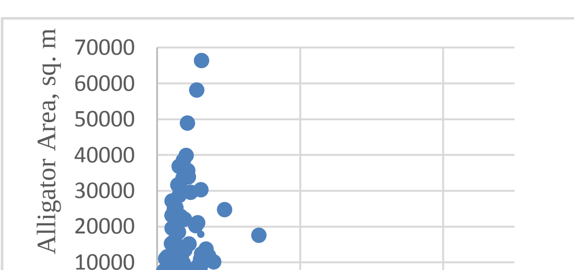
In the local calibration process, the predicted distress is compared to the observed distress. So, at first a local calibration database needed to be developed. Two types of data should be included in the database: (i) observed distress of the pavement and (ii) input data for the AASHTOWare Pavement ME software. The second one contains general project information, traffic data, climate condition, pavement structure and the material properties.

In this research, MTO's second generation PMS data (PMS-2) is used to develop the calibration database. First the pavement sections were selected. Then screenings were done on the selected sections to select the final sections for the calibration database. This study used AASHTOWare Pavement ME version 2.2 software and the related transfer functions for the performance prediction. Generally a large number of pavement sections with long-term recorded PMS data are selected for the calibration process. This lead to a very tedious effort including considerable time in the analyses of the pavement sections in AASHTOWare Pavement ME. Therefore this study avoids the regular procedure of calculating the optimal calibration parameter to eliminate bias and reduce standard errors. This study uses regression analyses of the observed and predicted distress data which saves the time a lot. This approach is used because the biases after the regression is always zero. Finally, a residual plot between the predicted distress and the residuals were conducted to fit the model properly. After that, the calibration models are validated with another set of pavement section database.

3.3. Local Calibration Database Development

Two types of data are needed for the calibration process: Observed distress data and input data for the software. There are approximately 16,500 center-line kilometers of freeways, collectors, arterial and local roads in Ontario under the supervision of MTO (Kazmierwski 2001). MTOS's second generation pavement management system (PMS-2) contains 48,000 of data for about 1800 pavement sections. The section length of PMS-2 ranges from 0.4km to about 20km which is different from the standard length in MEPDG (500ft or approximately 152.5m). So, to convert the PMS performance data into MEPDG format is one of the major constraints in this study. Because, though the IRI and the total rut depth are consistent, the crack data are variable and hence it is a very major issue. MTO stored the crack data for each section at 50(fifty) meters interval by using ARAN vehicle. This database is needed for the following reason:

- The Long Term Pavement Performance (LTPP) database inventory was used for the global calibration which also includes the pavement sections of standard dimension (500 feet).
- The Guide for the Local Calibration of Mechanistic Empirical Pavement Design Guide also follows the same dimension of the pavement section as in LTPP database.
- Previous local calibrations of MEPDG cracking models have indicated that in all cases observed crack data for standard pavement section (500 feet) was used for analysis to be consistent with that of the software defined section dimension.
- Using the PMS-2 data (with differential dimension), a graph was plotted for the alligator data against the pavement section length and it was found that the alligator data is zero or close to zero with the incremental length (Figure 1). To show the trend more clearly, the graph was re-plotted in log-log scale (Figure 2), which is also exhibiting the same behavior as Figure 1.



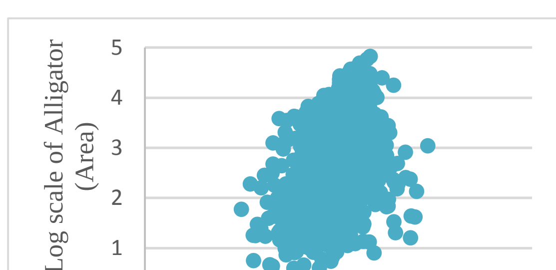


Figure 1: Alligator (Area) Vs Pavement Section Length **Figure 2: Alligator (Area) Vs Pavement Section Length [Log scale]**

From both figure, it can be stated that the crack damage is more in shorter length. Crack damage is decreasing with the increasing of the length. Therefore, crack data at 50 meter interval for each pavement section is used to calculate the observed data. First, the crack damage in the adjacent section is added so that the data at 150-meter length of pavement section can be found. Thus a number of crack damage for 150-meter section is obtained for a pavement section, from which the maximum value is considered as the observed crack damage for the pavement section. In this study, 60 sections are considered for the calibration process. The input data for these sections are collected from MTO staff to prepare the calibration database. MEPDG used three levels of accuracy for the input parameter. Level-1 is for the most accurate data whereas level-3 is for the default values used in the software. In this study, level-3 is used for the input parameter. Traffic data is extracted from the MTO’s icorridor data. Climate data is used from the GPS data. Material and pavement structure data are used from the MTO’s Superpave section database.

