GEORGIA DOT RESEARCH PROJECT 14-25

FINAL REPORT

GEORGIA LONG-TERM PAVEMENT PERFORMANCE (GALTPP) PROGRAM – MAINTAINING GEORGIA'S CALIBRATION SITES AND IDENTIFYING THE POTENTIAL FOR USING MEPDG FOR CHARACTERIZATION OF NON-STANDARD MATERIALS AND METHODS (PHASE 1)

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1.Report No.:
FHWA-GA-16-1425

2. Government Accession No.:

3. Recipient's Catalog No.:

4. Title and Subtitle:
Georgia Long-Term Pavement Performance (GALTPP) Program – Maintaining Georgia’s Calibration Sites and Identifying The Potential for Using MEPDG For Characterization of Non-standard Materials and Methods (Phase 1)

5. Report Date: October 2016

6. Performing Organization Code:

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8. Performing Organ. Report No.:
RP 14-25

9. Performing Organization Name and Address:
Georgia Institute of Technology
790 Atlantic Drive
Atlanta, GA 30332-0355

10. Work Unit No.:

11. Contract or Grant No.:

12. Sponsoring Agency Name and Address:
Georgia Department of Transportation
Office of Research
15 Kennedy Drive
Forest Park, GA 30297-2534

13. Type of Report and Period Covered:
Final; March 2014 – October 2016

14. Sponsoring Agency Code:

15. Supplementary Notes:
Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract:

The Georgia Department of Transportation (GDOT) has initiated a Georgia Long-Term Pavement Performance (GALTPP) monitoring program 1) to provide data for calibrating the prediction models in the AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG) and 2) to monitor sites for evaluating the effect of various materials and methods on pavement performance. A total of 38 flexible pavement sites (17 LTPP and 21 non-LTPP) and 23 rigid pavement sites (11 LTPP and 12 non-LTPP sites) sites were selected for the MEPDG calibration and various field and laboratory testing, including condition surveys in accordance with LTPP Distress Identification Manual, Falling Weight Deflectometer (FWD), etc., were conducted on the non-LTPP sites. The detailed data collected for the calibration, is very valuable for future recalibration of the MEDPG and evaluation of the performance of different pavement designs and materials. Thus, the objectives of this project are 1) to maintain the data (e.g., distress data and FWD data) that has been collected on the sites, and 2) to identify the potential for the characterization of non-standard methods and materials using the MEPDG to provide suggestions on the implementation. In Phase 1 of this project, a GALTPP database was designed and populated with the inputs used for initial MEPDG calibration and the data (e.g., distress data, FWD, etc.) collected on the non-LTPP sites with a focus on flexible pavement sites. The site location data were corrected to ensure they can be correctly located for long-term monitoring using core data collected by GDOT’s coring data collection application. A GIS (Geographic Information Systems) project, along with add-in tools, was developed to visualize the sites. In addition, the predicted distresses by the MEPDG on interstate sites were verified and the differences in the designs between the MEPDG and the 1972 AASHTO Interim Design Guide were discussed to provide suggestions on the MEPDG implementation.

17. Key Words:
Georgia LTPP; GALTPP

18. Distribution Statement:
No Restriction

19. Security Classification (of this report):
Unclassified

20. Security classification (of this page):
Unclassified

21. Number of Pages:
84

22. Price:

Contract Research

GDOT Research Project No. 14-25
Draft Report

GEORGIA LONG-TERM PAVEMENT PERFORMANCE (GALTPP) PROGRAM – MAINTAINING GEORGIA'S CALIBRATION SITES AND IDENTIFYING THE POTENTIAL FOR USING MEPDG FOR CHARACTERIZATION OF NON-STANDARD MATERIALS AND METHODS (PHASE 1)

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Contract with
Georgia Department of Transportation
In cooperation with
U.S. Department of Transportation
Federal Highway Administration
October 2016

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EXECUTIVE SUMMARY

The Georgia Department of Transportation (GDOT) is in the process of evaluating the use of the AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG) for designing its new and rehabilitated pavement structures. GDOT has undertaken projects to establish the groundwork for the use of the MEPDG, including characterizing material properties, analyzing traffic loading, and calibrating the MEPDG performance prediction models for Georgia's local conditions and materials. A Georgia Long-term Pavement Performance (GALTPP) program was initiated by GDOT to provide a sufficient number of sites for the initial MEPDG local calibration, and, more importantly, to conduct long-term performance monitoring on the sites of GDOT's interest to support the performance evaluation and/or future MEPDG recalibration. The outcomes/findings will improve GDOT's practices of pavement design, material, construction, and maintenance. Currently, the GALTPP comprises 38 flexible pavement sites (17 LTPP and 21 non-LTPP sites) and 23 rigid pavement sites (11 LTPP and 12 non-LTPP sites). Various field and laboratory tests, including condition surveys in accordance with LTPP Distress Identification Manual, Falling Weight Deflectometer (FWD), Dynamic Cone Penetration (DCP) tests of the base and subgrade, bulk specific gravity measured on each layer, etc., were conducted on the non-LTPP sites, and documents (e.g., as-built plans and construction files) were gathered to provide the data needed for the calibration. These data are essential for further recalibration of the MEPDG. Therefore, it is essential to manage and maintain the data collected for the GALTPP program, including the existing data and the data to be collected in the future. In addition, the potential for characterizing non-standard designs and materials (e.g., micro-milling and Stone Matrix Asphalt (SMA)) used in Georgia must be identified using the MEPDG to provide suggestions

on the implementation and future calibration.

This project consists of three consecutive one-year phases with each phase focusing on 1) a component for maintaining the GALTPP data and 2) the use of MEPDG for a specific design or material identified by GDOT. Phase 1 of this project focused on developing a database for the flexible pavement sites and evaluating the use of the MEPDG for designing Georgia's interstate pavement structures because they account for a major part of total capital investments on the roadways. Phase 2 will focus on extending the database to rigid pavement sites, and the potential topics for studying include warm mix asphalt, jointed plain concrete pavement (JPCP) design, etc., and will be further discussed with and confirmed by GDOT. Phase 3 will focus on the procedures for incorporating additional data (e.g., performance data) and sites (e.g., warm mix asphalt sites). The potential topics for Phase 3 will be determined at the end of Phase 2. The following are the major findings from Phase 1 of the project:

1) The data collected on GALTPP sites, including FWD DCP, etc., were gathered and carefully reviewed. The site locations were verified by comparing them (x-y coordinates included in GDOT's calibration study) to the core locations collected using GDOT's PDA-based core data collection application to ensure the sites can be correctly located for long-term performance monitoring. It was found that the site location data does not match the core location data. Thus, the site location data was corrected based on the first core located along the travel direction. The location data was further processed to obtain additional location information (e.g., RCLINK and milepoint) using GDOT's location reference system.
2) A database (GALTPP database) with location reference information was designed to store and manage the input parameters used in the MEPDG calibration, the condition survey data,

the testing data, and the documents collected on the GALTPP sites. GALTPP database tables and fields for flexible pavement were designed based on a relational database concept with geospatial information so it can be integrated into a GIS (Geographic Information Systems) platform. The data were processed and populated into the GALTPP database. In addition, a GIS project, along with add-in tools, was developed using the GALTPP database for visualizing the sites.

3) A review of GDOT's pavement condition survey data shows raveling is the predominate distress on Georgia's interstate pavements; in FY 2015, 41% of interstate segments were reported with raveling. Raveling is also an important performance indicator that triggers the need for maintenance on the porous friction course (e.g., Open Graded Friction Course (OGFC) or Porous European Mix (PEM)) on the surface layer, but it is not modeled in the MEPDG.
4) A total of 38 sites (17 LTPP and 21 non-LTPP sites) were used to calibrate the coefficients in the MEPDG transfer functions to eliminate bias and improve accuracy (i.e., reducing the standard error). Among them, five sites are on interstates. Compared to the other sites, these interstate sites exhibited low fatigue cracking (less than 3%) and moderate rutting (between 0.15 in. and 0.3 in.) at the end of pavement service interval (i.e., before pavement rehabilitation). The only site that exhibited more cracking (approximately 10% in 17 years) is on I-520, which has 7 in. of asphalt concrete layers. Based on the limited data, the measured distresses were within the distresses predicted at 50% reliability using the MEPDG.
5) A case study was conducted on I-95 in Chatham County based on the existing pavement structure. Using the MEPDG, the predicted distresses would reach the distress performance

criteria (0.35 in. of rutting and 10% of fatigue cracking) at 95% reliability in 20 years. However, the observed distresses (0.25 in. of rutting and 3% of fatigue cracking) were close to the distresses predicted at 50% reliability.

6) Compared to the MEPDG, the current design procedure (1972 AASHTO Interim Design Guide; for brevity, called the 1972 Design Guide hereafter) is on the conservative side. The interstate pavement structure on the I-95 site was 10.17% under-designed when it was validated using the 1972 Design Guide. According to the 1972 Design Guide, to carry the 16.2 million heavy trucks, an additional 2 in. of asphalt base was needed. However, the design without the 2 in. of asphalt base passed all the performance criteria when it was validated using the MEPDG.
7) Though it is on the conservative side, the current 1972 Design Guide allows GDOT to replace only the top porous friction course in 10 to 12 years, and both the porous friction course and SMA layer in 20 to 24 years without the need to replace the underlying layers because the underlying layers are still structurally sound with few limited distresses. Analyses on multiple pavement service intervals (e.g., more than 20 years) based on GDOT's maintenance practices would help to determine the most cost-effective pavement structures.
8) Based on the field observation, SMA has better performance in terms of fatigue life on heavily traveled roads compared to Superpave. This benefit is not modeled in the current design procedure (1972 Design Guide) because both SMA and Superpave have the same structure coefficient of 0.44. This issue remains the same in the MEPDG. Moreover, using the Witczak predictive model in the MEPDG, the SMA has a slightly lower dynamic modulus than Superpave. This leads to higher predicted rutting and fatigue cracking,

although the differences are small. However, this is contrary to the observed field performance in Georgia with better rutting and fatigue resistance of SMA.

To move forward in maintaining an active GALTPP program, the following are recommended:

1) Because the pavements continue deteriorating, it is recommended that distress and FWD data be collected on an annual or biennial basis on the GALTPP sites to establish a long-term performance monitoring. Especially, it is recommended that cracking data be collected before and after resurfacing on the I-95 site in Chatham County, which will be resurfaced next year. Such data allows GDOT to validate the performance of this site and assess the development of cracking on micro-milled surface.
2) The 3D laser technology (e.g., 3D pavement data, video log images, etc.) can be used for collecting consistent and detailed pavement distress data on the GALTPP sites. The high-resolution 3D laser data can be used for detecting cracks and quantitatively and objectively measuring raveling on the porous friction course surface. In addition, it can collect the cracking data before and after the micro-milling is performed on the porous friction course. These data are invaluable for assessing the development of top-down and bottom-up cracking on Georgia's pavements.
3) A raveling prediction model (including a measure for quantifying raveling) should be developed and incorporated into the life-cycle analysis of the interstate pavement design (for new and rehabilitated pavement structures). This will allow GDOT to reliably quantify raveling and identify the timing for adequate treatment(s), which is difficult using current visual inspection.

4) It is recommended life-cycle cost analysis be performed based on GDOT’s maintenance practices to determine the pavement structure design that is most cost-effective for the full life cycle.

ACKNOWLEDGMENTS

The authors would like to thank the Georgia Department of Transportation (GDOT) for its support. The work conducted in this report was sponsored by the GDOT's Office of Research (Research Project 14-25). The authors would like to thank the support provided by the Office of Research and the Office of Materials and Testing. The strong support and valuable inputs provided by Mr. Moussa Issa, Mr. Steve Panaho, and Mr. Monzy Mathews of GDOT, and Dr. James Lai in the course of this research project are highly appreciated.

1. INTRODUCTION

1. 1 Background and Research Need

The Georgia Department of Transportation (GDOT) is in the process of evaluating the use of the AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG), developed under the National Cooperative Highway Research Program (NCHRP) Project 1-37A (*NCHRP 2000*), for designing its new and rehabilitated pavement structures. The MEPDG models pavement responses (stresses, strains, and deflections) using traffic loading, material properties, and environmental data, and it relates the cumulative damage to field-observed pavement performance empirically using pavement distress transfer functions (or distress prediction models). GDOT has undertaken several projects to establish the inputs for the MEPDG, including conducting tests to characterize material properties, studying traffic load spectra, etc., and, also, conducted verification and local calibration of the MEPDG performance models for use in Georgia (*ARA 2015a*). During the verification, it was found that the number of LTPP sites in Georgia is insufficient to cover the range of pavement structures, materials, and other design features commonly used by GDOT, and the levels of distress exhibited on these LTPP sites are inadequate for the calibration of the MEPDG. Therefore, GDOT initiated a Georgia Long-Term Pavement Performance (GALTPP) program, which includes LTPP sites in Georgia and additional sites (referred as non-LTPP sites) to cover common design features used in Georgia for support of the MEPDG calibration (*ARA 2015a*). Currently, the GALTPP program comprises 38 flexible pavement sites (17 LTPP and 21 non-LTPP sites) and 23 rigid pavement sites (11 LTPP and 12 non-LTPP sites). Extensive field and laboratory testing, including condition surveys in accordance with LTPP Distress Identification Manual, Falling Weight Deflectometer (FWD), Dynamic Cone Penetration (DCP) tests of the base and subgrade, bulk specific gravity measured on each layer, etc., were conducted on the non-LTPP sites to obtain input data, including pavement design, material properties, performance data, etc., for the MEPDG.

Though the initial calibration was completed, it is recognized that the recalibration of the MEPDG is still needed in the future as MEPDG performance models (e.g., reflective cracking model) are improved, as more distress data becomes available over time, and as new pavement methods and materials are implemented in Georgia. The rich data collected on the GALTPP sites (both LTPP and non-LTPP sites) are valuable to GDOT and essential for support of MEPDG recalibration in the future. Besides the current sites, the GALTPP program is expected to include additional sites in the future for evaluating the effects of different designs, materials, construction methods, maintenance levels, etc., on pavement performance. For example, GDOT has built research sites with new methods and materials, such as the use of micro-milling, warm mix asphalt (WMA), and crumb rubber modified asphalt. These research sites should be documented, monitored, and tracked through the GALTPP program. In addition, studies are required to evaluate the feasibility of modeling non-standard methods and materials used in Georgia using the MEPDG. Therefore, the objectives of this project are 1) to maintain the data (e.g., LTPP survey and FWD) that has been collected and will be collected on the GALTPP sites to support the recalibration, 2) to include pavement research sites built with new designs, materials, etc., into the GALPP program to document and monitor their long-term performance, and 3) to identify the potential for the characterization of non-standard methods and materials using the MEPDG to provide suggestions on the MEPDG implementation and future recalibration.

This project consists of three consecutive one-year phases with each phase focusing on one component for maintaining the data collected for the GALTPP program and one specific method and material identified by GDOT. Table 1.1 lists the work by phases. This allows GDOT to prioritize the methods and materials to study in this project and provides the flexibility to study the sites that are relatively new in later phases. Phase 1 of this project focused on developing a GALTPP database for maintaining the data collected on the flexible pavement sites and evaluating the design of pavement structure on Georgia's interstate highways using the MEPDG. Phase 2 will focus on extending the database onto rigid pavement sites, and the potential topics for studying, such as jointed plain concrete pavement (JPCP), will be further discussed with and confirmed by GDOT. Phase 3 will focus on the procedures for incorporating additional data (e.g., performance data) and sites (e.g., WMA sites). The potential topics for Phase 3 will be determined at the end of Phase 2.

Table 1.1 Work by Phases

	Maintaining GALTPP data	Potential Topics
Phase 1	Flexible pavement sites	• Interstate highway
Phase 2	Rigid pavement sites	• To be determined (e.g., jointed plain concrete pavement)
Phase 3	Incorporating research sites	• To be determined

1.2 Significance of Research

Maintaining the data collected for the GALTPP program will allow GDOT to track and share data collected on the sites with different designs, materials, construction methods, and maintenance levels to support quantitative assessment of their effects on long-term pavement performance. The GALTPP database will serve as one of the most important sources of data for further validation and calibration of the MEPDG models and the evaluation of the effects of different pavement designs, materials, etc. The outcomes/findings can be used to improve GDOT's practices for pavement design, material selection, construction methods, and maintenance strategies. In addition, the outcomes on the potential for characterizing non-standard methods and materials used in Georgia using the MEPDG will enable GDOT to better utilize the MEPDG for understanding the distresses based on different designs and materials.

1.3 Research Objectives and Scope

The objectives of Phase 1 of this project were to develop a GALTPP database for maintaining the data collected on the flexible pavement sites and 2) evaluate the design of interstate pavement structure using the MEPDG. The specific activities for each work task are presented below:

1) Work Task 1: Manage the data collected on the flexible pavement sites.

   In this task, the Georgia Tech research team worked with GDOT’s GALTPP Task Force and the Office of Research to gather the data (including LTPP distress survey data, FWD, DCP, and coring data) that were used to support the calibration of the MEPDG. A relational database (GALTPP database) with location references was designed and developed for more efficient and easier data management and manipulation; the data for the flexible pavement sites was carefully reviewed and populated into the developed GALTPP database. In addition, a GIS project was developed to visualize the GALTPP sites (including LTPP and non-LTPP sites) and the data from various sources.

2) Work Task 2: Identify pavement structure designs to be evaluated using the MEPDG and gather data for the sites.

   Because interstate highways account for a major part of capital investment, GDOT's GALTPP Task Force set the focus of this phase to evaluate the feasibility of designing interstate pavement structures using the MEPDG based on the procedure and input parameters recommended in the Georgia ME Design User Guide (*ARA 2015b*). In addition, the distresses on the interstate highways were studied based on GDOT's pavement condition survey conducted in FY 2015 to better understand the distresses on the interstate highways.

3) Work Task 3: Evaluate the feasibility of designing Georgia's interstate pavement structures using the MEPDG.

   This work task is to evaluate the feasibility of designing Georgia's interstate pavement structures using the MEPDG. This includes verifying the distress predicted by the MEPDG and comparing the pavement structures designed by using the MEPDG and the 1972 AASHTO Interim Design Guide (for brevity, called 1972 Design Guide hereafter) (*AASHTO 1972*) to provide suggestions on the implementation. The major subtasks are listed as follows:

   - Review the distresses data used for calibrating the MEPDG performance models, especially the data on interstate sites;
   - Run the AASHTOWare Pavement ME Design to predict pavement performance (e.g., fatigue cracking and rutting) and compare the predicted and observed distresses on interstate sites;
   - Compare the pavement structures designed by the MEPDG and the 1972 Design Guide and provide suggestions on the implementation of the MEPDG.

4) Work Task 4: Prepare final report. This task is to summarize the findings of Phase 1 and make recommendations.

1.4 Organization of this Report

This report is organized as follows:

1) Chapter 1 introduces the background, significance, scope, objective, and work tasks of this project.
2) Chapter 2 presents the development of a GALTPP database for a) the data, such as distresses, coring, etc., collected on the GLAPP sites, b) a data repository, including a database design and structured folder, for the collected data and the inputs to the MEPDG, and c) a GIS project for integrating and visualizing the data.
3) Chapter 3 describes current pavement structure design and maintenance practices on the interstates and analyzes the distresses on interstates based on pavement condition evaluation data collected by GDOT in FY 2015.
4) Chapter 4 evaluates the design of Georgia's interstate pavement structures, which is comprised of porous friction layer (e.g., Open Graded Friction Course (OGFC) or Porous European Mix (PEM)) and Stone Matrix Asphalt (SMA), using the MEPDG. The differences between the MEPDG and the 1972 Design Guide are discussed.
5) Chapter 5 summarizes the findings of this project and makes recommendations.

