



TRC1003

Calibration of the M-E Design Guide

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Final Report

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16. Abstract <p>Because of potential differences between 'national' and 'local' conditions, the Mechanistic-Empirical Pavement Design Guide (MEPDG) should be calibrated to a local level. Arkansas has invested heavily in efforts to implement the MEPDG. This report details the initial local calibration of flexible pavement models in the MEPDG for Arkansas. Data from the Long-Term Pavement Performance (LTPP) database and local pavement management system (PMS) were used. The Solver function within Microsoft Excel was used to optimize the coefficients in the alligator cracking. Iterative runs of the MEPDG using discrete calibration coefficients were conducted to optimize rutting models. In general, the alligator cracking and rutting models are improved by calibration. However a question remains regarding the suitability of the calibrated models for routine design. Many default values were used in MEPDG due to lack of data. It is recommended that additional sites be established and a more robust data collection procedure be implemented for future calibration efforts. The difference in defining transverse cracking between the MEPDG and LTPP may be critical in terms of data collection and identification. Thermal cracking should be specifically identified in a transverse cracking survey to calibrate the transverse cracking model in MEPDG. The procedure for local calibration of the MEPDG using LTPP and PMS data in Arkansas is established. Additional development of database software for data manipulation, pre-processing, and quality control – currently underway in Arkansas – will significantly streamline the calibration process.</p>					
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CALIBRATION OF THE M-E DESIGN GUIDE

PROJECT OBJECTIVES

Because of potential differences between 'national' and 'local' conditions, the Mechanistic-Empirical Pavement Design Guide (MEPDG) should be calibrated to a local level. The objectives of this study include: (1) provide refinements to the calibration coefficients for distress prediction models in the MEPDG; (2) establish the local calibration procedure for Arkansas, and identify steps necessary for the ongoing/periodic calibration process.

SCOPE

The Project Final Report focuses on the calibration of models associated with flexible pavements; data from rigid pavements was not sufficient to perform the necessary calibration and validation functions. Data from the Long-Term Pavement Performance (LTPP) database and local pavement management system (PMS) were used. The Solver function within Microsoft Excel was used to optimize the coefficients in the alligator cracking. Iterative runs of the MEPDG using discrete calibration coefficients were conducted to optimize rutting models.

RECOMMENDATIONS

Major findings from the study include:

1. In general, the alligator cracking and rutting models are improved by calibration. However a question remains regarding the suitability of the calibrated models for routine design.
2. Many default values were used in MEPDG due to lack of data. It is recommended that additional sites be established and a more robust data collection procedure be implemented for future calibration efforts.
3. The difference in defining transverse cracking between the MEPDG and LTPP may be critical in terms of data collection and identification.
4. Thermal cracking should be specifically identified in a transverse cracking survey to calibrate the transverse cracking model in MEPDG.

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FINAL REPORT

TRC-1003

Calibration of the M-E Design Guide

by

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Conducted by

Department of Civil Engineering
University of Arkansas

In cooperation with

Arkansas State Highway and Transportation Department

U.S. Department of Transportation
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ABSTRACT

Because of potential differences between ‘national’ and ‘local’ conditions, the Mechanistic-Empirical Pavement Design Guide (MEPDG) should be calibrated to a local level. Arkansas has invested heavily in efforts to implement the MEPDG. This report details the initial local calibration of flexible pavement models in the MEPDG for Arkansas. Data from the Long-Term Pavement Performance (LTPP) database and local pavement management system (PMS) were used. The Solver function within Microsoft Excel was used to optimize the coefficients in the alligator cracking. Iterative runs of the MEPDG using discrete calibration coefficients were conducted to optimize rutting models. In general, the alligator cracking and rutting models are improved by calibration. However a question remains regarding the suitability of the calibrated models for routine design. Many default values were used in MEPDG due to lack of data. It is recommended that additional sites be established and a more robust data collection procedure be implemented for future calibration efforts. The difference in defining transverse cracking between the MEPDG and LTPP may be critical in terms of data collection and identification. Thermal cracking should be specifically identified in a transverse cracking survey to calibrate the transverse cracking model in MEPDG. The procedure for local calibration of the MEPDG using LTPP and PMS data in Arkansas is established. Additional development of database software for data manipulation, pre-processing, and quality control – currently underway in Arkansas – will significantly streamline the calibration process.

INTRODUCTION

The Mechanistic-Empirical Pavement Design Guide (MEPDG) was produced in 2004 through National Cooperative Highway Research Program (NCHRP) Project 1-37A, and subsequently delivered to the American Association of State Highway and Transportation Officials (AASHTO) in 2008. Pavement performance prediction models contained in the current MEPDG were calibrated primarily using data from the Long-Term Pavement Performance (LTPP) program. Because of potential differences between ‘national’ and ‘local’ conditions – including climate, material properties, traffic patterns, construction and maintenance activities – pavement performance predicted by the MEPDG should be compared to and verified against local experience. Moreover, LTPP data from sites located in some states (e.g. Arkansas) were not used in the national calibration; local calibration is likely necessary for these locations.

