

Asphalt Pavement Response and Fatigue Performance Prediction with Viscoelastic Continuum Damage Modeling Approach

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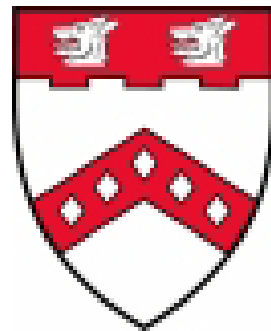
North Carolina State University

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*Validation of Predictive Models Using Full-Scale and Field
Pavement Performance***



Laramie, Wyoming

July 16, 2009



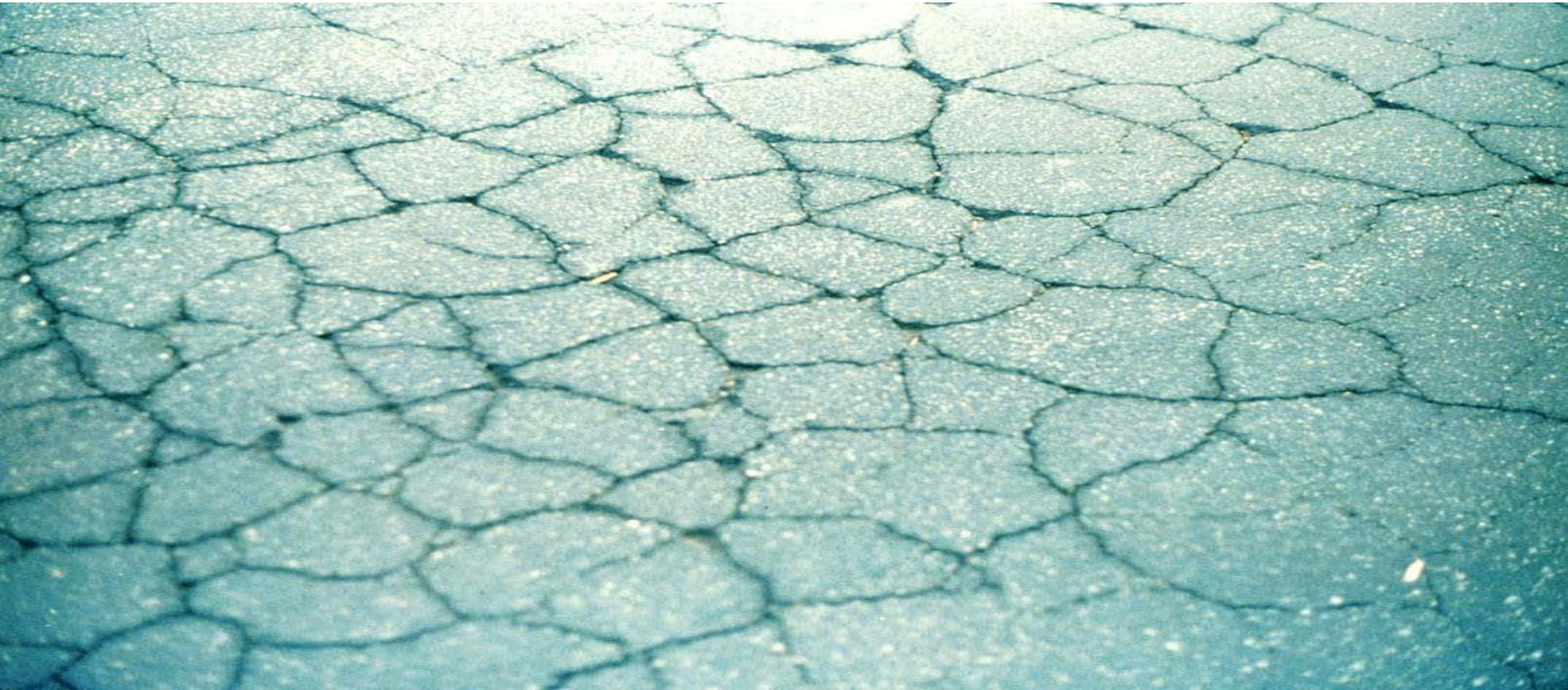
Outline

- ❑ Objective
- ❑ VECD material model
- ❑ Pavement response modeling
- ❑ Pavement performance modeling
 - Integrated model
 - Discrete model
- ❑ Future direction of performance modeling
- ❑ Summary
- ❑ Questions for audience

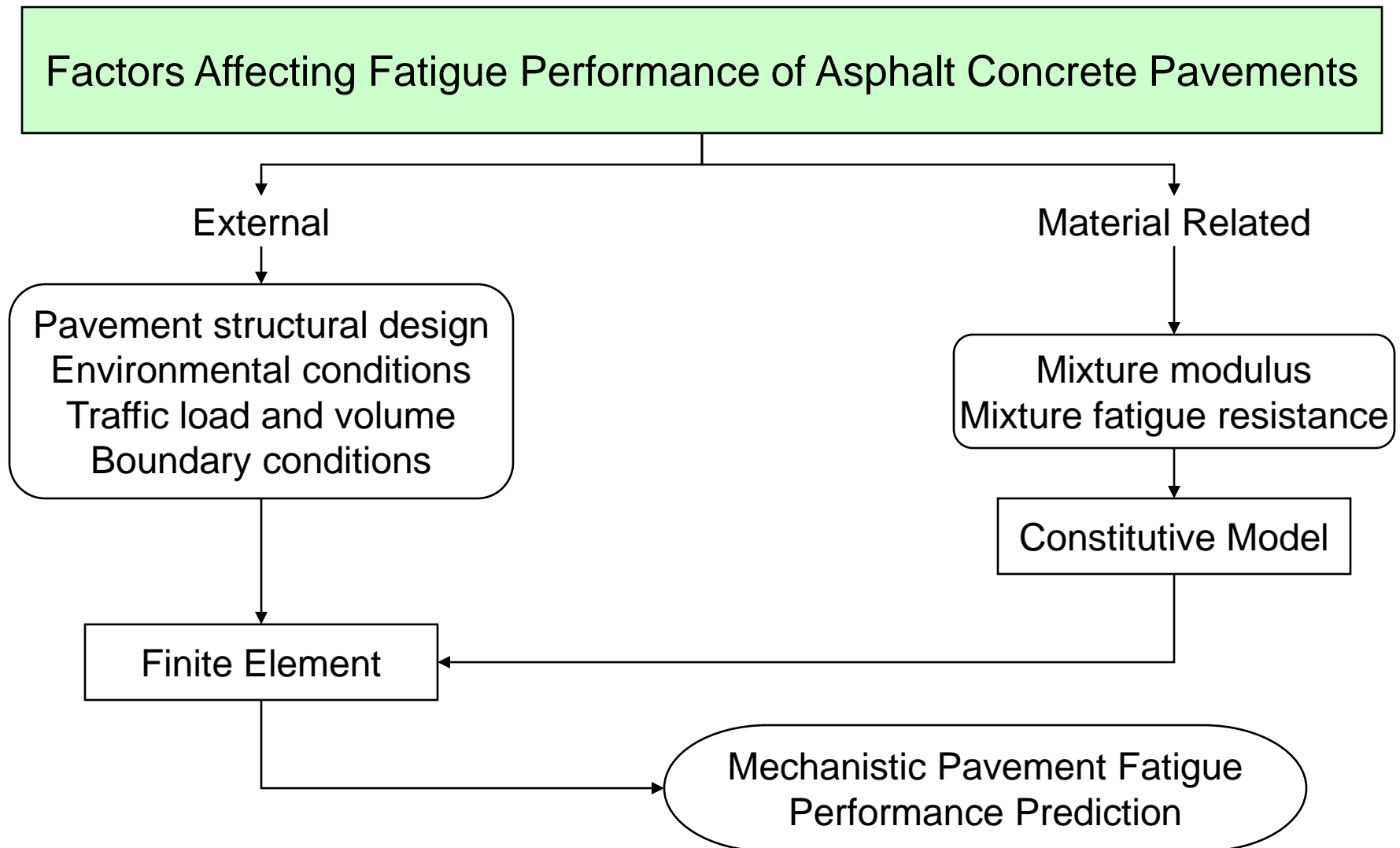


Objective

- Develop a comprehensive mechanistic model capable of accurately describing the field behavior and performance of asphalt concrete pavements in fatigue.



