

Documenting  
Performance Related Specifications  
Shadow Projects

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# Outline

- Background on FHWA Performance Related Specifications Contract and Shadow Projects
- Audience for the Shadow Project Reports
- Outline for the Shadow Project Reports
- Content of Selected Sections

# *Develop and Deploy Performance-Related Specifications (PRS) for Pavement Construction*

*FHWA DTFH61-13-C-00025*



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Federal Highway Administration

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**ADVANCED ASPHALT TECHNOLOGIES, LLC**  
Engineering Services for the Asphalt Industry

**Ray Bonaquist (flexible)**



**Jason Weiss (rigid)**

# Objective and Scope

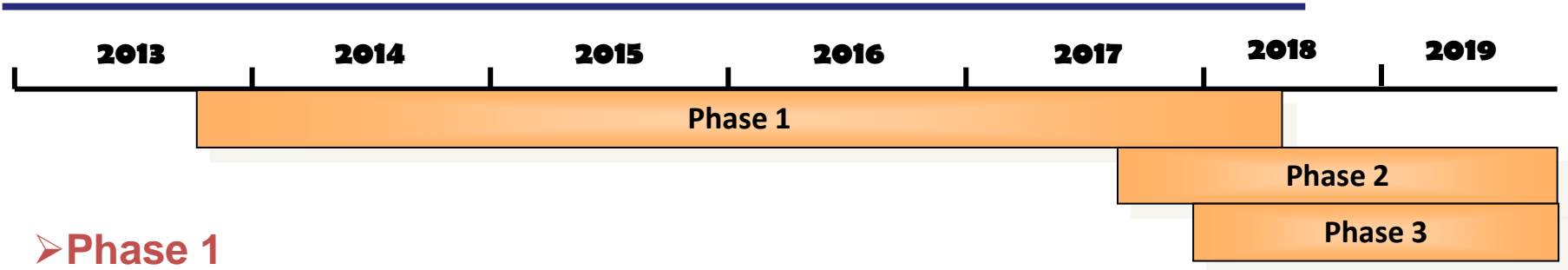
- Further the advancement and deployment of PRS for pavements
  - Viable option for use during pavement construction
  - Agencies can confidently use them for acceptance purposes for a wide variety of construction projects.
- Addresses both flexible and rigid pavements

*“Someday we are going to have to raise the bar”*

– Dale Decker 9/20/2017

# *Develop and Deploy Performance-Related Specifications (PRS) for Pavement Construction*

FHWA DTFH61-13-C-00025



## ➤ Phase 1

- Development of PRS models and software
  - Asphalt and Jointed Plain Concrete Pavements
- Guidelines development
- Deployment projects and PRS validation

## ➤ Phase 2

- Sensitivity analysis
- Software integration
- Inspection and material testing program optimization
- PRS refinements

## ➤ Phase 3

- Pay factor weighting evaluation
- Risk evaluation
- PRS final refinements

# What Are Shadow PRS Projects?

- Paving projects selected by the participating agency
  - Data for PRS are being collected in addition to the agency's normal acceptance data
- Shadow Project Benefits
  - Training in PRS testing and analysis
  - Demonstrates how would project have been accepted, if PRS were used
  - Understand ways that PRS may impact normal testing and acceptance operations
  - Collect data for PRS improvement

# Shadow PRS Status

- Maryland SHA – Underway (10 projects)
- Maine DOT – Underway
- Missouri DOT – Underway (3 projects)
- Ontario MOT – Underway
- Western Federal Lands – 1<sup>st</sup> Project Complete, 2<sup>nd</sup> in 2018



# Shadow Project Report Audience

- Agency and contractor personnel responsible for PRS implementation
  - Experienced engineers
    - Construction
    - Specifications
    - Asphalt Materials
    - Testing
    - Pavement design
  - Probably not familiar with viscoelastic continuum damage theory



# Shadow Project Report Outline

- Introduction
  - Benefits of using PRS
  - Available assistance
- Overview of PRS for Asphalt
  - Supporting software
  - Concise description of the major steps
- Project description
- Performance volumetric relationships and life differences
- PRS pay tables
- Acceptance data and payment
  - PRS compared to agency practice
- Lessons Learned

