Asphalt Pavement Response and Fatigue Performance Prediction Using the VECD Approach-Application to Warm Mix Asphalt

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Cold and Warm Asphalt Mixture Design/Characterization and Pavement Design

Identification of Worldwide Best Practices

Fortaleza, Brazil

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Outline

- FHWA PRS Project
- VEPCD Model
  - Characterization
  - Verification
  - Application
- NCHRP 1-42A Integrated VECD-FEP++

FHWA H[illegible]A-PRS Project

- Four year long project started in Feb. 2007
- Objectives
  - To develop various tools for testing and analysis of HMA mixture
  - To develop a hierarchical system for performance-related specification
- The original research plan includes a wide range of HMA mixtures from various pavement sections.
- Recently incorporated RAP and WMA mixtures from NCAT Test Track and Manitoba projects

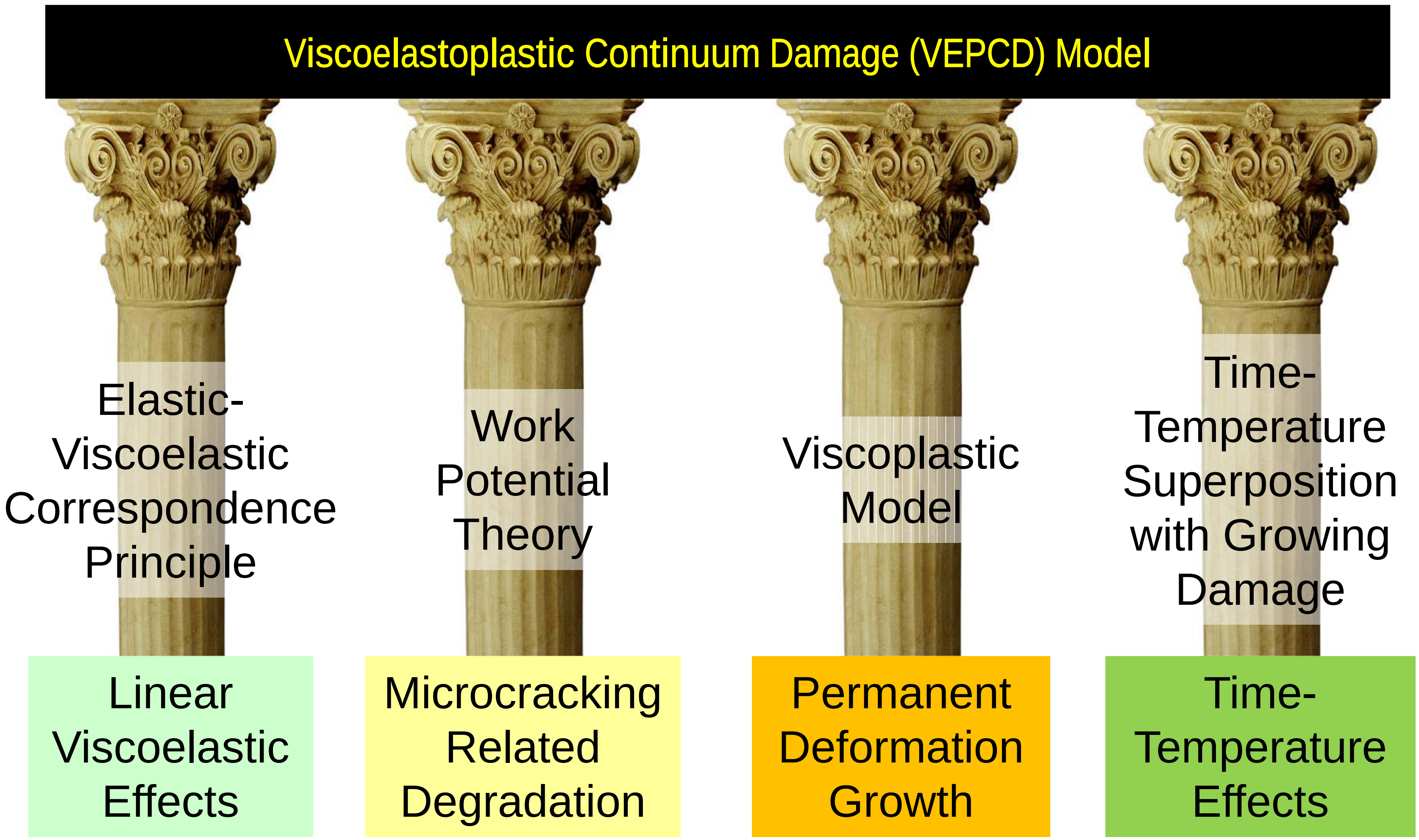
Summary of PRS Pavements

- FHWA ALF Pavements (control and modified)
- NY I-86 Perpetual Pavements
- NCAT RAP and WMA Pavements
  - Control, OGFC w/15% RAP, High RAP (50%), High RAP plus WMA (Evotherm and Advera)
- Manitoba RAP and WMA Pavements
  - WMA (Sasobit, Advera, Evotherm)
  - RAP (0, 15, 50%)
- Chinese Perpetual Pavements in Binzhou, Shandong
- KEC Test Road Pavements

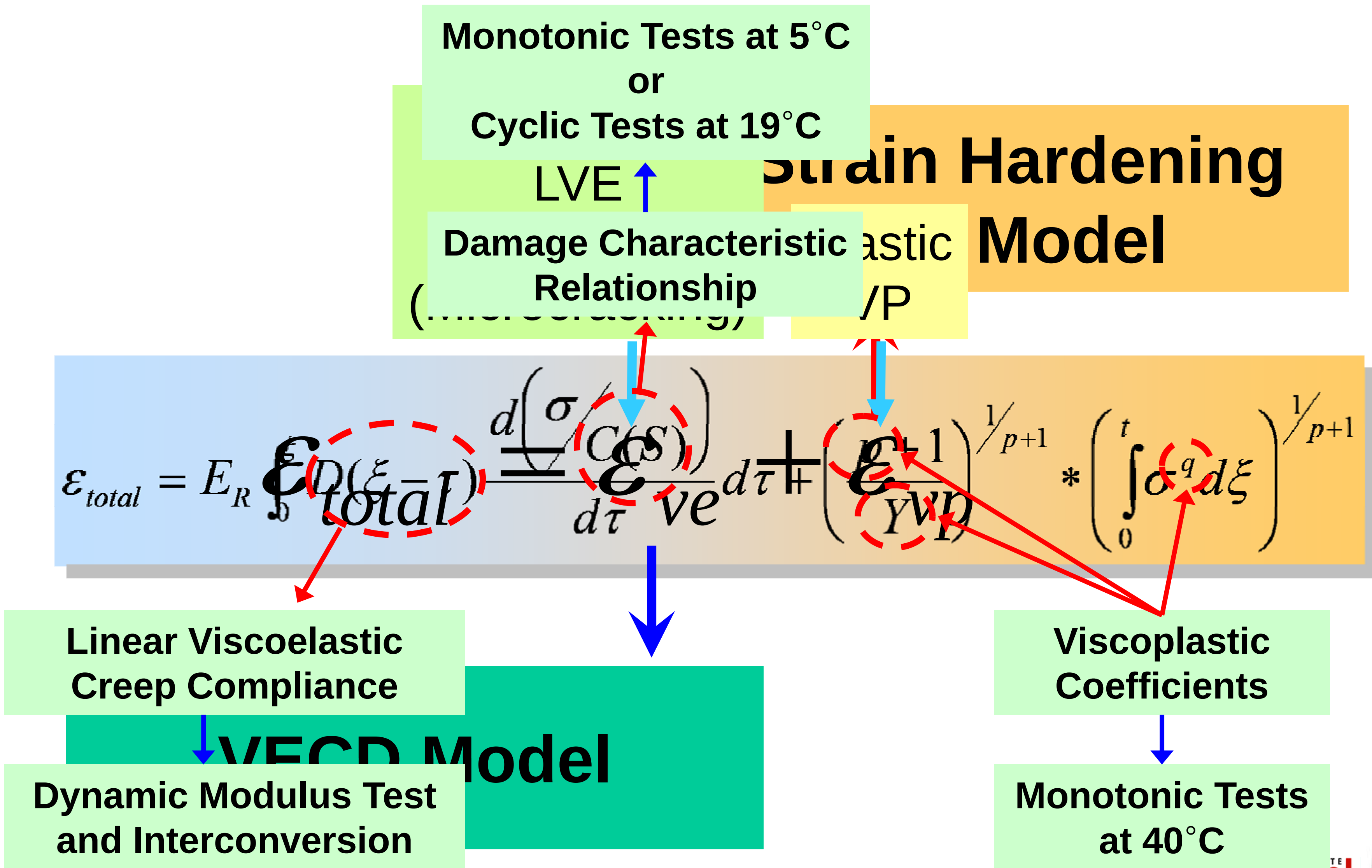
Proposed Hierarchical PRS

Model Description		Level 1	Level 2	Level 3
E*		Unconfined and Confined E*	AMPT E*	IR E* and 55°C Predictive Equation
HMA Model	Cracking (Tension)	Uniaxial VEPCD	Uniaxial VEPCD	Predictive Equation for VEPCD Coefficients from Mix Characteristics
HMA Model	Rutting (Compression)	MVEPCD	VP at a Representative Confining Pressure	Predictive Equation for VP Coefficients from Mix Characteristics
Pavement Model		MVEPCD-FEP++	Layered Viscoelastic Model	Layered Viscoelastic Model
Testing Time		17 days	5 days	Less than 1 day
Analysis Time		3 days	2 days	Less than 1 day
Total Time		20 days	7 days	1 day

VEPCD Model


Viscoelastoplastic Continuum Damage (VEPCD) Model
Elastic-Viscoelastic Correspondence Principle
Work Potential Theory
Viscoplastic Model
Time-Temperature Superposition with Growing Damage
Linear Viscoelastic Effects
Microcracking Related Degradation
Permanent Deformation Growth
Time-Temperature Effects

