NC STATE UNIVERSITY

Performance-Based Mix Design

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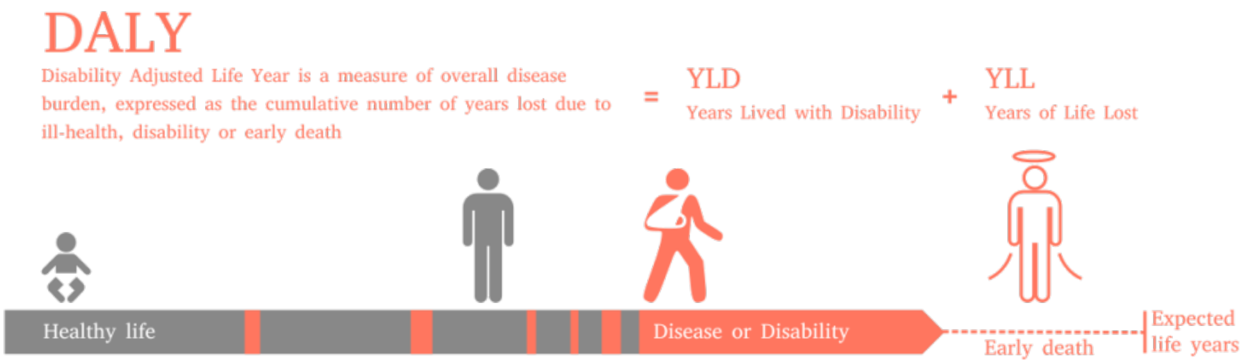
Integration between PBMD and PRS

- Same test methods and same underlying principles and models used in PBMD and PRS
- Index properties can be used in PBMD whereas full models are used in PRS.
- Integration necessary to apply incentive/disincentive to contractors
- PBMD index properties allow go/no-go decisions during construction
- Allows changes in mix production during construction

https://en.wikipedia.org/wiki/Disability-adjusted_life_year



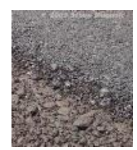
Going Forward

PRS

Predict Pavement Performance
How much life was lost? Gained ?

Make it simpler

PBMD



Hit the target.
Walk away.
Calibrated to performance data.

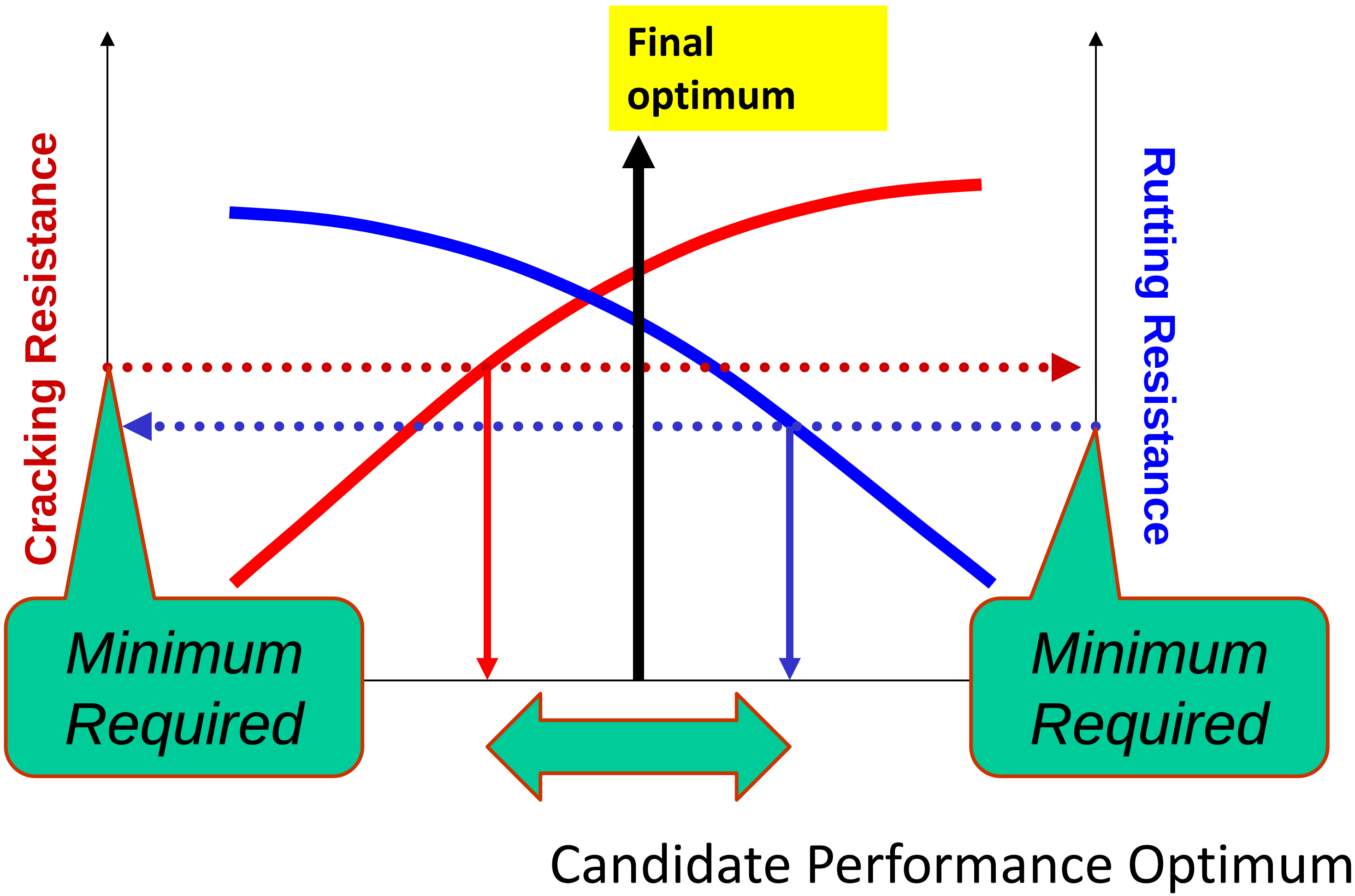
Binder Content

a number

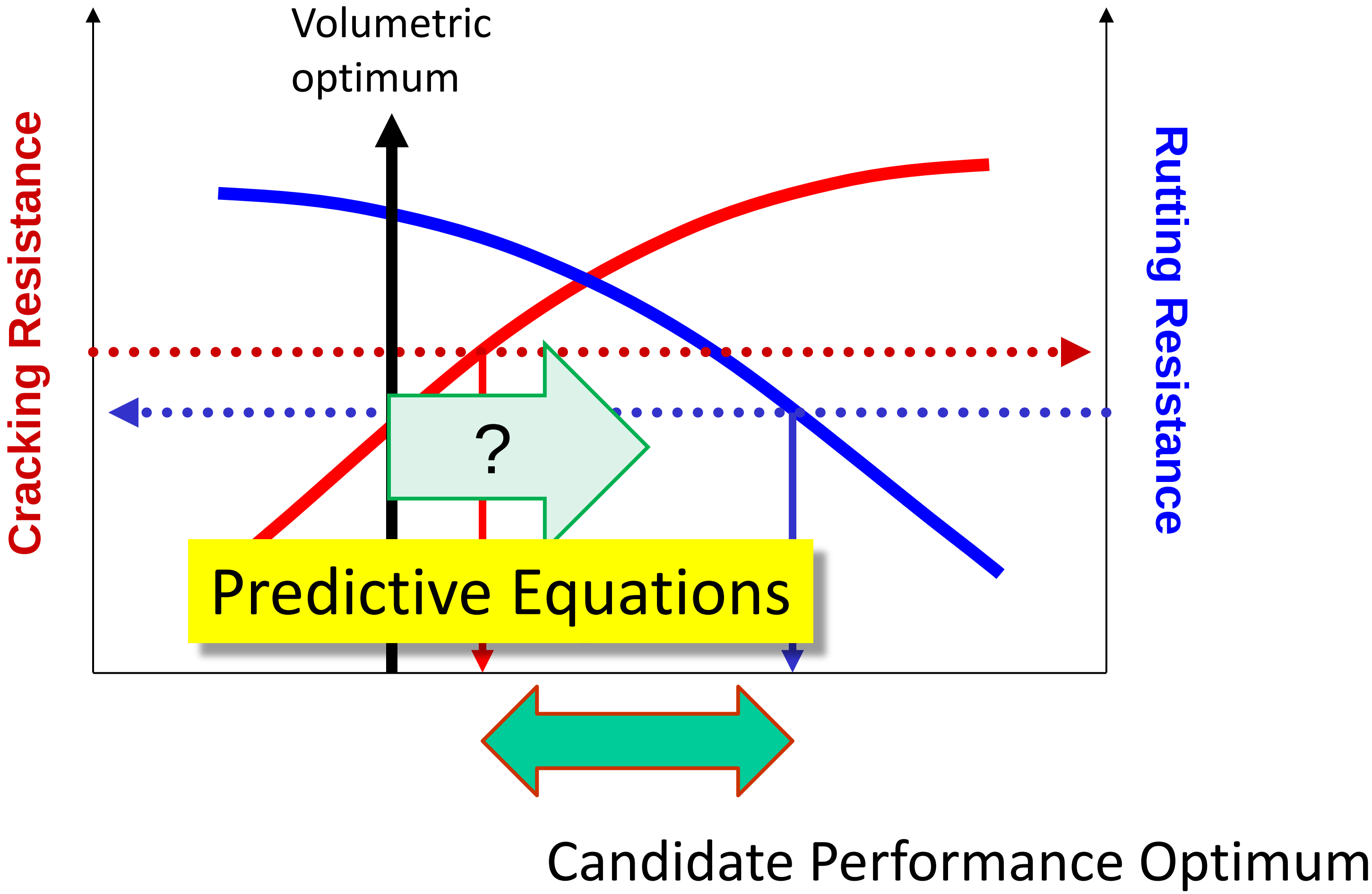
a number

PBMD Framework

Performance-Based Mix Design



Performance-Based Mix Design



PBMD Framework

- Step 1: Perform Superpave volumetric mix design to determine the volumetric optimum.
- Step 2: Conduct performance tests on the volumetric optimum using AMPT.
- Step 3: Check against the minimum performance criteria.
- Step 4: If okay, the volumetric optimum becomes the final optimum.
- Step 5: If not okay, adjust the asphalt content using predictive equations.
- Step 6: Conduct performance tests on the adjusted optimum.
- Step 7: Check against the minimum performance criteria.
- Step 8: If okay, the adjusted optimum becomes the final optimum.
- Step 9: If not okay, use different aggregate gradation and repeat the above steps.

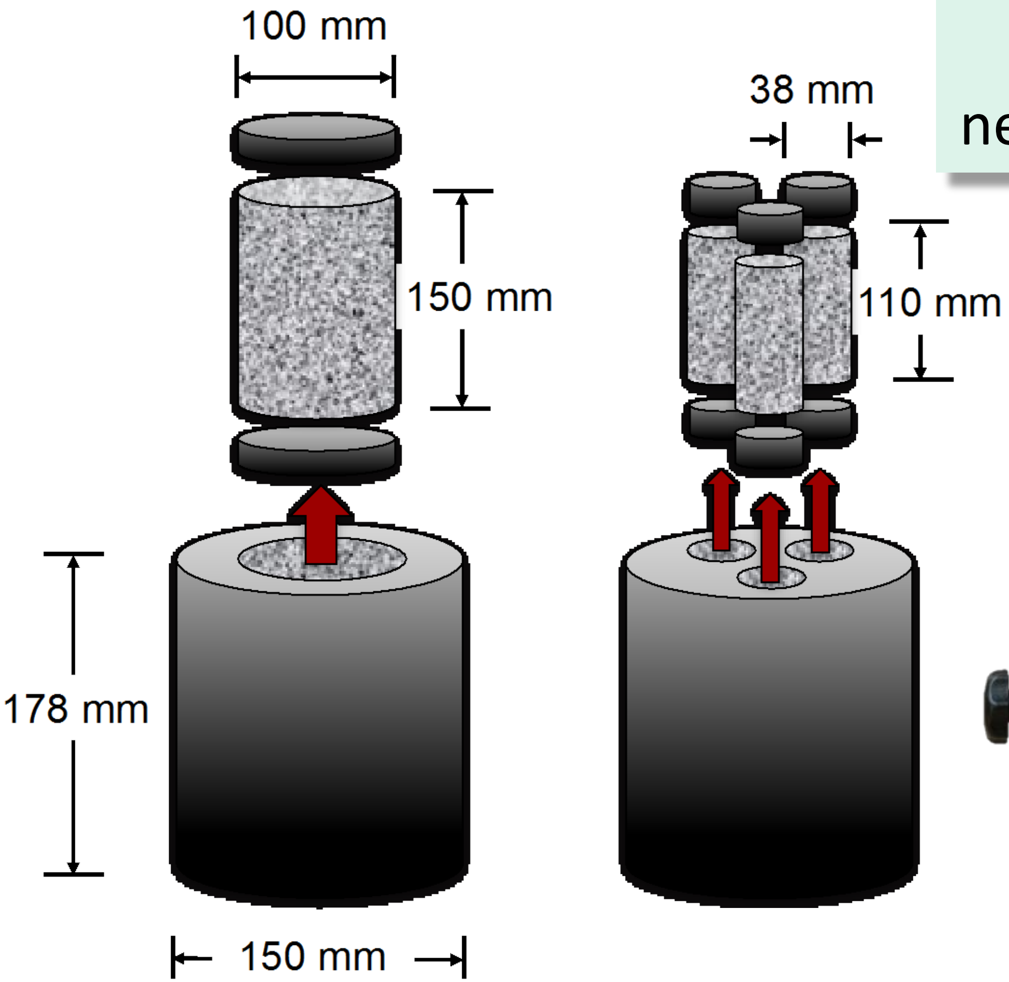
Possible Scenarios for PBMD

- Pavement structure ***unknown***
  - Pre-approval of mix design
  - Use index properties to determine pass/fail
  - Or run LVECD program on critical pavement designs with measured mixture properties to check against the minimum required pavement performance
- Pavement structure ***known***
  - Run LVECD program on known pavement design with measured mixture properties to check against the minimum required pavement performance.