# Steps in PRS for Asphalt

Preliminary  
Research

Step 1: Material database development

PRS Project

Step 2: Pavement design

Step 3: Predict pavement life for various mix volumetric conditions

Step 4: Develop pay tables

Step 5: Write the PRS specification

Step 6: Send the contract out for bid and award

Step 7: Mix design and approval\*

Step 8: Construction: monitoring through AQC's

Step 9: Pay based on pay tables

# Step 1 Material Database Example

## NCDOT Superpave Mixtures

Layer Type	Mix Type	Loading Range (Million ESALs)	% Asphalt Binder	Asphalt Binder PG Grade
Surface	<b>S9.5A</b>	Less than 0.3	6.5	PG 64-22
	<b>S9.5B</b>	Less than 3	6.5	PG 64-22
	<b>S9.5C</b>	3 to 10	6.5	PG 70-22
	<b>S12.5B</b>	Less than 3	5.5	PG 64-22
	<b>S12.5C</b>	3 to 30	5.5	PG 70-22
	<b>S12.5D</b>	Over 30	5.5	PG 76-22
Intermediate	<b>I19.0B</b>	Less than 3	4.7	PG 64-22
	<b>I19.0C</b>	3 to 30	4.7	PG 64-22
	<b>I19.0D</b>	Over 30	4.7	PG 70-22
Base	<b>B25.0B</b>	Less than 3	4.3	PG 64-22
	<b>B25.0C</b>	3 or Greater	4.3	PG 64-22
	<b>B37.5C</b>	3 or Greater	4.3	PG 64-22

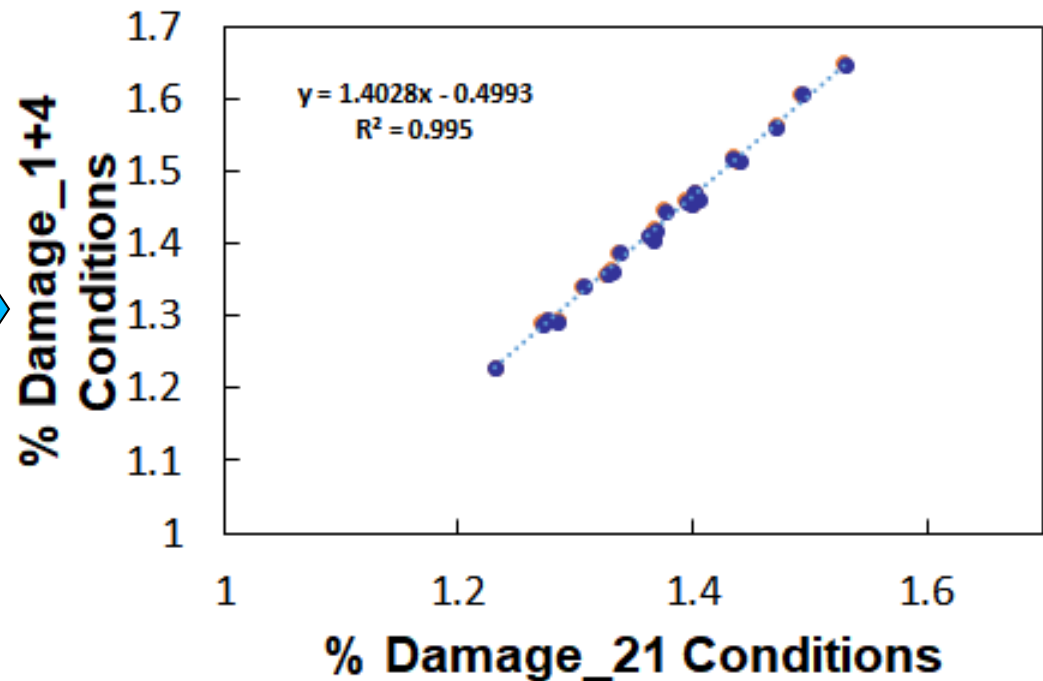
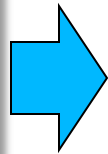
# Step 1 Material Database Example

- ❑ Select a typical mix or two in each mixture classification
- ❑ Conduct AMPT performance tests on five volumetric conditions (mix design plus four extreme volumetric conditions)
- ❑ Store performance properties in the material database

# 1+4 Volumetric Conditions

Volumetrics	Cond #1	Cond #2	Cond #3	Cond #4	Cond #5
In-place VMA	Design	High	High	Low	Low
In-place VFA	Design	Low	High	Low	High

Predicting % damage for 21 different volumetric conditions from PVR calibrated by 1+4 conditions