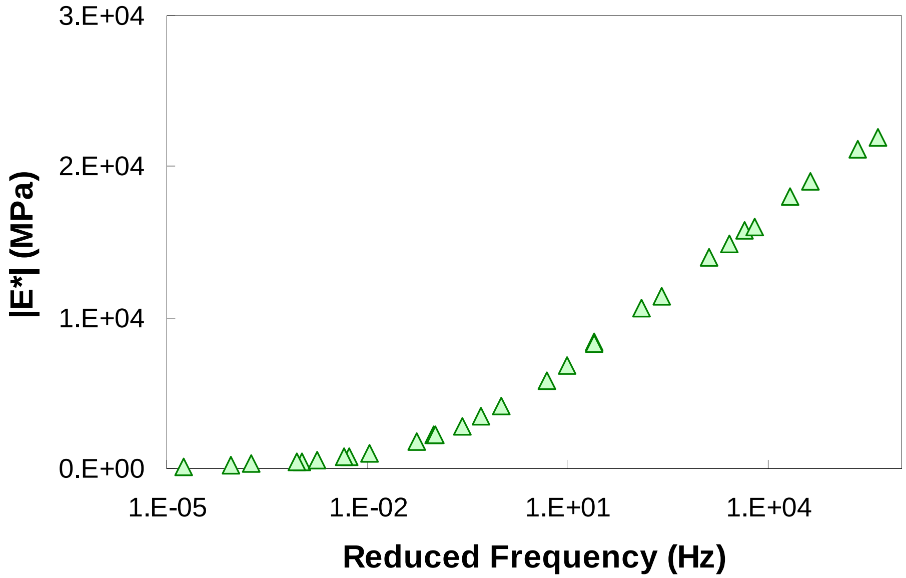
VEPCD Modeling Approach

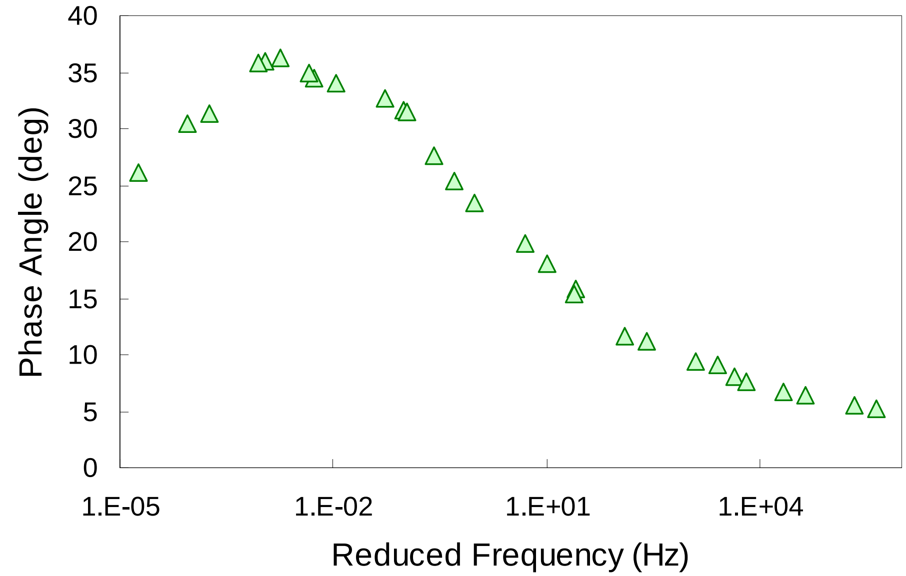


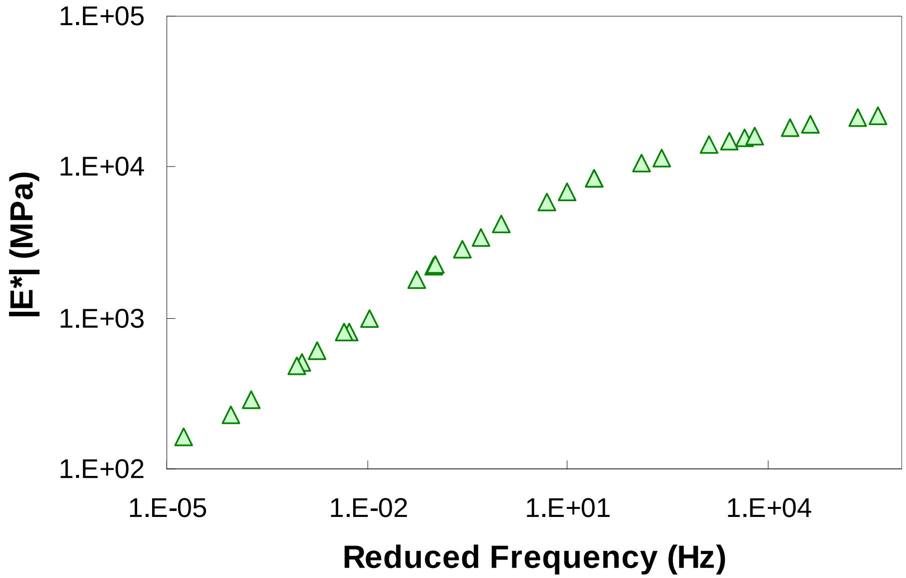
VECD Experimental Program

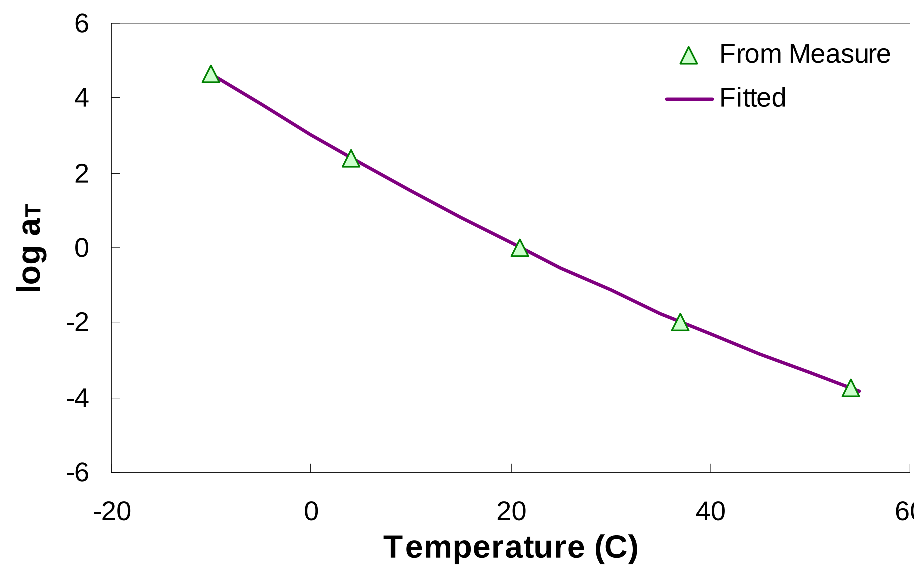
- Dynamic modulus (LVE Characterization)
  - -10°, 5°, 20°, 40° and 54°C
  - 25, 10, 5, 1, 0.5 and 0.1 Hz
  - 50 – 75 microstrain peak-to-peak strain amplitude
  - Tension-compression protocol
- Monotonic at 19°C or controlled crosshead cyclic at 19°C and 10 Hz (Damage Characterization)

Linear Viscoelastic Behavior



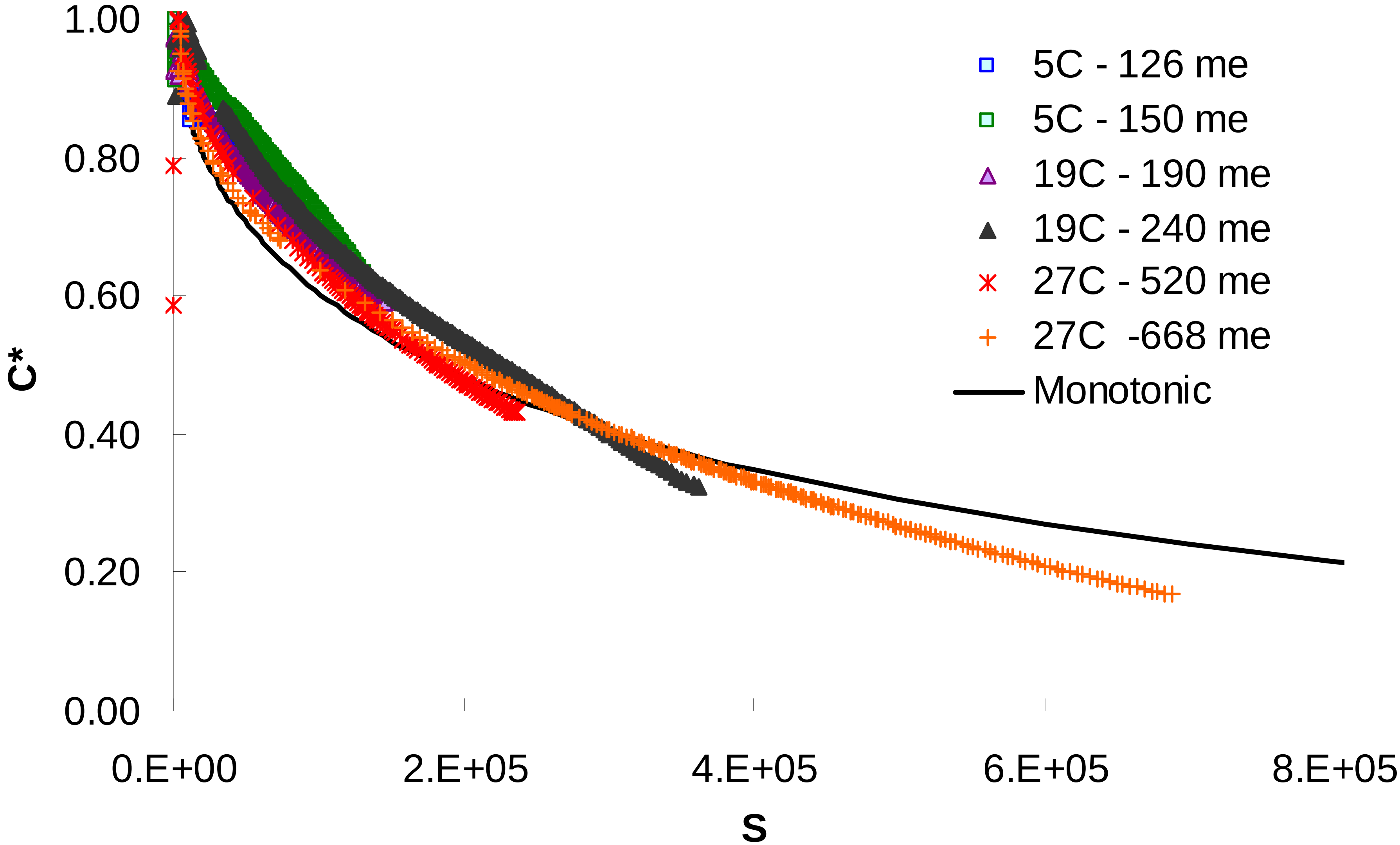






Damage Characteristic Curve

Cyclic and Monotonic

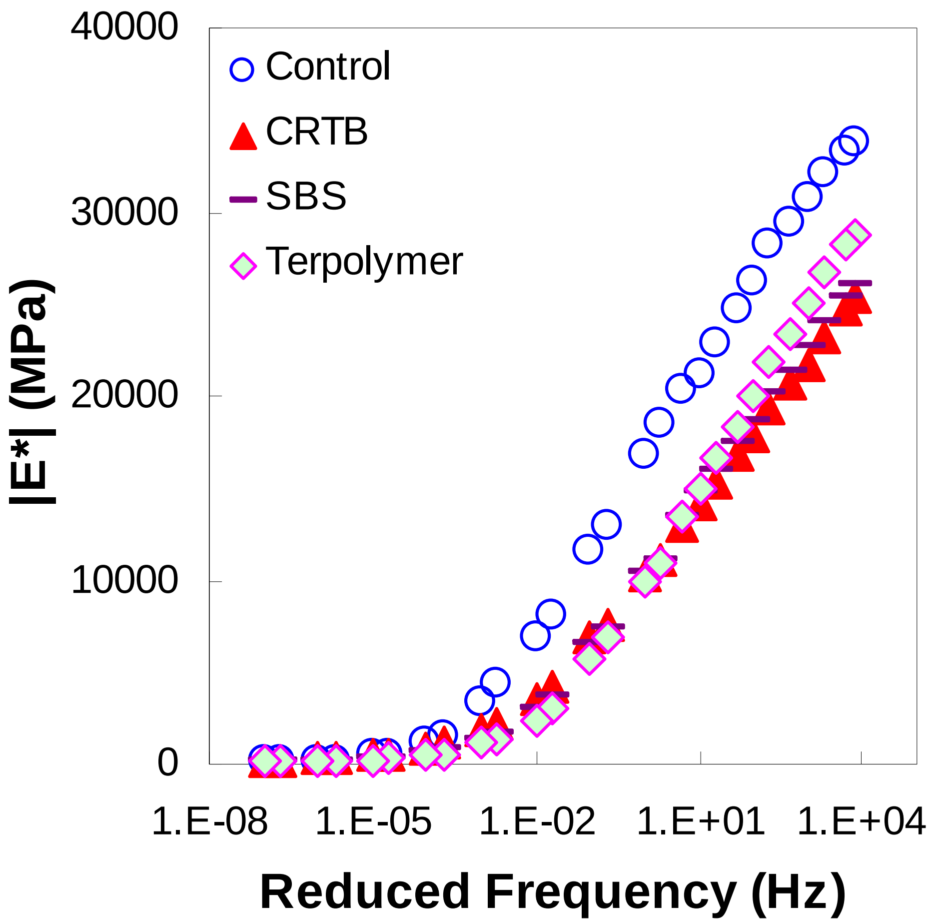


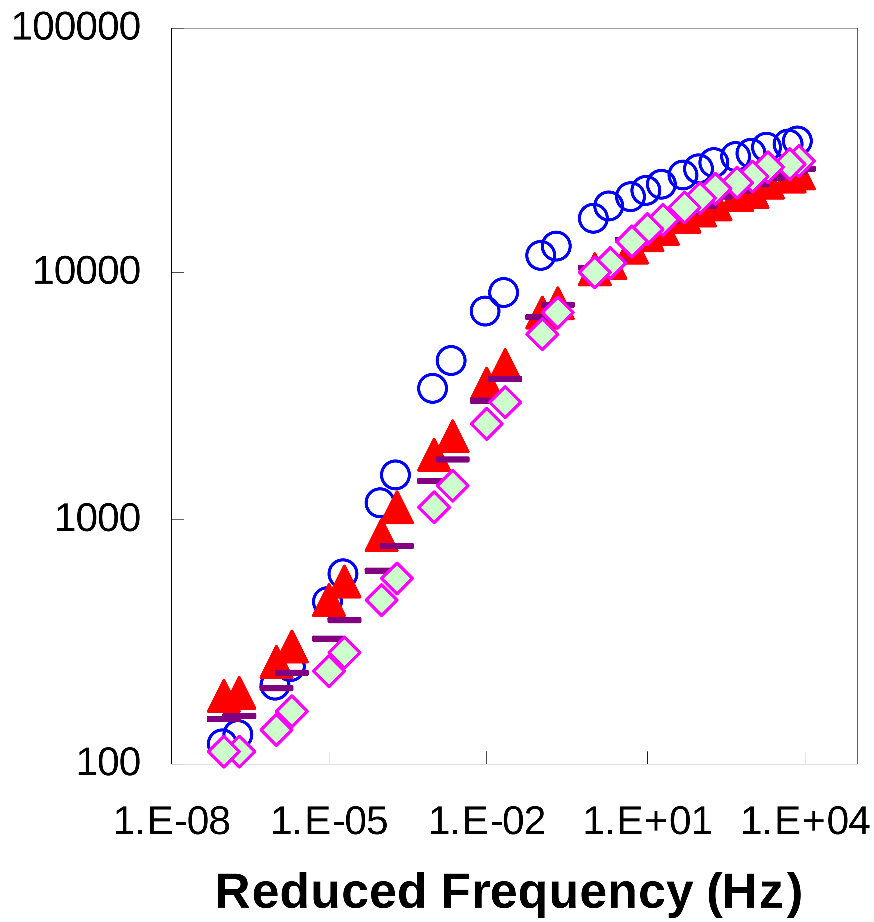
Study Mixtures

- FHWA ALF pooled fund study TPF-5(019)
- Four mixtures each the same coarse 12.5 mm gradation with the same asphalt content (5.3%)
  - Unmodified PG 70-22 (Control)
  - Crumb Rubber Terminal Blend (CRTB, PG 76-28)
  - Styrene Butadiene Styrene (SBS, PG 70-28)
  - Ethylene Terpolymer (Terpolymer, PG 70-28)