2. MANAGEMENT OF GALTPP DATA

The goal of the GALTPP program is to provide data that supports quantitative evaluation of the effects of various pavement designs, materials, and maintenance strategies on pavement performance. The findings can help improve GDOT's practices for pavement design, material selection, construction methods, and maintenance strategies that will lead to more cost-effective and better performing pavements. To achieve this goal, the GALTPP program needs to gather, process, and share the data that describes the pavement structures, material properties, traffic loads, long-term performance, etc., on each site. This chapter presents the data gathered for the GALTPP program, suggestions on the location references, the database designed to store the data gathered for GALTPP program, and a GIS project developed to facilitate the data visualization and integration.

2.1 Data Gathered for the GALTPP Program

This section describes the data gathered for the GALTPP program with a focus on flexible pavement sites, including 17 LTPP and 21 non-LTPP sites. For the LTPP sites, the data included in the LTPP database were used in support of the MEPDG calibration. For the non-LTPP sites, project construction files and GDOT's Pavement Condition Evaluation Systems (PACES) (*GDOT 1993*) data were gathered for each site. In addition, field data collection and laboratory testing was performed in 2014 by the Applied Research Associates (ARA) and the National Center for Asphalt Technology (NCAT) to collect the inputs needed for the MEPDG calibration (*ARA, 2015a*). The collected data included (a) condition surveys in accordance with the LTPP Distress Identification Manual (*FHWA 2003*), (b) FWD deflection basin testing, (c) DCP tests of the base and subgrade, and (d) drilling cores. The appropriate input parameters were then determined for each of the LTPP and non-LTPP sites based on the field laboratory testing data. A final set of MEPDG input parameters and field and laboratory testing data were received in April, 2016. The following describes the data included in the data set.

- Distress surveys were conducted in accordance with the LTPP Distress Identification Manual (*FHWA 2003*) to identify the severity level and extent of distresses observed on each sites. It is noted that there were typically more than one LTPP survey on each LTPP site. However, they were conducted in earlier years when the distresses were limited. The distress data were carefully reviewed, and the data with an irregular trend were removed from the calibration. For non-LTPP sites, there was only one survey conducted in 2014. However, the amount of cracking on non-LTPP sites was much higher than the one on LTPP sites. In addition, some PACES data on non-LTPP sites were converted into the distresses defined in the LTPP (*FHWA 2003*) and used in the calibration.
- FWD deflection basin measurements were made every 50-feet in the outside wheel path for each non-LTPP site; the data was stored in a proprietary format (.F25)
- A total of nine cores were taken on each non-LTPP site. Three cores were taken in distressed areas directly over the cracks to determine whether the cracks initiated from the top or bottom of the HMA layers. The other six cores were taken randomly in areas without distresses. Individual layer thicknesses were measured from the cores in the lab. The bulk specific gravity of each layer was measured in accordance with AASHTO T 166, “Bulk Specific Gravity (Gmb) of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens.” The maximum specific gravity of each layer was measured in accordance with AASHTO T 209: “Theoretical Maximum Specific Gravity

(Gmm) and Density of Hot Mix Asphalt (HMA)." The asphalt concrete content was measured for selected layers near the bottom of the pavement. The bulk specific gravity and maximum specific gravity of each layer were listed in an Excel sheet.

- DCP measurements were performed and recorded at three core holes on each non-LTPP site. The DCP penetration rates (mm/blow) were then used to estimate the in-place resilient modulus for the unbound layers using Equation (1), which was developed by ARA (ARA, 2015a). The raw data such as penetration and calculated resilient modulus were stored in an Excel sheet.

$$Relilient\ modulus = 0.145 * 17.6 * \left(\frac{292}{Penetration_{Rate}{}^{1.12}}\right)^{0.64} \quad (1)$$

- Pictures taken at the non-LTPP sites and cores were organized by site and included in the data set. It also included MEPDG files for all the GALTPP sites.

It is noted that these various field and laboratory testing data need to be integrated by site location). Thus, it is crucial to accurately record the site or location information. It is that GDOT's PDA-based core data collection application (*Wang and Tsai 2013*) be used for collecting coring data and photos on each site. In this way, coring location and photos were automatically tagged with x-y coordinates from the high-accuracy, built-in GPS. For the data, using a template, as shown in

Table 2.1, is suggested for recording the data with consistent location information for easy data integration. Columns 1-9 show the location information and Column 10 shows the data if collected in a proprietary format. This is especially important when the data is collected by different crews (or contractors) at different times.

Table 2.1 Example Template for Recording Data with Location Information

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Site ID	X	Y	County	Route No	Route Alias	Direction	Lane No	Milepoint	File
R1			Chatham	0405		Pos	2	8.1	.\\
R2			Camden	0405		Neg	2	20.1	.\\

2.2 Correction of Site Locations

The site locations (x-y coordinates) were verified to ensure the sites can be located correctly for conducting long-term performance monitoring. This is especially important for the non-LTPP sites that do not have any signage to indicate site locations. The site locations were verified by comparing them to the core locations recorded using GDOT’s core data collection application that runs on a GPS-enabled PDA (*Wang & Tsai 2013*). Figure 2.1 shows all the non-LTPP sites for flexible pavements and the core locations. It was found that the site locations don’t match the core locations; that is, the sites were outside the area where the cores were taken for the specific site. It was determined that the core locations recorded by GPS are more accurate than the site locations included in a previous study (*ARA 2015a*). For example, the flexible pavement site on I-85 was found wrongly located near Milepost 66 on concrete pavement based on the site location data; however, the cores were correctly located near Milepost 68 on asphalt pavement using the location data recorded by GPS, as shown in Figure 2.2. Therefore, the site locations were corrected using the first core located in the travel direction. In addition, the locations were processed to obtain the route and milepoint information using GDOT’s linear reference system (LRS). The corrected site location information is listed in Appendix I. It is noted that the research team obtained core location information for twenty sites. Core information for the remaining sites will be requested and obtained to verify the locations for these sites.

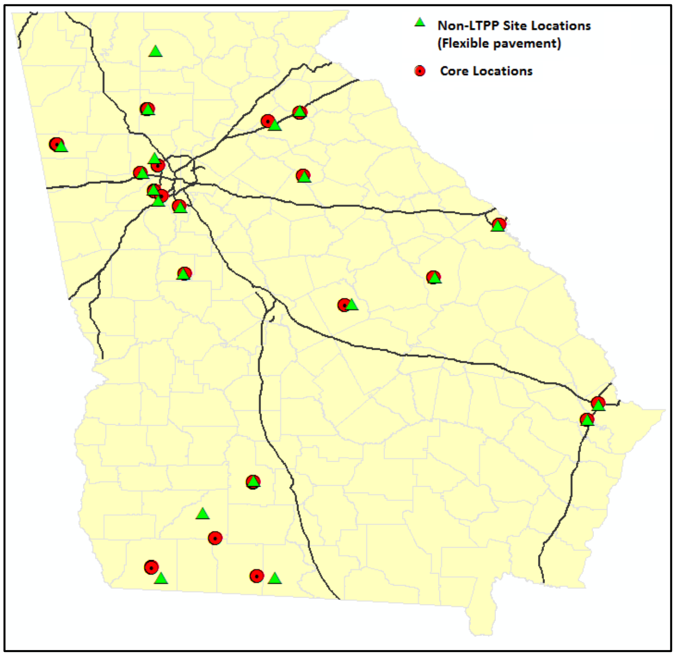
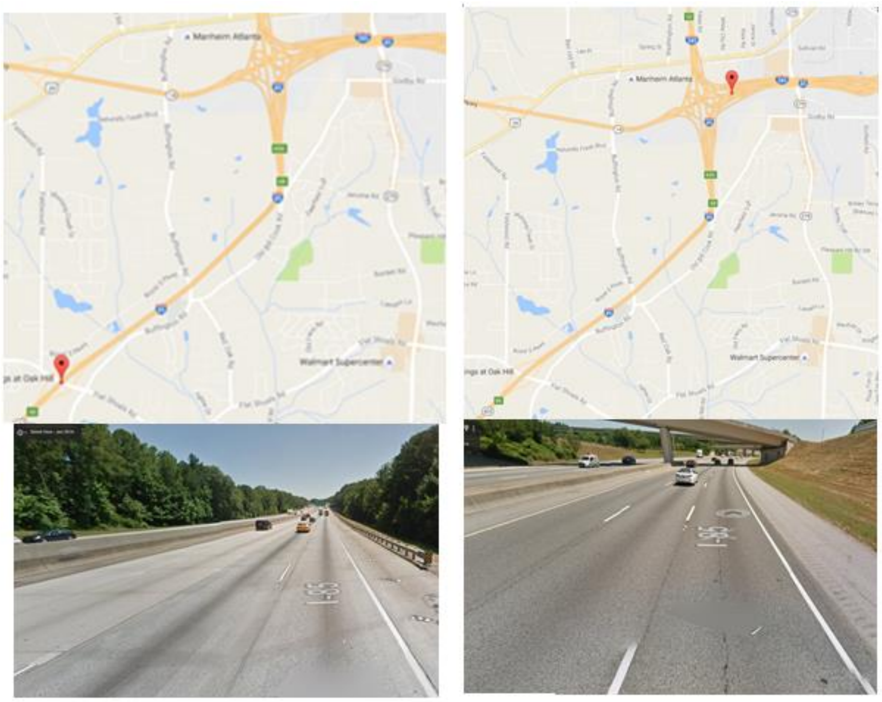


Figure 2.1 Site and Core Locations



(a) Site location (b) Core location(s)

Figure 2.2 Verification of Site Location (I-85 site)

2.3 Design of GALTPP Database

A database is needed to store and organize various data collected for the GALTPP program and to manage the data efficiently. This database will serve as a centralized source of the GALTPP data to be used for studying the effects of different pavement designs, materials, etc., on pavement performance. To take advantage of information technologies, a relational database (GALTPP database) with location reference information was designed to house the MEPDG input parameters used in the calibration, the field and laboratory testing data collected on the GALTPP sites, and other information gathered on the sites. With the location reference information, the GALTPP database can be readily tied into a GIS platform for visualizing the data on a map and performing spatial query. The current GALTPP database was developed using the geopersonal database in ArcGIS for its easy access and GIS integration functions. The database will be enhanced throughout the course of this project based on GDOT's comments; the final version can be created in an enterprise database (e.g., Oracle database or SQL server) based on GDOT's requirements. The design of the GALTPP database involved identifying data elements to be stored, designing a database architecture that relates foreign and primary keys and table structures, and designing location reference information to be used in the GALPP database. Figure 2.3 illustrates the high-level conceptual design of the GALTPP database. The GALTPP database is the central place for storing data on both LTPP sites and non-LTPP sites. Although the distress data collected based on both LTPP and PACES protocols can be available on a site, the performance data stored the GALTPP database followed the LTPP format. A conversion between LTPP and PACES distresses was recommended in Georgia's MEPDG User Guide (*ARA, 2015b*). In addition, the GALTPP database is not intended to duplicate the completed LTPP database or the existing GDOT PACES database; instead, it was designed for easy access and management of the MEPDG input parameters used in the calibration and the field and laboratory testing data collected on the GALTPP sites. The data to be stored in the GALTPP database can be primarily organized into eight different categories; (1) site information, (2) pavement structures, (3) pavement performance, (4) traffic, (5) material properties, (6) environment (or climate), (7) testing data, and (8) files to cover various data collected on the GALTPP sites. The data to be stored in each category were briefly described in this section. Appendix II provides a tabular listing of the tables in the GALTPP database.

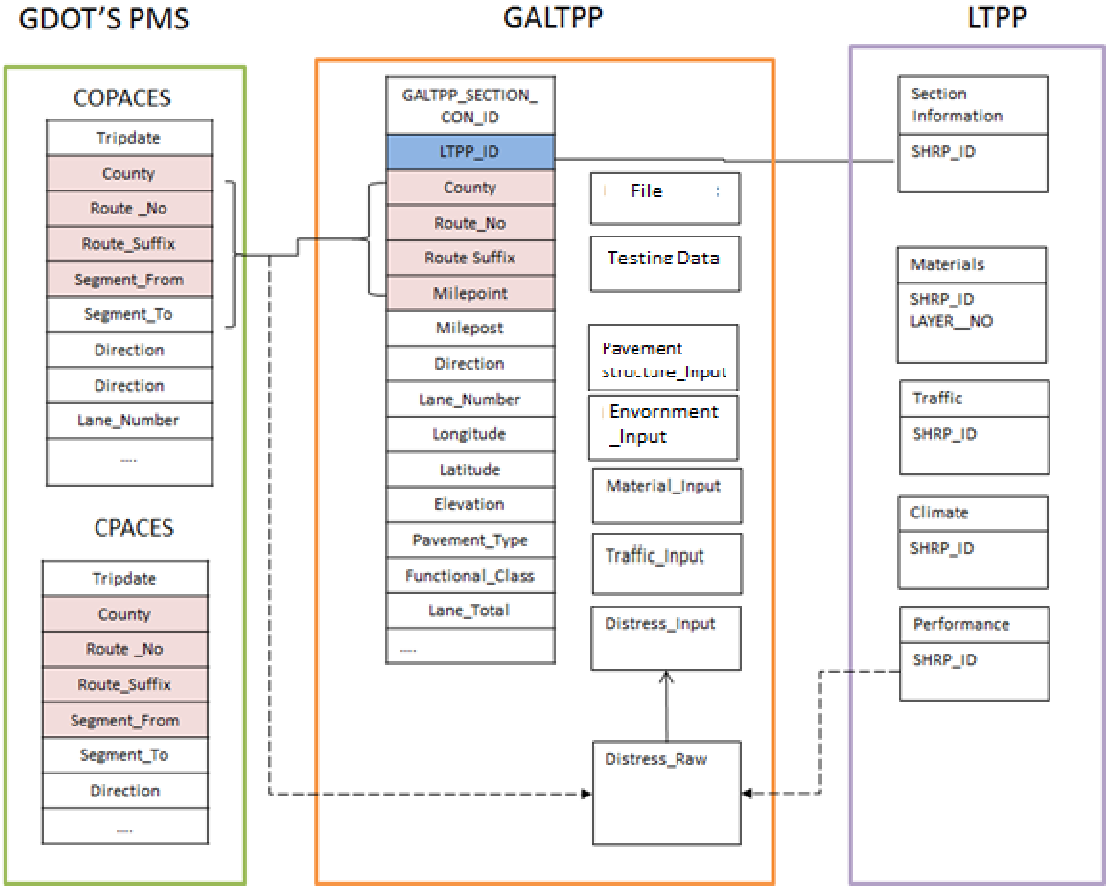


Figure 2.3 Conceptual Design for GALTPP Database

- Site information

  The site information table contains the location reference information. The table contains both x-y coordinates (Columns 2 and 3 in Table 2.1) and GDOT's Road Characteristic Link (RCLINK) (Columns 4 to 9 in Table 2.1) for identifying site location. RCLINK (defined using county, route type, route number, route suffix) is a unique identifier for a route. Each RCLINK typically begins with zero in its linear measure (e.g., milepoint). This means for the same route the milepoint is reset to zero at the county boundary. RCLINK along with milepoint(s) can be used to identify the location of a point or linear event on a route. In addition to location information, data such as functional class and number of lanes are also stored in the table. A unique identifier (e.g., site_ID) was assigned to each individual GALTPP site. For LTPP sites, the SHRP_ID is used; for non-LTPP sites, a unique ID is assigned.

- Pavement structures

  Pavement structure data, including total number of layers, layer number, layer type, and layer thickness, were stored in a table. It is noted that for calibration purposes, a site can be used as a new pavement structure at the beginning and later as a rehabilitated pavement structure after a treatment is applied on it. Any construction-related change to the pavement structures is recorded by defining a new identifier for the construction (e.g., construction ID) in the table. Thus, site_ID alone cannot uniquely identify a pavement structure on a site. Instead, the combination of site_ID and construction_ID must be used to identify a pavement structure on a site.

- Pavement performance

  Distress data is stored in a format that is similar to the one in the LTPP database. It is noted that not all distress data can be used for a MEPDG calibration. The distress data with irregular trends were considered as outliers, and were excluded when calibrating any MEPDG prediction model. For example, the decrease of distresses without proper treatment was considered unreliable and was not used in the calibration. Therefore, a field is designed in the table to indicate whether or not the observed distresses can be used in a calibration.

- Traffic

  Tables were designed to store traffic data on each site, including AADTT, growth rate, vehicle class distribution, etc.

- Material properties

  Tables were designed to store the material properties for each layer, including aggregate gradation for asphalt mix, effective binder content, air voids (at time of construction), total unit weight, asphalt binder data, etc. These tables typically include a layer number to identify the material properties for each layer.

- Environment (or climate)

  A table was designed to store environmental/climatic factors used in the MEPDG, including elevation, weather station, and groundwater depth.

- Testing data

  Field and laboratory testing data, such as DCP, bulk specific gravity, and maximum specific gravity, were stored in different tables. It is noted that the data stored in these tables are considered raw data and are not necessarily the same as the MEPDG input parameters.

- Files

  Tables in this category were designed to provide a link to the documentation (e.g., pdf file), images, and data collected in a proprietary format (e.g., FWD file). Instead of storing these files in the database, workspaces were designed to house electronic files, such as the as-built plans, the construction records, the FWD files, etc.; tables were designed to store the file path for retrieving the files. These tables typically contain site ID, date of data collected, file type, file path, and x-y coordinates (if available).

2.4 Visualization of GALTPP Data in a GIS Project

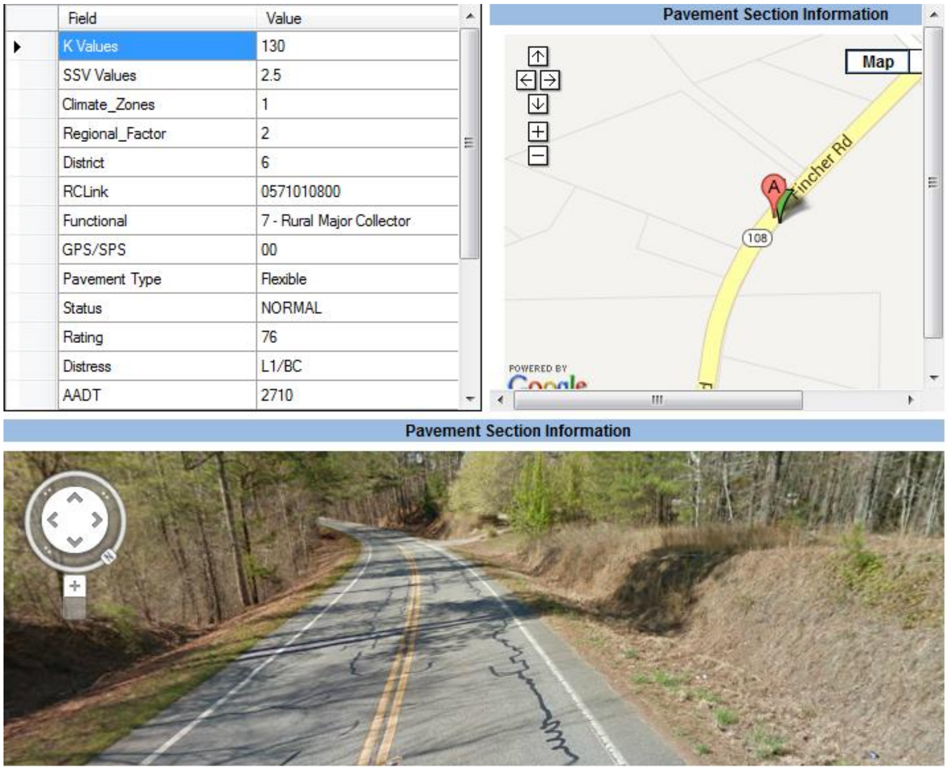
With the location references, a GIS project was developed using ArcMap to allow the users 1) to visualize the geographic distribution of candidate sites, and 2) to integrate with the data from other sources. The use of GIS allows GDOT to facilitate the coordination among GDOT's offices. The functions in the GIS project are described in the cases below:

- Case 1: Visualize GALTPP sites

  Using GDOT's LRS and the dynamic segmentation function in GIS, GALTPP sites were spatially integrated onto a map with other data, such as the pavement design data and soil data. GDOT's engineers can navigate the map to visualize information on the map, as shown in Figure 2.4. With their knowledge of Georgia's soil, weather, and pavement conditions, they can effectively identify any issue in the geographic distribution of the GALTPP sites. For example, the distribution of the sites in northern and southern Georgia may be a concern for the GALTPP sites because of the significant differences in the geologic conditions. In addition, a cluster of the sites in certain areas (e.g., in one district) can be identified effectively using visualization.

