Update: AASHTO TP 107
AMPT Cyclic Fatigue

FHWA Mixture and Construction Expert Task Group
May 1, 2017
Ames, Iowa

U.S. Department of Transportation
Federal Highway Administration

Acknowledgements

- Y. Richard Kim, Cassie Castorena – NC St. Univ.
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- FHWA Offices of Asset Management, Pavement, and Construction; Office of Infrastructure R&D

Agenda

- FHWA Performance-Related Specification (PRS) initiative
- AASHTO TP 107 improvements
- Integration of AASHTO TP 107 into PRS
- Asphalt Mixture Performance Tester (AMPT) implementation
- Asphalt Technology Guidance Program

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

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)
- Structural response model (stresses and strains)
- Performance volumetric relationships used in construction

FHWA PRS Initiative

PERFORMANCE TESTING ONLY IN DESIGN PHASE!!!

- ...f fundamental tests to capture ...tween as-designed and as-built
- As... ...ance Tester (AMPT) ... ngineered mixture desig...
- Structural response ... strains)
- Performance volumetric relatio... in construction

Performance-Engineered Mixture Design

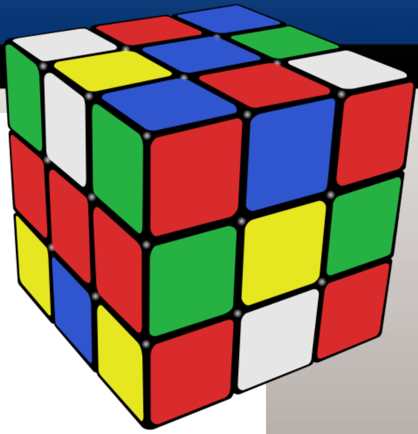
- Fundamental
  - How much distress? How much life?
  - Stresses and strains
  - Material properties (i.e., modulus)
  - Use with structural response model (FlexPAVE™)
  - Many temperature/loading conditions represented
- Index-Based
  - Go/no-go: correlation-based
  - Some engineering properties, some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

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
- Verifying performance prediction models
  - Completed/continuous
- Performance volumetric relationships
  - Ongoing
- Same principles and methods between mix design and PRS
  - Ongoing

Testing Efficiency and Simplicity AASHTO TP 107 Revisions

- Submitted to AASHTO SOM TS 2d
- Add failure criterion
- Simplification of language
- AMPT-specific
- Removal of spreadsheet derivation
- New strain selection guidance
- Small-specimen appendix
- Instructional videos (links available)

Standardization of Test Methods

FULL SIZE SPECIMEN

Specimen Prep
AASHTO R 83

Dynamic Modulus
AASHTO T 378

Cyclic Fatigue
AASHTO TP 107

Stress Sweep Rutting
AASHTO TP XXX

SMALL SIZE SPECIMEN

Specimen Prep
AASHTO PP XXX

Dynamic Modulus
AASHTO TP XXX

Cyclic Fatigue
AASHTO TP XXX

Performance-Related Specification PASSFlex™

Field Validation of AMPT Cyclic Fatigue

- Pavement prediction software built from models (FlexMAT^{TM} and FlexPAVE^{TM})
- Field validation
  - 59 mixtures
  - 55 different pavement structures
- Develop laboratory-to-field transfer functions
- **Volumetrics have a seat at the table!**

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

FlexMAT™ (2)

Description: Fits the sigmoidal and time-temperature shift factor models to the storage modulus data obtained from the dynamic modulus test results.

Instructions:

(1) Enter the percentage of average Voids in Mineral Aggregate (VMA) and percentage of Voids Filled with Asphalt (VFA) of the dynamic modulus test specimens into the green cells within the maximum limiting modulus table.

(2) If the buttons within the Import Data tab were not used to import the test data, copy and paste the data corresponding to the fields included in the Measured Data table into the green cells from the summary dynamic modulus test files. Each block of test data should correspond to a single replicate and temperature of testing. Include data for each test specimen. Do not average data prior to entry into the spreadsheet.

(3) Review the load standard error, average deformation drift, average deformation standard error, deformation uniformity, and phase uniformity cells within the Measured Data table. The cells will appear yellow where the data quality requirements of AASHTO TP 79 and AASHTO PP 61 are not met, which may indicate an invalid test.