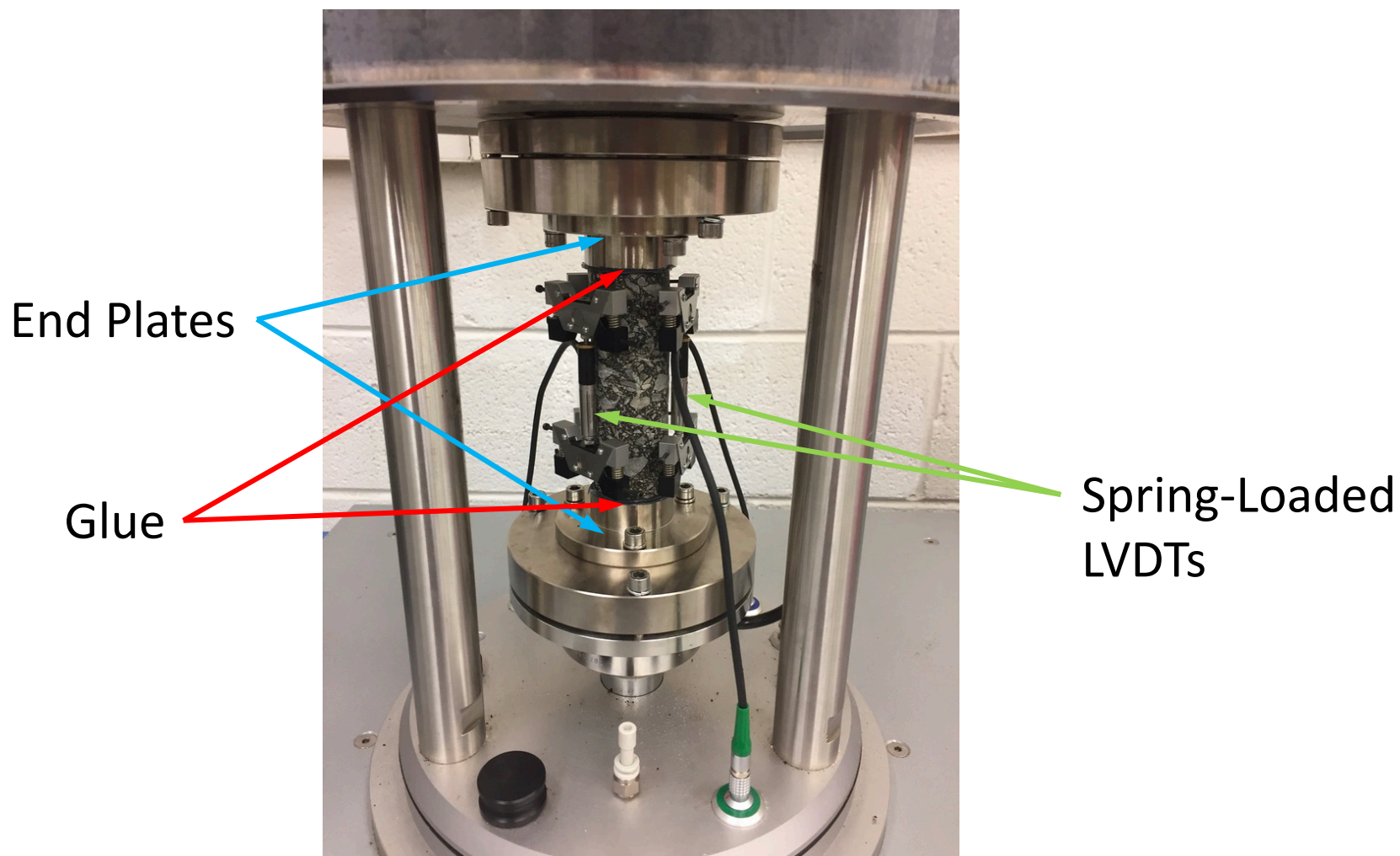
# AMPT Performance Test Methods

- ❑ Dynamic modulus test
  - AASHTO TP 79
- ❑ Cyclic fatigue test
  - AASHTO TP 107
- ❑ Stress sweep rutting (SSR) test
  - Draft AASHTO specification under review by the Mixture ETG

# Dynamic Modulus



# Cyclic Fatigue Test Setup





# Stress Sweep Rutting Test Setup



# FlexMAT™ Program

## *Import Data from AMPT*

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	<p><b>Description:</b> 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.</p> <p><b>Instructions:</b> 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.</p> <p>To import dynamic modulus data for the first test replicate into the template, press the <b>Dynamic Modulus Specimen 1</b> 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 <b>Dynamic Modulus Specimen 2</b> and <b>Dynamic Modulus Specimen 3</b> buttons, respectively.</p> <p>To import cyclic fatigue data for the first fatigue test, press the <b>Fatigue Specimen 1</b>. 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 <b>Fatigue Specimen 2</b>, <b>Fatigue Specimen 3</b>, and <b>Fatigue Specimen 4</b> 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.</p> <p>Press the <b>Clear Template</b> button to remove all data that is currently in the template. Note that the <b>Clear Template</b> button should only be used if the user wants to revert to the blank template.</p>					Dynamic Modulus Specimen 1		Fatigue Specimen 1		Clear Template				
2						Dynamic Modulus Specimen 2		Fatigue Specimen 2						
3						Dynamic Modulus Specimen 3		Fatigue Specimen 3						
4								Fatigue Specimen 4						
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24														

# FlexMAT™ Program

## Analysis

### E\* Mastercurve

**Description:** Fits the sigmoidal and time-temperature shift to the test data.

**Instructions:**

- Enter the percentage of average yield in Minor/Average loading module table.
- Click the button within the input Data tab were not used to summary dynamic modulus test file. Each block of test data.
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**MEASURED DATA**

