Attachment 1. Meeting Participants

TPF-5(305) Technical Advisory Committee (TAC) and Pooled Fund Member Participants

Name	Agency	TAC Member	Pvt ME Design TF Member	Email Address
Tom Yu Jennifer Albert	FHWA	Yes Yes	FHWA Liaison No	tom.yu@dot.gov jennifer.albert@dot.gov
Ryan Fragapane Tinika Fowlkes	AASHTO	Yes No	Yes No	rfragapane@aashto.org tfowlkes@aashto.org
John Jennings Leah Clifton	Alabama DOT	Yes No	No No	jenningsj@dot.state.al.us cliftonl@dot.state.al.us
Nour Ali Zareh Ashek Rana	Arizona DOT	No Yes	No No	azareh@azdot.gov arana@azdot.gov
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John Senger LaDonna Rowden	Illinois DOT	No No	No No	John.Senger@illinois.gov LaDonna.Rowden@illinois.gov
Chris B. Brakke	Iowa DOT	Yes	No	Chris.Brakke@iowadot.us
Nat Valesquez Jr.	Kansas DOT	Yes	No	nat.velasquez@ks.gov
Sunil Saha Brad Frazier Jonathan Reynolds	Kentucky TC	Yes No No	No No No	sunil.saha@ky.gov Brad.Frazier@ky.gov Jonathan.Reynolds@ky.gov
Yasir Shah Marcus Wong	Manitoba Transportation	Yes No	No No	Yasir.Shah@gov.mb.ca marcus.wong@gov.mb.ca
Hector Figueroa Robert Steudler	Maryland SHA	No No	No No	hfigueroa@mdot.maryland.gov RSteudler@mdot.maryland.gov
Fawaz Kaseer	Michigan DOT	No	No	kaseerf@michigan.gov
Abhinash Subedi	Mississippi DOT	No	No	asubedi@mdot.ms.gov
Clark Morrison Shihai Zhang	North Carolina DOT	Yes No	Yes (Chair) No	cmorrison@ncdot.gov szhang2@ncdot.gov
TJ Murphy	North Dakota DOT	No	No	tjmurphy@nd.gov
Josh Freeman Lydia Peddicord	Pennsylvania DOT	Yes Yes	No No	josfreeman@pa.gov lpeddicord@pa.gov
Dahae Kim Srinivasan Nagarajan	South Carolina DOT	Yes No	No No	kimd@scdot.org nagarajans@scdot.org
Hari Nair Bipad Saha Mesbah Ahmed	Virginia DOT	Yes No No	Yes No No	harikrishnan.nair@vdot.virginia.gov bipad.saha@vdot.virginia.gov mesbah.ahmed@vdot.virginia.gov
Ali Morovatdar	Wisconsin DOT	Yes	No	ali.morovatdar@dot.wi.gov

Non-TAC / Non-Pooled Fund Member Participation

Name	Agency	Pvt ME Design TF Member	Email Address
Jane Jiang* Chu Wei	FHWA	No No	jane.jiang@dot.gov chu.wei@dot.gov
Kelly Smith	APTech	No	klsmith@appliedpavement.com
Chadwick Becker Harold Von Quintus	ARA	No No	cbecker@ara.com hvonquintus@ara.com
Linda Pierce	NCE	No	LPierce@ncenet.com
John Arambarri Seung Baek	Idaho Transportation Dept	No No	john.arambarri@itd.idaho.gov seung.baek@itd.idaho.gov
Kumar Dave Pankaj Patel	Indiana DOT	Yes No	KDAVE@indot.IN.gov papatel@indot.in.gov
Xingwei Chen	Louisiana DOTD	No	xingwei.chen@la.gov
Miles Yerger	Montana DOT	No	myerger@mt.gov
Bruce Barrett	Nebraska DOT	No	Bruce.Barrett@nebraska.gov
Patrick Bierl	Ohio DOT	Yes	Patrick.Bierl@dot.ohio.gov
Felix Doucet	Quebec	Yes	Felix.Doucet@transports.gouv.qc.ca
David Holmgren Lauriane Collins Jason Simmons	Utah DOT	Yes No No	dholmgren@utah.gov lwales@utah.gov jasonsimmons@utah.gov
Karen Carlie	Washington State DOT	No	carliek@wsdot.wa.gov
Ryan Steinbrenner	Wyoming DOT	No	ryan.steinbrenner@wyo.gov

*Presented Virtually

Academia/Consultant/Industry Representative Participation

Name	Agency	Pvt ME Design TF Member	Email Address
Eric Ferrebee Larry Scofield	ACPA	No No	eferrebee@acpa.org lscofield@pavement.com
Claudia Zapata Austin Olaiz	Arizona State University	No No	czapata@asu.edu aholaiz@asu.edu
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Carlos Chang	Florida International Univ.	No	cachang@fiu.edu
Kean Ashurst	Kentucky Transp. Center	No	kean.ashurst@uky.edu
Syed Haider	Michigan State University	No	syedwaqa@egr.msu.edu
Timin Punnackal	NCE	No	tpunnackal@ncenet.com
Wiley Cunagin	Pavement Analytics, LLC	No	wcunagin@gmail.com
Leila Sadeghi Brian Trenner	Resource International	No No	leilas@resourceinternational.com briant@resourceinternational.com
Jay Goldbaum	RockSol Consulting Group	No	goldbaum@rocksol.com
Vladimir Mitchev Md Mostaqur Rahman	S&ME	No No	vmitchev@smeinc.com mrahman@smeinc.com
Tomm James	Tensar International Corp	No	tjames@tensarcorp.com
Tito Nyamuhokya	Texas Transportation Institute	No	t-nyamuhokya@tti.tamu.edu
Clark Graves	University of Kentucky	No	clark.graves@uky.edu
Julie Vandenbossche	University of Pittsburgh	No	jmv7@pitt.edu
Paul Mykytka	WSP	No	paul.mykytka@wsp.com
Tim Hufford	-	No	not available

Attachment 2. Meeting Agenda

Session 1—Tuesday November 1, 2022

Time (MT)	Session and Topics
8:00 - 8:45 AM	1A. WELCOME AND INTRODUCTIONS Welcome | Linda Pierce (NCE) and Kelly Smith (APTech) FHWA Welcome and Remarks | Jennifer Albert (FHWA Task Manager & Pooled Fund Manager) AASHTO COMP Technical Subcommittee 5D Remarks | LaDonna Rowden (Illinois DOT, 5D Vice-Chair) AASHTO ME Task Force Remarks | Clark Morrison (North Carolina DOT, Taskforce Co-Chair) Canadian Update | Felix Doucet (Quebec Ministry of Transportation, TAC MEPD Subcommittee Liaison) Review of meeting agenda and goals | Linda Pierce (NCE) and Kelly Smith (APTech)
8:45 - 10:00 AM	1B. AGENCY IMPLEMENTATION UPDATES/REPORT-OUTS Agency briefings on implementation plans, timelines, and progress | Designated Agency Speakers
10:00 - 10:15 AM	BREAK
10:15 - 11:30 AM	1B. AGENCY IMPLEMENTATION UPDATES/REPORT-OUTS (continued)
11:30 - 11:45 AM	1C. AASHTOWARE PAVEMENT ME DESIGN SOFTWARE UPDATE AASHTO Briefing (announcements/news, customer relations) | Ryan Fragapane (AASHTO)
11:45 AM - 1:15 PM	LUNCH (On your own)
1:15 - 2:15 PM	1C. AASHTOWARE PAVEMENT ME DESIGN SOFTWARE UPDATE (continued) Software Enhancements/Updates (incl. new features/capabilities) | Chad Becker (ARA)
2:15 - 2:45 PM	1D. ME RESEARCH SUMMARIES NCHRP Research Update | Linda Pierce (NCE) FHWA Research Update | Tom Yu (FHWA)
2:45 - 3:00 PM	BREAK
3:00 - 4:30 PM	1E. TECHNICAL PRESENTATIONS—GENERAL/MISCELLANEOUS Effect of Subgrade, Granular Base, and Concrete Mix Properties on the PMED Predicted Distresses | Yasir Shah (Manitoba Infrastructure) Kentucky ME Design Catalog | Clark Graves (Kentucky Transportation Center) Indiana ME Design Catalog for Small Structure Replacements | Kumar Dave (Indiana DOT)
4:30 - 4:45 PM	DAY 1 WRAP UP Key takeaways and closing thoughts on Day 1 | All

Session 2—Wednesday November 2, 2022

Time (MT)	Session and Topics
8:00 - 8:10 AM	OPENING Day 2 Overview | Linda Pierce (NCE)
8:10 - 10:00 AM	2A. TECHNICAL PRESENTATIONS—IMPLEMENTATION FHWA/Montana Pavement Design Peer Exchange | Miles Yerger (Montana DOT) Pavement ME Rehabilitation Design Implementation: Challenges | Hari Nair (Virginia DOT) Improved Consideration of the Influence of Subgrade Soils Susceptible to Shrink/Swell and/or Frost Heave on Pavement Performance (NCHRP 1-59) | Claudia Zapata (Arizona State University) LTPP Analysis-Ready Materials Dataset (ARMAD) | Jane Jiang (FHWA) (virtual demo)
10:00 - 10:15 AM	BREAK
10:15 - 11:45 AM	2B. TECHNICAL PRESENTATIONS—CALIBRATION Nebraska Calibration and Backcalculation Challenges | Bruce Barrett (Nebraska DOT) Michigan Rigid Pavement Model Calibration | Dr. Syed Haider (Michigan State University) Calibration of AASHTOWare Pavement ME for Maryland Conditions | Hector Figueroa (Maryland SHA)
11:45 AM - 1:15 PM	LUNCH (On your own)
1:15 - 2:30 PM	2B. TECHNICAL PRESENTATIONS—CALIBRATION (continued) Quebec Calibration efforts | Felix Doucet (Quebec Ministry of Transportation) Overview of new IDOT Test Track | John Senger (Illinois DOT) 2C. OPEN FORUM — IMPLEMENTATION/ADOPTION OF MEPDG/PMED Implementation RoadMap Workshop and Report | Kelly Smith (APTech) Open Forum Discussion | Linda Pierce (NCE) and Meeting Participants
2:30 - 2:45 PM	BREAK
2:45 - 4:15 PM	2D. SOFTWARE TRAINING TOPIC 1 PMED Models and Calculations: HMA Rutting | Linda Pierce (NCE) PMED Models and Calculations: HMA IRI | Linda Pierce (NCE)
4:15 - 4:30 PM	DAY 2 WRAP UP Key takeaways and closing thoughts on Day 2 | All

Session 3—Thursday November 3, 2022

Time (MT)	Session and Topics
8:00 - 8:05 AM	OPENING Day 3 Overview | Linda Pierce (NCE)
8:05 - 9:30 AM	3A. SOFTWARE TRAINING TOPIC 2 PMED Models and Calculations: PCC Joint Faulting | Julie Vandenbossche (University of Pittsburgh) PMED Models and Calculations: PCC IRI | Julie Vandenbossche (University of Pittsburgh)
9:30 - 9:45 AM	BREAK
9:45 - 11:00 AM	3B. SOFTWARE TRAINING TOPIC 3 Pavement ME Intermediate Files: Structural Response | Harold Von Quintus (ARA)
11:00 - 11:30 AM	3C. FUTURE USER GROUP EVENTS Future Software Training Webinars | Kelly Smith (APTech) and Linda Pierce (NCE) Additional Event Planning | Tom Yu (FHWA) Future User Group Meetings | Ryan Fragapane (AASHTO)
11:30 - 11:45 AM	MEETING WRAP UP Concluding remarks | Linda Pierce (NCE) and Kelly Smith (APTech)

Attachment 3. Meeting Presentations

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Presentation 3—Chad Becker, ARA 43
Presentation 4—Linda Pierce, NCE 57
Presentation 5—Tom Yu, FHWA 59
Presentation 6—Yasir Shah, Manitoba Infrastructure 61
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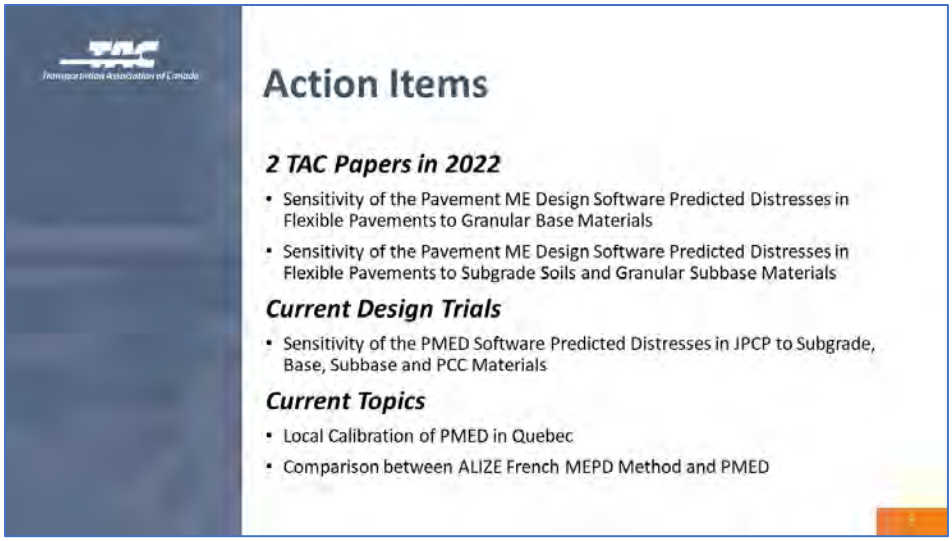
Presentation 22—Ryan Fragapane, AASHTO 220

Presentation 1—Felix Doucet, Quebec Ministry of Transportation



TAC Liaison Role

Communication between the PMED Task Force and

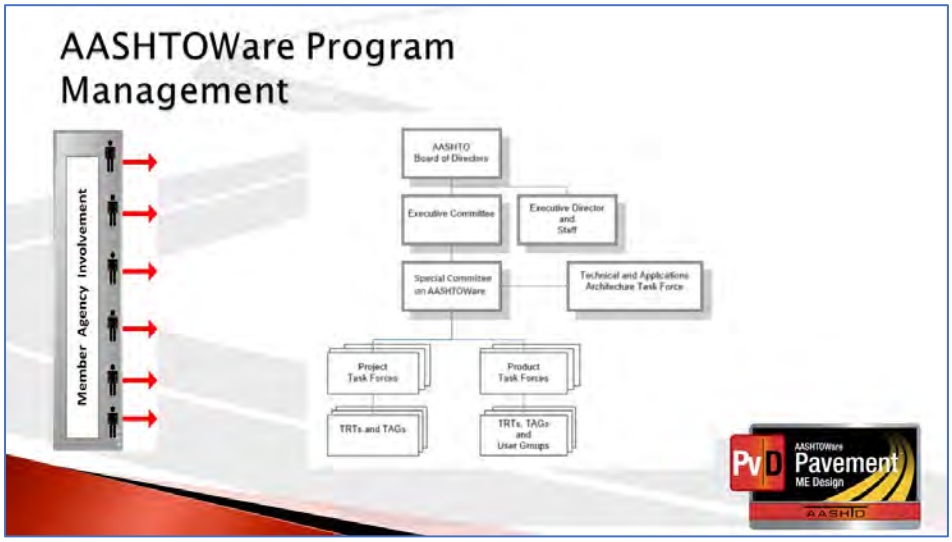
- TAC Pavement Committee, ME Subcommittee and User Group
- Provinces and consultant practitioners
- Researchers and technical staff

Consideration of Canadian Conditions in PMED

- SI Units
- Cold Climate
- Thermal Cracking
- Frost Heave & Thawing
- Thick Granular Base & Subbase

Questions & discussion

Presentation 2—Ryan Fragapane, AASHTO



Pavement ME Design Task Force Membership

- Clark Morrison – Chair, North Carolina DOT
- Harikrishnan Nair – Vice Chair, Virginia DOT
- Ian Rish – Gerogia DOT
- Felix Doucet – Quebec MOT
- Patrick Bierl – Ohio DOT
- Dulce Feldman – CalTrans
- Kumar Dave – Indiana DOT

- Liaisons
  - Tamuna Cullison – SCOA Liaison
  - Ryan Hilton – T&AA Liaison
  - Tom Yu – FHWA Liaison
  - Susanne Chan – TAC Liaison

Where Can I Find Information about Pavement ME Design?

- AASHTO's Website
  - https://www.aashtoware.org/products/pavement
- ARA's Support Site
  - www.me-design.com

AASHTO's Website Provides Information On:

- Licensing
- Ordering
- AASHTO Contacts

ARA's Pavement ME Design site provides:

- Software Download Information
- Release Notes
- Access to Technical Help
- Access to the Tools
- Climatic Data
- Webinars
  - Training
  - Enhancments

AASHTOWare Pavement ME Design Licensee Map – FY22

41 Sates Licensing to date
FHWA DC DOT, &
Maricopa County ,
AZ also Licensing

AASHTOWare Pavement ME Design Licensee Map – FY22

6 Canadian Provinces currently Licensing

Additional License Types – FY22

- No Cost Educational Licenses
  - 42
- Private Sector and Universities
  - 84
- International Sales
  - 50+

- AASHTOWare Service Units
  - Overview
  - Process
- AASHTOWare Software Renewals

Training and Implementation Assistance

- Implementation Assistance
  - Provide agencies with implementation assistance to start using the Pavement ME software. The scope of the work for this bundle is customizable to accommodate agency specific needs.
- Pavement ME Application Training—1
  - Experience level:
    - First time users
    - Users needing a refresher of software usage
- Pavement ME Application Training—2

Customer Success

- Executive Business Reviews
  - Completed 2 in FY22
  - Michigan and Virginia
- 4 more to be conducted in FY23
  - Virtual and In person

The goal is to become proactive not reactive

Version 3.0

- Full Web Version
  - Reduced support needed from internal state IT departments
- Fully Integrated with the LTPP InfoPave Site for MERRA Climate Data
- User Roles
  - Admin Role
  - Access control

Strategic Direction

- Goal:
  - Production ready tool usable by everyone in the department
- Changes to the design modules released on 5 year cycles
  - Allow states to catch up on calibrations!

Other AASHTOWare Activities

- Data Integration Project
- Partnership Program

Save the Date!

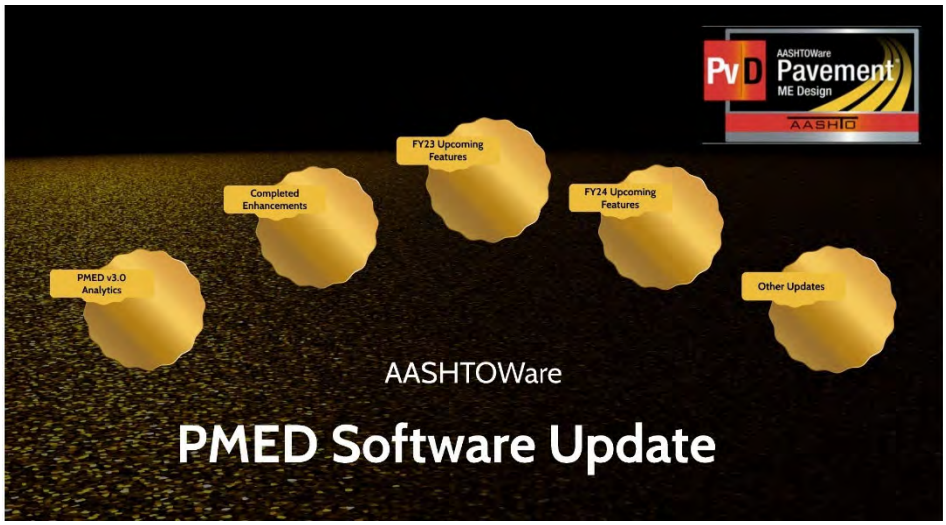
AASHTOWare Pavement ME Design User Group

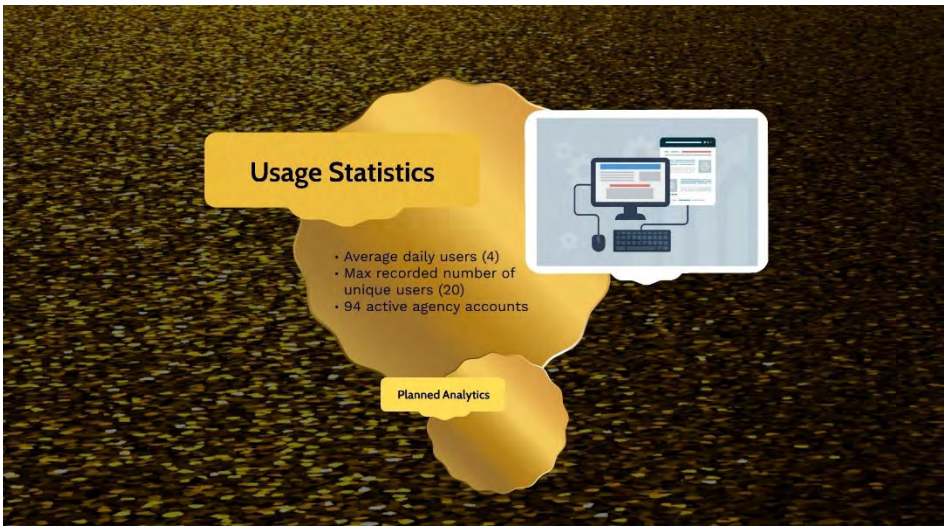
- September 6th & 7th, 2023
- Madison, WI

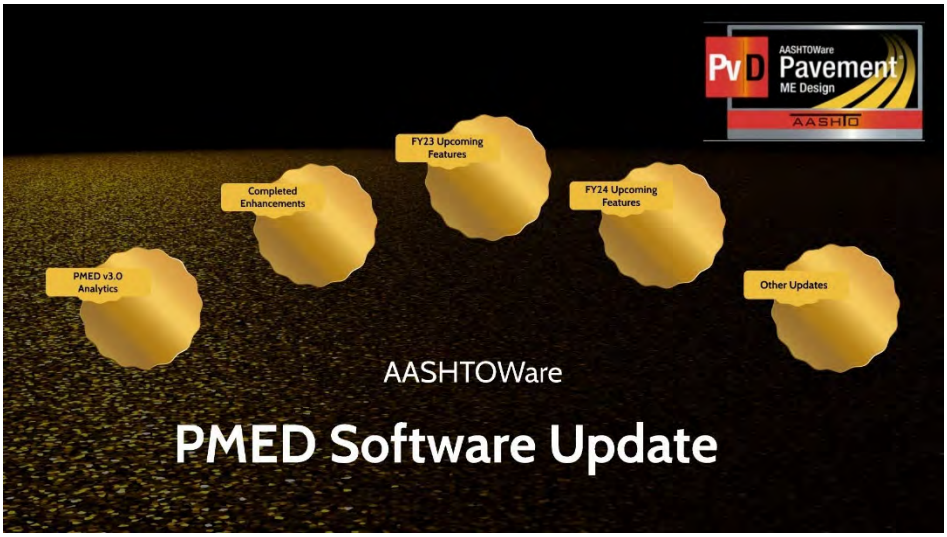
Questions?

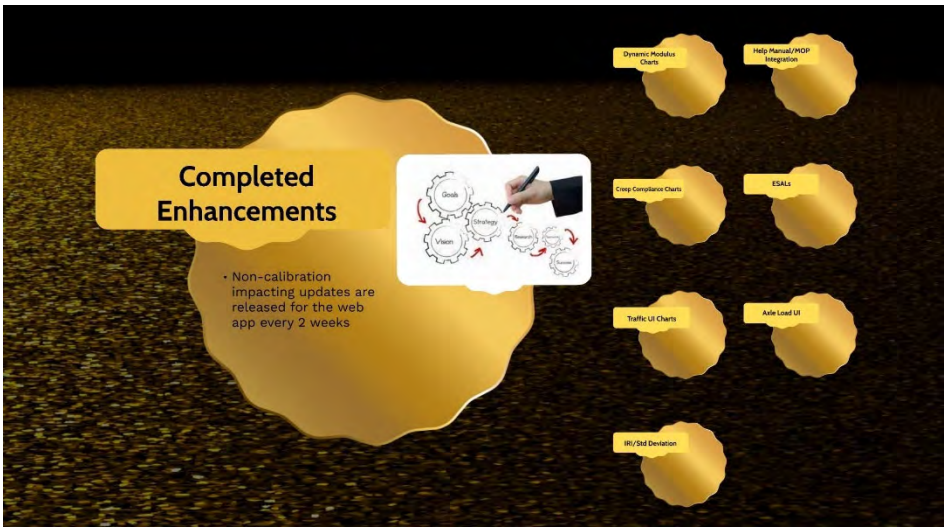
Ryan Fragapane
AASHTO Project Manager
rfragapane@aashto.org
(202) 624 – 3632
AASHTOWare
Pavement
ME Design
AASHTO

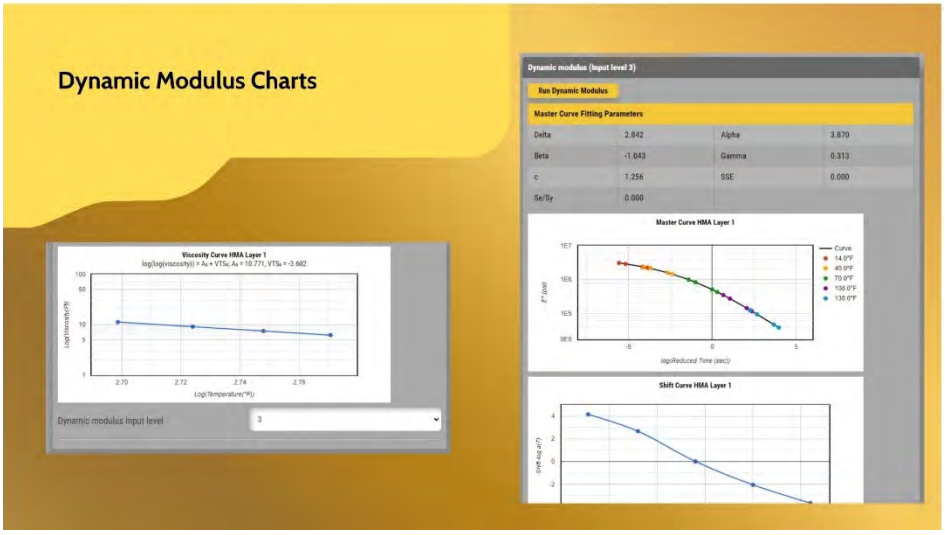
Presentation 3—Chad Becker, ARA



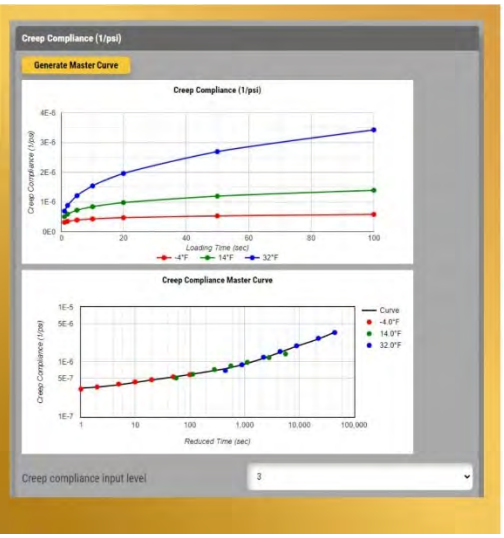



AASHTOWare
Pavement
ME Design
AASHTO
FY23 Upcoming Features
Completed Enhancements
FY24 Upcoming Features
PMED v3.0 Analytics
Other Updates
AASHTOWare
PMED Software Update


Dynamic Modulus Charts
Help Manual/MOP Integration
Completed Enhancements
Goals
Strategy
Vision
Creep Compliance Charts
ESALs
• Non-calibration impacting updates are released for the web app every 2 weeks
Traffic UI Charts
Axle Load UI
IRI/Std Deviation

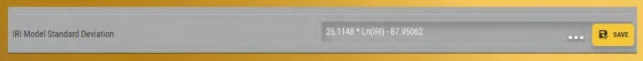

Dynamic Modulus Charts
Dynamic modulus (Input level 3)
Run Dynamic Modulus
Master Curve Fitting Parameters
Delta 2.842 Alpha 3.870
Beta -1.043 Gamma 0.313
c 1.256 SSE 0.000
Se/Sy 0.000
Master Curve HMA Layer 1
Viscosity Curve HMA Layer 1
Shift Curve HMA Layer 1
Dynamic modulus input level 3

Creep Compliance Master Curve Chart

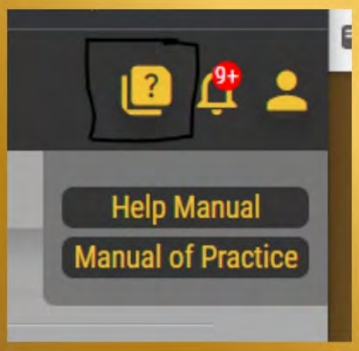


Traffic UI Charts

IRI Model Std. Deviation - Editable



Help Manual/MOP

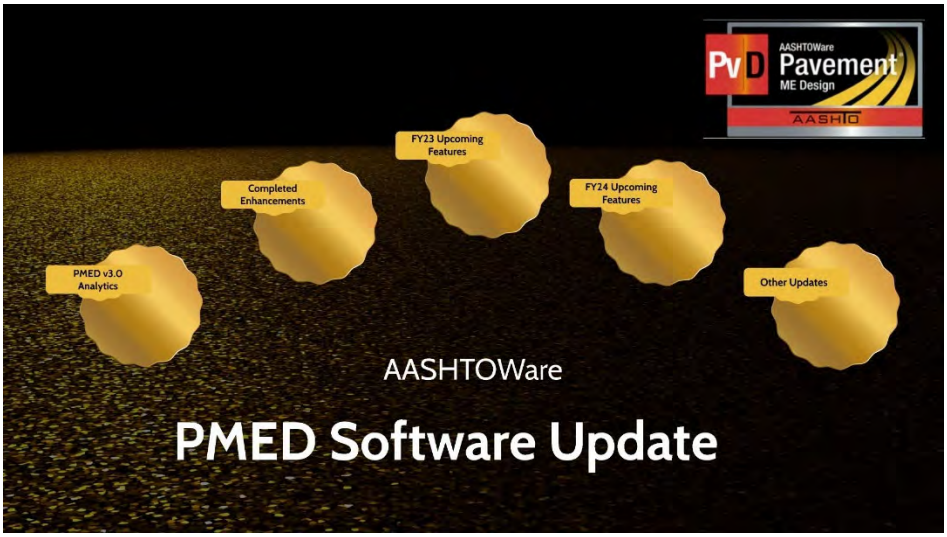


ESALs in the Outputs

ESALs are now included in the DOCX and XLSX report for reference

Note: ESALs are not used in the PMED analysis. They are in the output reports for informational purposes only.

Axle Load UI Updates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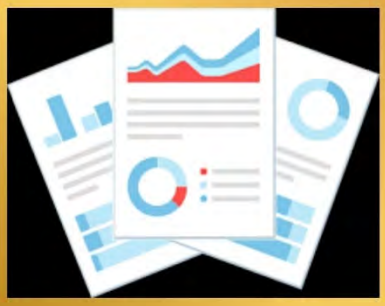
FY23 Upcoming Enhancements
• Planned enhancements for FY23 release
Custom Metadata
Multiple Overlays
Report Customization
Creep Compliance/ Dynamic Modulus
Training Videos
Climate Model - Cold Regions
Test Procedures/ Protocols
Library Viewer

Custom Metadata Module
• Allow user specified "Identity" fields.
• Allow for strings, numerics, dates, and geometries
• Change "Identity" to "Design Metadata"
42METADATA20

Report Customization

- Granular control for chart, table, and formula outputs in DOCX and XLSX reports
- Workspace specific configurations



PMED Training Videos

- Update the "Principles of M-E Design Concepts for Pavement Design" video series so that the course is consistent with the current edition of the MEPDG Manual of Practice and software.
- This will be done with a series of training videos available on the PMED website.

Test Procedures and Protocols

- Prepare AASHTO test procedure/ protocol documentation for material related inputs without an AASHTO or ASTM designation

Multiple Overlays

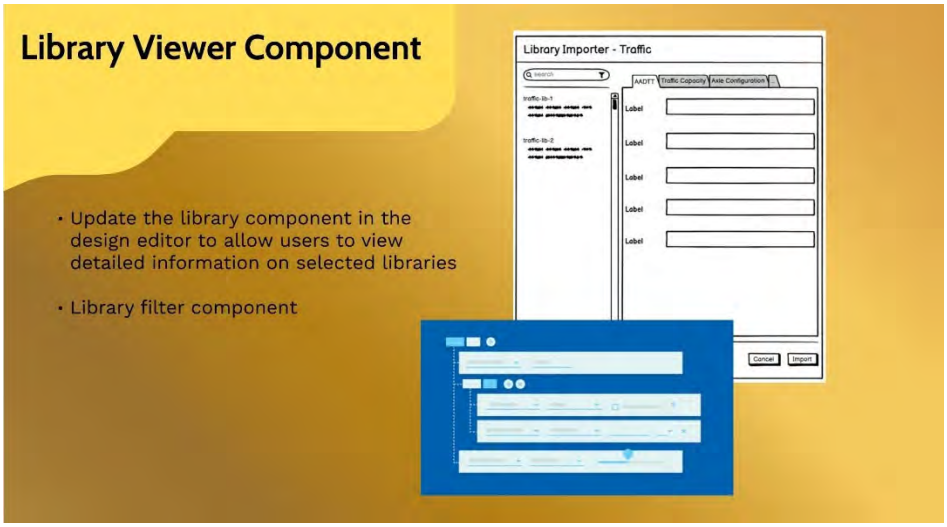
- State DOTs have many miles of existing jointed concrete and flexible pavements, and many of these roadways already have at least one asphalt overlay.
- Going to create a new design strategy feature to allow for design considerations of a second or third overlay of flexible and rigid pavements.

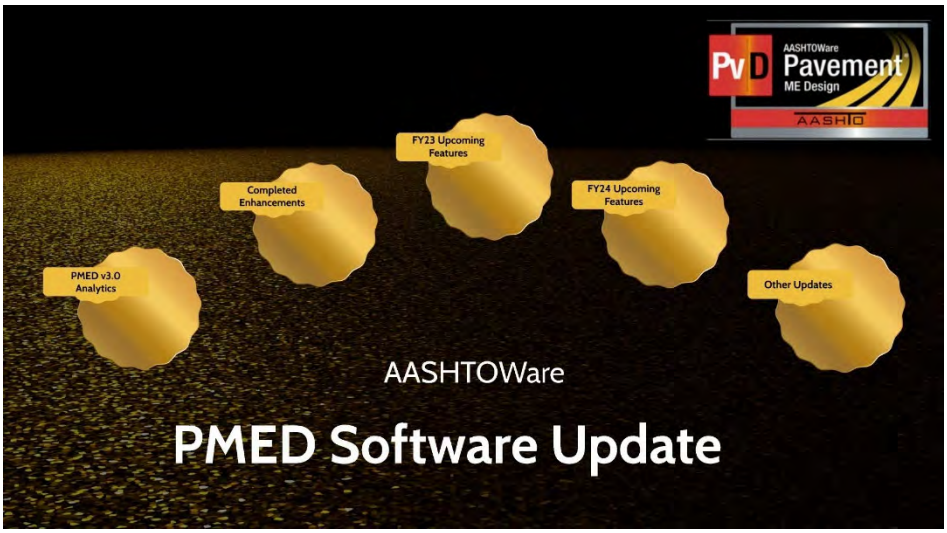
Dynamic Modulus to Creep Compliance Conversion

- Develop standard procedure to transform the frequency-based measured dynamic modulus master curve to a time-based creep compliance master curve. (For input level 2).

Climate Model Adjustments for Very Cold Regions

- Enhance and adjust the climatic model to account for geographical locations where the MAAT is below freezing
- Currently cannot run analysis when the MAAT is below freezing


Library Viewer Component
• Update the library component in the design editor to allow users to view detailed information on selected libraries
• Library filter component
Library Importer - Traffic
Traffic-lib-1
Traffic-lib-2
AADT
Traffic Capacity
Axle Configuration
Label
Label
Label
Label
Label
Cancel
Import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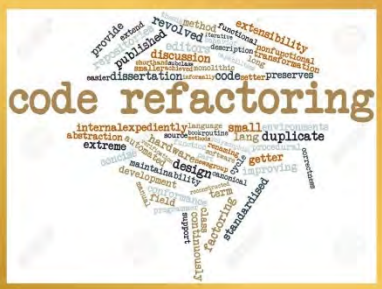
• Planned enhancements for FY24 release
Refactor EICM
Shrink-Swell & Frost Heave
Damaged dynamic modulus charts
Default Material Properties of CIR/FDR for Asphalt
Customer website update
Pulverized or RAP layers
Integration of MSCR
Lack of Bond for Asphalt Layers

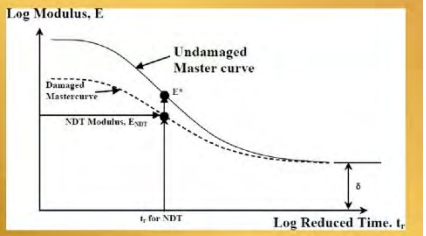
Refactor EICM

- The EICM will be completely refactored to improve maintainability and performance
- Part of the ongoing effort to completely refactor the analysis modules
- Users will see performance improvements
- Improve maintainability, extensibility, and scalability of the analysis



Damaged Dynamic Modulus Charts

- Add the damaged dynamic modulus chart to the user interface
- Will require a review of NCHRP project 1-54 and its impacts on fatigue damage



Customer Website Update

- Customer website will be reorganized by category and moved from https://me-design.com to the landing page on https://pavementmedesign.com
- Desktop licensing services will be updated and moved to the the new site as well

Integration of MSCR

- Integrate multi-stress creep recovery (MSCR) asphalt designations to determine input level 3 defaults

Shrink/Swell Frost Heave

*NCHRP 1-59 integration

- Integrate effects of shrink-swell and frost heave potential of soils on pavement performance.
- Would be released as part of the 5-year calibration guide schedule, but completed out of cycle

Default Material Properties of CIR/FDR for Aphalt Designs

*Potentially combined with NCHRP 9-52

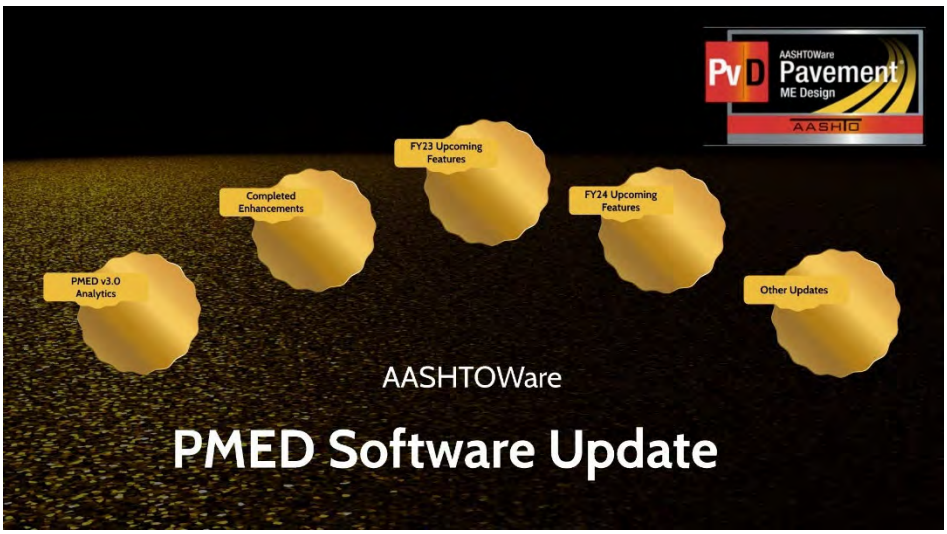
- Integrate CIR & FDR as a new rehabilitation design strategy

Pulverized, RAP (millings) Layers in Sandwich Granular Layer for Rehab Designs

- Allow the use of pulverized or RAP (millings) layer as a sandwich granular layer for rehabilitation designs

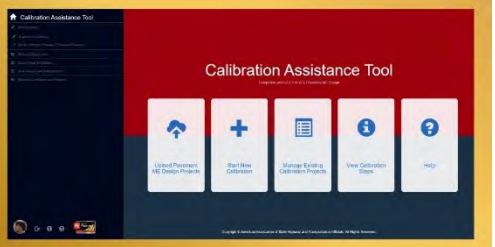
Lack of Bond Between Asphalt Layers for Rehab Designs

- Provide guidance for selecting specific values when setting bond parameters in PMED.



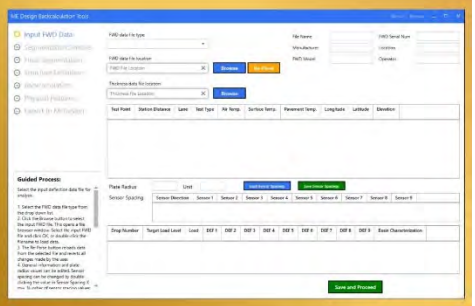
CAT Updates

- CAT for PMED v3.0 is now published and available for immediate use.
- Note that users must first run v3.0 designs once through PMED v3.0 to ensure proper execution of the analysis prior to utilizing the designs in the v3.0 integrated CAT ecosystem.



BcT

- Happy to announce the start of work for the Backcalculation web application tool!
- Full integration with PMED subscriptions, authentication, and services
- Looking for beta testers in March/April timeframe - email pavementmedesign@ara.com if interested
- Available for use in July 2023



PMED v2.6

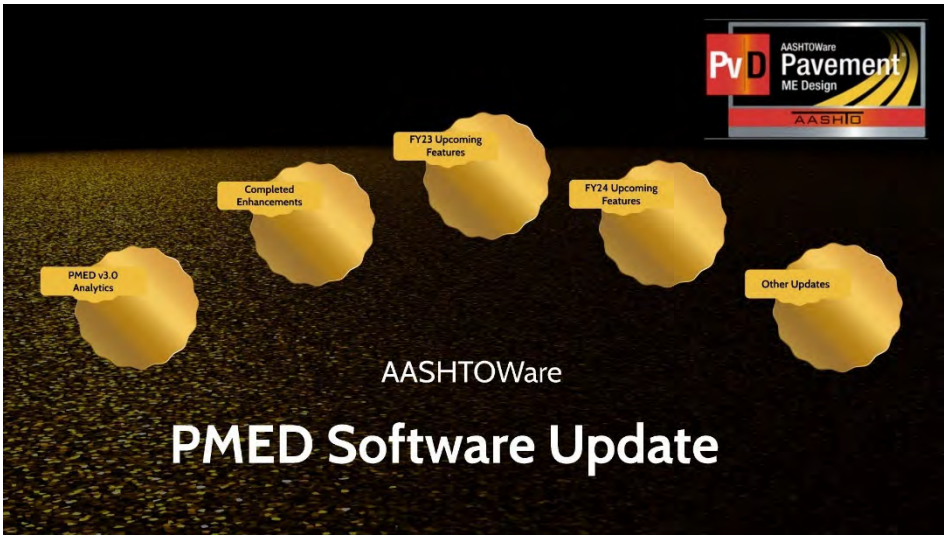
- PMED v2.6.2.2 was released which corrected a climate node issue.
- Corrected several small UI issues
- Note that v2.6.2.2 does not contain the JULEA performance improvements, nor does it contain the NCHRP 1-51 slab interface friction updates.

JULEA Refactoring

- Refactor for performance and maintainability
- Acheived a 40% performance boost in JULEA in PMED v3

PMED Future Releases

- PMED updates not affecting calibration or analysis results are released approximately every 2 weeks.
- PMED updates affecting calibration (including NCHRP integrations) will follow the PMED calibration guide recommendations with releases every 5 years


AASHTOWare
Pavement
ME Design
AASHTO
PvD
PMED v3.0 Analytics
Completed Enhancements
FY23 Upcoming Features
FY24 Upcoming Features
Other Updates
AASHTOWare
PMED Software Update

Presentation 4—Linda Pierce, NCE

NCHRP Projects

AASHTO ME User Group Meeting
November 2, 2022

NCE

Projects To Date

1-37A: 2002 Guide → Rudimentary Software
1-39: TrafLoad
9-30: HMA Performance Models
9-23: Environ. Effects
1-40A-D: MEPDG Implementation → Manual of Practice & Calibration Guide
1-42A: Top-Down Cracking (see 1-52)
9-38: Endurance Limit
9-44: Endurance Limit Plan
20-07(251): Consider Pavement Preservation in MEPDG

2004 | 2005 | 2006 | 2007 | 2008 | 2009

LEGEND:
Deliverable
NCHRP Project

NCE

Projects To Date (continued)

1-41: Reflection Cracking 2015
9-23A: Implement SWCC
9-23B: SWCC Catalog
9-30A: Calibration of Rutting Models 2014
20-07(317): Update Manual of Practice
20-05: MEPDG Implementation Synthesis
20-07(327): Recalibrated Concrete Models 2014

2010 | 2011 | 2012 | 2013 | 2014 | 2015

1-47: Sensitivity Evaluation
20-07(288): Rigid Model Calib. with Corrected CTE 2011
9-44A: Validate Endurance Limit
4-36: Cement Stabilized Layers 2018
1-48: Pavement Maintenance 2018 – reset surface distress (e.g., rutting, faulting, IRI)

LEGEND:
Year in PaveME

NCE

Projects To Date (continued)

1-51 Slab/Underlying Layer, global calibration, MERRA PMED 2022
1-50 Geosynthetics (priority 2021 – COMP review)
9-51 CIP/Reclamation Material Properties addendum
1-53 Subgrade/Unbound Layers (priority 2021 – COMP review)

2016 | 2017 | 2018 | 2019 | 2020 | 2021

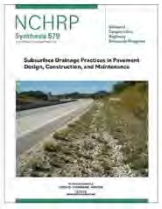
1-52 Top-Down Cracking 2018-19
20-07(422) Review Local Calibration Guide
9-54 Performance Prediction of Long-Term Aging (HMA)
20-50(21): Climatic Inputs and Related Models Using MERRA 2022

LEGEND:
Year in PaveME
Task Force decision
In progress

NCE

Recently "Completed"

- 1-59 Effects of Shrink/Swell and Frost Heave (2021)
  - Arizona State University, Dr. Zapata
- NCHRP Synthesis 579 Subsurface Drainage Practices in Pavement Design, Construction, and Maintenance (2022)



NCE

Anticipated

- NCHRP Project 9-67: New Materials & Technology Deployment in Asphalt Pavement Structural Design (2021)
  - Identify and develop methods for rapidly calibrating transfer functions for M-E design
- NCHRP Project 1-62: Impact of Flooding and Inundation on the Resiliency of Pavements (2023)

NCE

Project Summary

General (6)
- Rudimentary Software
- Manual of Practice & update
- Calibration Guide & User Review
- Sensitivity Evaluation

Traffic/Climate (2)
- TrafLoad
- MERRA-2

Subgrade/Base (7)
- SWCC
- Cementitious-Stabilized
- Geosynthetics
- Subgrade/Unbound Layers
- Shrink/Swell/Frost Heave

30+ projects, 25+ years, $20M+

Pres/Rehab (3)
- Considering preservation
- Incorporating preservation
- CIR/Reclamation

Concrete (4)
- Corrected CTE Values
- Recalibrated Models
- Modeling Slab/Underlying Layer
- BCOA

Asphalt (10)
- Rutting Model
- Endurance Limit
- Top-Down Cracking Model
- Reflection Cracking Model
- Long-Term Aging
- New Materials & Tech.
- Long-term aging

NCE

Questions?

Linda Pierce
Principal
lpierce@ncenet.com
(505) 603-7993

NCE

Presentation 5—Tom Yu, FHWA

Pavement-Design

Program Objectives and Priorities

Image Source: FHWA

H. Thomas Yu, P.E.
Program Manager, Pavement Design
Federal Highway Administration
Office of Infrastructure

October 2022

Disclaimer

Except for any statutes or regulations cited, the contents of this presentation do not have the force and effect of law and are not meant to bind the public in any way. This presentation is intended only to provide information to the public regarding existing requirements under the law or agency policies.

Pavement-Design Program

Vision

FHWA should lead the way to providing durable, long-life pavements that remain in excellent condition throughout their service lives

Approach

- Demonstrate performance and sustainability advantages of long-life, distress-free pavements
- Provide technical resources needed to improve long-term, pavement performance

Vision

US DOT Mission Statement
FY2022-26 Strategic Plan

"To deliver the world's leading transportation system, serving the American people and economy through the safe, efficient, sustainable, and equitable movement of people and goods." (emphasis added)

Pavement-Design Program

Strategic Objectives

- Improve pavement design and construction practices and promote transition to long-life pavements
- Provide resources for effective pavement rehabilitation
- Enhance resiliency of pavement structures

Keys to achieving well-performing pavement

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

Structural Model

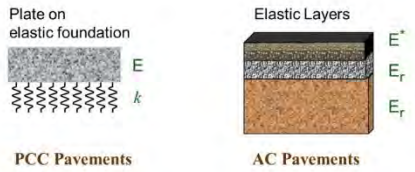


Image Source: FHWA

Foundation

- More emphasis should be given to foundation design in the U.S., especially for concrete pavements
  - Greater emphasis on the structural analysis
  - Difficult to quantify the benefit
- Good foundation design is essential to good pavement performance
  - Foundation performs important functions, which cannot be provided by the surface layer
  - The foundation layers must remain in good condition throughout the life of the pavement

Roman Road

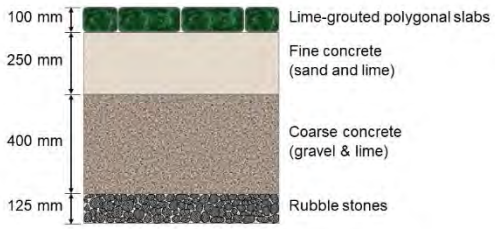


Image Source: FHWA

Thank you!