ALF Mixtures Comparison

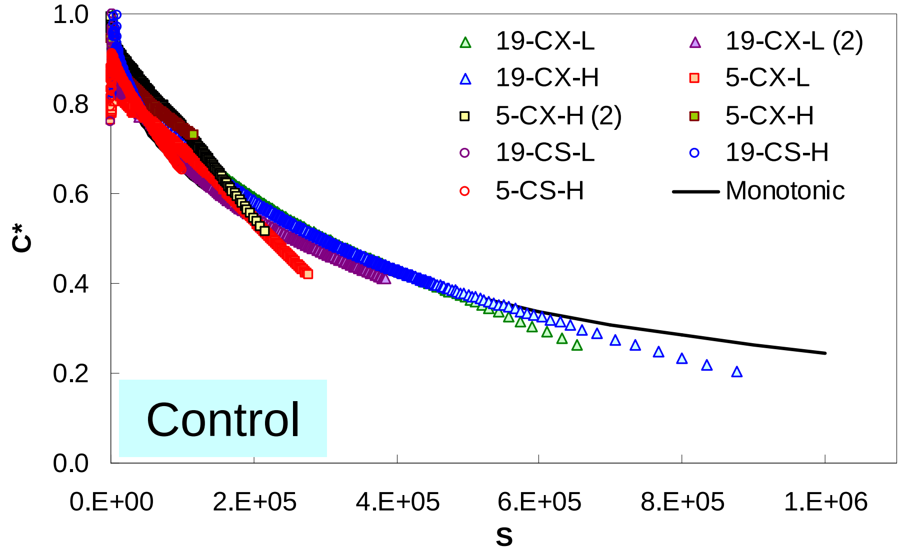
LVE Characteristics

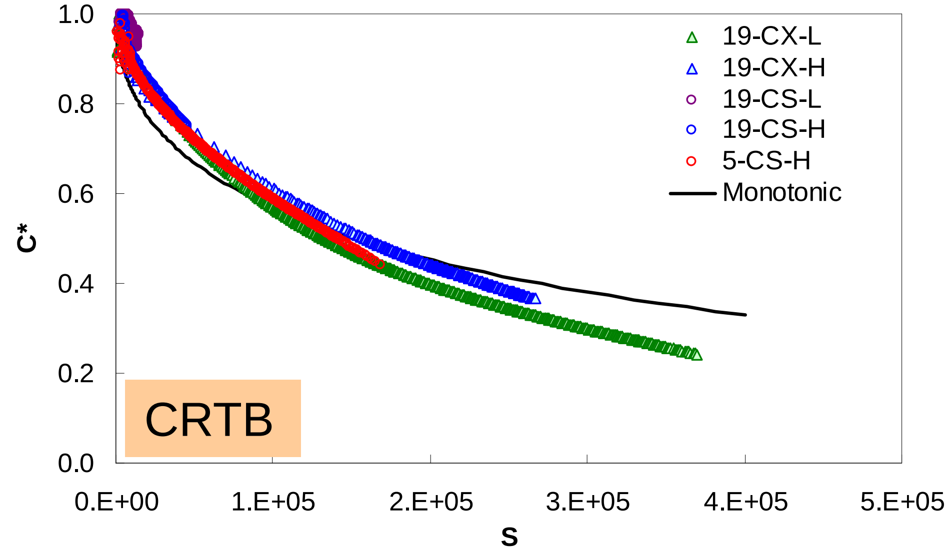


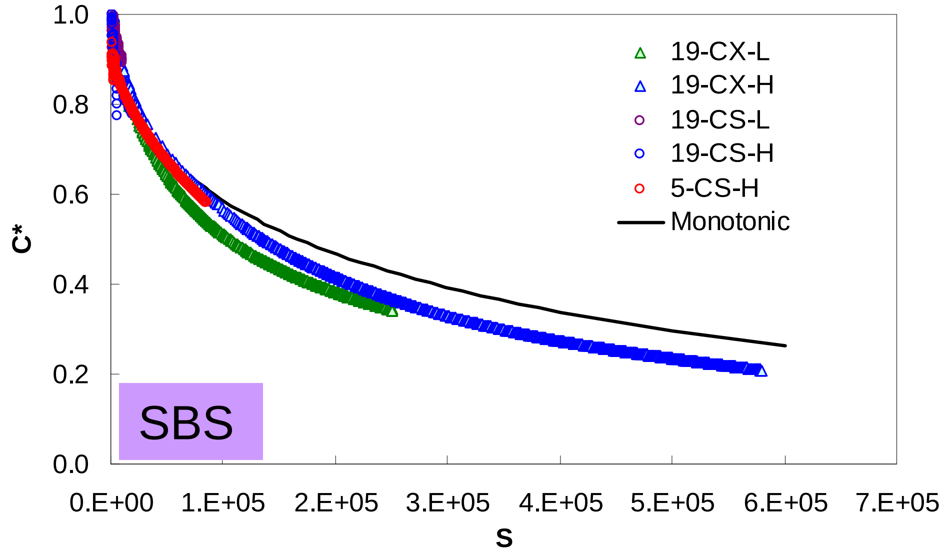


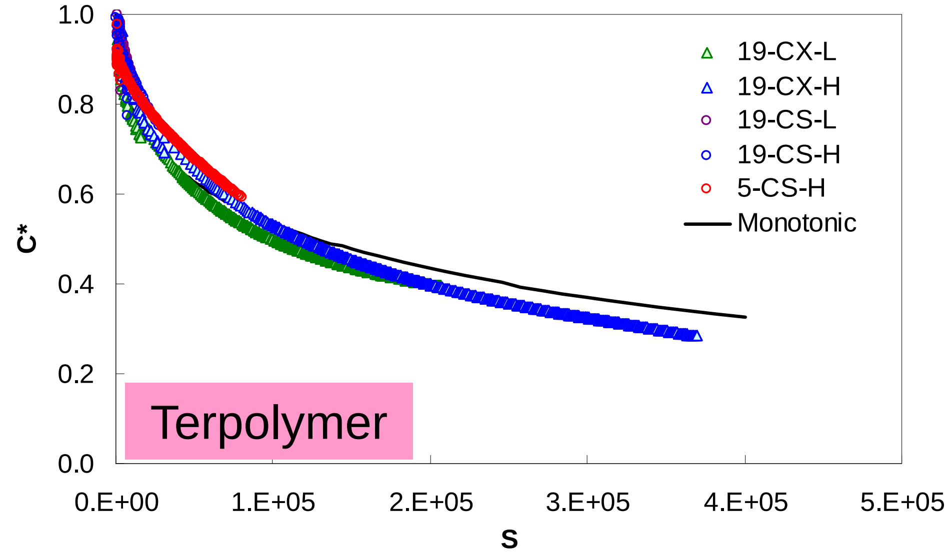
Simplified Formulation

Verification



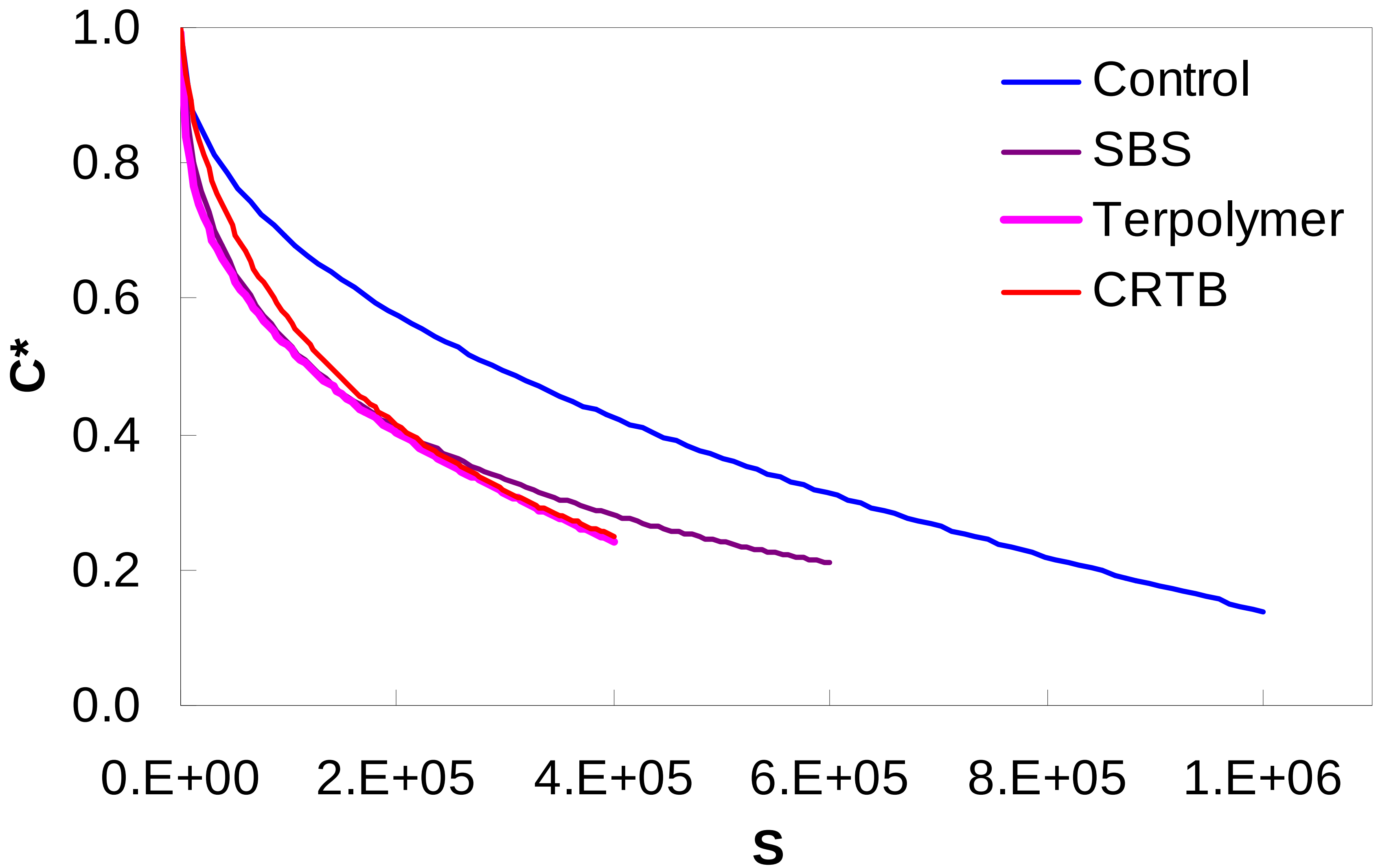






VECD Comparison of ALF Mixtures

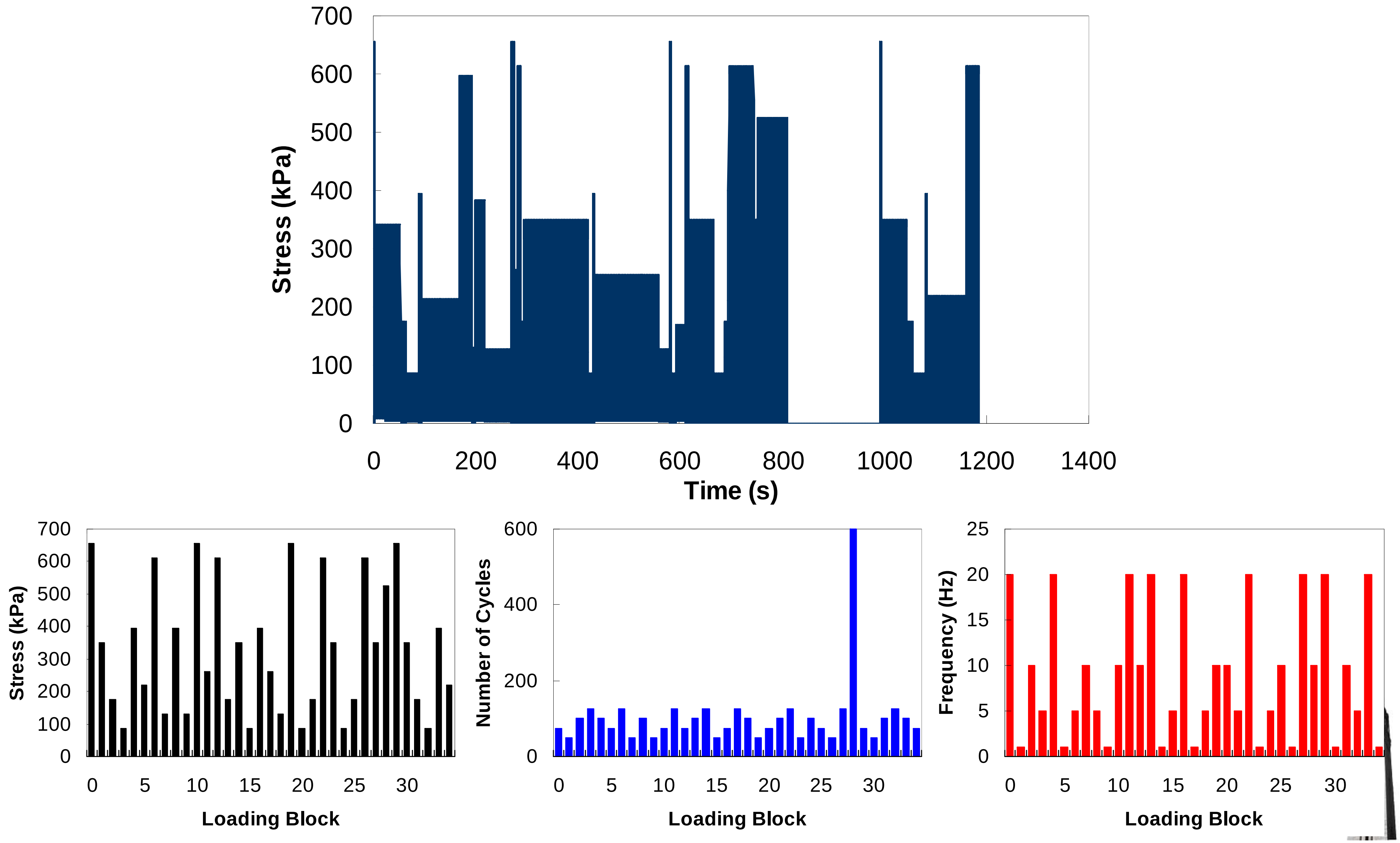
Damage Characteristics



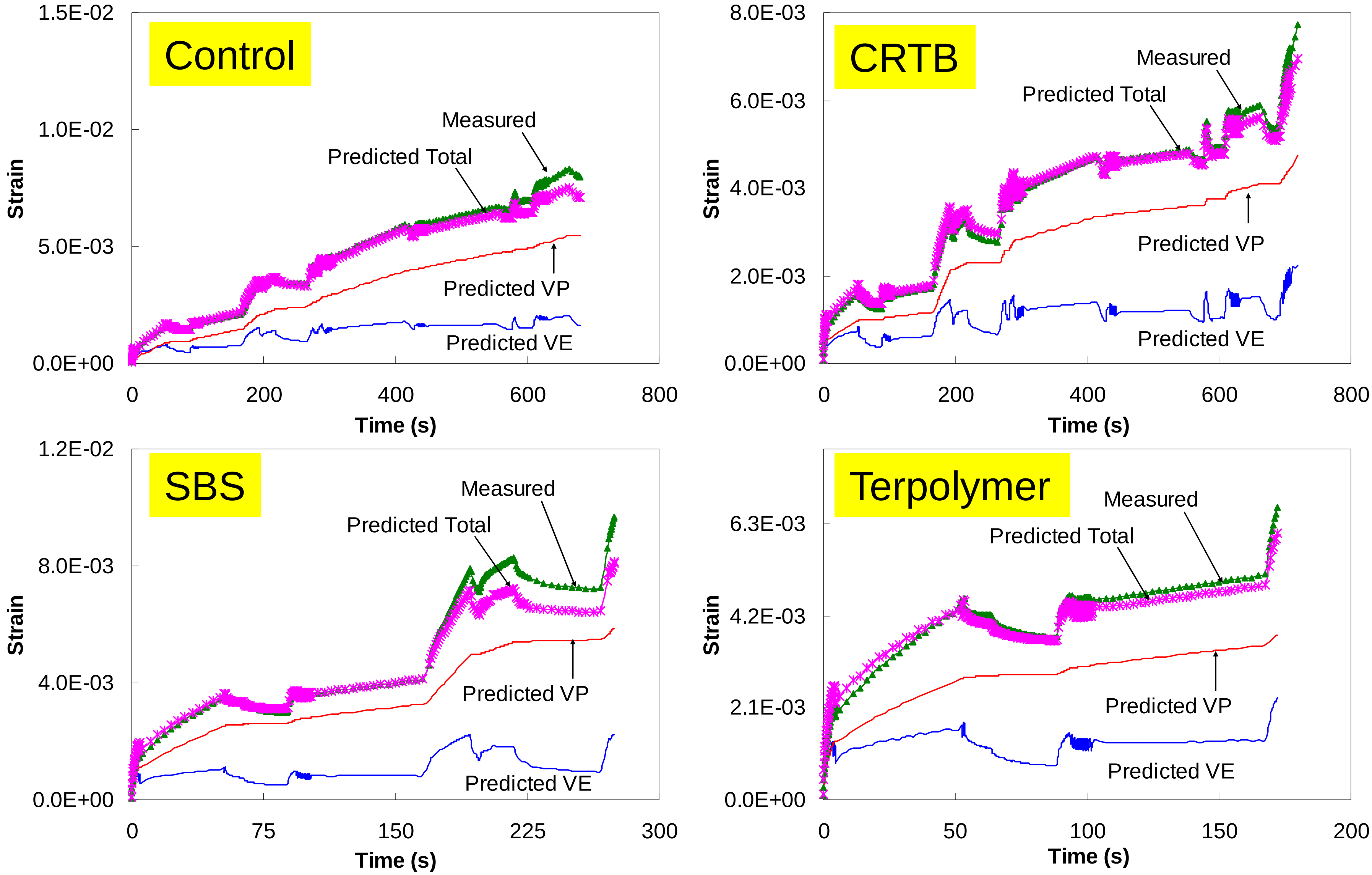
VEPCD Model Verification

Random Loading Validation

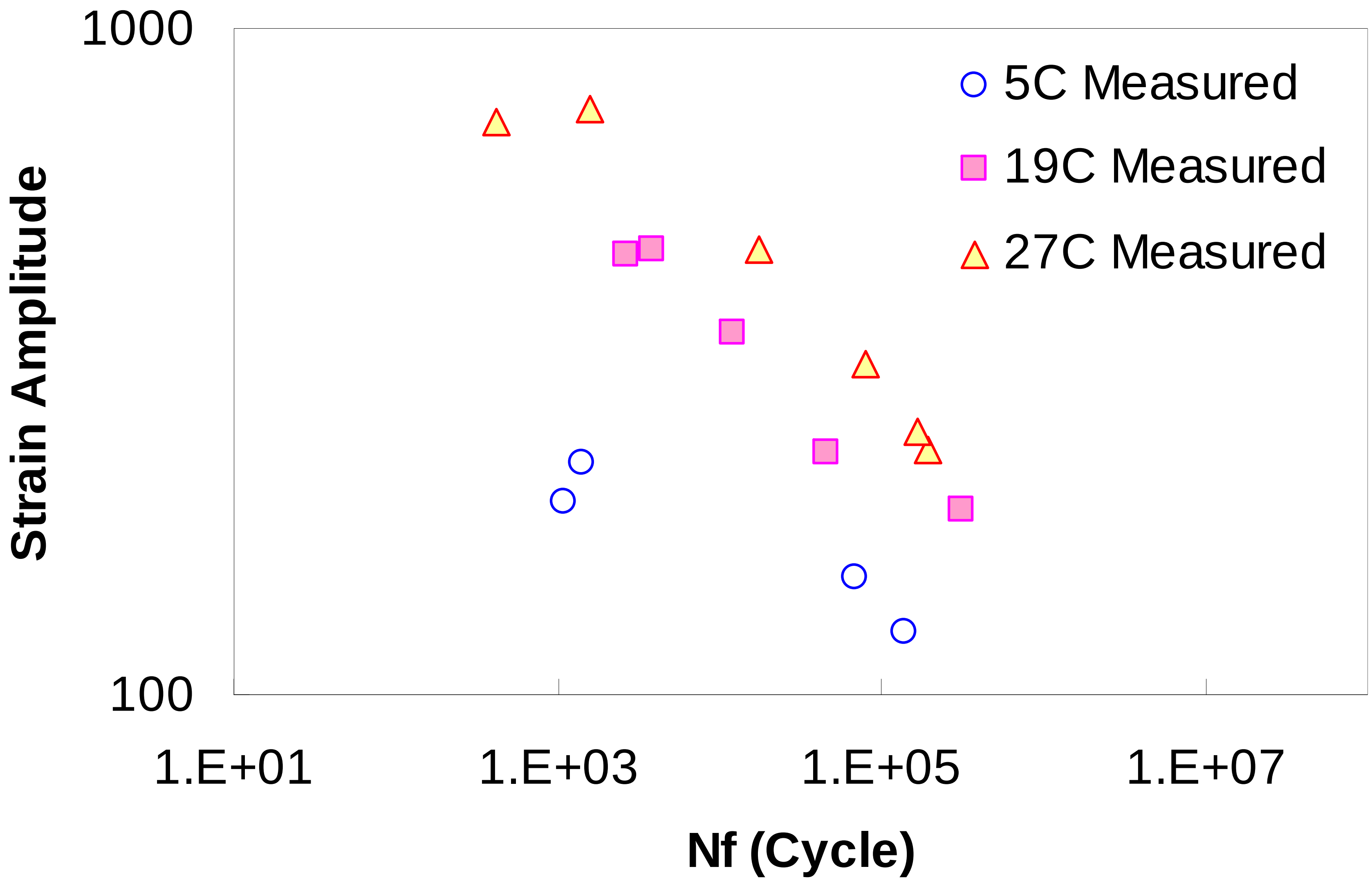
Random Stress level and frequency, *87.5-650 kPa, 1-20 Hz, 25°C*