Modeling Philosophy



VECD Model

Constitutive Material Model

Viscoelastic Continuum Damage (VECD) Model



Elastic-Viscoelastic
Correspondence
Principle

Linear viscoelastic
effects



Continuum
Damage Mechanics

Microcracking related
strength/stiffness degradation

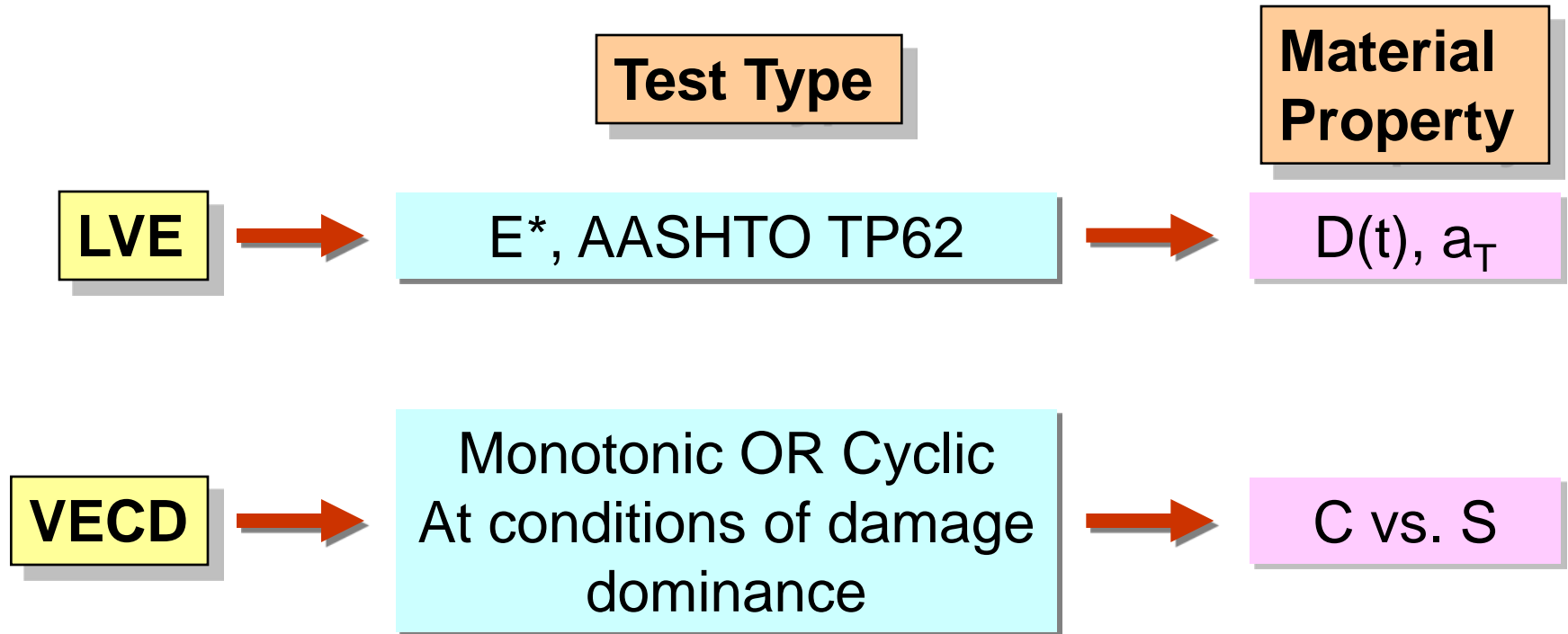


Time-Temperature
Superposition with
Growing Damage

Joint time/rate-
temperature effects

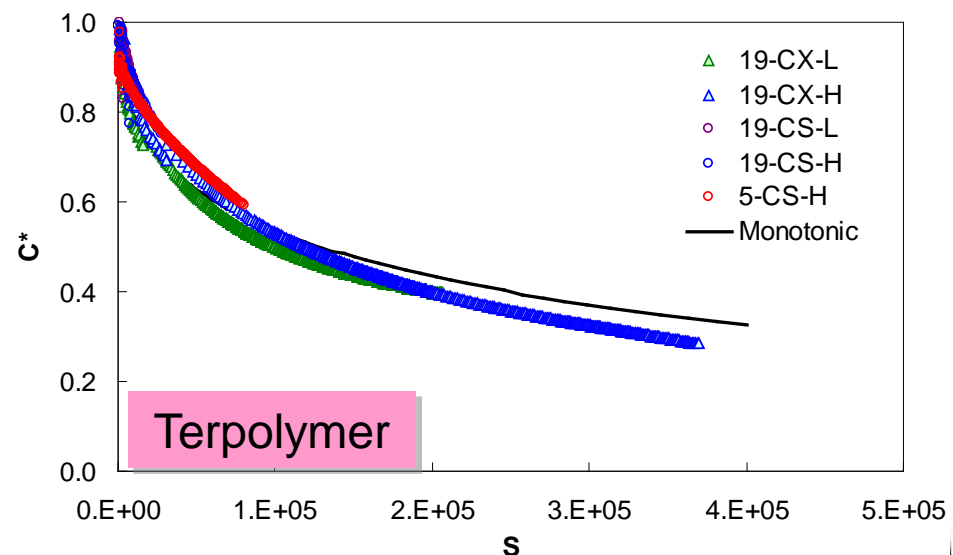
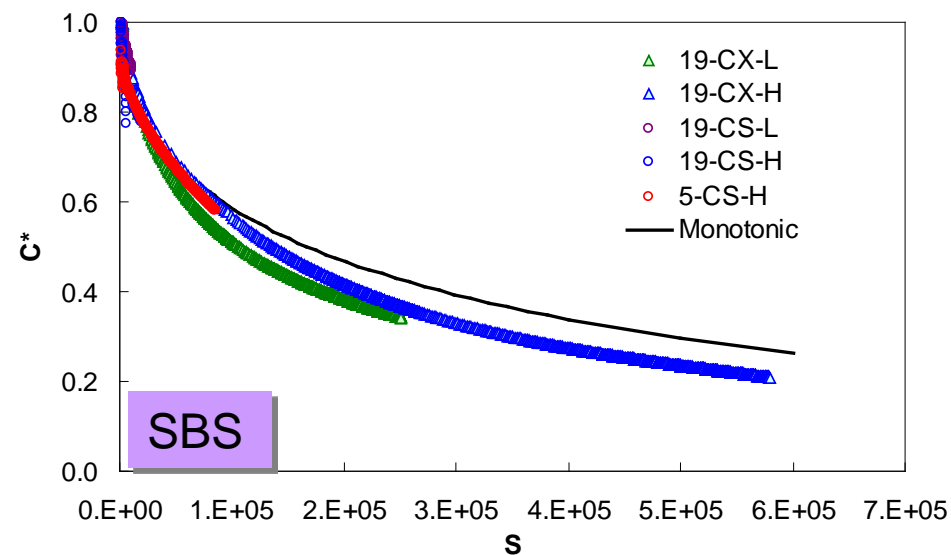
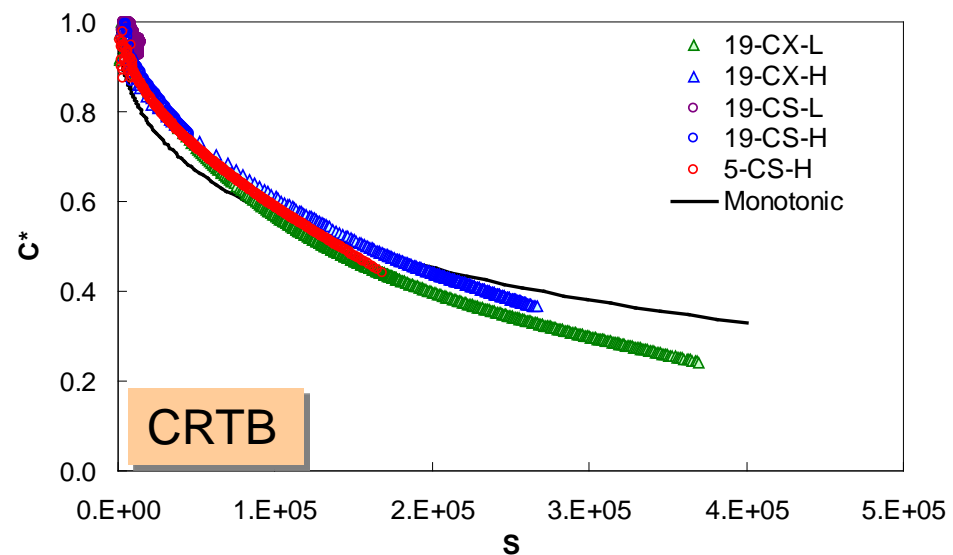
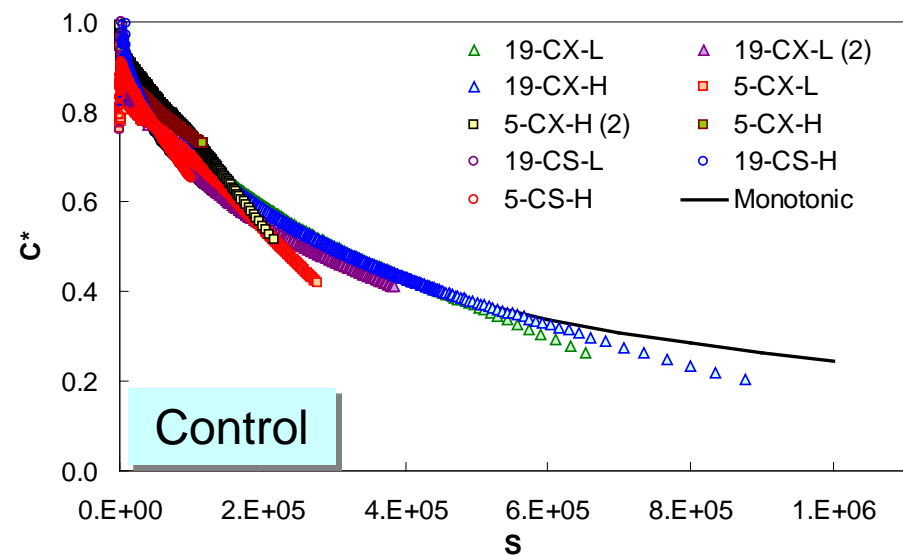