Tom Yu
tom.yu@dot.gov
202-366-1198

Presentation 6—Yasir Shah, Manitoba Infrastructure

PMED Trials by TAC ME Design Subcommittee

Sensitivity of PMED Software Predicted Distresses in JPCP to Subgrade, Base, Subbase and PCC Materials

Lead: M. Alauddin Ahammed, Ph.D., P. Eng.
Manager Pavement and Materials Section
Manitoba Transportation and Infrastructure

Presented by: Yasir Shah, P. Eng.,
Pavement Design Engineer

PMED National Users Group Meeting, Salt Lake City, Nov. 1-3, 2022

Acknowledgment

- Tetra Tech
- Alberta Transportation
- Saskatchewan Ministry of Highway and Infrastructure
- Manitoba Transportation and Infrastructure
- Ministry of Transportation Ontario
- Ministère des Transports du Québec
- Thurber Engineering Ltd.
- Cement Association of Canada

Introduction

- TAC ME Design Subcommittee completed many coordinated trials over the last several years
  - Results were presented in different meetings and conferences
- Current focus: Assess the effect of key inputs to JPCP design
  - This presentation covers the sensitivity of subgrade, base, subbase and PCC materials
- All participants used the PMED software v2.6 or 2.6.1
  - Limited trials were done using v3.0

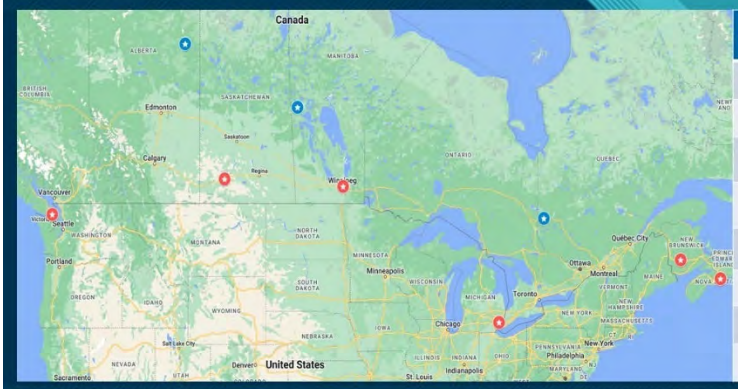
Fixed Input Parameters in All Trials

- Vehicle class distribution and ALS: Manitoba Level 1
- Joint configuration: 4.5 m spacing and 4.3 m wide
- Design life = 25 years
- Initial IRI = 1.0 m/km
- Reliability = 90%

PCC Trial #1- Effect of Subgrade Materials: Design Inputs

- Variable inputs
  - Five untreated subgrade materials
  - 300 mm crushed rock (CR-M50) subgrade
  - Varying climate across Canada
- Fixed inputs
  - Traffic loading: 1,000 trucks/day on design lane
  - Surface: 250 mm concrete (35 MPa; 340 kg/m^3 cm; 0.40 w/c)
  - Dowel size: 32 mm spaced at 300 mm c/c
  - Base layer: 200 mm GBC I (Mr = 250 MPa)

Selected Climate Stations Across Canada



Province	Stations
BC	Victoria
AB	Fort McMurray
SK	Swift Current
MB	Winnipeg, The Pas
ON	Windsor
QC	Rouyn
NS	Halifax
NB	Fredericton

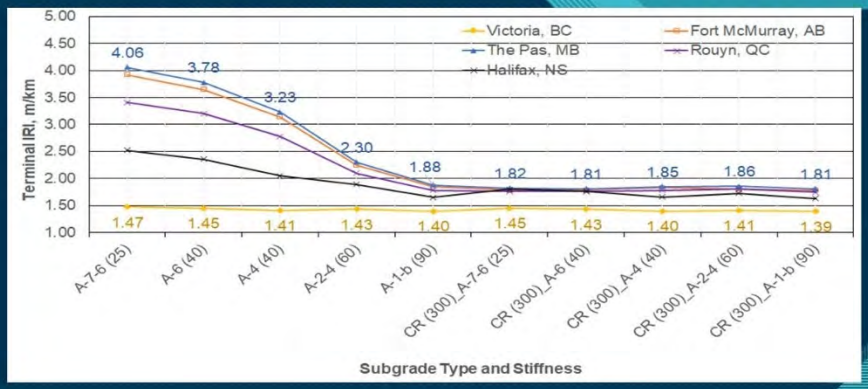
NARR/MERRA Climate Data Summary

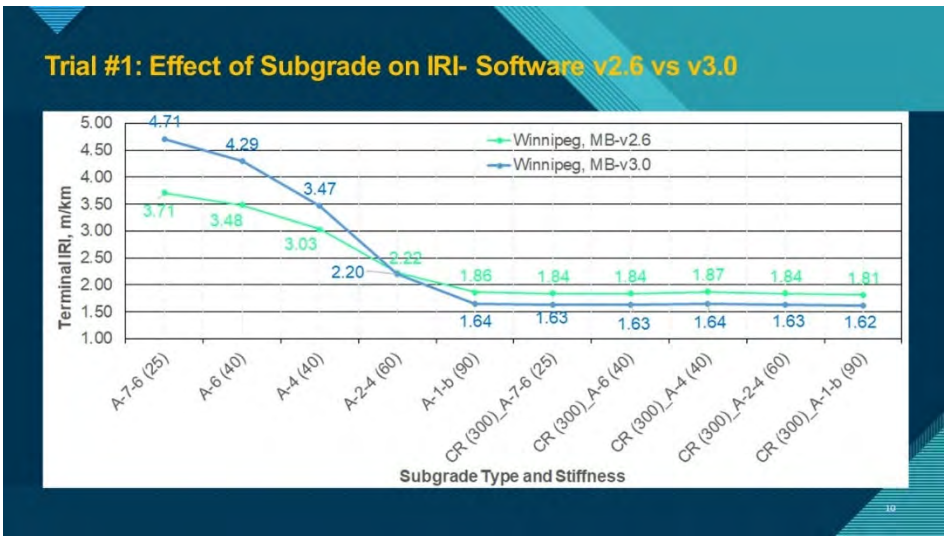
Climate Station	Mean Annual Air Temp. (°C)	Mean Annual Precipitation (mm)	Mean Annual Number of Wet Days	Mean Annual Freezing Index (°C-days)	Mean Annual No. Freeze-Thaw Cycles
Victoria, BC	10.6/10.9	1002/1494	221/333	1.1/10.4	1.2/7.2
Fort Mamurray, AB	1.9/1.4	567/643	241/339	1900/1926	47.2/72.3
Swift Current, SK	5.0/	414/	203/	1361/	50.5
Winnipeg, MB	4.0/3.3	506/623	205/302	1653/1760	36.2/67.6
The Pas, MB	1.7/0.4	477/600	219/329	2017/2357	43.4/59.1
Windsor, ON	10.0/9.6	776/1094	199/301	383/304	56.7/52.2
Rouyn, QC	3.5/2.1	890/1236	240/350	1443/1767	45.4/67.4
Halifax, NS	7.8/7.3	801/1584	211/340	432/315	69.8/68.8
Fredericton, NB	6.0/5.0	913/1426	220/344	819/996	72.3/81.0

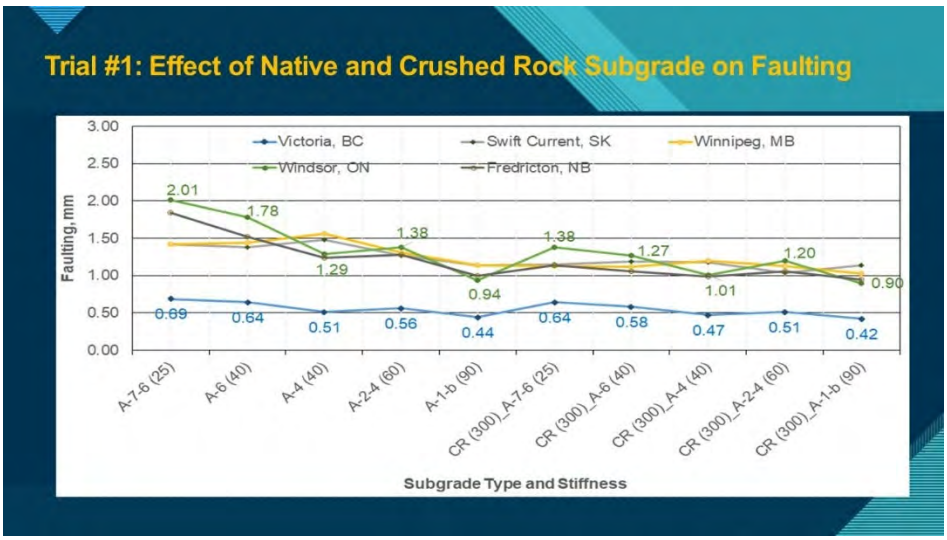
PCC Trial #1: Subgrade Types

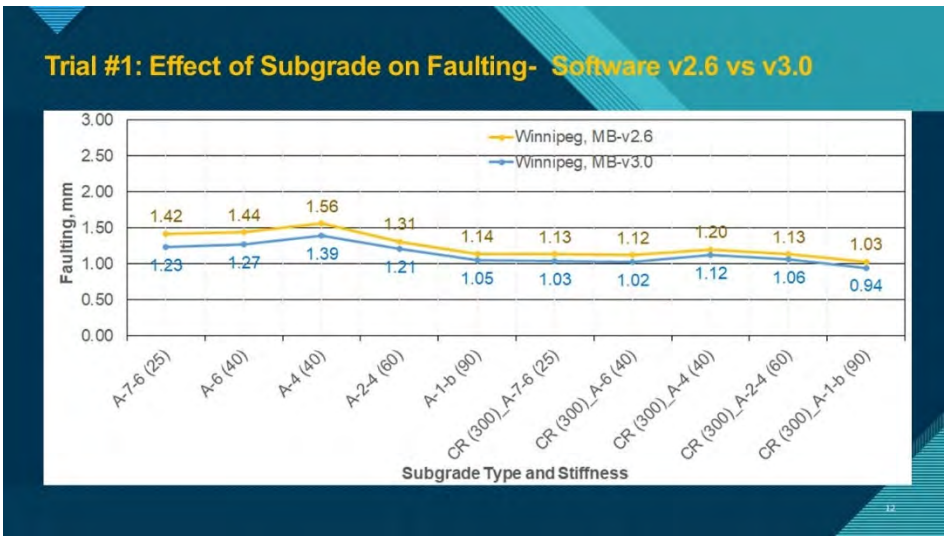
SG Class	Mr, MPa	Minus 4.75mm, %	Minus 0.075mm, %	Density, kg/m^3	MC, %	LL, %	PI, %
A-7-6 (HP Clay)	25	99.0	92.0	1410	33.0	79	49
A-6 (LP Clay)	40	99.2	80.0	1650	21.5	38	20
A-4 (Sandy Silt)	40	92.0	56.0	1780	22.5	25	3
A-2-4 (Silty Sand)	60	91.0	22.0	1710	15.3	18	3
A-1-b (Gran. Fill)	90	81.0	8.4	2075	8.5	14	0
CR- M50	250	29.6	7.8	2065	6.8	NP	NP

Trial #1: Effect of Native and Crushed Rock Subgrade on IRI

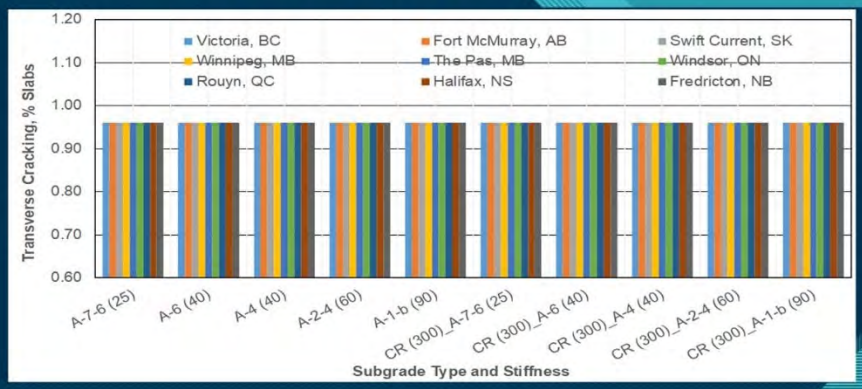



Trial #1: Effect of Subgrade on IRI- Software v2.6 vs v3.0
Winnipeg, MB-v2.6
Winnipeg, MB-v3.0
Terminal IRI, m/km
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
4.71
4.29
3.47
2.20
3.71
3.48
3.03
2.22
1.86
1.84
1.84
1.87
1.84
1.81
1.64
1.63
1.63
1.64
1.63
1.62
A-7-6 (25)
A-6 (40)
A-4 (40)
A-2-4 (60)
A-1-b (90)
CR (300)_A-7-6 (25)
CR (300)_A-6 (40)
CR (300)_A-4 (40)
CR (300)_A-2-4 (60)
CR (300)_A-1-b (90)
Subgrade Type and Stiffness

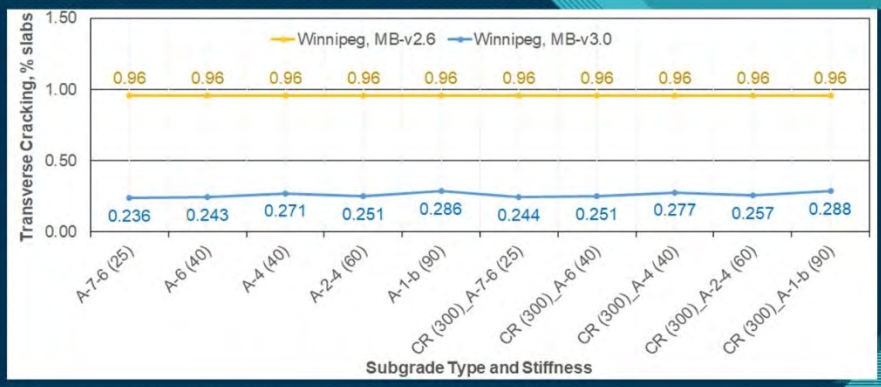

Trial #1: Effect of Native and Crushed Rock Subgrade on Faulting
Victoria, BC
Swift Current, SK
Winnipeg, MB
Windsor, ON
Fredricton, NB
Faulting, mm
3.00
2.50
2.00
1.50
1.00
0.50
0.00
2.01
1.78
1.29
1.38
0.94
1.38
1.27
1.01
1.20
0.90
0.69
0.64
0.51
0.56
0.44
0.64
0.58
0.47
0.51
0.42
A-7-6 (25)
A-6 (40)
A-4 (40)
A-2-4 (60)
A-1-b (90)
CR (300)_A-7-6 (25)
CR (300)_A-6 (40)
CR (300)_A-4 (40)
CR (300)_A-2-4 (60)
CR (300)_A-1-b (90)
Subgrade Type and Stiffness


Trial #1: Effect of Subgrade on Faulting- Software v2.6 vs v3.0
Winnipeg, MB-v2.6
Winnipeg, MB-v3.0
Faulting, mm
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1.42
1.44
1.56
1.31
1.14
1.13
1.12
1.20
1.13
1.03
1.23
1.27
1.39
1.21
1.05
1.03
1.02
1.12
1.06
0.94
A-7-6 (25)
A-6 (40)
A-4 (40)
A-2-4 (60)
A-1-b (90)
CR (300)_A-7-6 (25)
CR (300)_A-6 (40)
CR (300)_A-4 (40)
CR (300)_A-2-4 (60)
CR (300)_A-1-b (90)
Subgrade Type and Stiffness

Trial #1: Effect of Subgrade on Transverse Cracking



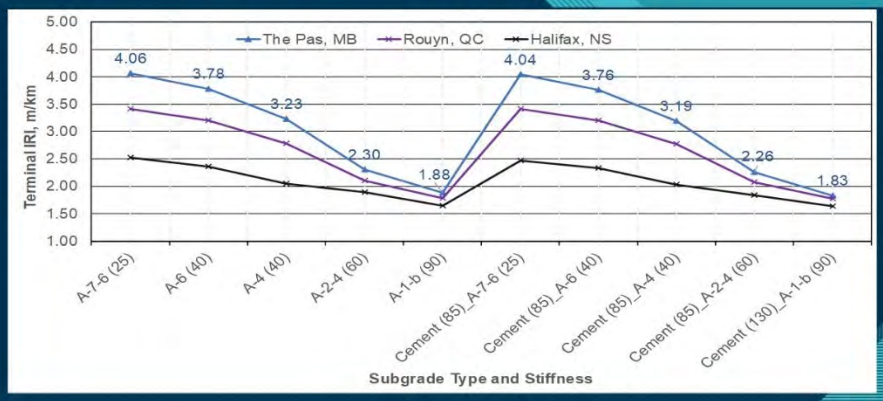
Trial #1: Effect of Subgrade on Cracking- Software v2.6 vs v3.0



PCC Trial #1- Soil Cement as Subgrade

- PMED does not allow soil cement below the subbase
- We can consider soil cement a granular subgrade with a high modulus value
  - However, gradation and physical properties inputs are still required in that case
- Trials were also done with soil cement as subgrade materials
  - Used higher moduli values than native subgrade
  - There was no significant effect of soil cement on the predicted distresses using this approach

Trial #1: Effect of Soil Cement as Subgrade on IRI



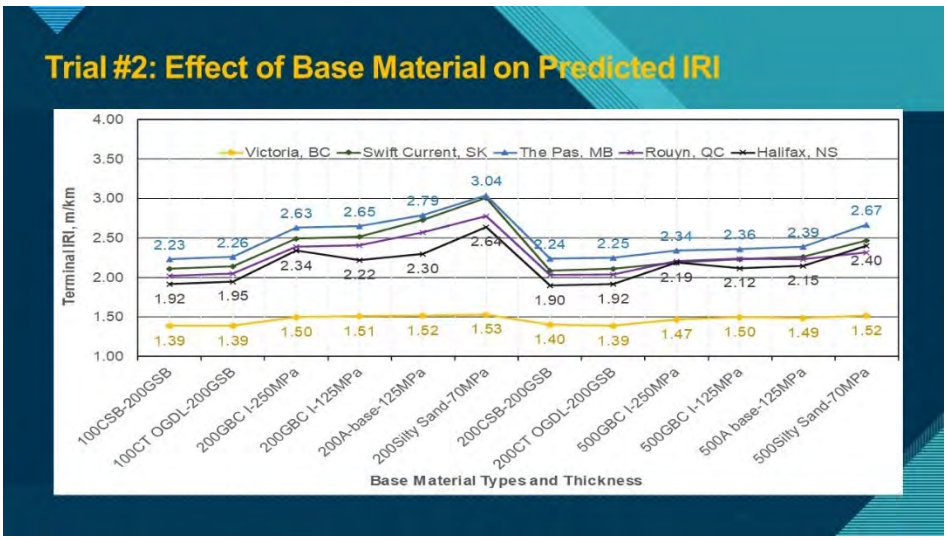
PCC Trial #2- Effect of Base/Subbase: Design Inputs

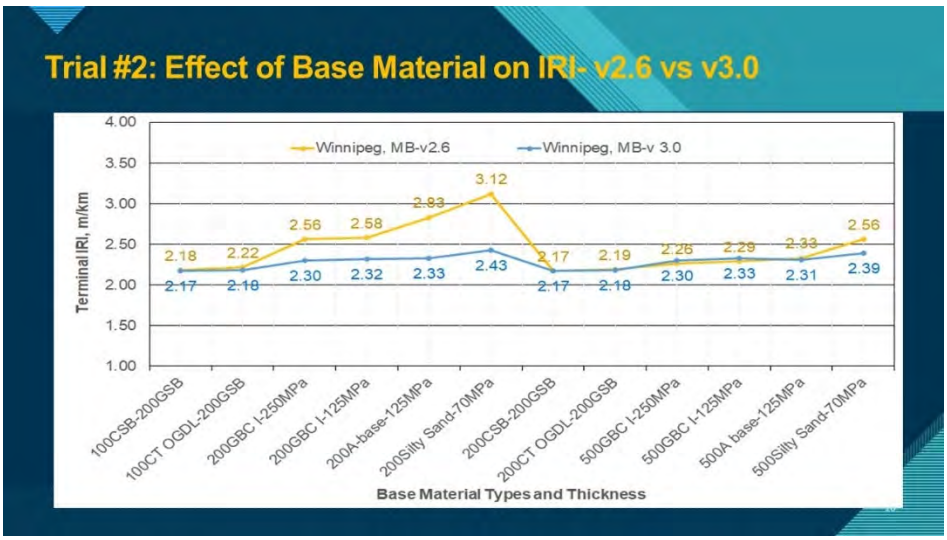
- Variable inputs
  - Five different base materials (cement stabilized and unbound granular)
  - Two different subbase materials (unbound granular)
  - Varying thickness of base and subbase materials
- Fixed inputs
  - Traffic loading: 2,000 trucks per day on the design lane
  - Surface: 200 mm concrete
  - Dowel size: 28 mm
  - Subgrade: Silty Sand (A-2-4) with Mr = 60 MPa

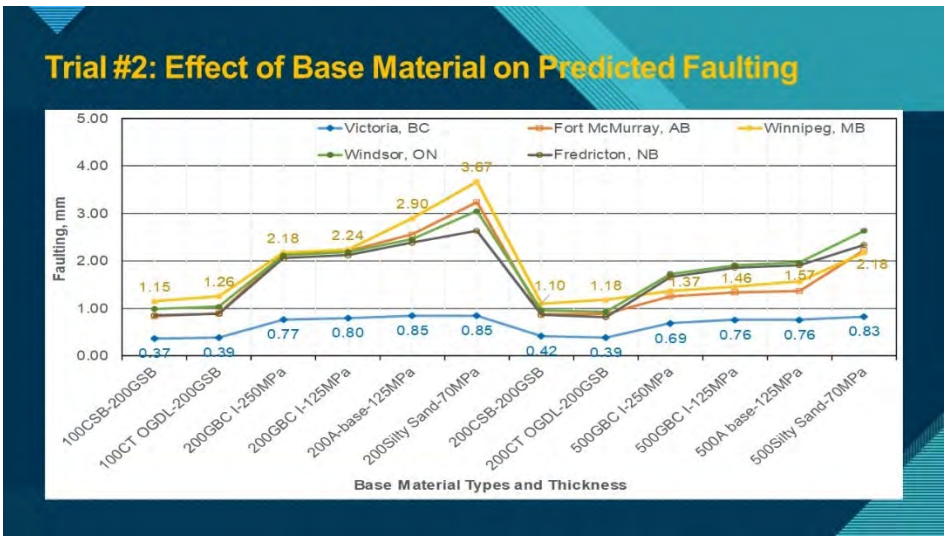
Trial #2: Base/Subbase Inputs

Base/Subbase Materials	Thickness, mm	E or Mr, MPa	Minus 4.75mm, %	Minus 0.075mm, %	Density, kg/m^3	MC, %	LL, %	PI, %
*Cement stabilized base (Default), EI = 1	100/ 200	13,790						
*OGDL (ON), EI = 2	100/ 200	5,170						
GBC- I (MB), EI = 3	200/ 500	250/ 125	55	4.9	2240	7.1	13	0
Gran. A (MB- Old), EI = 4	200/ 500	125	61	12.4	2240	8.5	20	4
A-2-4 (Silty Sand), EI = 5	200/ 500	70	91.0	22.0	1764	15.3	18	3
CR- M50 (MB SB)**	200/ 500	200	29.6	7.8	2065	6.8	NP	NP
SK Subbase**	200/ 500	100	87	7.0	1989	9.2	25	6

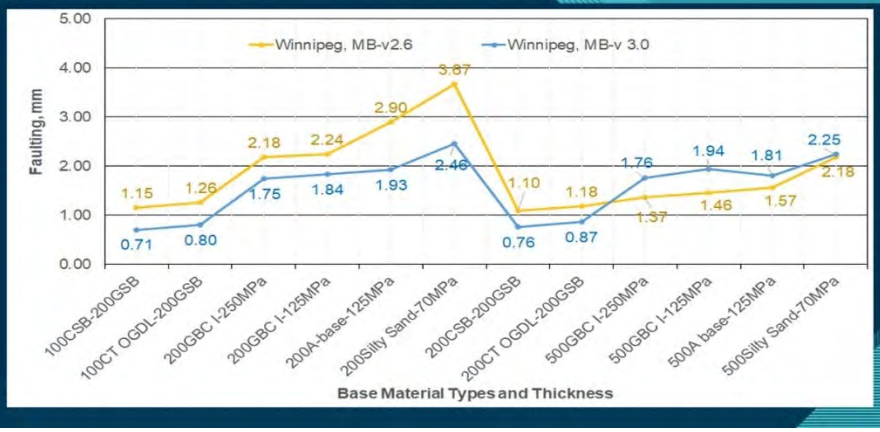
*** With 200 mm GBC- I as subbase layer; ** with 100 mm GBC- I as base layer**


Trial #2: Effect of Base Material on Predicted IRI
Victoria, BC
Swift Current, SK
The Pas, MB
Rouyn, QC
Halifax, NS
Terminal IRI, m/km
4.00
3.50
3.00
2.50
2.00
1.50
1.00
2.23 2.26 2.63 2.65 2.79 3.04 2.24 2.25 2.34 2.36 2.39 2.67
1.92 1.95 2.34 2.22 2.30 2.64 1.90 1.92 2.19 2.12 2.15 2.40
1.39 1.39 1.50 1.51 1.52 1.53 1.40 1.39 1.47 1.50 1.49 1.52
100CSB-200GSB
100CT OGDL-200GSB
200GBC I-250MPa
200GBC I-125MPa
200A-base-125MPa
200Silty Sand-70MPa
200CSB-200GSB
200CT OGDL-200GSB
500GBC I-250MPa
500GBC I-125MPa
500A base-125MPa
500Silty Sand-70MPa
Base Material Types and Thickness

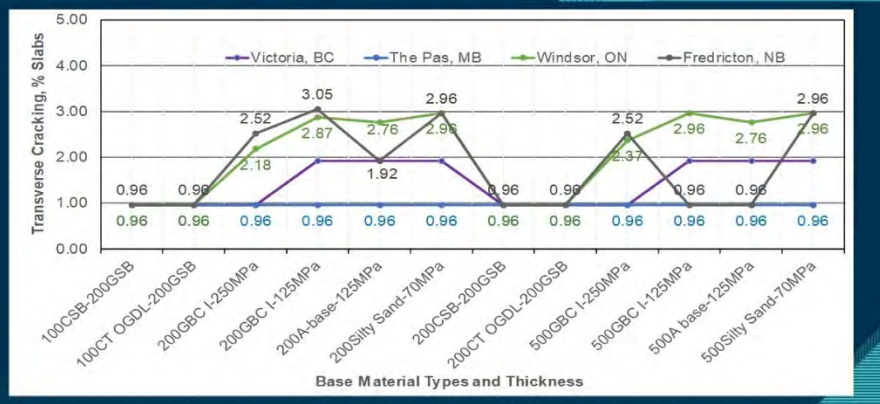

Trial #2: Effect of Base Material on IRI- v2.6 vs v3.0
Winnipeg, MB-v2.6
Winnipeg, MB-v 3.0
Terminal IRI, m/km
4.00
3.50
3.00
2.50
2.00
1.50
1.00
2.18 2.22 2.56 2.58 2.83 3.12 2.17 2.19 2.25 2.29 2.33 2.56
2.17 2.18 2.30 2.32 2.33 2.43 2.17 2.18 2.30 2.33 2.31 2.39
100CSB-200GSB
100CT OGDL-200GSB
200GBC I-250MPa
200GBC I-125MPa
200A-base-125MPa
200Silty Sand-70MPa
200CSB-200GSB
200CT OGDL-200GSB
500GBC I-250MPa
500GBC I-125MPa
500A base-125MPa
500Silty Sand-70MPa
Base Material Types and Thickness


Trial #2: Effect of Base Material on Predicted Faulting
Victoria, BC
Fort McMurray, AB
Winnipeg, MB
Windsor, ON
Fredricton, NB
Faulting, mm
5.00
4.00
3.00
2.00
1.00
0.00
1.15 1.26 2.18 2.24 2.90 3.67 1.10 1.18 1.37 1.46 1.57 2.18
0.37 0.39 0.77 0.80 0.85 0.85 0.42 0.39 0.69 0.76 0.76 0.83
100CSB-200GSB
100CT OGDL-200GSB
200GBC I-250MPa
200GBC I-125MPa
200A-base-125MPa
200Silty Sand-70MPa
200CSB-200GSB
200CT OGDL-200GSB
500GBC I-250MPa
500GBC I-125MPa
500A base-125MPa
500Silty Sand-70MPa
Base Material Types and Thickness

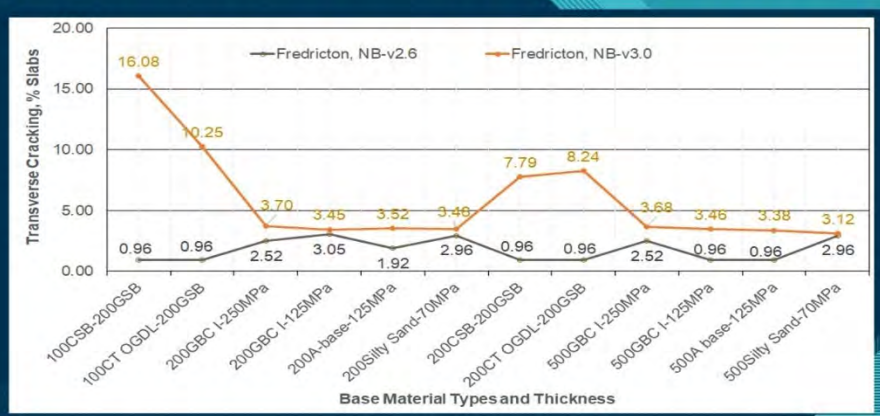
Trial #2: Effect of Base Material on Faulting- v2.6 vs v3.0



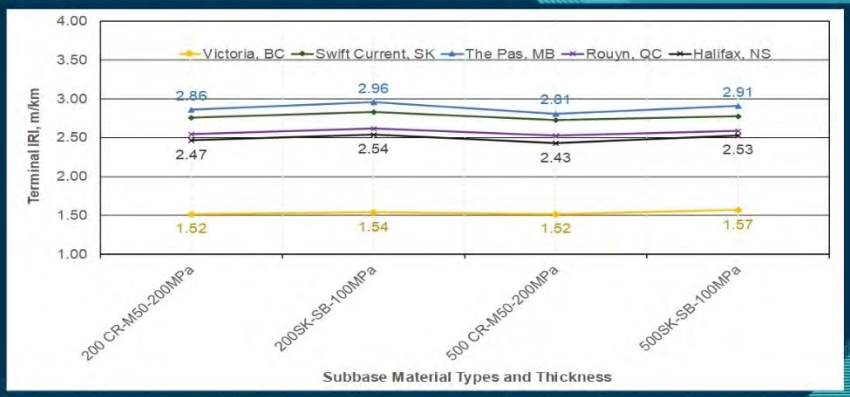
Trial #2: Effect of Base Material on Transverse Cracking



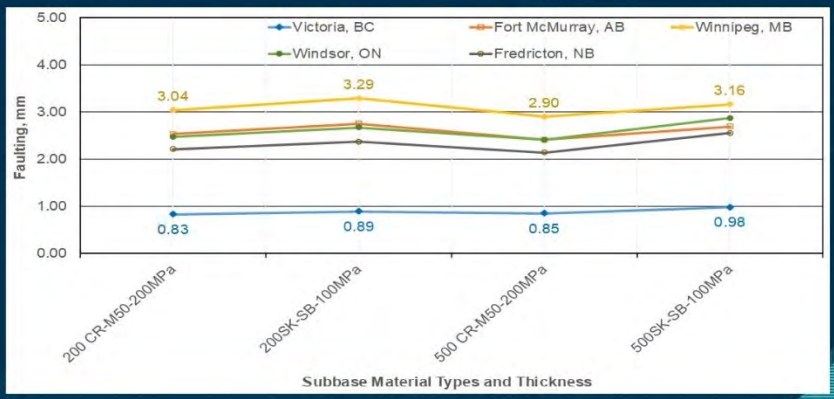
Trial #2: Effect of Base Material on Cracking- v2.6 vs v3.0



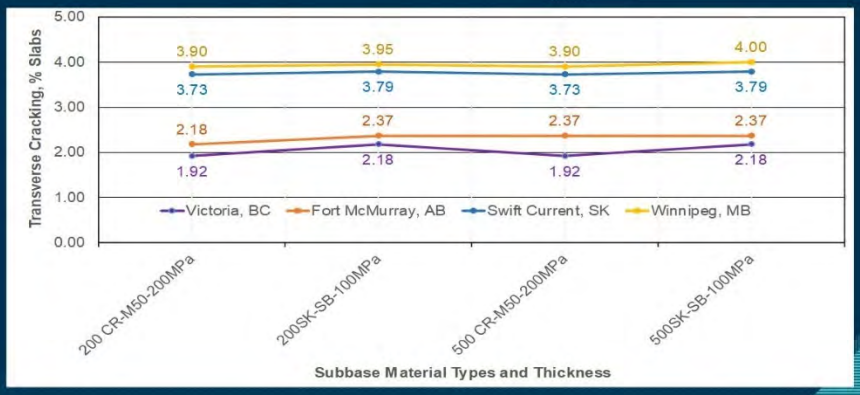
Trial #2: Effect of Subbase on Predicted IRI



Trial #2: Effect of Subbase on Predicted Faulting



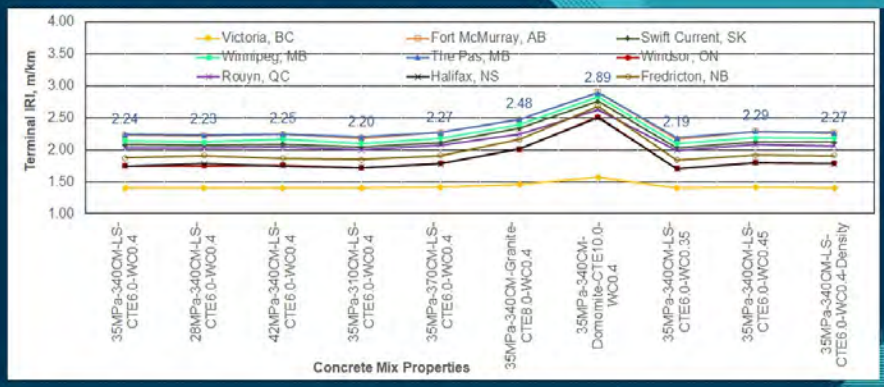
Trial #2: Effect of Subbase on Transverse Cracking



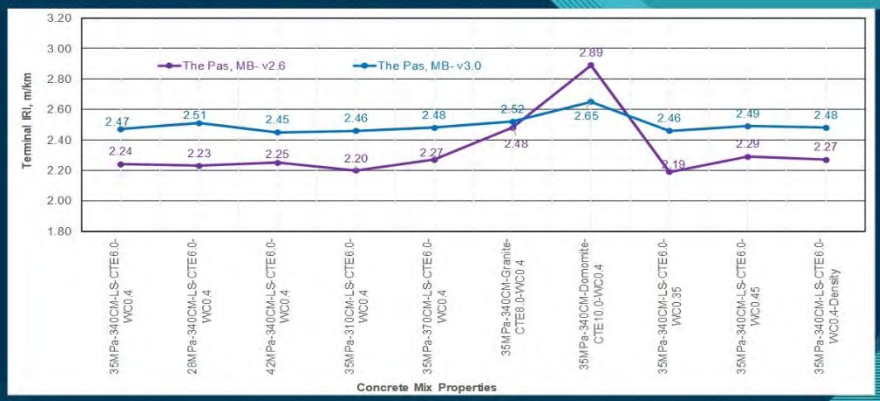
PCC Trial #3- Effect of PCC Mix Properties: Design Inputs

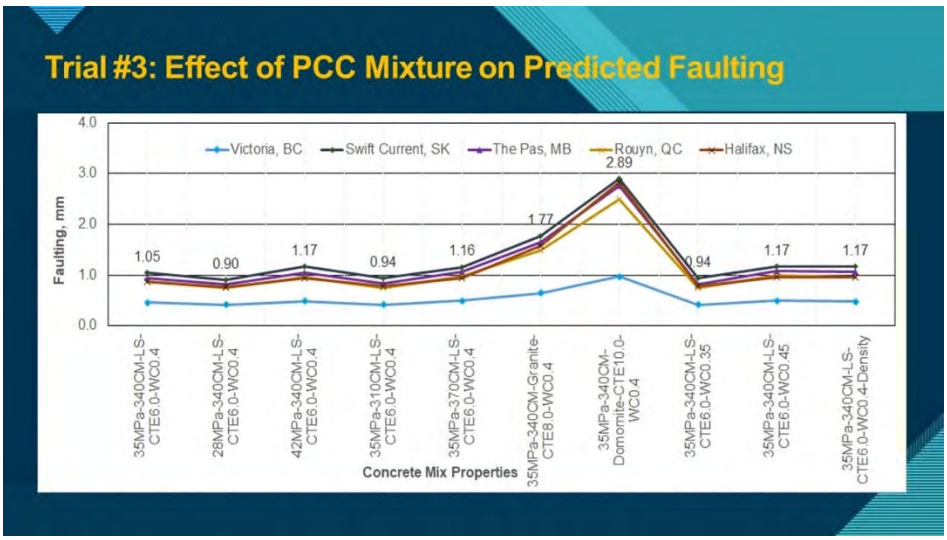
- Variable inputs:
  - Compressive strength
  - Cementitious materials content
  - Coefficient of thermal expansion (CTE)
  - w/c ratio
  - Mix density
- Fixed inputs
  - Same as Trial #2, except 200 mm GBC I with a Mr of 250 MPa was used

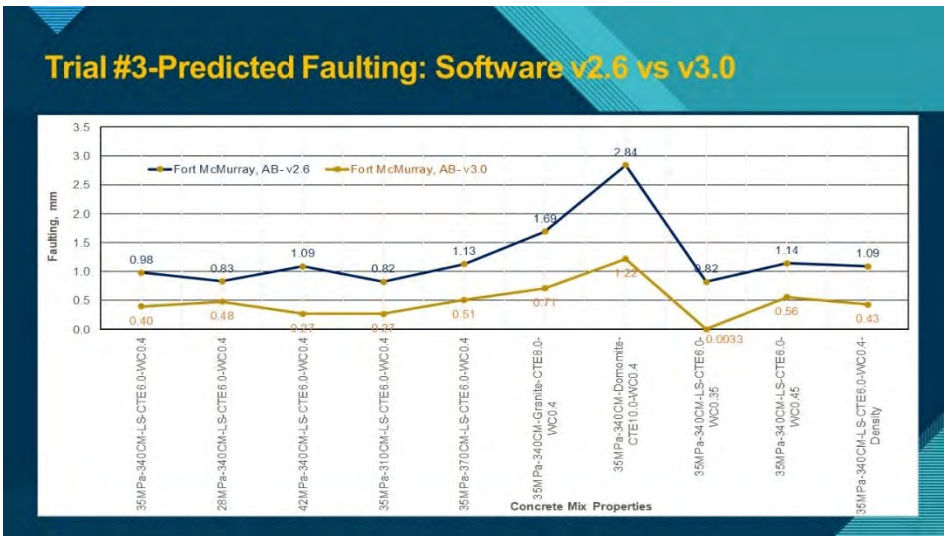
Trial #3: Effect of PCC Mixture on Predicted IRI

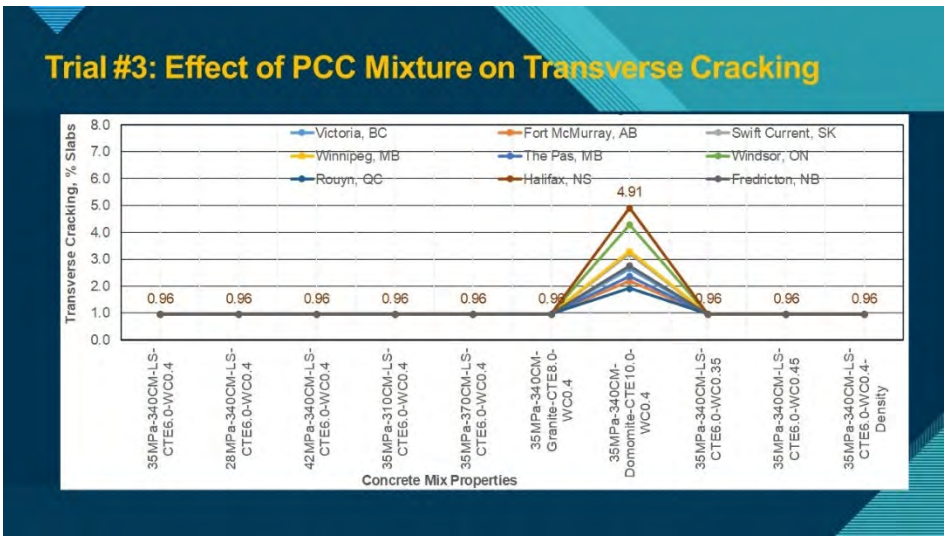


Trial #3- Predicted IRI: Software v2.6 vs v3.0

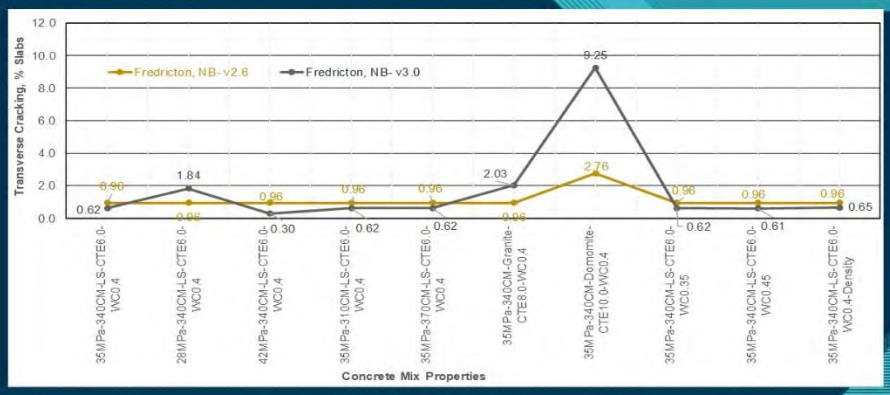



Trial #3: Effect of PCC Mixture on Predicted Faulting
Victoria, BC
Swift Current, SK
The Pas, MB
Rouyn, QC
Halifax, NS
Faulting, mm
4.0
3.0
2.0
1.0
0.0
1.05
0.90
1.17
0.94
1.16
1.77
2.89
0.94
1.17
1.17
35MPa-340CM-LS-CTE6.0-WC0.4
28MPa-340CM-LS-CTE6.0-WC0.4
42MPa-340CM-LS-CTE6.0-WC0.4
35MPa-310CM-LS-CTE6.0-WC0.4
35MPa-370CM-LS-CTE6.0-WC0.4
35MPa-340CM-Granite-CTE8.0-WC0.4
35MPa-340CM-Domomite-CTE10.0-WC0.4
35MPa-340CM-LS-CTE6.0-WC0.35
35MPa-340CM-LS-CTE6.0-WC0.45
35MPa-340CM-LS-CTE6.0-WC0.4-Density
Concrete Mix Properties


Trial #3-Predicted Faulting: Software v2.6 vs v3.0
Fort McMurray, AB- v2.6
Fort McMurray, AB- v3.0
Faulting, mm
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.98
0.83
1.09
0.82
1.13
1.69
2.84
0.82
1.14
1.09
0.40
0.48
0.51
0.71
1.22
0.0033
0.56
0.43
35MPa-340CM-LS-CTE6.0-WC0.4
28MPa-340CM-LS-CTE6.0-WC0.4
42MPa-340CM-LS-CTE6.0-WC0.4
35MPa-310CM-LS-CTE6.0-WC0.4
35MPa-370CM-LS-CTE6.0-WC0.4
35MPa-340CM-Granite-CTE8.0-WC0.4
35MPa-340CM-Domomite-CTE10.0-WC0.4
35MPa-340CM-LS-CTE6.0-WC0.35
35MPa-340CM-LS-CTE6.0-WC0.45
35MPa-340CM-LS-CTE6.0-WC0.4-Density
Concrete Mix Properties


Trial #3: Effect of PCC Mixture on Transverse Cracking
Victoria, BC
Fort McMurray, AB
Swift Current, SK
Winnipeg, MB
The Pas, MB
Windsor, ON
Rouyn, QC
Halifax, NS
Fredricton, NB
Transverse Cracking, % Slabs
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.96
0.96
0.96
0.96
0.96
0.96
4.91
0.96
0.96
0.96
35MPa-340CM-LS-CTE6.0-WC0.4
28MPa-340CM-LS-CTE6.0-WC0.4
42MPa-340CM-LS-CTE6.0-WC0.4
35MPa-310CM-LS-CTE6.0-WC0.4
35MPa-370CM-LS-CTE6.0-WC0.4
35MPa-340CM-Granite-CTE8.0-WC0.4
35MPa-340CM-Domomite-CTE10.0-WC0.4
35MPa-340CM-LS-CTE6.0-WC0.35
35MPa-340CM-LS-CTE6.0-WC0.45
35MPa-340CM-LS-CTE6.0-WC0.4-Density
Concrete Mix Properties

Trial #3- Predicted Transverse Cracking: Software v2.6 vs 3.0



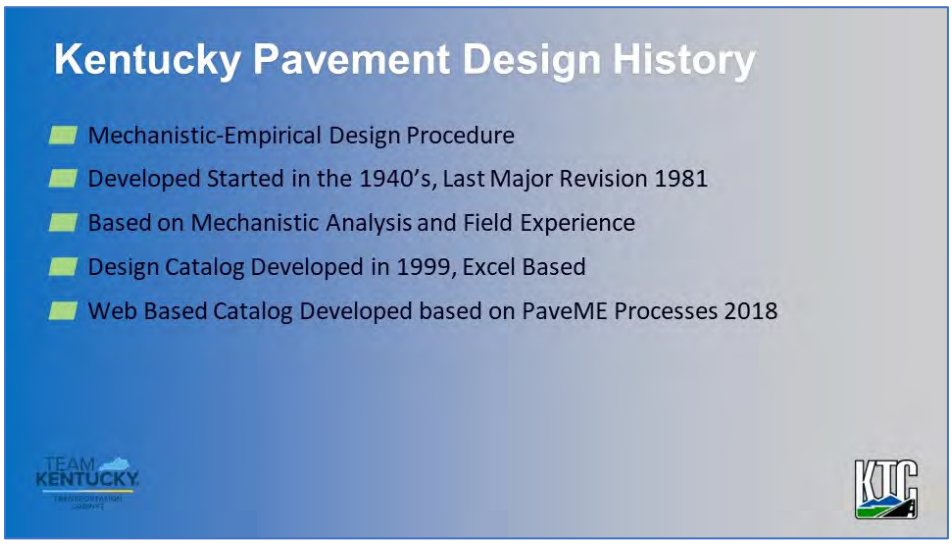
Upcoming Design Trials

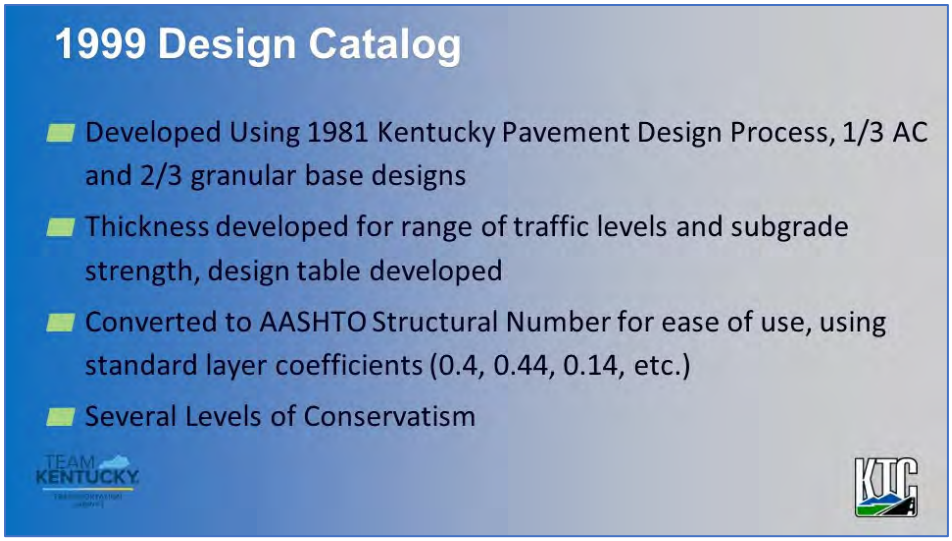
- Thickness and joint configuration
  - Vary concrete thickness together with CTE
  - Vary joint spacing
  - Vary dowels: Un-dowelled vs different dowel sizes
- Vary traffic loading

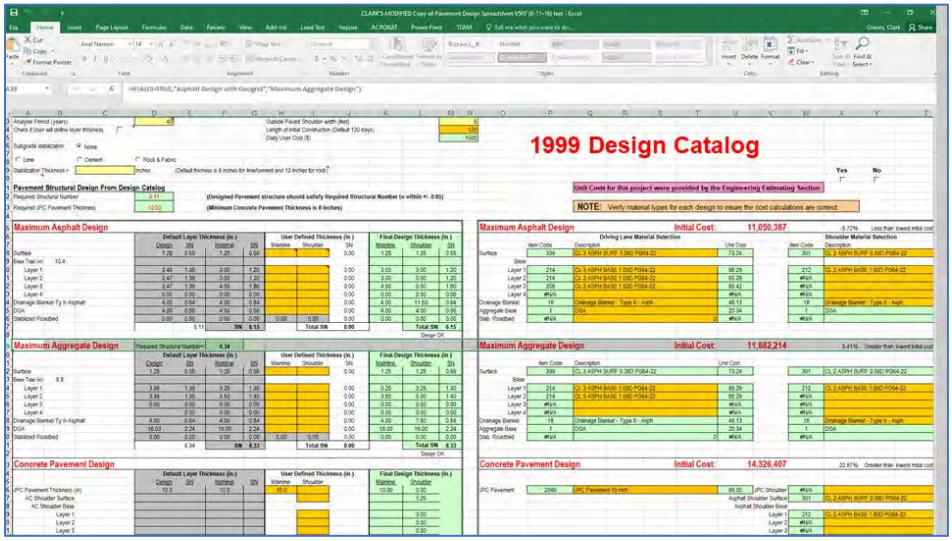
Thank You

Questions or Comments?

Presentation 7—Clark Graves, Kentucky Transportation Center







Why An Updated Design Catalog

- Easy transition from current catalog system
- Efficiently develop pavements designs by engineers with limited PaveME experience
- Consistent cost estimation process
- PaveME to be use for specialized designs and forensic evaluations
- State Highway Engineer's Office looking for quick implementation

Web-Based Design Catalog Development

- Developed design space of typical designs
- Standard DGA Thicknesses
- Standard HMA and PCC Mix Properties from historical designs
- Typical subgrade strengths and properties
- Formulate for easy transition from current design catalog and design process

PROGRAM DEVELOPMENT

- Table of possible solutions based on results from PaveME
- Calibration/Verification done using surrounding states calibration factors and Kentucky verification sites
  - Various thicknesses, traffic levels and subgrade strengths
    - Traffic Levels AADTT from 100 – 11,000
    - Base AC Thicknesses from 6.75” – 15.75”
    - PCC Thickness 7” to 13”
    - Subgrade CBR from 1 to 11 (Kentucky CBR)
    - Minimum AC Design 6.75” AC over 6” DGA
    - Maximum AC Design 14” AC over 6” DGA

Program Development (Cont.)

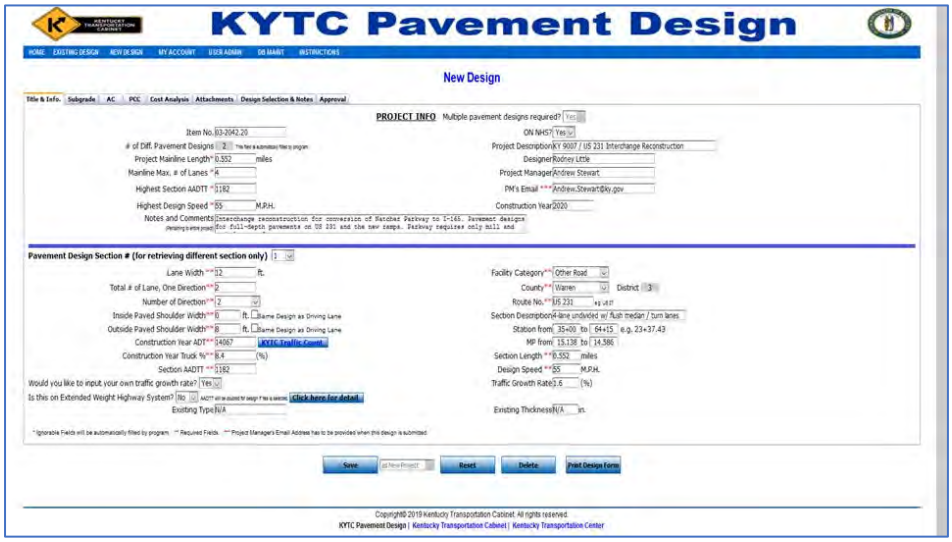
- Using standard default input values for materials from historical data
- Performance thresholds selected
- Version 2.3
  - 10% fatigue cracking
  - 0.25-inch rutting
  - 0.1-inch Transverse Faulting for PCC Pavements
  - Performance Thresholds are fixed can’t be changed, same for all roadway types
  - Reliability 95%
- Design table developed based on AADTT and subgrade strength
- Essentially just an update to the current process, using PaveME

Web Based Design Process

- Replacement of previous Excel Pavement Design Spreadsheet
- Based on AASHTO PaveME design process
- Web-Based Tool
- Provides tracking of designs and approvals
- User Credentials Required
- http://kytcpavementdesign.engr.uky.edu/

Title and Information Page

- Project Manager must be KYTC Employee
- AADT vs AADTT
  - AADT – Average Annual Daily Traffic
  - AADTT – Average Annual Daily Truck Traffic
- Project may have several pavement design sections
- Is project on Extended Weight System



Project Subgrade

- Current Catalog uses CBR
  - Will be transitioning to average Resilient Modulus in the future
  - On hold for now
  - …stay tuned
- Multiple Subgrade Stabilization Options
- Add section on chemical benefit
- CBR less than 6 requires stabilization
- Chemical is preferred, constructability may impact decision

Project Subgrade Cont.

- Multiple Subgrade Stabilization Options
  - Chemical Stabilization (Cement and Lime)
  - Geogrid/Fabric + 6 inches additional DGA
  - Fabric Wrapped #2/#3 Stone
- CBR less than 6 requires stabilization
- Chemical is preferred, constructability may impact decision

Stabilization Options

Design CBR # 3 Preferably from Geotechnical Report, but may be estimated based on previous reports or local knowledge. Use 3 if small project and no other known soil information.

Design M_R # Preferably from Geotechnical Report, but may be estimated as 1500 X CBR.

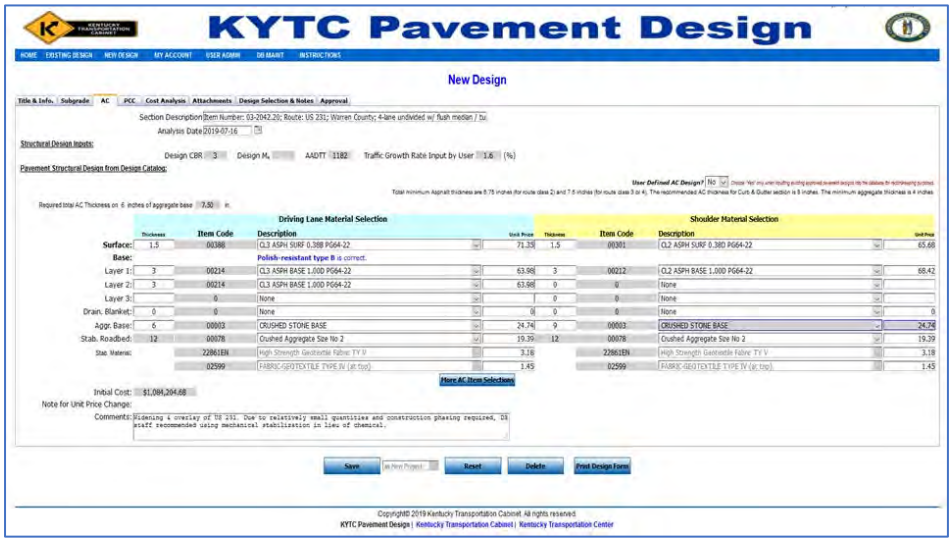
Geotechnical Report stabilization recommendation: None

Chosen Stabilization Method:

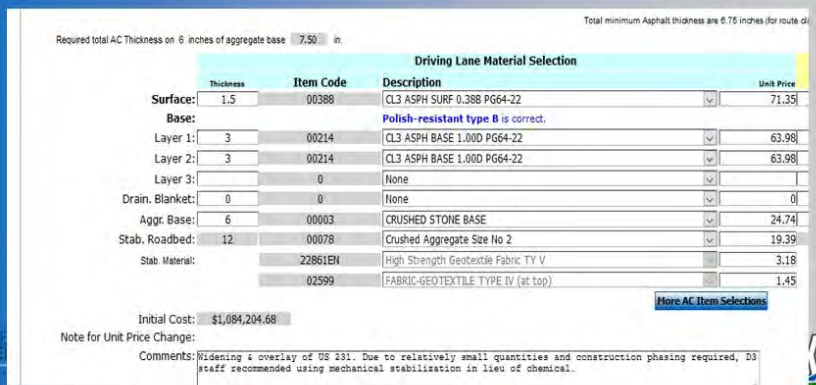
- ☐ Chemical Stabilization Note: May be cement or lime stabilized as determined by the Geotechnical Branch. Typically provides the most economical pavement design.
- ☐ Geogrid, Fabric, & 6 additional inches of DGA/CSB
- ☑ 2s, 3s, or 23s underlain with TY V fabric and TY IV Fabric on Top: Depth = 12 in. (Minimum 12")
- ☐ Other: Note: May not be accurately accounted for structurally in the pavement design.
- ☐ None Note: Not recommended in most instances.