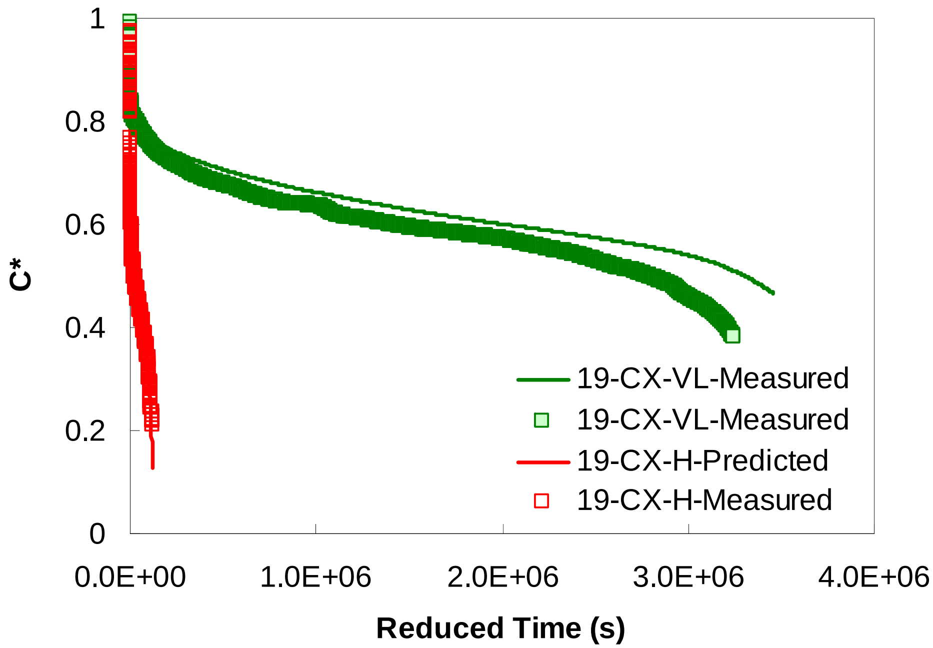
Random Loading Verification

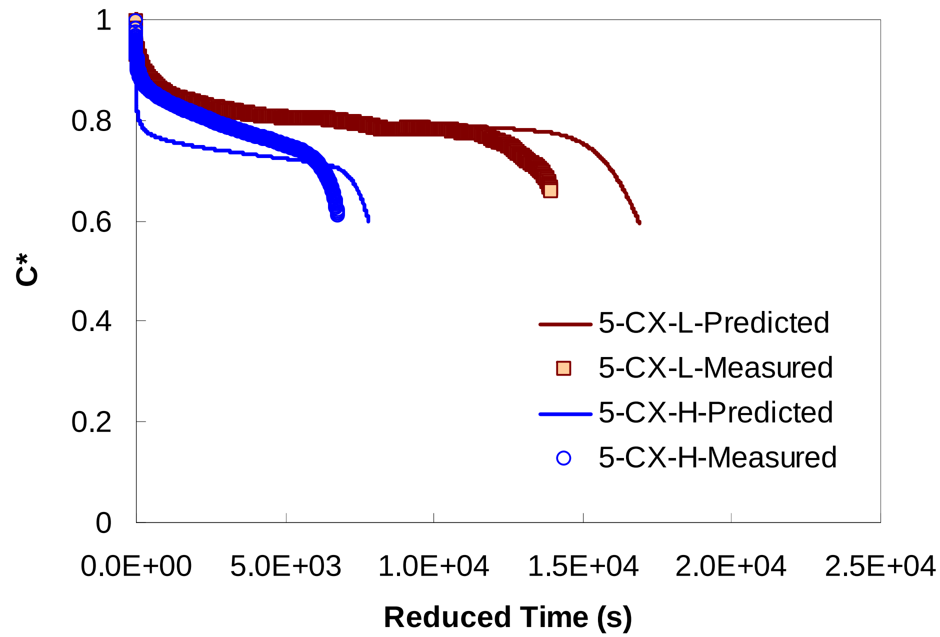


MEPDG Fatigue Model

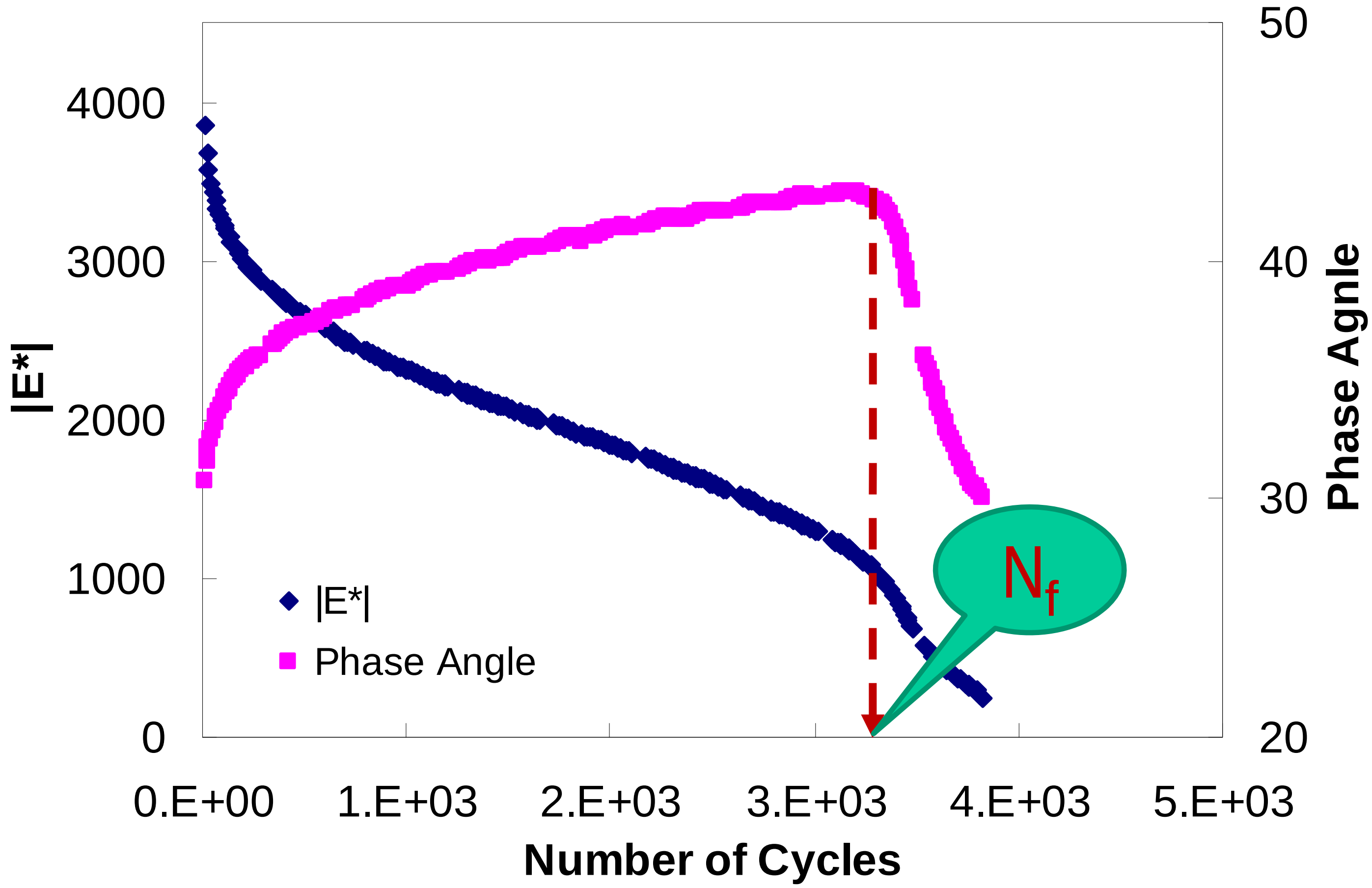


Fatigue Life Prediction Using Monotonic Data

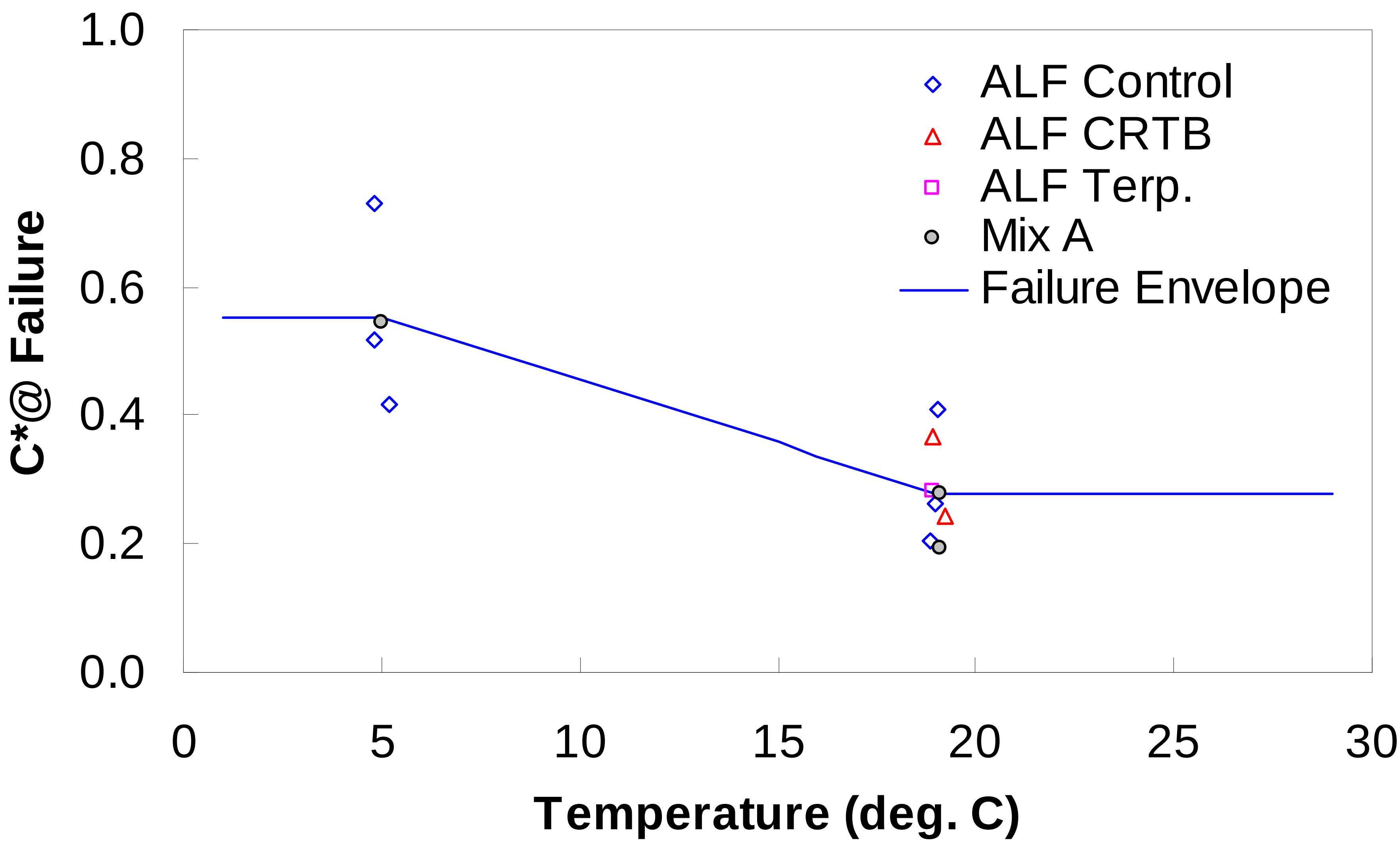




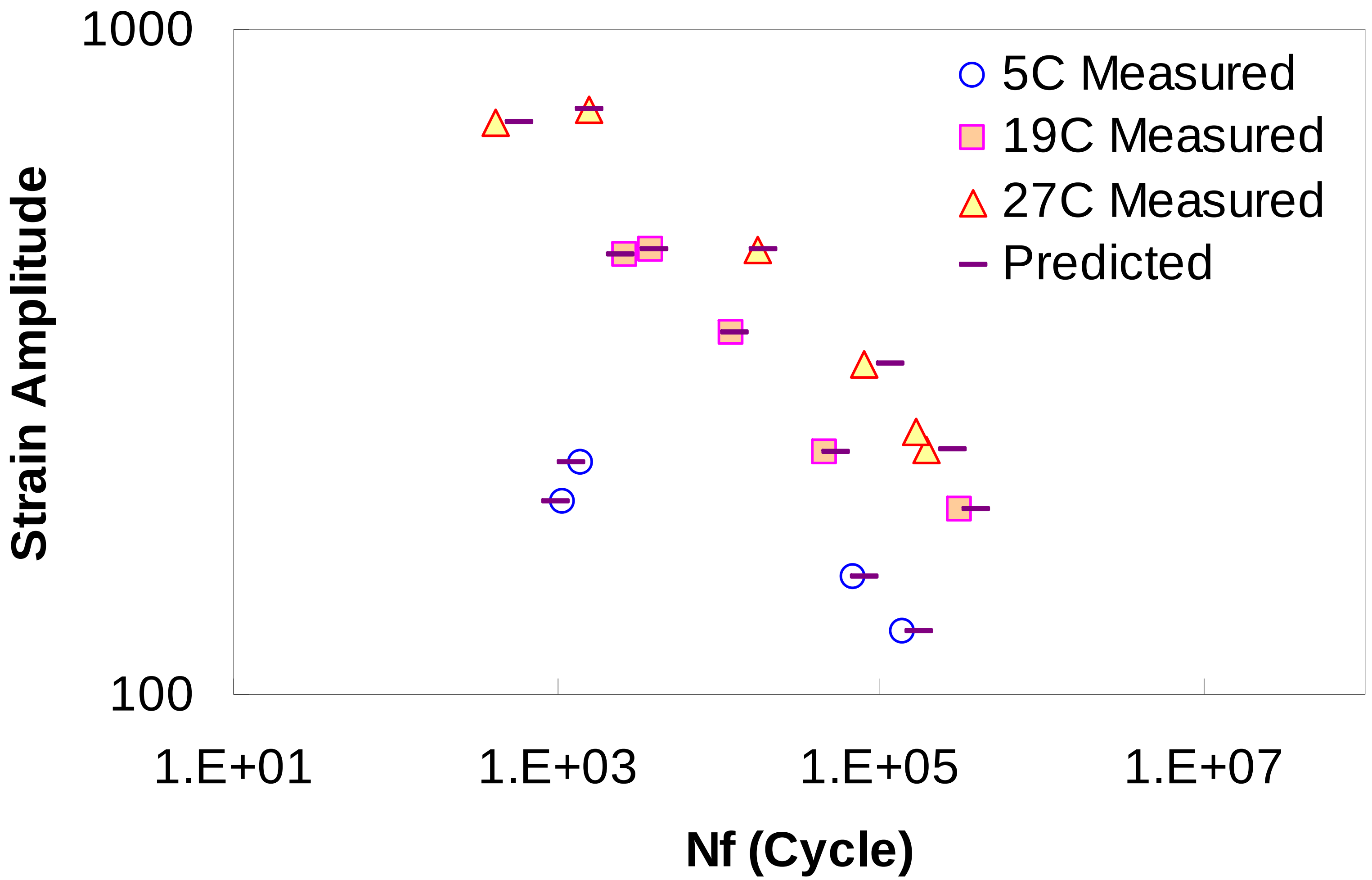
Failure Criteria



VECD Failure Criteria

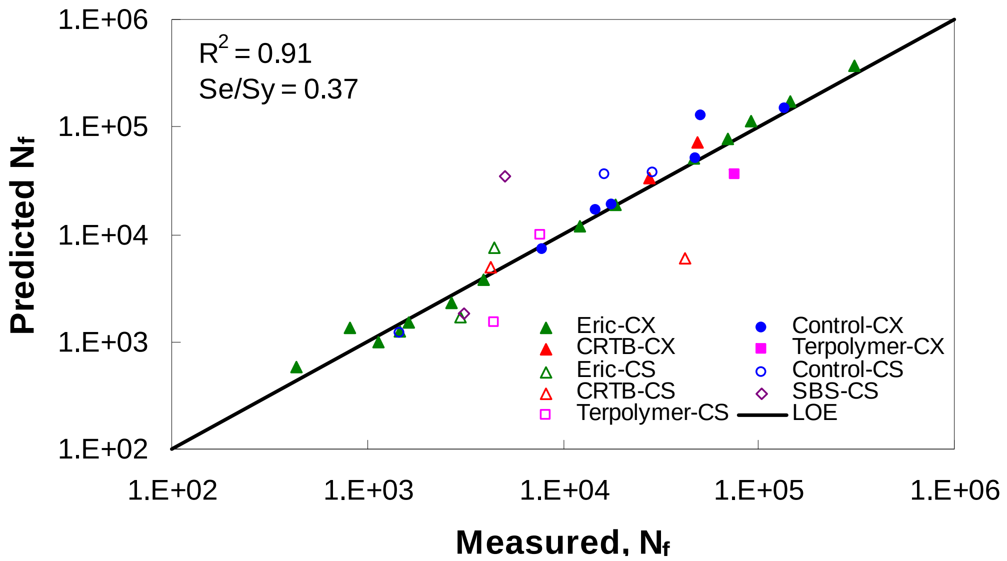


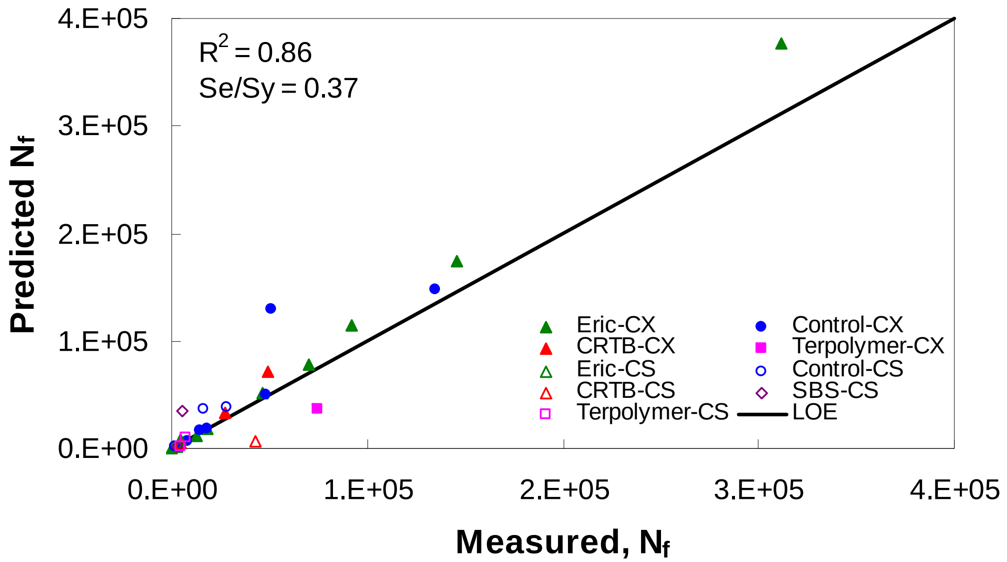
Prediction of N_f vs. ε_t Fatigue Relationship