VECD Model Characterization

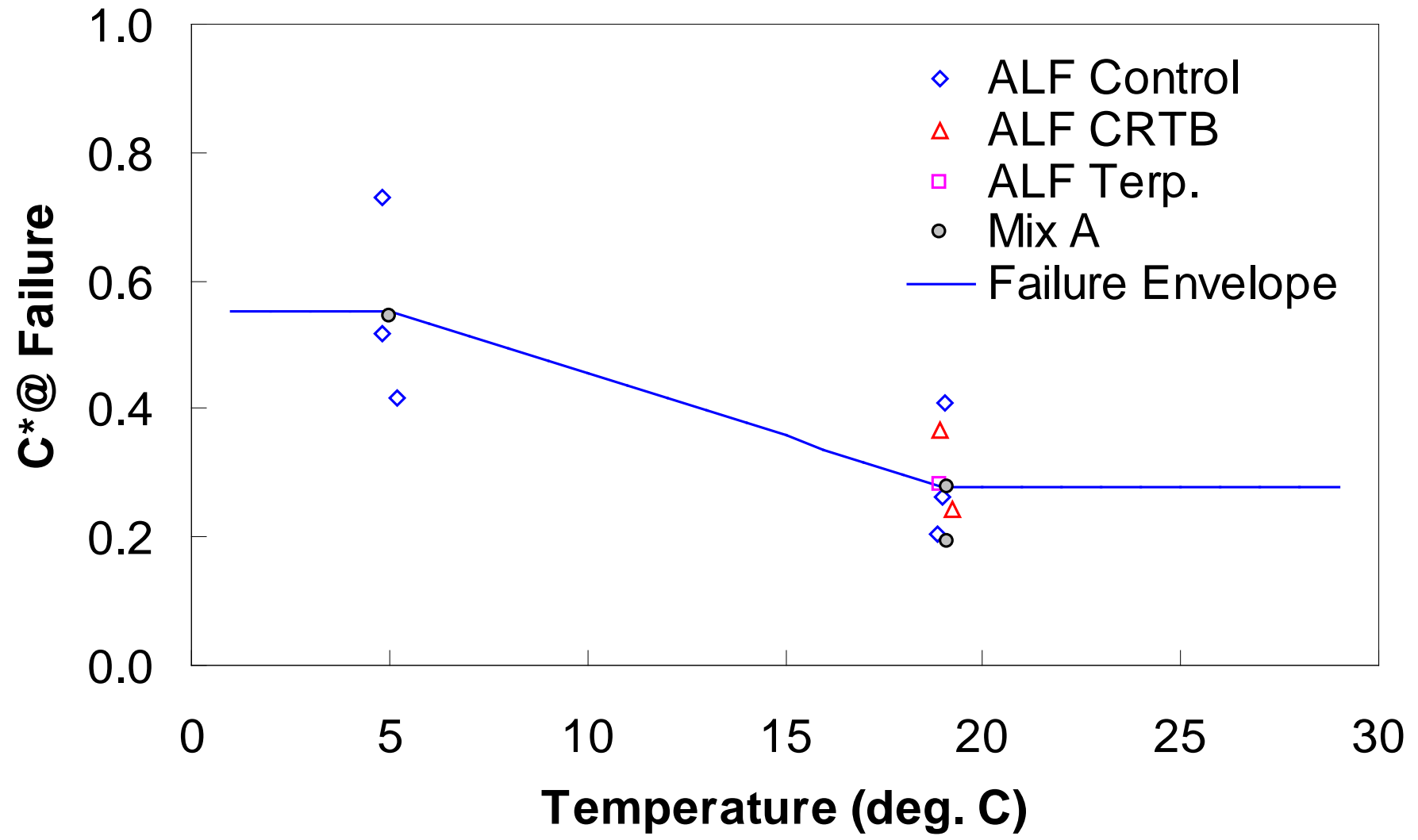


Simplified VECD Method

C vs. S Functions

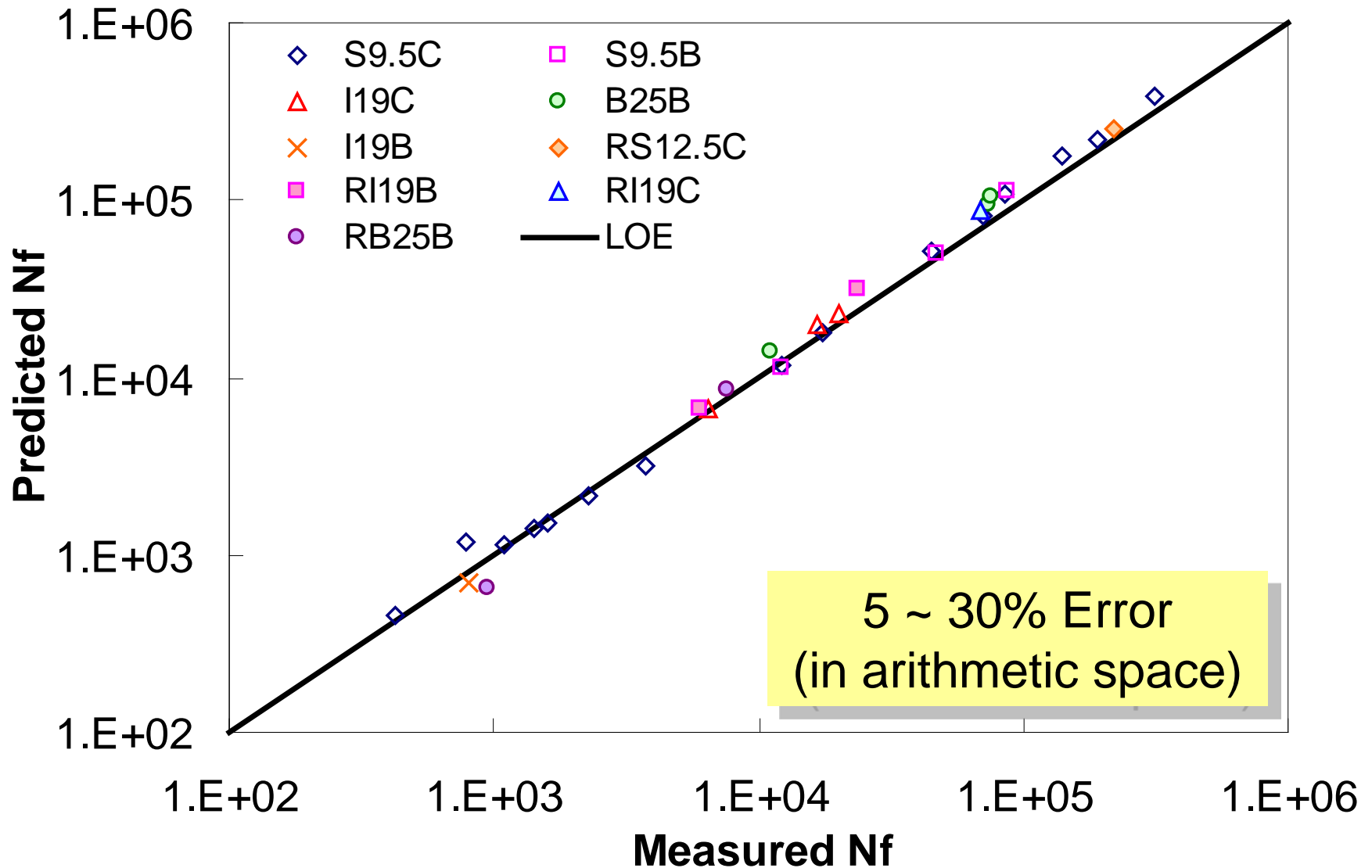


Failure Criteria



Fatigue Life Verification

Multiple mixtures, 10 Hz, 100 – 700 $\mu\epsilon$, 5°, 19°, and 27°C



Pavement Response Modeling



Response Modeling

3-D FEM Verification

□ Load Details

- Contact Pressure = 110 psi (758 kPa)
- Wheel Load = 10.3 kip (46 kN)
- Load Area (L X W) = 11.7 in x 7 in (29.65 cm X 17.79 cm)

□ Pavement Details

- Full depth AC = 18 in (46 cm)
- Subgrade = 12.5 ksi (86 MPa)

□ Analysis Factors

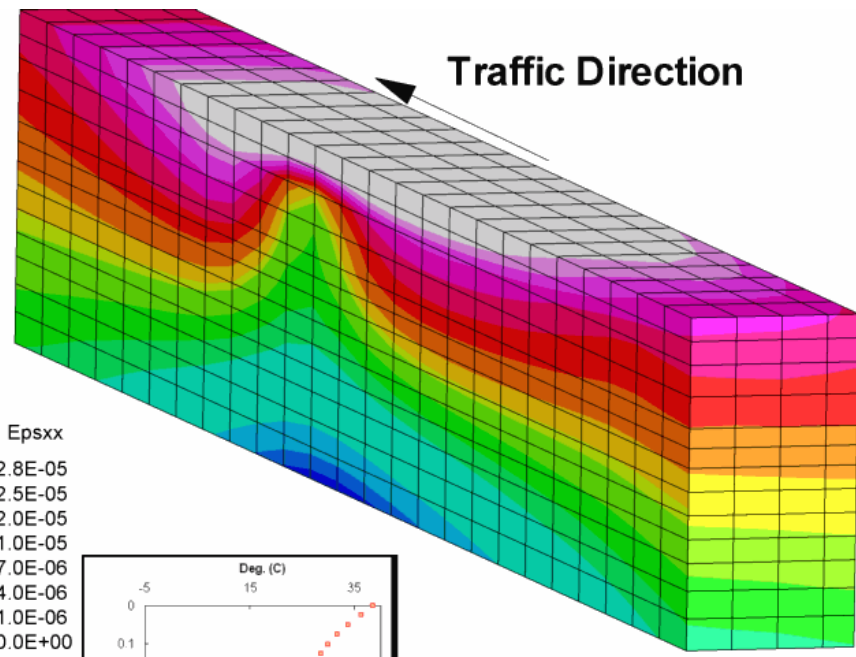
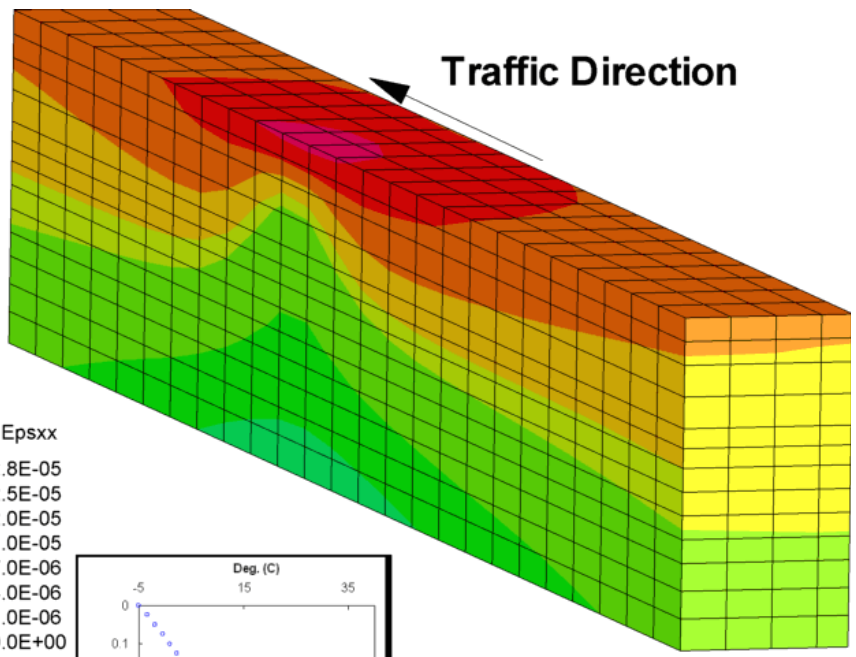