Test Methods and Models for PBMD and PRS

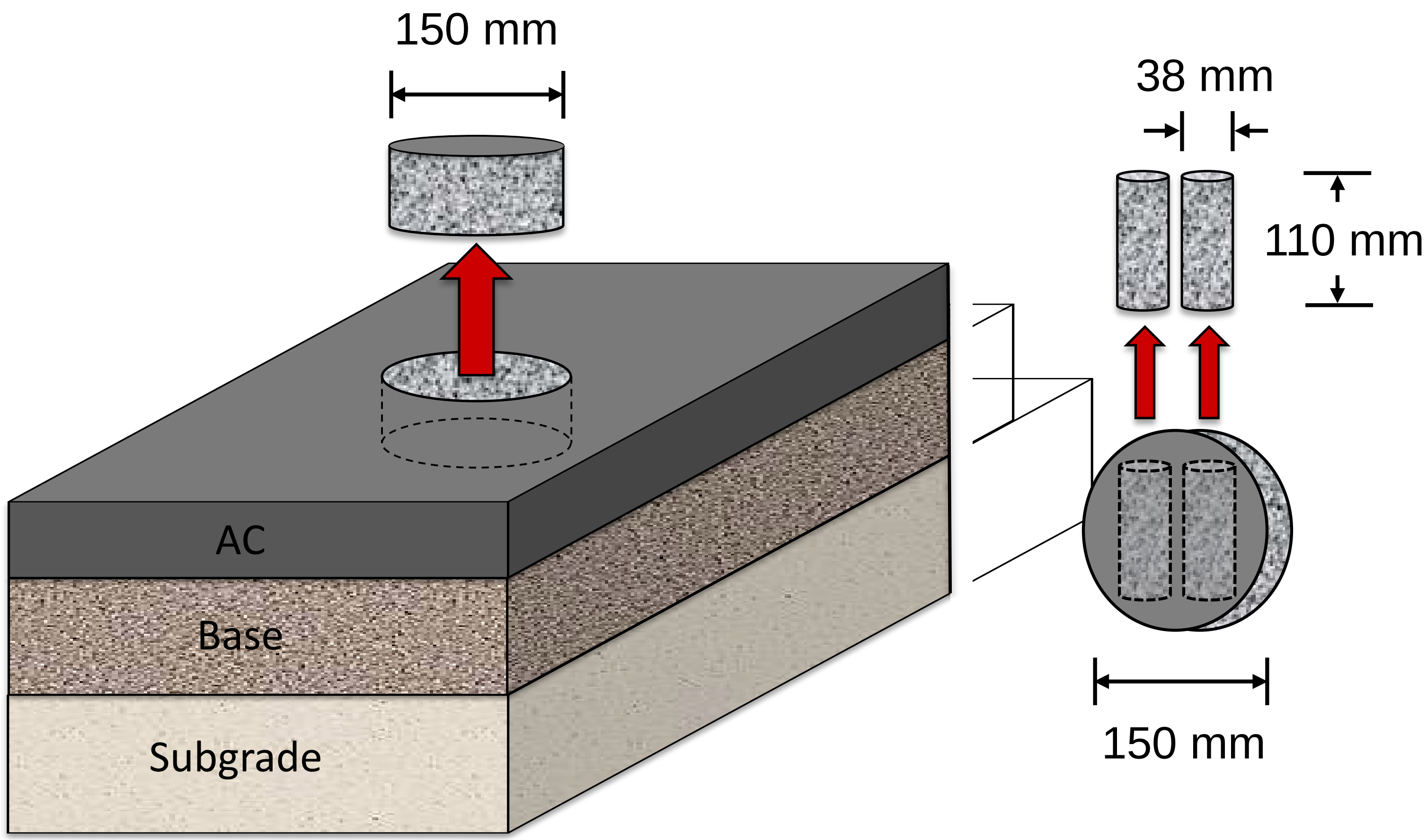
Asphalt Mixture Performance Tester

38 mm Cores for AMPT Cyclic Fatigue Testing

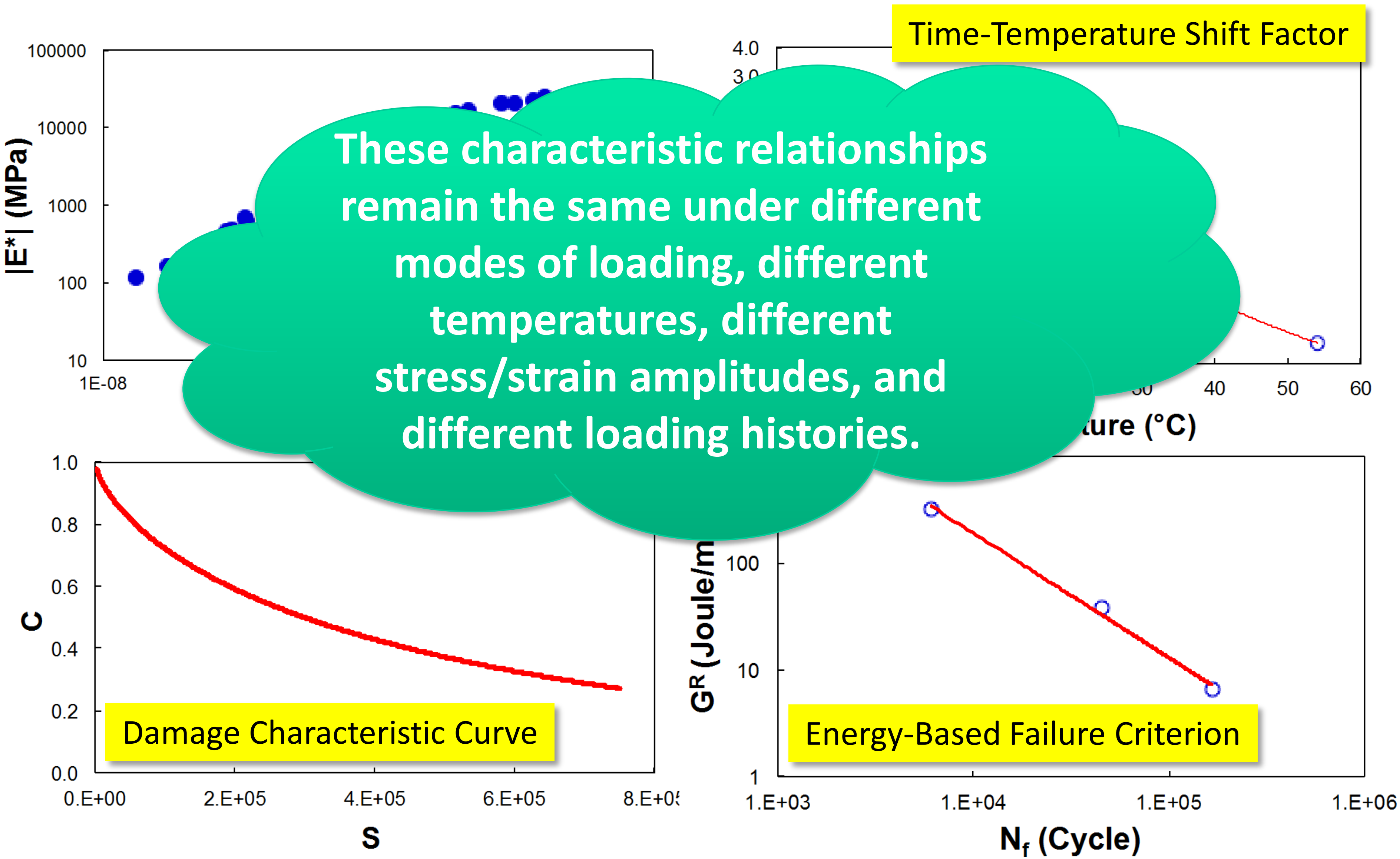


Only 1 gyratory specimen needed for PBMD fatigue testing

Horizontal Cores from Field Core



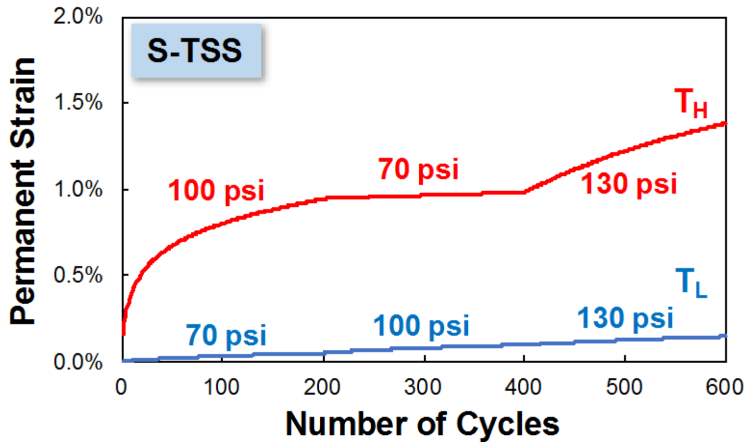
S-VECD Material Functions

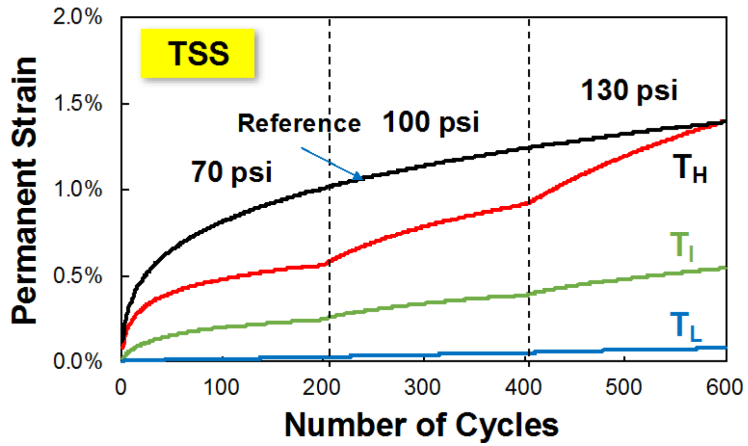


These characteristic relationships remain the same under different modes of loading, different temperatures, different stress/strain amplitudes, and different loading histories.

S-TSS for Rutting Test

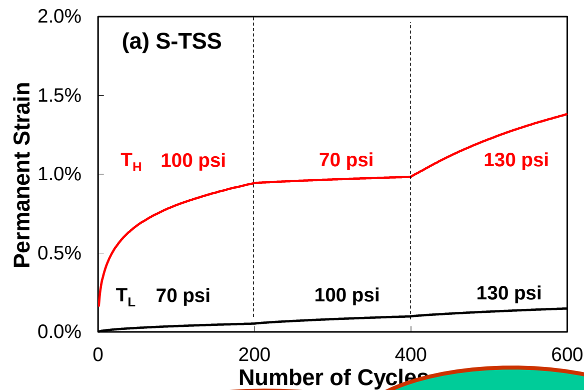
Test Method	S-TSS	TSS
Reference	-	1 (T_H)
Temp.	2 (T_H and T_L)	3 (T_H, T_I, and T_L)
Pulse Time (s)	0.4	0.4
Rest Period (s)	3.6 (T_H) 1.6 (T_L)	10 (T_H) 1.6 (T_I, T_L)
Deviator Stress (psi)	100, 70, and 130 (T_H) 70, 100, and 130 (T_L)	70, 100, and 130
Number of Samples	**4**	**8**
Testing Time (days)	**1.5**	**3**

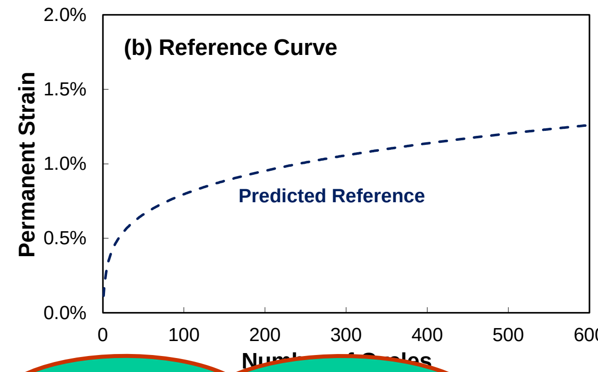




Permanent strains determined from machine displacements. No on-specimen LVDTs necessary.

