AMPT Cyclic Fatigue Test

Y. Richard Kim

Jimmy D. Clark Distinguished University Professor

Alumni Distinguished Graduate Professor

NC State University

North East Asphalt User/Producer Group Meeting

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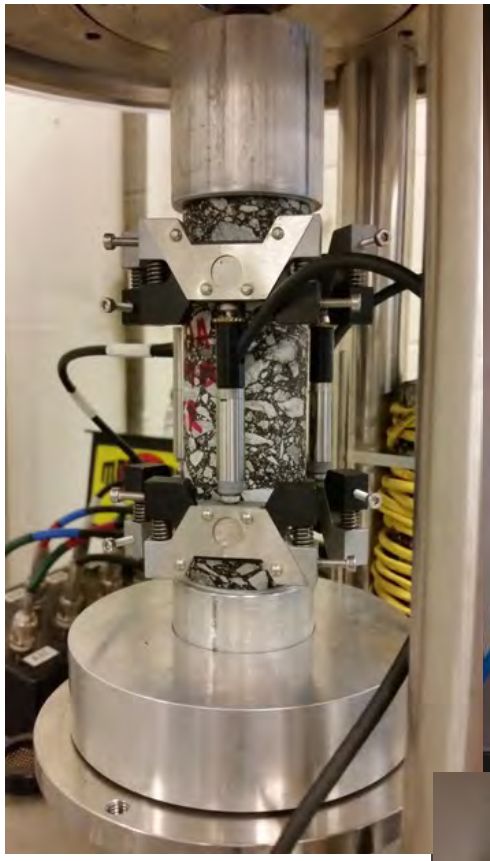
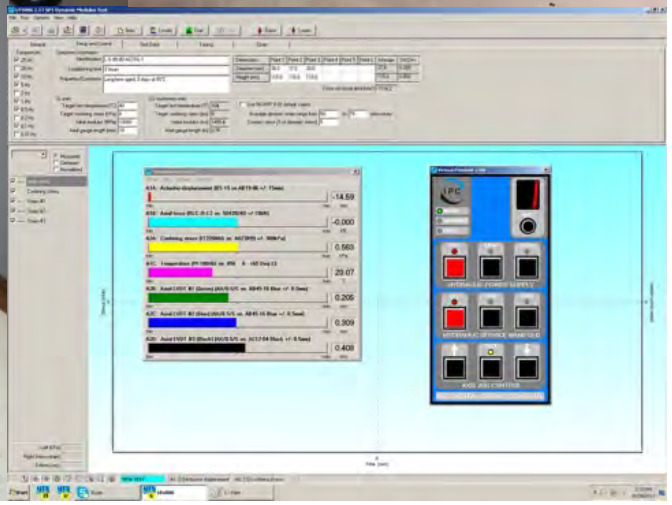
Outline

- AMPT Cyclic Fatigue Test Method
- Material Properties
- FlexMAT™ and FlexPAVE™
- Field Validation
- Applications
- Summary

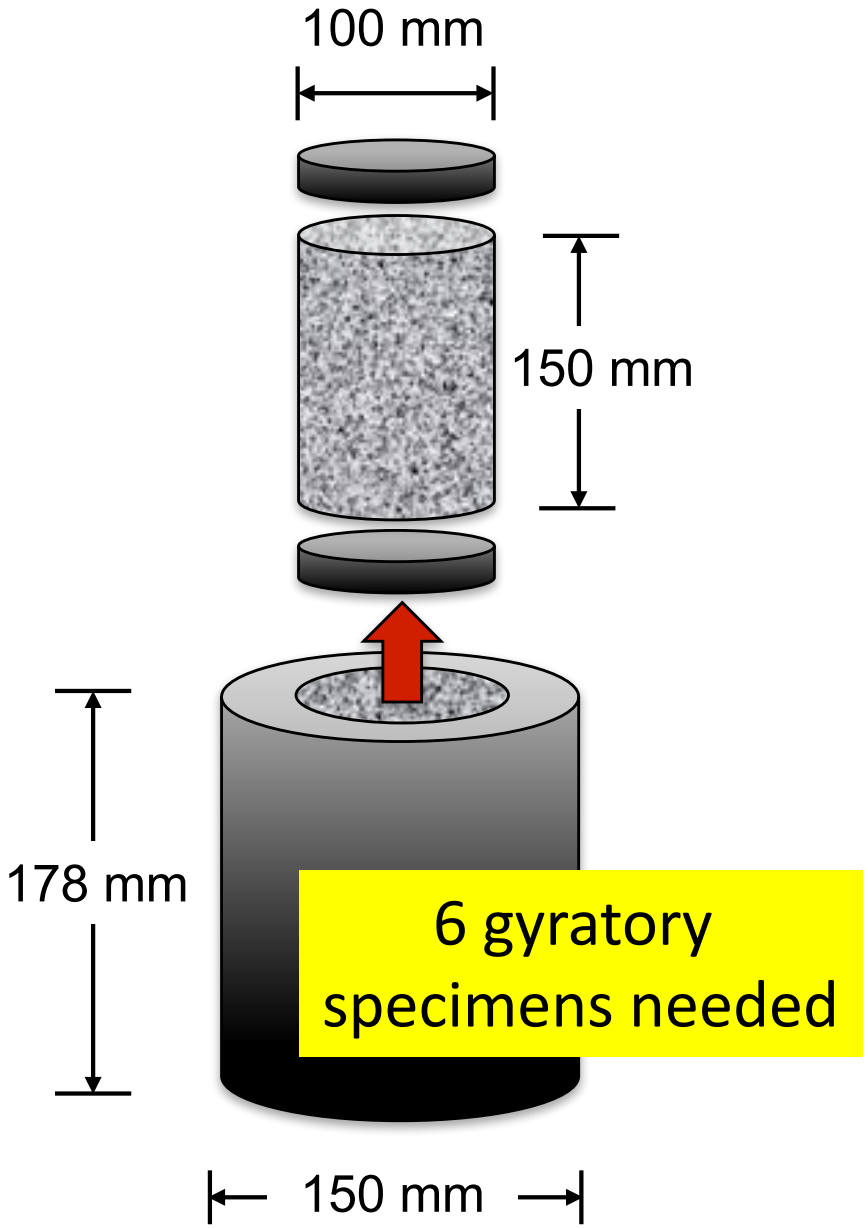
AMPT Cyclic Fatigue Test Method (AASHTO TP 107)

Asphalt Mixture Performance Tester



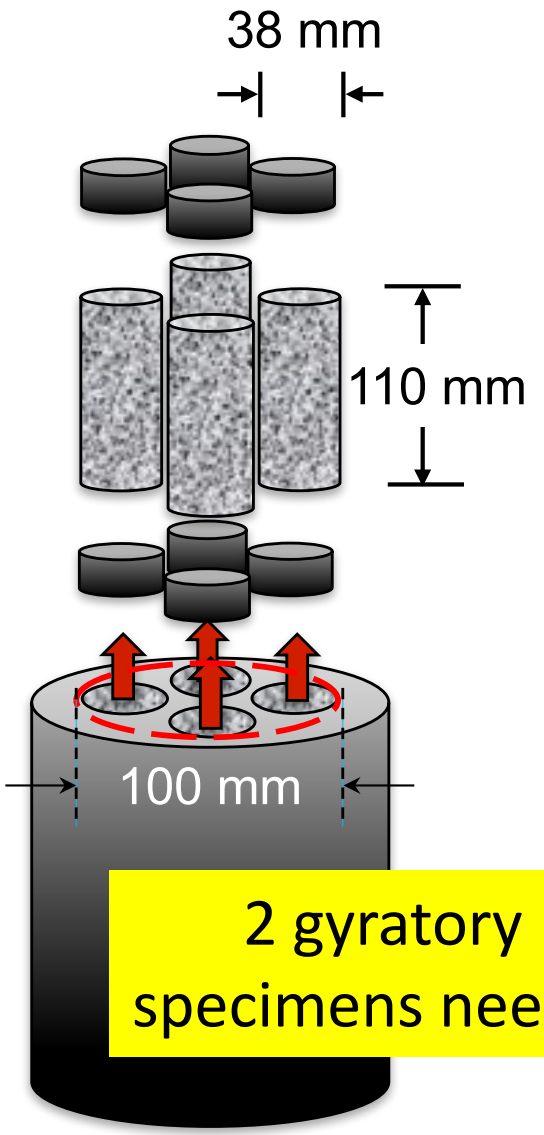


100 mm Dia. Specimen



6 gyratory specimens needed

38 mm Dia. Specimen



2 gyratory specimens needed

Advantages of 38 mm Geometry

- Saving materials (asphalt mixture and glue) and time (16 hrs curing time vs. less than 1 hr)
- Lower load capacity needed
- Five-minute epoxy strong enough
- Allows testing field cores by horizontal coring of cores

AMPT E* and Cyclic Fatigue Tests

Modulus

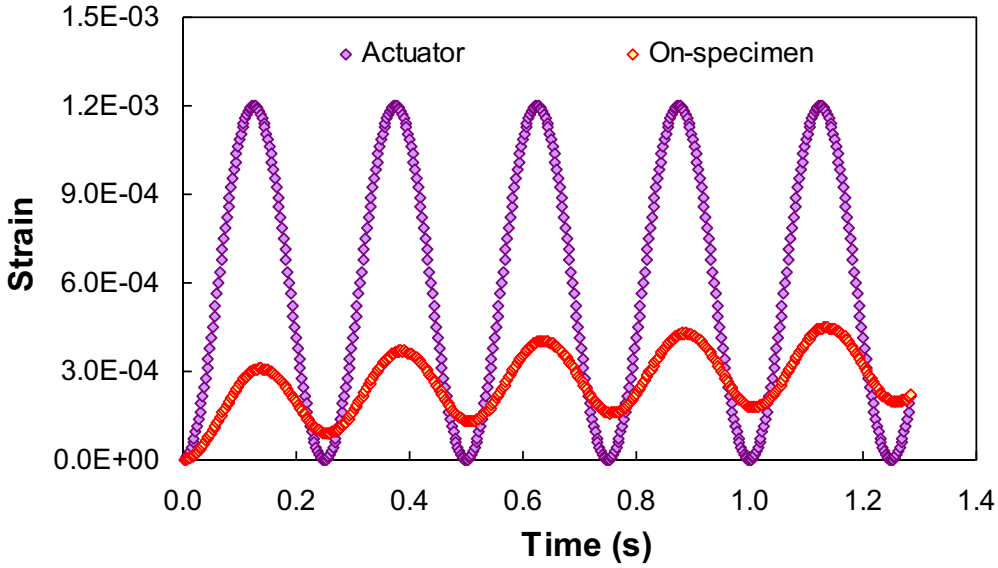
- Axial compression dynamic modulus test (AASHTO T 378)
- Dynamic modulus mastercurve and time-temperature shift function