3.4. Calibration Process

At first, AASHTOWare Pavement ME software with default transfer functions and calibration parameter were used at 50% reliability. By following *The Guide for the Local Calibration of the Mechanical-Empirical Pavement Design Guide* (AASHTO 2010), the null hypothesis was evaluated which is:

$$\sum(y_{measured} - x_{predicted}) = 0$$

where,

$y_{measured}$= Observed value

$x_{predicted}$ = Predicted value

After that, a regression model was fitted to fully evaluate the distress model. For alligator damage, the transfer equation can be rewritten as below to set the regression model:

$$\ln\left(\frac{100}{FC_{obs}} - 1\right) \times \frac{1}{C_2''} = -2C_1 + C_2 \ln(D \times 100)$$

Transfer function for the longitudinal damage can be rewritten as below to set the regression model:

$$\ln\left(\frac{10560}{FC_{obs}} - 1\right) = C_1 - C_2 \ln(D \times 100)$$

From the regression model, the intercepts and the slope were used to calculate new predicted distress and the residual plot was drawn.

4. Results and discussion:

- **Alligator Damage:**

The calculated standard deviations for each set of calibration parameter in N_f model are given below:

Table 1: Comparison of Standard Deviations

Parameter value	Standard Deviations in N_f Model	Standard Deviations after setting Regression Model
$\beta_{f1} = 1.0$ $\beta_{f2} = 1.0$ $\beta_{f3} = 1.0$	15.78	15.84
$\beta_{f1} = 1.0$ $\beta_{f2} = 0.9$ $\beta_{f3} = 0.9$	15.70	15.44
$\beta_{f1} = 1.0$ $\beta_{f2} = 0.8$ $\beta_{f3} = 0.8$	19.22	15.10
$\beta_{f1} = 1.0$ $\beta_{f2} = 0.7$ $\beta_{f3} = 0.7$	34.71	15.30

The above table represents the calculated the standard deviations for four sets of calibration parameter in N_f model. From the table it can be said that, with the decreasing of the value of calibration parameter($\beta_{f2},\ \beta_{f3}$) and after doing the local calibration part, the standard deviations was decreasing and in last set of the calibration parameter ($\beta_{f1} = 1.0$, $\beta_{f2} = 0.7$, $\beta_{f3} = 0.7$) the standard error was increased. But, no sets of calibration parameter showed significant reduction in standard deviations.

The residual plots for each set of calibration parameter in N_f model are presented below:

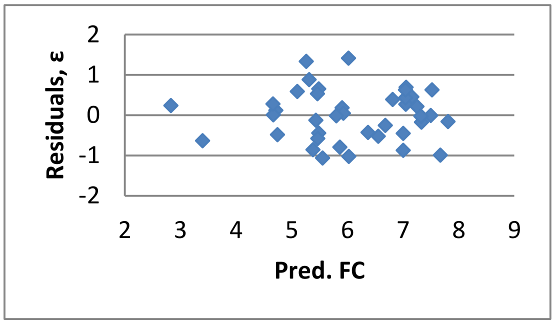


Figure 3: Residual Plot for Alligator damage with Default Parameter ($\beta_{f1} = 1.0, \beta_{f2} = 1.0, \beta_{f3} = 1.0$)