- Temperature = winter and summer temperature gradients
- Speed = 60 mph and 30 mph (96.6 km/hr and 48.3 km/h)
- Material = SBS versus Control



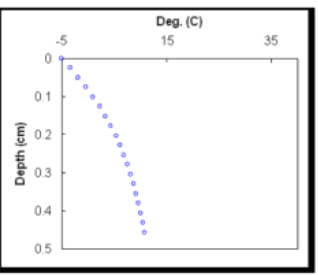
Effect of Temperature Distribution Transverse Strain

Winter

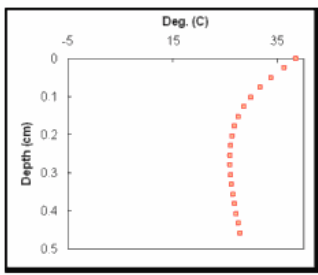
Summer



- 2.8E-05
- 2.5E-05
- 2.0E-05
- 1.0E-05
- 7.0E-06
- 4.0E-06
- 1.0E-06
- 0.0E+00
- 2.0E-06
- 5.0E-06
- 8.0E-06
- 1.1E-05
- 1.4E-05
- 1.7E-05
- 2.0E-05

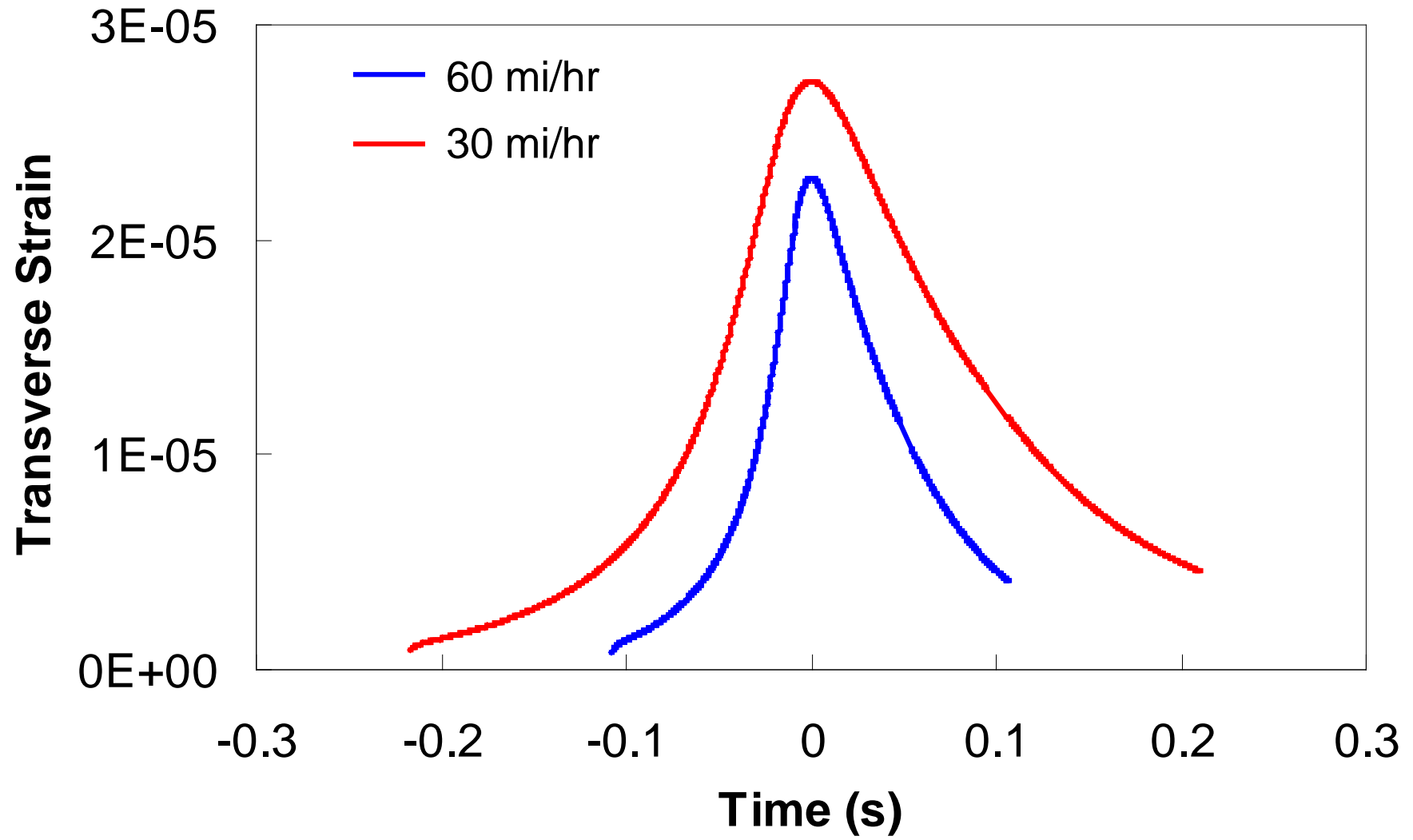


- 2.8E-05
- 2.5E-05
- 2.0E-05
- 1.0E-05
- 7.0E-06
- 4.0E-06
- 1.0E-06
- 0.0E+00
- 2.0E-06
- 5.0E-06
- 8.0E-06
- 1.1E-05
- 1.4E-05
- 1.7E-05
- 2.0E-05