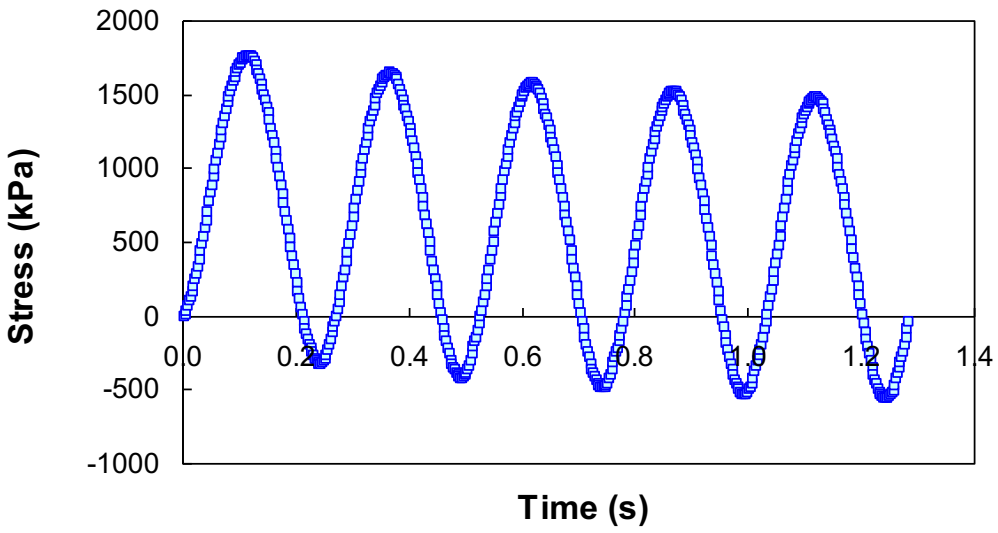
Cracking Resistance

- AMPT cyclic fatigue test (AASHTO TP 107)
- Damage characteristic curve
  - ✓ Defines how fatigue damage grows under cyclic loading
- Energy-based failure criterion
  - ✓ Defines when test specimen fails

TP 107 Test Protocol

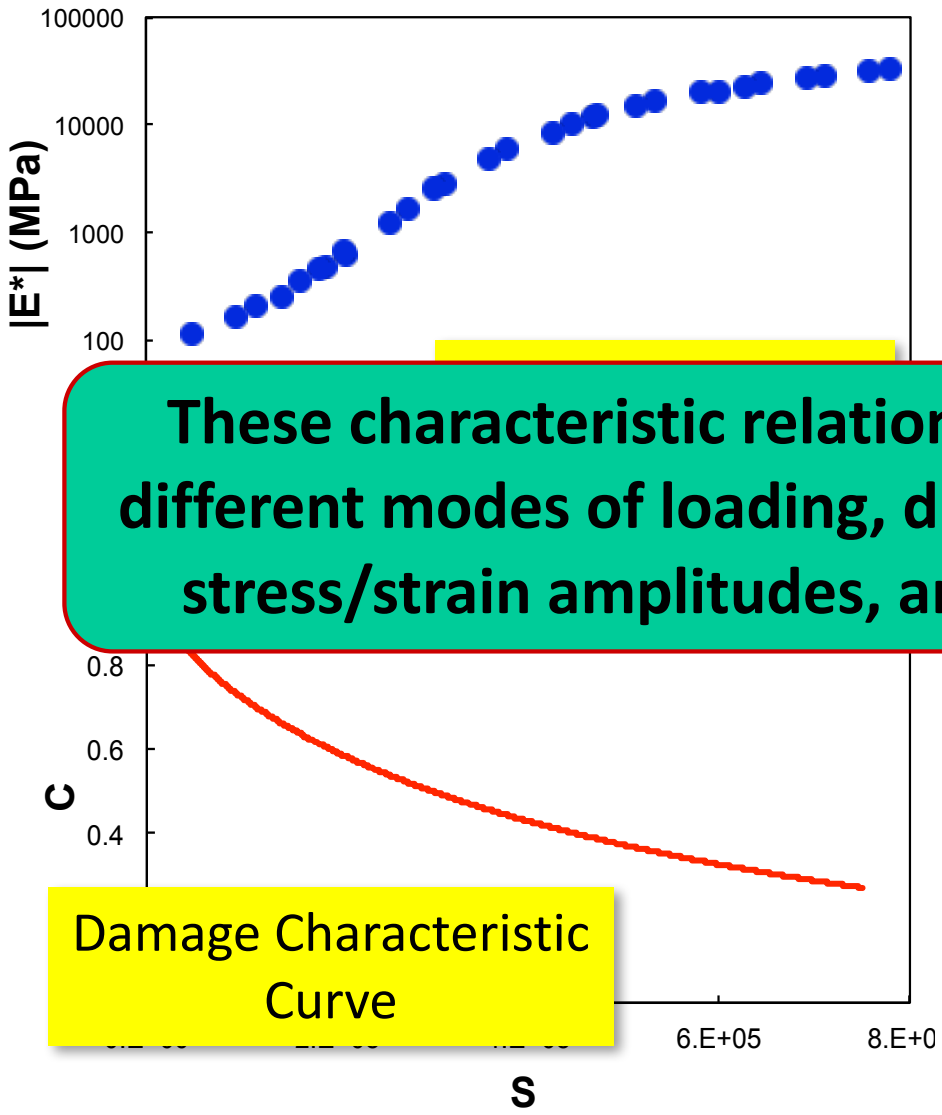
- Controlled actuator displacement cyclic test
  - Range of number of cycles to failure between 10,000, and 100,000 cycles
- On-specimen strains measured by LVDTs
- Total test time for characterization of 1 mixture (3 specimens): within 1 day