- Case 2: Facilitate the communication among different offices

  Coordination among GDOT's offices is crucial for maintaining the GALTPP sites in the long-term. Especially, some of the sites will be resurfaced in the near future, and these activities should be coordinated between the Office of Research, the Office of Materials and Testing, and the Office of Maintenance. A pavement condition evaluation can be planned before maintenance and rehabilitation activity, and the maintenance record can be gathered and recorded in the GALTPP program. Currently, the Office of Maintenance can output the planned resurfacing projects in an Excel format using GDOT's PMS. This file can be sent to the Office of Research and with the location information (county, route number, route suffix, milepoint from, and milepoint to) the planned resurfacing projects can be mapped using the GIS project to identify the GALTPP sites that will be resurfaced. The Office of Research, the Office of Materials and Testing, and the Office of Maintenance can coordinate on the data to be collected on the GALTPP site(s) before being resurfaced and other activities.



Field	Value
K Values	130
SSV Values	2.5
Climate_Zones	1
Regional_Factor	2
District	6
RCLink	0571010800
Functional	7 - Rural Major Collector
GPS/SPS	00
Pavement Type	Flexible
Status	NORMAL
Rating	76
Distress	L1/BC
AADT	2710

Figure 2.4 An example of visualizing data in GIS

3. PAVEMENT DESIGN, MAINTENANCE PRACTICES, AND PERFORMANCE OF GEGORIA'S INSTERSTATE HIGHWAYS

Interstate highways account for a major part of the capital investment in the transportation infrastructure. The decisions on interstate pavement structure design, maintenance, and rehabilitation have a great financial impact. Thus, GDOT's GALTPP Task Force set the focus in the Phase 1 of this project to evaluate the feasibility of designing Georgia's interstate pavement structures using the MEPDG to provide inputs on the MEPDG implementation. This chapter briefly describes pavement structure design and maintenance practices currently used on Georgia's interstate highways. In addition, the predominant distresses on interstate highways were reviewed base on GDOT's pavement condition evaluation data collected in FY 2015 to identify the performance indicator(s) needed on interstate highways.

3.1 Pavement Design and Maintenance Practices

Georgia's interstate highways have commonly been constructed with four different asphalt concrete layers, a 0.875 – 1.25-in.porous friction course; a 1.5-in. 12.5-mm SMA; a 2-in.19-mm binder layer, and a 4-10 in. 25-mm base layer on the top of graded aggregate base (GAB). Figure 3.1 shows the current typical pavement structure design for Georgia's interstate highways. The use of porous friction course and SMA is a somewhat unique design, and it provides safety during wet weather and durable pavements under heavy traffic volume.

GDOT's use of porous friction course (e.g., D mix) dates back to the 1970s. Porous asphalt layers have a high air void content (10-20%), which allows rapid removal of surface water in light to moderate rain through the pores. Thus, it has been used to enhance safety on the roadways during wet weather, such as reducing splash and spray, improving visibility of traffic stripes, etc. Since the 1990s, GDOT started using OGFC and PEM, which include stabilizing fibers and polymer modified asphalts (PMA) and perform better than D mix. SMA is a gap graded mix with a high concentration of course aggregates that increase stone-to-stone contact, create a more efficient network for load distribution, and make it a good choice of mix for high-volume roadways. The stone-to-stone skeleton held together by rich asphalt cement is the key to its ability to withstand rutting and fatigue cracking. GDOT became interested in the use of SMA after the European Asphalt Study Tour of 1990 because of SMA's potential durability improvements (*Watson et al. 1995*); GDOT began researching the viability of using SMA in Georgia in 1990. Test sites were built on I-85 in 1991 to evaluate the performance of SMA; studies were also conducted to determine optimized SMA mix design (*Watson et al. 1995; Barksdale 1995; Jared 1997a and 1997*). Based on previous studies (*Jared 1997a and 1997b*), SMA is expected to have 30-40% less rutting, a 30-40% longer fatigue life, and a lower annualized cost than standard mixes. Since the 1990s, a 1.5-in of SMA has been used on interstates due to the high traffic volumes that interstates in Georgia carry.

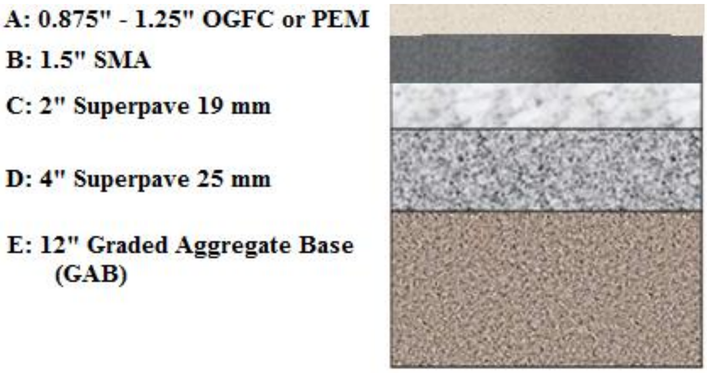


Figure 3.1 Typical pavement design in Georgia's interstate highways

GDOT has had an active resurfacing program since the 1980s. The resurfacing program focuses on the use of thin-resurfacing (1.5 in.) to replace a worn-out surface layer at the right time to prolong pavement life. Based on GDOT's experiences, the porous friction course typically wears out after 10 to 12 years, while the underlying SMA layer is still sound. Prior to 2007, the common practice for replacing the worn-out open-graded layer was to mill and replace this layer together with the underlying 1.5 in of SMA using conventional milling (*Lai et al., 2012; Tsai et al., 2014; Tsai et al., 2015*). Milling and replacing only the porous friction course (0.875 – 1.25 in. of OGFC or PEM) using conventional milling was not considered because of the concern about placing such a thin, open-graded mix on the resulting surface texture from conventional milling. With conventional milling, the ridge-to-valley depth (RVD) caused by the milling teeth can be 0.25 in. or greater. Placing the open-graded mix on this irregular surface concerned GDOT about the improper channelization of water and insufficient bonding between the coarser aggregate used in the open-graded mix and the milled surface. The purpose of milling and replacement of a1.5-in. of sound SMA layer, in addition to the worn-out porous friction course, is to 1) provide good bonding between the open-graded surface layer and the rough milled surface and 2) reduce the potential for water entrapment in the valleys created by the milling head teeth in the rough milled surface texture. In 2007, GDOT developed a new, cost-effective method (micro-milling and thin-overlay operation) to replace only the porous friction course directly over the micro-milled surface without removing the sound underlying layer (*Lai et al., 2012; Tsai et al., 2015*). With the new method, GDOT's maintenance practices have been changed to utilize the new method to replace only the worn-out OGFC or PEM when the underlying SMA is still sound. In addition, the 2 in. of SMA is expected to withstand the micro-milling operation and provide sufficient structure capacity. As shown in Figure 3.2, the OGFC is expected to be replaced in 10-12 years. With the use of micro-milling and thin-overlay, only the OGFC layer will be replaced directly on the top of SMA layer. As the OGFC deteriorates in another 10-12 years, both the OGFC and SMA layers will be replaced. This provides a cost-effective approach to maintaining Georgia’s interstates.

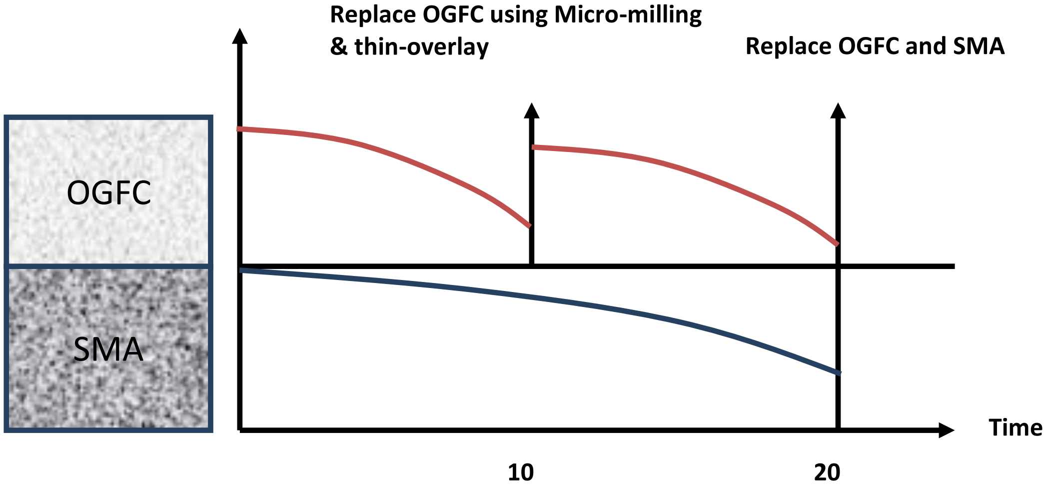


Figure 3.2 Interstate life-cycle maintenance activities

3.2 Predominant Distresses on Interstates

Since the 1980s, GDOT has been conducting an annual pavement condition evaluation of its 18,000-centerline miles of roadway based on its PACES. This section presents the predominant distresses recorded on interstate highways based on the PACES data collected in FY 2015. PACES surveys involve recording the severity and extent of various types of pavement surface distresses. They include rutting, load cracking, block cracking, reflective cracking, raveling, edge distress, bleeding/flushing, corrugation/pushing, loss of site, and potholes/patches/localized failure, as listed in Table 3.1 Distresses in PACESTable 3.1. It is noted that a walking survey is conducted for cracking; the survey is of a 100-foot representative sample location per mile-long segment. The distresses are recorded for each segment (which is about one mile long), then aggregated/averaged to obtain the representative pavement condition for a project (typically several miles long).

Table 3.1 Distresses in PACES

Distress	Unit	Severity	Sample Location
Load Cracking	%	1, 2, 3, 4	100-ft
Block Cracking	%	1, 2, 3	100-ft
Reflection Cracking	Number of cracks Length in foot	1, 2, 3	100-ft
Edge Distress	%	1, 2, 3	1-mie
Rutting	1/8 inch	-	100-ft
Patches/Potholes/Local failure	Number	-	1-mile
Bleeding	%	1, 2, 3	1-mile
Raveling	%	1, 2, 3	1-mile
Corrugation	%	1, 2, 3	1-mile
Loss of Site	%	1, 2, 3	1-mile

The distresses recorded at the segment level for the interstate highways in Georgia in FY 2015 were analyzed. The pavement distress evaluation is performed according to the GDOT's PACE protocol (*GDOT 1993*). There were a total of 1,495 interstate segments surveyed in FY 2015. Figure 3.3 shows the rating distribution for these segments. Of the segments, 88% of them had a rating greater than or equal to 70, and 12% of them had a rating less than 70. 3% of the segments had a rating less than 60.

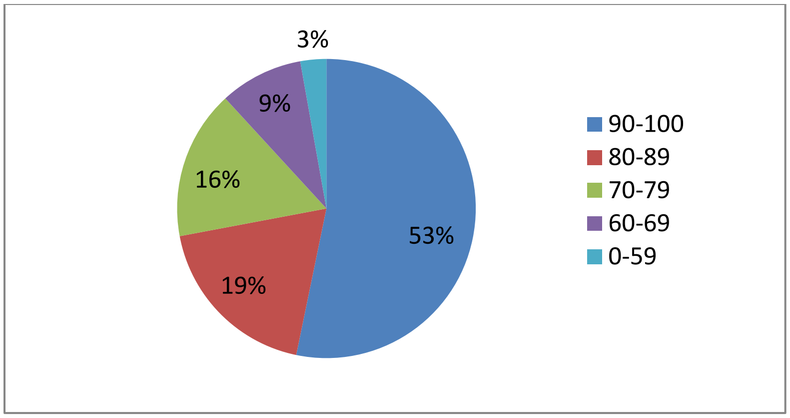


Figure 3.3 Interstate rating distribution (FY 2015)

Figure 3.4 shows the percent of segments for each type of distresses. Different colors are also used to highlight the percent of segments with different severity levels. It can be seen that rutting was the most commonly reported distress (46%) on interstates; however, it is not a concern from pavement maintenance point of view because the majority of the distresses were 1/8 in. (highlighted in green). There were 17% of segments with ¼ in of rutting (highlighted in blue), and only 1% of the segments had 3/8 in. of rutting (highlighted in red). Raveling was the second most frequently reported distress (41%) on interstates because of the use of porous friction course. It is also an important performance indicator for triggering maintenance needs because severe raveling raises safety concerns. A rapid deterioration of raveling in terms of its severity and extent was observed in the PACES data. In the current visual inspection, it was difficult to capture the early-stage raveling. Inconsistencies in the severity level and extent have been observed in the data. For example, some segments had Severity Level 2 raveling in one year, but they became severity level 1 in the following year. This makes it difficult to reliably determine the timing for preservation treatments (e.g., fog seal). In addition, raveling is currently not modeled in the MEPDG. Approximately 35% of the segments were reported with load cracking. The extents ranged from 2% to 100% with an average of 23%. It is noted that load cracking is defined as cracks in wheel paths within the 100-ft sample location. Studies (*Dauzats & Rampal, 1987; Craus et al., 1994; Uhlmeyer et al., 2000*) show that wheel path longitudinal and fatigue cracks in the thicker asphalt concrete pavements more often initiate from the top of the wearing course downward. Based on GDOT's experience, there has been limited bottom-up cracking observed on interstate highways. It is noted that cracks initiated with truck rim cut or at the open-graded course are also considered as load cracking, as shown in Figure 3.5. The scratches on the surface can develop into wide cracks because of the loose aggregates. Thus, the load cracking reported in PACES does not necessarily relate to the bottom-up cracking. They could be developed on the open-graded course only or into the SMA layer.

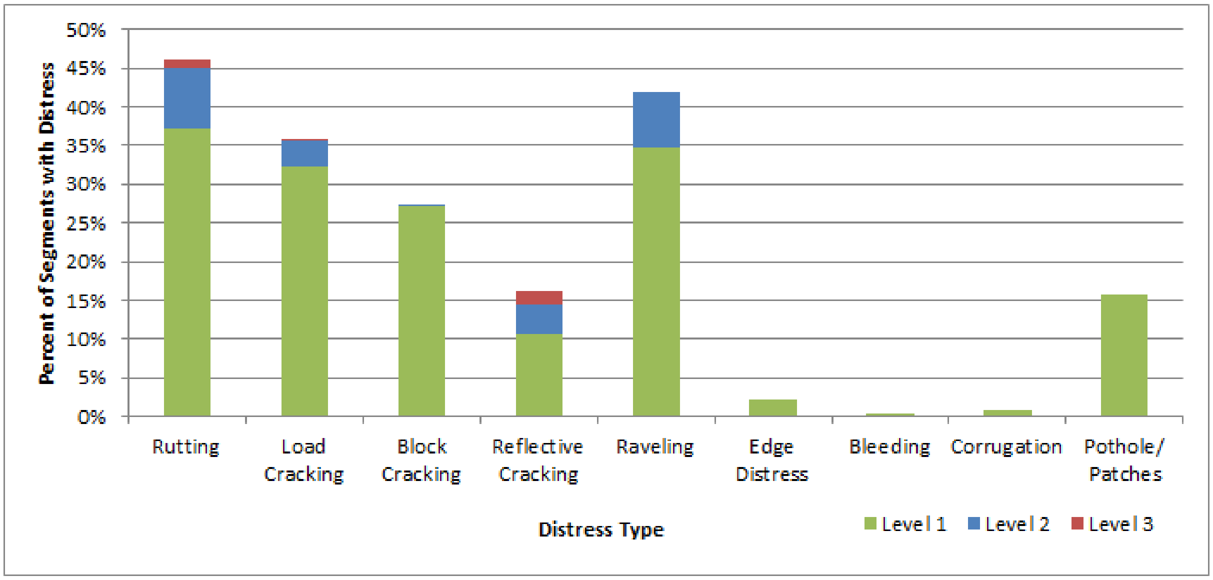


Figure 3.4 Interstate distresses frequency (FY 2015)

Figure 3.5 Photo taken on I-95 Northbound MP 13-14 Chatham County in 2014

Current 3D sensing technology has the unique capability to capture accurate raveling data on the surface of porous friction course. These data are invaluable for developing the raveling prediction model for Georgia's interstates. In addition, the technology can be used to detect cracking with location reference at different stages (prior to the micro-milling, after the micro-milling, and after resurfacing is performed) for assessing the development of top-down and bottom-up cracking. These data are also invaluable for studying the impact of the cracks on milled surfaces and the resurfacing performance, and for evaluating the effectiveness of the crack pre-treatments (such as cracking sealing). Figure 3.6 illustrates the use of 3D sensing technology for collecting and tracking (a) cracks on a raveled surface before micro-milling; (b) cracks on the micro-milled surface; and (c) the performance on the resurfaced surface.

(a) Before milling (b) After milling (c) After resurfacing

Figure 3.6 Photos taken on I-95 before and after resurfacing

In summary, raveling is the predominate distress on Georgia’s interstates with porous friction course, but the current MEPDG is not capable of predicting raveling. Therefore, developing a raveling prediction model and incorporating it into the life-cycle analysis of the interstate pavement structure design (for new and rehabilitated pavements) is important for GDOT. In addition, the current visual inspection cannot reliably quantify raveling to identify the timing for adequate treatment(s). Current 3D laser technology with high-resolution data covering a full lane-width has the unique capability to quantitatively and objectively measure raveling on the surface of porous friction course. In the meantime, it can also collect cracking data before and after micro-milling is performed on the porous friction course. These data are invaluable for developing a distress prediction models for this particular pavement type. Furthermore, it can potentially be used for assessing the development of top-down and bottom-up cracking on Georgia’s interstates.