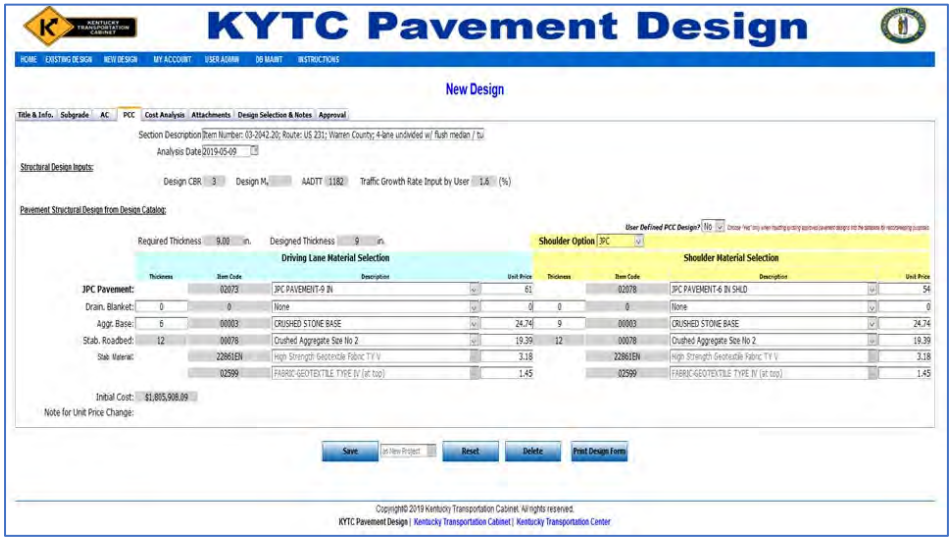
AC and PCC Designs

- Standard Design Process
- Making modifications to default information
- Comments/Note Section …use this section if making changes that are not matching the program, example would be matching existing, etc..
- User Defined Design



AC Design Information





PCC Design Information

Pavement Structural Design from Design Catalog:

Required Thickness 9.00 in. Designed Thickness 9 in.

Driving Lane Material Selection

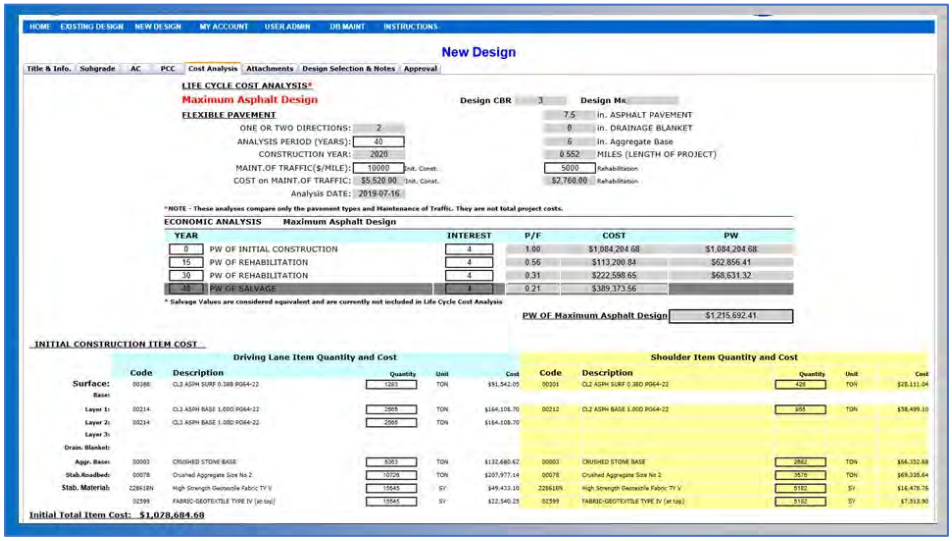
	Thickness	Item Code	Description	Unit Price
JPC Pavement:		02073	JPC PAVEMENT-9 IN	61
Drain. Blanket:	0	0	None	0
Aggr. Base:	6	00003	CRUSHED STONE BASE	24.74
Stab. Roadbed:	12	00078	Crushed Aggregate Size No 2	19.39
Stab. Material:		22861EN	High Strength Geotextile Fabric TY V	3.18
		02599	FABRIC-GEOTEXTILE TYPE IV (at top)	1.45

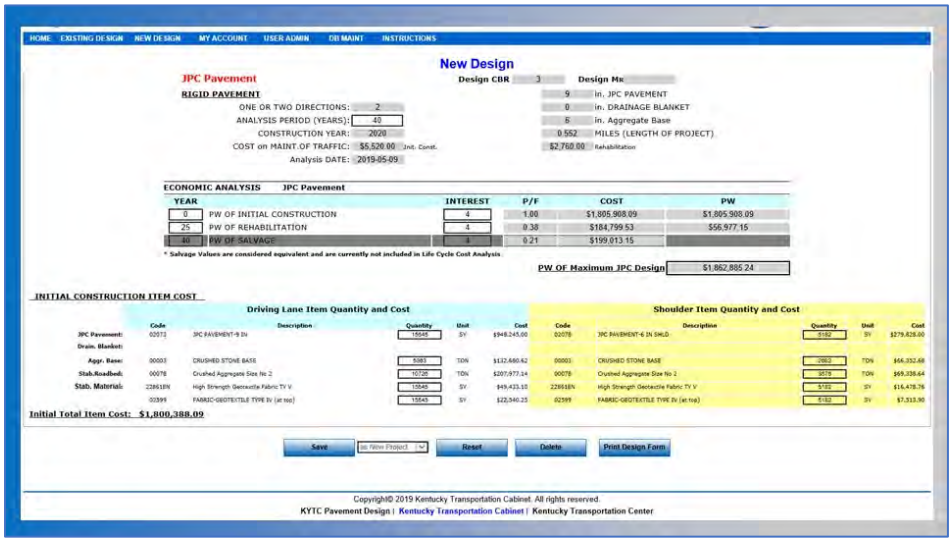
Initial Cost: $1,805,908.09

Note for Unit Price Change:

Cost Analysis

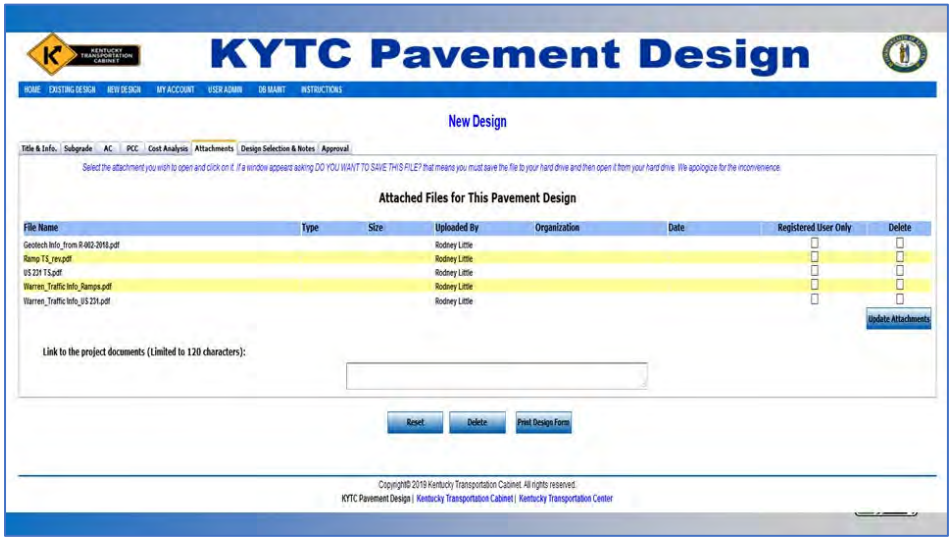
- Cost analysis, for project decision making only
- LCCA with fixed rehabilitation intervals based on roadway type
  - Interstate/Parkways, AC – 10 years, PCC – 15 years
  - Other Routes, AC – 15 years, PCC 25 years
- MOT cost, initial and future rehabilitations
- Present Worth Analysis





Project Attachments

- Examples
  - Typical Sections
  - Traffic Forecast
  - Geotechnical Report
  - Design Executive Summary
  - Etc.


KYTC Pavement Design
HOME EXISTING DESIGN NEW DESIGN MY ACCOUNT USER ADMIN DB MAINT INSTRUCTIONS
New Design
Title & Info. Subgrade AC PCC Cost Analysis Attachments Design Selection & Notes Approval
Select the attachment you wish to open and click on it. If a window appears asking DO YOU WANT TO SAVE THIS FILE? that means you must save the file to your hard drive and then open it from your hard drive. We apologize for the inconvenience.
Attached Files for This Pavement Design
File Name Type Size Uploaded By Organization Date Registered User Only Delete
Geotech Info_from R-062-2018.pdf Rodney Little
Ramp TS_rev.pdf Rodney Little
US 231 TS.pdf Rodney Little
Warren_Traffic Info_Ramps.pdf Rodney Little
Warren_Traffic Info_US 231.pdf Rodney Little
Update Attachments
Link to the project documents (Limited to 120 characters):
Reset Delete Print Design Form
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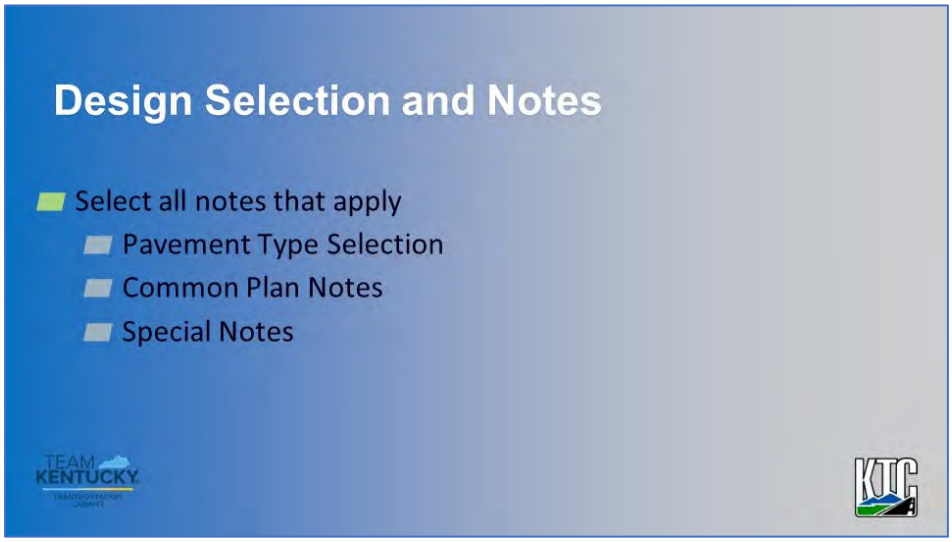
KYTC Pavement Design | Kentucky Transportation Cabinet | Kentucky Transportation Center


Design Selection and Notes
Select all notes that apply
Pavement Type Selection
Common Plan Notes
Special Notes
TEAM KENTUCKY
KTC

KYTC Pavement Design
HOME EXISTING DESIGN NEW DESIGN MY ACCOUNT USER ADMIN DB MAINT INSTRUCTIONS
New Design
Title & Info. Subgrade AC PCC Cost Analysis Attachments Design Selection & Notes Approval
Pavement Design Selected:* Asphalt Pavement
Pavement Design Notes: (Select following notes for this design by checking the front check box)
Common Plan Notes
233 – Earthwork adjustments for alternate pavement designs
275 – Cement stabilized roadbed
276 – Lime stabilized roadbed
444a – Asphalt pavement ride quality (specify category A) (>0.4 mi. unbroken length, all interstate/parkways)
444b – Asphalt pavement ride quality (specify category B) (>0.4 mi. unbroken length, all interstate/parkways)
447 – Specifies Compaction option A (<1000 tons of any one mix)
448 – Specifies Compaction option B (<1000 tons of any one mix)
455 – Edge Key
555a – JPC ride quality (specify category A) (>0.4 miles unbroken length, all interstate/parkways)
555b – JPC ride quality (specify category B) (>0.4 miles unbroken length, all interstate/parkways)
Special Notes
ASPHALT
11N LONGITUDINAL PAVEMENT JOINT ADHESIVE (5-30-14)
Use a Material Transfer Vehicle (MTV) according to Section 403.03-05A of the Standard Specifications.
JPC PAVEMENT
11J FULL DEPTH CONCRETE PAVEMENT REPAIR (5-15-12)
11K PARTIAL DEPTH CONCRETE PAVEMENT REPAIR (5-15-12)
Special Note for Dowel Bar and Tie Bar Placement in JPC Pavement
OTHERS
Special Note for Inlaid Pavement Markers
Asphalt Seal Coat required from the outside edge of the paved shoulder to a point 2 feet down the ditch or fill slope. Apply two (2) applications at the rate of:
2.40 lbs/SY Item: 00109 Asphalt Seal Coat
20 lbs/SY Item: 00100 Asphalt Seal Aggregate
Special Note for Fog Seal
Special Note for Fiber Reinforcement of Asphalt
Special Note for Asphalt Material for Tack Non-Tracking
Special Note for Geogrid Reinforcement for Asphalt
Special Note for Subgrade Stabilization Alternates
* Required field when this design is submitted.
Save Reset Delete Print Design Form
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KYTC Pavement Design | Kentucky Transportation Cabinet | Kentucky Transportation Center

Common Plan Notes

Common Plan Notes

- ☐ 233 – Earthwork adjustments for alternate pavement designs
- ☐ 275 – Cement stabilized roadbed
- ☐ 276 – Lime stabilized roadbed
- ☑ 444a – Asphalt pavement ride quality (specify category A) (>0.4 mi. unbroken length, all interstate/parkways)
- ☐ 444b – Asphalt pavement ride quality (specify category B) (>0.4 mi. unbroken length, all interstate/parkways)
- ☑ 447 – Specifies Compaction option A (>1000 tons of any one mix)
- ☐ 448 - Specifies Compaction option B (<1000 tons of any one mix)
- ☑ 455 – Edge Key
- ☐ 555a – JPC ride quality (specify category A) (>0.4 miles unbroken length, all interstate/parkways)
- ☐ 555b – JPC ride quality (specify category B) (>0.4 miles unbroken length, all interstate/parkways)

Special Notes

Special Notes

Special Notes

ASPHALT

- ☑ 11N LONGITUDINAL PAVEMENT JOINT ADHESIVE (5-30-14)
- ☑ Use a Material Transfer Vehicle (MTV) according to Section 403.03.05A of the Standard Specifications.

JPC PAVEMENT

- ☐ 11J FULL DEPTH CONCRETE PAVEMENT REPAIR (6-15-12)
- ☐ 11K PARTIAL DEPTH CONCRETE PAVEMENT REPAIR (6-15-12)
- ☐ Special Note for Dowel Bar and Tie Bar Placement in JPC Pavement

Other Notes

OTHERS

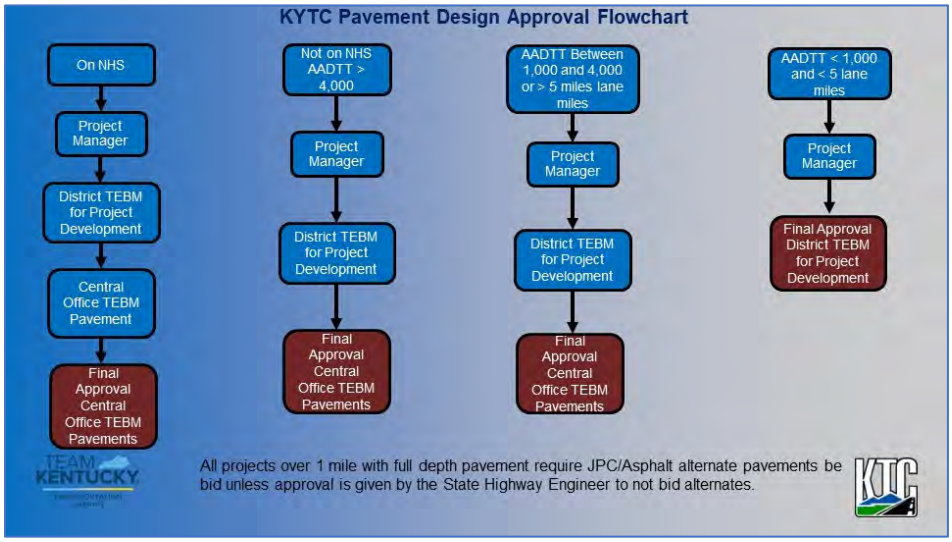
- ☑ Special Note for Inlaid Pavement Markers
- ☑ Asphalt Seal Coat required from the outside edge of the paved shoulder to a point 2 feet down the ditch or fill slope. Apply two (2) applications at the rate of:

```
2.40 Lbs/SY     Item: 00103 Asphalt Seal Coat
20 Lbs/SY       Item: 00100 Asphalt Seal Aggregate
```

- ☐ Special Note for Fog Seal
- ☐ Special Note for Fiber Reinforcement of Asphalt
- ☑ Special Note for Asphalt Material for Tack Non-Tracking
- ☐ Special Note for Geogrid Reinforcement for Asphalt
- ☐ Special Note for Subgrade Stabilization Alternates

Project Approval Process

- Steps in Approval
  - Project Manager
  - District Project Development Branch Manager
  - Central Office Pavement Branch Manager
- Ability to request changes along the way
- Program outlines process from Highway Design Manual



Alternative – Use AASHTO PaveME

- AASHTO PaveME may be used after consultation with Pavement Design Branch
- KYTC Input Guide must be used

Future Directions

- Version 2.62 future work and version 3.0
  - Multiple soil types, A-7-6, A-6, A-4, bedrock
  - Additional Vehicle Class Distributions
- Evaluate Version 3.0 Rigid Designs with Merra Data
- Rehabilitation design

Thank You

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Brad@Frazier@ky.gov
502-782-4762

Clark Graves, PE
Kentucky Transportation Center
Clark.Graves@uky.edu
859-257-7388

Presentation 8—Kumar Dave, Indiana DOT

Indiana ME Design Catalog for Small Structure Replacement

Kumar Dave, P.E. INDOT

November 01, 2022

INDOT History

- 100 Years in July 2019

https://www.youtube.com/watch?v=tJ5VIemzdfM

3

INDOT Facts

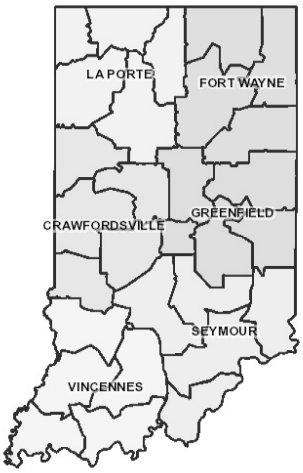
- **INDOT maintains almost 29,600 lane miles (over 11,200 centerline miles) of highways in Indiana.**
- **INDOT is responsible for maintaining more than 5,700 bridges across the state.**
- **INDOT supports approximately 4,500 rail miles, regulates more than 110 public access airports across the state.**

Slide 4

Continue….

- **INDOT has approximately 3,500 employees, making it one of the state's largest agencies.**
- **INDOT's capital expenditures budget is approximately $1.5 billion annually.**
- **INDOT's FY 2022 capital expenditures budget was more than $2.55 billion**
- **INDOT's operating budget was approximately $570.6 million.**

Slide 5



Slide 6

Pavement Designs

QUICK QUIZ:

How many pavement designs your DOT does annually?

Introduction.

- Total pavement designs
  - FY 14=426
  - FY 15=560
  - FY 16=542
  - FY 17 =649
  - FY 18 =498
  - FY 19= 510
  - CY 20=669
  - CY 21=593

Ave=500+

40 to 50 PD/Month

Pavement Design Team(Central Office)

- Kumar Dave
  1. Nick Cosenza
  2. Pankaj Patel
  3. Matt Thomas
  4. Allen Davidson
  5. Tony Jones

Indot Pavement Design History

- AASHTO 93(1990-2009)
- Pavement ME(since 2010)
- Pavement ME Implementation(2002-2010)
- AASHTO 93 has limited inputs
- AASHTO Pavement ME has 1000's inputs(traffic, material, climate)
- Currently Indot uses AASHTO Pavement ME Ver 2.3
- In process of calibration/verification to use Ver 2.6
- Goal is to use Ver 3.0 in 2023

Work Types

- New Road/Road Reconstruction
- Added Travel Lanes
- Road Rehabilitation
  - Single lift
  - Two lift
  - Three lift
  - Recycling(CIR/CCPR/FDR)
  - CPR
  - TCO/Unbonded Concrete Overlay
  - Intersection Improvement/Land slides
  - Small Structure Replacement
  - Bridge projects

Introduction

- Work Distributions(CY 2020)
- 20% small structures
  - 100% In house
  - One Professional Engineer(Tony Jones)
- ~~25% LPA~~
  - 100% Review In house…
- 30 % bridge projects
  - 100% In house
  - One Professional Engineer(Allen Davidson)
- 50 % Minor & major projects
  - 20% In house
  - 80% consultant

Chapter 304 Revisions/ IDM Part 6

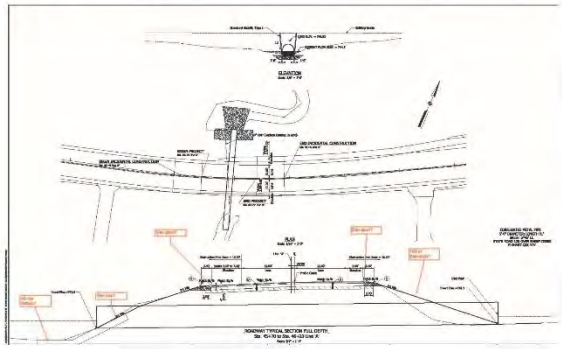
- Chapter 304 Published in 2014
- IDM Part 6 Published in …2020
  - Recycling existing pavement(FDR & Cold R..)
  - Design lives table
  - Patching
  - MEPDG Inputs
  - LPA
  - Thin Concrete Overlays
  - Drainage and separation layers

  - Design Memo 22-02, LCPCA Update
  - Design Memo 22-03: Pavement Design for Small Structure and Bridge Projects

Pavement Designs for Small Structure Projects

- Reasons for the catalog pavement design
  - One P.E full time(100+ projects/year)
  - Pavement design turn around time>120 days
  - Consultant's involvement(fees, review, approval)
  - Around 100-200 ft new pavement
  - Came up with conservative catalog pavement design(10, 12 and 14 inches HMA)
- Small Structure Replacement(mostly road is closed)
- Bridge Rehabilitation(MOT by the existing shoulder strengthening)
- The pavement design is selected based on the ESAL category(based on truck traffic, AADTT) & various applications(New/Reconstructed Full Depth Pavement(HMA, PCCP, Composite)

Small Structure Replacements



Small Structure Replacements

- Design Process
  - Accumulate Pavement Design Request Info
    - SPMS, Geotechnical Report, Cores, Traffic etc....
  - Is project eligible for the condensed abbreviated catalog design process?
    - MOT design? Road closure vs. using shoulders or temporary pavement. Are existing shoulders full depth?
  - If no need for additional shoulder or temporary pavement design, then use the abbreviated catalog design process.

Small Structure Replacements

- Catalog Design
  - Which District?
    - Determines the abbreviated weather information and LTPP Bind information
  - What ESAL Category?
    - Determines the binder categories.
  - Travel Speed?
    - Less than or greater than 40 mph?
    - Determines LTPP Bind information
  - 48 Combinations

Catalog Design Table

STANDARDIZED PAVEMENT DESIGNS FOR SMALL STRUCTURE REPLACEMENT PROJECTS

Road Category	Annual Avg Daily Trucks Contruction Year AADTT	ESAL (millions)	**Pavement Design - Roadway** (ESAL Category, PG Binder Temperature, Depth)*
Interstates (A)	1900 < AADTT < 5700	10 < ESAL < 30	Roadway Catalog ID High ESAL (4,76,14")
Freeways and Principal Arterials (B)	AADTT < 570	< 3	Roadway Catalog ID Low ESAL (3,64,10")
	570 < AADTT < 1900	3 < ESAL < 10	Roadway Catalog ID Med. ESAL (3,70,12")
	1900 < AADTT < 5700	10 < ESAL < 30	Roadway Catalog ID High ESAL (4,76,14")
Remaining Road Classes (C)	AADTT < 510	< 3	Roadway Catalog ID Low ESAL (3,64,10")
	510 < AADTT < 1700	3 < ESAL < 10	Roadway Catalog ID Med. ESAL (3,70,12")
	1700 < AADTT < 5700	10 < ESAL < 30	Roadway Catalog ID High ESAL (4,76,14")

* Subgrade Treatment Type ID is assumed, unless otherwise determined in the project's Geotechnical Report

Example Catalog Excerpt

This pavement design for a small structure replacement was designed in accordance with Chapter 304 of the Indiana Design Manual for the specific project conditions. The design data are as follows:

District:	Fort Wayne
ESAL Category:	Between 3 Million and 10 Million ESALs
Traffic Speed:	40 MPH or Greater

Based on the design data listed above, the pavement design is as follows:

1. For construction of new mainline and adjacent shoulder pavement, use:

   165 lbs/syd QC/QA-HMA, 3, 64, *Surface*, 9.5 mm on
   275 lbs/syd QC/QA-HMA, 3, 64, *Intermediate*, 19.0 mm on
   850 lbs/syd QC/QA-HMA, 3, 64, *Base*, 25.0 mm on
   Subgrade Treatment, Type D.

2. For construction of new shoulder pavement adjacent to existing mainline pavement that will not be replaced, remove any existing shoulder pavement, then use:

   165 lbs/syd QC/QA-HMA, 3, 64, *Surface*, 9.5 mm on
   275 lbs/syd QC/QA-HMA, 3, 64, *Intermediate*, 19.0 mm on
   850 lbs/syd QC/QA-HMA, 3, 64, *Base*, 25.0 mm on
   Subgrade Treatment, Type D.

3. To adjust the profile grade of existing asphalt pavement where the profile grade change is between 1.5 and 4 inches, transition mill the existing asphalt pavement up to 2.5 inches for vertical alignment purposes, then use:
   165 lbs/syd QC/QA-HMA, 3, 64, *Surface*, 9.5 mm on 275 lbs/syd QC/QA-HMA, 3, 64, *Intermediate*, 19.0 mm.

4. To adjust the profile grade of existing asphalt pavement where the profile grade change is between 0 and 1.5 inches, transition mill the existing asphalt pavement up to 1.5 inches for vertical alignment purposes, then use:
   165 lbs/syd QC/QA-HMA, 3, 64, *Surface*, 9.5 mm.

5. To provide a smooth transition from existing pavement to new pavement where the profile grade will not change, mill the existing asphalt pavement 1.5 inches, then use 165 lbs/syd QC/QA-HMA, 3, 64, *Surface*, 9.5 mm.

6. After milling the existing pavement surface, any cracks that remain wide with 0.25 inch width or greater shall be sealed before applying tack coat to the milled surface. The materials used to fill the cracks shall be PG 64-22 only; no emulsion should be used. The sealed cracks should not be overbanded.

7. HMA pavements shall have joint adhesive installed at all longitudinal joints in the surface layer and intermediate layer as per Standard Specification 401.15. A 24-inch-wide liquid asphalt seam shall be placed centered on longitudinal joints that have joint adhesive installed, as per Standard Specification 401.15.

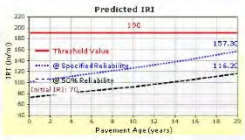
8. The most recent version of the special provision addressing *Subgrade Treatment, Type D* should be included with the contract documents.

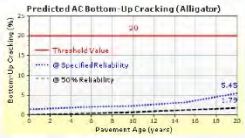
The above pavement design assumes a minimum 20-year design life for the new HMA pavement based on adherence to maintenance guidelines. Sealing for HMA pavements should be applied according to INDOT Standard Specifications Section 406 in the third year after construction and in three-year intervals thereafter. Potholes and isolated failures should be patched as soon as possible. Any roadside ditches should have flow lines validated on a five-year cycle, and shall be regraded or cleaned as necessary to ensure the intended drainage flow if validation is not achieved. This list is not all-inclusive, and other measures can and should be taken to ensure that the pavement performs as intended. A record of what maintenance measures were performed and when shall be kept for the roadway.

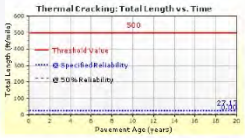
If the above maintenance guidelines are not followed, the life of the new full-depth pavement will be reduced below the 20-year design life for which this pavement design was prepared.

NextLevel INDIANA

10 in. HMA, for Low ESAL(<3 million)

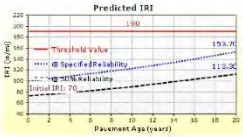


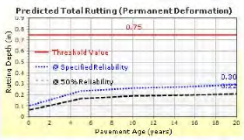


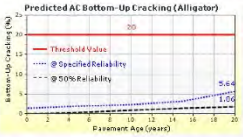


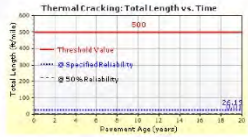
NextLevel INDIANA

12 in. HMA for Medium ESAL(3 to 10 million)



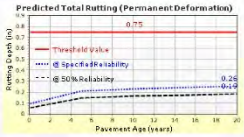


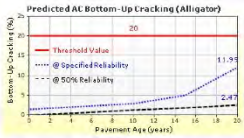


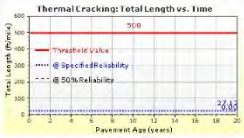


NextLevel INDIANA

14 in. HMA for ESAL(10 to 30 million)







NextLevel INDIANA

Conclusions…./Lessons learned

- For Pavement ME Implementation, do homework
- Develop traffic and material library
- You don't have to run Pavement ME for all your projects
- Catalog pavement designs can be developed for the small structure replacement
- Catalog pavement designs can be developed for the bridge rehab/ replacement
- Catalog pavement design table can save time and money for the department
- Do not throw away practical experience.
- Pavement ME is a better tool to design pavement

NextLevel INDIANA

Thank You

Questions?

NextLevel INDIANA

Presentation 9—Miles Yerger, Montana DOT

Presentation 10—Hari Nair, Virginia DOT

VDOT

VTRC
Virginia Transportation Research Council

PAVEMENT ME REHABILITATION DESIGN IMPLEMENTATION: CHALLENGES

Hari Nair, Ph.D., P.E
Associate Principal Research Scientist

AASHTO Pavement ME National Users Group Meeting
November 1–3, 2022

ACKNOWLEDGEMENT

PROJECT TEAM and PD&E DIVISION

Bipad Saha, P.E
Girum Merine, P.E
Mesbah Ahmed, Ph.D., P.E
Michael Wells, P.E

2

INTRODUCTION

Virginia Department of Transportation (VDOT)
- Maintains a roadway network of more than 126,000 lane-miles

- VDOT implemented MEPDG in January 2018
- VDOT uses MEPDG procedure to design:
  - ✓ New alignment
  - ✓ Reconstruction
  - ✓ Lane widening
  - ✓ **<u>Using Version 2.2.6 of the Pavement ME software</u>**

AASHTOWare Pavement ME Design

VDOT has **not implemented** Pavement ME for **Rehabilitation Design**

3

INTRODUCTION

Planned a Staged Implementation: New construction first then Rehab design

Can we implement both New and Rehab design same time?

"It is possible to implement both designs simultaneously but it is best to determine the **cracking and rutting calibration coefficients for new design first and apply them to the rehab sections**."

Reference: Fifth Annual National Meeting of the AASHTO Pavement ME User Group

4

DEVELOPING A REHABILITATION IMPLEMENTATION STRATEGY

To assist VDOT in the implementation of Pavement ME for design of overlays using **version 2.2.6 of the Pavement ME software.**.

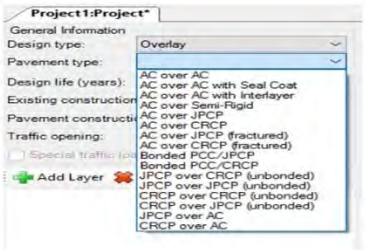
Performed limited analysis/investigation on selected projects to assess the reasonableness of the predicted distresses using VDOT current calibration coefficients.

https://www.virginiadot.org/vtrc/main/online_reports/pdf/22-R13.pdf

5

TYPICAL REHAB SCENARIOS FOR VDOT

- AC over AC
- AC over Semi-Rigid
- AC over JCP
- AC over CRCP
- AC over Composite pavements (Option currently not available in pavement ME)



6

REHABILITATION DESIGN

- A good rehabilitation design requires an assessment of the overall condition of the existing pavement

-AASHTO recommends that agencies collect and evaluate sufficient information about the existing pavement to minimize the chances of under or over-designing the rehabilitated structure

Challenges:
- What is the extent of pavement evaluation needed?
- What are the tools needed? (FWD, GPR, coring, laboratory testing, DCP testing, back calculation software etc…)
- Sometimes, for existing pavement input values, only distress data from Pavement Management System (PMS) are available.

7

PAVEMENT INVESTIGATION

Engineering judgment must be applied

Core Evaluation: Look for moisture damage, mix deterioration, delamination etc.

Challenges: A guidance document and pavement investigation policy needed??

8

Input Levels to Characterize Damage in the Existing Pavement

Rehabilitation design considers continuation of damage from the existing pavement structure

AC over AC and (AC over Semi-rigid)

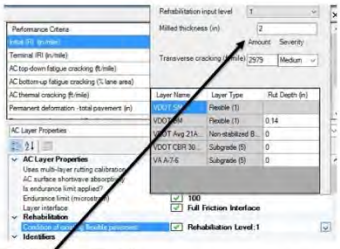
Level 1 – Non Destructive Testing (FWD, GPR, Transverse cracking)
Level 2 – Distress Data (Cracking, Rutting, Transverse cracking)
Level 3 – Rating (Not recommended if level 1 or level 2 inputs are available)

AC over JPCP and AC over CRCP
Rehab input level is not an option

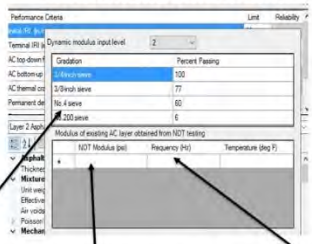
Challenges: Level 1 inputs may not be feasible always and probably not cost-effective in some cases.

9

Damage Characterization: For AC over AC Design
Level 1 (Requires FWD Testing)



Backcalculated Modulus



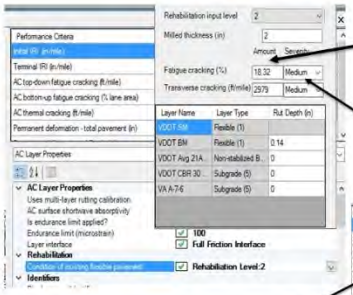
Used for undamaged modulus prediction

Damaged Modulus

Typical Value (15, 25Hz)?

The depth of milling is an input in Pavement ME Design

Damage Characterization: AC OVER AC
Level 2 : Distress Data



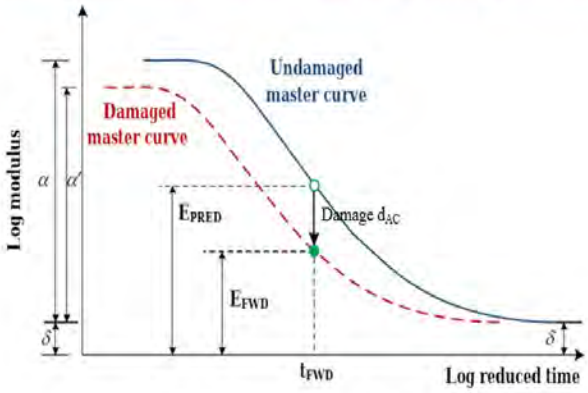
Fatigue Cracking defines the level of damage for the existing layers. Which value to use for mill and fill?

How to select this value? Based on Severity level?

Used for undamaged modulus prediction

11

Damage Characterization: Level 1 (FWD) Vs Level 2 (Distress Data)



It is helpful if damage calculation or graph provided in the output file!! 12

Level 1 (FWD) Vs Level 2 (Distress Data) ?

Challenge: Very Few Guidelines Available

- Use of rehabilitation input levels 1 and 2 should result in comparable designs. If not, investigate further (**Reference**: FY21 AASHTO Pavement ME Webinar 4)
- Ayyala et al. (2018) showed that large differences in the predicted amount of fatigue cracking between rehabilitation input Levels 1 and 2 when all other inputs are equal.
- Zeng et al. (2021) found that Levels 1, 2, and 3 can each lead to significantly different damaged master curves. They recommended the Level 1 method if the existing pavement was a multilayered asphalt pavement.

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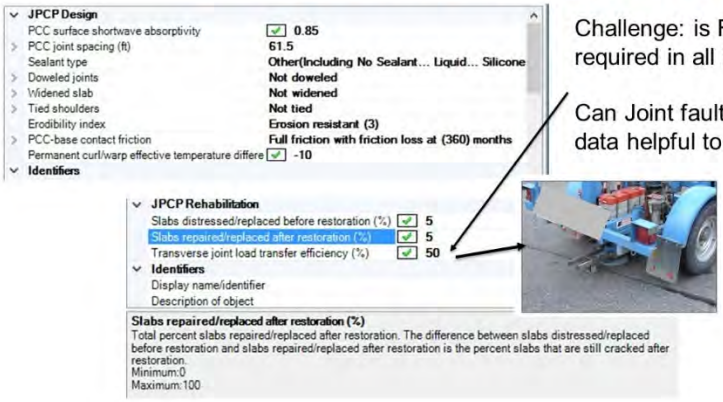
Level 1 (FWD) Vs Level 2 (Distress Data) ?

Level 1 input is an additional effort and expense with limited benefits in some cases?

Challenge: Is a study needed to further evaluate level 1 and level 2 inputs for existing pavement? Develop guidelines or calibrate damage prediction equation?

14

Damage Characterization: AC Over JPCP



Challenge: is FWD testing required in all Projects?

Can Joint faulting from distress data helpful to calculate LTE?

15

Damage Characterization: AC Over CRCP

CRCP Design	
PCC surface shortwave absorptivity	0.85
Shoulder type	Asphalt (2)
Permanent curl/warp effective temperature differe	-10
Steel (%)	0.7
Bar diameter (in)	0.625
Steel depth (inch)	4
Base/slab friction coefficient	2.5
Crack spacing	Generate crack spacing using prediction model
Identifiers	
Display name/identifier	Default

CRCP Rehabilitation	
Number of punchouts per mile	6
Identifiers	
Display name/identifier	
Description of object	
Author	
Date created	7/20/2021 9:18 AM
Approver	
Date approved	7/20/2021 9:18 AM

Number of punchouts per mile
Medium and high severity punchouts plus full depth repairs. The program assumes all existing medium and high severity punchouts will be full depth repaired.

16

Need for separate local calibration factor for rehabilitation and new design?

AC Over AC
- 53 sites from 9 VDOT districts (Final: 26 sites)
- Rehab year from 2005 to 2016
- Total AC thickness ranges from 4 to 13 inch

AC Over JPCP
- 18 sites (Final: 14 sites)
- Rehab year ranged from 2005 -2011
- AC thickness ranged from 2 to 8 inch
- Concrete thickness ranged from 8 to 9 inch

AC Over CRCP
- 15 sites (Final: 12 sites)
- Rehab year ranged from 2005 -2011
- AC thickness ranged from 2 to 5.5 inch
- Concrete thickness ranged from 8 to 9 inch

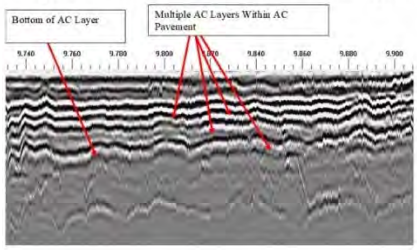
Challenge: Limited field sites available for calibration with detailed information

17

Calibration Challenges

Several Assumptions…
•Full friction interface among layers was assumed.
•It was also assumed that existing distressed slabs were restored/repaired before overlay.

Delamination of layers observed in GPR analysis (12 to15 projects)



Pavement coring confirmed delamination

18

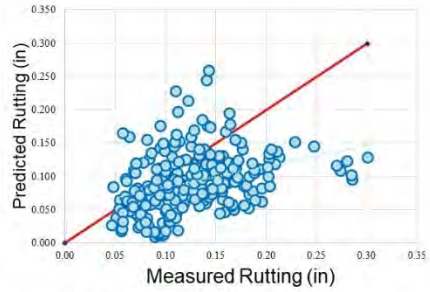
Local calibration factor for rehabilitation: AC Over AC

VDOT uses a rutting criterion of 0.26 in for 15 years (for New construction)

$$Asphalt\ rutting = \beta_r k_z 10^{k_1} T^{k_2 \beta_2} n^{k_3 \beta_3}$$

Requires Calibration. But does it require separate rutting calibration for rehab and new design?

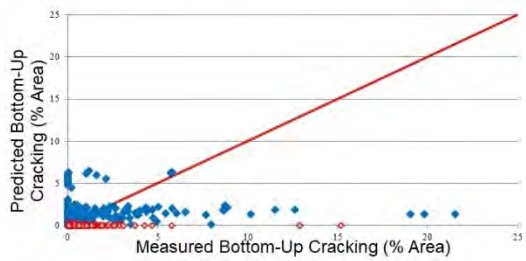
Global Calibration coefficients changed in the latest versions (V2.6 and V3.0)



Asphalt Pavement Rutting Comparison with VDOT Calibration Coefficients

19

Local calibration factor for rehabilitation: AC Over AC



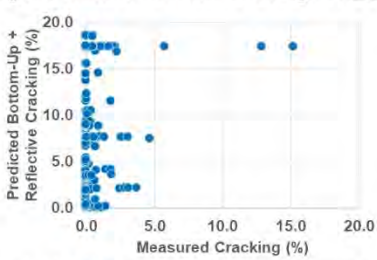
Comparison of Measured vs. Predicted Data. Data in blue are for new construction and are from a previous study (Smith and Nair, 2015); data in red are from the current study.

Requires Calibration. But global calibration coefficients changed in the latest versions (V2.6 and V3.0)

20

Local calibration factor for rehabilitation: AC Over AC

A good criteria for Rehab design is bottom-up cracking + reflective cracking



Requires a major calibration effort

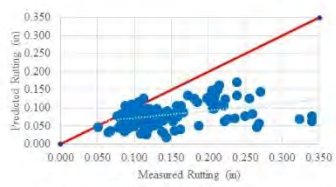
Possible Path??: Recalibrate rutting and bottom up cracking for new construction using latest version (V2.6 or V3.0) and use the same for rehab design

Then

Calibrate the only reflective cracking model in bottom-up cracking + reflective cracking for rehab design.

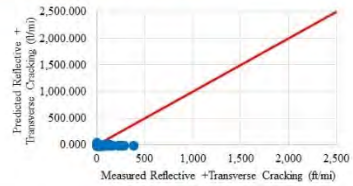
21

Local calibration factor for rehabilitation: AC Over JCP and AC Over CRCP

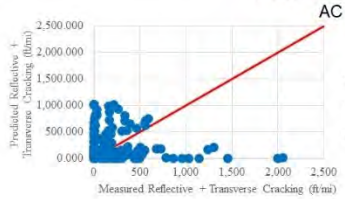


AC over CRCP

Requires Calibration



AC over CRCP



AC over JCP

Relatively less challenges for implementation compared to AC over AC

22

Designing Overlays over composite pavement

Currently not a design option in Pavement ME.

AASHTO ME webinar FY21 offers some guidelines to model using existing software version. (https://me-design.com/MEDesign/data/FY21_Webinar_4_Multiple%20Overlay%20Design_May2021.pdf)

However, further guidelines needed to

1. Simulating multiple overlays in pavement ME
2. Entering damaged modulus for existing AC layer

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SUMMARY

There are some challenges for successful Implementation of Pavement ME for Rehabilitation.

An assessment of the overall condition of the existing pavement is an important part of rehabilitation design as it identifies damage.

Implementation of V2.2.6 with the current calibration coefficients presents some challenges.

State DOT's require additional help, guidance documents, and training for pavement ME rehab implementation.

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Questions ?

Contact:
Hari Nair, Ph.D., P.E
Associate Principal Research Scientist
harikrishnan.nair@vdot.virginia.gov

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Presentation 11—Claudia Zapata, Arizona State University

An improved framework for volume change of shrink/swelling and frost heaving soils subjected to time-varying climatic effects

2022 AASHTO Pavement ME User Group Meeting

Claudia E. Zapata, Ph.D. (ASU) and Bill Yu, Ph.D (CWRU)
Austin Olaiz, PhD (ASU), Mohammad Mosawi, PhD (ASU) and Yusheng "Bear" Jiang (CWRU)

November 2, 2022

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Introduction

- The ability to estimate the **continuous volume change due to weather changing conditions** is important to:
  - Forensic geotechnical/pavement engineering
  - Understand issues that can arise during or after construction
  - Account for the distress during the design process
- Arizona State and Case Western Reserve universities
  - NCHRP Project 01-59: Proposed Enhancements to Pavement ME Design: Improved Consideration of the Influence of Subgrade Soils Susceptible to Shrink/Swell and/or Frost Heave on Pavement Performance
- Allow for the **prediction of potential cumulative pavement roughness due to volume change**
- Allow for a **transitional implementation** into the current AASHTOWare ME Pavement design guide

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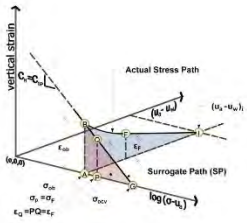
Objective: Incorporating Volume Change into Pavement Performance Design

1. **Development of Climatic-Site Distress Models**
   - Estimating volume change on expansive/shrinking soils caused by suction changes (**wetting/drying**)
   - Estimating volume change caused by frost heave (**heating/cooling**)
2. **Incorporating Models into Pavement Design Guide**
   - Models Linked to IRI
   - Calibration and Validation of Models
3. **Implementation Considerations**
   - Hierarchical Levels
   - Software Developed



Work in Progress

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1. Development of Climatic Driven Site Distress Models General Framework
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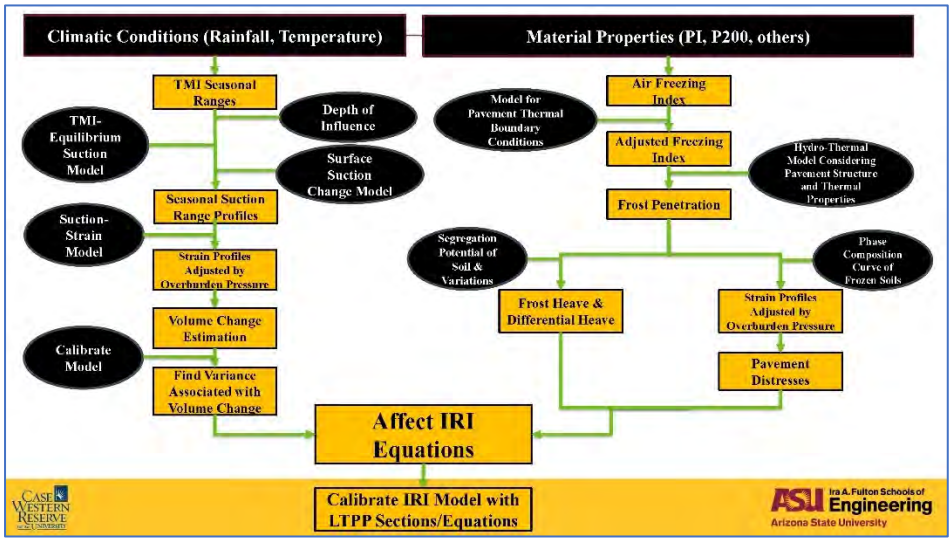
Climatic Conditions (Rainfall, Temperature)
Material Properties (PI, P200, others)
TMI Seasonal Ranges
Depth of Influence
TMI-Equilibrium Suction Model
Surface Suction Change Model
Seasonal Suction Range Profiles
Suction-Strain Model
Strain Profiles Adjusted by Overburden Pressure
Volume Change Estimation
Calibrate Model
Find Variance Associated with Volume Change
Model for Pavement Thermal Boundary Conditions
Air Freezing Index
Adjusted Freezing Index
Hydro-Thermal Model Considering Pavement Structure and Thermal Properties
Frost Penetration
Segregation Potential of Soil & Variations
Phase Composition Curve of Frozen Soils
Frost Heave & Differential Heave
Strain Profiles Adjusted by Overburden Pressure
Pavement Distresses
Affect IRI Equations
Calibrate IRI Model with LTPP Sections/Equations
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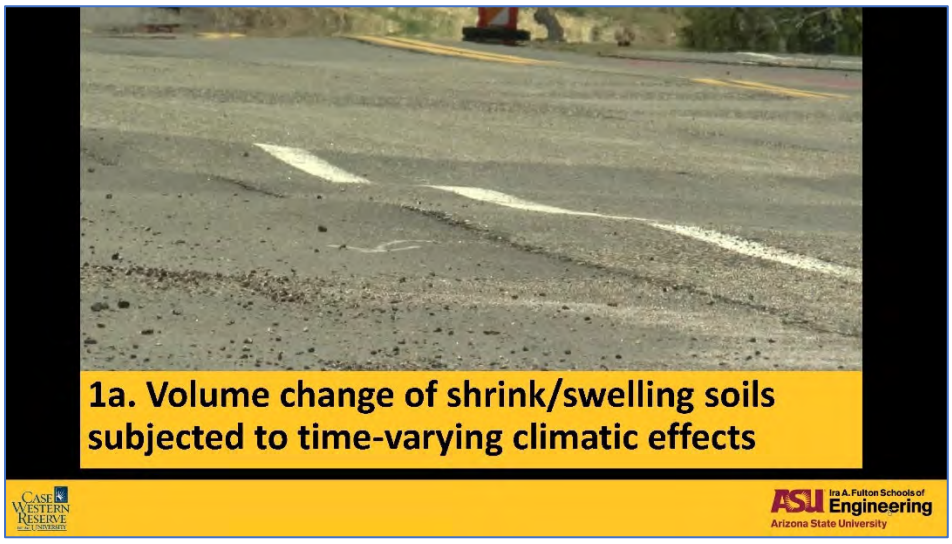
1a. Volume change of shrink/swelling soils subjected to time-varying climatic effects
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Arizona State University

Objective

- Present an **improved suction-based framework** for estimating the volume change of shrink/swell soils due to **time-varying climatic effects**
- **Based on the approach for long term volume change prediction**
  - **Lytton, Aubeny and Bulut** (2005)
  - **Suction envelope** models published by Vann and Houston (2021)
- **Updated with considerations of short-term varying climate**
  - **Includes spatial variability between edges and center of pavement**
- **Implementation** of a mechanistic-stochastic approach solution (and associated uncertainty) on pavement design procedures

Existing Standards & Practice

- AASHTOWare Pavement ME uses an empirical approach
- PTI uses a mechanistic and deterministic approach
- AS2870-2011 Slab & Footing Classification uses a mechanistic and deterministic approach
- Various simplified or judgement-based methods from practicing engineers

Approaches to Estimate Volume Change

- **Mechanistic** determination based on 1-D lab procedures (ASTM D4546)
  - Results are function of **full inundation (fixed suction range)**
  - **High probability** the soil will not reach full saturation for whole profile during its design life
- **Empirical** determination of potential volume change
  - Density, initial moisture content, mineralogy, Atterberg limits, fines content
  - Convenient, **easy to implement**
- **Mechanistic-Empirical** approach (moisture and/or suction based)
  - It combines laboratory results with empirical relationships with index properties
  - Approach is **mostly focused on a moisture-based** rather than suction-based approach
    - Potential Vertical Rise (TxDOT-12-E 1978) – **moisture-based approach**

Research on Three Approaches

Mechanistic

Jennings and Knight (1957)
De Bruijn (1961, 1965)
Burland (1962)
Sampson et al. (1965)
Noble (1966)
Sullivan and McCelland (1969)
Komornik et al. (1969)
Holtz (1970)
NAVFAC (1971)
Wong and Yong (1973)
Gibbs (1973)
Jennings et al. (1973)
Smith (1973)
Teng et al. (1972, 1973)
Teng and Clisby (1975)
Porter and Nelson (1980)
Fredlund et al. (1980)
Sridharan et al. (1986)
Erol et al. (1987)
Shanker et al. (1987)
Nelson et al. (1998, 2001)
Al-Shamrani and Al-Mhaidib (1999)
Basma et al. (2000)
Subba Rao and Tripathy (2003)

Empirical

Seed et al. (1962)
van der Merve (1964)
Ranganatham and Satyanarayana (1965)
Komornik and David (1969)
Nayak and Christensen (1971)
Vijayvergiya and Ghazzaly (1973)
Schneider and Poor (1974)
McCormack and Wilding (1975)
Brackely (1975b)
O'Neil and Ghazzally (1977)
Chen (1975)
Johnson (1978)
Weston (1980)
Bandyopadhyay (1981)
Picornell and Lytton (1984)
Dhowian (1990a)
Basma (1993)
Cokca (2002)
Erguler and Ulusay (2003)
Rao et al. (2004)
Erzin and Erol (2004)
Sabtan (2005)
Azam (2007)
Yilmaz (2009), Turkoz and Tosum (2011)
Cimen et al. (2012), Zumrawi (2013)

Suction based Mechanistic-Empirical

Johnson and Snethan (1978)
Snethan (1980)
Aitchison (1983)
Mitchell and Avalle (1984)
Hamberg and Nelson (1984)
Dhowian (1990)
Fityus and Smith (1998)
Briaud et al. (2003)
Lu (2010)
Tu and Vanapalli (2015, 2016)
Vann and Houston (2021)

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Suction based Mechanistic-Empirical Approach

- Adopted by the Texas DOT and the Post-Tensioned Institute
- Incorporated the work done by Lytton, Aubeny and Bulut (2005)
  - *Holtz and Gibbs (1956), Lytton (1977), McKeen and Hamberg (1981), Covar and Lytton (2001), Lytton et al. (2004)*
- Accounted not only for swelling but for the shrinkage of soil during dry climatic periods
- Accounted for changes in **matric suction and net normal stress**
- Used a closed-form solution of Richard's unsaturated moisture flow equation developed by Mitchell (1979)