Effect of Traffic Speed

Transverse Strain



Pavement Performance Modeling

- ❑ Integrated Modeling
- ❑ Discrete Modeling



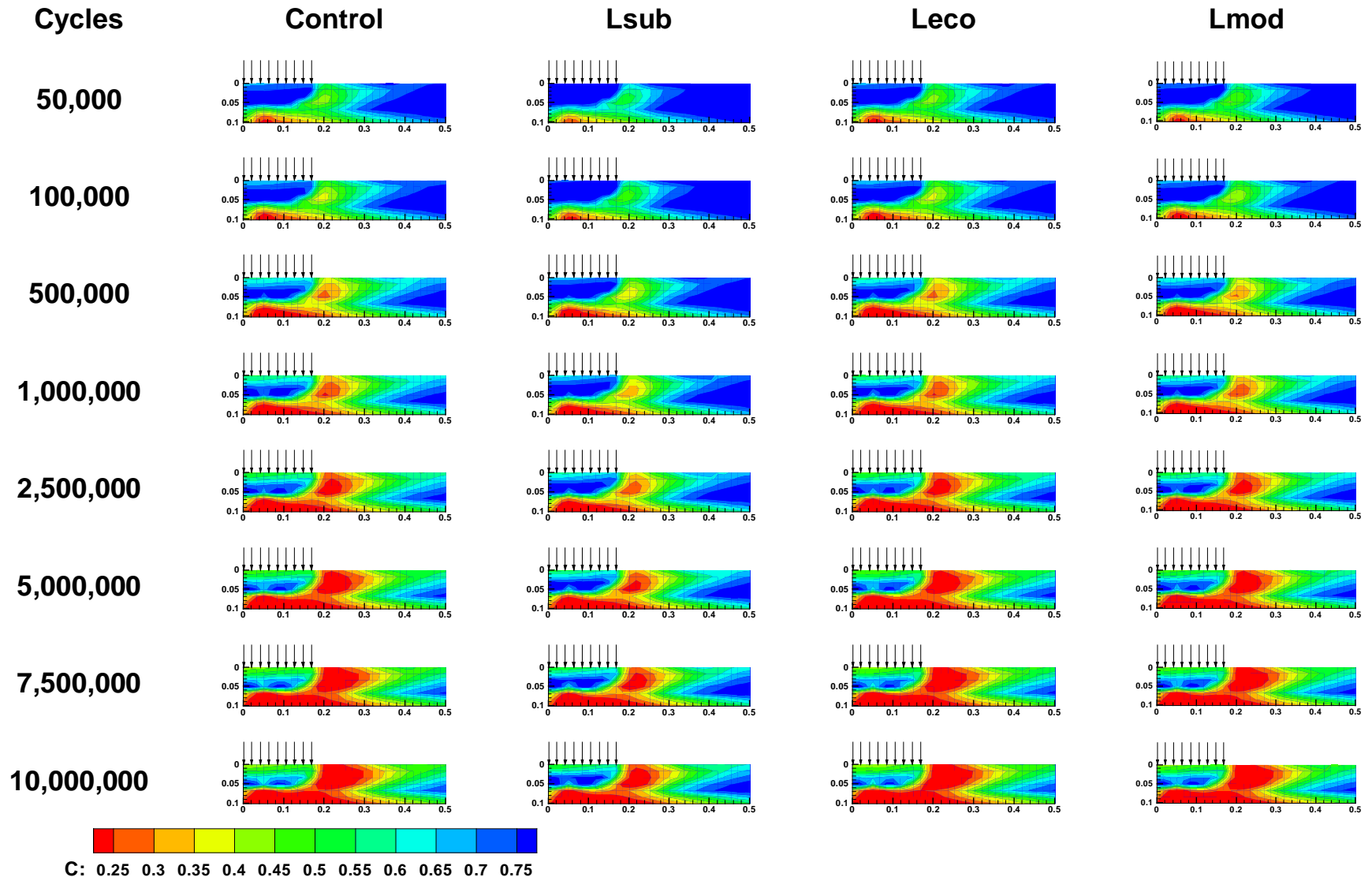
Integrated Modeling

- ❑ 2-D axisymmetric FEM analysis, FEP++
- ❑ Inputs
 - Pavement structural design
 - Material properties ($D(t)$, a_T , C vs. S)
 - Load conditions
 - Temperature
- ❑ Asphalt concrete layers modeled with VECD model.
- ❑ Unbound layers modeled as linear elastic.



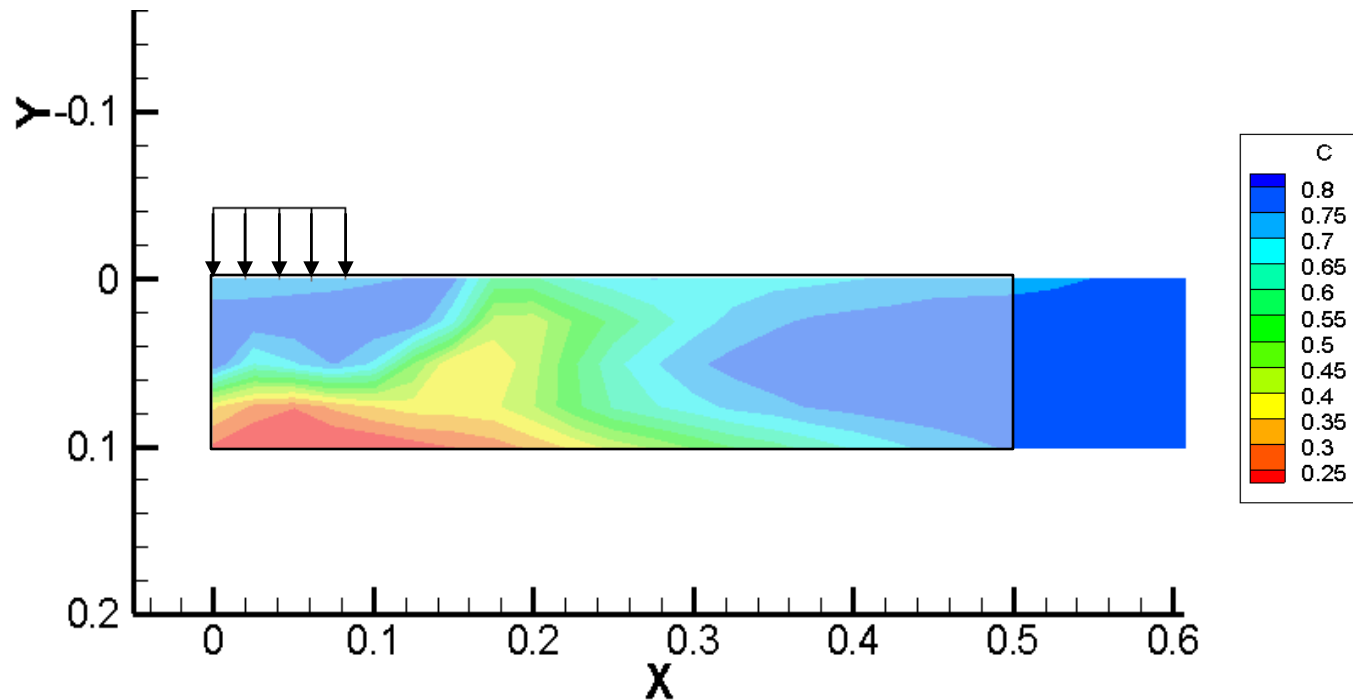
FEP++ simulation

Damage contour for lime addition method



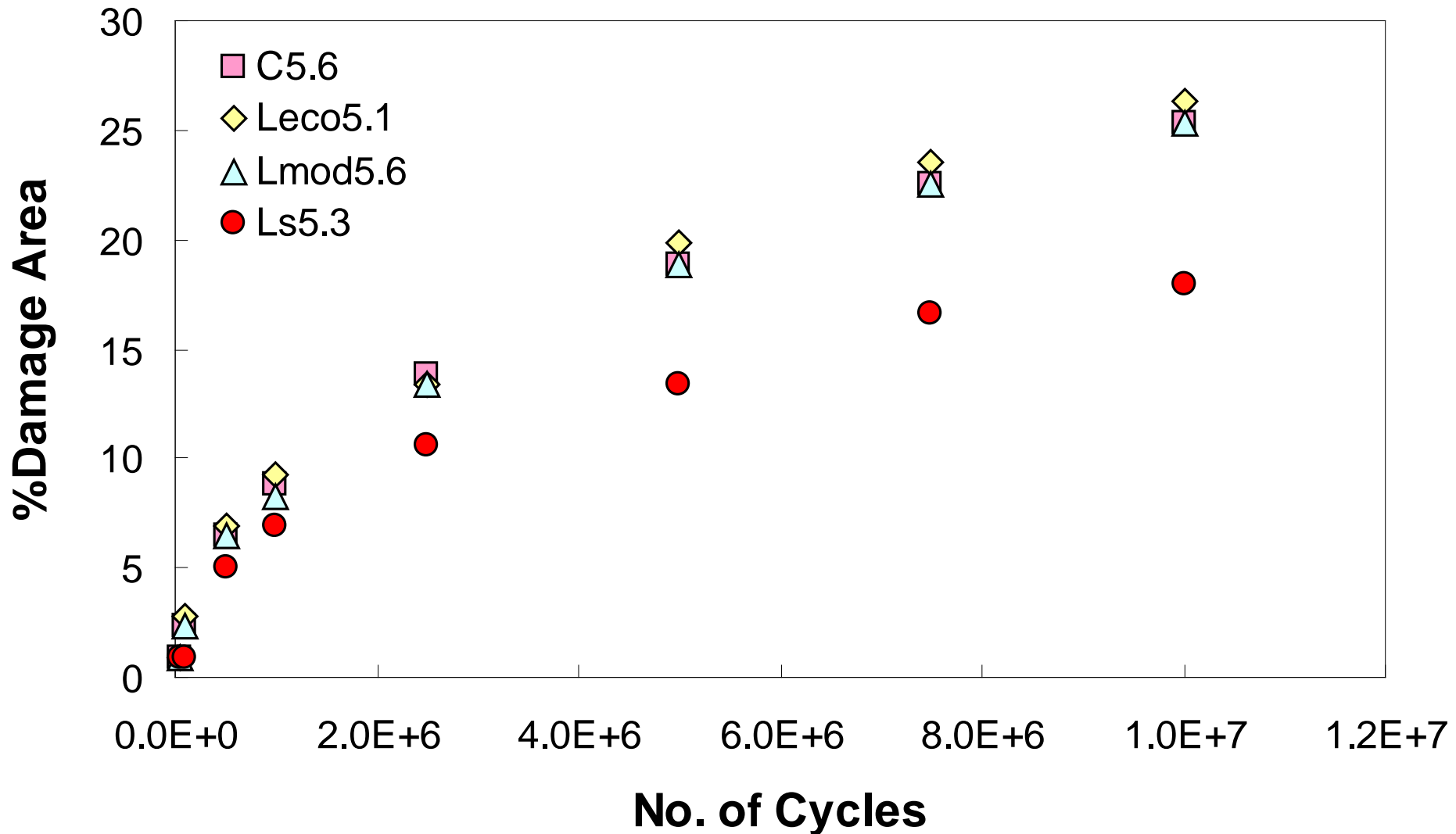
Percent Damage Area

$$\text{Percent Damage Area} = \frac{\text{\# of nodes with } C \text{ value below } 0.25}{\text{Total \# of nodes in } 0.5 \text{ m wide AC layer}} * 100$$