4. EVALUATION OF DESIGN OF GEORGIA’S INTERSTATE PAVEMENT STRUCTURES USING DIFFERENT METHODS

Currently, GDOT designs its new and rehabilitated pavement structures in accordance with the 1972 Design Guide. It is an empirical method based on the AASHO Road Test equations that relate the loss in pavement serviceability to the pavement structures and load applications. While the 1972 Design Guide has been successful implemented for designing Georgia’s pavement structures, it is recognized that there exist some limitations, including limited traffic inputs, a limited number of pavement test sites, a limited set of materials, and one climatic condition. In addition, it is difficult to relate the design to its performance (e.g., surface distresses). On the other hand, the MEPDG, developed under the NCHRP Project 1-37A (*NCHRP 2000*), is considered a more advanced pavement design tool. With its basis in empirical performance calibrations and mechanistic principles, resulting designs are considered to produce improved thickness estimates over the traditional empirical designs. GDOT has calibrated the MEPDG performance prediction models to Georgia’s conditions and materials for flexible and rigid pavements using the sites in the GALTPP program. The calibration followed the procedure in the AASHTO MEPDG Local Calibration Guide (*NCHRP 2004*) to determine Georgia’s calibration coefficients for eliminating the bias in using the global coefficients and to improve the accuracy (i.e., reducing the standard error). A total of 38 sites (17 LTPP and 21 non-LTPP sites) were used for calibrating the flexible pavements. The standard errors of the estimate for fatigue cracking and rutting are 5.8% and 0.105 in., respectively. These values are comparable with the ones reported in the global calibration and suggested in the local calibration guide (*NCHRP 2004*).

This chapter first reviews the distresses observed on interstate sites and compares them to the distresses predicted by the MEPDG to verify the accuracy of using the MEPDG performance prediction models on interstate sites. Second, a case study was conducted on a site on I-95 in Chatham County to analyze the pavement structures using different methods (1972 Design Guide and the MEPDG) to provide insight into the differences and their implications. Finally, the characterization of SMA in the MEPDG is discussed.

Table 4.1 Georgia's Calibration Coefficients

	Transfer Function Coefficient	**Global Value**	**GDOT Value**	
			Neat[1] Mixtures	**PMA[2] Mixtures**
AC Rutting	K1	-3.35412	-2.45	-2.55
	K2	1.5606	1.5606[3]	1.5606[3]
	K3	0.4791	0.30	0.30
Subgrade Rutting	Coarse-Grained, Bs1	1.0	0.50	
	Fine-Grained, Bs1	1.0	0.30	
AC Fatigue Cracking	K1	0.007566	0.000653	0.00151
	K2	3.9492	3.9492[3]	
	K3	1.281	1.281[3]	
Bottom-up Cracking	C1	1.0	2.2	
	C2	1.0	2.2	
	C3	6,000	6,000[3]	
Top-down Cracking	C1	7	7[3]	
	C2	3.5	3.5[3]	
	C3	0	0[3]	
Thermal Cracking	Bt1	1.5	35	45
	Bt3	1.5	35	45

1. Unmodified HMA mixtures
2. Polymer Modified Asphalt mixtures
3. Use global values

4.1 Review of MEPDG Predicted Distresses on Interstate Sites

A total of 38 sites were used for calibrating Georgia's transfer coefficients for flexible pavements. Among the 38 sites, five sites were on interstate highways. Figure 4.1 shows these five sites: three sites on I-95, one site on I-85, and one site on I-520. These five sites include both new pavement design and overlay design. It is noted that these sites were built prior to 1996 (three sites were built in the 1970s and two sites in the early 1990s); SMA mixtures were not used on these sites. Therefore, they may not represent the actual performance of interstate pavements built with the recent pavement materials (e.g., SMA). This means additional interstate sites can be included to monitor the performance of SMA on Georgia interstate highways and to be considered in the calibration of coefficients for PMA mixtures..

Table 4.2 lists the pavement design of these five sites. It is noted that when the overlay design is modeled in the MEPDG, a 0% fatigue cracking was assumed on the existing milled pavement surface. This implies the underlying layers are sound without bottom-up or top-down cracking.

Figure 4.1 GALTPP sites

Table 4.2 Interstate Sites

Site ID	4112	4113	F9	F12	F19
Route	I-95	I-95	I-85	I-95	I-520
County	Camden	Camden	Fulton	Chatham	Richmond
Construction Year	1977	1977	-	1994	1995
Pavement Design	Dense Graded HMA (3.1”)	Dense Graded HMA (3.6”)	-	Porous friction layer (0.75”)	Dense Graded HMA, Type E (1.5”)
	Dense Graded HMA Base (12.7”)	Asphalt Stabilized/Treated Base (11.5”)		Dense Graded HMA, Type D (1.5”)	Dense Graded HMA, Type B (2”)
	Poorly Graded Sand; A-3	Poorly Graded Sand with Silt; A-3		Dense Graded HMA Base (6”)	Dense Graded HMA, Type C (4”)
				Granular Aggregate Base (14”)	Granular Aggregate Base (12”)
				Silty and Sandy Clay, A-2-4	
Overlay Year	1998	1998	2002	2002	-
Overlay Design	Dense Graded HMA (1.8”)	Dense Graded HMA (1.8”)	Open Graded Friction Course (1.7”)	Porous friction layer	
			Dense Graded SMA with RAP, PG 76-22 (1.4”)	Dense Graded HMA, SMA (1.5”)	
			Milling to remove existing HMA surface	Dense Graded HMA, Type D (2.25”)	
			Dense Graded HMA (1.4”)		
			Dense Graded HMA (1.6”)		
			Dense Graded HMA Base (8”)		
			Granular Aggregate Base (12”)		
			Clayey Silt		

4.1.1 Observed Distresses

This section presents the observed distresses on the interstate sites based on the data used to calibrate Georgia’s coefficients (*ARA 2015b*). Figure 4.2 shows the measured fatigue cracking on all of the 38 flexible pavement sites with the interstate sites highlighted in red. It is noted that the magnitudes of the cracking occurring on the interstate and non-interstate sites are different. Compared to the non-interstate sites, the interstate sites exhibited less fatigue cracking. Less than 3% of fatigue cracking were recorded on the interstate sites, except for the site on I-520, which has less than 10 in. of AC. It is noted that other than the LTPP sites, most of the non-LTPP sites were resurfaced approximately every 11.6 years (*Tsai, 2015*)**.** Thus, there were fewer cracks recorded with an age greater than 11.6 years. The resurfacing would remove distresses (e.g., cracking and rutting) on the surface layer, which makes it difficult to accumulate cracking data. It is noted that there were cracks recorded with an age greater than 15 years. This means these sites had not been resurfaced in more than 15 years, which is much longer than GDOT’s average resurfacing years (*Tsai, 2015*). In addition, some interstate sites show almost no cracking after more than 15 years. These sites should be further investigated to verify if resurfacing was indeed applied after more than 15 years and to study the factors (e.g., preventive treatment) that led to their long longevity.

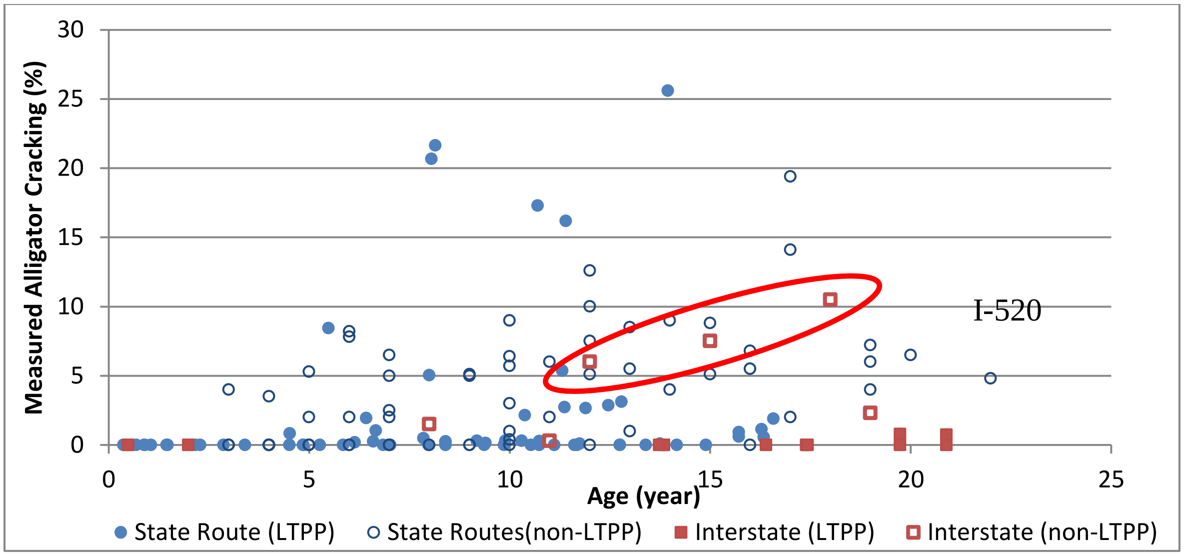


Figure 4.2 Measured fatigue cracking

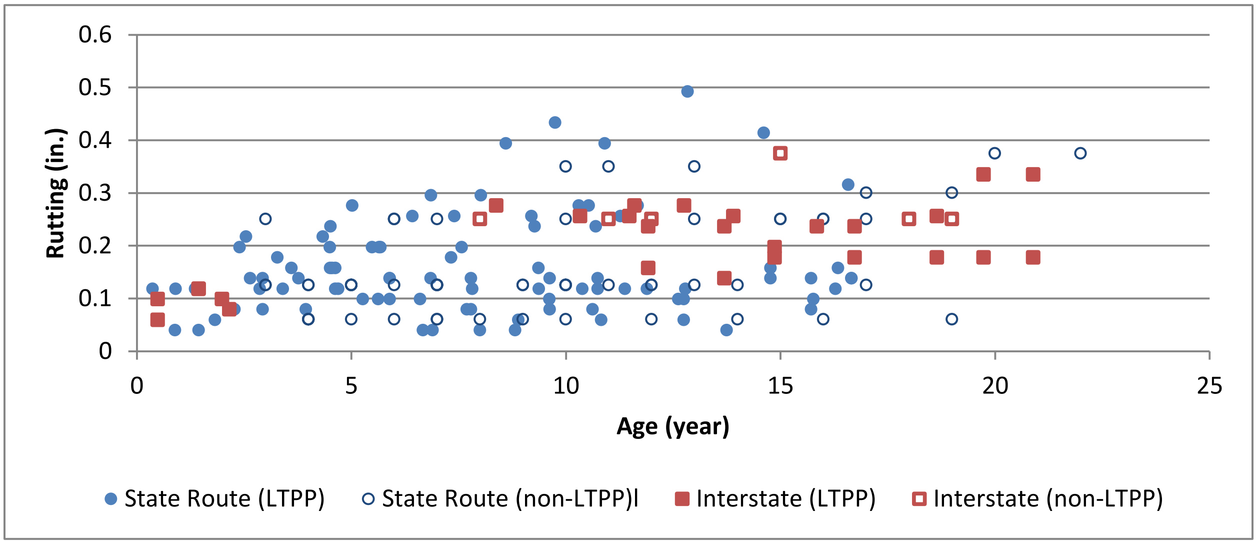


Figure 4.3 shows the measured rutting. Most of the measured rutting was between 0.05 in. and 0.35 in. Compared to the other non-interstate sites, the interstate sites exhibited moderate rutting (between 0.1in. and 0.3 in.).

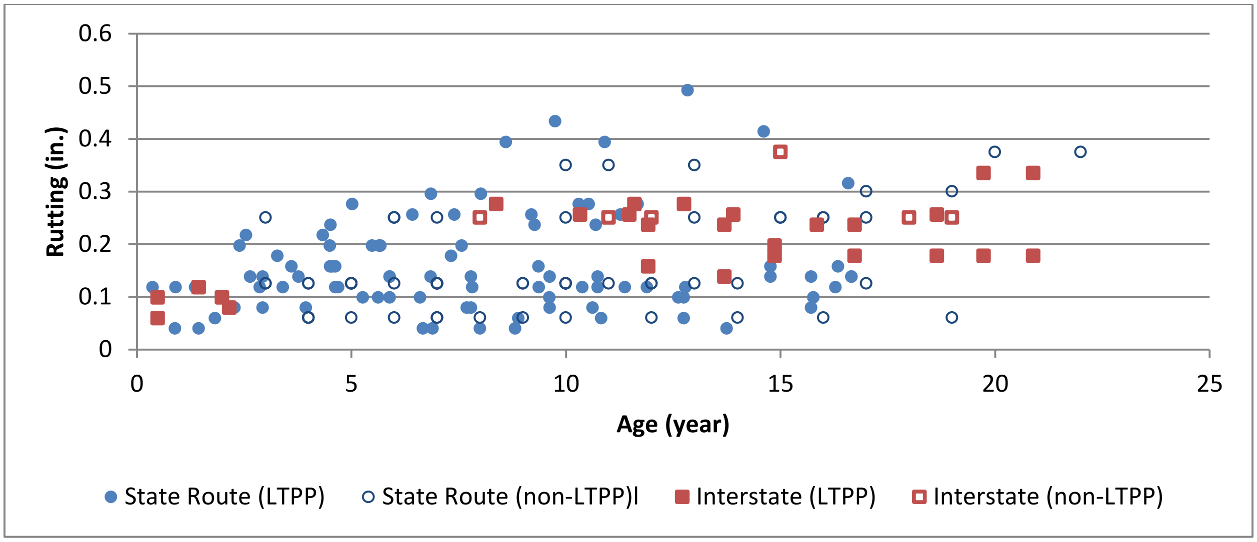


Figure 4.3 Measured rutting

Figure 4.4 shows the measured non-wheel path longitudinal cracking. There is dispersion in the non-wheel path longitudinal cracking with a range from 0 to 12,000 ft/mile among the 38 sites. The interstate sites, in general, exhibited minimum non-wheel path longitudinal cracking. Non-wheel path longitudinal cracking was observed on the sites on I-520 in Richmond County and I-95 in Chatham County. Again, some interstate sites show minimum longitudinal cracking after more than 15 years of service. These sites should be further investigated to verify if resurfacing was applied after more than 15 years and to study the factors that contribute to their long longevity.

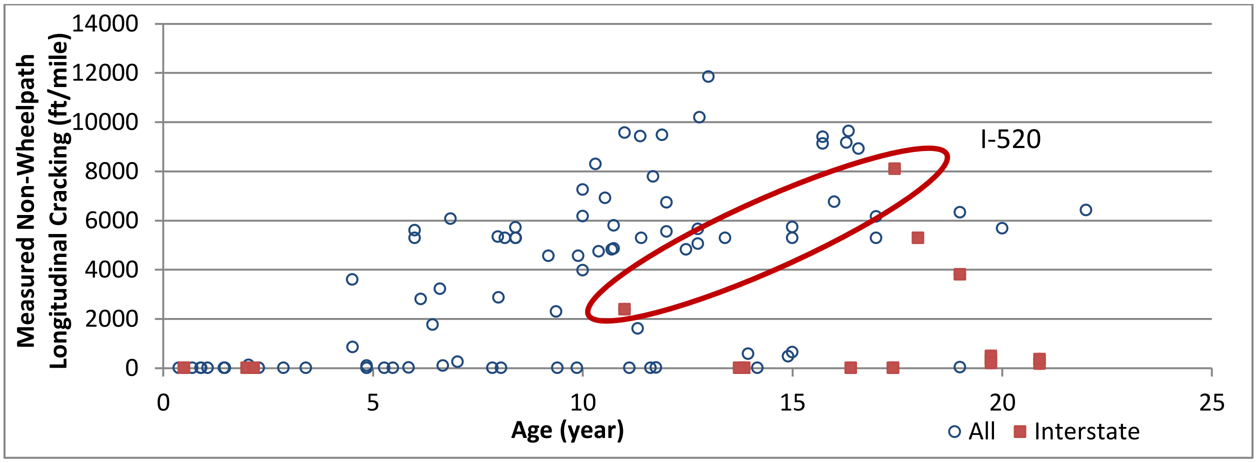
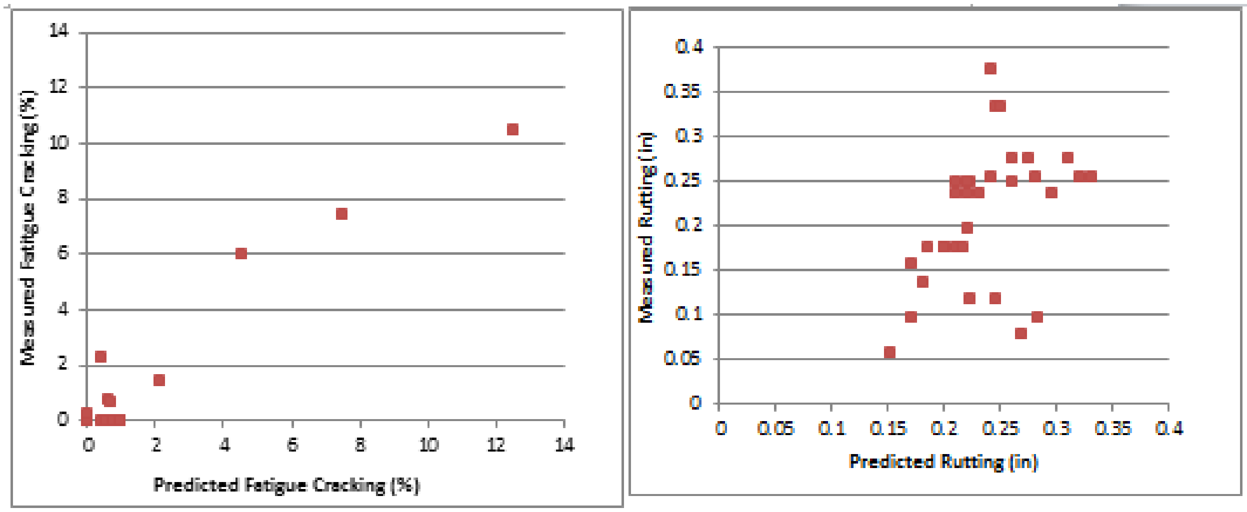


Figure 4.4 Measured longitudinal cracking (non-wheel path)

4.1.2 Predicted Distresses

This section compares the predicted and measured distresses on the interstate sites to verify the accuracy of the prediction models. Figure 4.5(a) shows the measured and predicted (at 50% reliability) fatigue cracking based on the data used in the calibration (*ARA 2015a*). The prediction is unbiased and reasonable with the data scattered around the equality line. Most of the measured and observed fatigue cracking was less than 2%. The only site with more fatigue cracking is on I-520. It is noted that for this site there was inconsistently in the predicted cracking reported in the study (ARA 2015a) and in the MEPDG file. While a 12.6% of the predicted fatigue was reported in the study, the MEPDG file output a lower cracking (3%). The MEPDG inputs and outputs should be further checked for future recalibration. Figure 4.5(b) shows the measured and predicted rutting on the interstate sites. Again, the data scattered around the equality line and the prediction was reasonable.