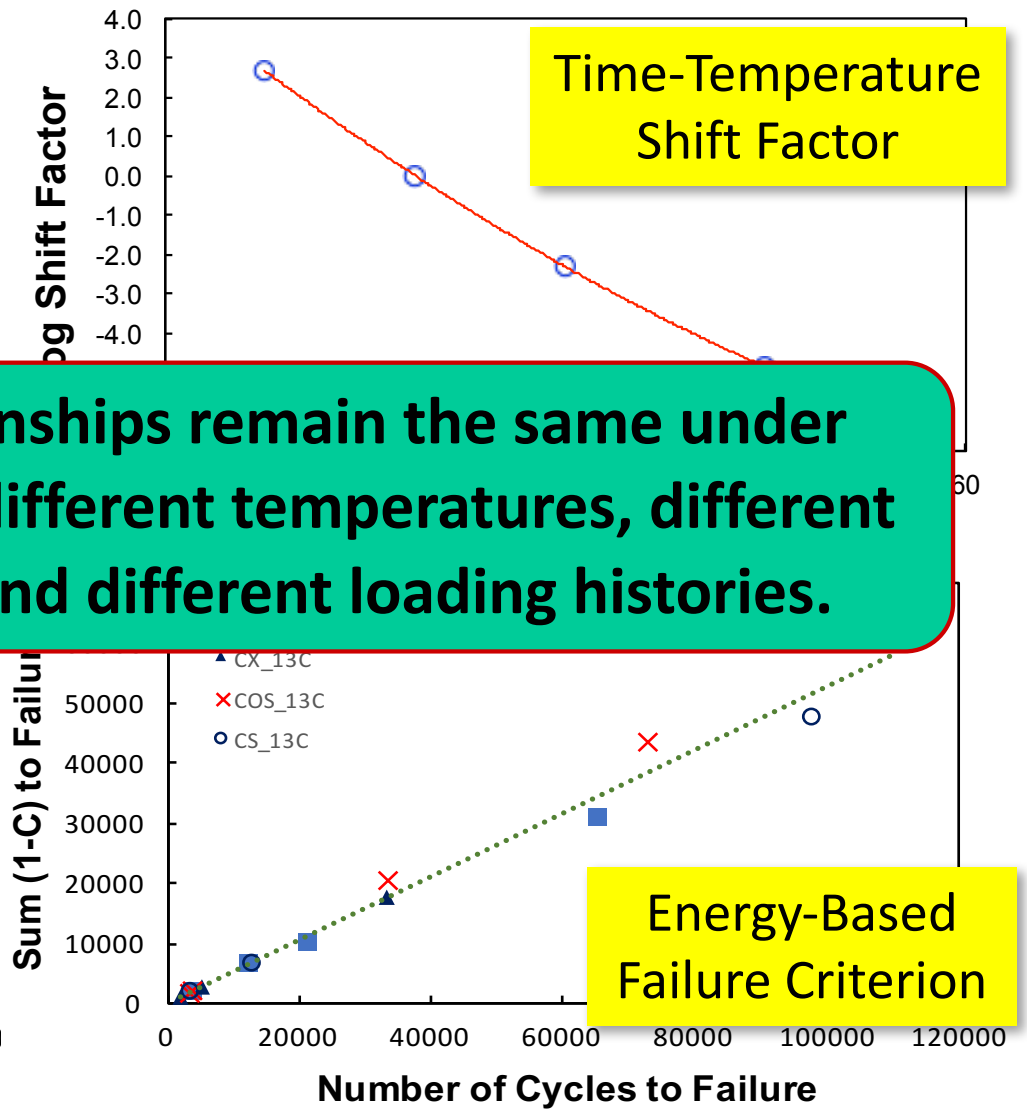


Material Properties

S-VECD Model for Cracking



Damage Characteristic Curve



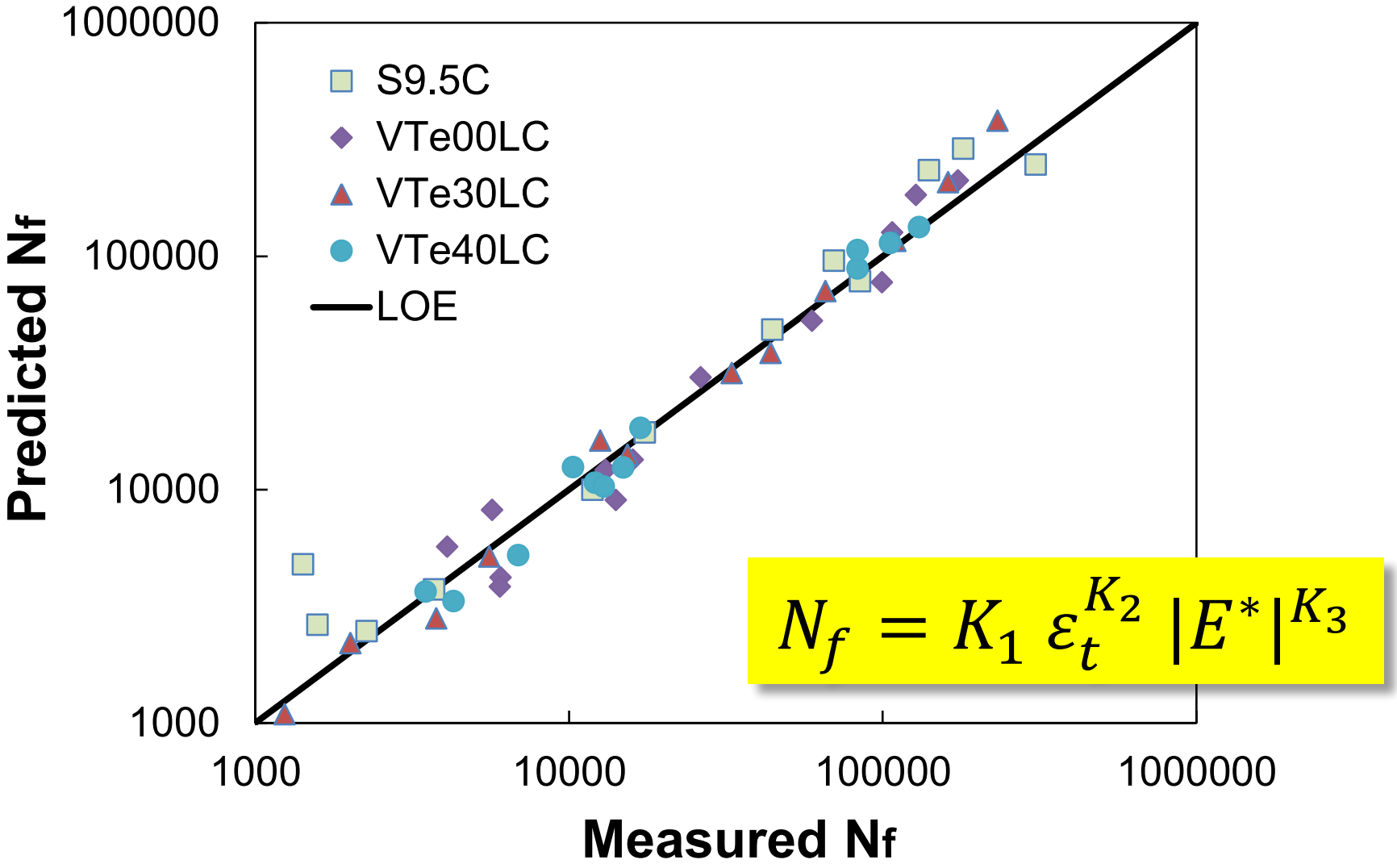
Time-Temperature Shift Factor

Energy-Based Failure Criterion

These characteristic relationships remain the same under different modes of loading, different temperatures, different stress/strain amplitudes, and different loading histories.

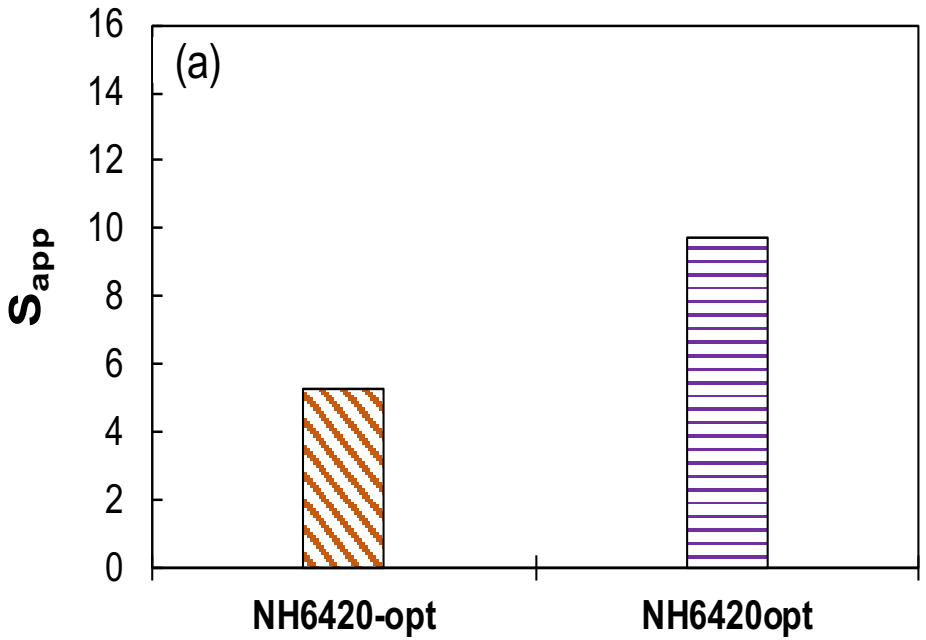
Fatigue Life Prediction

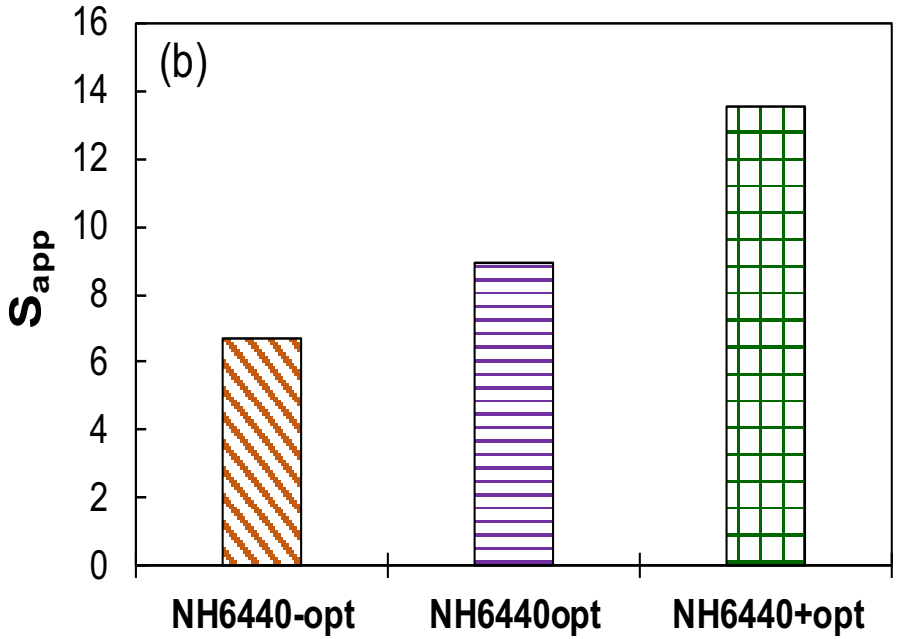
10 Hz, 100 – 700 microstrains, three temperatures



$$N_f = K_1 \, \varepsilon_t^{K_2} \, |E^*|^{K_3}$$

S_{app} as an Index Property





$$S_{app} = \frac{1}{10000} \times \left(\frac{1}{C_{11}} \times D^{R} \right)^{\frac{1}{C_{12}}}$$

FlexMAT™

Excel-Based Analysis of AMPT Data

Import Data from AMPT

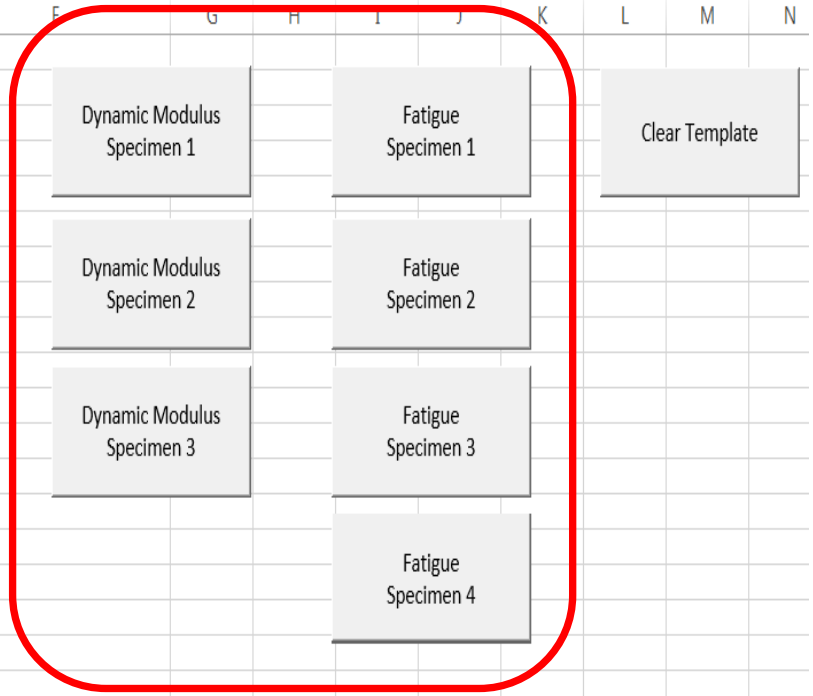
Description: This tab can be used to import test data from IPC Global AMPT files directly into the template. Alternatively, the user can copy and paste data directly into the green cells within the green tabs. Note that if data is imported using this tab, the user must still enter mixture volumetric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

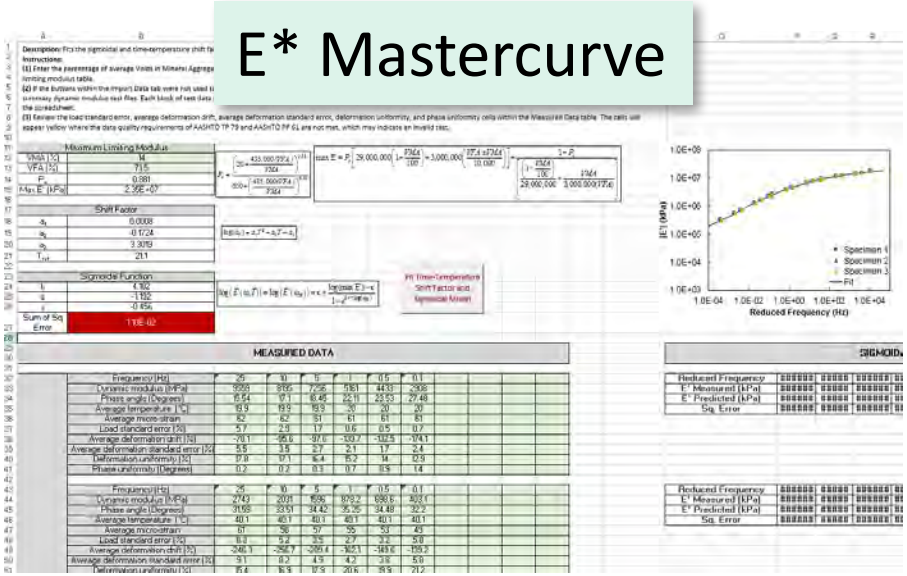
To import cyclic fatigue data for the first fatigue test, preess the **Fatigue Specimen 1**. A prompt will appear. Select the folder where the AMPT output for the cyclic fatigue test are stored. After selecting the appropriate folder, the data from the cyclic fatigue test data will be imported into the 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.