Frequency (Hz)	W	S	1	0.5	0.1
Dynamic modulus (MPa)	3995	1995	2065	385	4435
Phase angle (Degrees)	6.54	9.1	16.45	22.1	23.53
Average temperature (°C)	5.3	5.3	5.3	20	20
Average microstrain	5.3	5.3	5.3	5.3	5.3
Load standard error (%)	5.7	2.9	1.7	0.6	0.5
Average deformation (mm)	79.1	6.6	20.6	300.9	103.4
Average deformation standard error (%)	5.5	3.5	2.7	2.1	1.7
Deformation uniformity (%)	0.9	0.9	0.4	0.5	0.5
Phase uniformity (Degrees)	0.2	0.2	0.3	0.7	0.9

**Fit Time-Temperature Shift Factor and Sigmoidal Model**

**SIGMOID**

Reduced Frequency	Reduced Modulus	Reduced Phase Angle
0.000	3.995	6.54
0.000	1.995	9.1
0.000	2.065	16.45
0.000	0.385	22.1
0.000	4.435	23.53

### Damage Characteristic Curve

**Description:** Calculates the damage characteristic curve for a material under cyclic loading.

**Inputs:** Material properties, loading parameters, and test data.

**Outputs:** Damage characteristic curve showing the relationship between damage and cycles.

**Damage Characteristic Curve Data:**

Cycles	Damage
0	0.00
100,000	0.10
200,000	0.20
300,000	0.30
400,000	0.40
500,000	0.50
600,000	0.60
700,000	0.70
800,000	0.80
900,000	0.90
1,000,000	1.00

### Failure Criterion

**Description:** Determines the failure criteria for a material based on test data.

**Instructions:**

- Enter the failure criteria parameters.
- Click the button to calculate the failure criteria.
- Click the button to plot the failure criteria.

**Fit vs. 3 Model**

**Failure Criterion Data:**

Sample	Failure Criterion
Sample 1	0.000
Sample 2	0.000
Sample 3	0.000
Sample 4	0.000

**Failure Criterion Plot:**

### Rotting Shift Model

**Description:** Optimizes the shift model parameters to fit the test data.

**Instructions:**

- Enter the shift model parameters.
- Click the button to optimize the shift model.
- Click the button to plot the shift model.

**Rotting Shift Model Data:**

Code	Material	Temperature	Frequency	Modulus	Phase Angle
1	0.000	5.3	5.3	3.995	6.54
2	0.000	5.3	5.3	1.995	9.1
3	0.000	5.3	5.3	2.065	16.45
4	0.000	20.0	5.3	0.385	22.1
5	0.000	20.0	5.3	4.435	23.53

**Rotting Shift Model Plot:**

# FlexMAT™ Program

## 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		$\log(a_T) = a_1 T^2 + a_2 T + a_3$	S-VECD Fatigue Properties	
$E_{\infty}$	2.59E+04		$\alpha$	3.37
$T_{ref}$	21.1		C vs. S	
Shift Factor $a_1$	2.274E-03		$C_{11}$	4.19E-03
Shift Factor $a_2$	-2.870E-01		$C_{12}$	4.10E-01
Shift Factor $a_3$	5.044E+00	G <sup>R</sup> Failure Criterion		
Prony Series		$E(t) = E_{\infty} + \sum_{m=1}^N E_m e^{-t/\tau_m}$	$G^R = \gamma \cdot N_f^{\delta}$	$D^R = \frac{\int_0^{N_f} (1-C) dN}{N_f}$
TI(s)	Ei (kPa)	$\gamma$	2.18E+10	
2.00E+08	4.77E+03	$\delta$	-1.857	$\left( \frac{C_{12}}{a_T^{\alpha+1} C_{11}} D^R \right)^{\frac{1}{C_{12}}}$
2.00E+07	2.83E+03	D <sup>R</sup> Failure Criterion		
		$D^R$	0.64	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		$\epsilon_{vp} = \frac{\epsilon_0 \times N}{(N_I + N)^{\beta}}$	$\epsilon_{vp} = \frac{\epsilon_0 \times N_{red}}{(N_I + N_{red})^{\beta}}$	<b>Export FlexPAVE Inputs</b>
$\epsilon_0$	0.00224	$a_{\xi_p} = p_1 \log(\xi_p) + p_2$	$N_{red} = A \cdot N \left( \frac{\xi_p}{1} \right)^{p_1} \left( \frac{\sigma_v}{P_a} \right)^{d_1}$	
$N_1$	1.78777			
$\beta$	0.76643			
Reduced Load Time		$A = 10^{p_2} \cdot 10^{d_2}$		
$p_1$	0.705			
$p_2$	0.281			
Vertical Stress Shift		$a_{\sigma_v} = d_1 \log(\sigma_v / P_a) + d_2$		
$d_1$	3.191			
$d_2$	-2.782			
$T_{ref}$ (°C)	54			