Prediction of Fatigue Life

Characterized with Cyclic





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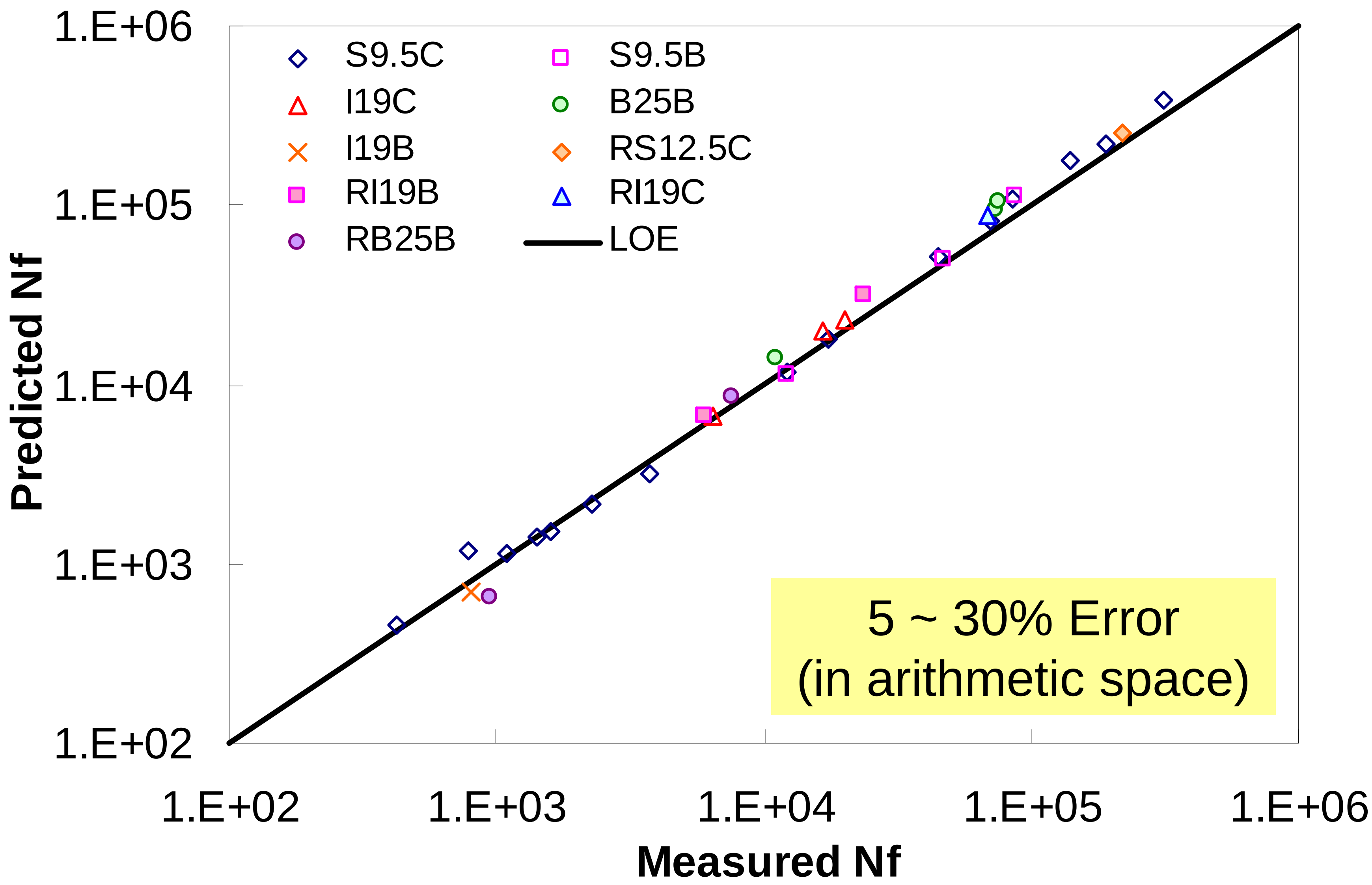
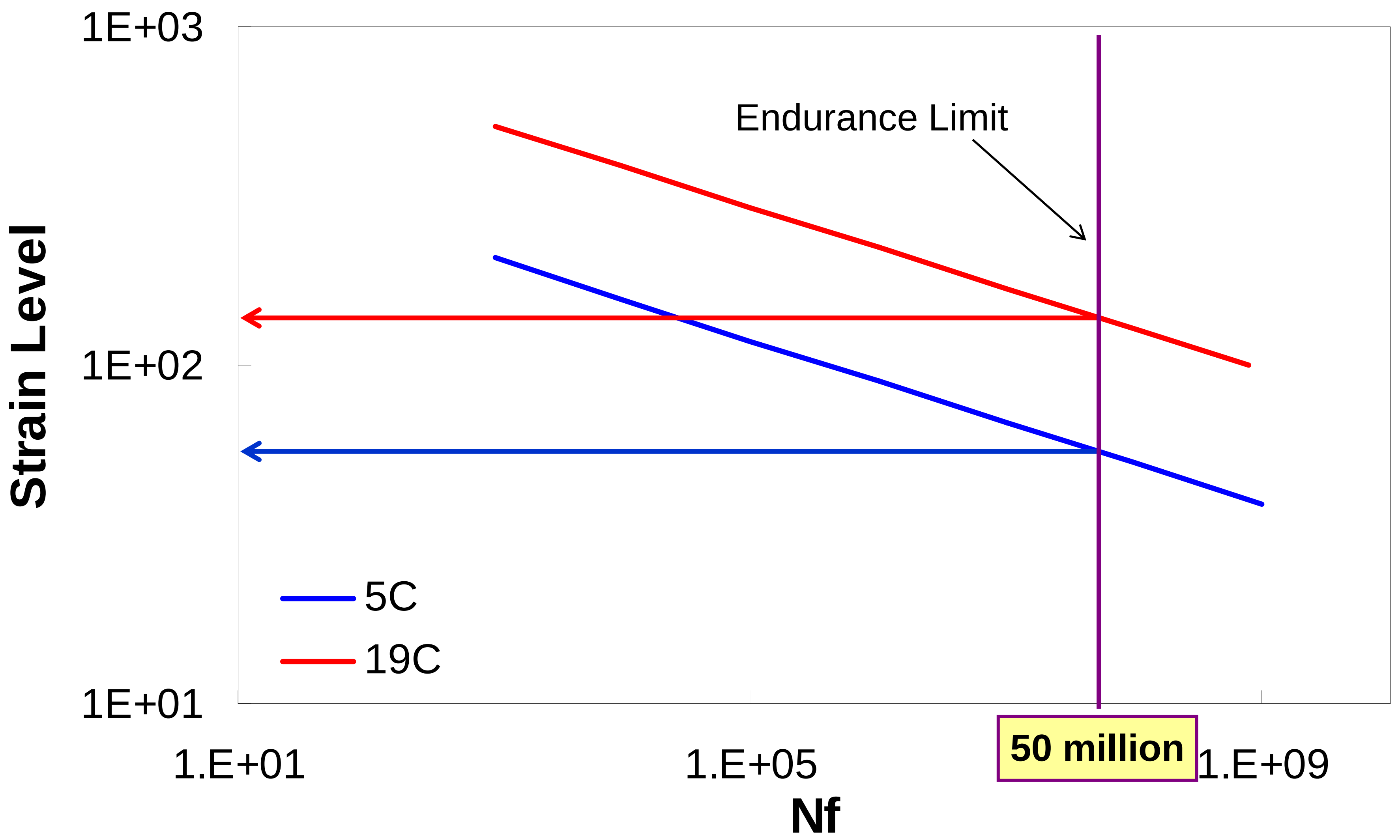
Fatigue Life Verification

Multiple mixtures, 10 Hz, 100 – 700 με, *5°*, *19°*, and *27°*C



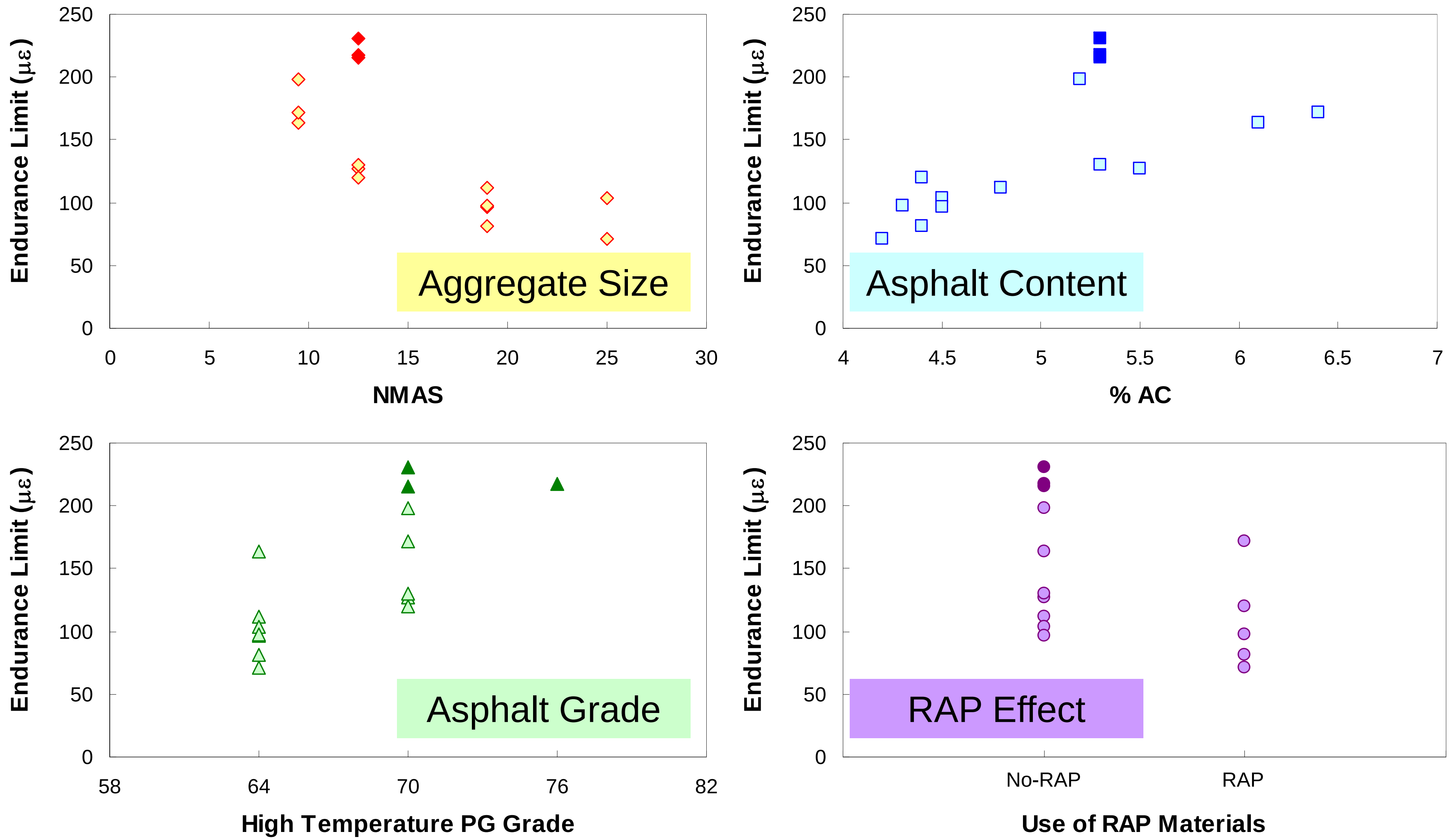
Fatigue Endurance Limit

Using VECD Model

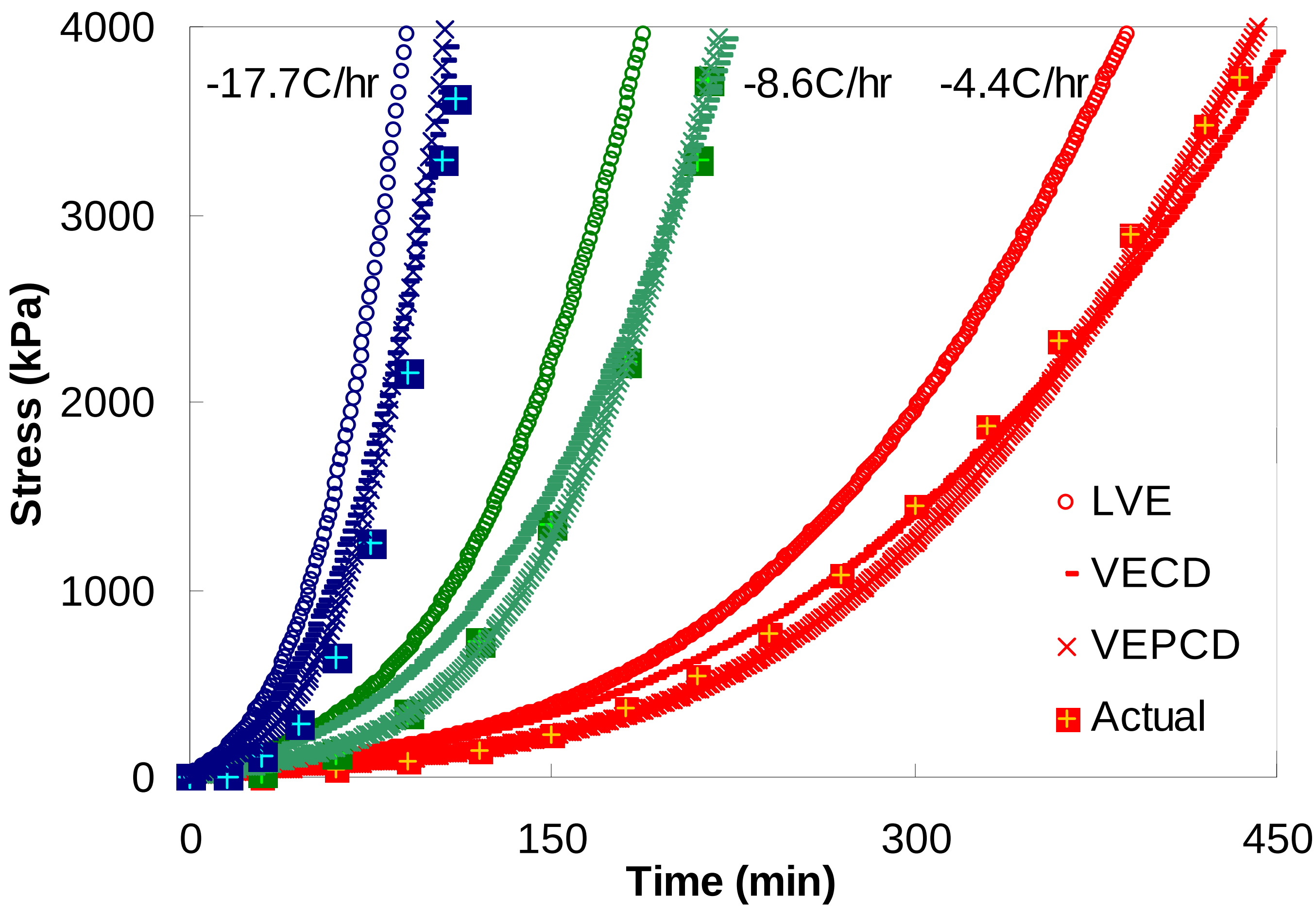


Effect of Mixture Variables

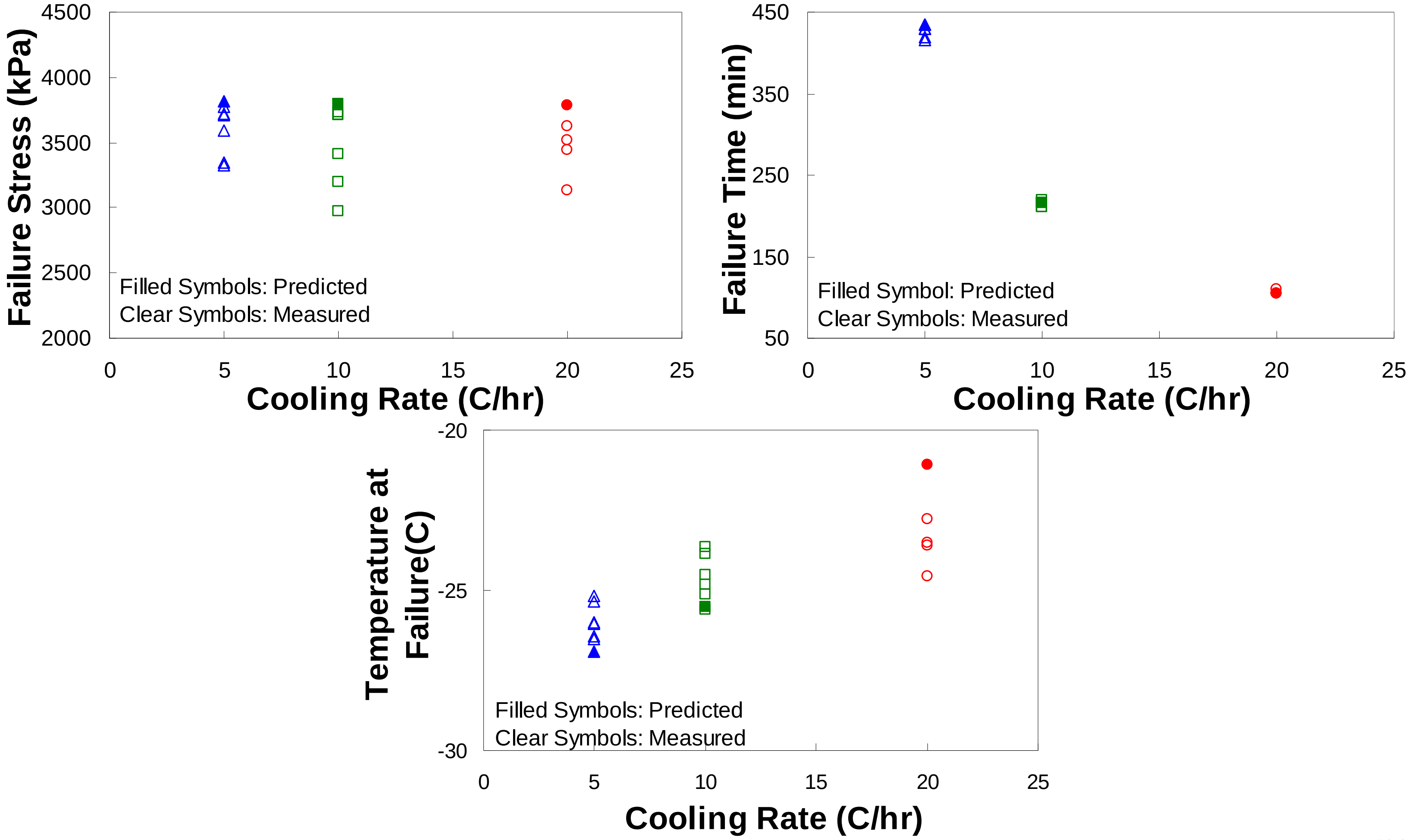
Solid Symbols = Modified Mixes



Thermal Cracking Verification



TSRST Prediction



Predictions from the VEPCD Model

- Stress-strain behavior of asphalt mix in:
  - monotonic tests at varying rates of loading and temperature; and
  - random load cyclic tests under varying stress/strain magnitudes, temperatures, and loading frequencies.
- N_f vs. ε_t relationship at various temperatures
- Endurance limit
- TSRST results under different cooling rates including:
  - thermal stress development history;
  - fracture time, fracture stress, and fracture temperature.