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Framework Outline

1. Weather station identification
2. Determination of monthly **Thornthwaite Moisture Index**
   - *Witczak, Zapata & Houston (2006)*
3. Determination of the long-term **suction envelope** parameters
   - *Vann and Houston (2021)*
4. Back-calculation of variables for Mitchell's (1979) equation
5. Development of long-term wet/dry suction profiles
6. Initial estimation of monthly changes in suction at the surface
   - *Perera (2003); Olaiz et al. (2021)*
7. Estimation of limits of monthly suction variation at the surface
   - *Vann and Houston (2021)*
8. Fourier equation fit to the monthly surface suction change
   - *Aubeny and Long (2007)*
9. Generation of monthly suction profile
   - *Aubeny and Long (2007)*
10. Suction profile adjustments for varying surface boundary conditions
11. Determination of net normal stress profile
12. Estimation of suction compression index
    - *Covar and Lytton (2001)*
    - *Houston and Houston (2017)*
13. Calculation of **strain** (monthly basis)
14. Calculation of **volume change** (monthly basis)
15. Generation of Random Soil Properties for Input into Stochastic Analyses
16. MCMC Forecast Model for Random Generations of Time-Series Climate Parameters
17. Application of Proposed Models for Estimation of Potential Monthly Shrink-Swell Volume Change

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Framework Outline

1. Weather station identification
2. Determination of monthly **Thornthwaite Moisture Index**
   - **Witczak, Zapata & Houston (2006)**

Climatic boundary conditions

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1: Climate Data

- MERRA
- National Oceanic and Atmospheric Administration
  - Extraction of climate data from nearest weather station
  - Year, Month
  - Monthly precipitation and average temperature
- Open-access Thornthwaite Moisture Index GIS map
  - *Olaiz et al. (2017)*
  - Latitude, Longitude, Elevation
  - Annual precipitation
  - Annual potential evaporation
  - 30-year based TMI

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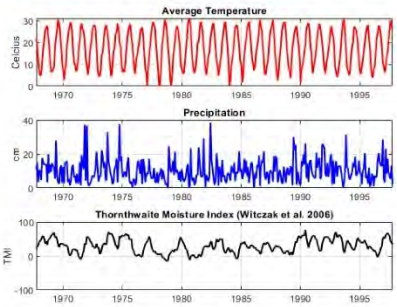
2: Monthly Thornthwaite Moisture Index

- TMI is a **yearly index**
- It can be calculated in a **monthly** basis
  - *Witczak, Zapata & Houston, W. (2006)*

$$PET(cm) = f_1 f_2 1.6\left(\frac{10t}{I}\right)^a$$

$$I = \sum_{i=1}^{12}\left(\frac{t_i}{5}\right)^{1.514}$$

$$TMI = 75\left(\frac{P}{PET} - 1\right) + 10$$



NOAA weather station Paris, TX

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Framework Outline

3. Determination of the long-term **suction envelope** parameters
   - *Vann and Houston (2021)*
4. Back-calculation of variables for Mitchell's (1979) equation
5. Development of long-term wet/dry suction profiles

Suction envelopes

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3: Shrink-Swell Volume Change (SSVC) Framework

Unsaturated Soil Volume Change

Lytton (1997)

$$\frac{\Delta V}{V} = -\gamma_h \log_{10}\left(\frac{h_f}{h_i}\right) - \gamma_\sigma \log_{10}\left(\frac{\sigma_f}{\sigma_i}\right) - \gamma_\pi \cancel{\log_{10}\left(\frac{\pi_f}{\pi_i}\right)}$$

$\frac{\Delta V}{V}$ = volumetric strain

γ_h = suction compression index

$\log \frac{\psi_f}{\psi_i}$ = log change in matric suction

γ_σ = mean principal stress compression index

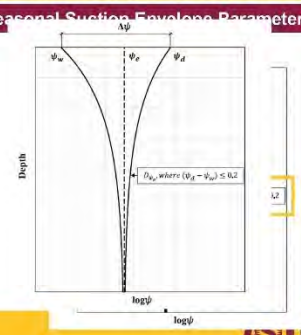
$\log \frac{\sigma_f}{\sigma_i}$ = log change in normal stress

γ_π = osmotic suction compression index

$\log \frac{\pi_f}{\pi_i}$ = log change in osmotic suction

Equilibrium Suction Envelope Parameters

Seasonal Suction Envelope Parameters



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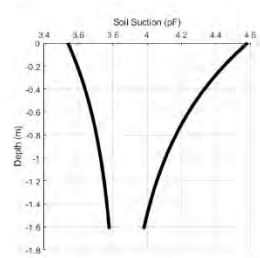
3: Model Components

- The suction envelope defines the **maximum and minimum suction values at the surface, the soil will be subjected to due to weather conditions,** and within the subsurface to a depth of **stable suction**
- Parameters needed to define the envelope
  a. Depth to equilibrium suction
  b. Equilibrium suction value
  c. Change in suction at the ground surface
  d. Climate parameter to represent the skeweness
- Suction envelope by Vann and Houston (2021)
  - Over **40 geotechnical studies** in San Antonio (TX) Denver (CO), Phoenix and Munds Park (AZ)
    - *Vann (2019)*
  - Literature ranging from 1970's to 2018



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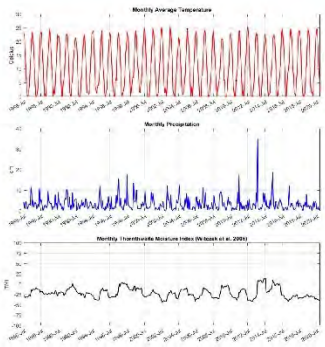
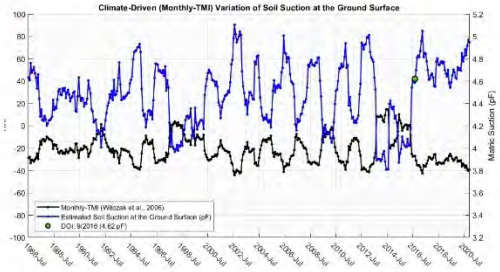
Climate-Driven Suction at the Ground Surface





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Framework Outline

6. Initial estimation of monthly changes in suction at the surface
   - *Perera (2003)*
7. Estimation of limits of monthly suction variation at the surface
   - *Vann and Houston (2021)*
8. Fourier equation fit to the monthly surface suction change
   - *Aubeny and Long (2007)*
9. Generation of monthly suction profile
   - *Aubeny and Long (2007)*
10. Suction profile adjustments for varying surface boundary conditions
11. Determination of net normal stress profile

Generation of monthly suction profiles

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6: Time-varying Suction at the Surface

- **Deterministic approach**
  - Case study
  - Forensic analysis
  - Calibration effort
- **Stochastic analysis** with randomly generated **monthly TMI** based on historic data and associated variability **is also proposed**
  - Design of future structures
- **Time-varying suction at the surface**
  - Based on an adjusted model by Perera (2003), already incorporated in the AASHTOWare
  - *Perera, Zapata, Houston & Houston (2004)*
  - NCHRP 9-23 project

30 visited sites within the continental US

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8: Fitting Surface Suction - Order of the Fourier Series Fit

Periodic Suction(t)

$$u(z=0,t)=U_c+U_e\cos(2\pi nt)$$

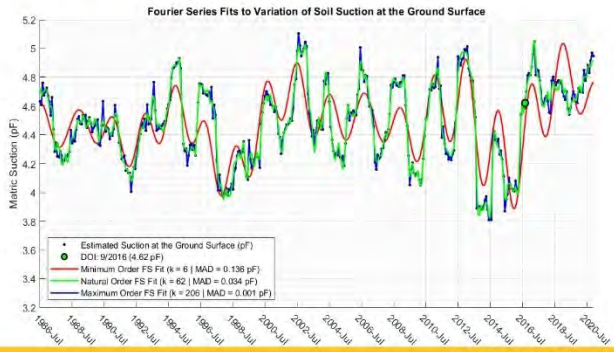
Fourier Series Suction(t)

$$u(z,t)=U_c+\sum_{k=1}^{\infty}\left[a_k\cos(\tau k)+b_k\cos(\tau k)\right]$$

Improving on the 8-order limitation from Olaiz et al. (2021)

- Does not capture major seasonal trends when fitting > 4 years
- Does not capture extreme events
- MATLAB often provides poor fits for high frequency data due to R^2 optimization

New Algorithm developed to optimize selection of order of Fourier Series



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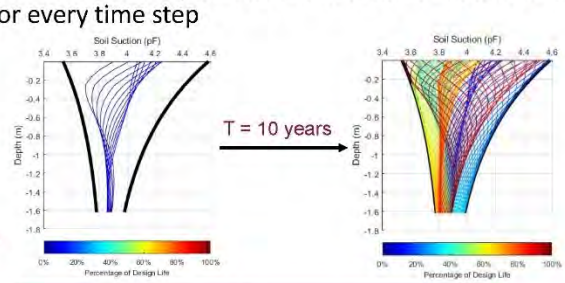
9: Monthly Suction Profile

- The adjusted Mitchell equation is then used to model the suction profile for every time step

T=1 month → T=2 months → T=12 months



$$u(y,t)=U_e-\left(U_{dry}-U_{wet}\right)\sum_{k=1}^{\infty}\alpha_k\exp\left(-\sqrt{\lambda k}\right)\cos\left(\tau k-\sqrt{\lambda k}\right)$$

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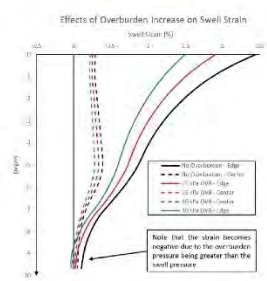
10: Adjustments due to Varying Boundary Conditions (future work)

- Adjustments can be accommodated
  - Variable **groundwater table**
  - Nearby **vegetation**
  - Moisture **barriers**

11: Net Normal Stress and Location

- **Oveburden effect** is fully considered
  - Reduce swelling potential
  - Increase soil shrinkage
- Volume change estimated under the **shoulder** and under the center of the pavement



$$\sigma_z=\sum\left(\gamma_{soil}z\right)$$

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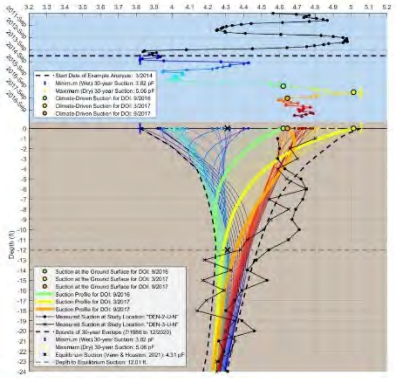
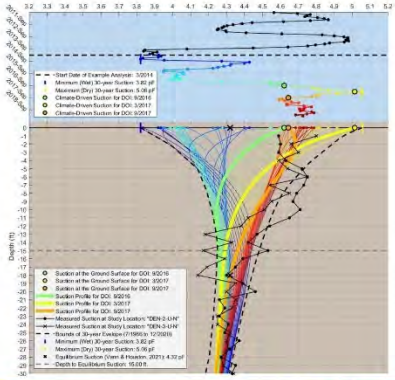
Validation Study #1

Equilibrium parameters based off measured suction



Validation Study #3

Adjusted Equilibrium values based on uncovered profiles only.



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Framework Outline

Volume change

12. Estimation of suction compression index
    - *Covar and Lytton (2001)*
    - *Houston and Houston (2017)*
13. Calculation of **strain** (monthly basis)
14. Calculation of **volume change** (monthly basis)

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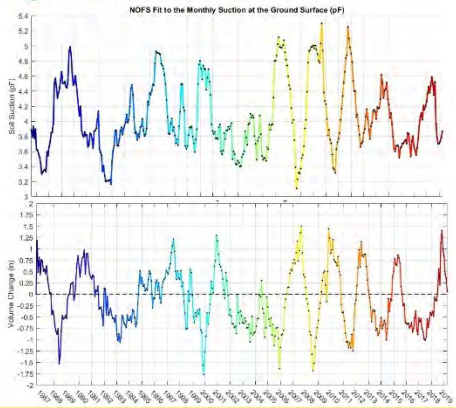
14: Volume Change Prediction

San Antonio Study #1



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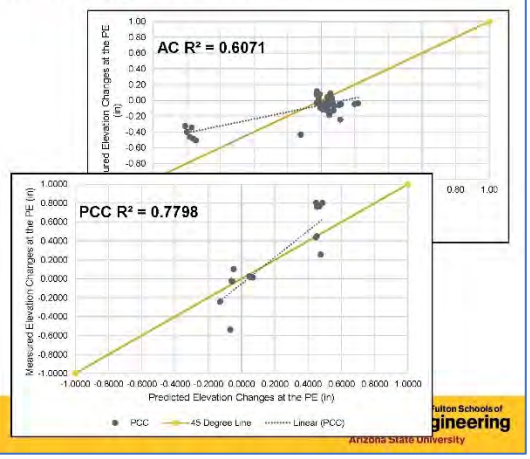
Model Calibration Preliminary Results

- Calibrating the Olaiz et al. (2021) method
  - Adjust to the first value
  - Develop statistical correlation of measured vs predicted
- **Results**
  - 58 calibration points
    - 41 from AC sections
    - 17 from PCC sections
- Re-calibration is in progress after some adjustments to the model



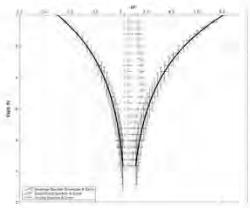
Framework Outline

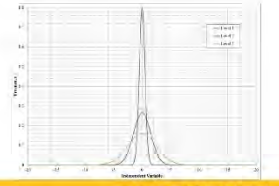
15. Generation of Random Soil Properties for Input into Stochastic Analyses
16. Markov-Chain Monte Carlo Forecast Model for Random Generations of Time-Series Climate Parameters
17. Application of Proposed Models for Estimation of Potential Monthly Shrink-Swell Volume Change

Stochastic solution

Stochastic Analysis

- **Stochastic solution** allows for the incorporation of the variability associated with:
  - Climate
  - Material properties
- Monte Carlo simulations predicts variability associated with time-varying conditions and material heterogeneity
- **Hierarchical approach allows** for the determination of the most accurate estimate of each variable
- **Variance** associated with the volume change response is representative of the **roughness experienced by the pavement**



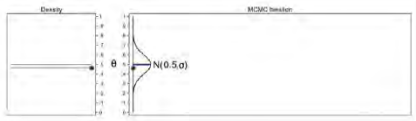


Markov-Chain Monte Carlo (MCMC) Techniques

Extensive review of Bayesian statistical theory and **Markov Chain Monte Carlo** (MCMC) applications for **stochastically forecasting time-series data**

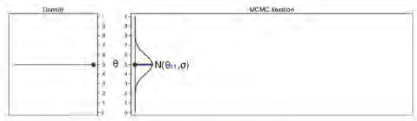
Kulhaway, Zhang, Wang, Medina-Cetina, Griffiths, Vrugt

Monte Carlo



Draw θ_t ~ Normal(0.5,σ) = 0.460

Markov-Chain "Random Walk"



Draw θ_t ~ Normal(θ_{t-1},σ)

Normal(0.500,σ) = 0.497

(Huber, 2018)

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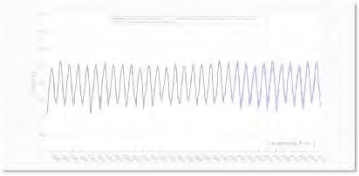
Stochastic Forecast of TMI



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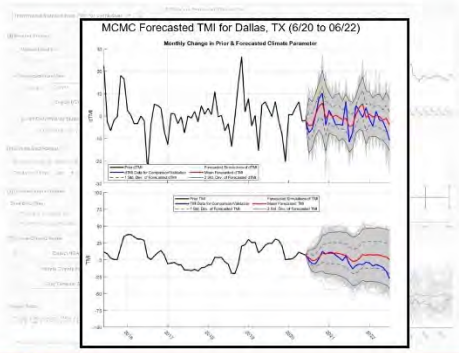
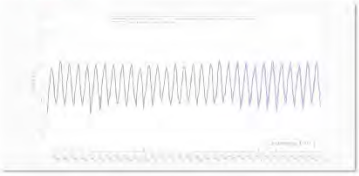
Stochastic Forecast of TMI





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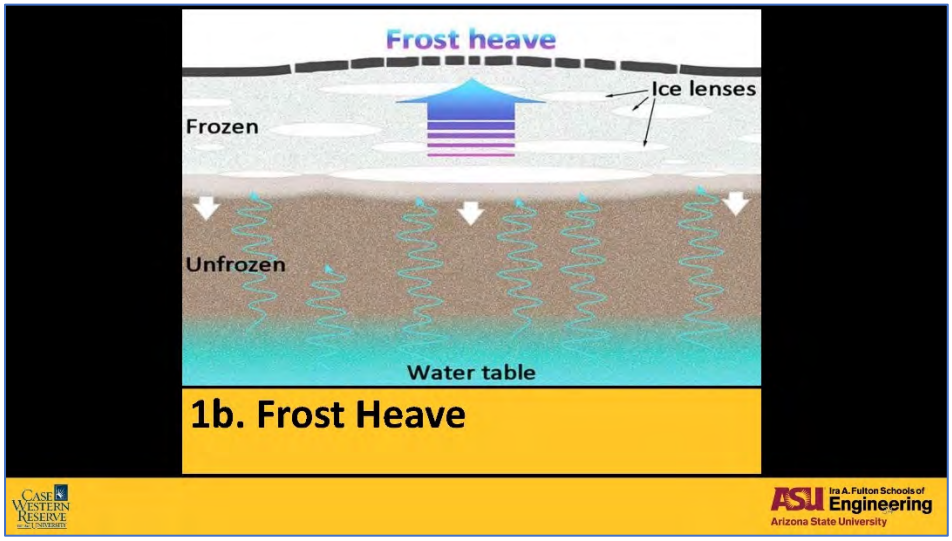


Objectives

- Development of a simplified 1-D FE model to determine **frost depth and frost heave**
- IRI model **calibration** based on 1-D model
- Development of an **empirical regression IRI model**
- Development of a **user interface** for IRI estimation

Model Features

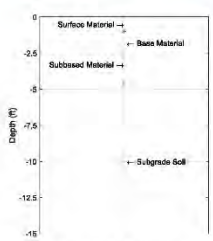


Figure 1 Model geometry

The simplified 1-D model is governed by Fourier's equation:

$$C_a \frac{\partial T}{\partial t} = \nabla(\lambda \nabla T)$$

Boundary conditions: Neumann boundary condition; heat flux caused by ground surface temperature gradient

Ground water table impact is incorporated

Support level-based design based on the availability of model inputs

Both the **frost heave and frost depth** values can be evaluated

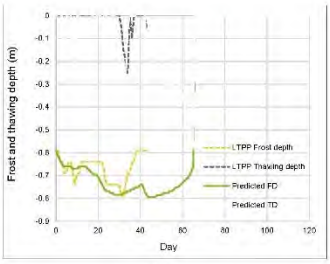
Other models were built-in: Initial Temperature; Segregation potential; thermal properties;

Frost heave = water expansion caused heave + Segregation potential (SP) caused heave

Segregation potential = *F*(Gradation, Atterberg limits)

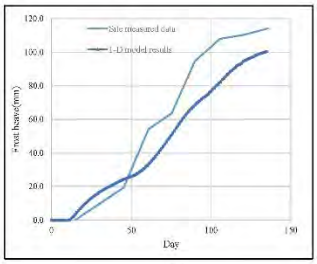
General 1-D Model Output

The 1-D model can be solved by FEM software COMSOL or PDE solver in MATLAB



(a)

Frost and thawing depth vs. time (Vermont 1002)

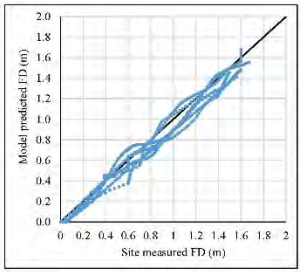


(b)

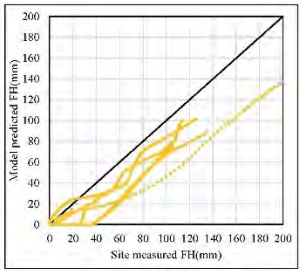
Frost heave vs. time (Finland site Piipola)

Model Calibration and Verification

The 1-D model was calibrated using data from LTPP and verified using data from 6 sites in Finland



(a)



(b)

Model Level 1 prediction 1-1 plots: (a) Site-measured frost depth vs. model predicted frost heave; (b) Site-measured frost heave vs. model predicted frost depth (data from Finland sites)

Empirical Regression IRI Model Equations

$$IRI = IRI_0 + \boxed{IRI_{SF}} + c_1(FC_{Total}) + c_2(TC) + c_3(RD)$$

$$IRI_{sf} = IRI_{sf_{ref}} * [age^{beta} + gama * FI_{accum} * sin(2\pi * month/12 + eta)]$$

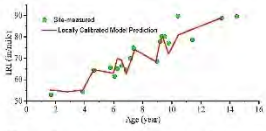
$$IRI_{sf_{max}} = e_1 * ln(e_2 * FI + 1) * ln(e_3 * Precip + 1) * ln(e_4 * Silt_{percentage} + 1)$$

$$beta = \frac{c_4}{thickness}$$

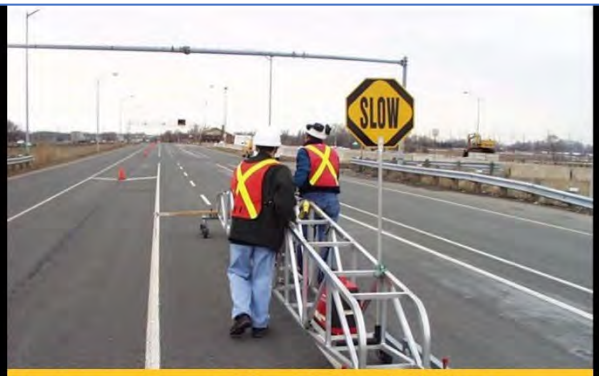
$$IRI_{sf_{ref}} = IRI_{sf_{max}} * DF_f$$

$$DF_f = -C_5 * ln(C_6 * thickness(ft)) + C_7$$

- Influence **of climatic factors** (temperature, rainfall), **material factors** (soil gradation), and **structural factors** (age, thickness)
- High accuracy for local calibration



Locally calibrated model prediction vs. site measured IRI for section 30-8129 in Montana



2. Incorporating Models into Pavement Design Guide

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Implementation of Stochastic Solution on Pavement Design Procedure

- Currently, IRI takes care of "**volume change**":

$$IRI = IRI_o + 0.0150(SF) + 0.400(FC_{Total}) + 0.0080(TC) + 40.0(RD)$$

$$SF = Age^{1.5}\{ln[(Precip + 1)(FI + 1)p_{02}]\} + \{ln[(Precip + 1)(PI + 1)p_{200}]\}$$

- **Variance and standard deviation associated with the volume change response will serve as surrogate and replacement of the Site Factor**

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Current Design IRI Predicted Equations

- **Effects of shrink/swell and/or frost heave are considered on the Site Factor**
- New HMA Pavements and HMA Overlays of Flexible Pavements:
- $IRI = IRI_0 + \mathbf{0.0150(SF)} + 0.400(FC_{Total}) + 0.0080(TC) + 40.0(RD)$
- HMA Overlays of Rigid Pavements:
- $IRI = IRI_0 + \mathbf{0.00825(SF)} + 0.575(FC_{Total}) + 0.0014(TC) + 40.8(RD)$
- Jointed Plain Concrete Pavements (JPCP):
- $IRI = IRI_0 + 0.8203(CRK) + 0.4417(SPALL) + 1.4929(T_{FAULT}) + \mathbf{25.24(SF)}$
- Continuous Reinforced Concrete Pavements (CRCP):
- $IRI = IRI_0 + 3.15(PO) + \mathbf{28.35(SF)}$

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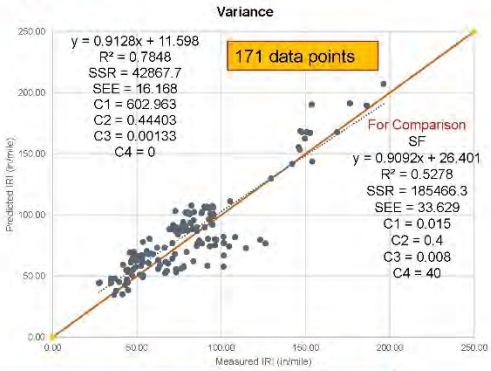
Shrink-Swell Stochastic Model Calibration

- AC pavements
  - Variance found to provide the best fit
    - SSR dropped more than 75%
    - SSE dropped more than 50%
    - R^2 slightly decreased from 91 to 90.5%
    - Environmental weight generally < 3.5%



Preliminary Model for AC pavements

$$IRI = IRI_0 + 602.96\sigma_{SS}^2 + 0.444\,FC_{Total} + 0.00133\,TC$$

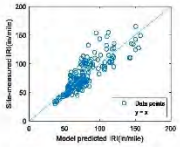
Calibrated 1-D IRI Model for Flexible Pavements

- MEPDG IRI model for flexible pavements:

$$IRI = IRI_0 + 0.0150(SF) + 0.400(FC_{Total}) + 0.0080(TC) + 40.0(RD)$$

$$SF = Age^{1.5}\{ln[(Precip + 1)(FI + 1)p_{02}]\} + \{ln[(Precip + 1)(PI + 1)p_{200}]\}$$

235 points
25 sections
12 states

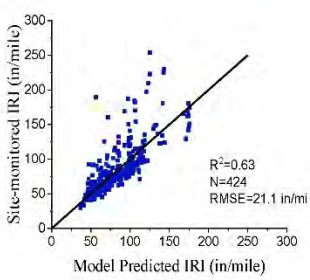


R^2 = 0.75 > R^2 = 0.54 AASHTOWare

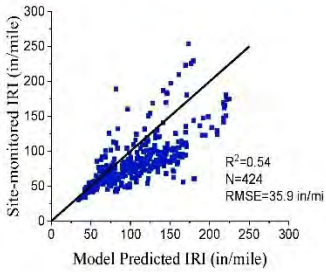
$$IRI = IRI_0 + 0.12 * \sigma_{FH} + 0.455 * FC + 0.0006 * TC + 47.17 * RD$$

σ_{FH} = standard deviation of estimated frost heave based on 1000 Monto Carlo simulations of the 1-D model

Empirical Regression IRI Model Performance



(a) new IRI model for AC pavements



(b) the MEPDG model for AC pavements

AASHTOWare

AASHTO

3. Implementation Considerations

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Considerations for Implementation

- **Stand-alone program** capable of communicating/bridging with AASHTOWare
  - Most of parameters needed **are already being requested** by AASHTOWare
  - The stand-alone program will provide more granular climate data
  - Latitude/longitude of the project site will be required
- **Manual of Practice** will present in detail laboratory/field protocols and correlations used and needed to implement Level 1, 2 and 3 analyses
- Currently, the program has been written in MatLab

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Input Parameters Required for All Three Levels – Expansive soil

	Parameter	Levels 1	2	3
Pavement Structure Parameters	Pavement type and layer thicknesses	Needed	Needed	Needed
Environmental Parameters (TMI)	Mean temperature in for the ith month in degrees Celsius (t_i)	Needed	Needed	Needed
	Annual precipitation in cm (P_i)	Needed	Needed	Needed
	The number of days in the month (N_i)	Needed	Needed	Needed
	Longitude and Latitude	Needed	Needed	Needed
	Groundwater Table Depth	Needed	Needed	Needed
Soil Index Properties	Plasticity Index (PI)	Not Needed	Needed	Needed
	Liquid Limit (LL)	Not Needed	Needed	Needed
	Percent Passing No. 200 Sieve (P200)	Not Needed	Not Needed	Needed
	Percent Passing 2-Micron (P02)	Not Needed	Not Needed	Needed
In Situ Soil Properties	Water Content (w)	Not Needed	Needed	Needed
	Density	Needed	Needed	Needed
	Total Suction	Needed	Not Needed	Not Needed
Strain Parameters	Wetted oedometer strain (ε_{sh})	Not Needed	Needed	Not Needed
	Swell pressure (σ_{sw})	Not Needed	Needed	Not Needed
	Final suction profile	Needed	Not Needed	Not Needed
	Suction Compression Index	Needed	Not Needed	Not Needed

Already required by AASHTOWare

Details on field and lab testing need to be provided

Studies on the sensitivity of each input parameter on the results need to be done

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Input Parameters Required for All Three Levels – Frost Heave

	Level 1	Level 2	Level 3
Climatic inputs			
• Latitude and longitude of the site, used to determine the average monthly air temperature	√	√	√
Geological inputs			
• Monthly groundwater table depth	√	X (Needs freezing and non- freezing season GWT)	X (Needs freezing and non- freezing season GWT)
Structure and materials inputs			
• Pavement layer geometry	√	√	√
• Layer material type or soil classification	X	√	X
• Physical properties of layers: gradation, percent of fine content, percent of silt, Atterberg limits	√	√	√
• Specific gravity of solids	√	X Default values	X Default values
• Dry unit weight	√	√	X Default values
• Gravimetric water content at the beginning of the freezing season simulation	√	√	√
• Initial soil temperature profile	√	X	X
• Thermal properties: thermal conductivity and heat capacity of pavement surface materials	√	X Thermal conductivity: Johansen (1975) method; Heat capacity: USACE correlation equations	X Thermal conductivity: Johansen (1975) method; Heat capacity: USACE correlation equations

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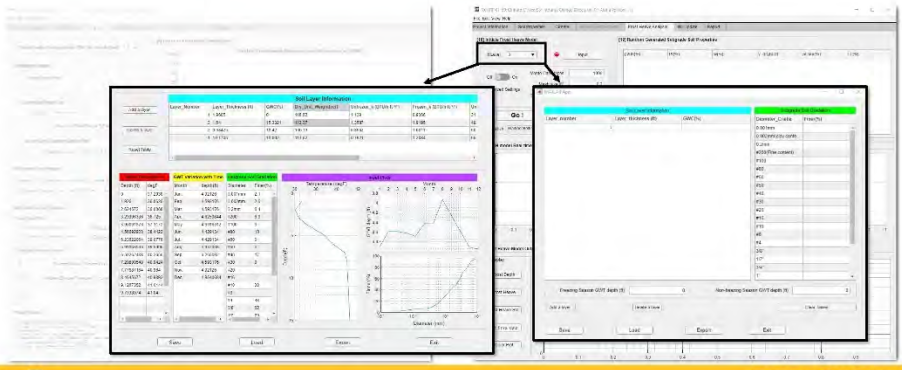
NCRHP 01-59 Software Development



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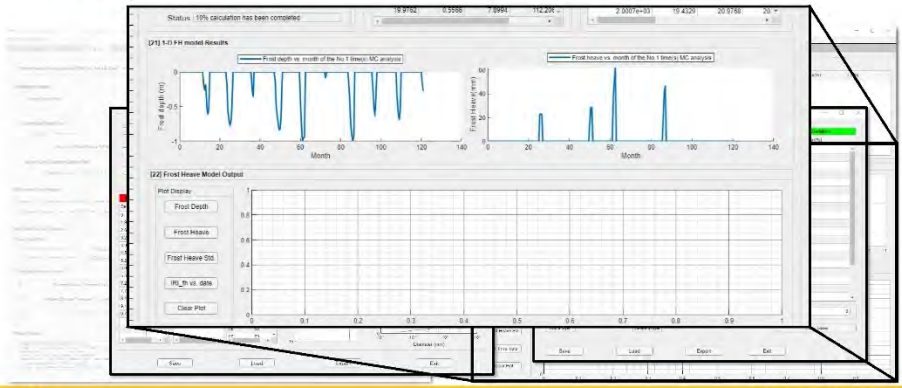
NCRHP 01-59 Software Development



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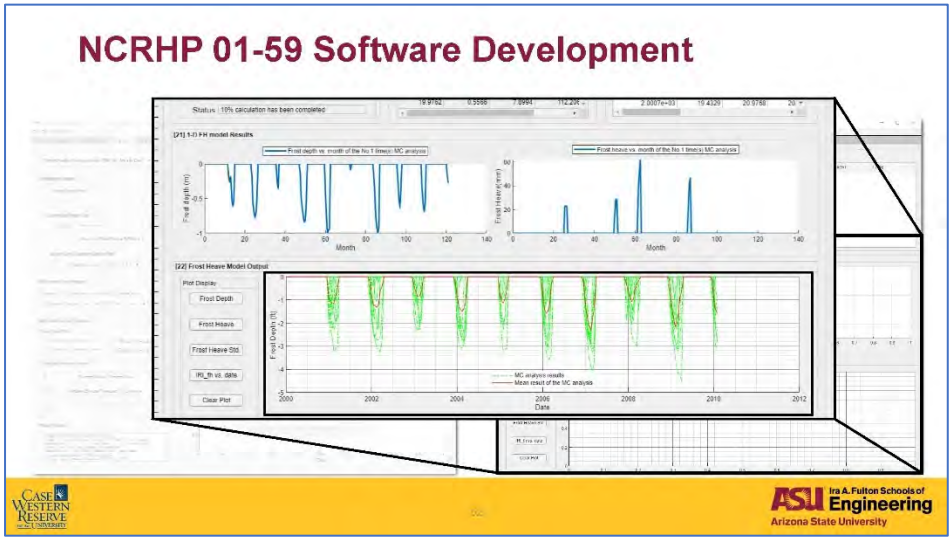
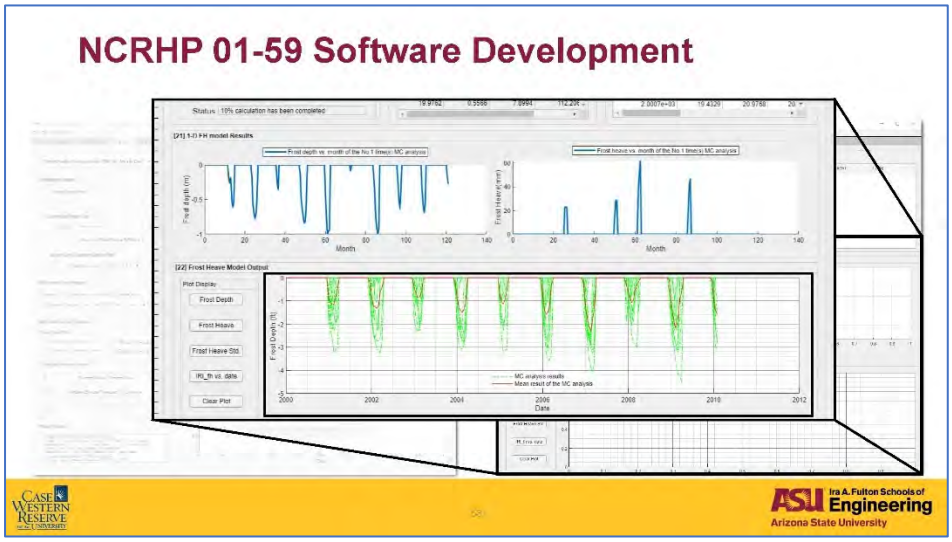

NCRHP 01-59 Software Development
Case Western Reserve University
Ira A. Fulton Schools of Engineering
Arizona State University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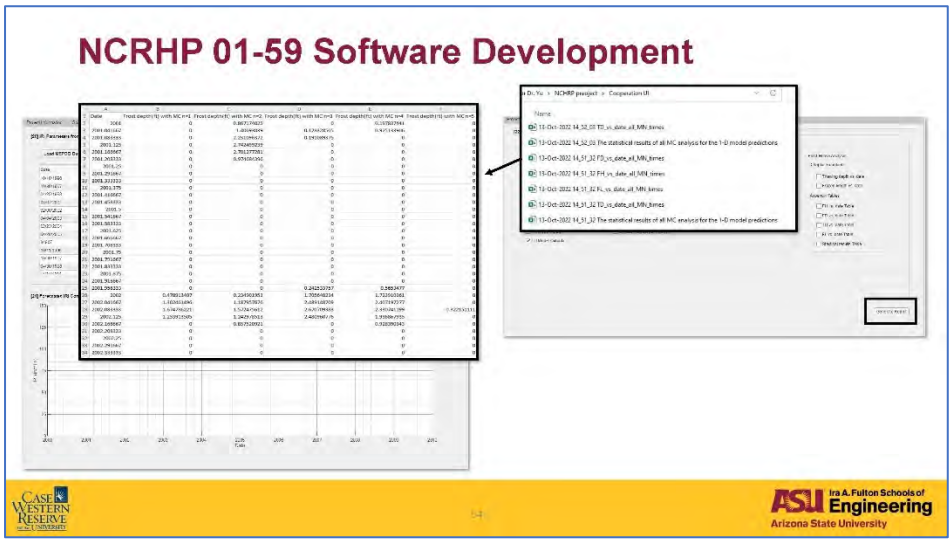
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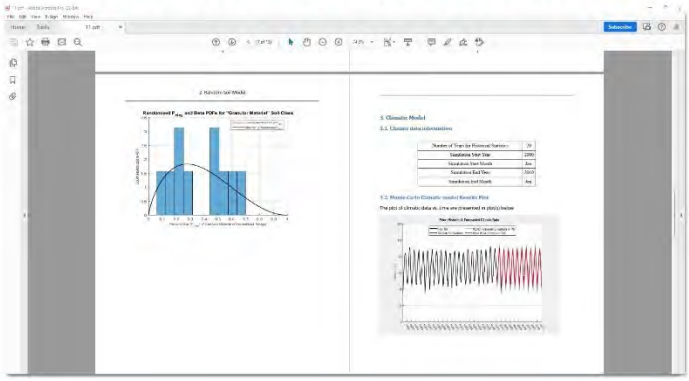

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Conclusions

- A stochastic **mechanistic model in conjunction with the random generation of soil properties** will allow for a more rational approach to volume change predictions and the variability associated with it
- Model fully accounts for the effect of overburden pressure
- Models accounts for the rigidity of the pavement
- Model uses **similar input parameters** than the current AASHTOWare ME design guide
- **Facilitate the implementation** into current design procedures
- **Models are universal** and can be used in any part of the world provided measured data is available to calibrate for local conditions

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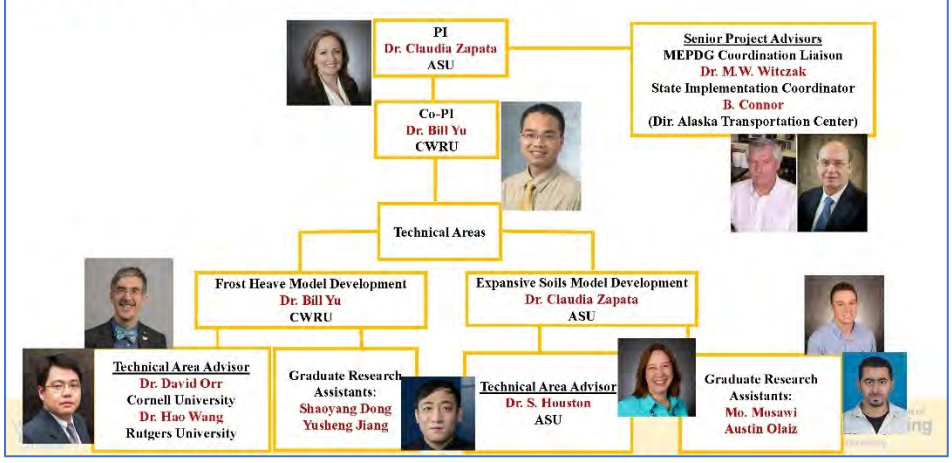
NCHRP 01-59 Team, Thanks!



Presentation 12—Jane Jiang, FHWA

Long-Term Pavement Performance Program

LTPP

Source: FHWA

LTPP Analysis-Ready Materials Dataset (ARMAD)

Jane Jiang, Sr. Research Engineer, FHWA

October 2022

U.S. Department of Transportation
Federal Highway Administration
Turner-Fairbank Highway Research Center

Introduction

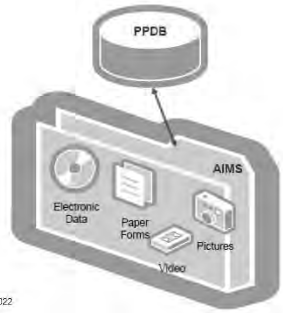
LTPP program is to assess long-term performance of pavements under various loading and environmental conditions.

- Includes 8 General Pavement Studies (GPS) experiments.
- Includes 10 Specific Pavement Studies (SPS) experiments.
- Has included 2,581 total sections over more than 30 years.
- Currently includes 332 active sections.

2

LTPP Data Management

- LTPP tabular data stored in Pavement Performance Database (PPDB).
- LTPP nontabular data stored in Ancillary Information Management System (AIMS).
- PPDB composed of more than 1,100 tables.
- Data available through Data Selection and Download option on InfoPave™ website: https://infopave.fhwa.dot.gov/.[1]



[1] Federal Highway Administration. 2022. "LTPP InfoPave" (website). https://infopave.fhwa.dot.gov. last accessed September 16, 2022.

Source: FHWA

3

Significance of LTPP Data

- Data-driven design, planning, and decision-making.
- Continuous health monitoring of highway pavements.

Structure and Materials
- Experiment and section information.
- Materials sampling and testing information.
- Structure and features information.
- Maintenance and rehabilitation data.

Traffic
- Traffic inputs for pavement analyses.
- Monitored traffic.
- Computed parameters.

Climate
- Temperature, humidity, precipitation, wind, and solar data.
- Virtual weather station data.
- Modern-Era Retrospective Analysis for Research and Applications (MERRA) data.

Performance
- Distress (crack, patch, potholes).
- Surface characteristics (International Roughness Index, rutting, texture).
- Deflection (falling weight deflectometer data).

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4

Using LTPP Data Requires In-Depth Knowledge and Data Wrangling

Challenges in acquisition and interpretation of LTPP data may include:

- Data distributed across many tables.
- Multiple values for a given layer.
- Data missing for some sections or time intervals.
- The need for knowledge of PPDB and LTPP experiments.

Source: FHWA

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5

LTPP Analysis-Ready Datasets (ARD) Development

- Using American Association of State Highway and Transportation Officials' (AASHTO) AASHTOWare® Pavement Mechanistic-Empirical Design™ (PMED) and other applications as a yardstick…[1]
- …In order to formulate datasets, which include the following:
  - ▷ **ARMAD—materials property data.**
  - ▷ Analysis-Ready Performance Dataset (ARPED).
  - ▷ Analysis-Ready Climate Dataset (ARCLD).
  - ▷ Analysis-Ready Traffic Dataset (ARTRD).

Source: AASHTO

[1] AASHTO. 2020. "AASHTOWare Pavement ME Design" (software). Version 2.8. Washington, DC: American Association of State Highway and Transportation Officials. https://me-design.com/MEDesign/Home.aspx, last accessed September 15, 2022.

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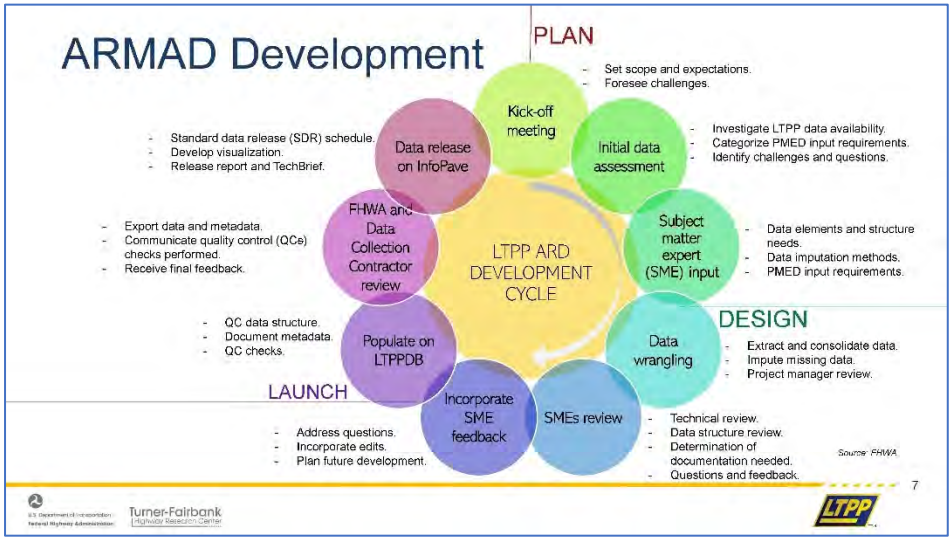
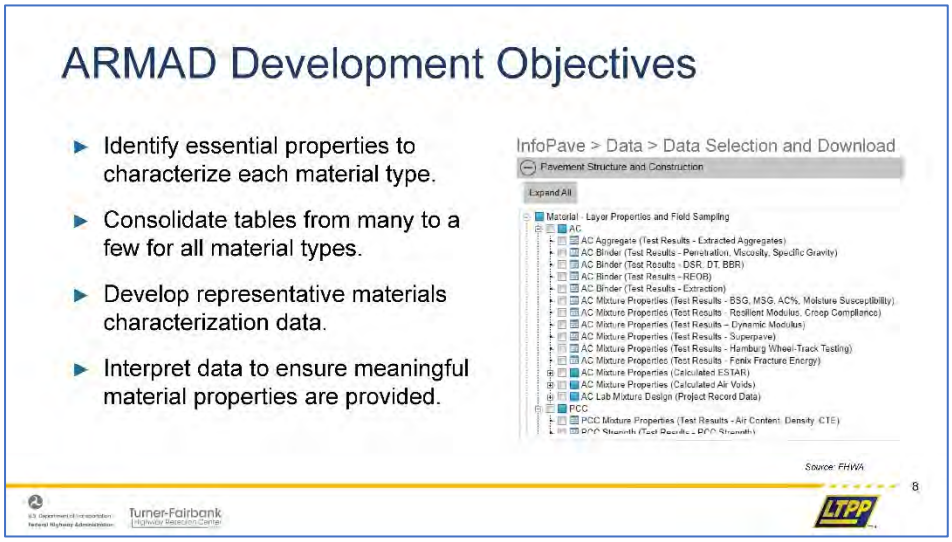
6


ARMAD Development
PLAN
- Set scope and expectations.
- Foresee challenges.
Kick-off meeting
Initial data assessment
- Investigate LTPP data availability.
- Categorize PMED input requirements.
- Identify challenges and questions.
Subject matter expert (SME) input
- Data elements and structure needs.
- Data imputation methods.
- PMED input requirements.
DESIGN
Data wrangling
- Extract and consolidate data.
- Impute missing data.
- Project manager review.
SMEs review
- Technical review.
- Data structure review.
- Determination of documentation needed.
- Questions and feedback.
Incorporate SME feedback
- Address questions.
- Incorporate edits.
- Plan future development.
LAUNCH
Populate on LTPPDB
- QC data structure.
- Document metadata.
- QC checks.
FHWA and Data Collection Contractor review
- Export data and metadata.
- Communicate quality control (QCs) checks performed.
- Receive final feedback.
Data release on InfoPave
- Standard data release (SDR) schedule.
- Develop visualization.
- Release report and TechBrief.
LTPP ARD DEVELOPMENT CYCLE
Source: FHWA
7
Turner-Fairbank Highway Research Center
LTPP


ARMAD Development Objectives
Identify essential properties to characterize each material type.
Consolidate tables from many to a few for all material types.
Develop representative materials characterization data.
Interpret data to ensure meaningful material properties are provided.
InfoPave > Data > Data Selection and Download
Pavement Structure and Construction
Expand All
Material - Layer Properties and Field Sampling
AC
AC Aggregate (Test Results - Extracted Aggregates)
AC Binder (Test Results - Penetration, Viscosity, Specific Gravity)
AC Binder (Test Results - DSR, DT, BBR)
AC Binder (Test Results - REOB)
AC Binder (Test Results - Extraction)
AC Mixture Properties (Test Results - BSG, MSG, AC%, Moisture Susceptibility)
AC Mixture Properties (Test Results - Resilient Modulus, Creep Compliance)
AC Mixture Properties (Test Results - Dynamic Modulus)
AC Mixture Properties (Test Results - Superpave)
AC Mixture Properties (Test Results - Hamburg Wheel-Track Testing)
AC Mixture Properties (Test Results - Fenix Fracture Energy)
AC Mixture Properties (Calculated ESTAR)
AC Mixture Properties (Calculated Air Voids)
AC Lab Mixture Design (Project Record Data)
PCC
PCC Mixture Properties (Test Results - Air Content, Density, CTE)
Source: FHWA
8
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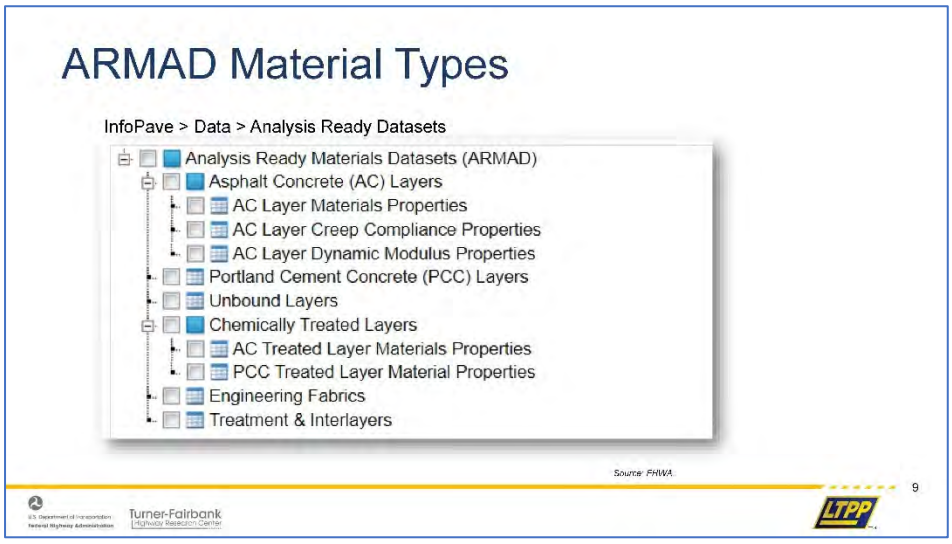
LTPP


ARMAD Material Types
InfoPave > Data > Analysis Ready Datasets
Analysis Ready Materials Datasets (ARMAD)
Asphalt Concrete (AC) Layers
AC Layer Materials Properties
AC Layer Creep Compliance Properties
AC Layer Dynamic Modulus Properties
Portland Cement Concrete (PCC) Layers
Unbound Layers
Chemically Treated Layers
AC Treated Layer Materials Properties
PCC Treated Layer Material Properties
Engineering Fabrics
Treatment & Interlayers
Source: FHWA
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LTPP

Example ARMAD Key Properties (1 of 2)

Category	Material Element
Unbound base/ subbase/subgrade materials	• Layer thickness • Material type • Poisson's ratio • Resilient modulus • Soil classification (gradation and Atterberg limits) • Compaction characteristics (optimum moisture content and maximum dry density) • Specific gravity • Resilient modulus and parameters • Saturated hydraulic conductivity

Source: FHWA

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Example ARMAD Key Properties (2 of 2)

Category	Material Element
Asphalt concrete (AC) Mixture and Asphalt-Treated Layers	• Layer thickness • Material type • Poisson's ratio • Asphalt binder complex shear modulus (G^*) and phase angle (δ)—set of values at different frequencies and temperature to create master curve • Binder type • Viscosity • Dynamic modulus (E^*) – set of values at different temperatures and frequencies to build a master curve • Tensile strength • Creep compliance • Volumetric properties (unit weight, bulk specific gravity, maximum specific gravity, aggregates specific gravity, air voids, binder content, VMA, VFA) • Aggregate gradation • Thermal conductivity • Heat capacity • Aggregate coefficient of thermal contraction • Surface shortwave absorptivity

VMA = voids in the mineral aggregate; VFA = voids filled with asphalt

Source: FHWA

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ARMAD Tables

Table Name	Description
ANALYSIS_TST_UNBOUND	Properties of unbound materials.
ANALYSIS_TST_UNBOUND_SUPPORT	Unbound materials support information.
ANALYSIS_TST_PCC	Properties of portland cement concrete (PCC) materials.
ANALYSIS_TST_PCC_SUPPORT	PCC materials support information.
ANALYSIS_TST_AC	Properties of AC materials.
ANALYSIS_TST_AC_SUPPORT	AC materials support information.
ANALYSIS_TST_AC_ESTAR	AC dynamic modulus data; no support table.
ANALYSIS_TST_AC_CREEP_COMP	AC creep compliance testing properties.
ANALYSIS_TST_AC_CRCOM_SUPPORT	AC creep compliance support information.
ANALYSIS_TST_ACT	Properties of asphalt-treated materials.
ANALYSIS_TST_ACT_SUPPORT	Asphalt-treated materials support information.
ANALYSIS_TST_PCT	Properties of cement-treated materials.
ANALYSIS_TST_PCT_SUPPORT	Cement-treated materials support information.
ANALYSIS_TST_TR	Representative properties of treatment layers.
ANALYSIS_TST_TR_SUPPORT	Support information for treatment layer types.
ANALYSIS_TST_EF	Properties of engineering fabric layers.
ANALYSIS_TST_EF_SUPPORT	Engineering fabric layers support information.

Source: FHWA

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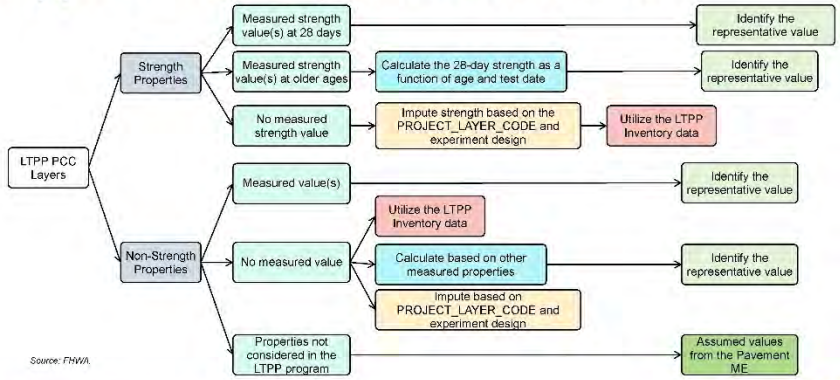
Approach Example: PCC Material



Source: FHWA.