Material Database

Name	Date modified	Type	Size
RB25C	9/8/2017 4:52 PM	File folder	
RI19C	9/8/2017 4:51 PM	File folder	
RI19D			
<b>RS9.5C</b>			
RS9.5D			

Material Database > RS9.5C

Name	Date modified	Type	Size
Condition 1	9/8/2017 4:39 PM	File folder	
<b>Condition 2</b>	9/8/2017 4:47 PM	File folder	
Condition 3			
Condition 4			
Design			

Material Database > RS9.5C > Condition 2

Name
DM_RS95C_Cond2.csv
<b>Fatigue_RS95C_Cond2.csv</b>
Rutting_RS95C_Cond2.csv


S-VECD Fatigue Properties

	A	B	C	D
1	S-VECD Fatigue Properties			
2	alpha	3.78		
3	C vs. S			
4	C11	2.64E-03		
5	C12	4.62E-01		
6	GR Failure Criterion			
7	gamma	3.96E+07		
8	delta	-1.268		
9	DR Failure Criterion			
10	DR	0.65		
11	Damage Capacity			
12	Sapp	17.72		
13				
14				
15				

Structure General Information

Structure Name

Pavement/Lane Width (m)



AC (Click to Edit Layer)

Base (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer

Thickness (cm)   Infinite Layer

Material Type

Specific Gravity (optional)  Expansion Co. (1/C)

GR Based Criterion  DR Based Criterion

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	4
Einf (KPa)	9.7300e+04	C11	0.0017
Ref. Temp. (C)	5	C12	0.5449
Shift Factor a1	6.9619e-04	Initial C	0.8000
Shift Factor a2	-0.1620	Gamma	1000000
Shift Factor a3	0.7928	Delta	-1.3500

Beta	0.8026	p1	0.6069
Epsilon0	0.0052	p2	0.0719
NI	0.8024	d1	0.0396
TR(C)	61	d2	1.6831

	Ti (sec)	Ei (KPa)	
1	<input type="checkbox"/> 2.0000e+16	757.4885	+
2	<input type="checkbox"/> 2.0000e+15	97.6079	-
3	<input type="checkbox"/> 2.0000e+14	267.7187	
4	<input type="checkbox"/> 2.0000e+13	366.0952	
5	<input type="checkbox"/> 2.0000e+12	686.5036	
6	<input type="checkbox"/> 2.0000e+11	1.2298e+03	
7	<input type="checkbox"/> 2.0000e+10	2.2287e+03	
8	<input type="checkbox"/> 2.0000e+09	4.0690e+03	

Please note that FlexPAV C11 and C12 coefficients instead of

Condition 2

File Home Share View

Clipboard

Organize

09-20-17 ETG Meeting > Material Database >

Name

- DM\_RS95C\_Cond2.csv
- Fatigue\_RS95C\_Cond2.csv**
- Rutting\_RS95C\_Cond2.csv

# Steps in PRS for Asphalt

Preliminary  
Research

Step 1: Material database development

PRS Project

**Step 2: Pavement design**

Step 3: Predict pavement life for various mix volumetric conditions

Step 4: Develop pay tables

Step 5: Write the PRS specification

Step 6: Send the contract out for bid and award

Step 7: Mix design and approval\*

Step 8: Construction: monitoring through AQC's

Step 9: Pay based on pay tables

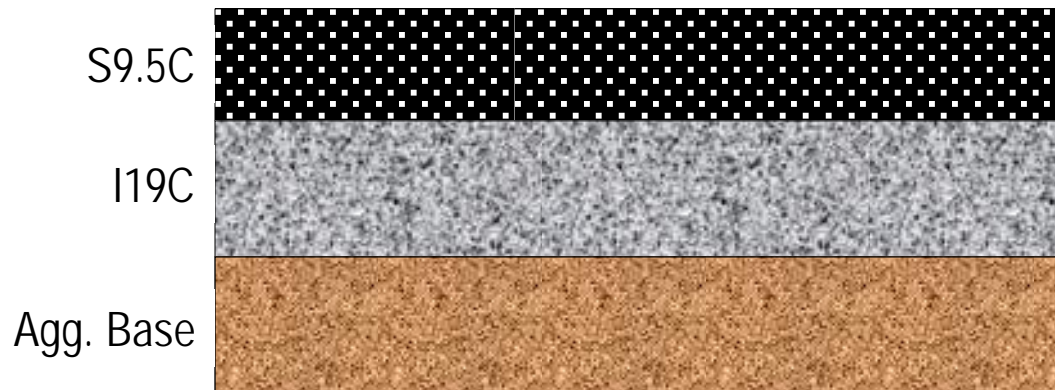
# Step 2 Pavement Design

- Use current agency pavement design method



**AASHTO® Guide for  
Design of Pavement Structures  
1993**

**AND MORE!**





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# Step 3 Predict Pavement Performance for Various Volumetrics

