APPENDIX A. MEETING PARTICIPANTS

TAC and Pooled Fund Member Participants

Name	Agency	TAC Member	Pvt ME Design TF Member	Email Address
Tom Yu Chris Wagner	FHWA	Yes Yes	Liaison No	tom.yu@dot.gov christopher.wagner@dot.gov
Vicki Schofield	AASHTO	Yes	Yes	vschofield@aashto.org
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Non-TAC / Non-Pooled Fund Member Participation

Name	Agency	Pvt ME Design TF Member	Email Address
Kelly Smith	APTech	No	klsmith@appliedpavement.com
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Academia/Consultant/Industry Representative Participation

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Baoshan Huang	University of Tennessee Knoxville	No	bhuang@utk.edu

APPENDIX B. MEETING AGENDA

Wednesday November 7

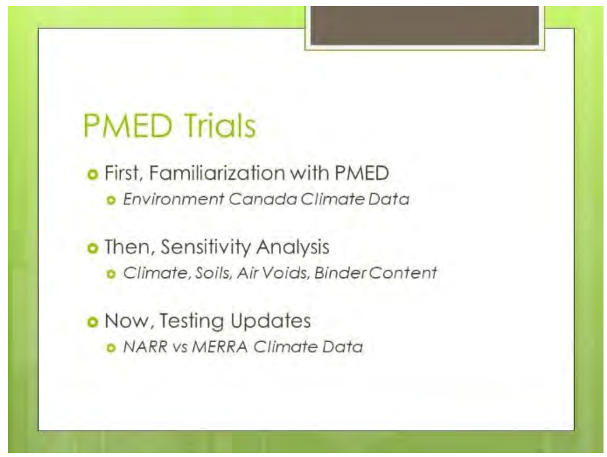
Time	Topic
8:00–8:45 AM	WELCOME AND INTRODUCTIONS Welcome | Chris Wagner (FHWA). Introduction and Remarks | John Donahue (Missouri DOT, AASHTO Committee on Materials and Pavements, and Chair, AASHTOWare Pavement ME Design Taskforce). Canadian Users Group Update | Felix Doucet (Ministry of Transportation of Quebec) Review of agenda and meeting goals | Linda Pierce (NCE) and Kelly Smith (APTech)
8:45–10:15 AM	AGENCY IMPLEMENTATION STATUS Implementation map updates | Linda Pierce (NCE) and Kelly Smith (APTech) Agency briefings on implementation plans, timelines, and progress | All
10:15-10:30 AM	BREAK
10:30-11:00 AM	ME RESEARCH SUMMARIES FHWA Research Summary | Tom Yu (FHWA) NCHRP Research Summary | Linda Pierce (NCE)
11:00 AM-Noon	AASHTOWARE PAVEMENT ME DESIGN SOFTWARE UPDATE Announcements and news regarding latest software and purchasing/licensing | Vicki Schofield (AASHTO) Software enhancements/updates, including new features/capabilities | Chad Becker and Harold Von Quintus (ARA)
Noon-1:15 PM	LUNCH (ON YOUR OWN)
1:15-2:45 PM	AGENCY IMPLEMENTATION EXPERIENCES Georgia's Implementation Efforts on Climate Research | Ian Rish (Georgia DOT) and Stephen Durham (University of Georgia) Successful Implementation: Challenges Overcome and Current Areas of Focus/Refinement | Affan Habib (Virginia DOT) Struggles with Implementation: Why Implementation Hasn't Occurred, Unique Challenges, Plans for Overcoming Challenges | Robert Shugart (Alabama DOT) New Reflection Cracking Model for HMA: Challenges and Experiences | Dr. Halil Ceylan (Iowa State University)
2:45-3:00 PM	BREAK
3:00-4:45 PM	SPOTLIGHT ON ME RESEARCH (NCHRP, FHWA, and Other Key Projects Impacting PMED) NCHRP 1-53, Improved Consideration of the Influence of Subgrade and Unbound Layers on Pavement Performance | Dr. Bob Lytton (Texas A&M University) NCHRP 20-07 Task 422, User Review of the AASHTO Guide for Local Calibration of the MEPDG | Georgene Geary (GGfGA Engineering)
4:45–5:00 PM	DAY ONE WRAP UP Discuss key takeaways of Day one | All

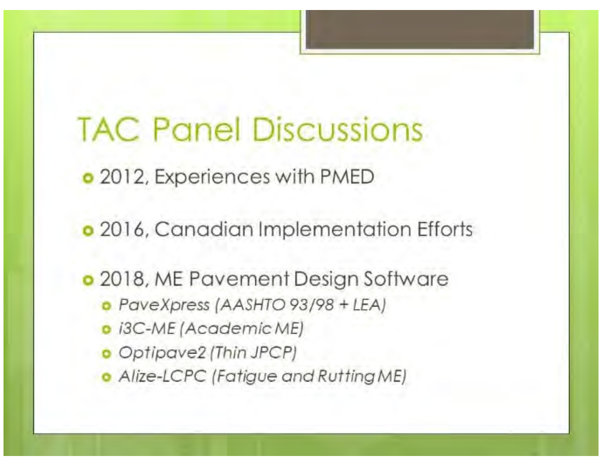
Thursday November 8

Time	Topic
8:00-9:00 AM	DESIGN APPLICATIONS AND PERFORMANCE CRITERIA Adjustments in Design Inputs | Jeffrey Mann (New Mexico DOT) Comparisons with AASHTO '93 and Adjustments in Design Reliability and Performance Thresholds | Ryan Barrett (Kansas DOT) Incorporation of Recycled Asphalt Mixtures into the MEPDG | Ramon Bonaquist (Advanced Asphalt Technologies)
9:00–10:00 AM	LOCAL CALIBRATION EXPERIENCES Missouri's Second Calibration Effort | Jason Blomberg (Missouri DOT) Michigan's Recalibration Effort | Dr. Syed Haider (Michigan State University) Data Challenges for Local Calibration/Validation: Issues with Test Sites and/or Data Collection Procedures and Changes Made to Resolve Those Issues | Rhonda Taylor (Florida DOT) AASHTO Effort in Developing Automated Calibration Tool "Calibrator" | Chad Becker/Wouter Brink (ARA)
10:00–10:15 AM	BREAK
10:15 AM–NOON	SOFTWARE TRAINING Live demonstration-based training on new software features and example applications | Harold Von Quintus and Chad Becker (ARA)
NOON–1:15 PM	LUNCH (ON YOUR OWN)
1:15–3:00 PM	SOFTWARE TRAINING (Continued) Live demonstration-based training on new software features and example applications | Harold Von Quintus and Chad Becker (ARA)
3:00–3:15 PM	BREAK
3:15–4:00 PM	RESEARCH, TRAINING, AND SOFTWARE NEEDS Role of User Group TAC in developing Research Needs Statements (RNS) | All Summary of research, training, and software needs suggestions (from pre-meeting survey) | All Consensus on key challenges/issues/roadblocks and identification of warranted RNS | All
4:00–4:30 PM	MEETING WRAP UP Discuss key takeaways | All Meeting evaluation and concluding remarks | Linda Pierce (NCE) and Kelly Smith (APTech)

APPENDIX C. MEETING PRESENTATIONS

Presentation 1—Felix Doucet, Quebec Ministry of Transportation





AB Implementation Status

- Alberta
  - *Still running parallel designs*
  - *Heading in right direction but very slowly*
  - *Eagerly awaiting local calibration tool*
  - *Need to dive deeper into parallel design comparison before local calibration*

MB Implementation Status

- Manitoba
  - *Moving slowly but in positive direction*
  - *MERRA data does not appear to be dependable*
  - *Level 1 traffic primary highways, Level 2-3 secondary*
  - *Level 1 material inputs but materials specifications are currently changing*
  - *Calibration trials did not produce meaningful results*
  - *Waiting for top down and unbound materials models*
  - *IT setting also need to be resolved*

ON Implementation Status

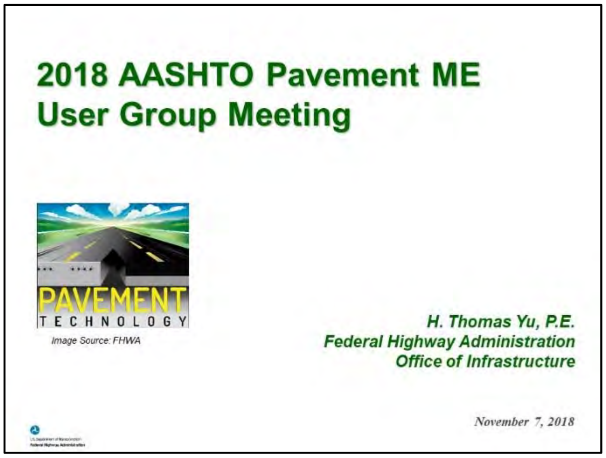
- Ontario
  - *Network license accessed by regional offices*
  - *Run PMED as a check for pavement performance*
  - *Need to recalibrate the local calibration coefficients*
  - *Need to train staff in regard to latest changes*
  - *Local calibration factors for rigid pavement under final review*

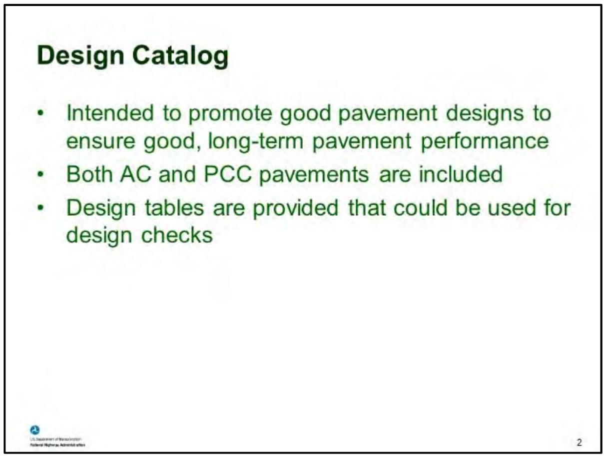
QC Implementation Status

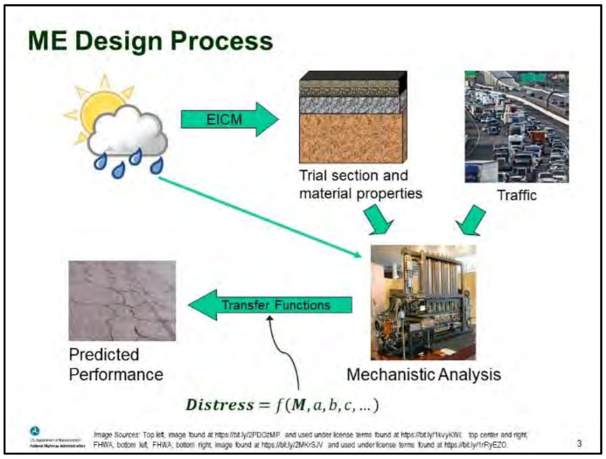
- Quebec
  - *Continue evaluation of the software through*
    - *MTQ Special Projects (checks)*
    - *TAC Design Trials (sensitivity)*
    - *PMED Beta Testing (metric)*
  - *Considering the elaboration of an implementation plan following the publication of the*
    - *Recalibrated Flexible Pavement Models (2018)*
    - *Calibration Tool (2019)*

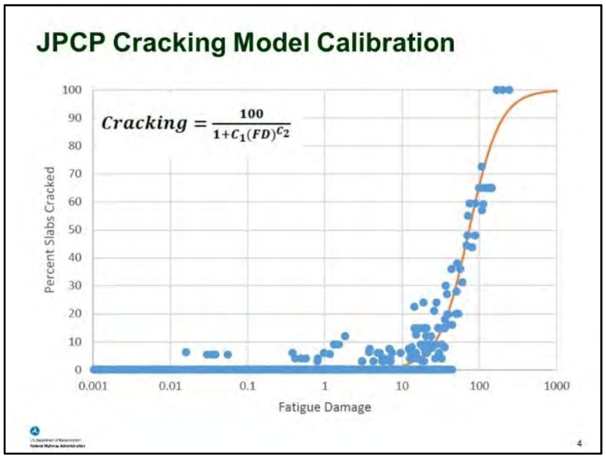
Thank You

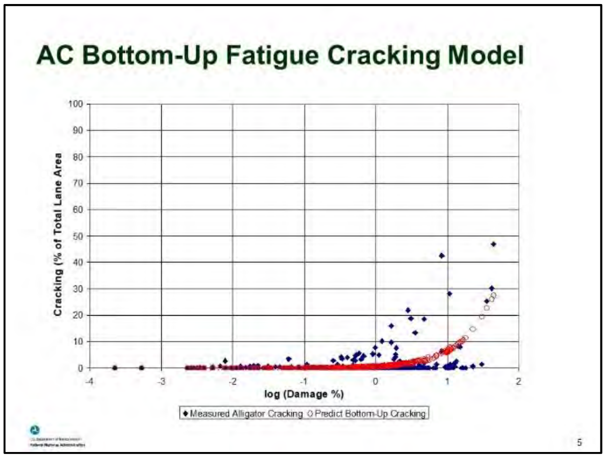
Presentation 2—Tom Yu, FHWA

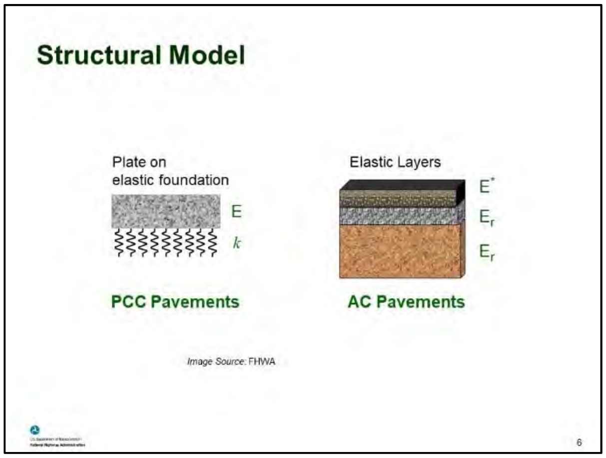












German Design Catalog for Concrete Pavement Alternatives

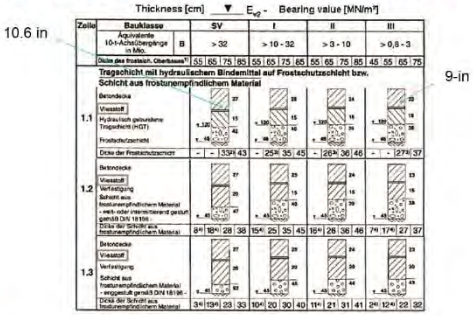


Image Source: Hall, K.T, et al, 2007. Long-Life Concrete Pavements in Europe and Canada. Report FHWA-PL-07-027.

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German Design Catalog for Highways

(>32 million ESALs)

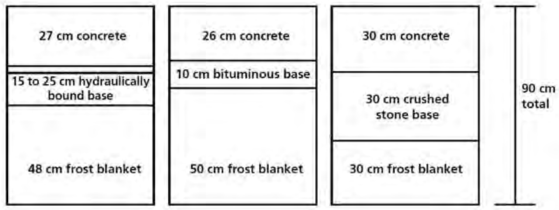

Image Source: Hall, K.T, et al, 2007. Long-Life Concrete Pavements in Europe and Canada. Report FHWA-PL-07-027.

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Keys to Achieving Well-Performing Pavement

Minimize the risk of poor performance

- Effective structural design
  - Good foundation
  - Adequate structural section
  - Appropriate design features
- Durable material
  - Durable surface
  - No material-related problems
- Quality construction

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Guidelines Are the Catalog's Main Feature

- Design features for different design conditions
- Material considerations
  - AC and PCC
  - Base and subbase
  - Subgrade
- Special subsurface conditions
  - Subsurface problems and investigations
  - Subsurface water flow and saturated soils
  - Collapsible, swelling, and frost-susceptible soils
  - Variability of soil types
  - Subgrade improvement by stabilization
- Minimizing potential for early distress development

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Content of the Design Catalog

Chapter 1: Introduction
Chapter 2: Design considerations
Chapter 3: Subsurface drainage recommendations
Chapter 4: Special subsurface conditions
Chapter 5: Recommendations to reduce early distresses
Chapter 6: Structural design, JPCP
Chapter 7: Structural design, AC pavement
Chapter 8: References
Appendices

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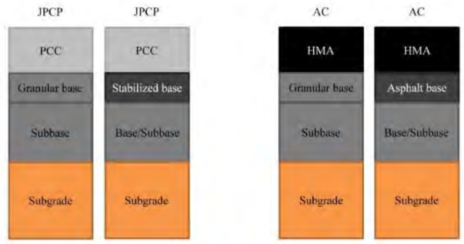
Types of Pavements Considered



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Key Design Parameters Considered

- Design Life
  - 20-year and 40-year (long-life) designs
- Subgrade
  - M_R of 8,000 to 18,000 psi
  - Three categories
- Traffic levels
  - Average Daily Truck Traffic (AADTT) from ≤ 500 to 10,000
  - Four categories
- Climate
  - Four LTPP climatic zones

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Status

- Draft report near completion
  - Guidelines are mostly complete
  - Design tables are being completed
- Anticipated completion of the draft report: December 2018
- Final report will be released March 2019

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Related Work

- Improving Foundation Designs
  - *Effective Foundation Design for Concrete Pavements (January 2020)*
- Improving Pavement Strategy (Long Life Pavements)
  - *Strategies for Concrete Pavement Preservation (January 2020)*
- Transportation Pooled-Fund – open solicitation
  - **TPF 1469**: *Road Foundation Contamination and Drainage – In-Service Evaluation and Best-Practice Recommendations*

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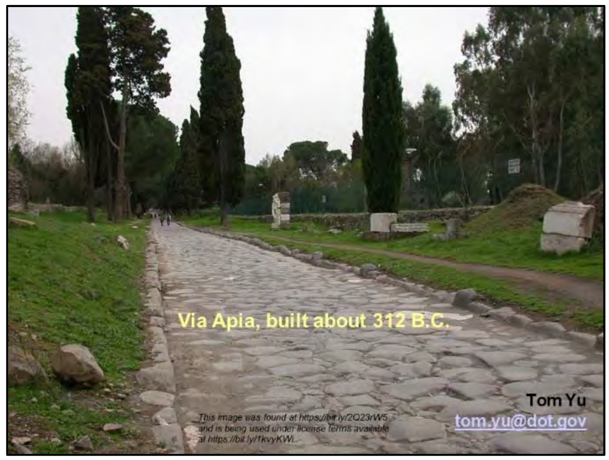
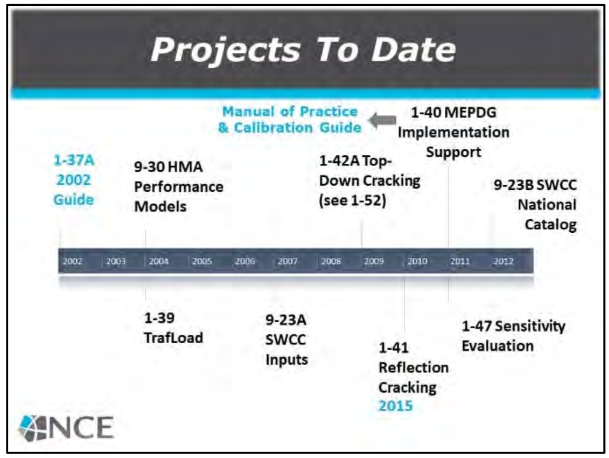
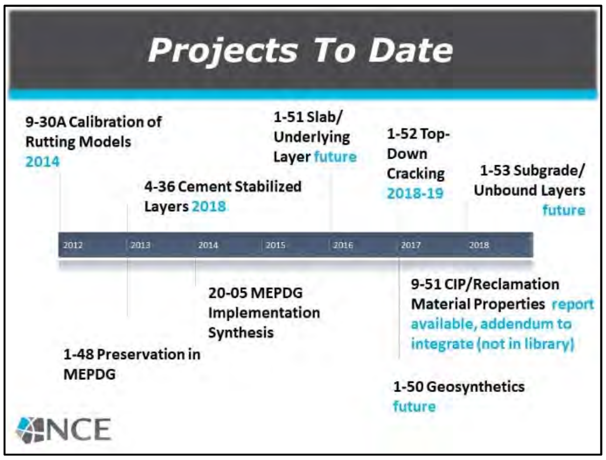
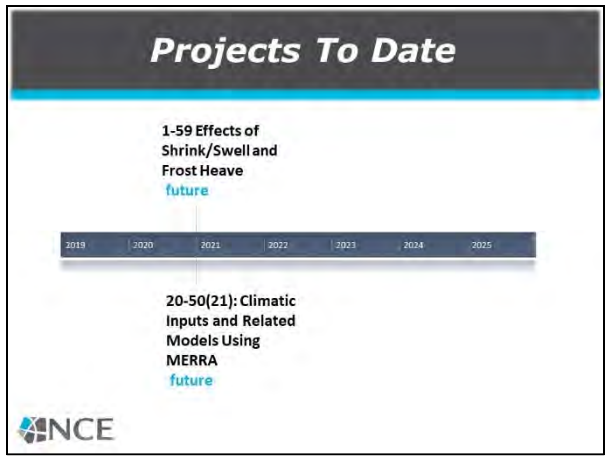
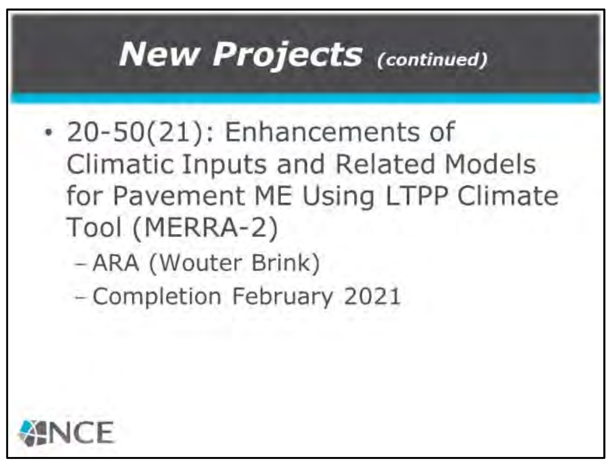


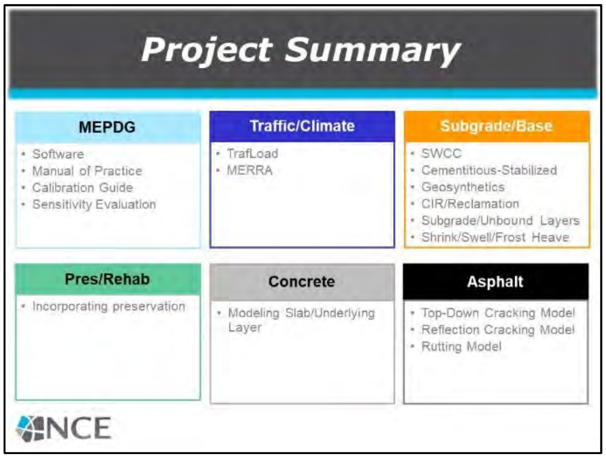
Presentation 3—Linda Pierce, NCE










Project Summary
MEPDG
• Software
• Manual of Practice
• Calibration Guide
• Sensitivity Evaluation
Traffic/Climate
• TrafLoad
• MERRA
Subgrade/Base
• SWCC
• Cementitious-Stabilized
• Geosynthetics
• CIR/Reclamation
• Subgrade/Unbound Layers
• Shrink/Swell/Frost Heave
Pres/Rehab
• Incorporating preservation
Concrete
• Modeling Slab/Underlying Layer
Asphalt
• Top-Down Cracking Model
• Reflection Cracking Model
• Rutting Model
NCE


Questions?
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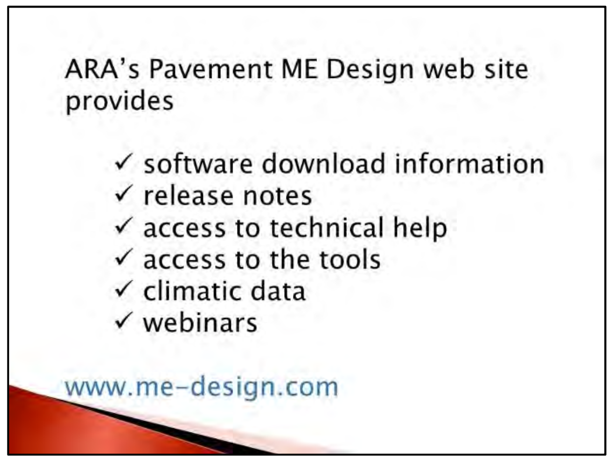
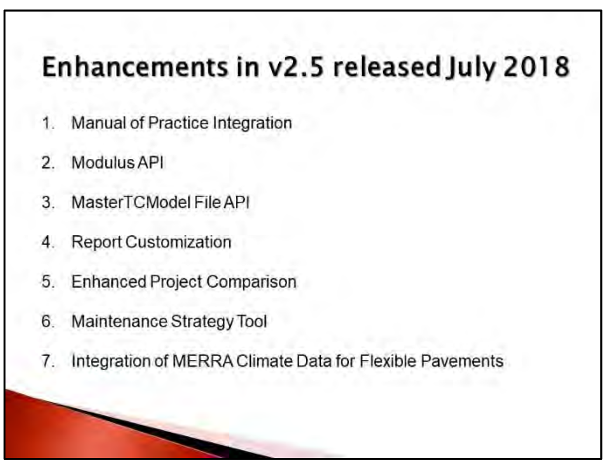
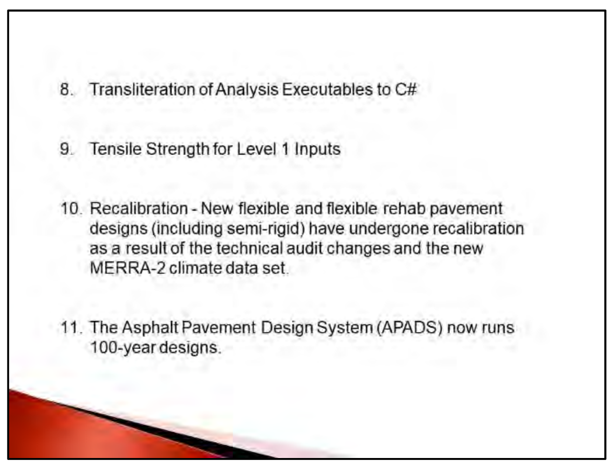
Presentation 4—Vicki Schofield, AASHTO



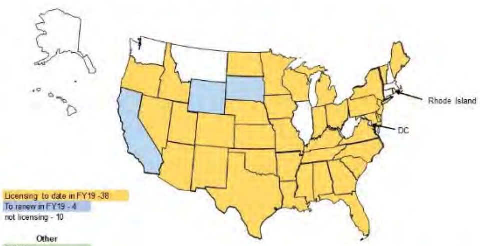




Enhancements in FY2019

- Calibration Tool (The Calibrator) – a tool to assist in local calibration efforts that is independent of the user as much as possible. It will help the user accomplish the following three objectives for each distress transfer function.
  1. Determine whether there is any bias in the predictions.
  2. Establish the cause of any bias if it is found through the calibration process.
  3. Optimize the calibration coefficient of the transfer function(s) for each distress to eliminate bias and minimize the standard error of the estimate.
- Top-down cracking model from NCHRP 1-52

AASHTOWare Pavement ME Design Licensee Map – FY19



Licensing to date in FY19 -38
To renew in FY19 - 4
not licensing - 10

Other
FHWA
Maricopa County, AZ

AASHTOWare Pavement ME Design Licensee Map

Licensing
Nova Scotia is evaluating

Additional License Types

	2019 (as of 10/11)
No Cost Educational	50
Private Sector	76
Universities	14
Backcalculation Tool	5

International

2018 - Brazil (2), Chile, China, Colombia (2), Guatemala, Hong Kong, Jordan, Lebanon, Liberia, Norway, Peru, Poland, Qatar (3), Saudi Arabia, South Korea (3), Spain, Sweden, Turkey, UAE (2), UK (2)

Licensing in FY 2019

Single user	$ 5,800
Site License – up to 9 concurrent users	$23,100
Site License – up to 14 concurrent users	$34,700
Site License – up to 20 concurrent users	$46,200
Backcalculation Tool	$ 1,250
Service Units (about 65 hours)	$13,500

- ARA manages international licenses

Backcalculation Tool

The Pavement ME Deflection Data Analysis and Backcalculation Tool is a standalone software program that can be used to generate backcalculation inputs from Falling Weight Deflectometer (FWD) files to the AASHTO Pavement ME Design software for rehabilitation design.

Although the tool is included with the Pavement ME Design software, it can also be licensed separately and used as a standalone single user application.

A training presentation is available at http://me-design.com/MEDesign/Webinars.html.

Web Technology

- Move from a single user desktop application to a web technology based software application.
- The current ME Design analysis software components exist as stand-alone CLI programs that require an external file system exclusively for all input and output, and are built with a variety of software programming languages, runtimes, and dependencies.
- A web technology application will improve the efficiency of the pavement designer by simplifying the user interactions with the software so the user can more effectively focus on designing pavement.
- Nov 30, 2017 - Completed a new web technology application as a "minimally viable product" (MVP), containing only the minimum inputs required to run a single ME Design analysis type, new JPCP, to assess the effort to make the move.

- Completed the transliteration work resulting in all of the code now being written in C#. The analysis executables existed in three different languages (C#, C++, and FORTRAN). Testing has confirmed consistency.
- The Task force reviewed a five year budget projection and recommends increasing license fees 10% each year for four years (FY2020 through 2023) to cover the cost of the project.
- Work is planned to begin in FY2019.

SHRP2 R23

The rePave scoping tool from the SHRP2 R23 project is an interactive web-based pavement design scoping tool that provides guidance for deciding where and under what conditions to use existing pavement as part of roadway renewal projects. It is being transferred to AASHTO to be included in the Pavement ME Design tool box. Incorporation of the rePave tool is expected to be completed in the second quarter for 2019.

AASHTOWare Pavement ME Design Product Task Force

John Donahue - Missouri DOT - Chair
Marta Juhasz - Alberta Transportation – Vice Chair
Patrick Bierl, Ohio DOT
David Holmgren, Utah DOT
Clark Morrison – North Carolina DOT
Bob Shugart – Alabama DOT
Karen Strauss, Oregon DOT

Liaisons:
Tom Yu, FHWA
Felix Doucet, Ministère des Transports du Québec - TAC
Shane Marshall, Utah DOT - SCOA
Travis Tackett, Florida DOT - TAA

For Additional Information:

Vicki Schofield
AASHTO Project Manager
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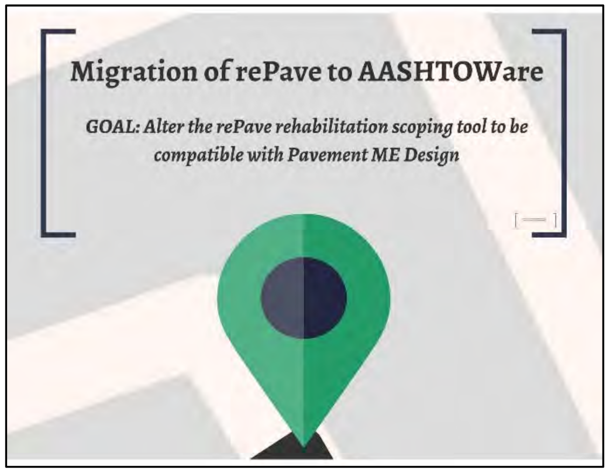
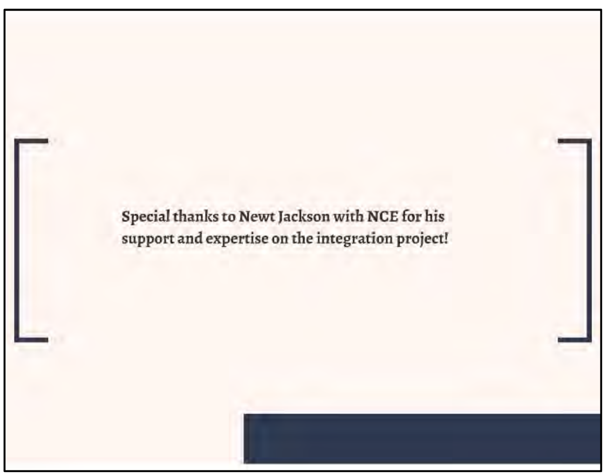
(202) 624-3640

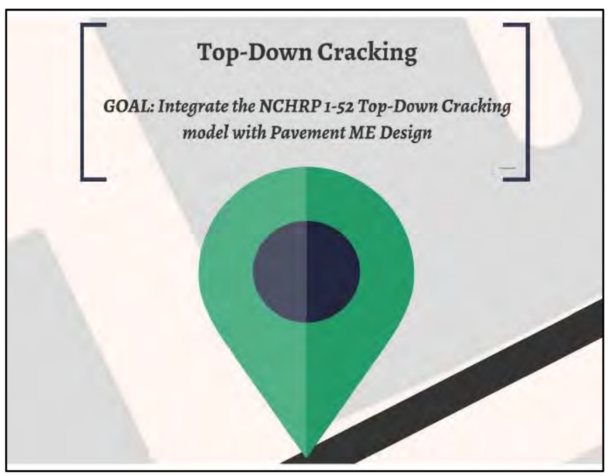
Presentation 5—Chad Becker, Applied Research Associates Inc. (ARA)


v2.5 Release
v2.5.3 patch release
Manual of Practice Integration
Maintenance Strategies
Customizable Reports
Indirect Tensile Strength
MERRA-2
Recalibration

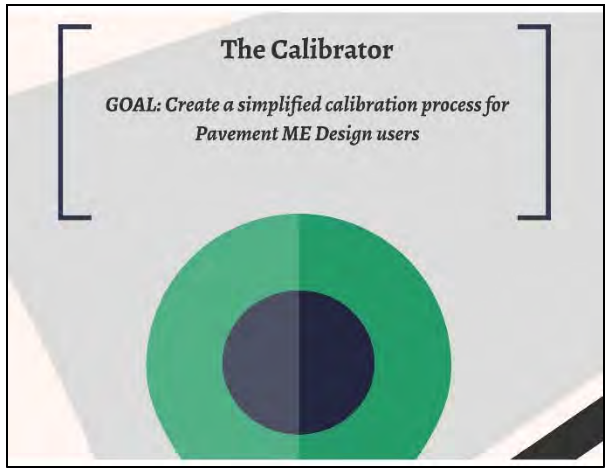

Arrival:
June 30th 2019
Pavement ME Design v2.6
75 mph
Pavement ME Design v2.5
Pavement ME Design v2.6


Migration of rePave to AASHTOWare
GOAL: Alter the rePave rehabilitation scoping tool to be compatible with Pavement ME Design


Special thanks to Newt Jackson with NCE for his support and expertise on the integration project!

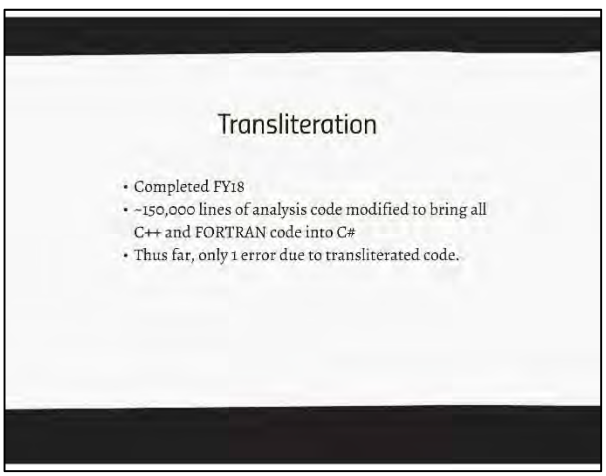

Top-Down Cracking
GOAL: Integrate the NCHRP 1-52 Top-Down Cracking model with Pavement ME Design

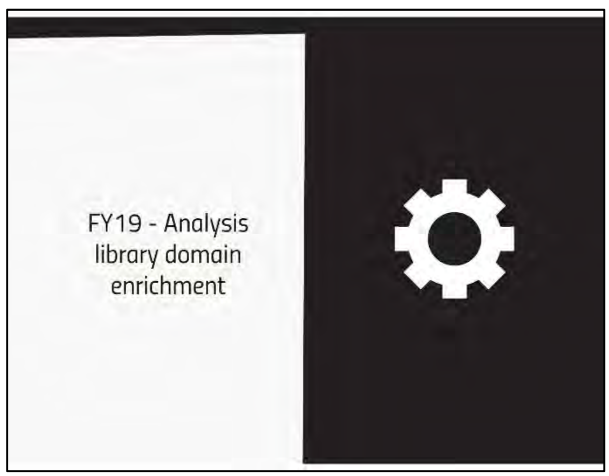

Special thanks to Bob Lytton for his support and expertise on the integration effort!


The Calibrator
GOAL: Create a simplified calibration process for Pavement ME Design users


Arrival:
June 30th 2019
Pavement ME Design v2.6
75 mph
Pavement ME Design v2.5
Pavement ME Design v2.6


Web technology application progress
19,264
Hours of work required...


Transliteration
• Completed FY18
• ~150,000 lines of analysis code modified to bring all C++ and FORTRAN code into C#
• Thus far, only 1 error due to transliterated code.