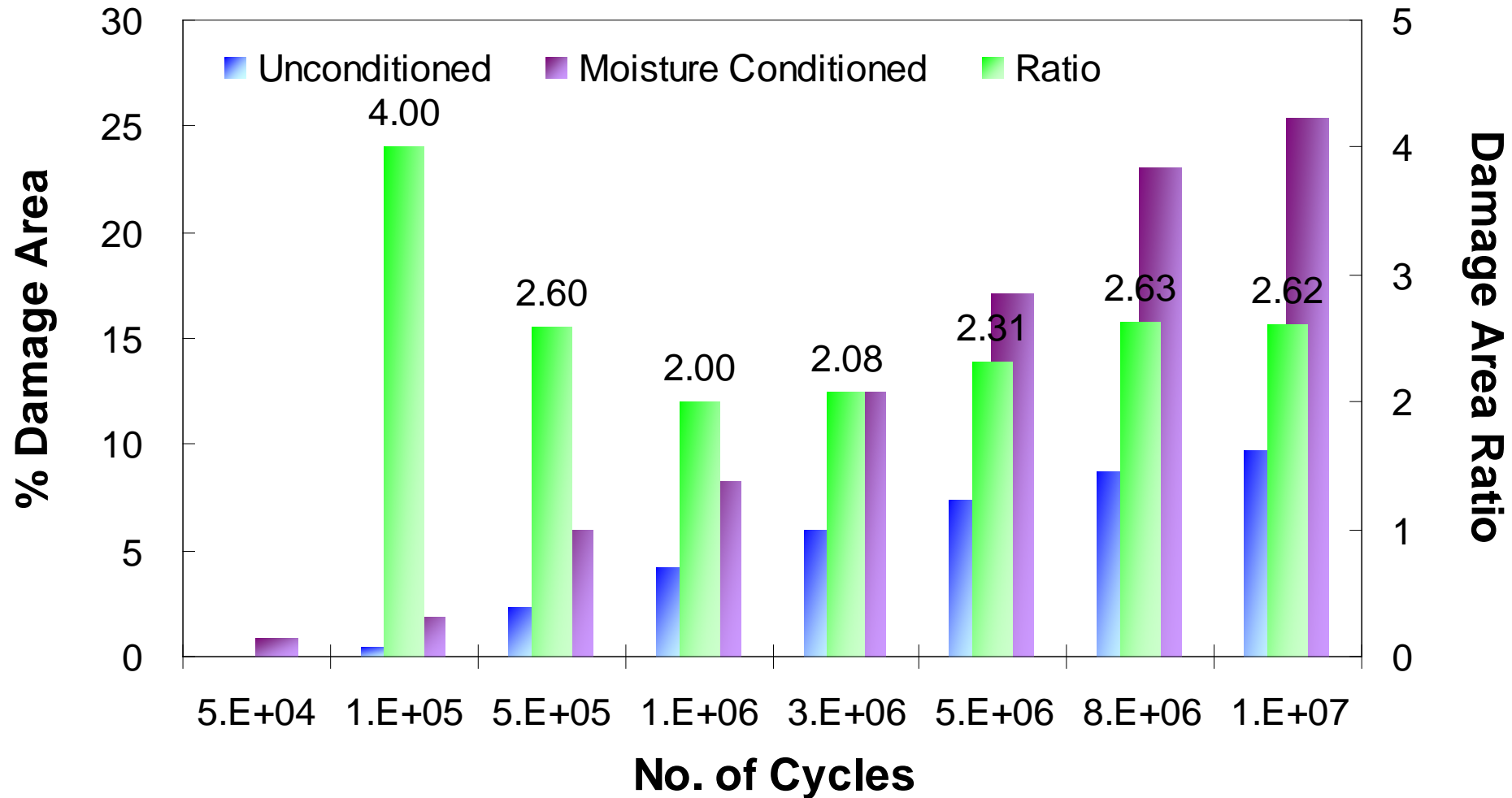
FEP++ Simulation

% Damage Area for lime addition method

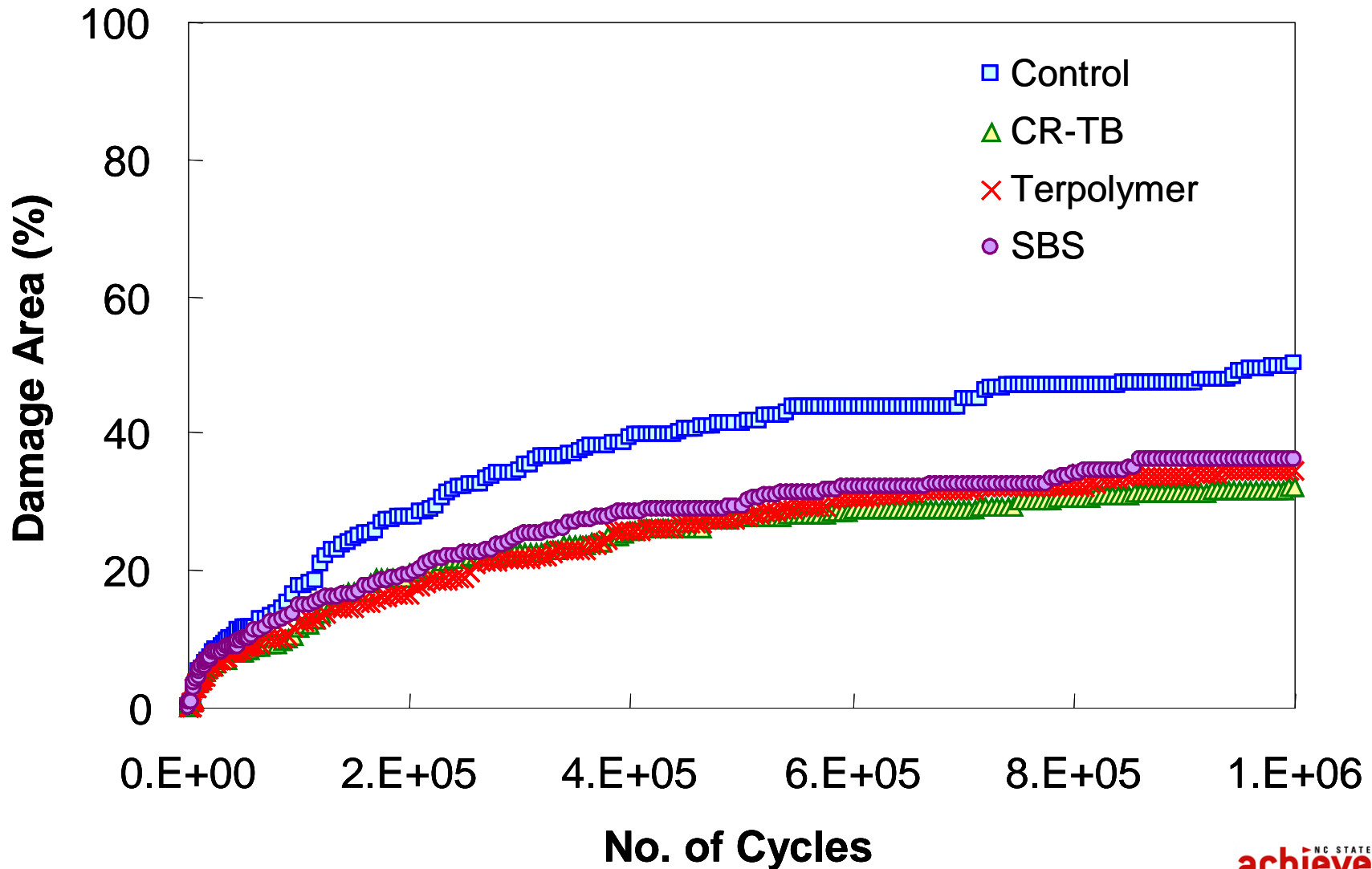


FEP++ Simulation

Effect of Moisture Damage



Performance Prediction of ALF Pavements

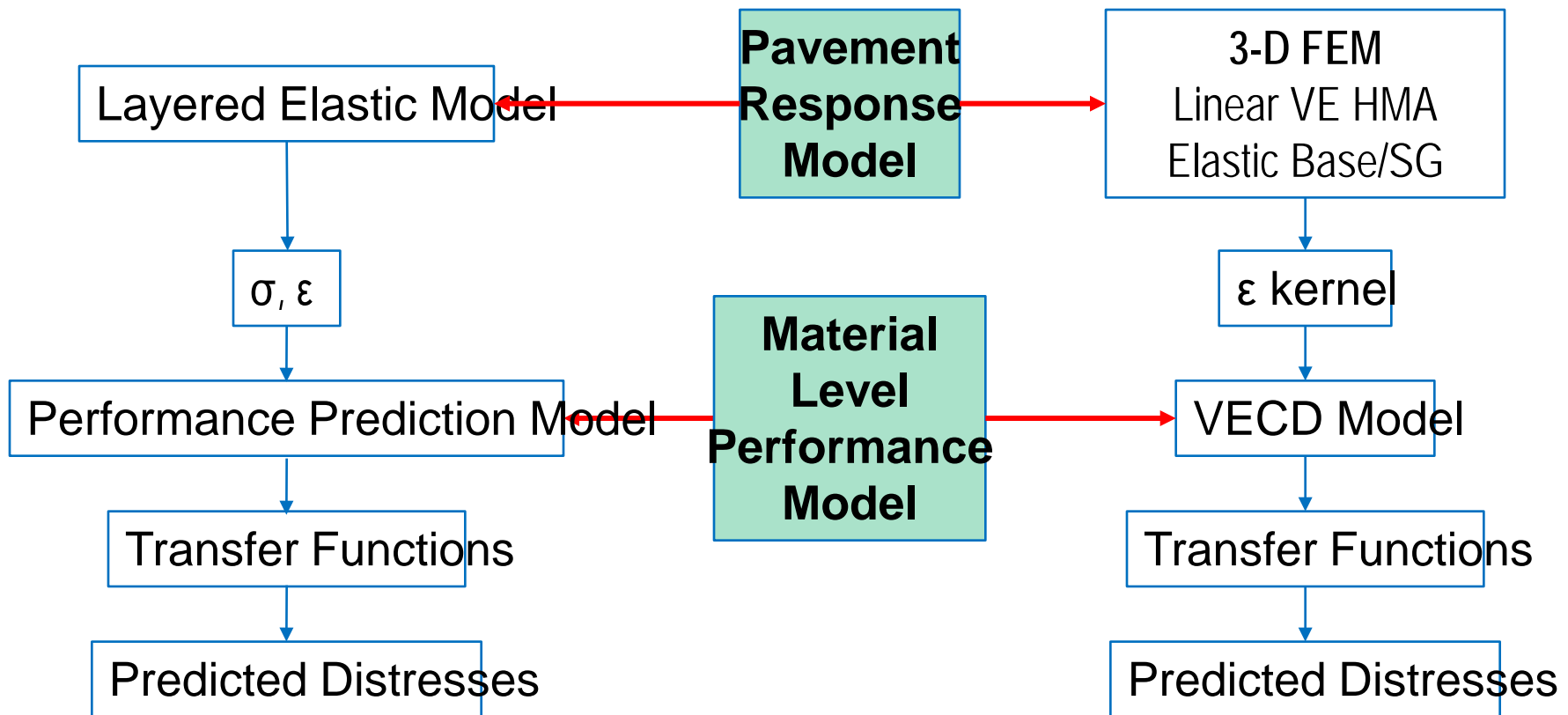


Pavement Performance Prediction

Discrete Modeling

M-E PDG

M-VECD Analysis



Determination of ϵ Kernel

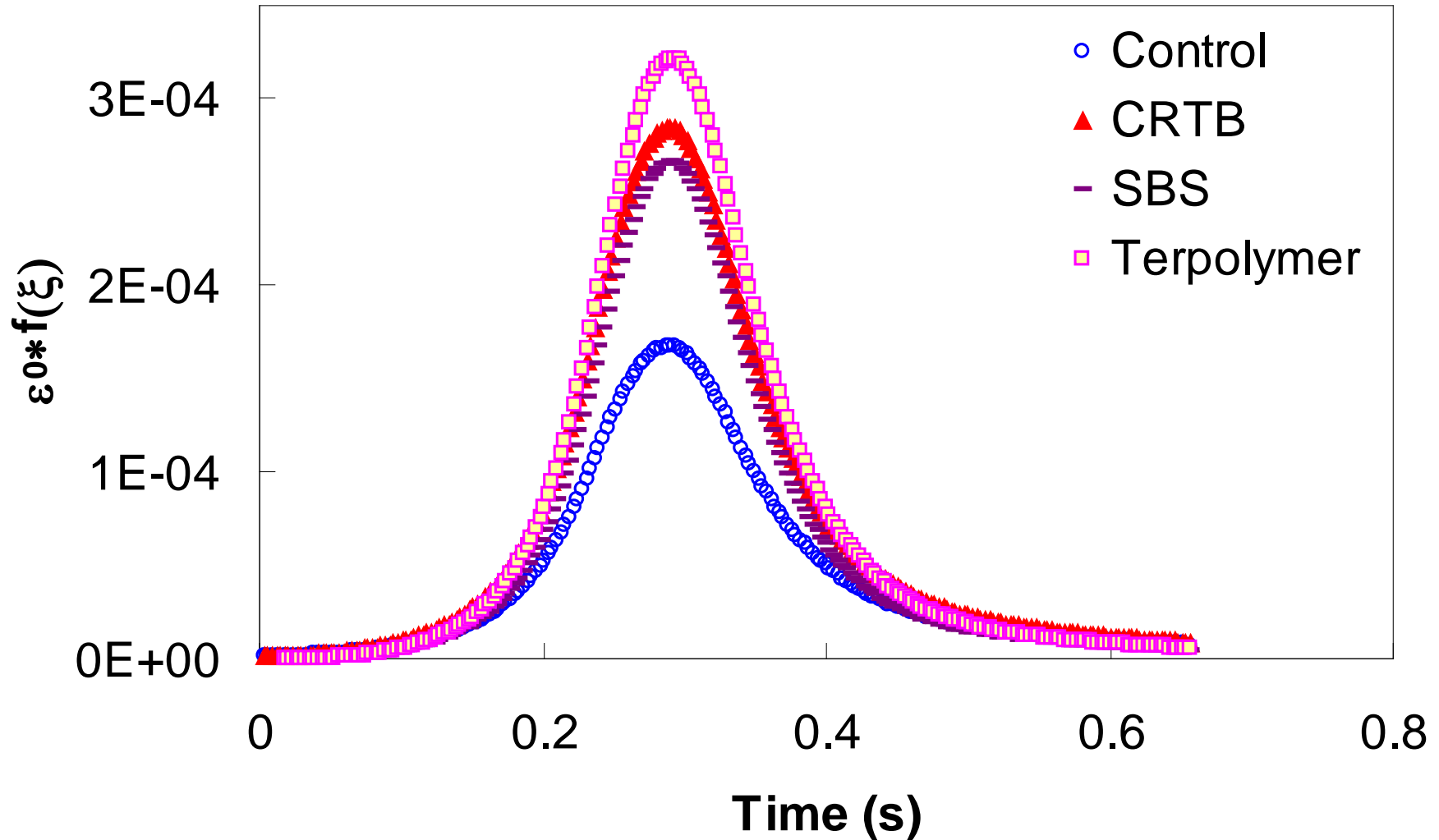
□ Simulation Conditions

- Temperature: 66.2 F (19 C)
- Load level: 16.6 kip (73.8 kN)
- Contact pressure: 120 psi (827 kPa)
- Load Speed: 11 mph (18 km/hr)
- Asphalt concrete layers
 - ✓ Linear viscoelastic from laboratory compacted laboratory tested samples
- Unbound layers
 - ✓ Linear elastic with moduli backcalculated from FWD