States are reporting either a partial or full calibration of the MEPDG on a local level. Kang and Adams calibrated the longitudinal and alligator fatigue cracking models for Michigan, Ohio and Wisconsin (1). All models except top-down longitudinal cracking model were validated for Montana (2). It was found that the MEPDG over predicted total rutting because significant rutting was predicted in unbound base and subgrade soil. Muthadi and Kim calibrated the rutting and bottom-up fatigue cracking model for North Carolina using a spreadsheet-based approach (3). In an overview of selected calibration studies, Von Quintus found that the measurement error of the performance data has the greatest effect on the precision of MEPDG models (4). California utilized data from accelerated pavement testing (APT) to calibrate its mechanistic empirical pavement models (5). Although data from APT could be ideal for model calibration considering its advantages of controlled climate condition, precise loading, and testing until pavement fails, most of states that do not have APT facilities can only rely on in-service pavement sites. Texas was divided into five regions for the calibration of rutting models (6). Washington selected two representative calibration sections to calibrate all distress models (7). A national guideline for local calibration was also developed by NCHRP Project 1-40B (8). Using Pavement Management Information System (PMIS), MEPDG were verified for Iowa (9). Systematic difference was found for rutting and cracking models.

Arkansas has invested heavily in efforts to implement the MEPDG. An initial sensitivity analysis was conducted to determine the most significant parameters of the MEPDG (10). Selected primary inputs required by the MEPDG, but not available through traditional testing, were then analyzed – including hot-mix asphalt (HMA) dynamic modulus, various aspects of the traffic load spectra, and the coefficient of thermal expansion of Portland cement concrete (PCC) (11). In addition, a project aimed to manage all data for the MEPDG was completed in which a software, named PrepME, was developed to conveniently prepare data sets for MEPDG use (12). Currently, a local calibration effort is progressing to allow the routine use of the MEPDG in Arkansas.

This report details the process of local calibration, including data retrieval, data quality checks, validation, calibration, and verification. Problems and issues encountered during the process are highlighted.

DATA PREPARATION

The MEPDG differs from many traditional pavement design methods in that the MEPDG requires substantially more data related to climate, traffic, and materials. In Arkansas, two data sources are available for local calibration: the LTPP database from Federal Highway Administration (FHWA) and the Pavement Management System (PMS) maintained by the Arkansas State Highway and Transportation Department (AHTD). Unfortunately, Arkansas has relatively few LTPP sections. For flexible pavements, General Pavement Studies (GPS) sites in GPS-1 and GPS-2, and Specific Pavement Studies (SPS) sites in SPS-1 and SPS-8 may be used. The AHTD PMS contains pavement materials, construction, and performance data for a variety of sites, focused primarily on sites constructed since 1996 when the Superpave HMA mixture design system was implemented in Arkansas.

Table 1 lists 38 sections available from both LTPP and PMS sources, categorized by HMA thickness and base types. Eighty percent of the sections (30 sections) were randomly selected for calibration efforts; twenty percent (8 sections) were preserved for subsequent validation. It was also noted that there was no section with thin HMA over unbound base and no section with thick HMA over asphalt treated base (ATB) and cement treated base (CTB). This is reasonable considering the low strength of unbound base and high strength of ATB and CTB.

Figure 1 shows the locations of these sections. It has to be pointed out that a site may include many experimental sections. For example, SPS-1 contains 12 sections located 10 miles south of Jonesboro, and PMS sites have three sections designated as Good, Average and Poor. Overall, the 38 sections are well distributed across the five physiographic regions of Arkansas: Ozark Plateaus, Arkansas River Valley, Ouachita Mountains, West Gulf Coastal Plain, and the Mississippi River Alluvial Plain.

Data for the LTPP sections was obtained from the latest LTPP Standard Data Release 24, which was released in January 2010. Data for the AHTD sites was collected from responsible divisions and sections of AHTD such as the Pavement Management Section, Technical Services Section, Materials Division and Construction Division. Note that no field and forensic investigation was conducted to determine missing data at this stage. MEPDG Version 1.100 was used to generate pavement performance predictions in this study.

Traffic

The LTPP database contains sufficient traffic data, such as volume count, vehicle classification and axle load distribution, to be used directly in the MEPDG. However, only volume count and truck percentage are available from the Arkansas PMS. Therefore, results from previous research were used to provide consistent data for all sections (11). Default values were used for monthly adjustment, hourly truck distribution, and general traffic input (Level 3 input). Site specific vehicle class distribution data was used whenever it was available (Level 1 input); otherwise, recommended values from MEPDG were used according to Truck Traffic Classification (TTC) groups (Level 2 input). Statewide axle load distribution factors from previous research were used in this study (Level 2 input).