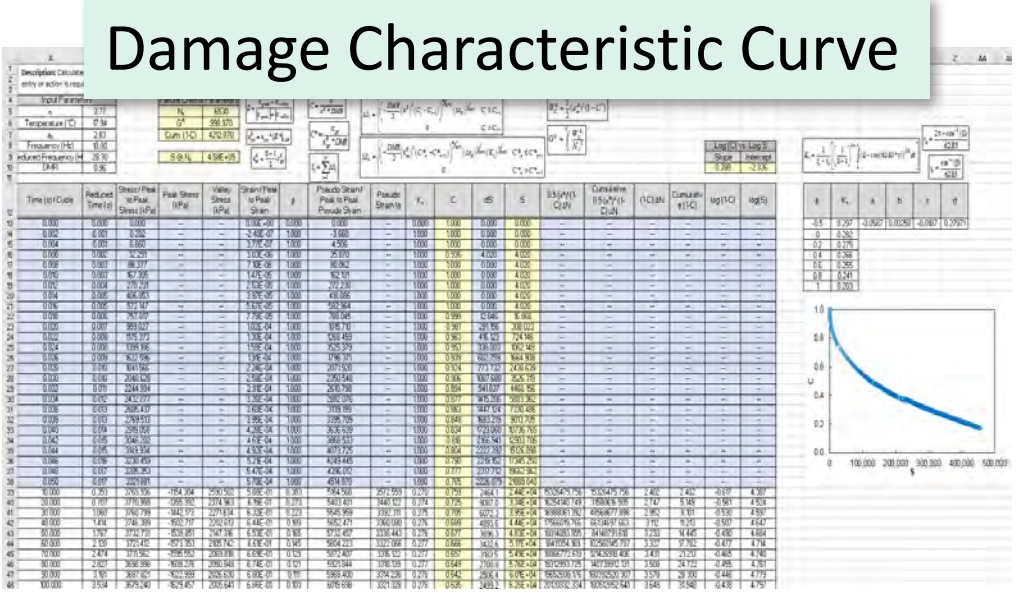


FlexMAT™ Analysis

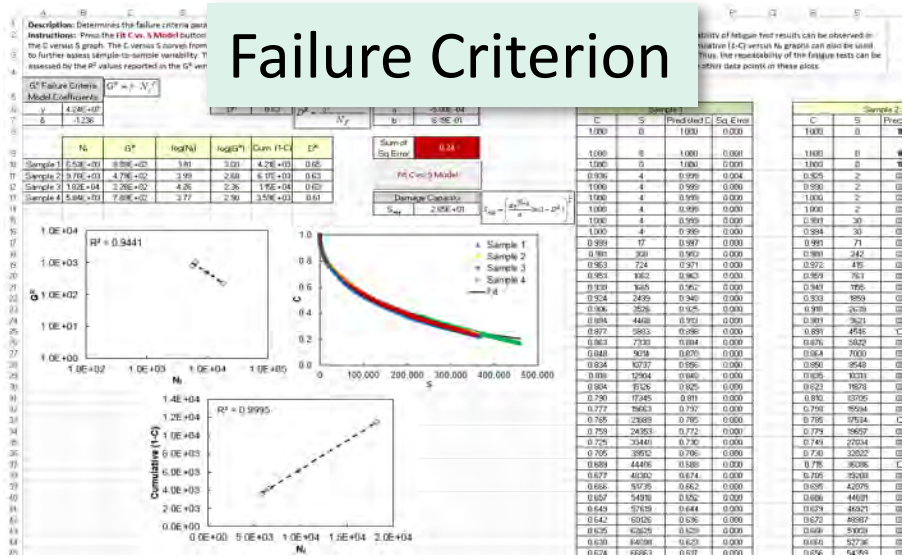
E* Mastercurve



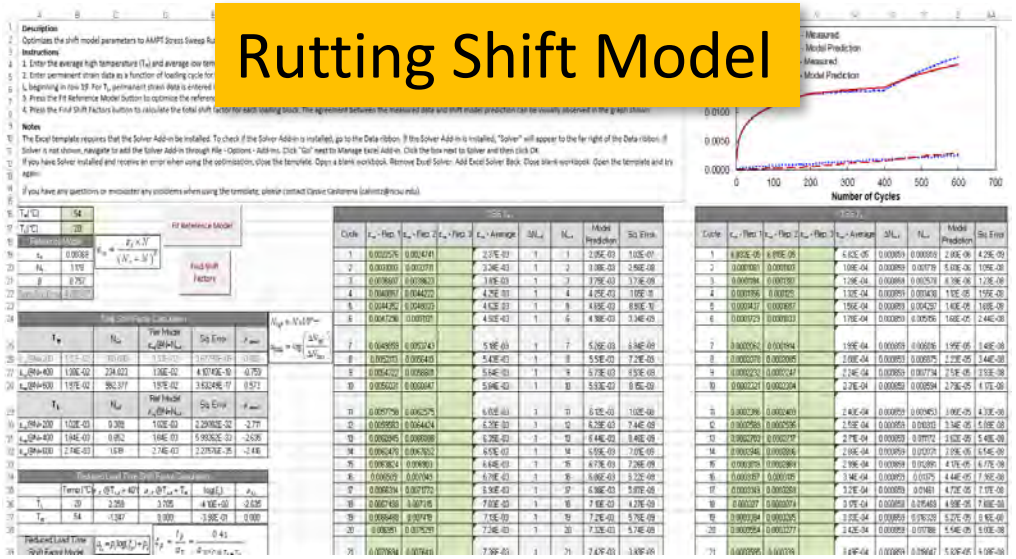
Damage Characteristic Curve



Failure Criterion



Rutting Shift Model



Export Data to FlexPAVE™

Description: Provides a summary of the linear viscoelastic and fatigue analysis results, which can be exported as input files to FlexPAVE. No data entry is required. Note that the use of this tab is optional.

Instructions: Press the **Export FlexPAVE Dynamic Modulus Inputs** button to export a dynamic modulus material input file for use in FlexPAVE. Press the **Export FlexPAVE Fatigue Inputs** button to export a fatigue material input file for use in FlexPAVE.

Linear Viscoelastic Properties	
E_∞	2.59E+04
T_{ref}	21.1
Shift Factor a_1	2.274E-03
Shift Factor a_2	-2.870E-01
Shift Factor a_3	5.044E+00
Prony Series	
Ti(s)	Ei (kPa)
2.00E+08	4.77E+03
2.00E+07	2.83E+03
2.00E+06	7.27E+03
2.00E+05	1.49E+04
2.00E+04	3.48E+04

$$\log(a_T) = a_1 T^2 + a_2 T + a_3$$

$$E(t) = E_\infty + \sum_{i=1}^{N} E_m e^{-t/\rho_m}$$

S-VECD Fatigue Properties	
α	3.37
C vs. S	
C_{11}	4.19E-03
C_{12}	4.10E-01
G^R Failure Criterion	
γ	2.18E+10
δ	-1.857
D^R Failure Criterion	
D^R	0.64
Damage Capacity	
S_{app}	29.10

$$C = 1 - C_{11} \cdot S^{C_{12}}$$

$$G^R = \gamma \cdot N_f^{\ \delta}$$

$$D^R = \frac{\int_0^{N_f} (1-C)dN}{N_f}$$

$$\frac{\left(\frac{a_T^{\frac{C_{12}}{\alpha+1}}}{C_{11}} D^R\right)^{\frac{1}{C_{12}}}}{10,000}$$

Export FlexPAVE Dynamic Modulus Inputs

Export FlexPAVE Fatigue Inputs

Description: Provides a summary of the shift factor model coefficients, which can be exported as an input file to FlexPAVE. Not data entry is required.

Instructions: To export a FlexPAVE input file, press the **Export FlexPAVE Inputs** button.

Reference Model	
ε_0	0.00224
N_1	1.78777
β	0.76643

$$\varepsilon_{vp} = \frac{\varepsilon_0 \times N}{(N_1 + N)^\beta}$$

$$\varepsilon_{vp} = \frac{\varepsilon_0 \times N_{red}}{(N_1 + N_{red})^\beta}$$

$$N_{red} = A \cdot N \left(\frac{\xi_p}{1}\right)^{p1} \left(\frac{\sigma_v}{P_a}\right)^{d1}$$