(a) Fatigue cracking (b) Rutting

Figure 4.5 Measured vs. Predicted distresses (based on the data submitted by the ARA, ARA 2015b)

4.2 Case Study on I-95 Site in Chatham County

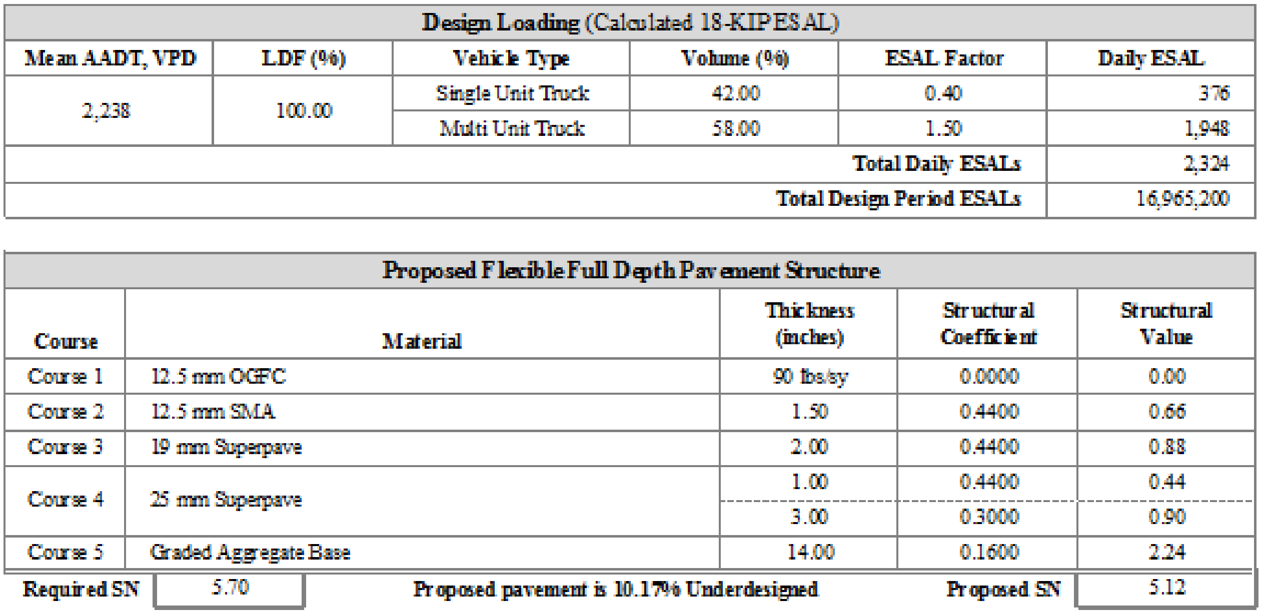
This section analyzes a typical interstate pavement structure designed in accordance with GDOT's current design procedures using the 1972 Design Guide and the MEPDG to provide some insight into the differences and their implications. The non-LTPP site on I-95 in Chatham County was selected as representative of GDOT's interstate pavement design (with four asphalt layers, OGFC, SMA, 19-mm binder layer, and 25-mm base layer on top of GAB). First, the pavement structures (e.g., as-built thickness) and actual traffic data collected on this section were analyzed using GDOT's pavement design tool, which was developed based on the 1972 Design Guide, to evaluate the design. Second, using the same data and the Georgia-calibrated distress transfer functions, the design was evaluated using the MEPDG. Finally, the optimized design to achieve the specified performance criteria suggested in GDOT's user guide was obtained using the new AASHTO Pavement ME Design® software and compared to the current design.

The site on I-95 in Chatham County was originally constructed in 1964 with a 10 in., non-doweled jointed plain concrete pavement (JPCP) having a 30-ft joint spacing; it was later widened and overlaid using asphaltic concrete. In 1994, this section was widened with 8.5 in.of asphalt concrete layer on top of a 14 in. GAB. The top four layers were a 7/8 in. of open-graded layer (asphaltic concrete "D"), a 1.5 in. of dense-graded layer (asphaltic concrete "E"), a 2 in. of asphaltic concrete "B" (19 mm), and a 4 in. of 25-mm base layer, as shown in Figure 4.6. This section was resurfaced in 2002 to replace the open-graded layer. Since then, it has carried about 10 million heavy trucks over a 14-year time period. The one-way AADTT was 2,425 on the 6-lane roadway (3 lanes in each direction), and the AADTT grew at a linear rate of 4.2%. The subgrade was found to be an AASHTO A-2-4 soil with a resilient modulus of 16,500 psi based on the value used in the calibration.

Figure 4.6 Pavement Structure on I-95 Site in Chatham County

4.2.1 Analysis Using 1972 AASHTO Interim Design Guide

In this section, the pavement structures and the traffic data on the selected site were analyzed using GDOT’s pavement design tool, which is based on the 1972 Design Guide. The default soil support value (4) and regional factor (1.7) for Chatham County were used in the analysis. The percentages of single and multiple units were calculated based on the vehicle classification distribution of this section; the default single unit ESAL factor (0.4) and multiple unit ESAL factor (1.5) were used to calculate the design ESALs. Figure 4.7 shows the pavement design analysis generated by using GDOT’s pavement design tool. To carry the 16.2 million heavy trucks for a 20-year design life, the required structure number is 5.70. The structure number based on the pavement structures on I-95 site is 5.12; thus, it was under-designed by 10.17%. It reached the required structure number at 8 million heavy trucks. To carry 16.2 million heavy trucks, the current pavement structure needs an additional 2 in. of asphalt concrete layer.



Design Loading (Calculated 18-KIP ESAL)					
Mean AADT, VPD	LDF (%)	Vehicle Type	Volume (%)	ESAL Factor	Daily ESAL
2,238	100.00	Single Unit Truck	42.00	0.40	376
		Multi Unit Truck	58.00	1.50	1,948
				Total Daily ESALs	2,324
				Total Design Period ESALs	16,965,200

Proposed Flexible Full Depth Pavement Structure				
Course	Material	Thickness (inches)	Structural Coefficient	Structural Value
Course 1	12.5 mm OGFC	90 lbs/sy	0.0000	0.00
Course 2	12.5 mm SMA	1.50	0.4400	0.66
Course 3	19 mm Superpave	2.00	0.4400	0.88
Course 4	25 mm Superpave	1.00	0.4400	0.44
		3.00	0.3000	0.90
Course 5	Graded Aggregate Base	14.00	0.1600	2.24
Required SN	5.70	Proposed pavement is 10.17% Underdesigned	Proposed SN	5.12

Figure 4.7 Pavement structure analysis using 1972 AASHTO Interim Design Guide

4.2.2 Analysis Using MEPDG

The same pavement structure was analyzed using the MEPDG with Georgia's coefficients (*ARA 2015a*). As shown in Figure 4.8, this pavement structure can meet the performance criteria; all the predicted distresses at the specified reliability were lower than the threshold values at the end of the 20-year design life with accumulated 16 million heavy trucks. It is noted that a 95% reliability is used for fatigue cracking and rutting, as suggested in GDOT's user guide. When 50% reliability was used, the predicted distresses were much lower (0.25 in. of rutting, 0.62% of fatigue cracking). When the reliability increased from 50% to 95%, the predicted fatigue cracking significantly increased from 0.62% to 8.61%. This means the selection of reliability level has a big impact on the distress threshold values, which determines whether or not the pavement structure design passes the criteria. At 95% reliability, the MEPDG predicted an 8.61% of fatigue cracking, 0.35 in. of rutting, and 802 ft/mile of thermal cracking at the end of

20 years. The pavement structure can last longer than 20 years and can reach the performance criteria in 21 years with 16 million heavy trucks.

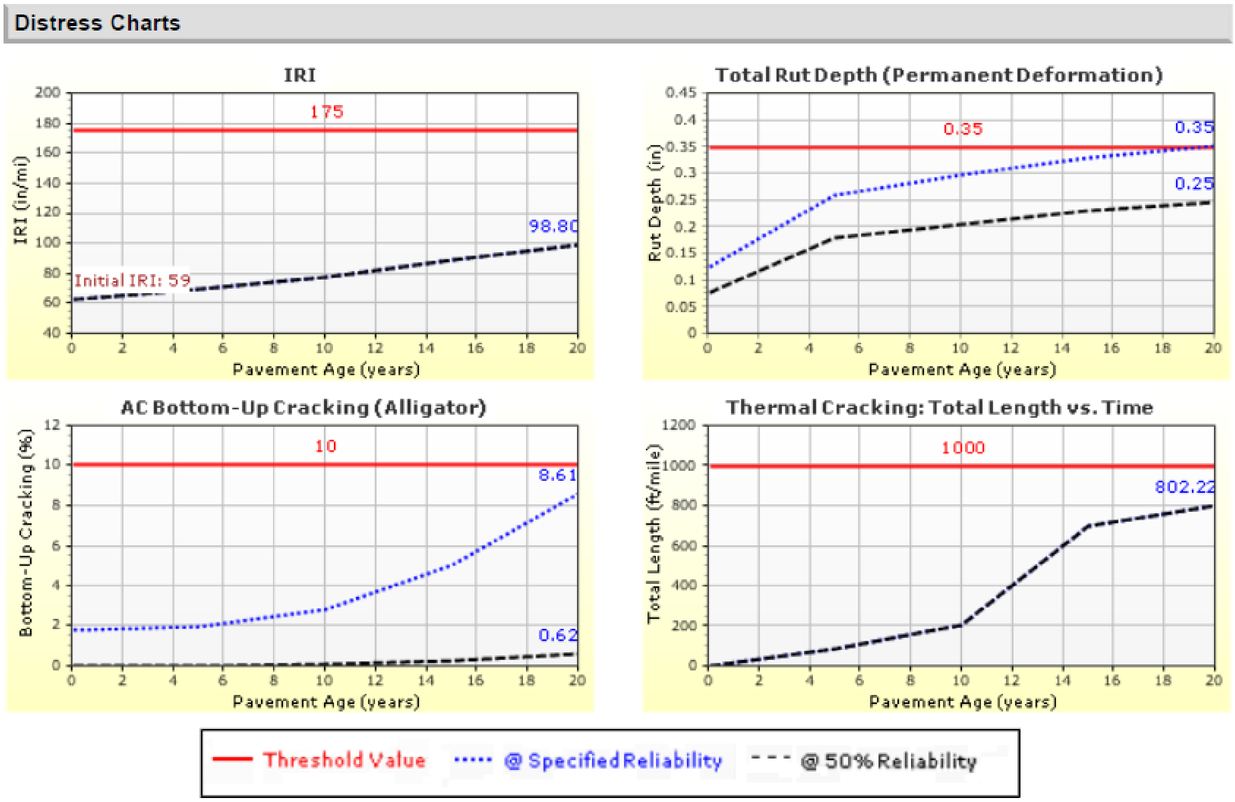
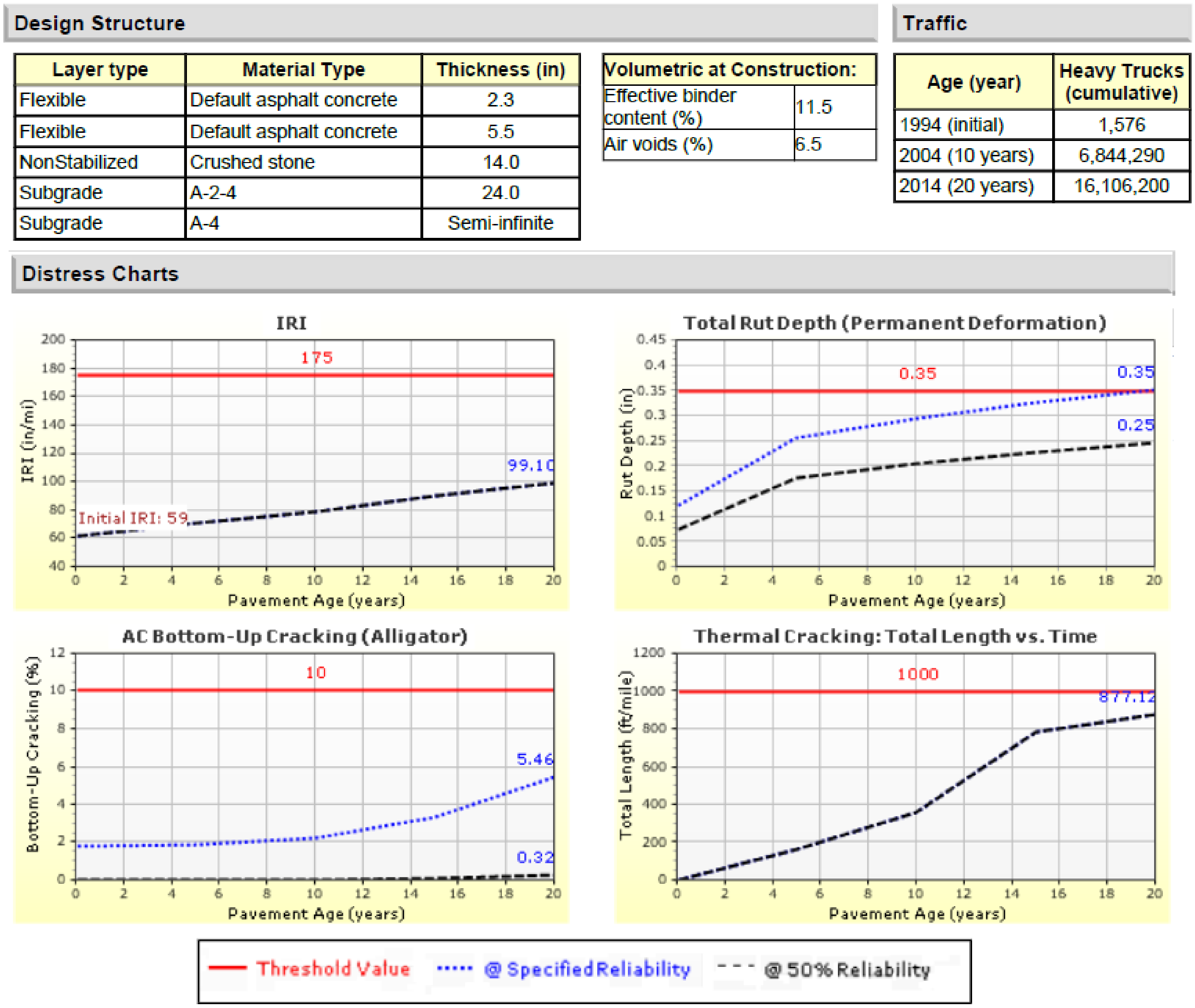


Figure 4.8 Pavement structure analysis using MEPDG

Since the predicted distresses were below the performance criteria, an optimized redesign was performed to seek a pavement structure with thinner layers that met the performance criteria. Figure 4.9 shows the resulting design and summarizes the predicted distresses. The total HMA thickness for the 20-year design period is reduced by 0.5 inches. Thus, this new design costs less than the original design but still meets all the performance requirements.



Design Structure

Layer type	Material Type	Thickness (in)
Flexible	Default asphalt concrete	2.3
Flexible	Default asphalt concrete	5.5
NonStabilized	Crushed stone	14.0
Subgrade	A-2-4	24.0
Subgrade	A-4	Semi-infinite

Volumetric at Construction:	
Effective binder content (%)	11.5
Air voids (%)	6.5

Traffic

Age (year)	Heavy Trucks (cumulative)
1994 (initial)	1,576
2004 (10 years)	6,844,290
2014 (20 years)	16,106,200

Distress Charts

Figure 4.9 Redesign of I-95 site

Figure 4.10 shows the design thicknesses under different traffic using different methods. In general, the thicknesses designed by using the MEPDG are 0.5 in. to 1 in. less than the ones required by the 1972 Design Guide. However, it is noted that the OGFC was considered differently in these two methods. OGFC was not considered in the 1972 Design Guide because its structure coefficient was 0; it was considered in the MEPDG with reduced thickness (using a factor of 0.75). The more conservative design by using the 1972 Design Guide could allow GDOT to replace only the top porous friction course in 10-12 years and both the porous friction course and SMA layer in 20-24 years without touching the underlying layers, which are protected by the extra pavement thickness and remain structurally sound.

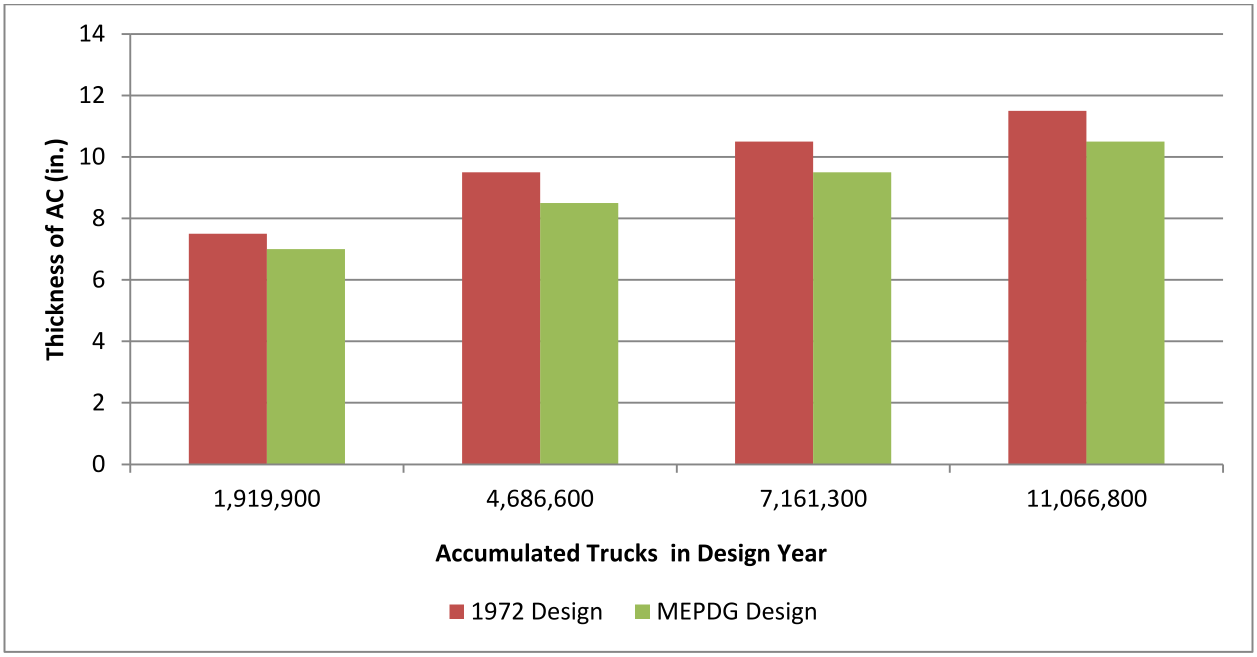


Figure 4.10 AC thickness (1972 design vs. MEPDG)

4.3 Characterization of SMA

Using GDOT's current 1972 Design Guide, both SMA and Superpave have a structure coefficient of 0.44, which means their contribution to the structure number is considered to be the same. As a result, the benefit of SMA (e.g., longer fatigue life, better rutting resistance and durability) cannot be counted during the design stage. In this section, we explore the characterization of SMA using the MEPDG and compare the predicted performance of SMA and Superpave. The principal mechanical property input for hot-mix asphalt in the MEPDG is dynamic modulus. The methods for specifying dynamic modulus at each of the three input levels in the MEDPG are as follows:

- Level 1: Laboratory-measured dynamic modulus |*E**| at multiple temperatures and loading frequencies (AASHTO TP62). In addition, binder stiffness and phase angle data are required for the global aging model.
- Level 2: The Witczak |*E**| predictive model is used to predict dynamic modulus based on gradation, volumetric data, binder stiffness, and phase angle data. The model used in the MEPDG is as follows:

$$\log E^* = 1.249937 + 0.249937 + 0.02932\rho_{200} - 0.001767\ \rho_4{}^2 - 0.002841\rho_4 - 0.058097V_a$$
$$-0.802208\left(\frac{V_{beff}}{V_{beff}+V_a}\right) + \frac{3.871977 - 0.0021\rho_4 + 0.003958\rho_{38} - 0.000017\ \rho_{38}{}^2 + 0.005470\rho_{34}}{1+e^{-0.603313-0.313351\log f\ -0.393532\log\eta}}$$

[4]

Where,

E* = dynamic modulus, 10^5 psi
η = asphalt viscosity at the age and temperature of interest, 106 Poise (use of RTFO aged viscosity is recommended for short-term oven aged lab blend mix)
f = loading frequency, Hz
Va = air void content, %
Vbeff = effective asphalt content, % by volume
ρ34 = cumulative % retained on 3/4 in (19 mm) sieve
ρ38 = cumulative % retained on 3/8 in (9.5 mm) sieve
ρ4 = cumulative % retained on #4 (4.76 mm) sieve
ρ200 = % passing #200 (0.075 mm) sieve.