The 38 sections cover different levels of traffic. The Average Annual Daily Truck Traffic (AADTT) ranges from 10 to 10,475 vehicles per day. Traffic growth rate ranges from 0 to 6.9%. In terms of functional classification, these sites include rural interstates, rural major arterials, minor arterials and major collectors.

Climate

By providing the GPS coordinate of each site, climate data was generated by interpolating from nearby climate stations. Depth of water table was extracted from the National Water Information System of the United States Geological Survey (USGS). Note that this is only a rough estimation because the well with valid data may not be close to the site.

Structure

Layer structures of LTPP sites are recorded in *Section_Layer_Structure* in *Administration.mdb*. Information regarding HMA mixtures, such as gradation, binder type, and volumetric properties are available in *Inventory.mdb* and *Material_Test.mdb*. Default values were accepted for thermal properties. It should be noted that the as-built air voids was assumed to be 8 percent for all sections according to Arkansas construction specifications (13). Only a limited amount of information is available for base and subgrade properties, such as gradation, plasticity index, liquid limit and stiffness/modulus. Therefore, MEPDG Level 3 default values were accepted as long as the material type was accurately determined.

Performance Data

Five flexible pavement performance predictions are provided by the MEPDG: alligator cracking, longitudinal cracking, transverse cracking, rutting, and International Roughness Index (IRI). For LTPP sections, the corresponding measured performance data are recorded in *Monitoring.mdb*. Similar to the national calibration (14), low, medium and high severity alligator cracking were summed as ‘alligator cracking’ without adjustment; low, medium and high severity in-wheelpath

longitudinal cracking were added without adjustment as ‘longitudinal cracking’; and low, medium and high severity transverse cracking were summed as ‘transverse cracking’ using the same weighting function in the national calibration. Note that only new flexible pavement was included in this study. In other words, only performances belong to Construction_NO=1 were analyzed.

Sections in the Arkansas PMS have hard-copy records of yearly manual distress surveys, rutting measurements using straightedge method and some profile measurements. The *LTPP Distress Identification Manual* was followed in all the manual distress surveys (15). The records were interpreted manually according to the distresses listed in LTPP database. Therefore, the performance data of LTPP sections and PMS sections are somewhat comparable. However, a concern was noted. Crack length, as recorded on hard-copy forms in the PMS, have been found to vary from the actual distance in the field. This may be exacerbated by the shortened length of the PMS sections (100 ft) as compared to the LTPP sections (500 ft). A small error in the hard-copy forms may become significant when extrapolated to feet-per-mile.

RESULTS AND ANALYSIS

Verification

After data preparation, MEPDG was run with the national-default calibration coefficients. The comparison of predicted and measured alligator cracking, longitudinal cracking, transverse cracking, IRI and total rutting are shown in Figure 2a, Figure 3 and Figure 4a.

It is observed that predicted distresses do not match well with measured distresses, particularly for longitudinal and transverse cracking. However, it should be pointed out that most of the data points group near the origin. For example, 94 percent of measured alligator cracking is lower than 10 percent; in addition, all predicted longitudinal cracking are lower than 1000 ft/mi. In general, the pavement sections available for this study are in good condition (on average, only 2.1% alligator cracking, 860 ft/mi longitudinal cracking, 131 ft/mi transverse cracking, 0.19 inches total rutting, and 72.9 in/mi for IRI). Additional observations related to the results follow.

- **Fatigue Cracking:** Both alligator cracking and longitudinal cracking predicted by MEPDG are forms of fatigue cracking. Transfer functions are used to predict visual cracking from mechanistic “damage” at the bottom and top of HMA layers. This makes the HMA layer thickness to be an extremely significant factor affecting performance predictions.
- **Asphalt Treated Base (ATB):** Although it is a type of stabilized base, ATB is not modeled as “Stabilized Base” but as “Asphalt” (albeit with a reduced stiffness). Therefore, the HMA layer in the sections with asphalt treated base becomes very thick in the MEPDG, which reduces the stress and strain at the bottom and top of the HMA layer,

in turn reducing the predicted alligator cracking and longitudinal cracking. The other method to model ATB is by considering it as “Granular Base”, which is moisture sensitive instead of temperature sensitive. However, both methods may induce errors in predicted distresses.