$$A = 10^{p_2} \cdot 10^{d_2}$$

Reduced Load Time	
p_1	0.705
p_2	0.281

$$a_{\xi_p} = p_1 \log(\xi_p) + p_2$$

Vertical Stress Shift	
d_1	3.191
d_2	-2.782

$$a_{\sigma_v} = d_1 \log(\sigma_v / P_a) + d_2$$

T_{ref} (°C)	54

Export FlexPAVE Inputs

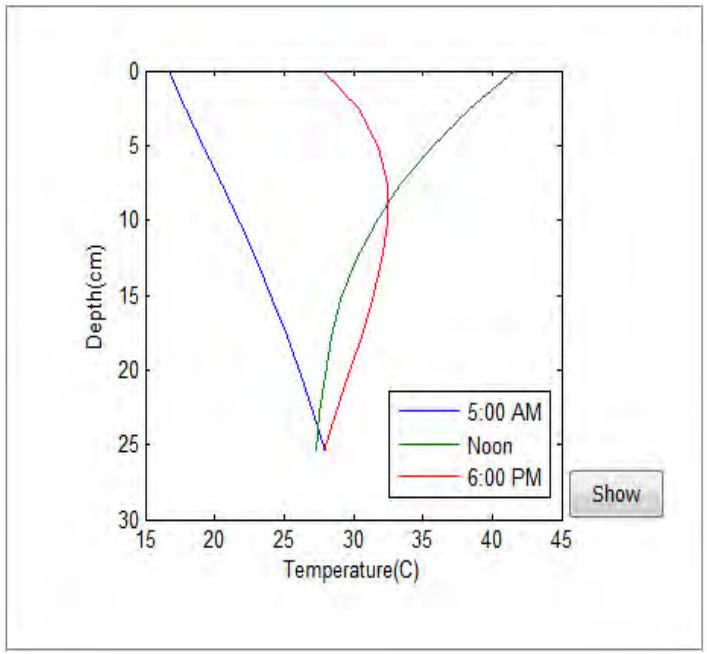
FlexPAVE™ 1.0

Pavement Performance Analysis

EICM in FlexPAVE™

Temperature Profile Input

- EICM
- EICM Text File
- Isothermal



EICM DataBase Temperature

State AL Year 2014 Day 6

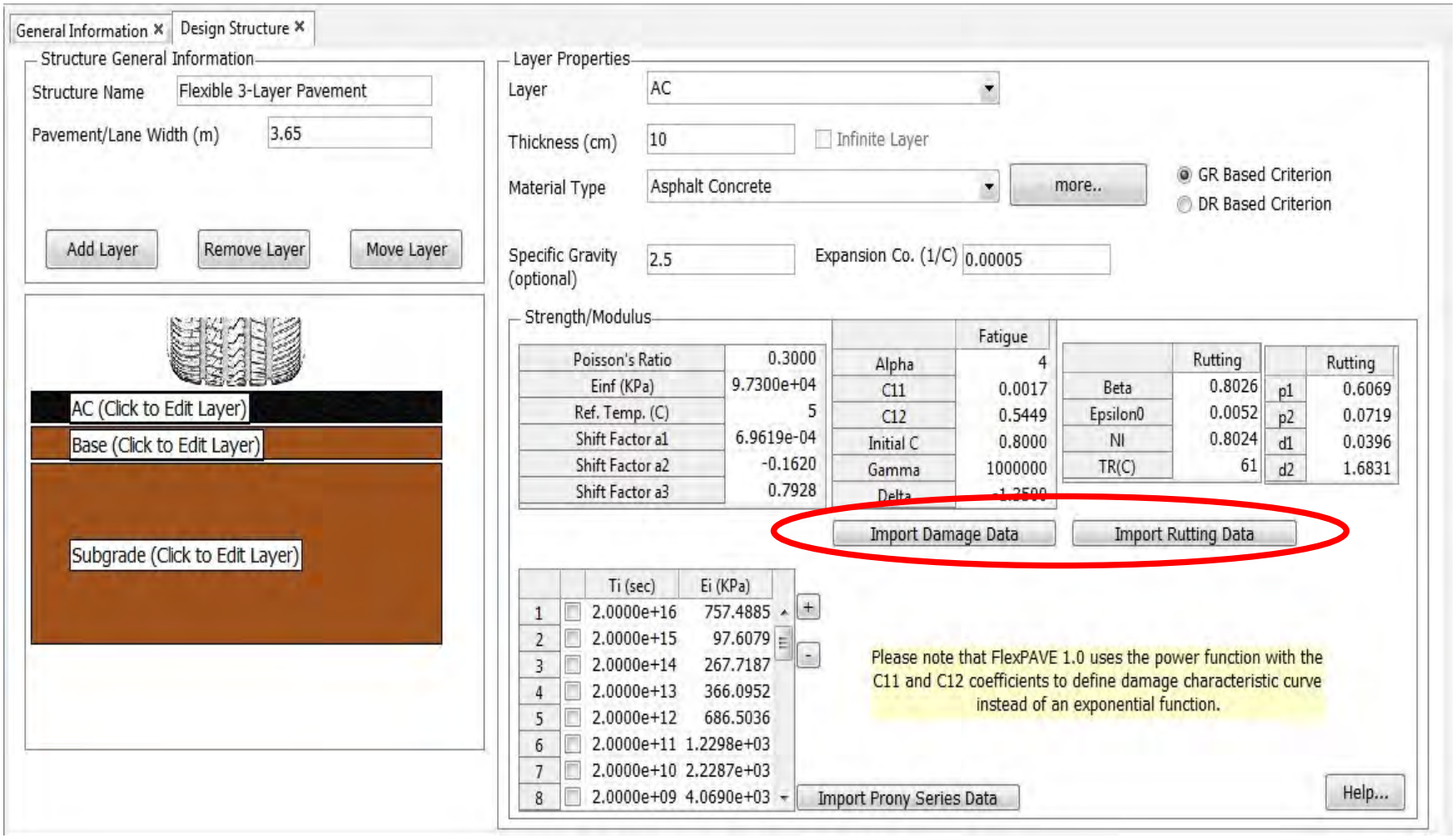
City DECATUR Month Aug

Time\Depth (cm)	0	2.54	5.08	7.62	10.16	12.7
Midnight	17.17	19.56	21.56	23.22	24.56	25.67
1:00 AM	17.22	18.94	20.72	22.28	23.72	24.89
2:00 AM	16.11	18.22	20.06	21.67	23.06	24.28
3:00 AM	16.67	18.17	19.67	21.11	22.50	23.78
4:00 AM	16.11	17.78	19.33	20.78	22.11	23.39
5:00 AM	16.67	17.89	19.22	20.56	21.83	23.06
6:00 AM	19.44	19.33	19.89	20.78	21.78	22.89
7:00 AM	25.17	23.06	22.17	22.06	22.50	23.17
8:00 AM	30.56	27.39	25.39	24.33	24.00	24.11
9:00 AM	35.17	31.39	28.72	26.94	25.94	25.50
10:00 AM	38.28	34.83	31.83	29.61	28.11	27.17
11:00 AM	39.89	36.50	33.78	31.61	29.94	28.78
Noon	41.56	38.39	35.67	33.39	31.56	30.17
1:00 PM	41.94	39.33	36.89	34.72	32.89	31.39
2:00 PM	41.00	39.33	37.44	35.56	33.83	32.28
3:00 PM	39.00	38.11	36.94	35.61	34.17	32.83
4:00 PM	36.83	36.67	36.06	35.17	34.11	32.94
5:00 PM	33.06	34.17	34.44	34.17	33.56	32.72
6:00 PM	27.89	30.39	31.83	32.44	32.44	32.00

