# EVALUATION OF PAVEMENT ME DESIGN SOFTWARE FOR FLEXIBLE PAVEMENTS

Final Report

Prepared for the Florida Department of Transportation
**Research Project BEA88**

**Darlene C. Goehl**
Research Engineer
Texas A&M Transportation Institute

**Tito Nyamuhokya**
Assistant Research Scientist
Texas A&M Transportation Institute

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# DISCLAIMER

# METRIC CONVERSION TABLE

Notes: 1) volumes greater than 1000 L shall be shown in $m^3$ 2) *SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

| SYMBOL | WHEN YOU KNOW | MULTIPLY BY | TO FIND | SYMBOL | SYMBOL | WHEN YOU KNOW | MULTIPLY BY | TO FIND | SYMBOL |
|---|---|---|---|---|---|---|---|---|---|
| in | inches | 25.4 | millimeters | mm | mm | millimeters | 0.039 | inches | in |
| ft | feet | 0.305 | meters | m | m | meters | 3.28 | feet | ft |
| yd | yards | 0.914 | meters | m | m | meters | 1.09 | yards | yd |
| mi | miles | 1.61 | kilometers | km | km | kilometers | 0.621 | miles | mi |
| $in^2$ | square inches | 645.2 | square millimeters | $mm^2$ | $mm^2$ | square millimeters | 0.0016 | square inches | $in^2$ |
| $ft^2$ | square feet | 0.093 | square meters | $m^2$ | $m^2$ | square meters | 10.764 | square feet | $ft^2$ |
| $yd^2$ | square yard | 0.836 | square meters | $m^2$ | $m^2$ | square meters | 1.195 | square yards | $yd^2$ |
| ac | acres | 0.405 | hectares | ha | ha | hectares | 2.47 | acres | ac |
| $mi^2$ | square miles | 2.59 | square kilometers | $km^2$ | $km^2$ | square kilometers | 0.386 | square miles | $mi^2$ |
| fl oz | fluid ounces | 29.57 | milliliters | mL | mL | milliliters | 0.034 | fluid ounces | fl oz |
| gal | gallons | 3.785 | liters | L | L | liters | 0.264 | gallons | gal |
| $ft^3$ | cubic feet | 0.028 | cubic meters | $m^3$ | $m^3$ | cubic meters | 35.314 | cubic feet | $ft^3$ |
| $yd^3$ | cubic yards | 0.765 | cubic meters | $m^3$ | $m^3$ | cubic meters | 1.307 | cubic yards | $yd^3$ |
| oz | ounces | 28.35 | grams | g | g | grams | 0.035 | ounces | oz |
| lb | pounds | 0.454 | kilograms | kg | kg | kilograms | 2.202 | pounds | lb |
| T | short tons (2000 lb) | 0.907 | megagrams or "metric ton" | Mg or "t" | Mg or "t" | megagrams or "metric ton" | 1.103 | short tons (2000 lb) | T |
| °F | Fahrenheit | 5 (F-32)/9 or (F-32)/1.8 | Celsius | °C | °C | Celsius | 1.8C+32 | Fahrenheit | °F |
| fc | foot-candles | 10.76 | lux | lx | lx | lux | 0.0929 | foot-candles | fc |
| fl | foot-Lamberts | 3.426 | candela/$m^2$ | cd/$m^2$ | cd/$m^2$ | candela/$m^2$ | 0.2919 | foot-Lamberts | fl |
| lbf | pound force | 4.45 | newtons | N | N | newtons | 0.225 | pound force | lbf |
| lbf/$in^2$ | pound force per square inch | 6.89 | kilopascals | kPa | kPa | kilopascals | 0.145 | pound force per square inch | lbf/$in^2$ |

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16. Abstract

This research project is the first step toward Mechanistic-Empirical (ME) Design implementation for flexible pavements in Florida. The Florida Department of Transportation currently uses the American Association of State Highway and Transportation Officials 93 Method for flexible pavement design and is considering changing to the Pavement ME Design Method (PMED) in the future. Before implementation, the PMED must undergo a series of analyses, calibrations, and validation. First, the research team performed PMED sensitivity analysis to determine which failure models are most relevant to Florida using global inputs. After that, the research team evaluated pavement distresses using the Florida-specific parameters. Lastly, the research team developed a work plan that covered the locally based steps for the PMED calibrations and implementation for Florida. Version 2.6 or higher should be used with local calibration of the ME Design Method for flexible pavements. The Version 2.6 and higher versions include an improved top-down cracking model. The omission of the top-down cracking model in the previous versions was the primary reason for delaying implementation of the PMED for flexible pavements in Florida in past years. Implementation is recommended to be delayed until the roadmap Phases 1 and 2 are completed.

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flexible pavement design, mechanistic-empirical, calibration

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No restrictions.

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The cooperation of several state agency representatives in helping the researchers obtain FDOT information is greatly appreciated.

# EXECUTIVE SUMMARY

The American Association of State Highway and Transportation Officials Pavement Mechanistic-Empirical Design Method (PMED) software (AASHTOWare), Version 2.6 implementation, was evaluated for the Florida Department of Transportation (FDOT). A sensitivity analysis was performed using the global calibration factors (default) in the PMED software and was divided into two parts.

The first part covered the sensitivity analysis of typical pavement design inputs to PMED distress models. The design inputs' sensitivities were evaluated using multivariate linear regression models. A matrix was developed to show the input parameter versus the hierarchical level with the sensitivity value defined.

The second part covered the accuracy analysis of the models based on existing pavement design case studies in Florida. The accuracy of each distress model, alligator cracking, longitudinal cracking, transverse cracking, reflection cracking, and permanent deformation, was evaluated to determine the failure models most relevant for Florida. The case studies included the following:

- A pavement design that quickly fails with a specific distress model.
- A pavement design that performs as designed based on Florida pavement design history. Five pavement design reports (SR45, SR483, SR597, SR804, and SR20) and falling weight deflectometer (FWD) data were provided by FDOT as case studies for reference.
- An overdesigned pavement that was anticipated to not fail in a typical design life.

The research team tested FDOT materials and evaluated FWD data to develop Florida-specific inputs.

A three-phased implementation “roadmap” was developed that included the following:

- Phase 1: Evaluation and calibration to Florida-specific criteria
    - PMED target values
    - Traffic data evaluation
    - Local calibration of distress models
    - Reevaluation of sensitivity
- Phase 2: Training
- Phase 3: Maintenance of Design System.

The implementation of Phases 1 and 2 will be a significant investment in both time (over four years) and money (estimated at just over $1.3 million). The research team recommends delaying the implementation until additional research and model calibrations are performed, as described in Phase 1.

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# LIST OF ABBREVIATIONS AND ACRONYMS

| Abbreviation Acronym | Description |
|---|---|
| AADT | Average Annual Daily Traffic |
| AADTT | Annual Average Daily Truck Traffic |
| AASHTO | American Association of State Highway and Transportation Officials |
| AC | Asphaltic Concrete |
| BU-FC | Bottom-Up Fatigue Cracking |
| DM | Dynamic Modulus |
| DSR | Dynamic Shear Rheometer |
| ESALD | Design Equivalent Single-Axle Load |
| FC | Friction Course |
| FDOT | Florida Department of Transportation |
| FPS21 | Texas Flexible Pavement Design System |
| FWD | Falling Weight Deflectometer |
| IDT | Indirect Tensile Strength |
| IRI | International Roughness Index |
| MAAT | Mean Annual Air Temperatures |
| ME | Mechanistic Empirical |
| MERRA | Modern-Era Retrospective Analysis for Research and Applications |
| MVLR | Multivariate Linear Regression models |
| PCS | Pavement Condition Survey |
| PD-AC | Permanent Deformation, Asphaltic Cement |
| PD-T | Permanent Deformation, Total Pavement |
| PG | Performance Grade |
| PMED | Pavement Mechanistic-Empirical Design |
| RAP | Recycled Asphalt Pavement |
| SC | Structural Course |
| SMO | State Materials Office |
| SN | Structural Number |
| SP | Superpave |
| TC | Thermal Cracking |
| TD-FC | Top-Down Fatigue Cracking |
| TTI | Texas A&M Transportation Institute |
| TxDOT | Texas Department of Transportation |
| ULS | Unbound Layers and Subgrade |

# CHAPTER 1
# INTRODUCTION

## PROBLEM STATEMENT

This research project was the first necessary step to mechanistic-empirical (ME) design implementation for flexible pavements in Florida. The Florida Department of Transportation (FDOT) uses the American Association of State Highway and Transportation Officials (AASHTO) 93 Method for flexible pavement design. FDOT is considering changing to the ME Design Method in the future.

The pavement design software that FDOT desires to use for ME design is AASHTOWare Pavement ME Design (PMED). Previously, FDOT decided to delay any further research for the implementation of ME Design for flexible pavements until improvements were made to the top-down cracking model in PMED. National research was recently completed that developed an improved top-down cracking model, which has been incorporated into the latest version of PMED (Version 2.6).

FDOT is ready to begin the process of evaluating the implementation of the ME Design Method for flexible pavements, specifically with PMED Version 2.6. Therefore, in order to make an informed decision on whether to change design methods, this research was needed.

## RESEARCH GOALS AND SCOPE

This research provides the first step for the implementation of ME design for flexible pavements in Florida. As such, a full understanding of the implications of switching design methodologies is imperative. This requires a comparison of the two design methods: AASHTO 93 Method and ME Design Method. Additionally, a comparison of predicted versus observed distresses were necessary to understand the accuracy level of PMED Version 2.6. Therefore, the objectives of this research were as follows:

2. Compare the AASHTO 93 Method and the ME Design Methods for flexible pavement. FDOT's *Flexible Pavement Design Manual* was used for the AASHTO 93 Method, and PMED Version 2.6 (using global calibration) was used for the ME Design Method.

3. Compare predicted distresses (from PMED Version 2.6 using global calibration) to observed distresses (documented in FDOT's Pavement Condition Survey [PCS] Database).

4. Provide recommendations for Florida-specific input parameters for PMED Version 2.6.

5. If deemed necessary, provide a plan to accomplish the local calibration of PMED Version 2.6. (Local calibration will be completed, if necessary, outside of and subsequent to this project).

## RESEARCH OUTLINE

In order to achieve the research goals, three main tasks were performed by the research team and are described in more detail in Chapter 2 through Chapter 4. The following is a summary of the main research tasks:

1. PMED Sensitivity Analysis. The global calibration factors (default) in PMED Version 2.6 were used to perform a sensitivity analysis. An analysis of the input parameters and the distress models was performed.

    a While the most common type of flexible pavement failure in Florida is top-down cracking, it was necessary to understand the accuracy of each of the distress models within PMED Version 2.6. The distress models include alligator cracking (bottom-up), longitudinal cracking (top-down), transverse cracking, reflection cracking, and rutting.

    b The research team determined which failure models were most relevant to Florida and provided recommendations on whether local calibration of any or all distress models should be pursued with future research.

    The critical inputs for Florida in PMED Version 2.6 were determined, and recommendations were provided on the use of hierarchical input levels 1, 2, or 3 (as defined in the 2020 *Mechanistic-Empirical Pavement Design Guide*) for each input parameter. Refer to Chapter 2 for more details.

2. Develop Florida-Specific Input Parameters. The outcomes of analyses performed in Task 1 were used to determine which Florida-specific parameters needed to be developed for a Level 2 hierarchical input. (Level 1 will be project-specific, and Level 3 has default values from the program, so recommendations are not necessary for those levels.) FDOT provided asphaltic concrete pavement materials for laboratory testing, which was performed by the research team. Refer to Chapter 3 for more details.

3. Develop a Work Plan. A “roadmap” for the remaining steps necessary to complete the local calibration for PMED Version 2.6 for flexible pavements in Florida was developed. Refer to Chapter 4 for more details.

# CHAPTER 2
# PMED SENSITIVITY ANALYSES

## SENSITIVITY ANALYSIS OVERVIEW

The objective was to perform sensitivity analyses using the global calibration factors (default) in the AASHTOWare PMED software Version 2.6. The results of the sensitivity analyses were used to develop recommendations for the critical inputs for Florida in PMED Version 2.6. and to provide recommendations for each input parameter using hierarchical input levels 1, 2, or 3, as defined in the 2020 *Mechanistic-Empirical Pavement Design Guide*.

The methodology to accomplish this task's goals was divided into two parts. The first part covers the sensitivity analysis of typical pavement design inputs to PMED distress models. The second part covers the accuracy analysis of the model based on existing pavement design case studies in Florida.

## SENSITIVITY ANALYSIS METHODOLOGY

### *Typical Pavement Design Inputs*

The design inputs' sensitivity was evaluated using multivariate linear regression models (MVLR). The coefficient of the MVLR models estimated the sensitivity of the pavement input parameters in PMED Version 2.6. Each input parameter was evaluated for use in the hierarchical input levels. A matrix was developed to show the input parameter versus the hierarchical level with the sensitivity value defined.

Since the ME design and analysis is based on the accumulation of damage as a function of climate and traffic loadings over time, a matrix of different climactic and loading levels was used in the sensitivity analysis.[1] Table 2-1 contains the traffic levels evaluated and their corresponding design equivalent single axle load ($ESAL_D$). The levels are based on Chapter 5.6.5, “Traffic Levels” of Florida's *Flexible Pavement Design Manual*, including revisions to the manual that occurred during the study. The FDOT research team was instrumental in ensuring that the researchers had the most up to date information concerning changes in the manual.

**Table 2-1. FDOT Updated Traffic Levels.[2]**

| AASHTO Design $ESAL_D$ Range (Million) | Traffic Level |
|---|---|
| 0 to < 3 | B |
| 3 to < 10 | C |
| ≥ 10 | E |

The sensitivity ranges were developed based on combinations of the following scenarios:

1. Two-way annual average daily truck traffic (AADTT): The 18-kip ESAL ranges are based on the FDOT traffic levels. The design charts in the FDOT *Flexible Pavement Design Manual* are in 500,000, 18k ESAL increments for lower levels, then increase to 1,000,000, 18k ESAL increments.[2]

2. Pavement Material: The FDOT construction specifications book *Standard Specifications for Road and Bridge Construction 2021* was used to develop the ranges for various material inputs.

The research team assessed new flexible pavement designs with the PMED default distress levels. The criteria for a new flexible pavement used for each model is shown in Table 2-2.