ARMAD Data Source and Variability Rating

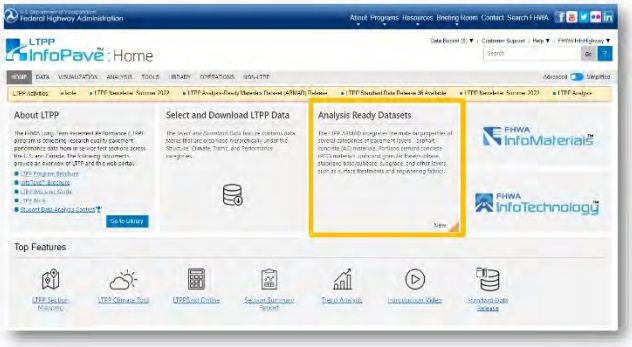
Lower rating

DATA_SOURCE	Description	DATA_SOURCE_CODE	Sub-groups	REP_CODE_SOURCE_VARIABILITY[1]
MEASURED	Properties directly measured using standard testing in LTPP program.	A	2+ measurements Low coefficient of variation (COV) High COV 1 measurement	AI AH AS
CALCULATED	Properties are calculated using measured parameters and assumed conditions.	B	Calculated from 2+ measured parameters Measured parameters low COV At least one measured parameter high COV Calculated from 1 measured parameter	BL BH BS
EXPANDED	Properties are expanded to similar sections in an LTPP experiment using the PROJECT_LAYER_CODE.	C	2+ measured data from similar sections Low COV High COV 1 data point from similar sections	CL CH CS
IMPUTED	Properties are estimated using statistical methods and typical models.	D	Imputed from 2+ measurements Low COV High COV Imputed from 1 measurement	DL DH DS
INVENTORY	Properties are adopted from inventory presenting agency typical practices.	E	Inventory median for 2+ values Low COV High COV Inventory single value	EL EH ES
ASSUMED	Properties are estimated based on the *MEPDG* or other reliable sources.[1]	F	Assumed values	F

Source: FHWA.

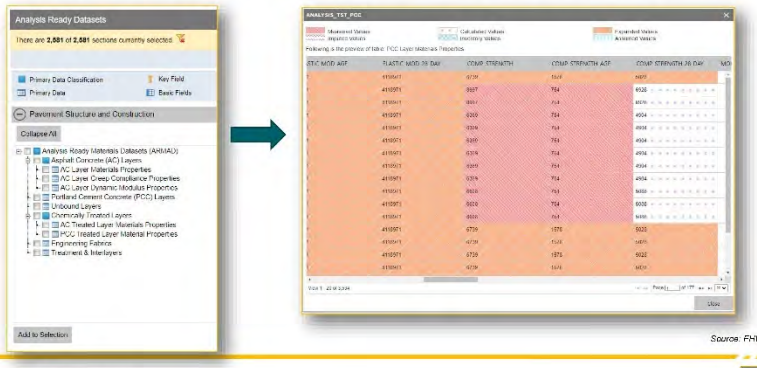
[1]AASHTO. 2008. *Mechanistic-Empirical Pavement Design Guide*. Washington, DC: American Association of State Highway and Transportation Officials.

LTPP ARMAD Now on InfoPave™!



Source: FHWA.

ARMAD on InfoPave User Interface



Source: FHWA

Example Studies Using ARMAD:

- Development of materials dataset for selection of test sections as part of a broader pavement research study.
- Materials data studies of in-service pavements.
- Development of correlations between material properties.
- Lab-to-field comparisons of advanced materials testing analysis.
- Local calibration of PMED software (AASHTO 2020).[1]

[1] AASHTO. 2020. "AASHTOWare Pavement ME Design" (software), Version 2.8, Washington, DC, American Association of State Highway and Transportation Officials. https://me-design.com/MEDesign/Home.aspx; last accessed September 15, 2022.

1. Use Case: Air Void Study

- NCHRP 20-50(18) "LTPP Data Analysis: Significance of As-Constructed Asphalt Pavement Air Voids to Pavement Performance."[1]
- Air voids can have a significant effect on performance of asphalt pavements:
  - Too low can cause bleeding, rutting, and shoving.
  - Too high can lead to increased potential for water infiltration, accelerated oxidation, raveling, cracking, and rutting in wheelpath (WP).

[1] E. T. Harrigan. 2002. "Significance of As-Constructed HMA Air Voids to Pavement Performance from an Analysis of LTPP Data." *National Cooperative Highway Research Program Research Results Digest 269.*

1. Air Void Study: Computation

- Percent air voids:

$$\%Air\ Voids = \left((G_{mm} - G_{mb})/G_{mm}\right) \times 100\%$$

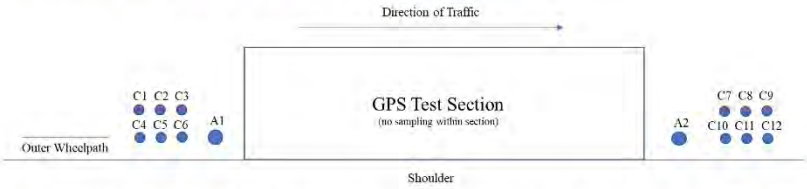
Where:

G_{mm} = maximum specific gravity.

G_{mb} = bulk specific gravity.

Simple formula but challenging to obtain!!

1. Air Voids Study: Sampling

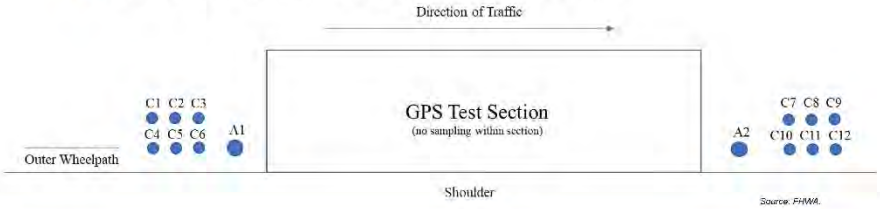


Source: FHWA.

- Took 4-inch cores at C-type locations—used for bulk specific gravity.
- Took 6-inch cores at A1 and A2 locations—used for maximum specific gravity.

1. Air Voids Study: Data Wrangling

- Combine C1–C3 results with A1 and C4–C6 results with A1 results to obtain WP and not-in-WP (NWP) air voids at start of section—six measurements.
- Similar approach used at test section end—six measurements.
- Develop WP and NWP air voids for entire section.



Source: FHWA.

1. Air Voids Study: Data Summary

- Daunting task to develop air void content or other material properties for large number of LTPP test sections.
- Expert knowledge required of LTPP experiments and materials sampling and testing details.
- Cost large amount of the research project budget to develop the analysis ready dataset.

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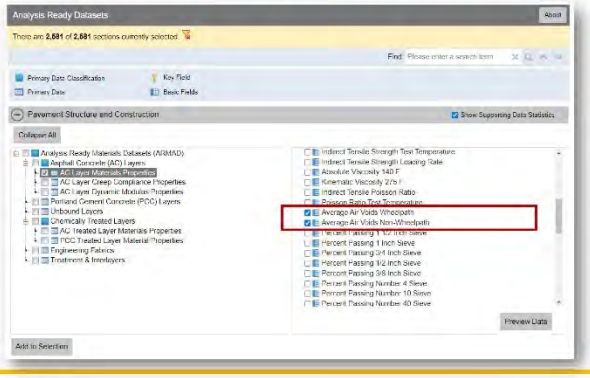
1. Air Voids Part of ARMAD on InfoPave!



Source: FHWA.

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Concluding Remarks

- Analysis-ready datasets will save thousands of data wrangling hours, allowing researchers to focus on their analyses.
- LTPP program will continue creating easier access to LTPP data and providing new datasets on InfoPave.

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Future Plan and Events

- Release of additional ARD datasets on InfoPave as part of the upcoming SDR37 (planned in August 2023):
  - ARPED—pavement performance data.
  - ARCLD—climate data.
  - ARTRD—traffic loading data.
  - Enhancements and updates to ARMAD—SDR37.
- ARD presentations at Transportation Research Board 2023 Annual Meeting.

https://infopave.fhwa.dot.gov/

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Disclaimer

The U.S. Government does not endorse products or manufacturers. Trademarks or manufacturers' names appear in this presentation only because they are considered essential to the objective of the presentation. They are included for informational purposes only and are not intended to reflect a preference, approval, or endorsement of any one product or entity.

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Presentation 13—Bruce Barrett, Nebraska DOT

Nebraska DOT

Backcalculation Lessons Learned
&
Calibration Effort
Bruce Barrett

Layer Thickness File

Total Thickness=
Foundation Course
Plus Subgrade

	A	B	C	D	E
1	StationDistance	Layer1	Layer2	Layer3	Layer4
2	1	14	24		
3	2	13	24		
4	3	13.5	24		
5	4	11	24		
6	5	14.25	24		
7	6	13.75	24		
8	7	15	24		
9	8	13	24		
10	9	13.5	24		
11	9.8	15.25	24		
12					

- Add thicknesses from Asphalt Core Samples or GPR thicknesses.
- BcT does not interpret raw GPR data

Asphalt Core Sample Identification

Project Name: N Jct N-70 Northwest	Date Cored: 8/3/2022
Project Number: NH-281-3(114)	Requested By: NDOT
Control Number: 81080	Core Diameter: 4"
Reference Posts: US-281 148.24 to 158.09	Sampled By: Rel Sykora and Matthew Bowman

Core Field #	Core Location (By Highway # & RP)	Distance in Ft. Rt. Or Lt. of Road Way CL	Total Depth to Subgrade Inches & Type of Material	Subgrade Type	Remarks *Examples: Depth of Breaks, Depth and severity of Stripping, ect.*
C-01	US-281 149	9' Rt	14" AC/BSBC	-	41.99189884, -98.5550554- 10" AC, 2.75" BSBC, 0.75" AC, no breaks, no stripping, Offset 9' Rt (instead of 6') due to road cracks, core > 14"
C-02	US-281 150	9' Rt	13" AC/BSBC	Silty Sand with gravel (A-1-b)	42.00199147, -98.56910703- 11.75" AC, 0.75" BSBC, no breaks, no stripping
C-03	US-281 151	6' Rt	13.5" AC/BSBC	-	42.01198145, -98.58312741- 9.5" AC, 4" BSBC, no breaks, no stripping
C-04	US-281	Shoulder	[illegible]	Silty Sand	42.01199906, -98.58310073- 6" AC, no breaks, low severity stripping

Backcalculations

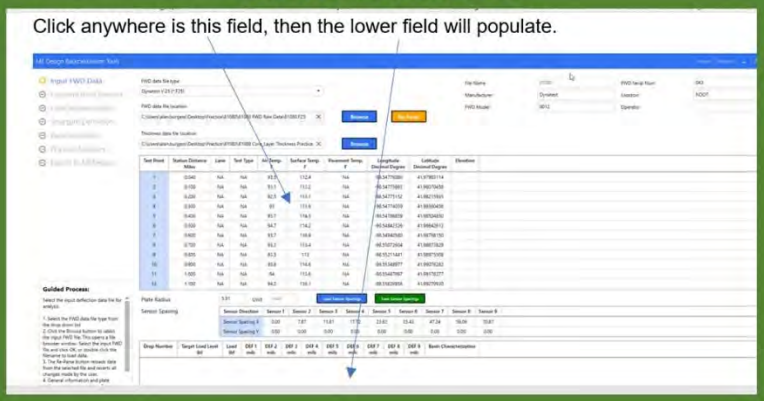
Important – won't run if file type is incorrect

Click browse at FWD data file location and select data file from job folder.

Click browse at Thickness data file location and select Core Layer Thickness file, da
will automatically populate.

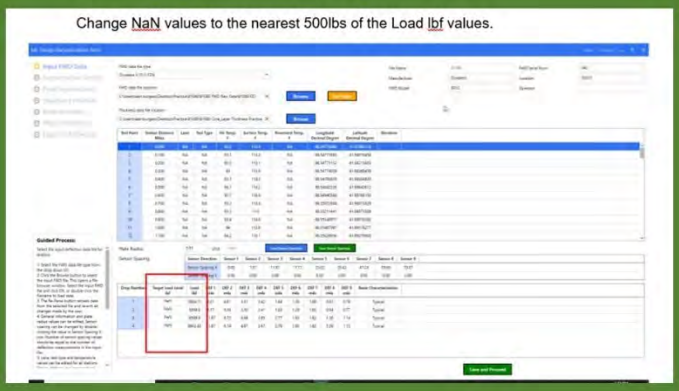
Backcalculations

Click anywhere is this field, then the lower field will populate.

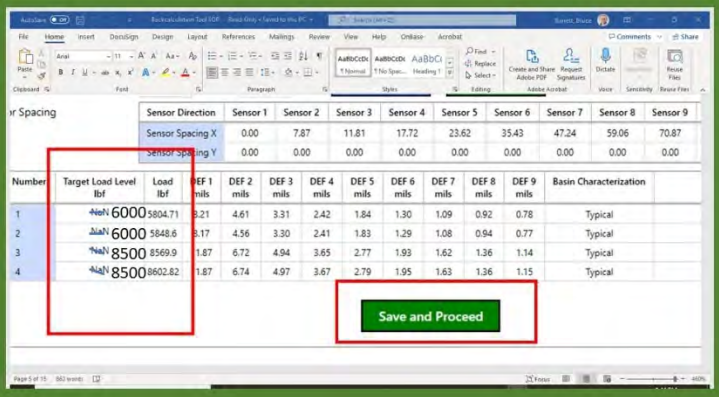


Backcalculations

Change NaN values to the nearest 500lbs of the Load lbf values.



Backcalculations



Sensor Direction	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6	Sensor 7	Sensor 8	Sensor 9
Sensor Spacing X	0.00	7.87	11.81	17.72	23.62	35.43	47.24	59.06	70.87
Sensor Spacing Y	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Number	Target Load Level lbf	Load lbf	DEF 1 mils	DEF 2 mils	DEF 3 mils	DEF 4 mils	DEF 5 mils	DEF 6 mils	DEF 7 mils	DEF 8 mils	DEF 9 mils	Basin Characterization
1	NaN 6000	5804.71	8.21	4.61	3.31	2.42	1.84	1.30	1.09	0.92	0.78	Typical
2	NaN 6000	5848.6	8.17	4.56	3.30	2.41	1.83	1.29	1.08	0.94	0.77	Typical
3	NaN 8500	8569.9	1.87	6.72	4.94	3.65	2.77	1.93	1.62	1.36	1.14	Typical
4	NaN 8500	8602.82	1.87	6.74	4.97	3.67	2.79	1.95	1.63	1.36	1.15	Typical

Save and Proceed

Backcalculations

Segmentation and Sensor

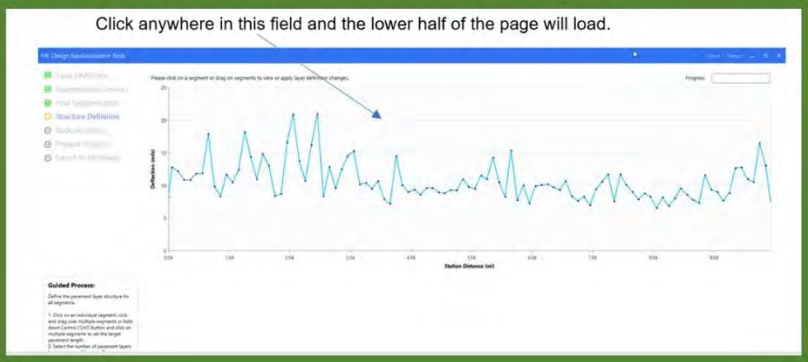
Save and Proceed

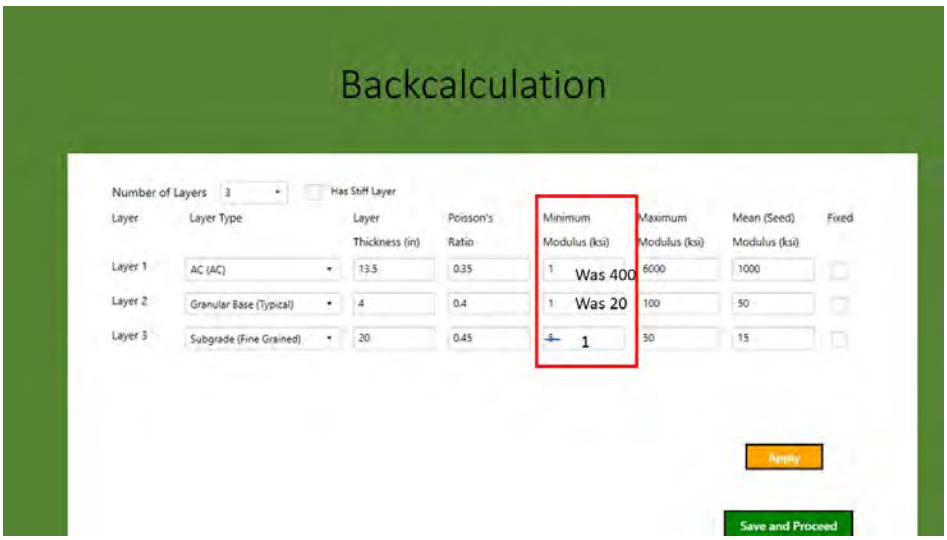
Backcalculations

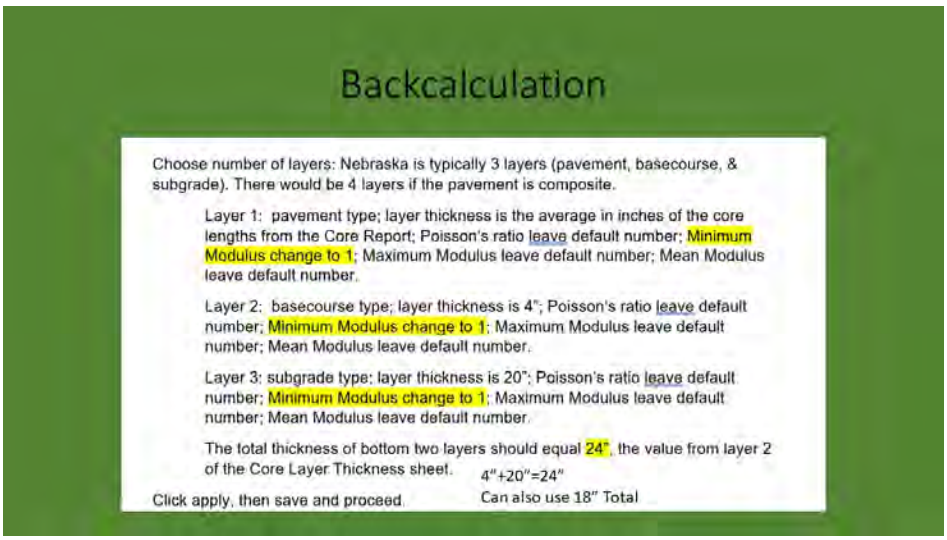
Final Segmentation

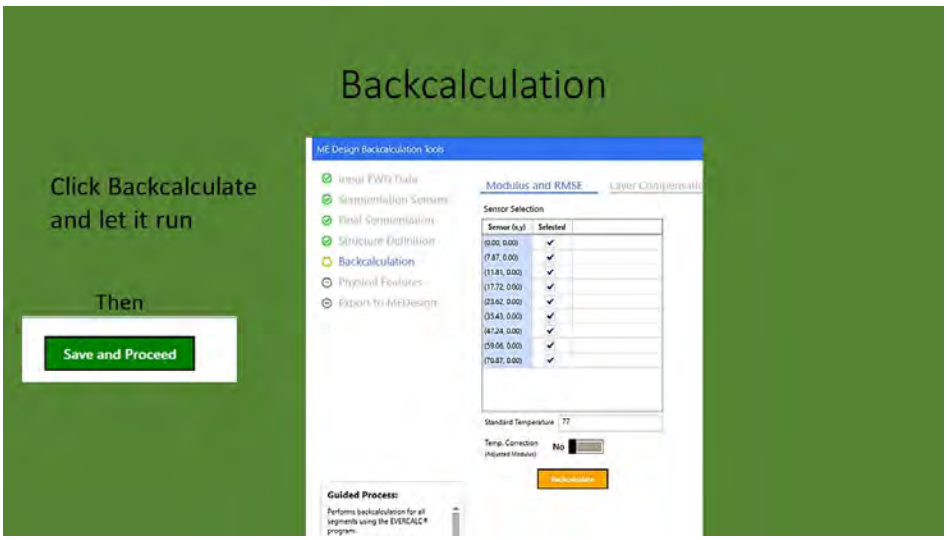
Save and Proceed

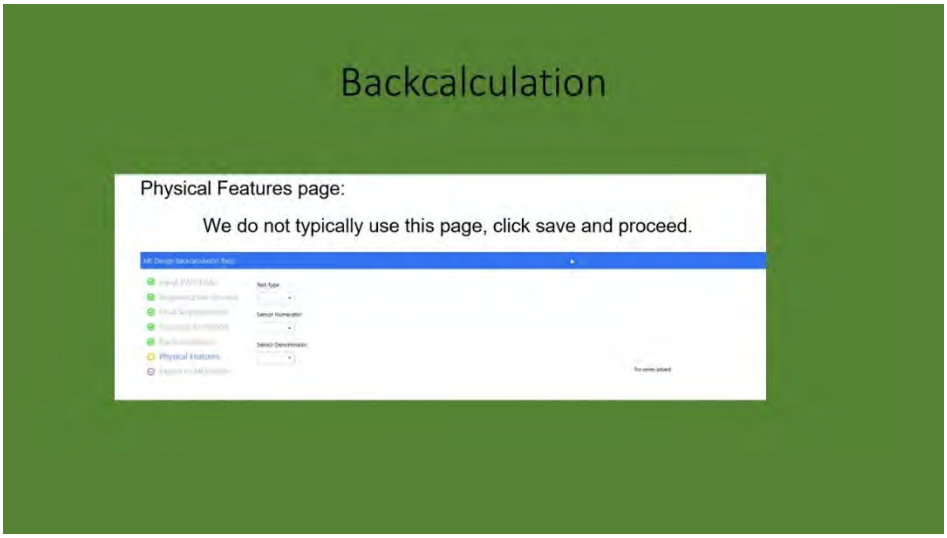
Backcalculation

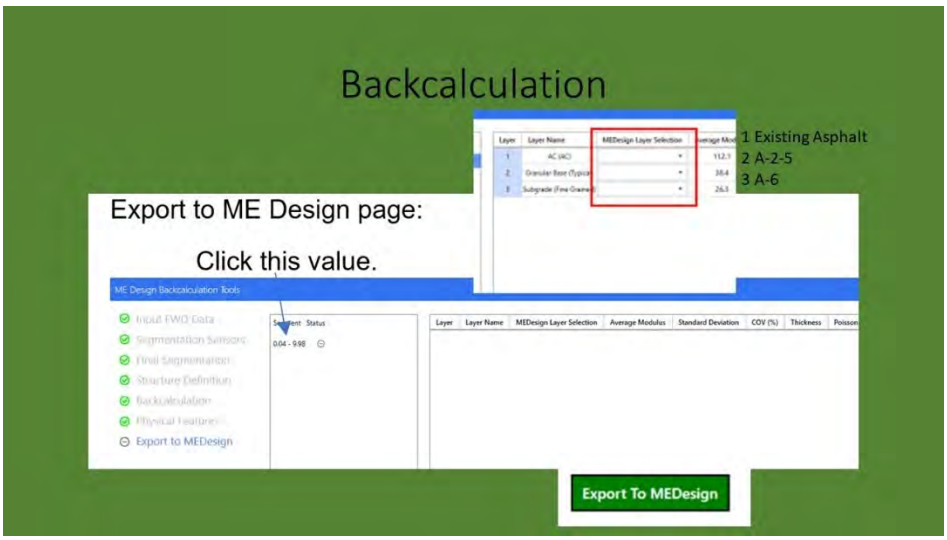


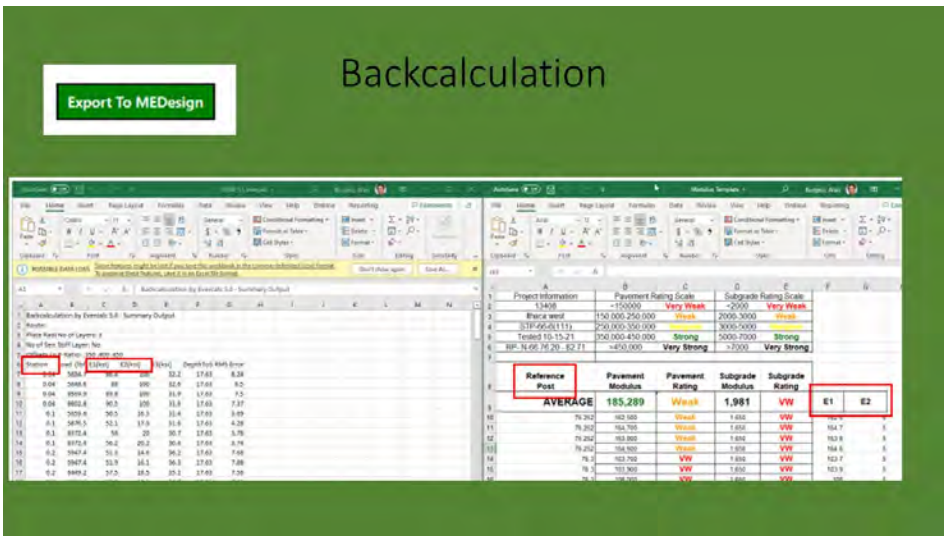

Backcalculation
Number of Layers 3
Has Stiff Layer
Layer
Layer Type
Layer Thickness (in)
Poisson's Ratio
Minimum Modulus (ksi)
Maximum Modulus (ksi)
Mean (Seed) Modulus (ksi)
Fixed
Layer 1
AC (AC)
13.5
0.35
1
Was 400
6000
1000
Layer 2
Granular Base (Typical)
4
0.4
1
Was 20
100
50
Layer 3
Subgrade (Fine Grained)
20
0.45
1
50
15
Apply
Save and Proceed


Backcalculation
Choose number of layers: Nebraska is typically 3 layers (pavement, basecourse, & subgrade). There would be 4 layers if the pavement is composite.
Layer 1: pavement type; layer thickness is the average in inches of the core lengths from the Core Report; Poisson's ratio leave default number; Minimum Modulus change to 1; Maximum Modulus leave default number; Mean Modulus leave default number.
Layer 2: basecourse type; layer thickness is 4"; Poisson's ratio leave default number; Minimum Modulus change to 1; Maximum Modulus leave default number; Mean Modulus leave default number.
Layer 3: subgrade type; layer thickness is 20"; Poisson's ratio leave default number; Minimum Modulus change to 1; Maximum Modulus leave default number; Mean Modulus leave default number.
The total thickness of bottom two layers should equal 24", the value from layer 2 of the Core Layer Thickness sheet.
4"+20"=24"
Can also use 18" Total
Click apply, then save and proceed.


Backcalculation
Click Backcalculate and let it run
Then
Save and Proceed
ME Design Backcalculation Tools
Backcalculation
Modulus and RMSE
Sensor Selection
Standard Temperature
Guided Process:


Backcalculation
Physical Features page:
We do not typically use this page, click save and proceed.


Backcalculation
1 Existing Asphalt
2 A-2-5
3 A-6
Export to ME Design page:
Click this value.
Export To MEDesign


Export To MEDesign
Backcalculation

Backcalculation

Common Concerns With FWD raw data

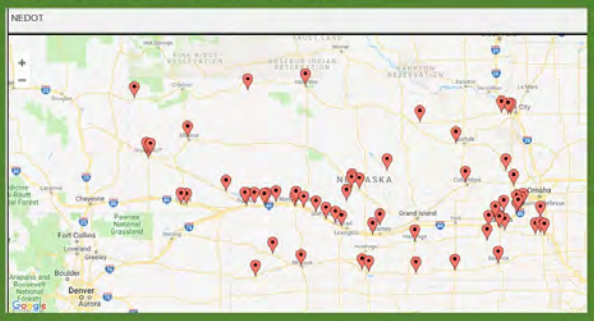
- Start FWD DMI at a Mile Marker don't just default to zero, these need to correlate with the core thickness Mile Markers
- Get rid of FWD warm-ups or multiple tests at the same location.
- Ask FWD operator to add comment lines to explain data Anomalies/Errors so it can be edited in the office
- MMs need to be in sequence, edit as appropriate.

Nebraska Calibration Effort

- ARA worked with us to get fully calibrated last fall.
- Used a total on 63 Nebraska Sites and 18 LTPP Sites
- Nebraska Sites
  - Distress Surveys-Rutting, Transverse and Fatigue Cracking, IRI
  - FWD Testing – Elastic Moduli and LTE for PCC
  - Dynamic Cone Penetration Testing – Elastic Modulus vs depth
  - Cores – confirm depth and condition

Nebraska Calibration Effort

Location of Sites in Sampling Plan



Nebraska Calibration Effort

Field Sample Testing

PCC Testing
- Coefficient of Expansion
- Compressive Strength & Elastic Modulus of cores

Asphalt Testing
- Dynamic Modulus
  - Calculated from PavementME regression equation
- Backcalculated modulus for asphalt layers
- ITS/Strain Failure
- Creep Compliance, new asphalt mixes
- Air Voids, Binder Content, Gradation

Nebraska Calibration Effort

Determine Inputs for Calibration Sites
- Traffic
- Material Properties
- Initial Smoothness

Derive Calibration Coefficients
- Based on Distress

Nebraska Calibration Coefficients

No Changes to Calibration Coefficients For:
- Faulting
- PCC and Flexible IRI
- Rutting
- Fatigue Cracking
- Transverse Cracking, originally changed but reassessed to Global

Changed Calibration Coefficient For:
- Mid-Slab Cracking C1 from Global 2.0 to Nebraska 4.5

Nebraska Calibration Effort

ARA created Input XML files based on material characterization and traffic hose counts and categories:

- Nebraska Asphalt Mixes
- 3 Types of Foundation Course
- Standard PCC Mixes

Traffic (We don't have fixed WIMs)

- Arterial Principal Minor Rural
- Arterial Principal Minor Urban
- Interstate Urban
- Local Road Higher Trucks
- Local Road Lower Trucks

Presentation 14—Syed Haider, Michigan State University

Local Calibration of Rigid Pavement Models

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

MICHIGAN STATE UNIVERSITY

AASHTO Pavement ME National Users Group Meeting

Salt Lake City, Utah. November 1 to 3 , 2022

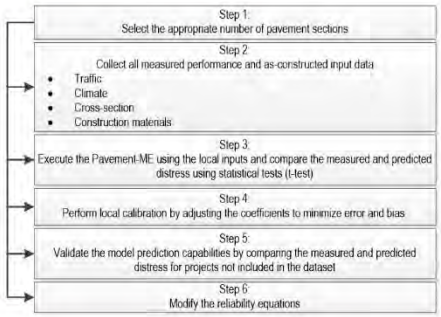
Presentation Outline

- Introduction and objectives
- Background
- Performance data
- PMED inputs
- Model calibration approaches
- Reliability in PMED
- Summary

Introduction — *Why locally calibrate the performance models*

- The PMED performance models have been 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.
- The globally calibrated models may not represent local weather conditions, materials, and construction practices for a particular region. Therefore, local calibration of the models may be necessary for local State Highway Agency (SHA) to incorporate local conditions in the Pavement ME design.
- 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.

Introduction — *Local calibration process*



Objectives

The main objectives are to discuss:

- Input data for the pavement sections
- Extent of performance
- Model calibration approaches
- Concept of reliability in the PMED

Background — *Mechanistic-empirical performance models*

- The PMED 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

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

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

Background — *Joint faulting model*

- The transverse joint faulting is calculated monthly in the PMED using the material properties, climatic conditions, present faulting level, pavement design properties, and axle loads applied. Total faulting is the sum of faulting increments from previous months

$$Fault_m = \sum_{i=1}^{m} \Delta Fault_i$$

$$\Delta Fault_i = C_{34} \times (FAULTMAX_{i-1} - Fault_{i-1})^2 \times DE_i$$

$$FAULTMAX_i = FAULTMAX_0 + C_7 \times \sum_{j=1}^{m} DE_j \times \log(1 + C_5 \times 5.0^{ERODE})^{C_6}$$

$$FAULTMAX\,X_0 = C_{12} \times \delta_{curling} \times \left[\log(1 + C_5 \times 5.0^{ERODE}) \times \log\left(\frac{P_{200} \times WetDays}{P_s}\right)\right]^{C_6}$$

Background — *IRI model*

- IRI is a critical distress for rigid pavements. In Pavement-ME, IRI is a linear relationship between the IRI at the time of construction and change in other distresses (transverse cracking, joint faulting, and joint spalling) over time.

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

$$SF = AGE(1 + 0.5556 \times FI)(1 + P_{200}) \times 10^{-6}$$

$$SPALL = \left[\frac{AGE}{AGE + 0.01}\right]\left[\frac{100}{1 + 1.005(-12 \times AGE + SCF)}\right]$$

$$SCF = -1400 + 350 \times AC_{PCC} \times (0.5 + PREFORM) + 3.4 f_c^{0.4} - 0.2(FTcycles \times AGE) + 43 h_{PCC} - 536 WC_{PCC}$$

Performance Data — *Extraction of performance data*

- MDOT performance database includes the Pavement Management System (PMS) database for transverse cracking and sensor data for IRI and joint faulting. Both PMS and sensor data is recorded for every 0.1mile section

CSNUM	ROUTE	DIR	SURVEY_YEAR	BMP	EMP	PDCODE_F	PD_TITLE_DESC	LENGTHORCOUNT	DSC
1052	U523	I	2013	2.451	2.551	103	TC (straight)		4 Occurence(s)
1052	U523	I	2013	13.661	13.824	104	TC (irregular)		1 Occurence(s)
2041	M28	I	2013	0	0.1	103	TC (straight)		3 Occurence(s)
2041	M28	I	2013	0.1	0.2	103	TC (straight)		1 Occurence(s)
2041	M28	I	2013	0.1	0.2	103	TC (straight)		1 Occurence(s)
2041	M28	I	2013	0.2	0.3	103	TC (straight)		3 Occurence(s)
2041	M28	I	2013	0.2	0.3	103	TC (straight)		1 Occurence(s)

Screenshot of MDOT PMS data

SURVEY_YEAR_F	CS	ROUTE	MILEPOSTS_DIRECTION_IND	CS_BMP	CS_EMP	IRI_LEFT	IRI_RIGHT	FAULTING_NUM_RIGHT	FAULTING_AVG_RIGHT	FAULTING_MAX_RIGHT	FAULTING_NUM_LEFT	FAULTING_AVG_LEFT	FAULTING_MAX_LEFT
2013	15022	M6	I	12.18	12.4	241	241	1	0.06	0.06	1	0.04	0.04
2013	2041	M28	I	22.1	22.8	157	241	28	0.12	0.72	24	0.08	0.59
2013	2041	M28	I	24.1	24.6	264	157	14	0.12	0.08	54	0.12	0.79
2013	2041	M28	I	24.9	25	157	155	37	0.12	0.64	55	0.08	0.45
2013	2041	M28	I	25	25.1	155	155	16	0.08	0.56	16	0.04	0.32
2013	2041	M28	I	25.1	25.2	224	157	31	0.16	1.4	30	0.12	0.79
2013	2041	M28	I	26.3	26.4	157	145	23	0.16	0.28	21	0.12	0.48
2013	2041	M28	I	26.6	26.808	208	145	4	0.08	0.12	3	0.12	0.16

Screenshot of MDOT sensor data

Performance Data — *Extraction of performance data*

- Transverse cracking is stored in PMS database as number of occurrences and should be converted to percent cracking.

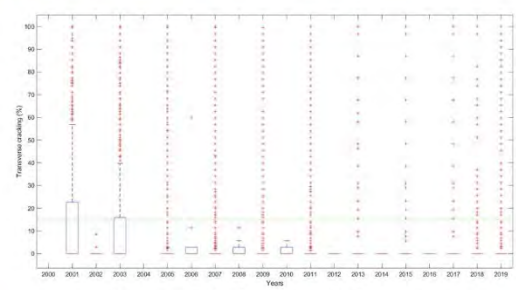
$$\%Slab\ Cracked = \frac{\sum No.\ of\ Occurences \times Joint\ Spacing\ (ft)}{Project\ Length\ (miles)}$$

- Joint faulting is stored in the sensor database as the average faulting (FAULavg) for certain number of faulted joints (FAULnum). Total faulting is calculated by averaging the faulting over all joints (N_{joints}).

$$Fault_{total} = \frac{FAULnum \times FAULavg}{N_{joints}}$$

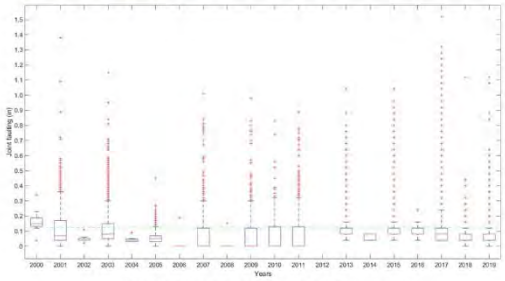
- IRI in the sensor database does not require any conversion and the values can be directly used.

Performance Data — *Extraction of performance data*



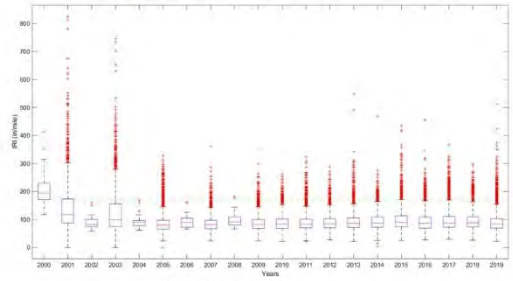
Transverse cracking data for every 0.1mile segment

Performance Data — *Extraction of performance data*



Joint faulting data for every 0.1 mile segment

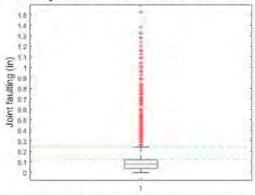
Performance Data — *Extraction of performance data*



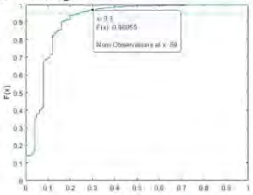
IRI data for every 0.1 mile segment

Performance Data — *Extraction of performance data*

- To include the effect of outliers for faulting data, calibration was performed using entire faulting data and with filtered faulting data considering a cap of 0.3 in. for the average joint faulting for every 0.1mile.
- A cap of 0.3 in. covers 97% of the faulting data.



Range of faulting for every 0.1mile

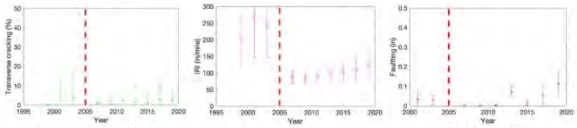


CDF of faulting for every 0.1mile

Performance Data — *Selection of pavement sections*

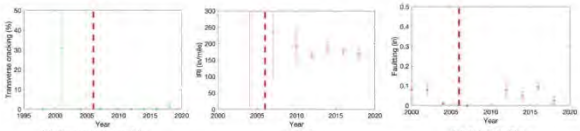
- Selection of rigid sections (JPCP + unbonded overlay) for each model calibration is based on:
  - At least 3 data points in the analysis period.
  - No major rehabilitation in the analysis period.
  - An overall increasing trend
- The performance measures predicted for JPCP are:
  - Transverse Cracking
  - IRI
  - Joint faulting

Performance Data — *Selection of pavement sections*



(a) Transverse cracking (b) IRI (c) Joint faulting

Example of time series data of measured performance for a selected section



(a) Transverse cracking (b) IRI (c) Joint faulting

Example of time series data of measured performance for a rejected section

Performance Data — *Selection of pavement sections*

- Although, a total of 114 sections were identified for calibration, sections used for individual models may be different. A sections showing joint faulting may not exhibit any transverse cracking in the same period.

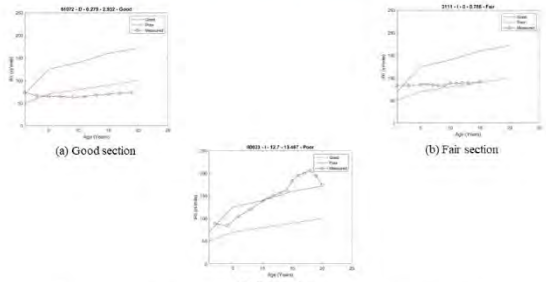
Summary of selected projects and sections for each surface type

Pavement type	Surface type	Number of projects	Number of sections
Freeway	JPCP	45	84
Freeway	Unbonded	11	28
Non-freeway	JPCP	2	2
Total		**58**	**114**

Performance Data — *Selection of pavement sections*

- 114 sections were selected out of a total of 442 sections in the MDOT database. In order to evaluate the representation of the selected sections in the available database, overall performance was compared.
- Each section was assigned a performance category (good, fair or poor) based on FHWA criteria. The performance categories depend on the measured performance trend relative to the reference lines.
- When the performance trend passes through more than one category zone, the zone with maximum number of points is considered as the performance category for that section.
- In case of equal number of points for two different categories, the low performance category is selected.

Performance Data — *Selection of pavement sections*



(a) Good section (b) Fair section

(c) Poor section

Categorization of pavement sections based on IRI trends (FHWA criteria)

Performance Data — *Selection of pavement sections*

(a) All MDOT sections (b) Selected sections

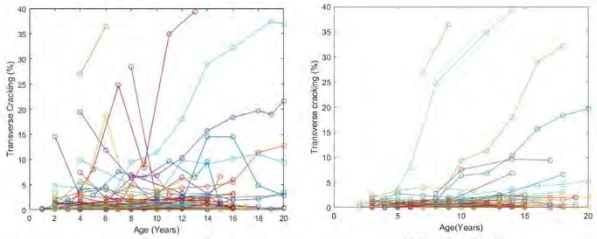
Comparison of performance based on transverse cracking

(a) All MDOT sections (b) Selected sections

Comparison of performance based on IRI

Performance Data — *Time series trend for transverse cracking*

64 sections (JPCP + unbonded overlay) sections were used for calibration of transverse cracking model

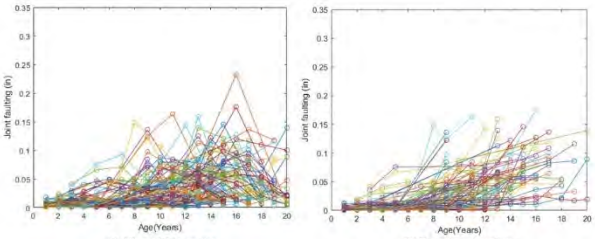


(a) All available points (b) Data for calibration

Time series data for transverse cracking

Performance Data — *Time series trend for joint faulting*

107 sections (JPCP + unbonded overlay) sections were used for calibration of Joint faulting model

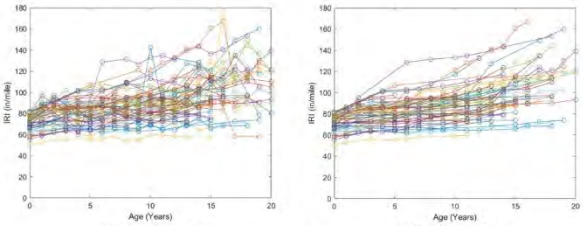


(a) All available points (b) Data for calibration

Time series data for joint faulting

Performance Data — *Time series trend for IRI*

65 sections (JPCP + unbonded overlay) sections were used for calibration of IRI model



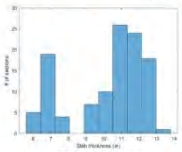
(a) All available points (b) Data for calibration

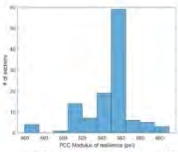
Time series data for IRI

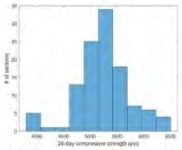
Pavement-ME inputs — *Extraction of Pavement-ME inputs*

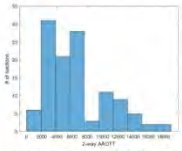
- Layer inputs: Pavement structure and material properties were obtained from plans available and construction records.
- Traffic: Level 2 traffic data was used from MDOT database.
- Climate: MDOT-NARR data files were used which have been updated for the state of Michigan.
- Necessary assumptions were made for missing data. For example, a 28-day compressive strength of 5239 psi was assumed for sections with missing compressive strength data.

Pavement-ME inputs — *Extraction of PMED inputs*

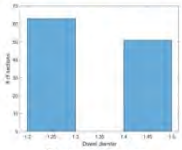

Slab thickness

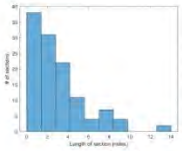

Modulus of rupture (MOR)

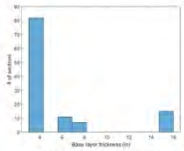

28-day compressive strength

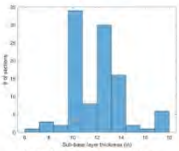

2-way average annual daily truck traffic

Pavement-ME inputs — *Extraction of PMED inputs*


Dowel diameter

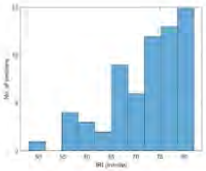

Section length


Base layer thickness


Sub-base layer thickness

Pavement-ME inputs — *Extraction of PMED inputs*

- Initial IRI was also unavailable for all sections. IRI time series trends were used to back-calculate the initial IRI at zeroth year. A cap of 82 in/mile was implemented such that sections with initial IRI greater than 82 in/mile were not used for calibration.


Distribution of initial IRI

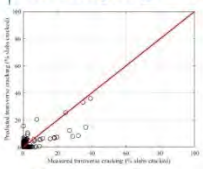
Model Calibration Approaches

- The performance prediction models were locally re-calibrated by minimizing the bias and sum of squared error between the measured and predicted distresses by using the following statistical techniques:
  a. No sampling (include all data)
  b. Bootstrapping (for transverse cracking and IRI)
  c. Repeated split sampling (for transverse cracking and IRI)
- 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.
- Genetic algorithm was used to optimize the calibration coefficients by minimizing the bias and standard deviation.
- PMED Ver 2.6.0 is used.

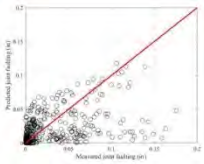
Model Calibration Approaches

- Joint faulting model has been calibrated using the Calibration Assistance Tool (CAT), therefore resampling techniques (bootstrapping and repeated split sampling) have not been used for joint faulting calibration.
- JPCP and unbonded overlay sections were combined for the local calibration.
- Calibration of all three models has been performed using three different approaches:
  1. Using modulus of resilience (MOR) for PCC slab
  2. Using 28-day compressive strength (fc') for PCC slab
  3. Using 28-day compressive strength (fc') for PCC slab and a cap of 0.3 in. on faulting data

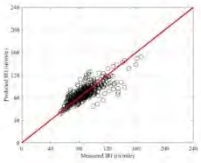
No Sampling — *Predicted vs measured (Approach 3)*



Transverse cracking

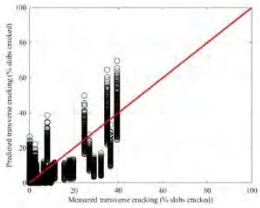


Joint faulting

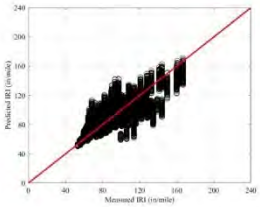


IRI

Bootstrapping — *Predicted vs measured (Approach 3)*

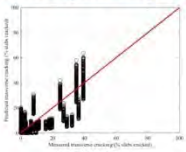


Transverse cracking

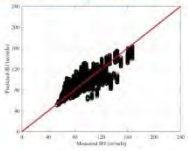


IRI

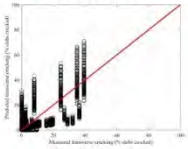
Repeated split sampling — *Predicted vs measured (Approach 3)*



(a) Calibration set

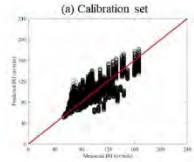


(a) Calibration set



(b) Validation set

Transverse cracking



(b) Validation set

IRI

Reliability in Pavement-ME

- PMED uses a reliability-based design to incorporate variabilities in measured performance and design inputs. Reliability for any prediction can be defined as the probability of getting a prediction lower than the threshold prediction over the design life.

$$Reliability = P[distress\ at\ the\ end\ of\ design\ life < Critical\ distress]$$

- To compute reliability for transverse cracking and joint faulting, all predicted and measured data points are grouped by creating bins on the predicted cracking.
- The average and standard deviation of measured cracking and predicted cracking is computed for each group.
- A relationship is determined between the standard deviation of the measured cracking on y-axis and average predicted cracking on the x-axis.

Reliability in Pavement-ME

- Since the error term is assumed to be normally distributed, the predicted cracking can be adjusted to the desired reliability level

$$C_R = C_{50} + S_e \times Z_{\alpha/2}$$

where,

C_R = Predicted cracking at reliability R (%)

C_{50} = Predicted cracking at 50% reliability

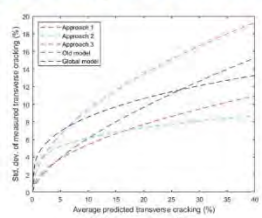
S_e = Standard deviation of cracking which can be estimated from the relationship

$Z_{\alpha/2}$ = Standardized normal deviate (mean = 0; standard deviation =1) at reliability R

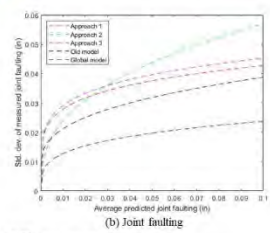
Summary statistics of reliability analysis for joint faulting (Approach 3)

No. of points	Lower limit	Upper limit	Average measured faulting	Average predicted faulting	Standard dev. of measured faulting	Standard dev. of predicted faulting
103	0	0.005	0.010	0.002	0.020	0.001
77	0.005	0.01	0.020	0.007	0.031	0.001
39	0.01	0.015	0.038	0.012	0.038	0.001
83	0.015	0.03	0.031	0.022	0.037	0.004
90	0.05	0.08	0.040	0.048	0.035	0.013
14	0.08	0.2	0.102	0.096	0.022	0.012

Reliability in Pavement-ME



(a) Transverse cracking



(b) Joint faulting

Reliability plots for different approaches

- Since a closed form solution and the variances of different components of IRI is known, the reliability model for IRI is based on the variance analysis of its individual components. The basic assumption implies that the error in predicting IRI is roughly normally distributed.