FY19 - Analysis library domain enrichment

FY20

- Domain and Behavior Enrichment

FY21

- Adapt and Develop a Uniform Data Persistence Model
- Adapt and Develop a Modular Reporting Subsystem

FY21-22

- Core Platform Integration
- Web Technology Application User Interface Development

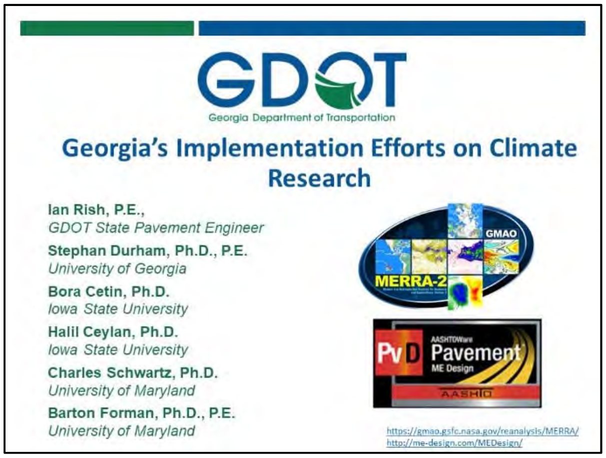
FY22

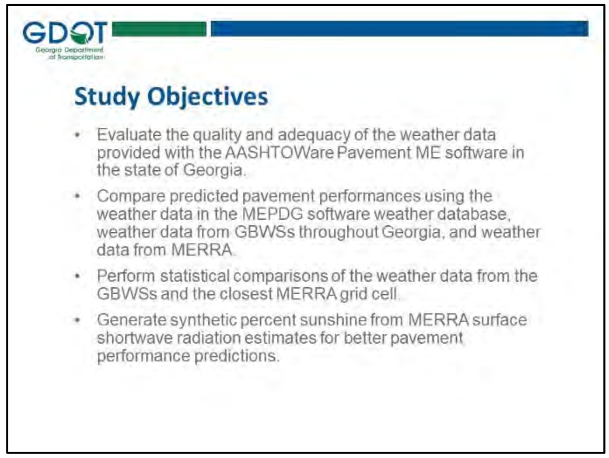
Release of Pavement ME Design v3.0

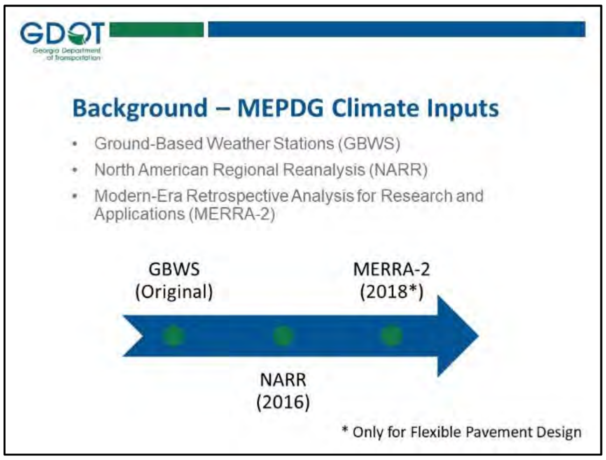
Future Enhancements

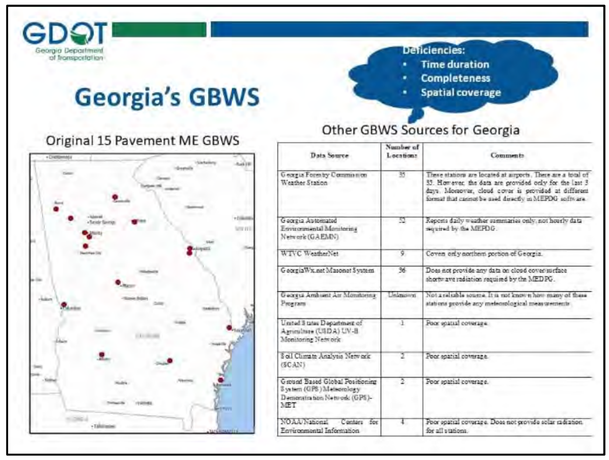
- Characterization of cementitious stabilized layers (NCHRP4-36 [Report 789])
- Material Properties of Cold In-Place Recycled and Full-Depth Reclamation Asphalt Concrete for Pavement Design (NCHRP 9-51 [Report 863])
- Slab/underlying layer interaction (NCHRP 1-51)
- Influence of geosynthetics (NCHRP 1-50)

Presentation 6—Steven Durham, University of Georgia

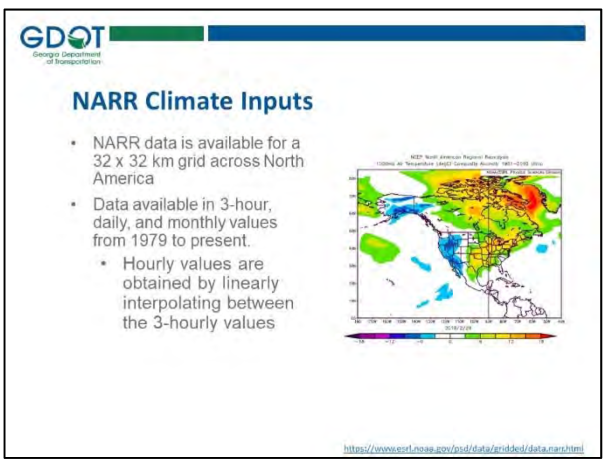


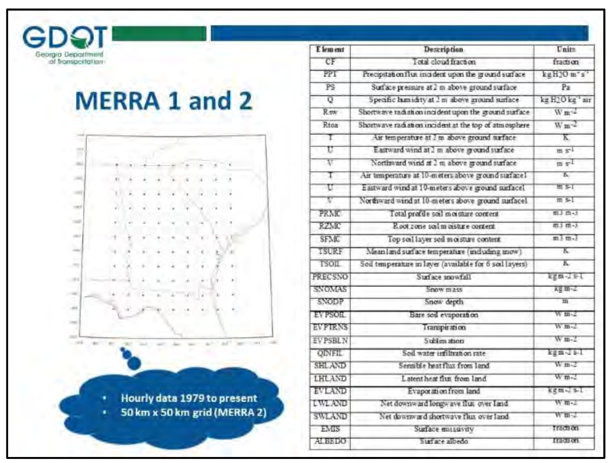






Data Source	Number of Locations	Comments
Georgia Forestry Commission Weather Station	35	These stations are located at airports. There are a total of 35. However, the data are provided only for the last 3 days. Moreover, cloud cover is provided at different format that cannot be used directly in MEPDG software.
Georgia Automated Environmental Monitoring Network (GAEMN)	52	Reports daily weather summaries only, not hourly data required by the MEPDG.
WTVC WeatherNet	9	Covers only northern portion of Georgia.
GeorgiaWx.net Mesonet System	36	Does not provide any data on cloud cover/surface shortwave radiation required by the MEDPG.
Georgia Ambient Air Monitoring Program	Unknown	Not a reliable source. It is not known how many of these stations provide any meteorological measurements.
United States Department of Agriculture (USDA) UV-B Monitoring Network	1	Poor spatial coverage.
Soil Climate Analysis Network (SCAN)	2	Poor spatial coverage.
Ground Based Global Positioning System (GPS) Meteorology Demonstration Network (GPS)-MET	2	Poor spatial coverage.
NOAA/National Centers for Environmental Information	4	Poor spatial coverage. Does not provide solar radiation for all stations.





Element	Description	Units
CF	Total cloud fraction	fraction
PPT	Precipitation flux incident upon the ground surface	kg H2O m-2 s-1
PS	Surface pressure at 2 m above ground surface	Pa
Q	Specific humidity at 2 m above ground surface	kg H2O kg-1 air
Rsw	Shortwave radiation incident upon the ground surface	W m-2
Rtoa	Shortwave radiation incident at the top of atmosphere	W m-2
T	Air temperature at 2 m above ground surface	K
U	Eastward wind at 2 m above ground surface	m s-1
V	Northward wind at 2 m above ground surface	m s-1
T	Air temperature at 10-meters above ground surface1	K
U	Eastward wind at 10-meters above ground surface1	m s-1
V	Northward wind at 10-meters above ground surface1	m s-1
PRMC	Total profile soil moisture content	m3 m-3
RZMC	Root zone soil moisture content	m3 m-3
SFMC	Top soil layer soil moisture content	m3 m-3
TSURF	Mean land surface temperature (including snow)	K
TSOIL	Soil temperature in layer (available for 6 soil layers)	K
PRECSNO	Surface snowfall	kg m-2 s-1
SNOMAS	Snow mass	kg m-2
SNODP	Snow depth	m
EVPSOIL	Bare soil evaporation	W m-2
EVPTRNS	Transpiration	W m-2
EVPSBLN	Sublimation	W m-2
QINFIL	Soil water infiltration rate	kg m-2 s-1
SHLAND	Sensible heat flux from land	W m-2
LHLAND	Latent heat flux from land	W m-2
EVLAND	Evaporation from land	kg m-2 s-1
LWLAND	Net downward longwave flux over land	W m-2
SWLAND	Net downward shortwave flux over land	W m-2
EMIS	Surface emissivity	fraction
ALBEDO	Surface albedo	fraction

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Collocation of GBWS and MERRA 1 and 2

- Based on spatial resolution of MERRA sources, it was guaranteed that at least one MERRA grid cell would correspond to every available ground based weather station
- Typical separation distances between the center of the MERRA grid cell and the collocated GBWS location ranged between 5 and 40 km.

Distance between MEPDG (GBWS) to MERRA-1 and MERRA-2			
Location ID	Airport	MERRA-1 Distance (mi)	MERRA-2 Distance (mi)
3813	Middle Georgia Regional Airport	22.74	14.1
3820	Augusta Regional Airport	9.2	10.3
3822	Savannah/Hilton International Airport	11.2	8.6
3888	Fulton County Airport	17.4	17.4
13837	Daniel Field Airport	3.2	8.7
13869	SW Georgia Regional Airport	11.6	10.9
13870	Bacon County Airport	9.7	2.5
13873	Athens Ben Epps Airport	3.6	12.1
13874	Hartsfield-Jackson International Airport	16.8	10.1
13878	Malcolm McKinnon Airport	17.4	19
53819	Falcon Field Airport	11.5	14.9
53838	Lee Gilmer Memorial Airport	18.4	16.3
53873	Cartersville Airport	13.4	12.1
93801	Richard B Russell Airport	14.3	13.9
93842	Columbus Metro Airport	16	3.5

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Pavement Performance Predictions

- The traffic levels and major pavement design inputs required by the AASHTOWare Pavement ME software for conducting analyses are determined based on standard base cases used by the Georgia Department of Transportation (Von Quintus et al. 2015).
- Only climate data inputs were changed.
- Asphalt Concrete Predictions
  - Total Rutting, AC Layer Rutting, Alligator Cracking, IRI, and Thermal Cracking
- JPCP Predictions
  - IRI, Joint Faulting, and Transverse Cracking

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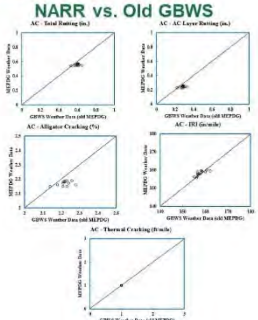
AC Pavement Predictions

NARR vs. Old GBWS



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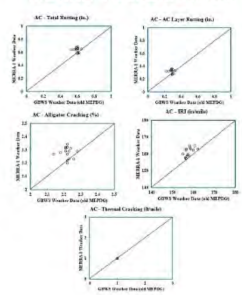
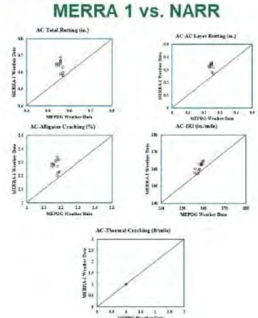
AC Pavement Predictions

MERRA 1 vs. Old GBWS



MERRA 1 vs. NARR



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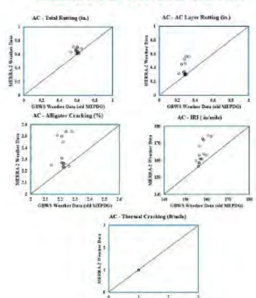
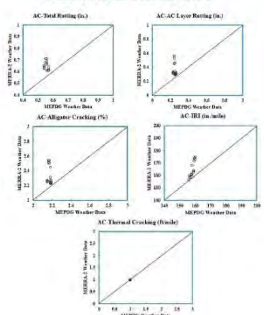
AC Pavement Predictions

MERRA 2 vs. Old GBWS



MERRA 2 vs. NARR



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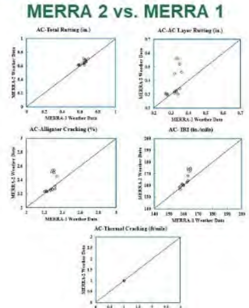
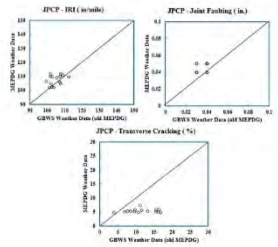
AC Pavement Predictions

MERRA 2 vs. MERRA 1



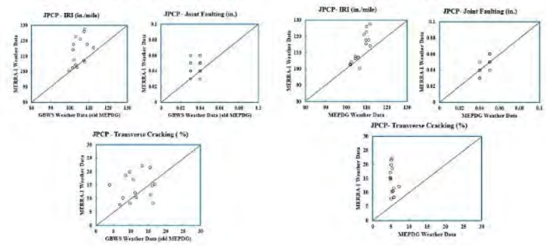
JPCP Predictions

NARR vs. Old GBWS



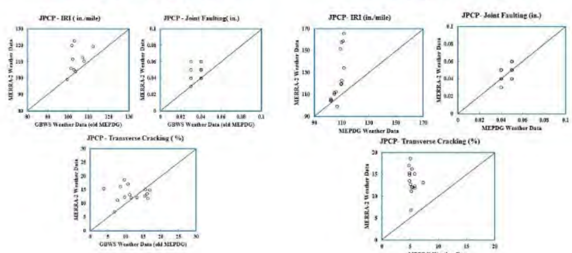
JPCP Predictions

MERRA 1 vs. Old GBWS / MERRA 1 vs. NARR



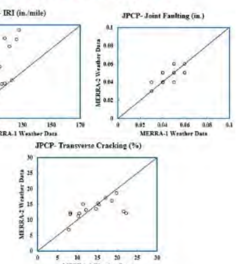
JPCP Predictions

MERRA 2 vs. Old GBWS / MERRA 2 vs. NARR



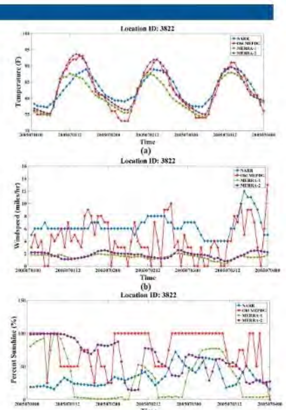
JPCP Predictions

MERRA 2 vs. MERRA 1



Reasons for Discrepancies

- For flexible pavements, the major reason for differences in predictions among climate data sources is due to considerable differences in percent sunshine values predicted by different climate data sources
- For rigid pavements, the reason for differences could be high wind speed values recorded for NARR compared to other sources and wind speed



Surface Shortwave Radiation

- The climate model embedded in the AASHTOWare Pavement ME software has traditionally used percent sunshine input values.
- The primary function of the percent sunshine inputs in the AASHTOWare Pavement ME software is to compute the surface shortwave radiation (SSR).
- Percent sunshine is a function of both percent cloud cover and time of the day.
- Surface shortwave radiation can provide more accurate, physically-based, and reliable inputs for use in MEPDG design in the future.
- Under this task, the research team developed a shortwave radiation model to back-calculate the synthetic percent sunshine by incorporating the shortwave radiation values.

Net Shortwave Radiation – MEPDG

- The current study used a pavement heating/shortwave radiation model to generate the synthetic percent sunshine by incorporating the surface shortwave radiation values collected from MERRA-1 and MERRA-2 in order to improve the accuracy of the pavement performance predictions.

$$Q_s = \alpha R(A + B\frac{S}{100})$$

Q_s = net incoming surface shortwave radiation (SSR)
α = surface shortwave absorptivity
R = top of atmosphere solar radiation
S = percent sunshine = (1 - %cloud cover)
A, B = empirical coefficients for atmospheric absorption, diffusion of solar energy

Net Shortwave Radiation – MEPDG

$$Q_s = \alpha R(A + B\frac{S}{100})$$

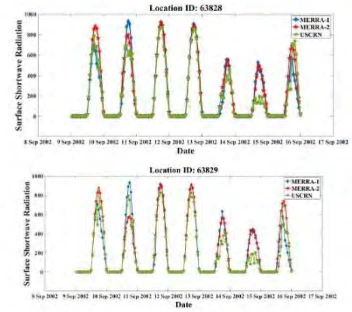
Problems:

- α is poorly known
- S is poorly defined/measured, plus different cloud types have different shortwave radiation absorption characteristics
- A, B are empirical (Baker and Haines, **1969**) and were calibrated only for northern tier states and Canada

Is There a Better Way?

- **YES!** MERRA provides state-of-the-art direct physics-based predictions of SSR
- **So why don't we use this instead?** Pavement ME Design does not permit direct input of surface shortwave radiation
- **Can we "trick" Pavement ME Design as an expedient?** Yes, by using backcalculated percent sunshine to give the same SSR as predicted directly by MERRA.

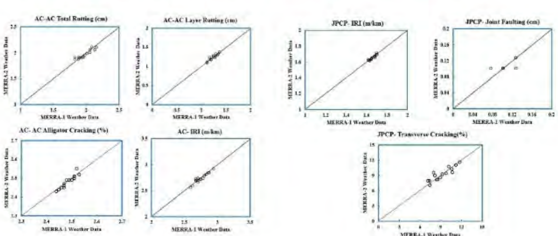
Comparing MERRA 1 and 2 SSR with USCRN



SSR in MERRA-1, MERRA-2, and USCRN data sets are showing that SSR values from all three data sets are in good agreement

MERRA 1 vs. MERRA 2

Using Back-Calculated Percent Synthetic Sunshine



Conclusions

- The agreement between the MERRA-1 and the MERRA-2 percent sunshine data was particular poor, which is the likely reason for the differences in predicted pavement performance using these two climate data sources.
- The empirical relationship between SSR and percent sunshine (Equation 1) was inverted to back calculate synthetic percent sunshine data that were consistent with the MERRA-1/2 SSR values.
- These back calculated synthetic percent sunshine histories were used to replace the percent sunshine values in the climate data files provided with the Pavement ME Design software
- Companion study (Phase II) to evaluate the effect of longwave radiation on pavement performance

Recommendations

- Recommendation for the re-evaluation of the percent sunshine approach currently used in Pavement ME Design.
- Percent sunshine as obtained from percent cloud cover, whether measured or predicted, is a non-fundamental derived property that is just too imprecise for use in pavement performance modeling.
- Recommendation for converting to SSR as the direct input to Pavement ME Design for pavement environmental modeling.
  - The modifications to the Pavement ME Design code necessary to effect this change are trivial.

Questions?

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sdurham@uga.edu

Presentation 7—Affan Habib, Virginia DOT

VDOT
Virginia Department of Transportation

Successful Implementation: Challenges Overcome and Current Areas of Focus/Refinement

November 7, 2018

Affan Habib, PE
Pavement Program Manager
VDOT

VDOT

Outline

- VDOT's successful MEPDG implementation
- Challenges encountered and overcome
- Challenges ahead
- Opportunities

2

VDOT

Virginia's MEPDG Implementation at a Glance

- Where does VDOT plan to use MEPDG?
  - Interstate and Primary routes.
    - New alignment, reconstruction, and lane widening
    - Rehab design: sometime in the future
  - Continue to use VDOT's Secondary & Subdivision Pavement Design Guide & Procedures on Secondary & Subdivision streets
    - Some high volume secondary roads with AADT > 10,000 maybe designed using MEPDG at discretion of Districts Material Engineer.
- http://www.virginiadot.org/business/materials-download-docs.asp

3

VDOT

Virginia's MEPDG Implementation at a Glance

/materials-download-docs.asp

Geotechnical Software Support

Customized gINT Library, Data Templates, and MicroStation Converter (zip 113 MB) Updated May 1, 2018

Readme and Documentation (pdf 662 KB)

Pavement Design and Evaluation Documents:

- 2018 Pavement Design Guide for Subdivision and Secondary Roads in Virginia (pdf 3 MB)
- Pavement Design Software for Secondary Roads in Virginia

AASHTOWare Pavement ME Pavement Design Input Files

- Materials
- Traffic
- Climate Stations.dat
- Climate (Virginia and Surrounding States)
  VA | MD | WV - Part 1 and WV - Part 2 | NC - Part 1 and NC - Part 2 | TN | KY
- VDOT Pavement ME User Manual

4

VDOT

What it takes for a successful implementation?

- A lot of friends
- A lot of patience
- A very specific project plan

Goal: Implementing MEPDG by January 1, 2018

Objective(s):
- Create MEPDG Stakeholders and Technical Working Group (TWG) and conduct meetings during the implementation stage of MEPDG.
- Finalize outstanding material characterization, modeling, and performance target issues.
- Finalize MEPDG user manual and upload on VDOT consultant site.

Timeframe: December 2016 – September 2017

Activities	Lead/Partners	Target Date for Completion	Status of Progress/Issues	Actual Completion Date	Scope of Activities	Impact of Activities on Implementation Timeline
Activity 1: Establishing Stakeholders and Technical Working Committee						
Activity 1A: Establish stakeholders group (VDOT, Industry, and FHWA)	PD&E	December 2016/January 2017		December 2016	Stakeholder group will include representatives of VDOT, FHWA, and Industry. The group will be provided periodic update on status and progress of the implementation.	Critical*
Activity 1B: Establish Technical Working Group (TWG)	PD&E	December 2016/January 2017		January 2017	The TWG will include VDOT (Maintenance, CO Material, Districts, and VCTIR), and Industry representatives. The team will address technical issues encountered during the implementation.	Critical*
Activity 2 Addressing MEPDG material characterization issues						
Activity 2.A: Consolidate existing asphalt mixes characteristics to one mix property per mix type (Surface, Intermediate, Base, and SMA)	Girum/ Ben	January 30 2017		January 30 2017	This activity will consolidate the existing test results from previous VTCR study to one unique value per mix type (Surface, Intermediate, Base, and SMA).	Important*
Activity 2.B Reviewing Material Characterization input for CTA Layers and assess the impact of stiff layers on rigid pavements	Girum /PD&E/TWG	May 1, 2017		April 18,2017	This activity will incorporate the findings of VCTIR research study on characterization of CTA for MEPDG Design in the user manual. This activity will also look the impact of CTA under flexible and rigid pavement.	Important*
Activity 2.C Capping Subgrade Resilient Modulus (RM) value	Girum/PD&E/TWG	March 15 2017		March 15, 2017	This activity will assess the need to provide capping on the resilient modulus value of subgrade soil. (Current VDOT MOI limits the maximum RM value of subgrade soils to 15,000 psi)	Important*
Activity 2.D: Providing Level 1 low temperature input values for Surface Mixes	Girum	March 3,2017		March 3,2017	This activity includes creating Level 1 low temperature input values (creep compliance and indirect tensile strength at 14 degrees) for Surface Mixes. The task involves creating input values in a tabular and xml format from VTRC research study.	Important*
Activity 2.E: Finalizing the Development of Virginia Test Method on test to determine subgrade resilient modulus from Unconfined Compression (UC) test	Girum/PD&E/Soil Lab /Quality Assurance	June 1, 2017		April 27, 2017	PD& E will facilitate the implementation of the proposed VTM. The VTM will be finalized & readily available as an alternative testing method to determine RM.	Important*

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"Success": How is it measured?

- Short term
  - Yourself is comfortable
  - DOT designers can handle the design
  - External consultants can handle the design
  - No major surprises to anyone with the design
- Long term
  - Time will tell

5

VDOT

Challenges Overcome

Technical

- Insensitivity to aggregate base, subgrade
- Use of specialized materials
- Local calibration
- Passing the "smell" test
- Version change

Non Technical

- Answering questions
- Expectation for perfection
- Fear of complications
- Getting stakeholders buy in

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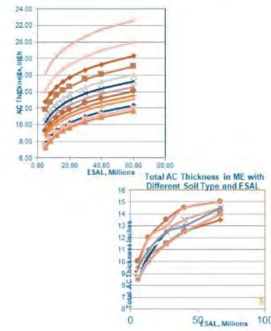
Technical Challenges: Insensitivity to agg. Base, subgrade

- Mandated the use of 6" aggregate base unless stabilized materials is used
  - Reflects our prevailing practice
- In MEPDG, subgrade is not that sensitive like it is in 1993 method
- Waiting on NCHRP 1-53



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Technical Challenges: Use of specialized materials

- Stabilized & Recycled materials
  - Modeling stabilized materials as 80ksi agg. base disabling EICM
    - FDR: 50% reliability
  - Modeling CCPR as AC base, using thickness multiplier
- SMA & polymer modified mixes
  - MEPDG doe not predict expected better performance
  - Using one surface mix, intermediate and base mix
  - Initiated a study to address this
- Similar situation with other newer materials not present on LTPP sections

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Technical Challenges: Local Calibration

- Done in house (VTRC/Materials)
- AC: Bottom up fatigue cracking & total rutting
- CRC: Punhnout
- JCP: No local calibration
- Tried to "calibrate" IRI model but ended up in not using IRI as a design distress parameter

VDOT

Technical Challenges: Passing the 'Smell Test'

- Ran thousands of sensitivities covering different potential scenarios covering wide range of
  - Traffic
  - Subgrade
  - Environment
  - Materials
- The objective was to 'catch' anything 'unusual' so we can -
  - Address it (if there is a solution)
  - Come up with work around
  - Make concerned aware of it (at a minimum)
- Enhanced our level of comfort

VDOT

Technical Challenges: Version Change

- AASHTO releases "new" version "once" a year
  - Cannot move to new release w/o assessing changes
  - Set some base designs to assess changes
  - Separate laptop to assess changes
  - Newer version may need re-doing local calibration
- VDOT using the version used for local calibration
  - AASHTO's vendor "supports" current & n-1 version
  - Need support on the chosen version
  - Potential issue consultants working for multiple DOTs

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Non-technical Challenges: Answering questions

Why is it taking so long?

Communication

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VDOT

Non-technical Challenges: Expectation for Perfection

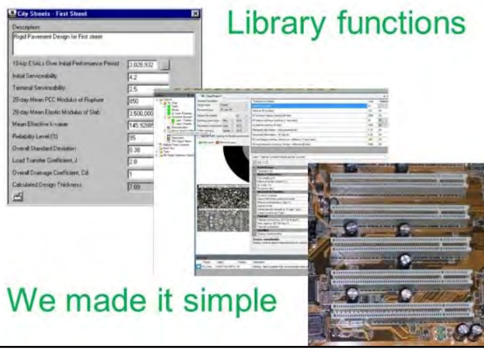
"Enemy of excellence is PERFECTION"

14

VDOT

Non-technical Challenges: Fear of complication

Library functions



We made it simple

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VDOT

Non-technical Challenges: Getting stakeholders' buy in

- Obtained executive and industry buy in
- Provided a year out notice to industry before flipping switch
- Established TWG and stakeholders group
  - VDOT, industry, FHWA
- TWG addressed the technical issues/concerns
  - Transparent & open
- Provided monthly update to the stakeholders group
- Provided "training" to local consultants
  - https://www.vtca.org/resources/other-resources/vtca-mepdg-seminar-video/

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VDOT

Challenges Ahead

- Implementing MEPDG on rehab design
  - A plan is being drafted
  - Looking for a two year out
  - The critical issue is whether or not to do local calibration for rehab
- How to separate the mixes?
  - SMA, dense grade, polymer modified
- How to characterize the new materials
  - Recycling

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VDOT

Challenges Ahead

- Changing models
  - By far, the most significant one
  - May impact current local calibration
  - Local calibration may be needed:
    - NARR to MEERA
    - Version 2.2 to 2.5
    - Incorporation of ongoing NCHRP study recommendations
  - Local calibration involves huge resource
    - Careful coordination of changes is critical
    - DOTs feedback before finalizing changes

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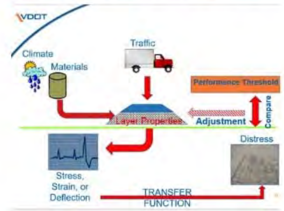
Challenges Ahead

- Securing resources for future updates
  - Characterization of traffic, materials
  - How often?
- So the work is not done yet..
  - Resource, commitment etc.
- Is the chain/executive plugged in?
  - They need to hear that from the "owner"
- Who is the "owner"?
  - AASHTO, FHWA, Task force, COMP?

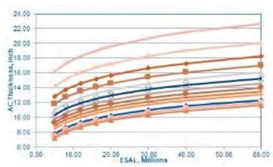
Challenges Ahead

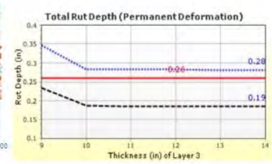
- Lack of knowledge on the fundamentals

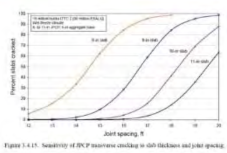


- Don't want to see MEPDG as "black box"
  - NHI, online class, "cheat sheet"

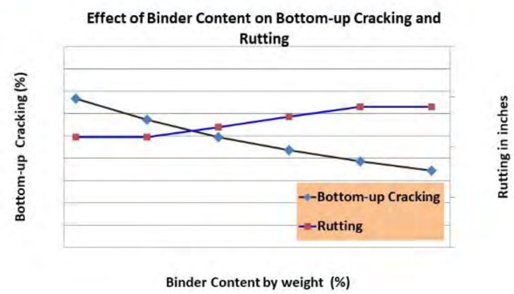
Opportunities: MEPDG is not all about thickness



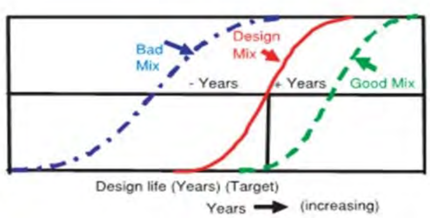




Opportunities: Assess impact of spec change



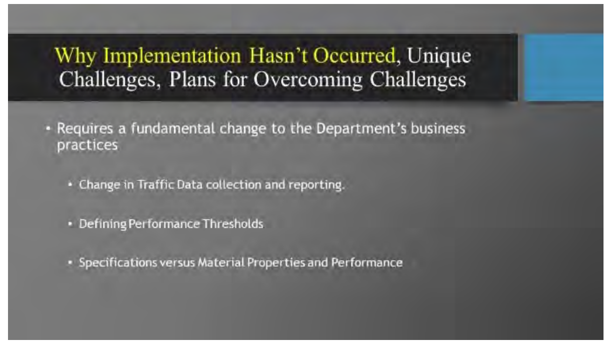
Opportunities: Justify/quantify pay adjustment

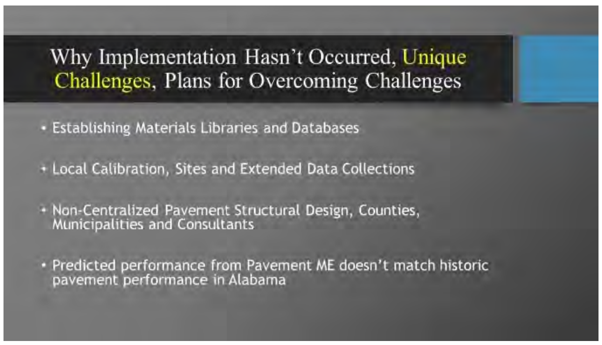


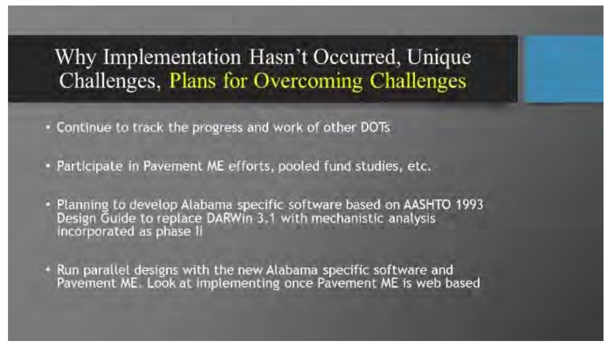
Thank You
Any Questions?

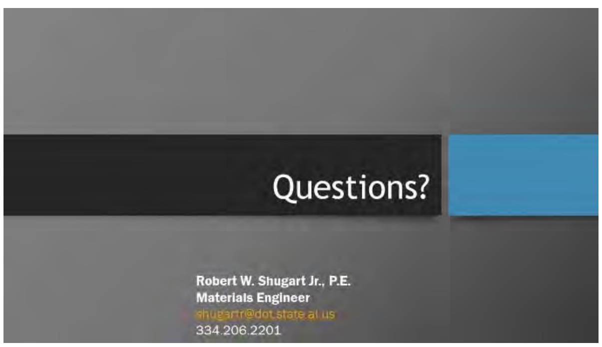
Affan Habib
(affan.habib@vdot.virginia.gov)

Presentation 8—Scott George, Alabama DOT









Presentation 9—Halil Ceylan, Iowa State University

IOWA STATE UNIVERSITY
Institute for Transportation

New Reflection Cracking Model for Hot Mix Asphalt (HMA) over Jointed Plain Concrete Pavements (JPCP): Sensitivity Analysis

Presented by
Halil Ceylan, Ph.D., Director, PROSPER

Dept. of Civil, Construction and Environmental Engineering (CCEE)
Program for Sustainable Pavement Engineering and Research (PROSPER)
Institute for Transportation (InTrans), Iowa State University (ISU)

AASHTO Pavement ME User Group Meeting
Nashville, Tennessee, November 7-8, 2018

Authors / Research Team

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Acknowledgments

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- Ben Behnami, P.E. (TAC – IA DOT)
- Robert Lytton, Ph.D., P.E. (Texas A&M University)

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Outline

- Background: Reflective Cracking Models
  - NCHRP 1-41
  - Pavement ME Design
- Pavement ME Design Reflective Cracking Predictions for Iowa HMA over JPCP
- Sensitivity Analysis of Pavement ME Design Reflective Cracking Predictions
- Summary

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Enhancements to MEPDG

- Before Version 2.2
  - Regression equation
  - Fatigue cracks
- Version 2.2 and later
  - Fracture mechanics
  - Fatigue cracks
  - Transverse cracks

$$RC = \frac{100}{1+e^{a(c)+bt(d)}}$$

$$RCR_i = C\left(\frac{100}{c_4 + e^{c_5(Log(DI_i))}}\right)$$

(Von Quintus 2017)

Performance Criteria and Reliability: AC over Rigid Pavements

- AC of intact JPCP, AC of CRCP, and AC of fractured JPCP

AC over JPCP Pavements

Performance Criteria	Limit	Reliability	Report Visibility
Initial IRI (in/mile)	63		☑
Terminal IRI (in/mile)	172	90	☑
AC top-down fatigue cracking (ft/mile)	2000	90	☑
AC bottom-up fatigue cracking (% lane area)	25	90	☑
AC thermal cracking (ft/mile)	1000	50	☑
Permanent deformation - AC only (in)	0.25	90	☑
AC total transverse cracking: thermal + reflective (ft/mile)	2500	90	☑
JPCP transverse cracking (percent slabs)	15	90	☑

Performance Criteria and Reliability: AC over Flexible Pavements

- AC of AC, AC of AC with seal coat, AC of AC with interlayer

AC over AC Pavements

Perfomance Criteria	Limit	Reliability	Report Visibility
Initial IRI (in/mile)	63		☑
Terminal IRI (in/mile)	172	90	☑
AC top-down fatigue cracking (ft/mile)	2000	90	☑
AC bottom-up fatigue cracking (% lane area)	25	50	☑
AC thermal cracking (ft/mile)	1000	50	☑
Permanent deformation - total pavement (in)	0.75	90	☑
Permanent deformation - AC only (in)	0.25	90	☑
AC total fatigue cracking: bottom up + reflective (% lane area)	25	90	☑
AC total transverse cracking: thermal + reflective (ft/mile)	2500	90	☑

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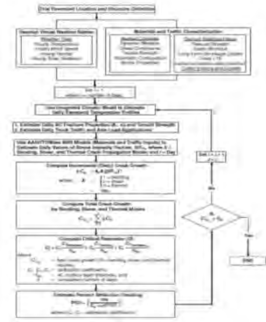
Procedure for Forecasting Progression of Reflection Cracking

- Calibration coefficients
  - K1, K2, K3 for crack propagation model
  - C1, C2, C3 for critical response parameter (D_T)
  - C4, C5 for reflection cracking rate (PCR)



(Titus-Glover et al. 2016)

Calibration Coefficients: AC over Rigid Pavements

Calibration Coefficients, AC over JPCP Pavements

Reflective Cracking

$$\Delta C = k_1 \Delta_{Bending} + k_2 \Delta_{Shearing} + k_3 \Delta_{thermal}$$

$$\Delta D = \frac{C_1 k_1 \Delta_{Bending} + C_2 k_2 \Delta_{Shearing} + C_3 k_3 \Delta_{thermal}}{h_{OL}}$$

$$\Delta_{Bending} = A(SIF)_B^n$$

$$\Delta_{Shearing} = A(SIF)_S^n$$

$$\Delta_{Thermal} = A(SIF)_T^n$$

$$D = \sum_{i=1}^{N} \Delta D$$

$$RCR = \left(\frac{100}{C4 + e^{C5 \log D}}\right) * EX\_CRK$$

Where

ΔC	=	Crack length increment, in
ΔD	=	Incremental damage ratio
$k_1, k_2, k_3, C_1, C_2, C_3, C_4, C_5$	=	Calibration factors (local and global)
$\Delta_{Bending}, \Delta_{Shearing}, \Delta_{thermal}$	=	Crack length increments caused by bending, shearing, and thermal loading
A, n	=	HMA material fracture properties
N	=	Total number of days
$(SIF)_B, (SIF)_S, (SIF)_T$	=	Stress intensity factors caused by bending, shearing, and thermal loading
D	=	Damage ratio
h_{OL}	=	Overlay thickness, in
RCR	=	Cracks in the underlying layers reflected, %
EX_CRK	=	Transverse cracking in underlying pavement layers, ft/mile (transverse cracking) Alligator cracking in underlying pavement layers, % lane area (alligator cracking)

Pavement Type	Distress Type	k1	k2	k3	C1	C2	C3	C4	C5	Standard Deviation
AC over Intact JPCP	Transverse	0.012	0.005	1	0.1	0.52	3.1	79.5	-2.71	5.1025 * Pow (TRANSVERSE,0.6513) + 30.12

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Calibration Coefficients: AC over Flexible Pavements

Calibration Coefficients, AC over AC Pavements

Reflective Cracking

$$\Delta C = k_1 \Delta_{Bending} + k_2 \Delta_{Shearing} + k_3 \Delta_{thermal}$$

$$\Delta D = \frac{C_1 k_1 \Delta_{Bending} + C_2 k_2 \Delta_{Shearing} + C_3 k_3 \Delta_{thermal}}{h_{OL}}$$

$$\Delta_{Bending} = A(SIF)_B^n$$

$$\Delta_{Shearing} = A(SIF)_S^n$$

$$\Delta_{Thermal} = A(SIF)_T^n$$

$$D = \sum_{i=1}^{N} \Delta D$$

$$RCR = \left(\frac{100}{C4 + e^{C5 \log D}}\right) * EX\_CRK$$

Where

ΔC	=	Crack length increment, in
ΔD	=	Incremental damage ratio
$k_1, k_2, k_3, C_1, C_2, C_3, C_4, C_5$	=	Calibration factors (local and global)
$\Delta_{Bending}, \Delta_{Shearing}, \Delta_{thermal}$	=	Crack length increments caused by bending, shearing, and thermal loading
A, n	=	HMA material fracture properties
N	=	Total number of days
$(SIF)_B, (SIF)_S, (SIF)_T$	=	Stress intensity factors caused by bending, shearing, and thermal loading
D	=	Damage ratio
h_{OL}	=	Overlay thickness, in
RCR	=	Cracks in the underlying layers reflected, %
EX_CRK	=	Transverse cracking in underlying pavement layers, ft/mile (transverse cracking) Alligator cracking in underlying pavement layers, % lane area (alligator cracking)

Pavement Type	Distress Type	k1	k2	k3	C1	C2	C3	C4	C5	Standard Deviation
AC over AC	Transverse	0.012	0.005	1	3.22	25.7	0.1	133.4	-72.4	70.98 * Pow (TRANSVERSE,0.2994) + 30.12
AC over AC	Fatigue	0.012	0.005	1	0.38	1.66	2.72	105.4	-7.02	1.1097 * Pow (FATIGUE,0.6804) + 1.23

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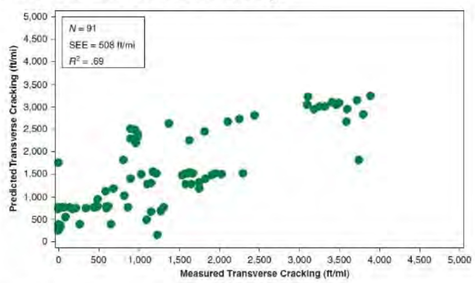
Predicted vs. Measured: AC over Semirigid Pavements