**Table 2-2. PMED Distress Levels.**

| Criteria | Threshold | Unit |
|---|---|---|
| Reliability (R) | 90 | percent (%) |
| Terminal International Roughness Index (IRI) | 172 | inches per mile |
| Asphalt Concrete (AC) top-down fatigue cracking (TD-FC) | 25 | % of lane area (%LA) |
| AC bottom-up, fatigue cracking (BU-FC) | 35 | %LA |
| AC thermal cracking (TC) | 1000 | feet per mile |
| Permanent deformation in total pavement (PD-T) | 0.75 | inches |
| Permanent deformation in AC only (PD-AC) | 0.25 | inches |

The sensitivity analysis performed focused on the effects of the range of FDOT pavement design input parameters on distress models in the PMED. Table 2-3 shows the pavement design input range used in the sensitivity analysis. The thermal cracking model formula changes at a mean annual air temperature (MAAT) of 57°F. To display the effects of the changes, the climatic data of Champaign, Illinois, was used in a few runs to show the sensitivity of the thermal cracking model for MAAT below 57°F.

**Table 2-3. Pavement Design Input Ranges.**

| Parameters | Minimum | Maximum |
|---|---|---|
| AADTT | 1941 | 7781 |
| Posted Speed (mph) | 30 | 80 |
| Growth Rate (%) | 2 | 4 |
| Depth to the Water Table (ft) | 2 | 14 |
| Climate | Miami, Florida | Champaign, Illinois |
| AC Thickness (inch) | 1.0 | 12 |
| Air Voids (%) | 2.0 | 6 |
| AC Binder Performance Graded (PG) | PG70-22 | PG76-22 |
| AC Effective Binder Content (%) | 7 | 15 |
| AC Percent Binder Content by weight (%) | 4 | 8 |
| AC Dynamic Modulus (DM) Input Level | Level 3 | Level 1[1] |
| Base Thickness (inch) | 4 | 14 |
| Base Resilient Modulus (psi) | 18,000 | 70,000 |
| Base Poisson's Ratio | 0.3 | 0.4 |
| Sub-base Thickness (inch) | 6 | 15 |
| Sub-base Resilient Modulus (psi) | 10000 | 50000 |
| Sub-base Poisson's Ratio | 0.3 | 0.4 |
| Sub-grade Resilient Modulus (psi) | 5000 | 30000 |
| Sub-grade Poisson's Ratio | 0.3 | 0.4 |

[1] Level 1 dynamic modulus (DM) and Dynamic Shear Rheometer (DSR) inputs, see Table 2-4.

**Table 2-4: Level 1 Input for AC DM and DSR.**

| Dynamic Modulus (psi) | | | | | Dynamic Shear Rheometer | |
|---|---|---|---|---|---|---|
| Temp °F | Frequency (Hz) | | | | G* (Pa) | δ |
| | 0.1 | 1 | 10 | 25 | | |
| 14 | 3172667 | 4078333 | 4795000 | 4984333 | | |
| 40 | 1533000 | 2268000 | 3043333 | 3304333 | | |
| 70 | 188000 | 509000 | 1034333 | 1319000 | | |
| 100 | 26000 | 64333.33 | 230666.7 | 375000 | | |
| 130 | 12666.67 | 20333.33 | 69666.67 | 128666.7 | | |
| 136 | | | | | 13600 | 81.2 |
| 147 | | | | | 5620 | 83.72 |
| 158 | | | | | 2470 | 85.5 |
| 169 | | | | | 1110 | 87 |

### *Accuracy of PMED Distress Models*

The accuracy of each distress model, alligator cracking (BU-FC), longitudinal cracking (TD-FC), transverse cracking, reflection cracking, and permanent deformation within PMED Version 2.6 was evaluated to determine the failure models most relevant for Florida. Recommendations were developed for further evaluation of the distress models using local calibrations.

The following pavement design constraints were used to evaluate the distress models:

1. A pavement design that quickly fails with a specific distress model.
2. A pavement design that performs as designed based on Florida pavement design history. Three pavement design reports (SR45, SR483, SR597) and FWD data were provided by FDOT as case studies for reference. Two additional project reports and FWD data for SR 804 and SR20 were provided after the initial evaluation of the first three case studies.
3. An overdesigned pavement that was anticipated to not fail in a typical design life.

## SENSITIVITY ANALYSIS RESULTS

### *Typical Pavement Design Inputs*

The sensitivities based on the MVLR analysis of input parameters were grouped into five levels which were separated by one standard deviation, as shown in Table 2-5. The sensitivities of each design input against the distress models were evaluated based on the standard deviation grouping and are shown in Table 2-6.

**Table 2-5. Sensitivity Analysis Descriptions.**

| Description | Abbreviation | Levels |
|---|---|---|
| Moderately Sensitive | Mod-S | < 1 standard deviation |
| Sensitive | S | 1–2 standard deviations |
| Extra Sensitive | Extra-S | 2–3 standard deviations |
| Very Sensitive | VS | 3–4 standard deviations |
| Extremely Sensitive | Xtrm-S | 4–5 standard deviations |

**Table 2-6. Distress Model Input Sensitivity.**

| Input | PD-T | PD-AC | FC-BU | FC-TD | IRI | TC |
|---|---|---|---|---|---|---|
| AC Air Voids | Mod-S | VS | Mod-S | Mod-S | S | S |
| AC Binder Content (%) by weight | Mod-S | S | S | Mod-S | Mod-S | Mod-S |
| AC Binder PG grade | Mod-S | Mod-S | Mod-S | Mod-S | Mod-S | Mod-S |
| AC Effective Binder | Mod-S | Extra-S | Mod-S | Mod-S | Mod-S | Mod-S |
| AC Modulus | Mod-S | Mod-S | Mod-S | Xtrm-S | Mod-S | Mod-S |
| AC Thickness | S | Mod-S | S | S | S | Mod-S |
| Base Poisson's Ratio | S | Extra-S | Extra-S | Mod-S | S | S |
| Base Resilient Modulus | Mod-S | S | Mod-S | Mod-S | Mod-S | Mod-S |
| Base Thickness | Mod-S | Mod-S | S | Mod-S | Mod-S | Mod-S |
| Posted Speed | Mod-S | Extra-S | Mod-S | Mod-S | Mod-S | Mod-S |
| Sub-base Poisson's Ratio | Mod-S | Mod-S | Mod-S | Mod-S | Extra-S | Mod-S |
| Sub-base Resilient Modulus | Mod-S | Mod-S | Extra-S | Mod-S | Mod-S | S |
| Sub-base Thickness | Mod-S | S | Mod-S | Mod-S | S | Extra-S |
| Sub-grade Poisson's Ratio | S | Extra-S | Mod-S | Mod-S | Mod-S | Extra-S |
| Sub-grade Resilient Modulus | Xtrm-S | VS | VS | S | VS | VS |
| Traffic Growth Rate | Mod-S | Mod-S | S | Mod-S | S | Mod-S |
| Traffic | Extra-S | Mod-S | Mod-S | S | Extra-S | Extra-S |
| Water Table | Mod-S | Mod-S | Mod-S | Mod-S | Mod-S | Mod-S |

### *Accuracy of PMED Distress Models*

Initially, the research team used three FDOT pavement projects (SR 483, SR45, and SR597) to compare the PMED, AASHTO93, and the Texas Department of Transportation (TxDOT) design methods. Two FDOT pavement projects (SR20 and SR804) were analyzed later in the project. The design life of all of the projects is 20 years. In addition, the research team incorporated a weather station using the modern-era retrospective analysis for research and applications (MERRA) data in Middleburg, Florida (MERRA_ID_132638).

The following software programs and procedures developed by the Texas A&M Transportation Institute (TTI) for TxDOT were used as part of the TxDOT design method:

- Modulus 7.0 was used to back-calculate the layer modulus for the FDOT projects from the FWD data provided by FDOT. The subgrade depth used is an estimated depth to bedrock.
- Texas flexible pavement design system (FPS21) was used to design the pavement structure with checks for total pavement rutting and fatigue cracking.
- Texas ME check (TxDOT Mechanistic Empirical Design check) was used to evaluate the fatigue cracking and rutting potential over a 20-year life.

Table 2-7 shows the input traffic and climatic conditions used in the design methods along with specific information found in each of the case studies' pavement design reports. The number of trucks was calculated from the average annual daily traffic (AADT) and percentage of trucks.

**Table 2-7. Design Comparison: Traffic and Weather Inputs.**

| Highway | SR483 | SR45 | SR597 |
|---|---|---|---|
| Proposed Work | mill/replace 2.5 inch | mill/replace 2.25 inch to 3.25 inch | mill/replace 2.25 inch |
| Traffic Data | Traffic Level "B"<br>0 to <3,000,000 | Traffic Level "C"<br>3,000,000 to <10,000,000 | Traffic Level "C"<br>3,000,000 to <10,000,000 |
| Begin AADT | 8,300 to 36,800 | 34,500 | 21,500 |
| End AADT | 9,750 to 43,200 | 42,500 | 30,100 |
| Growth Rate | 0.92% | 1.22% | 2.11% |
| % Trucks | 4% to 5.2% | 9% | 18% |
| Number of Trucks[2] | 432 to 1472 | 3105 | 3870 |
| Est. 20 yr. ESAL | 1,585,000 to 3,371,000 | 8,513,000 | 4,757,000 |
| Climate | Middleburg, FL | Middleburg, FL | Middleburg, FL |
| Depth to Water Table[1] | 4 feet | 0.5 feet | 0.5 feet |

1. The depth to water table was obtained from the United States Department of Agriculture's web soil survey (https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm).
2. For SR483, the number of trucks was determined from the FDOT provided pavement design reports indicating that the 432 trucks was determined from an 8,300 AADT with 5.2% trucks and the 1472 trucks was determined from 36,800 AADT with 4% trucks.

Table 2-8 contains the layer coefficient (a), layer thicknesses (D), and structural number (SN) based on the current FDOT design procedures. The AC layer material descriptions are friction course (FC) and structural course (SC). The subgrade depth to bedrock is noted since it is used in the FPS21 design method. The comparison of the results from the design methods are shown in Table 2-9. The asphaltic concrete modulus is not shown since the layer temperature at time of testing is needed to normalize the layer modulus.The FC/SC modulus is not shown since the layer temperature at time of testing is needed to normalize the layer modulus.

Table 2-9 For SR483, both level 1 (LV1) and level 3 (LV3) inputs were used in the PMED procedure. The conclusions drawn from the sensitivity analysis based on the influence of pavement input variables on PMED distress models are described for each model after Table 2-9.

**Table 2-8. Design Comparison: Layer Thickness and Structural Number.**

| Highway | SR483 | | | | SR45 | | | | SR597 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Material | FWD Modulus (E) (ksi) | a | D (inch) | a*D | FWD Modulus (ksi) | a | D (inch) | a*D | FWD Modulus (ksi) | a | D (inch) | a*D |
| FC/SC | E[1] | 0.4 | 3.5 | 1.54 | E[1] | 0.44 | 5.5 | 2.42 | E[1] | 0.44 | 4.5 | 1.98 |
| Base | 142 | 0.2 | 10 | 1.8 | 85 | 0.18 | 9.5 | 1.71 | 136 | 0.18 | 8.5 | 1.53 |
| Stabilized Subgrade | 42 | 0.1 | 12 | 0.96 | 40 | 0.08 | 12 | 0.96 | 38 | 0.08 | 12 | 0.96 |
| SN | | | SN | 4.3 | | | SN | 5.09 | | | SN | 4.47 |
| Subgrade at Depth to Bedrock | 12.7 | | 120 | 0 | 18.2 | | 133 | 0 | 22.6 | | 120 | 0 |

1. The FC/SC modulus is not shown since the layer temperature at time of testing is needed to normalize the layer modulus.

**Table 2-9. Comparison of All Design Methods.**

<table>
<tr><th colspan="2">Highway</th><th></th><th colspan="3">SR 483</th><th colspan="3">SR45</th><th colspan="3">SR597</th></tr>
<tr><td rowspan="8">AASHTO ME</td><td></td><td>Target</td><td colspan="2">Predicted<br>(LV3|LV1)</td><td>Result</td><td colspan="2">Predicted</td><td>Result</td><td colspan="2">Predicted</td><td>Result</td></tr>
<tr><td>Terminal IRI (inch per mi.)</td><td>172</td><td colspan="2">163.75 | 160.34</td><td>Pass</td><td colspan="2">164.57</td><td>Pass</td><td colspan="2">167.56</td><td>Pass</td></tr>
<tr><td>PD-T (inch)</td><td>0.75</td><td colspan="2">0.36 | 0.32</td><td>Pass</td><td colspan="2">0.38</td><td>Pass</td><td colspan="2">0.45</td><td>Pass</td></tr>
<tr><td>AC BU-FC (%LA)</td><td>25</td><td colspan="2">1.45 | 1.45</td><td>Pass</td><td colspan="2">1.46</td><td>Pass</td><td colspan="2">1.56</td><td>Pass</td></tr>
<tr><td>AC thermal cracking (ft./mi.)</td><td>1000</td><td colspan="2">3197 | 3197</td><td>Fail</td><td colspan="2">3197.38</td><td>Fail</td><td colspan="2">3197.38</td><td>Fail</td></tr>
<tr><td>AC TD-FC (%LA)</td><td>25</td><td colspan="2">13.86 | 4.69</td><td>Pass</td><td colspan="2">14.06</td><td>Pass</td><td colspan="2">14.11</td><td>Pass</td></tr>
<tr><td>PD-AC, (inch)</td><td>0.25</td><td colspan="2">0.13 | 0.15</td><td>Pass</td><td colspan="2">0.13</td><td>Pass</td><td colspan="2">0.15</td><td>Pass</td></tr>
<tr><td>ESAL$_D$ estimate</td><td></td><td colspan="2">6.62 million</td><td>high</td><td colspan="2">9.99 million</td><td>high</td><td colspan="2">13.39 million</td><td>high</td></tr>
<tr><td rowspan="3">AASHTO93</td><td>SN</td><td></td><td colspan="3">4.3</td><td colspan="3">5.09</td><td colspan="3">4.47</td></tr>
<tr><td>Min SN Required</td><td></td><td colspan="3">4.1</td><td colspan="3">3.57</td><td colspan="3">2.97</td></tr>
<tr><td>Design</td><td></td><td colspan="3">Exceeds Required SN</td><td colspan="3">Exceeds Required SN</td><td colspan="3">Exceeds Required SN</td></tr>
<tr><td rowspan="6">Texas Design Methods</td><td>FPS21 Time to First Overlay</td><td></td><td colspan="3">31 years (high ESAL)</td><td colspan="3">13 years</td><td colspan="3">25 years</td></tr>
<tr><td>FPS21 ME Check</td><td></td><td colspan="3">Rut and Crack Ok</td><td colspan="3">Rut and Crack Ok</td><td colspan="3">Rut and Crack Ok</td></tr>
<tr><td>FPS21 Modified Triaxial Check</td><td></td><td colspan="3">Design Is Ok (Rutting)</td><td colspan="3">Design Is Ok (Rutting)</td><td colspan="3">Design Is Ok (Rutting)</td></tr>
<tr><td>Texas ME Check at 95% Reliability</td><td></td><td>Result</td><td>Month</td><td>Year</td><td>Result</td><td>Month</td><td>Year</td><td>Result</td><td>Month</td><td>Year</td></tr>
<tr><td>AC FC Area (%)</td><td></td><td>25%</td><td>165</td><td>13.8</td><td>25%</td><td>204</td><td>17</td><td>25%</td><td>144</td><td>12</td></tr>
<tr><td>Total Rut Depth (inch)</td><td></td><td>0.39</td><td>240</td><td>20</td><td>0.5</td><td>134</td><td>11.2</td><td>0.5</td><td>218</td><td>18.2</td></tr>
</table>

## Fatigue Cracking

The FDOT case studies, which were modeled in PMED, did not fail in top-down cracking. Nevertheless, the pavements should have failed since the distress existed in the field. Additionally, the PMED predicted higher ESALs than were found in the case study reports for all projects; nevertheless, the pavements did not fail in top-down cracking.

