Performance-Related Specifications: Integration of the Asphalt Mixture Performance Tester (AMPT)

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U.S. Department of Transportation
Federal Highway Administration

Acknowledgements

- Office of Preconstruction, Construction, and Pavements
- Office of Infrastructure Research and Development
- Office of Technical Services

Background

- Owner agencies short on funding
  - Need more pavement life
  - Less rehab
  - More “bang for buck”
- MAP-21 introduced performance-based administering of federal funds
  - FHWA established measures for States to set own targets

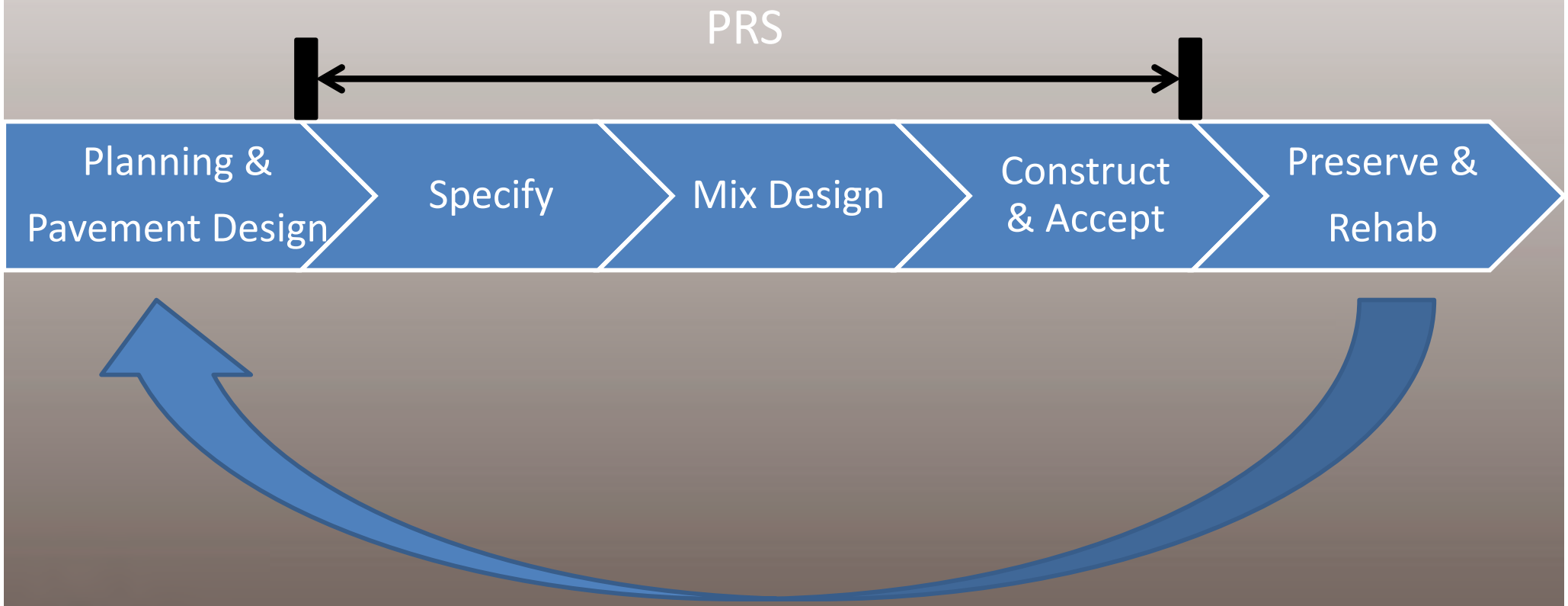
AMPT – Addressing a Need

- Late 1980s-Early 1990s: Strategic Highway Research Program
  - Superpave mixture design approach
  - Performance grade binders
  - But no viable performance tests for mixture
- National Cooperative Highway Research Program
  - 9-19: Identify simple performance tests for Superpave (rutting, fatigue)
    - Dynamic modulus, flow number, flow time
  - 9-29: Produce prototype, conduct ruggedness and interlaboratory studies
    - Simple Performance Tester (now known as AMPT) was born!

AMPT

- Temperature range from about 4° to 70°C
- Computer-controlled device
  - Software built-in for various test procedures
- Fundamental tests
  - Stress and strain modeling
  - "Bulk testing"
  - Pavement ME or FlexPAVE™
- Kits available for other tests

Continuum of Performance



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Performance

- Asphalt distress?
- Frequency of sampling/testing?
- How to quantify/manage data?
- Cost of life loss?
- Appropriate methods to measure?

Overview of Asset Management

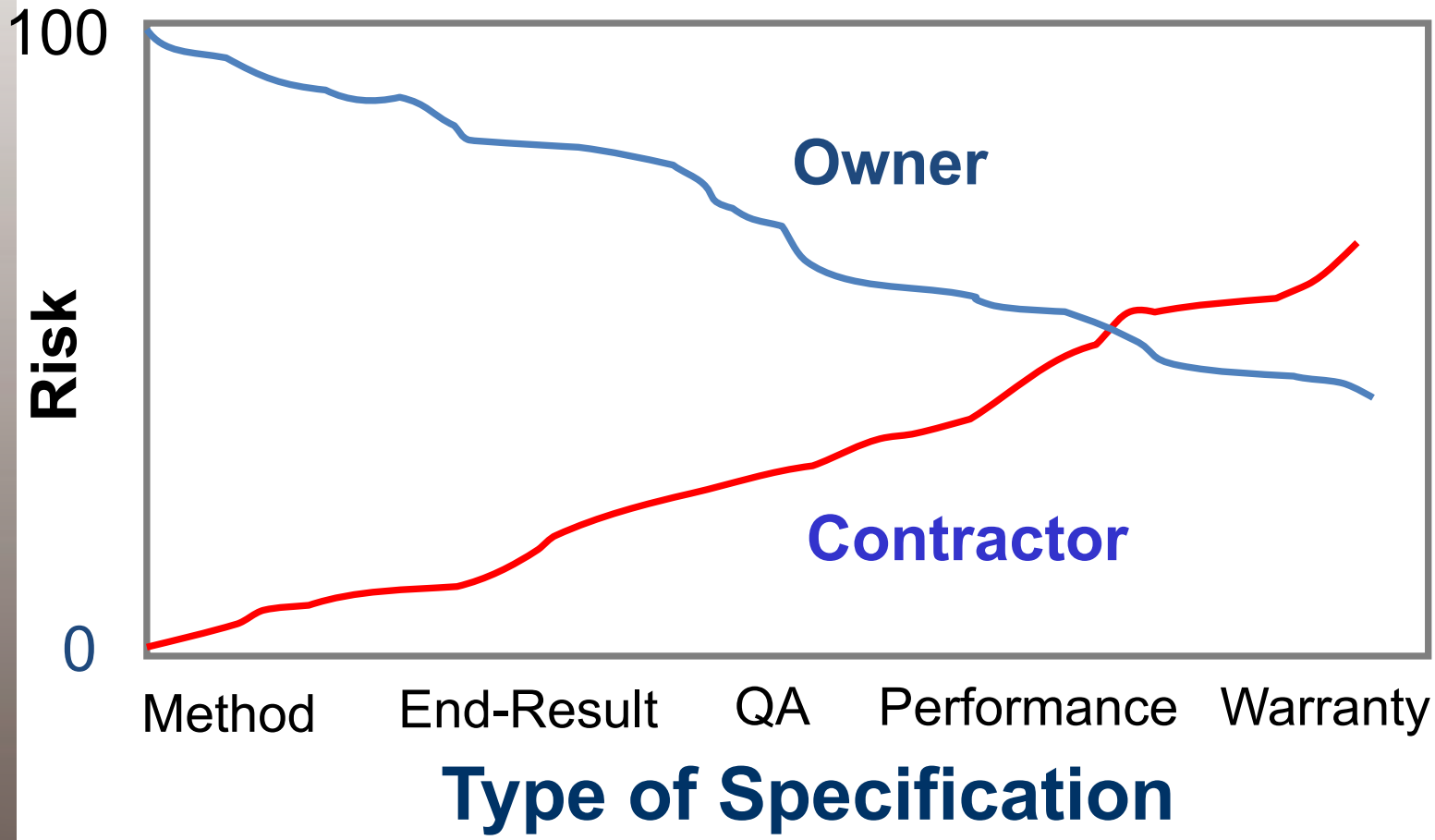
- Preserve assets and minimize whole life costs
- Operate in a financially sustainable manner
- Provides a framework to improve performance on a long-term basis
- **A plan is now required!**

Two Questions

- How can I extend pavement life?
  - Specification development/targets
  - Exceeding performance thresholds
  - Optimizing asset management plan
- How can I measure performance upfront?
  - Effect of RAP, WMA, etc., and pavement structure
  - Laboratory testing and conditioning
    - Fundamental
    - Index-based
    - Lots of tests

Need for Uniformity

Continuum of Specifications



Performance-Related Specifications (PRS)

"QA specifications that describe the desired levels of key materials and construction quality characteristics that have been found to ***correlate with fundamental engineering properties that predict performance****"*

Transportation Research Circular Number E-C137
Glossary of Highway Quality Assurance Terms