Maximum Limiting Modulus	
VMA (%)	16
VFA (%)	73
P_c	0.874
Max E' (kPa)	2.28E+07

$$P_c = \frac{\left(20 + \frac{435,000(VFA)}{VMA}\right)^{0.58}}{650 + \left(\frac{435,000(VFA)}{VMA}\right)^{0.58}}$$

$$\max E' = P_c\left[29,000,000\left(1-\frac{VMA}{100}\right) + 3,000,000\left(\frac{VFA \, x VMA}{10,000}\right)\right] + \frac{1-P_c}{\left[\frac{\left(1-\frac{VMA}{100}\right)}{29,000,000} + \frac{VMA}{3,000,000(VFA)}\right]}$$

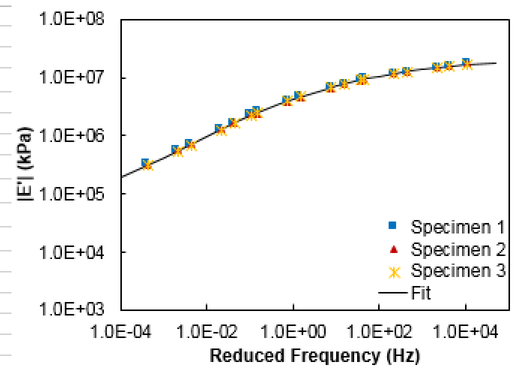
Shift Factor	
a_1	0.0008
a_2	-0.1738
a_3	3.3172
T_{ref}	21.1

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

Sigmoidal Function	
k	4.257
δ	-1.177
γ	-0.468
Sum of Sq Error	1.11E-02

$$\log\left(E'(\omega, T)\right) = \log\left(E'(\omega_R)\right) = \kappa + \frac{\log(\max E') - \kappa}{1 + e^{\delta + \gamma \log(\omega_R)}}$$

Fit Time-Temperature Shift Factor and Sigmoidal Model



MEASURED DATA

Frequency (Hz)	25	10	5	1	0.5	0.1
Dynamic modulus (MPa)	9559	8195	7256	5161	4433	2908
Phase angle (Degrees)	15.54	17.1	18.45	22.11	23.53	27.48
Average temperature (°C)	19.9	19.9	19.9	20	20	20
Average micro-strain	62	62	61	61	61	61
Load standard error (%)	5.7	2.9	1.7	0.6	0.5	0.7
Average deformation drift (%)	-78.1	-95.6	-97.6	-139.7	-132.5	-174.1
Average deformation standard error (%)	5.5	3.5	2.7	2.1	1.7	2.4
Deformation uniformity (%)	17.8	17.1	16.4	15.2	14	12.9
Phase uniformity (Degrees)	0.2	0.2	0.3	0.7	0.9	1.4
Frequency (Hz)	25	10	5	1	0.5	0.1
Dynamic modulus (MPa)	2743	2031	1596	878.2	698.6	403.1
Phase angle (Degrees)	31.59	33.51	34.42	35.25	34.48	32.2
Average temperature (°C)	40.1	40.1	40.1	40.1	40.1	40.1
Average micro-strain	61	58	57	55	53	49
Load standard error (%)	8.3	5.2	3.5	2.7	3.2	5.8

SIGMOID

Reduced Frequency	######	#####	######	#
E' Measured (kPa)	######	#####	######	#
E' Predicted (kPa)	######	#####	######	#
Sq. Error	######	#####	######	#
Reduced Frequency	1.02E-01	#####	######	#
E' Measured (kPa)	######	#####	######	#
E' Predicted (kPa)	######	#####	######	#
Sq. Error	######	#####	######	#

FlexMAT™ (3)

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P

Description: Determines the failure criteria parameters, calculates the damage capacity, and optimizes the damage characteristic curve model coefficients

Instructions: No data action or entry is required. The quality of the damage characteristic curve model fit and repeatability of fatigue test results can be observed in the C versus S graph. The C versus S curves f be in good agreement. The failure criteria parameters are calculated automatically. The G^R versus N_f and Cumulative (1-C) versus N_f graphs can also be used to further assess sample-to-sample variability. The re N_f should be linear in log space. The relationship between Cumulative (1-C) and N_f should be linear. Thus, the repeatability of the fatigue tests can be assessed by the R^2 values reported in the G^R versus N_f and C graphs and outliers can be identified by visually observing deviations from the trend line of the other data points in these plots.

Criteria Model Coefficients	
γ	######
δ	-1.220

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

D^R Failure Criteria	
D^R	0.63

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

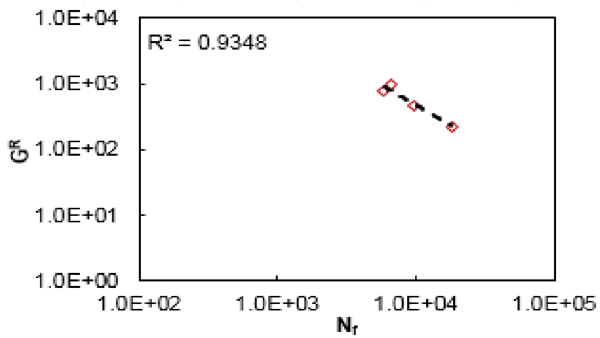
C vs. S Model Coefficients	
C_{11}	3.174E-03
C_{12}	4.299E-01