- Reflective transverse cracking



(Titus-Glover et al. 2016)

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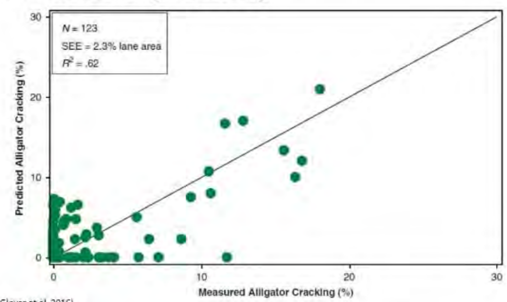
Predicted vs. Measured: AC over Semirigid Pavements (Cont'd)

- Reflective fatigue cracking



(Titus-Glover et al. 2016)

Outline

- Background: Reflective Cracking Models
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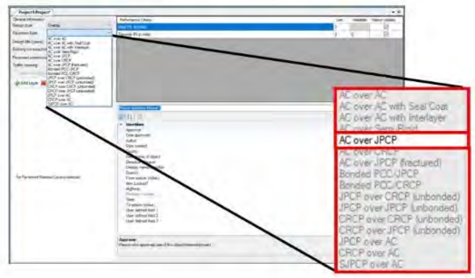
HMA over JPCP Design Option in Pavement ME Design



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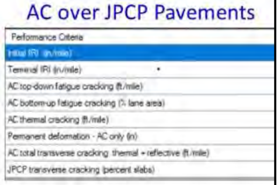
HMA over JPCP Design Option in Pavement ME Design (Cont'd)

- Performance predictions
  - International roughness index (IRI)
  - Fatigue cracking
    - Top-down
    - Bottom-up
  - Rutting
  - Transverse cracking
    - Thermal
    - Reflective
    - AC total: thermal + reflective)
    - JPCP transverse cracking

AC over JPCP Pavements



Iowa HMA over JPCP Design Examples

- Two Iowa HMA over JPCP roads
  - US34/Clarke Co./1/MP 117.04 to 117.57
  - IA5/Monroe Co./1/MP 25.74 to 34.23
- Two analysis cases for existing JPCP conditions on each road
  - Case 1: 20 ft. joint spacing and 10% slabs repaired/replaced after restoration
  - Case 2: 20 ft. joint spacing and 0% slabs repaired/replaced after restoration

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Iowa HMA over JPCP Design Examples: Assumption

- In current, Iowa PMIS does not distinguish reflection cracking measures from transverse cracking measures
- Assumption for historical transverse cracking records in Iowa PMIS
  - Maximum possible reflection cracking measurements could be recorded when each of transverse cracking was observed on each joint of existing JPCP
    - Number of joints of existing 20 ft. joint spacing JPCP per mile: 5,280 ft./20 ft. +1 = 265 joints
    - HMA overlay lane width: 12 ft.
    - **Maximum possible reflection cracking measurement rate** = 265 joints × 12 ft. = **3,180 ft. per mile**
  - If transverse cracking measurements are less than 3,180 ft. per mile
    - Assume these measurements as reflection cracking measurements
  - If transverse cracking measurements are higher than 3,180 ft. per mile
    - Assume the difference between these measurements and 3,180 ft. per mile as thermal cracking measurements

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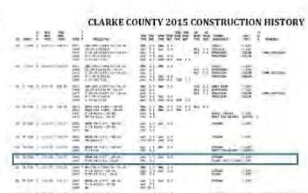
HMA over JPCP Design Example: US34/Clarke Co./1/MP 117.04 to 117.57

- Traffic (AADTT): 664
- Clarke county
- Structure properties
  - 3.5 inch HMA overlay
  - 9.0 inch existing PCC



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HMA over JPCP Design Example: US34/Clarke Co./1/MP 117.04 to 117.57 (Cont'd)

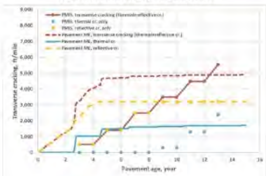
- Transverse cracking measurements vs. predictions:

Case 1/US34

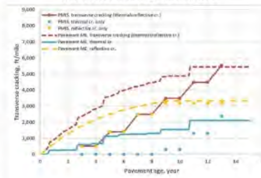
Maximum possible reflection cracking (ft./mile)	3,180
Pavement ME predictions (version 2.3 / version 2.5) (20 years) (ft./mile)	3,201 / 3,342

- 50% reliability
- 20 ft. joint spacing with 15% slabs distressed
- 10% slabs repaired/replaced after restoration

Pavement ME version 2.3



Pavement ME version 2.5



HMA over JPCP Design Example: US34/Clarke Co./1/MP 117.04 to 117.57 (Cont'd)

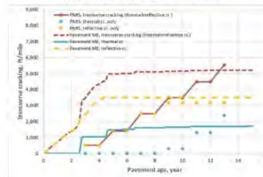
- Transverse cracking measurements vs. predictions:

Case 2/US34

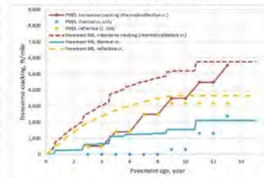
Maximum possible reflection cracking (ft./mile)	3,180
Pavement ME predictions (version 2.3 / version 2.5) (20 years) (ft./mile)	3,505 / 3,659

- 50% reliability
- 20 ft. joint spacing with 15% slabs distressed
- 0% slabs repaired/replaced after restoration

Pavement ME version 2.3



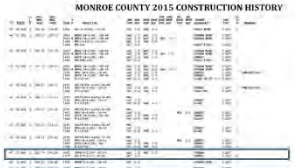
Pavement ME version 2.5



HMA over JPCP Design Example: IA5/Monroe Co./1/MP 25.74 to 34.23

- Traffic (AADTT): 473
- Monroe county
- Structure properties
  - 3.5 inch HMA overlay
  - 9.0 inch existing PCC

MONROE COUNTY 2015 CONSTRUCTION HISTORY



HMA over JPCP Design Example: IA5/Monroe Co./1/MP 25.74 to 34.23 (Cont'd)

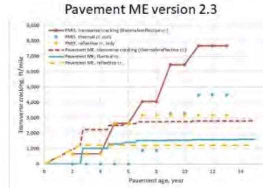
- Transverse cracking measurements vs. predictions:

Case 1/IA5

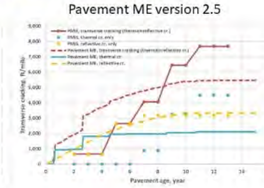
Maximum possible reflection cracking (ft./mile)	3,180
Pavement ME predictions (version 2.3 / version 2.5) (20 years) (ft./mile)	1,208 / 3,337

- 50% reliability
- 20 ft. joint spacing with 15% slabs distressed
- 10% slabs repaired/replaced after restoration

Pavement ME version 2.3



Pavement ME version 2.5



HMA over JPCP Design Example: IA5/Monroe Co./1/MP 25.74 to 34.23 (Cont'd)

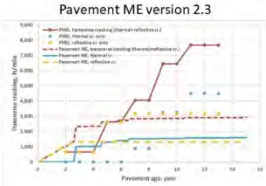
- Transverse cracking measurements vs. predictions:

Case 2/IA5

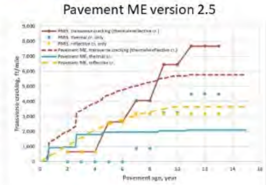
Maximum possible reflection cracking (ft./mile)	3,180
Pavement ME predictions (version 2.3 / version 2.5) (20 years) (ft./mile)	1,323 / 3,654

- 50% reliability
- 20 ft. joint spacing with 15% slabs distressed
- 0% slabs repaired/replaced after restoration

Pavement ME version 2.3



Pavement ME version 2.5



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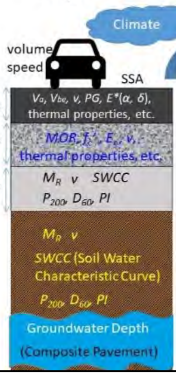
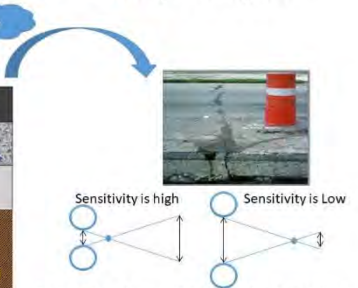
Objective of Sensitivity Analysis





Determine the sensitivity of the reflective cracking performance predicted by the Pavement ME Design to variability of the design input values for composite pavements

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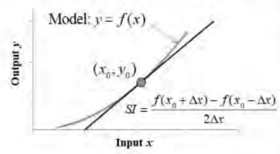
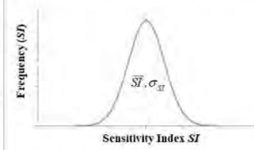
Types of Sensitivity Analyses

Local Sensitivity Analyses



- Inputs varied one-at-a-time
- Only evaluates sensitivity around the reference value(s)
- Ignores input correlations, interactions
- Employed in most past studies

Global Sensitivity Analyses



- Inputs varied simultaneously
- Evaluates sensitivity over the entire problem domain
- Can include input correlations
- Can quantify input interactions
- Extremely computation intensive

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Sensitivity Analysis: Design Inputs

- Design Inputs related to traffic levels and layer thicknesses

Traffic level	Low Traffic			Medium Traffic			High Traffic		
Input Parameter	Base Case	Lower Case (Alternative Case 1)	Upper Case (Alternative Case 2)	Base Case	Lower Case (Alternative Case 1)	Upper Case (Alternative Case 2)	Base Case	Lower Case (Alternative Case 1)	Upper Case (Alternative Case 2)
AADTT	1,000	500	5,000	7,500	5,000	10,000	25,000	20,000	30,000
AC Thickness	2	1.5	3	3	2	4	6	4	8
JPCP Layer Thickness	8	4	12	10	5	14	12	6	16
Base Thickness	4	2	6	6	3	9	8	5	12

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Sensitivity Analysis: Design Inputs (Cont'd)

- Fixed design inputs for all cases

Input Parameter	Base Case
Design Life	20 years
Reliability	50% for all distresses
AADTT Category	Principal Arterials – Interstate and Defense Route
TTC	4
Number of Lanes in Design Direction	2 for low traffic/3 for medium and high traffic
Truck Direction Factor	50
Truck Lane Factor	75 for low traffic/55 for medium traffic/50 for high
Default Growth Rate	0
First Layer Material Type	Asphalt Concrete
Second Layer Material Type	Portland Cement Concrete
Base Type	Granular Base
Subgrade Material Type	Soil

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Sensitivity Analysis: Design Inputs (Cont'd)

- All design input parameters and variations

Input Parameter	Base Case	Lower Case (Alternative Case 1)	Upper Case (Alternative Case 2)
AC Layer Input Parameters			
AC Surface Shortwave Absorption	0.85	0.80	0.98
Delta in AC Sigmoidal Curve	2.83[4]	x0.99	x1.01
Alpha in AC Sigmoidal Curve	3.90[4]	x0.998	x1.01
Effective Binder Content in AC	10.1[4]	x0.9	x1.1
Air Voids in AC	6.5[4]	x0.9	x1.1
Tensile Strength at 14° F	500	100	2000
Aggregate Coefficient of Contraction in AC	5e-6	2e-6	7e-6
JPCP Layer Input Parameters			
Design Lane Width	12	10	14
Joint Spacing	15	10	20
Dowel Diameter	1.2	1.0	1.5
Tied PCC LTE (%)	50	25	75
PCC Unit Weight	150	140	160
PCC Poisson's Ratio	0.15	0.10	0.20
PCC Coef. of Thermal Expansion	5.5	5	6
PCC Thermal Conductivity	1.25	0.5	2
PCC Modulus of Rupture at 28 days	690	× 0.8	× 1.2
Slabs distressed or replaced after restoration (%)/ before restoration (%)	20/20	0/0	40/40
A ratio of slabs distressed or replaced after restoration (%)/before restoration (%)	1 (= 20/20)	0 (= 0/20)	0.5 (= 10/20)
Transverse joint load transfer efficiency (%)	50	25	75
Granular Base Layer Input Parameters			
Base Resilient Modulus	25,000	15,000	40,000
Subgrade Layer Input Parameters			
Subgrade Resilient Modulus	10,000	5,000	20,000

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Selected Sensitivity Metric: Design Limit Normalized Sensitivity Index (NSI)

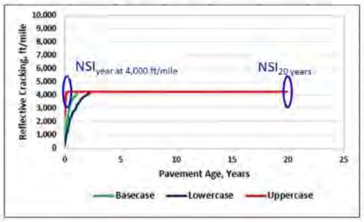
$$NSI_{jk}^{DL} = \frac{(\Delta Y_j / DL_j)}{(\Delta X_k / X_k)}$$

- Design Limit Normalized Sensitivity Index for Design Input *k* and Distress *j*
- ΔY_j: change in predicted distress *j* corresponding to change of design input
- DL_j: the design limit of the distress *j*
- ΔX_k: change in design input *k* about the baseline
- X_k: baseline value of design input *k*

Example:
Reflective cracking distress, Design Limit (DL) = 2,500 ft/mile
Normalized Sensitivity Index (NSI) of reflective cracking to JPCP layer thickness = -1.33
What is change in reflective cracking if JPCP layer thickness is increased by ΔX/X = 20%?
Change in reflective cracking ΔY = (-1.33)(20%)(2,500 ft/mile) = -665 ft/mile

Selected Sensitivity Metric: NSI

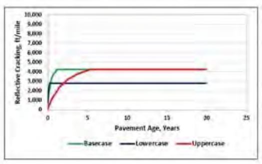
- Two NSI values for reflective cracking predictions
  - At a 20-year design life: $NSI_{20\ years}$
  - At a year reaching 4,000 ft/mile of reflective cracking predictions: $NSI_{year\ at\ 4{,}000\ ft/mile}$

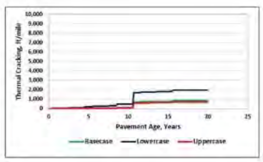


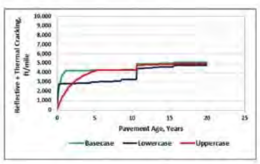
Time vs. Distress Plots: Low Traffic

Traffic level	Low Traffic			Medium Traffic			High Traffic		
Input Parameter	Base Case	Lower Case (Alternative Case 1)	Upper Case (Alternative Case 2)	Base Case	Lower Case (Alternative Case 1)	Upper Case (Alternative Case 2)	Base Case	Lower Case (Alternative Case 1)	Upper Case (Alternative Case 2)
AADTT	1,000	500	5,000	7,500	5,000	10,000	25,000	20,000	30,000
AC Thickness	2	1.5	3	3	2	4	6	4	8
JPCP Layer Thickness	8	4	12	10	5	14	12	6	16
Base Thickness	4	2	6	6	3	9	8	5	12

AC Thickness

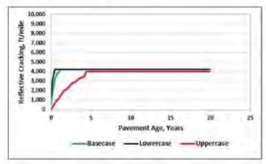


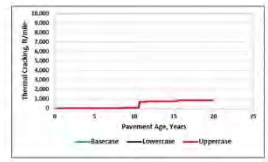


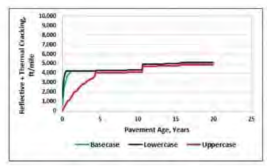


Base case	2 in
Lower case	1.5 in
Upper case	3 in

Transverse Joint LTE

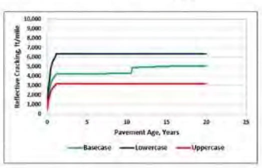


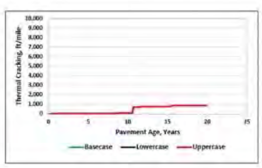


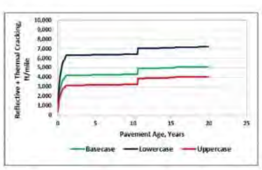


Base case	50 %
Lower case	25 %
Upper case	75 %

Joint Spacing

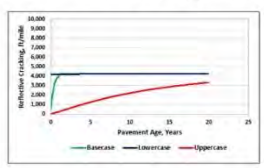


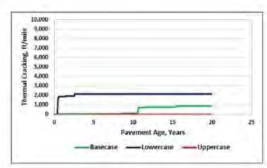


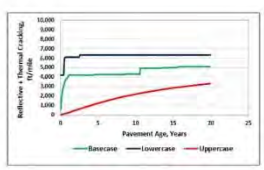


Base case	15 ft
Lower case	10 ft
Upper case	20 ft

Tensile Strength at 14 F

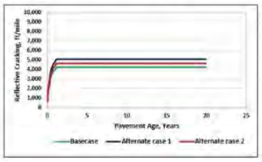


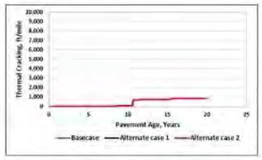


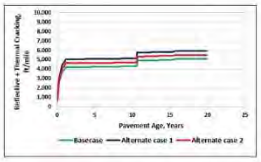


Base case	500 psi
Lower case	100 psi
Upper case	2000 psi

A ratio of Slabs Distressed or Replaced After Restoration (%)/Before Restoration (%)

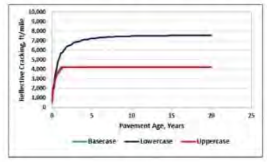


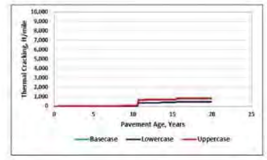


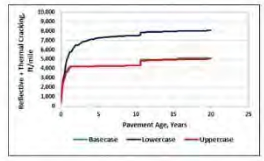


Base case	1 (20/20)
Alternate case 1	0 (0/20)
Alternate case 2	0.5 (10/20)

JPCP Layer Thickness

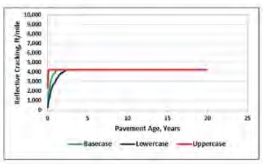


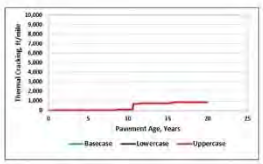


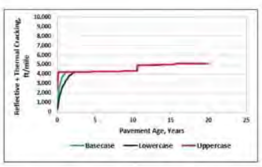


Base case	8 in
Lower case	4 in
Upper case	12 in

AADTT





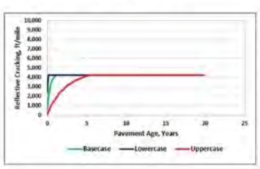


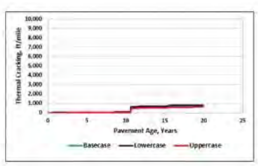
Base case	1,000
Lower case	500
Upper case	5,000

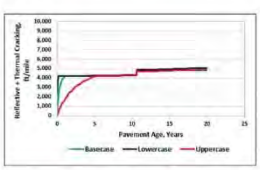
Time vs. Distress Plots: Medium Traffic

Traffic level	Low Traffic			Medium Traffic			High Traffic		
Input Parameter	Base Case	Lower Case (Alternative Case 1)	Upper Case (Alternative Case 2)	Base Case	Lower Case (Alternative Case 1)	Upper Case (Alternative Case 2)	Base Case	Lower Case (Alternative Case 1)	Upper Case (Alternative Case 2)
AADTT	1,000	500	5,000	7,500	5,000	10,000	25,000	20,000	30,000
AC Thickness	2	1.5	3	3	2	4	6	4	8
JPCP Layer Thickness	8	4	12	10	5	14	12	6	16
Base Thickness	4	2	6	6	3	9	8	5	12

AC Thickness

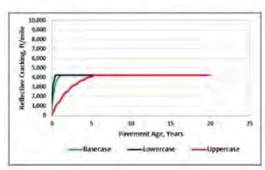


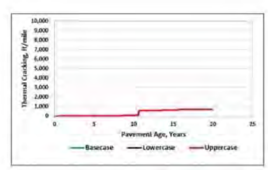


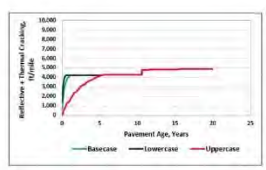


Base case	3 in
Lower case	2 in
Upper case	4 in

Transverse Joint LTE

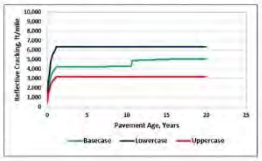


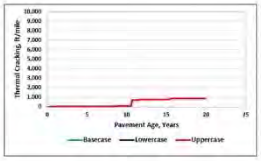


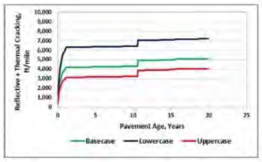


Base case	50 %
Lower case	25 %
Upper case	75 %

Joint Spacing



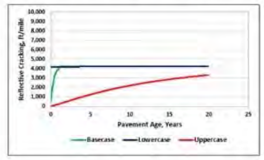


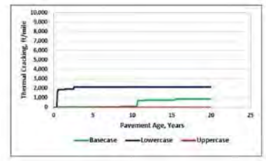


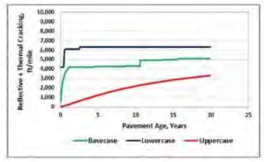
Base case	15 ft
Lower case	10 ft
Upper case	20 ft

66

Tensile Strength at 14 F



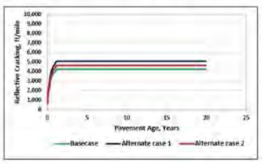


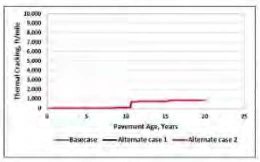


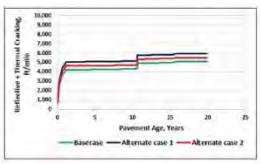
Base case	500 psi
Lower case	100 psi
Upper case	2,000 psi

67

A ratio of Slabs Distressed or Replaced After Restoration (%)/Before Restoration (%)



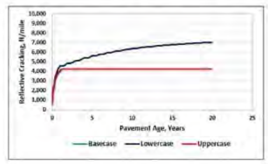


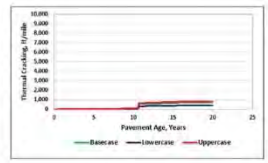


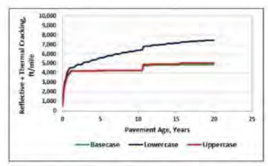
Base case	1 (20/20)
Alternate case 1	0 (0/20)
Alternate case 2	0.5 (10/20)

68

JPCP Layer Thickness



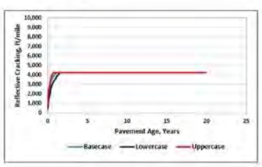


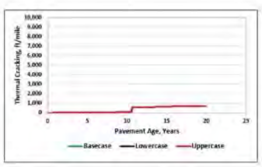


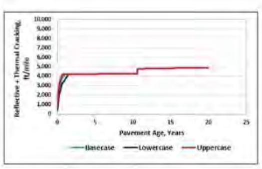
Base case	10 in
Lower case	5 in
Upper case	14 in

69

AADTT







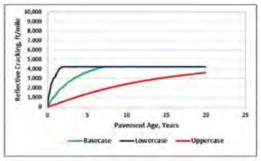
Base case	7,500
Lower case	5,000
Upper case	10,000

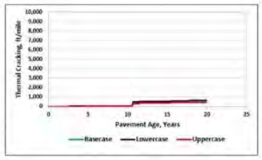
70

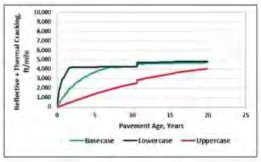
Time vs. Distress Plots: High Traffic

Traffic level	Low Traffic			Medium Traffic			High Traffic		
Input Parameter	Base Case	Lower Case (Alternative Case 1)	Upper Case (Alternative Case 2)	Base Case	Lower Case (Alternative Case 1)	Upper Case (Alternative Case 2)	Base Case	Lower Case (Alternative Case 1)	Upper Case (Alternative Case 2)
AADTT	1,000	500	5,000	7,500	5,000	10,000	25,000	20,000	30,000
AC Thickness	2	1.5	3	3	2	4	6	4	8
JPCP Layer Thickness	8	4	12	10	5	14	12	6	16
Base Thickness	4	2	6	6	3	9	8	5	12

AC Thickness

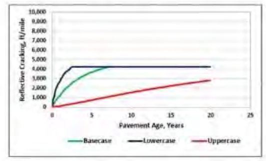


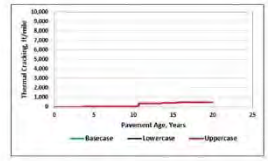


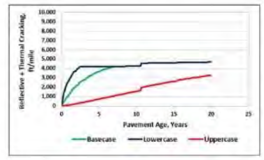


Base case	6 in
Lower case	4 in
Upper case	8 in

Transverse Joint LTE

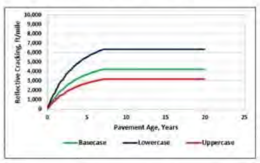


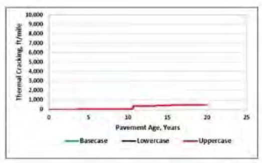


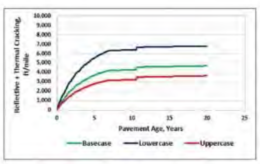


Base case	50 %
Lower case	25 %
Upper case	75 %

Joint Spacing

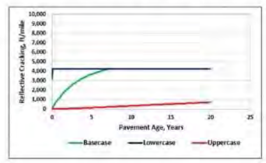


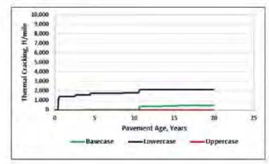


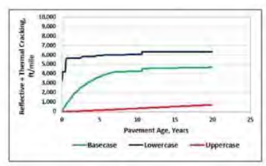


Base case	15 ft
Lower case	10 ft
Upper case	20 ft

Tensile Strength at 14 F

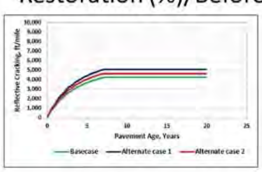


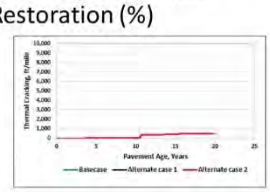


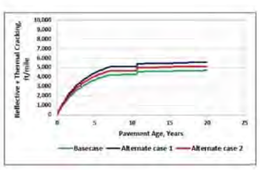


Base case	500 psi
Lower case	100 psi
Upper case	2,000 psi

A ratio of Slabs Distressed or Replaced After Restoration (%)/Before Restoration (%)

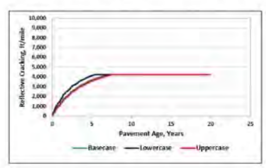


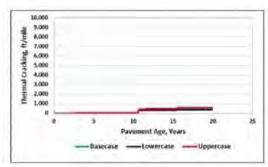


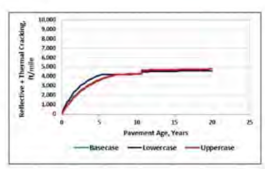


Base case	1 (20/20)
Alternate case 1	0 (0/20)
Alternate case 2	0.5 (10/20)

JPCP Layer Thickness

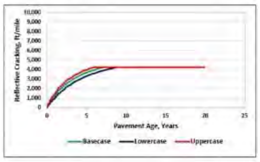


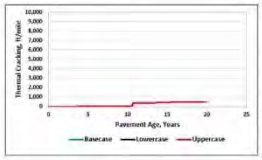


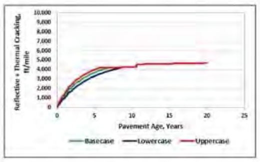


Base case	12 in
Lower case	6 in
Upper case	16 in

AADTT







Base case	25,000
Lower case	20,000
Upper case	30,000

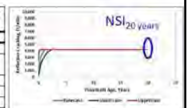
78

Normalized Sensitivity Index (NSI): Iowa HMA over JPCP

79

$NSI_{20\ years}$: Reflective Cracking

Design Input	Low Traffic	Medium Traffic	High Traffic	Average |NSI|	Sensitivity Rating
Joint Spacing	***-1.80***	***-1.90***	***-1.90***	***1.86***	***VS***
JPCP Layer Thickness	*-1.33*	*-1.25*	*-0.001*	*0.86*	*S*
Ratio of Slabs Distressed or Replaced After Restoration (%)/Before Restoration (%)	*-0.33*	*-0.33*	*-0.33*	*0.33*	*S*
Transverse Joint Load Transfer Efficiency	*-0.08*	*0.00*	*-0.56*	*0.21*	*S*
Tensile Strength at 14 F	*-0.09*	*-0.08*	*-0.36*	*0.17*	*S*
AC Thickness	*0.76*	*0.00*	*-0.37*	*0.13*	*S*
PCC Thermal Conductivity	-0.001	-0.01	-0.03	0.01	NS
Design Lane Width	-0.01	0.00	0.00	0.00	NS
PCC Coefficient of Thermal Expansion	0.01	0.00	0.00	0.00	NS
PCC Modulus of Rupture at 28 days	-0.01	0.00	0.00	0.00	NS
AC Surface Shortwave Absorption	0.00	0.00	0.00	0.00	NS
Alpha in AC Sigmoidal Curve	0.00	0.00	0.00	0.00	NS
Tied PCC Load Transfer Efficiency	0.00	0.00	0.00	0.00	NS
PCC Unit Weight	0.00	0.00	0.00	0.00	NS
AADTT	0.00	0.00	0.00	0.00	NS
Base Thickness	0.00	0.00	0.00	0.00	NS
Delta in AC Sigmoidal Curve	0.00	0.00	0.00	0.00	NS
Effective Binder Content in AC	0.00	0.00	0.00	0.00	NS
Air Voids in AC	0.00	0.00	0.00	0.00	NS
Aggregate Coefficient of Contraction in AC	0.00	0.00	0.00	0.00	NS
Dowel Diameter	0.00	0.00	0.00	0.00	NS
PCC Poisson's Ratio	0.00	0.00	0.00	0.00	NS
Slabs Distressed/Replaced After Restoration & Before Restoration	0.00	0.00	0.00	0.00	NS
Base Resilient Modulus	0.00	0.00	0.00	0.00	NS
Subgrade Resilient Modulus	0.00	0.00	0.00	0.00	NS



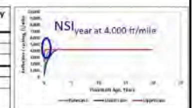
***Absolute values to be considered for NSI ratings

NSI > 1	Very sensitive (Bold Italics)
0.1< NSI< 1	Sensitive (Italics)
NSI < 0.1	Insensitive (Regular font)

80

$NSI_{year\ at\ 4,000\ ft/mile}$: Reflective Cracking

Design Input	Low Traffic	Medium Traffic	High Traffic	Average |NSI|	Sensitivity Rating
AC Thickness	***0.76***	***-2.29***	***-2.14***	***1.73***	***VS***
Transverse Joint Load Transfer Efficiency	***-1.37***	***-1.33***	***-1.49***	***1.39***	***VS***
Joint Spacing	***-1.24***	***-1.37***	***-0.97***	***1.19***	***VS***
Tensile Strength at 14 F	*-0.44*	*-0.44*	*-0.44*	*0.44*	*S*
Alpha in AC Sigmoidal Curve	*0.31*	*0.33*	*0.33*	*0.32*	*S*
Ratio of Slabs Distressed or Replaced After Restoration (%)/Before Restoration (%)	*-0.28*	*-0.27*	*-0.27*	*0.27*	*S*
JPCP Layer Thickness	*-0.31*	*-0.18*	*-0.26*	*0.25*	*S*
Delta in AC Sigmoidal Curve	*0.14*	*0.14*	*0.14*	*0.14*	*S*
AADTT	*0.01*	*0.10*	*0.21*	*0.10*	*S*
Effective Binder Content in AC	-0.15	-0.04	-0.04	0.07	NS
Air Voids in AC	-0.03	-0.08	-0.11	0.07	NS
AC Surface Shortwave Absorption	-0.05	-0.04	-0.05	0.04	NS
PCC Unit Weight	-0.13	-0.01	0.00	0.04	NS
PCC Thermal Conductivity	-0.01	-0.04	-0.02	0.02	NS
Base Resilient Modulus	0.00	0.00	0.00	0.00	NS
PCC Coefficient of Thermal Expansion	0.00	0.00	0.00	0.00	NS
Base Thickness	0.00	0.00	0.00	0.00	NS
Aggregate Coefficient of Contraction in AC	0.00	0.00	0.00	0.00	NS
Design Lane Width	0.00	0.00	0.00	0.00	NS
Dowel Diameter	0.00	0.00	0.00	0.00	NS
Tied PCC Load Transfer Efficiency	0.00	0.00	0.00	0.00	NS
PCC Poisson's Ratio	0.00	0.00	0.00	0.00	NS
PCC Modulus of Rupture at 28 days	0.00	0.00	0.00	0.00	NS
Slabs Distressed/Replaced After Restoration & Before Restoration	0.00	0.00	0.00	0.00	NS
Subgrade Resilient Modulus	0.00	0.00	0.00	0.00	NS



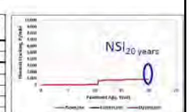
***Absolute values to be considered for NSI ratings

NSI > 1	Very sensitive (Bold Italics)
0.1< NSI< 1	Sensitive (Italics)
NSI < 0.1	Insensitive (Regular font)

81

$NSI_{20\ years}$: Thermal Cracking

Design Input	Low Traffic	Medium Traffic	High Traffic	Average |NSI|	Sensitivity Rating
Effective Binder Content in AC	***-6.30***	***-5.66***	***-0.55***	***4.17***	***VS***
Air Voids in AC	***3.65***	***2.91***	***1.60***	***2.72***	***VS***
AC Thickness	*-1.68*	*-0.28*	*-0.26*	*0.74*	*S*
PCC Unit Weight	*-0.74*	*-0.70*	*-0.70*	*0.71*	*S*
PCC Thermal Conductivity	*-0.67*	*-0.62*	*-0.64*	*0.64*	*S*
Tensile Strength at 14 F	*-0.55*	*-0.55*	*-0.55*	*0.55*	*S*
JPCP Layer Thickness	*0.33*	*0.44*	*0.24*	*0.33*	*S*
Aggregate Coefficient of Contraction in AC	*0.38*	*0.31*	*0.06*	*0.25*	*S*
AC Surface Shortwave Absorption	*-0.35*	*-0.24*	*0.02*	*0.20*	*S*
Base Thickness	0.02	0.00	0.00	0.00	NS
AADTT	0.00	0.00	0.00	0.00	NS
Delta in AC Sigmoidal Curve	0.00	0.00	0.00	0.00	NS
Alpha in AC Sigmoidal Curve	0.00	0.00	0.00	0.00	NS
Design Lane Width	0.00	0.00	0.00	0.00	NS
Joint Spacing	0.00	0.00	0.00	0.00	NS
Dowel Diameter	0.00	0.00	0.00	0.00	NS
Tied PCC Load Transfer Efficiency	0.00	0.00	0.00	0.00	NS
PCC Poisson's Ratio	0.00	0.00	0.00	0.00	NS
PCC Coefficient of Thermal Expansion	0.00	0.00	0.00	0.00	NS
PCC Modulus of Rupture at 28 days	0.00	0.00	0.00	0.00	NS
Slabs Distressed/Replaced After Restoration & Before Restoration	0.00	0.00	0.00	0.00	NS
Ratio of Slabs Distressed or Replaced After Restoration (%)/Before Restoration (%)	0.00	0.00	0.00	0.00	NS
Transverse Joint Load Transfer Efficiency	0.00	0.00	0.00	0.00	NS
Base Resilient Modulus	0.00	0.00	0.00	0.00	NS
Subgrade Resilient Modulus	0.00	0.00	0.00	0.00	NS



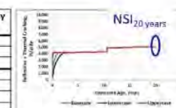
***Absolute values to be considered for NSI ratings

NSI > 1	Very sensitive (Bold Italics)
0.1< NSI< 1	Sensitive (Italics)
NSI < 0.1	Insensitive (Regular font)

82

$NSI_{20\ years}$:Reflective + Thermal Cracking

Design Input	Low Traffic	Medium Traffic	High Traffic	Average |NSI|	Sensitivity Rating
Effective Binder Content in AC	***-2.55***	***-2.26***	***-1.60***	***2.13***	***VS***
Joint Spacing	***-1.80***	***-1.90***	***-1.90***	***1.80***	***VS***
Air Voids in AC	***1.46***	***1.16***	***0.64***	***1.08***	***VS***
PCC Thermal Conductivity	*-0.68*	*-0.81*	*-0.62*	*0.70*	*S*
Tensile Strength at 14 F	*-0.31*	*-0.30*	*-0.59*	*0.40*	*S*
JPCP Layer Thickness	*-1.20*	*0.12*	*0.00*	*0.35*	*S*
Ratio of Slabs Distressed or Replaced After Restoration (%)/Before Restoration (%)	*-0.33*	*-0.33*	*-0.33*	*0.33*	*S*
PCC Unit Weight	*-0.29*	*-0.28*	*-0.28*	*0.28*	*S*
Transverse Joint Load Transfer Efficiency	*-0.08*	*0.00*	*-0.56*	*0.21*	*S*
AC Thickness	*0.09*	*-0.11*	*-0.47*	*0.16*	*S*
Aggregate Coefficient of Contraction in AC	*0.15*	*0.12*	*0.03*	*0.10*	*S*
AC Surface Shortwave Absorption	-0.13	0.09	0.00	0.07	NS
Design Lane Width	-0.01	0.00	0.00	0.00	NS
PCC Coefficient of Thermal Expansion	-0.01	0.00	0.00	0.00	NS
PCC Modulus of Rupture at 28 days	-0.01	0.00	0.00	0.00	NS
Base Thickness	-0.01	0.00	0.00	0.00	NS
Alpha in AC Sigmoidal Curve	0.00	0.00	0.00	0.00	NS
Tied PCC Load Transfer Efficiency	0.00	0.00	0.00	0.00	NS
AADTT	0.00	0.00	0.00	0.00	NS
Delta in AC Sigmoidal Curve	0.00	0.00	0.00	0.00	NS
Dowel Diameter	0.00	0.00	0.00	0.00	NS
PCC Poisson's Ratio	0.00	0.00	0.00	0.00	NS
Slabs Distressed/Replaced After Restoration & Before Restoration	0.00	0.00	0.00	0.00	NS
Base Resilient Modulus	0.00	0.00	0.00	0.00	NS
Subgrade Resilient Modulus	0.00	0.00	0.00	0.00	NS



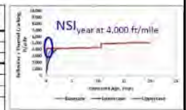
***Absolute values to be considered for NSI ratings

NSI > 1	Very sensitive (Bold Italics)
0.1< NSI< 1	Sensitive (Italics)
NSI < 0.1	Insensitive (Regular font)