The Mechanistic-Empirical Pavement Design Guide indicates that the longitudinal cracking should be in feet per mile; however, the software requires the percentage of lane area. Also, the top-down cracking is by default limited at 25 percent of the lane area. This value looks to be high based on the graph in the Top-Down Cracking Enhancement addendum, which compares the measured and predicted area of top-down cracking (Figure 2-1).

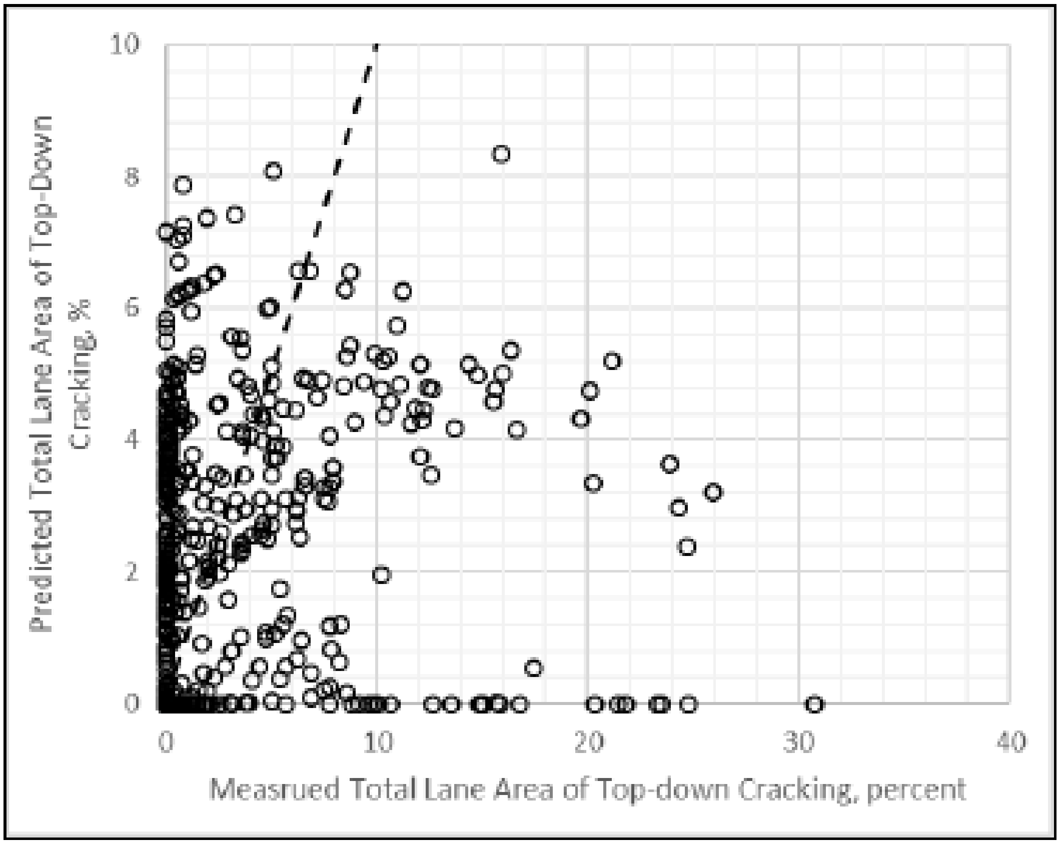
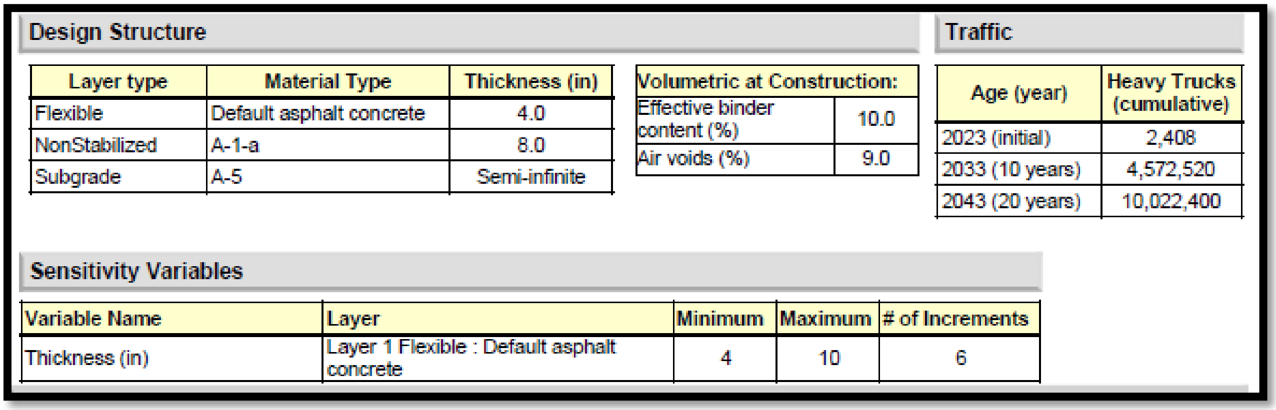


Figure 5.3. Measured versus Predicted Area of Top-Down Cracking

**Figure 2-1. Long-Term Pavement Performance Data.[3]**

Worst case scenarios were input into the PMED to attempt to force top-down cracking failure. The AC air void was increased to 9 percent, AC content was lowered to 4 percent, and PG binder PG64-22 was used. The design criteria and sensitivity variables are shown in Figure 2-2. Examples of the design results with a 4-inch and 10-inch AC layer (AC layers ranged from 2 inches to 10 inches) are shown in Figure 2-3. None of these designs failed at the 25 percent criteria recommended, with the worst case at about 15 percent of the lane area. In contrast, FDOT has indicated that top-down cracking is one of the significant distress types in Florida flexible pavements. Therefore, to predict results that are closer to field observations in Florida, higher level material input (i.e., dynamic modulus of the AC) and distress models' local calibrations will be needed.



Design Structure

| Layer type | Material Type | Thickness (in) |
|---|---|---|
| Flexible | Default asphalt concrete | 4.0 |
| NonStabilized | A-1-a | 8.0 |
| Subgrade | A-5 | Semi-infinite |

| Volumetric at Construction: | |
|---|---|
| Effective binder content (%) | 10.0 |
| Air voids (%) | 9.0 |

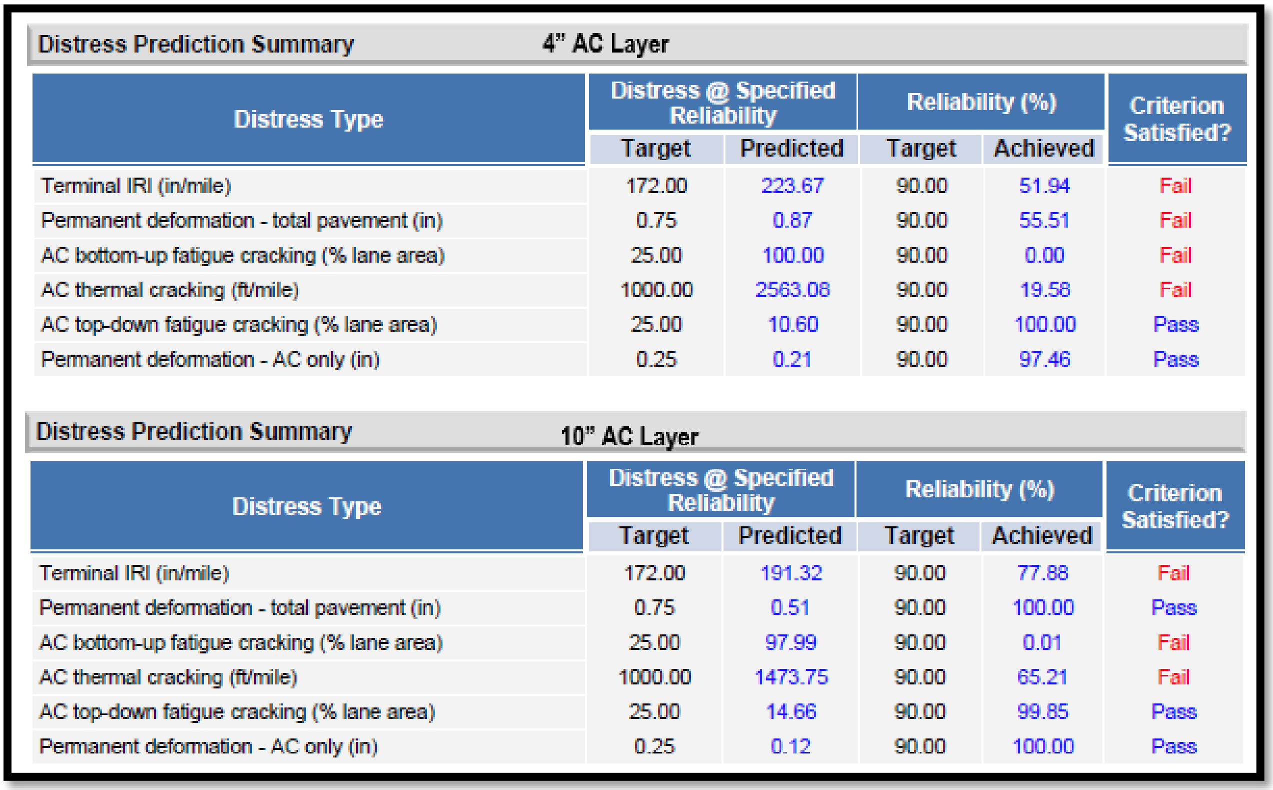
Traffic

| Age (year) | Heavy Trucks (cumulative) |
|---|---|
| 2023 (initial) | 2,408 |
| 2033 (10 years) | 4,572,520 |
| 2043 (20 years) | 10,022,400 |

Sensitivity Variables

| Variable Name | Layer | Minimum | Maximum | # of Increments |
|---|---|---|---|---|
| Thickness (in) | Layer 1 Flexible : Default asphalt concrete | 4 | 10 | 6 |

Figure 2-2. AC Design Sensitivity Variables.



Distress Prediction Summary 4" AC Layer

| Distress Type | Distress @ Specified Reliability | | Reliability (%) | | Criterion Satisfied? |
|---|---|---|---|---|---|
| | Target | Predicted | Target | Achieved | |
| Terminal IRI (in/mile) | 172.00 | 223.67 | 90.00 | 51.94 | Fail |
| Permanent deformation - total pavement (in) | 0.75 | 0.87 | 90.00 | 55.51 | Fail |
| AC bottom-up fatigue cracking (% lane area) | 25.00 | 100.00 | 90.00 | 0.00 | Fail |
| AC thermal cracking (ft/mile) | 1000.00 | 2563.08 | 90.00 | 19.58 | Fail |
| AC top-down fatigue cracking (% lane area) | 25.00 | 10.60 | 90.00 | 100.00 | Pass |
| Permanent deformation - AC only (in) | 0.25 | 0.21 | 90.00 | 97.46 | Pass |

Distress Prediction Summary 10" AC Layer

| Distress Type | Distress @ Specified Reliability | | Reliability (%) | | Criterion Satisfied? |
|---|---|---|---|---|---|
| | Target | Predicted | Target | Achieved | |
| Terminal IRI (in/mile) | 172.00 | 191.32 | 90.00 | 77.88 | Fail |
| Permanent deformation - total pavement (in) | 0.75 | 0.51 | 90.00 | 100.00 | Pass |
| AC bottom-up fatigue cracking (% lane area) | 25.00 | 97.99 | 90.00 | 0.01 | Fail |
| AC thermal cracking (ft/mile) | 1000.00 | 1473.75 | 90.00 | 65.21 | Fail |
| AC top-down fatigue cracking (% lane area) | 25.00 | 14.66 | 90.00 | 99.85 | Pass |
| Permanent deformation - AC only (in) | 0.25 | 0.12 | 90.00 | 100.00 | Pass |

Figure 2-3. Design Results (Designed to Fail).

### Rutting

It was not anticipated that the FDOT typical pavement designs would fail in rutting. Adjustments were made to thin both the AC and base layers, including removing the subbase layer, yet the designs still passed.

### Thermal Cracking/Transverse Cracking

This distress has not been observed in Florida and is not anticipated based on Florida's climate. All of Florida has MAAT greater than 57°F. There is a formula change in PMED when the MAAT is greater than 57°F. Therefore, when the MAAT is greater than 57°F, the PMED model (at global settings) does not accurately predicting thermal cracking.

Since thermal cracking is not observed in the pavement, the formula overpredicts the thermal cracking on all case studies analyzed (SR 483, SR45, and SR597). While this distress is not typically a problem in Florida, it indirectly affects terminal IRI in the MEPD analysis. Because of the overpredicted thermal cracking, terminal IRI becomes rougher. Local calibration may be needed to provide improved predictions. Until local calibrations can be performed, a low level of reliability for this model should be used to minimize the impacts to the IRI. Table 2-10 is an example of a comparison for SR-597 using a Florida weather station (MAAT > 57°F) and an Illinois weather station (MAAT < 57°F).