- **Transverse Cracking:** In the MEPDG, transverse cracking is primarily related to thermal cracking, caused by thermal stress in pavement. However, transverse cracking in LTPP database and PMS are measured according to the *LTPP Distress Identification Manual*, in which transverse cracking is defined as *cracks that are predominately perpendicular to pavement centerline (15)*. The implementation of Performance-Graded (PG) binders for HMA in Arkansas has all-but eliminated thermal cracking in flexible pavements; accordingly the MEPDG predicts no thermal cracking for Arkansas climate and a properly selected PG binder. However, transverse cracking is recorded in distress surveys, suggesting that additional cracking mechanisms may be predominate in Arkansas.
- **Rutting:** Eighty percent of the pavement sections have 0.1 to 0.3 inches of rutting, even for the sites older than 15 years. This suggests either: (a) rutting reached a maximum of 0.3 inches by consolidation under traffic, without plastic failure; or (b) rutting measurements (typically by straightedge) were recorded as a maximum of 0.3 inches regardless of the actual measurement.

Calibration

Generally, prediction models are calibrated by minimizing the sum of standard error (SSE) between predicted and measured values:

$$SSE = \sum_{i=1}^N (\text{predicted} - \text{measured})^2 \quad (1)$$

Due to the nature of the data, longitudinal cracking and transverse cracking model were not calibrated. In addition, the smoothness model (IRI) was not calibrated, since the predicted IRI is a function of other predicted distresses. The Solver function within Microsoft Excel was used to optimize the coefficients in the alligator cracking model. Iterative runs of the MEPDG using discrete calibration coefficients were utilized to optimize rutting models. For this analysis, it was assumed that the national rutting model for granular base is the same as it for Arkansas because rutting mainly occurs in the HMA layers and subgrade; hence, the default coefficient for rutting in granular base was not adjusted. The adjusted calibration coefficients for Arkansas are listed in Table 2. Figure 2 and Figure 4 provide a comparison of the predicted and measured distresses before and after calibration. In addition, statistical analysis was conducted to test the difference

of means (using t -test) and variances (using F -test) between measured and predicted distresses, as well as before and after the calibration.

Observations based on the calibration process and results follow.

- In general, the alligator cracking and rutting models are improved by calibration. R-square of the alligator cracking is improved (Figure 2). Bias is eliminated by calibration, as shown in Table 3 that p -values after calibration are over 0.05. The regression line of total rutting is very close to the line of equality.
- However a question remains regarding the suitability of the calibrated models for routine design. The predicted alligator cracking are all less than 10 percent but the measured values range from 0 to 40 percent. The variation of predicted alligator cracking is statistically different from the measured alligator cracking; and it is not improved by calibration.
- Considering the difficulty to classify cracking types, it may be possible to use ranges instead of exact number in MEPDG prediction to accommodate errors from measurement and models. For example, measured alligator cracking of 3.4 percent would be acceptable if the predicted alligator cracking was in the range of 0 to 5 percent. As shown in Figure 5, prediction and measurement match better when they are viewed by this new method.
- Quality of Input Data: Many default values are used in MEPDG in this study because these data are not available. There is a continuing concern that the quality of input data reduces the accuracy of MEPDG. It is recommended that additional sites be established and a more robust data collection procedure be implemented for future calibration efforts.

Validation

The calibrated models were validated by running the MEPDG on the remaining eight sections using adjusted calibration coefficients in Table 2. The predicted and measured performance is compared and shown in Figure 6. It is clear that local calibration reduced the difference between predicted and measured distress; additional efforts (sites, data) will be necessary to further reduce this difference.

CONCLUSIONS

This report details the initial local calibration of flexible pavement models in the MEPDG for Arkansas. The following conclusions are drawn from this study.

- The procedure for local calibration of the MEPDG using LTPP and PMS data in Arkansas is established. Overall, alligator cracking and rutting models were improved by

local calibration. However, more sites and data collection are recommended before the full implementation of MEPDG in Arkansas.

- The availability and quality of design, materials, construction, and performance data are critical for local calibration. It is likely that states like Arkansas will need to establish additional calibration sites to supplement available LTPP and PMS data.
- The difference in defining transverse cracking between the MEPDG and LTPP may be critical in terms of data collection and identification. Thermal cracking should be specifically identified in a transverse cracking survey to calibrate the transverse cracking model in MEPDG. Since new features are developed to better handle climate files in DARWin-ME, it will be necessary to recalibrate the thermal cracking model when DARWin-ME is released.
- Proper modeling of asphalt treated base is vital to producing realistic predictions of alligator cracking and longitudinal cracking, due to the influence of total HMA thickness on the damage predictions at the bottom and top of HMA layer.
- Additional development of database software for data manipulation, pre-processing, and quality control – currently underway in Arkansas – will significantly streamline the calibration process.

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FIGURE 2 Alligator cracking model: (a) verification, (b) calibration.

FIGURE 3 Verification of national calibrated model: (a) longitudinal cracking, (b) transverse cracking, (c) IRI.