- Level 3: The Witczak |*E**| predictive model is still used to predict *E* for Level 3. However, default binder stiffness and phase angle data are based on the default for the binder. The required data inputs are gradation and volumetric data.

The Witczak's prediction model is a purely empirical regression model developed from a large database of over 2700 laboratory test measurements. The databases used to develop and calibrate the Witczak's prediction model contain mostly conventional dense-graded mixtures but very few gap-graded SMA mixtures. Several studies (Ceylan et al., 2009; Cross et al., 2009; ODOT, 2009) have found that the Witczak predictive model is dominated by temperature influences and does not do a good job of ranking mixtures in terms of their measured stiffness values at a given temperature and loading frequency. Especially, with higher AC content and a coarse stone skeleton, SMA has a lower E* compared to Superpave. Figure **4.11** shows the dynamic modulus estimated using the Witczak predictive model in the MEPDG based on the mix properties (e.g., gradation and AC content) suggested in GDOT's user guide. It shows the SMA has a slightly (~3%) lower dynamic modulus compared to Superpave. The difference in dynamic modulus is small, and it does not make much difference in the predicted distresses. However, this means that by using the Witczak predictive model (levels 2 and 3), the MEPDG cannot be used to justify the benefit of SMA in the design stage, either. Previous studies (e.g., Sotil et al., 2007; ODOT, 2009) have shown that, when tested without confinement, certain gap-graded mixtures (such as SMA mixtures) may have lower |E*| values than dense-graded mixtures. SMA mixtures may, therefore, show lower rutting resistance when modeled in the current MEPDG software, contrary to the observed superior rutting and cracking resistance of SMAs (Michael et al., 2003) in the field. A summary of states' studies on the dynamic modulus of SMA is in Appendix III.

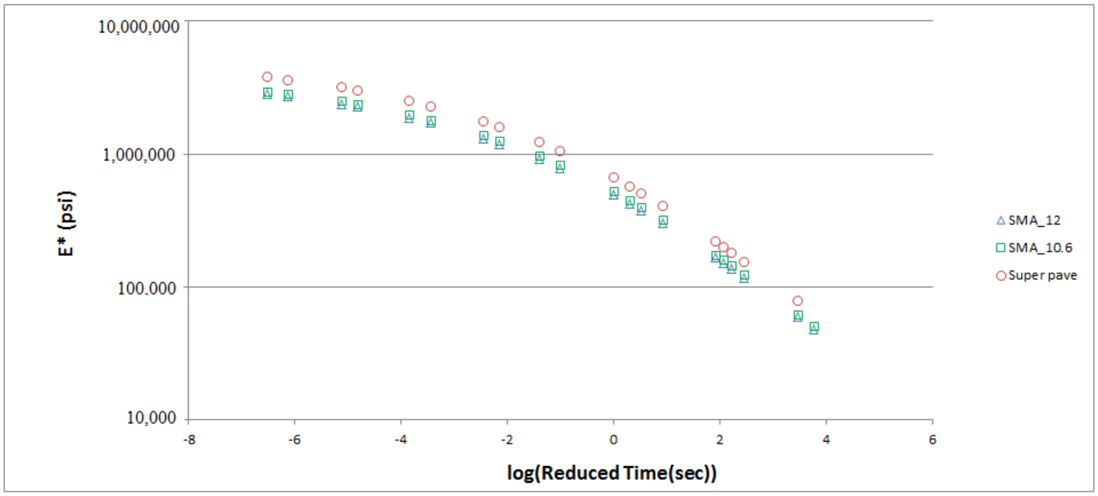


Figure 4.11 **E* for SMA and Superpave**

5. CONCLUSIONS AND RECOMMENDATAIONS

The Georgia Department of Transportation (GDOT) is in the process of evaluating the use of the MEPDG for designing its new and rehabilitated pavement structures. GDOT has undertaken projects to establish the groundwork for the use of the MEPDG, including characterizing material properties, analyzing traffic loading, and calibrating the MEPDG performance prediction models to Georgia’s conditions and materials. The GALTPP program was initiated by GDOT to provide sufficient sites for the initial MEPDG local calibration, and, more importantly, to continue long-term performance monitoring on the sites in which GDOT is interested to support performance evaluation and/or future MEPDG recalibration. The outcomes/findings will improve GDOT's practices on pavement design, material, construction, and maintenance. Currently, the GALTPP comprises 38 flexible pavement sites (17 LTPP and 21 non-LTPP sites) and 23 rigid pavement sites (11 LTPP and 12 non-LTPP sites). Various field and laboratory tests, including condition surveys in accordance with the LTPP Distress Identification Manual, FWD, and DCP for base and subgrade, bulk specific gravity measured on each layer, etc., were conducted on the non-LTPP sites, and documents (e.g., as-built plans and construction files) were gathered to provide the data needed for the calibration. These data are essential for further recalibration of the MEPDG, and additional data (e.g., performance data on current sites and data on new warm mix asphalt sites) are expected to be incorporated into the GALTPP program. Therefore, this project is designed to maintain the data collected for the GALTPP program, including the existing data and the data to be incorporated in the future. In addition, the project evaluates the MEPDG performance prediction for Georgia’s interstate highways because they account for a major part of the capital investments for roadways. The following are the major findings from Phase 1 of the project:

1) The data collected on GALTPP sites, including FWD, DCP, locations, etc., were gathered and carefully reviewed. The site locations were verified by comparing them (x-y coordinates included in GDOT's calibration study) to the core locations collected using GDOT's PDA-based core data collection application to ensure the sites can be correctly located for long-term performance monitoring. It was found that the site location data does not match the core location data. Thus, the site location data was corrected based on the first core located along the travel direction. The location data was further processed to obtain additional location information (e.g., RCLINK and milepoint) using GDOT's location reference system.
2) A database (GALTPP database) with location reference information was designed to store and manage the input parameters used in the MEPDG calibration, the condition survey data, the testing data, and the documents collected on the GALTPP sites. GALTPP database tables and fields for flexible pavement were designed based on a relational database concept with geospatial information so it can be integrated into a GIS (Geographic Information Systems) platform. The data was processed and populated into the GALTPP database. In addition, a GIS project, along with an add-in tool, was developed using the GALTPP database for visualizing the sites.
3) A review of GDOT's pavement condition survey data shows raveling is the predominate distress on Georgia's interstate pavements; 41% of interstate segments were reported with raveling in FY 2015. Raveling is also an important performance indicator that triggers the need for maintenance on the porous friction course (e.g., Open Graded Friction Course

(OGFC) or Porous European Mix (PEM)) on the surface layer, but it is not modeled in the MEPDG.

4) A total of 38 sites (17 LTPP and 21 non-LTPP sites) were used to calibrate the coefficients in the MEPDG transfer functions to eliminate bias and improve accuracy (i.e., reducing the standard error). Among them, five sites are on interstates. Compared to the other sites, these interstate sites exhibited low fatigue cracking (less than 3%) and moderate rutting (between 0.15 in and 0.3 in) at the end of pavement service interval (i.e., before pavement rehabilitation). The only site that exhibited more cracking (approximately 10% in 17 years) is on I-520, which has 7 in. of asphalt concrete layers. Based on the limited data, the measured distresses were within the distresses levels predicted at 50% reliability using the MEPDG.

5) A case study was conducted on I-95 in Chatham County based on the existing pavement structure. Using the MEPDG, the predicted distresses would reach the distress performance criteria (0.35" of rutting and 10% of fatigue cracking) at 95% reliability in 20 years. However, the observed distresses (0.25 in. of rutting and 3% of fatigue cracking) are close to the distresses predicted at 50% reliability.

6) Compared to the MEPDG, the current design procedure (1972 AASHTO Interim Design Guide is on the conservative side. The interstate pavement structure on the I-95 site is 10.17% under-designed when it was validated using the 1972 Design Guide. According to the 1972 Design Guide, to carry the 16.2 million heavy trucks, an additional 2 in. of asphalt base would be needed. However, the design without the 2 in. of asphalt base passed all the performance criteria when it was validated using the MEPDG.

7) Though it is on the conservative side, the current 1972 Design Guide allows GDOT to replace only the top porous friction course in 10 to 12 years, and both the porous friction course and SMA layer in 20 to 24 years without the need to replace the underlying layers because the underlying layers are still structurally sound with very limited distresses. Analyses on multiple pavement service intervals (e.g., more than 20 years) based on GDOT's maintenance practices would help to determine the most cost-effective pavement structures.
8) Based on the field observation, SMA performs better in term of fatigue life on heavily traveled roads than does Superpave. This benefit is not modeled in the current design procedure (the 1972 Design Guide) because both SMA and Superpave have the same structure coefficient of 0.44. This issue remains the same in the MEPDG. Moreover, using the Witczak predictive model in the MEPDG, the SMA has a slightly lower dynamic modulus than Superpave. This leads to higher predicted rutting and fatigue cracking, although the differences are small. However, this is contrary to the observed field performance in Georgia, which shows better rutting and fatigue resistance of SMA.

To move forward in maintaining an active GALTPP program, the following are recommended:

1) It is recommended that distress and FWD data be collected on an annual or biennial basis on the GALTPP sites as the pavements continue deteriorating to establish a long-term performance monitoring. Especially, it is recommended cracking data be collected before and after resurfacing on I-95 site in Chatham County, which will be resurfaced next year. Such data will allow GDOT to validate the performance on this site and assess the development of cracking on micro-milled surfaces.
2) The 3D laser technology (e.g., 3D pavement data, video log images, etc.) can be used for collecting consistent and detailed pavement distress data on the GALTPP sites. The high-

resolution 3D laser data can be used for detecting cracks and quantitatively and objectively measuring raveling on the porous friction course surfaces. In addition, it can collect the cracking data before and after micro-milling is performed on the porous friction course. These data are invaluable for assessing the development of top-down and bottom-up cracking on Georgia’s pavements.

3) A raveling prediction model (including a measure for quantifying raveling) can be developed and incorporated into the life-cycle analysis of the interstate pavement design (for new and rehabilitated pavement structures). This allows GDOT to reliably quantify raveling and identify the timing for adequate treatment(s), which is difficult using current visual inspection methods.
4) It is recommended that life-cycle cost analysis (based on GDOT’s maintenance practices) be conducted to determine the pavement structure design that is most cost-effective for a pavement's full life cycle.

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APPENDIX A: SITE LOCATION

Site	Type	County	Route	X	Y	RCLINK	MP
F1	Widening, Mill, & Overlay	Banks & Jackson	SR-15	-83.45407	34.23695	1571001500	16.30
F2	Mill & Overlay	Cobb	SR-180	-84.50888	33.85098	0671028000	2.94
F3	Widening & Overlay	Jackson	SR-11/ US-129	-83.68865	34.17628	1571033200	10.40
F4	Mill & Overlay	Douglas	SR-6	-84.63973	33.79584	0971000600	1.03
F7	Overlay	Fulton & Clayton	SR-6	-84.53662	33.66042	1211000600	6.70
F8	Mill & Inlay	Clayton	SR-54	-84.34891	33.54670	0631005400	5.95
F9	Mill & Overlay	Fulton	I-85/ SR-403	-84.48281	33.61924	1211040300	11.84
F10	Widening & Overlay	Bryan	SR-144	-81.32511	31.95789	0291014400	9.15
F11	Semi-Rigid; Overlay	Decatur	SR-1/ US-27	-84.55647	30.86661	0871000100	16.84
F12	Widening &Overlay	Chatham & Effingham	I-95/I-16	-81.23941	32.08687	0511040500	8.39
F13	Reconstruction, Semi-Rigid	Thomas & Brooks	SR-38/US-84	-83.77603	30.80000	2751003800	23.68
F16	Overlay	Mitchell	SR-3/ US-19	-84.08231	31.08023	2051000300	0.22
F18	Mill & Overlay	Wilkinson & Washington	SR-57	-83.12303	32.81008	3191005700	17.29
F19	Reconstruction, Conventional	Richmond	I-520	-81.97540	33.41180	2451041500	10.81
F20	Reconstruction, Conventional	Polk	SR-6/ US-278	-85.26138	34.00514	2331000600	9.28
F21	Reconstruction, Conventional	Cherokee	SR-108	-84.58756	34.26446	0571010800	3.98
F23	Reconstruction, Full-Depth	Jefferson	SR-171	-82.46211	33.01921	1631017100	18.19
F24	Overlay	Oconee	SR-24/ US-129	-83.42801	33.77210	2191002400	3.92
F25	Widening & Overlay	Pike	SR-109	-84.31036	33.04869	2311010900	15.07
F26	Reconstruction, Conventional	Worth	SR-256	-83.79793	31.49693	3211025600	14.26

APPENDIX B: GALTPP TABLES

- Section information

Field Name	Units	Field Type	Description
GALTPP_SEC_CON_ID		CHARACTER	An identification number GALTPP_SECTION_ID+ CONSTRUCTION _ID.
GALTPP_SECTION_ID		CHARACTER	Test section identification number (one for each section).
CONSTRUCTION_ID		CHARACTER	Construction event in sequence.
LTPP_SECTION_ID		CHARACTER(6)	LTPP test section identification.
COUNTY		CHARACTER(3)	County in which the test section is located.
ROUTENO		CHARACTER(4)	The route number for the route that the section is located on.
ROUTE_SUFFIX		CHARACTER(2)	The route suffix for the route that the section is located on.
Milepoint_FROM		NUMBER	Beginning mile point
Milepoint_TO		NUMBER	Ending mile point
Milepost_FROM		NUMBER	Beginning mile post for interstate highways
Milepost_TO		NUMBER	Ending mile post for interstate highways
DIRECTION_OF_TRAVEL		CHARACTER(1)	E for East, W for West, N for North, S for South base on the direction of travel within the lane for which data is being collected.
LANE_NUMBER		NUMBER(1,0)	The number of the lane on which data is being collected. 1 is the outside lane. The others are numbered consecutively as you move to the inside edge of the pavement.
FUNCTIONAL_CLASS		CHARACTER	Functional class of roadway on which section is located.
TOT_LANES		NUMBER(1,0)	Total number of lanes in one direction.
PAVEMENT_TYPE		CHARACTER	
LANE_WIDTH	ft	NUMBER(2,0)	Width of the lane the test section occupies.
SHOULDER_TYPE		CHARACTER(7)	Indication of whether the shoulder is “paved,” “unpaved,” or “none.”
SHOULDER_WIDTH	ft	NUMBER(2,0)	The width of the shoulder in feet.
DIVIDED		CHARACTER(1)	Y or N indicating that the roadway does or does not have a median.
DATE_EARTHWORK		DATE	Date the earthwork was completed in the construction of the project.
DATE_HMA_PLACED		DATE	Date the hot-mix asphalt was placed in the construction of the project.
TRAFFIC_OPEN_DATE		DATE	Date the test section was opened to traffic.

Field Name	Units	Field Type	Description
LATITUDE	Degrees	NUMBER(5,3)	Latitude of the test section in degrees.
LONGITUDE	Degrees	NUMBER(5,3)	Longitude of the test section in degrees.
ELEVATION	Ft	NUMBER(4,0)	Estimate of the elevation of the test section relative to sea level.
LOCATION_INFO		CHARACTER(100)	Description of the location of the test section.

- Performance information

This table stores the distress inputs for the MEPDG models for flexible pavement.

Field Name	Units	Field Type	Description
GALTPP_SEC_CON_ID		CHARACTER	A unique identifier for GALTPP
SOURCE		CHARACTER	Source of the distress data (COPACES, LTPP)
SURVEY_DATE		DATE	Date of distress survey.
SURFACE_DOWN_FATIGUE	%	NUMBER(3,1)	Percentage of wheel path area that has experienced surface-down fatigue.
BOTTOM_UP_CRACKING	%	NUMBER(3,1))	Percentage of wheel path area that has experienced bottom-up cracking.
THERMAL_CRACK	ft/mi	NUMBER(4,1)	Total length of thermal cracking per lane-mile.
AVG_WIRELINE_RUT_DEPTH	in	NUMBER(3,2)	Average rut depth for the 500-ft test section.
STD_WIRELINE_RUT_DEPTH	in	NUMBER(3,2)	Standard deviation of rut depth measurements taken on the test section.
STUDDED_TIRE_WEAR	in	NUMBER(3,2)	Portion of rut depth due to wearing of the surface from studded tires.

This table stores the distress data for flexible pavement.

Field Name	Units	Field Type	Description
GALTPP_SEC_CON_ID		CHARACTER	Test section identification number.
SOURCE		CHARACTER	Source of the distress data (COPACES, LTPP)
SURVEY_DATE		DATE (mm/dd/yyyyhh:mi:s)	Date of distress survey.
GATOR_CRACK_A_L	ft^2	NUMBER(5,1)	Area of alligator (fatigue) cracking of low severity
GATOR_CRACK_A_M	ft^2	NUMBER(5,1)	Area of alligator (fatigue) cracking of moderate severity may be evident).
GATOR_CRACK_A_H	ft^2	NUMBER(5,1)	Area of alligator (fatigue) cracking of high severity may be evident).
BLK_CRACK_A_L	ft^2	NUMBER(5,1)	Area of block cracking of low severity
BLK_CRACK_A_M	ft^2	NUMBER(5,1)	Area of block cracking of moderate severity
BLK_CRACK_A_H	ft^2	NUMBER(5,1)	Area of high severity block cracking (mean crack width greater than 19 mm or under 19 mm with moderate to high severity random cracking).
EDGE_CRACK_L_L	ft	NUMBER(4,1)	Length of low severity edge cracking (cracks without break up or loss of material).
EDGE_CRACK_L_M	ft	NUMBER(4,1)	Length of moderate severity edge cracking (cracks with some break up and loss of material for up to 10 percent of the affected length).