83

$NSI_{\text{year at 4,000 ft/mile}}$: Reflective Cracking+ Thermal Cracking

Design Input	Low Traffic	Medium Traffic	High Traffic	Average |NSI|	Sensitivity Rating
AC Thickness	***0.18***	***2.29***	***-2.14***	***1.54***	***VS***
Transverse Joint Load Transfer Efficiency	***-1.37***	***-1.33***	***-1.49***	***1.39***	***VS***
Joint Spacing	***-1.24***	***-1.31***	***-0.97***	***1.17***	***VS***
Tensile Strength at 14 F	*-0.44*	*-0.44*	*-0.44*	*0.44*	*S*
Alpha in AC Sigmoidal Curve	*0.31*	*0.33*	*0.33*	*0.32*	*S*
PCC Thermal Conductivity	*-0.27*	*-0.28*	*-0.27*	*0.27*	*S*
Ratio of Slabs Distressed or Replaced After Restoration (%)/Before Restoration (%)	*0.28*	*0.27*	*0.27*	*0.27*	*S*
JPCP Layer Thickness	*-0.31*	*0.18*	*-0.26*	*0.25*	*S*
Delta in AC Sigmoidal Curve	*0.14*	*0.14*	*0.14*	*0.14*	*S*
AADTT	*0.01*	*0.10*	*0.23*	*0.11*	*S*
Effective Binder Content in AC	*-0.20*	*-0.07*	*-0.08*	*0.11*	*S*
AC Surface Shortwave Absorption	-0.05	-0.04	-0.06	0.05	NS
Air Voids in AC	-0.04	-0.07	-0.08	0.05	NS
PCC Unit Weight	-0.13	0.02	-0.01	0.05	NS
Base Resilient Modulus	0.00	0.00	0.00	0.00	NS
Base Thickness	0.00	0.00	0.01	0.00	NS
Aggregate Coefficient of Contraction in AC	0.00	0.00	0.00	0.00	NS
Design Lane Width	0.00	0.00	0.00	0.00	NS
Dowel Diameter	0.00	0.00	0.00	0.00	NS
Tied PCC Load Transfer Efficiency	0.00	0.00	0.00	0.00	NS
PCC Poisson's Ratio	0.00	0.00	0.00	0.00	NS
PCC Coefficient of Thermal Expansion	0.00	0.00	0.00	0.00	NS
PCC Modulus of Rupture at 28 days	0.00	0.00	0.00	0.00	NS
Slabs Distressed/Replaced After Restoration & Before Restoration	0.00	0.00	0.00	0.00	NS
Subgrade Resilient Modulus	0.00	0.00	0.00	0.00	NS



***Absolute values to be considered for NSI ratings

NSI > 1	Very sensitive (Bold Italics)
0.1< NSI< 1	Sensitive (Italics)
NSI < 0.1	Insensitive (Regular font)

Normalized Sensitivity Index (NSI): Different Climate Categories

Climate Categories

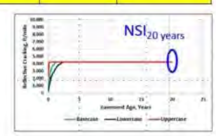
Climate Category	Location
Cold-Wet	Des Moines, IA
Hot-Wet	Orlando, FL
Hot-Dry	Phoenix, AZ
Cold-Wet	Portland, ME
Cold-Dry	International Falls, MN
Temperate	Los Angeles, CA

Climate stations investigated in NCHRP 1-47

$NSI_{\text{20 years}}$: Reflective Cracking

Design Input	Average |NSI|					
	Cold-Wet, Des Moines, IA	Hot-Wet, Orlando, FL	Hot-Dry, Phoenix, AZ	Cold-Wet, Portland, ME	Cold-Dry, International Falls, MN	Temperate, Los Angeles, CA
AC Thickness	*0.13*	*0.71*	*0.51*	*0.19*	*0.37*	*0.21*
JPCP Layer Thickness	*0.86*	***1.37***	*0.62*	*0.61*	***1.61***	***1.03***
Joint Spacing	***1.86***	***2.27***	***1.54***	***1.67***	***2.36***	***1.44***

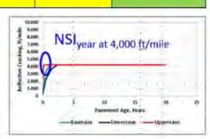
Very Sensitive | *Sensitive* | Insensitive



$NSI_{\text{year at 4,000 ft/mile}}$: Reflective Cracking

Design Input	Average |NSI|					
	Cold-Wet, Des Moines, IA	Hot-Wet, Orlando, FL	Hot-Dry, Phoenix, AZ	Cold-Wet, Portland, ME	Cold-Dry, International Falls, MN	Temperate, Los Angeles, CA
AC Thickness	***1.73***	***2.39***	*0.97*	***1.52***	***1.79***	*0.37*
JPCP Layer Thickness	*0.25*	*0.11*	*0.49*	*0.19*	*0.32*	*0.47*
Joint Spacing	***1.19***	***1.86***	***1.14***	***1.31***	***1.86***	*0.74*

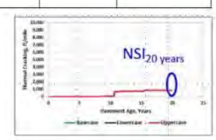
Very Sensitive | *Sensitive* | Insensitive



$NSI_{\text{20 years}}$: Thermal Cracking

Design Input	Average |NSI|					
	Cold-Wet, Des Moines, IA	Hot-Wet, Orlando, FL	Hot-Dry, Phoenix, AZ	Cold-Wet, Portland, ME	Cold-Dry, International Falls, MN	Temperate, Los Angeles, CA
AC Thickness	*0.74*	*0.17*	*0.09*	*0.58*	*0.74*	*0.31*
JPCP Layer Thickness	*0.33*	*0.51*	*0.76*	*0.41*	*0.17*	*0.33*
Joint Spacing	0.00	0.01	0.00	0.01	0.00	0.00

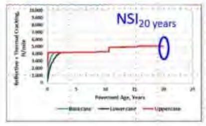
Very Sensitive | *Sensitive* | Insensitive



$NSI_{20\ years}$: Reflective + Thermal Cracking

Design Input	Average |NSI|					
	Cold-Wet, Des Moines, IA	Hot-Wet, Orlando, FL	Hot-Dry, Phoenix, AZ	Cold-Wet, Portland, ME	Cold-Dry, International Falls, MN	Temperate, Los Angeles, CA
AC Thickness	0.16	0.80	0.31	0.34	0.67	0.24
JPCP Layer Thickness	0.35	0.46	**1.27**	0.26	0.11	0.41
Joint Spacing	**1.80**	0.66	**3.54**	**1.71**	0.87	**1.45**

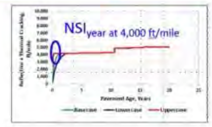
Very Sensitive | *Sensitive* | Insensitive



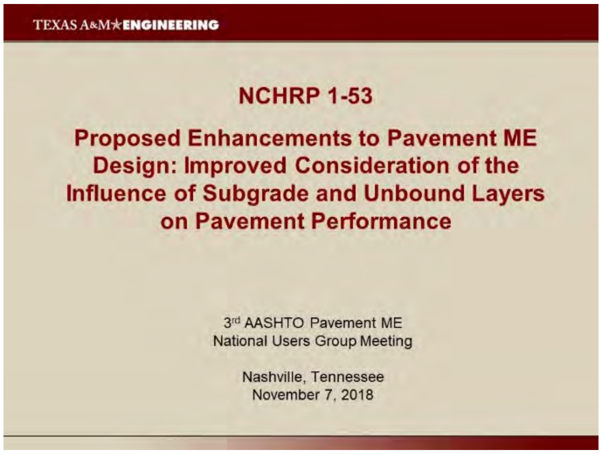
$NSI_{year\ at\ 4,000\ ft/mile}$: Reflective Cracking + Thermal Cracking

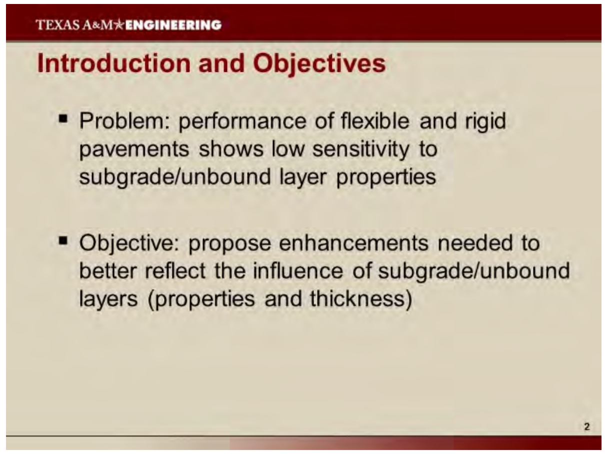
Design Input	Average |NSI|					
	Cold-Wet, Des Moines, IA	Hot-Wet, Orlando, FL	Hot-Dry, Phoenix, AZ	Cold-Wet, Portland, ME	Cold-Dry, International Falls, MN	Temperate, Los Angeles, CA
AC Thickness	**1.54**	0.87	**3.42**	**1.41**	**2.02**	0.41
JPCP Layer Thickness	0.25	0.31	0.57	0.28	0.86	**2.14**
Joint Spacing	**1.17**	**1.45**	**2.02**	**1.39**	**1.61**	0.77

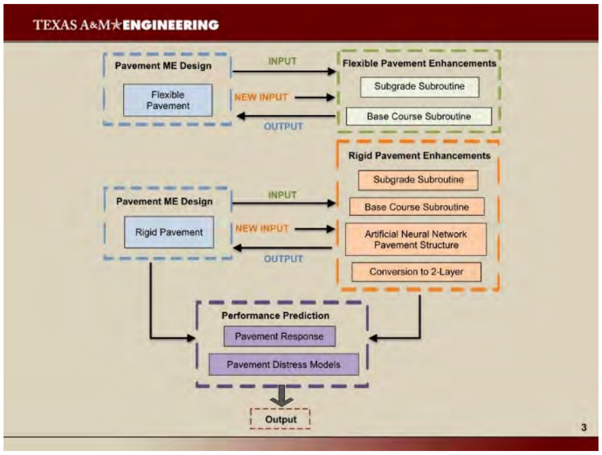
Very Sensitive | *Sensitive* | Insensitive

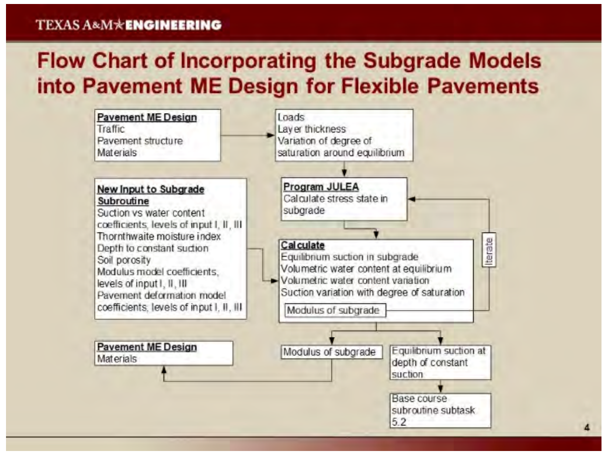


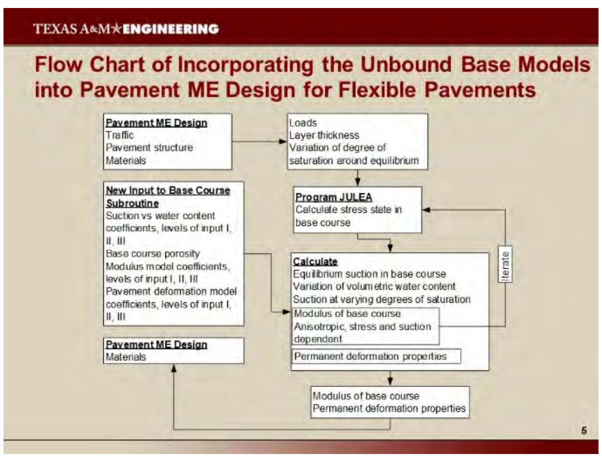
Presentation 10—Bob Lytton, Texas A&M University

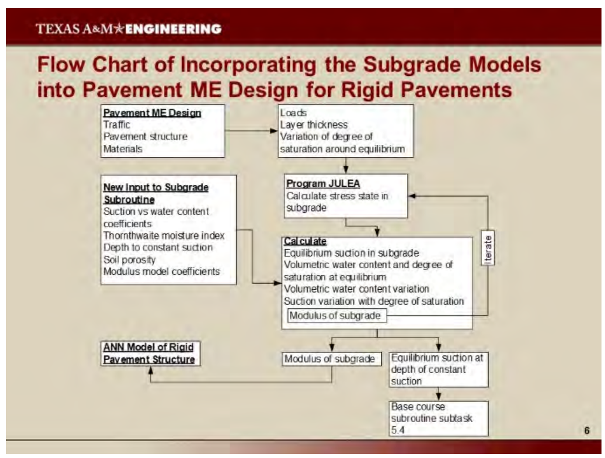


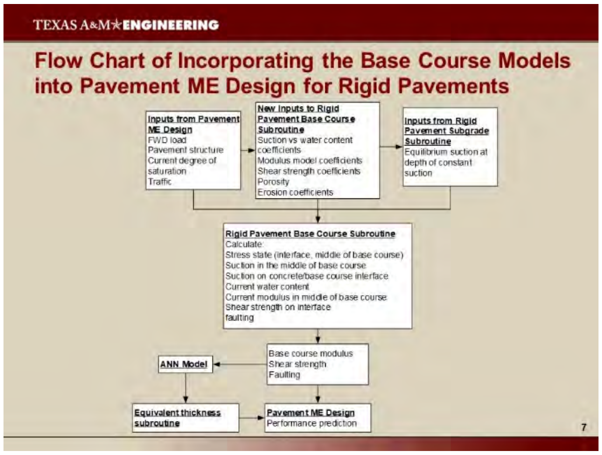


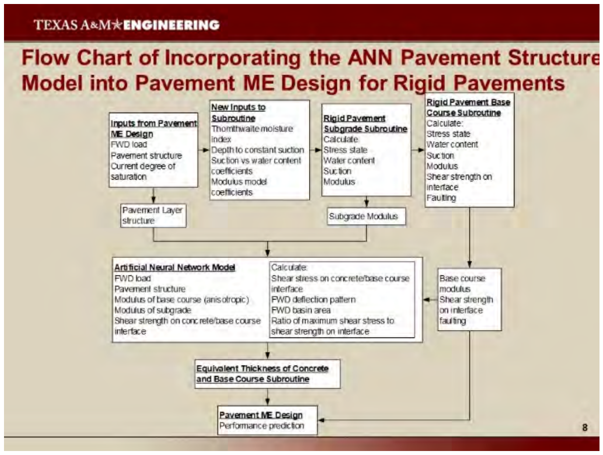


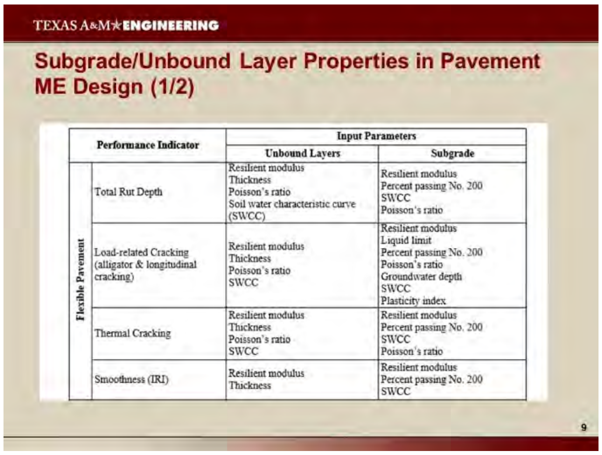




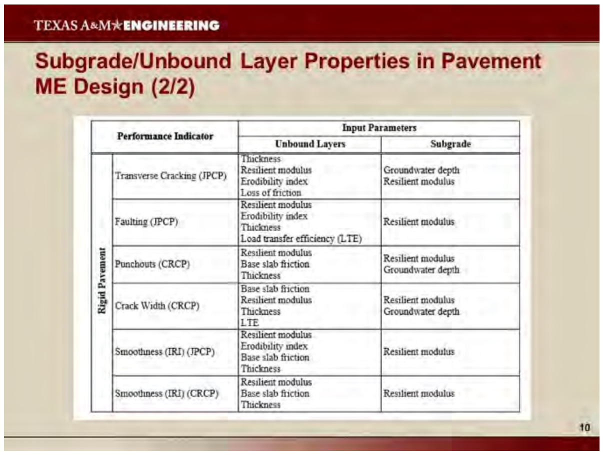




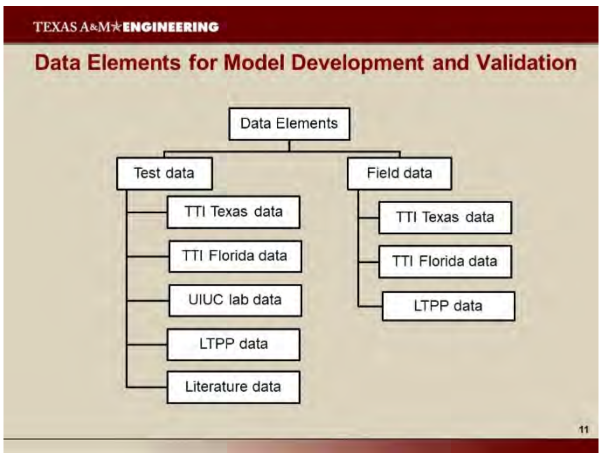


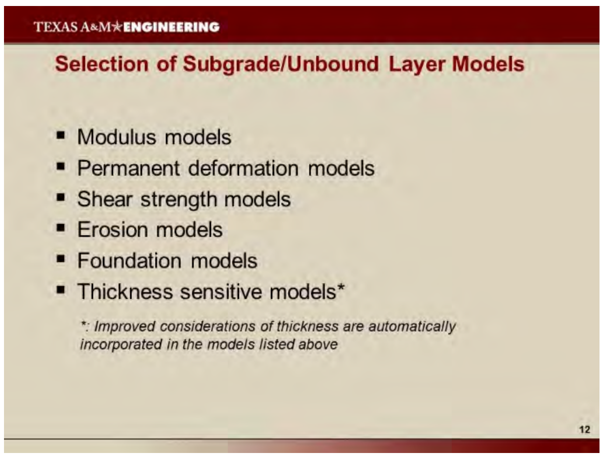


Performance Indicator		Input Parameters	
		Unbound Layers	Subgrade
Flexible Pavement	Total Rut Depth	Resilient modulus Thickness Poisson's ratio Soil water characteristic curve (SWCC)	Resilient modulus Percent passing No. 200 SWCC Poisson's ratio
	Load-related Cracking (alligator & longitudinal cracking)	Resilient modulus Thickness Poisson's ratio SWCC	Resilient modulus Liquid limit Percent passing No. 200 Poisson's ratio Groundwater depth SWCC Plasticity index
	Thermal Cracking	Resilient modulus Thickness Poisson's ratio SWCC	Resilient modulus Percent passing No. 200 SWCC Poisson's ratio
	Smoothness (IRI)	Resilient modulus Thickness	Resilient modulus Percent passing No. 200 SWCC



Performance Indicator		Input Parameters	
		Unbound Layers	Subgrade
Rigid Pavement	Transverse Cracking (JPCP)	Thickness Resilient modulus Erodibility index Loss of friction	Groundwater depth Resilient modulus
	Faulting (JPCP)	Resilient modulus Erodibility index Thickness Load transfer efficiency (LTE)	Resilient modulus
	Punchouts (CRCP)	Resilient modulus Base slab friction Thickness	Resilient modulus Groundwater depth
	Crack Width (CRCP)	Base slab friction Resilient modulus Thickness LTE	Resilient modulus Groundwater depth
	Smoothness (IRI) (JPCP)	Resilient modulus Erodibility index Base slab friction Thickness	Resilient modulus
	Smoothness (IRI) (CRCP)	Resilient modulus Base slab friction Thickness	Resilient modulus





TEXAS A&M ENGINEERING

Moisture-Sensitive, Stress-Dependent, and Cross-Anisotropic Modulus Model

- Proposed model (Gu, Luo, et al. 2015)

$$M_R^V = k_1 P_a \left(\frac{I_1 - 3\theta f h_m}{P_a}\right)^{k_2} \left(\frac{\tau_{oct}}{P_a}\right)^{k_3}$$

$$s = \frac{M_R^H}{M_R^V} \; ; \; r = \frac{G_{VH}}{M_R^V}$$

- Model components
  - Laboratory test design
  - Numerical verification
  - Hierarchical input level

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TEXAS A&M ENGINEERING

Cross-Anisotropy Test

Test Equipment

Test Protocol

Stress state	Static Stress (kPa)		Dynamic Stress (kPa)					
			Compression		Shear		Extension	
	σ_y	σ_x	σ_y^c	σ_x^c	σ_y^s	σ_x^s	σ_y^e	σ_x^e
1	40	25	5	0	10	-5	-5	5
2	50	25	10	0	10	-5	-10	5
3	70	40	10	0	10	-5	-10	10
4	130	60	20	0	20	-10	-10	10
5	150	70	20	0	20	-10	-10	10
6	170	100	20	0	20	-10	-20	20
7	220	120	30	0	30	-15	-20	20
8	250	140	30	0	30	-15	-20	20
9	250	120	30	0	30	-15	-20	20
10	250	105	30	0	30	-15	-20	20

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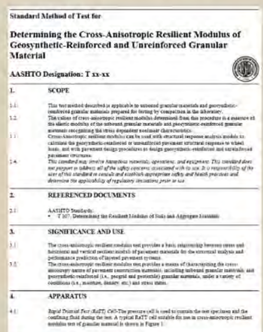
TEXAS A&M ENGINEERING

Proposed AASHTO Standard for Cross-Anisotropy Test



Standard Method of Test for

Determining the Cross-Anisotropic Resilient Modulus of Geosynthetic-Reinforced and Unreinforced Granular Material

AASHTO Designation: T xx-xx

1. SCOPE

2. REFERENCED DOCUMENTS

3. SIGNIFICANCE AND USE

4. APPARATUS

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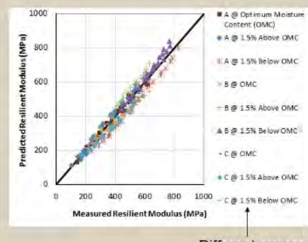
TEXAS A&M ENGINEERING

Cross-Anisotropy Test Results



Different aggregate types & moisture contents

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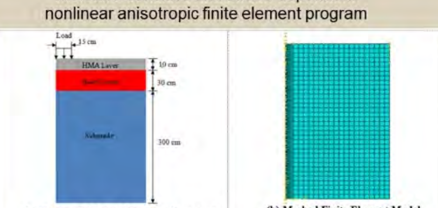
TEXAS A&M ENGINEERING

Numerical Study of Pavement Responses

Moisture-sensitive and stress-dependent nonlinear anisotropic finite element program



(a) Schematic Plot of Pavement Structure

(b) Meshed Finite Element Model

Traffic Load	565 kPa (9 kips)		
Base Moisture Conditions	Moist (1.5% above optimum)	Optimum	Dry (1.5 below optimum)
Material Properties	HMA layer	Viscoelastic	
	Unbound base course	Nonlinear cross-anisotropic & moisture-sensitive	
	Subgrade	Elastic	

(c) Modeling Parameters

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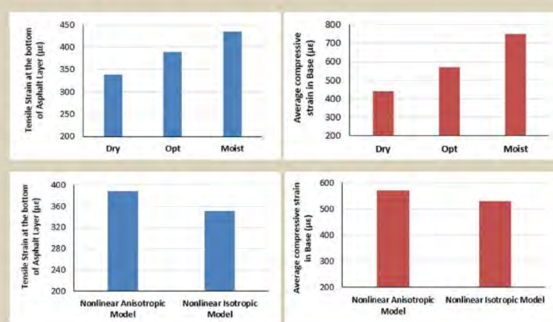
TEXAS A&M ENGINEERING

Results of Numerical Study



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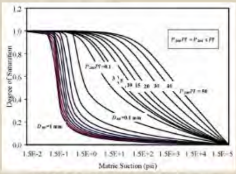
TEXAS A&M ENGINEERING

Hierarchical Input Level

Level 1:
- Laboratory-measured k_1, k_2, k_3
- SWCC
- Equilibrium suction and its depth



SWCC in Pavement ME Design

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TEXAS A&M ENGINEERING

Regression Models for Moisture-Sensitive and Stress-Dependent Modulus Model Coefficients

- Proposed model (Gu et al. 2015)

$$\ln k_1 = -137.19 + 13.60\ln(\gamma_d) + 4.35\ln(\lambda_A) - 0.62\lambda_S + 1.68\ln(\lambda_T)$$

$$k_2 = 36.14 + 0.04\,pfc - 3.81\ln(\lambda_A) - 0.22a_S - 0.77\ln(\lambda_T)$$

$$k_3 = -4.39 + 0.45\ln(\gamma_d) - 0.01\,pfc + 0.05a_S + 0.15\ln(\lambda_T)$$

- Model components
  - Performance indicators from laboratory tests
  - Laboratory verification
  - Hierarchical input level

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TEXAS A&M ENGINEERING

Laboratory Tests for Performance Indicators

- Methylene blue test
- Aggregate imaging system (AIMS) test
- Percent fines content test

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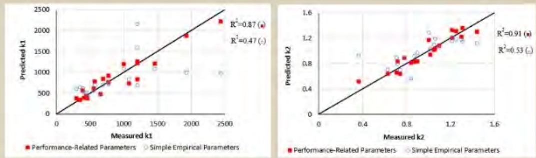
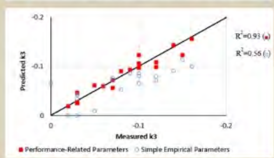
TEXAS A&M ENGINEERING

Laboratory Verification by Repeated Load Triaxial Test





Simple empirical parameters:
- Dry unit weight
- Optimum water content
- Plasticity index
- Liquid limit
- Percent passing No. 200

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TEXAS A&M ENGINEERING

Hierarchical Input Level (1/2)

- Level 2
  - Performance-related properties
    - Dry density
    - Percent fines content
    - Gradation
    - Shape, angularity, and texture of aggregates
  - SWCC
  - Equilibrium suction and its depth

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TEXAS A&M ENGINEERING

Hierarchical Input Level (2/2)

- Level 2
  - Simple properties
    - Dry unit weight
    - Optimum water content
    - Plastic index
    - Liquid limit
    - Percent passing No. 200
  - Default SWCC
  - Default equilibrium suction
- Level 3
  - Default performance-related properties
  - Default SWCC

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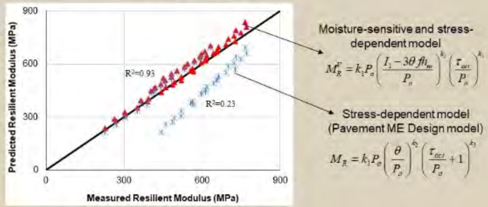
TEXAS A&M ENGINEERING

Development of Evaluation Criteria

- Accuracy Criterion

How close between prediction by model & measurements

Here are some examples



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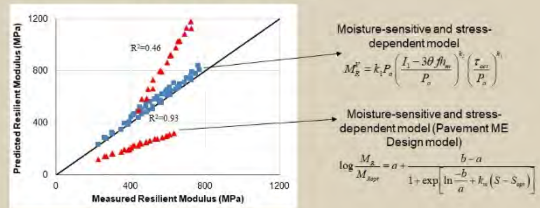
TEXAS A&M ENGINEERING

Development of Evaluation Criteria

- Accuracy Criterion

How close between prediction by model & measurements

Here are some examples



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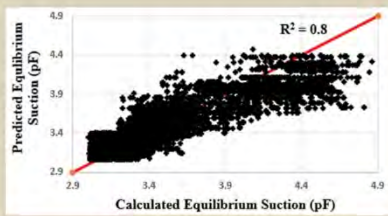
TEXAS A&M ENGINEERING

Calculated Versus Predicted Equilibrium Suction



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TEXAS A&M ENGINEERING

Thornthwaite Moisture Index (TMI) versus Equilibrium Suction (cm)

$$pF(u_e) = 0.0261 * PI - 0.0001 * TMI + 3.0731$$

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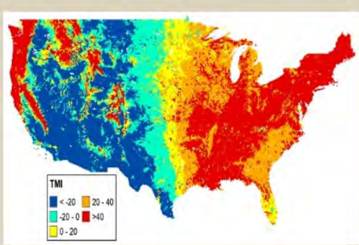
TEXAS A&M ENGINEERING

GIS Based Contour Map of TMI (1981 to 2010)



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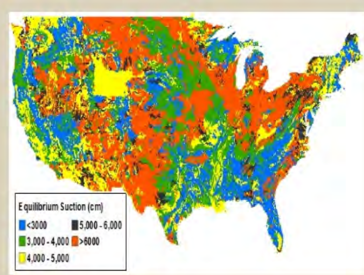
TEXAS A&M ENGINEERING

GIS Based Equilibrium Suction Map



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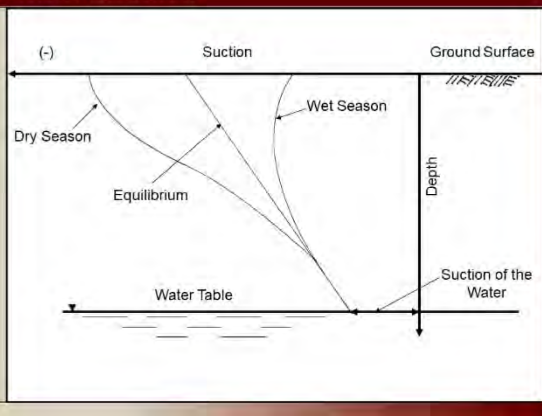
TEXAS A&M ENGINEERING



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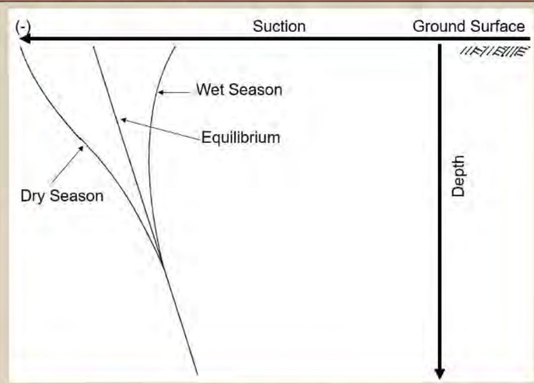
TEXAS A&M ENGINEERING



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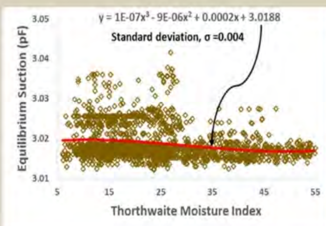
TEXAS A&M ENGINEERING

AASHTO soil type: A-3



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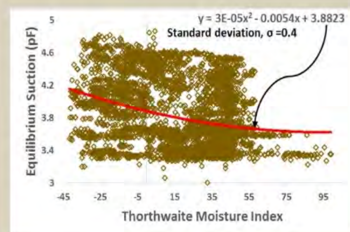
TEXAS A&M ENGINEERING

AASHTO soil type: A-7-6



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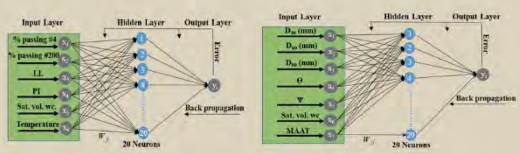
TEXAS A&M ENGINEERING

Illustration of Three-Layered Neural Network Architecture



(a) Plastic soil (b) Non-plastic soil

Soil-water Characteristic Curve

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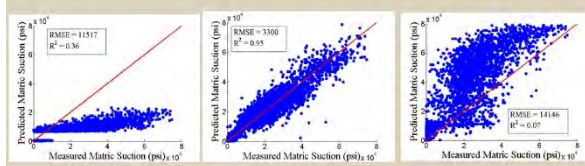
TEXAS A&M ENGINEERING

Comparison of Measured versus Predicted Suction at Various Saturation Levels for Plastic Soils



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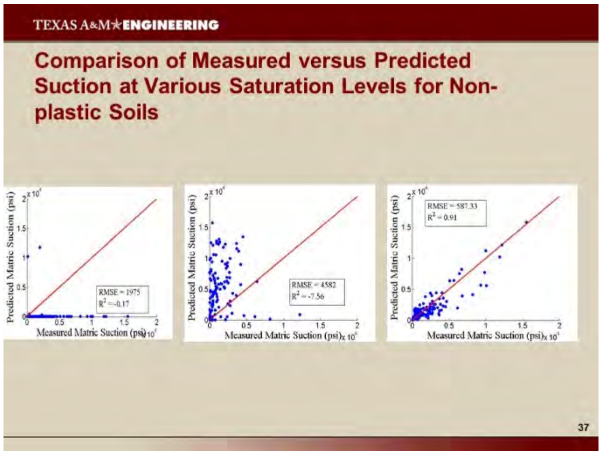
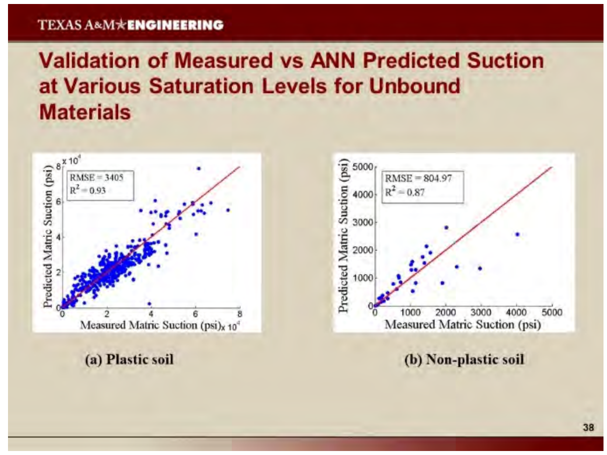
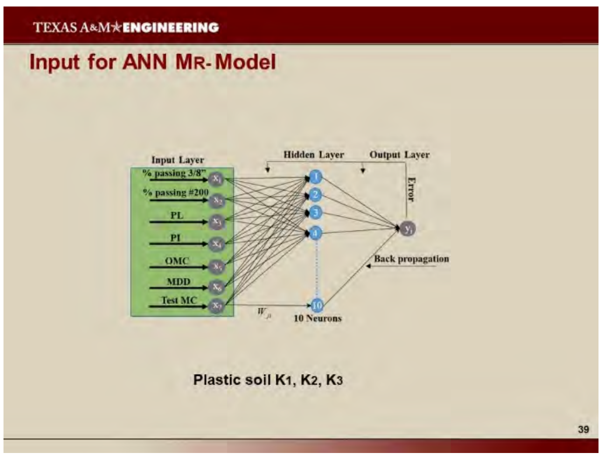
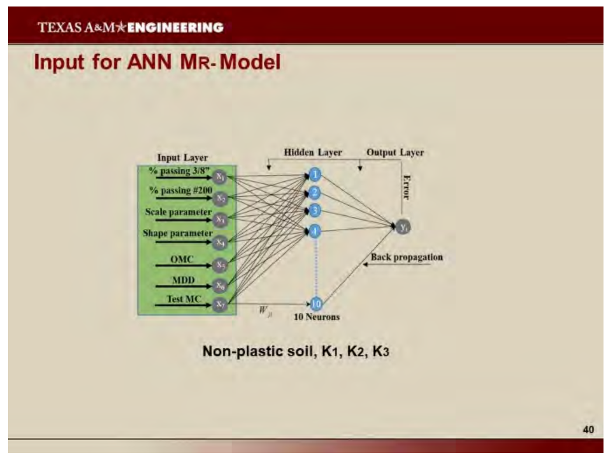
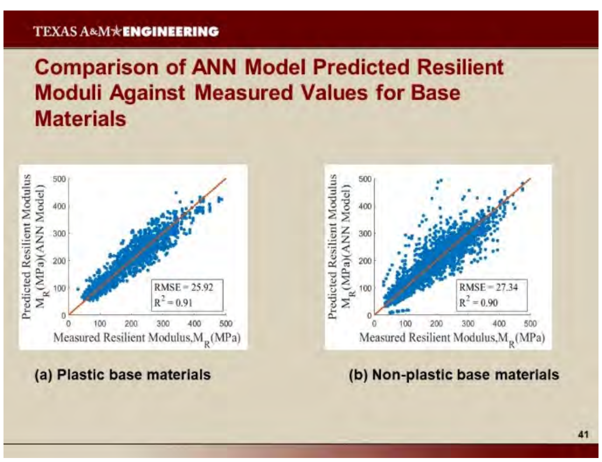
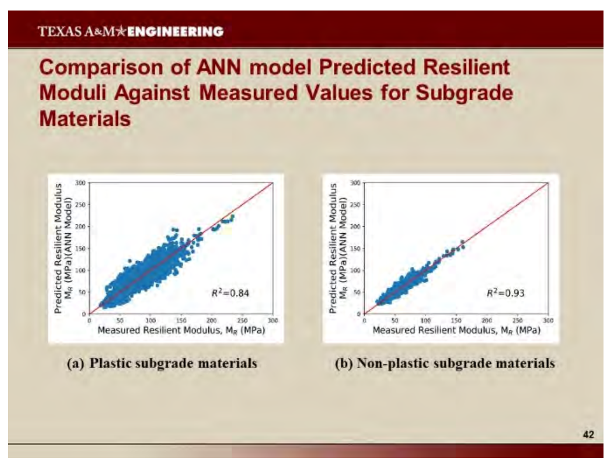

TEXAS A&M ENGINEERING
Comparison of Measured versus Predicted Suction at Various Saturation Levels for Non-plastic Soils
Predicted Matric Suction (psi)
Measured Matric Suction (psi)
RMSE = 1975
R² = -0.17
RMSE = 4582
R² = -7.56
RMSE = 587.33
R² = 0.91
37


TEXAS A&M ENGINEERING
Validation of Measured vs ANN Predicted Suction at Various Saturation Levels for Unbound Materials
Predicted Matric Suction (psi)
Measured Matric Suction (psi)
RMSE = 3405
R² = 0.93
RMSE = 804.97
R² = 0.87
(a) Plastic soil
(b) Non-plastic soil
38


TEXAS A&M ENGINEERING
Input for ANN MR-Model
Input Layer
% passing 3/8"
% passing #200
PL
PI
OMC
MDD
Test MC
Hidden Layer
Output Layer
Error
Back propagation
10 Neurons
Plastic soil K1, K2, K3
39

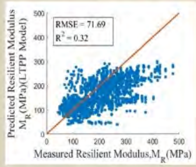

TEXAS A&M ENGINEERING
Input for ANN MR-Model
Input Layer
% passing 3/8"
% passing #200
Scale parameter
Shape parameter
OMC
MDD
Test MC
Hidden Layer
Output Layer
Error
Back propagation
10 Neurons
Non-plastic soil, K1, K2, K3
40

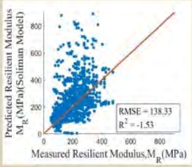

TEXAS A&M ENGINEERING
Comparison of ANN Model Predicted Resilient Moduli Against Measured Values for Base Materials
Predicted Resilient Modulus M_R (MPa)(ANN Model)
Measured Resilient Modulus, M_R (MPa)
RMSE = 25.92
R² = 0.91
RMSE = 27.34
R² = 0.90
(a) Plastic base materials
(b) Non-plastic base materials
41

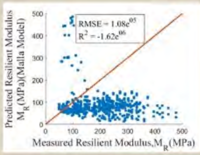

TEXAS A&M ENGINEERING
Comparison of ANN model Predicted Resilient Moduli Against Measured Values for Subgrade Materials
Predicted Resilient Modulus M_R (MPa)(ANN Model)
Measured Resilient Modulus, M_R (MPa)
R²=0.84
R²=0.93
(a) Plastic subgrade materials
(b) Non-plastic subgrade materials
42

TEXAS A&M ENGINEERING

Comparison of Measured Versus Predicted Resilient Moduli Using Regression Models







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TEXAS A&M ENGINEERING

Outline

- Introduction and objectives
- Subgrade/unbound layer properties currently included in Pavement ME Design
- Subgrade/unbound layer properties needed in Pavement ME Design
- **Subgrade/unbound layer Models**
  - Resilient modulus model
  - Permanent deformation model
  - Shear strength model
  - Erosion model
  - Foundation model

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TEXAS A&M ENGINEERING

Permanent Deformation Models for Subgrade/Unbound Layers

Model type

- Stress-dependent mechanistic-empirical model
- Regression models for Pavement ME Design model coefficients

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TEXAS A&M ENGINEERING

Stress-Dependent Mechanistic-Empirical Permanent Deformation Model

- Proposed model (Gu, Zhang, et al. 2015)

$$\varepsilon_p(N) = \varepsilon_0 e^{-(\rho/N)^\beta} \left(\frac{\sqrt{J_2}}{p_a}\right)^m \left(\frac{\alpha I_1 + K}{p_a}\right)^n$$

$$\alpha = \frac{2\sin\phi}{\sqrt{3}(3-\sin\phi)} \qquad K = \frac{c\cdot 6\cos\phi}{\sqrt{3}(3-\sin\phi)}$$

- Model components
  - Laboratory test design
  - Laboratory verification
  - Numerical verification
  - Hierarchical input level

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TEXAS A&M ENGINEERING

Repeated Load Permanent Deformation Test

Test Equipment

Stress State	Confining Pressure, σ_3 (kPa)	Deviatoric Stress, σ_d (kPa)	Bulk Stress, I_1 (kPa)	Second Invariant of Shear Stress Tensor, J_2 (kPa^2)	Test Purpose
1	27.6	192.9	275.6	12406.0	Model Calibration
2	48.2	130.9	275.6	5712.5	
3	68.9	68.9	275.6	1582.4	
4	91.9	0	275.6	0	
5	48.2	192.9	337.6	12406.0	
6	68.9	192.9	399.6	12406.0	
7	89.6	192.9	461.6	12406.0	
8	34.5	172.3	275.6	9890.0	Model Validation
9	103.4	192.9	503.0	12406.0	

Test Protocol

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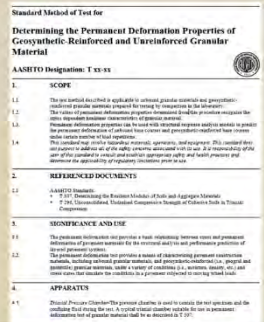
TEXAS A&M ENGINEERING

Proposed AASHTO Standard for Permanent Deformation Test



Standard Method of Test for

Determining the Permanent Deformation Properties of Geosynthetic-Reinforced and Unreinforced Granular Material

AASHTO Designation: T xx-xx

1. SCOPE

2. REFERENCED DOCUMENTS

3. SIGNIFICANCE AND USE

4. APPARATUS

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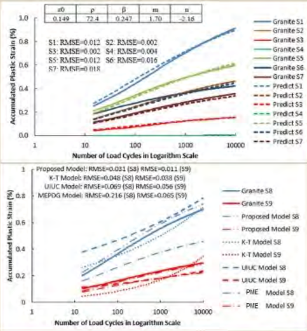
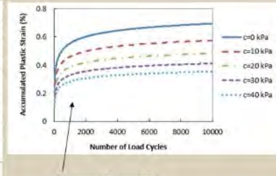
TEXAS A&M ENGINEERING

Repeated Load Permanent Deformation Test Results





Proposed model is sensitive to cohesion. Moisture change results in change of cohesion.