FIGURE 4 Rutting models: (a) verification of national calibrated, (b) local calibrated.

FIGURE 5 Histogram of (a) national and (b) local-calibrated alligator cracking model.

FIGURE 6 Validation of calibrated alligator cracking and rutting models.

TABLE 1 Experimental Matrix^a

Base Type ^b	Hot-Mix Asphalt (HMA) Thickness			No. of sections
	Thin (≤ 4 in.)	Intermediate	Thick (≥ 8 in.)	
Unbound base		<u>0113</u> ,0114,0804, 070079G,070079A, 070079P	R20149G,R20149P,090001G, 090001A,090001P, <u>090048G</u> , <u>090048A</u> ,090048P,070018G, 070018A,070018P	17
ATB	0803	0115,0116,0117,0118,0119 <u>0120</u> ,0121,0122,0123, <u>0124</u> R80065G,R80065A, R80065P, <u>R50067G</u> , R50067A,R50067P		17
CTB		2042, <u>3048</u> , 3058,3071		4
No. of sections	1	26	11	38

^a Underlined sections are randomly selected for validation; G is Good; A is Average; P is Poor

^b ATB: Asphalt Treated Base; CTB: Cement Treated Base.

TABLE 2 Summary of Calibration Factors

Calibration Factor	National Default	Arkansas
Alligator cracking		
C1	1	0.688
C2	1	0.294
C3	6000	6000
AC rutting		
β_{r1}	1	1.20
β_{r2}	1	1
β_{r3}	1	0.80
Base rutting		
Bs1	1	1
Subgrade rutting		
Bs1	1	0.50

TABLE 3 Statistical Analyses of Alligator Cracking and Total Rutting

	Alligator cracking			Total rutting		
	Measured	Before calibration	After calibration	Measured	Before calibration	After calibration
Average	2.0688	0.5512	2.0070	0.1945	0.2586	0.1852
Standard deviation	4.9029	2.0661	1.4456	0.0670	0.0885	0.0628
<i>p</i> -value (<i>t</i> -test)	N/A	0.0000	0.8160 (>0.05)	N/A	0.0000	0.0552 (>0.05)
<i>p</i> -value (<i>F</i> -test)	N/A	0.0000	0.0000	N/A	0.0000	0.2176 (>0.05)
N	371	371	371	363	363	363