**Table 2-10. Hot and Cold Climate Comparison for SR597.**

| | |
|---|---|
| Highway | SR597 |
| County | Hillsborough |
| Latitude | 28.093148 |
| Longitude | −82.502363 |
| Depth water table (ft.) | 0.5 to 1 |
| Proposed Work | mill/replace 2.25 inch |
| Begin AADT | 21,500 |
| End AADT | 30,100 |
| Growth Rate | 2.11% |
| % Trucks | 18% |
| No. of Trucks | 3870 |
| Est. 20 yr. ESAL | 4,757,000 |

| AASHTO ME Results | Target | Predicted | Result | Predicted | Result |
|---|---|---|---|---|---|
| Climate: Weather Station Locations | | Middleburg, FL | Middleburg, FL | Champagne, IL | Champagne, IL |
| Terminal IRI (inches per mi.) | 172 | 167.56 | Pass | 153.5 | Pass |
| Permanent deformation in total pavement (inch) | 0.75 | 0.45 | Pass | 0.41 | Pass |
| AC bottom-up fatigue cracking (% lane area) | 25 | 1.56 | Pass | 1.46 | Pass |
| AC thermal cracking (ft. per mi.) | 1000 | 3197.38 | Fail | 307.49 | Pass |
| AC top-down fatigue cracking (% lane area) | 25 | 14.11 | Pass | 14.23 | Pass |
| Permanent deformation in AC only (inch) | 0.25 | 0.15 | Pass | 0.11 | Pass |
| Design ESAL estimate | | 13.39 mill | high | 13.39 mill | high |

### IRI

The results of the IRI distress model depend on initial IRI, fatigue cracking, thermal cracking, and permanent deformation. The PMED thermal cracking model predicts higher values than are expected in Florida; therefore, the predicted IRI values are impacted. This was shown to be the case in the previous example for SR597 in Table 2-10 when the Illinois weather station data indicated less thermal cracking and lower IRI than the Florida weather station.

## SENSITIVITY ANALYSIS SUMMARY

### *Distress Models*

The PMED predicted results were not the anticipated results based on PMED computations and the historical performance of the pavement designs modeled (including Florida project case studies). The following are notable concerns with the distress models:

- Thermal cracking failed in all runs when Florida weather stations were used.
- Higher than anticipated thermal cracking impacted the IRI estimate, which resulted in rougher estimates of ride quality.
- Overall, the designs that were anticipated to fail did not fail. Therefore, more work is needed to develop local calibration factors and higher-level inputs may be needed (depending on local calibration) to predict distresses more accurately. A revised sensitivity analysis should be performed after local calibration factors are developed to ensure a complete understanding of the local calibrations.

### *PMED Inputs*

For the PMED traffic inputs, the growth rate was determined based on the current and future AADT, while the number of trucks was estimated from the AADT and the percent of trucks provided. The remainder of the traffic data was based on the default PMED values. This resulted in ESALs higher than those estimated for the case studies (in all cases) provided by FDOT. Based on the increased ESALs estimated, all designs should have failed in fatigue cracking before the end of the design life. The following is an example from the SR45 case study:

- The SR45 FDOT pavement report estimated 8,513,000 ESALs, equating to a composite truck factor of 0.67.
- The PMED estimated 9,990,000 ESALs, which equates to a composite truck factor of 0.78.
- This means that the traffic in the default axle load spectrum does not have the same truck type and weight distribution as was estimated when determining the composite truck factor in the FDOT design report.

A detailed analysis of Florida traffic data should be performed to ensure that the default values are reasonable.

The hierarchical input level 1, 2, and 3 (as defined in the 2020 *Mechanistic-Empirical Pavement Design Guide*) recommendations for each input parameter are shown in Table 2-11. Hierarchical input levels should be further evaluated once local calibration factors are improved. The following are the input level definitions:

- *"**Input Level 1**: Input parameter is measured directly; it is site- or project-specific. This level represents the greatest knowledge about the input parameter for a specific project but has the highest testing and data collection costs to determine the input value. Level 1 is used for pavement designs with unusual site features, materials, or traffic conditions outside the inference-space used to develop the correlations and defaults included for input Levels 2 and 3.*
- ***Input Level 2**: Input parameter is estimated from correlations or regression equations. In other words, the input value is calculated from other site-specific data or parameters that are less costly to measure. Input Level 2 also represents measured regional values that are not project-specific.*
- ***Input Level 3**: Input parameter is based on "best-estimated" or default values. Level 3 inputs are based on global or regional default values—the median value from a*

*group of data with similar characteristics. This input level has the least knowledge about the input parameter for the specific project but has the lowest testing and data collection costs."* [4]

**Table 2-11. FDOT Input Levels—Traffic Data, Climate, and Pavement Layers.**

| Input Group and Input Parameter | PMED Typical Input Level [4] | FDOT Input Level |
|---|---|---|
| Truck Traffic: Axle load distributions (single, tandem, tridem) | Level 1 | Level 1[1] |
| Truck volume distribution | Level 1 | Level 3 |
| Lane and directional truck distributions | Level 1 | Level 3 |
| Tire pressure | Level 3, default | Level 3 |
| Axle configuration, tire spacing | Level 3, default | Level 3 |
| Truck wander | Level 3, default | Level 3 |
| Growth rate | n/a | Level 1 or 2[1] |
| Climate: Temperature, wind speed, cloud cover, precipitation, relative humidity | Level 1 weather stations | Level 1[2] |
| AC dynamic modulus | Level 3, defaults | Level 3 |
| AC creep compliance and indirect tensile strength | Levels 1, 2, and 3 | Level 1,2 |
| AC volumetric properties | Level 1 | Level 1 |
| AC coefficient of thermal expansion | Level 3, default | Level 3 |
| Unbound Layers and Subgrade (ULS): Resilient modulus—all unbound layers | Level 1; back-calculation | Level 1; back-calculation[3] or Level 2 |
| ULS: Classification and volumetric properties | Level 1 | Level 3 |
| ULS: Moisture-density relationships | Level 1 | Level 3 |
| ULS: Soil-water characteristic relationships | Level 3, defaults | Level 3 |
| ULS: Saturated hydraulic conductivity | Level 3, defaults | Level 3 |
| All materials: Unit weight | Level 1 | Level 3 |
| Poisson's ratio | Level 3, default | Level 3 |
| Other thermal properties: Conductivity, heat capacity dentifrice absorptivity | Level 3, defaults | Level 3 |
| Existing pavement: Condition of existing layers | Levels 1 and 2 | Levels 1 and 2 |

1. Perform FDOT traffic WIM data analysis to establish Level 1 and Level 2 values.
2. Use the closest weather station (MERRA) data for the project.
3. Recommend back-calculation of existing pavements to develop design values typical to FDOT since the default modulus values are lower than expected based on the back-calculated modulus of the case studies.

# CHAPTER 3
# FLORIDA-SPECIFIC INPUT PARAMETERS

## FLORIDA-SPECIFIC INPUT OVERVIEW

The research team initially analyzed Florida pavements primarily based on Level 3 global inputs (default values) and found discrepancies between the FDOT case studies and PMED computed distresses. In order to improve the predictions, locally developed input data is needed.

In the AASHTO PMED program, the locally developed input, either project-specific or derived from project data, is characterized as levels 1 and 2, respectively. To help develop the local input data, the FDOT State Pavement Management Office supplied AC material to TTI for laboratory testing. The tests performed included the following:

- AC mixtures
    - Creep compliance.
    - Indirect tensile strength (IDT).
    - Dynamic Modulus (DM).
- Binder
    - Dynamic Shear Rheometer (DSR).

It should be noted that even with the supply of locally based input, there is a need to calibrate the existing prediction models utilized in the AASHTO PMED program to suit local conditions and environment. Further discussion of the local calibration is included in Chapter 4. This chapter includes information about the detailed testing and computing of the input parameters for levels 1 and 2.

## FLORIDA-SPECIFIC INPUT METHODOLOGY

### *Laboratory Characterization of Level 2 Inputs for AC*

The material input parameters recommended for Level 2 are AC-creep compliance, AC IDT, and existing pavement condition. The methodology for the characterization of AC mixture, binder, and existing pavement conditions are explained in this section.

The research team performed creep compliance, IDT, and DSR tests on three AC Superpave (SP) mixtures. One mixture contained recycled asphaltic pavement (RAP). The SP mixtures tested were as follows:

- SP-12.5, PG 76-22 (Granite).
- SP-9.5, PG 67-22 (Limestone).
- SP-19.0, PG 52-28 (Granite with 40 percent RAP).

## Creep Compliance and Indirect Tensile Strength Test

The research team performed the creep compliance test using the IPC Universal Testing Machine 30 according to AASHTO T322 protocol (Figure 3-1). This test is nondestructive and typically conducted at low temperatures. The required test temperatures are −20°C, −10°C, and 0°C. The specimens for this test were 6 inches in diameter by 1.5 inches thick (150 mm x 38 mm); examples are shown in Figure 3-2.

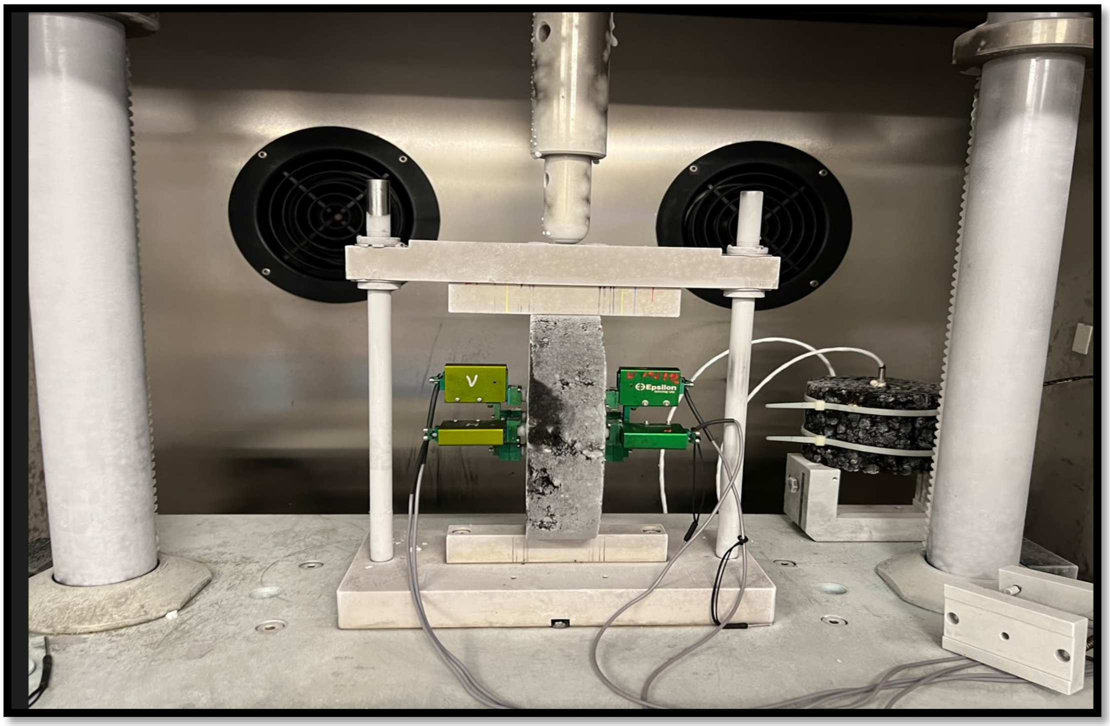


**Figure 3-1. Creep Compliance Test.**

**Figure 3-2. Creep Compliance Specimens.**

Table 3-1 contains the results of the creep compliance test performed on the three FDOT mixtures. The results indicate similarity between the laboratory-determined creep compliance of the PG67-22 mixture and the estimated Level 3 default value.

**Table 3-1. AC Creep Compliance Test Results.**

| AASHTO T322 Creep Compliance Values | | | | | |
|---|---|---|---|---|---|
| Temp | Time | Granite SP-12.5 PG 76-22 | Limestone SP-9.5 PG 67-22 | Granite SP-19 PG 52-28 RAP 40% | Level 3 Default |
| °F | sec | 1/psi | 1/psi | 1/psi | 1/psi |
| −4 | 1 | 3.46576E-07 | 4.27268E-07 | 3.57155E-07 | 4.226707E-07 |
| −4 | 2 | 3.6081E-07 | 4.44626E-07 | 3.72059E-07 | 4.548487E-07 |
| −4 | 5 | 3.83333E-07 | 4.71598E-07 | 3.94912E-07 | 5.011756E-07 |
| −4 | 10 | 4.03246E-07 | 4.94123E-07 | 4.14554E-07 | 5.393302E-07 |
| −4 | 20 | 4.26956E-07 | 5.22623E-07 | 4.37989E-07 | 5.803895E-07 |
| −4 | 50 | 4.65083E-07 | 5.66304E-07 | 4.75513E-07 | 6.395029E-07 |
| −4 | 100 | 5.01195E-07 | 6.0595E-07 | 5.07295E-07 | 6.881884E-07 |
| 14 | 1 | 4.49546E-07 | 5.23993E-07 | 4.85296E-07 | 5.278570E-07 |
| 14 | 2 | 4.85288E-07 | 5.64193E-07 | 5.20068E-07 | 6.043154E-07 |
| 14 | 5 | 5.45919E-07 | 6.41363E-07 | 5.77801E-07 | 7.226425E-07 |
| 14 | 10 | 6.07047E-07 | 6.82302E-07 | 6.30133E-07 | 8.273150E-07 |
| 14 | 20 | 6.83991E-07 | 7.99663E-07 | 6.94679E-07 | 9.471490E-07 |
| 14 | 50 | 8.10407E-07 | 9.46754E-07 | 8.07078E-07 | 1.132604E-06 |
| 14 | 100 | 9.40729E-07 | 1.09385E-06 | 9.19433E-07 | 1.296658E-06 |
| 32 | 1 | 7.96711E-07 | 8.40518E-07 | 7.70815E-07 | 6.464963E-07 |
| 32 | 2 | 9.266E-07 | 9.5816E-07 | 8.46535E-07 | 8.022924E-07 |
| 32 | 5 | 1.15296E-06 | 1.15151E-06 | 9.78492E-07 | 1.067297E-06 |
| 32 | 10 | 1.39065E-06 | 1.32542E-06 | 1.12085E-06 | 1.324500E-06 |
| 32 | 20 | 1.72396E-06 | 1.60275E-06 | 1.30641E-06 | 1.643685E-06 |
| 32 | 50 | 2.33358E-06 | 2.08742E-06 | 1.62267E-06 | 2.186611E-06 |
| 32 | 100 | 2.9488E-06 | 2.44495E-06 | 1.98243E-06 | 2.713551E-06 |

## Indirect Tensile Strength Test

After completing the creep compliance test, the same specimens were frozen at a temperature of −10°C before being subjected to an IDT test. Similarly, this test was performed according to AASHTO T322. The results of the IDT tensile strength test are shown in Table 3-2. The real-time development of the forces applied to break the specimens is shown in Figure 3-3, Figure 3-4, and Figure 3-5. The test setting and time was around 15 seconds. This allowed the research team to break the frozen specimens without losing temperature. The IDT test indicates that the FDOT mixture testing results are stiffer than the Level 3 default value.