Field Name	**Units**	**Field Type**	**Description**
EDGE_CRACK_L_H	ft	NUMBER(4,1)	Length of high severity edge cracking (considerable break up and loss of material for more than 10 percent of the affected length).
LONG_CRACK_WP_L_L	ft	NUMBER(4,1)	Length of low severity, longitudinal cracking in wheel path (cracks of unknown width well sealed or with mean width of 6 mm or less).
LONG_CRACK_WP_L_M	ft	NUMBER(4,1)	Length of moderate severity, longitudinal cracking in wheel path (mean crack width from 6 to 19 mm or under 19 mm with adjacent low severity random cracking).
LONG_CRACK_WP_L_H	ft	NUMBER(4,1)	Length of high severity, longitudinal cracking in wheel path (mean crack width greater than 19 mm or under 19 mm with adjacent moderate to high severity random cracking).
LONG_CRACK_WP_SEAL_L_L	ft	NUMBER(4,1)	Length of low severity, well-sealed longitudinal cracking in wheel path (cracks of unknown width or with mean width of 6 mm or less).
LONG_CRACK_WP_SEAL_L_M	ft	NUMBER(4,1)	Length of moderate severity, well-sealed longitudinal cracking in wheel path (mean crack width from 6 to 19 mm or under 19 mm with adjacent low severity random cracking).
LONG_CRACK_WP_SEAL_L_H	ft	NUMBER(4,1)	Length of high severity, well-sealed longitudinal cracking in wheel path (crack mean width greater than 19 mm or under 19 mm with adjacent moderate to high severity random cracking).
LONG_CRACK_NWP_L_L	ft	NUMBER(4,1)	Length of low severity, non-wheel path longitudinal cracking (cracks of unknown width well sealed or with mean width of 6 mm or less).
LONG_CRACK_NWP_L_M	ft	NUMBER(4,1)	Length of moderate severity, non-wheel path longitudinal cracking (mean crack width from 6 to 19 mm or under 19 mm with adjacent low severity random cracking).
LONG_CRACK_NWP_L_H	ft	NUMBER(4,1)	Length of high severity, non-wheel path longitudinal cracking (mean crack width greater than 19 mm or fewer than 19 mm with adjacent moderate to high severity random cracking).
LONG_CRACK_NWP_SEAL_L_L	ft	NUMBER(4,1)	Length of low severity, well-sealed non-wheel path longitudinal cracking (cracks of unknown width or with mean width of 6 mm or less).
LONG_CRACK_NWP_SEAL_L_M	ft	NUMBER(4,1)	Length of moderate severity, well-sealed non- wheel path longitudinal cracking (mean crack width from 6 to 19 mm or under 19 mm with adjacent low severity random cracking).
LONG_CRACK_NWP_SEAL_L_H	ft	NUMBER(4,1)	Length of high severity, well-sealed non-wheel path longitudinal cracking (mean crack width greater than 19 mm or fewer than 19 mm with adjacent moderate to high severity random cracking).
REFL_CRACK_TRANS_NO_L		NUMBER(3,0)	Number of low severity, transverse reflection cracks (cracks of unknown width well sealed or with mean width of 6 mm or less).
REFL_CRACK_TRANS_NO_M		NUMBER(3,0)	Number of moderate severity, transverse reflection cracks (mean crack width of 6 to 19 mm or under 19 mm with adjacent low severity random cracking).
REFL_CRACK_TRANS_NO_H		NUMBER(3,0)	Number of high severity, transverse reflection cracks (mean crack width greater than 19 mm or under 19 mm with adjacent moderate to high severity random cracking).
REFL_CRACK_TRANS_L_L	ft	NUMBER(5,1)	Length of low severity, transverse reflection cracking at joints (cracks of unknown width well sealed or with

Field Name	Units	Field Type	Description
			mean width of 6 mm or less).
REFL_CRACK_TRANS_L_M	ft	NUMBER(5,1)	Length of moderate severity, transverse reflection cracking at joints (mean crack width of 6 to 19 mm or under 19 mm with adjacent low severity random cracking).
REFL_CRACK_TRANS_L_H	ft	NUMBER(5,1)	Length of high severity, transverse reflection cracking at joints (mean crack width greater than 19 mm or fewer than 19 mm with adjacent moderate to high severity random cracking).
REFL_CRACK_TRANS_SEAL_L_L	ft	NUMBER(5,1)	Length of well-sealed, low severity transverse cracking (cracks of unknown width or with mean width of 6 mm or less).
REFL_CRACK_TRANS_SEAL_L_M	ft	NUMBER(5,1)	Length of well-sealed, moderate severity transverse cracking (mean crack width from 6 to 19 mm or under 19 mm with adjacent low severity random cracking).
REFL_CRACK_TRANS_SEAL_L_H	ft	NUMBER(5,1)	Length of well-sealed, high severity transverse cracking (mean crack width greater than 19 mm or under 19 mm with adjacent moderate to high severity random cracking).
REFL_CRACK_LONG_L_L	ft	NUMBER(4,1)	Length of low severity, longitudinal reflection cracking at joints (cracks of unknown width well sealed or with mean width of 6 mm or less).
REFL_CRACK_LONG_L_M	ft	NUMBER(4,1)	Length of moderate severity, longitudinal reflection cracking at joints (mean crack width from 6 to 19 mm or under 19 mm with adjacent low severity random cracking).
REFL_CRACK_LONG_L_H	ft	NUMBER(4,1)	Length of high severity, longitudinal reflection cracking at joints (mean crack width greater than 19 mm or fewer than 19 mm with adjacent moderate to high severity random cracking).
REFL_CRACK_LONG_SEAL_L_L	ft	NUMBER(4,1)	The length of well-sealed, low severity longitudinal reflection cracking at joints (cracks of unknown width or with mean width of 6 mm or less).
REFL_CRACK_LONG_SEAL_L_M	ft	NUMBER(4,1)	The length of well-sealed, moderate severity longitudinal reflection cracking at joints (mean crack width from 6 to 19 mm or under 19 mm with adjacent low severity random cracking).
REFL_CRACK_LONG_SEAL_L_H	ft	NUMBER(4,1)	The length of well-sealed, high severity longitudinal reflection cracking at joints (mean crack width greater than 19 mm or under 19 mm with adjacent moderate to high severity random cracking).
TRANS_CRACK_NO_L		NUMBER(3,0)	Number of low severity transverse cracks (cracks of unknown width well sealed or with mean width of 6 mm or less).
TRANS_CRACK_NO_M		NUMBER(3,0)	Number of moderate severity transverse cracks (mean crack width from 6 to 19 mm or under 19 mm with adjacent low severity random cracking).
TRANS_CRACK_NO_H		NUMBER(3,0)	Number of high severity transverse cracks (mean crack width greater than 19 mm or under 19 mm with adjacent moderate to high severity random cracking).
TRANS_CRACK_L_L	ft	NUMBER(5,1)	Length of low severity transverse cracking (cracks of unknown width well sealed or with mean width of 6 mm or less).
TRANS_CRACK_L_M	ft	NUMBER(5,1)	Length of moderate severity transverse cracking (crack mean width from 6 to 19 mm or under 19 mm with adjacent low severity random cracking).
TRANS_CRACK_L_H	ft	NUMBER(5,1)	Length of high severity transverse cracking (mean crack width greater than 19 mm or under 19 mm with adjacent

Field Name	Units	Field Type	Description
			moderate to high severity random cracking).
TRANS_CRACK_SEAL_L_L	ft	NUMBER(5,1)	The length of well-sealed, low severity transverse cracking (cracks of unknown width or with mean width of 6 mm or less).
TRANS_CRACK_SEAL_L_M	ft	NUMBER(5,1)	The length of well-sealed, moderate severity transverse cracking (mean crack width from 6 to 19 mm or under 19 mm with adjacent low severity random cracking).
TRANS_CRACK_SEAL_L_H	ft	NUMBER(5,1)	The length of well-sealed, high severity transverse cracking (mean crack width greater than 19 mm or under 19 mm with adjacent moderate to high severity random cracking).
PATCH_NO_L		NUMBER(3,0)	Number of patches/patch deteriorations with low severity distress of any type.
PATCH_NO_M		NUMBER(3,0)	Number of patches/patch deteriorations with moderate severity distress type.
PATCH_NO_H		NUMBER(3,0)	Number of patches/patch deteriorations with high severity distress of any type.
PATCH_A_L	ft^2	NUMBER(5,1)	Area of patching with low severity distress or patch deterioration.
PATCH_A_M	ft^2	NUMBER(5,1)	Area of patching with moderate severity distress or patch deterioration.
PATCH_A_H	ft^2	NUMBER(5,1)	Area of patching with high severity distress or patch deterioration.
POTHOLES_NO_L		NUMBER(3,0)	Number of low severity potholes (less than 25 mm deep).
POTHOLES_NO_M		NUMBER(3,0)	Number of moderate severity potholes (from 25 to 50 mm deep).
POTHOLES_NO_H		NUMBER(3,0)	Number of high severity potholes (more than 50 mm deep).
POTHOLES_A_L	ft^2	NUMBER(5,1)	Area of low severity potholes (less than 25 mm deep).
POTHOLES_A_M	ft^2	NUMBER(5,1)	Area of moderate severity potholes (from 25 to 50 mm deep).
POTHOLES_A_H	ft^2	NUMBER(5,1)	Area of high severity potholes (more than 50 mm deep).
SHOVING_NO		NUMBER(3,0)	Number of areas where shoving exists.
SHOVING_A	ft^2	NUMBER(5,1)	The area of shoving, localized longitudinal displacement of the pavement surface.
BLEEDING	ft^2	NUMBER(5,1)	Presence of excess asphalt on the pavement surface, which may create a shiny, glass-like reflective surface.
POLISH_AGG_A	ft^2	NUMBER(5,1)	Area of polished aggregate (binder worn away to expose coarse aggregate).
RAVELING	ft^2	NUMBER(5,1)	Wearing away of the pavement surface caused by the dislodging of aggregate particles and loss of asphalt binder.
PUMPING_NO		NUMBER(3,0)	Number of occurrences of water bleeding and pumping.
PUMPING_L	ft	NUMBER(4,1)	Length of pavement affected by water bleeding and pumping.
OTHER		CHARACTER(80)	A description of other surface distress.

This table stores the distress inputs for the MEPDG models for JPCP.

Field Name	Units	Field Type	Description
GALTPP_SEC_CON_ID		CHARACTER	A unique identifier for GALTPP
LTPP_SECTION_ID		CHARACTER(6)	LTPP test section identification.

Field Name	Units	Field Type	Description
SURVEY_DATE		DATE	Date of distress survey.
FAULTING	in	NUMBER(3,1)	Mean joint faulting
CRACKING	%	NUMBER(3,1)	% slabs cracked

This table stores the distress data for JPCP.

Field Name	Field Type	Description
GALTPP_SEC_CON_ID	CHARACTER	A unique identifier for GALTPP
SOURCE	CHARACTER	Source of the distress data (COPACES, LTPP).
SURVEY_DATE	DATE	Date survey was performed.
SURVEYOR	CHARACTER	Person who conducts the survey.
BEFORE_TEMP	NUMBER	Pavement surface temperature at the beginning of the distress survey.
AFTER_TEMP	NUMBER	Pavement surface temperature at the end of the distress survey.
AVG_FAULTING	NUMBER	Average edge faulting calculated per site per survey.
MIN_FAULTING	NUMBER	Minimum edge faulting per site per survey.
MAX_FAULTING	NUMBER	Maximum edge faulting per site per survey.
STD_FAULTING	NUMBER	Standard deviation for edge faulting calculated per site per survey.
BROKEN_SLABS	NUMBER	Total number of broken slabs.
CORNER_BREAKS_NO_L	NUMBER	Number of low severity corner breaks. (Notspalled for more than 10 percent of length; no measurable faulting; corner piece not broken in two or more pieces.)
CORNER_BREAKS_NO_M	NUMBER	Number of moderate severity corner breaks. (Spalled at low severity for more than 10 percent; or faulting less than 13 mm; corner piece not broken in two or more
CORNER_BREAKS_NO_H	NUMBER	Number of high severity corner breaks. (Spalled at moderate to high severity for more than 10 percent of crack; or faulting exceeds 13 mm or corner piece in two or more pieces.)
LONG_CRACK_L_L	NUMBER	Length of low severity longitudinal cracking. (Crack widths less than 3 mm, no spalling or measurable faulting.)
LONG_CRACK_L_M	NUMBER	Length of well-sealed, moderate severity longitudinal cracking. (Crack widths between 3 and 13 mm or spalling less than 75 mm or faulting up to 13 mm.)
LONG_CRACK_L_H	NUMBER	Length of high severity longitudinal cracking. (Crack widths greater than 13 mm or spalling greater than 75 mm or faulting greater than 13 mm.)
LONG_CRACK_SEAL_L_L	NUMBER	Length of well-sealed, low severity longitudinal cracking. (Crack widths less than 3 mm, no spalling or measurable faulting.)
LONG_CRACK_SEAL_L_M	NUMBER	Number of transverse cracks for which moderate severity distress is the highest level observed for at least 10 percent of the crack.
LONG_CRACK_SEAL_L_H	NUMBER	Length of well-sealed, high severity longitudinal cracking. (Crack widths greater than 13 mm or spalling greater than 75 mm or faulting greater than 13 mm.)
TRANS_CRACK_NO_L	NUMBER	Number of low severity transverse cracks. (No spalling exceeding 10 percent of length).
TRANS_CRACK_NO_M	NUMBER	Number of transverse cracks for which moderate severity distress is the highest level observed for at least 10
TRANS_CRACK_NO_H	NUMBER	Number of transverse cracks for which high severity distress exceeds 10 percent of the length.
TRANS_CRACK_L_L	NUMBER	Length of low severity transverse cracking. (Crack widths less than 3 mm, no spalling and no measurable faulting.)

Field Name	Field Type	Description
TRANS_CRACK_L_M	NUMBER	Length of moderate severity transverse cracking. (Crack widths between 3 and 6 mm or spalling fewer than 75 mm or faulting up to 6 mm.)
TRANS_CRACK_L_H	NUMBER	Length of high severity transverse cracking. (Crack widths greater than 6 mm or spalling over 75 mm or faulting over 6 mm.)
LONG_SPALLING_L_L	NUMBER	Length of low severity spalling of longitudinal joints. (Spalls less than 75 mm measured to center of joint with no loss of material.)
LONG_SPALLING_L_M	NUMBER	Length of moderate severity spalling of longitudinal joints. (Spalls between 75 and 150 mm wide measured to center of joint with loss of material.)
LONG_SPALLING_L_H	NUMBER	Length of high severity spalling of longitudinal joints. (Spalls greater than 150 mm measured to center of joint with loss of material.)
TRANS_SPALLING_NO_L	NUMBER	Number of transverse joints with low severity spalling. (Spalls less than 75 mm wide measured to center of joint.)
TRANS_SPALLING_NO_M	NUMBER	Number of transverse joints with moderate severity spalling. (Spalls between 75 and 150 mm wide measured to center of joint.)
TRANS_SPALLING_NO_H	NUMBER	Number of transverse joints with high severity spalling. (Spalls more than 150 mm wide measured to center of joint.)
TRANS_SPALLING_L_L	NUMBER	Length of low severity spalling of transverse joints. (Spalls less than 75 mm measured to center of joint or with no loss of material.)
TRANS_SPALLING_L_M	NUMBER	Length of moderate severity spalling of transverse joints. (Spalls 75 to 150 mm wide measured to center of joint with loss of material).
TRANS_SPALLING_L_H	NUMBER	Length of high severity spalling of transverse joints. (Spalls more than 150 mm wide measured to center of joint with loss of material.)
SCALING_NO	NUMBER	Number of areas with scaling.
SCALING_A	NUMBER	Area of scaling (Deterioration of upper slab surface between 3 and 13 mm).
POLISH_AGG_A	NUMBER	Area of polished aggregate (Surface worn away to expose coarse aggregate).
BLOWUPS_NO	NUMBER	Number of blowups.
PATCH_FLEX_NO_L	NUMBER	Number of flexible patches showing at most low severity distress of any type and no settlement at the perimeter.
PATCH_FLEX_NO_M	NUMBER	Number of flexible patches showing moderate severity distress of any type or settlement of up to 6 mm at the perimeter.
PATCH_FLEX_NO_H	NUMBER	Number of flexible patches showing high severity distress or settlement of 6 mm or more at the perimeter.
PATCH_FLEX_A_L	NUMBER	Area of flexible patching showing, at most, low severity distress of any type and no settlement at the perimeter.
PATCH_FLEX_A_M	NUMBER	Area of flexible patching showing moderate severity distress of any type or settlement of up to 6 mm at the perimeter.
PATCH_FLEX_A_H	NUMBER	Area of flexible patching showing high severity distress of any type or settlement of 6 mm or more at the perimeter.
PATCH_RIGID_NO_L	NUMBER	Number of rigid patches showing, at most, low severity distress of any type and no settlement at the perimeter.
PATCH_RIGID_NO_M	NUMBER	Number of rigid patches showing moderate severity distress of any type or settlement of up to 6 mm at the perimeter.
PATCH_RIGID_NO_H	NUMBER	Number of rigid patches showing high severity distress of any type or settlement of 6 mm or more at the perimeter.
PATCH_RIGID_A_L	NUMBER	Area of rigid patching showing, at most, low severity distress of any type and no settlement at the perimeter.
PATCH_RIGID_A_M	NUMBER	Area of rigid patching showing moderate severity distress of any type or settlement of up to 6 mm at the perimeter.
PATCH_RIGID_A_H	NUMBER	Area of rigid patching showing high severity distress of any type or settlement of 6 mm or more at the perimeter.
PUMPING_NO	NUMBER	Number of occurrences of water bleeding and pumping.
PUMPING_L	NUMBER	Length of pavement affected by water bleeding and pumping.

- Traffic Inputs (HIF-11-026)

This table includes a description of each traffic data element.

Name	Description
GALTPP_SEC_CON_ID	A unique identifier for GALTPP
AADTT	Initial two-way average annual daily truck traffic
Direction	Direction of traffic
No_Design_Lane	Number of lanes in the design direction
%_Trcks_Dsgn_Dir	Percent of trucks in the design direction (%)
%_Trcks_Dsgn_Lane	Percent of trucks in design lane (%)
Speed	Operational speed (mph)
Growth_Rate	Traffic growth rate (%)
General Traffic Inputs	
Wheel_Location	Mean wheel location (inches from the lane marking)
Trffc_Wander_Stdev	Traffic wander standard deviation (in)
Design_Lane_Width	Design lane width (ft)
Axle Configuration	
Avg_Axle_Width	Average axle width (edge-to-edge), outside dimension (ft)
Dual_Tire_Spacing	Dual tire spacing (in)
Tire_Pressure	Tire pressure (psi)
Axle_Spcing_Tandem	Tandem axle spacing (in)
Axle_Spcing_Tridem	Tridem axle spacing (in)
Axle_Spcing_Quad	Quad axle spacing (in)
Wheelbase	
Wheelbase_Short	Average short axle spacing (ft)
% Trucks_Short	Percent of trucks – short axle spacing (%)
Wheelbase_Medium	Average medium axle spacing (ft)
% Trucks_Medium	Percent of trucks – medium axle spacing (%)
Wheelbase_Long	Average long axle spacing (ft)
% Trucks_Long	Percent of trucks – long axle spacing (%)
Axle/Truck	*Number of axles/truck*
Class	FHWA truck class 4 – 13
Single	Average number of single axles per truck class
Tandem	Average number of tandem axles per truck class
Tridem	Average number of tridem axles per truck class
Quad	Average number of quad axles per truck class
Traffic Volume Adjustment Factors	
Hour Distrib	Hourly distribution
Midnight – 11:00 PM	Hourly truck traffic distribution by hour (%)

Name	Description
Total	Sum of hourly distribution (must total 100%)
Monthly Adjust	Monthly adjustments
Month	Month of the year (January – December)
Class_1 – Class_13	Monthly adjustment factor for each FHWA truck class 1 – 13
Vehicle Distrib	Vehicle class distribution
Class_1 – Class_13	AADTT distribution by vehicle class (%)
Total	Sum of AADTT distribution (must total 100%)
Axle Load Distribution Factors	
Single	Single axle
Month	Month of the year (January – December)
Class	FHWA truck class 1 – 13
Total	Sum of axle load distribution factors (must total 100%)
3000 – 41000	Percent of axles in each load interval (1000 lb increments)
Tandem	Tandem axle
Month	Month of the year (January – December)
Class	FHWA truck class 1 – 13
Total	Sum of axle load distribution factors (must total 100%)
6000 – 82000	Percent of axles in each load interval (2000 lb increments)
Tridem	Tridem axle
Month	Month of the year (January – December)
Class	FHWA truck class 1 – 13
Total	Sum of axle load distribution factors (must total 100%)
12000 – 102000	Percent of axles in each load interval (3000 lb increments)
Quad	Quad axle
Month	Month of the year (January – December)
Class	FHWA truck class 1 – 13
Total	Sum of axle load distribution factors (must total 100%)
12000 – 102000	Percent of axles in each load interval (3000 lb increments)

- Materials Inputs (HIF-11-026):
  This table includes a description of each AC material data element.