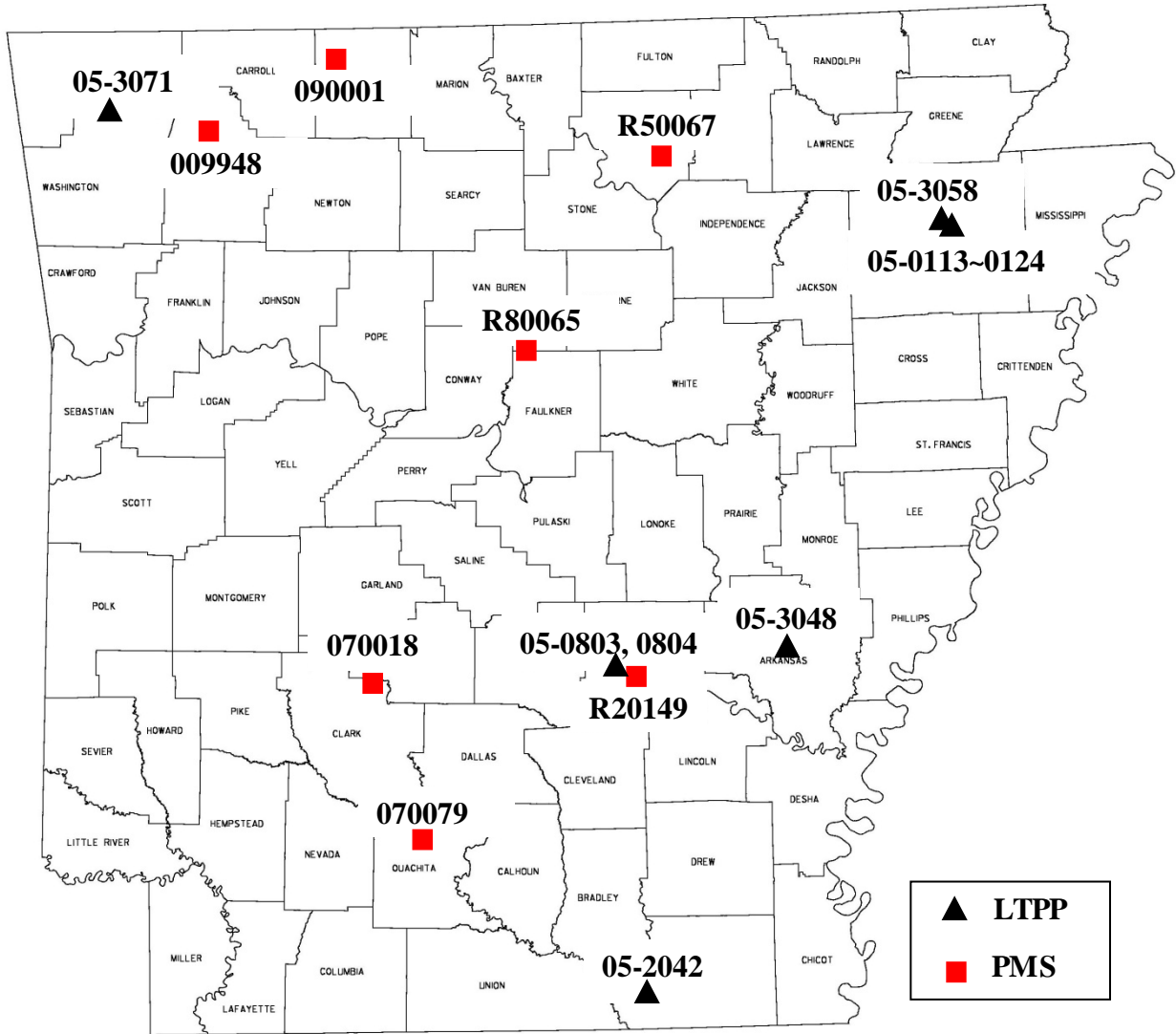


FIGURE 1 Locations of calibration sites.

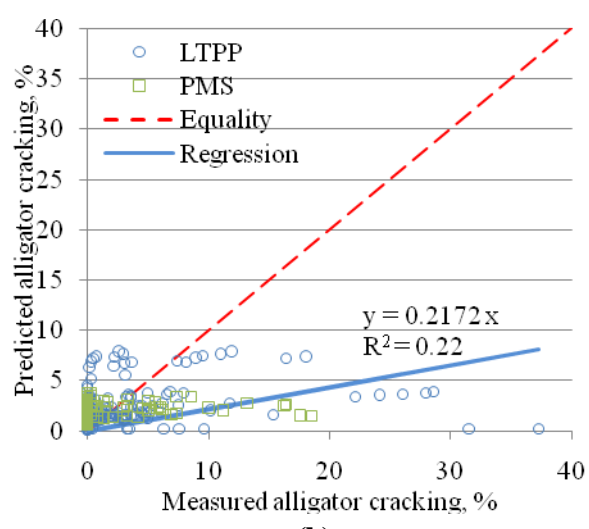
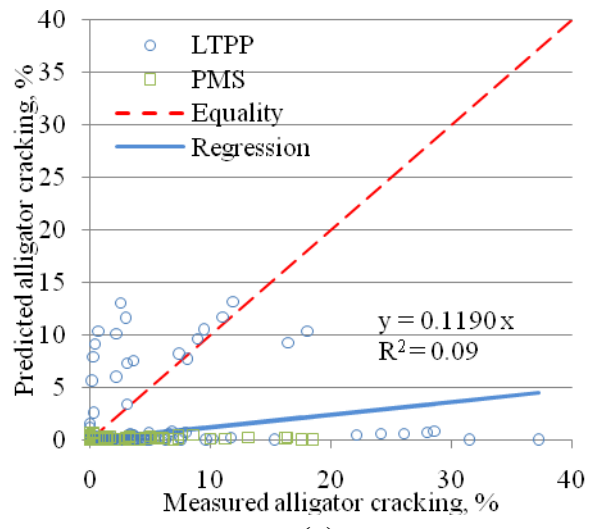


FIGURE 2 Alligator cracking model: (a) verification, (b) calibration.