Summary — *All approaches*

Local calibration summary

Performance prediction model	Approach 1	Approach 2	Approach 3	Old model	Global model
Transverse cracking	$C_4 = 0.164$ $C_5 = -1.111$ SEE = 5.98 Bias = 0.15	$C_4 = 0.425$ $C_5 = -1.311$ SEE = 2.67 Bias = -0.23	$C_4 = 0.426$ $C_5 = -0.953$ SEE = 3.85 Bias = -0.36	$C_4 = 0.23$ $C_5 = -1.80$ SEE = 7.81 Bias = 0.30	$C_4 = 0.52$ $C_5 = -2.17$ SEE = 2.69 Bias = -0.52
Transverse joint faulting	$C_1 = 0.4285$ $C_2 = 1.6552$ $C_3 = 0.00217$ $C_4 = 0.00444$ $C_5 = 250$ $C_6 = 0.4285$ $C_7 = 7.3$ $C_8 = 400$ SEE = 0.05 Bias = 0.00	$C_1 = 0.300$ $C_2 = 1.556$ $C_3 = 0.00217$ $C_4 = 0.00444$ $C_5 = 250$ $C_6 = 0.500$ $C_7 = 7.3$ $C_8 = 400$ SEE = 0.05 Bias = 0.00	$C_1 = 0.500$ $C_2 = 1.6111$ $C_3 = 0.00217$ $C_4 = 0.00444$ $C_5 = 250$ $C_6 = 0.25$ $C_7 = 7.3$ $C_8 = 400$ SEE = 0.03 Bias = -0.01	$C_1 = 0.400$ $C_2 = 1.636$ $C_3 = 0.00217$ $C_4 = 0.00444$ $C_5 = 250$ $C_6 = 0.4285$ $C_7 = 7.3$ $C_8 = 400$ SEE = 0.02 Bias = 0.00	$C_1 = 0.595$ $C_2 = 1.636$ $C_3 = 0.00217$ $C_4 = 0.00444$ $C_5 = 250$ $C_6 = 0.47$ $C_7 = 7.3$ $C_8 = 400$ SEE = 0.06 Bias = 0.01
IRI	$C_1 = 0.067$ $C_2 = 0.680$ $C_3 = 0.805$ $C_4 = 19.576$ SEE = 11.02 Bias = 0.00	$C_1 = 0.1722$ $C_2 = 2.400$ $C_3 = 0.9268$ $C_4 = 14.1961$ SEE = 10.48 Bias = 0.00	$C_1 = 0.0892$ $C_2 = 2.2453$ $C_3 = 1.5094$ $C_4 = 20.6632$ SEE = 10.39 Bias = 0.00	$C_1 = 1.198$ $C_2 = 3.570$ $C_3 = 1.4929$ $C_4 = 25.24$ SEE = 13.42 Bias = -0.38	$C_1 = 0.8203$ $C_2 = 0.4417$ $C_3 = 1.4929$ $C_4 = 25.24$ SEE = 19.57 Bias = 11.64

NOTE: Coefficients marked in red are calibrated while keeping other coefficients at global value

Summary — *Standard error equations*

Summary of standard error equations using different approaches

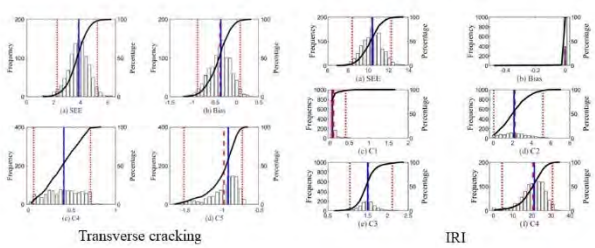
Performance prediction model	Approach 1	Approach 2	Approach 3	Old model	Global model
Transverse cracking	$1.6754(CRK)^{0.5086}$	$3.4942(CRK)^{0.2468}$	$2.8285(CRK)^{0.5205}$	$1.34(CRK)^{0.6595}$	$0.75 + 3.5522(CRK)^{0.5612}$
Transverse joint faulting	$0.0655(Fault)^{0.5185}$	$0.1358(Fault)^{0.8777}$	$0.0702(Fault)^{0.5909}$	$0.0442(Fault)^{0.3698}$	$0.00806 + 0.07162(Fault)^{0.388}$
IRI	internally determined by software				

Summary

- Comparing the performance of selected sections with all sections in MDOT database shows that the selected sections are a representative sample based on their performance
- The global model for transverse cracking underpredicts whereas IRI and joint faulting model overpredicts performance compared to the measured values
- Local calibration significantly improves performance predictions. 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
- Bootstrapping is more robust in estimating the standard deviation and confidence intervals of the point estimate compared no sampling technique

Thank You

Bootstrapping — *Distribution of coefficients (Approach 3)*



Transverse cracking IRI

Summary — *Transverse cracking (Approach 3)*

Local calibration summary for transverse cracking

Sampling technique	Parameter	SEE	Bias	C4	C5
No sampling	Global model	5.99	-2.39	0.52	-2.17
	Local model	3.95	-0.40	0.39	-0.93
Bootstrapping	Global model mean	5.83	-2.39	0.52	-2.17
	Global model median	5.82	-2.32	0.52	-2.17
	Local model mean	3.85	-0.36	0.43	-0.95
	Local model median	3.84	-0.36	0.43	-0.91
Repeated Split Sampling	Global model mean	5.93	-2.38	0.52	-2.17
	Global model median	5.93	-2.38	0.52	-2.17
	Local model mean	3.95	-0.41	0.40	-0.97
	Local model median	4.08	-0.37	0.41	-0.92
	Local model mean - validation	4.12	-0.38	0.40	-0.97
	Local model median - validation	3.90	-0.39	0.41	-0.92

Summary — *IRI (Approach 3)*

Local calibration summary for IRI

Sampling technique	Parameter	SEE	Bias	C1	C2	C3	C4
No sampling	Global model	19.72	11.70	0.82	0.44	1.49	25.24
	Local model	10.67	0.00	0.06	1.81	1.55	22.25
Bootstrapping	Global model mean	19.58	11.64	0.82	0.44	1.49	25.24
	Global model median	19.44	11.54	0.82	0.44	1.49	25.24
	Local model mean	10.39	0.00	0.09	2.25	1.51	20.66
	Local model median	10.42	0.00	0.05	2.14	1.50	21.38
Repeated Split Sampling	Global model mean	19.68	11.68	0.82	0.44	1.49	25.24
	Global model median	19.83	11.71	0.82	0.44	1.49	25.24
	Local model mean	10.61	0.00	0.07	2.13	1.50	21.99
	Local model median	10.65	0.00	0.05	2.07	1.48	22.22
	Local model mean - validation	11.06	0.07	0.07	2.13	1.50	21.99
	Local model median - validation	11.06	0.01	0.05	2.07	1.48	22.22

MICHIGAN STATE UNIVERSITY

AASHTO Pavement ME National Users Group Meeting
Salt Lake City, Utah
43

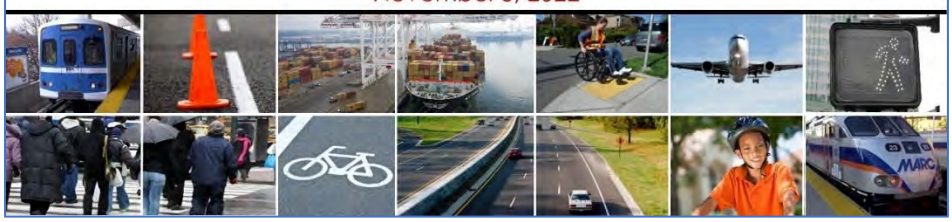
Presentation 15—Hector Figueroa, Maryland DOT SHA

MARYLAND DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION

AASHTO Pavement ME National Users Group Meeting

Calibration of AASHTOWare Pavement ME for Maryland Conditions

Hector Figueroa – Senior Pavement Engineer MDOT SHA
Robert Steudler – Team Leader – MDOT SHA
November 3, 2022



Outline of Presentation

- **Phase I – Verification of National Models**
- **Phase II – Sensitivity Analysis**
- **Phase III – Local Calibration**
  - New Flexible
  - AC over AC (rehab)
  - AC over JPCP (rehab)
  - AC over Semi-Rigid (rehab)
- **Phase IV – Updates**

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Phase I – Verification of National Models

- **Purpose**
  - Identify models requiring local calibration.
- **Data**
  - Maryland LTPP sections and Limited MDSHA sections.
  - Structural Cracking Index: Cracking load areas (wheel paths).
  - Function Cracking Index: Cracking non-load areas (edge, transverse, block and non-wheel path cracking).
  - Traffic and material: MDSHA libraries.
- **Units Conversion**
  - Structural and Functional cracking reported in linear feet.

$$Cracking\ (\%\ Lane\ Area) = \frac{Cracking\ Index}{1000 \times 12} \times 100$$

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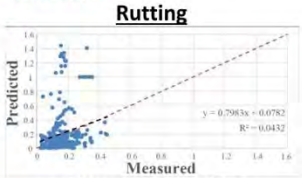
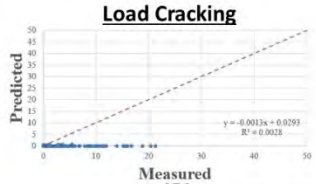
Phase I – Verification National Models

- **Results**

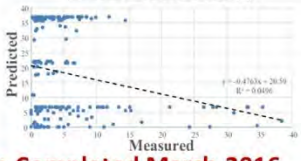
Rutting



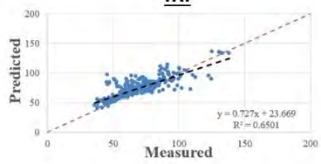
Load Cracking



Non- load Cracking



IRI



- **Completed March 2016**

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Phase II – Sensitivity Analysis

- **Purpose**
  - Assess MDOT SHA's pavement design, construction, traffic, climate and long-term performance data.
  - Develop an experimental design factorial in preparation for local calibration.
- **Analysis**
  - Normalized Sensitivity Index (NSI) was developed to rank the design parameters from most to least sensitive for AC new and AC over AC.
  - Verification study was performed for composite pavements to evaluate the applicability of the national models.
  - Baseline projects set up with typical MD data inputs.
  - Experimental factorial defined by three climatic zones (Western MD, Central MD, Eastern MD) and three traffic level (low, medium and high).

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Phase II – Sensitivity Analysis

- **Design Parameters**
  - 17 design parameters were defined:
    - Axle load distribution
    - AADTT
    - Operation speed (mph)
    - Vehicle class distribution (%)
    - Asphalt surface air voids (%)
    - Asphalt surface binder content (%)
    - Asphalt surface type
    - Asphalt base air voids (%)
    - Asphalt base binder content (%)
    - Asphalt base thickness (in)
    - Asphalt base type
    - Unbound base resilient modulus (psi)
    - Unbound base type
    - Unbound base thickness (in)
    - Water table depth (ft)
    - Subgrade resilient modulus (psi)
    - Subgrade type

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Phase II – Sensitivity Analysis

- **Results**
  - 4 categories were defined to present the results:
    - No effect
    - Low effect
    - Marginal effect
    - Significant effect
  - Asphalt base course thickness
  - Asphalt binder content (base and surface)
  - Air void content (base and surface)

  } Most significant effect (AC New and AC over AC)

- **Completed November 2016**

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Phase III – Local Calibration

- **Data**
  - Project specific data inputs (level I to III).
  - Compatibility of MDOT SHA's pavement performance data units with MEPDG prediction data units.
  - LTPP project excluded from calibration.
- **CAT**
  - Optimization of calibration coefficients.
  - Data visualization.
  - Run MEPDG files in batch mode.

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Phase III – Local Calibration

- **Traffic data**
  - WIM station (axle load distribution).
  - Google Earth map (traffic volume, vehicle distribution, truck percentages).

MD 198

MD 198	
ID_PREFIX	MD
ID_RTE_NO	198
AADT_2010	24603
AADT_2011	22420
AADT_2012	22241
AADT_2013	23900
AADT_2014	23631
AADT_2015	21340
AADT_2016	21751
AADTT	881
VD_CLS_4	15.12
VD_CLS_5	52.22
VD_CLS_6	7.77
VD_CLS_7	1.71
VD_CLS_8	8.79
VD_CLS_9	13.64
VD_CLS_10	0.74
VD_CLS_11	0
VD_CLS_12	0
VD_CLS_13	0
PCT_COMB	23.17
Vehicle Distribution Source	B
Percent Trucks	4.05
Route Name	MD 198

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Phase III – Local Calibration

- **Geotechnical Properties**
  - Google Earth map (resilient modulus, Atterberg limits, size distribution).

s3162

s3162	
ID	s3162
AASHTO_01	A-4
GroupIndex_01	2
TopDepth_01 (in)	0
BottDepth_01 (in)	7.086614
Thickness_01 (in)	7.086614
Pass_4_01 (%)	95
Pass_10_01 (%)	90
Pass_40_01 (%)	77.5
Pass_200_01 (%)	60
Clay0_002_01 (%)	18
LL_01 (%)	26
PI_01 (%)	7
Ksat_01 (ft/hr)	0.091688
Satiated_01 (%)	42
af_01 (psi)	7.833221019
bf_01	0.856990083
cf_01	0.809856837
hr_01 (psi)	3000.001835
CBR_FROM_PI_01 (%)	18.483833
MR_FROM_PI_01 (psi)	16524.8606
Elev_01 (m)	77
Comppct_01 (%)	11
BedroDepth_01 (ft)	N/A
wtdepannmin_01 (ft)	N/A
wtdepanjunmin_01 (ft)	N/A
Name	s3162

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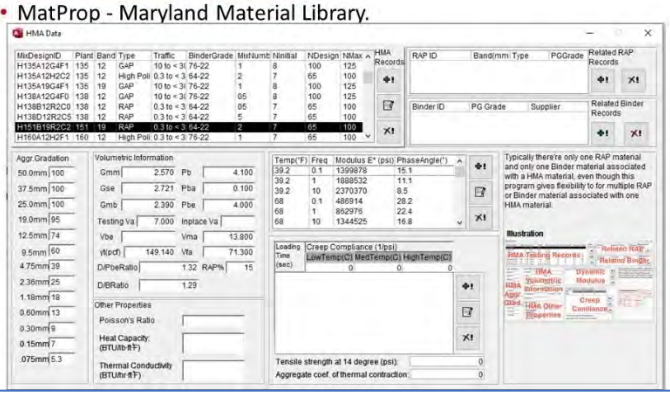
Phase III – Local Calibration

- **Asphalt Material Properties**
  - MatProp - Maryland Material Library.



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Phase III – Local Calibration

- **Asphalt Material Properties (Cont')**
  - Dynamic Modulus E* at temperatures (39.2, 68 and 104 °F) and frequencies (0.1, 1 and 10 Hz).
  - Dynamic Modulus E* at 130 °F extrapolated using E* solver procedure.

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Phase III – Local Calibration

- **Pavement Performance**
  - Cracking data from 2008 to 2018.
  - Pavement performance data extracted at 25-feet intervals.
  - Structural Cracking Density (SCD): AC Total Fatigue Cracking.
  - Functional Cracking Data (FCD): AC Total Transverse cracking.
  - Rutting: Total Pavement Deformation.
  - IRI: IRI.

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Phase III – Local Calibration

- **Pavement Sections**
  - 0.1 miles long.
  - Mapped using Google Earth.
  - Coordinates extracted.

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Phase III – Local Calibration

- **Pavement Sections**
  - Review of ROW imageries (MDOT SHA's videolog) year by year.
  - Verification of constructed treatment (bridge approaches, intersections, base widening without performance data, merging lanes were removed from dataset).
  - Limited AC new and AC over AC projects data.

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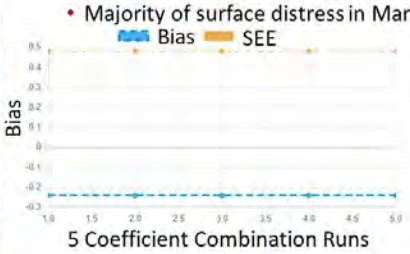
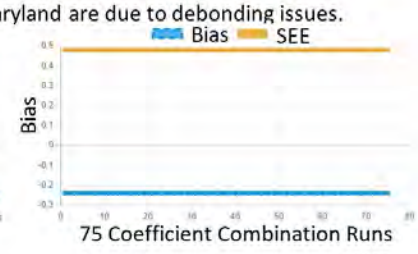
Phase III – Local Calibration

- **Top-down cracking data**
  - Preliminary CAT optimization resulted in similar outputs.
  - No predictions for low to medium traffic.
  - Performance data not available for top-down.
  - Majority of surface distress in Maryland are due to debonding issues.





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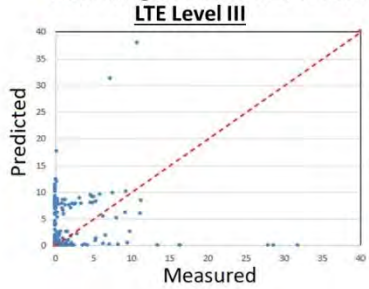
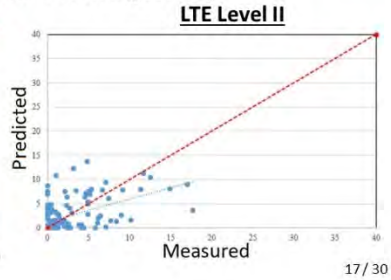
Phase III – Local Calibration

- **LTE fatigue and environment cracks**
  - Level III – Poor prediction.
  - Level II – Better prediction & identification of outliers.
  - ROW imageries reviewed to determine cracking severity.





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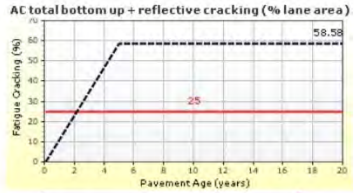
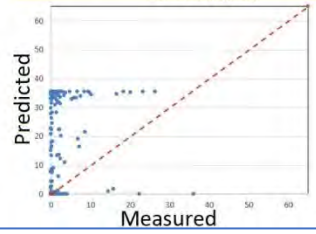
Phase III – Local Calibration

- **AC over semi-rigid**
  - Initial attempt to calibrate models but preliminary data analysis showed unexpected results.
  - Over-prediction of the total fatigue (bottom up + reflective) due to high initial damage deterioration of the cement treated base.





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Phase III – Local Calibration

- **AC over semi-rigid**
  - Data analysis and review of the inputs were performed to find errors but, no inconsistences were identified.
  - Additional effort needed to investigate issues.
  - Calibration not practical due to and uncommon pavement type in Maryland.
  - Small percentage of the pavement network is semi-rigid.
  - Pavement type removed from calibration effort.

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Phase III – Local Calibration

- **Transverse cracking**
  - MDOT SHA does not collect transverse cracking data (perpendicular direction of traffic).
  - Functional Cracking Density (FCD) = Cracks < 45°.
  - Transverse cracking data of up to 33,000 ft./mile were observed in the data set, which represents a transverse crack every 2 ft. (unrealistic field condition).
  - Transverse cracking data was limited to 2,500 ft./mile, which represent a transverse crack every 25 ft. (realistic field condition and software default value).

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Phase III – Local Calibration

- **CAT Experience**
  - Automates the process to review observed performance data.
  - Develops predicted versus measured graphs and displays bias and SEE.
  - Optimizes calibration coefficients to eliminate bias and reduce SEE.
  - Helps evaluate if further optimization is needed by displaying variations of bias and SEE for different calibration sets.
  - Speed up process to run of MEPDG files.

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Phase III – Local Calibration

- **CAT Experience**
  - The software tool was utilized for the calibration of all pavement models, except for the total fatigue cracking model of AC over AC pavements.
  - The research team observed that the predicted total fatigue cracking in the CAT tool displayed the new bottom up predictions and missed the reflection cracking component of fatigue cracking, which was the main component of total fatigue cracking.

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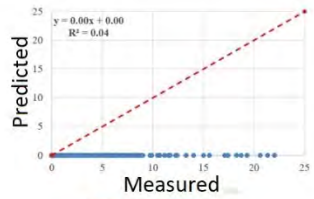
Phase III – Local Calibration

- **CAT Experience**
  - Verification Step



  - Optimization Step

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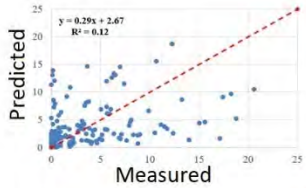
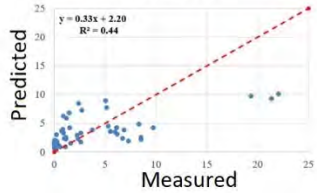
Phase III – Local Calibration

- **CAT Experience**
  - Calibration Step



  - Validation Step



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Phase III – Local Calibration

- **CAT Experience**
  - Optimization Results (new flexible – bottom up)

Parameter	Global	Optimization Set	Validation Set	Optimization & Validation Set Combined
Bias	-3.61	0.08	-0.12	0.03
SEE	5.90	4.78	3.84	4.54
C1	1.31		0.16	
C2 Multiplier Factor	1		0.22	

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Phase III – Local Calibration

- **Results**
  - Systematic elimination of bias and reduction of the standard error of the estimate.
  - Noticeable enhancement of prediction results prior and post calibration.
  - Validation sets were rejected.
  - Implementation of calibration coefficients for pavement design practices.

- **Completed April 2022**

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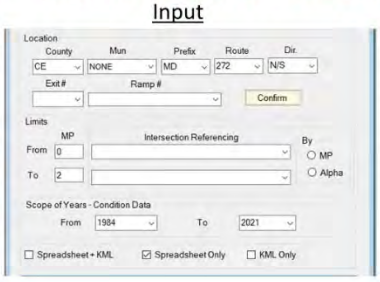
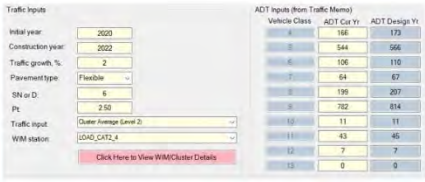
Phase IV – Updates

- **Implement traffic and material libraries into MDOT -SHA Engineering Data Warehouse.**

Input



Traffic Data



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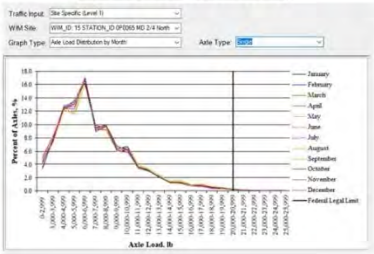
Phase IV – Updates

- **Implement traffic and material libraries into MDOT -SHA Engineering Data Warehouse.**

Axle Load Distribution



Material Properties

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Phase IV – Updates

- **MDOT – SHA's pavement design guide updates with local coefficients, materials and traffic properties.**

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Questions

Thank You

?

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Presentation 16—Felix Doucet, Quebec Ministry of Transportation

Local calibration of AASHTOWare PMED software for flexible pavements in Quebec, including climate change considerations.

ME Pavement Design Subcommittee

Meeting #61

Virtual Fall Conference Call

UNIVERSITÉ LAVAL

Transports Québec

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Transports Québec

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McGill

Ce projet a bénéficié d'un soutien financier du gouvernement du Québec et répond aux objectifs du Plan pour une économie verte 2030

This project received financial support from the Quebec government and meets the objectives of the Plan for a Green Economy 2030

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Outline

- Objectives and methodology
- Work done
- Work to be done and conclusions

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Objectives

Calibrate the AASHTOWare Pavement ME Design software performance models to local conditions in the province of Quebec using the Calibration Assistance Tool (CAT).

- Develop databases on the performance of flexible pavements
- Calibrate the performance models of the AASHTOWare PMED software using the Calibration Assistance Tool
- Develop a tool to take into account the effects of climate change predicted for the Quebec territory

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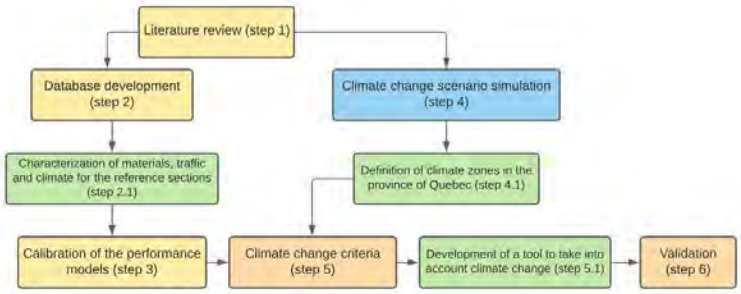
Methodology



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Outline

- Objectives and methodology
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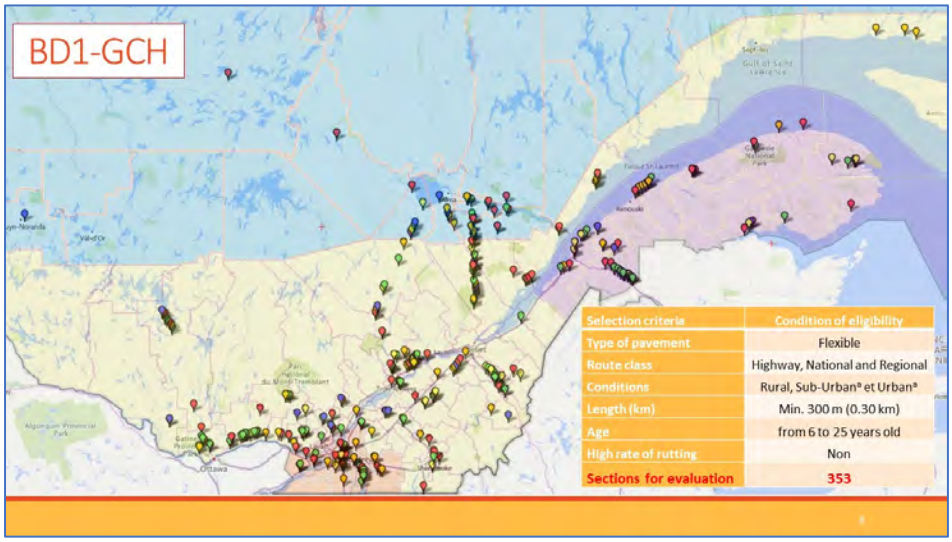
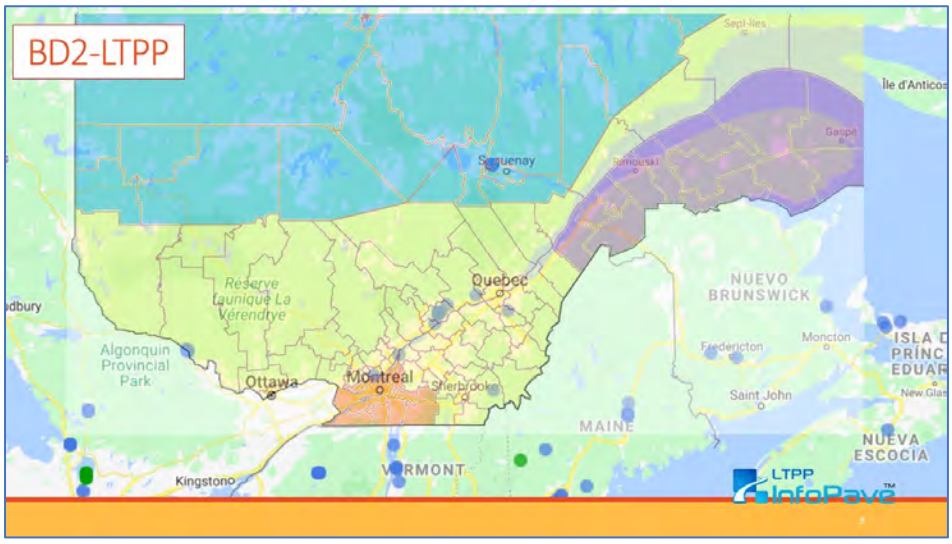
Databases with reference pavement sections

BD1-GCH	BD2-LTPP
• GCH 6011 Pavement Management System (MTQ)	• LTPP Infopave
Calibration database	Database for validation



Selection criteria	Condition of eligibility
Type of pavement	Flexible
Route class	Highway, National and Regional
Conditions	Rural, Sub-Urban[a] et Urban[a]
Length (km)	Min. 300 m (0.30 km)
Age	from 6 to 25 years old
High rate of rutting	Non
Sections for evaluation	353



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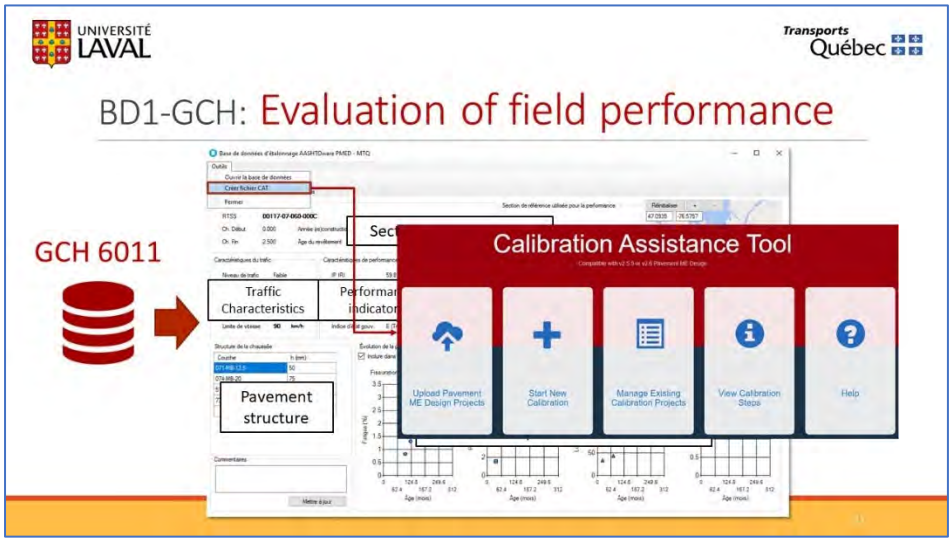
BD1-GCH: Conditions in the sections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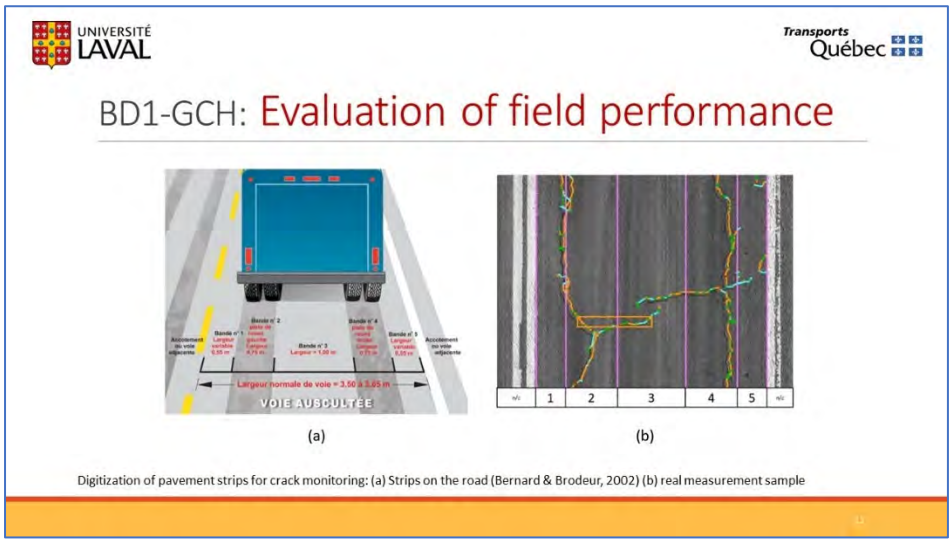
BD1-GCH: Evaluation of field performance
GCH 6011
Traffic Characteristics
Pavement structure
Calibration Assistance Tool
Upload Pavement ME Design Projects
Start New Calibration
Manage Existing Calibration Projects
View Calibration Steps
Help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BD1-GCH: Evaluation of field performance
VOIE AUSCULTÉE
(a)
(b)
Digitization of pavement strips for crack monitoring: (a) Strips on the road (Bernard & Brodeur, 2002) (b) real measurement sample

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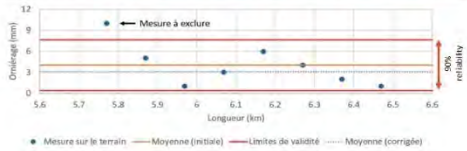
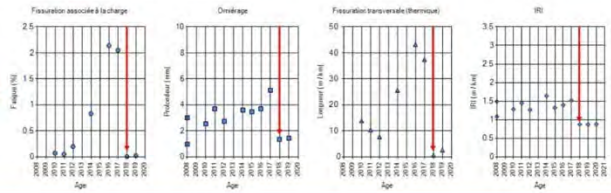
BD1-GCH: Evaluation of field performance



Elimination of outliers in field measurements

Criteria for the time interval to be used during the calibration process



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Fatigue type discretization

$$DI_E = 1 - \frac{E_{FWD}}{E^*_{pre}}$$

Most probable fatigue crack types according to the parameter DI_E (FHWA, 2018)

DI_E	Cracking (area in %)						
	0	0 - 2	2 - 10	10 - 20	20 - 35	35 - 50	> 50
Negative	NN[a]	Top down	Top down	Top down	Top down	Top down	Top down
0 – 0,25	Bottom-up	NN[a]	NN[a]	Top down	Top down	Top down	Top down
0,25 – 0,50	Bottom-up	Bottom-up	Bottom-up	NN[a]	NN[a]	Top down	Top down
0,50 – 0,75	Bottom-up	Bottom-up	Bottom-up	Bottom-up	Bottom-up	NN[a]	Top down
> 0,75	Bottom-up	Bottom-up	Bottom-up	Bottom-up	Bottom-up	Bottom-up	NN[a]

[a]NN : Neutral or unclassified.

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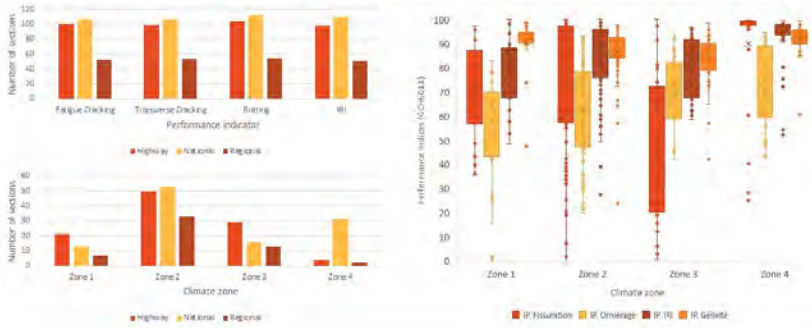
BD1-GCH: Summary of reference sections



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Information for sections: Material properties

Asphalt concrete		GB-20	ESG-14	ESG-10	EG-10
Volumetric properties					
Unit weight (kg/m³)		2390	2360	2350	2370
Effective binder content (%)		10,2	11,4	12,2	12,4
Air voids (%)		7,0	7,0	7,0	7,0
Poisson's ratio		0,35	0,35	0,35	0,35
Aggregate gradation (% passing)	19 mm	98 %	100 %	100 %	100 %
	10 mm	64 %	80 %	96 %	95 %
	4,75 mm	42 %	50 %	58 %	46 %
	75 µm	4,9 %	5,3 %	5,7 %	5,6 %
Mechanical properties					
Dynamic modulus		Level 1			
Asphalt binder		Level 1			
Reference temperature		10 °C			
Indirect tensile strength at -10 °C(MPa)		Level 3			
Creep compliance (1/GPa)		Level 3			
Thermal properties					
Thermal conductivity (watt/meter-Kelvin)		1,48			
Heat capacity (joule/kg-Kelvin)		870			
Thermal contraction		Level 3			

	Base layer		Subbase layer	
Granular materials	MG 20	MG 56	MG 112	MG 56
Poisson's ratio	0,20	0,20	0,20	0,20
Coeff. Lateral Earth Pressure (k_e)	0,50	0,50	0,50	0,50
Resilient modulus (MPa)	Tableau 26		150	215

Material	$H_{AC} \leq 100$	$100 < H_{AC} < 150$	$150 < H_{AC} < 200$	$200 < H_{AC} < 250$	$250 \leq H_{AC}$
MG 20	425 MPa	300 MPa	200 MPa	150 MPa	135 MPa
MG 56	395 MPa	280 MPa	200 MPa	160 MPa	145 MPa
Gradation (% passing)	25 mm	100%	72%	100%	60%
	19 mm	94%	66%	100%	55%
	14 mm	77%	60%	100%	48%
	10 mm	61%	55%	99%	42%
	5,0 mm	37%	43%	97%	33%
	1,25 mm	15%	24%	85%	17%
	75 µm	4%	4%	5%	3%
Liquid limit (%)		20	20	20	20
Plastic Index (%)		5	5	5	5
Max. Dry Unit Weight (kg/m³)		2220	2220	1790	2220
Saturated hydraulic conductivity (m/h)		Level 3		Level 3	
SWCC		Level 3		Level 3	
Specific gravity of solids		2,72	2,65	2,64	2,65
Water content (%)		6,0	5,0	10,6	5,0

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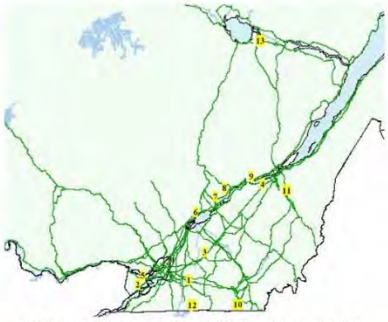
Information for sections: Traffic



WIM stations with known axle load spectra (Martineau, 2012; Paquet, 2009)

Truck factor values in the absence of vehicle classification data (St-Laurent, 2006b, 2006a)

Road class	Heat capacity of heavy vehicles			
	0 % – 10 %	10 % – 20 %	20 % – 30 %	> 30 %
Regional	1,4	2,7	-	-
National				
Urban	1,2	1,3	-	-
Rural	2,1	3,1	3,7	5,3
Highway				
Urban	1,1	1,3	-	-
Suburban	1,7	2,0	-	-
Rural	2,1	2,7	3,4	-

Known axle load spectra will be combined with truck factor experience to establish synthetic axle load spectra that can be used in all traffic conditions in the province of Quebec.

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Outline

- Objectives and methodology
- Work done
- Work to be done and conclusions

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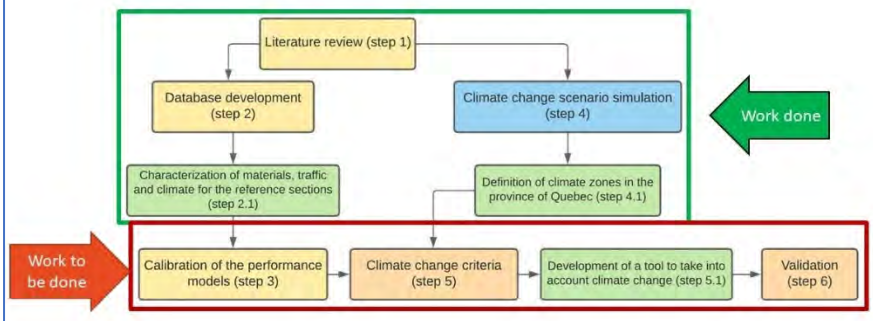
Methodology



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Conclusions

- Calibration of the AASTHOWare PMED software should be performed using references and conditions that emulate routine pavement design practice.
- Climate zoning is useful for the analysis of climate change effects, however, for routine design a good definition of climate variables is sufficient.
- The development of a complementary tool to the pavement design process allows the practical inclusion of considerations for the effects and uncertainties associated with climate change.

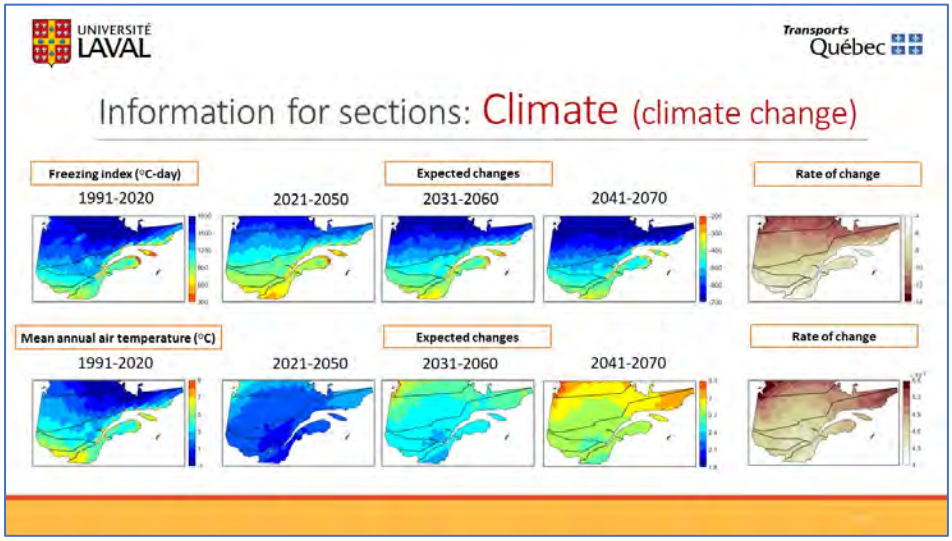
Erdrick Leandro Pérez-González, Ph.D.
Research Professional
Department of Civil and Water Engineering
Université Laval
erdrick.perez-gonzalez@gci.ulaval.ca

Thank you
Merci

ME Pavement Design Subcommittee

Meeting #61

Virtual Fall Conference Call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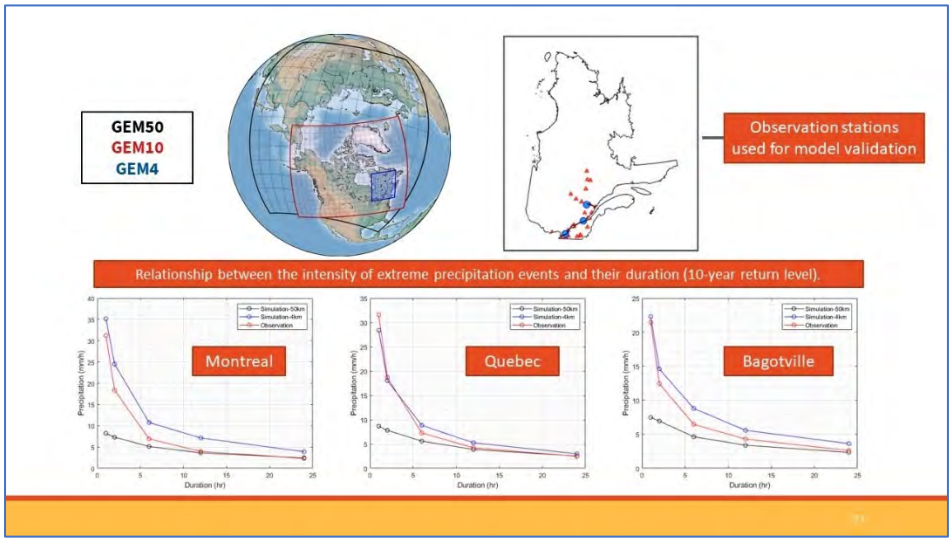
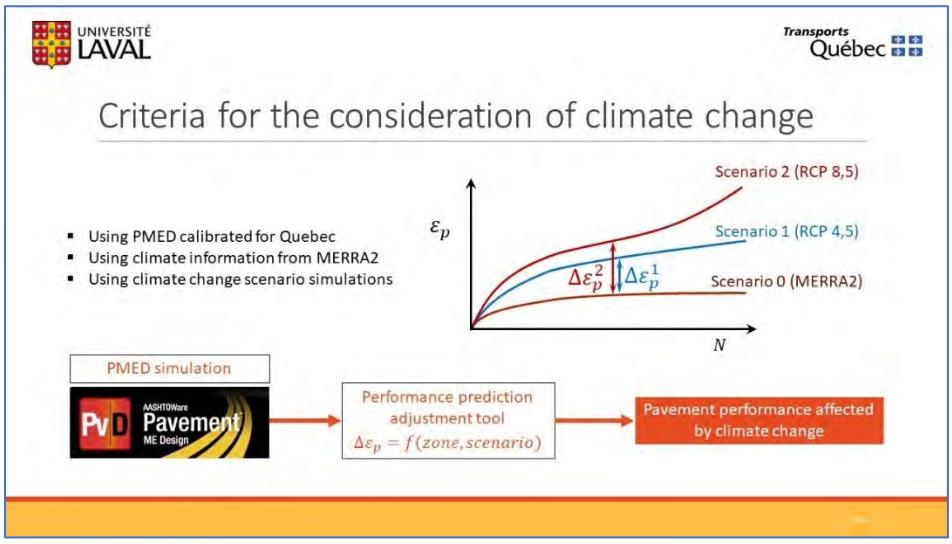
Information for sections: Climate (climate change)
Freezing index (°C-day)
Expected changes
Rate of change
1991-2020
2021-2050
2031-2060
2041-2070
Mean annual air temperature (°C)
Expected changes
Rate of change
1991-2020
2021-2050
2031-2060
2041-2070


GEM50
GEM10
GEM4
Observation stations used for model validation
Relationship between the intensity of extreme precipitation events and their duration (10-year return level).
Montreal
Quebec
Bagotville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Criteria for the consideration of climate change
Using PMED calibrated for Quebec
Using climate information from MERRA2
Using climate change scenario simulations
Scenario 2 (RCP 8,5)
Scenario 1 (RCP 4,5)
Scenario 0 (MERRA2)
ε_p
$\Delta\varepsilon_p^2$
$\Delta\varepsilon_p^1$
N
PMED simulation
Performance prediction adjustment tool
$\Delta\varepsilon_p = f(zone, scenario)$
Pavement performance affected by climate change

Presentation 17—John Senger, Illinois DOT

ILLINOIS DOT

John Senger, P.E.
Engineer of Pavement Technology
Bureau of Research

USE OF AASHTOWARE PAVEMENT M-E

- We have two licenses and have barely used them
- Designed one project with AASHTO Pavement M-E
  - 8.5" CRCP
  - 8.5" FD HMA
  - 8.5" JPCP

ILLINOIS CERTIFICATION AND RESEARCH TRACK

PAVEMENT DESIGN CRITERIA

Table 3. Pavement distress criteria.

Distress Type	Target Distress at 90% Design Reliability
Terminal International Roughness Index (IRI) (in./mi)	125
Mean joint faulting (in.)	0.05
JPCP transverse cracking (percent slabs)	1
CRCP punchouts (#/mile)	1
Permanent deformation - total pavement (in.)	0.25
Asphalt concrete (AC) bottom-up fatigue cracking (percent)	5.0
AC thermal fracture (ft/mile)	500
AC top-down fatigue cracking (percent)	10
Permanent deformation - AC only (in.)	0.15

DESIGN OUTPUTS - CRCP

Initial IRI 41 in./mi.

Design Outputs

Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in/mile)	125.00	94.13	90.00	99.78	Pass
CRCP punchouts (1/mile)	1.00	0.18	90.00	100.00	Pass

Distress Charts

DESIGN OUTPUTS - FDHMA

Initial IRI 38 in./mi.

Design Structure

Layer type	Material Type	Thickness (in)
Flexible	IL 9.5mm DGSurface	2.0
Flexible	IL 19mm Binder	6.5
Flexible	Stabilized Subbase - HMA	3.0
NonStabilized	Granular Subbase - CA-6	12.0
Subgrade	A-7-6	Semi-infinite

Volumetric at Construction:	
Effective binder content (%)	11.0
Air voids (%)	4.0

Traffic

Age (year)	Heavy Trucks (cumulative)
2021 (initial)	600
2031 (10 years)	391,731
2041 (20 years)	783,461

Design Outputs

Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in/mile)	125.00	122.35	90.00	91.71	Pass
Permanent deformation - total pavement (in)	0.25	0.14	90.00	100.00	Pass
AC bottom-up fatigue cracking (% lane area)	5.00	1.45	90.00	100.00	Pass
AC thermal cracking (ft/mile)	500.00	428.02	90.00	94.74	Pass
AC top-down fatigue cracking (% lane area)	10.00	4.69	90.00	99.69	Pass
Permanent deformation - AC only (in)	0.15	0.04	90.00	100.00	Pass

DESIGN OUTPUT – FDHMA SMA

Design Structure

Layer type	Material Type	Thickness (in)
Flexible	SMA 12.5mm Surface	2.0
Flexible	IL 19mm Binder	6.5
Flexible	Stabilized Subbase - HMA	3.0
NonStabilized	Granular Subbase - CA-6	12.0
Subgrade	A-7-6	Semi-infinite

Volumetric at Construction:	
Effective binder content (%)	12.0
Air voids (%)	4.0

Traffic

Age (year)	Heavy Trucks (cumulative)
2021 (initial)	600
2031 (10 years)	391,731
2041 (20 years)	783,461

Design Outputs

Distress Prediction Summary

Initial IRI
34 in./mi.

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in/mile)	125.00	120.49	90.00	92.81	Pass
Permanent deformation - total pavement (in)	0.25	0.13	90.00	100.00	Pass
AC bottom-up fatigue cracking (% lane area)	5.00	1.45	90.00	100.00	Pass
AC thermal cracking (ft/mile)	500.00	217.89	90.00	99.84	Pass
AC top-down fatigue cracking (% lane area)	10.00	4.94	90.00	99.59	Pass
Permanent deformation - AC only (in)	0.15	0.04	90.00	100.00	Pass

DESIGN OUTPUTS - JPCP

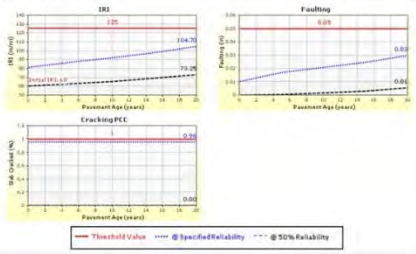
Initial IRI
63 in./mi.

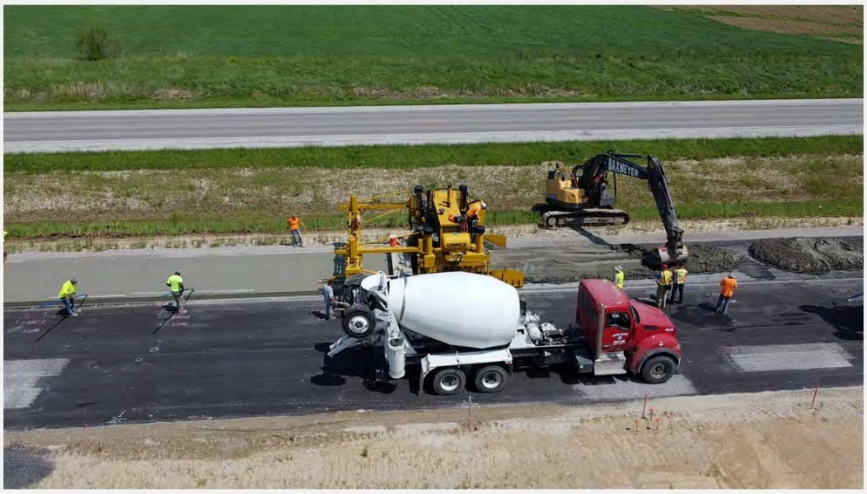
Design Outputs

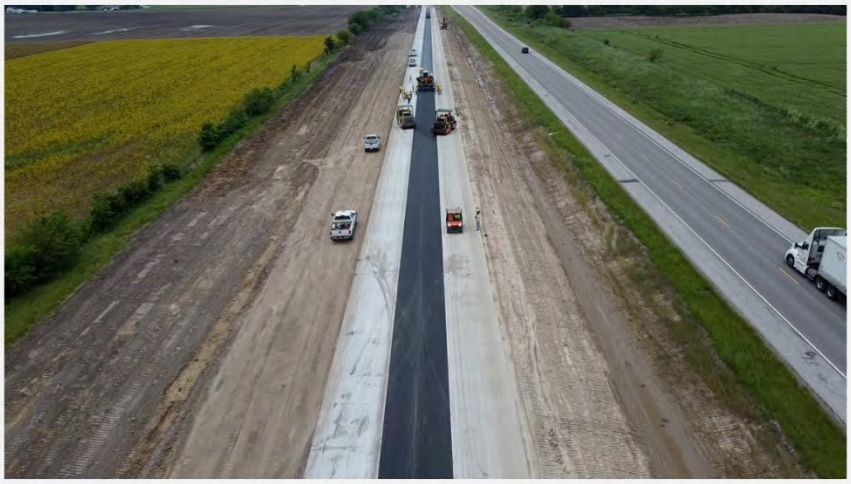
Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in/mile)	125.00	104.70	90.00	98.25	Pass
Mean joint faulting (in)	0.05	0.03	90.00	99.06	Pass
JPCP transverse cracking (percent slabs)	1.00	0.96	90.00	90.86	Pass

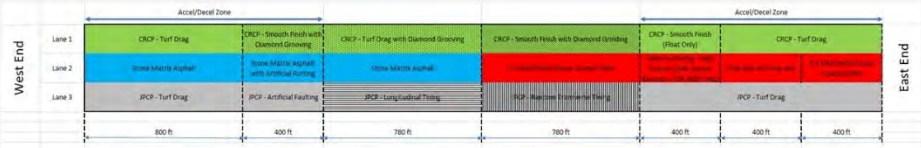
Distress Charts







LAYOUT



Certification Track

QUESTIONS

Illinois Department of Transportation

John Senger, P.E.
Engineer of Pavement Technology

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Springfield, IL 62704
Tel: 217-782-8582
John.Senger@illinois.gov

Presentation 18—Kelly Smith, APTech

MEPDG Implementation RoadMap Workshop and Report

AASHTO Pavement ME Users Group Meeting
November 1-3, 2022
Salt Lake City, Utah

Kelly Smith, P.E.
klsmith@appliedpavement.com
applied pavement TECHNOLOGY

Presentation Outline

- Implementation History
- Overview of RoadMap Workshop
- Overview of RoadMap Report
- Moving Forward

Implementation History

- Pavement Mechanistic-Empirical (ME) Design

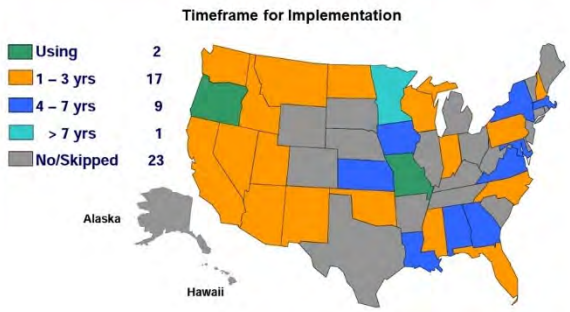
	Design Procedure	Design Software
NCHRP Project 1-37A	2004 MEPDG (project report)	MEPDG v1 (rudimentary)
AASHTO/AASHTOWare	MEPDG Manuals of Practice (2008, 2015, 2020, 2021 sup)	DARWin-ME PMED v1 – v3

NCHRP Studies

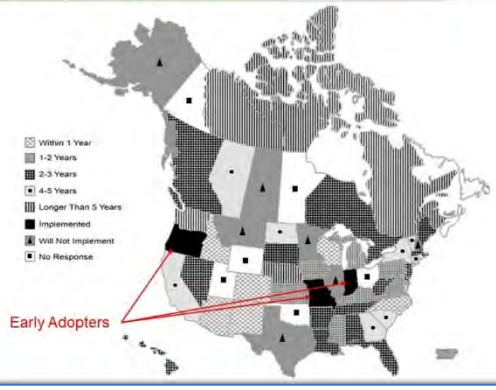
Implementation of Pavement ME

- Implementation Agents
  - Lead states (19)
  - FHWA: NHI training courses, DGIT workshops and webinars, Pooled Fund regional peer exchanges, national users group meetings, software training webinars
  - AASHTO: software training webinars
  - NCHRP
- Implementation Progress
  - Early adopters (2008-2010)
  - Steady growth (2010-2020)
  - Recent stagnation (2020-present)

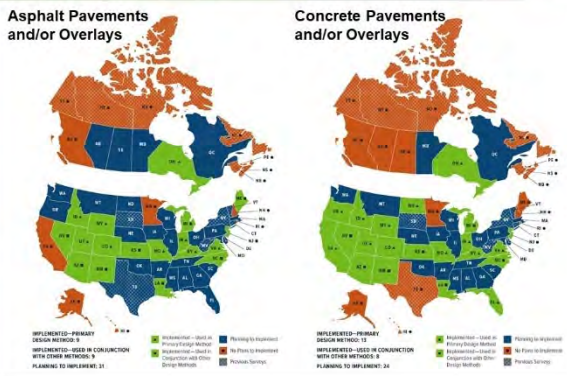
FHWA DGIT Team—2006/07 Survey



NCHRP Synthesis 457—2013 Survey



2021 PMEUG Meeting Assessment



What Does Implementation Mean?

- Challenge of a Common Definition
  - How is Pavement ME being used?
    - sole, parallel, check, shadow?
  - What types of pavement designs?
    - new asphalt (conventional, deep-strength, full-depth, semi-rigid)
    - new concrete (JPC, CRC)
    - asphalt overlays
    - concrete overlays
    - concrete restoration
  - What performance parameters are used and have the models been verified or calibrated?