**Table 3-2. Indirect Tensile Strength of the Mixtures at −10°C.**

| AASHTO T322 Tensile Strength | | | | | |
|---|---|---|---|---|---|
| | Tensile Strength at | | | | |
| | −10°C (14°F) | | 40°F[1] | 70°F[1] | 100°F[1] |
| Mixture | kPa | psi | psi | psi | psi |
| Granite SP-12.5 PG 76-22 | 4280 | 620.8 | 445.83 | 166.66 | 74.67 |
| Limestone SP-9.5 PG 67-22 | 2702 | 391.8 | 281.38 | 105.18 | 47.13 |
| Granite SP-19 PG 52-28 RAP 40% | 3643 | 528.4 | 379.48 | 141.85 | 63.56 |
| Level 3 Default Values | | 308.28 | 221.39 | 82.76 | 37.08 |

1. Software estimates values at these temperatures for Level 2 inputs.

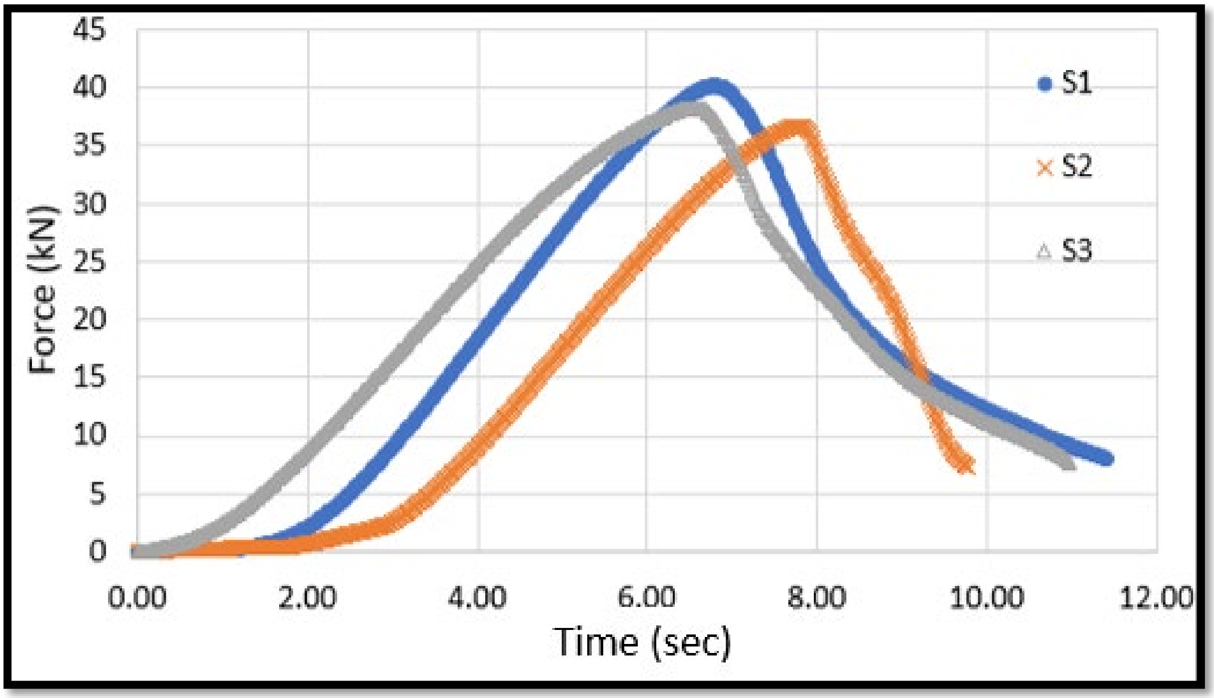


**Figure 3-3. FDOT Mixture SP-12.5 (Granite)—PG 76-22.**

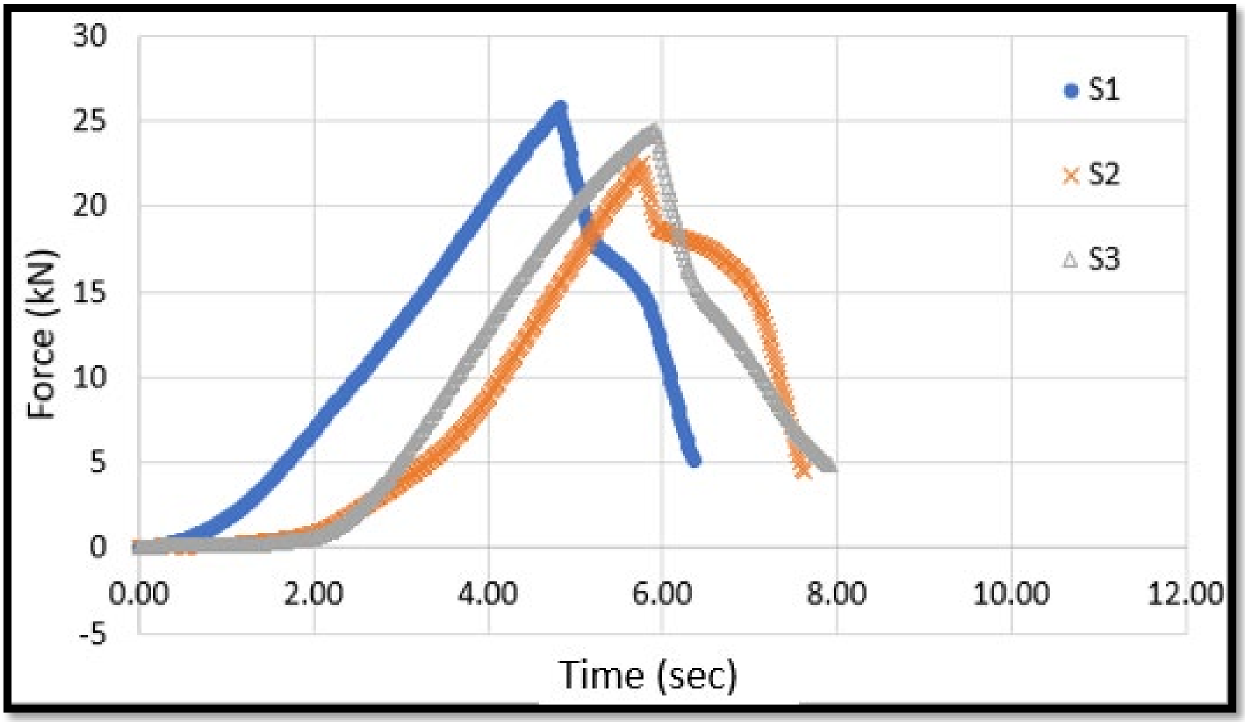


Figure 3-4. FDOT Mixture SP-9.5 (Limestone)—PG 67-22.

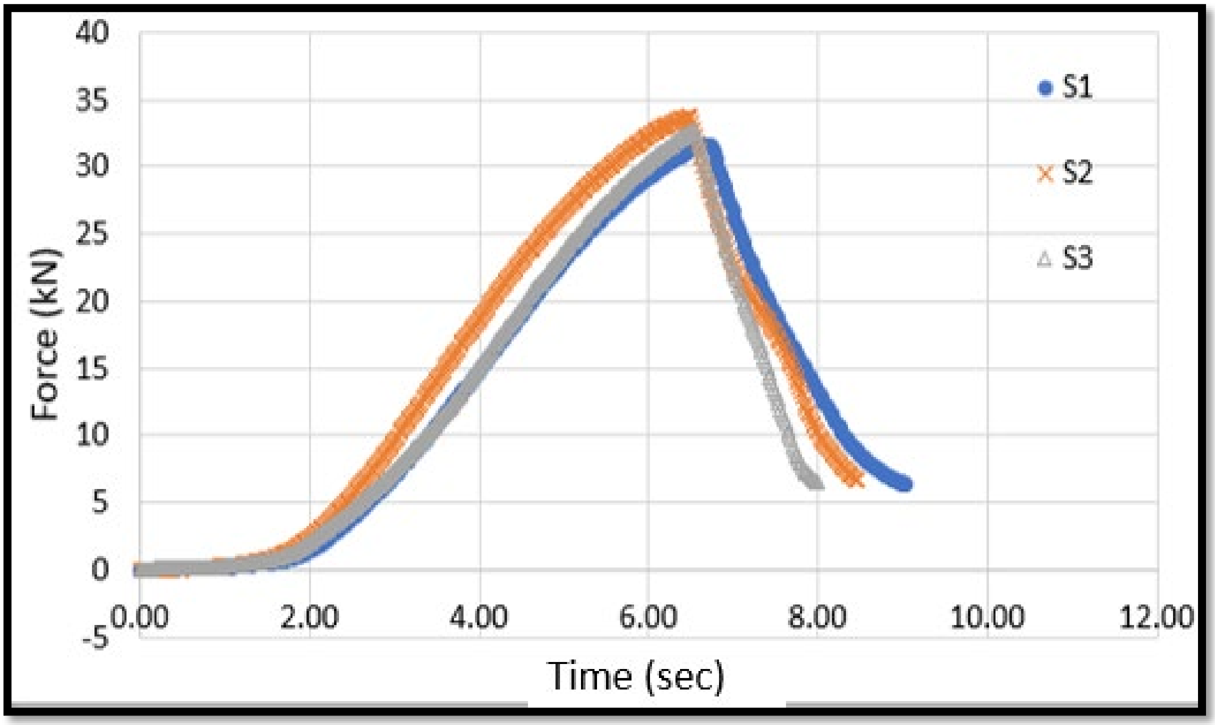


Figure 3-5. FDOT Mixture SP-19 (Granite)—PG 52-28 RAP 40 percent.

## Asphalt Binder Shear Properties—The DSR Test

The research team used the DSR to characterize the viscous and elastic behavior of asphalt binders at medium to high temperatures (Figure 3-6). Since the binder was unaged, the research team prepared and used 0.04-inch thick by 1-inch diameter (1 mm x 25 mm) specimens for the DSR test at high temperatures as recommended in the AASHTO T315 protocol (Figure 3-7). Among other binders, Florida uses PG 67, which is not an allowed binder grade in the PMED program. However, due to the DSR tests, the research team used the complex shear modulus (G*) and phase angle (δ °) to represent the shear properties of the binders instead of defaulting to a PG grade. In addition, the research team tested two asphalt binders used in FDOT Mixture SP-12.5 (granite) and Mixture SP-9.5 (limestone), respectively. Table 3-3 shows the DSR test results confirming the binders are PG 67 and 76. The DSR results are needed when the Level 1 or 2 dynamic modulus is used.

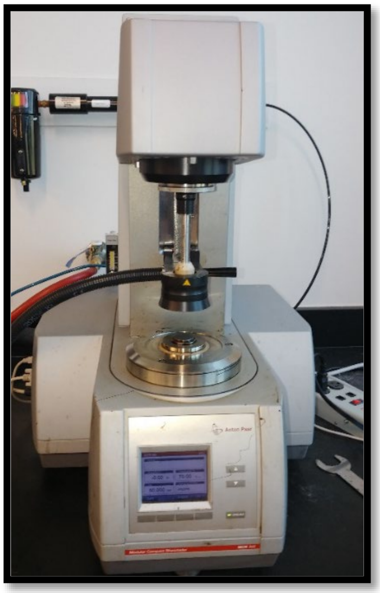


Figure 3-6. Dynamic Shear Rheometer.

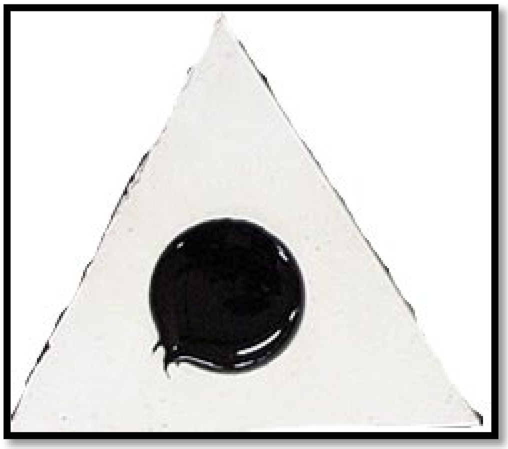


Figure 3-7. DSR Test 25 mm Binder Sample.

**Table 3-3. DSR Results.**

| BINDER GRADE VERIFICATION | | | AASHTO WARE INPUT | | |
|---|---|---|---|---|---|
| PG 67 | | | | | |
| Temperature (°F) | G*/Sin (δ°) (kPa) | PG Verification G*/Sin (δ°) ≥ 1000 | Temperature (°F) | G* (Pa) | Phase angle (δ°) |
| 58 | 4.1818 | | 136.4 | 4171 | 85.88 |
| 64 | 1.8033 | | 147.2 | 1801.3 | 87.29 |
| 70 | 0.8263 | | 158 | 826 | 88.34 |
| 68.5 | 1.000 | PG67 | | | |
| PG 76 | | | | | |
| Temperature (°F) | G*/Sin (δ°) (kPa) | PG Verification G*/Sin (δ°) ≥ 1000 | Temperature (°F) | G* (Pa) | Phase angle (δ°) |
| 64 | 3.8327 | | 136.4 | 3551.9 | 67.93 |
| 70 | 2.1214 | | 147.2 | 1972.3 | 68.4 |
| 76 | 1.2193 | | 158 | 1138.8 | 69.06 |
| 82 | 0.7239 | | 179.6 | 680.2 | 69.99 |
| 78.3 | 1.000 | PG76 | | | |

## Existing Pavement Layers

In addition, to the Level 2 material testing, the research team analyzed five existing pavement designs and FWD data provided by FDOT. The back-calculation software used was Modulus 7.0, which TTI developed for TxDOT. This back-calculation procedure uses the back-calculation modulus results directly in the design program. FWD data collection and back calculations are recommended for the existing base course, stabilized base course, and subgrade. Default material values can also be determined for typical FDOT materials when project level FWD data are unavailable.

A summary of the evaluation results is shown in Table 3-4. Each case study report contains the measured resilient modulus of the subgrade ($M_R$), which was provided by the FDOT State Materials Office (SMO). The PMED software has a range of allowable moduli for base and subgrade layers. For four of the five case studies, the maximum base moduli allowed by the software was lower than the actual back-calculated modulus of the existing pavement. For SR45, the average base modulus was close to, but just below, the PMED maximum. The subgrade $M_R$ and the calculated moduli were used to estimate the resilient moduli of the subsequent top layers, as shown in the following example:

- Generally, as a rule of thumb, the ratio of the resilient modulus of the granular layer to the resilient modulus of the supporting layers should be kept to a maximum of three to avoid decompaction of the supporting layer.[4] This rule is consistent with the in-place back-calculated modulus of the pavement structures evaluated. For FDOT, the ratio can be estimated for both the base and subbase layers.