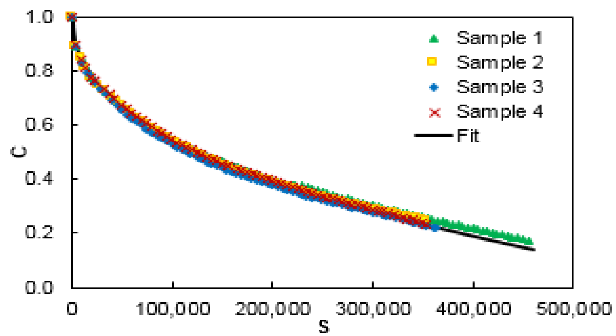
$$C = 1 - C_{11} \cdot S^{C_{12}}$$

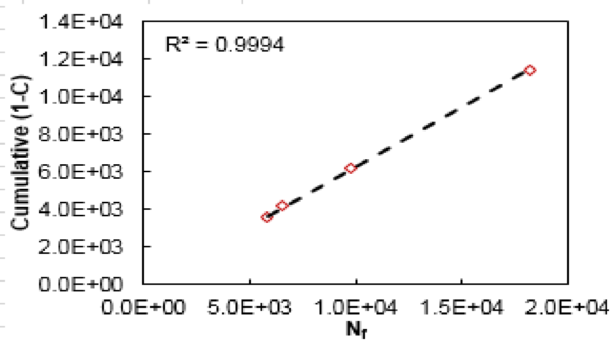
Damage Capacity @ Fatigue Test Temperature	
S_{app}	27.11

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

	N_f	G^R	$\log(N_f)$	$\log(G^R)$	Cum. (1-C	D^R
Sample 1	######	1.00E+03	3.81	3.00	######	0.65
Sample 2	######	4.81E+02	3.99	2.68	######	0.63
Sample 3	######	2.28E+02	4.26	2.36	1.15E+04	0.63
Sample 4	######	7.68E+02	3.77	2.89	######	0.61