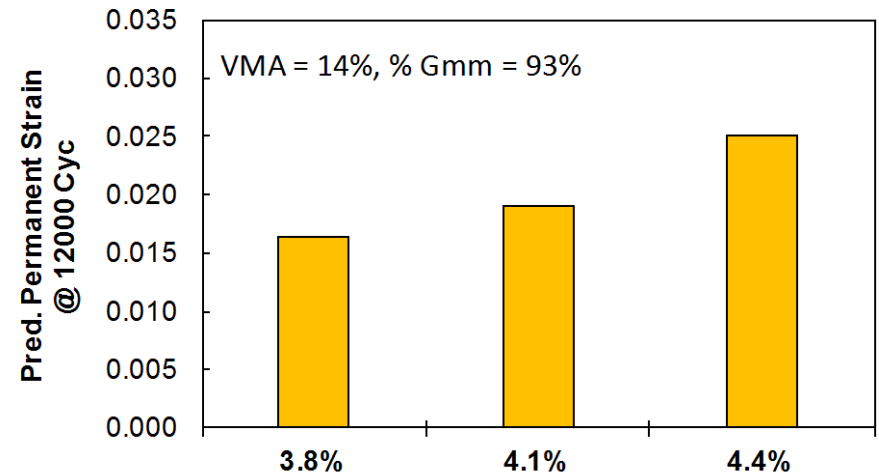
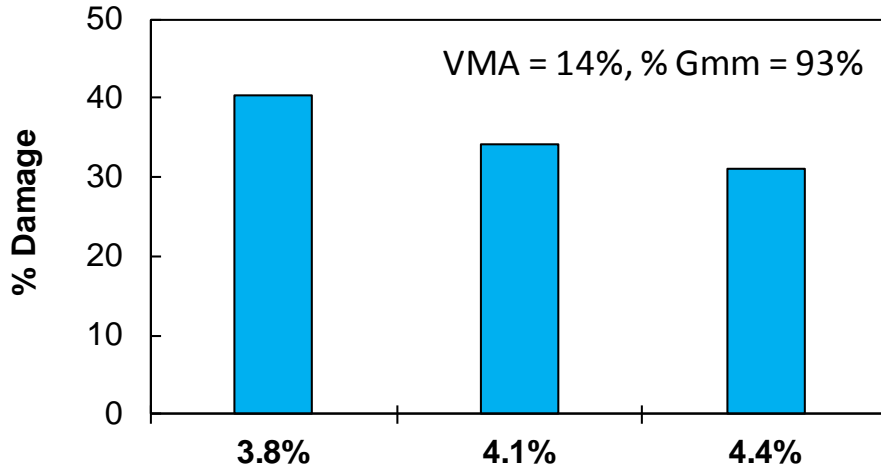
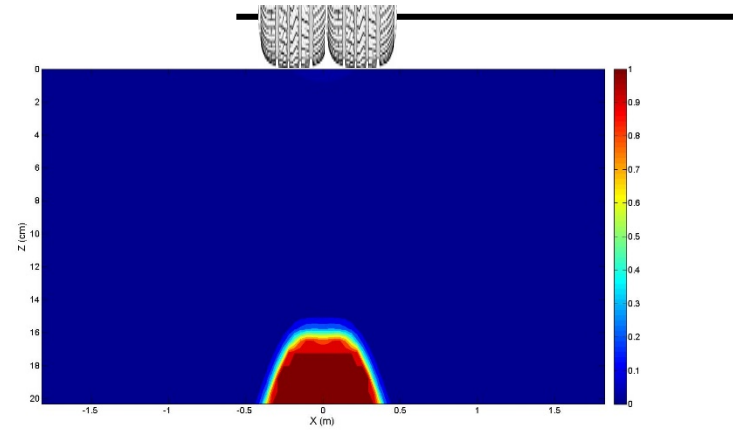
- ❑ Estimate the life of the design pavement structure via FlexPAVE™ for five volumetric conditions using performance properties in the material database
- ❑ Develop performance-volumetric relationships
- ❑ Determine life difference (i.e., as-designed vs. deviated) for a range of volumetric conditions