Korkiala-Tanttu (K-T) model (Korkiala-Tanttu 2009)
UIUC model (Chow et al. 2014)

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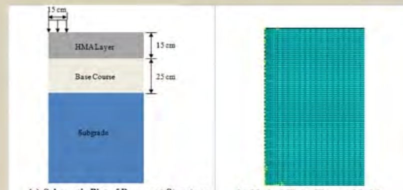
TEXAS A&M ENGINEERING

Numerical Study of Pavement Responses (1/2)



(a) Schematic Plot of Pavement Structure (b) Meshed Finite Element Model

Traffic Load	9, 12, and 16 kips	
Material Properties	HMA layer	E_{HMA}=2400 MPa; ν_{HMA}=0.35
	Unbound base course	k_1=1081, 1281, and 1481; k_2=0.81; k_3=-0.08; s=0.45; r=0.35; ν_{yx}=0.38; ν_{xx}=0.43
	Subgrade	E_{SG}=69 MPa ν_{SG}=0.4

(c) Modeling Parameters

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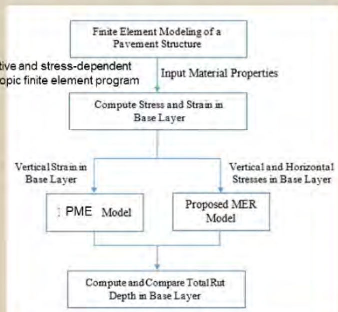
TEXAS A&M ENGINEERING

Numerical Study of Pavement Responses (2/2)

Moisture-sensitive and stress-dependent nonlinear anisotropic finite element program



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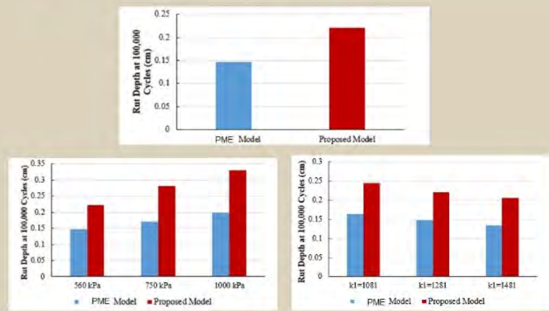
TEXAS A&M ENGINEERING

Results of Numerical Study



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TEXAS A&M ENGINEERING

Hierarchical Input Level

Level 1

- Laboratory-measured ε_0, ρ, β, m, and n
- SWCC
- Equilibrium suction and its depth

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TEXAS A&M ENGINEERING

Regression Models for Pavement ME Design Rutting Model Coefficients

- Proposed model (Epps et al. 2014)

$$\ln \varepsilon_0 = 10.24 - 0.03MBV + 0.10pfc + 0.88a_A - 3.95\ln\lambda_T$$
$$\ln \rho = 6.74 + 0.02MBV + 0.04pfc - 0.85a_G + 0.03\lambda_G - 0.13a_T$$
$$\ln \beta = 10.17 - 2.75\ln\gamma_d - 0.05pfc - 2.00a_G - 1.61\ln\lambda_A - 0.34a_T$$

- Model components
  - Performance indicators from laboratory tests
  - Laboratory verification
  - Hierarchical input level

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TEXAS A&M ENGINEERING

Laboratory Tests for Performance Indicators

- Methylene blue test
- Aggregate imaging system (AIMS) test
- Percent fines content test

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TEXAS A&M ENGINEERING

Hierarchical Input Level (1/2)

- Level 2
  - Performance-related properties
    - Dry density
    - Percent fines content
    - Methylene blue value
    - Gradation
    - Shape, angularity, and texture of aggregates
  - SWCC
  - Equilibrium suction and its depth

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TEXAS A&M ENGINEERING

Hierarchical Input Level (2/2)

- Level 2
  - Simple properties
    - Dry unit weight
    - Optimum water content
    - Plastic index
    - Liquid limit
    - Percent passing No. 200
  - Default SWCC
  - Default equilibrium suction
- Level 3
  - Default performance-related properties
  - Default SWCC

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TEXAS A&M ENGINEERING

Shear Strength Model of Unbound Layers

- Proposed model (Epps et al. 2014)

$$\tau = c' + (\sigma_n - \theta f h_m)\tan\phi'$$

$$c' = -1676.624 - 2.088MBV - 13.260a_A - 0.113\lambda_A + 270.722\ln\gamma_d + 38.778a_G$$

$$\phi' = -2.827 - 0.016MBV - 0.0005\lambda_A - 0.051a_S + 0.763\ln\gamma_d - 0.008pfc$$

- Model components
  - Laboratory verification
  - Hierarchical input level

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TEXAS A&M ENGINEERING

Hierarchical Input Level

- Level 1
  - Laboratory-measured c' and ϕ'
- Level 2
  - Performance-related properties
    - Dry density
    - Percent fines content
    - Methylene blue value
    - Gradation
    - Shape, angularity, and texture of aggregates
  - SWCC
  - Equilibrium suction and its depth

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Shear Strength Model of Subgrade

- Proposed model (Titus-Glover and Fernando 1995)

$$\tau = c + \sigma_n\tan\phi = \left[c' + (u_a - u_w)\tan\phi^b\right] + \sigma_n\tan\phi$$

$$c = 83.95 + 1.58N40 - 2.57n - 0.043N40_N^2 - 6.88PL_N G_{sN} + 0.14\psi - 0.81\psi\tan\phi$$

$$\phi = 1.61 - 0.96PI - 0.88n - 4.13\psi + 31.82G_{sb}$$

- Model components
  - Laboratory verification
  - Hierarchical input level

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TEXAS A&M ENGINEERING

Hierarchical Input Level

- Level 2
  - Simple properties
    - Specific gravity
    - Plasticity index
    - Porosity
    - Percent passing 0.42 mm
  - Default SWCC
  - Default equilibrium suction
- Level 3
  - Default performance-related properties
  - Default SWCC

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TEXAS A&M ENGINEERING

Outline

- Introduction and objectives
- Subgrade/unbound layer properties currently included in Pavement ME Design
- Subgrade/unbound layer properties needed in Pavement ME Design
- **Subgrade/unbound layer Models**
  - Resilient modulus model
  - Permanent deformation model
  - Shear strength model
  - Erosion model
  - Foundation model

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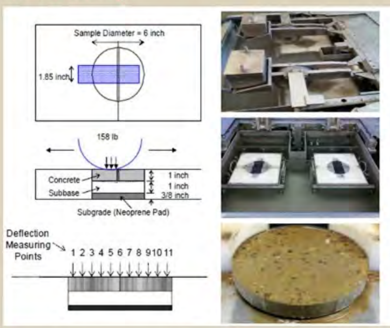
TEXAS A&M ENGINEERING

Hamburg Wheel-Tracking Device (HWTD) to Measure Erodibility



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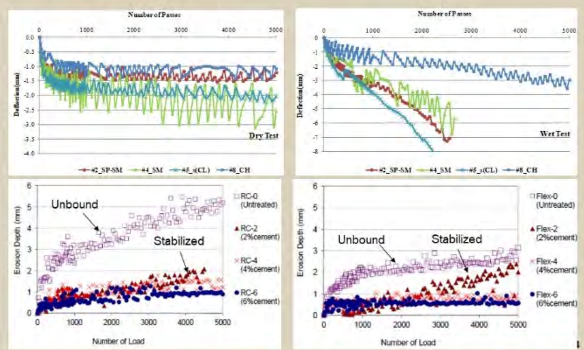
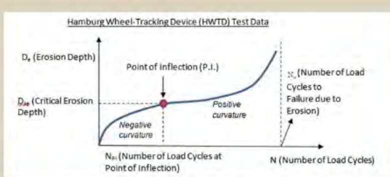
TEXAS A&M ENGINEERING

HWTD Test Results



TEXAS A&M ENGINEERING

Critical Erosion Depth Model



Erosion depth curve:

$$N = N_{\infty} e^{-\left(\frac{\rho_e}{D_e}\right)^{\beta_e}}$$

Critical erosion depth:

$$D_{ce} = \rho_e \left(\frac{\beta_e}{\beta_e + 1}\right)^{\frac{1}{\beta_e}}$$

Number of load cycles at the point of inflection:

$$N_{PI} = N_{\infty} e^{-\left(\frac{\beta_e + 1}{\beta_e}\right)}$$

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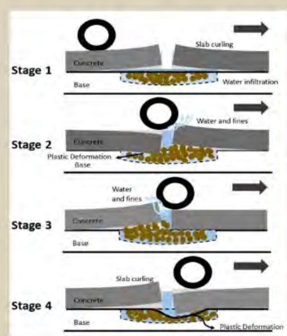

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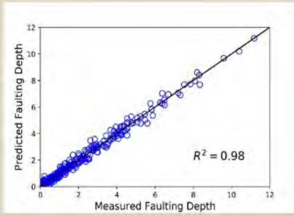
TEXAS A&M ENGINEERING

Comparison between Measured and Predicted Faulting Depth



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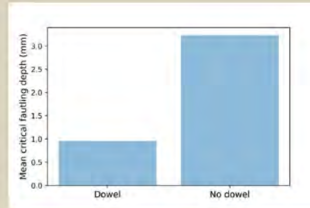
TEXAS A&M ENGINEERING

Mean Critical Faulting Depth with or without Dowels



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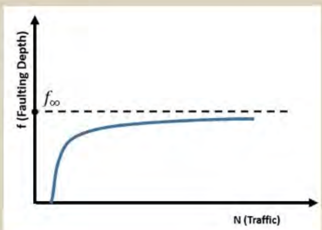
TEXAS A&M ENGINEERING

Plastic Deformation Curve before the Inflection Point -Load-related



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$$f(N_i) = \sum_{i=1}^{k} f_\infty e^{-\left(\frac{\rho}{N_i-N_0}\right)^{\beta}} \left(\frac{\sqrt{J_{2i}}}{P_a}\right)^{m} \left(\frac{\alpha I_{1i}+K}{P_a}\right)^{n}$$

Load-Related Faulting Model

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Strength Properties

$$\alpha = \frac{2\sin\phi}{\sqrt{3}(3-\sin\phi)} \qquad K = \frac{6c\cos\phi}{\sqrt{3}(3-\sin\phi)}$$

Load-Related Faulting Model

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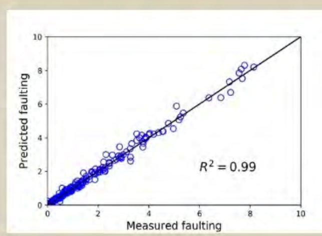
TEXAS A&M ENGINEERING

Comparison between Measured versus Predicted Faulting before Critical Depth



Load-Related Faulting Model

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TEXAS A&M ENGINEERING

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Foundation Model of Subgrade

Model components
- Interface bond stiffness model
- Subgrade k-value model

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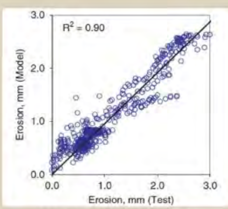
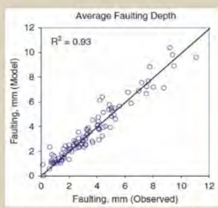
TEXAS A&M ENGINEERING

Validation of Erosion Model



Model prediction vs. lab measurements from HWTD



Model prediction vs. observed performance from 17 LTPP sections

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TEXAS A&M ENGINEERING

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TEXAS A&M ENGINEERING

Foundation Model of Subgrade

Model components
- Interface bond stiffness model
- Subgrade k-value model

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TEXAS A&M ENGINEERING

Role of Interface Bond Stiffness Model

- In Pavement ME Design
  - Interface condition is described by degree of bonding
  - Degree of bonding = 1 (bonded) or 0 (unbonded)
- In reality
  - Shear restraints exist between slab and base
  - Degree of bond limited by shear strength
  - Effect of shear strength limitation is to decrease overall stiffness

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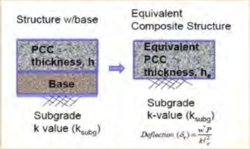
TEXAS A&M ENGINEERING

Subgrade k-value Model (1/3)

Determine Equivalent PCC Thickness



Interface shear bonding:

$$\delta = \frac{\tau}{\tau_{xz}}$$

Predicted by shear strength model

PCC layer and base layer are unbonded:

$$h_{e-u} = \left(h_1^3 + n h_2^3\right)^{1/3}$$

PCC layer and base are partially unbonded:

$$h_{e-p} = h_{e-u}(1-\alpha) + \alpha h_{e-b}$$

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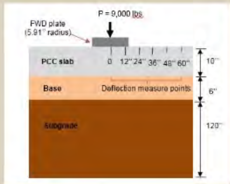
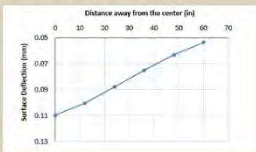
Subgrade k-value Model (2/3)

Determine Effective Relative Stiffness Length

$$l_e = a + b \times (BA) + c \times (BA)^2$$

$$BA\ (basin\ area) = \frac{SS}{2 \times D_0}\left[D_0 + 2\left(D_1 + D_2 + \ldots + D_{j-1}\right) + D_j\right]$$





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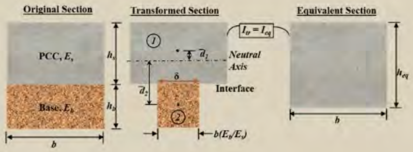
TEXAS A&M ENGINEERING

Illustration of Transformed-Section Method for a Cooperated Concrete Slab and Base Course System



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Transformed Section Moment of Inertia

$$I_{tr} = I_{slab} + I_{base} + \delta \sum A_i \bar{d}_i^{\,2}$$

δ = Degree of Bonding

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TEXAS A&M ENGINEERING

Degree of Bonding

$$\delta = \frac{Shear\ Strength\ in\ Base\ Course}{Shear\ Stress\ in\ Base\ Course}$$

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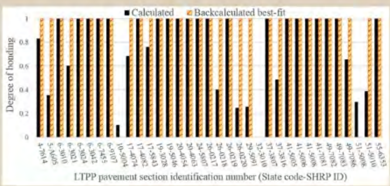
TEXAS A&M ENGINEERING

Comparison of Calculated Slab-base Interface Degree of Bonding Ratio with the Backcalculated Best-fit Approach



(a) treated base

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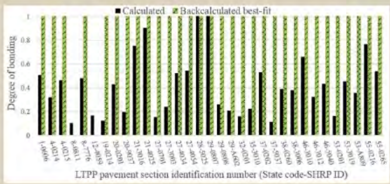
TEXAS A&M ENGINEERING

Comparison of Calculated Slab-base Interface Degree of Bonding Ratio with the Backcalculated Best-fit Approach



(b) unbound base layer

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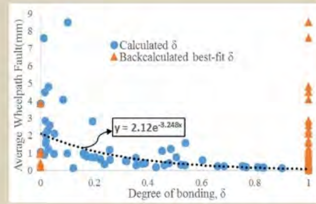
Sensitivity of Slab-base Degree of Bonding on Wheelpath Fault (mm)



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TEXAS A&M ENGINEERING

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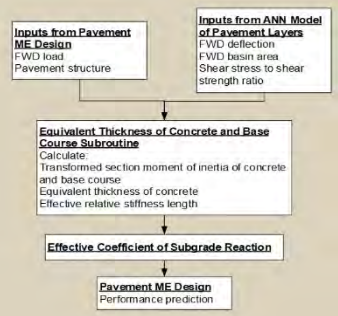

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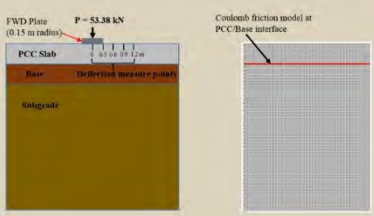
TEXAS A&M ENGINEERING

Finite Element Model Development



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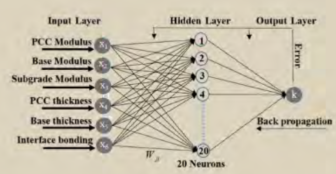
TEXAS A&M ENGINEERING

Illustration of Three-Layered Neural Network Architecture for k-values



ANN Model of Pavement Structure

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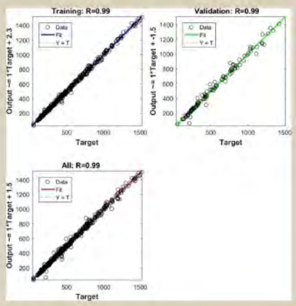
TEXAS A&M ENGINEERING

Target and Output k-values for Training, Validation, and Overall Data Sets for 1296 Simulation Cases



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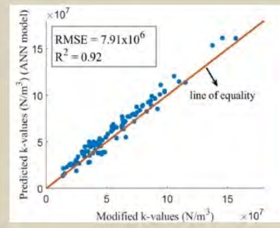
TEXAS A&M ENGINEERING

Comparison of Calculated versus Predicted Modified k-values



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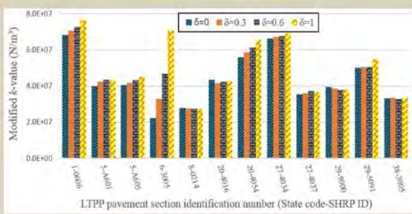
TEXAS A&M ENGINEERING

Modified *k*-values at 0, 0.3, 0.6 and 1 degree of Bonding for Selected LTPP Pavement Sections



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TEXAS A&M ENGINEERING

Sensitivity of Proposed NCHRP Models

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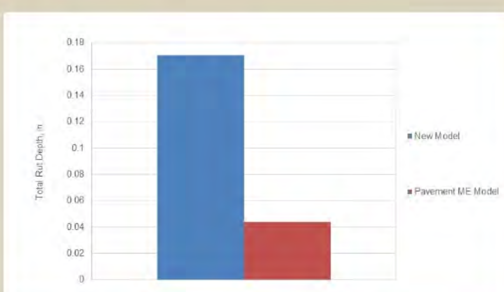
TEXAS A&M ENGINEERING

Rut Depth in the Base Layer Using Different Models



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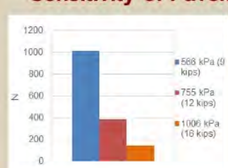
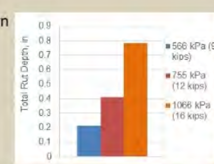
TEXAS A&M ENGINEERING

Sensitivity of Pavement Performance



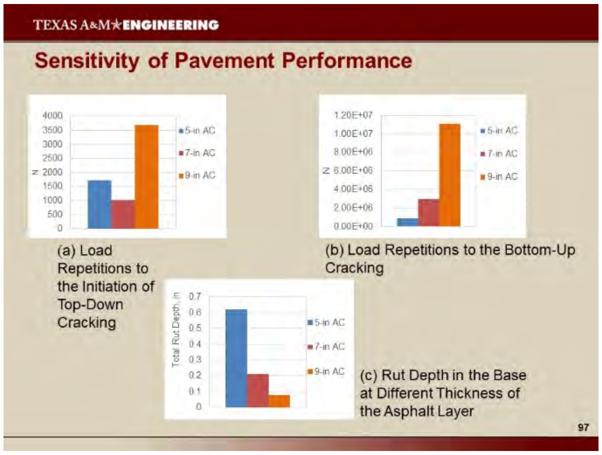
(a) Load Repetitions to the Initiation of Top-Down Cracking

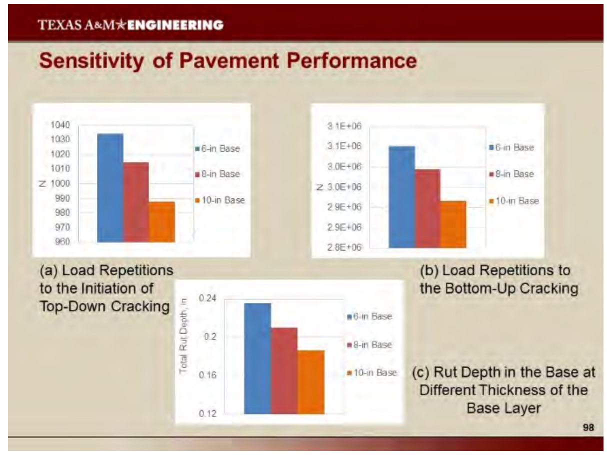
b) Load Repetitions to the Bottom-Up Cracking

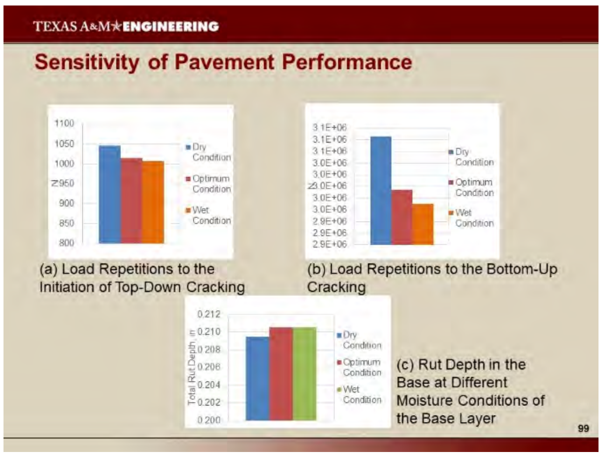


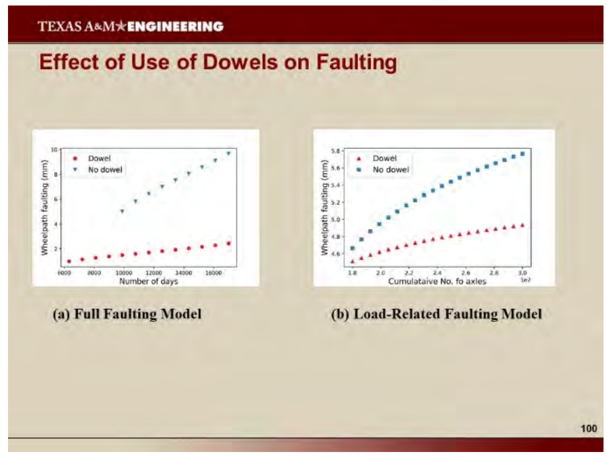
(c) Rut Depth in the Base at Different Loading Levels

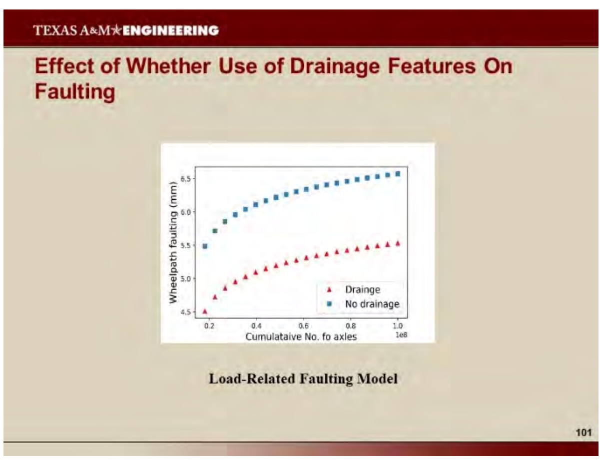
96

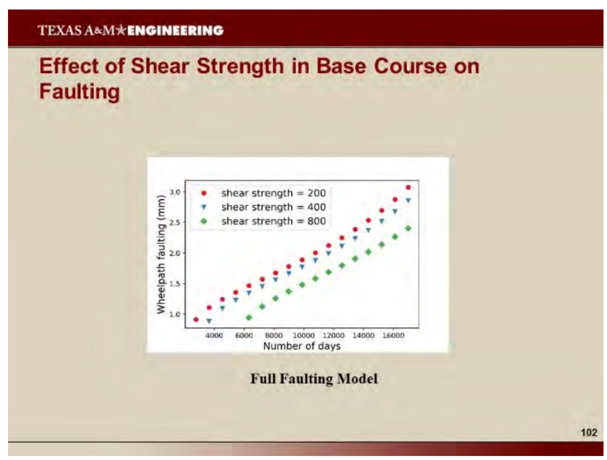

TEXAS A&M ENGINEERING
Sensitivity of Pavement Performance
5-in AC
7-in AC
9-in AC
(a) Load Repetitions to the Initiation of Top-Down Cracking
(b) Load Repetitions to the Bottom-Up Cracking
Total Rut Depth, in
(c) Rut Depth in the Base at Different Thickness of the Asphalt Layer
97


TEXAS A&M ENGINEERING
Sensitivity of Pavement Performance
6-in Base
8-in Base
10-in Base
(a) Load Repetitions to the Initiation of Top-Down Cracking
(b) Load Repetitions to the Bottom-Up Cracking
Total Rut Depth, in
(c) Rut Depth in the Base at Different Thickness of the Base Layer
98


TEXAS A&M ENGINEERING
Sensitivity of Pavement Performance
Dry Condition
Optimum Condition
Wet Condition
(a) Load Repetitions to the Initiation of Top-Down Cracking
(b) Load Repetitions to the Bottom-Up Cracking
Total Rut Depth, in
(c) Rut Depth in the Base at Different Moisture Conditions of the Base Layer
99

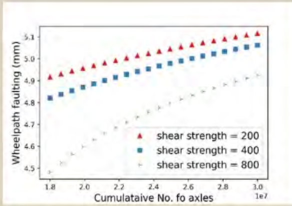

TEXAS A&M ENGINEERING
Effect of Use of Dowels on Faulting
Dowel
No dowel
Wheelpath faulting (mm)
Number of days
Cumulataive No. fo axles
(a) Full Faulting Model
(b) Load-Related Faulting Model
100


TEXAS A&M ENGINEERING
Effect of Whether Use of Drainage Features On Faulting
Wheelpath faulting (mm)
Drainge
No drainage
Cumulataive No. fo axles
Load-Related Faulting Model
101


TEXAS A&M ENGINEERING
Effect of Shear Strength in Base Course on Faulting
shear strength = 200
shear strength = 400
shear strength = 800
Wheelpath faulting (mm)
Number of days
Full Faulting Model
102

TEXAS A&M ENGINEERING

Effect of Shear Strength in Base Course on Faulting



Load-Related Faulting Model

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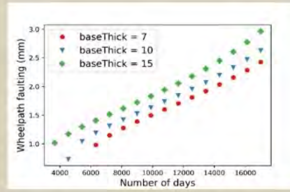
TEXAS A&M ENGINEERING

Effect of Thickness of Base Layer on Faulting



Full Faulting Model

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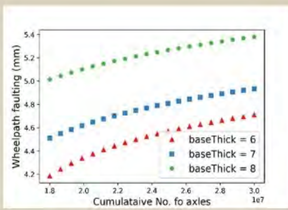
TEXAS A&M ENGINEERING

Effect of Thickness of Base Layer on Faulting



Load-Related Faulting Model

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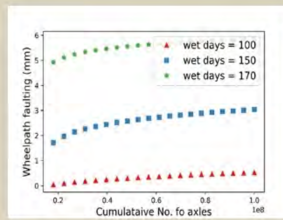
TEXAS A&M ENGINEERING

Effect of Number of Wet Days on Faulting



Effect of Number of Wet Days on Faulting

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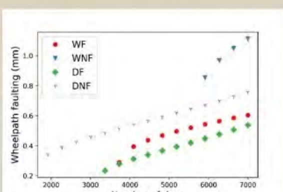
TEXAS A&M ENGINEERING

Effect of Climatic Zone on Faulting Over Time



Full Faulting Model

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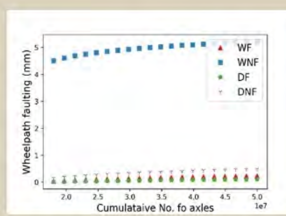
TEXAS A&M ENGINEERING

Effect of Climatic Zone on Faulting Over Time



Load-Related Faulting Model

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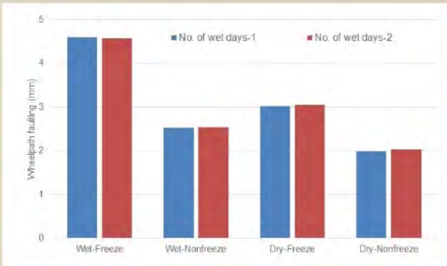
TEXAS A&M ENGINEERING

Sensitivity of Faulting Depth to Number of Wet Days Based on Pavement ME Design Model



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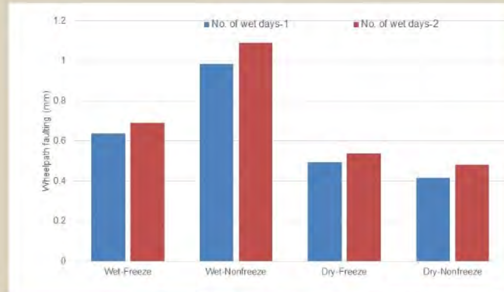
TEXAS A&M ENGINEERING

Sensitivity of Number of Faulting Depth to Number of Wet Days Based on Proposed Full Faulting Model



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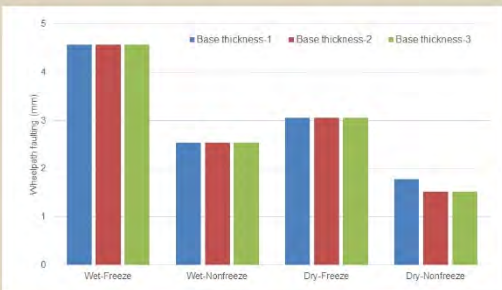
TEXAS A&M ENGINEERING

Sensitivity of the Thickness to the Thickness of the Base Layer on Based on Pavement ME Design Model



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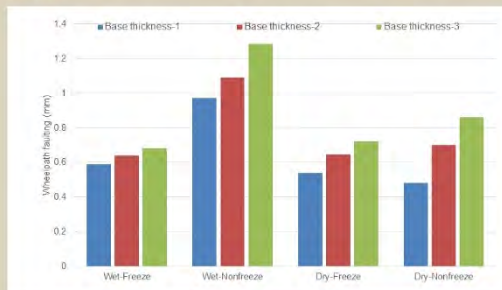
TEXAS A&M ENGINEERING

Sensitivity of the Faulting Depth to the Thickness of Base Layer Based on Proposed Full Faulting Model



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Our Models Emphasize

- Unbound layers
  - Modulus: moisture-sensitive, stress-dependent, cross-anisotropic
  - Permanent deformation: moisture-sensitive, stress-dependent
  - Shear strength: moisture-sensitive
  - Erosion
  - Thickness
- Subgrade
  - Modulus: moisture-sensitive, stress-dependent
  - Permanent deformation: moisture-sensitive, stress-dependent
  - Shear strength: moisture-sensitive
  - Foundation: interface bond stiffness & k-value

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TEXAS A&M ENGINEERING

NCHRP 1-53

Proposed Enhancements to Pavement ME Design: Improved Consideration of the Influence of Subgrade and Unbound Layers on Pavement Performance

3RD AASHTO Pavement ME
National Users Group Meeting

Nashville, Tennessee
November 7, 2018

Presentation 11—Georgene Geary, GGfGA Engineering

User Review of the AASHTO 'Guide for the Local Calibration of the Mechanistic -Empirical Pavement Design Guide'

NCHRP 20-07/ Task 422
GGfGA Engineering, LLC
Georgene Geary, P.E., Principal Engineer

Report to Pavement ME Users Group
November 7, 2018
Nashville, Tennessee

GGfGA

Outline

- **What** was the User Review of the AASHTO 'Guide for the Local Calibration of the MEPDG Guide'?
- **Where** are the results?
- **What** does it say?
- **Who** cares?

GGfGA

Main Issues driving the Project

- PMED Software has changed and continues to change
  - Local calibration efforts have identified needs for new research for improvements to the models, this will likely continue
- The equations used in the software are essential to local calibration
- Specific methods to calibrate are not clear in the existing LC Guide
- **Practitioners need to be part of the process, but the LC Guide is not written for them now**

GGfGA

User Review (NCHRP 20-07 project)consisted of:

1. Survey of AASHTO States through COMP
2. Review of existing resources on local calibration of MEPDG
   I. Global calibration factors and changes
   II. Local calibration reports from State research projects
3. Review of current contents of the Local Calibration Guide
4. Proposed specific revisions to the Local Calibration Guide

GGfGA

Survey Results

AASHTO Pavement ME Design Local Calibration

COMP (Committee on Materials and Pavements) Survey – Thanks Again for completing the survey!!

GGfGA

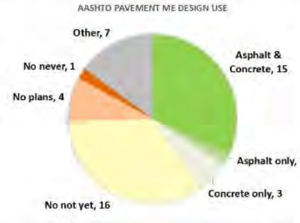
General survey results

- 46 States and Ontario Responded
- Only 2 respondents noted that they were not familiar with the Local Calibration Guide
  - 1 respondent offered that they used the Design Guide (MOP) Also
- 29 States and Ontario noted they had performed a local calibration
  - 3 Others in process
- 24 noted they had performed a local calibration after 2010

GGfGA

Have you ever performed (or contracted) a local calibration of AASHTO Pavement ME?

Do you currently use AASHTO Pavement ME either for your State/Provinces pavement designs or for comparison designs (parallel effort)?



GGfGA

Global and Local Calibration Factors

- Affected by MOP and software changes
- >20 State Local Calibration reports found
  - 5 Master/PhD Thesis
- History of Global Calibration Factors included in Appendix of report

GGfGA

NCHRP Report Appendix A History of Global Calibration Factors

Table A1 – HMA/AC Rutting

Transfer Function Coefficient	Global Value (MOP 2008)	Global Value (MOP 2015)	Current Software*
k1r	-3.35412	-3.35412	-3.35412
k2r	0.4791	0.4791**	1.5606
k3r	1.5606	1.5606**	0.4791
B1r	1.0	1.0	1.0
B2r	1.0	1.0	1.0
B3r	1.0	1.0	1.0

*Current Software has ability to have different values for 3 different layers and it notes a Std Dev of 0.24POW(RUT,0.8062) + 0.001
**MOP 2015 notes in the Preface (Page v1) that these values have changed to what is in the current software, but they are not changed in the body of the document (pg 39)

Table A6 – JPCP Mid-slab (Transverse) Cracking

Transfer Function Coefficient	Global Value (MOP 2008)	Global Value (MOP 2015)	Task 288	NNC*	Current Software
C1	2.0	2.0	2	2	2
C2	1.22	1.22	1.22	1.22	1.22
C4	Not defined (1)	1.00	0.6	0.6	0.52
C5	Not defined (-1.98)	-1.98	-2.05	-2.05	-2.17
Standard Deviation	-0.00198*POW (CRACK,2) – 0.56857 CRACK + 2.76825	POW(5.3116*CRACK,0.390 1) + 2.99	POW(57.08*CRACK, 0.33) + 1.5		[illegible]*POW(CRACK, 0.3415) + 0.75

*Task 288 values shown are as defined in the Task 327 report, NNC was defined as the Task 288 values in a paper (Mu et al. 2016); current software uses the Task 327 values

GGfGA

Minimum info needed to perform Local Cal

In LC Guide	Partially in LC Guide	Not in LC Guide
Local Calibration Process Flow Chart (current LC Guide Chapter 6)	Calibration factors & transfer equations	Basic description of what all the calibration factors affect/relate to
	Statistical methods and examples	National SEE terms to evaluate local calibration (does not now include the current ones)
	Distress definitions used in PMED	
	Examples of how best to use PMS data that is not exactly as defined	

GGfGA

Panel Member Comment:

"Learned way more from this (Task 3) than from the original LC Guide."