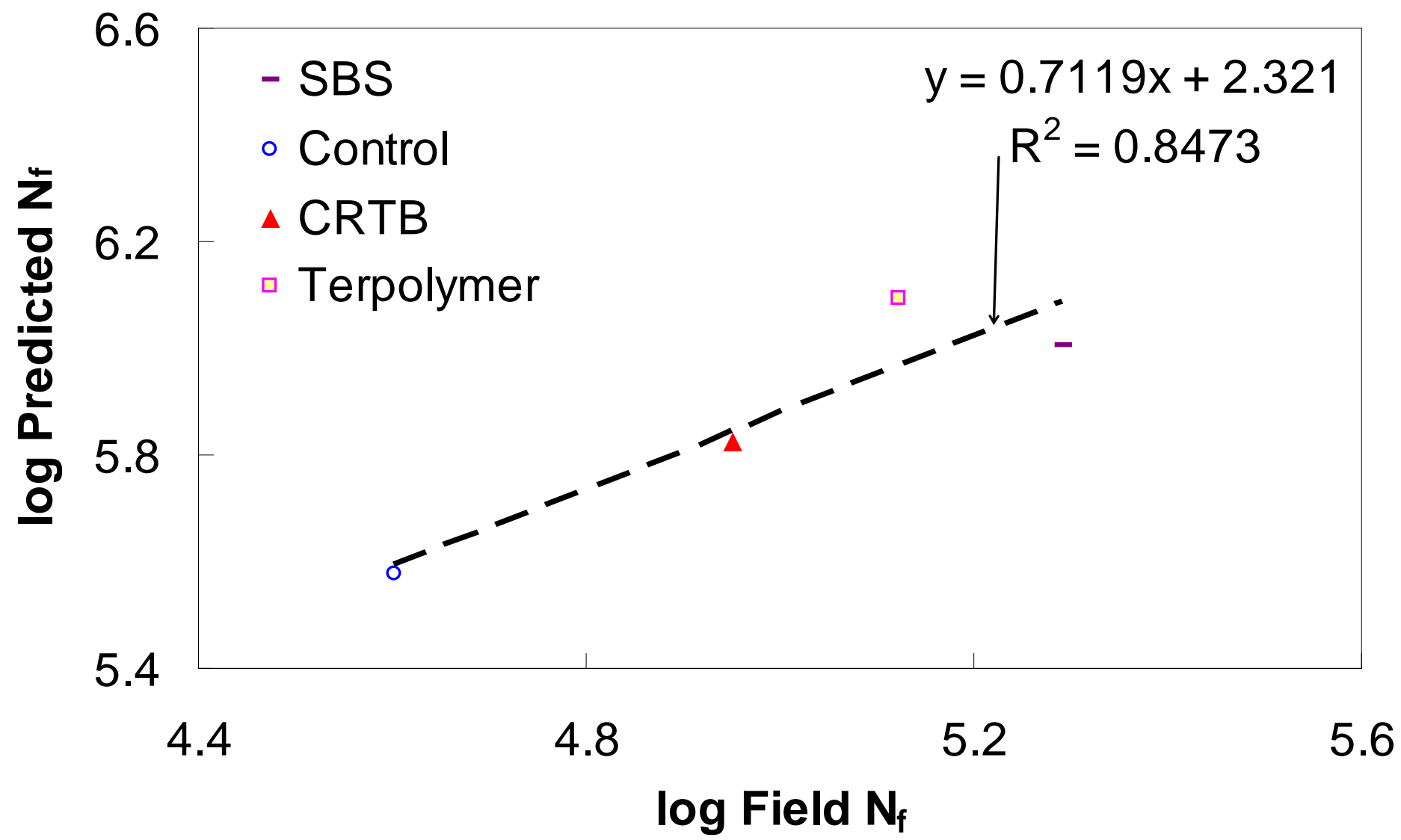


ALF Pavement

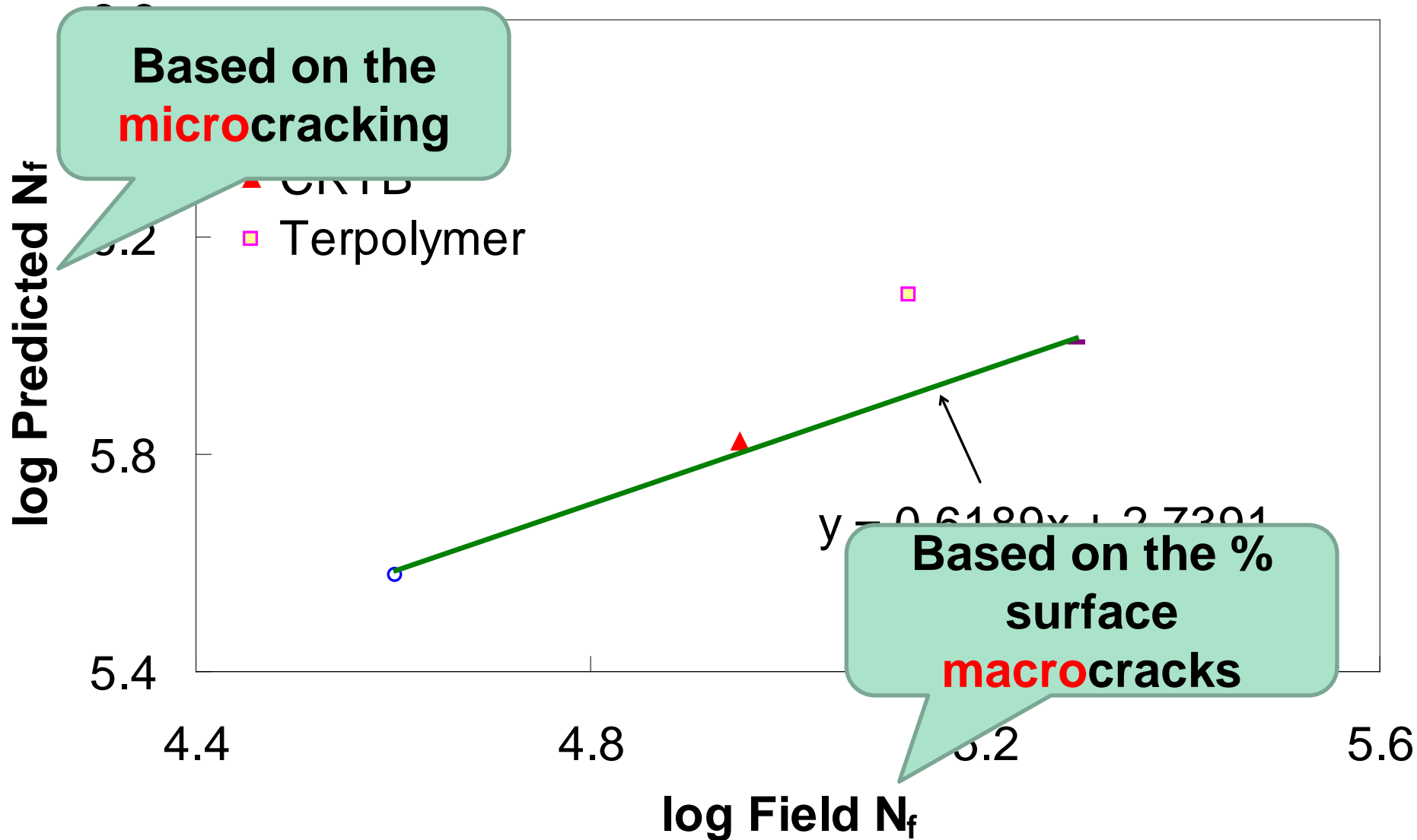
Transverse Strain Response, VECD Input ε Kernel



ALF Fatigue Life Prediction



ALF Fatigue Life Prediction



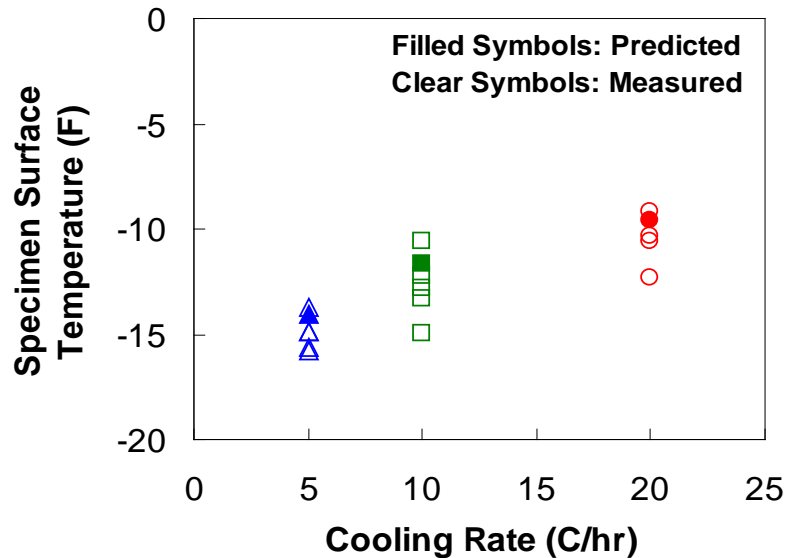
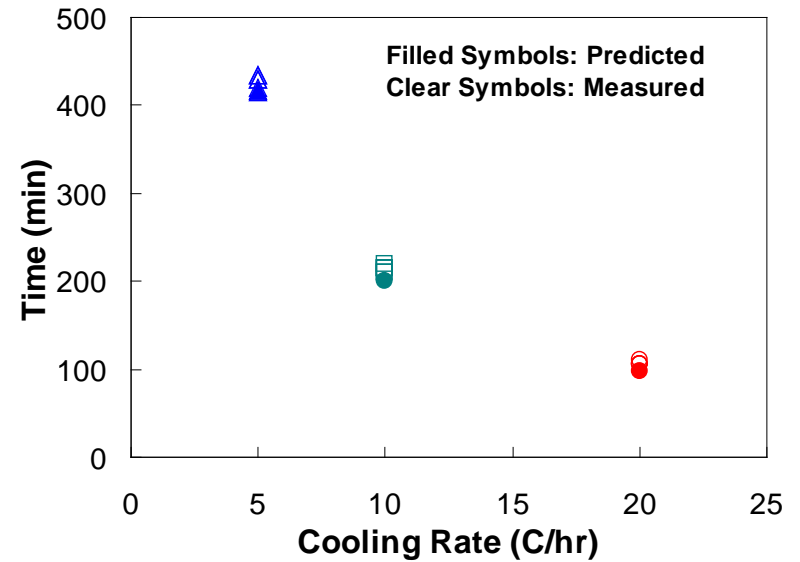
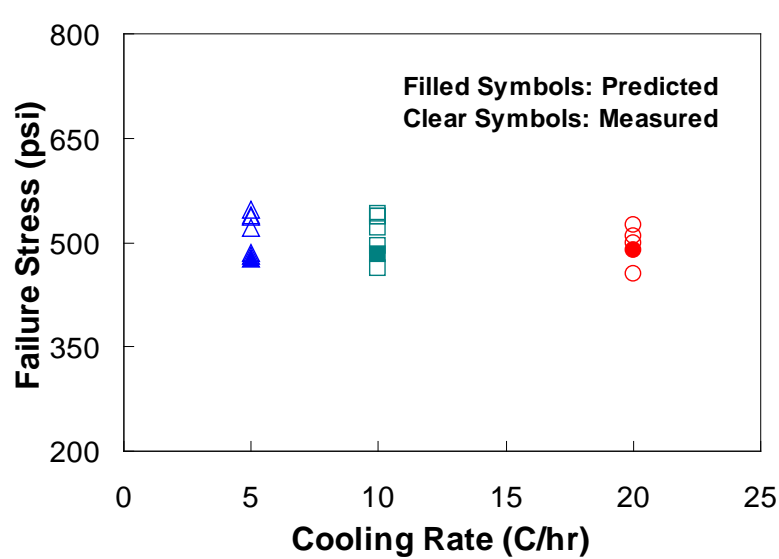
Future of Performance Modeling

- ❑ Thermal Damage
- ❑ Healing
- ❑ Aging
- ❑ Viscoplasticity



Thermal Analysis

Failure Predictions of TSRST

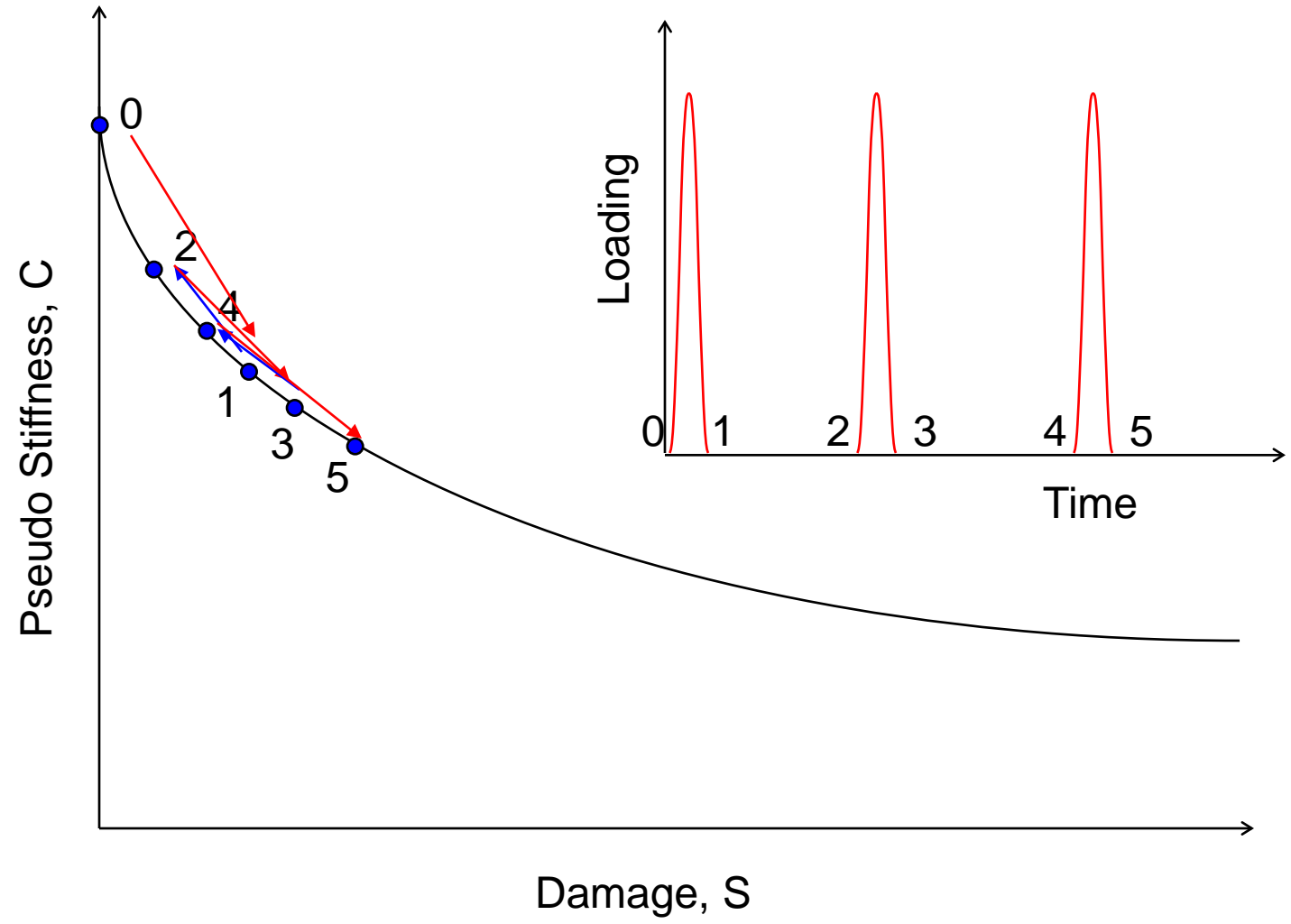


Healing

- ❑ Formulation of Lee and Kim (1998)
 - Multiple damage parameter formulation
 - Characterized mixtures with AAD and AAM binder
- ❑ Simplified formulation with single damage parameter
 - Regression analysis with Lee and Kim model
 - Normalized formulation for general application