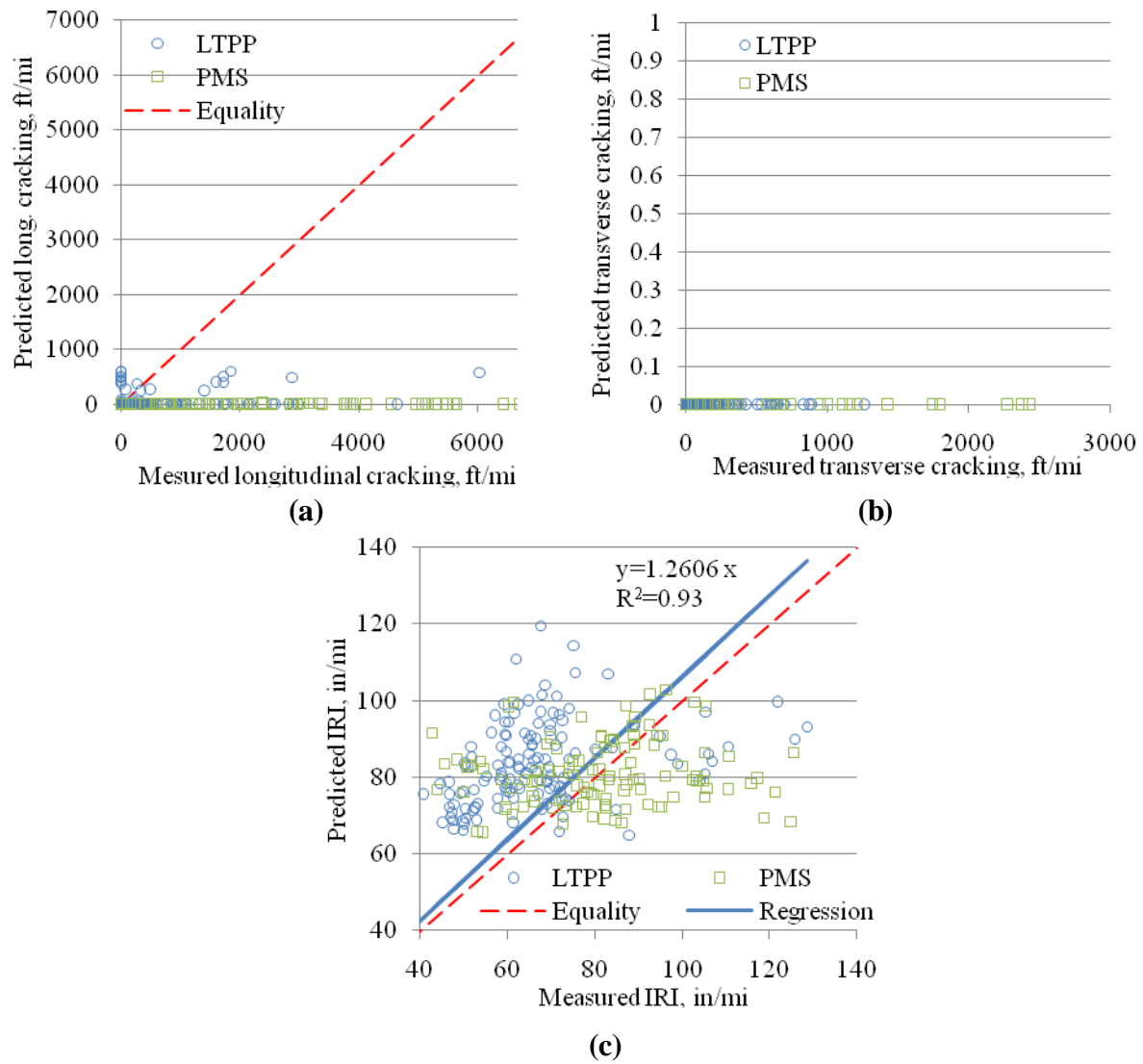
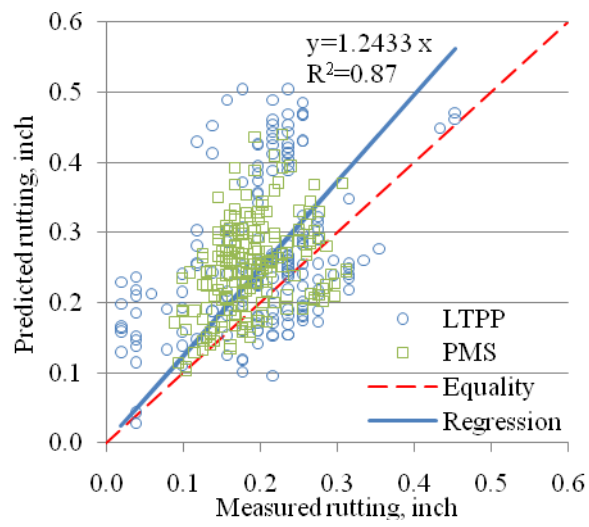
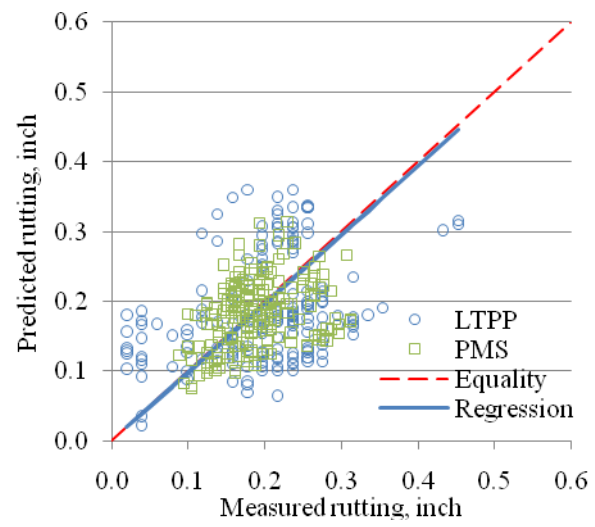


FIGURE 3 Verification of national calibrated model: (a) longitudinal cracking, (b) transverse cracking, (c) IRI.