Shift Model as the Rutting Model

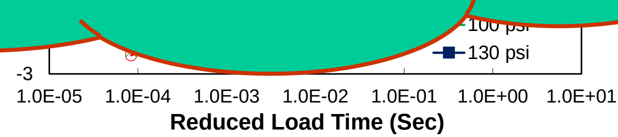




$$\varepsilon_{vp} = \frac{\varepsilon_0 N_{red} \ldots}{(N_I \ldots}$$

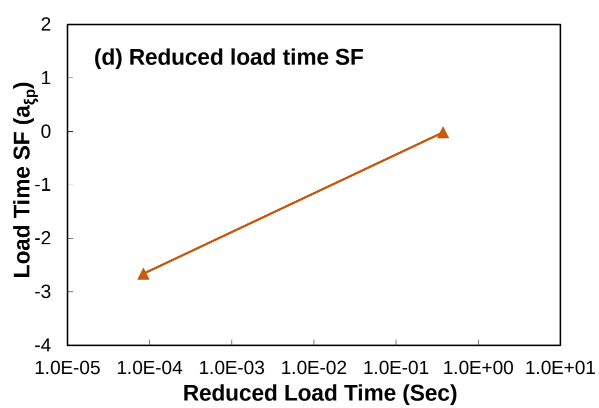
$$\ldots a_{\xi_p} + a_{\sigma_v}$$

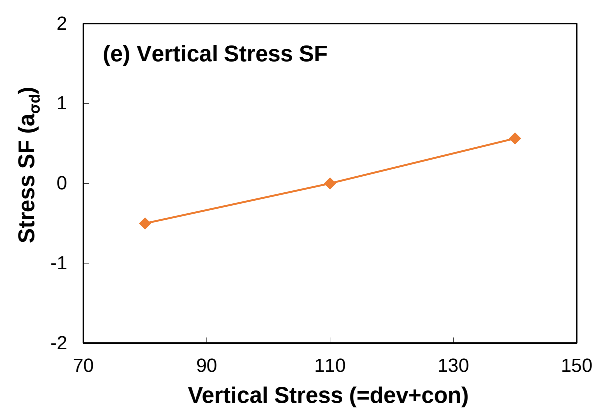
Accounts for the effects of stress level, temperature, and loading time on rutting



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

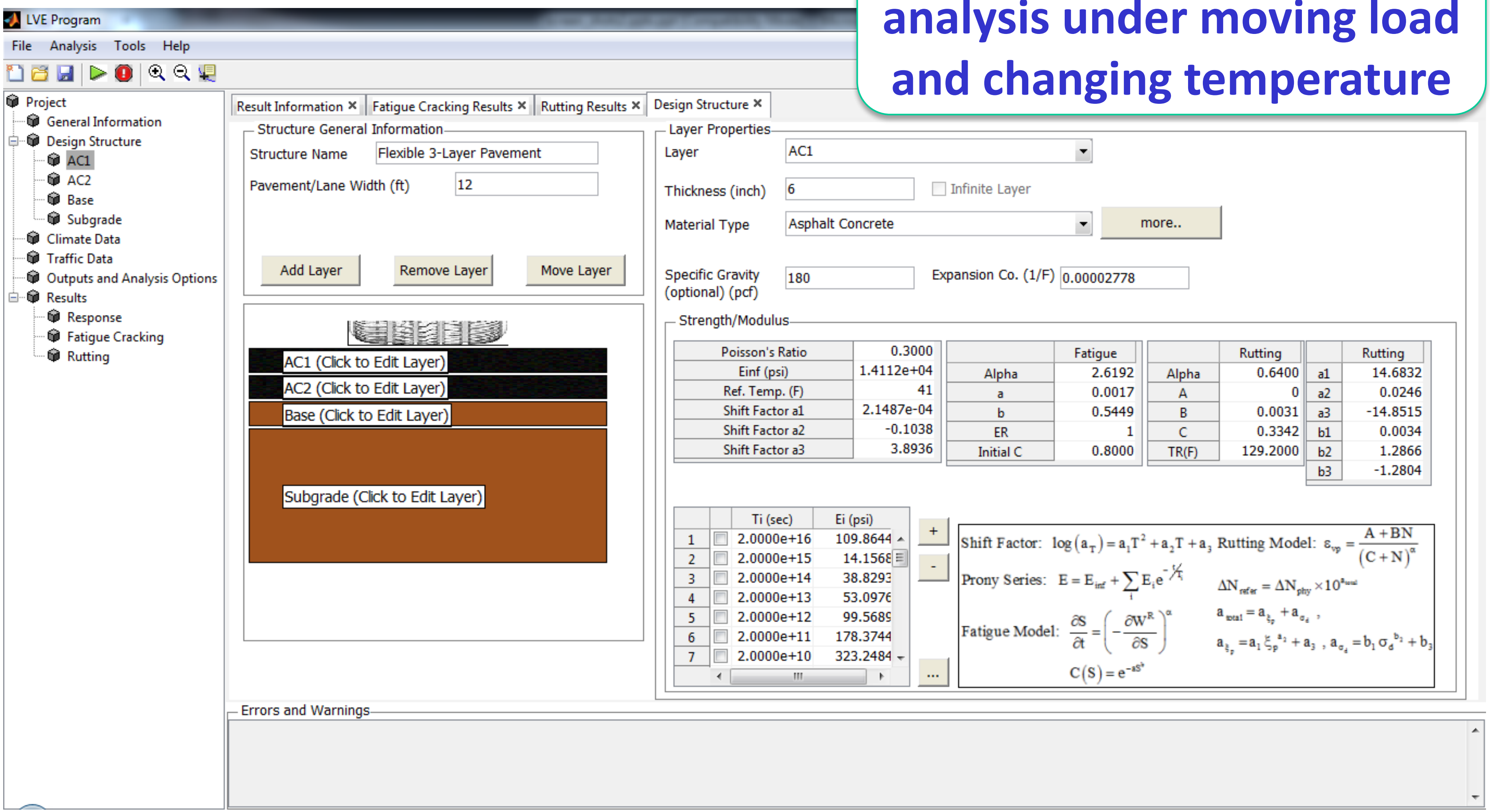
$$a_{\sigma_v} = d_1 \log(\sigma_v / P_a) + d_2$$



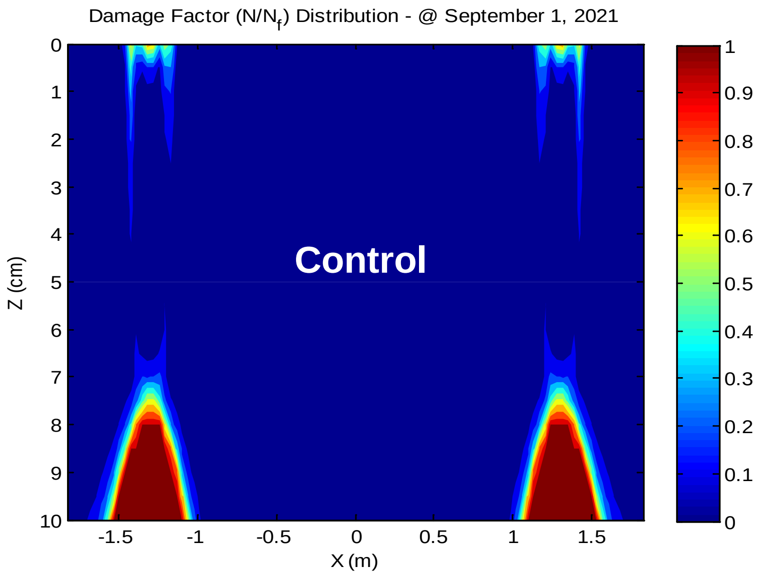


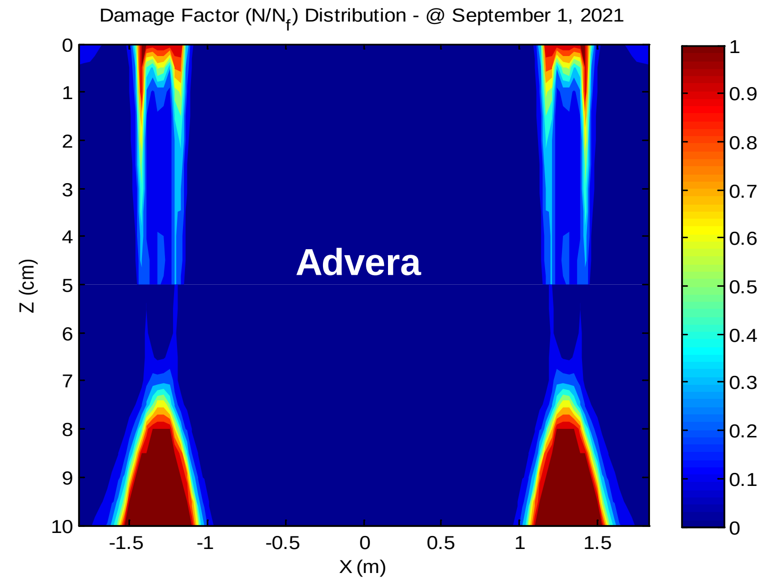
LVECD for Pavement Model

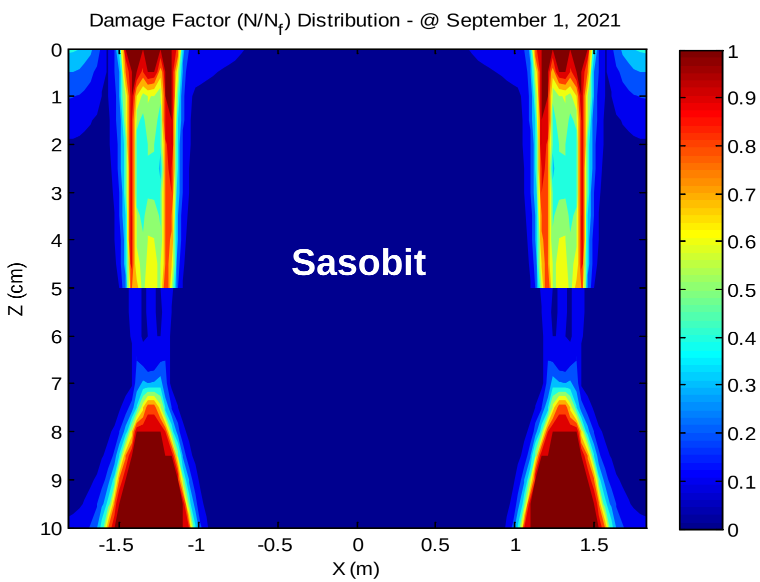
3-dimensional viscoelastic analysis under moving load and changing temperature

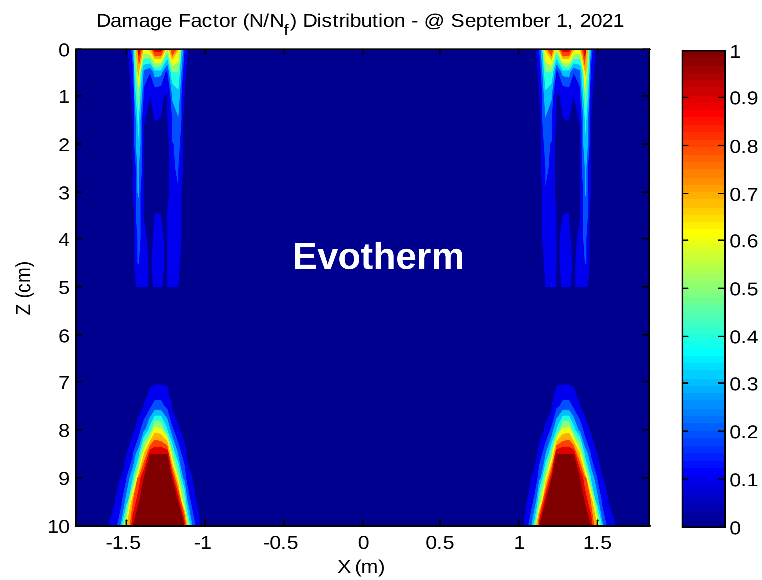


Damage after 20 Years Loading



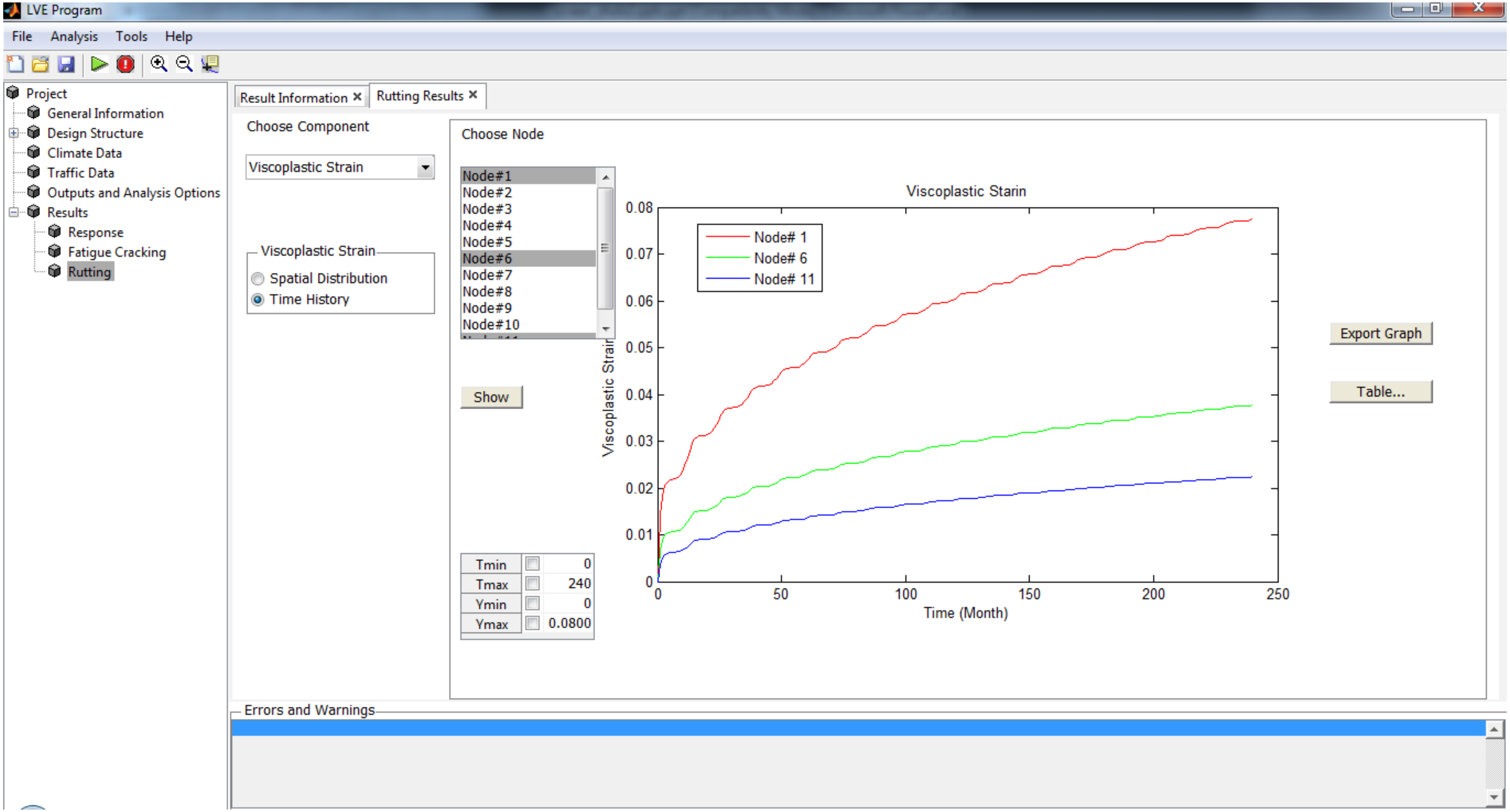






Rut Depth Prediction in LVECD

Time History



Required Testing Time

Property	Operation	Time
Modulus[a]	Dynamic Modulus Test	1 day
Cracking	AMPT Cyclic Fatigue Test (TP-107)	1 day
Rutting	S-TSS Test (TP-116 Option B[b])	1.5 days
Pavement Performance[a]	LVECD Program	40 min.
Total Time for PBMD Performance Testing	For Index Properties	2.5 days
	For Pavement Performance	3.5 days

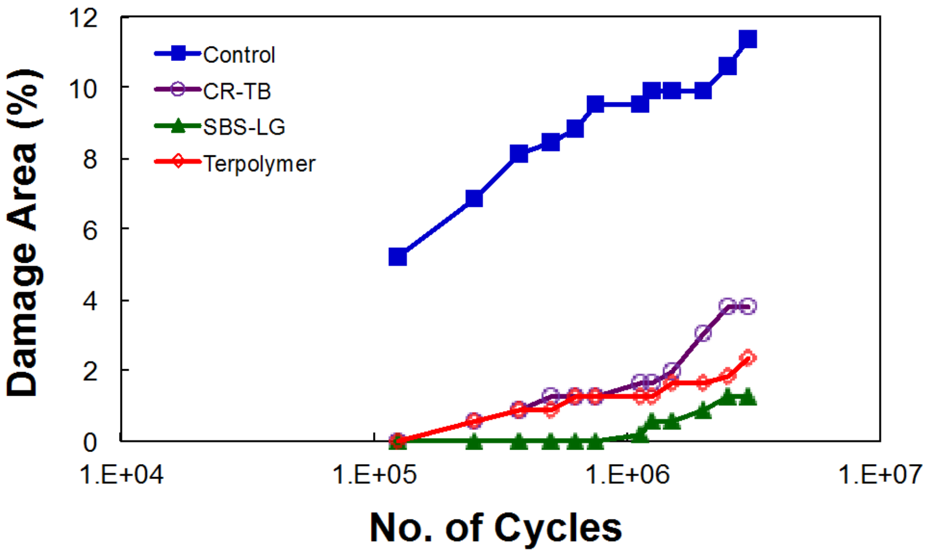
Note: [a] Only needed when the pavement performance analysis is desired.
[b] AASHTO specification being developed.