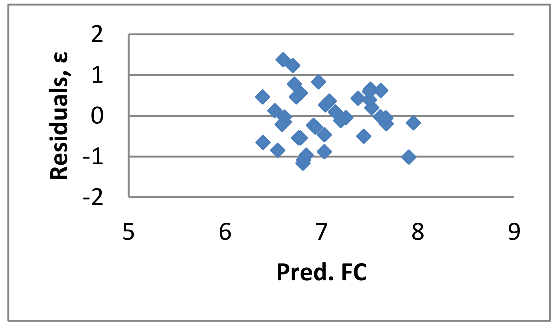


Figure 4: Residual Plot for Alligator damage with 2nd Set of Parameter ($\beta_{f1} = 1.0, \beta_{f2} = 0.9, \beta_{f3} = 0.9$)

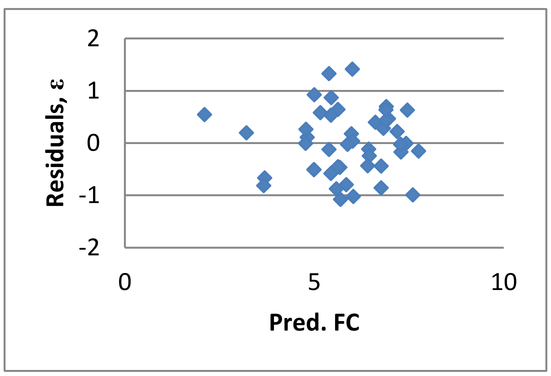


Figure 5: Residual Plot for Alligator damage with 3rd Set of Parameter ($\beta_{f1} = 1.0, \beta_{f2} = 0.8, \beta_{f3} = 0.8$)

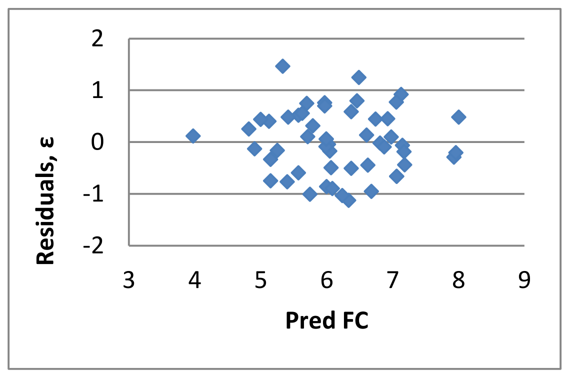


Figure 6: Residual Plot for Alligator damage with 4th Set of Parameter ($\beta_{f1} = 1.0, \beta_{f2} = 0.7, \beta_{f3} = 0.7$)

All of these figures are showing no patterns. The slop of the residual plot is relatively constant.

- **Longitudinal Damage:**

The calculated standard deviations for each set of calibration parameter are given below:

Table 2: Comparison of Standard Deviations

Parameter value	Standard Deviations in N_f Model	Standard Deviations after setting Regression Model
$\beta_{f1} = 1.0$ $\beta_{f2} = 1.0$ $\beta_{f3} = 1.0$	**430.99**	**423.30**
$\beta_{f1} = 1.0$ $\beta_{f2} = 0.8$ $\beta_{f3} = 0.8$	**831.34**	**435.62**

The above table represents the calculated the standard deviations for two sets of calibration parameter in N_f model. From the table it can be said that, with the decreasing of the value of calibration parameter(β_{f2}, β_{f3}) the standard deviation was increased and after doing the local calibration part, the standard deviations was decreased than that value in N_f model. Second set of parameter shows significant changes in the standard deviation.

The residual plots for each set of calibration parameter in N_f model are presented below:

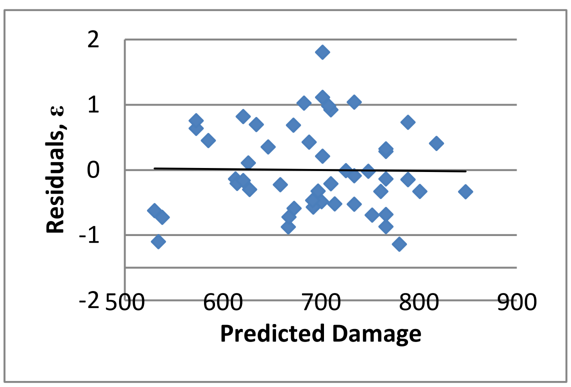


Figure 7: Residual Plot for Longitudinal damage with Default Parameter ($\beta_{f1} = 1.0, \beta_{f2} = 1.0, \beta_{f3} = 1.0$)