PASSFlex™ Software in development with a target completion date of mid 2018

# Step 3 Predict Pavement Performance for Various Volumetrics

4 in. AC

10 in. Aggregate Base



# Step 3 Predict Pavement Life for Various Volumetrics

Life Change (years)*		Design VMA																			
		13	13	13	13	13	14	14	14	14	14	15	15	15	15	15	16	16	16	16	16
		Design A.V.																			
		2	3	4	5	6	2	3	4	5	6	2	3	4	5	6	2	3	4	5	6
In-Place A.V.	4	1.4	0.9	0.0	-1.8	-5.1	1.6	1.5	1.3	0.6	-0.7	1.4	1.6	1.6	1.5	1.0	1.0	1.4	1.6	1.7	1.7
	5	1.1	0.5	-0.7	-2.9	-7.1	1.3	1.3	0.9	0.1	-1.6	1.2	1.4	1.4	1.2	0.6	0.8	1.2	1.4	1.5	1.4
	6	0.7	0.0	-1.5	-4.3	-9.6	1.1	1.0	0.5	-0.6	-2.6	1.0	1.2	1.2	0.9	0.1	0.5	0.9	1.2	1.3	1.1
	7	0.3	-0.6	-2.5	-6.0	-12.8	0.8	0.6	0.0	-1.3	-3.9	0.7	0.9	0.9	0.5	-0.5	0.3	0.7	1.0	1.0	0.8
	8	-0.2	-1.4	-3.7	-8.2	-17.0	0.5	0.2	-0.6	-2.3	-5.6	0.5	0.6	0.5	0.0	-1.2	0.0	0.5	0.7	0.7	0.4
	9	-0.8	-2.3	-5.3	-11.0	-20.0	0.1	-0.3	-1.3	-3.5	-7.6	0.2	0.3	0.1	-0.6	-2.1	-0.2	0.2	0.4	0.4	-0.1
	10	-1.5	-3.4	-7.2	-14.6	-20.0	-0.3	-0.8	-2.2	-4.9	-10.2	-0.1	-0.1	-0.4	-1.3	-3.3	-0.5	0.1	0.1	-0.1	-0.7
	11	-2.3	-4.8	-9.6	-19.2	-20.0	-0.8	-1.5	-3.3	-6.7	-13.5	-0.5	-0.5	-0.9	-2.1	-4.6	-0.9	-0.5	-0.3	-0.5	-1.3
	12	-3.4	-6.5	-12.7	-20.0	-20.0	-1.3	-2.3	-4.6	-9.0	-17.7	-0.9	-1.0	-1.6	-3.2	-6.3	-1.2	-0.8	-0.7	-1.1	-2.1

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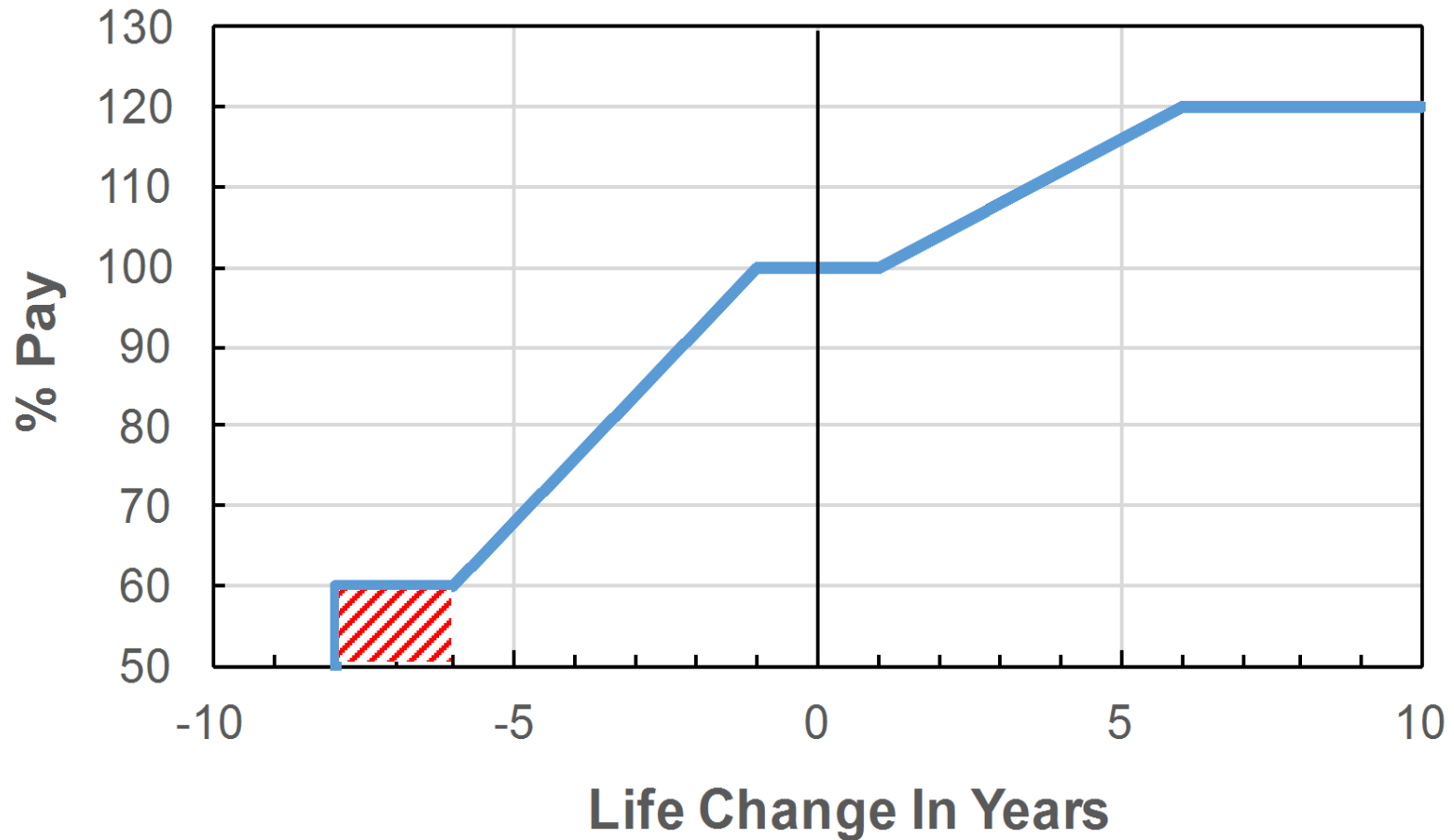
Step 7: Mix design and approval\*