My Comment:

"Learned way more from trying to do a mini- Local Calibration than from the original LC Guide, but I still don't know how to explain this:

LC Guide page 6-5: " *Since the square of s_e is a variance, the confidence interval on the variance can be used to show the relationship between sample size and the relative error variance (s_e/s_e)* "

GGfGA

Recommendations provided for the new Revised Guide:

- Use the **Basic step-by-step procedure as the main format/outline**
- Use **consistent nomenclature** and **non-statistical language**
- **ADD**:
  - Method required for calibration of distress: software runs required or regression possible?
  - Equations to be calibrated
  - Calibration coefficients and how, why to adjust
  - Detailed examples of computing calibration factors
- **Show examples for each Step in the process**

GGfGA

Final NCHRP Report completed in June- on the TRB website

CONTENTS

1. Background and Introduction (includes COMP Survey results)
2. Current Contents of the Local Calibration Guide
3. **Proposed Specific Revisions to the Local Calibration Guide**

References (including listing of local calibration reports)

Appendices

A. Global Calibration Factors
B. Detailed Survey Results
C. Example for New Guide

GGfGA

Recommended Outline for the new "Guide for the Local Calibration of PMED"

Introduction

1. Select Input Levels
2. Develop Experiment Plan and Sampling Template
3. Estimate Sample Size
4. Select Roadway Segments
5. Extract and Evaluate Distress and Project Data
6. Conduct Field and Forensic Investigations
7. Assess Local Bias
8. Eliminate Local Bias
9. Assess the Standard Error (SEE, or Se)
10. Reduce the Standard Error
11. Interpretation of Results

'Set up' portion (steps 1–6)

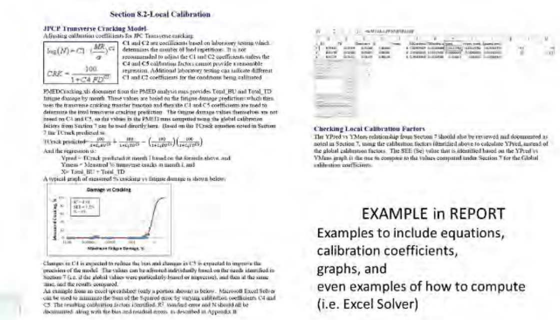
Calibration portion (steps 7–11)

Appendix A Lessons Learned
Appendix B Statistical References

Potential Lessons Learned from Local Calibration Reports (Proposed Appendix A)

- Different values beyond Standard error used to evaluate calibration LOE R^2- (line of equality) and MAPE (mean absolute percentage error)
- Separate calibrations based on different subgrade modulus
- Using an FEM analysis to determine a new C1 cracking factor for 20 ft jointed pavement
- Method developed to compute rutting using transverse profile
- Residual plots to compare errors to different inputs

GGfGA



EXAMPLE in REPORT

Examples to include equations,
calibration coefficients,
graphs, and
even examples of how to compute
(i.e. Excel Solver)

Main Points from Report

- LC Guide needs to be reorganized and updated – *outline provided*
- LC Guide needs more detail to perform a consistent local calibration and to compare local calibration efforts in the future
- Changes, updates or identified errors in equations need to be communicated clearly and timely to users outside the 'printed' Guide
  - Add Calibration site to AASHTOWare PMED website which will always contain the latest values and equations

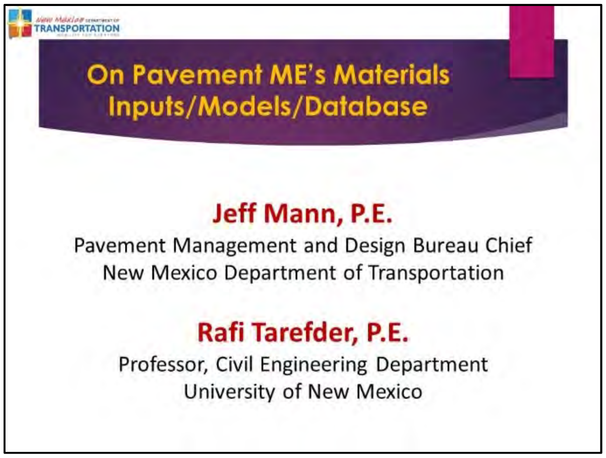
GGfGA

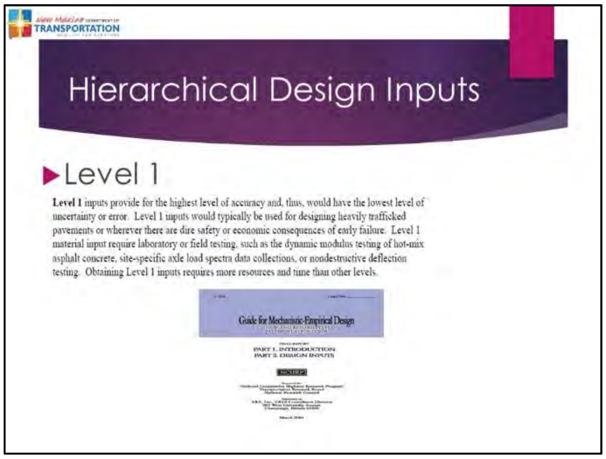
Thanks!

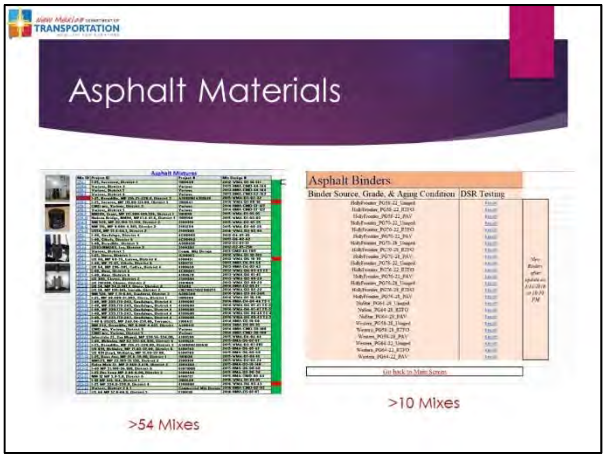
Any Questions??

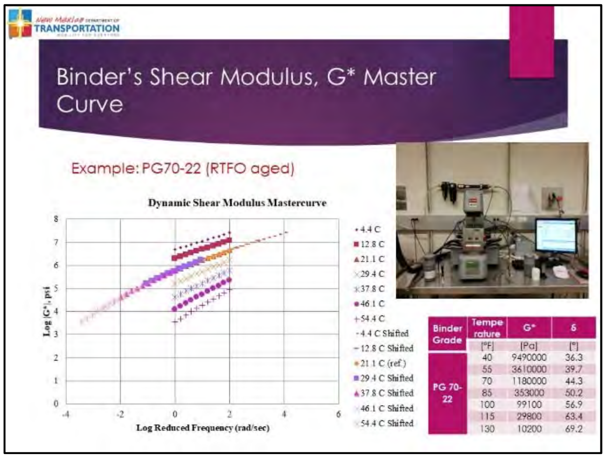
GGfGA

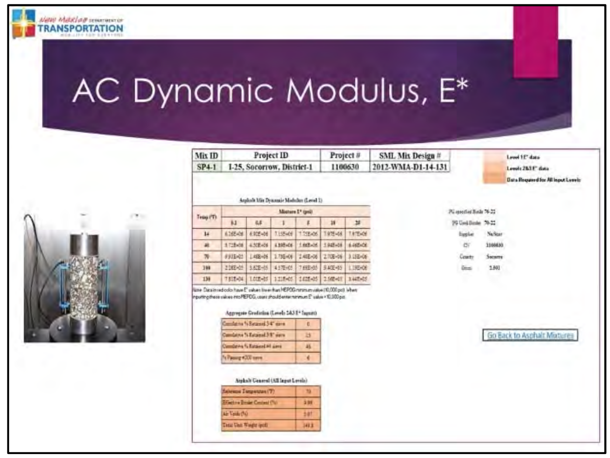
Presentation 12—Jeffrey Mann, New Mexico DOT

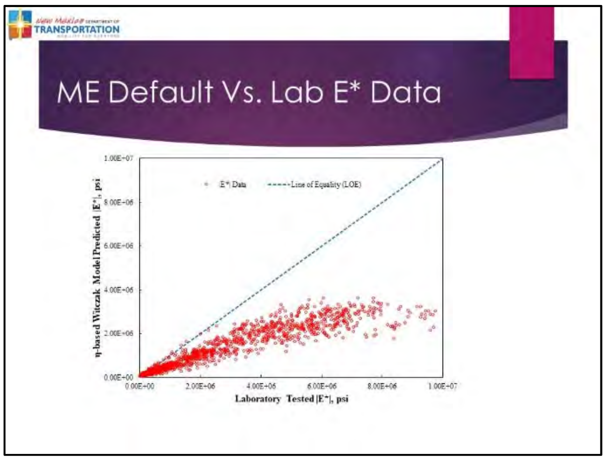


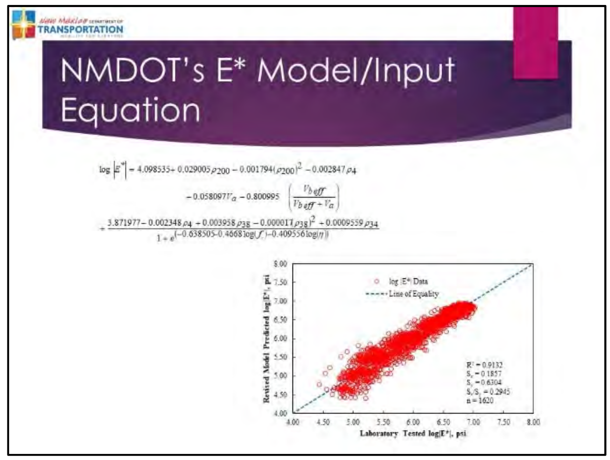


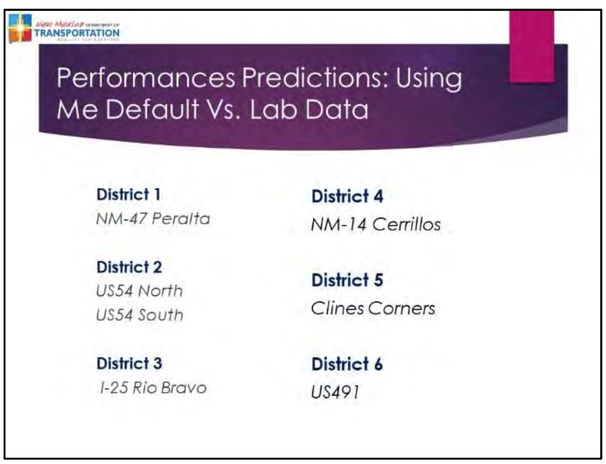


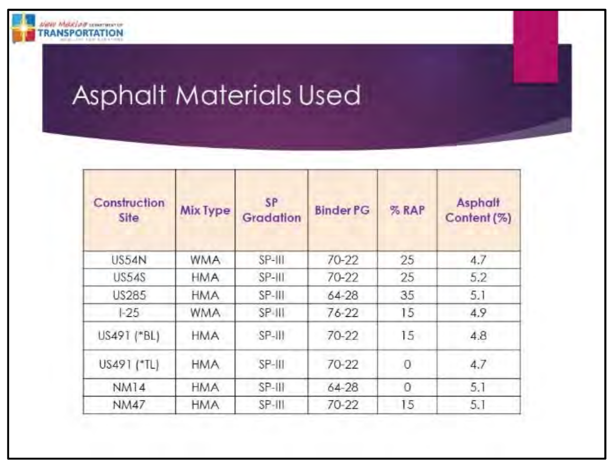

TRANSPORTATION
Binder's Shear Modulus, G* Master Curve
Example: PG70-22 (RTFO aged)
Dynamic Shear Modulus Mastercurve
Log |G*|, psi
Log Reduced Frequency (rad/sec)
4.4 C
12.8 C
21.1 C
29.4 C
37.8 C
46.1 C
54.4 C
4.4 C Shifted
12.8 C Shifted
21.1 C (ref)
29.4 C Shifted
37.8 C Shifted
46.1 C Shifted
54.4 C Shifted
Binder Grade	Temperature	G*	δ
	[°F]	[Pa]	[°]
PG 70-22	40	9490000	36.3
	55	3610000	39.7
	70	1180000	44.3
	85	353000	50.2
	100	99100	56.9
	115	29800	63.4
	130	10200	69.2


TRANSPORTATION
AC Dynamic Modulus, E*
Mix ID
Project ID
Project #
SML Mix Design #
SP4-1
I-25, Socorrow, District-1
1100630
2012-WMA-D1-14-131
Go Back to Asphalt Mixtures


TRANSPORTATION
ME Default Vs. Lab E* Data
E* Data
Line of Equality (LOE)
η-based Witczak Model Predicted |E*|, psi
Laboratory Tested |E*|, psi

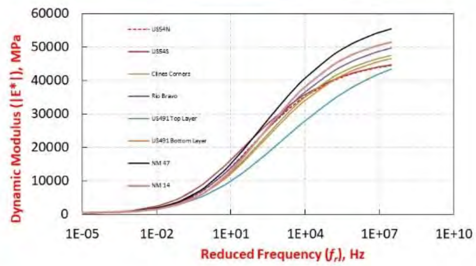

TRANSPORTATION
NMDOT's E* Model/Input Equation
$\log|E^*| = 4.098535 + 0.029005\rho_{200} - 0.001794(\rho_{200})^2 - 0.002847\rho_4 - 0.058097V_a - 0.800995\left(\frac{V_{beff}}{V_{beff}+V_a}\right) + \frac{3.871977 - 0.002348\rho_4 + 0.003958\rho_{38} - 0.000017(\rho_{38})^2 + 0.0009559\rho_{34}}{1+e^{(-0.638505-0.4668\log(f)-0.409556\log(\eta))}}$
log |E*| Data
Line of Equality
Revised Model Predicted log|E*|, psi
Laboratory Tested log|E*|, psi
n = 1620


TRANSPORTATION
Performances Predictions: Using Me Default Vs. Lab Data
District 1
NM-47 Peralta
District 2
US54 North
US54 South
District 3
I-25 Rio Bravo
District 4
NM-14 Cerrillos
District 5
Clines Corners
District 6
US491


TRANSPORTATION
Asphalt Materials Used
Construction Site	Mix Type	SP Gradation	Binder PG	% RAP	Asphalt Content (%)
US54N	WMA	SP-III	70-22	25	4.7
US54S	HMA	SP-III	70-22	25	5.2
US285	HMA	SP-III	64-28	35	5.1
I-25	WMA	SP-III	76-22	15	4.9
US491 (*BL)	HMA	SP-III	70-22	15	4.8
US491 (*TL)	HMA	SP-III	70-22	0	4.7
NM14	HMA	SP-III	64-28	0	5.1
NM47	HMA	SP-III	70-22	15	5.1

New Mexico Department of Transportation

Lab Tested E* Master Curves



New Mexico Department of Transportation

Performance Comparison Using ME default vs. Lab Inputs

US285

Distress Type	Level 1		Level 2		Level 3	
	Target	Predicted	Target	Predicted	Target	Predicted
Terminal IRI (in/mile)	172	153.51	172	177.2	172	163.64
Permanent deformation - total pavement (in)	0.75	0.62	0.75	1.13	0.75	0.87
AC bottom-up fatigue cracking (% lane area)	25	2.46	25	21.64	25	4.54
AC thermal cracking (ft/mile)	1000	27.17	1000	27.17	1000	27.17
AC top-down fatigue cracking (ft/mile)	2000	278.51	2000	1090.92	2000	1394.47
Permanent deformation - AC only (in)	0.25	0.23	0.25	0.64	0.25	0.59

New Mexico Department of Transportation

Performance Comparison Using ME default vs. Lab Inputs

US54N

Distress Type	Level 1		Level 2		Level 3	
	Target	Predicted	Target	Predicted	Target	Predicted
Terminal IRI (in/mile)	172	132.77	172	151.59	172	145.34
Permanent deformation - total pavement (in)	0.75	0.38	0.75	0.82	0.75	0.69
AC bottom-up fatigue cracking (% lane area)	25	1.56	25	2.14	25	1.73
AC thermal cracking (ft/mile)	1000	27.17	1000	27.17	1000	27.17
AC top-down fatigue cracking (ft/mile)	2000	1023.05	2000	3114.07	2000	2257.49
Permanent deformation - AC only (in)	0.25	0.22	0.25	0.61	0.25	0.53

New Mexico Department of Transportation

Performance Comparison Using ME default vs. Lab Inputs

US54S

Distress Type	Level 1		Level 2		Level 3	
	Target	Predicted	Target	Predicted	Target	Predicted
Terminal IRI (in/mile)	172	139.17	172	176.15	172	165.99
Permanent deformation - total pavement (in)	0.75	0.49	0.75	1.28	0.75	1.1
AC bottom-up fatigue cracking (% lane area)	25	2.04	25	20.88	25	8.66
AC thermal cracking (ft/mile)	1000	27.17	1000	27.17	1000	27.17
AC top-down fatigue cracking (ft/mile)	2000	1352.39	2000	5678.52	2000	3360.99
Permanent deformation - AC only (in)	0.25	0.3	0.25	1.04	0.25	0.88

New Mexico Department of Transportation

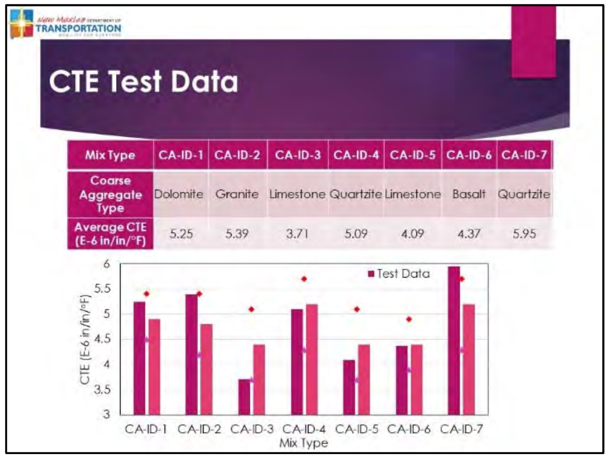
NMDOT on FEL Testing of Asphalt Concrete

Construction Site	Grade Specified	Aggregate Type	Measured FEL
US54N	70-22	SP III with 25% RAP (WMA)	121
US54S	70-22	SP III with 25% RAP (HMA)	130
US285	64-28	SP III with 35% RAP (HMA)	103
I-25	76-22	SP III with 15% RAP (WMA)	117
US491 (*BL)	70-22	SP III with 15% RAP (HMA)	137
US491 (*TL)	70-22	SP III with 0% RAP (HMA)	140
NM47	70-22	SP III with 15% RAP (HMA)	133
NM14	64-28	SP III with 0% RAP (HMA)	119

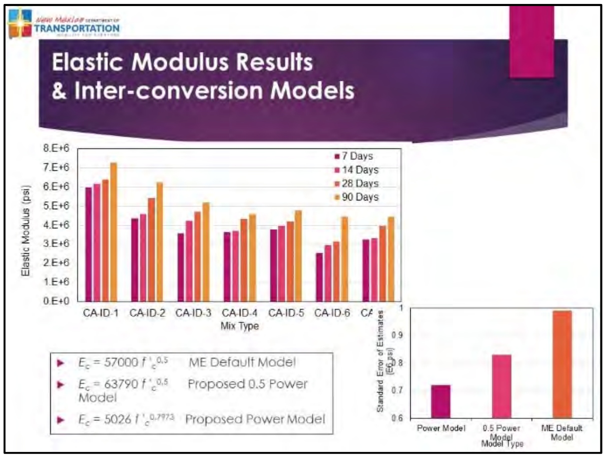
New Mexico Department of Transportation

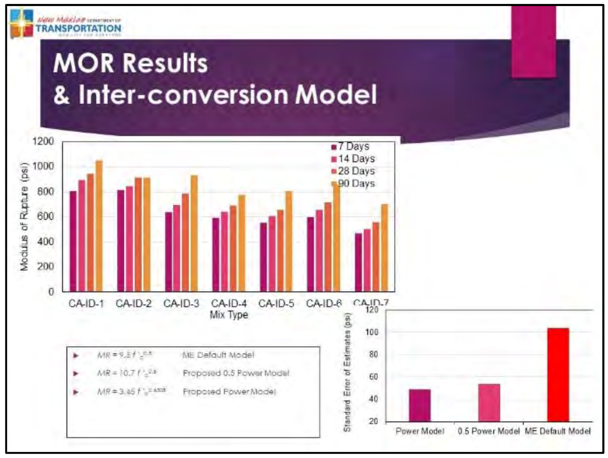
NMDOT on Concrete Pavements

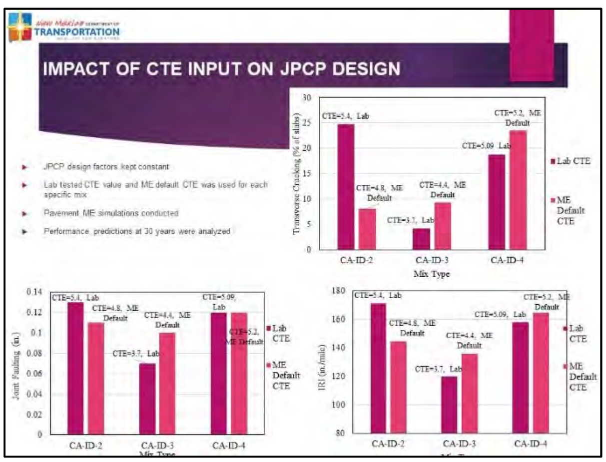
Mix ID	Company	Coarse Aggregate Source	Coarse Aggregate Type	Fine Aggregate	Concrete Class	Cement Type	Location
CA-ID-1	PB Materials	Dark Canyon	Dolomite	Grand Falls Sand	AA-HPD	GCC Tijeras	Hobbs
CA-ID-2	K Barnett	Steele pit	Granite	Steele pit	F-LS	GCC Tijeras	Clovis
CA-ID-3	C&E Concrete	Tinaja	Lime stone	Tinaja	F	GCC Tijeras	Granis
CA-ID-4	Vulcan Materials	Placitas	Quartzite	Placitas	F	GCC Tijeras	Santa Fe
CA-ID-5	Jobe Materials	Avispa Quarry	Lime stone	Dyer	F-LS	GCC Samaluyuca	Vado
CA-ID-6	Duke City Redimix	South Valley	Basalt	Orona	F	Holcim	Albuquerque
CA-ID-7	BTU Block & Concrete	Watrous pit	Quartzite	Watrous pit	F	GCC Tijeras	Las Vegas

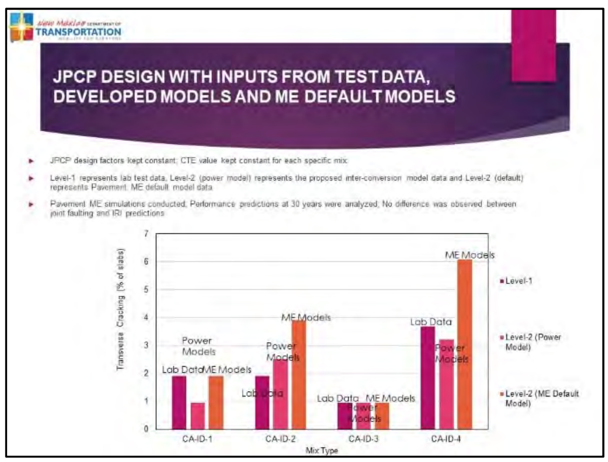


Mix Type	CA-ID-1	CA-ID-2	CA-ID-3	CA-ID-4	CA-ID-5	CA-ID-6	CA-ID-7
Coarse Aggregate Type	Dolomite	Granite	Limestone	Quartzite	Limestone	Basalt	Quartzite
Average CTE (E-6 in/in/°F)	5.25	5.39	3.71	5.09	4.09	4.37	5.95



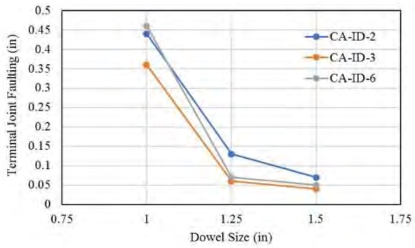






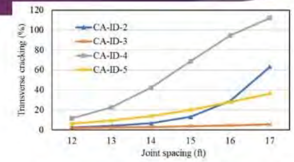
EFFECTS OF DOWEL SIZE ON JPCP DESIGN AND PERFORMANCE

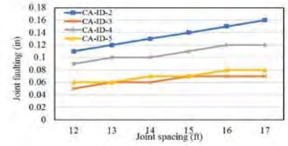
- JPCP design factors kept constant
- Lab test material inputs were used for CTE, elastic modulus and MOR
- Dowel size was varied from 1 to 1.5 inch
- Pavement ME simulations conducted
- Performance predictions at 30 years were analyzed
- Significant variation for joint faulting predictions
- No difference was observed for transverse cracking

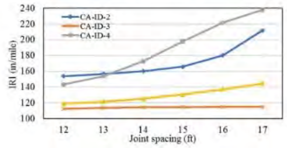


EFFECTS OF JOINT SPACING ON JPCP PERFORMANCE

- JPCP design factors kept constant
- Lab test material inputs were used for CTE, elastic modulus and MOR
- Joint spacing was varied from 12 to 17 feet
- Pavement ME simulations conducted
- Performance predictions at 30 years were analyzed







EFFECTS OF CTE ON % Steel Reinforcement NM 136

- Sensitivity Study for CRCP Project NM 136
  - Crack Spacings of ~36 Inches and ¾" Diameter Steel
- CRCP Pavement Thickness of ***9.5*** Inches
  - Level 1 CTE 4.1 in/in/F*10-6 = 0.7% Steel
  - Level 3 CTE 5.8 in/in/F*10-6 = 0.78% Steel
  - 12% Reduction in Steel
- CRCP Pavement Thickness of ***10*** Inches
  - Level 1 CTE 4.1 in/in/F*10-6 = 0.64 % Steel
  - Level 3 CTE 5.8 in/in/F*10-6 = 0.69 % Steel
- Final Design of 9.5" CRCP at 0.7% Steel

On Pavement ME's Materials Inputs/Models/Database

Jeff Mann, P.E.
Pavement Management and Design Bureau Chief
New Mexico Department of Transportation

Rafi Tarefder, P.E.
Professor, Civil Engineering Department
University of New Mexico

Presentation 13—Ryan Barrett, Kansas DOT

KDOT Pavement ME Comparisons with AASHTO ’93 Designs

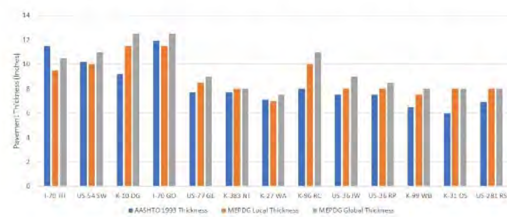
Third Annual Pavement ME Users Group Meeting
Nashville, TN
November 8, 2018

Outline

- Full-Depth Pavement Design Thickness Comparisons (AASHTO ’93 versus Pavement ME)
- Performance Criteria (Before and After)
- Impacts of Performance Criteria Tweaks
- Further Evaluation While Moving Toward Full Implementation
- Agency Perspective – Concerns and Possible Solutions

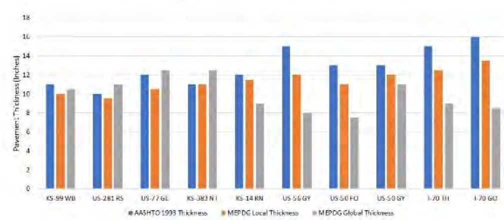
Rigid Pavement Highway Segment Locations

Rigid Pavement Thickness Results



Flexible Pavement Highway Segment Locations

Flexible Pavement Thickness Results



Initial Performance Criteria

Rigid Pavement

Type of Distress	Threshold Value at End of Design Life
Initial IRI (inches/mile)	83
Terminal IRI (inches/mile)	164
Transverse Cracking (% slabs cracked)	5
Mean Joint Faulting (inches)	0.375
Punchouts	—

Flexible Pavement

Type of Distress	Threshold Value at End of Design Life
Initial IRI (inches/mile)	60
Terminal IRI (inches/mile)	119
Top-Down Longitudinal Cracking (feet/mile)	500
Bottom-Up Alligator Cracking (% lane area)	4
Thermal Cracking (feet/mile)	100
Chemically Stabilized Layer Fatigue Fracture (%)	10
Total Permanent Deformation (inches)	0.50
Permanent Deformation (Asphalt Only) (inches)	0.50

Updated Performance Criteria – Rigid Pavement

Rigid Pavement (JPCP)			
Distress Criteria	Performance Criteria - End of Design Life	Reliability New Pavement Design	Reliability Overlay Design
Terminal IRI (in./mile)	Interstate (A): 160	85%	85%
	Principal Arterial (B): 180	75%	75%
	Principal/Minor Arterial (C): 190	75%	75%
	Minor Arterial (D): 200	65%	65%
	Major/Minor Collector & Local (E): 200	60%	60%
Transverse Slab Cracking (%)	Interstate (A): 10	95%	95%
	Principal Arterial (B): 10	85%	85%
	Principal/Minor Arterial (C): 10	85%	85%
	Minor Arterial (D): 10	75%	75%
	Major/Minor Collector & Local (E): 10	70%	70%
Mean Joint Faulting (in.)	Interstate (A): 0.12	95%	95%
	Principal Arterial (B): 0.15	85%	85%
	Principal/Minor Arterial (C): 0.20	85%	85%
	Minor Arterial (D): 0.25	75%	75%
	Major/Minor Collector & Local (E): 0.25	70%	70%

Updated Performance Criteria–Flexible Pavement

Full Depth New Flexible Pavement		
Distress Criteria	Performance Criteria End Design Life	Reliability New Pavement Design
Terminal IRI (in./mile)	Interstate (A): 150	85%
	Principal Arterial (B): 180	75%
	Principal/Minor Arterial (C): 190	75%
	Minor Arterial (D): 200	65%
	Major/Minor Collector & Local (E): 200	60%
AC Top-Down Fatigue Cracking (ft./mile)	Interstate (A): 1500	95%
	Principal Arterial (B): 2000	85%
	Principal/Minor Arterial (C): 2000	85%
	Minor Arterial (D): 2500	75%
	Major/Minor Collector & Local (E): 2500	70%
AC Bottom-Up Fatigue Cracking (% Lane Area)	Interstate (A): 10	95%
	Principal Arterial (B): 20	85%
	Principal/Minor Arterial (C): 25	85%
	Minor Arterial (D): 30	75%
	Major/Minor Collector & Local (E): 30	70%
AC Thermal Cracking (ft./mile/lane)	Interstate (A): 750	85%
	Principal Arterial (B): 750	75%
	Principal/Minor Arterial (C): 750	75%
	Minor Arterial (D): 750	65%
	Major/Minor Collector & Local (E): 750	60%

Permanent Deformation (Rutting) AC Pavement Only (in.)	Interstate (A): 0.35	95%
	Principal Arterial (B): 0.45	85%
	Principal/Minor Arterial (C): 0.50	85%
	Minor Arterial (D): 0.55	75%
	Major/Minor Collector & Local (E): 0.60	70%
Permanent Deformation (Rutting) Total Pavement Structure (includes subgrade (in.)	Interstate (A): 0.45	95%
	Principal Arterial (B): 0.55	85%
	Principal/Minor Arterial (C): 0.60	85%
	Minor Arterial (D): 0.65	75%
	Major/Minor Collector & Local (E): 0.70	70%
Fatigue Fracture (For Semi Rigid Base Layer) (Percent Lane Area)	Interstate (A): 10	95%
	Principal Arterial (B): 25	85%
	Principal/Minor Arterial (C): 25	85%
	Minor Arterial (D): 25	75%
	Major/Minor Collector & Local (E): 25	70%
AC Total Fatigue Cracking Bottom Up + Reflective (For Semi-Rigid Base Layer) (Percent Lane Area)	Interstate (A): 10	95%
	Principal Arterial (B): 25	85%
	Principal/Minor Arterial (C): 25	85%
	Minor Arterial (D): 25	75%
	Major/Minor Collector & Local (E): 25	70%
AC Total Transverse Cracking Thermal + Reflective (For Semi Rigid Base Layer) (feet/mile)	Interstate (A): 2500	85%
	Principal Arterial (B): 2500	75%
	Principal/Minor Arterial (C): 2500	75%
	Minor Arterial (D): 2500	65%
	Major/Minor Collector & Local (E): 2500	60%

Impacts of Design Criteria Changes

- To be investigated as part of the current local calibration efforts on the following research projects:
  - Pooled Fund TPF 5 (311)
  - K-TRAN KSU-18-2
- No data yet

Future Local Calibration Effort – Rigid Pavement

- Refinement of the initial local calibration effort is under way
- More accurate data needed for concrete, subbase, and soil properties to improve accuracy of local calibration.
  - Resilient modulus values for CTB, FDR, and aggregate bases
  - Resilient modulus values for treated and compacted subgrade
  - Identify city and county JPCP segments where transverse slab cracking is occurring to study historical performance and compare with predicted values to improve local calibration

Future Local Calibration Effort – Flexible Pavement

- Refinement of the initial local calibration effort is under way
- Better characterization of typical hot mix asphalt mixtures (virgin & with RAP/RAS)
  - Dynamic Modulus Testing
  - Fracture Testing
- Investigate low-temperature cracking behavior
  - Creep Compliance Testing
  - Indirect Tensile Strength Testing
- Derive K_1, K_2, and K_3 for Rutting model
  - Repeated Load Deformation Testing

Long-Term KDOT Concerns & Possible Solutions

- Time, effort, and resources (both human and monetary) to refine local calibration of the Pavement ME software each time the software is updated will be difficult to estimate and budget for in future years
  - Possible Solution: Python Software
- Difficult to model climate and soil conditions over time and negative effects they may have on a pavement structure
- How often will the Pavement ME local calibrations need to be revisited?
  - 5-Year cycle
- Will the benefits of adopting the Pavement ME software outweigh costs of updating load spectra, climate data, and other updates to the software over time?
  - To date, lots of time, resources, and effort has been put forth with no implementation to date

QUESTIONS??

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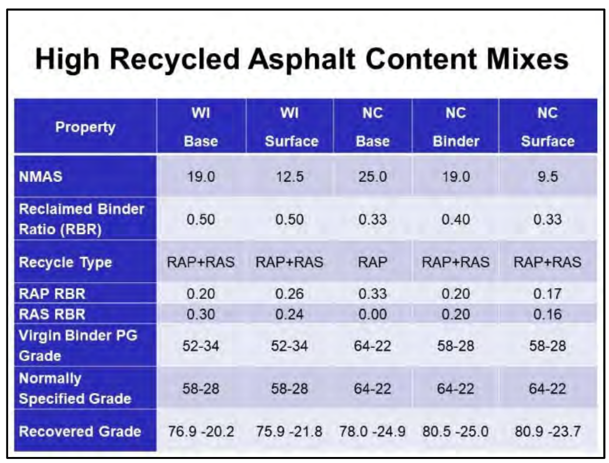
Presentation 14—Ramon Bonaquist, Advanced Asphalt Technologies



Property	WI Base	WI Surface	NC Base	NC Binder	NC Surface
NMAS	19.0	12.5	25.0	19.0	9.5
Reclaimed Binder Ratio (RBR)	0.50	0.50	0.33	0.40	0.33
Recycle Type	RAP+RAS	RAP+RAS	RAP	RAP+RAS	RAP+RAS
RAP RBR	0.20	0.26	0.33	0.20	0.17
RAS RBR	0.30	0.24	0.00	0.20	0.16
Virgin Binder PG Grade	52-34	52-34	64-22	58-28	58-28
Normally Specified Grade	58-28	58-28	64-22	64-22	64-22
Recovered Grade	76.9 -20.2	75.9 -21.8	78.0 -24.9	80.5 -25.0	80.9 -23.7

Ground Tire Rubber & Polymer Mixes

Property	MA ARGG	FL Dense Surface	PA Dense Surface	PA Dense Surface
NMAS	12.5	9.5	9.5	9.5
RAP RBR	0.10	0.24	0.00	0.00
GTR Content	≥ 15 %	≥ 7 % + polymer	rubber + polymer	None
M 320 Grade	85.2-33.2	78.6-27.5	78.7-26.1	78.3-27.8
Normally Specified Grade	58 -28	67 -22	64 -22	64 -22

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Performance Testing for M-E Design

- Only Minor Differences for R^2AMs
  - Specimen Preparation
    - RAP and RAS Handling
    - GTR Handling
    - Sawing and Coring of GTR and High Binder Content Mixtures
  - Dynamic Modulus Testing
    - High Testing Temperature Selection for Master Curve Construction Using AASHTO R 84
      - RAP Increases High Temperature Grade 6 ºC / 0.15 RBR
      - RAS Increases High Temperature Grade 6 ºC / 0.07 RBR
      - Use 45 ºC ASTM D 6114
      - Follow AASHTO R 84 High Temperature Rules for Performance Graded GTR Binders.

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Practitioners Guide for Performance Testing of Asphalt Mixtures to Support Mechanistic Empirical Pavement Design

Chapter 1	Introduction
Chapter 2	Dynamic Modulus - AASHTO R 84
Chapter 3	Repeated Load Permanent Deformation - Modified AASHTO T 378
Chapter 4	Low Temperature Creep Compliance and Strength - AASHTO T 322
Chapter 5	Flexural Fatigue - AASHTO T 321
Chapter 6	Summary of Special Considerations for R^2AMs

Contents of Chapters 2 - 5

- Background
  - Use in M-E Design
  - Applicable Standards
- Equipment
  - Specimen Fabrication
  - Testing
- Procedures
  - Specimen Fabrication
  - Testing
- Data Analysis
  - Data Quality
  - Material Properties
- Example
  - Project Data
- Summary of Recommended Testing and Analysis Practices
- Typical Properties for R^2AMs
  - Project Data

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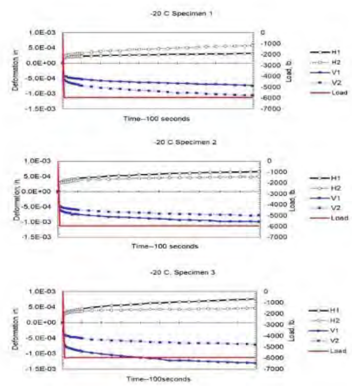
Compaction Equipment for Flexural Fatigue Testing

a. Linear Kneading Compactor. b. Vibratory Compactor c. Segmented Roller Compactor. d. Shear Box Compactor.