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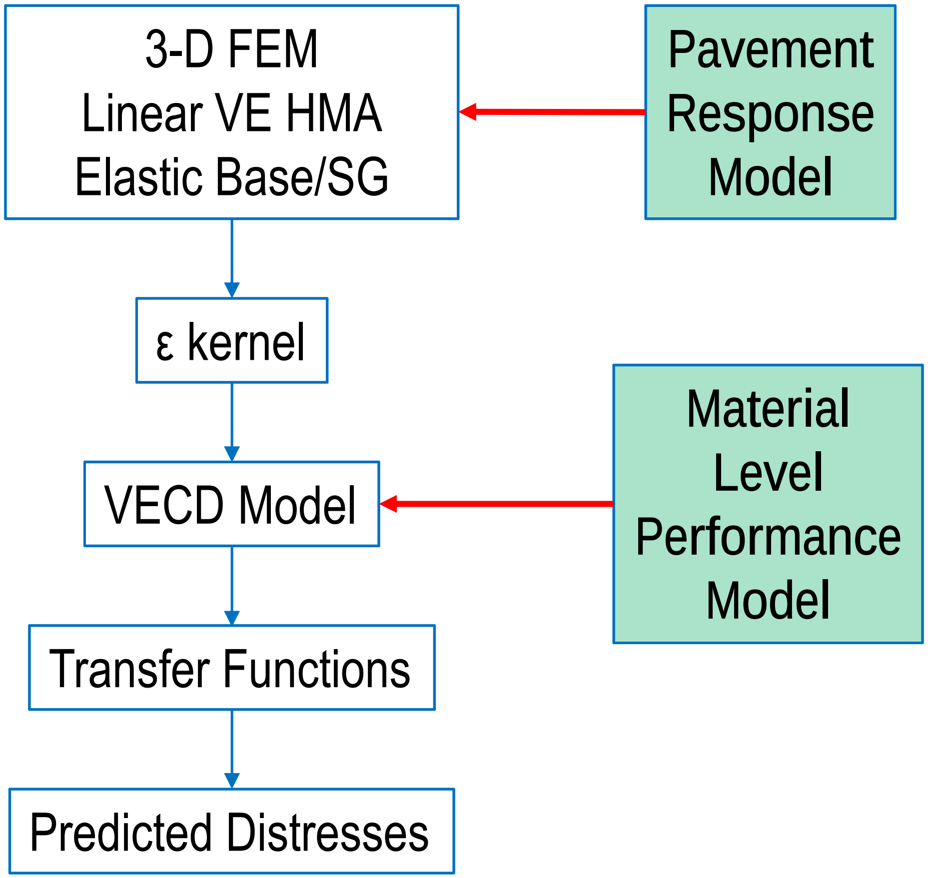
VECD Model Application

Fatigue Performance Prediction of HMA Pavement

- Two-Step Method
  - Pavement response model (3-D FEP++) plus VECD model
- Integrated Method
  - Finite element simulation of damage under continuous loading cycles