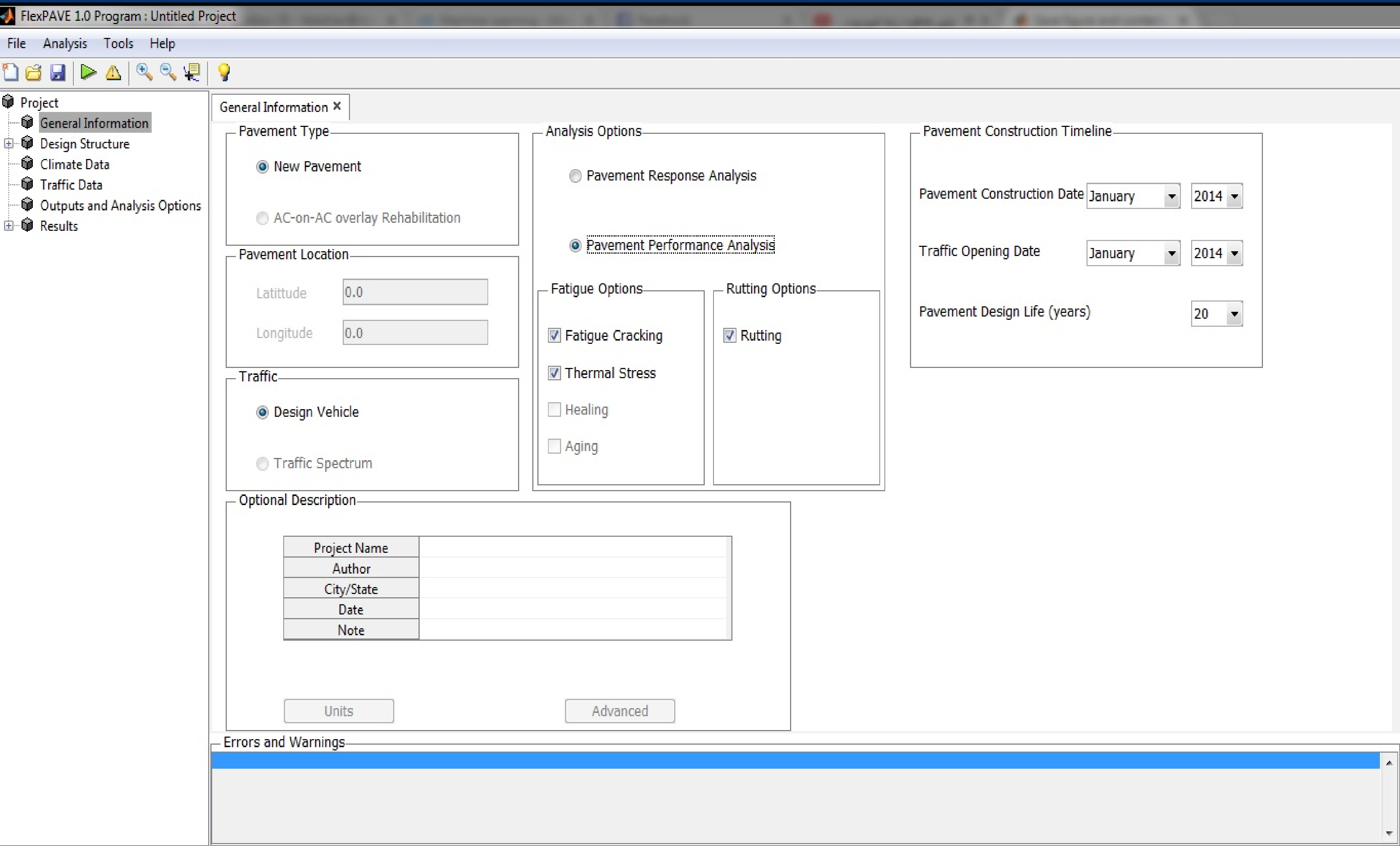




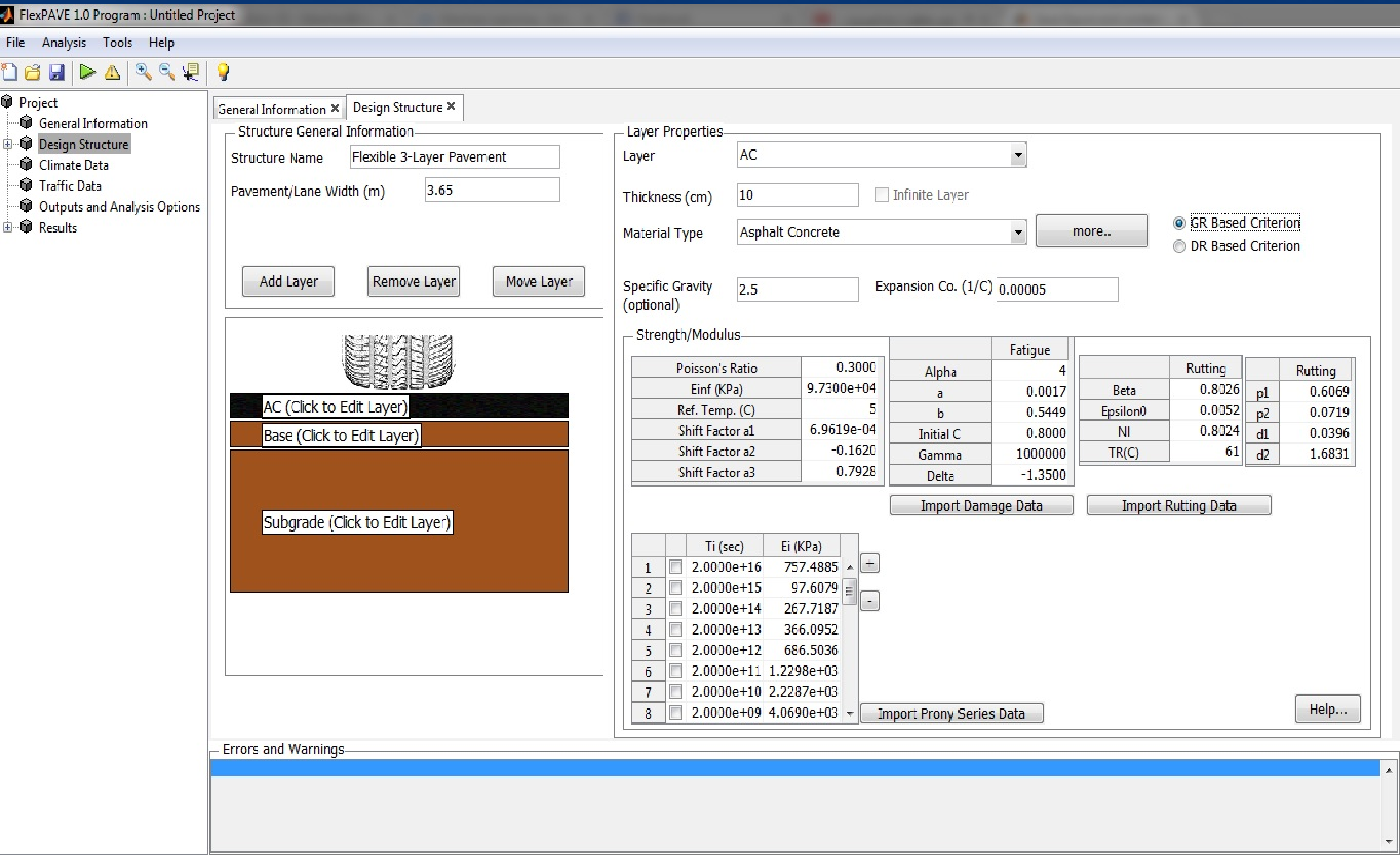


C vs. S Data				
	C	S	log(1-C)	Log(S)
Sample 1	1.000	0		
	0.894	4485	-0.976	3.652
	0.848	9064	-0.818	3.957
	0.819	12982	-0.741	4.113
	0.777	19792	-0.651	4.296
	0.759	24511	-0.617	4.389
	0.759	24511	-0.617	4.389
	0.725	33629	-0.561	4.527
	0.705	39722	-0.530	4.599
	0.689	44632	-0.507	4.650
	0.677	48541	-0.490	4.686
	0.666	51984	-0.477	4.716
	0.649	57887	-0.455	4.763
	0.630	64988	-0.431	4.813
	0.619	69019	-0.419	4.839
	0.606	74313	-0.404	4.871
	0.594	78985	-0.392	4.898
	0.581	84527	-0.378	4.927
	0.571	89369	-0.367	4.951
	0.559	94913	-0.355	4.977
	0.548	99974	-0.345	5.000
	0.539	104655	-0.336	5.020
	0.529	109918	-0.327	5.041
	0.520	114715	-0.318	5.060
	0.510	119879	-0.310	5.079
	0.502	124572	-0.302	5.095
	0.492	129951	-0.294	5.114
	0.489	131880	-0.292	5.120
	0.482	139914	-0.286	5.146
	0.474	144967	-0.279	5.161
	0.466	149665	-0.273	5.175
	0.459	154590	-0.267	5.189
	0.451	159760	-0.260	5.203
	0.443	164968	-0.255	5.217
	0.437	169710	-0.249	5.230
	0.430	174674	-0.244	5.242
	0.423	179623	-0.239	5.254
	0.416	184991	-0.233	5.267
	0.410	189605	-0.229	5.278