- The research team recommends continuing to have the SMO provide the subgrade modulus. The designer should then check the subbase and base modulus based on the following:
    - Base modulus equals three times the subbase modulus.
        - When the maximum base modulus of 100 ksi is used, then the resulting subbase modulus (using recommended ratio estimation) would be 33 ksi.
    - Subbase equals two times the subgrade modulus.
        - When the maximum base modulus is used, resulting in a subbase estimated modulus of 33 ksi, the resulting subgrade modulus (using recommended ratio estimation) would be 17 ksi.
    - These are reasonable design assumptions for the maximum design values for the FDOT base and subbase at 100 ksi and 33 ksi, respectively.

## Table 3-4. Case Study Back-Calculation Summary.

| Back-Calculation Summary | | Thickness (inch) | Avg. Moduli (ksi) | Moduli (ksi) min | Moduli (ksi) max | SMO $M_R$ (ksi) | Computed $M_R$ (ksi) |
|---|---|---|---|---|---|---|---|
| SR597 | Limerock Base (LRB): | 8.5 | 245.1 | 128.7 | 357.4 | | 102, 150 |
| | Subbase: | 12 | 34.8 | 29.9 | 40.1 | | 34, 50 |
| | Subgrade: | 120 | 18.0 | 15.7 | 21.8 | 17, 25 | |
| SR804 | Base: LRB | 8 | 126.8 | 122.9 | 130.8 | | 156, 192 |
| | Subbase: | 12 | 80.3 | 73.2 | 87.3 | | 52, 64 |
| | Subgrade: | 163 | 22.5 | 18.1 | 26.9 | 26, 32 | |
| SR20 Left Side | Base: LRB | 8 | 133.6 | | | | 96, 132, 156, 192 |
| | Subbase: | 12 | 32.6 | | | | 32, 44, 52, 64 |
| | Subgrade: | 195.79 | 27.1 | | | 16, 22, 26, 32 | |
| SR483 | Base: LRB | 8 | 120.1 | | | | 114, 138, 180 |
| | Subbase: | 12 | 57.2 | | | | 38, 46, 60 |
| | Subgrade: | 120 | 13.0 | | | 19, 23, 30 | |
| SR45 | Base: LRB or Asphalt Base | 9 to 11 | 90.0 | 63.5 | 110.2 | | 126 |
| | Subbase: | 12 | 23.9 | 16.6 | 31.0 | | 42 |
| | Subgrade: | 110-225 | 16.1 | 8.4 | 23.9 | 21 | |
| PMED Ranges | Base: | | | 10 | 100 | | |
| | Subbase: | | | 10 | 100 | | |
| | Subgrade: | | | 5 | 50 | | |
| All | Base: | | 143.1 | 90.0 | 245.1 | | 144 |
| | Subbase: | | 45.7 | 23.9 | 80.3 | | 48 |
| | Subgrade: | | 19.3 | 16.1 | 27.1 | 24 avg. | |
| | | | Ratio | Ratio | Ratio | | |
| | Base to Subbase | | 3.1 | 3.8 | 3.1 | | |
| | Subbase to Subgrade | | 2.4 | 1.5 | 3.0 | | |

FDOT construction specification Item 911 classifies Base and Stabilized Base Materials differently than the AASHTO classification. For pavement design purposes, the AASHTO A-1-a soil properties are the closest to the FDOT base. The FDOT base is designated by a Limerock Bearing Ratio (LBR). The FDOT *Flexible Pavement Design Manual* allows several types of bases. The typical LBR for the FDOT base is 100, and stabilized subbase is 70.

Table 3-5 contains the Mechanistic-Empirical Pavement Design Guide's recommendations for Level 3 modulus input values based on the material description. It also contains the researchers recommended design value ranges based on the five FDOT case studies.

**Table 3-5. Base or Subbase Design Values.**

| Description | AASHTO | FDOT | Research Team | Research Team |
|---|---|---|---|---|
| | Resilient Modulus[1] (ksi)[4] | LBR[2] (ksi) | Typical Moduli Back-Calculation Range (ksi) | Design Modulus (E) Range[2] (ksi) |
| AASHTO: A-1-a | 40 | | | |
| AASHTO: A-1-b | 38 | | | |
| Limerock,<br>Cemented Coquina,<br>Shell Rock,<br>Graded Aggregate Base | | 100 | 20–250 | 60–180<br>Typical Values:<br>3ft BC = 120<br>2ft BC = 90<br>1ft BC = 60 |
| Recycled Concrete Aggregate | | 150 | 20–250 | 60–180<br>Typical Values:<br>3ft BC = 120<br>2ft BC = 90<br>1ft BC = 60 |
| Limerock Stabilized,<br>Shell,<br>Shell Stabilized | | 70 | 10–150 | 20–60<br>Typical Values:<br>3ft BC = 35<br>2ft BC = 26<br>1ft BC = 18 |
| Sand-Clay | | 75 | 10–150 | 20–60<br>Typical Values:<br>3ft BC = 35<br>2ft BC = 26<br>1ft BC = 18 |
| General Subgrade[3] | | | 5–50 | |
| General Design Modulus Layer Ratios[4] | | | $E_b/E_{sb} \ge 3$ $E_{sb}/E_{sg} \ge 2$ | $E_b/E_{sb} \ge 3$<br>$E_{sb}/E_{sg} \ge 2$ |

1. Recommended resilient modulus at optimum moisture (AASHTO T180).
2. Base Clearance (BC) as defined in FDOT's *Flexible Pavement Design Manual,* Section 5.2.2 Design Base Highwater Clearance.
3. SMO provides back-calculated modulus for design purposes.
3. $E_b$ is modulus of base, $E_{sb}$ is the modulus of the subbase and $E_{sg}$ is the modulus of the subgrade.

## FLORIDA-SPECIFIC INPUT SUMMARY

A summary of the PMED inputs that were developed from the laboratory testing and evaluation of the case studies is shown in

Table 3-6Table 3-6.

**Table 3-6. Summary of PMED Inputs.**

<table>
<tr><th colspan="3">DSR Values</th></tr>
<tr><td colspan="3">PG 67</td></tr>
<tr><td>Temperature (°F)</td><td>G* (Pa)</td><td>Phase angle (δ°)</td></tr>
<tr><td>136.4</td><td>4171</td><td>85.88</td></tr>
<tr><td>147.2</td><td>1801.3</td><td>87.29</td></tr>
<tr><td>158</td><td>826</td><td>88.34</td></tr>
<tr><td colspan="3">PG 76</td></tr>
<tr><td>Temperature (°F)</td><td>G* (Pa)</td><td>Phase angle (δ°)</td></tr>
<tr><td>136.4</td><td>3551.9</td><td>67.93</td></tr>
<tr><td>147.2</td><td>1972.3</td><td>68.4</td></tr>
<tr><td>158</td><td>1138.8</td><td>69.06</td></tr>
<tr><td>179.6</td><td>680.2</td><td>69.99</td></tr>
<tr><th colspan="3">Creep Compliance Values</th></tr>
<tr><td>Material</td><td colspan="2">PMED Inputs</td></tr>
<tr><td>PG 67-22 Mixes</td><td colspan="2">Use Level 3 Default</td></tr>
<tr><td>Other Mixtures</td><td colspan="2">Refer to Table 3-1 for a similar mixture or use Level 3 Default[1]</td></tr>
<tr><th colspan="3">Indirect Tensile Strength Values</th></tr>
<tr><td colspan="2" rowspan="3">Mixture</td><td>PMED Inputs</td></tr>
<tr><td>at 14 °F</td></tr>
<tr><td>psi</td></tr>
<tr><td colspan="2">Limestone SP-9.5 PG 67-22</td><td>3921</td></tr>
<tr><th colspan="3">Existing Pavement</th></tr>
<tr><td>Layer</td><td colspan="2">PMED Inputs (Modulus)</td></tr>
<tr><td>Subgrade</td><td colspan="2">SMO provided</td></tr>
<tr><td>Subbase</td><td colspan="2">2 x subgrade Modulus with a maximum of 33 ksi</td></tr>
<tr><td>Base</td><td colspan="2">3 x subbase Modulus with a maximum of 100 ksi</td></tr>
</table>

[1] This will be a conservative value for most FDOT mixtures.

# CHAPTER 4
# PMED IMPLEMENTATION ROADMAP

## OVERVIEW

This chapter provides a detailed implementation work plan (roadmap) focused on using the PMED software to perform flexible pavement designs for FDOT. The roadmap outlines the remaining steps necessary to complete the local calibration for the AASHTO PMED software, Version 2.6, for flexible pavements in Florida.

## PMED COMPARISON TO FDOT PAVEMENT CONDITION DATA

The research team analyzed pavement condition data from five Florida asphalt pavement project case studies from the reports provided by FDOT and the pavement condition data found in the online reports on FDOT's official website [5]. The research team assumed that the FDOT pavement condition rating was correct.

The case study distresses were compared to those computed with the PMED software. Table 4-1 contains data for the five roadways used in the analysis and shows the cracking and ride rating by year, along with the PMED predicted distresses for the same pavement structure. The pavement performance ratings from the FDOT *Flexible Pavement Condition Survey Handbook* were extracted and analyzed. Key points from the analysis are as follows:

- Cracking:
    - The load related top-down cracking usually develops in the wheel paths. The FDOT crack rating is a combination of cracking in the wheel path and outside the wheelpath. The handbook indicates that when the rating is below eight, there is at least 25 percent cracking; when it is below six, there is more than 50 percent cracking (see Figure 4-1).
    - After evaluating the case studies, the research team concluded that 25 percent cracking is a reasonable design threshold for cracking.
        - All projects' cracking ratings are below eight. However, the ratings include cracking that is outside the wheelpath.
            - The lowest rating ranged from 3.5 to 7.
            - In the rating system, the outside the wheelpath rating of 26 percent to 50 percent cracking shows a deduct range of 1 to 2. In four of the five projects when assuming the outside wheelpath rating has a deduct of 1, then the wheelpath cracking would range from 4.5 to 8 which would fall into the 25 percent or more cracking range in the wheelpath.
        - Additional evaluation should be conducted to compare only the wheelpath cracking percentages to the design threshold.

  - In all cases, the PMED software predicted minimal cracking when compared to pavement condition reports. Therefore, the software underpredicts the cracking distresses.
- Ride:
  - For all five projects, the PMED predicted the maximum IRI values of 164, which would rate the pavement at approximately 5.5 based on the handbook; however, the roughest actual IRI for all five roads was 6.9. Therefore, the IRI threshold of 172 is too rough (high) based on conditions that FDOT used to select projects.

## Table 4-1. FDOT Pavement Design Examples.

| Highway | SR804 (93200000) | | SR20 (55080000, Left) | | SR45 (10060000) | | SR483 (79270000, Right) | | SR597 (10160000) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Report Date | February 2019 | | August 2018 | | February 2020 | | February 2012 | | May 2020 | |
| Surface Age (years) | 15 | | 14 | | 13 | | 13 | | 16 | |
| Last work date(s) | 2021 & 2006 | | 2021 & 2007 | | 2009 | | 2010 | | 2007 | |
| Begin Milepoint | 1.049 | | 0.931 | | 8.884 | | 0 | | 4.846 | |
| End Milepoint | 2.172 | | 14.32 | | 17.422 | | 3.357 | | 9.142 | |
| Surveyed Year | Crack [1] | Ride[1] | Crack[1] | Ride[1] | Crack[1] | Ride[1] | Crack[1] | Ride[1] | Crack [1] | Ride[1] |
| 2010 | 10 | 7.9 | 10 | 8.2 | 10 | 8 | 10 | 7.8 | 10 | 8.2 |
| 2011 | 9.5 | 7.7 | 10 | 8.2 | 10 | 7.7 | 10 | 7.7 | 10 | 8.1 |
| 2012 | 9.5 | 7.8 | 10 | 8.2 | 10 | 7.9 | 10 | 7.6 | 10 | 8.1 |
| 2013 | 9.5 | 7.7 | 9.5 | 8.1 | 10 | 7.9 | 9 | 7.4 | 10 | 8 |
| 2014 | 9 | 7.5 | 9.5 | 8.1 | 10 | 7.8 | 9 | 7.4 | 10 | 8 |
| 2015 | 6.5 | 7.5 | 7 | 8 | 8.5 | 7.7 | 9 | 7.5 | 10 | 7.9 |
| 2016 | 6.5 | 7.5 | 7 | 8.4 | 7.5 | 7.8 | 9 | 7.3 | 9 | 8.1 |
| 2017 | 6.5 | 7.4 | 7 | 8.4 | 7.5 | 7.7 | 7.5 | 7.1 | 7.5 | 8.1 |
| 2018 | 6.5 | 7.4 | 7 | 8.5 | 7 | 7.7 | 7.5 | 7.1 | 6.5 | 8.1 |
| 2019 | 6.5 | 7 | 4.5 | 8.4 | 5.5 | 7.7 | 7 | 7.1 | 6.5 | 8.1 |
| 2020 | 6.5 | 7.3 | 4.5 | 8.5 | 5.0 | 7.6 | 7 | 6.9 | 4.5 | 8.1 |
| 2021 | 4.5 | 7 | | | 5.0 | 7.5 | 7 | 7 | 4.5 | 8 |
| 2022 | 10 | 7.9 | 10 | 8.9 | 5.0 | 7.4 | 7 | 7 | 3.5 | 8 |
| IRI range | | 71–107 | | 35–70 | | 67–93 | | 75–111 | | 59–74 |

| AASHTO ME Results | Limit | SR804 | | SR20 | | SR45 | | SR483 Right | | SR597 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ESALs (millions) | | 6.28 | | 2.66 | | 8.61 | | 3.37 | | 4.76 | |
| Terminal IRI (inches per mi.) | 172 | 160 | Pass | 158 | Pass | 163 | Pass | 160 | Pass | 161 | Pass |
| Rutting-Total Pavement (inch) | 0.75 | 0.32 | Pass | 0.22 | Pass | 0.34 | Pass | 0.27 | Pass | 0.31 | Pass |
| AC, BU-FC (% lane area) | 25 | 1.45 | Pass | 1.45 | Pass | 1.45 | Pass | 1.45 | Pass | 1.45 | Pass |
| AC, thermal Cracking (ft./mi.) | 1000 | 3197 | Fail | 3197 | Fail | 3197 | Fail | 3197 | Fail | 3197 | Fail |
| AC, TD-FC (% lane area) | 25 | 13.63 | Pass | 12.56 | Pass | 14.01 | Pass | 13.23 | Pass | 13.56 | Pass |
| Rutting-AC only (inch) | 0.25 | 0.12 | Pass | 0.08 | Pass | 0.11 | Pass | 0.10 | Pass | 0.11 | Pass |

1. Rating from FDOT Pavement Management, any rating < 6.5 is deficient.[5] The crack rating includes both outside and in the wheelpath cracking levels.