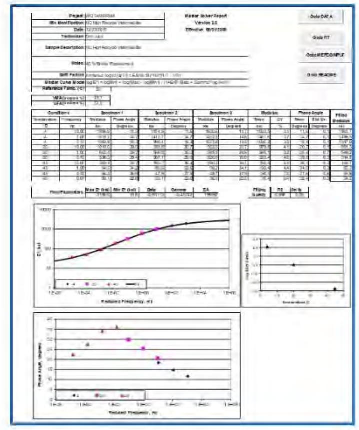
Dynamic Modulus Instrumentation

a. AASHTO T 342 b. AASHTO T 378

Data Traces from Low Temperature Creep Test



Master Solver Screen Showing Good Quality Master Curve Data



Status

- Guides are Completed
- Review Completed for Testing Guide and Revisions in Progress
- Review In Progress for Mechanistic-Empirical (ME) Design of Pavements With R^2AMs
- Anticipate 1st Quarter 2019 Publication

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Questions / Comments

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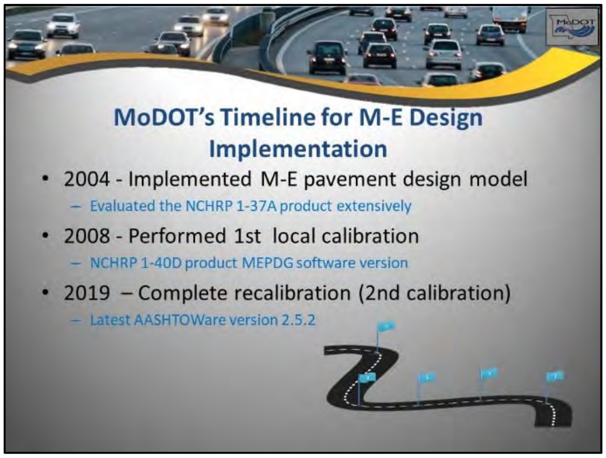
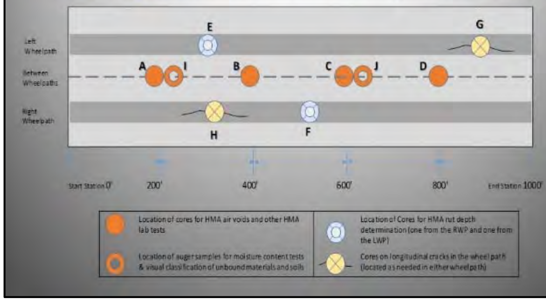
Presentation 15—Jason Blomberg, Missouri DOT



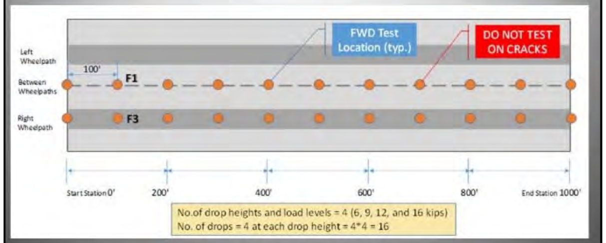
ME Design Calibration – Lab/Field Testing



ME Design Calibration – Lab/Field Testing

	Test Method		Full depth sections Field Cores			HMA overlay on existing HMA Field Cores			HMA overlay on PCC Field Cores		
	Description	AASHTO Protocol	A-D (midlane)	E-F (wheelpath)	G-H (distress)	A-D (midlane)	E-F (wheelpath)	G-H (distress)	A-D (midlane)	E-F (wheelpath)	G-H (distress)
1	Visual Examination of Distress and Photographs		X	X	X	X	X	X	X	X	X
2	Core Thickness		X	X		X	X		X	X	
3	Bulk Specific Gravity	T166	X	X		X	X		X	X	
4	Asphalt Binder Content by Extraction	T319	D, E, F, G, H A,B,C (Lower Layers only)			D, E, F, G, H A,B,C (Lower Layers only)			D, E, F, G, H A,B,C (Lower Layers only)		
5	Effective PG of Asphalt Binder (High Temperature Grade only) using Dynamic Shear Rheometer (Binder G* and Phase Angle)	T 315									
6	HMA Creep Compliance & IDT Strength	T 323	A, B, C (Surface Layers only)			A, B, C (Surface Layers only)			A, B, C (Surface Layers only)		

ME Design Calibration – FWD Testing

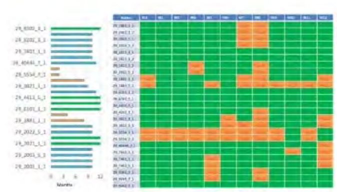


Collecting Loose Mix Samples for Materials Database

- 16 asphalt mixtures were collected on new projects
  - 2 Stone Mastic (SMA) Mixtures
  - 7 SuperPave Surface Mixtures
  - 2 Plant Mix for Low Volume Routes
  - 5 SuperPave Base Mixtures

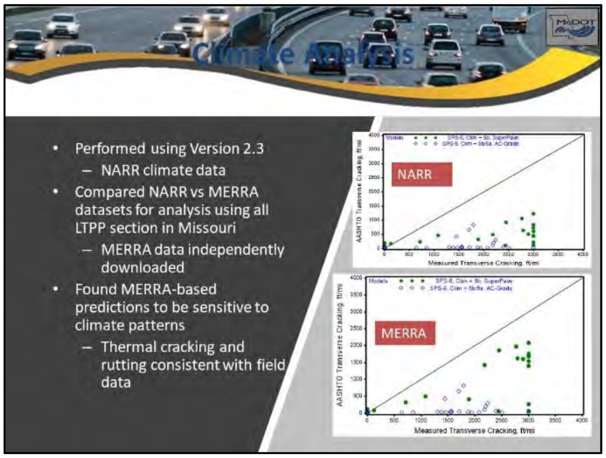
Testing Loose Mix Samples (MoDOT Testing)

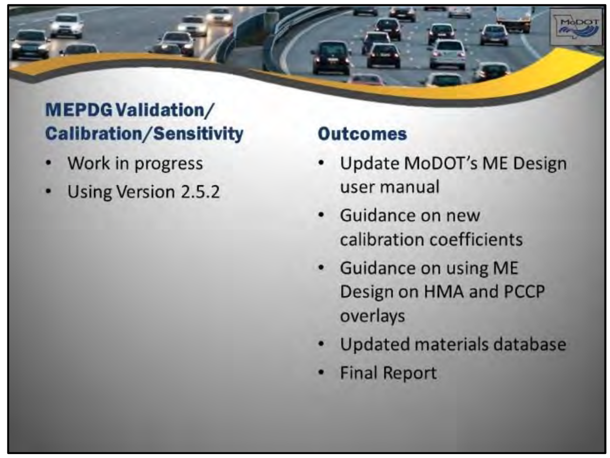
Sequence	Test Method		Notes
	Description	AASHTO Protocol	
1	HMA Dynamic Modulus	T 342	For materials library
2	Asphalt Binder G* and Phase Angle	T 315	For materials library
3	Asphalt Binder MSCR Jnr	T 350	Supplemental information for calibration
4	Hamburg Wheel Tracking Test	T 324	Supplemental information for calibration
5	Repeated Load (Triaxial) Permanent Deformation Test		Supplemental information for calibration. Rao Research to provide test protocols
6	HMA Creep Compliance & IDT Strength	T 322	Surface mixtures only. For materials library.



Traffic Data Analysis

- 20 WIM sites
- Reused ATLAS for the current effort (as in 2007)
- Verified data adequacy
- Observed discrepancies in data trends (e.g. axles/truck vs truck classification)
- Verified and corrected using the first principles
  - Vehicle class distribution
  - Axles/truck
  - Monthly adjustment Factors
  - Axle load distribution


Climate Analysis
• Performed using Version 2.3
– NARR climate data
• Compared NARR vs MERRA datasets for analysis using all LTPP section in Missouri
– MERRA data independently downloaded
• Found MERRA-based predictions to be sensitive to climate patterns
– Thermal cracking and rutting consistent with field data
NARR
MERRA
Measured Transverse Cracking, ft/mi
AASHTO Transverse Cracking, ft/mi


MEPDG Validation/ Calibration/Sensitivity
• Work in progress
• Using Version 2.5.2
Outcomes
• Update MoDOT's ME Design user manual
• Guidance on new calibration coefficients
• Guidance on using ME Design on HMA and PCCP overlays
• Updated materials database
• Final Report


MoDOT's Alternate Bidding Concept:
• "Structurally Equivalent", PCCP & HMA bid competitively by using LCCA correction factors.


Sometimes It's Best to Leave Sleeping Dogs Lie!


Pavement Team Regroup?

Presentation 16—Syed Haider, Michigan State University

Michigan's Local Calibration Efforts — Resampling Techniques

Syed Waqar Haider, Ph.D., P.E.

MICHIGAN STATE UNIVERSITY

AASHTO Pavement ME National Users Group Meeting
November 7 & 8, 2018, Nashville, Tennessee

Presentation Outline

- Introduction and Objectives
- Background
- Local calibration of JPCP performance models
- Impact of calibrated models on pavement designs
- Summary

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Introduction — *Why locally calibrate the performance models*

- The performance prediction models in the Pavement-ME design software are nationally calibrated using in-service pavement material properties, pavement structure, climate and truck loadings, and performance data obtained from the Long-Term Pavement Performance (LTPP) program.
- Local calibration of the models may be necessary because the global models may not represent local State Highway Agency (SHA) design practices and conditions.
- The local calibration is performed to:
  - Confirm that the prediction models can predict pavement distress and smoothness without bias.
  - Determine the standard error associated with the prediction equations.

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Introduction — *Local calibration process*

Step 1: Select the appropriate number of pavement sections

Step 2: Collect all measured performance and as-constructed input data
- Traffic
- Climate
- Cross-section
- Construction materials

Step 3: Execute the Pavement-ME using the local inputs and compare the measured and predicted distress using statistical tests (t-test)

Step 4: Perform local calibration by adjusting the coefficients to minimize error and bias

Step 5: Validate the model prediction capabilities by comparing the measured and predicted distress for projects not included in the dataset

Step 6: Modify the reliability equations

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Introduction — *JPCP models locally calibration Michigan*

- A study was completed in 2014 to locally calibrate the performance prediction models for the AASHTOWare Pavement-ME Design Version 2.0.
- AASHTO has released Versions 2.2, 2.3 and 2.3.1 of the software since the completion of the last study. In the newer versions, several bugs were fixed and some of the performance models were modified.
- As a result, the concrete pavement IRI predictions have been impacted.
- There was an urgent need to verify the performance predictions for rigid pavements in the State of Michigan for the Pavement-ME Versions 2.2, 2.3, and 2.3.1.

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Challenges in Local Calibration

The main objectives are to highlight:

a. Pre-calibration challenges
   - Input data for the pavement sections
   - Extent of performance
   - Model calibration approaches

b. Post-calibration challenges
   - Efficiency and robustness of calibrated models
   - Impact of models on designs

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Background — *Mechanistic-empirical performance models*

- The Pavement-ME Design Guide calculates responses from mechanistic models and uses empirical transfer functions to predict the pavement performance.
- Pavement structural responses (stress, strain or deflection) for a given cross-section are calculated based on axle loads, climate and material properties by using mechanistic models.
- These structural responses are used to predict pavement performance through empirical models (i.e., transfer functions).
- The performance measures predicted for JPCP are:
  - Transverse Cracking
  - IRI
  - Faulting

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Background — *Transverse cracking model*

- Transverse cracking in JPCP is a load-related distress cause by repeated axle loads.
- It can initiate either at the top or bottom of the concrete slab because of curling and warping. The percentage slabs cracked (including all severity levels) in a given traffic lane is predicted by:

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

DI_F is the fatigue damage accumulations considering all critical factors (i.e., age, month, axle type, load level, temperature gradient, axle wander, and hourly traffic). C_4 and C_5 are the calibration coefficients.

- The total cracking is computed using the following equation

$$TCRACK = (CRK_{Bottom\text{-}up} + CRK_{top\text{-}down} - CRK_{Bottom\text{-}up} \times CRK_{top\text{-}down}) \times 100\%$$

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Background — *Surface roughness (IRI) model*

- The predicted IRI in the Pavement-ME is a function of the as-constructed initial smoothness of pavement surface and any change in the longitudinal profile over time due to distresses and foundation movements.

$$IRI = IRI_o + C1 \times CRK + C2 \times SPALL + C3 \times TFAULT + C4 \times SF$$

IRI = Predicted IRI, in/mile
IRI_0 = Initial smoothness measured as IRI, in/mile
CRK = Percent slabs with transverse cracks (all severities)
$SPALL$ = Percentage of joints with spalling (medium and high severities)
$TFAULT$ = Total joint faulting cumulated per mile, inch
SF = Site factor

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Background — *Rigid performance model coefficients*

Local calibration coefficients for the rigid transverse cracking and IRI models

Calibration coefficient	Transverse cracking		IRI			
	C4	C5	C1 (Cracking)	C2 (Spalling)	C3 (Faulting)	C4 (Site factors)
New national coefficients(1)	0.52	-2.17	0.820	0.442	1.493	25.24
Old national coefficients(2)	1	-1.98	0.820	0.442	1.493	25.24
Arizona	0.6	-2.067	0.60	3.48	1.22	45.20
Colorado	1	-1.98	0.82	0.44	1.49	25.24
Iowa(3)	1.08	-1.81	0.04	0.02	0.07	1.17
Louisiana	1.16	-1.73	0.82	0.44	1.49	25.24
Minnesota	0.9	-2.64	-	-	-	-
Missouri	1	-1.98	0.82	1.17	1.43	66.80
Ohio	1	-1.98	0.82	3.70	1.71	5.70
Washington	1	-1.98	0.820	0.442	1.493	25.24

*Note: (1) from Version 2.2 onwards, (2) before Version 2.2, (3) The coefficients for Iowa predict IRI in SI units.

Not much variation among states — Some variation — Some variation — Large variation

Overall SF seems to have more impact on IRI; however, one should be careful in making such conclusions since all the variables have different units.

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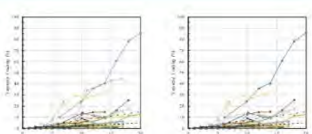
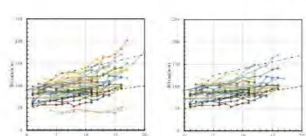
Performance Data

MDOT PMS database was used to extract performance data for 28 JPCP (new and unbonded overlay) sections.



(a) All pavement sections (b) Pavement sections for re-calibration

Measured transverse cracking performance



(a) All pavement sections (b) Pavement sections for re-calibration

Measured IRI

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Model Calibration Approaches

- The performance prediction models were locally re-calibrated by minimizing the sum of squared error between the measured and predicted distresses by using the following statistical techniques:
  a. No sampling (include all data)
  b. Bootstrapping
  c. Repeated split sampling
- The use of these techniques is considered because of data limitations, especially due to limited sample size for rigid pavements, and to utilize a more robust way of quantifying model standard error and bias.

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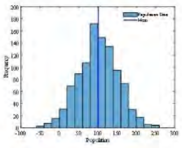
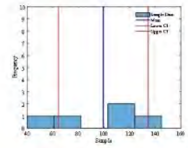
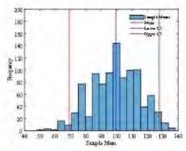
Bootstrapping — *Example (small sample size, high variability)*







Sample size =	5		CoV =	51%	
Type	Mean	Std.	SE	LCI	UCI
Population	101.0	51.5			
Sample	99.4	40.0	17.9	64.4	134.5
Bootstrapping	99.4	34.7	15.5	69.1	127.6

For a small sample size with high variability, bootstrap estimates lower std. error of the mean and narrower 95% CI.

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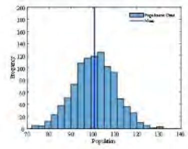
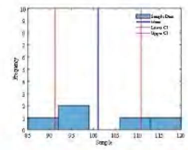
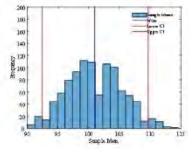
Bootstrapping — *Example (small sample size, low variability)*







Sample size =	5		CoV =	9%	
Type	Mean	Std.	SE	LCI	UCI
Population	100.7	9.5			
Sample	101.1	11.2	5.0	91.2	110.9
Bootstrapping	101.0	9.7	4.4	92.4	109.7

Even for a small sample size with low variability, although the differences are not substantial, bootstrap estimates lower std. error of the mean and narrower 95% CI.

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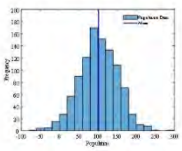
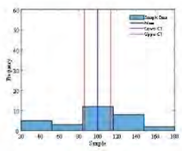
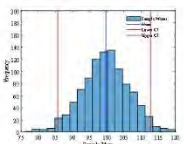
Bootstrapping — *Example (large sample size, high variability)*







Sample size =	30		CoV =	49%	
Type	Mean	Std.	SE	LCI	UCI
Population	101.7	49.9			
Sample	99.5	38.3	7.0	85.8	113.2
Bootstrapping	99.7	37.6	7.0	85.7	112.8

For a large sample size with high variability, bootstrap estimates similar std. error of the mean and narrower 95% CI. Note that differences are minimal because of larger sample size.

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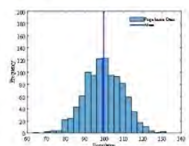
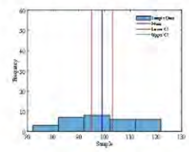
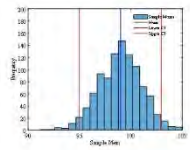
Bootstrapping — *Example (large sample size, low variability)*







Sample size =	30		CoV =	10%	
Type	Mean	Std	SE	LCI	UCI
Population	99.7	9.9			
Sample	99.0	11.4	2.1	94.9	103.1
Bootstrapping	99.0	11.1	2.1	95.0	102.9

For a large sample size with low variability, bootstrap still estimates similar std. error of the mean and slightly narrower 95% CI. This is because of larger sample size and low variability.

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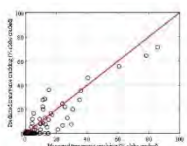
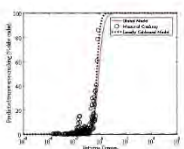
No Sampling — *Transverse cracking*



(a) Measured vs. predicted cracking



(b) Fatigue damage predicted cracking

Local calibration results for transverse cracking using entire dataset

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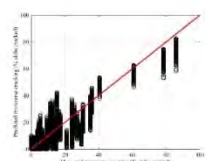
Bootstrapping — *Transverse cracking*



Bootstrap sampling measured versus predicted results (1000 bootstraps)

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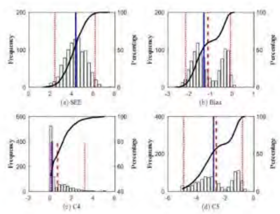
Bootstrapping — *Transverse cracking*



Bootstrap sampling calibration results (1000 bootstraps)

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Summary — *Transverse cracking*

Local calibration summary for transverse cracking

Sampling technique	Parameter	SEE	Bias	C4	C5
No sampling	Global model	6.07	-2.23	0.52	-2.17
	Local model	4.93	-1.61	0.13	-3.18
Bootstrapping	Global model mean	5.90	-2.26	0.52	-2.17
	Global model median	5.83	-2.21	0.52	-2.17
	Local model mean	4.33	-1.14	0.66	-2.63
	Local model median	**4.35**	**-1.33**	**0.16**	**-2.82**
Repeated Split Sampling	Global model mean	5.97	-2.22	0.52	-2.17
	Global model median	5.97	-2.22	0.52	-2.17
	Local model mean	4.52	-1.27	0.54	-2.81
	Local model median	4.54	-1.53	0.12	-3.20
	Local model mean - validation	7.12	-2.04	0.54	-2.81
	Local model median - validation	6.34	-1.98	0.12	-3.20

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Bootstrapping Justification

- It gives a better approximation on how the point estimate might vary.
- It is based on law of large numbers which implies that the empirical distribution based on enough data will be a good approximation of the true distribution.
- It may not improve the point estimate (mean, median etc.) but will be more robust in estimating the variance of the point estimate. It implies that CI for a point estimate will be more robust and independent of the distribution type.

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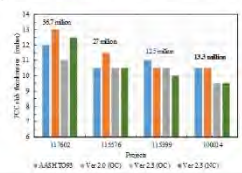
Assessment — *Impact of calibration on pavement designs*

- The initial trial design thicknesses are based on AASHTO 93.
- For the same design, different Pavement-ME versions were used to analyze the thickness for which the predicted pavement performance is 15% slabs cracked or 172 inches/mile for transverse cracking and IRI, respectively at 20 years.
- Another criteria used by MDOT is to limit the designed slab thickness by the Pavement-ME within ±1 inch of AASHTO 93 design thickness.



OC = Previous local calibration
NC = New re-calibration

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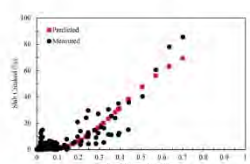
Assessment — *Impact of calibration on pavement designs*

- The critical distress for all the designs was IRI and no predicted cracking was observed.
- However, noticeable cracking was observed in a few pavement sections used in re-calibration.
- The main reason for zero cracking prediction is very low fatigue damage predictions at the end of design life (20 years).



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Assessment — *Impact of calibration on pavement designs*

- A few pavement sections used in the re-calibration exhibited high levels of cracking; however, the predicted cracking for those sections using the as-built design inputs showed negligible cracking.
- As a result, the input permanent curl/warp effective temperature difference was changed from -10ºF which is the recommended default to a lower value for a section.
- The values of permanent curl/warp were selected such that the predicted cracking is close to measured cracking.

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Assessment — *Impact of calibration on pavement designs*

- However, when designing a new pavement project, the default value of -10ºF is used since it is difficult to anticipate the as-constructed permanent curl/warp for future projects.
- A model was developed to predict the built in curl/warp for future projects.
- Changing the permanent curl/warp value to match the measured cracking implies that the predicted cracking also includes non-structural cracking (i.e., material and construction related), if any.

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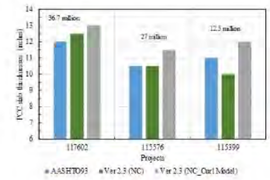
Assessment — *Impact of calibration on pavement designs*

Project name	Location	Design thickness	Curl value	Failure criteria
63191 & 63192_117602	Detroit	13.0	-30	Cracking
63191 & 63192_117602 ramp	Detroit	9.0	-23	IRI
63174_115576	Pontiac	11.5	-30	IRI
63174_115576 ramp	Pontiac	9.5	-28	IRI
47013 & 81075_115399	Ann Arbor	12.0	-26	IRI
47013 & 81075_115399 ramp	Ann Arbor	9.0	-20	IRI



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MDOT Designs — *Impact of calibration on pavement designs*

Source: MDOT

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Summary

- The initial local calibration of JPCP models showed no predicted cracking mainly because the inputs used for design are different from those used in model calibration.
- All the previous ME designs showed no or very limited predicted cracking (i.e., negligible damage) and were controlled by IRI performance.
- The permanent curl values were varied to match the measured performance for each pavement section in the calibration dataset.
- Climate data, material properties, and design parameters were used to develop a model for predicting permanent curl for each location. This model can be used at the design stage to estimate permanent curl for a given location in Michigan.
- The SEE and bias for the global models for cracking and IRI models are much higher as compared to the locally calibrated models using all the selected pavement sections.

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Thank You

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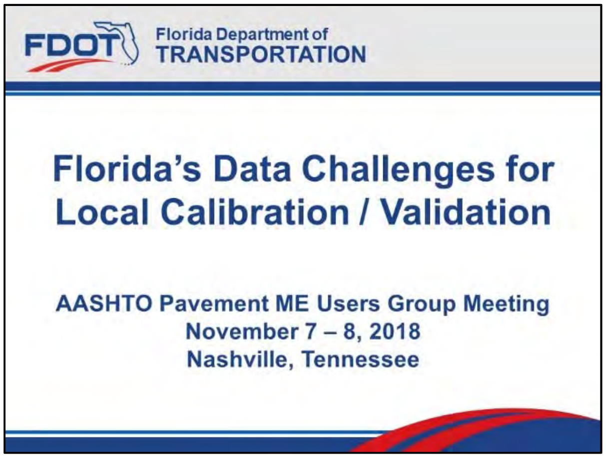
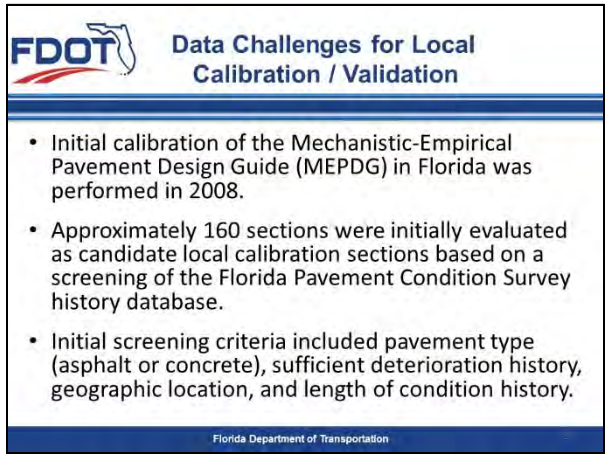
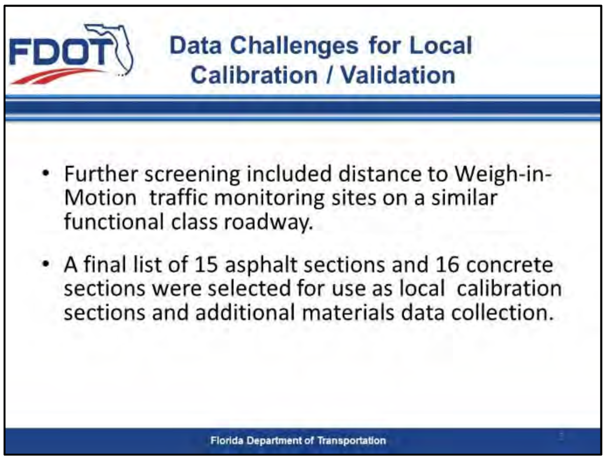
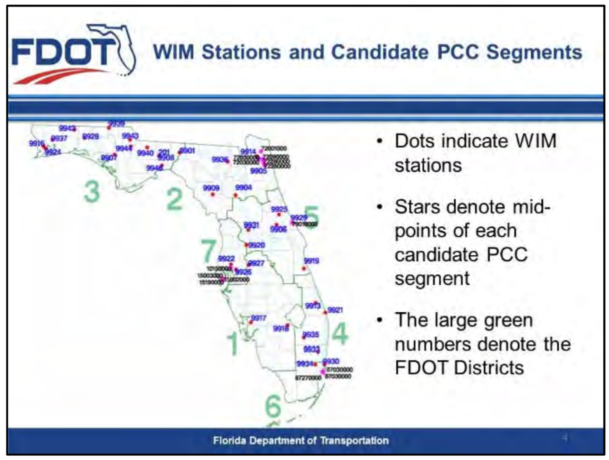
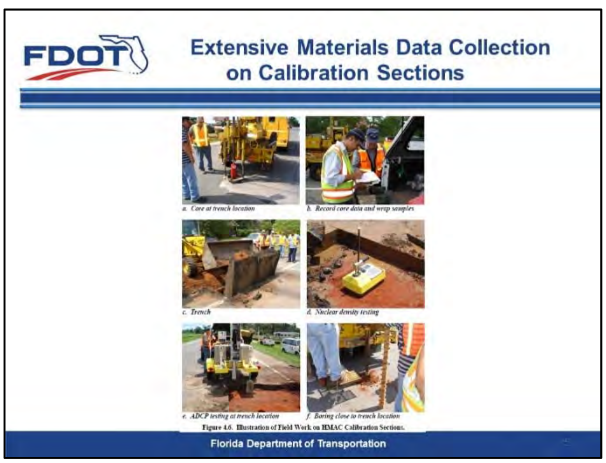
Presentation 17—Rhonda Taylor, Florida DOT

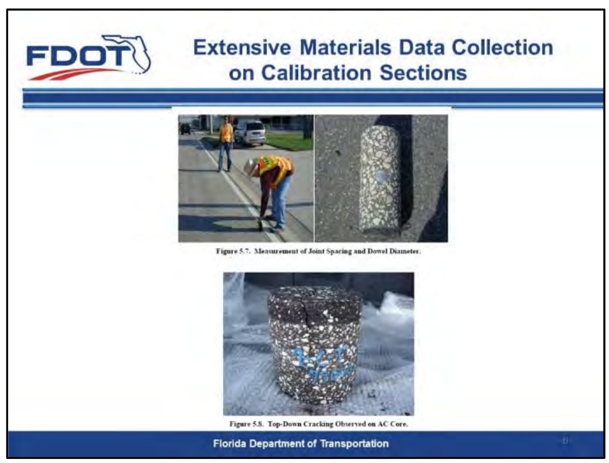












Developments During Local Calibration

- Most asphalt cracking in Florida is top down and primary reason for resurfacing.
- Decision was made to wait for top down cracking models to be added to MEPDG before design implementation for asphalt.
- National recommendation on concrete pavement bonding to base was changed from unbonded to fully bonded in the AASHTO 2008 MEPDG Manual of Practice.
- Error in the AASHTO concrete coefficient of thermal expansion (CTE) test was discovered.

Florida Department of Transportation

Additional Local Calibration Issues

- Due to the significant performance prediction changes from the base bonding condition and CTE test changes, the decision was made to perform another local calibration for concrete using the new input values.
- MEPDG cracking predictions versus measured values were highly scattered for the initial 16 Florida concrete sections.
- Due to numerous performance problems, Florida had decided to no longer use cement treated bases under concrete pavements.

Florida Department of Transportation

Additional Issues

- Decision was made to eliminate the concrete local calibration sections with cement bases due to the high performance variability and their elimination from future use.
- This significantly reduced the concrete local calibration sections in Florida, so 2 LTPP sections from Georgia and 1 from Alabama with similar designs to Florida were added.

Florida Department of Transportation

Additional Issues

- Thirteen sections were used in the recalibration that was completed in 2011.
- This recalibration adjusted all four cracking coefficients (C1,C2,C4,C5) from the national default calibration values.

Florida Department of Transportation

Additional Issues

- Another recalibration was completed in 2015 using eight concrete sections, including two LTPP sites from Alabama and Georgia.
- Only the C4 and C5 cracking coefficients were adjusted from the national values in this recalibration.

Florida Department of Transportation

Additional Issues

- Due to the small number of Florida concrete sections for use in local calibration, the FDOT has decided to construct a 2.5 mile Florida concrete test road containing 52 test sections of 15 slabs each.
- This test road is expected to be completed in 2019 and will provide extensive local calibration data to improve the design process.

Florida Department of Transportation

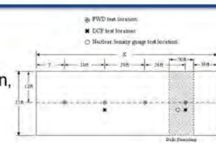
How Will We Measure Performance?

- Comprehensive material characterization (lab & field)
- WIM system and vehicle classification
- Routine pavement performance monitoring
  - Distress development, smoothness/faulting, NDT, etc.
  - Traffic diverted from roadway to allow access
- On-site weather station to characterize ambient conditions
- Embedded instrumentation to measure critical pavement responses
  - Two different data collection modes: Static and dynamic
  - Primary instrumentation: PCC Strain, Temp, and Deflection
  - Secondary instrumentation: Granular layer moisture, edge drain flow, groundwater table

FDOT Florida Department of Transportation

Test Road Experiments

- 52 total test sections over 3 primary experiments
- Design variables: joint spacing, mix design, base type, layer thickness, drainage features (joint sealant, edge drains)



FDOT Florida Department of Transportation

FDOT Florida Department of TRANSPORTATION

Questions?

Rhonda Taylor, P.E.
State pavement Design Engineer
Rhonda.Taylor@dot.state.fl.us

Presentation 18—Wouter Brink, ARA

AASHTO Pavement ME National Users Group Meeting 2018
Nashville, Tennessee

The Calibrator: Status and Overview

8 November 2018

Outline

1. Background
2. Calibration Coefficients?
3. Steps within the Process
4. Demonstration
5. Summary Comments

Background

Why a Calibration Assistance Tool is needed?

- Calibration of ME-based models and transfer functions can be challenging.
- Many decisions need to be made and guidance is needed.
- Many computations can be made in the background.

Background

Enhancement work included in FY 2019: a tool to assist agencies in local calibration, as a result of:

- **Evaluating and deriving calibration coefficients** – a major topic/concern of agencies.
- **Provide guidance or direction on calibration** – high priority of the AASHTOWare Pavement ME Design Task Force.

Background

Purpose/Objectives:

1. Determine bias in prediction, if any. — Verify
2. Establish cause for bias. — Investigate
3. Derive calibration coefficients, or field adjustment factors, and optimize to: — Calibrate
   - Eliminate bias.
   - Minimize standard error or standard deviation of the residual errors.
4. Validate field adjustment factors. — Validate

Background

Deliverables – two which are interconnected through various user inputs and decisions:

1. The tool or "The Calibrator"
2. The global calibration database.

Calibration tool is integrally connected to the calibration database.

Calibration Database ⇄ Calibration Tool

Background

Schedule for development:

Background

Primary development team:

- Wouter Brink; Engineer.
- Dinesh Ayyala; Engineer.
- Yanbin Zhang, Software Engineer.

Primary Contact Information:
Phone: 217-356-4500
E-Mail: wbrink@ara.com

Outline

1. Background
2. Calibration Coefficients?
3. Steps within the Process
4. Demonstration
5. Summary Comments

Calibration Coefficients?

What coefficients are we considering or talking about?

Two sets of coefficients or factors: K-values and β-Values:

- **K-Values** – represent the properties or values derived from the laboratory tests.
- **β-Values** – represent the field-shift values to eliminate bias between the predicted and measured distress values.

Calibration Coefficients?

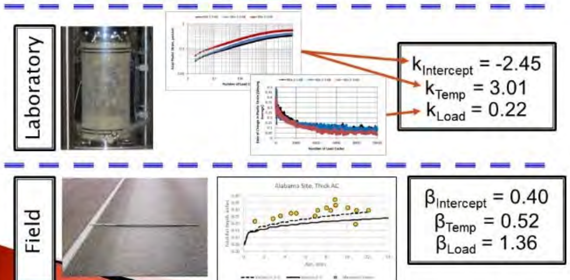
Examples:

- Rut Depth
- Transverse Cracks
- Fatigue/Alligator Cracks

Calibration Coefficients?

Rut Depth, Neat AC Mixtures:

$$\varepsilon_p = (\varepsilon_r)\beta_{Intercept}(10)^{k_{Intercept}} k_z T^{\beta_{Temp} k_{Temp}} N^{\beta_{Load} k_{Load}}$$

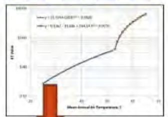


Calibration Coefficients?

Transverse Cracks

$\Delta C = (\beta_t k_t)^{n+1} A(\Delta K)^n$

Laboratory



$k_t = 3 * 10^{-7}(MAAT)^{4.0319}$

$k_t = 0.13(MAAT)^2 - 11.68(MAAT) + 244.14$

Field

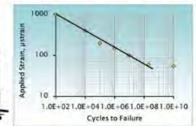
$\beta_t = 1.0$

Calibration Coefficients?

Alligator/Fatigue Cracks

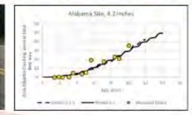
$N_f = \beta_{Intercept} k_{Intercept} C \left(\frac{1}{\varepsilon_t}\right)^{\beta_{Strain} k_{Strain}} \left(\frac{1}{E}\right)^{\beta_{Modulus} k_{Modulus}}$

Laboratory



$k_{Intercept} = 3.75$
$k_{Strain} = 2.87$
$k_{Modulus} = 1.46$

Field

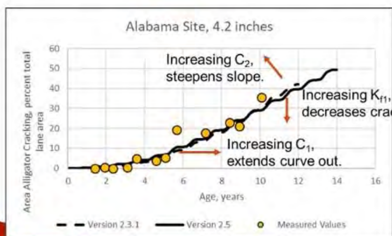


$\beta_{Intercept} = t_{AC}$ dependent
$\beta_{Strain} = 1.38$
$\beta_{Modulus} = 0.88$

Calibration Coefficients?

Alligator/Fatigue Cracks

$FC = \left(\frac{100}{1 + e^{(C_1' C_1 + C_2 C_2'[Log_{10}(DI*100)])}}\right)$



Outline

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2. Calibration Coefficients?
3. Steps within the Process
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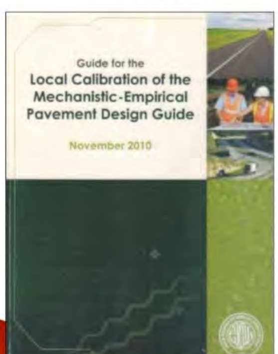
Steps within the Process

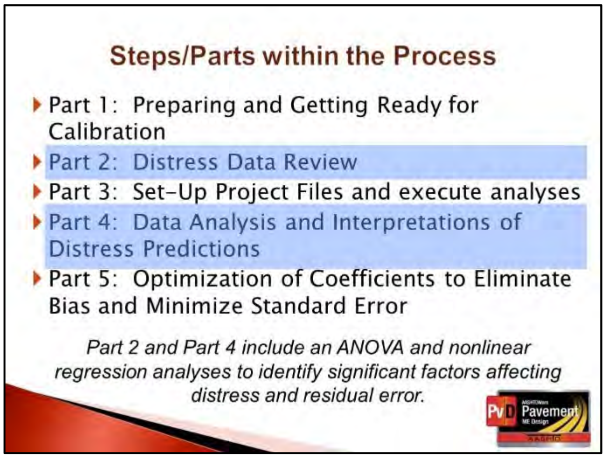


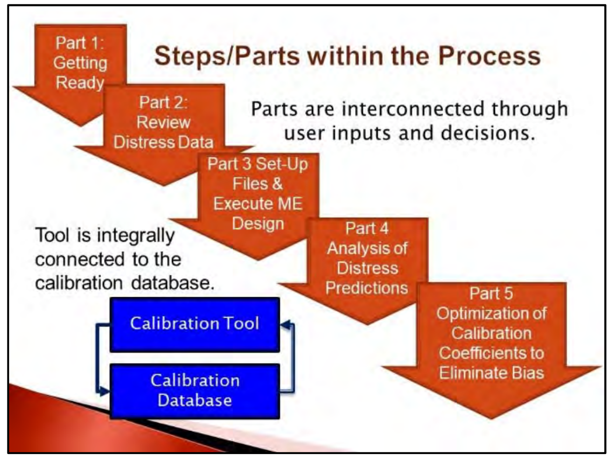
- Based on the 2010 Manual of Practice, 1st Edition.

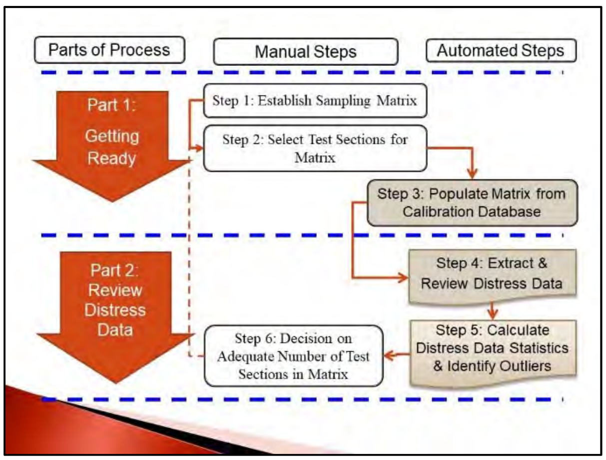
Steps within the Process

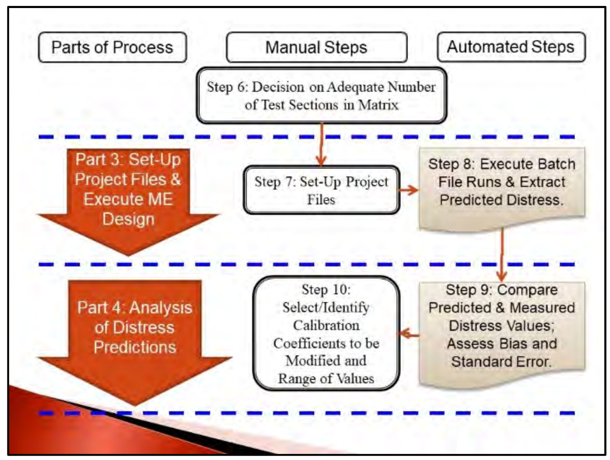
Directions for Tool Development:

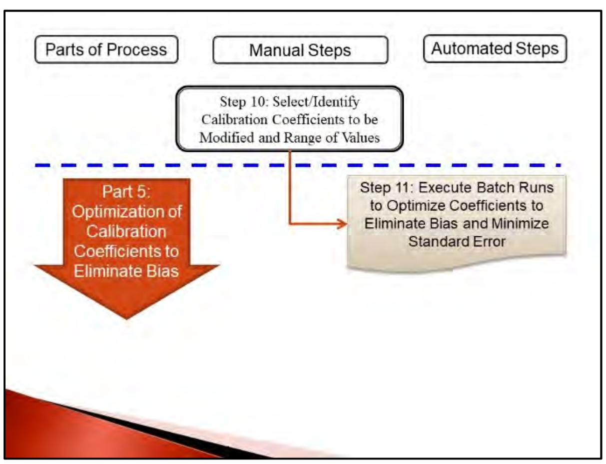
- Provide clear guidance.
- Automate mathematical operations without user interaction or data mining/manipulation.
- Provide a quick and easy way to verify local calibration coefficients after new features are added to Pavement ME.