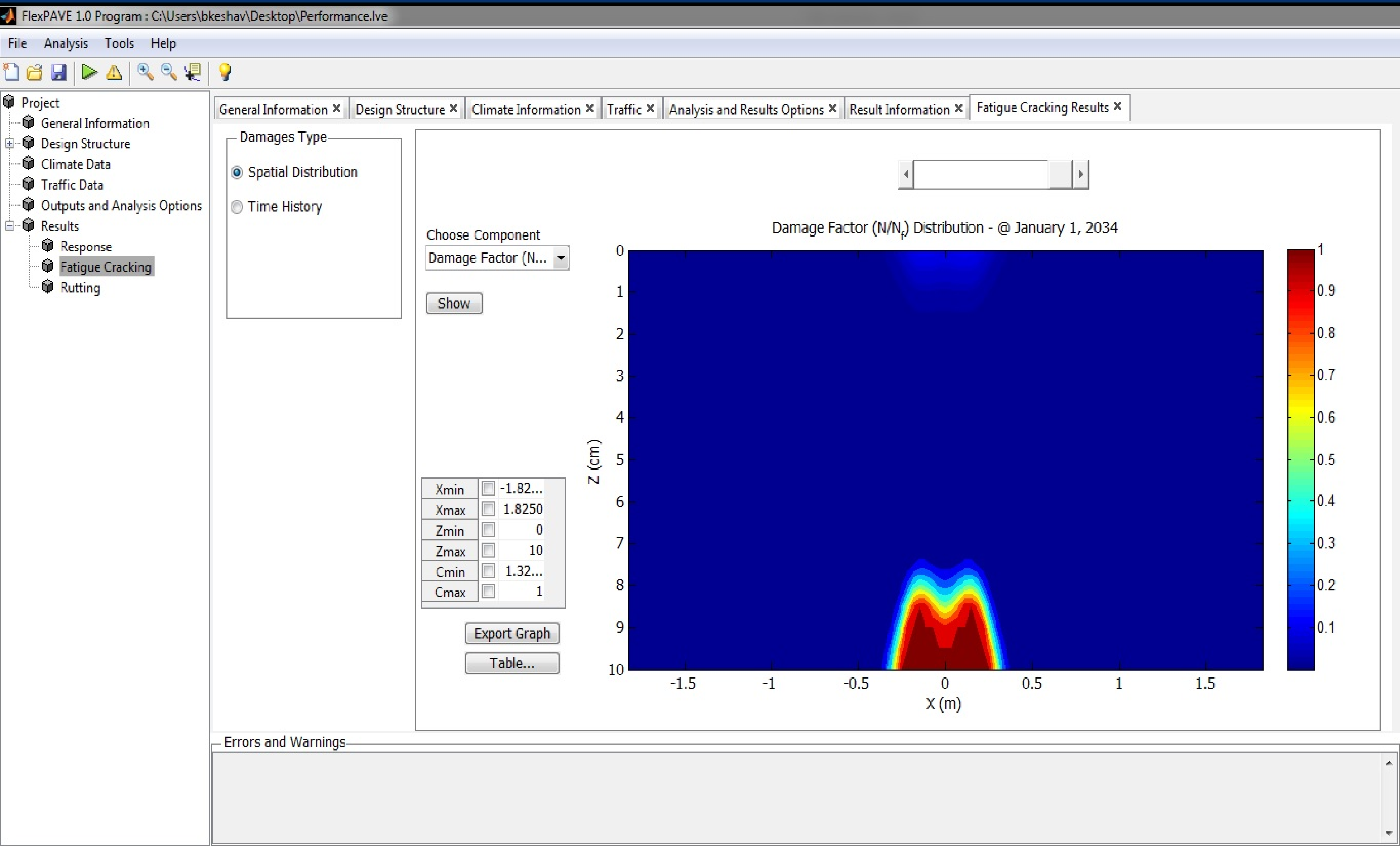
FlexPAVE^{TM}


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
Pavement Type
New Pavement
AC-on-AC overlay Rehabilitation
Pavement Location
Latittude
0.0
Longitude
0.0
Traffic
Design Vehicle
Traffic Spectrum
Analysis Options
Pavement Response Analysis
Pavement Performance Analysis
Fatigue Options
Fatigue Cracking
Thermal Stress
Healing
Aging
Rutting Options
Rutting
Pavement Construction Timeline
Pavement Construction Date
January
2014
Traffic Opening Date
January
2014
Pavement Design Life (years)
20
Optional Description
Project Name
Author
City/State
Date
Note
Units
Advanced
Errors and Warnings

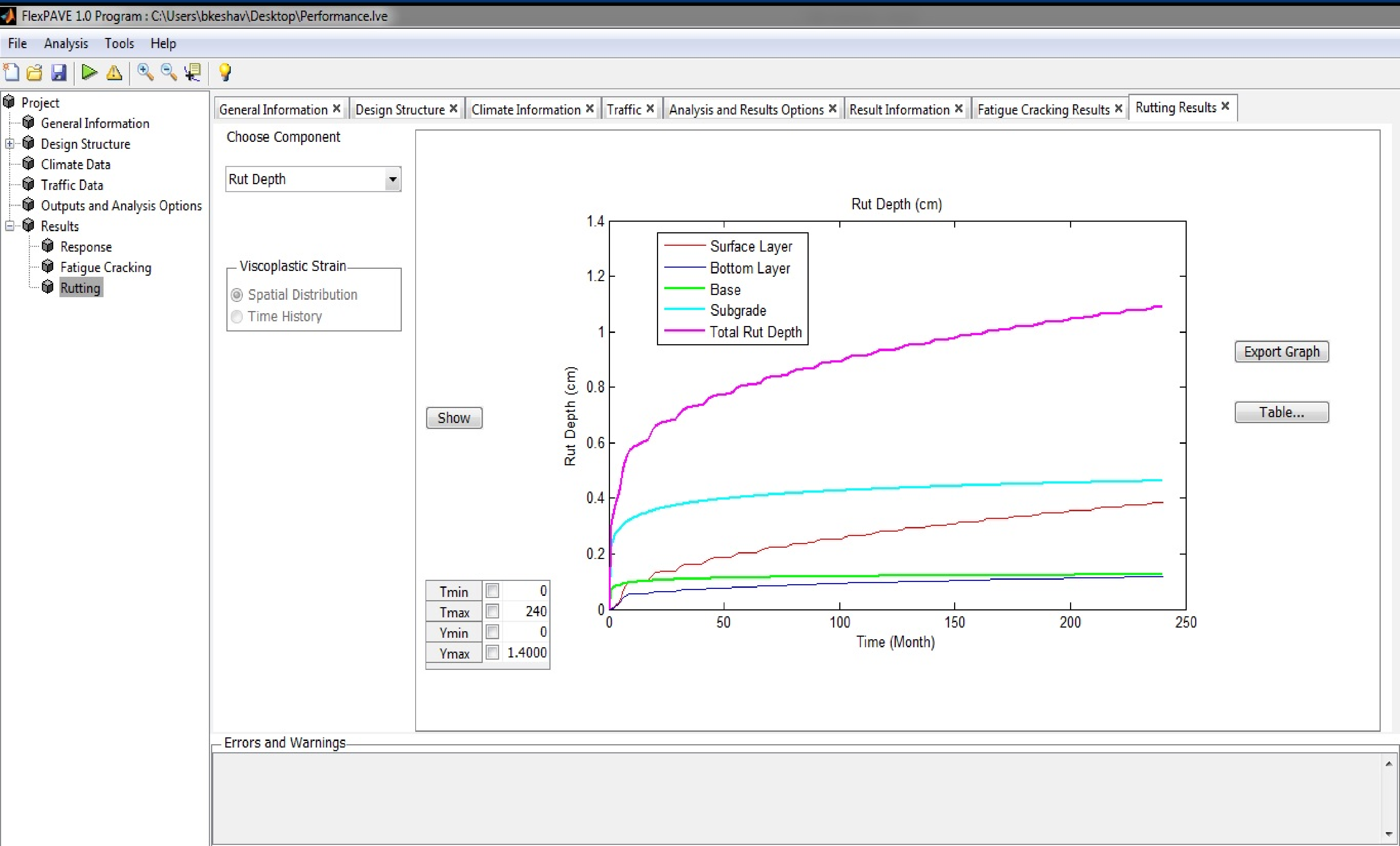
FlexPAVE^{TM} (2)