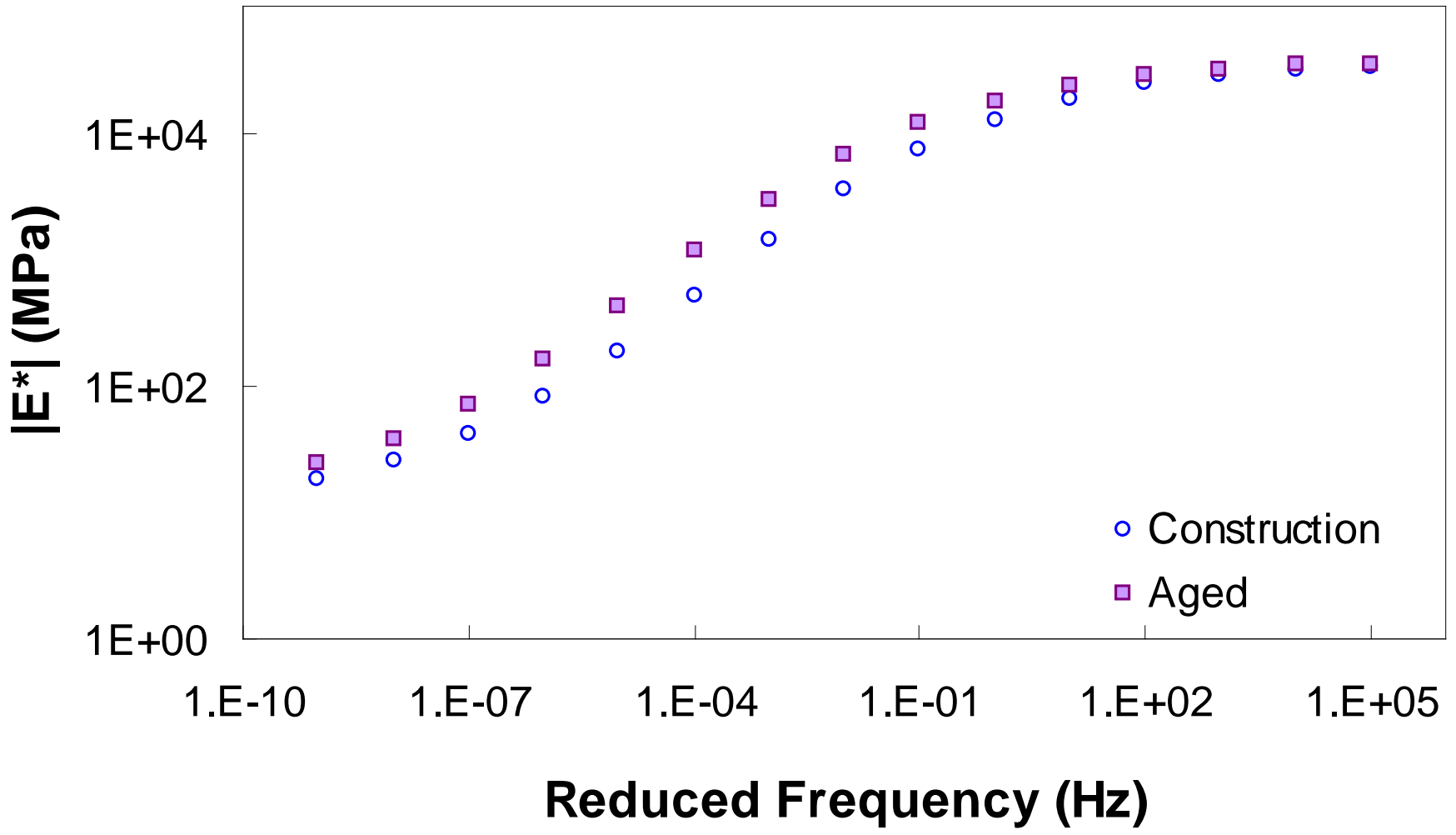


Healing

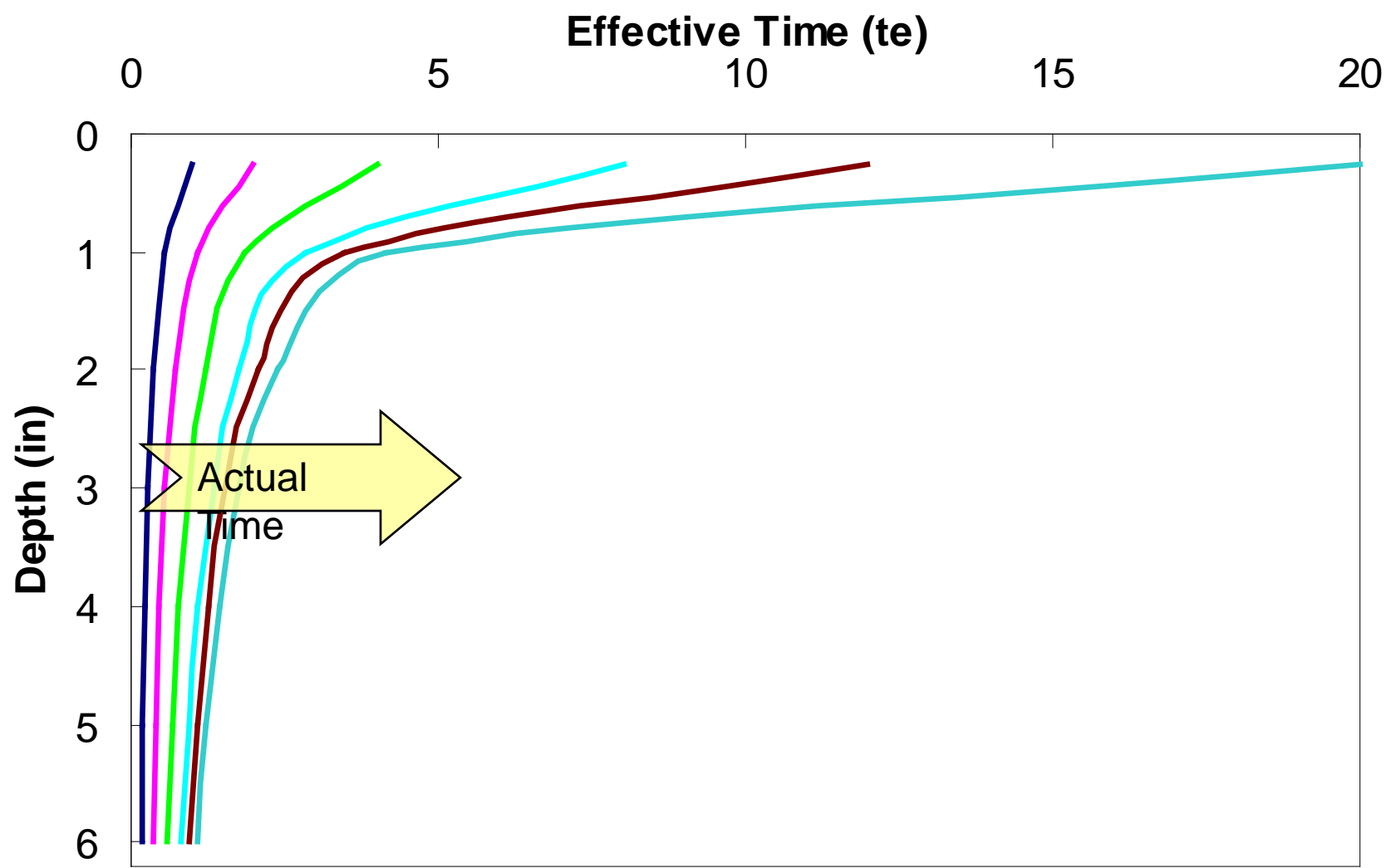


Aging

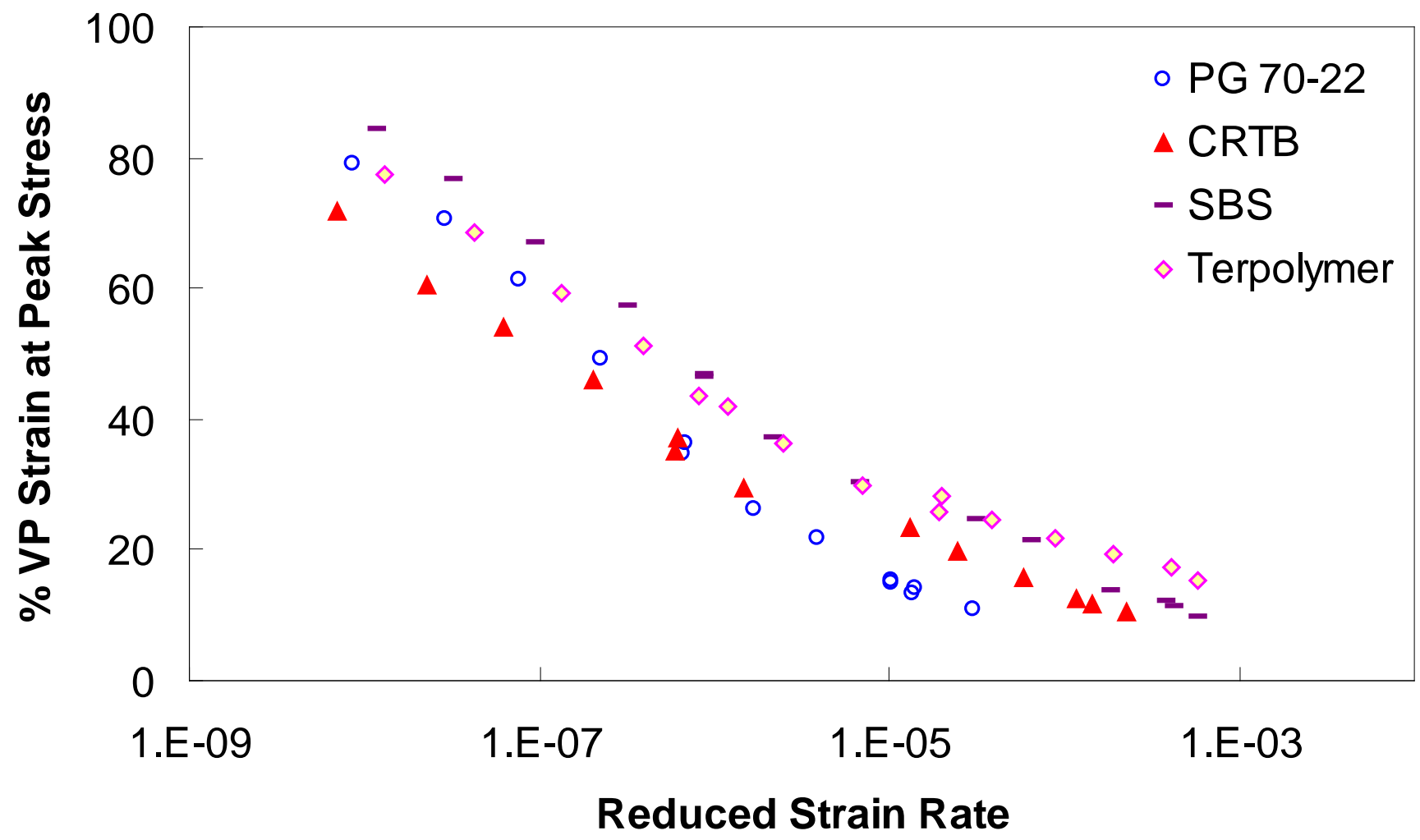
Linear Viscoelastic Characteristics



Aging Structural Effects



Viscoplastic Effects



Summary

- ❑ Modeling philosophy focuses on fundamental material model formulation and characterization coupled with robust structural model.
- ❑ VECD model shows the ability to capably predict fatigue performance and fatigue life of asphalt concrete materials.
- ❑ When coupled with an accurate structural model in either a discrete or integrated formulation the VECD model shows the ability to predict the performance of asphalt concrete pavements in the field.
- ❑ In service pavements may also be strongly influenced by additional mechanisms that are targeted for inclusion in the next generation of pavement performance models.



Questions for Audience

- ❑ How much testing are users willing to perform for projects of different significance?
- ❑ How long are users willing to wait to see the results?



Acknowledgements

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Thank You!