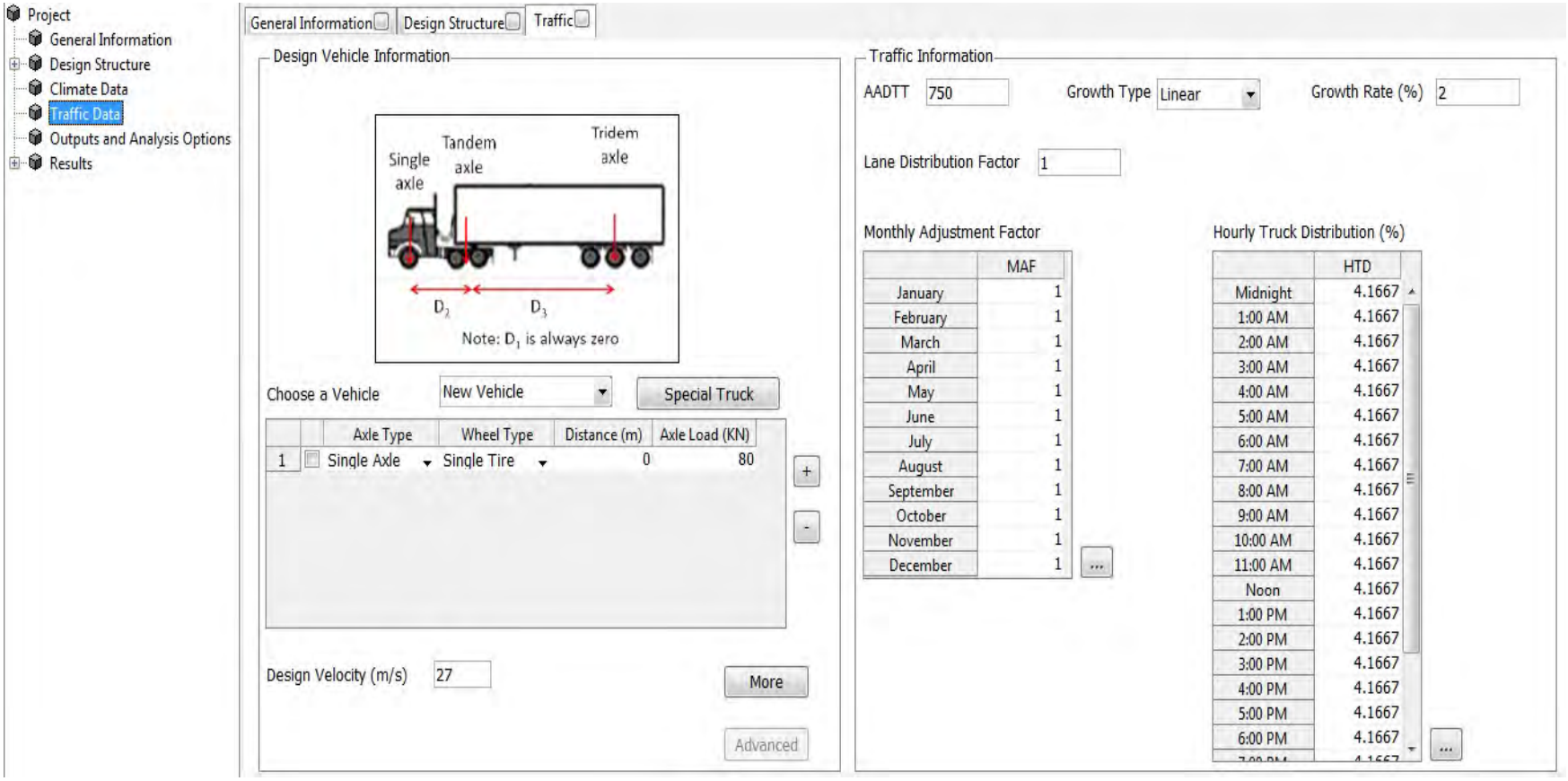
Refresh

Show

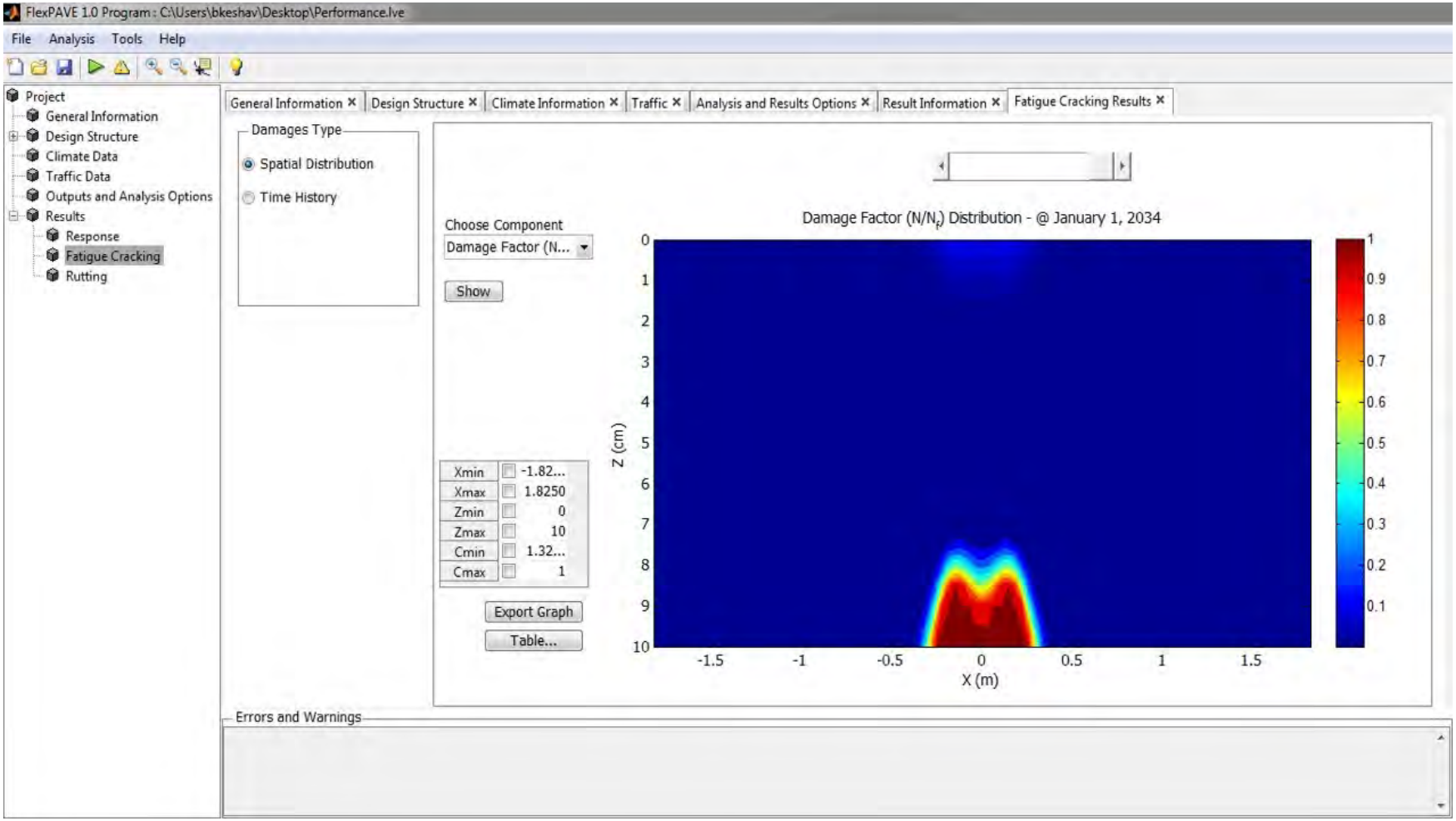
Material Properties



Traffic Data

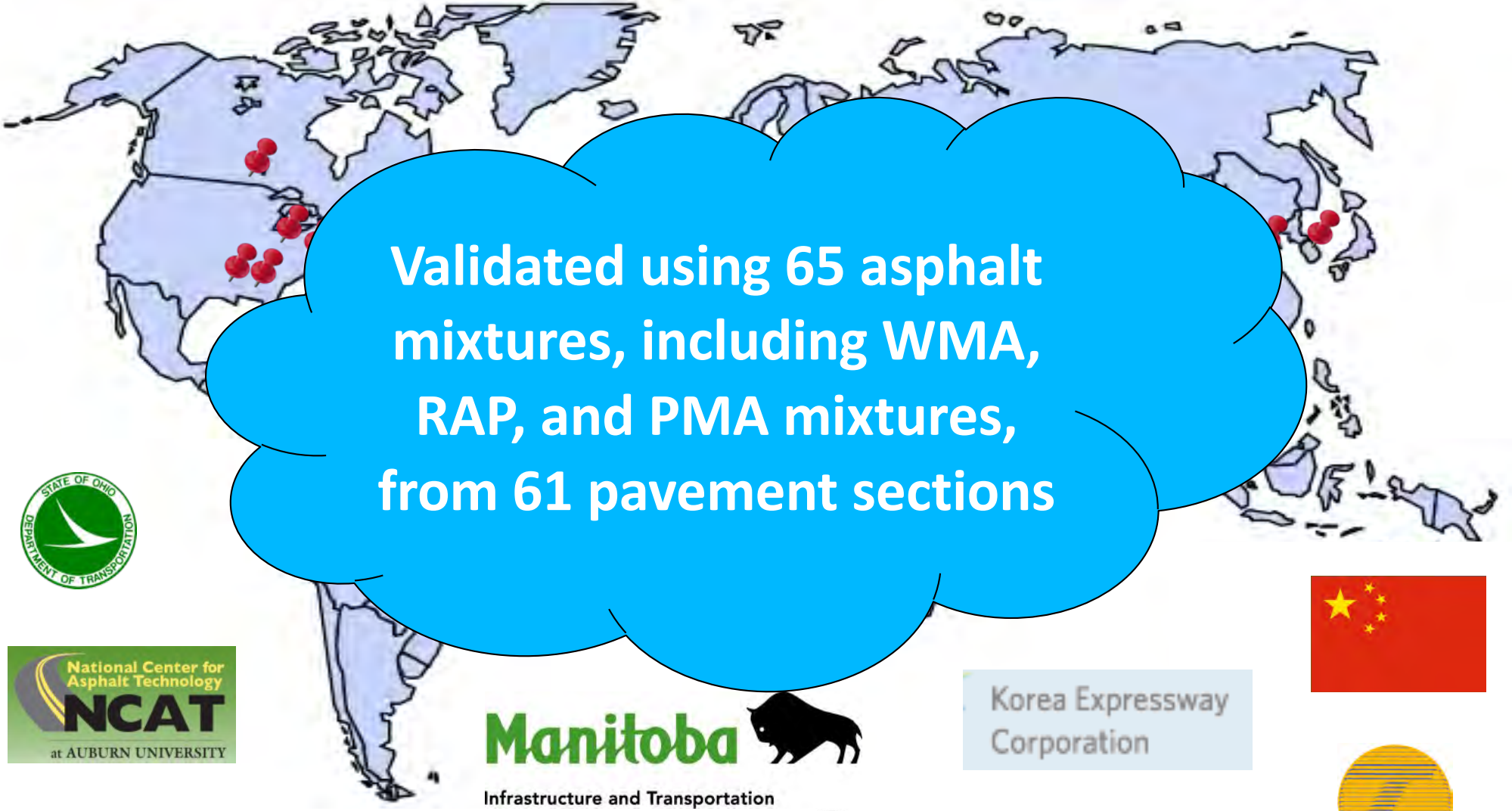


Damage Contour



Field Validation

Validation Sections



Validated using 65 asphalt mixtures, including WMA, RAP, and PMA mixtures, from 61 pavement sections

STATE OF OHIO DEPARTMENT OF TRANSPORTATION

National Center for Asphalt Technology NCAT at AUBURN UNIVERSITY

Manitoba Infrastructure and Transportation

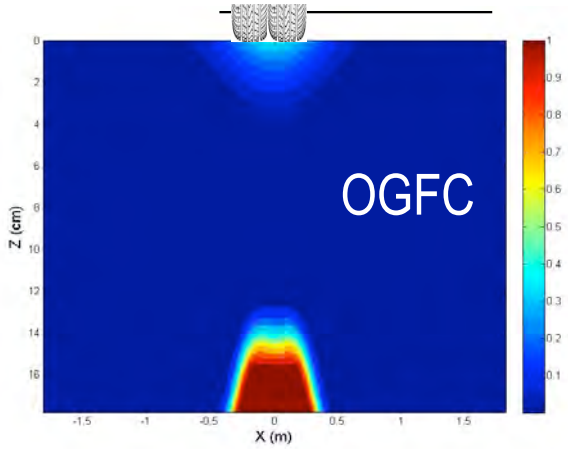
Korea Expressway Corporation

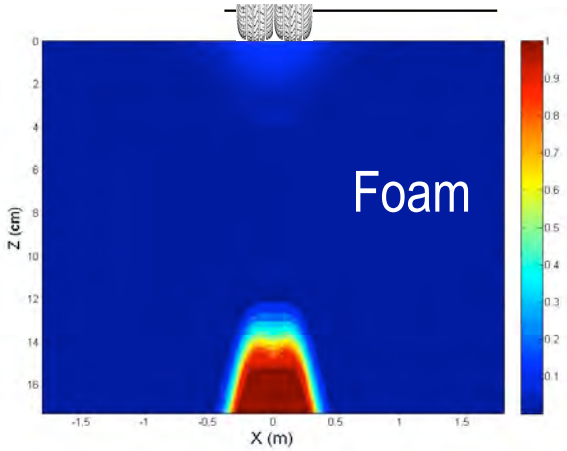
Western Research INSTITUTE

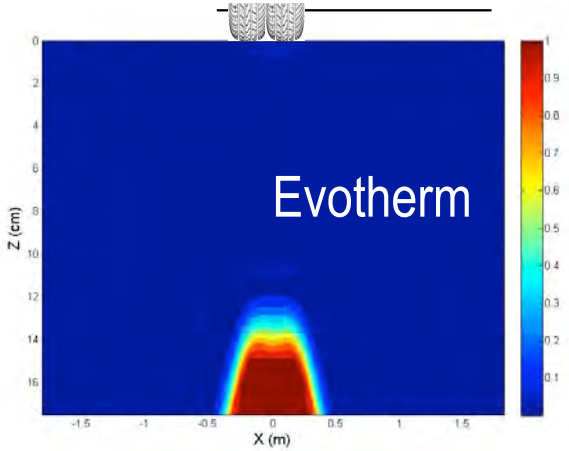
U.S. Department of Transportation Federal Highway Administration