Two-Step Method

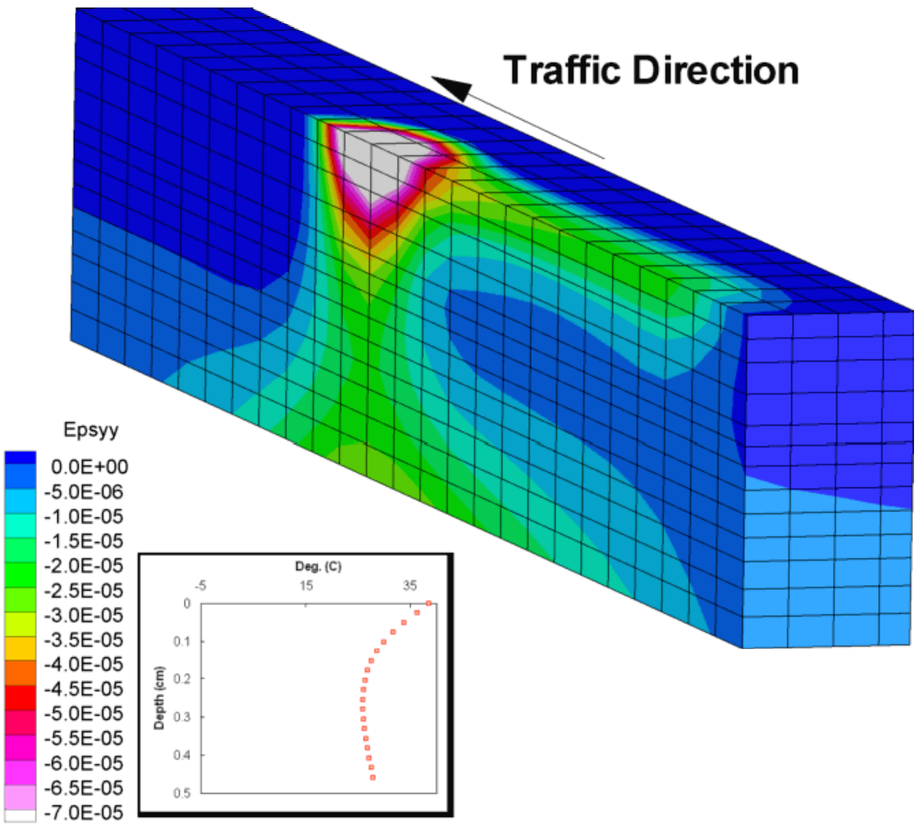


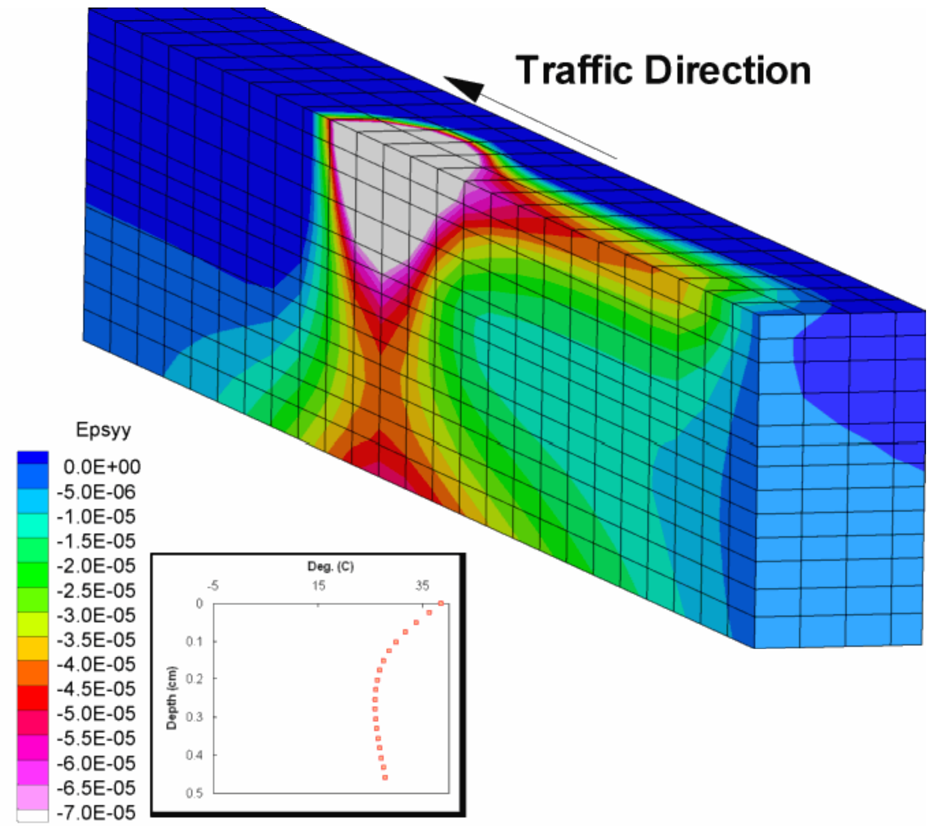
Effect of Material Type

Vertical Strain

Control

SBS-Modified

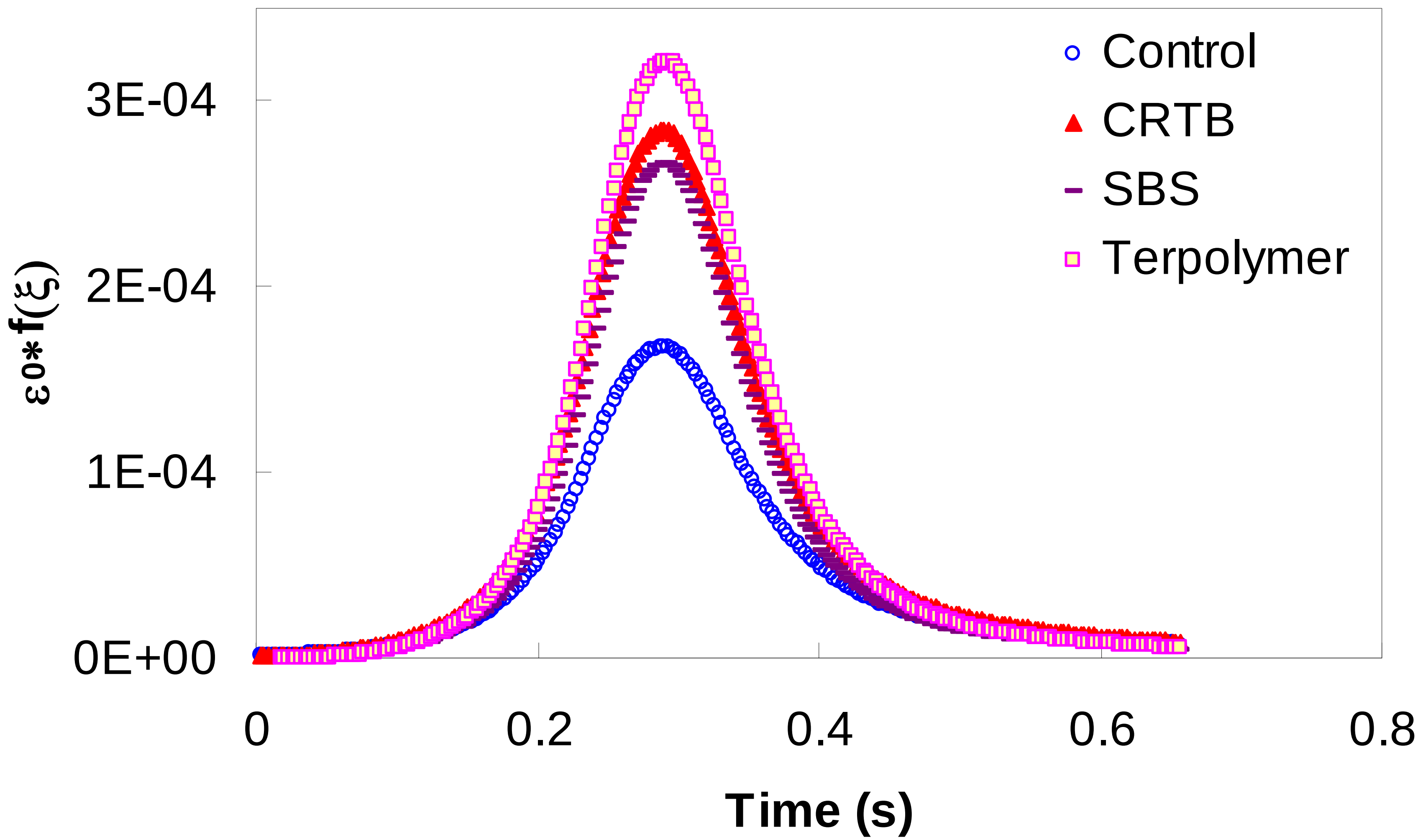




ALF Pavement

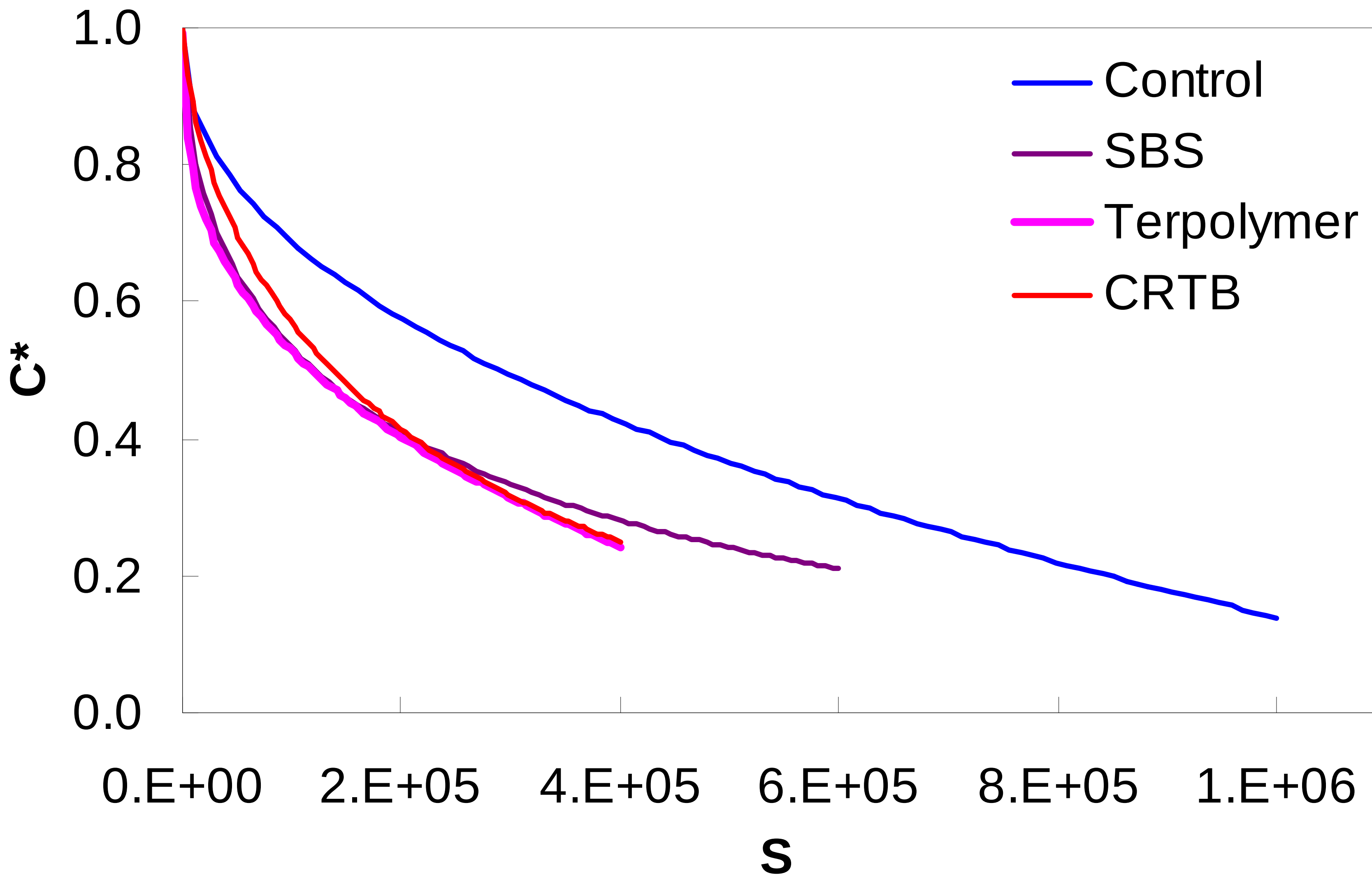
Transverse Strain Response