How PRS Works

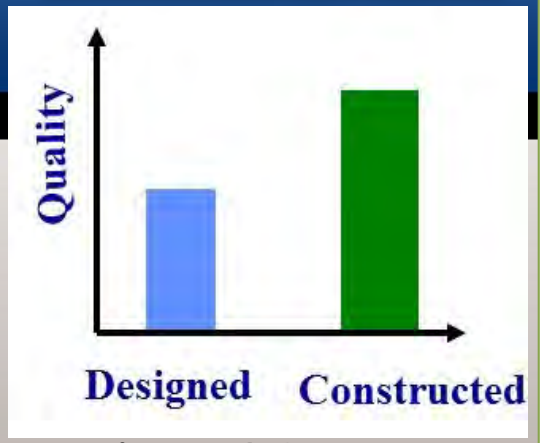
Pavement Design

Planning

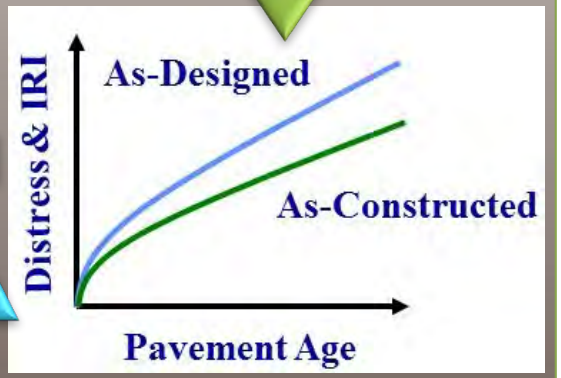
Establish Performance Criteria

Identify AQCs and Target Values

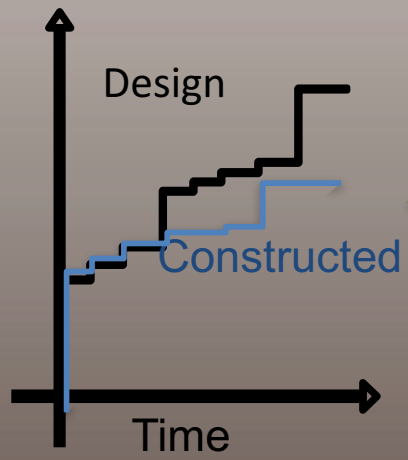
SOFTWARE



Design AQC vs. As-Constructed AQC



Model Performance



Compare As-Built and As-Designed

Pay Factor

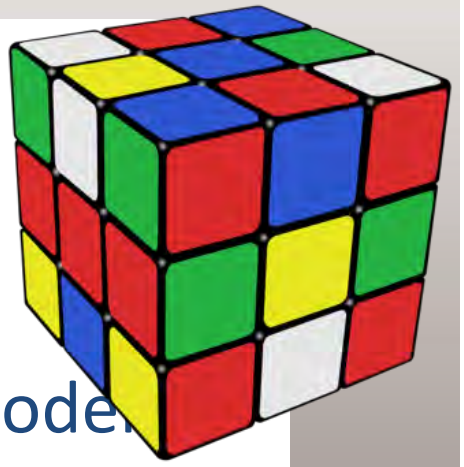
Value of Performance?

Benefits of PRS

- Long term pavement performance predicted from fundamental engineering properties
- Incentives and disincentives justified through reduction or increase in pavement life
- Allow contractors to be more innovative and more competitive

YES!

Challenges with PRS

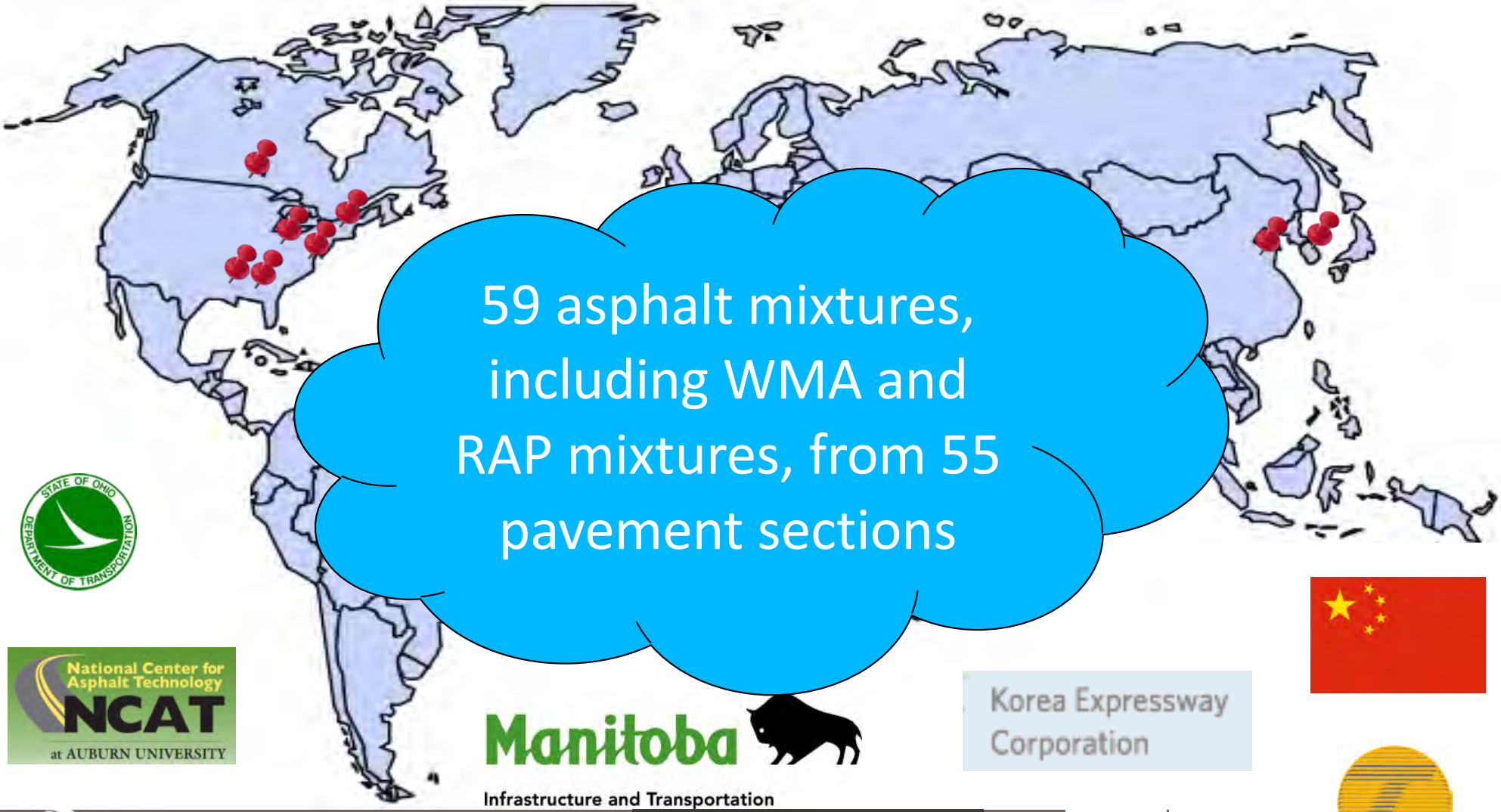


- Testing efficiency and simplicity
  - Completed/Continuous
- Standardization of test methods
  - Ongoing
- Reliability of performance prediction model
  - Complete
- Performance volumetric relationships
  - Ongoing
- Same principles and methods between mix design and PRS
  - Ongoing

Standardization of Test Methods

FULL SIZE SPECIMEN	SMALL SIZE SPECIMEN
Specimen Prep AASHTO R 83	Specimen Prep AASHTO PP XXX
Dynamic Modulus AASHTO T 378	Dynamic Modulus AASHTO TP XXX
Cyclic Fatigue AASHTO TP 107	Cyclic Fatigue AASHTO TP XXX
Stress Sweep Rutting AASHTO TP XXX	

Reliability of Performance Prediction Models



59 asphalt mixtures, including WMA and RAP mixtures, from 55 pavement sections

STATE OF OHIO DEPARTMENT OF TRANSPORTATION

National Center for Asphalt Technology NCAT at AUBURN UNIVERSITY

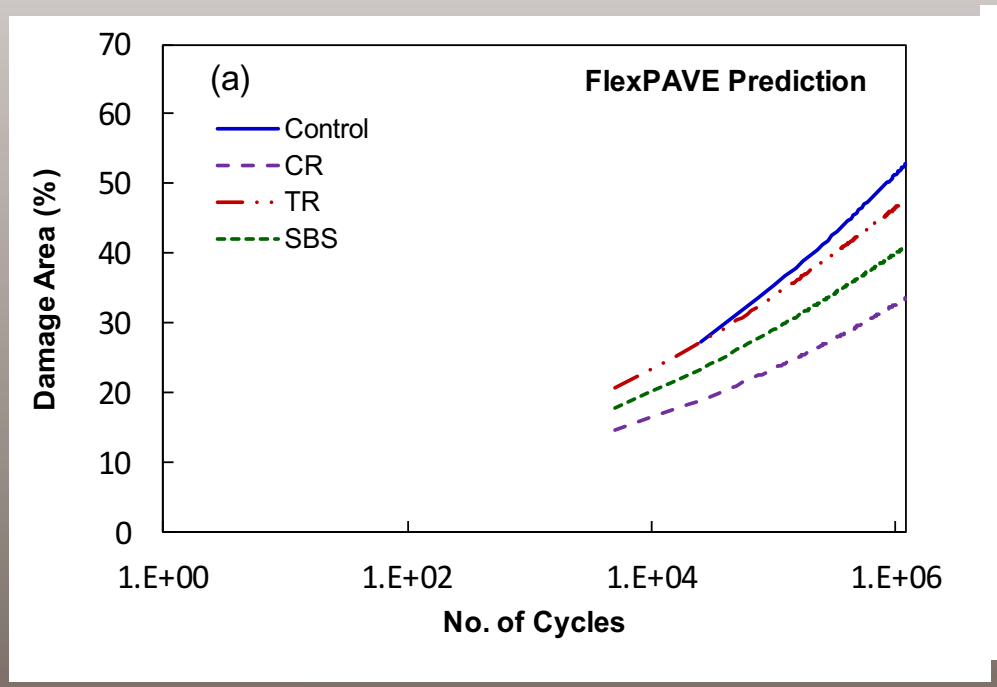
Manitoba Infrastructure and Transportation