Validation Using Field Data

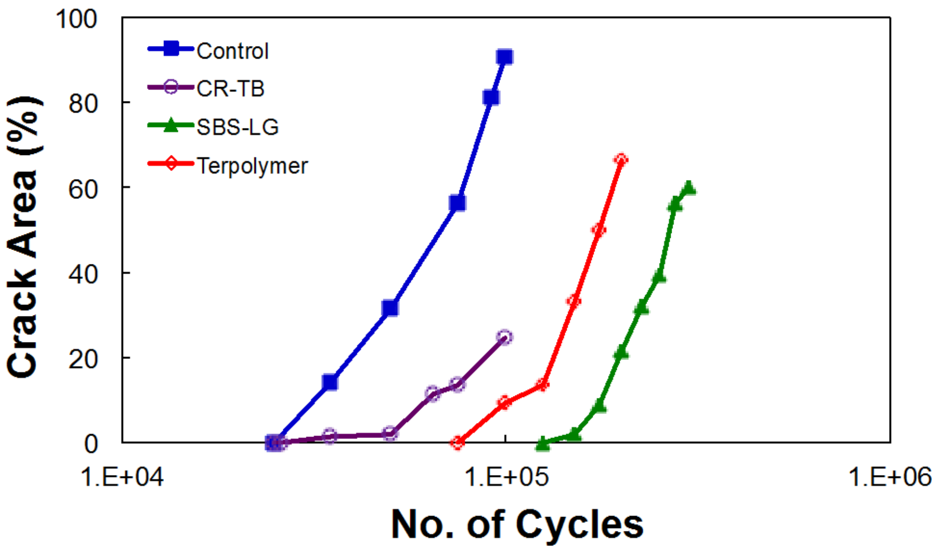
Laboratory-to-Field Correlation

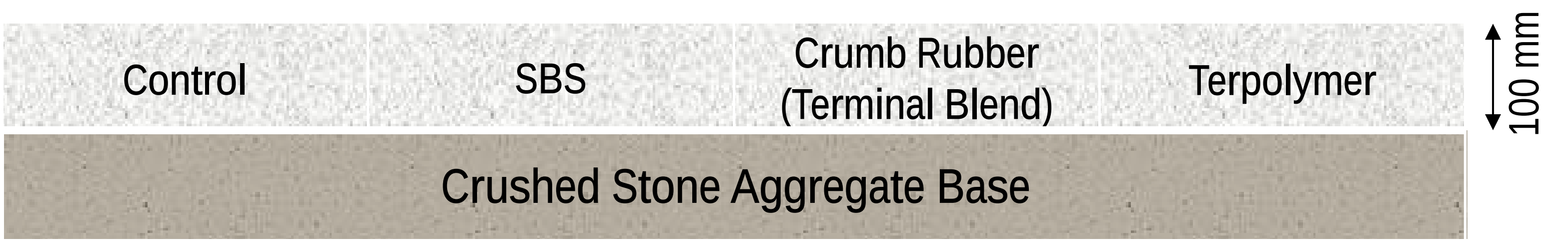
FHWA-ALF (100 mm Pavement)