Field Name	Description
GALTPP_SEC_CON_ID	Test section identification number.
LAYER_NO	Unique sequential number assigned to pavement layers, starting with layer 1 as the deepest layer (subgrade).
DESCRIPTION	Code indicating general type of layer.
LAYER_TYPE	A character code indicating the type of layer.
LAYER_THICKNESS	Thickness of the layer.
MATERIAL	Code indicating the material used in the layer.

This table includes a description of each AC material data element.

Name	Description
GALTPP_SEC_CON_ID	Test section identification number.
LAYER_NO	Layer number
Effctv_Bndr_Cntnt	Effective binder content (by weight)
Poisson_Ratio	Poisson’s ratio
Existing_Layer	Existing layer as opposed to a new layer
Layer_Thickness	Layer thickness (in)
Air_Voids	Percent air voids
Thermal_Cndctvy	Thermal conductivity. (BTU/hr-ft-°F)
Ref_Temp	Reference temperature (°F)
Unit_Weight	Total unit weight (pcf)
Heat_Capacity	Heat capacity (BTU/lb-°F)
E*	**Dynamic modulus of asphalt mixture (Level 1)**
Temperature	Temperature (°F)
E*_0_1	Dynamic modulus (psi) at 0.1 Hz
E*_1	Dynamic modulus (psi) at 1 Hz
E*_10	Dynamic modulus (psi) at 10 Hz
E*_25	Dynamic modulus (psi) at 25 Hz
RTFO_SP	**Superpave binder test data (Level 1 and Level 2)**
Temperature	Temperature (°F)
G*	Binder dynamic modulus (Pa)
Delta	Phase angle
RTFO_Conv	**Conventional binder properties (Level 1 and Level 2)**
Temp	Temperature (°F)
Softening_Pnt	Softening point (P)
Abslt_Vscsty	Absolute viscosity (P)
Knmtc_Vscsty	Kinematic viscosity (CS)
Spcfc_Grvty	Specific gravity
Penetration	Penetration
Brkfld_Vscsty	Brookfield viscosity
Gradation	**Gradation properties of asphalt mixture (Level 2 and Level 3)**
Retained_3/4	Cumulative percent retained on the ¾ in sieve.
Retained_3/8	Cumulative percent retained on the ⅜ in sieve.

Name	Description
Retained_ No_4	Cumulative percent retained on the #4 sieve.
Passing_No_200	Percent passing the No. 200 sieve.
Creep	**Creep compliance properties (thermal cracking).**
Load_Time	Loading time (sec).
Creep_-4F	Low temperature (-4 °F).
Creep_-14F	Mid temperature (14 °F).
Creep_-32F	High temperature (32 °F).
Binder	**Asphalt binder properties (Level 3).**
Binder_Type	Binder Type
Binder_Grad	Binder grade
ThermCrk	**Thermal cracking properties**
Tnsl_Strngth	Average tensile strength at 14 °F (psi)
VMA	Mixture voids in mineral aggregate (%)
Aggrgt_CTC	Aggregate coefficient of thermal contraction (in/in/°F)
Mix_CTC	Mix coefficient of thermal contraction (in/in/°F)

This table includes a description of each PCC material data element.

Name	Description
GALTPP_SEC_CON_ID	Test section identification number.
LAYER_NO	Layer number
CTE	Coefficient of thermal expansion (per °F x 10-6)
Existing_Layer	Existing layer as opposed to a new layer
Unit_Weight	Unit weight (pcf)
Therm_Conduct	Thermal conductivity (BTU/hr-ft-°F)
Poisson_Ratio	Poisson’s ratio
Heat_Capacity	Heat capacity (BTU/lb-°F)
Design	**Concrete pavement design features**
Curl/Warp_Effective_ Temperature_Difference	Permanent curl/warp effective temperature difference (°F)
Joint_Spacing	Joint spacing (ft)
Sealant_Type	Joint sealant type
Dowel_Diameter	Dowel bar diameter (in)
Dowel_Spacing	Dowel bar spacing (in)
Tied_PCC	Identifies the presence of a tied concrete shoulder

Name	Description
Tied_LTE	Load transfer efficiency of the tied concrete shoulder
Widened_Slab	Identifies the presence of a widened lane
Slab_Width	Width of the widened slab (ft)
PCC-Base_Interface	Level of friction between the base and PCC
Base_Erodobility_Index	Base erodobility index
Loss_of_Friction	Loss of full friction (age in months)
Steel_Reinforcement	Percent steel (%)
Reinforcement_Steel_Diameter	Bar diameter (in)
Depth_of_Reinforcement	Steel depth (in)
Base/Slab_Friction_Coefficient	Base/slab friction coefficient
Crack_Spacing	Mean crack spacing (in)
Mix	**Mix design properties**
Cmnt_Typ	Cement type
Cmntitious_Cntnt	Cementitious content
W/C_Ratio	Water-cement ratio
Ultimate_Shrinkage	Ultimate shrinkage
Reverse_Shrink	Reverse shrinkage
Curing_Type	Curing type
Strength	**Strength properties**
Age	Age (yrs)
Elstc_Modulus	Elastic modulus (psi)
Modulus_of_Rupture	Modulus of rupture (psi)
Comp. Strength	Compressive strength (psi)

This table includes a description of each unstabilized/stabilized material data element.

Name	Description
GALTPP_SEC_CON_ID	Test section identification number.
LAYER_NO	Layer number
Last_Layer (semi-infinite)	Identifies layer as the last layer of the pavement section
Bedrock	**Bedrock layer inputs**
Type	Soil type
Unit_Weight	Unit weight (pcf)
Poisson_Ratio	Poisson’s ratio

Name	Description
Resilient_Modulus	Resilient modulus (psi)
Gradation (for each layer)	**Gradation inputs for each unstabilized/stabilized layer**
Passing_3_5	Mean percent passing 3-½ in screen
Passing_3	Mean percent passing 3 in screen
Passing_2_5	Mean percent passing 2-½ in screen
Passing_2	Mean percent passing 2 in screen
Passing_1_5	Mean percent passing 1-½ in screen
Passing_1	Mean percent passing 1 in screen
Passing_3/4	Mean percent passing ¾ in screen
Passing_1/2	Mean percent passing ½ in screen
Passing_3/8	Mean percent passing ⅜ in screen
Passing_#4	Mean percent passing #4 screen
Passing_#8	Mean percent passing #8 screen
Passing_#10	Mean percent passing #10 screen
Passing_#16	Mean percent passing #16 screen
Passing_#20	Mean percent passing #20 screen
Passing_#30	Mean percent passing #30 screen
Passing_#40	Mean percent passing #40 screen
Passing_#50	Mean percent passing #50 screen
Passing_#60	Mean percent passing #60 screen
Passing_#80	Mean percent passing #80 screen
Passing_#100	Mean percent passing #100 screen
Passing_#200	Mean percent passing #200 screen
Passing_0_02mm	Mean percent passing 0.020 mm screen
Passing_0_002mm	Mean percent passing 0.002 mm screen
Passing_0_001mm	Mean percent passing 0.001 mm screen
PI	Plasticity index
LL	Liquid limit
Compacted_Layer	Compacted layer
Stabilized	**Inputs for stabilized layer**
Unit_Wght	Unit weight (pcf
Poisson_Ratio	Poisson’s ratio

Name	**Description**
Elastic/Resilient_Mod	Elastic/resilient modulus (psi)
Minimum_Mod	Minimum elastic/resilient modulus (psi)
Mod_of_Rupture	Modulus of rupture (psi)
Therm_Cndctvty	Thermal conductivity (BTU/hr-ft-°F)
Heat_Capacity	Heat capacity (BTU/lb-°F)
Strength (for each layer)	**Strength inputs for each unstabilized/stabilized layer**
k1	Regression constants (used for Level 1 calculation of MR)
k2	Regression constants (used for Level 1 calculation of MR)
k3	Regression constants (used for Level 1 calculation of MR)
Poisson_Ratio	Poisson’s ratio
Ltrl_Pressure	Lateral pressure
Modulus	Resilient modulus (psi)
CBR	California Bearing Ratio
R_Val	R-Value
Lyr_Coefnt	AASHTO layer coefficient
DCP	Dynamic Cone Penetrometer (mm/blow)

APPENDIX C: STUDIES RELATED TO SMA

Oklahoma

The Oklahoma DOT conducted a study that evaluated and compared the performance of SMA mixes to conventional ODOT S-4 mixes (a Superpave mixture) to determine the performance benefits. Dynamic modulus testing and Hamburg Rut Tests were conducted on S-4 mixes and SMA; performance predicted by the MEPDG was used to evaluate the performance. Hamburg rut depth testing was performed in general accord with OHD L-55. The results showed S-4 mixes had a mean rut depth of 8.41 mm and SMA mixes a mean rut depth of 5.98 mm. SMA mixes had statistically significant lower Hamburg rut depths than S-4 mixes. Dynamic modulus testing was performed at three temperatures and five frequencies in accordance with NCHRP 9-29 PP 02 with the exception of additional test frequencies. The comparisons between SMA and S-4 HMA mixtures at 1 Hz in Figure 26 show that SMA mixes were not as stiff as S-4 HMA mixes at any of the temperatures evaluated. The S-4 mix was 30 to 70 percent stiffer than the SMA mix over the range of temperatures and frequencies tested. SMA, with its lower dynamic modulus, had more total permanent deformation, top-down cracking, bottom-up (alligator) cracking predicted by the MEPDG compared to S-4 mixes. The percent increase in total permanent deformation was not impacted by subgrade resilient modulus and depth to the water table. The lower the subgrade resilient modulus and less depth to water table, the more alligator cracking. Based on the results, the report concluded that it appears that when it comes to asphalt layers, stiffer is better. The MEPDG results seem to go against Hamburg rut test results and published literature on the field performance of the SMA.

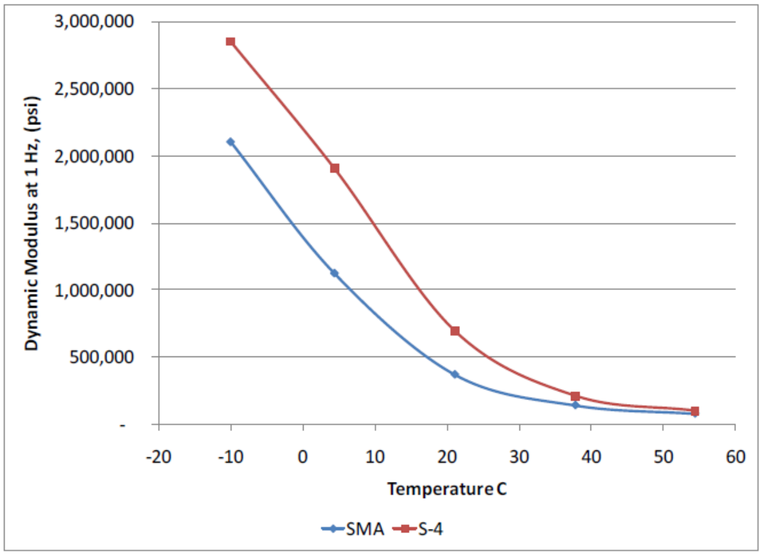

Figure 26. Average SMA and S-4 dynamic modulus, 1 Hz.

Louisiana

A study of Louisiana asphalt mixtures was completed by Mohammad et al., 2007, in which measured E* values of various mixtures were compared with predicted values from the Witczak 1-37A model). The mixtures tested included Superpave mixes designed for high, medium, and low volume roads, SMA mixes, and Marshall mixes. Three types of binder were used: PG 76-22M, PG 70-22M and PG 64-22, of which the first two were modified. We looked at three wearing mixes, including I10-2 (12.5 mm Superpave with PG 76-22), I10-3 (12.5 mm SMA with PG 76-22), and I55-2 (12.5 mm Superpave with PG 82-22) to compare the stiffness of SMA and Superpave. Figure 12 shows dynamic modulus at specific temperature and load frequency. The lab measured dynamic modulus for I10-3 (SMA) was slightly lower than the Superpave with same binder (I-10-2). The lower modulus for SMA was consistent in the master curves shown in Figure 20. In addition, dynamic modulus test results obtained from axial and IDT modes showed no statistical differences for the majority of the mixtures tested.

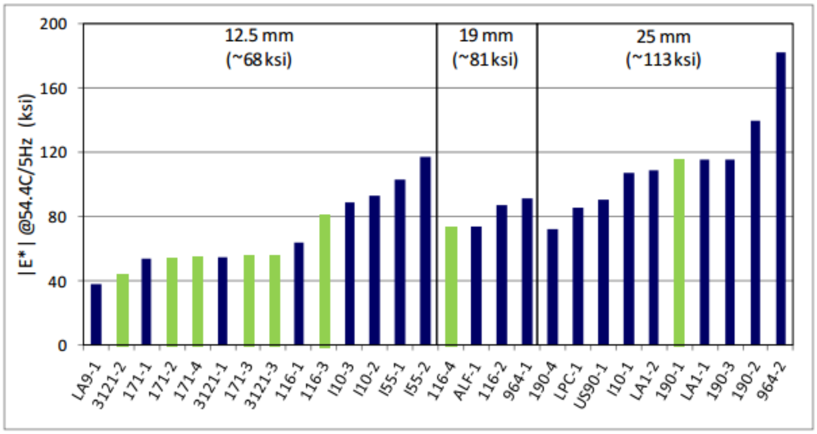

Figure 12
$|E^*|_{54C,\ 5Hz}$ values of mixtures grouped by NMAS

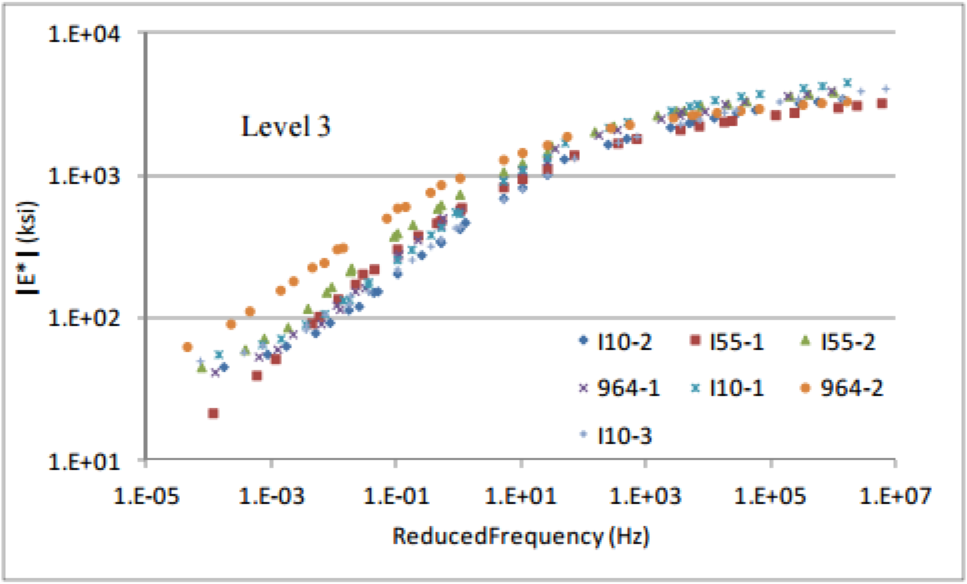

Figure 20
Master curves for Level 3 traffic mixtures

Maryland.

Maryland conducted a study to establish database of material properties for the most common paving materials used in Maryland. The PI found that the Witczak predictive model used for Level 3 dynamic modulus inputs is dominated by temperature influences and does not do a good job of ranking mixtures in terms of their measured stiffness values at a given temperature and loading frequency (Ceylan et al., 2009). In addition, the databases used to develop and calibrate the Witczak and other similar dynamic modulus predictive models contain very few gap-graded

SMA mixtures of the type commonly used on high volume roads in Maryland. The authors concluded the Witczak predictive equation used to generate the Level 2/3 dynamic modulus data is not intended for SMA mixtures, which is a common premium mixture type in Maryland, and often does not adequately differentiate among different dense graded mixtures.

Virginia

|E*| tests were performed with the IPC Global (IPC) 100-UTM universal testing machine in accordance with AASHTO TP 62 (AASHTO, 2007a). Five testing temperatures ranging from 14°F to 130°F and six testing frequencies ranging from 0.1 Hz to 25 Hz were used. The two SMA mixes (08-1025E and 08-1012E) have slightly lower E* compared to the Superpave mixes (08-1036D and 08-1055D).

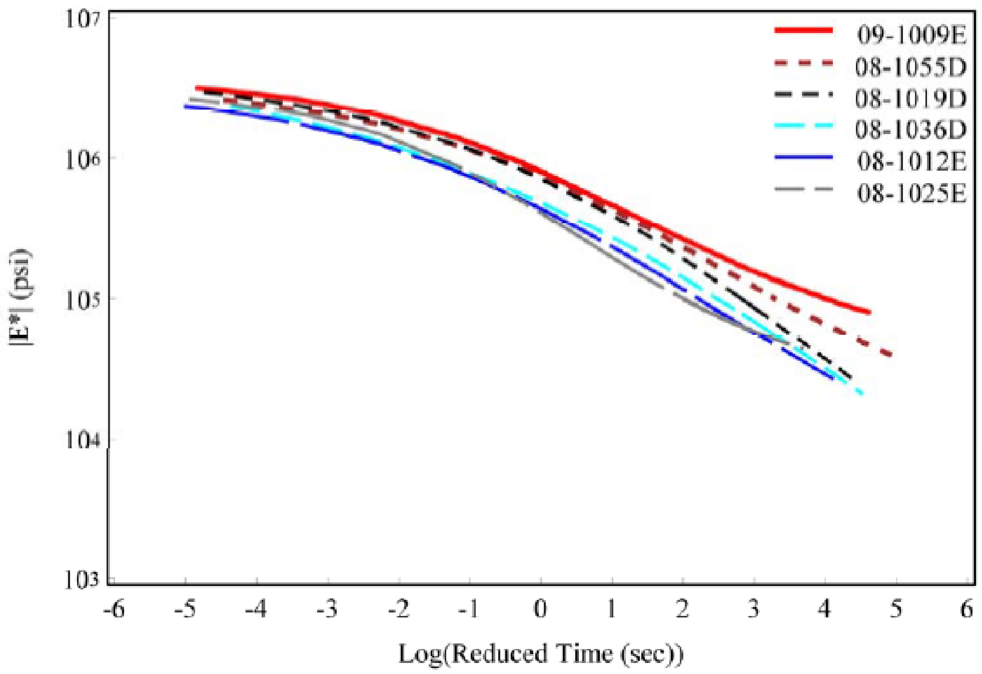

Figure 5. Comparison of Measured |E*| (Level 1) for Six Different Surface Mixtures. Notice the large differences among the mixtures.

Studies (e.g., Sotil et al., 2007) have shown that when tested without confinement, certain gap-graded mixtures, such as SMA mixtures, may have lower |E*| values than dense-graded mixtures. SMA mixtures may, therefore, show lower rutting resistance when modeled in the current

MEPDG software, contrary to the observed superior rutting resistance of SMAs (Michael et al., 2003) in the field. Future studies should, therefore, include confinement to characterize SMA rutting better in the MEPDG when such procedures become standardized.