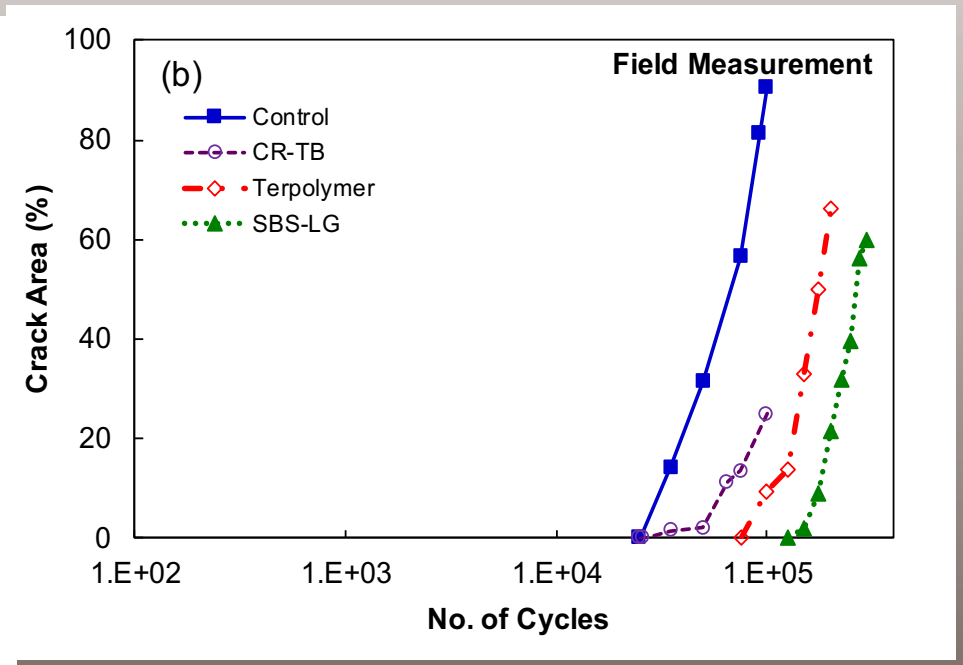
Korea Expressway Corporation

U.S. Department of Transportation Federal Highway Administration

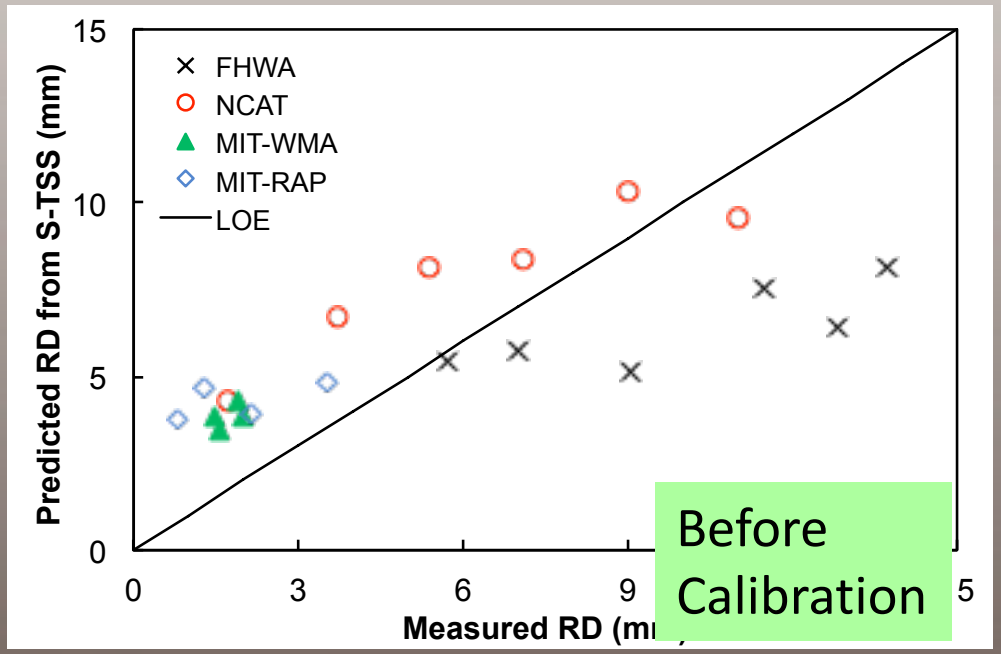
Western Research INSTITUTE

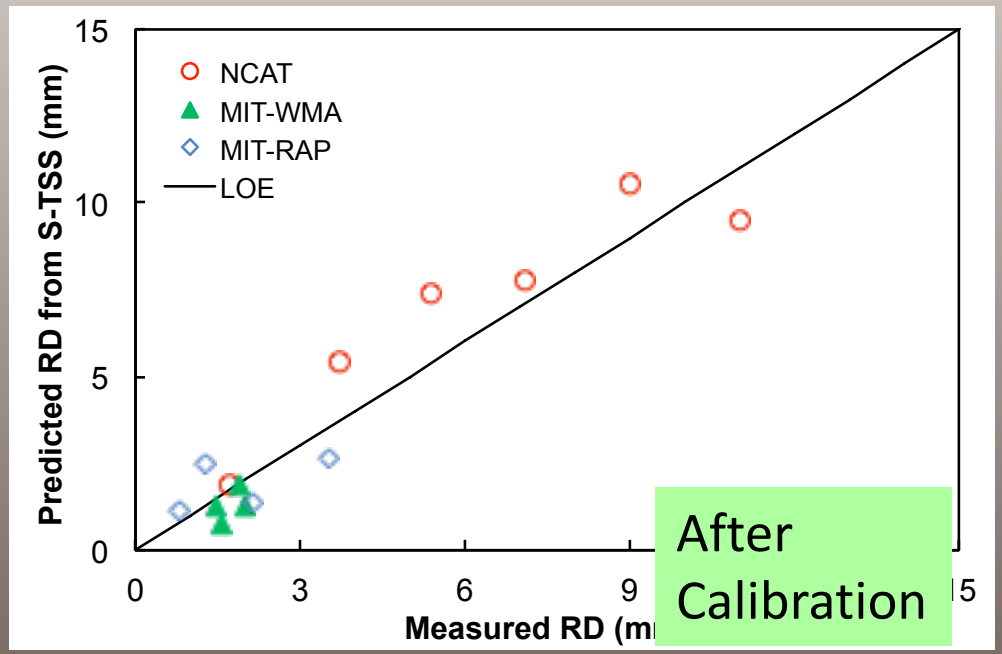
FHWA-ALF Sections





Rut Depth Predictions





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Performance Volumetric Relationships (PVR)

- Predict as-built performance
  - Without performance testing
- Database developed at TFHRC
- Expansion underway in shadow projects
  - Will use plant-produced variations
- Agency and contractor guidance for planning purposes

FHWA PRS Initiative

- Use of fundamental tests to capture variance between as-designed and as-built AQCs
- Asphalt Mixture Performance Tester (AMPT) used in performance-engineered mixture design (PEMD)
- Performance volumetric relationships used in construction
- Structural response model (stresses and strains)

FHWA PRS Initiative

PERFORMANCE TESTING ONLY IN DESIGN PHASE!!!

f fundamental tests to capture
ween as-designed and as-built

- As ance Tester (AMPT) engineered mixture desig
- Performance volum l in construction
- Structural response model (stres strains)

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Performance-engineered mixture design (balanced mixture design)

- Fundamental
  - How much distress? How much life?
  - Stresses and strains
  - Material properties (i.e., modulus)
  - Use with structural response model
  - Many temperature/loading conditions represented
- Index-Based
  - Go/no-go: correlation-based
  - Some engineering properties, some empirical
    - More tied to a material database
  - Not used with structural response model (FlexPAVE)
  - Only a few temperature/loading conditions represented

Performance-engineered mixture design (balanced mixture design)

- Fundamental → FHWA PRS
  - How much distress? How much life gained/lost?
  - Stresses and strains
  - Material properties (i.e., modulus)
  - Use with structural response model
  - Many loading conditions represented
- Index-Based
  - Go/no-go: correlation-based
  - Some engineering properties, some empirical
    - More tied to a material database
  - Not used with structural response model
  - A few loading conditions represented
- Cost-efficient way to account for relevant distress!

AASHTOWare Pavement ME-FlexPAVE™ Compatibility

- Graphical user interfaces similar to Same climate, traffic inputs
  - Fewer unbound layer inputs needed
- AASHTO TP 107 results proven to be compatible with K1, K2, K3 fatigue coefficients
- AASHTO T 378 (|E*|) remains critical input

FlexMAT™ and FlexPAVE™ Available

- FlexMAT™ – Excel spreadsheet
  - Analyzes cyclic fatigue, |E*|, and SSR data
  - Import files directly
  - Output → FlexPAVE™
- FlexPAVE™ – performance prediction tool
  - PEMD through acceptance
  - Simulate as-design and as-built performance

FlexMAT™

Description: This tab can be used to import test data from IPC Global AMPT files directly into the template. Alternatively, the user can copy and paste data directly into the green cells within the green tabs. Note that if data is imported using this tab, the user must still enter mixture volumetric properties in the Sigmoidal Model Fit tab. This tab can also be used to clear all data that is currently in the template.

Instructions: Separate folders should be created for each dynamic modulus test and cyclic fatigue test. Each folder should contain the AMPT data output files for one dynamic modulus or one cyclic fatigue test.

To import dynamic modulus data for the first test replicate into the template, press the **Dynamic Modulus Specimen 1** button. A prompt will appear. Select the folder where the AMPT output files for the dynamic modulus test are stored. After selecting the appropriate folder, the data from the dynamic modulus test data will be imported into the required cells within the template. Repeat this process for the second and third replicates by pressing the **Dynamic Modulus Specimen 2** and **Dynamic Modulus Specimen 3** buttons, respectively.

To import cyclic fatigue data for the first fatigue test, preess the **Fatigue Specimen 1**. A prompt will appear. Select the folder where the AMPT output for the cyclic fatigue test are stored. After selecting the appropriate folder, the data from the cyclic fatigue test data will be imported into the required cells within the template. Repeat this process for the remaining cyclic fatigue tests by pressing the **Fatigue Specimen 2**, **Fatigue Specimen 3**, and **Fatigue Specimen 4** buttons. Note that it is not necessary to press all of the buttons if you have fewer than three dynamic modulus and / or four cyclic fatigue tests.

Press the **Clear Template** button to remove all data that is currently in the template. Note that the **Clear Template** button should only be used if the user wants to revert to the blank template.

Dynamic Modulus Specimen 1

Dynamic Modulus Specimen 2

Dynamic Modulus Specimen 3

Fatigue Specimen 1

Fatigue Specimen 2

Fatigue Specimen 3

Fatigue Specimen 4

FlexPAVE™

FlexPAVE 1.0 Program : Untitled Project

File Analysis Tools Help

- Project
  - General Information
  - Design Structure
  - Climate Data
  - Traffic Data
  - Outputs and Analysis Options
  - Results

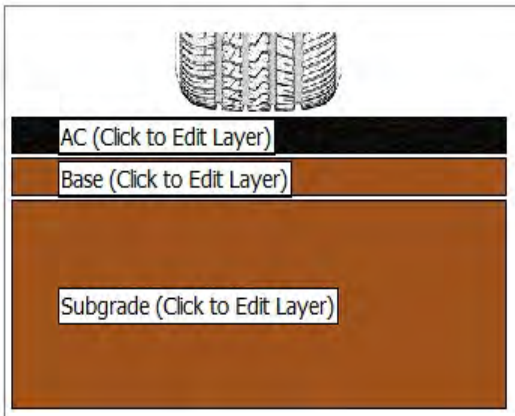
General Information × | Design Structure ×

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer | Remove Layer | Move Layer



Layer Properties

Layer: AC

Thickness (cm): 10 — Infinite Layer

Material Type: Asphalt Concrete — more..