LVECD Analysis



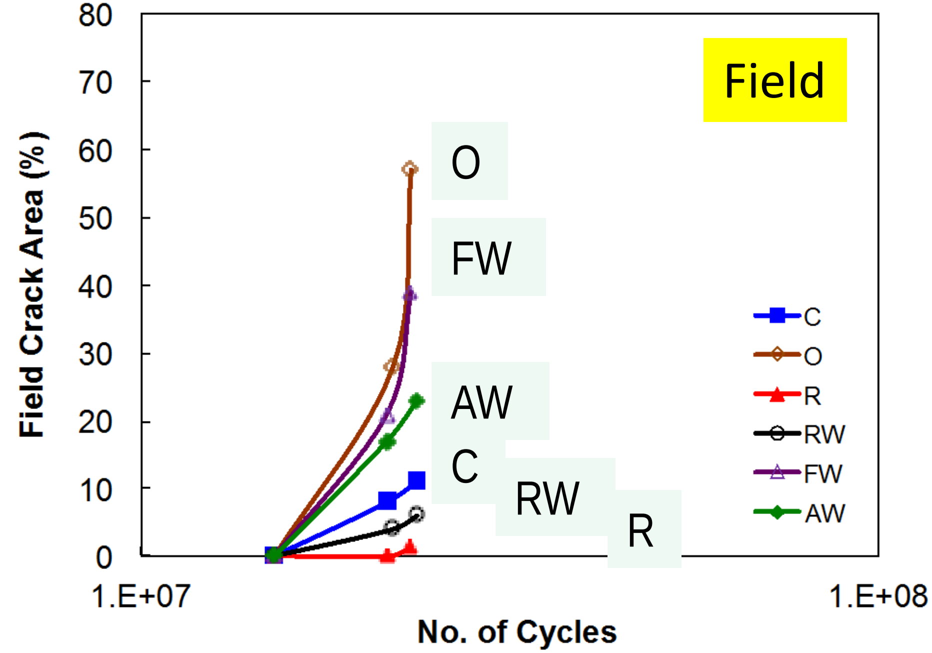
Field Cracking Data

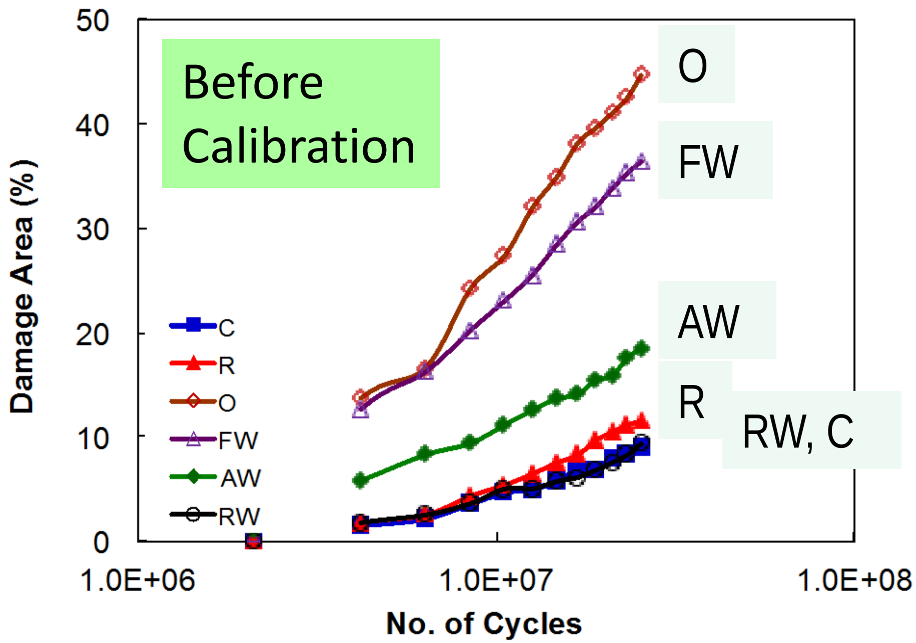


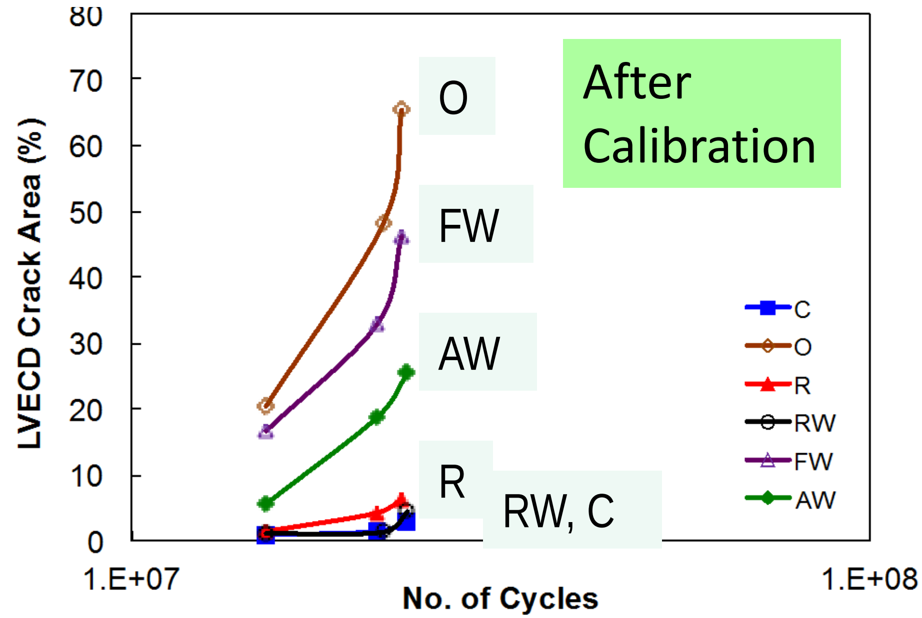


Fatigue Prediction

NCAT Test Track

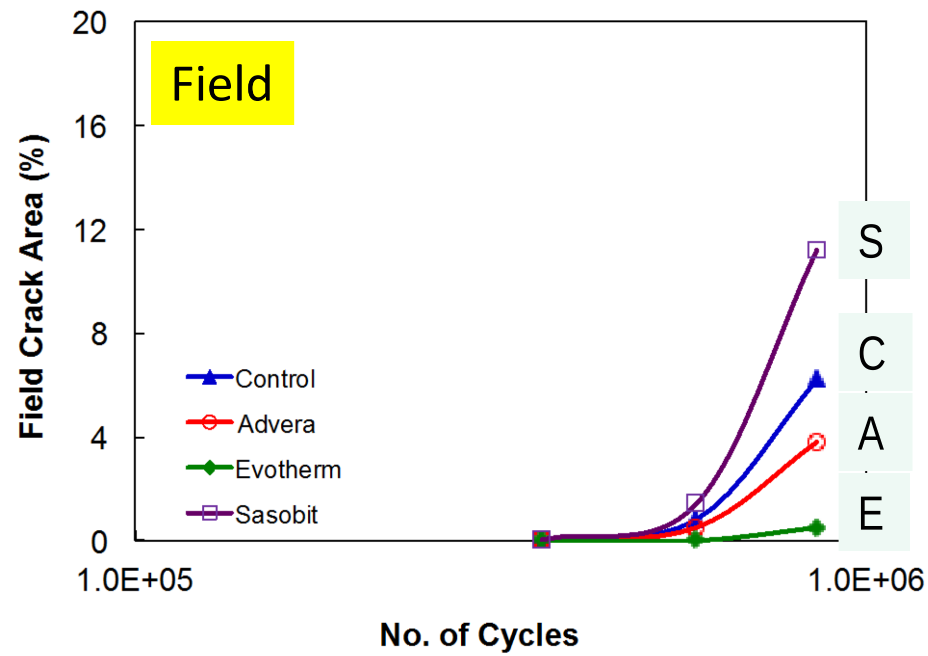


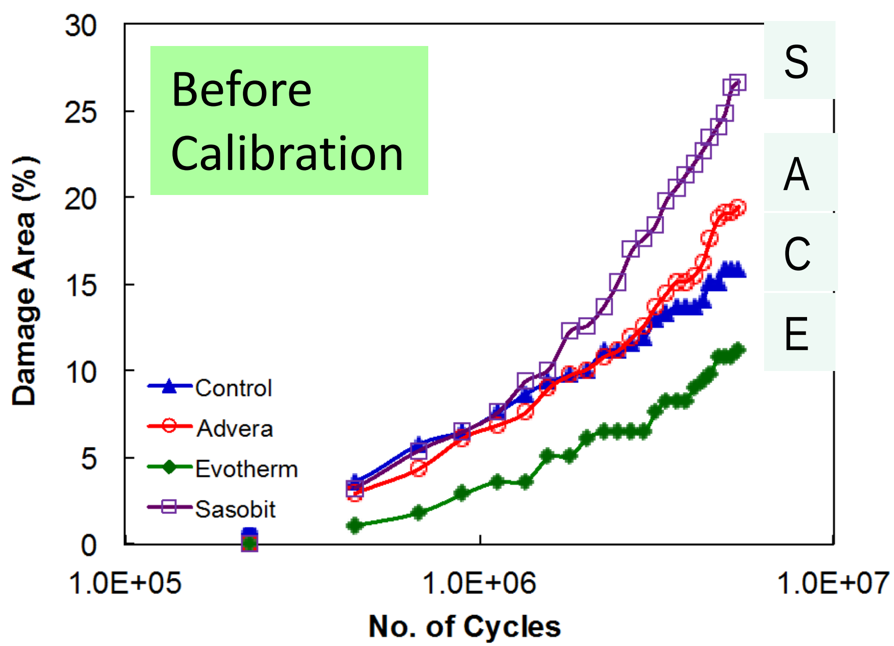


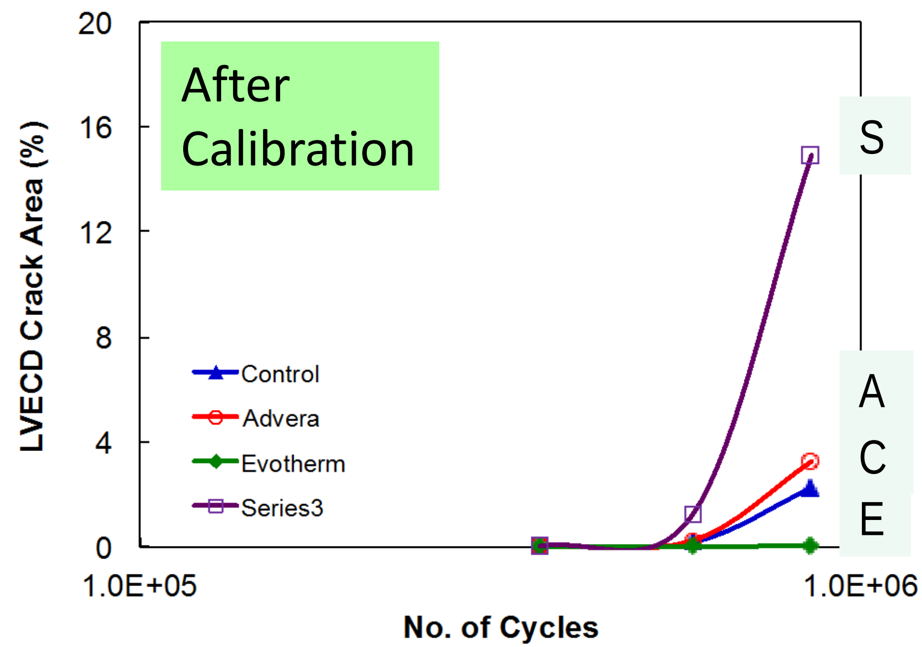


Fatigue Prediction

MIT-WMA





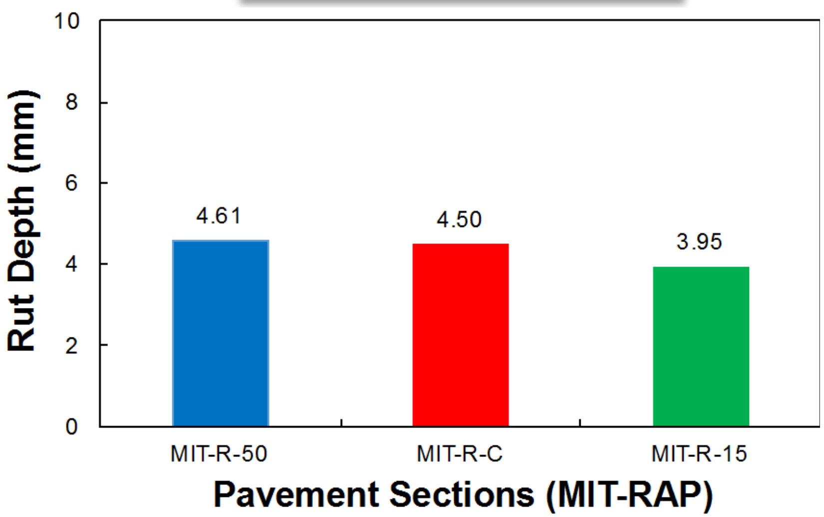


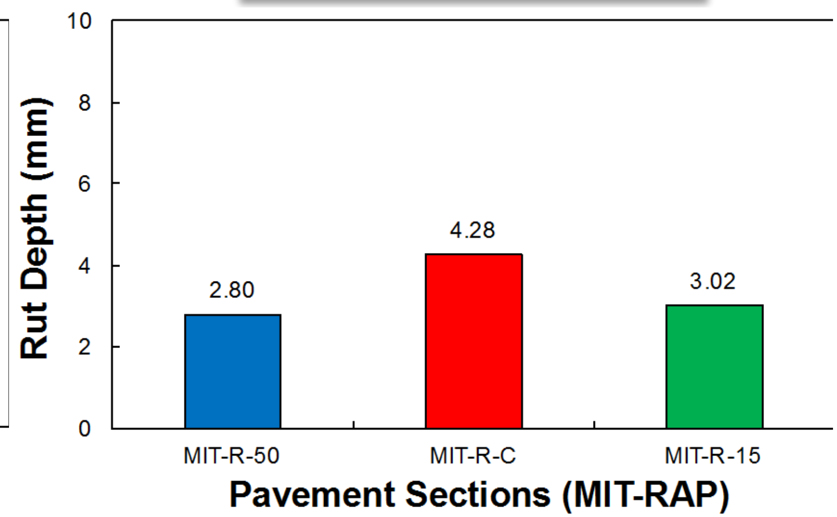
Rutting Performance Prediction

Field Measured

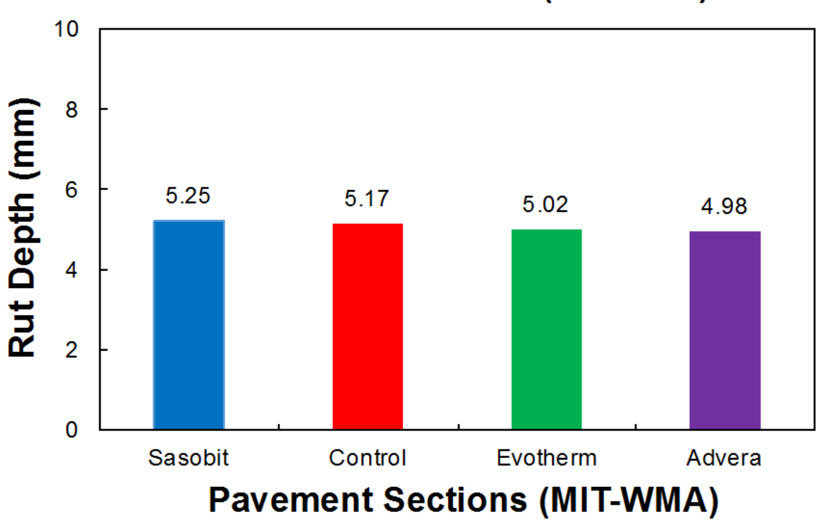
LVECD Predicted

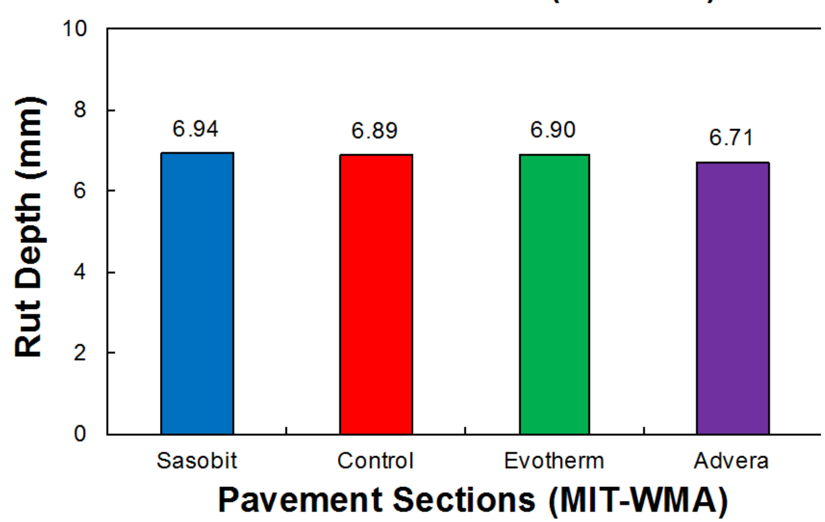
MIT RAP





MIT WMA

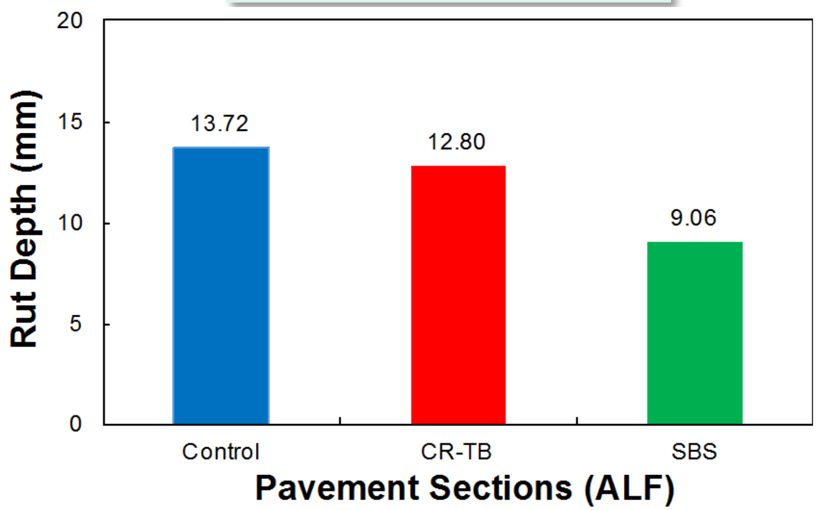


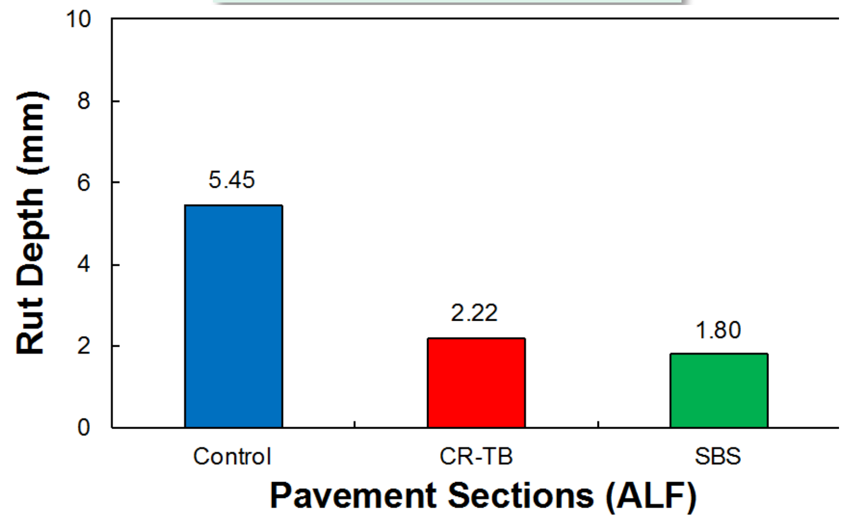


Rutting Performance Prediction

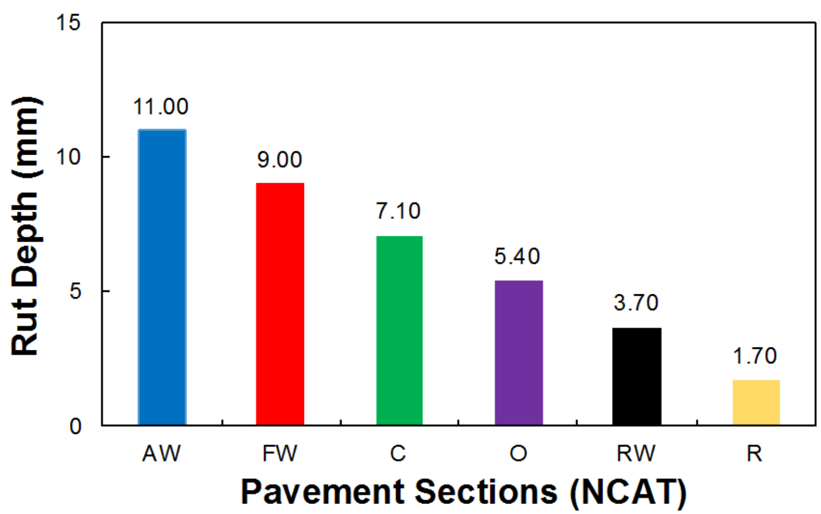
Field Measured | **LVECD Predicted**

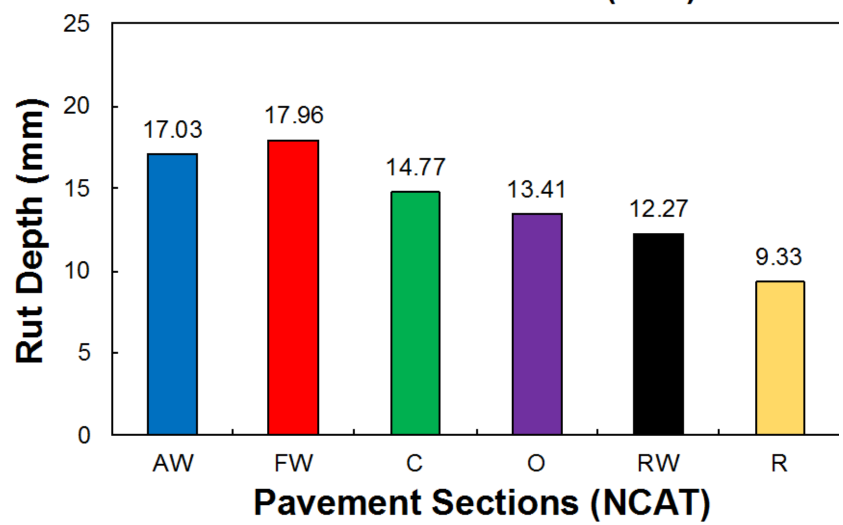
FHWA ALF





NCAT