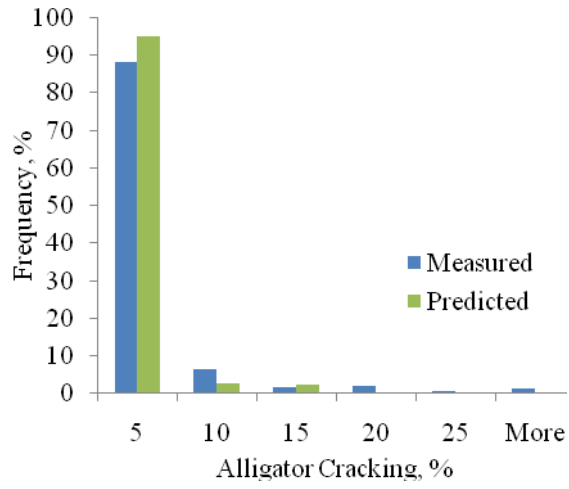


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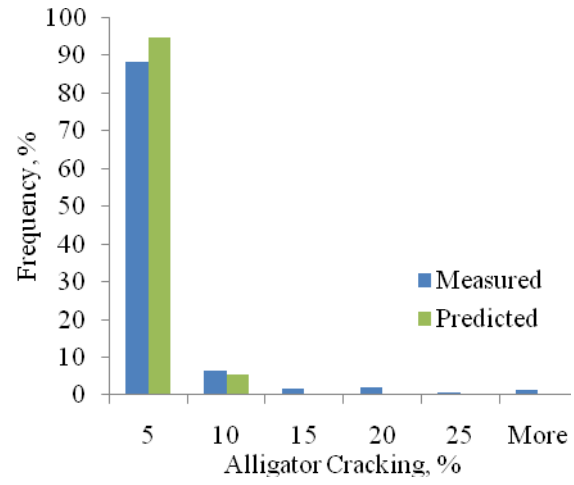


(b)

FIGURE 4 Rutting models: (a) verification of national calibrated, (b) local calibrated.

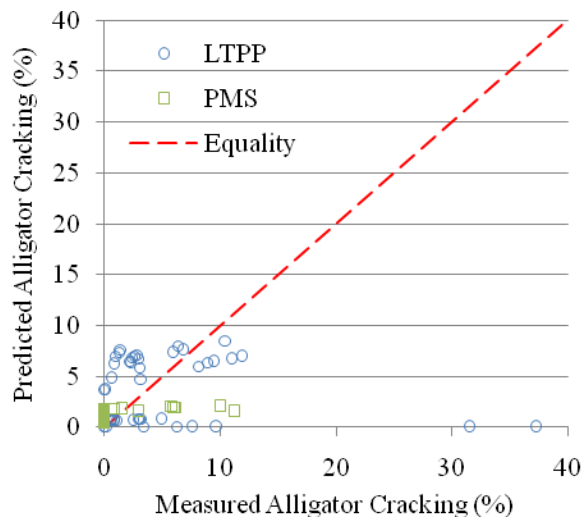


(a)

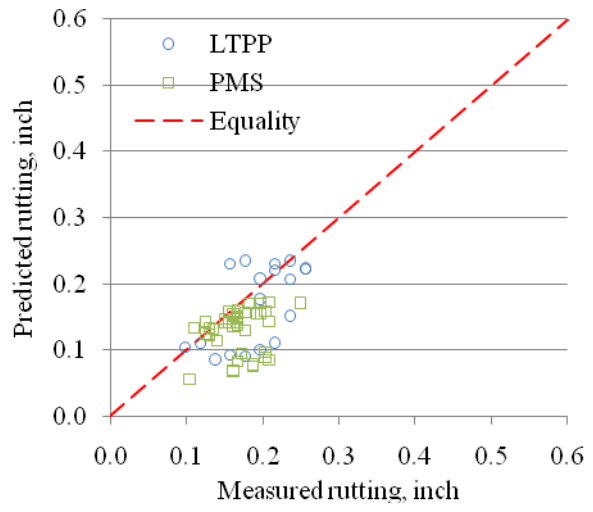


(b)

FIGURE 5 Histogram of (a) national and (b) local-calibrated alligator cracking model.



(a)



(b)

FIGURE 6 Validation of calibrated (a) alligator cracking and (b) rutting models.