GR Based Criterion / DR Based Criterion

Specific Gravity (optional): 2.5 — Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000
Einf (KPa)	9.7300e+04
Ref. Temp. (C)	5
Shift Factor a1	6.9619e-04
Shift Factor a2	-0.1620
Shift Factor a3	0.7928

	Fatigue
Alpha	4
a	0.0017
b	0.5449
Initial C	0.8000
Gamma	1000000
Delta	-1.3500

	Rutting
Beta	0.8026
Epsilon0	0.0052
NI	0.8024
TR(C)	61

	Rutting
p1	0.6069
p2	0.0719
d1	0.0396
d2	1.6831

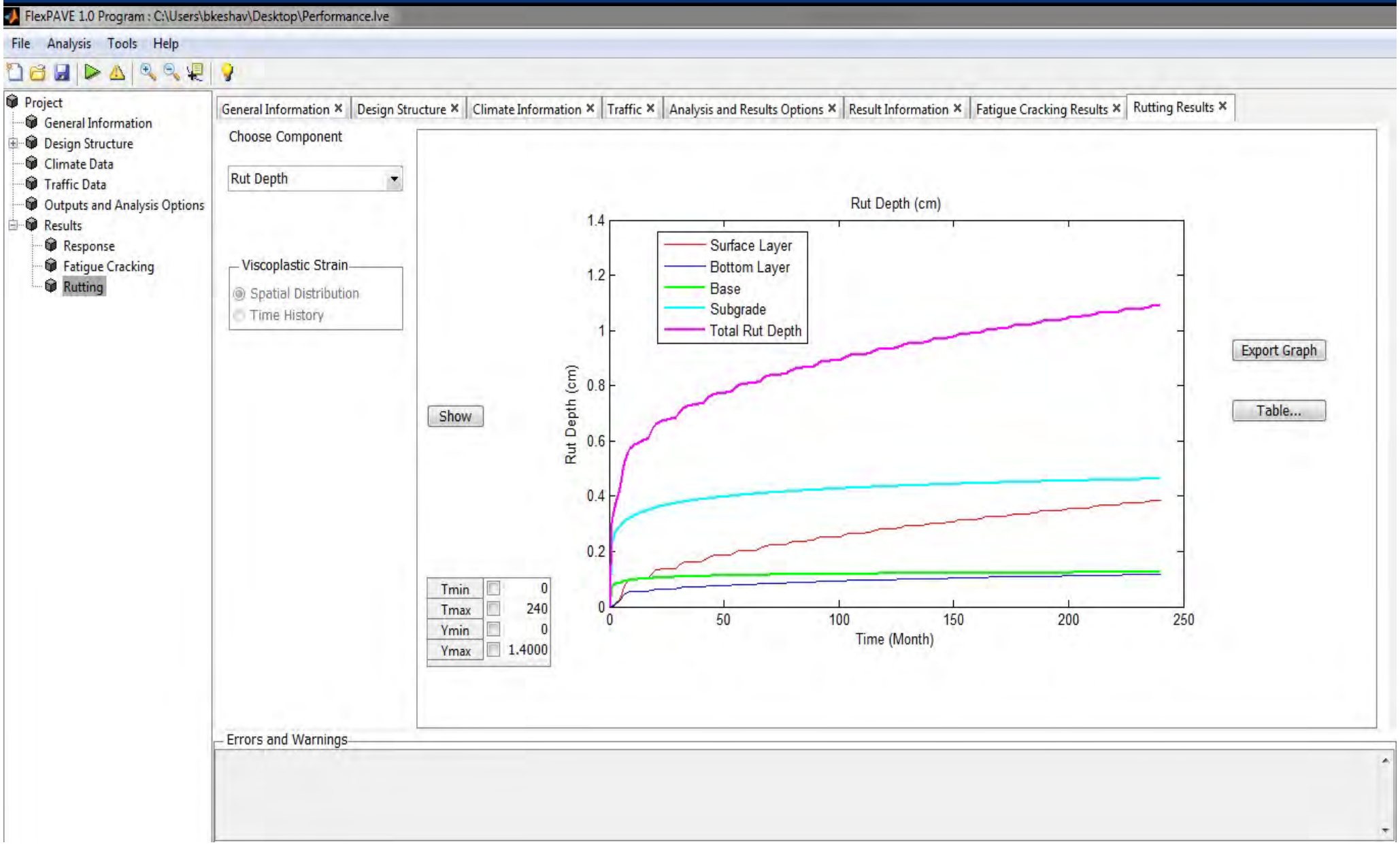
Import Damage Data | Import Rutting Data

		Ti (sec)	Ei (KPa)
1		2.0000e+16	757.4885
2		2.0000e+15	97.6079
3		2.0000e+14	267.7187
4		2.0000e+13	366.0952
5		2.0000e+12	686.5036
6		2.0000e+11	1.2298e+03
7		2.0000e+10	2.2287e+03
8		2.0000e+09	4.0690e+03

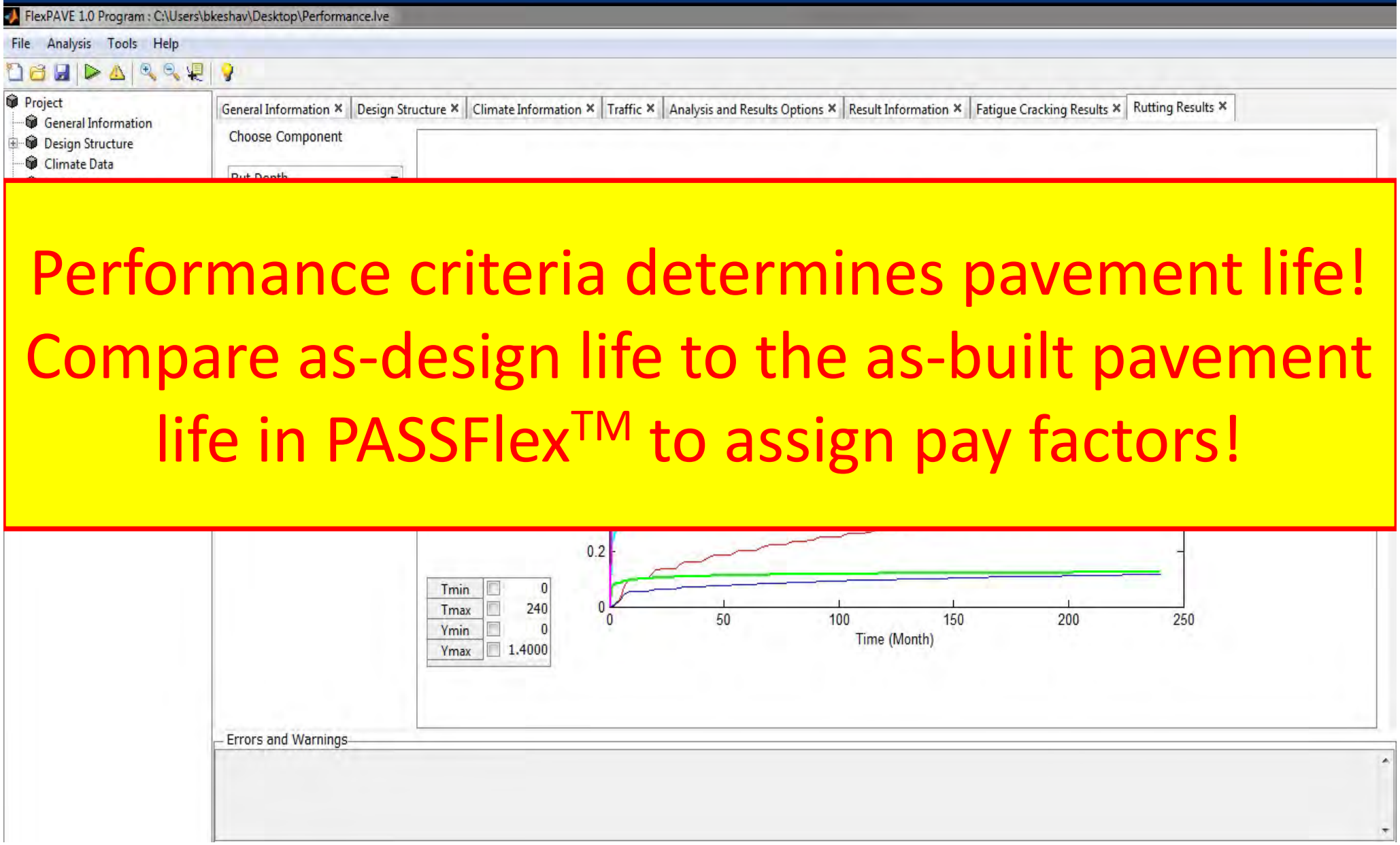
Import Prony Series Data | Help...

Errors and Warnings

Predicts Performance!



Predicts Performance!



Performance criteria determines pavement life!
Compare as-design life to the as-built pavement life in PASSFlex™ to assign pay factors!

Material Behavior Across All Loading Conditions

- Time-temperature superposition
  - Major benefit
  - Reduces testing time/specimens
  - Enables robustness of models
- **Fundamental properties required to describe behavior across wide-range of conditions**
- **Allows for direct incorporation of pavement structure into predictions**

Material Behavior Across All Loading Conditions

mperature superposition

fit

lels

- Fun d to
  describe f
  conditions
- Allows for direct incor
  pavement structure into pr

THIS IS THE KEY DIFFERENCE BETWEEN OTHER AVAILABLE METHODS!

FHWA Shadow PRS Program

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Objectives of Shadow PRS

- How would project have been accepted, (and contractor paid), if PRS were used
- Understand ways that PRS may impact normal testing and acceptance operations

How Will This All Work?

- DOT determines project(s)
- Develop sampling plan with FHWA, NC St., ARA
  - 10 plant-produced samples
  - Proficiency sample (1 project only)
  - Mix design replication sample
- Training before AMPT testing begins
- Volumetric testing as normally done
- AMPT testing whenever DOT has time

Shadow PRS Status

- Maryland SHA – Underway (10 projects)
- Maine DOT – Underway
- Missouri DOT – Underway (3 projects)
- Ontario MOT – Underway
- Western Federal Lands – 1st Project Complete

- Marketing of success stories

AMPT Users Group

- National/International
  - TRB Annual Meeting
  - Discussion of issues, best practices, future efforts
  - 164 members
    - 28 DOTs represented
- Regional
  - User-Producer Groups
  - State Asphalt Paving Assoc. meetings

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Office of Asset Management,
Pavements, & Construction

Asphalt Technology Guidance Program (ATGP)

Long-Life Asphalt Pavement for the 21st Century

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Program Focus Areas

- Provide Support to National Initiatives
  - Increased Pavement Density
  - Increased RAP/RAS Usage
  - Understanding GTR Testing
  - Mixture Performance Testing and the AMPT
  - Stone Matrix Asphalt
  - Binder Performance Testing
  - Long-Term Aging

Program Focus Areas (2)

- Equipment Development & Refinement
  - Asphalt Mixture Performance Tester (AMPT)
    - Standardization of Equipment, Test Methods
  - Binder Performance Testing
- Development of New QA Concepts for HMA
  - Performance-Based/Related and Risk-Based Acceptance
- Advanced Rapid Test Tools
  - AIMS, CoreLok, CoreDry, Small-Scale Geometry

Solutions to Agency Needs

- Project-Specific Workplans
  - Material Characterization
    - High RAP/RAS, GTR, SMA, PRS…
  - Mix Design Replication and Testing
  - Mix Production Testing
  - Performance Prediction
  - Training and Demonstration

Thank you!