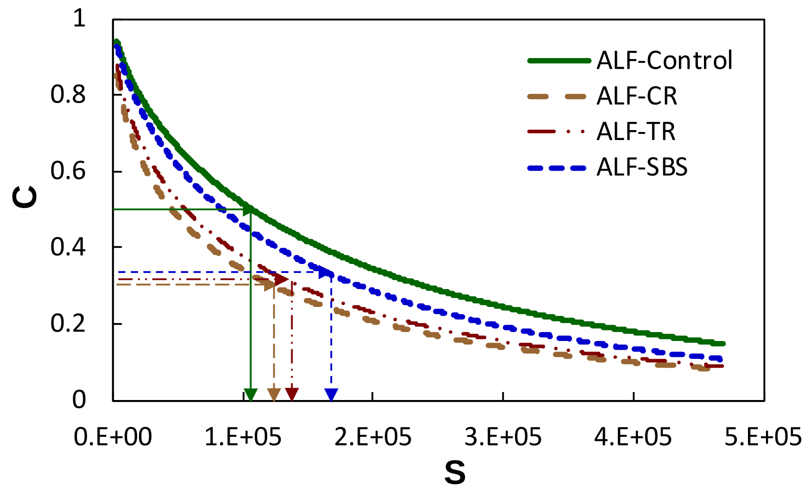


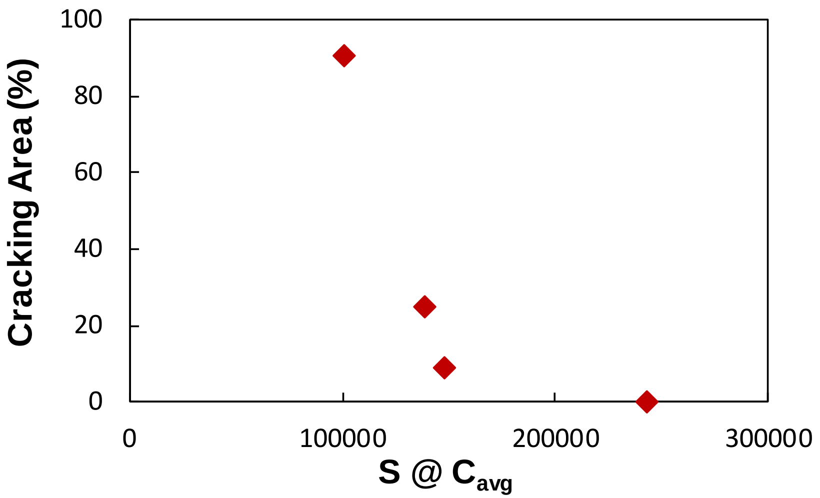
Index Property for Pass/Fail

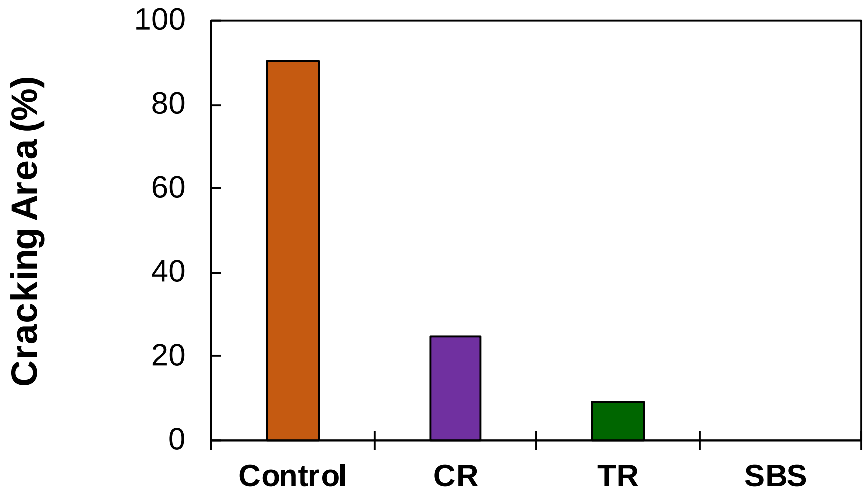
$S@C_{avg}$ as Cracking Index Property

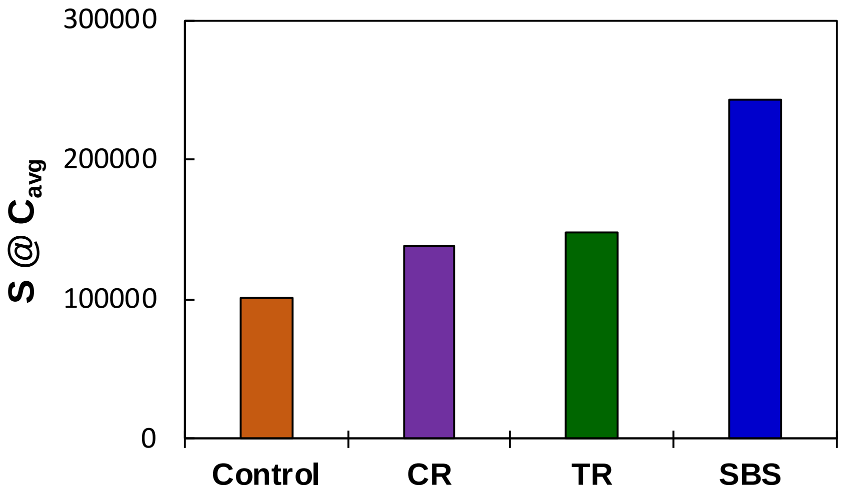
- $S@C_{avg}$ is 'cumulative effective dissipated pseudo strain energy'
- Use the temperature recommended in TP 107 as the reference temperature.
- $S@C_{avg}$ = 80,000 is the preliminary minimum required value.

S@C_{avg} for ALF Mixtures



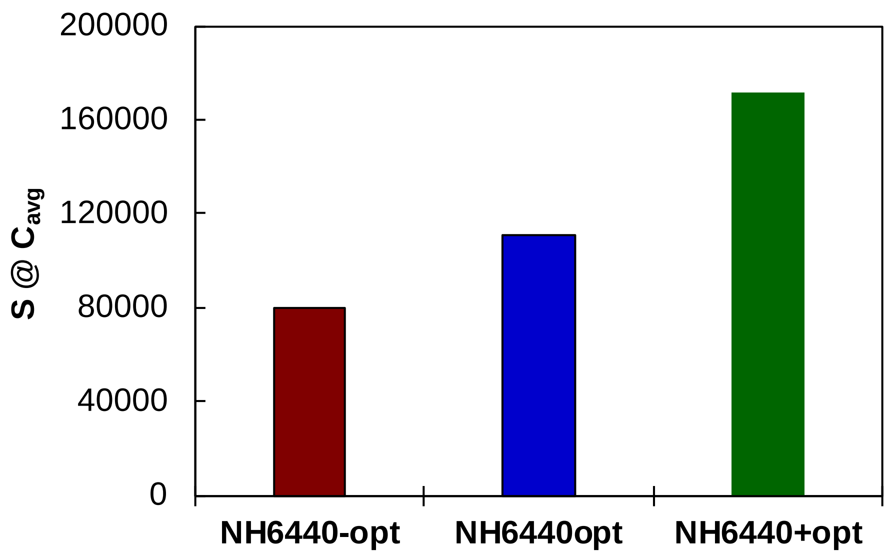




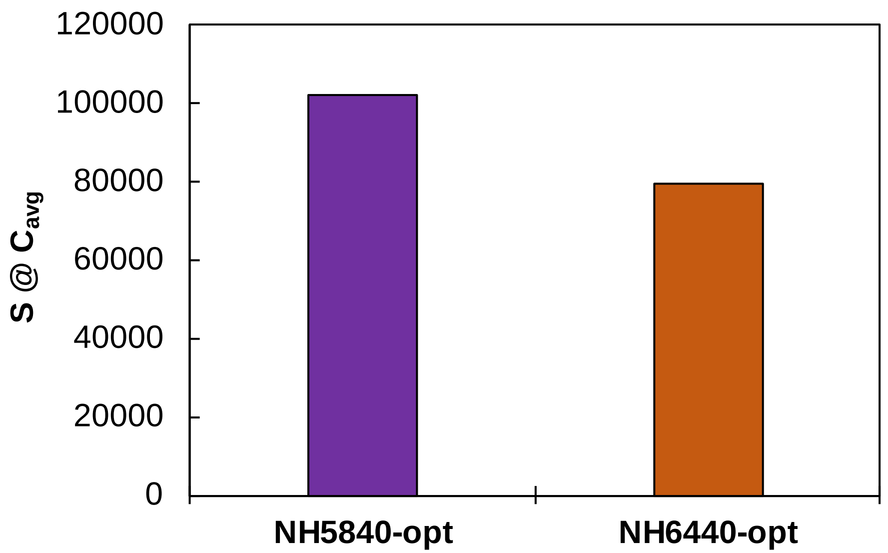


Factors Affecting S@C_{avg}

Binder Content



Binder Grade



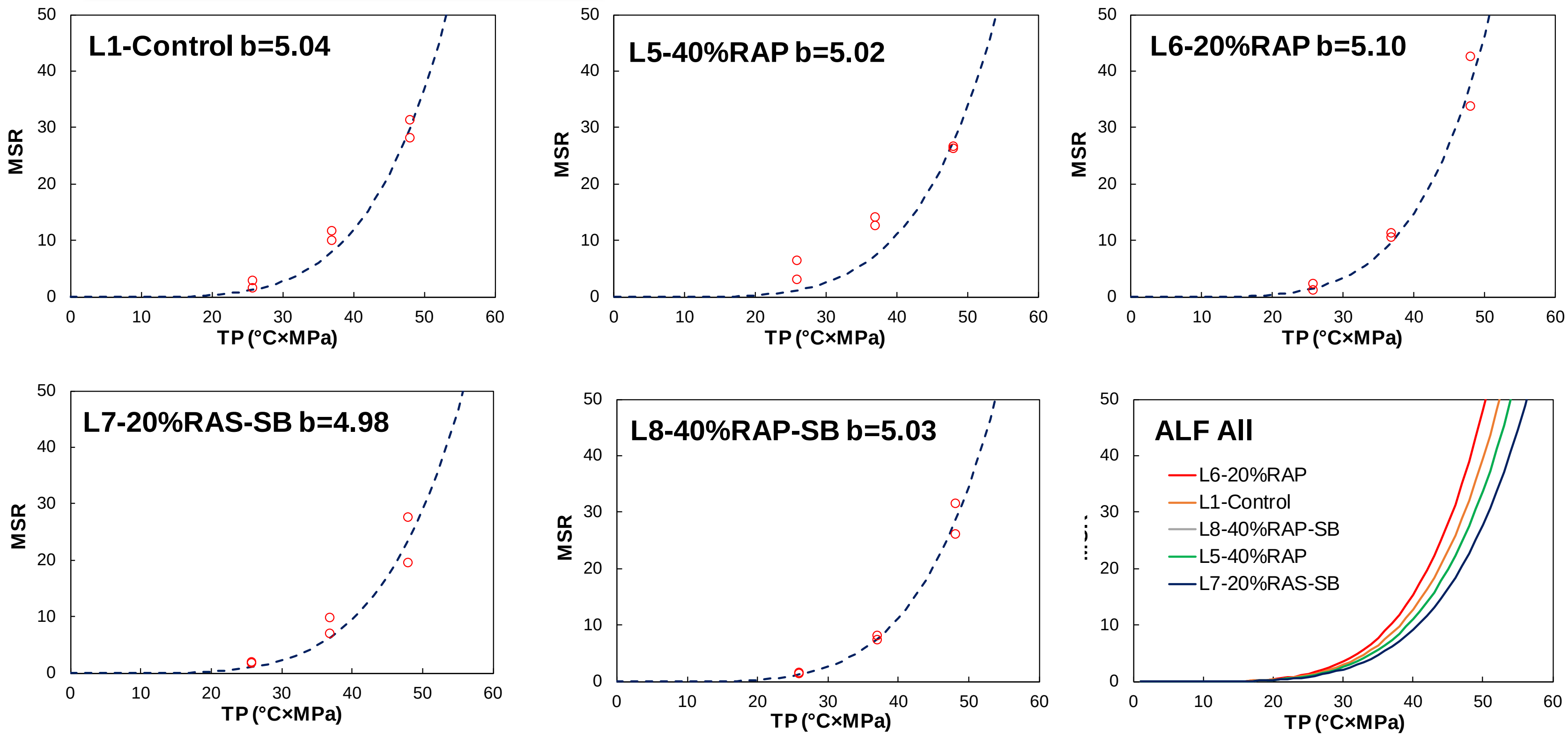
MSR for Rutting Index Property

TP-116 by Azari and Mohseni

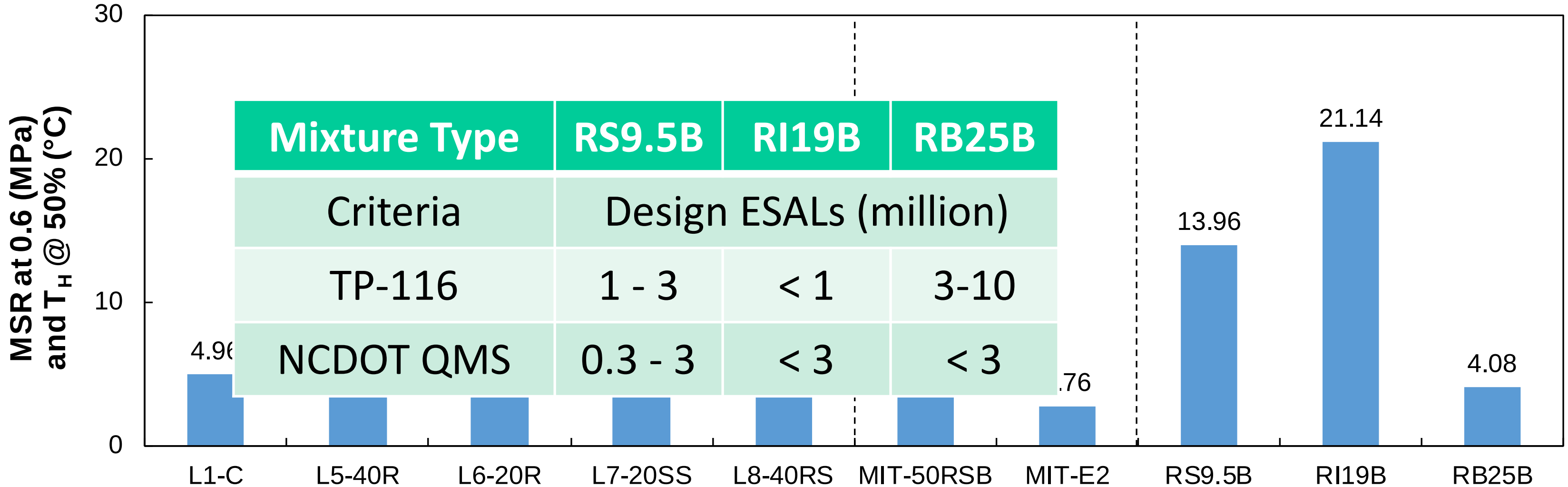
$$MSR = a(T \times P)^b = 10^{-7} \times TP^b$$

where T= temperature (°C) and P=deviatoric stress (MPa)