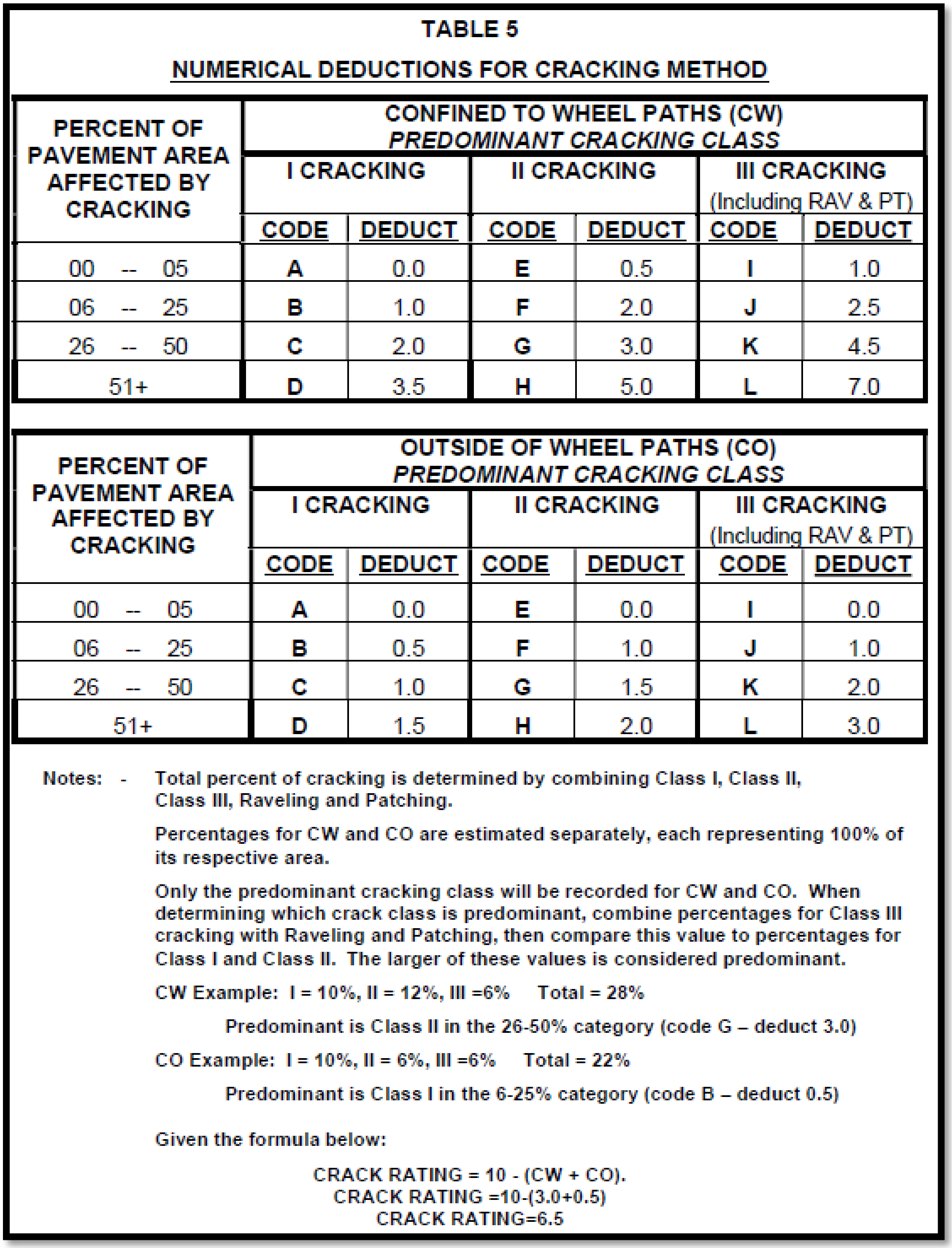


**TABLE 5**

**NUMERICAL DEDUCTIONS FOR CRACKING METHOD**

| PERCENT OF PAVEMENT AREA AFFECTED BY CRACKING | CONFINED TO WHEEL PATHS (CW) *PREDOMINANT CRACKING CLASS* | | | | | |
|---|---|---|---|---|---|---|
| | I CRACKING | | II CRACKING | | III CRACKING (Including RAV & PT) | |
| | CODE | DEDUCT | CODE | DEDUCT | CODE | DEDUCT |
| 00 -- 05 | A | 0.0 | E | 0.5 | I | 1.0 |
| 06 -- 25 | B | 1.0 | F | 2.0 | J | 2.5 |
| 26 -- 50 | C | 2.0 | G | 3.0 | K | 4.5 |
| 51+ | D | 3.5 | H | 5.0 | L | 7.0 |

| PERCENT OF PAVEMENT AREA AFFECTED BY CRACKING | OUTSIDE OF WHEEL PATHS (CO) *PREDOMINANT CRACKING CLASS* | | | | | |
|---|---|---|---|---|---|---|
| | I CRACKING | | II CRACKING | | III CRACKING (Including RAV & PT) | |
| | CODE | DEDUCT | CODE | DEDUCT | CODE | DEDUCT |
| 00 -- 05 | A | 0.0 | E | 0.0 | I | 0.0 |
| 06 -- 25 | B | 0.5 | F | 1.0 | J | 1.0 |
| 26 -- 50 | C | 1.0 | G | 1.5 | K | 2.0 |
| 51+ | D | 1.5 | H | 2.0 | L | 3.0 |

Notes: - Total percent of cracking is determined by combining Class I, Class II, Class III, Raveling and Patching.

Percentages for CW and CO are estimated separately, each representing 100% of its respective area.

Only the predominant cracking class will be recorded for CW and CO. When determining which crack class is predominant, combine percentages for Class III cracking with Raveling and Patching, then compare this value to percentages for Class I and Class II. The larger of these values is considered predominant.

CW Example: I = 10%, II = 12%, III =6% Total = 28%

Predominant is Class II in the 26-50% category (code G – deduct 3.0)

CO Example: I = 10%, II = 6%, III =6% Total = 22%

Predominant is Class I in the 6-25% category (code B – deduct 0.5)

Given the formula below:

CRACK RATING = 10 - (CW + CO).
CRACK RATING =10-(3.0+0.5)
CRACK RATING=6.5

**Figure 4-1. Crack Condition Rating.[6]**

## IMPLEMENTATION ROADMAP

This section outlines the implementation plan.

### *Timing*

The research team recommends delaying the PMED Version 2.6 implementation until additional research and model calibrations are performed since the models are not predicting the distress expected based on Florida's pavement conditions.

### *Roadmap*

The implementation roadmap is comprised of three phases. A simple roadmap to implementation schematic is in Figure 4-2. The main steps of each phase are listed and can be performed concurrently in many cases.

- Phase 1: Evaluation and Calibration to Florida-Specific Criteria.
    - Step 1: Evaluate and establish PMED target values.
    - Step 2: Analyze traffic data inputs.
    - Step 3: Perform local calibration of distress models.
    - Step 4: Reevaluate the sensitivity of PMED inputs.
        - Step 4a: Perform a sensitivity analysis with updated target values, traffic data, and local model calibrations.
        - Step 4b: Based on the sensitivity analysis, reevaluate the hierarchical input levels and testing requirements.
- Phase 2: Training.
    - Step 1: Develop training materials and workshops for FDOT employees and consultants.
    - Step 2: Deliver the training.
    - Step 3: Maintain and update training materials.
- Phase 3: Maintenance of Design System.
    - Step 1: Collect data.
    - Step 2: Evaluation of pavement performance and model predictions.
    - Step 3: Updates to PMED criteria as data dictate and based on software changes.

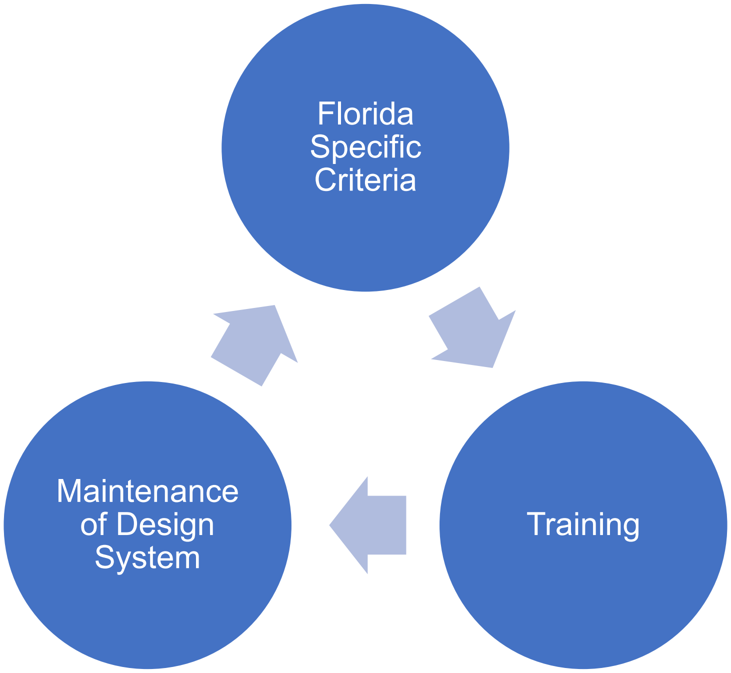


**Figure 4-2. Roadmap to Implementation.**

### *Phase 1 Steps*

1. PMED Target Values: Target threshold values should be adjusted based on the values expected in Florida. Perform the following steps to determine the threshold values:
    a. Gather pavement management data and perform on-site visual condition assessments as required for FDOT projects with pavement work.
        i. The FDOT proposed five-year work plan.
        ii. The FDOT previous five-year project history.
    b. Document the type of work and existing conditions to determine Florida's current conditions to program a project. The following will be documented for each project then an analysis will be performed to determine the threshold levels:
        i. Current IRI (inches per mi.).
        ii. Rutting.
            1. Total Pavement (inch).
            2. AC only (inch).
        iii. Fatigue Cracking.
            1. AC bottom-up (percent lane area).
            2. AC top-down (percent lane area).
        iv. Thermal cracking (ft./mi.).
    c. Determine the target values before finalizing the adjustments to the distress models so that adjustments align with the target values expected.

2. Traffic Data: The traffic ESALs were higher than anticipated; therefore, a detailed analysis of Florida traffic data should be performed to ensure that the default values are reasonable. The following are the proposed steps to analyze the traffic inputs:
    a. Perform an extensive review of existing WIM data for the FDOT system.
    b. Determine whether additional WIM data are needed. For example, data from existing ESAL pavement design estimates can be compared to WIM data on the same projects. A portable WIM device may be needed to collect the data.
    c. Develop a procedure to determine traffic data needed for PMED inputs.

3. Distress Models and Calibration: Significant work is needed to develop local calibration factors. The following information will assist FDOT in understanding and planning for local calibration, which is a multi-step process.

    a. The PMED software is built with a platform that allows users to adjust and convert global functions to local conditions. The *Mechanistic-Empirical Pavement Design Guide* (also known as PMED) states that "to minimize the impact or lack of data, the AASHTOWare PMED has included a unique feature that allows the designer to 'adjust' the global calibration or field-shift adjustment factors and use Agency specific regression constants for individual distress damage functions based on user-generated local and regional data sets."

    b. Calibration Process: The local calibration process involves two steps, model calibration and validation.
        i. In the model calibration, the fitting process of the field and PMED computed data produces constants that are evaluated based on the goodness of fit criteria to decide on the best coefficients of the formulated model function.
        ii. The validation process determines whether the derived models can accurately predict pavement distresses for local projects other than those used in the calibration.

    c. Typical Procedure for Local Calibration: *The Guide for the Local Calibration of the Mechanistic-Empirical Pavement Design Guide*, 1st Edition, provides specific guidance on determining agency-specific calibration adjustment factors with the AASHTOWare PMED[1, 3, 7].
        i. Select Input Level for Each Input Parameter: Input levels shall be selected to suit the local condition. This policy decision is influenced by current field and laboratory testing ability, materials and construction requirements, traffic data, etc. Furthermore, the selected input level will impact the standard error's accuracy.

        ii. Experimental Plan: An experimental statistical matrix will be developed for refining the calibration of the AASHTOWare PMED distress models and IRI based on local conditions. The experimental matrix shall be designed as a fractional factorial matrix as much as possible. This means that the experimental designs shall consist of a carefully chosen subset (fraction) of the experimental runs of a complete factorial design. The FDOT PCS unit will be consulted to establish the best matrix plan based on existing information. *The Guide for the Local Calibration of the Mechanistic-Empirical Pavement Design Guide*, 1st Edition, has an example of an experimental matrix that shows when using a Superpave mixture, three segments are needed for a full-depth pavement and five segments are needed for an overlay for a total of eight Superpave segments.