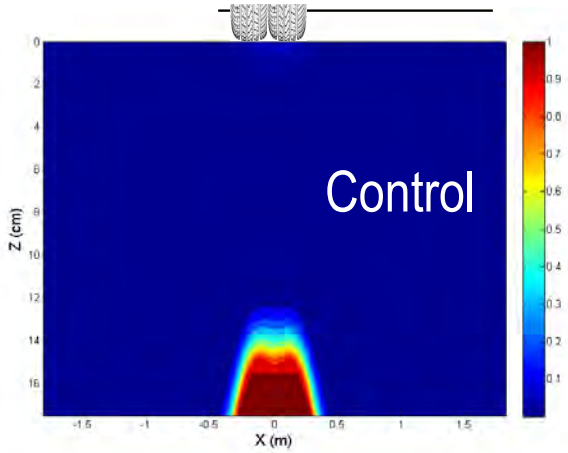
FlexPAVE™ Simulation

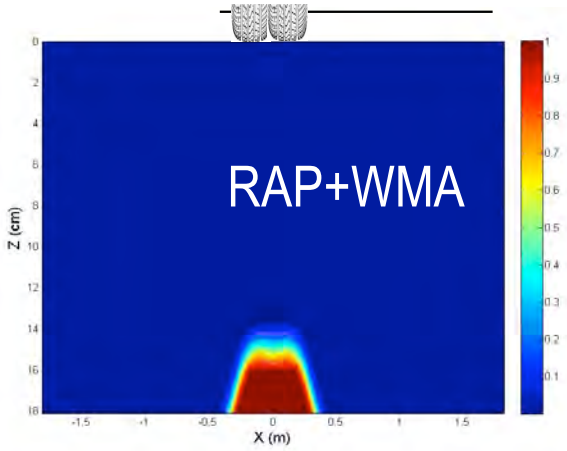
NCAT Test Track

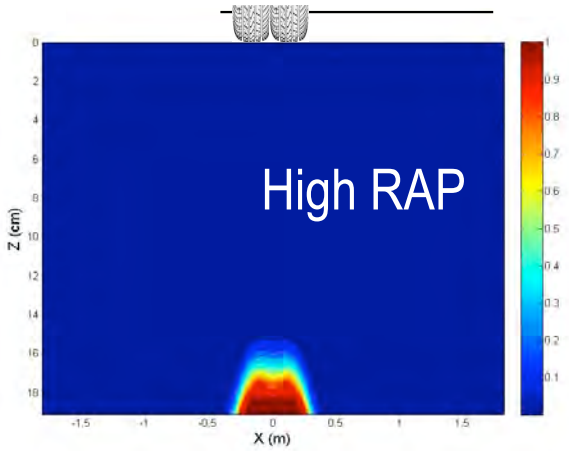






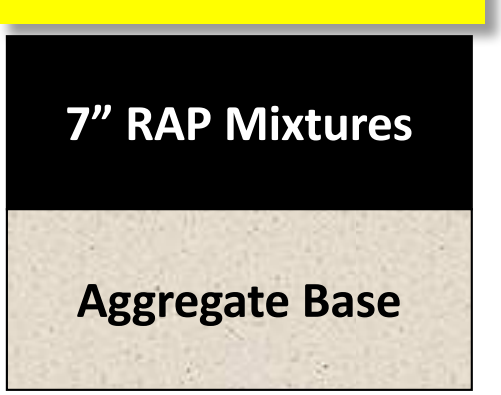


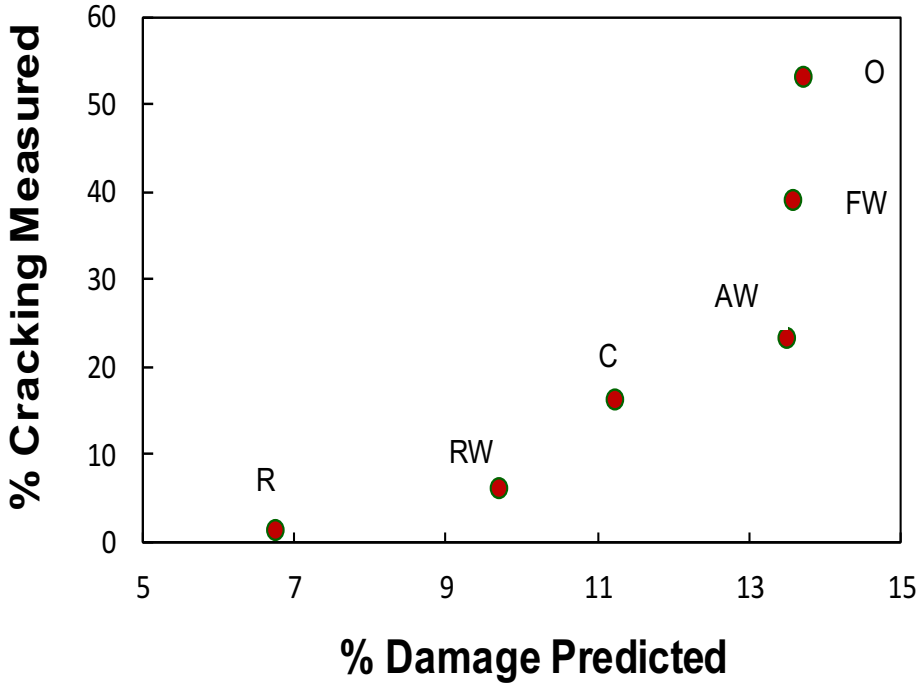




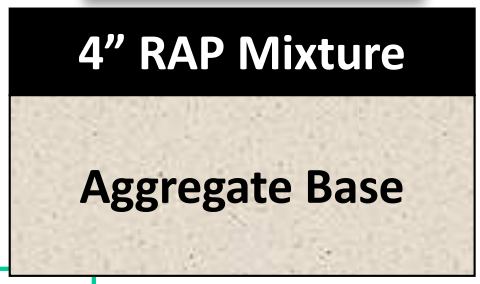
RAP Performance in Pavements

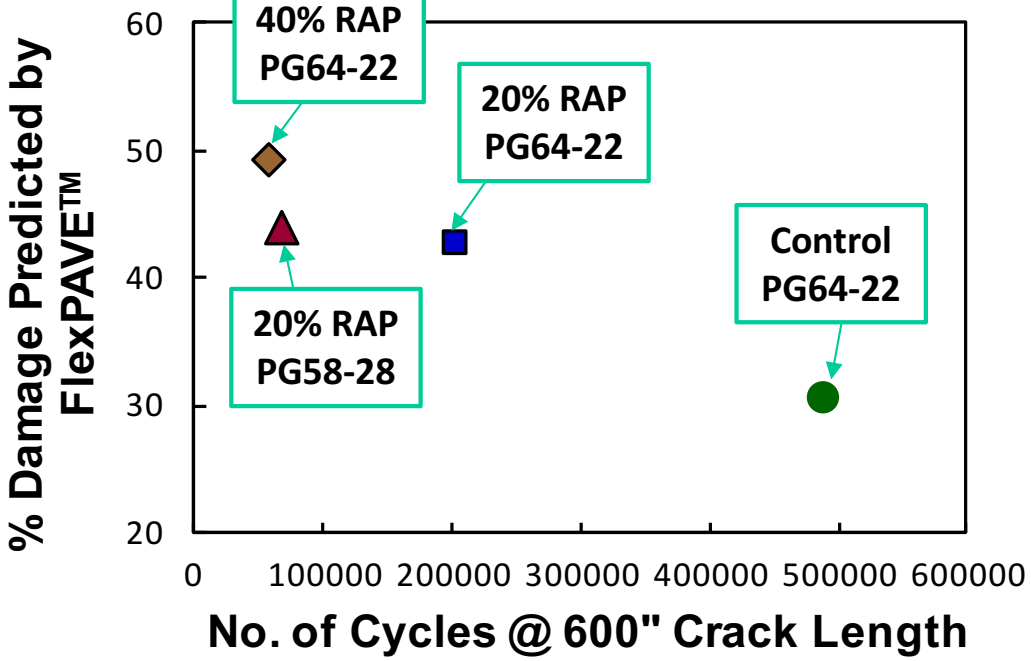
NCAT Test Track





FHWA-ALF

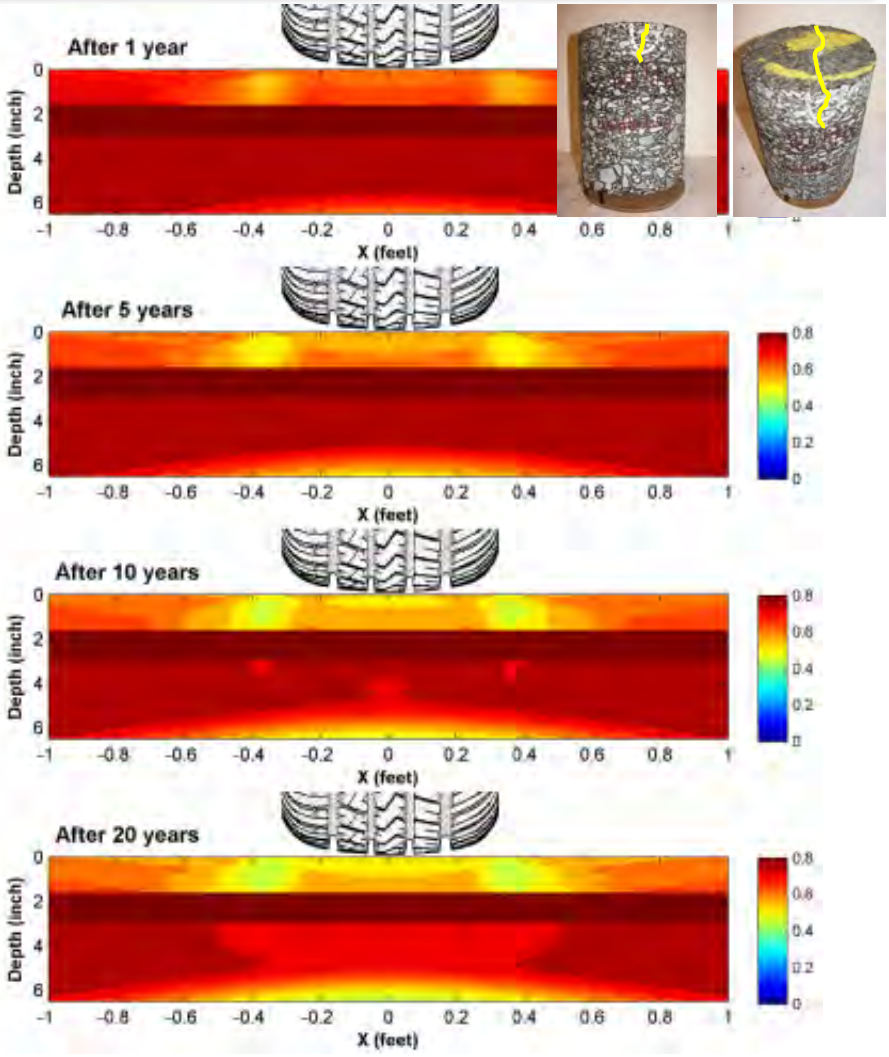




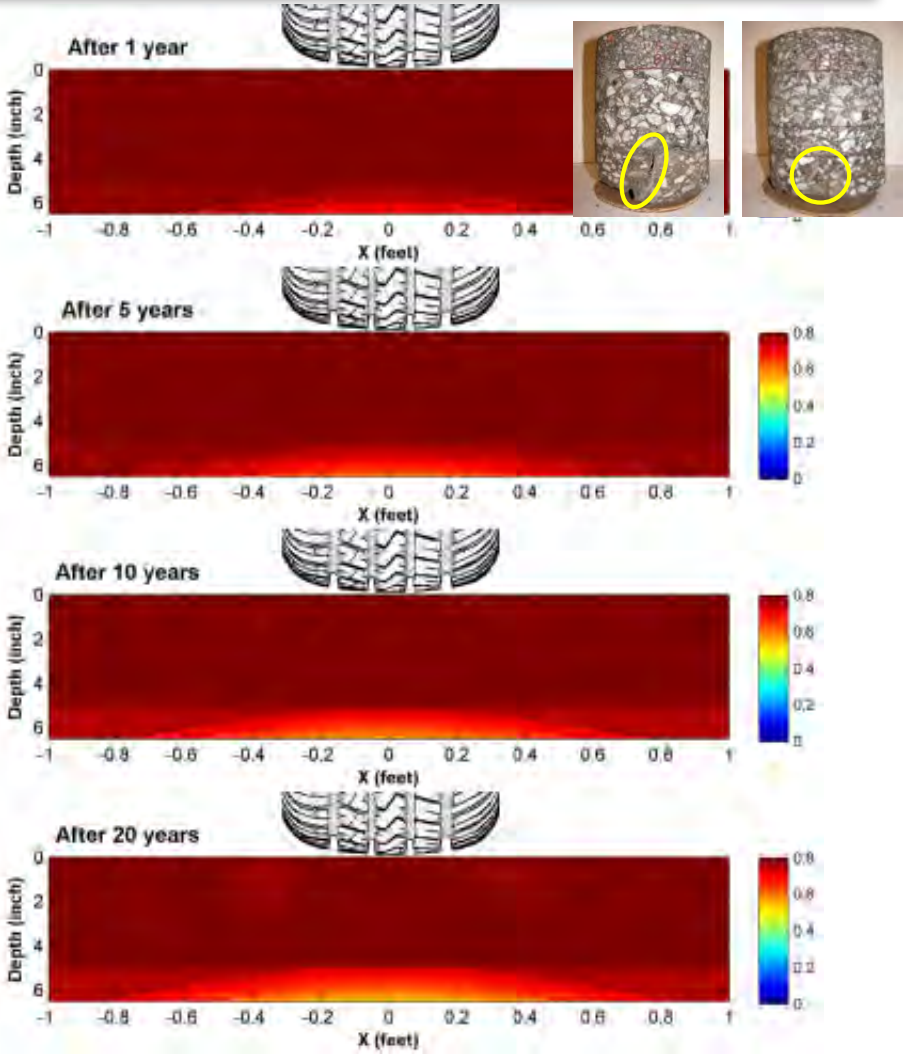
Applications

Forensic Investigation

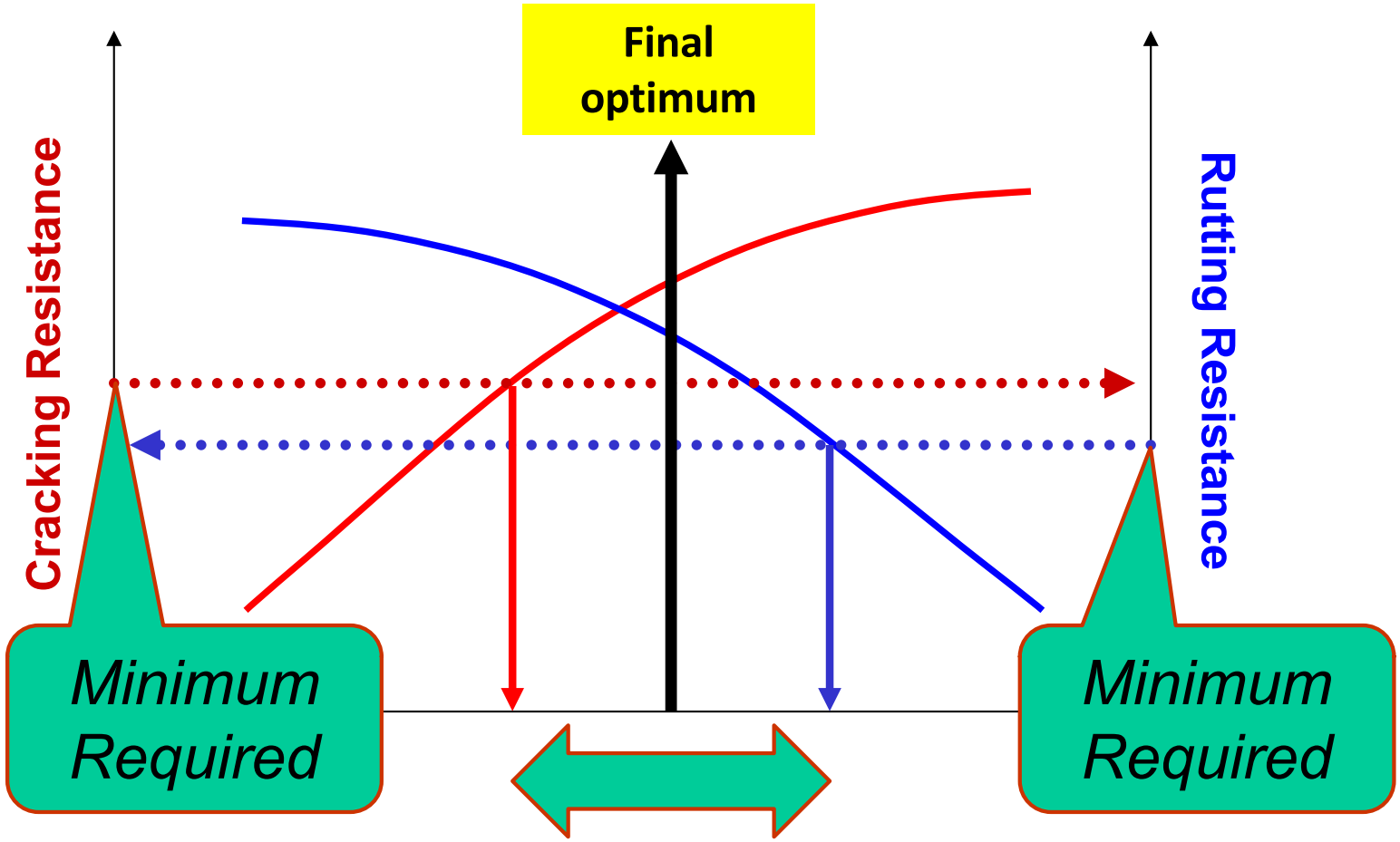
NC-24 with *Observed* TDC



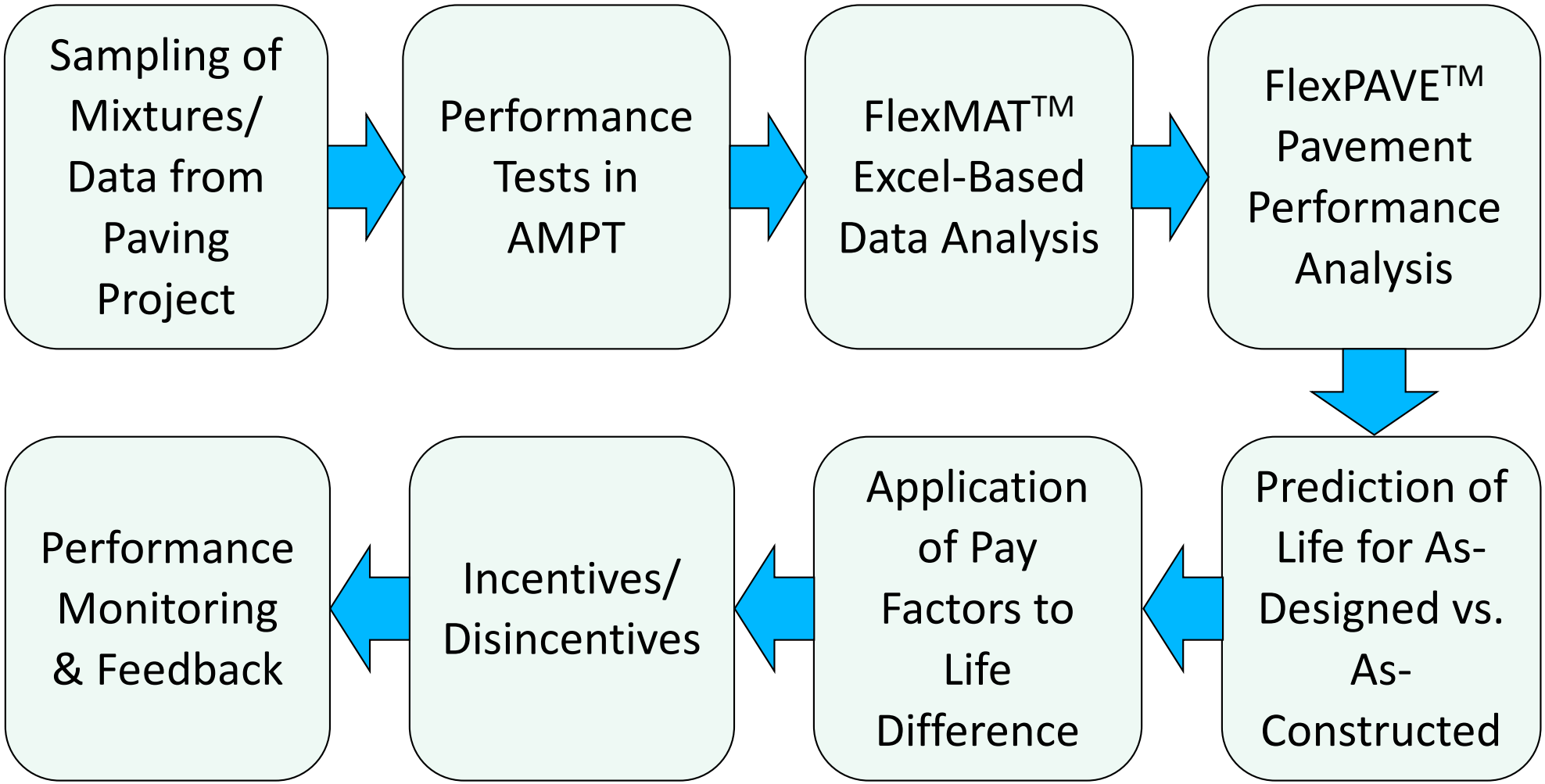
US-74 with *Observed* BUC



Performance-Engineered Mix Design



FHWA PRS Framework



Current Status

- Ruggedness and inter-laboratory study on TP 107 under FHWA project (both 100 mm and 38 mm geometries)
- Shadow projects for PRS specifications
  - Maine DOT
  - Missouri DOT
  - Maryland DOT
  - New Jersey DOT
  - Ontario Ministry of Transportation
  - FHWA/Federal Lands of Highway
  - North Carolina DOT

Summary

- AMPT cyclic fatigue test (TP 107) is an efficient test method based on sound mechanistic principles.
- The AMPT cyclic fatigue test and accompanying models have been validated using over 60 pavements and 60 mixtures, including RAP, WMA, and PMA.
- Applications include:
  - Determination of endurance limits
  - Prediction of thermal, bottom-up, and top-down cracking
  - Performance-engineered mixture design
  - Local calibration of Pavement ME Design
  - Performance-related QA specifications
  - Forensic investigation of cracking in pavements
- AMPT cyclic fatigue test can be used to integrate mix design, pavement design, and performance-related QA specifications.

Thank you!

Questions?