FHWA ALF Mixtures



Classification of Mixtures



Mixture Type	RS9.5B	RI19B	RB25B
Criteria	Design ESALs (million)		
TP-116	1 - 3	< 1	3-10
NCDOT QMS	0.3 - 3	< 3	< 3

TP-116 Criteria

Traffic Level	Design ESALs (million)	Maximum MSR Value
Light	< 1	24
Standard	> 1 to 3	17
Heavy	> 3 to 10	10
Very Heavy	> 10 to 30	3
Extreme	> 30	1

NCDOT 2016 QMS Manual

Mixture	Design ESALs (million)
S9.5B	> 0.3 to 3
I19B	< 3
B25B	< 3

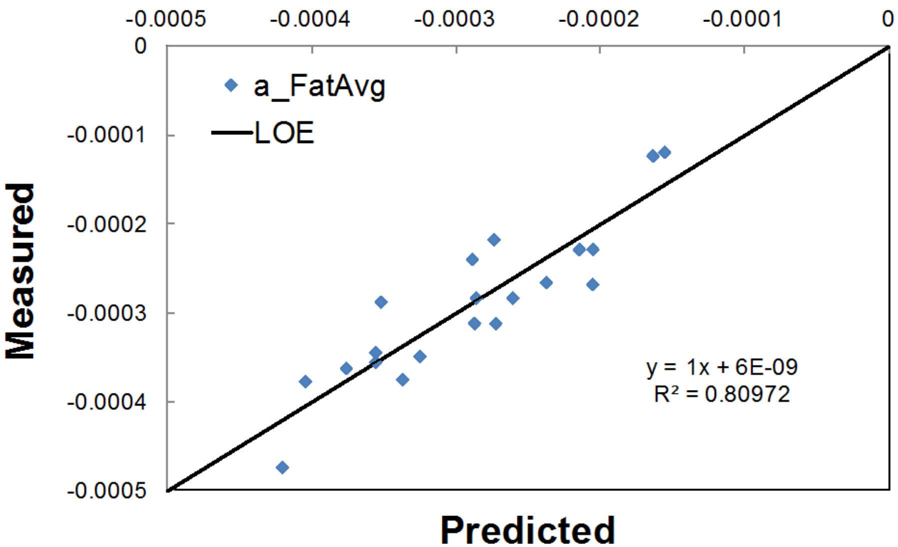
Predictive Equations

Materials and Mix Designs

- Accelerated Loading Facility (ALF) Lane 6
  - Superpave 12.5 mm HMA mixture
  - 23% RAP
  - PG 64-22 binder
- Volumetric Design Target
  - Design VMA: 13, 14, 15%
  - Design AV: 3, 4, 5%
  - In-Place AV: 5, 7, 9%
- Total of 21 Mix Designs
- AMPT Cyclic Fatigue and TSS Testing Completed

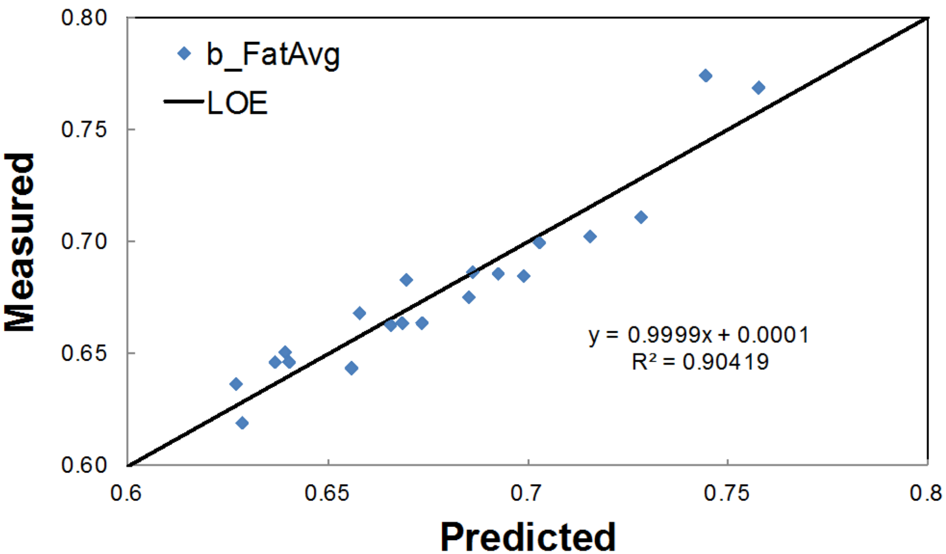
Predictive Equations for Damage Characteristic Curve

$$C = \exp\left(a \cdot S^b\right)$$

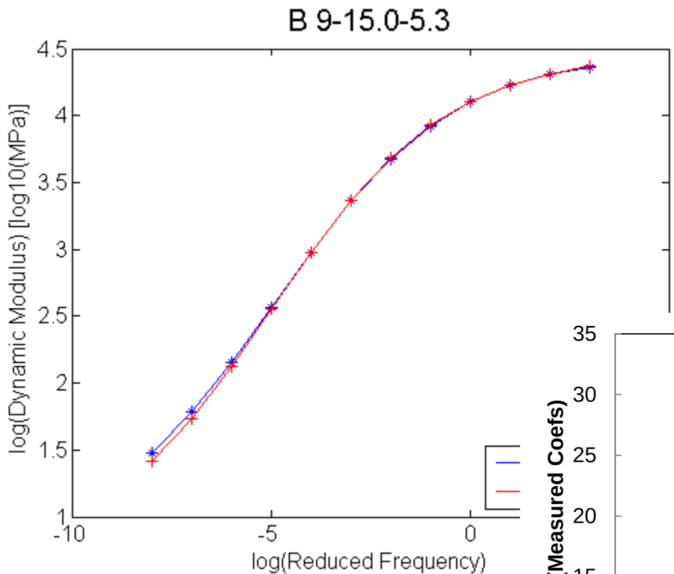


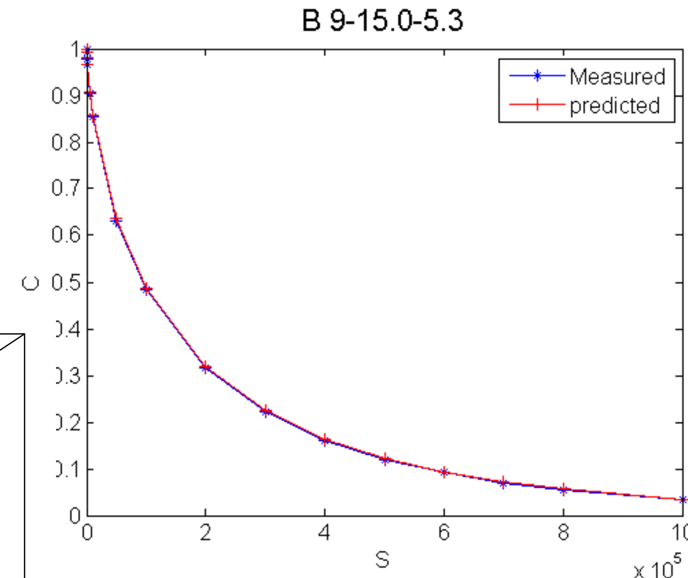
$$a = 0.0018026 + 0.00046641 \times V_a - 0.0021855 \times VMA$$

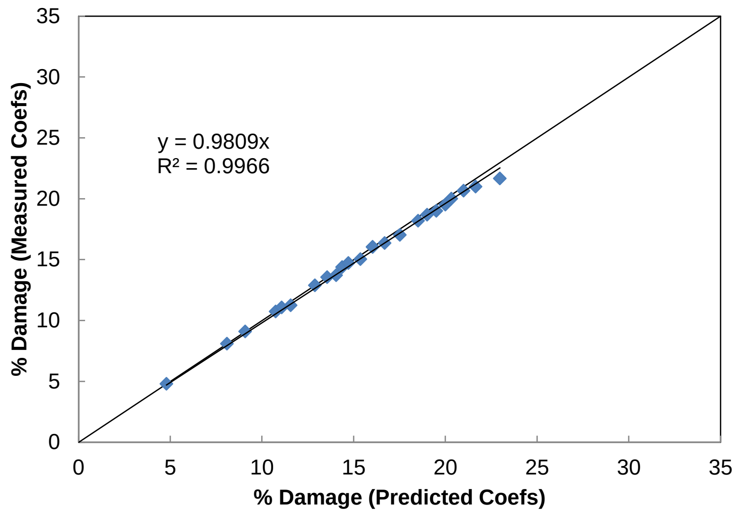
$$b = 2.3088 + 0.014604 \times V_a - 0.1235 \times VMA - 0.1452 \times V_{beff} + 0.010241 \times VMA \times V_{beff}$$