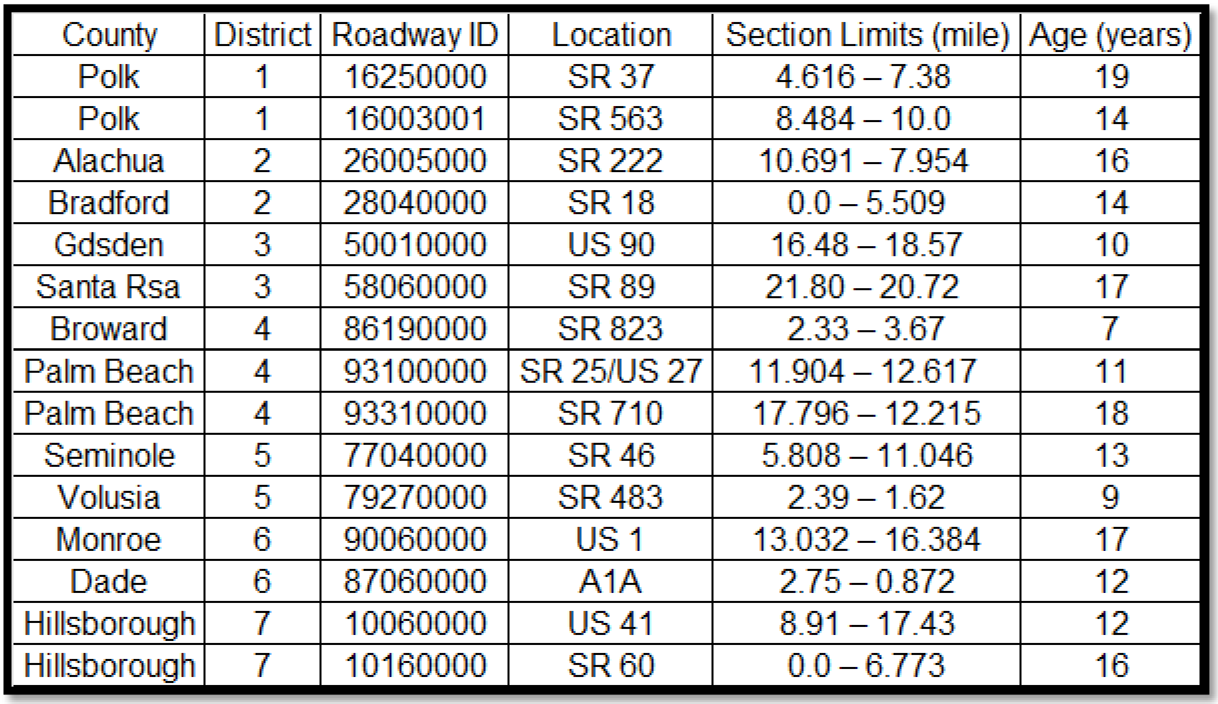
iii. The Sample Size for Specific Distress Prediction Models: The sample size selection (total number of segments) will depend on the anticipated average residual errors (bias) and the confidence interval on the mean. The detailed formulae and tables for determining the minimum number of segments are presented in the AASHTO's *"Guide for the Local Calibration of the Mechanistic-Empirical Pavement Design Guide"*.[7] According to the AASHTO guide, the following are examples of recommended minimum sample sizes.

   1. Total rutting—20 roadway segments.
   2. Load-related cracking—30 roadway segments.
   3. Non-load related cracking—26 roadway segments.
   4. Reflection cracking—26 roadway segments.

iv. Select Roadway Segments: The segment selection shall be based on maximizing the sections with existing information and data and minimizing the cost of collecting new data and testing. A statistically valid matrix will need to be developed for FDOT pavements. Projects should be selected to cover a range of distresses of similar ages. Previous work in Florida used the PCS Pavement Condition Rating (PCR) database to identify MEPDG/PMED calibration segments.[6] Segments were selected using the following criteria; however, this criterion should be reevaluated:

   1. The PCR critical value ≤ 6.6.
   2. Current reporting cycle interval ≥ 5 years.
   3. The rate of the PCR deterioration between current and previous year ≥ 5 years.
   4. For given distress, the range of the rating values ≥ 2.
   5. The rating value within the current cycle shows a decreasing trend.
   6. The proximity of the segment to the WIM station. Since MEPDG (now PMED) uses traffic weight data, segments were selected strategically to exploit the axle load distribution collected at the WIM station.

7. Figure 4-3 shows sample segments/sections selected for a previous calibration work performed in Florida. A segment can host more than one distress as long as the distresses can be quantified. Figure 4-4 shows the approximate geographic location of these segments. Individual segments are not marked. The intent of Figure 4-4 is to show general location compared to climate regions. The counties for the segments are highlighted in red and the climate regions are designated in yellow. It appears that while climate was not in the original criteria, the locations cover all climate regions of Florida.



| County | District | Roadway ID | Location | Section Limits (mile) | Age (years) |
|---|---|---|---|---|---|
| Polk | 1 | 16250000 | SR 37 | 4.616 – 7.38 | 19 |
| Polk | 1 | 16003001 | SR 563 | 8.484 – 10.0 | 14 |
| Alachua | 2 | 26005000 | SR 222 | 10.691 – 7.954 | 16 |
| Bradford | 2 | 28040000 | SR 18 | 0.0 – 5.509 | 14 |
| Gdsden | 3 | 50010000 | US 90 | 16.48 – 18.57 | 10 |
| Santa Rsa | 3 | 58060000 | SR 89 | 21.80 – 20.72 | 17 |
| Broward | 4 | 86190000 | SR 823 | 2.33 – 3.67 | 7 |
| Palm Beach | 4 | 93100000 | SR 25/US 27 | 11.904 – 12.617 | 11 |
| Palm Beach | 4 | 93310000 | SR 710 | 17.796 – 12.215 | 18 |
| Seminole | 5 | 77040000 | SR 46 | 5.808 – 11.046 | 13 |
| Volusia | 5 | 79270000 | SR 483 | 2.39 – 1.62 | 9 |
| Monroe | 6 | 90060000 | US 1 | 13.032 – 16.384 | 17 |
| Dade | 6 | 87060000 | A1A | 2.75 – 0.872 | 12 |
| Hillsborough | 7 | 10060000 | US 41 | 8.91 – 17.43 | 12 |
| Hillsborough | 7 | 10160000 | SR 60 | 0.0 – 6.773 | 16 |

**Figure 4-3. Previous Calibration Segments in Florida.[8]**

**Figure 4-4. Previous Calibration Segment Locations.[9]**

v. Evaluate Distresses and Project Data: At this step, a review will be performed to determine if there are missing data. Also, for the accuracy of the models, the distress values of the selected segment shall exceed 50 percent of the original design criteria.

vi. Conduct Field and Forensic Investigation: Where critical data are missing for validating selected road segments, field and laboratory investigation will be used to collect the missing information. A review and analysis of FWD data to assess uniformity, an evaluation of the available coring database, and an additional sensitivity analyses on the selected segments should be conducted to determine the scope of the field work and the number of samples needed for laboratory testing.

vii. Validation of Global Calibration to Local Condition: A comparison shall be performed with the AASHTOWare PMED global calibrated values and measured distress for each roadway segment. A null hypothesis shall then be performed. If the null hypothesis is rejected, the specific distress model shall be recalibrated to local conditions. The process of local recalibration involves adjusting the prediction model coefficients and exponents, as explained in the introduction of local calibration. For the recommended parameters that can be adjusted to eliminate bias and reduce standard errors, see AASHTO's, *"Guide for the Local Calibration of the Mechanistic-Empirical Pavement Design Guide".* Previous work indicates that validation of the local calibration was performed on rigid pavement only

    viii. <u>Accuracy of Calibration Parameters:</u>
        1. The local standard of the estimate for newly established distress and IRI must be examined for different designs and reliability levels. The outcome of this process could be:
            a. *Reasonable design life for the used reliability level*. Not overly designed when compared to historical data. If this is the case, the local calibration values and standard error can be entered in the AASHTOWare PMED for use.
            b. *Too long design life for the selected reliability level,* which could be interpreted as conservative and expensive design. If this is the case, the standard errors have to be further reduced. When the agency is satisfied, the local calibration values and standard error can be entered in the AASHTOWare PMED for use.
            c. *Too short design life for the used reliability level. Distress models cannot be fixed by further adjustment to the standard error*. This means the pure error component is relatively too large compared to the input error component. In this scenario, the agency should consider adjusting the failure criteria.

d. Calibration-Validation Accuracy: According to the AASHTO guidelines for local calibrations, there are two methods to improve the accuracy of the prediction models.
    i. Split-sample method (traditional):
        1. In this method, the concerned agency selects several field sites (a set of "n" sites) for which service pavement performance data exist for use in model calibration and validation.
        2. Alternatively, the agency could use a portion of the sites (typically n/2) to calibrate the coefficient of the performance models while reserving the other portion for subsequent model validation. However, since this method is not utilizing the entire population of the data, it has a high risk of

producing a misleading model accuracy, especially for small samples.

        ii. Jack-knifing (alternate method):
            1. For the "n" sample size, the jack-knife calibration procedure involves removing one set of measurements from the data matrix and calibrating the model with an n-1 sample size. Then, the withheld data are used to estimate the error ($e_1$) between the model-computed distresses and the field values. Next, the second data set is removed while replacing the first set. Finally, the new n-1 set is used to calibrate another model. Similarly, a new standard error ($e_2$) is determined. This process will continue until all n set data have been used for the prediction. The chi-square test could be used at a given significance level to determine whether the standard error is high.
            2. The jack-knife method is superior to the split sample because it uses a different data set for validation and could be used for small to large sample data.

4. <u>Reevaluate Sensitivity</u>: Hierarchical input levels should be further evaluated once local calibration factors are improved. This means work shall be conducted to compare predicted and observed distresses. A revised sensitivity analysis should be performed after local calibration factors are developed. This study would then be used to further validate the hierarchical input levels.
    a. Perform a sensitivity analysis with updated target values, traffic data, and local model calibrations.
    b. Based on the sensitivity analysis, reevaluate the hierarchical input levels and testing requirements.

## PMED IMPLEMENTATION COST

### *Software*

The current FDOT pavement design procedure uses the 1993 AASHTO Design Equation to determine pavement thickness and does not require software. The constants set in the formula are the present, initial, terminal, and change in serviceability, and standard deviation. The constants are used along with the following information to determine a required SN:

- Traffic loading data expressed as accumulated ESALs.
- FWD testing to estimate the subgrade resilient modulus ($M_R$).
- Reliability (%R), which ranges from 75 percent to 99 percent.

The cost of the existing system is based on the cost of acquiring traffic and FWD data. These same costs would be needed for the PMED; therefore, they were not included in the cost comparison.

The subscription costs for the PMED software are shown in Table 4-2. Software Cost. The cost of the software increased by 14.3 percent in one year and 60 percent since 2011. It is unknown how much the software will continue to increase over time. Based on these costs, FDOT would need more than three people using the software before the next pricing level would become cost-effective. The cost for four individuals is approximately the same as the subscription for up to nine. Suppose it is assumed that one subscription per FDOT district is needed and at least one for the state office, which results in a minimum of eight subscriptions that would be required. This results in an annual cost of $32,050. Since FDOT currently has subscriptions for the software to perform rigid pavement design, additional subscriptions are not anticipated at this time.

**Table 4-2. Software Cost.**

| **Description** | **Cost** | **Cost** | |
|---|---|---|---|
| **PMED** | **June 2022 (V3.0) [10]** | **Feb. 2021 (V2.6)** | **July 2011[11]** |
| Single User Subscription/Individual Workstation, Annual License Fee | $8,000 | $7,000 | $5,000 |
| | | June 2022 (ea) | |
| Subscription Service–9 Concurrent seats | $32,050 | $3,561.11 | |
| Subscription Service–14 Concurrent seats | $48,050 | $3,432.14 | |
| Subscription Service–20 Concurrent seats[1] | $64,000 | $3,200 | |
| **Back-Calculation Tool** | | | |
| Standalone Single User | $1,300 | | |

[1] Additional seats above 20 are $2,500 each.

### Material Testing

Typical material testing costs are in Table 4-3 and are for information only.

**Table 4-3. Testing Cost.**

| Test | Test Name | Quantity | Test Cost[12] |
|---|---|---|---|
| FM1-T166 | Bulk Specific Gravity of Compacted Bituminous Mixtures | Per roadway core or gyratory pill | $57.37 |
| FM5-563 | Ignition Oven Method | Per asphalt content | $137.09 |
| FM1-T209 | Max Specific Gravity | Per average of two flasks | $139.19 |
| AASHTO T312-04 | Superpave Gyratory Compaction | Per pair of gyratory pills | $107.00 |
| FM5-563<br>FM1-T030 | Ignition Oven and Mechanical Analysis | Per gradation | $207.50 |
| | | | **Estimated Test Cost** |
| AASHTO T315 | Dynamic Shear Rheometer | Each | $125.00 |
| | Indirect Tensile Strength Test | Set of 3 | $75.00 |
| | Creep Compliance | Set of 3 | $75.00 |
| | FWD | Day | $2,850.00 |

### Implementation Cost

Typically, state departments of transportation contract with researchers to perform the local calibration. Table 4-4 estimates the implementation roadmap's cost for Phase 1 and Phase 2.

**Table 4-4. Implementation Cost.**

| Phase.Step | Description | Estimated Timeframe | Estimated Cost |
|---|---|---|---|
| 1 | Evaluation and Calibration to Florida Specific Criteria | | |
| 1.1 | Evaluate and establish PMED target values | 12 months | $175,000 |
| 1.2 | Analyze traffic data input | 24 months | $350,000 |
| 1.3 | Perform local calibration of distress models | 24–36 months | $525,000 |
| 1.4 | Reevaluate the sensitivity of PMED inputs | 6 months | $75,000 |
| | Phase 1 subtotal | 36–42 months | $1,125,000 |
| 2 | Training | | |
| 2.1 | Develop training materials and workshops for FDOT employees and consultants | 6–12 months | $100,000 |
| 2.2 | Deliver the training | Assume 6, 8-hr classes | $60,000 |
| 2.3 | Maintain and update training materials | Annually | $25,000 |
| | Phase 2 subtotal | Year 1 | $185,000 |
| | Phase 2 subtotal | Annually after year 1 | $85,000 |
| 3 | Maintenance of Design System | | |
| 3.1 | Collect data | As needed | |
| 3.2 | Evaluation of pavement performance and model predictions | As needed | |
| 3.3 | Update PMED criteria as data dictate and based on software changes | As needed | |
| | Phase 3 subtotal | Per update | Depends on extent of changes needed. |
| | Estimated Phase 1 and 2 Initial Cost | | $1,310,000 |

## SUMMARY OF THE ROAD MAP

A roadmap to implementation consists of three phases. The phases are as follows:

- Phase 1: Evaluation and Calibration to Florida-Specific Criteria.
    - PMED target values.
    - Traffic data evaluation.
    - Local calibration of distress models.
    - Reevaluation of sensitivity.
- Phase 2: Training.
- Phase 3: Maintenance of Design System.

The implementation of Phases 1 and 2 require considerable investment in both time (four or more years) and money (estimated at just over $1.3 million).

# CHAPTER 5
# CONCLUSION AND RECOMMENDATIONS

Based on the activities performed, the research developed the following recommendations and conclusions:

- The sensitivity analysis using global factors established and ranked distress model input sensitivity from sensitive to extremely sensitive. (See Table 2-5 and Table 2-6)
- The team established PMED global distress models using an extreme range of changes in order to predict actual distresses, however even with the extreme changes, the models did not accurately predict actual Florida flexible pavement distress (i.e., fatigue cracking).
- The research team developed lab characteristics asphaltic concrete Level 2 inputs for the selected project. Also, using the back calculations, the research team developed a resilient modulus input recommendation for base and stabilized subgrade materials. The local inputs are essential when implementing project-level local calibration.
- The research team established step-by-step procedures for implementing local calibration and validation.
- The research team recommends delaying the implementation until additional research and model calibrations are performed as described in Phase 1 of the implementation roadmap. Please note that AASHTO will release version 3.0 of the PMED very soon which will also require model calibrations.

# REFERENCES

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