Overview of MEPDG Implementation RoadMap Workshop

- Workshop Purpose
  - Stimulate discussions of implementation challenges and strategies for overcoming them, as a basis for developing a RoadMap for expediting and streamlining the implementation process
- 1.5-day RoadMap workshop
  - June 1-2, 2022 (Chicago, IL)
  - Reps from 12 selected DOTs, as well as industry and academia

Workshop Participants

- State DOTs: Georgia, Idaho, Indiana, Iowa, Kentucky, Michigan, Missouri, North Carolina, New Jersey, Utah, Virginia, Wisconsin
- Industry: CEMEX/ACPA, NAPA, Kraton Polymers, NSSGA
- Universities: Iowa State, Kentucky, Michigan State, Pittsburgh
- FHWA
- AASHTO

Workshop Sessions

- Sharing
- Breakouts
  - Design policy
  - Design inputs
  - Verification, calibration, and validation
  - Application and use
- Key Takeaways

Sharing Session

- DOT Participants
  - Brief update on implementation status
  - What was your agency's biggest challenge to implementing MEPDG/PMED and how was it overcome?
- Industry & Academia Participants
  - What does your organization perceive as the issue with MEPDG/PMED implementation by SHAs and what are your recommendations to overcome this problem?

Breakout 1A—Design Policy

- Pavement Type Applications and Determination
- Hierarchical Input Levels
- Reliability
- Performance Criteria

Breakout 1B—Design Inputs

- Reliability Levels for Calibration
- Accounting for Variability in the Inputs
- Inputs Levels
- Materials Characterization
- Traffic
- Climate

Breakout 2A—Verification, Calibration, and Validation

- Calibration Planning (selection of sites and data considerations)
- Calibration Analyses
- Implementation

Breakout 2B—Applications and Use

- Champion
- Steering Committee
- Implementation Plan
- Industry Involvement
- Staffing (In-house vs. out-sourced resources)
- Training
- User Manual
- Concurrent Designs
- Input Libraries
- Catalog of Designs

RoadMap Workshop Meeting Minutes

- TPF-5(305) Pooled Fund website (https://www.pooledfund.org/details/study/549)
  - Click on Documents
  - "2022 Pavement ME Roadmap Workshop Minutes"

Overview of MEPDG Implementation RoadMap Report

- Objective
  - To aid highway agencies in shortening the timeframe for Pavement ME implementation by communicating the successful practices of some of the experienced agencies.
- Report Outline
  - Chapter 1—Introduction
  - Chapter 2—Implementation Planning
  - Chapter 3—Administrative-Level Activities
  - Chapter 4—Technical-Level Activities
  - Chapter 5—Closing Remarks

MEPDG Implementation RoadMap Report (cont)

- TPF-5(305) Pooled Fund website (https://www.pooledfund.org/details/study/549)
  - Click on Documents
  - "MEPDG Implementation Roadmap"

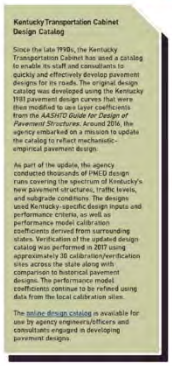
Implementation Challenges

- Software
  - Complexity
  - Cost
  - Contractual issues
- Inputs
  - Traffic
  - Materials
  - Existing conditions
- Calibration
  - Sites and data
  - Analysis expertise
  - PMED version changes
- Management support
- Staffing/resources
  - Retirements/turnover
  - Use of consultants and universities
- Training

Implementation Strategies

- Implementation Planning (chap 2)
  - Define objectives/scope (what does successful implementation look like)
  - Develop Plan (resources, schedule/milestones, inputs, etc.)
- Administrative-Level Activities (chap 3)
  - Identify human resources (champion, steering & other committees)
  - Establish/address policies
- Technical-Level Activities (chap 4)
  - Develop libraries of common inputs (traffic, materials, pavement rehab properties)
  - Performance model verification, calibration, and validation

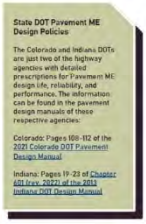
Highlighted Practices and Links to Resource Materials


Kentucky Transportation Cabinet Design Catalog

Since the late 1990s, the Kentucky Transportation Cabinet has used a catalog to enable its staff and consultants to quickly and effectively develop pavement designs for its roads. The original design catalog was developed using the Kentucky 1981 pavement design curves that were then modified to use layer coefficients from the *AASHTO Guide for Design of Pavement Structures*. Around 2016, the agency embarked on a mission to update the catalog to reflect mechanistic-empirical pavement design.

As part of the update, the agency conducted thousands of PMED design runs covering the spectrum of Kentucky's new pavement structures, traffic levels, and subgrade conditions. The designs used Kentucky-specific design inputs and performance criteria, as well as performance model calibration coefficients derived from surrounding states. Verification of the updated design catalog was performed in 2017 using approximately 28 calibration/verification sites across the state along with comparison to historical pavement designs. The performance model coefficients continue to be refined using data from the local calibration sites.

The online design catalog is available for use by agency engineers/officers and consultants engaged in developing pavement designs.


State DOT Pavement ME Design Policies

The Colorado and Indiana DOTs are just two of the highway agencies with detailed prescriptions for Pavement ME design life, reliability, and performance. The information can be found in the pavement design manuals of these respective agencies:

Colorado: Pages 108-112 of the 2021 Colorado DOT Pavement Design Manual

Indiana: Pages 19-23 of Chapter 401 (rev. 2022) of the 2013 Indiana DOT Design Manual

Michigan DOT Local Calibration Factors

The Michigan DOT currently uses Pavement ME in conjunction with the 1993 AASHTO Guide. The department has conducted two local calibration studies and has initiated a third calibration effort that will tie in with PMED v2.6.

Michigan DOT's 2021 User Guide for Mechanistic-Empirical Pavement Design contains the full suite of PMED calibration factors to be used for the design of new flexible pavements and overlays and new rigid pavements and overlays. The coefficients (listed in chapter 6 of the document) are a combination of the globally verified models and locally calibrated models for version 2.3 of the PMED software.

Moving Forward

- TPF-5(305) Pooled Fund website (https://www.pooledfund.org/details/study/549)
- Detailed RoadMap presentation in Software Training Webinar #5 (Spring 2023)

Presentation 19—Linda Pierce, NCE

Asphalt Pavement Rutting and IRI Models and Calculations

A Journey through the PMED Engine

1

Inputs for a Asphalt Pavement Response Models

Pavement Geometry
- Layer thicknesses
- Discontinuities

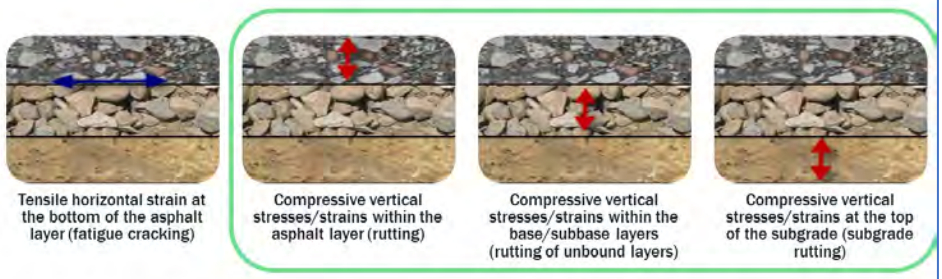
Environment
- Temperature vs. depth
- Moisture vs. depth

Material Properties
- Elastic properties
- Nonlinear properties

Traffic
- Load spectrum
- Tire contract pressure distributions and areas

2

Asphalt Pavement Response – Typical Critical Locations



Source: AASHTO *MEPDG Manual of Practice*

3

Factors Affecting Rut Depth

- Asphalt mixtures
  - » Layer thickness
  - » Dynamic modulus
  - » Binder grade
  - » Air voids
  - » Effective binder content
- Unbound base
  - » Type
  - » Thickness
  - » Stiffness
- Traffic
  - » Load, contact area, and tire pressure
  - » Operating speed
  - » Wander
- Temperature and environmental conditions

4

Rut Accumulation is also Defined by:

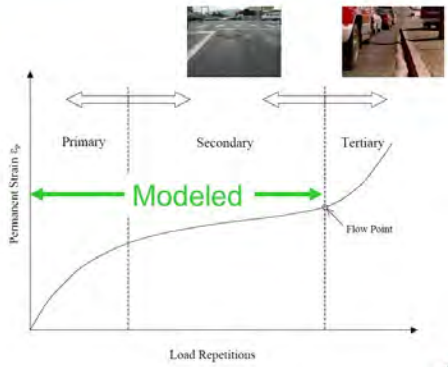
- Pavement age
  - » Changes in dynamic modulus and asphalt binder hardening
- Month
  - » Variations in surface and pavement temperatures (affects dynamic modulus)
  - » Moisture variation in base and subgrade
  - » Freezing and thawing conditions
- Traffic speed
  - » Affect on dynamic modulus
- Traffic wander
  - » If channelized, leads to higher rut depth, but wander reduces concentration, and thereby rutting

Source: AASHTO *MEPDG Manual of Practice*

5

NCHRP 1-37A Rutting Model

- Primary
  - » Predominantly associated with volumetric change
- Secondary
  - » Volumetric change + shear deformations increase
- Tertiary
  - » Shear deformations and no volume change conditions



Source: NCHRP 1-37A Final Report

6

NCHRP 1-37A Rutting Model (continued...)

- Repeated for each –
  - » Load level
  - » Sub season
  - » Month of the analysis period
- Rutting assumed to not occur in:
  - » Chemically stabilized materials
  - » Concrete fractured slabs
  - » Bedrock

Source: NCHRP 1-37A Final Report

7

NCHRP 1-37A Rutting Model (continued...)

- Asphalt Mixtures

$$\frac{\varepsilon_p}{\varepsilon_r} = k_1 \times 10^{-3.4488} \times T^{1.5606} \times N^{0.479244}$$

$$k_1 = (C_1 + C_2 \times depth) \times 0.328196^{depth}$$

$$C_1 = -0.1039 \times h_{ac}^2 + 2.4868 \times h_{ac} - 17.342$$

$$C_2 = 0.0172 \times h_{ac}^2 - 1.7331 \times h_{ac} + 27.428$$

where,
ε_p = accumulated plastic strain
ε_r = resilient strain, f(mix properties)
T = temperature (°F)
N = number of load repetitions

Source: NCHRP 1-37A Final Report

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NCHRP 1-37A Rutting Model (continued...)

- Unbound Materials

$$\delta_a(N) = 1.673 \times \left(\frac{\varepsilon_0}{\varepsilon_r}\right) e^{-\left(\frac{\rho}{N}\right)^{\beta}} \varepsilon_v h$$

- Subgrade Soils

$$\delta_a(N) = 1.35 \times \left(\frac{\varepsilon_0}{\varepsilon_r}\right) e^{-\left(\frac{\rho}{N}\right)^{\beta}} \varepsilon_v h$$

where,
δ_a = permanent deformation
N = number of load repetitions
ε_0, ρ, β = f(water content, modulus, ground water table)
ε_r = resilient strain (lab)
ε_v = average vertical resilient strain
h = layer thickness

Source: NCHRP 1-37A Final Report

9

NCHRP 1-37A Rutting Model (continued...)

- Total Pavement Structure

$$RD_{Total} = RD_{AC} + RD_{GB} + RD_{SG}$$

where,
RD_{Total} = total rut depth
RD_{AC} = rut depth of asphalt layer
RD_{GB} = rut depth of unbound base
RD_{SG} = rut depth of subgrade

Source: NCHRP 1-37A Final Report

10

PMED Rutting Model

- Incremental calculation for each:
  - » Sub season
  - » Mid-depth of each sublayer
- Strain-hardening approach to account for monthly changes
  - » Material stiffening at low temperatures
- Based on laboratory testing and adjusted to field conditions
  - » Triaxial tests for both asphalt and unbound materials
- LTPP database did not contain rut depth for each layer; "measured" layer rut depth based on proportioning total rut depth (MOP)

Source: AASHTO *MEPDG Manual of Practice*

11

PMED Rutting Model (continued...)

- Asphalt layer

$$\Delta_{p(AC)} = \varepsilon_{p(AC)} h_{AC} = \beta_{1r} k_z \varepsilon_{r(AC)} 10^{k_{1r} n^{k_{3r}\beta_{3r}} T^{k_{2r}\beta_{2r}}}$$

where,
$\Delta_{p(AC)}$ = accumulated permanent or plastic vertical deformation (in.)
$\varepsilon_{p(AC)}$ = accumulated permanent or plastic axial strain (in./in.)
$\varepsilon_{r(AC)}$ = resilient or elastic strain from structural response model at mid-depth (in./in.)
h_{AC} = AC layer thickness (in.)
n = load applications
T = mix or pavement temperature (°F)
k_z = depth confinement factor
k_{1to3r} = global laboratory-derived coefficients
β_{1to3r} = local or mix calibration or field-shift constants

Function of:
- Asphalt layer thickness
- Location depth
- Total asphalt thickness

Source: AASHTO *MEPDG Manual of Practice*

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PMED Rutting Model (continued...)

- Unbound layers and subgrade soils

$$\Delta_{p(soil)} = \beta_{s1} k_{s1} \varepsilon_v h_{soil} \left(\frac{\varepsilon_0}{\varepsilon_r}\right) e^{\left(\frac{\rho}{n}\right)^{\beta}}$$

where,
$\Delta_{p(soil)}$ = permanent or plastic deformation for layer or sublayer (in.)
ε_v = average vertical strain, calculated from response model. (in./in.)
ε_r = resilient or elastic strain from structural response model at mid-depth (in./in.)
ε_0 = laboratory intercept from repeated load permanent deformation test (in./in.)
h_{soil} = unbound or soil layer or sublayer thickness (in.)
n = load applications
β_{s1} = local calibration coefficient (set to 1.0 in global calibration effort)
$\beta = f$(water content)
k_{s1} = global coefficients, material or soil dependent
$\rho = f$(resilient modulus)

Source: AASHTO *MEPDG Manual of Practice*

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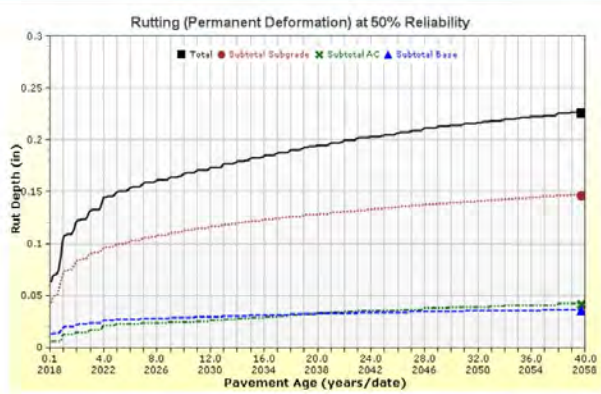
Example PMED Rut Prediction Output

- Modulus change
  - Temperature
  - Moisture
  - Aging
- Rut depth accumulation in each layer



14

NCHRP 1-37A IRI Model

- Based on primary distresses
  - Transverse (thermal) cracks, fatigue cracks, and rutting
  - Sealed longitudinal cracks and block cracks (user input)
- Other factors
  - Initial IRI
  - Age
  - Site factor
    - *f* (rainfall, %passing 0.02mm & 0.075mm sieves, plasticity index, annual freezing days)
- Function of base type

Source: NCHRP 1-37A Final Report

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NCHRP 1-37A IRI Model (continued...)

- Unbound Base

$$IRI = IRI_O + 0.0463\left[SF\left(e^{\frac{age}{20}} - 1\right)\right] + 0.00119(TC_L)_T + 0.1834(COV_{RD}) + 0.00384(FC)_T$$
$$+ 0.00736(BC)_T + 0.00115(LC_{SNWP})_{MH}$$

where:

IRI	=	IRI at any given time, m/km.
IRI_O	=	Initial IRI, m/km.
SF	=	Site factor
$e^{age/20} - 1$	=	Age term (where *age* is expressed in years).
COV_{RD}	=	Coefficient of variation of the rut depths, percent (assumed to be 20 percent).
$(TC_L)_T$	=	Total length of transverse cracks (low, medium, and high severity levels), m/km).
$(FC)_T$	=	Fatigue cracking in wheel path, percent total lane area
$(BC)_T$	=	Area of block cracking as a percent of total lane area (user input).
$(LC_{SNWP})_{MH}$	=	Length of moderate and high severity sealed longitudinal cracks outside wheel path, m/km (user input).

Source: NCHRP 1-37A Final Report

16

NCHRP 1-37A IRI Model (continued...)

- Asphalt Treated Base

$$IRI = IRI_O + 0.0099947(Age) + 0.0005183(FI) + 0.00235(FC)_T$$
$$+ 18.36\left[\frac{1}{(TC_S)_H}\right] + 0.9694(P)_H$$

Where,
IRI = IRI at any given time, m/km
IRI_0 = Initial IRI, m/km
Age = years
FI = average annual freezing index, °C-days
FC_T = fatigue cracking in wheel path, % lane area
$(TC_S)_H$ = average spacing of high severity transverse cracks (estimated from thermal cracking model), m
P_H = area of high severity patching, % lane area

Source: NCHRP 1-37A Final Report

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NCHRP 1-37A IRI Model (continued...)

- Chemically Stabilized Base

$$IRI = IRI_o + 0.00732(FC)_T + 0.07647(SD_{RD}) + 0.0001449(TC_L)_T$$
$$+ 0.00842(BC)_T + 0.0002115(LC_{NWP})_{MH}$$

Where,
IRI = IRI at any given time, m/km
IRI_0 = initial IRI, m/km
FC_T = wheel path fatigue cracking, % lane area
SD_{RD} = standard deviation of rut depth, mm
$(TC_L)_T$ = length of transverse cracks (all severities), m/km
BC_T = area of high severity patching, % lane area
$(LC_{SNWP})_{MH}$ = length moderate and high severity sealed longitudinal cracks, m/km

Source: NCHRP 1-37A Final Report

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Considerations for Reducing Rutting Potential

- Validate/calibrate rutting models to local conditions
- Asphalt layer
  - » Increase mixture stiffness
    - Increase binder grade
    - Lower asphalt binder content
  - » Rutting typically contained in upper layers
    - Ensure higher quality layer
    - Increasing lower quality layer thickness will not reduce rutting
- Unbound base/subgrade soils
  - » Improve layer quality
    - Material with higher CBR, R-value or layer moduli
  - » Use stabilized or treated layer
  - » Increase thickness of layers

Reducing stress and strain reduces rutting potential

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PMED IRI Model

- New and Asphalt Overlays

$$IRI = IRI_0 + C_1 RD + C_2(FC_{total}) + C_3(TC) + C_4(SF)$$

where,
IRI_0 = initial IRI (in/mi)
RD = average rut depth (in.)
FC_{total} = fatigue cracking (alligator, longitudinal, and reflection cracking in the wheel path) (% total area)
TC = transverse cracking (includes reflection cracking) (ft/mi)
$SF = f$(age, rainfall, plasticity index, freezing index, %passing 0.02 mm and 0.075 mm sieve)
$C_{1\text{-}4}$ = calibration factors

Source: AASHTO *MEPDG Manual of Practice*

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PMED IRI Model (continued...)

- Asphalt overlay of concrete and semi-rigid pavements

$$IRI = IRI_0 + \underline{PCC\ C_1} RD + \underline{PCC\ C_2}(FC_{total}) + \underline{PCC\ C_3}(TC) + \underline{PCC\ C_4}(SF)$$

where,
IRI_0 = initial IRI (in/mi)
RD = average rut depth (in.)
FC_{total} = fatigue cracking (alligator, longitudinal, and reflection cracking in the wheel path) (% total area)
TC = transverse cracking (includes reflection cracking) (ft/mi)
$SF = f$(age, rainfall, plasticity index, freezing index, %passing 0.02 mm and 0.075 mm sieve)
$PCC\ C_{1\text{-}4}$ = calibration factors

Source: AASHTO *MEPDG Manual of Practice*

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Example PMED IRI Prediction Output

- Performance threshold
- 50% reliability (----)
- Specified reliability (▪▪▪▪)

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NCHRP 1-47 Sensitivity of MEPDG (v1.1) Inputs

- Rutting (hyper and very sensitive)
  - » Asphalt Layer
    - E*
    - Poisson's ratio
    - Thickness
  - » Unbound base
    - None
    - Sensitive - thickness, Poisson's ratio, and modulus
  - » Subgrade
    - None
    - Sensitive - %passing no. 200 and liquid limit
  - » Total Rutting
    - E*
    - Thickness
    - Poisson's ratio

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NCHRP 1-47 Sensitivity of MEPDG (v1.1) Inputs

- IRI (hyper and very sensitive)
  - » Asphalt Layer
    - E*
    - Thickness
  - » Unbound base
    - None
    - Sensitive - modulus
  - » Subgrade
    - None
    - Sensitive - modulus and %passing no. 200

24

Transfer Function Calibration – Factors to Adjust

Distress	Eliminate Bias	Reduce Standard Error
Total Rutting: Unbound materials and HMA layers	k_{r1}, β_{s1}, or β_{r1}	k_{r2}, k_{r3} and β_{r2}, β_{r3}
IRI	C_4	C_1, C_2, and C_3

Source: AASHTO *Local Calibration Guide*

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QUESTIONS?

26

Presentation 20—Julie Vandenbossche, University of Pittsburgh

JPCP Faulting and IRI Models

A Journey through the PMED Engine

1

JPCP Joint Faulting and IRI Resources

Guide for ME Design of New and Rehabilitated Pavement Structures - Final Report (March 2004)

- Part 2. Chapter 2 Materials
- Part 3. Chapter 4 Design of New and Reconstructed Rigid Pavements
- Appendix QQ Structural response models for Rigid Pavements

Khazanovich, Darter, Yu TRR 1896 (2004) p34-45

NCHRP 20-07 Final Report (2014)

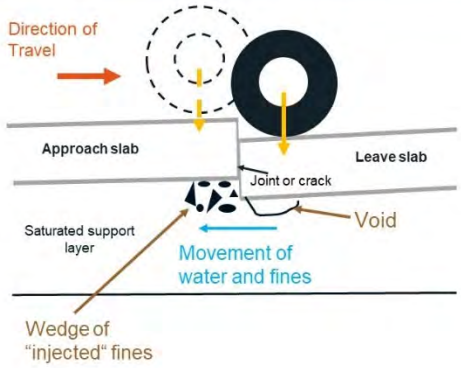
- CTE recal.; Task 327 national calibration

NCHRP 1-51 Final Report (2017)

- Slab-base interaction

2

Faulting



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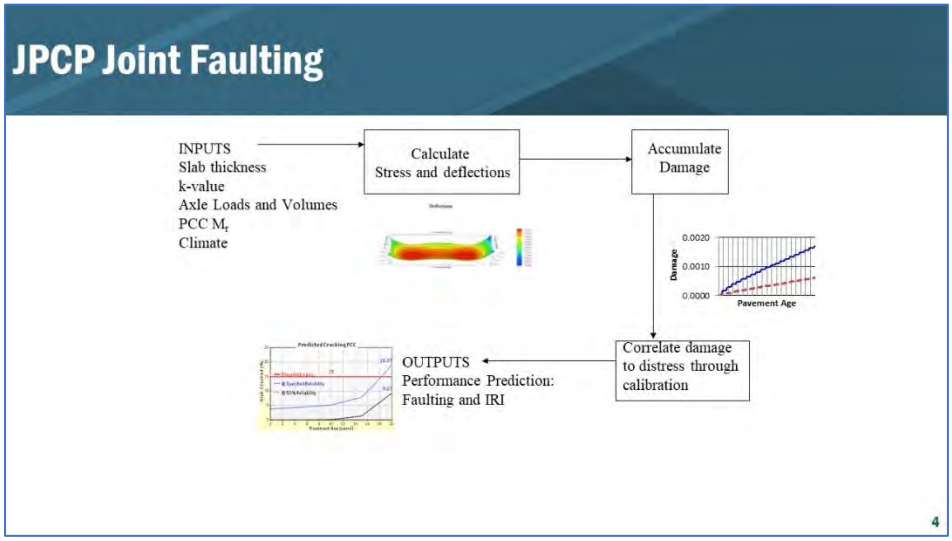
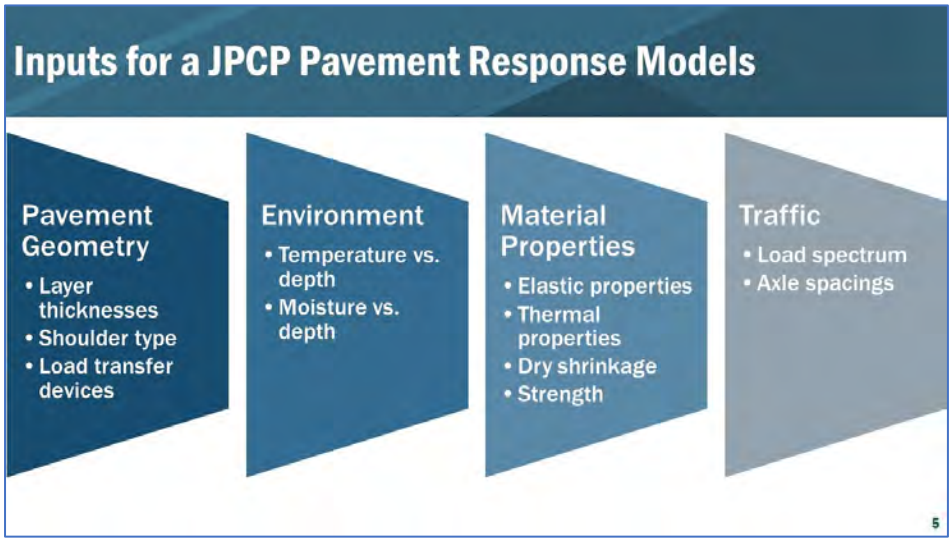
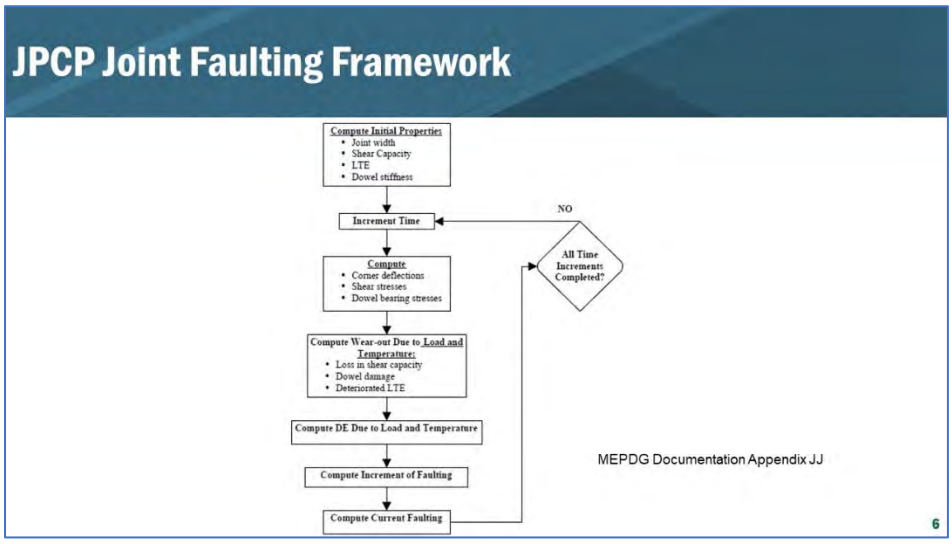

JPCP Joint Faulting
INPUTS
Slab thickness
k-value
Axle Loads and Volumes
PCC M_r
Climate
Calculate Stress and deflections
Accumulate Damage
0.0020
0.0010
0.0000
Damage
Pavement Age
Correlate damage to distress through calibration
OUTPUTS
Performance Prediction:
Faulting and IRI
4


Inputs for a JPCP Pavement Response Models
Pavement Geometry
• Layer thicknesses
• Shoulder type
• Load transfer devices
Environment
• Temperature vs. depth
• Moisture vs. depth
Material Properties
• Elastic properties
• Thermal properties
• Dry shrinkage
• Strength
Traffic
• Load spectrum
• Axle spacings
5

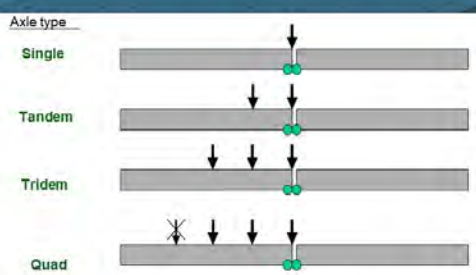

JPCP Joint Faulting Framework
Compute Initial Properties
• Joint width
• Shear Capacity
• LTE
• Dowel stiffness
Increment Time
NO
All Time Increments Completed?
Compute
• Corner deflections
• Shear stresses
• Dowel bearing stresses
Compute Wear-out Due to Load and Temperature:
• Loss in shear capacity
• Dowel damage
• Deteriorated LTE
Compute DE Due to Load and Temperature
Compute Increment of Faulting
Compute Current Faulting
MEPDG Documentation Appendix JJ
6

Faulting Prediction Procedure

1. Tabulate input data – summarize all inputs needed for predicting JPCP transverse joint faulting.
2. Process traffic data – the processed traffic data needs to be further processed to determine equivalent number of single, tandem, and tridem axles produced by each passing of tandem, tridem, and quad axles.
3. Process pavement temperature profile data – the hourly pavement temperature profiles generated using EICM (nonlinear distribution) need to be converted to effective nighttime differences by calendar month.
4. Process monthly relative humidity data – the effects of seasonal changes in moisture conditions on differential shrinkage is considered in terms of monthly deviations in slab warping, expressed in terms equivalent temperature differential.
5. Calculate initial maximum faulting.
6. Evaluate joint LTE.
7. Calculate current maximum faulting.
8. Determine critical pavement responses for the increment.
9. Evaluate loss of shear capacity and dowel damage.
10. Calculate faulting increment.
11. Calculate cumulative faulting.

7

Step 2: process traffic data

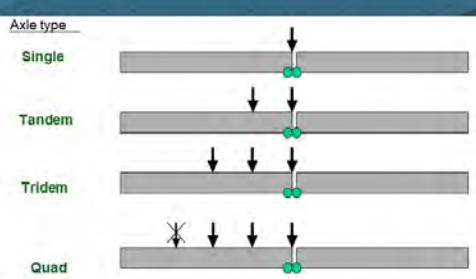


1. Each axle passing causes only 1 occurrence of a critical load
2. Only axle reps occurring between 8:00 pm and 8:00 am are accounted for

Figure 3.4.30. Accounting for different axle types in JPCP joint faulting damage accumulation:

8

Step 2: process traffic data

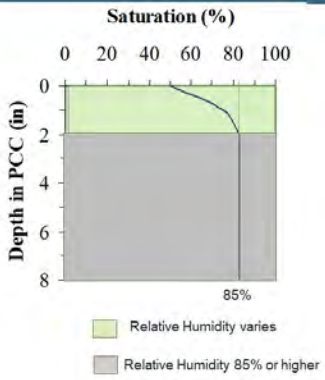


1. Each axle passing causes only 1 occurrence of a critical load
2. **Only axle reps occurring between 8:00 pm and 8:00 am are accounted for**

Figure 3.4.30. Accounting for different axle types in JPCP joint faulting damage accumulation:

9

Step 3: process mthly rel. humidity data



Typical moisture gradients- upward warping

- Irreversible – considered part of built-in
- Reversible
  - = f (ambient RH)
  - % of ult. Shrink.

10

Step 3: process mthly rel. humidity data

$$ETG_{Shi} = \frac{3(\varphi \cdot \varepsilon_{su})(S_{hi} - S_{h\,ave})h_S\left(\frac{h}{2} - \frac{h_S}{3}\right)}{\alpha\, h^2 \cdot 100}$$

ETG_{Shi} = Temp. difference equivalent for moisture warping in month i from the annual average, °F
φ = Reversible shrinkage factor, fraction of total shrinkage. (0.5 recommended)
ε_{su} = Ult. shrinkage based on PCC mix properties, x 10^6
S_{hi} = RH factor for month i:

$S_{hi} = 1.1\ RH_a$ for $RH_a < 30\ \%$
$S_{hi} = 1.4 - 0.01\ RH_a$ for $30\ \% < RH_a < 80\ \%$
$S_{hi} = 3.0 - 0.03\ RH_a$ for $RH_a \geq 80\ \%$

RH_a = Ambient average RH, percent
$S_{h\,ave}$ = Annual average of S_{hi}
h_s = Depth of shrinkage zone (typ. 2 in), in
h = PCC slab thickness, in
α = PCC coefficient of thermal expansion, /°F

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Step 3: process mthly rel. humidity data

Accounting for the time it takes to reach ultimate shrinkage:

$$ETG_{SHt} = S_t \cdot ETG_{SHi}$$

S_t = time factor for moisture-related slab warping.
Age = PCC age, days since placement.
n = time to develop 50% of ultimate shrinkage strain, days. Use 35 (the ACI Committee 209 recommended value), unless more accurate information is available (6).

$$S_t = \frac{Age}{n + Age}$$

ETG_{Sht} = ETG_{Shi} at any time t days from PCC placement, °F.
ETG_{Shi} = temperature difference equivalent of the deviation of moisture warping in month i from the annual average, °F.

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Step 4: process pavement temp. profile data

- Nighttime equivalent linear temp. difference for each mth

$$\Delta T_m = \Delta T_{t,m} - \Delta T_{b,m} + \Delta T_{sh,m} + \Delta T_{PCW} \qquad (3.4.24)$$

where,

ΔT_m = effective temperature differential for month m.
$\Delta T_{t,m}$ = mean PCC top-surface nighttime temperature (from 8 p.m. to 8 a.m.) for month m.
$\Delta T_{b,m}$ = mean PCC bottom-surface nighttime temperature (from 8 p.m. to 8 a.m.) for month m.
$\Delta T_{sh,m}$ = equivalent temperature differential due to reversible shrinkage for month m for old concrete (i.e. shrinkage is fully developed).
ΔT_{PCWt} = equivalent temperature differential due permanent curl/warp.

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Step 4: process pavement temp. profile data

LTE adjustment parameter:

- Mean nighttime PCC temp. @ mid-depth < 32F
  - » LTE_{base} = 90%

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Step 5. Determine max. faulting

$$FMAX_0 = (C_1 + C_2 * FR^{0.25}) * \delta_{curl} * \left[Log(1 + C_5 * 5^{EROD}) * Log(\frac{P_{200} * WetDays}{p_s})\right]^{C_6}$$

$FMAX_0$ = Initial maximum mean transverse joint faulting, in
C_1, C_2, C_5, C_6 = Calibration coefficients
FR = Base FI (% time top of the base is below freezing)
δ_{curl} = Max. mean mthly PCC upward slab corner deflection due ΔT_m (Step 4) from ANNs
$EROD$ = Base/subbase erodibility index (Input by user: Integer between 1 and 5)
P_{200} = Percent of the subgrade soil passing No. 200 sieve
$WetDays$ = Average number of annual wet days (> 0.1 in of rainfall)
p_s = overburden on subgrade, lb

15

Step 5. Determine max. faulting

$$FMAX_0 = (C_1 + C_2 * FR^{0.25}) * \delta_{curl} * \left[Log(1 + C_5 * 5^{EROD}) * Log(\frac{P_{200} * WetDays}{p_s})\right]^{C_6}$$

$FMAX_0$ = Initial maximum mean transverse joint faulting, in

C_1, C_2, C_5, C_6 = Calibration coefficients

FR = Base FI (% time top of the base is below freezing)

δ_{curl} = Max. mean mthly PCC upward slab corner deflection due ΔT_m (Step 4) from ANNs

$EROD$ = Base/subbase erodibility index (Input by user: Integer between 1 and 5)

P_{200} = Percent of the subgrade soil passing No. 200 sieve

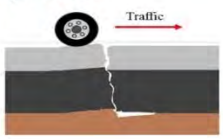
$WetDays$ = Average number of annual wet days (> 0.1 in of rainfall)

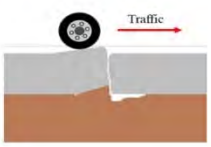
p_s = overburden on subgrade, lb

16

Step 5. Determine max. faulting

Layer directly below the PCC layer but.....





Erodibility Index	Material Description and Testing
1	(a) Lean concrete (approx. 8% cement) (b) HMA (6% AC) (c) Permeable drainage layer (AC or cement treated)
2	(a) Cement treated (5% cement) (b) Asphalt treated (4% AC)
3	(a) Cement treated (3% cement) (b) Asphalt treated (3.5% AC)
4	Unbound crushed, densely graded & high-quality aggregates.
5	Existing Soil (on prepared/compacted subgrade)

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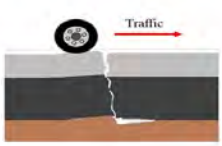
Step 5. Determine max. faulting

In reality, dictated by depth of working joints

- Overburden
  - » Overburden on layer that is undergoing pumping
- P_{200}
  - » Layer that is undergoing pumping



18

Step 6. Evaluate joint LTE

$$LTE_{joint} = 100\left(1-(1-LTE_{dowel}/100)(1-LTE_{agg}/100)(1-LTE_{base}/100)\right) \qquad (3.4.33)$$

where,

LTE_{joint} = total joint LTE, percent.
LTE_{dowel} = joint LTE if dowels are the only mechanism of load transfer, percent.
LTE_{base} = joint LTE if the base is the only mechanism of load transfer, percent.
LTE_{agg} = joint LTE if aggregate interlock is the only mechanism of load transfer, percent.

Dowel

Aggregate interlock

Base

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Step 6. Evaluate joint LTE

- LTEagg

Aggregate interlock

$$LTE_{agg} = \frac{1}{0.01+0.012(Log(J_{AGG}))^{-0.849}}$$

where,

LTE_{AGG} = load transfer efficiency on the transverse crack due to aggregate interlock.
J_{AGG} = transverse joint stiffness

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Step 6. Evaluate joint LTE

- LTEagg: J_{AGG} = f(e, f, S)

Aggregate interlock

$$Log\,(J_{AGG}) = -3.19626 + 16.09737 * e^{-e^{-\left(\frac{S-e}{f}\right)}}$$

J_{AGG} = (Agg/kl) = joint stiffness of transverse jt for current increment
e = 0.35
f = 0.38
S = joint shear capacity

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Step 6. Evaluate joint LTE

- LTEagg: Shear capacity = f(hpcc, jw, ΔS_{tot})

Aggregate interlock

$$S = 0.05 * h_{PCC} * e^{-0.028jw} - \Delta s_{tot}^{b}$$

S = dimensionless aggregate joint shear capacity
jw = joint opening, mils
Δs_{tot}^{b} = cumulative loss of shear capacity @ beginning of the current month

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Step 6. Evaluate joint LTE

Aggregate interlock

- LTEagg: Shear capacity = f(hpcc, jw, ΔS_{tot})

$$\mathrm{jw(m)} = \max(12000 * \mathrm{c} * \mathrm{JTSpace} * (\mathrm{CTE} * (\mathrm{T_c} - \mathrm{T(m)}) + \varepsilon_{\mathrm{sh}}), 0)$$

jw (m) = Joint Width for month m, mils
c = friction factor (0.65-stabilized layers, 0.85-unstabilized layers)
$JTSpace$ = joint spacing, ft
CTE = PCC coeff. of thermal exp., in/in/°F
T_c = PCC set temperature, °F
$T(m)$ = mean mid-depth PCC temp for month, m ,°F
ε_{sh} = PCC shrinkage strain

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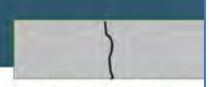
Step 6. Evaluate joint LTE



Aggregate interlock

- LTEagg: Shear capacity = f(hpcc, jw, ΔS_{tot})

$$\Delta S_i = \begin{cases} 0 & if\ JW < 0.001h_{PCC} \\ n_i * \dfrac{0.005 * 10^{-6}}{1.0 + \left(\dfrac{JW}{h_{PCC}}\right)^{-5.7}} \left(\dfrac{\tau_i}{\tau_{ref}}\right) & if\ 0.001h_{PCC} < JW < 3.8h_{PCC} \\ n_i * \dfrac{0.068 * 10^{-6}}{1.0 + 6.0 * \left(\dfrac{JW}{h_{PCC}} - 3\right)^{-1.98}} \left(\dfrac{\tau_i}{\tau_{ref}}\right) & if\ JW > 3.8h_{PCC} \end{cases}$$

ΔS_i = Loss of shear capacity from axle load group i,

h_{PCC} = Overlay slab thickness, in

JW = Joint opening, mils

$\tau_i = J_{AGG} * (\delta_L^2 - \delta_{UL}^2)$ = shear stress on the transverse joint surface from the response model,

$\tau_{ref} = 111.1 * \exp(-\exp(0.9988 * \exp(-0.1089 * \log(J_{AGG})))$ = reference shear stress derived from the Portland Cement Association (PCA) test results.

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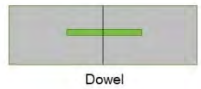
Step 6. Evaluate joint LTE

- LTE_{dowel}



$$LTE_{dowel} = \frac{100}{1 + 0.012 J_d^{-0.849}}$$

J_d = nondimensional dowel stiffness

25

Step 6. Evaluate joint LTE

- LTE_{dowel}: Nondimensional Jt stiffness= f(J_o, J^*_d, DOWDAM)

$$J_d = J_d^* + (J_0 - J_d^*)\exp(-DOWDAM)$$

J_d = nondimensional dowel stiffness

J_0= initial nondimensional dowel stiffness = $\frac{152.3\, A_d}{\text{hpcc}}$

h_{pcc}= PCC slab thickness, in

A_d = dowel diameter, in^2

J_d^* = critical nondimensional dowel stiffness

$DOWDAM$ = damage accumulated by doweled joint due to past traffic

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Step 6. Evaluate joint LTE

- LTE_{dowel}: Nondimensional Jt stiffness= f(J_o, J^*_d, DOWDAM)

$$J^*_d = \begin{cases} 118, & if\ \frac{A_d}{h_{PCC}} > 0.835 \\ 52.52\frac{A_d}{h_{PCC}} - 19.8, & if\ 0.039 \le \frac{A_d}{h_{PCC}} \le 0.835 \\ 0.4, & if\ \frac{A_d}{h_{PCC}} < 0.039 \end{cases} \quad (56)$$

Appendix JJ

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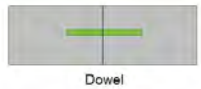
Step 6. Evaluate joint LTE

- LTE_{dowel}: Nondimensional Jt stiffness= f(J_o, J^*_d, DOWDAM)

$$J_d^* = \begin{cases} 118, & if\ \frac{A_d}{h_{pcc}} > 0.656 \\ 210.0845\frac{A_d}{h_{pcc}} - 19.8, & if\ 0.009615 \le \frac{A_d}{h_{pcc}} \le 0.656 \\ 0.4, & if\ \frac{A_d}{h_{pcc}} < 0.009615 \end{cases}$$



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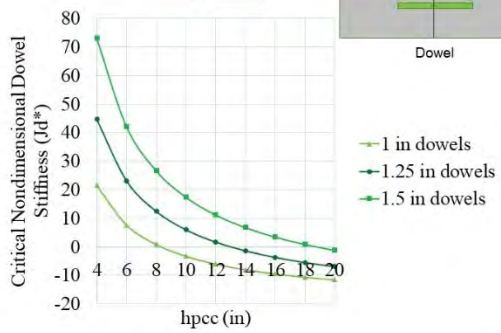
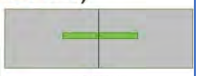
Step 6. Evaluate joint LTE

- LTE_{dowel}: Nondimensional Jt stiffness= f(J_o, J^*_d, DOWDAM)

Negative nondimensional dowel stiffness

$$J_d^* = \begin{cases} 118, & if\ \frac{A_d}{h_{pcc}} > 0.656 \\ 210.0845\frac{A_d}{h_{pcc}} - 19.8, & if\ 0.009615 \le \frac{A_d}{h_{pcc}} \le 0.656 \\ 0.4, & if\ \frac{A_d}{h_{pcc}} < 0.009615 \end{cases}$$





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Step 6. Evaluate joint LTE

- LTE_{dowel}: Nondimensional Jt stiffness= f(J_o, J^*_d, DOWDAM)

$$\Delta DOWDAM = C_8 * \frac{J_d*(\delta_L^2 - \delta_{UL}^2)*DowelSpace}{d*f_c'}$$

$\Delta DOWDAM$ = dowel damage increment from an individual axle application;
f_c^* = PCC compressive stress, psi
C_8 = calibration constant =
d = dowel diameter, in
J_d = non-dimensional dowel stiffness at the time of load application
δ_L = deflection at the corner of the loaded slab induced by the axle
δ_U = deflection at the corner of the unloaded slab induced by the axle
DowelSpace = the space between adjacent dowels in the wheel path, in

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Step 6. Evaluate joint LTE

LTE_{base}

Table 3.4.8. Assumed effective base LTE for different base types.

Base Type	LTE_{Base}
Aggregate base	20%
ATB or CTB base	30%
LCB base	40%

Unless mean nighttime PCC temp. @ mid-depth < 32F
then LTE_{base} = 90%

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Step 7. Calculate current maximum faulting

$$FMAX_i = FMAX_{i-1} + C_7 * DE_i * \left[Log\left(1 + C_5 * 5^{EROD}\right)\right]^{C_6}$$

$$DE_m = \sum_{A=1}^{3}\sum_{i=1}^{N_A} n_{i,A} k_m \left(\frac{\delta_{L,i,A}^2}{2} - \frac{\delta_{U,i,A}^2}{2}\right)$$

DE_m=differential energy density of subgrade deformation accumulated in month m

$\delta_{L,i,A}$ = corner deflection for loaded slab due to axle load

$\delta_{U,i,A}$ = corner deflections for unloaded slab caused by axle loading

$n_{i,A}$ = # of axle load applications for current increment and load group i

N_A = # of load categories for the axle type A

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Step 7. Calculate current maximum faulting

$$FMAX_i = FMAX_{i-1} + C_7 * DE_i * \left[Log\left(1 + C_5 * 5^{EROD}\right)\right]^{C_6}$$

FMAX equa. in documentation results in significantly larger predicted faulting

Faulting was closely replicated using the following:

$$FMAX_i = FMAX_{i-1} + \frac{1}{1000000} C_7 * DE_i * \left[Log\left(1 + C_5 * 5^{EROD}\right)\right]^{C_6}$$

33

Step 7. Calculate current maximum faulting

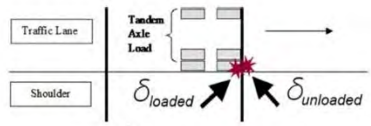
Good vs poor load transfer in terms of De_i

- Poor: faulting accumulates at a max rate when

$$\delta_U = 0 \quad \rightarrow \quad DE_i = \frac{k}{2}\delta_L^2$$

- Good: No faulting accumulation when

$$\delta_U = \delta_L \rightarrow \quad DE_i = 0$$



$$DE_i = \frac{k}{2}\left(\delta_{loaded}^2 - \delta_{unloaded}^2\right)$$

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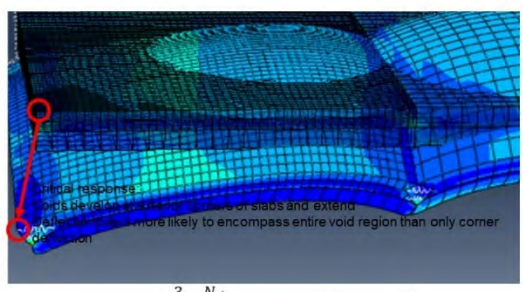
Step 7. Calculate current maximum faulting

Pavement response: differential energy density



$$DE_m = \sum_{A=1}^{3}\sum_{i=1}^{N_A} n_{i,A} k_m \left(\frac{\delta_{L,i,A}^2}{2} - \frac{\delta_{U,i,A}^2}{2}\right)$$

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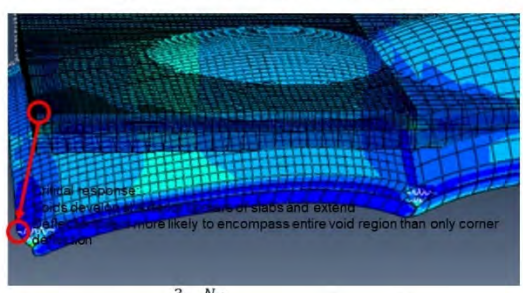
Step 7. Calculate current maximum faulting

Pavement response: differential energy density

Critical response:

- Voids develop at exterior corners of slabs and extend
- Deflection basin more likely to encompass entire void region than only corner deflection



$$DE_m = \sum_{A=1}^{3}\sum_{i=1}^{N_A} n_{i,A} k_m \left(\frac{\delta_{L,i,A}^2}{2} - \frac{\delta_{U,i,A}^2}{2}\right)$$

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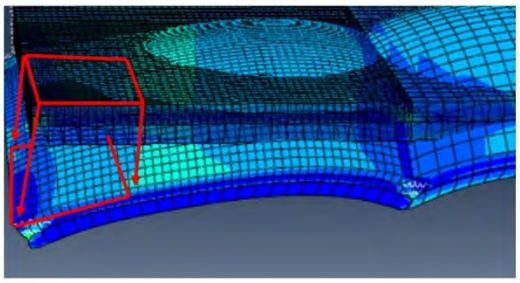
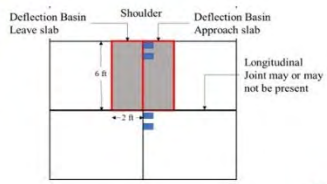
Step 7. Calculate current maximum faulting

Pavement response: differential energy density



Deflection Basin Slab:

- Approach: $\Sigma(\delta_{\Sigma L}^2 * Area)$
- Leave: $\Sigma(\delta_{\Sigma UL}^2 * Area)$
- 2 ft x 6 ft rectangle



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Step 8. Determine critical pavement response for the increment

$$DE = k/2\,(\delta^2_{loaded} - \delta^2_{unloaded})$$

Shear stress at the slab corner $\tau = \dfrac{AGG*(\delta_{loaded} - \delta_{unloaded})}{h}$

Max. dowel bearing stress $\sigma_b = \dfrac{D_d*(\delta_{loaded} - \delta_{unloaded})}{d*dsp}$

DE	=	differential energy, lb/in.
δ_{loaded}	=	loaded corner deflection, in.
$\delta_{unloaded}$	=	unloaded corner deflection, in.
AGG	=	aggregate interlock stiffness factor.
k	=	coefficient of subgrade reaction, psi/in.
D_d	=	dowel stiffness factor = $J_d*k*l*dsp$.
d	=	dowel diameter, in.
dsp	=	dowel spacing, in.

38

Step 9 Evaluate loss of shear capacity and dowel damage

$$\Delta S_i = \begin{cases} 0 & if\ JW < 0.001h_{PCC} \\ n_i * \dfrac{0.005*10^{-6}}{1.0 + \left(\dfrac{JW}{h_{PCC}}\right)^{-5.7}} \left(\dfrac{\tau_i}{\tau_{ref}}\right) & if\ 0.001h_{PCC} < JW < 3.8h_{PCC} \\ n_i * \dfrac{0.068*10^{-6}}{1.0 + 6.0*\left(\dfrac{JW}{h_{PCC}} - 3\right)^{-1.98}} \left(\dfrac{\tau_i}{\tau_{ref}}\right) & if\ JW > 3.8h_{PCC} \end{cases}$$

ΔS_i = Loss of shear capacity from axle load group i,

h_{PCC} = Overlay slab thickness, in

JW = Joint opening, mils

$\tau_i = J_{AGG} * (\delta_L^2 - \delta_{UL}^2)$ = shear stress on the transverse joint surface from the response model,

$\tau_{ref} = 111.1 * \exp(-\exp(0.9988 * \exp(-0.1089 * \log(J_{AGG}))))$ = reference shear stress derived from the Portland Cement Association (PCA) test results.