- Questions?
- Contact information (PRS and Shadow)
  - Richard Duval
  - 202.493.3365
  - Richard.duval@dot.gov
- Contact information (AMPT and PRS)
  - David Mensching
  - 202.366.1286
  - david.mensching@dot.gov

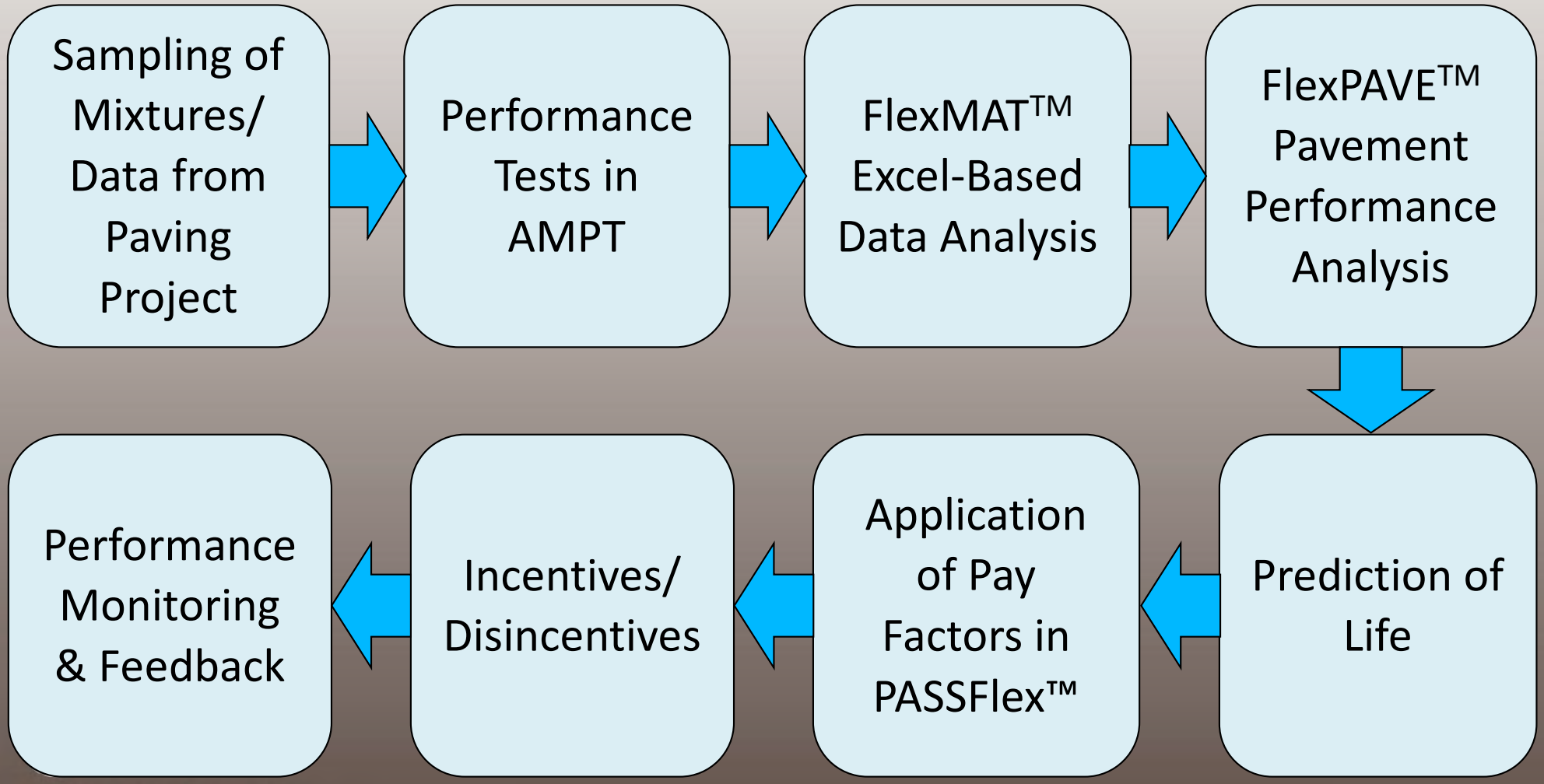
Asset Management Plans

- Pavement inventory and conditions (NHS)
- Objectives and measures
- Performance gap identification
- Lifecycle planning and risk management analysis
- Financial plan
- Investment strategies
- **Short term performance measures key to invest funds effectively and meet long-term goals!**
- **Performance prediction leads to smart planning!**

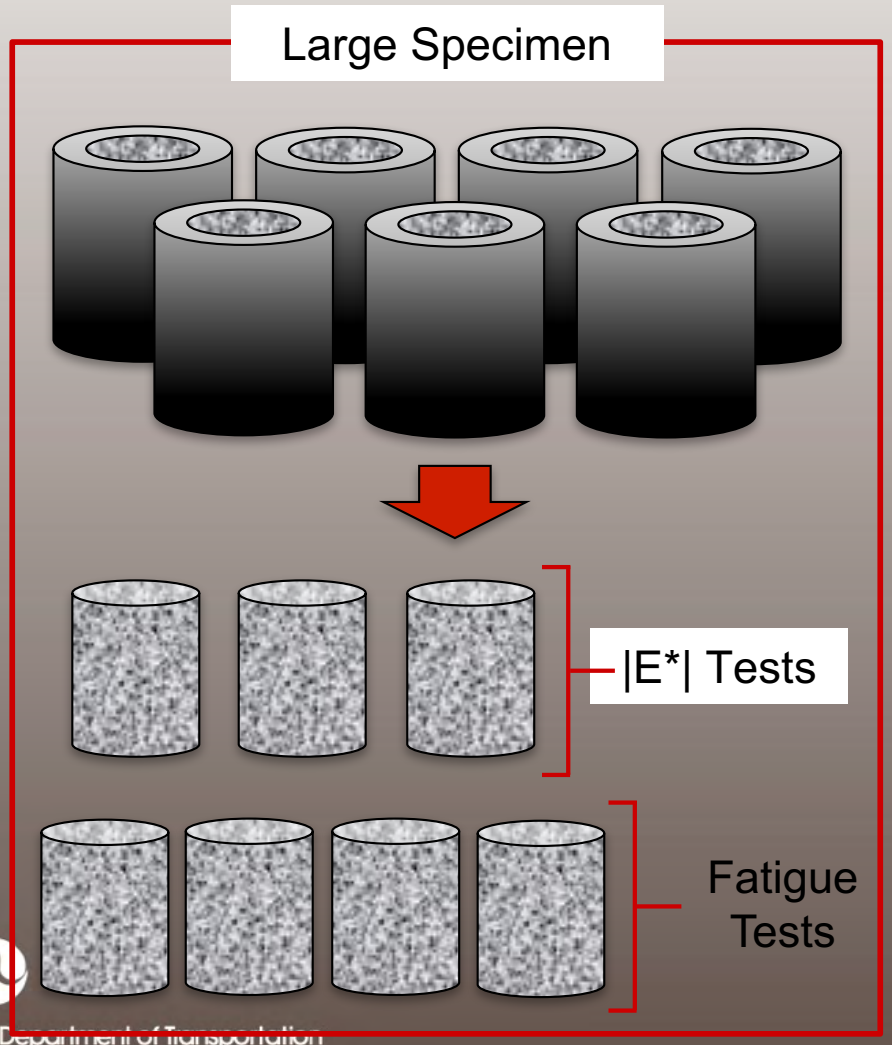
Asphalt Pavement Performance

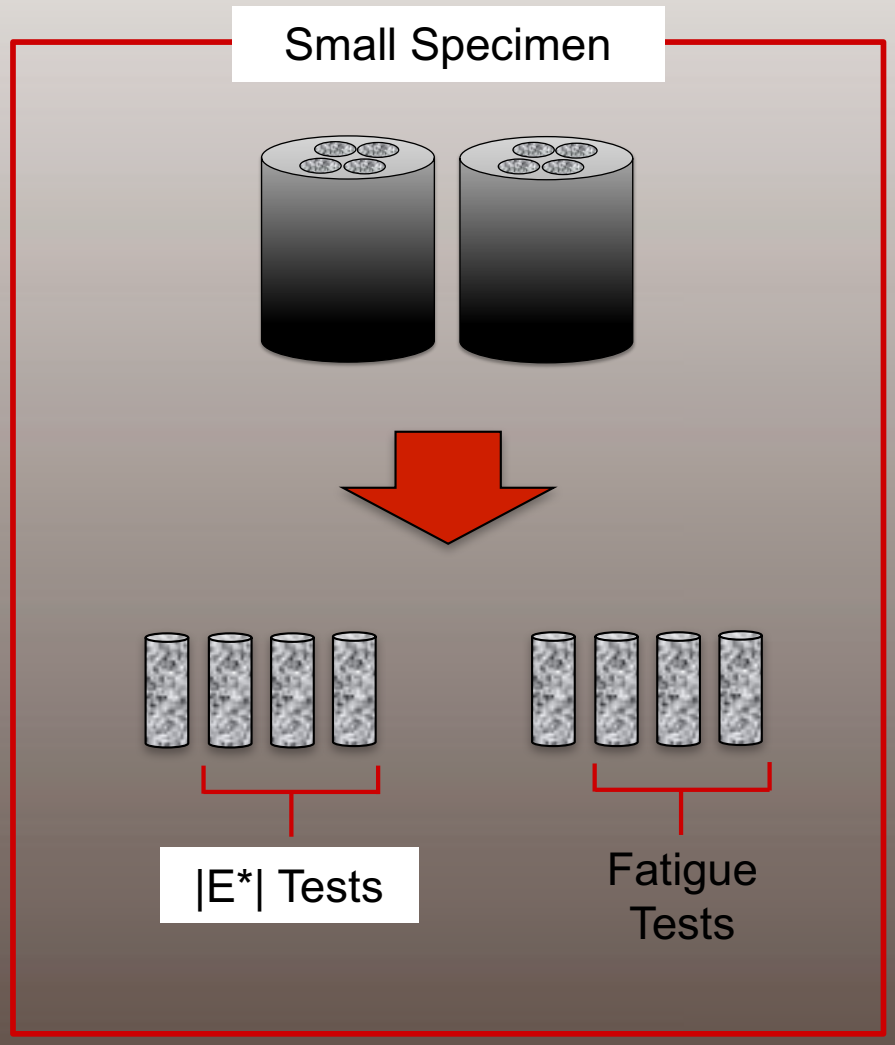
- Low temperatures or fast loading rate
  - Thermal cracking
- Intermediate temperatures and loading rates
  - Fatigue cracking
  - Durability cracking
  - Thermal fatigue
- High temperatures and slow loading rates
  - Rutting
  - Increased oxidative aging
- Insufficient structure
  - Rutting
  - Fatigue cracking
- All influence ride quality