FlexPAVE^{TM} (3)

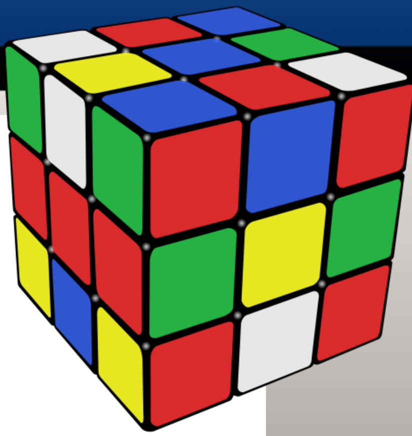


FlexPAVE™ (4)



FlexPAVE 1.0 Program : C:\Users\bkeshav\Desktop\Performance.lve
File Analysis Tools Help
Project
General Information
Design Structure
Climate Data
Traffic Data
Outputs and Analysis Options
Results
Response
Fatigue Cracking
Rutting
General Information
Design Structure
Climate Information
Traffic
Analysis and Results Options
Result Information
Fatigue Cracking Results
Rutting Results
Choose Component
Rut Depth
Viscoplastic Strain
Spatial Distribution
Time History
Show
Tmin 0
Tmax 240
Ymin 0
Ymax 1.4000
Rut Depth (cm)
Surface Layer
Bottom Layer
Base
Subgrade
Total Rut Depth
Rut Depth (cm)
Time (Month)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
50
100
150
200
250
Export Graph
Table...
Errors and Warnings

Challenges with PRS



- Testing efficiency and simplicity
  - Completed/Continuous
- Standardization of test methods
  - Ongoing
- Verifying performance prediction models
  - Completed/continuous
- **Performance volumetric relationships (PVR)**
  - Ongoing
- Same principles and methods between mix design and PRS
  - Ongoing