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Step 9 Evaluate loss of shear capacity and dowel damage

$$\Delta DOWDAM = C_8 * \frac{J_d*(\delta_L^2-\delta_{UL}^2)*DowelSpace}{d*f_c'}$$

$\Delta DOWDAM$ = dowel damage increment from an individual axle application;
f_c' = PCC compressive stress, psi
C_8 = calibration constant =
d = dowel diameter, in
J_d = non-dimensional dowel stiffness at the time of load application
δ_L = deflection at the corner of the loaded slab induced by the axle
δ_U = deflection at the corner of the unloaded slab induced by the axle
DowelSpace = the space between adjacent dowels in the wheel path, in

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Step 9 Evaluate loss of shear capacity and dowel damage

$$\Delta DOWDAM = C_8 * \frac{J_d*(\delta_L^2-\delta_{UL}^2)*DowelSpace}{d*f_c'}$$

- C_8 only coefficient affecting doweled pavements
- Cannot be decoupled from DE

Therefore: Should be a constant and not calibration coefficient

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Step 10. Calculate faulting increment

$$\Delta Fault_i = (C_3 + C_4 * FR^{0.25}) * (FMAX_{i-1} - Fault_{i-1})^2 * DE_i$$

$\Delta Fault_i$ = Incremental monthly change in mean transverse joint faulting during month i, in
C_3, C_4 = Calibration coefficients
FR = Base freezing index (percentage of the time top of base is below freezing (<32°F))
$FMAX_{i-1}$ =Max. mean trans. jt faulting for month i-1, inches (Max. faulting parameter at the beginning of month i. (If i =1, $FMAX_{i-1} = FMAX_0$)
$Fault_{i-1}$ = Mean joint faulting at the beginning of month i. 0 if i = 1.
DE_i = Differential energy density of subgrade accumulated during month i

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Step 11. Calculate cumulative faulting

$$\mathbf{Fault}_i = \mathbf{Fault}_{i-1} + \Delta\mathbf{Fault}_i$$

$Fault_i$ = Mean joint faulting at the end of month i, in
$Fault_{i-1}$ = Mean joint faulting at the beginning of month i (Mean joint faulting at the end of month i-1), in
$\Delta Fault_i$ = Incremental monthly change in mean transverse joint faulting during month i, in

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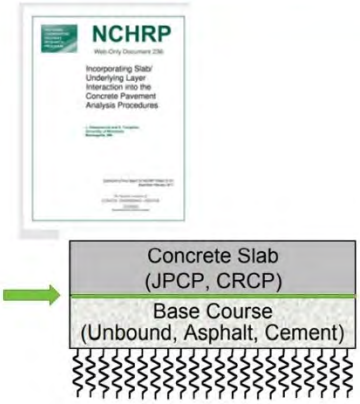
NCHRP 1-51-Incorporating Slab/Underlying Layer Interaction into the Concrete Pavement Analysis Procedures (2017)

- PI: Dr. Lev Khazanovich

Account for slab-base interface bond degradation



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NCHRP 1-51-Incorporating Slab/Underlying Layer Interaction into the Concrete Pavement Analysis Procedures (2017)

- Total LTE from aggregate interlock, dowels, and base layer:

$$\mathrm{LTE_{total}} = 100 \cdot \left(1 - \left(1 - \frac{LTE_{base}}{100}\right) \cdot \left(1 - \left(1 - \frac{LTE_{PCC}}{100}\right) \cdot \left(1 - \left(1 - \frac{LTE_{dowel}}{100}\right)\right)\right)\right)$$

- Ver. 2.6 recommends LTE_{base} = 20% for granular base, 30% for ATB, 40% for CTB, 40% for LCB (90% in all cases for frozen base)
- Modified procedure uses LTE_{base} = 20% for granular base, 40% for ATB, 40% for CTB, 30% for LCB

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Ver. 2.6 Calibration Coefficients

Pitt national calibration coefficients voted to be adopted by JTCoP (Fall 2014)

- Corrected CTE values (only Level 1 data)
- Balanced factorial designs
- Updated climatic files used in calibration
- Calibrations performed with updated version of Pavement ME

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Error in Estimating CTE

CTE of 304 SS calibration specimen

- $17.3 \times 10^{-6}/^{o}C$ at 0 to $500^{o}C$
- 15.8 to $16.2 \times 10^{-6}/^{o}C$ at 10 to $50^{o}C$

- CTE_{steel} too high → CTE_{PCC} too high (approx. $1.5 \times 10^{-6}/^{o}C$)
- LTPP database populated w/ incorrect CTEs
- Recalibrate with correct CTEs

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History

No.	Calibration coefficient	Calibration data set	CTE (u: uncorrected c: corrected)
1	M-E PDG Ver. 0.7	1-37	uCTE
2	M-E PDG Ver. 1.0	1-40D	uCTE
3	Task 288	Task 288	cCTE
4	Task 327	Task 327	cCTE

Variables between calibrations:

- Projects included in the data set
- Version of design software used in calibration
  - Appears Ver. 1.0 was used for Task 288 calibration
  - NCHRP Project 20-07/Task 327 used Version 1.3.29
- Changes in calibration database (CTE, friction, built-in curl, climatic data, etc.)

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Calibration Database
Task 327.7 – Ver.2.6

NCHRP Project 20-07/Task 327

- 410 JPCP sites
  - 394 LTPP
  - 7 AASHO Road test
  - 9 MnRoad
- 118 CRCP sites
  - 83 LTPP
  - 35 from IL (regular interstate and the Vandalia experimental site), SC, PA, Georgia and WI

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Data checks
Task 327.7 – Ver.2.6

Reasonableness – values +/- 1.5 to stan. devs from the mean
- Input compared to that in LTPP database
- Project excluded if discrepancy existed

- Traffic data outliers
  - Vehicle class distribution (2 CRPC & 4 JPCP excluded)
  - Growth rate (11 JPCP excluded)
  - 2-way ADTT (8 JPCP excluded)
- Material property outliers
  - None excluded
- Distress data outliers
  - 9 JCPC had cracking decrease by 3 to 8% slabs cracked for consecutive meas.
  - Corrected using MEPDG documentation and LTPP database

Total sites excluded: 13 JPCP

Total sites available: 397 JPCP

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Factorial Designs
Task 327.7 – Ver.2.6

Impetus

Complete data set – Potential for skewed representation of key inputs

Factorial design - Balanced representation of key inputs

51

Factorial Designs
Task 327.7 – Ver.2.6

- Two-level multivariate factorial matrices
  1. CRCP punchouts
  2. JPCP faulting and cracking
- Variables selected to represent key inputs
- High and low levels established for each key input
- Validation sites identified
  (not included in the factorial matrices)

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Factorial Designs
Task 327.7 – Ver.2.6

Faulting (Doweled JPCP):

- Dowel Diameter (≤ 1.25 in, > 1.25 in)
- Slab Thickness (≤ 9.5 in, > 9.5 in)
- Base erosion index (≤ 3, > 3)
- Average Annual Precipitation (≤ 31 in, > 31 in)
- ADTT*Age at Last Distress Measurement (≤ 9000 vehicle-yrs, > 9000 vehicle-yrs)
- Edge Support (no, yes)

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JPCP Faulting (Doweled) Matrix
Task 327.7 – Ver.2.6

			Dowel Diameter ≤ 1.25 in				Dowel Diameter > 1.25 in			
			T ≤ 9.5 in		T > 9.5 in		T ≤ 9.5 in		T > 9.5 in	
			EI ≤ 3	EI > 3	EI ≤ 3	EI > 3	EI ≤ 3	EI > 3	EI ≤ 3	EI > 3
Precip ≤ 31 in	ADTT*Age < 9000	No Edge	53_0205	53_0209	19_3028				53_0208	53_0212
		Support	8_0218	8_0222					8_0215	55_0223
		Edge	8_0217	MnRoad_IM5	19_3009	MnRoad_IM11		35_3010	53_0203	8_0216
		Support	MnRoad_IM6	MnRoad_IM7	MnRoad_IM12				8_0220	MnRoad_IM13
	ADTT*Age > 9000	No Edge	26_0218	26_0222	26_0215				4_0215	4_0223
		Support	4_0214	4_0218					26_0220	
		Edge	26_0221	26_0213	16_3017	26_0216			26_0224	4_0224
		Support	4_0213	4_0221	8_7776	4_7614			4_0220	
Precip > 31 in	ADTT*Age < 9000	No Edge		37_0205	18_3003		37_0201	37_0209	37_0204	48_3010
		Support			13_3015				37_0212	
		Edge	28_3018	37_3807	5_3011		37_0202	37_0210	37_0207	
		Support	55_6355	55_6352			37_0206	39_3801	37_0211	
	ADTT*Age > 9000	No Edge	18_3030	5_0214	18_3031		39_3013	89_3016	21_3016	5_0215
		Support		5_0222	39_0209				39_0208	5_0219
		Edge	18_3002	5_0213	12_3804	45_3012		89_3015	5_0220	5_0216
		Support	42_1623		13_3016			39_0207	5_0224	

Cases available for model validation:	12_4057	13_3020	26_0214	26_0217	26_0219	26_0223	26_3068	26_3069
	28_3019	37_0203	37_0208	37_3008	37_3011	37_3816	4_0216	4_0217
	4_0219	4_0222	5_0217	5_0221	5_0223	53_0201	53_0202	53_0204
	53_0206	53_0210	53_0211	55_0260	8_0214	8_0219	8_0221	8_0223
	8_0224	MnRoad_IM10	MnRoad_IM8	MnRoad_IM9				

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Factorial Designs
Task 327.7 – Ver.2.6

Faulting (Undoweled JPCP):

- Slab Thickness (≤ 9.5 in, > 9.5 in)
- Base erosion index (≤ 3, > 3)
- Average Annual Precipitation (≤ 22 in, > 22 in)
- ADTT*Age at Last Distress Measurement (≤ 6000 vehicle-yrs, > 6000 vehicle-yrs)
- Edge Support (no, yes)

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JPCP Faulting (Undoweled) Matrix
Task 327.7 – Ver.2.6

		T ≤ 9.5 in				T > 9.5 in			
		EI ≤ 3		EI > 3		EI ≤ 3		EI > 3	
		Precip ≤ 22"	Precip > 22"	Precip ≤ 22"	Precip > 22"	Precip ≤ 22"	Precip > 22"	Precip ≤ 22"	Precip > 22"
ADTT*Age < 6000	No Edge	32_3013	40_4160	46_3013	55_3009		1_3028	46_3012	55_3015
	Support	38_3005	89_3001		55_3016		19_3055		
	Edge	8_3032	27_3003	53_7409	53_3813			4_7613	55_3010
	Support	38_3006	31_3028	46_3053				49_7082	55_6354
ADTT*Age > 6000	No Edge	6_3019	12_3811	6_3021	89_3002	32_3010	13_3011		55_3014
	Support	6_7493	40_4162	6_3017		49_7086	13_3018		
	Edge			53_3013		31_3018		53_3014	53_3011
	Support					49_3011		53_3019	55_6353

Cases available for model validation:	12_4000	12_4138	13_3017	27_3013	31_3024	32_7084	55_3012	55_6351
	6_7456	83_3802						

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JPCP Faulting Factorial Sites
Task 327.7 – Ver.2.6

Background map is the Google Map of the US as of September, 2013

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JPCP Joint Faulting
Task 327.7 – Ver.2.6

$$FMAX_0 = (C_1 + C_2 * FR^{0.25}) * \delta_{curl} * \left[Log(1 + C_5 * 5^{EROD}) * Log(\frac{P_{200} * WetDays}{p_s})\right]^{C_6}$$

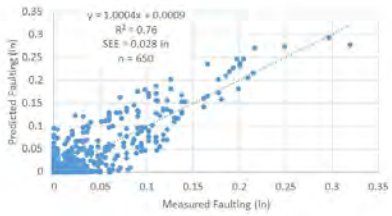
$$FMAX_i = FMAX_{i-1} + \frac{1}{1000000} * C_7 * DE_i * \left[Log(1 + C_5 * 5^{EROD})\right]^{C_6}$$

$$\Delta Fault_i = (C_3 + C_4 * FR^{0.25}) * (FMAX_{i-1} - Fault_{i-1})^2 * DE_i$$

$$Fault_i = Fault_{i-1} + \Delta Fault_i$$

$$\Delta DOWDAM_{tot} = \sum_{j=1}^{3}\sum_{i=1}^{N} C_8 * F_{ij}\frac{n_{ij}}{df_c^i}$$

Calibration Coefficient	Task 327.7
C_1	0.595
C_2	1.636
C_3	0.00217
C_4	0.00444
C_5	250
C_6	0.47
C_7	7.3
C_8	400



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JPCP Joint Faulting
Task 327.7 – Ver.2.6

$$FMAX_0 = (C_1 + C_2 * FR^{0.25}) * \delta_{curl} * \left[Log(1 + C_5 * 5^{EROD}) * Log(\frac{P_{200} * WetDays}{p_s})\right]^{C_6}$$

$$FMAX_i = FMAX_{i-1} + \frac{1}{1000000} * C_7 * DE_i * \left[Log(1 + C_5 * 5^{EROD})\right]^{C_6}$$

$$\Delta Fault_i = (C_3 + C_4 * FR^{0.25}) * (FMAX_{i-1} - Fault_{i-1})^2 * DE_i$$

$$Fault_i = Fault_{i-1} + \Delta Fault_i$$

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Calibration Coefficient	Task 327.7
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C_2	1.636
C_3	0.00217
C_4	0.00444
C_5	250
C_6	0.47
C_7	7.3
C_8	400

y = 1.0004x + 0.0009
R² = 0.76
SEE = 0.028 in
n = 650
Predicted Faulting (in)
Measured Faulting (in)

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JPCP Joint Faulting

	1-37	1-40D	Task 288	Task 327.5
C_1	1.29	1.0184	0.5104	0.873
C_2	1.1	0.9165	0.00838	0.675
C_3	0.001725	0.002185	0.00147	0.00165
C_4	0.0008	0.000884	0.008345	0.00569
C_5	250	250	5999	250
C_6	0.4	0.4	0.8404	0.53
C_7	1.2	1.83312	5.9293	6.9
R^2	0.74	0.62	0.59	0.80
SEE	0.027	0.028	0.032	0.025

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JPCP Faulting – Dowel bar cal. coef.
Task 327.7 – Ver.2.6

Eliminate C_8 as a calibration coefficient (make it a constant)

$$\Delta DOWDAM_{tot} = \sum_{j=1}^{3} \sum_{i=1}^{N} C_8 * F_{ij} \frac{n_{ij}}{df_c^*}$$

» Intent of C_8 is to better account for dowels (C_1 - C_7 are the same all JCPs (doweled and undoweled))

» C_8 can't be calibrated without access to NN

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Other considerations

- Socketing ?
- Corrosion ?
- Both ?

What really causes faulting when doweled?

How valid are current models for long-life dowels?

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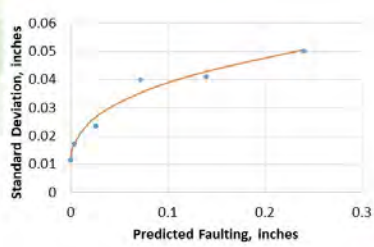
JPCP Faulting Reliability
Task 327.7 – Ver.2.6

Calibration Effort	Standard Deviation Model for Joint Faulting
1-37	$\text{Stdev(FLT)} = (0.03261 * \text{FLT} + 0.00009799)^{0.5}$
1-40D	$\text{Stdev(FLT)} = 0.014 + (0.0097 * \text{FLT})^{0.5178}$
Task 288	$\text{Stdev(FLT)} = 0.00521 + 0.0831 * (\text{FLT}^{0.3426})$
Task 327.7	$\text{Stdev(FLT)} = 0.00806 + 0.07162 * (\text{FLT}^{0.368})$



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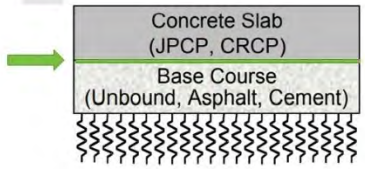
NCHRP 1-51-Incorporating Slab/Underlying Layer Interaction into the Concrete Pavement Analysis Procedures (2017)

- PI: Dr. Lev Khazanovich

Account for slab-base interface bond degradation



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NCHRP 1-51-Incorporating Slab/Underlying Layer Interaction into the Concrete Pavement Analysis Procedures (2017)

- New Calibration Coef.

$$Fault_m = \sum_{i=1}^{m} \Delta Fault_i$$

$$\Delta Fault_i = C_{34} \cdot DE_i \cdot (FAULTMAX_{i-1} - Fault_{i-1})^2$$

$$FAULTMAX_i = FAULTMAX_0 + C_7 \cdot C_{56} \cdot \sum_{j=1}^{m} DE_i$$

$$FAULTMAX_0 = C_{12} \cdot C_{56} \cdot \delta_{curl} \cdot Log\left(\frac{P_{200} \cdot WetDays}{p_s}\right)^{C_6}$$

$$C_{56} = Log(1 + C_5 \cdot 5^{ERODI})^{C_6}$$

$$C_{12} = C_1 + C_2\sqrt[4]{FR}$$

$$C_{34} = C_3 + C_4\sqrt[4]{FR}$$

- Modified coefficients considering new LTE_{base}:

Coefficient	Value
C1	0.27806
C2	1.63799
C3	0.00624
C4	0.001
C5	299.853
C6	0.3968
C7	8.69371

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NCHRP 1-51-Incorporating Slab/Underlying Layer Interaction into the Concrete Pavement Analysis Procedures (2017)

- New Calibration Coef.

Modified coefficients considering new LTE_{base}:

	1-37	1-40D	Task 288	Task 327.5	Ver. 3.0
C_1	**1.29**	**1.0184**	0.5104	**0.873**	**0.27806**
C_2	**1.1**	**0.9165**	0.00838	**0.675**	**1.63799**
C_3	0.001725	0.002185	0.00147	0.00165	0.00624
C_4	0.0008	0.000884	0.008345	0.00569	0.001
C_5	250	250	5999	250	299.853
C_6	0.4	0.4	0.8404	0.53	0.3968
C_7	1.2	1.83312	5.9293	6.9	8.69371
R^2	0.74	0.62	0.59	0.80	0.438
SEE	0.027	0.028	0.032	0.025	0.03

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NCHRP 1-51-Incorporating Slab/Underlying Layer Interaction into the Concrete Pavement Analysis Procedures (2017)

- New Calibration Coef.

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	1-37	1-40D	Task 288	Task 327.5	Ver. 3.0
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				0.00569	0.001
				250	299.853
				0.53	0.3968
				6.9	8.69371
				0.80	0.438
				0.025	0.03

Statistic	PMED v2.6 Verification	PMED v3.0 Calibration
N – sections	195	195
n – points	1155	1450
R^2	0.348	0.439
s_e/s_y	1.025	0.831
Bias	0.001	-0.009
Slope	0.720	0.677
Adj. R^2	0.347	0.438
SEE	0.039	0.03

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NCHRP 1-51-Incorporating Slab/Underlying Layer Interaction into the Concrete Pavement Analysis Procedures (2017)

- New Calibration Coef.

Modified coefficients considering new LTE_{base}:

	1-37	1-40D	Task 288	Task 327.5	Ver. 3.0
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68

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Adj. R^2	0.347	0.438
SEE	0.039	0.03

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Calibration database

Doweled pavements

LTPP sections with faulting > 3 mm/total number of sections

Climate	WF		WNF		DNF		DF		Total
STRUCTURE	D	U	D	U	D	U	D	U	
JPCP on GB	3/37	9/16	0/2	0/0	1/5	1/2	1/4	2/5	17/71
JPCP on CSB	0/37	3/3	1/2	1/3	0/4	1/4	1/6	3/6	10/65
JPCP on ASB	1/40	2/5	0/3	0/0	0/4	0/2	0/6	0/1	3/61
UBOL	0/3	1/3	0/2	1/3	0/2	0/0	0/0	1/1	3/14

WF-Wet Freeze; WNF-Wet no-freeze; DF-Dry Freeze; DNF-Dry no-freeze
D-Doweled; U-Undoweled

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Calibration database

Doweled pavements

LTPP sections with faulting > 3 mm/total number of sections

Climate	WF		WNF		DNF		DF		Total # dowled w/ faulting > 3 mm
STRUCTURE	D	U	D	U	D	U	D	U	
JPCP on GB	3/37	9/16	0/2	0/0	1/5	1/2	1/4	2/5	5
JPCP on CSB	0/37	3/3	1/2	1/3	0/4	1/4	1/6	3/6	2
JPCP on ASB	1/40	2/5	0/3	0/0	0/4	0/2	0/6	0/1	1
UBOL	0/3	1/3	0/2	1/3	0/2	0/0	0/0	1/1	0

WF-Wet Freeze; WNF-Wet no-freeze; DF-Dry Freeze; DNF-Dry no-freeze
D-Doweled; U-Undoweled

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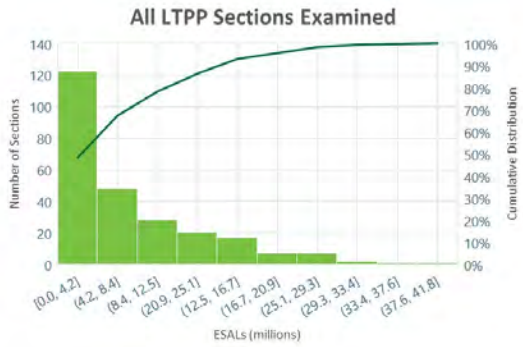
Calibration database: Traffic



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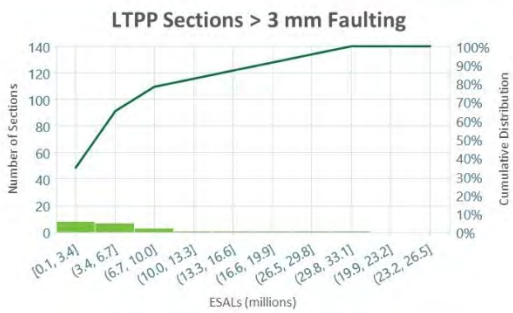
Calibration database: Traffic



Can laboratory testing be helpful?…ALFs, beam testing?

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Recommendations

- UPDATE DOCUMMENTATION
  - DE unit discrepancy
    - Correct units label on the tab for differential energy in the intermediate file JPCP_faulting.csv ("lb-in" changed to "lb/in")
  - FMAX equa. in documentation results in significantly larger predicted faulting

Faulting was closely replicated using the following:

$$FMAX_i = FMAX_{i-1} + \frac{1}{1000000} C_7 * DE_i * \left[Log\left(1 + C_5 * 5^{EROD}\right)\right]^{C_6}$$

- Consideration of max. pavement thickness limit
- Failure mode notification provided next to thickness output

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Recommendations

- C_8 for JPCP faulting model – revise model to better characterize dowel performance
- Provide delta curling value in output to avoid having to backcalculate
- Decouple faulting from thickness design

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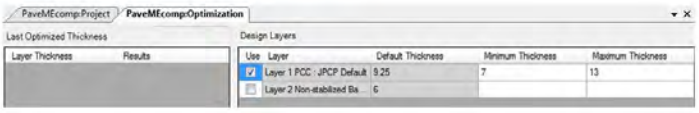
Recommendations

Design optimization mode can result in unreasonable slab thicknesses

Cause: Faulting is controlling slab thickness



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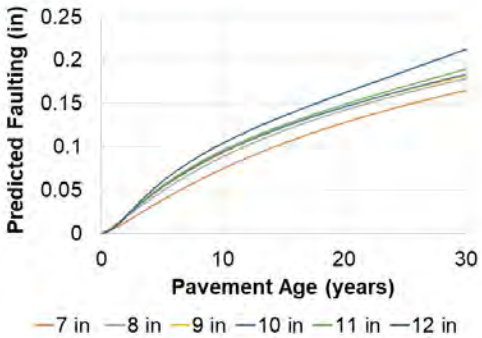
JPCP-Design optimization mode

Decouple slab thickness and faulting

- Joint Spacing: 15 feet
- Dowel Bars: 1.25 in diameter
- Shoulder Type: HMA
- Base: 6 in unbound gran. base (erodibility index: 4)
- Subgrade: A-4 material
- Climate: wet-freeze (Pittsburgh)
- AADTT: 6000



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Suggestion

Develop set of "reference" pavement sections for evaluating future software updates

- Include representative range of critical inputs

  Sources:

  1. Current LTPP or MnROAD sites
  2. A few newly constructed sites containing critical inputs not currently represented
- Archive designs for current and future versions of Pavement ME in LTPP database

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JPCP - IRI

$$SPALL = \left[\frac{AGE}{AGE + 0.01}\right]\left[\frac{100}{1 + 1.005^{(-12*AGE+SCF)}}\right] \quad (3.4.43)$$

where,

SPALL = percentage joints spalled (medium- and high-severities).
AGE = pavement age since construction, years.
SCF = scaling factor based on site-, design-, and climate-related variables:

$$SCF = -1400 + 350 \cdot AIR\% \cdot (0.5 + PREFORM) + 3.4\, f'c \cdot 0.4 - 0.2\,(FTCYC \cdot AGE) + 43\, h_{PCC} - 536\, WC\_Ratio \quad (3.4.44)$$

SCF = spalling prediction scaling factor used in equation 3.4.43.
AIR% = PCC air content, percent.
AGE = time since construction, years
PREFORM = 1 if preformed sealant is present; 0 if not.
f'c = PCC compressive strength, psi.
FTCYC = average annual number of freeze-thaw cycles.
h_{PCC} = PCC slab thickness, in.
WC_Ratio = PCC water/cement ratio.
Statistics: R^2 = 78 percent, N = 179, SEE = 6.8 percent of joints

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JPCP - IRI

- IRI models were not recalibrated since NCHRP 1-37A until version 3.0

$$IRI = IRI_I + C1*CRK + C2*SPALL + C3*TFAULT + C4*SF \quad (3.4.42)$$

where,

IRI = predicted IRI, in/mi.
IRI_I = initial smoothness measured as IRI, in/mi.
CRK = percent slabs with transverse cracks (all severities).
SPALL = percentage of joints with spalling (medium and high severities).
TFAULT = total joint faulting cumulated per mi, in.
C1 = 0. 8203
C2 = 0.4417
C3 = 1.4929
C4 = 25.24
SF = site factor
= $AGE\,(1+0.5556*FI)\,(1+P_{200})*10^{-6}$

where,

AGE = pavement age, yr.
FI = freezing index, °F-days.
P_{200} = percent subgrade material passing No. 200 sieve.

80

JPCP - IRI

- IRI models were not recalibrated since NCHRP 1-37A until version 3.0

$$IRI = IRI_I + C1*CRK + C2*SPALL + C3*TFAULT + C4*SF \quad (3.4.42)$$

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= $AGE\,(1+0.5556*FI)\,(1+P_{200})*10^{-6}$

where,

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FI = freezing index, °F-days.
P_{200} = percent subgrade material passing No. 200 sieve.

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$C3$	=	1.4929
$C4$	=	25.24
SF	=	site factor
	=	$AGE\ (1+0.5556*FI)\ (1+P_{200})*10^{-6}$

where,

AGE	=	pavement age, yr.
FI	=	freezing index, °F-days.
P_{200}	=	percent subgrade material passing No. 200 sieve.

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QUESTIONS?

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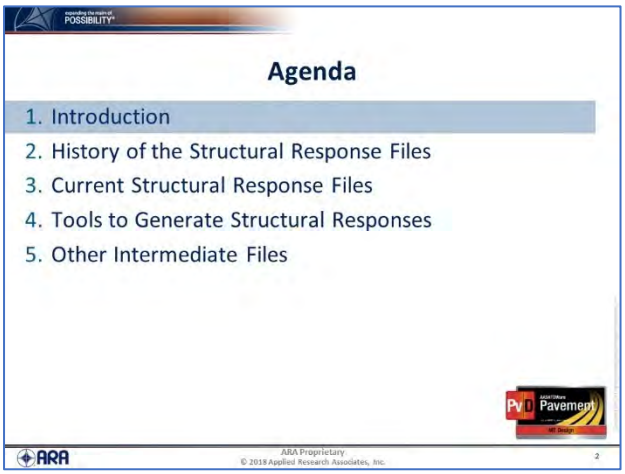
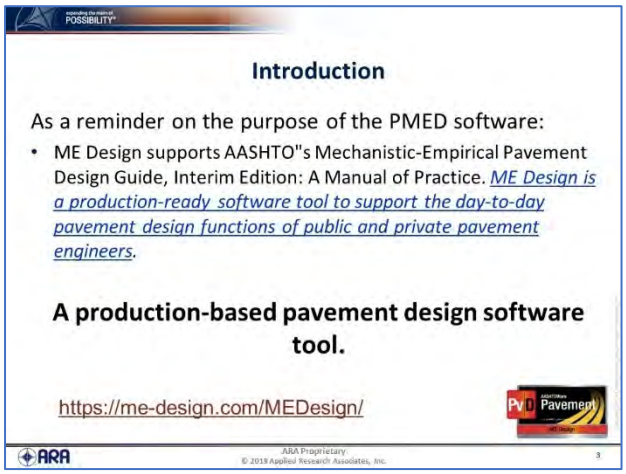
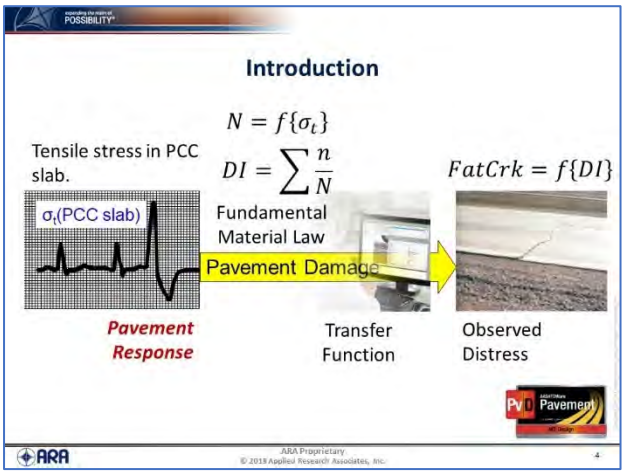
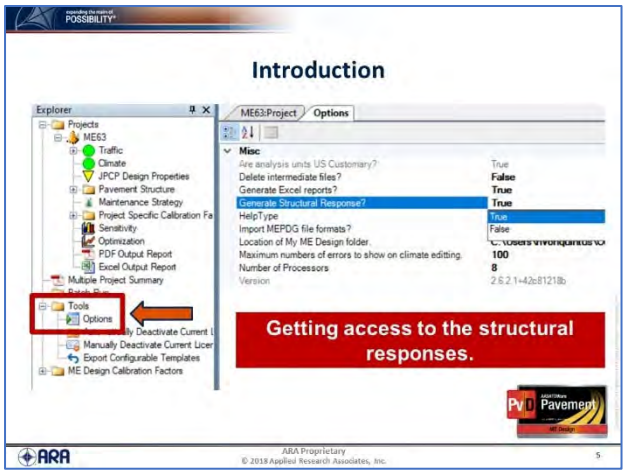
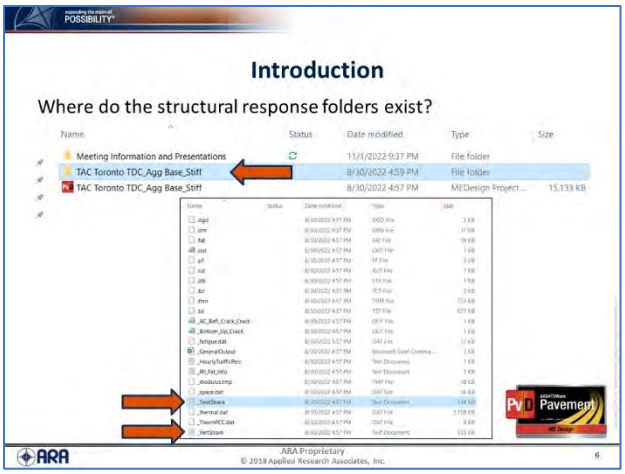
Presentation 21—Harold Von Quintus, ARA











Agenda

1. Introduction
2. History of the Structural Response Files
3. Current Structural Response Files
4. Tools to Generate Structural Responses
5. Other Intermediate Files

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History of Structural Response Files

- Pavement responses used within the transfer functions:
  - Deflections, horizontal strain and stress, and/or vertical strain and stress.
  - Multiple depths in all pavement layers and sublayers.
  - Computations on a grid pattern to consider truck or wheel load wander and axle geometry.
  - Multiple axle types.
  - All months within the design life.
  - 5 temperature quantiles.
  - Nighttime and daytime conditions.

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History of Structural Response Files

- Research grade/rudimentary version of the software
  - All structural responses used to predict distress were stored.
  - Used to verify results.
  - NCHRP 1-40D review team requested values.
  - Extensive structural response computations.
  - Lots of space (gigabits) required for storage.

- Later versions of software
  - All structural responses are still calculated.
  - But, only limited structural response computations stored.
  - Decision made prior to FY 2015.

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1. Introduction
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Current Version of Software – Structural Responses

- Flexible Pavements
  - Horizontal, Tensile Strain in wearing surface
  - Vertical, Compressive Strain in wearing surface
- Rigid Pavements
  - Deflection, loaded and unloaded side of joint
  - Stress, top of slab
  - Stress, bottom of slab

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Structural Response – Flexible Pavements

_TensStrain - Notepad

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Tensile Strain Response

Tensile Strain

Month	SubMonth	SubSeason	Axle Number	AC Modulus	Load	Loc	Strain	Analysis loc
1	1	1	1	2.333e+006	0.0	17.5	-1.040e-005	
1	1	1	1	2.333e+006	-16.9	1.3	-1.027e-005	
1	1	1	1	2.333e+006	16.9	0.0	-9.745e-006	
1	1	1	1	2.333e+006	-11.0	9.5	-9.863e-006	
1	1	1	1	2.333e+006	11.0	31.5	-9.487e-006	
1	1	1	1	2.333e+006	-7.5	9.5	-9.778e-006	
1	1	1	1	2.333e+006	7.5	25.5	-1.031e-005	
1	1	1	1	2.333e+006	-4.7	13.5	-1.027e-005	
1	1	1	1	2.333e+006	4.7	25.5	-9.807e-006	
1	1	1	1	2.333e+006	-2.3	17.5	-9.985e-006	
1	1	1	1	2.333e+006	2.3	25.5	-9.365e-006	
1	1	1	2	2.333e+006	0.0	0.0	-1.410e-005	
1	1	1	2	2.333e+006	-16.9	1.3	-7.321e-006	
1	1	1	2	2.333e+006	16.9	17.5	-1.407e-005	
1	1	1	2	2.333e+006	-11.0	0.0	-8.944e-006	
1	1	1	2	2.333e+006	11.0	9.5	-1.399e-005	
1	1	1	2	2.333e+006	-7.5	0.0	-1.147e-005	
1	1	1	2	2.333e+006	7.5	6.0	-1.399e-005	
1	1	1	2	2.333e+006	-4.7	0.0	-1.291e-005	

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Structural Response – Flexible Pavements

Vertical Strain

_VertStrain - Notepad

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Vertical Strain Response

Month	SubMonth	SubSeason	Axle Number	AC Modulus	Load loc	Strain
1	1	1	1	1.911e+006	0.0	-1.215e-005
1	1	1	1	1.911e+006	-16.9	-3.022e-006
1	1	1	1	1.911e+006	16.9	-3.022e-006
1	1	1	1	1.911e+006	-11.0	7.336e-006
1	1	1	1	1.911e+006	11.0	7.336e-006
1	1	1	1	1.911e+006	-7.5	2.941e-005
1	1	1	1	1.911e+006	7.5	2.941e-005
1	1	1	1	1.911e+006	-4.7	3.000e-005
1	1	1	1	1.911e+006	4.7	3.000e-005
1	1	1	1	1.911e+006	-2.3	7.812e-006
1	1	1	1	1.911e+006	2.3	7.812e-006
1	1	1	2	1.911e+006	0.0	-1.629e-006
1	1	1	2	1.911e+006	-16.9	-1.276e-006
1	1	1	2	1.911e+006	16.9	-1.276e-006
1	1	1	2	1.911e+006	-11.0	8.660e-006
1	1	1	2	1.911e+006	11.0	8.660e-006
1	1	1	2	1.911e+006	-7.5	2.918e-005
1	1	1	2	1.911e+006	7.5	2.918e-005
1	1	1	2	1.911e+006	-4.7	2.977e-005
1	1	1	2	1.911e+006	4.7	2.977e-005

Structural Response – Flexible Pavements

- Tensile and vertical strains:

Parameter	Range of Inputs
Month	1 to 12
Sub-month. Quantile	1 to 2; unfrozen, frozen
Sub-season; temperature quantiles	1 to 5
Axle Number	Single, Tandem, Tridem
Load Location	Grid location based on axle geometry; wheel wander
Load Level	One load magnitude.
Strain Computation Depth	Surface and mid-depth of wearing surface

Structural Response – Rigid Pavements, Deflection

	Year	Age(mo)	Epcc(Mpsi)	Total Temp Dif(deg F)	Axle Type	Load(Kips)	Loaded Defl(in)	Unloaded Defl(in)
2	1	1	4.29	-19.9	Single	18.5	0.0203	0.0202
3	1	1	4.29	-19.9	Tandem	37	0.0235	0.0232
4	1	2	4.41	-21.11	Single	18.5	0.021	0.0208
5	1	2	4.41	-21.11	Tandem	37	0.0244	0.0241
6	1	3	4.48	-21.15	Single	18.5	0.021	0.0208
7	1	3	4.48	-21.15	Tandem	37	0.0244	0.024
8	1	4	4.53	-19.89	Single	18.5	0.0202	0.0199
9	1	4	4.53	-19.89	Tandem	37	0.0235	0.023
10	1	5	4.56	-19.78	Single	18.5	0.0201	0.0198
11	1	5	4.56	-19.78	Tandem	37	0.0234	0.0229
12	1	6	4.59	-19.5	Single	18.5	0.0197	0.0195
13	1	6	4.59	-19.5	Tandem	37	0.023	0.0228
14	1	7	4.62	-15.82	Single	18.5	0.0166	0.0164
15	1	7	4.62	-15.82	Tandem	37	0.02	0.0197
16	1	8	4.64	-14.57	Single	18.5	0.0159	0.0158
17	1	8	4.64	-14.57	Tandem	37	0.0192	0.0189
18	1	9	4.66	-14.45	Single	18.5	0.0166	0.0162
19	1	9	4.66	-14.45	Tandem	37	0.0194	0.0188
20	1	10	4.68	-15.4	Single	18.5	0.0171	0.0168

_Deflection

Structural Response – Rigid Pavements, Stress - Bottom

	Year	Age(mo)	MR(psi)	Epcc(Mpsi)	Axle Type	Therm Grad(deg F)	Load(kips)	Stress(psi)
2	1	1	684	4.29	Sin	0	8.5	80.3
3	1	1	684	4.29	Sin	0	18	165.8
4	1	1	684	4.29	Sin	0	24.5	221.4
5	1	1	684	4.29	Sin	0	32.5	286.6
6	1	1	684	4.29	Sin	0	40.5	348.4
7	1	1	684	4.29	Sin	8.54	8.5	179.5
8	1	1	684	4.29	Sin	8.54	18	269.8
9	1	1	684	4.29	Sin	8.54	24.5	327.3
10	1	1	684	4.29	Sin	8.54	32.5	393.4
11	1	1	684	4.29	Sin	8.54	40.5	454.9
12	1	1	684	4.29	Sin	17.08	8.5	247.1
13	1	1	684	4.29	Sin	17.08	18	355.7
14	1	1	684	4.29	Sin	17.08	24.5	421.8
15	1	1	684	4.29	Sin	17.08	32.5	494.3
16	1	1	684	4.29	Sin	17.08	40.5	558
17	1	1	684	4.29	Sin	25.61	8.5	287.2
18	1	1	684	4.29	Sin	25.61	18	414.3
19	1	1	684	4.29	Sin	25.61	24.5	490.8
20	1	1	684	4.29	Sin	25.61	32.5	572.1

_StressBot

Structural Response – Rigid Pavements, Stress - Top

	Year	Age(mo)	MR(psi)	Epcc(Mpsi)	Axle Spacing	Therm Grad(deg F)	Load(kips)	Stress(psi)
2	1	1	684	4.29	Sho	30.8	25.5	144.9
3	1	1	684	4.29	Sho	30.8	51	175.8
4	1	1	684	4.29	Sho	30.8	73.5	193.7
5	1	1	684	4.29	Sho	30.8	97.5	210.3
6	1	1	684	4.29	Sho	30.8	121.5	228.2
7	1	1	684	4.29	Sho	43.9	25.5	204.1
8	1	1	684	4.29	Sho	43.9	51	242.6
9	1	1	684	4.29	Sho	43.9	73.5	259.9
10	1	1	684	4.29	Sho	43.9	97.5	273.3
11	1	1	684	4.29	Sho	43.9	121.5	290.3
12	1	1	684	4.29	Sho	57	25.5	242.8
13	1	1	684	4.29	Sho	57	51	291.4
14	1	1	684	4.29	Sho	57	73.5	310.9
15	1	1	684	4.29	Sho	57	97.5	325.6
16	1	1	684	4.29	Sho	57	121.5	341.6
17	1	1	684	4.29	Sho	70.1	25.5	261.2
18	1	1	684	4.29	Sho	70.1	51	321.5
19	1	1	684	4.29	Sho	70.1	73.5	346
20	1	1	684	4.29	Sho	70.1	97.5	364.2

_StressTop

Structural Response – Rigid Pavements, Stress - Top

Parameter	Range	Deflections	Stress – Bottom	Stress – Top
Year	1 to Design Life	√	√	√
Month	1 to Design Life	√	√	√
Axle Type	Response Dependent	Single, Tandem	Single, Tandem, Tridem	NA
Load Level	Response Dependent	Two Levels	Five Levels	Five Levels
Axle Spacing	Response Dependent	NA	NA	Short, Medium, Long

Current Version of Software – Structural Responses

- Limited responses, conditions, grid point locations, and depths are saved in the structural response folders.
- In my opinion:
  - Somewhat useful for rigid pavements.
  - Not very useful for flexible pavements.

Agenda

1. Introduction
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5. Other Intermediate Files

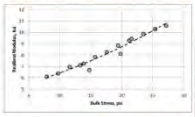
Tools to Generate Structural Response

- PMED calculates stresses, strains, and deflections on a grid basis and at multiple depths in the sublayers created by the software to calculate distress over time.
- The calculated responses are not retained or stored for all depths and grid points.
- Only a limited number of responses are stored in the *Structural Response* folder.
- APPs can be written to extract specific structural responses for extended use from APADS.

Tools to Generate Structural Response

Structural Responses for PMED Designs:

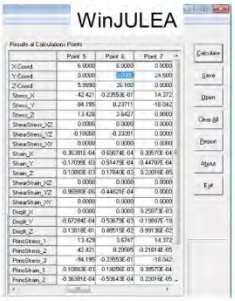
1. Prediction of pavement distress
2. Unbound layer/material characterization
   - Determine design resilient modulus of the stress dependent unbound layers (aggregate base, embankment soils, subgrade)
   - Prevent overstressing or shear failure in aggregate base and subgrade soils; limitation on compressive & shear stresses in unbound layers.
   - Not used in the PMED software itself, must be calculated external to the PMED software.



Use external programs to determine the design resilient modulus and prevent overstressing or shear failures in the unbound layers.

Asphalt Structural Response Model

WinJULEA



Agenda

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Other Intermediate Files

1. Daily Frost Depth
2. Equivalent Single Axle Loads, ESALs
3. JPCP Cracking; bottom-Up and top-down
4. Spalling of transverse joints

Name	Status	Date modified	Type	Size
Checkyourjson		10/31/2022 1:19 AM	JSON File	4 KB
DailyFrostDepth		10/31/2022 1:19 AM	Microsoft Excel Comma Separated Values File	180 KB
ESALs		10/31/2022 1:19 AM	Text Document	1 KB
EfOK		10/31/2022 1:19 AM	Microsoft Excel Comma Separated Values File	1 KB
ExecuteHeff		10/31/2022 1:19 AM	Text Document	1 KB
FaultGeneralInput		10/31/2022 1:19 AM	Text Document	1 KB
FoundationSupport		10/31/2022 1:19 AM	Text Document	1 KB
generalInput		10/31/2022 1:19 AM	Text Document	1 KB
GradientDist		10/31/2022 1:19 AM	Microsoft Excel Comma Separated Values File	77 KB
ICMNodalDepth		10/31/2022 1:19 AM	Microsoft Excel Comma Separated Values File	2 KB
input.tmp		10/31/2022 1:19 AM	TMP File	3,700 KB
iri		10/31/2022 1:19 AM	Text Document	9 KB

DailyFrostDepth; Rigid and Flexible

Date, Frost Depth, Thaw Depth

	A	B	C	D
1	Date	Frost Depth(in)	Thaw Depth(in)	
2	6/1/2009	0	0	
3	6/2/2009	0	0	
4	6/3/2009	0	0	
5	6/4/2009	0	0	
6	6/5/2009	0	0	
7	6/6/2009	0	0	
8	6/7/2009	0	0	
9	6/8/2009	0	0	
10	6/9/2009	0	0	
11	6/10/2009	0	0	
12	6/11/2009	0	0	
13	6/12/2009	0	0	
14	6/13/2009	0	0	
15	6/14/2009	0	0	
16	6/15/2009	0	0	
17	6/16/2009	0	0	
18	6/17/2009	0	0	
19	6/18/2009	0	0	
20	6/19/2009	0	0	
21	6/20/2009	0	0	
22	6/21/2009	0	0	
23	6/22/2009	0	0	
24	6/23/2009	0	0	
25	6/24/2009	0	0	
26	6/25/2009	0	0	
27	6/26/2009	0	0	

DailyFrostDepth

Date, Frost Depth, Thaw Depth

	A	B	C	D
271	2/25/2010	45.1	0	
272	2/26/2010	48.1	0	
273	2/27/2010	49.9	0	
274	2/28/2010	50.7	0	
275	3/1/2010	51.1	0	
276	3/2/2010	50.5	0	
277	3/3/2010	49.4	0	
278	3/4/2010	47.9	0	
279	3/5/2010	47.3	0	
280	3/6/2010	47.1	3.7	
281	3/7/2010	47	0	
282	3/8/2010	47.1	8.7	
283	3/9/2010	47.1	7.7	
284	3/10/2010	47.2	6.9	
285	3/11/2010	47.4	5.3	
286	3/12/2010	45.2	6.4	
287	3/13/2010	44.4	16.5	
288	3/14/2010	44	16.5	
289	3/15/2010	43.8	19.7	
290	3/16/2010	43.7	20.6	
291	3/17/2010	0	0	
292	3/18/2010	0	0	
293	3/19/2010	0.9	0	
294	3/20/2010	4.3	0	
295	3/21/2010	0	0	
296	3/22/2010	0	0	
297	3/23/2010	0	0	

DailyFrostDepth

ESALs (Rigid); flexibleESAL

ESALs - Notepad

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Design traffic = 20.65 million ESALs
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JPCP_Cracking

Year, Age, Month | MOR, E | E_{base}, K-Value | BU Cracking; Single, Tandem, Tridem, Quad, Total | TD Cracking; Short, Medium, Long, Total | Total; value & %

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	Year	Age(mo)	Month	MR(psi)	E(psi(Mpsi)	Elase(psi)	k(psi/in)	BU_Single	BU_Tandem	BU_Tridem	BU_Quad	Total_BU	TD_SMB	TD_MMB	TD_LMB	Total_TD	%Crack	
2	1	1	July	684	4.29	22.56	322	1.57E-03	1.75E-03	7.72E-05	0.00E+00	3.40E-03	2.62E-05	4.65E-05	4.12E-05	1.14E-04	0	0.963194
3	1	2	August	760	4.41	22.63	322	2.44E-03	2.65E-03	1.37E-04	0.00E+00	5.17E-03	6.11E-05	1.09E-04	9.52E-05	2.69E-04	0	0.963194
4	1	3	September	753	4.48	22.64	323	2.71E-03	2.83E-03	1.24E-04	0.00E+00	5.66E-03	1.01E-04	1.82E-04	1.57E-04	4.39E-04	0	0.963194
5	1	4	October	721	4.53	22.64	323	2.77E-03	2.88E-03	1.25E-04	0.00E+00	5.75E-03	1.07E-04	1.93E-04	1.66E-04	4.65E-04	0	0.963194
6	1	5	November	727	4.56	22.34	329	2.78E-03	2.86E-03	1.26E-04	0.00E+00	5.77E-03	1.07E-04	1.94E-04	1.67E-04	4.68E-04	0	0.963194
7	1	6	December	732	4.59	232.5	319	2.79E-03	2.87E-03	1.26E-04	0.00E+00	5.78E-03	1.07E-04	1.94E-04	1.67E-04	4.68E-04	0	0.963194
8	1	7	January	736	4.62	1124.05	278	2.79E-03	2.87E-03	1.26E-04	0.00E+00	5.78E-03	1.07E-04	1.94E-04	1.67E-04	4.68E-04	0	0.963194
9	1	8	February	739	4.64	1043.93	275	2.79E-03	2.87E-03	1.26E-04	0.00E+00	5.78E-03	1.07E-04	1.94E-04	1.67E-04	4.68E-04	0	0.963194
10	1	9	March	742	4.66	46.53	255	3.12E-03	3.36E-03	1.48E-04	0.00E+00	6.61E-03	1.07E-04	1.94E-04	1.67E-04	4.68E-04	0	0.963194
11	1	10	April	745	4.68	15.92	322	3.38E-03	3.82E-03	1.60E-04	0.00E+00	7.17E-03	1.07E-04	1.94E-04	1.67E-04	4.68E-04	0	0.963194
12	1	11	May	747	4.69	20.09	317	3.94E-03	4.32E-03	1.91E-04	0.00E+00	8.45E-03	1.07E-04	1.94E-04	1.67E-04	4.68E-04	0.03	1.915732
13	1	12	June	750	4.71	22.16	323	4.58E-03	5.04E-03	2.23E-04	0.00E+00	9.84E-03	1.08E-04	1.98E-04	1.70E-04	4.76E-04	0.01	1.915732
14	2	13	July	753	4.72	22.56	322	5.20E-03	5.91E-03	2.61E-04	0.00E+00	1.11E-02	1.18E-04	2.15E-04	1.84E-04	5.17E-04	0.01	1.915732
15	2	14	August	752	4.72	22.63	322	5.86E-03	6.61E-03	2.84E-04	0.00E+00	1.24E-02	1.44E-04	2.45E-04	2.08E-04	5.97E-04	0.01	1.915732
16	2	15	September	754	4.73	23.46	323	6.03E-03	6.56E-03	2.89E-04	0.00E+00	1.29E-02	1.55E-04	2.85E-04	2.49E-04	6.88E-04	0.02	2.178001
17	2	16	October	755	4.74	22.64	323	6.06E-03	6.58E-03	2.90E-04	0.00E+00	1.29E-02	1.58E-04	2.92E-04	2.46E-04	6.96E-04	0.02	2.178001
18	2	17	November	756	4.75	22.34	323	6.07E-03	6.59E-03	2.91E-04	0.00E+00	1.30E-02	1.58E-04	2.93E-04	2.46E-04	6.98E-04	0.02	2.178001
19	2	18	December	758	4.76	232.5	319	6.07E-03	6.59E-03	2.91E-04	0.00E+00	1.30E-02	1.58E-04	2.93E-04	2.46E-04	6.98E-04	0.02	2.178001
20	2	19	January	759	4.77	1124.05	278	6.07E-03	6.59E-03	2.91E-04	0.00E+00	1.30E-02	1.58E-04	2.93E-04	2.46E-04	6.98E-04	0.02	2.178001
21	2	20	February	760	4.77	1043.93	275	6.07E-03	6.59E-03	2.91E-04	0.00E+00	1.30E-02	1.58E-04	2.93E-04	2.46E-04	6.98E-04	0.02	2.178001
22	2	21	March	762	4.78	46.53	255	6.36E-03	7.01E-03	3.32E-04	0.00E+00	1.37E-02	1.59E-04	2.93E-04	2.46E-04	6.98E-04	0.02	2.178001
23	2	22	April	763	4.79	15.92	322	6.57E-03	7.24E-03	3.20E-04	0.00E+00	1.41E-02	1.59E-04	2.93E-04	2.46E-04	6.98E-04	0.02	2.178001
24	2	23	May	764	4.8	20.09	317	7.05E-03	7.83E-03	3.44E-04	0.00E+00	1.52E-02	1.59E-04	2.93E-04	2.46E-04	6.98E-04	0.02	2.178001
25	2	24	June	766	4.81	22.16	323	7.60E-03	8.45E-03	3.74E-04	0.00E+00	1.64E-02	1.60E-04	2.96E-04	2.49E-04	7.04E-04	0.03	2.365745
26	2	25	July	767	4.81	22.56	322	8.27E-03	9.22E-03	4.08E-04	0.00E+00	1.79E-02	1.67E-04	3.10E-04	2.60E-04	7.37E-04	0.03	2.365745
27	2	26	August	767	4.82	22.63	322	8.77E-03	9.68E-03	4.29E-04	0.00E+00	1.88E-02	1.80E-04	3.35E-04	2.79E-04	7.94E-04	0.03	2.365745

JPCP_Cracking

spalling

spalling - Notepad

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In Summary or Takeaways:

- Under the NCHRP 1-40D review and verification of the distress prediction transfer functions:
  - Used to compare the rut depth profiles and area alligator cracking in wheel paths; examples:
    - Accelerated load facility with and without wheel load wander and single versus dual tires.
    - Test tracks with and without wheel load wander.
- Current version of PMED software:
  - Only limited pavement responses stored in the project files, which are not that useful.

In Summary or Takeaways:

- Remember:
  - PMED is a production-based pavement design software tool for day-to-day practice.
  - Some of the other intermediate files can provide information for making design decisions; the two common ones are:
    - ESALs
    - Frost Depth

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Questions?

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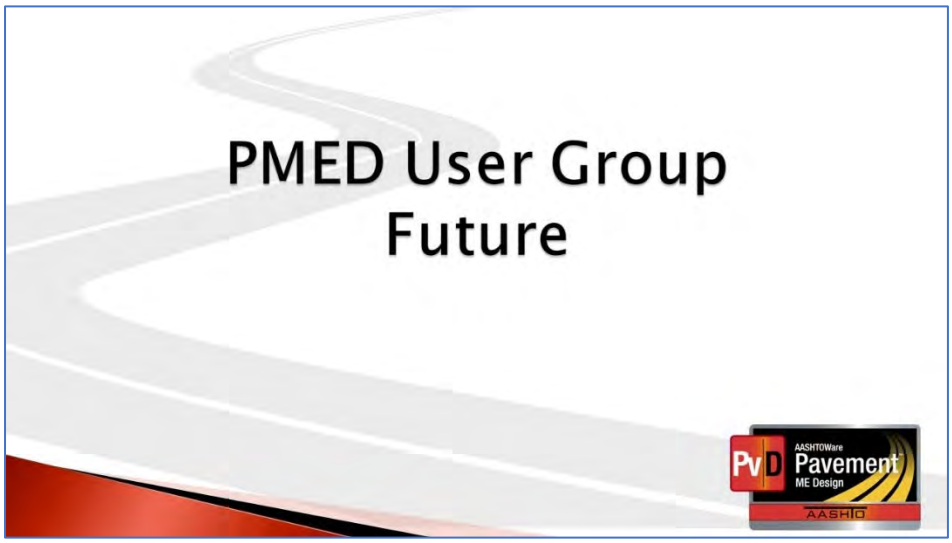
Presentation 22—Ryan Fragapane, AASHTO



Scholarship

- Members and Associate Members
  - Request forms will be sent to all agencies Late January
- Reimbursement directly through AASHTO
  - Exemptions can be made to meet states needs
- Concur

User Group Charter

- Drafted by the Task Force
- Ratified at the Wisconsin Meeting
- Leadership Roles
  - Meeting location selection

Leadership Time Commitments

- User Group Leadership
  - Agenda Development Assistance
  - Meeting Location selection
- AASHTO will handle all the contracts and meeting logistics
- Task Force will be responsible for the budget

Questions?
AASHTOWare
Pavement
ME Design
AASHTO

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