PRS Framework



Testing Efficiency and Simplicity





Testing Efficiency and Simplicity (2)

	Large Specimen	Small Specimen
Steel Putty	Devcon 10110	Devcon 10240
Working Time	10 – 20 min.	5 min.
Functional Cure	16 hours	1 hour
Amount of Putty (per specimen)	100 g	3 g

AASHTO TP 107 Revisions

- Add failure criterion
- Simplification of language
- AMPT-specific
- Removal of spreadsheet derivation
- New strain selection guidance
- Small-specimen appendix
- Instructional videos (links available)

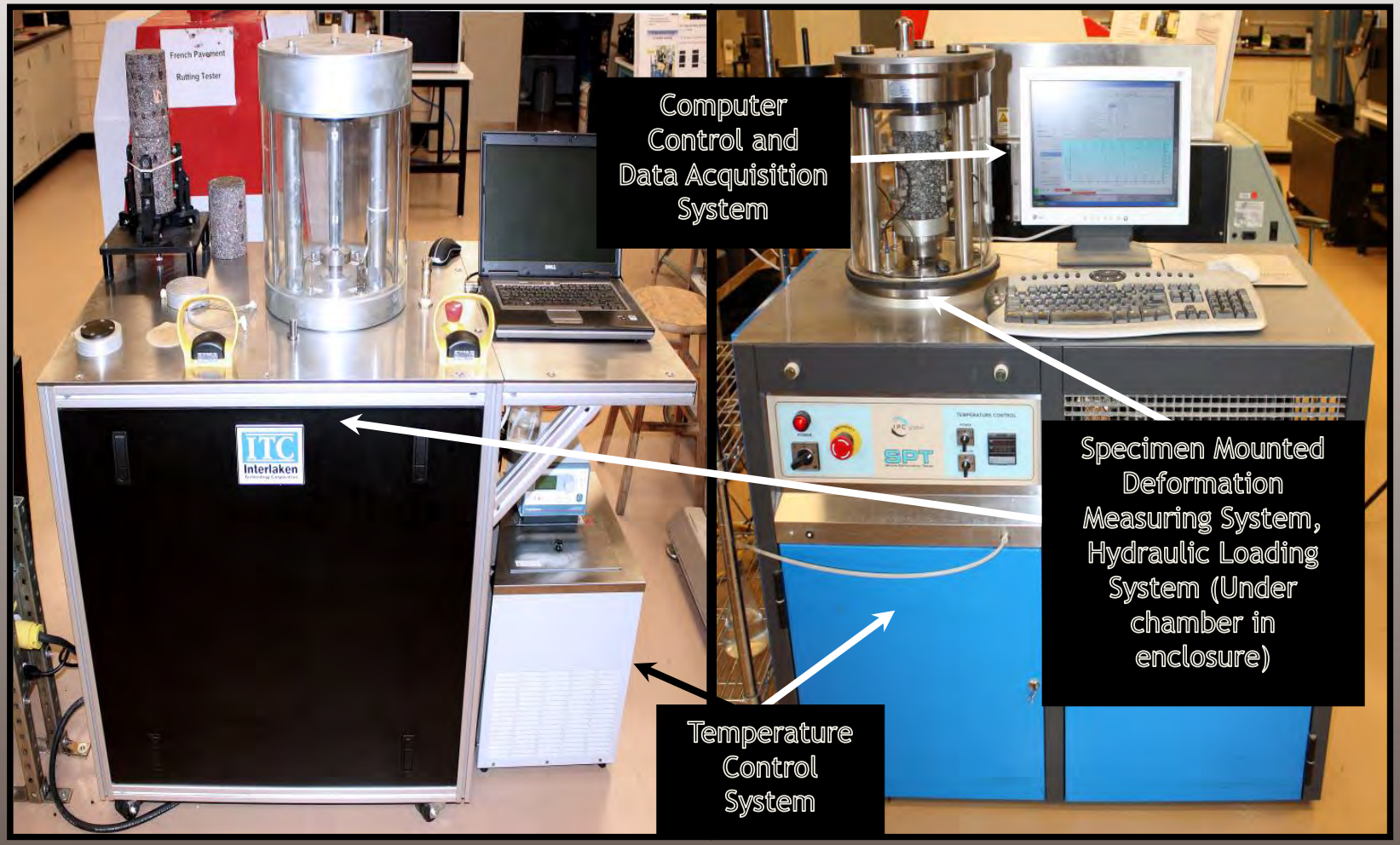
Same Principles and Methods in Design and PRS

- Testing is conducted at mix design phase
- Run predictions to establish as-design pavement life
- Same principles present
  - Prediction using cyclic fatigue and shift models
  - Pay factors assigned on a life difference

AMPT Implementation

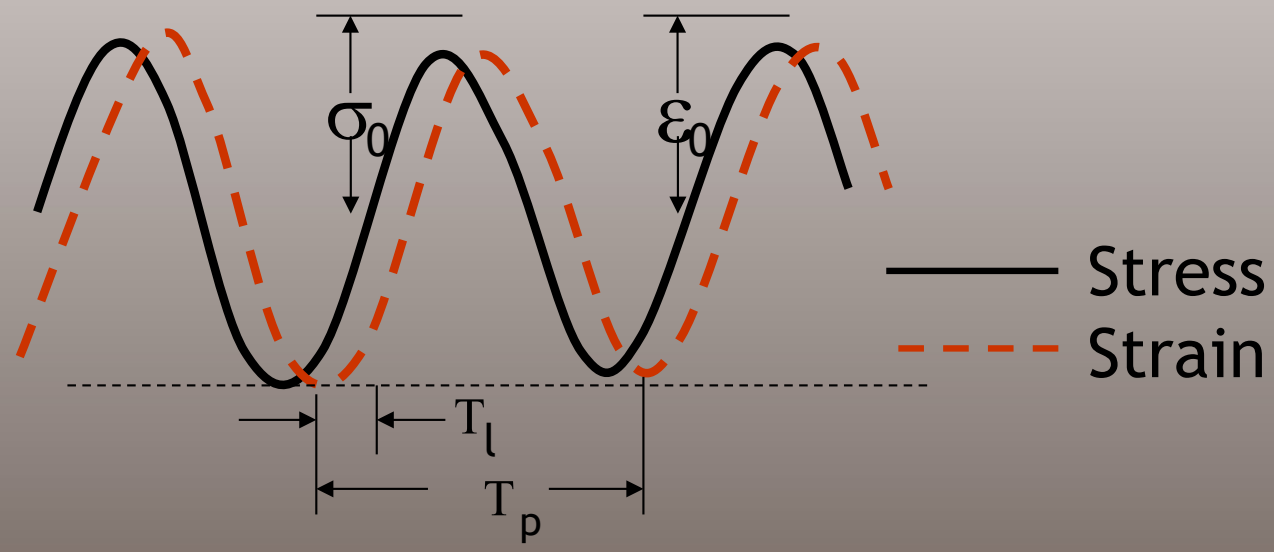
- Transportation Pooled Fund Study (TPF(5)-178)
  - Purchase, installation of 29 AMPTs
  - NHI Course (over 80 trainees)
  - Interlaboratory study on effect of air voids
  - National workshop
  - Equipment specification, and others!
- Test standard development, improvement, and revision
- Instructional videos, TechBriefs
- PRS shadow implementation (TFHRC-led)
- PRS workshops (2017, 2018, 2019)
- MATT projects/training
- User Groups at TRB and regional meetings