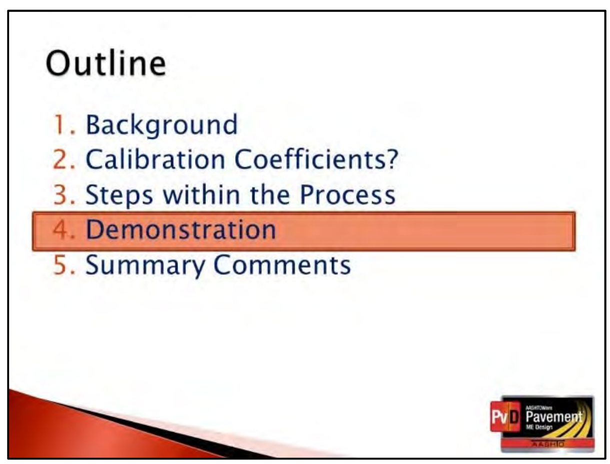

Steps/Parts within the Process
Part 1: Preparing and Getting Ready for Calibration
Part 2: Distress Data Review
Part 3: Set-Up Project Files and execute analyses
Part 4: Data Analysis and Interpretations of Distress Predictions
Part 5: Optimization of Coefficients to Eliminate Bias and Minimize Standard Error
Part 2 and Part 4 include an ANOVA and nonlinear regression analyses to identify significant factors affecting distress and residual error.


Steps/Parts within the Process
Part 1: Getting Ready
Part 2: Review Distress Data
Part 3 Set-Up Files & Execute ME Design
Part 4 Analysis of Distress Predictions
Part 5 Optimization of Calibration Coefficients to Eliminate Bias
Parts are interconnected through user inputs and decisions.
Tool is integrally connected to the calibration database.
Calibration Tool
Calibration Database


Parts of Process
Manual Steps
Automated Steps
Part 1: Getting Ready
Step 1: Establish Sampling Matrix
Step 2: Select Test Sections for Matrix
Step 3: Populate Matrix from Calibration Database
Part 2: Review Distress Data
Step 4: Extract & Review Distress Data
Step 5: Calculate Distress Data Statistics & Identify Outliers
Step 6: Decision on Adequate Number of Test Sections in Matrix


Parts of Process
Manual Steps
Automated Steps
Step 6: Decision on Adequate Number of Test Sections in Matrix
Part 3: Set-Up Project Files & Execute ME Design
Step 7: Set-Up Project Files
Step 8: Execute Batch File Runs & Extract Predicted Distress.
Part 4: Analysis of Distress Predictions
Step 10: Select/Identify Calibration Coefficients to be Modified and Range of Values
Step 9: Compare Predicted & Measured Distress Values; Assess Bias and Standard Error.


Parts of Process
Manual Steps
Automated Steps
Step 10: Select/Identify Calibration Coefficients to be Modified and Range of Values
Part 5: Optimization of Calibration Coefficients to Eliminate Bias
Step 11: Execute Batch Runs to Optimize Coefficients to Eliminate Bias and Minimize Standard Error


Outline
1. Background
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4. Demonstration
5. Summary Comments

Demonstration

Outline

1. Background
2. Calibration Coefficients?
3. Steps within the Process
4. Demonstration
5. Summary Comments

Summary

- Semi-Automated Tool; automated as many of the functions as possible.
- Agencies can use their own calibration test section data to supplement the global calibration data set.
- Comments on the Calibrator Tool are welcomed.
- Beta testers will be needed in April time frame.
  - Database, UI, and Calibration testing will be needed

Pavement ME Task Force Members

1. John Donahue, P.E.; Missouri DOT, Chairperson
2. Vicki Schofield, AASHTO Project Manager
3. Marta Juhasz, P.E.; Alberta Transportation, Vice-Chair
4. Clark Morrison, P.E., North Carolina DOT
5. Robert Shugart, P.E.; Alabama DOT
6. Karen Strauss, P.E.; Oregon DOT
7. David Holmgren, P.E.; Utah DOT
8. Patrick Bierl, P.E.; Ohio DOT
9. Felix Doucet; TAC Liaison
10. Tom Yu, P.E.; FHWA Liaison
11. Shane Marshall, P.E.; Utah DOT, SCOJD Liaison
12. Travis Tackett, Florida DOT; T&AA Liaison

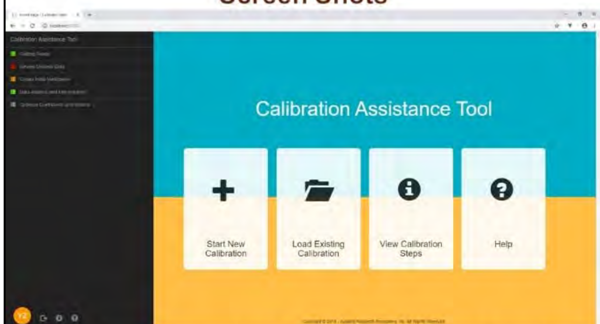
AASHTOWare: Pavement ME Design

QUESTIONS

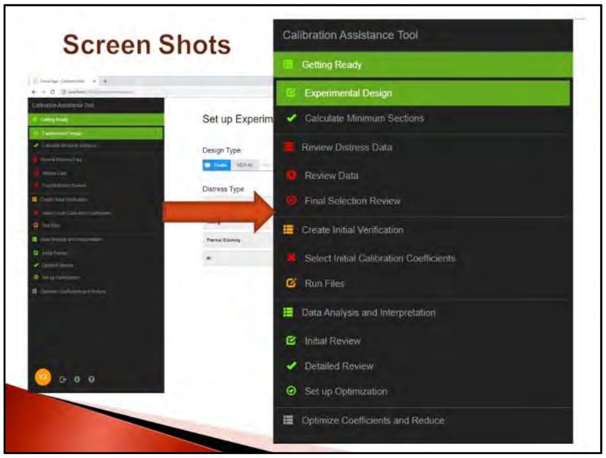
»

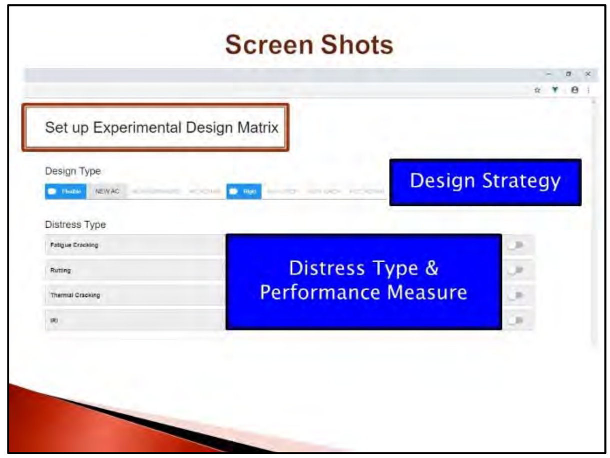
Comments & suggestions;
Send an email to
pavementmedesign@ara.com.

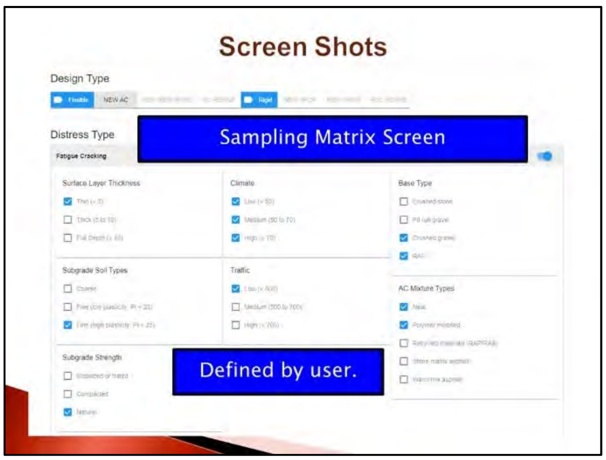
Screen Shots

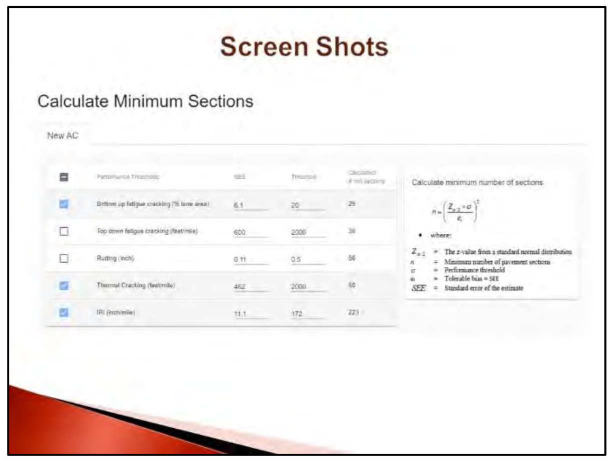


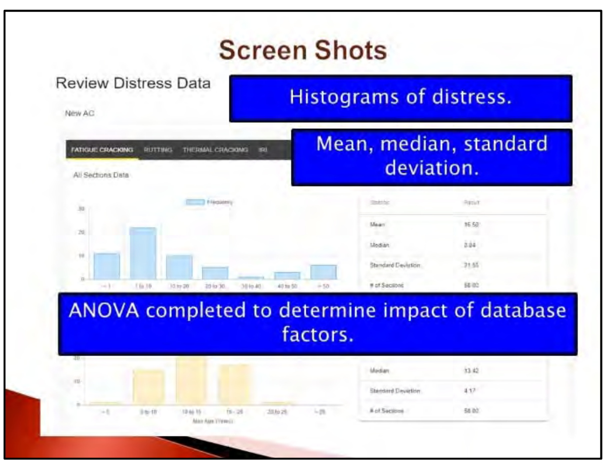
Screen shots included to provide a visual overview of the software.

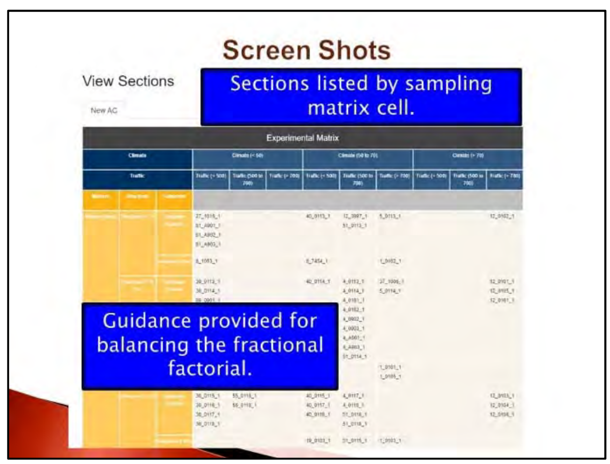

Screen Shots
Calibration Assistance Tool
Getting Ready
Experimental Design
Calculate Minimum Sections
Review Distress Data
Review Data
Final Selection Review
Create Initial Verification
Select Initial Calibration Coefficients
Run Files
Data Analysis and Interpretation
Initial Review
Detailed Review
Set up Optimization
Optimize Coefficients and Reduce
Set up Experim
Design Type
Distress Type

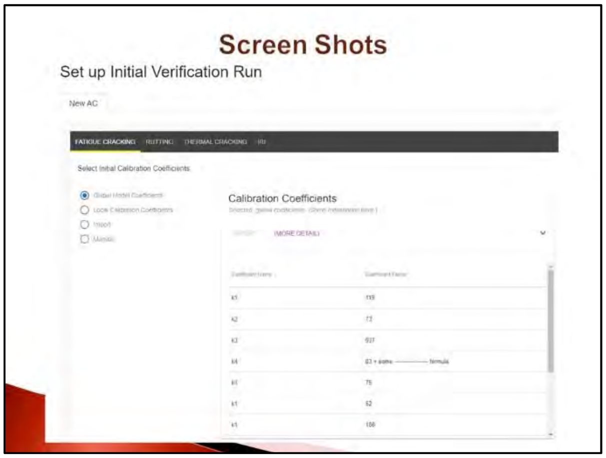

Screen Shots
Set up Experimental Design Matrix
Design Type
Design Strategy
Distress Type
Distress Type & Performance Measure

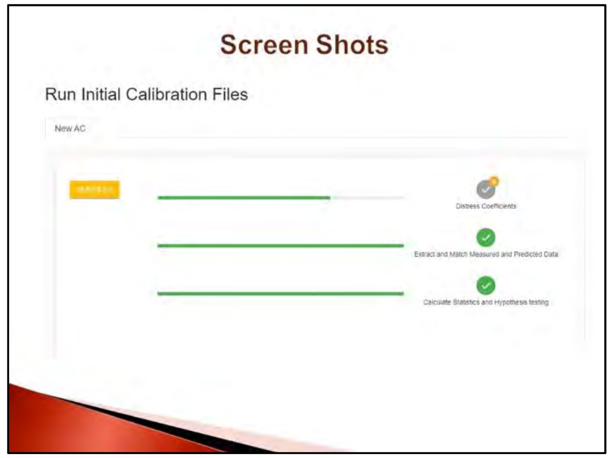

Screen Shots
Design Type
Distress Type
Sampling Matrix Screen
Surface Layer Thickness
Climate
Base Type
Subgrade Soil Types
Traffic
AC Mixture Types
Subgrade Strength
Defined by user.

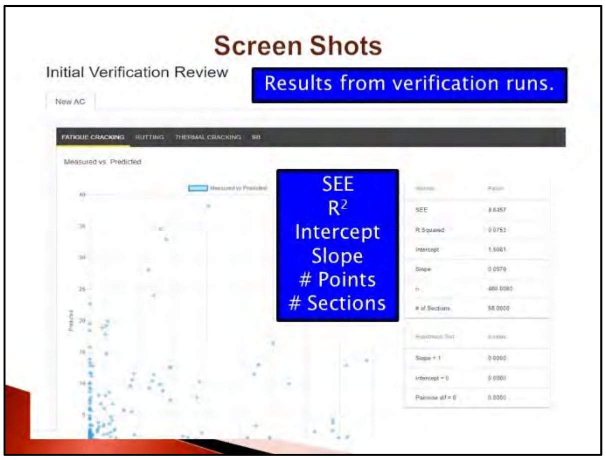

Screen Shots
Calculate Minimum Sections
New AC


Screen Shots
Review Distress Data
Histograms of distress.
Mean, median, standard deviation.
ANOVA completed to determine impact of database factors.

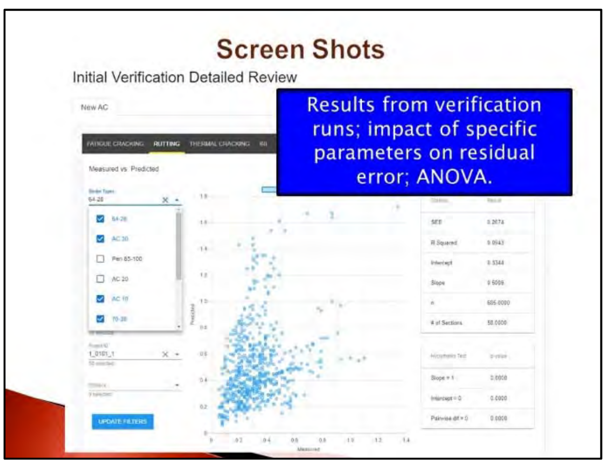

Screen Shots
View Sections
Sections listed by sampling matrix cell.
Experimental Matrix
Guidance provided for balancing the fractional factorial.


Screen Shots
Set up Initial Verification Run
Calibration Coefficients

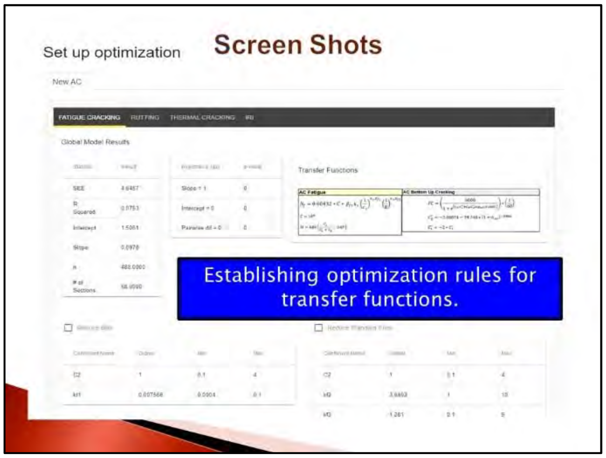

Screen Shots
Run Initial Calibration Files


Screen Shots
Initial Verification Review
Results from verification runs.
SEE
R2
Intercept
Slope
Points
Sections


Screen Shots
Initial Verification Detailed Review
Results from verification runs; impact of specific parameters.


Screen Shots
Initial Verification Detailed Review
Results from verification runs; impact of specific parameters on residual error; ANOVA.


Screen Shots
Review time series data for one or multiple test sections.


Screen Shots
Set up optimization
New AC
FATIGUE CRACKING
RUTTING
THERMAL CRACKING
IRI
Global Model Results
Transfer Functions
Establishing optimization rules for transfer functions.

Presentation 19—Harold Von Quintus, ARA

expanding the realm of POSSIBILITY

Software Training

AASHTOWare Pavement ME Design
MEPDG Users Group Meeting
Nashville, Tennessee
November 8, 2018

Harold L. Von Quintus, P.E.
Wouter Brink, Chad Becker

ARA

Outline

1. Designing Rehabilitation Strategies with Multiple AC Overlays
2. Designing Composite Pavements with Current Software
3. Using Laboratory Test Results to Characterize AC Mixtures for Design
4. Designing Flexible Pavements with Unique and Neat Dense-Graded AC Mixtures

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Designing Rehabilitation Strategies with Multiple AC Overlays

Rehabilitation design using Pavement ME Design:

- One structural repair strategy of existing pavements.

Second overlay.
First overlay: leveling mix & overlay.
Existing AC Layers with milling.

Designing Rehabilitation Strategies with Multiple AC Overlays

MEPDG Manual of Practice:

1. Construction dates and thicknesses of existing AC layers and AC overlays.
2. Thickness of existing layers and new AC overlay.

Combine and simulate existing AC layers and overlays with AC overlay design.

Designing Rehabilitation Strategies with Multiple AC Overlays; Example

AC overlay of rehabilitated flexible pavement demonstration using:

- Resetting distress values to account for preventive maintenance.
- Using input level 1 for indirect tensile strength.
- Multi-layer plastic deformation coefficients.

Designing Rehabilitation Strategies with Multiple AC Overlays; Example

Yr.	Layer Designation			Thick., in.
2011	10	Third Overlay	SMA PG64-28, 9.5 mm	1.5
	9		WMA PG64-28, 19 mm	2.5
	8		Leveling Course, 9.5 mm	0.5
2002	7	Second overlay	HMA PG64-22, 12.5 mm	1.5
	6		HMA PG64-22, 9.5 mm	1.0
1988	5	First overlay	Overlay, AC Surface	1.0
	4		Scratch Course, Bit.	0.5
1966	3	Existing Pavement	AC Wearing Surface	2.5
	2		Crushed Aggregate Base	10.0
	1	Subgrade	A-4 Soil	

Designing Rehabilitation Strategies with Multiple AC Overlays; Example

Construction Type and Year		Survey Year	Fatigue Cracks	Trans. Cracks	Rut Depth	IRI
		2017	14.0	450	0.25	118
2011	Third overlay; 4.5 inches					
		2010	2.0	300	0.38	96
2002	Second overlay; 2.5 inches					
1988	First overlay; 1.5 inches					
1966	2.5 inches; New Construction					

Remember, the area of alligator cracking defines the level of damage for the existing layers.

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Designing Rehabilitation Strategies with Multiple AC Overlays; Example

Mill all layers from the 2011 rehabilitation.

Yr.		Layer Designation			Thick., in.
2002	7	Second overlay	HMA PG64-22, 12.5 mm	2.5 in.	1.5
	6		HMA PG64-22, 9.5 mm		1.0
1988	5	First overlay	Overlay, AC Surface	4.0 in.	1.0
	4		Scratch Course, Bit.		0.5
1966	3	Existing Pavement	AC Wearing Surface		2.5
	2		Crushed Aggregate Base		10.0
	1	Subgrade	A-4 Soil		

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Designing Rehabilitation Strategies with Multiple AC Overlays

Outcome of demonstration – predicted distresses over design period.

- Report visibility.
- Resetting distress values to account for preventive maintenance.
- Using input level 1 for indirect tensile strength.
- Multi-layer plastic deformation coefficients.

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Designing Rehabilitation Strategies with Multiple AC Overlays

Outcome of demonstration – predicted distresses over design period.

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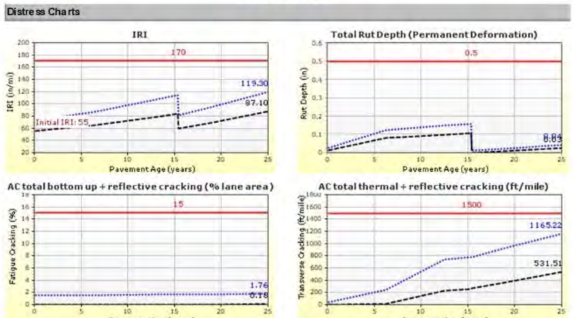
Designing Rehabilitation Strategies with Multiple AC Overlays

Distress Charts



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Designing Rehabilitation Strategies with Multiple AC Overlays

Questions?

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Outline

1. Designing Rehabilitation Strategies with Multiple AC Overlays
2. **Designing Composite Pavements with Current Software**
3. Using Laboratory Test Results to Characterize AC Mixtures for Design
4. Designing Flexible Pavements with Unique and Neat Dense-Graded AC Mixtures

Designing Composite Pavements with Current Software

Pavement Design Strategies with Pavement ME Design Software:

General Information
Design type: New Pavement
Pavement type:
Design life (years):
Existing construction
- Flexible Pavement
- Jointed Plain Concrete Pavement (JPCP)
- Continuously Reinforced Concrete Pavement (CRCP)
- Semi-Rigid Pavement

Designing Composite Pavements with Current Software

Pavement Design Strategies with Pavement ME Design Software:

General Information
Design type: Overlay
Pavement type:
Design life (years):
Existing construction
Pavement constructi
- AC over AC
- AC over AC with Seal Coat
- AC over AC with Interlayer
- AC over Semi-Rigid
- AC over JPCP
- AC over CRCP

Designing Composite Pavements with Current Software

Pavement Design Strategies with Pavement ME Design Software; Design Criteria – AC over JPCP:

Performance Criteria	Limit	Reliability	Report Visibility
Initial IRI (in/mile)	63		☑
Terminal IRI (in/mile)	172	90	☑
AC top-down fatigue cracking (ft/mile)	2000	90	☐
AC bottom-up fatigue cracking (% lane area)	25	90	☑
AC thermal cracking (ft/mile)	1000	50	☑
Permanent deformation - AC only (in)	0.25	90	☑
AC total transverse cracking: thermal + reflective (ft/mile)	2500	90	☑
JPCP transverse cracking (percent slabs)	15	90	☑

Faulting is not included in AC over JPCP.

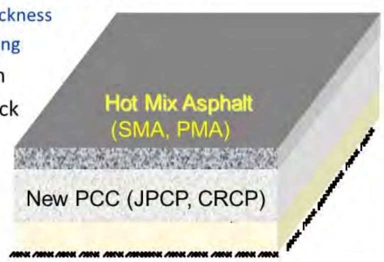
Designing Composite Pavements with Current Software

SHRP Renewal Research Project, R21, 2013:

- Composite Pavement Systems, Volume 1, HMA/PCC Composite Pavements
  - New HMA/JPC, HMA/RCC or LCB, and HMA/CRC can be designed using the overlay design feature in DARWin-ME.
- Composite Pavement Systems, Volume 2, PCC/PCC Composite Pavements
  - PCC/JPC and PCC/CRC can be designed using *MEPDG*

Designing Composite Pavements with Current Software

- PCC Damage and Cracking Determination
  - Minimum AC thickness
  - Reflection cracking
- IRI Determination
- PCC Faulting Check



Designing Composite Pavements with Current Software

Software demonstration for designing new composite pavements:

AC over JPCP

- Report Visibility
- Load Transfer Efficiency
- Faulting
- Reflection Cracking of Transverse Joints
- Climate
- Maintenance Strategy

Designing Composite Pavements with Current Software

Outcome of demonstration – predicted distresses over design period.

Design Inputs

Design Life: 30 years
Design Type: ACC_JPCP
Existing construction: May, 2019
Pavement construction: June, 2020
Traffic opening: September, 2020
Climate Data Sources: 41.5, -77.5

Design Structure

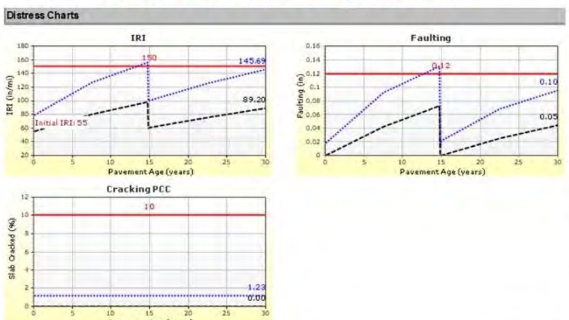
Layer type	Material Type	Thickness (in)
Flexible (OL)	Default asphalt concrete	2.0
Flexible (OL)	Default asphalt concrete	2.0
PCC	Mix1_Dist11_MixID14-200	10.0
NonStabilized	A-1-a	10.0
Subgrade	A-2-4	16.0
Subgrade	A-6	Semi-infinite

Volumetric at Construction:	
Effective binder content (%)	10.2
Air voids (%)	6.7

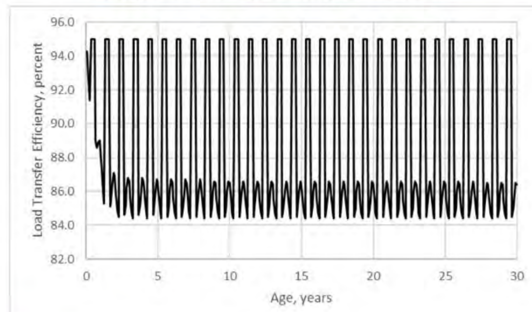
Traffic

Age (year)	Heavy Trucks (cumulative)
2020 (initial)	10,500
2035 (15 years)	31,150,800
2050 (30 years)	69,762,500

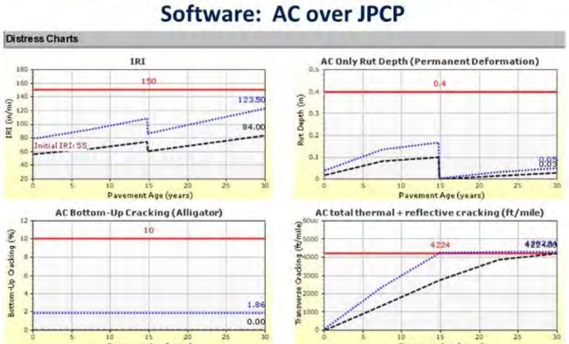
Designing Composite Pavements with Current Software: JPCP, Faulting Predicted



Designing Composite Pavements with Current Software: JPCP, Faulting Predicted



Designing Composite Pavements with Current Software: AC over JPCP



Designing Composite Pavements with Current Software

Questions?

Outline

1. Designing Rehabilitation Strategies with Multiple AC Overlays
2. Designing Composite Pavements with Current Software
3. **Using Laboratory Test Results to Characterize AC Mixtures for Design**
4. Designing Flexible Pavements with Unique and Neat Dense-Graded AC Mixtures

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Using Laboratory Test Results to Characterize AC Mixtures for Rehabilitation Design

Issues related to calibration and Pavement ME use relative to material characterization.

How do the global calibration coefficients compare between different AC mixtures?

1. Rut depth
2. Bottom-up fatigue cracking
3. Transverse cracking

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Structural Design

Select material/design features to minimize distress.

Layer thickness & material features to optimize the pavement design.

SMA Surface - 2 in.
PMA Layer - 3 in.
HMA Layer - 11 in.
Strain Tolerant Mix - 3 in.
Crushed Aggregate - 12 in.
Select fill or embankment

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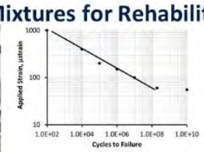
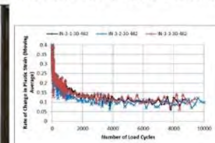
Using Laboratory Test Results to Characterize AC Mixtures for Rehabilitation Design



Earlier versions, K-values are a combination of lab and field results.



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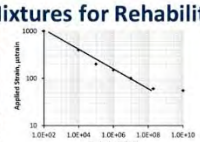
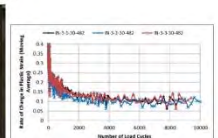
Using Laboratory Test Results to Characterize AC Mixtures for Rehabilitation Design



K-values defined by lab results.

β-values defined from field.



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AC Rut Depth

Final results from the global calibration, as compared to earlier version.

Type of Mixture	Coefficient	Version 2.3.1		Version 2.5; Lab-Field
		Lab-Field, [1-37A Rpt.]	Combined, [1-40D]	
Dense-Graded Neat Asphalt	K_{r1}	-3.15552	-3.35412	-2.45
	K_{r2}	1.734	1.5606	3.01
	K_{r3}	0.39937	0.4791	0.22
	β_{r1}	0.509	1.0	0.40
	β_{r2}	0.90	1.0	0.52
	β_{r3}	1.2	1.0	1.36

$$\varepsilon_{p(AC)} = \varepsilon_{r(AC)} k_z \beta_{r1} 10^{k_{r1}} T^{k_{r2}\beta_{r2}} N^{k_{r3}\beta_{r3}}$$

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Bottom-Up Alligator Cracks

Final results from the global calibration of K values, as compared to earlier versions.

Parameter	AC Thick.	Version 2.3.1	Version 2.5; Lab-Derived Values
K_{f1} Intercept	---	0.007566	3.75
K_{f1} E Exponent	---	1.281	1.46
K_{f3} Strain Exponent	---	3.95	2.87

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Bottom-Up Alligator Cracks

Final results from the global calibration of β values, as compared to earlier versions.

Parameter	AC Thick.	Version 2.3.1	Version 2.5; Field-Derived Values
β_{f1} Intercept	< 5	1.0	0.02054
	5 to 12		$\beta_{f1} = 5.014(h_{AC})^{-3.416}$
	> 12		0.001032
β_{f1} E Exponent	---	1.0	0.88
β_{f3} Strain Exponent	---	1.0	1.38

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Bottom-Up Alligator Cracks

Final results from the global calibration of C values, as compared to earlier versions.

Parameter	AC Thick.	Version 2.3.1	Version 2.5; Field-Derived Values
C_2	< 5	1.0	2.1585
	5 to 12		$C_2 = 0.867 + 0.2583(h_{AC})$
	> 12		3.9666
C_1	---	1.0	1.31

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Using Laboratory Test Results to Characterize AC Mixtures for Rehabilitation Design

Take away:

- Only measuring E* will not significantly increase the accuracy of the predicted values for both rut depth and fatigue cracking.
- My opinion: tests used to predict cracking will be more cost effective than for rut depth.

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Using Laboratory Test Results to Characterize AC Mixtures for Rehabilitation Design

Questions?

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Outline

1. Designing Rehabilitation Strategies with Multiple AC Overlays
2. Designing Composite Pavements with Current Software
3. Using Laboratory Test Results to Characterize AC Mixtures for Rehabilitation Design
4. Designing Flexible Pavements with Unique and Neat Dense-Graded AC Mixtures

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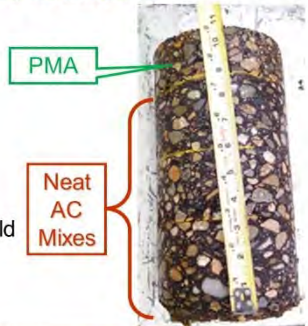
Designing Flexible Pavements with Unique and Neat Dense-Graded AC Mixtures

- Rut depth.
- Bottom-up alligator cracking.
- Transverse cracking.

What coefficients should be used for fatigue cracking?



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Layers that Control the Distress Predictions

- Transverse cracking.
- Rut depth.
- Bottom-up alligator cracking.

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Designing Flexible Pavements with Unique and Neat Dense-Graded AC Mixtures

Outcome of demonstration – predicted distresses over design period.

- Report visibility.
- Multi-layer plastic deformation coefficients.
- Alligator cracking fatigue coefficients.

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Designing Flexible Pavements with Unique and Neat Dense-Graded AC Mixtures

Software demonstration and designing flexible pavements with different unique AC mixtures.

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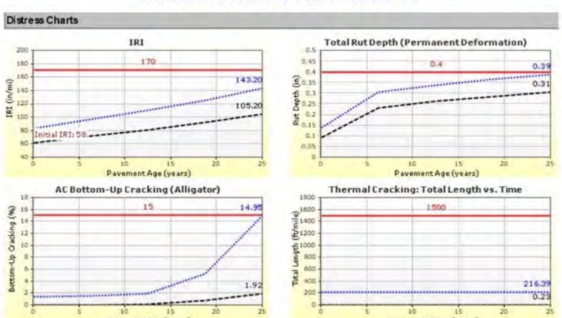
Designing Flexible Pavements with Unique and Neat Dense-Graded AC Mixtures



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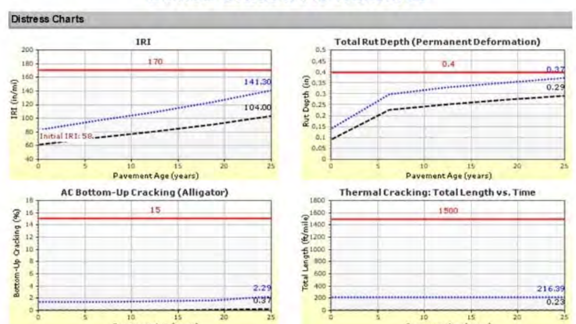
Designing Flexible Pavements with Unique and Neat Dense-Graded AC Mixtures



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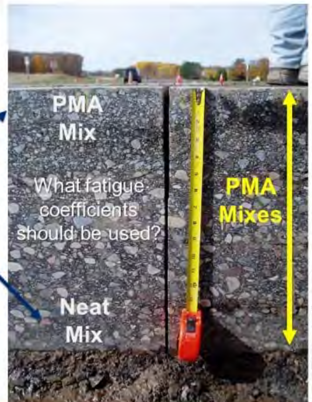
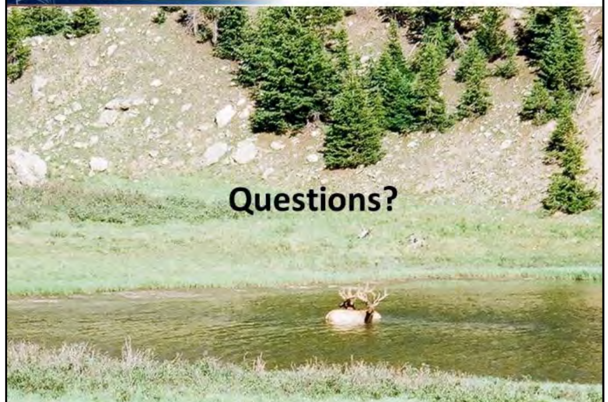
Layers that Control the Distress Predictions

- Transverse cracking.
- Rut depth.
- Bottom-up alligator cracking.





Designing Rehabilitation Strategies with Multiple AC Overlays

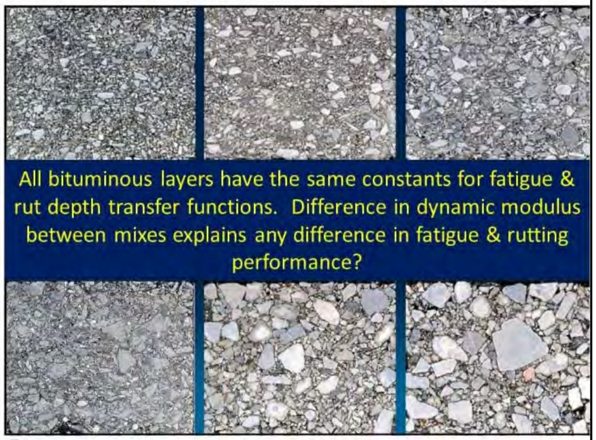
- Treating multiple AC overlays already placed within the life of the pavement.
- Application of current enhancements:
  - Resetting distress values for preventive maintenance activities within the design period.
  - Use of indirect tensile strength input levels 1 and 2.

HMA Cores: Confirm material condition and lift types & thicknesses

How does one consider these different mixtures in the MEPDG to accurately predict performance or load related distresses for new design and rehabilitation?

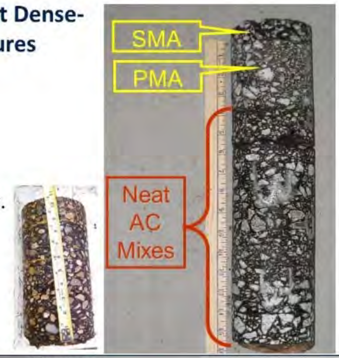
Designing Rehabilitation Strategies with Multiple AC Overlays

Layer Designation			Thick., in.
1	Second overlay	Fine-Graded wearing surface	1.5
2	First overlay	Fine-Graded wearing surface	1.75
3		Leveling course	1.2
		Wearing surface, milled	0.0
4	Existing Pavement	AC Binder Layer	2.5
5		AC Base Mix	3.0



Designing Flexible Pavements with Unique and Neat Dense-Graded AC Mixtures

- Rut depth.
- Bottom-up alligator/fatigue cracking.
- Transverse cracking.



Designing Flexible Pavements with Unique and Neat Dense-Graded AC Mixtures

- Rut depth.
- Bottom-up alligator cracking.
- Transverse cracking.

What coefficients should be used for fatigue cracking?

Using Laboratory Test Results to Characterize AC Mixtures for Rehabilitation Design

Global calibration based on using:

1. Neat AC mixtures designed via Marshall or Hveem; does this make a difference?
2. Few projects included RAP; when high RAP added, are the coefficients applicable?
3. Many sections had low levels of distress; do not just add sections with higher levels of distress – refer to GDOT.
4. Coefficients were assumed to be independent of other factors; this is not the case.
5. Etc.

Using Laboratory Test Results to Characterize AC Mixtures for Rehabilitation Design

Software demonstration and designing flexible pavements with different AC mixtures.

Using Laboratory Test Results to Characterize AC Mixtures for Rehabilitation Design

Outcome of demonstration – predicted distresses over design period.

Material characterization or testing is important – is it cost effective?