Step 8: Construction: monitoring through AQC's

Step 9: Pay based on pay tables

# Step 4 Develop Pay Tables

## *Agency Specific Cost Model*



# Step 4 Develop Pay Tables

Pay Factor		QA VMA @ Ndes = <b>13%</b>				
		QA Vbe @ Ndes				
		11	10	9	8	7
In-Place A.V.	4	101.5	100.0	100.0	93.9	67.3
	5	100.3	100.0	100.0	84.9	60.0
	6	100.0	100.0	96.3	73.7	0.0
	7	100.0	100.0	88.2	60.0	0.0
	8	100.0	97.1	78.3	0.0	0.0
	9	100.0	89.8	65.9	0.0	0.0
	10	96.1	80.8	60.0	0.0	0.0
	11	89.3	69.7	0.0	0.0	0.0
	12	81.1	60.0	0.0	0.0	0.0

Pay Factor		QA VMA @ Ndes = <b>14%</b>				
		QA Vbe @ Ndes				
		11	10	9	8	7
In-Place A.V.	4	102.3	102.1	101.0	100.0	100.0
	5	101.4	101.1	100.0	100.0	95.5
	6	100.4	100.0	100.0	100.0	87.1
	7	100.0	100.0	100.0	97.3	76.6
	8	100.0	100.0	100.0	89.7	63.5
	9	100.0	100.0	97.5	80.3	60.0
	10	100.0	100.0	90.5	68.6	0.0
	11	100.0	95.8	81.9	60.0	0.0
	12	97.3	89.2	71.4	0.0	0.0

Pay Factor		QA VMA @ Ndes = <b>15%</b>				
		QA Vbe @ Ndes				
		11	10	9	8	7
In-Place A.V.	4	101.6	102.4	102.6	102.0	100.2
	5	100.8	101.6	101.7	100.8	100.0
	6	100.0	100.7	100.6	100.0	100.0
	7	100.0	100.0	100.0	100.0	100.0
	8	100.0	100.0	100.0	100.0	98.1
	9	100.0	100.0	100.0	100.0	90.9
	10	100.0	100.0	100.0	97.6	82.0
	11	100.0	100.0	100.0	90.9	70.9
	12	100.0	100.0	95.1	82.7	60.0

Pay Factor		QA VMA @ Ndes = <b>16%</b>				
		QA Vbe @ Ndes				
		11	10	9	8	7
In-Place A.V.	4	100.0	101.4	102.4	102.9	102.6
	5	100.0	100.6	101.6	102.0	101.6
	6	100.0	100.0	100.8	101.1	100.5
	7	100.0	100.0	100.0	100.0	100.0
	8	100.0	100.0	100.0	100.0	100.0
	9	100.0	100.0	100.0	100.0	100.0
	10	100.0	100.0	100.0	100.0	100.0
	11	100.0	100.0	100.0	100.0	97.4
	12	98.0	100.0	100.0	99.3	90.9

# Steps in PRS for Asphalt

Preliminary  
Research

Step 1: Material database development

PRS Project

Step 2: Pavement design

Step 3: Predict pavement life for various mix volumetric conditions

Step 4: Develop pay tables

Step 5: Write the PRS specification

Step 6: Send the contract out for bid and award

Step 7: Mix design and approval\*

Step 8: Construction: monitoring through AQC's

Step 9: Pay based on pay tables



# Mix Design and Approval

## □ Two Options

- Normal volumetric mix design based on pay tables
- Performance Engineered Mix Design
  - ✓ Indices based on
    - Dynamic Modulus
    - Cyclic Fatigue
    - Stress Sweep Rutting Test

# Questions/Discussion