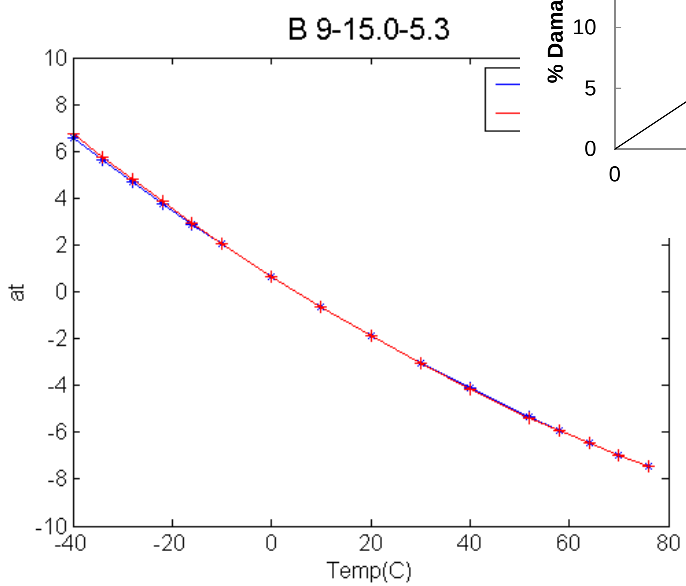


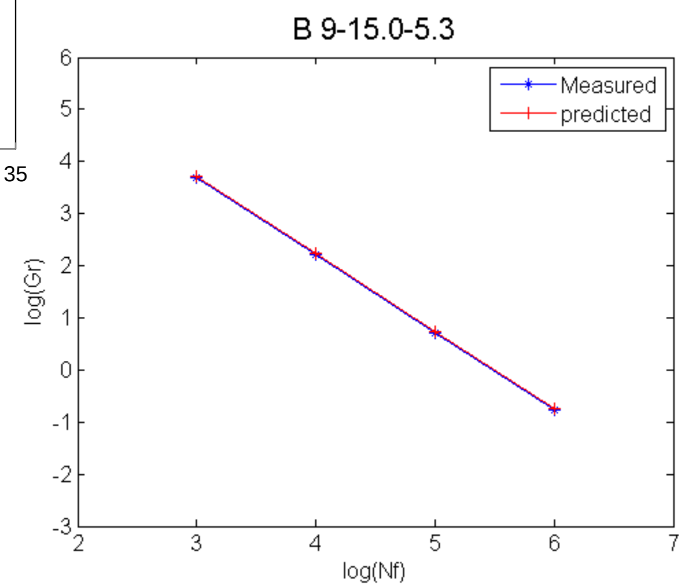
Prediction Results for Mix B



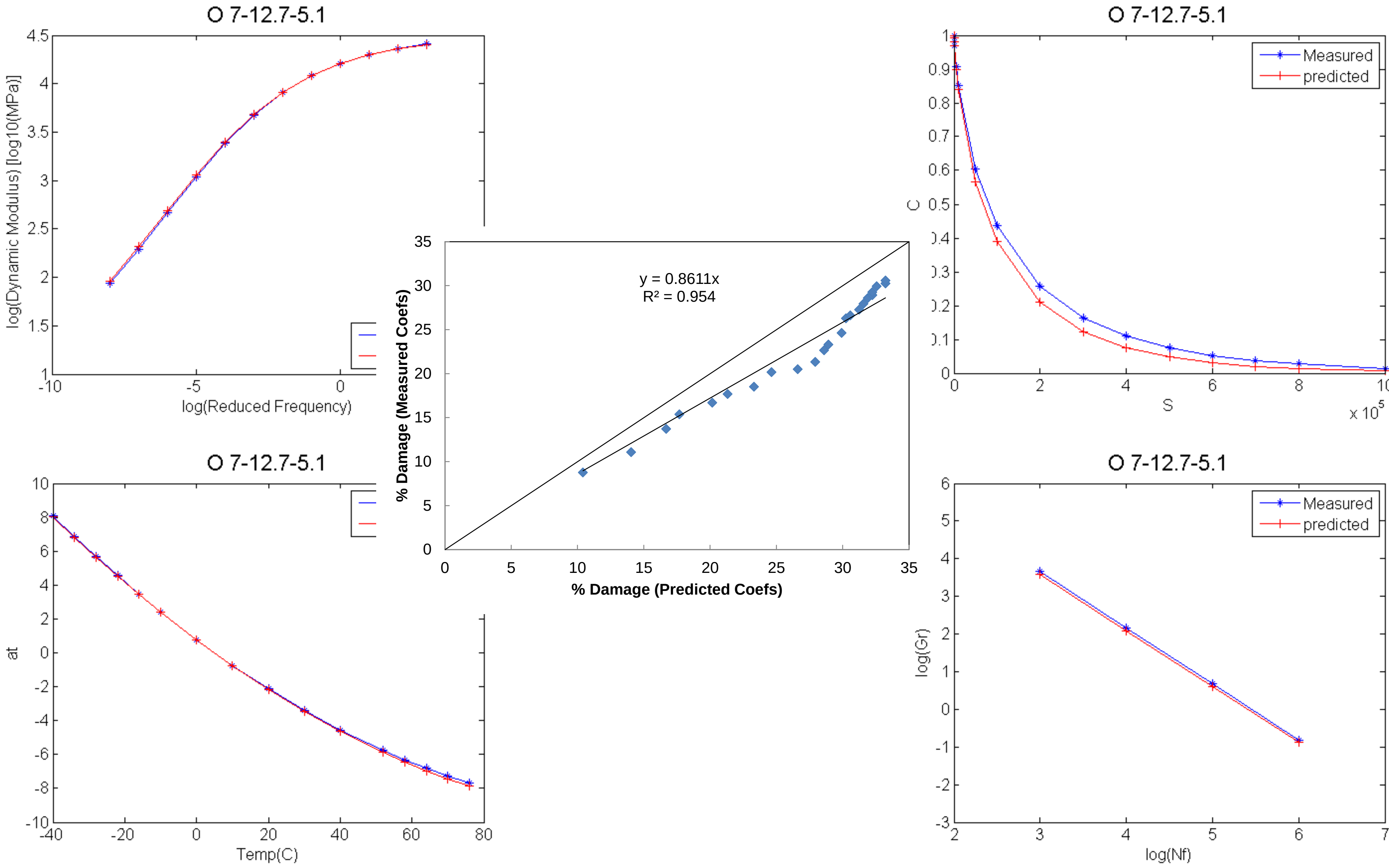




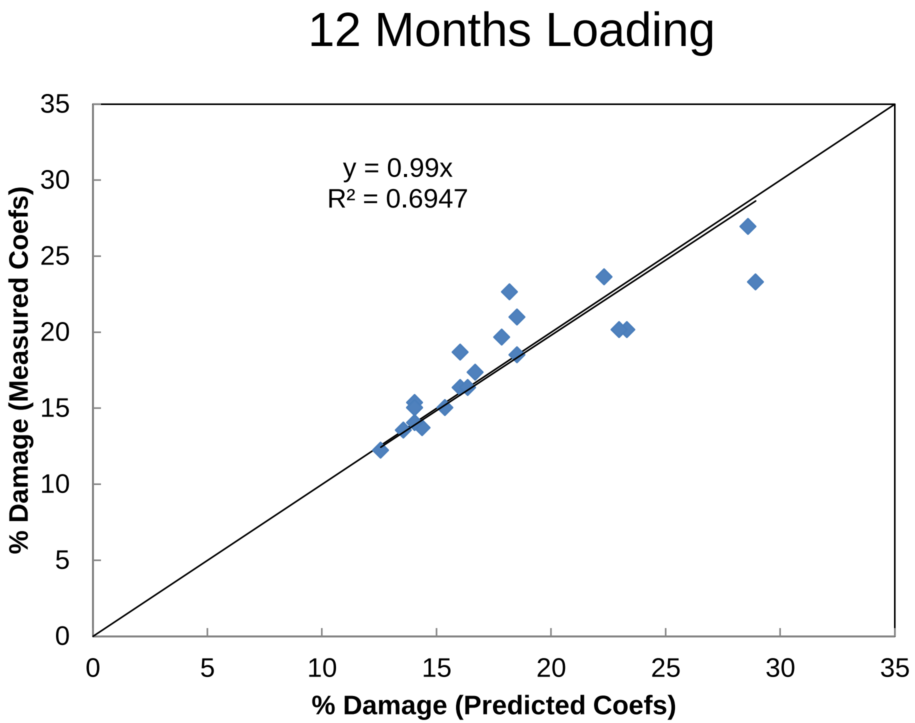


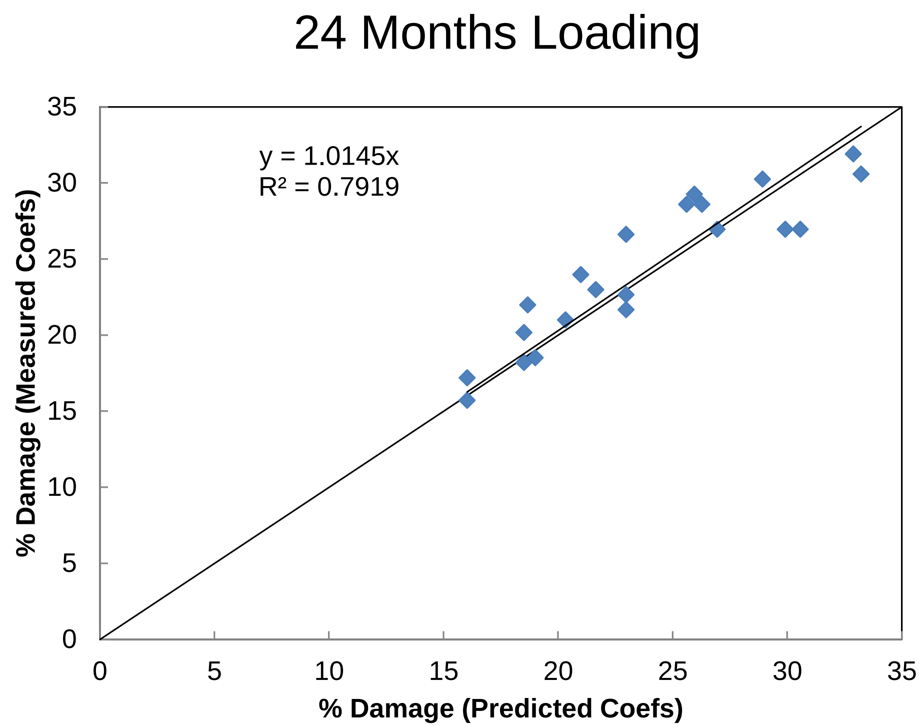


Prediction Results for Mix O

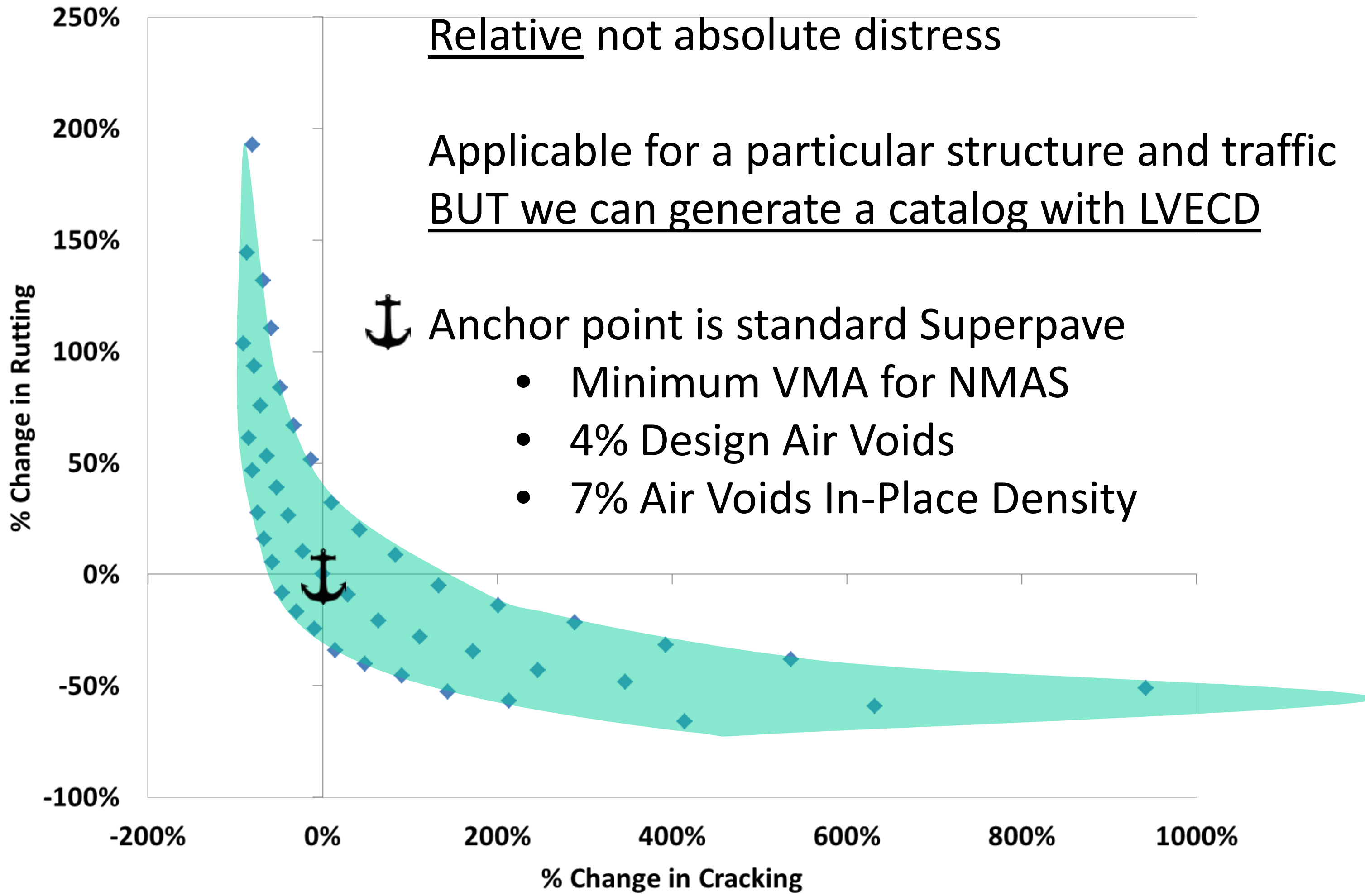


LVECD Prediction for 21 Pavements





Current PBMD Database



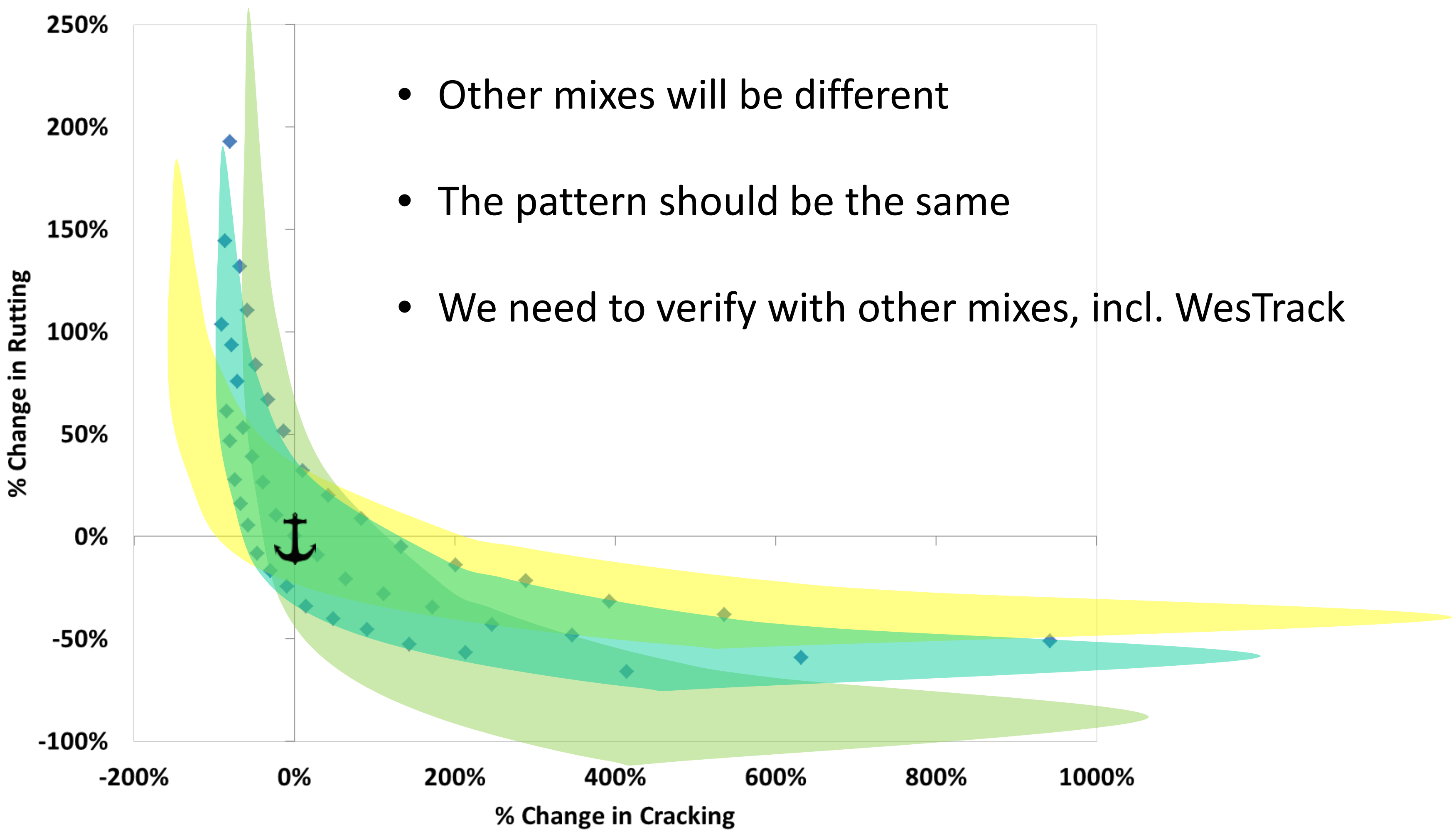
Relative not absolute distress

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

⚓ Anchor point is standard Superpave

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

Generalization to Any Mixture



- Other mixes will be different
- The pattern should be the same
- We need to verify with other mixes, incl. WesTrack

Summary of PBMD

- Starts with Superpave volumetric mix design
- AMPT cyclic fatigue and S-TSS tests as the performance tests
- LVECD program for pavement performance analysis
- Either index properties or pavement performance as the pass/fail criteria
- Predictive equations to adjust the mix design

Additional Remarks

- PBMD is a necessity in adequately implementing PRS.
- PBMD and PRS must be based on the same test methods and engineering properties.
- PBMD and PRS models have been successfully validated using the field data.
- Excel programs to be available for determination of material properties
- Predictive equations are being developed by testing additional mixtures at different volumetrics.

Thank you!
Questions?