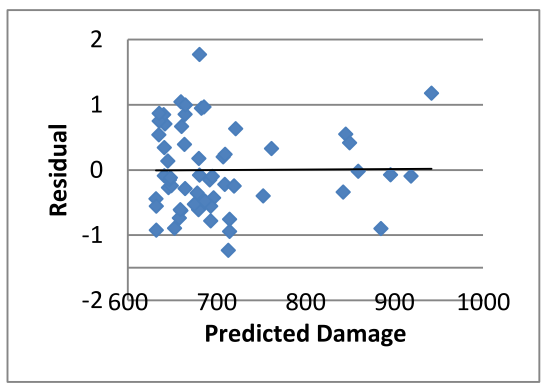


Figure 8: Residual Plot for Longitudinal damage ($\beta_{f1} = 1.0, \beta_{f2} = 0.8, \beta_{f3} = 0.8$)

Both figures are showing no patterns. The slop of the residual plot is relatively constant.

Since, there were no significant changes in standard deviations and residual plot for both types of damage, so it needs more extensive research in processing observed data (weighted value can be used. A sample weighted value was used and included in the spreadsheet). In addition, level of accuracy for prediction models needs to be changed with more accurate information (currently level 3 was used). Otherwise MEPDG would have failed to conclude for the load related cracking for Ontario's flexible pavement.

- **Transverse Damage:**

For transverse damage calibration, the procedure explained in MEPDG is followed and weighted observed distress is used by using the following formula:

$$\text{Transverse Damage} = (\text{Low severity X 1} + \text{Medium severity X 3} + \text{High severity X 5})/9$$

In the software the calibration parameter of 1.5, 4, 7 and 10 were used and the corresponding predicted data were compared. After comparison, it is found that with the weighted observed value, use of calibration factor of 7 shows minimum average bias (Table 3). Graphs of predicted damage against calibration factor for four random sections were plotted (Figure 9).

Table 3: Bias Comparison for Different Calibration Parameter for Thermal Damage

Parameter Value	1.5	3	4	7	10
Bias	6.36	2.70	1.07	-0.38	-0.62

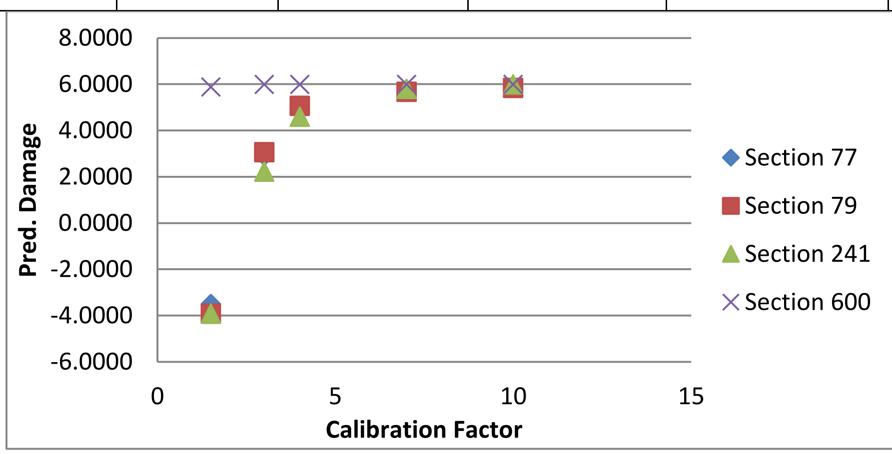


Figure 9: Calibration factor vs Predicted value (log scale)

The plotting shows that, the predicted value increases with the increased value of calibration factor. Hence after analysis, calibration factor of 7 is considered as the final calibration parameter for the thermal damage.

5. Conclusions

Results for the alligator, longitudinal and the thermal damage calibration are summarized in this paper. Processing and selection of the observed data and the collection of input data for the AASHTOWare Pavement ME software took lots of effort and researches.

This study recommends that more exclusive database or the weighted data is required for the load related cracking calibration. Level of input may be changed from level 3 to level 1 which requires more accurate information.

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