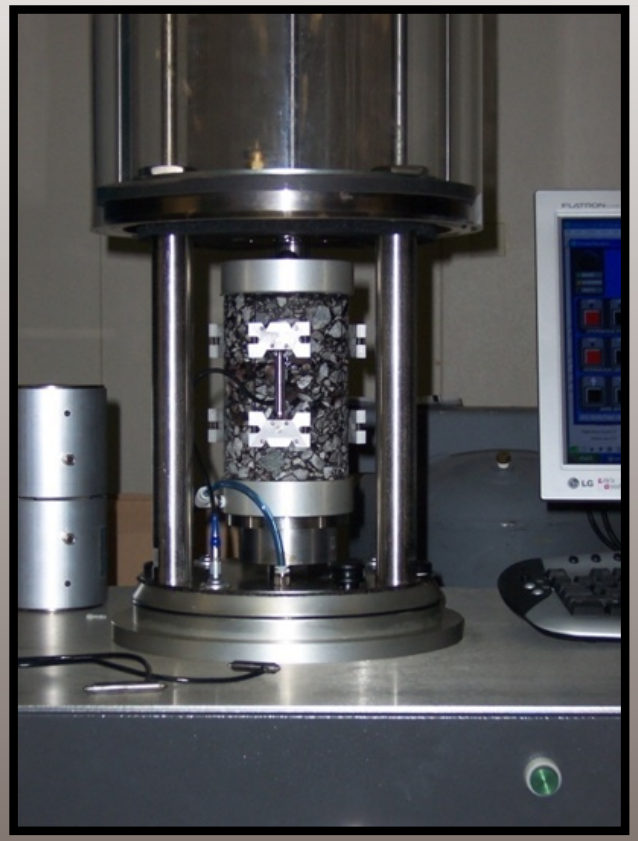
AMPT Overview



Dynamic Modulus Test

- Mixture Stiffness
- Rutting
- Fatigue Cracking





Dynamic Modulus

$$|E^*| = \frac{\sigma_0}{\varepsilon_0}$$

Phase Angle

$$\phi = \frac{T_l}{T_p}(360)$$

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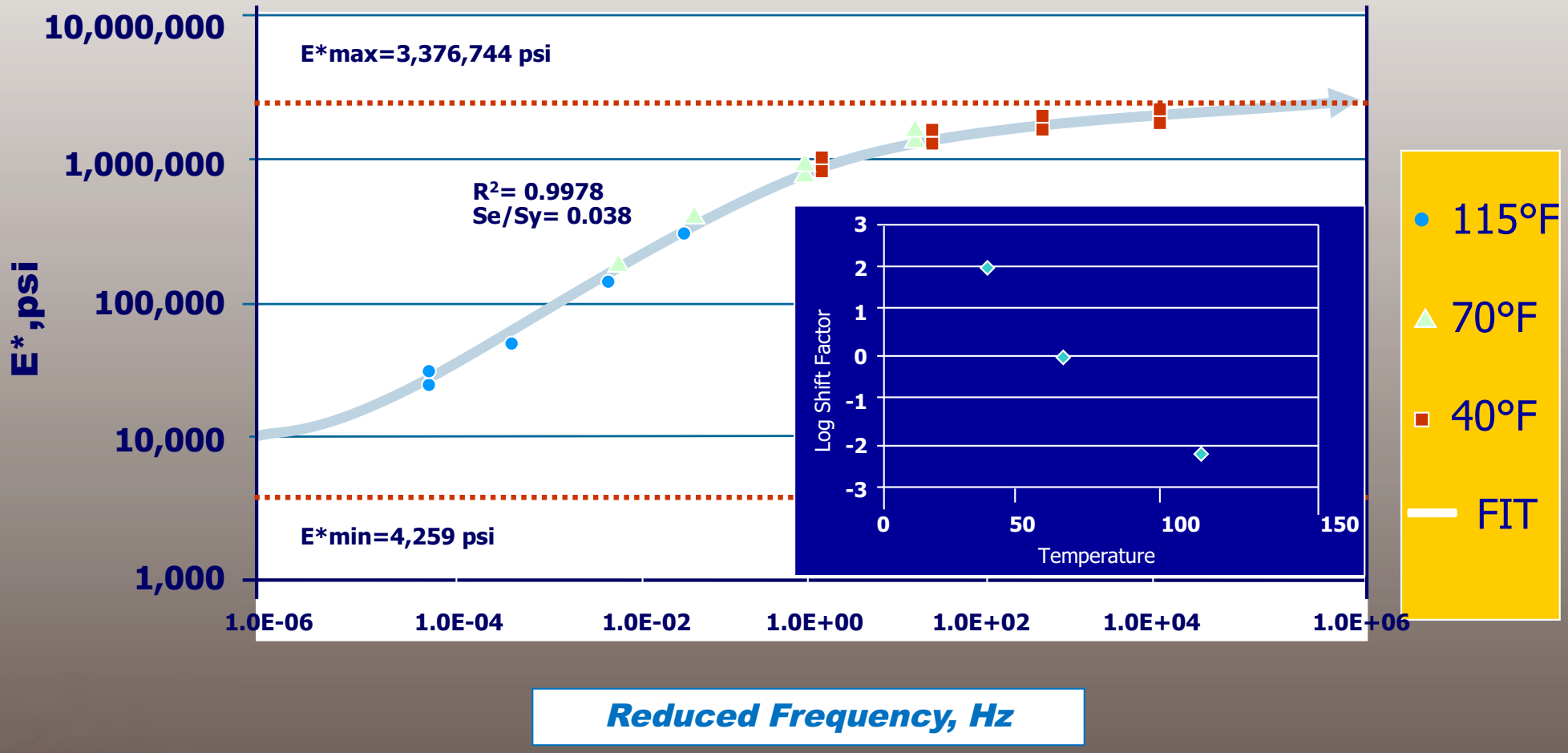
Dynamic Modulus Master Curve



Reduced Frequency, Hz

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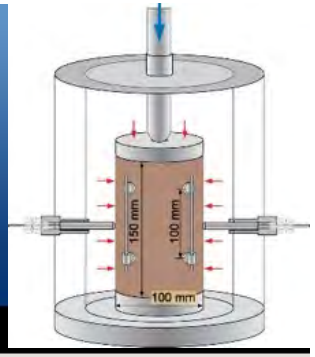
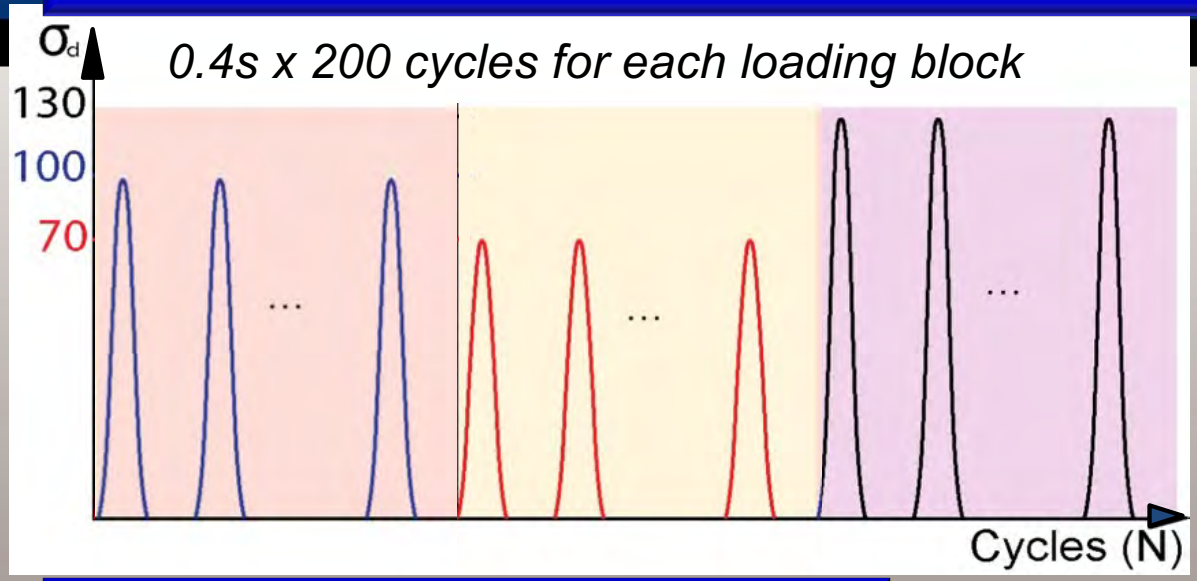
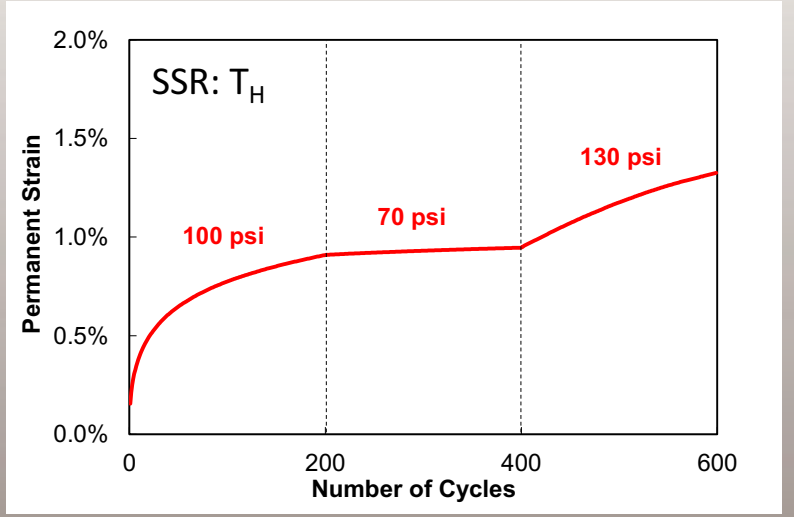
Stress Sweep Rutting (SSR) Test

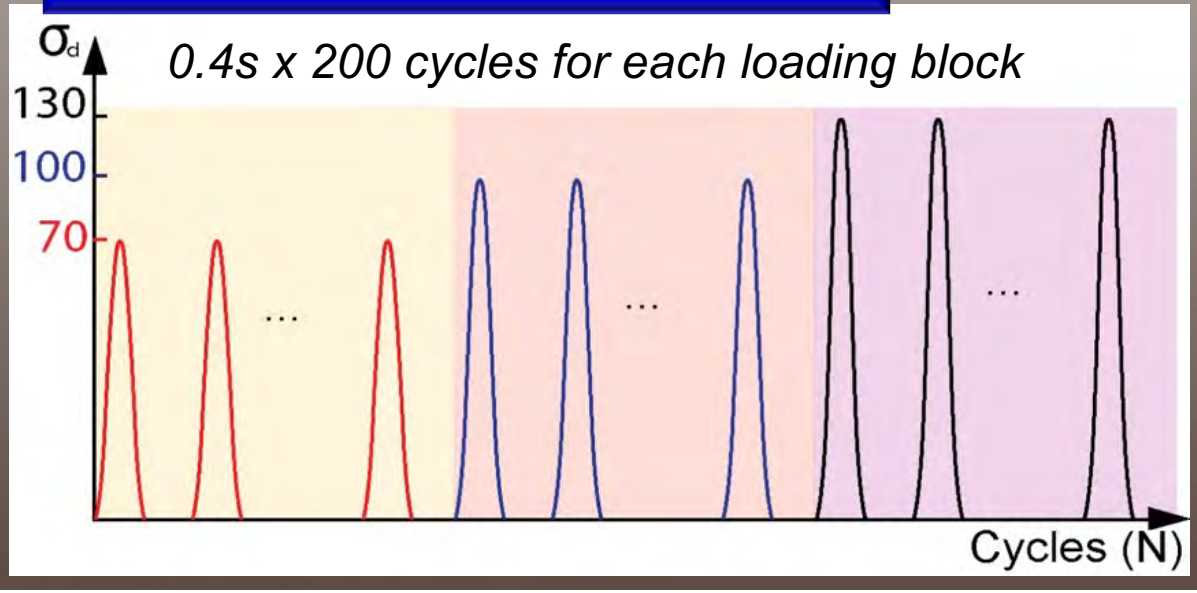


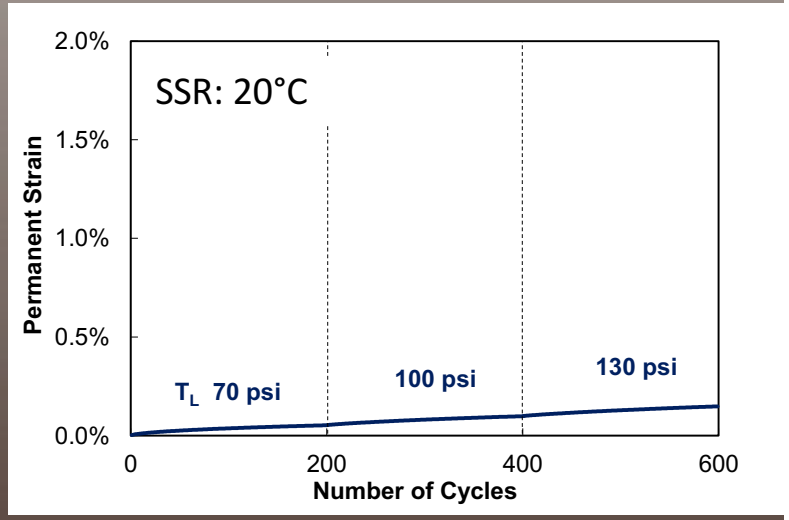
High Temperature: 0.4s pulse, 3.6s rest





20°C: 0.4s pulse, 1.6s rest





SSR Test

- Draft procedure ready for consideration by AASHTO
- FlexMAT™-Rutting available
  - Single tab spreadsheet
- Confined testing (10 psi)
- 1 day to complete all replicates
- **Model predicts permanent deformation at all loading conditions!**