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

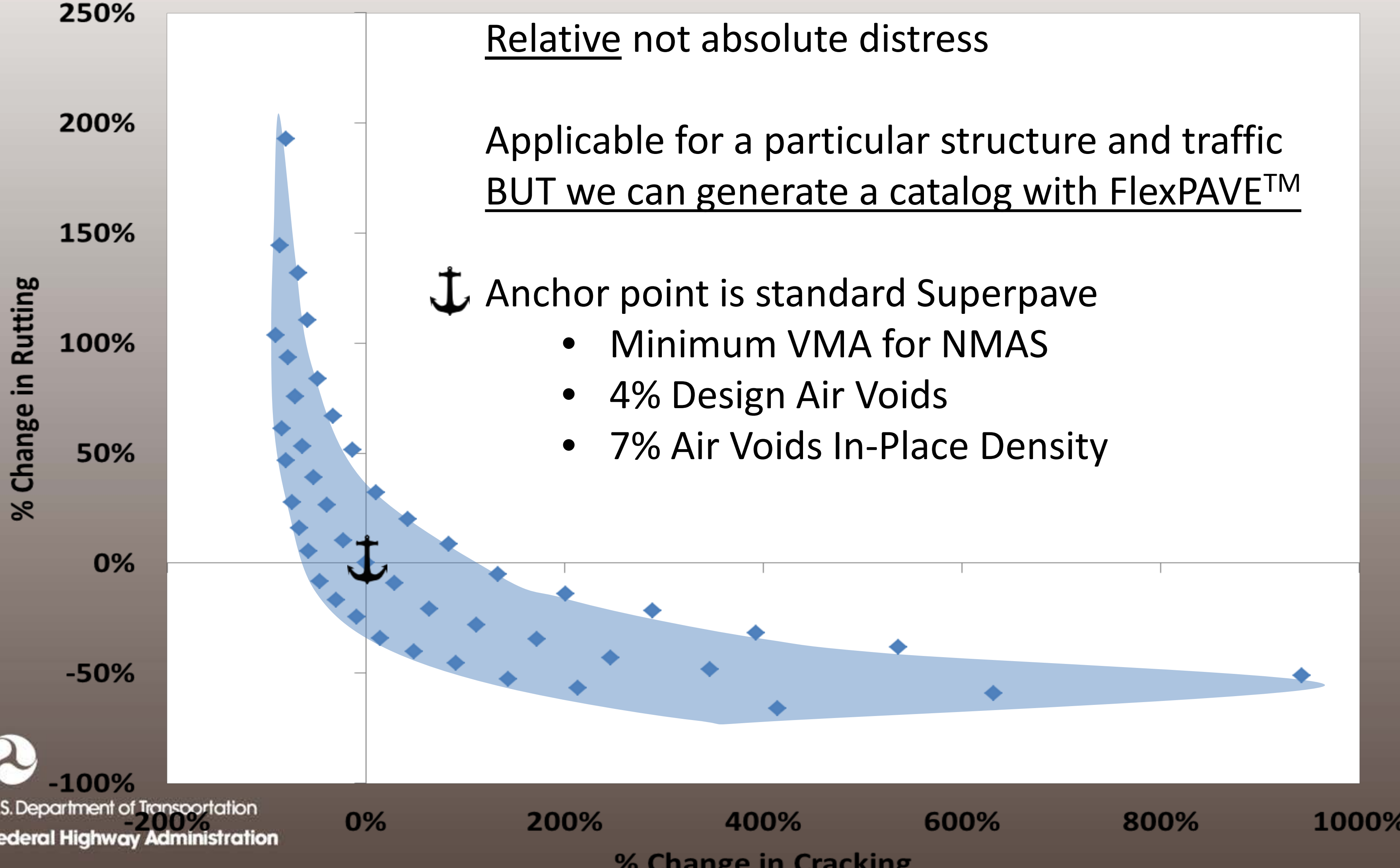
Initial PVR Database

<u>Relative</u> not absolute distress

Applicable for a particular structure and traffic
<u>BUT we can generate a catalog with FlexPAVE™</u>

⚓ Anchor point is standard Superpave

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



AMPT Cyclic Fatigue Summary

- 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 wide range of loading conditions!**

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?

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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 wide range of loading/temperature conditions!**

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)
- Mobile Asphalt Testing Trailer (MATT) projects/training
- User Groups at TRB and regional meetings

AMPT Users Group

- National/International
  - TRB Annual Meeting
  - Discussion of issues, best practices, future efforts
  - 70 attendees, 10 DOTs present
- Regional
  - User-Producer Groups
  - State Asphalt Paving Assoc. meetings

AMPT Users Group

- National/International
  - TRB Annual Meeting

NEXT AMPT USERS GROUP MEETING
JULY 25 AT 1 PM EASTERN

- Regional
  - User-Producer Groups
  - State Asphalt Paving Assoc. meetings

Shadow PRS Status

- Maine DOT – SHRP2 R07
- Western Federal Lands – SHRP2 R07
- Missouri DOT – 2 projects (3 total mixtures)
- North Carolina DOT – SHRP2 R07
- MATT support
- Marketing of success stories
- **SEEKING ADDITIONAL SHADOW PROJECTS WITH DOTs**

U.S. Department of Transportation
Federal Highway Administration

Office of Asset Management, Pavements, & Construction

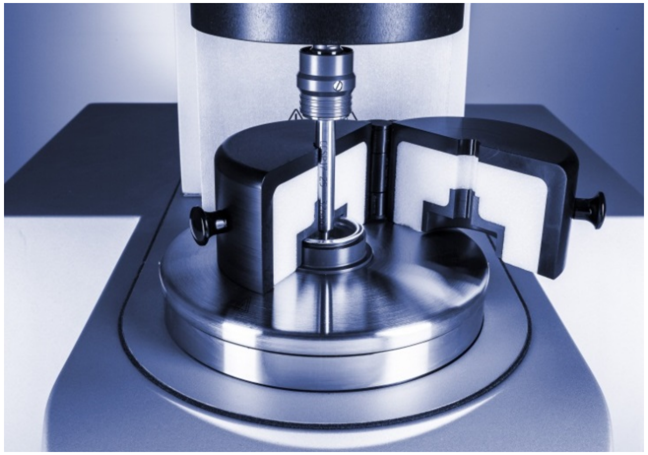
Asphalt Technology Guidance Program (ATGP)

Long-Life Asphalt Pavement for the 21st Century

U.S. Department of Transportation
Federal Highway Administration

Program Objectives

- Advance Performance
- Advance Quality Assurance
- Advance Innovation



Courtesy of Anton Paar

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?
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  - 202.493.3365
  - Richard.duval@dot.gov