AMPT Cyclic Fatigue

- Fundamental, repeated loading test
- Direct tension (pull-pull)
- Small-specimen testing available (AASHTO TP xxx)
- AASHTO TP 107 – revisions out for ballot!
- **Material behavior across all possible loading conditions!**

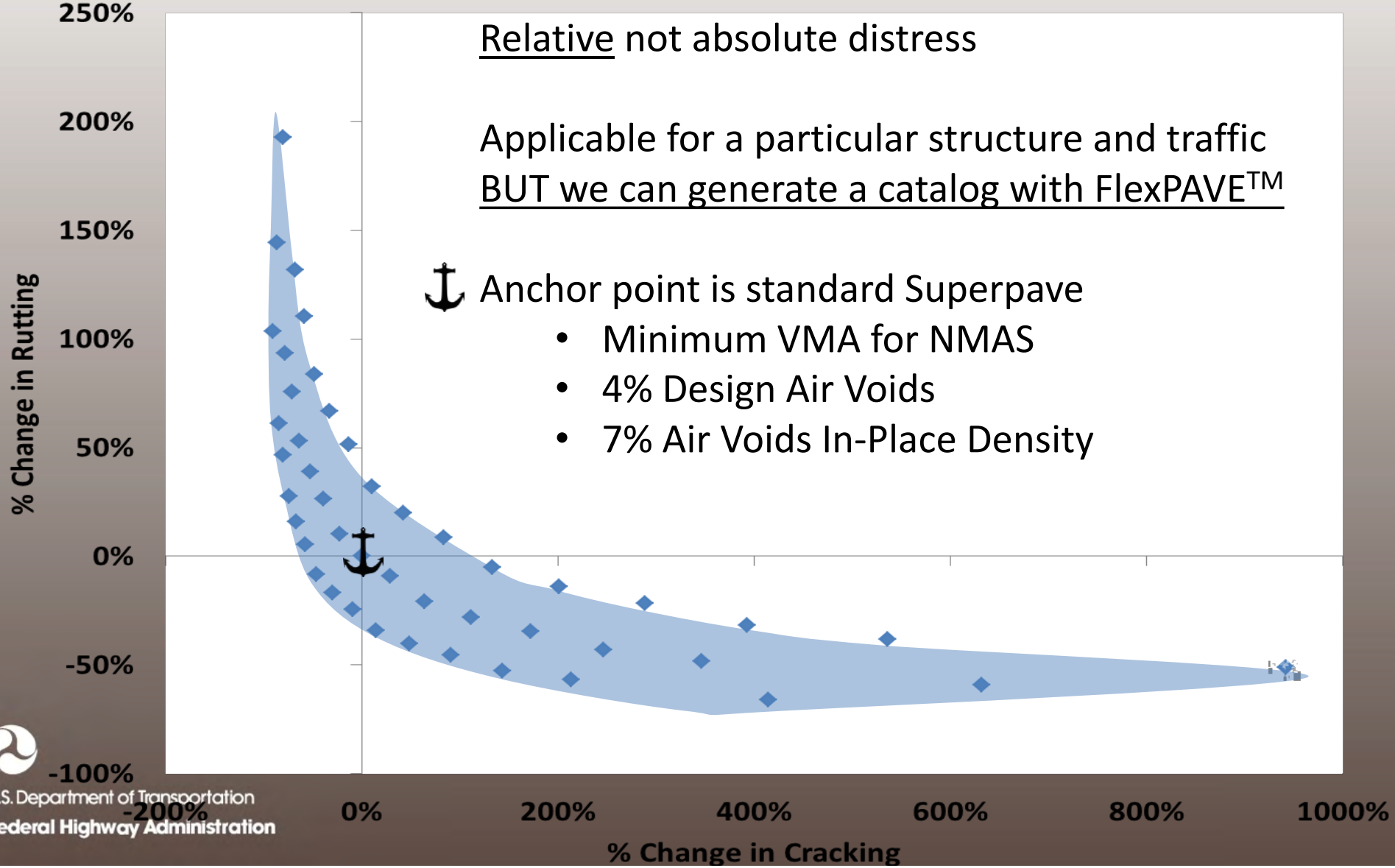
Field Validation of AMPT Cyclic Fatigue

- Pavement prediction software built from models
- Field validation
  - 59 mixtures
  - 55 different pavement structures
- Develop laboratory-to-field transfer functions
- **Volumetrics have a seat at the table!**

Ruggedness, Precision, and Bias

- AASHTO T 378 |E*| – Complete!
- AASHTO TP 107 – Ruggedness and precision and bias underway
- Small-specimen cyclic fatigue – Ruggedness and precision and bias underway
- Small-specimen |E*| – coming soon

Initial PVR Database



Relative not absolute distress

Applicable for a particular structure and traffic
BUT we can generate a catalog with FlexPAVE™

Anchor point is standard Superpave

- Minimum VMA for NMAS
- 4% Design Air Voids
- 7% Air Voids In-Place Density

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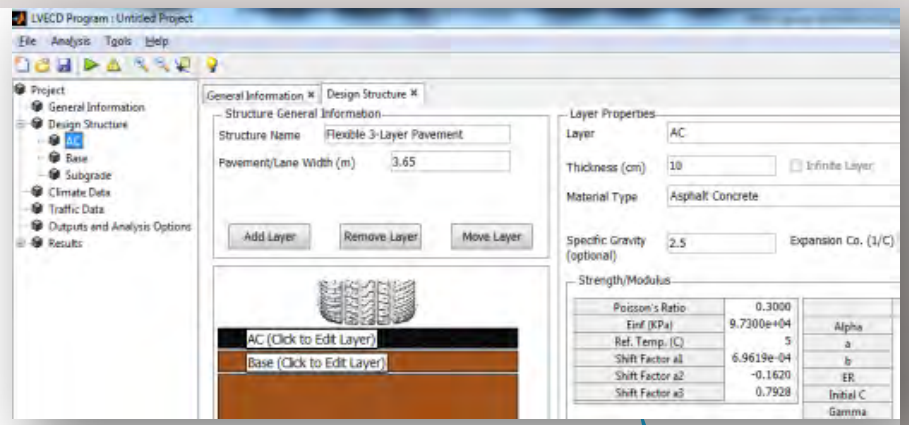
Federal Highway Administration

Standard Sample Preparation

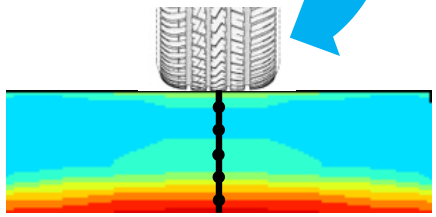
- Cylindrical specimens
  - AASHTO R 83 for full-size
  - Draft procedure ready for small-size
- Equipment required
  - Superpave gyratory compactor and molds
  - Core drill (bits depend on specimen size)
  - Wet saw
  - Water bath or other device (for Gmb)
  - Engineering square, piano wire

PRS Software

AMPT + Performance Prediction



✓ Structure ✓ Traffic ✓ Climate



Predicted Rutting
Predicted Cracking

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AMPT Cyclic Fatigue Process

Preparation

- Cylindrical specimen
- 100 mm x 130 mm
- Small-specimen:
38 mm x 110 mm
- End plate gluing, clamp system being explored
- **2-3 days for mix**

Testing

- Dynamic modulus fingerprint for specimen variability
- Pull-pull fatigue test
- Strain level based on TFHRC database
- Test temperature based on location of interest
- Load until crack forms
- **1-2 days for mix**

Analysis

- AMPT automatically captures data for analysis
- Calculate damage via FlexMAT or FlexPAVE
- Assign mixture rankings or use FlexPAVE
- **1-2 hours for mix**

About one week per mixture…worth it when considering the cost of premature failure?

Advantages of AMPT Cyclic Fatigue

- Standard sample preparation
- AASHTOWare Pavement ME compatible
- Ruggedness, precision and bias underway
- FlexMAT™ & FlexPAVE™ available
- Predicts performance!
- **Material behavior across all possible loading/temperature conditions!**

FlexPAVE™ Simulations

FHWA-ALF Sections

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Two Major Tasks for DOT

- Accept 'shadow' mixtures based on the performance engineered mix design (PEMD) approach
- Collect volumetric-based acceptance quality characteristics (AQCs) during construction (PASSFlex™)
  - These would be used to determine hypothetical contractor pay

Material Testing

- Proficiency Testing
  - Ensure repeatable results with separate laboratory AMPT
  - Only done on first shadow project
- PEMD Testing
  - Baseline for the as-designed condition
  - Needed in design phase of each project
- Production Testing with AMPT (Shadow only)
  - Establish PVR
- Production Testing with Volumetrics

What Will a DOT Get Out of Shadow Project Participation?

- Understanding concept of PRS
  - Understanding pavement fatigue and rutting using fundamental test procedures
  - Pavement performance as function of AQCs
  - Construction Acceptance
- AMPT training
  - ARA, NCSU, & FHWA will work with State Agency to determine the best solution for training. The FHWA-MATT provides opportunities for DOTs to look over the shoulder of its personnel when testing for performance.
- PRS Software training and analysis support
- Potential for FHWA project funding support
- Potential for Mobile Asphalt Testing Trailer support

Program Objectives

- Advance Performance
- Advance Quality Assurance
- Advance Innovation

Courtesy of Anton Paar