VECD Input Kernel

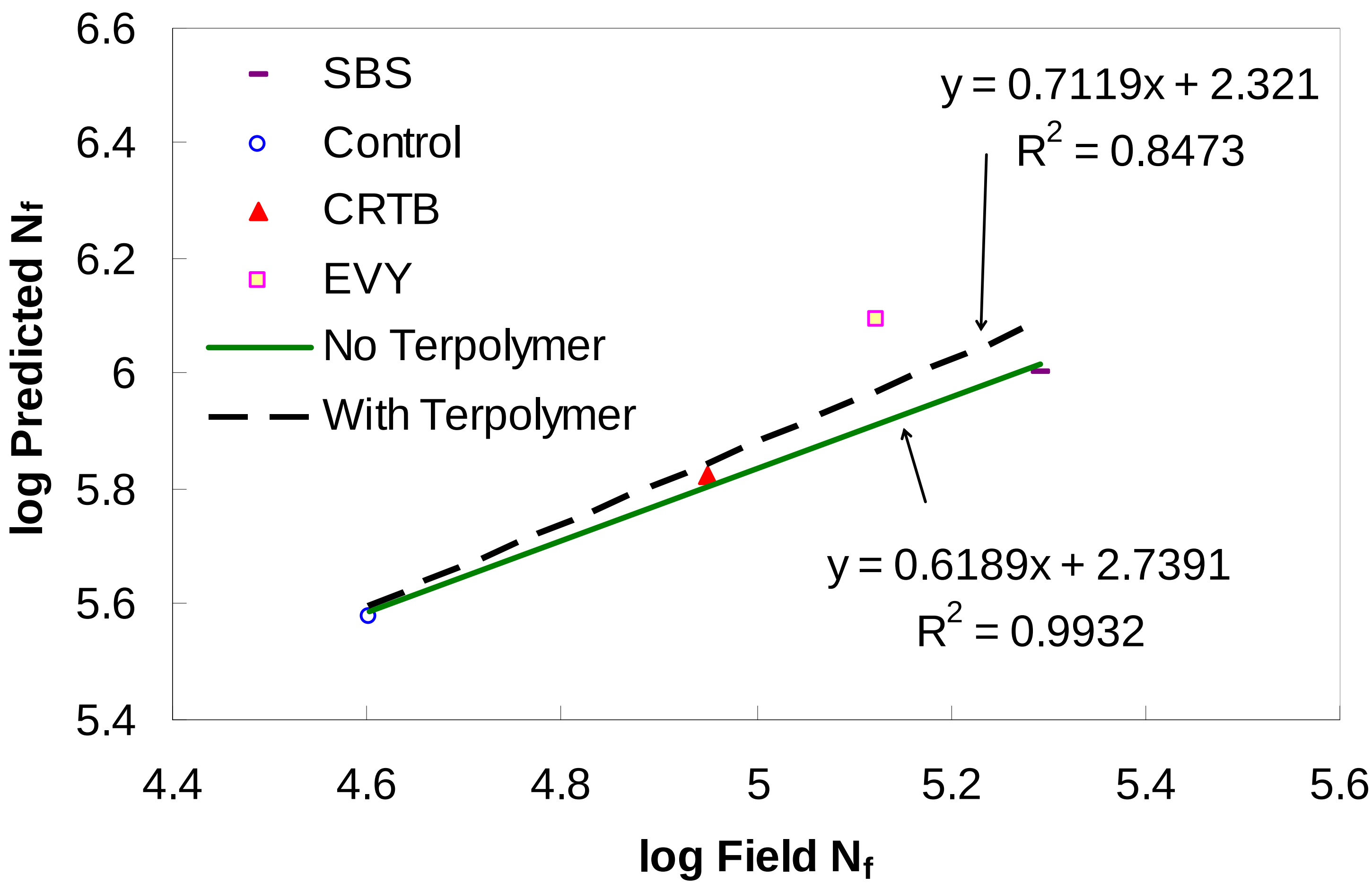


ALF Mixtures Comparison

Damage Characteristics



ALF Fatigue Life Prediction



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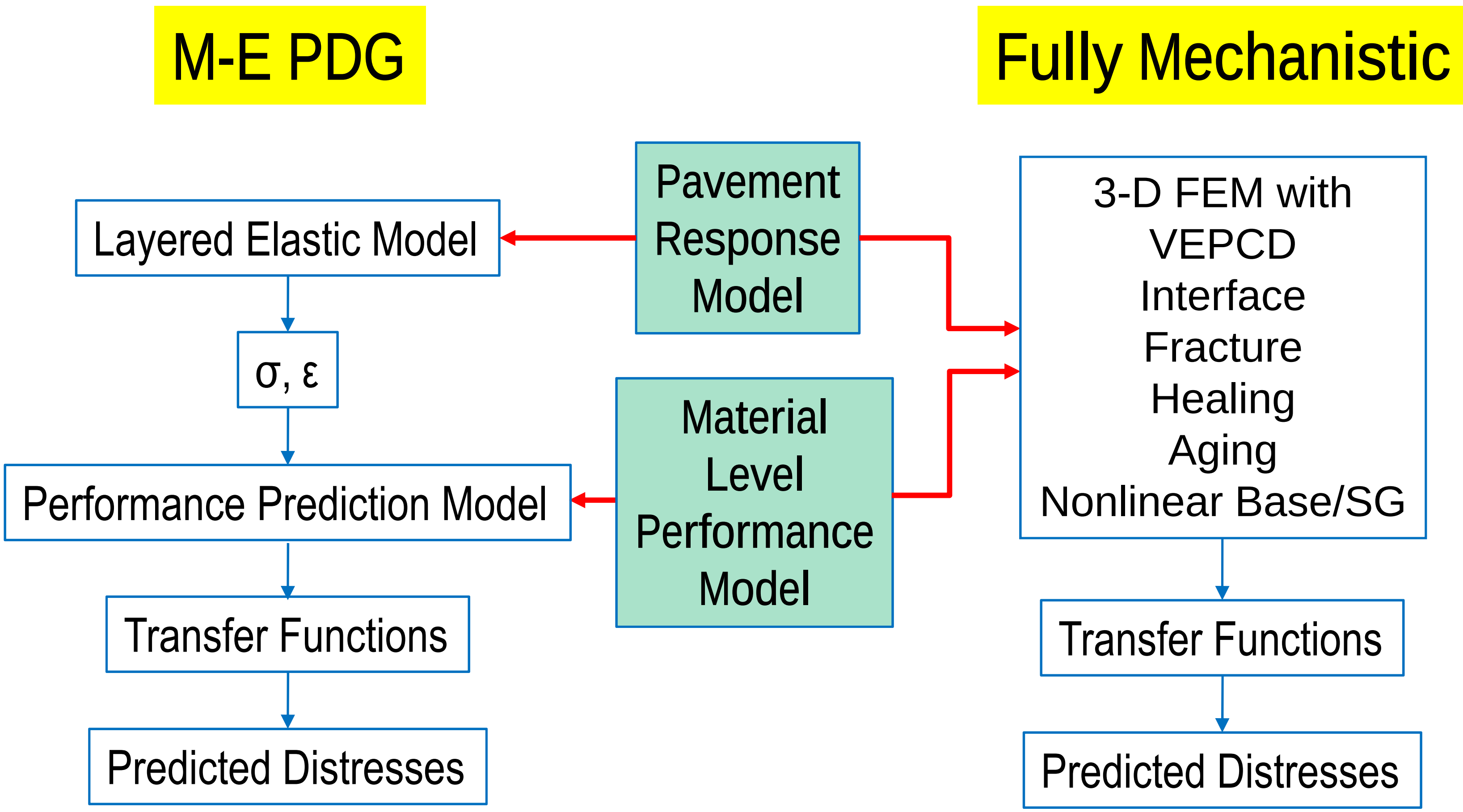
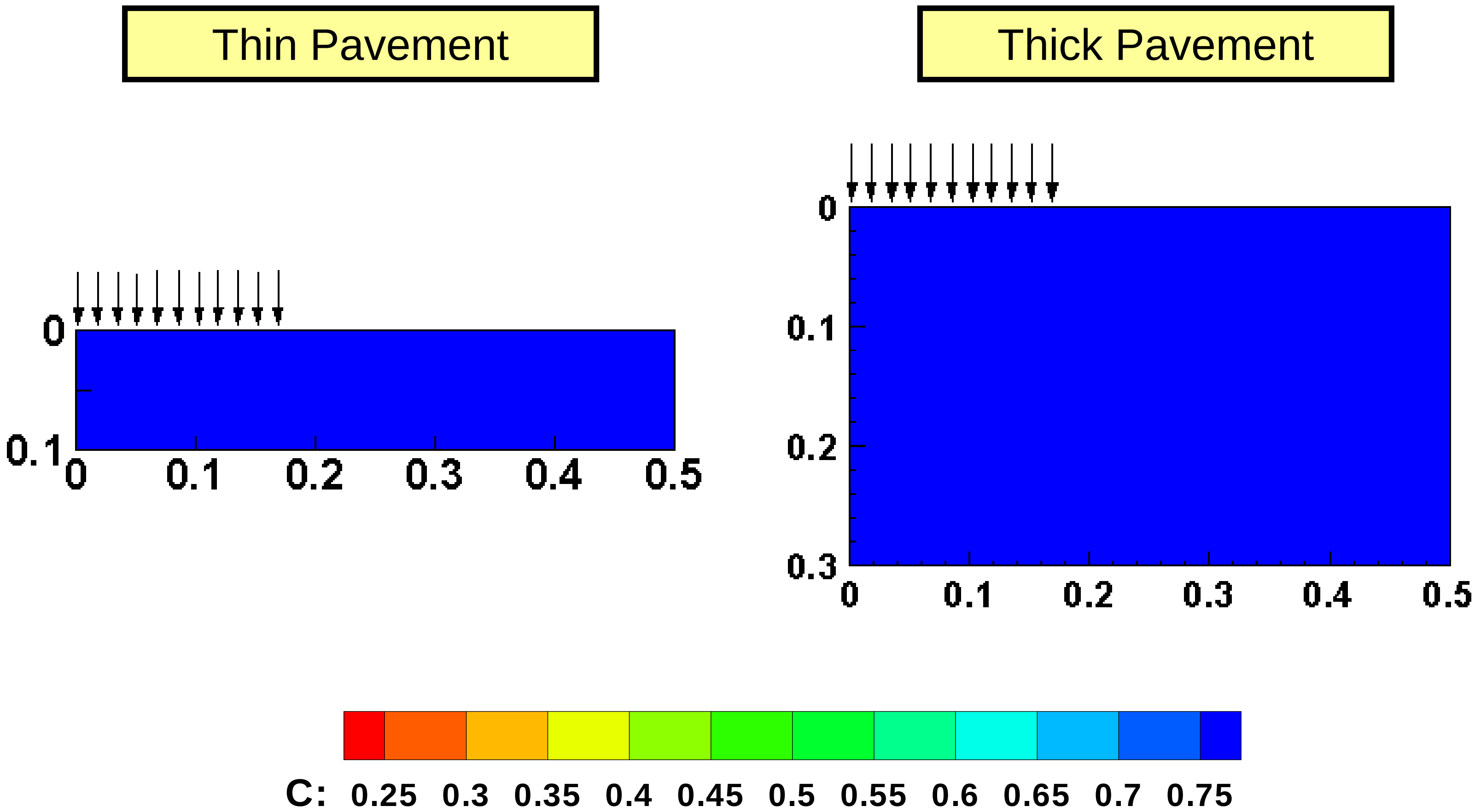
Integrated Method

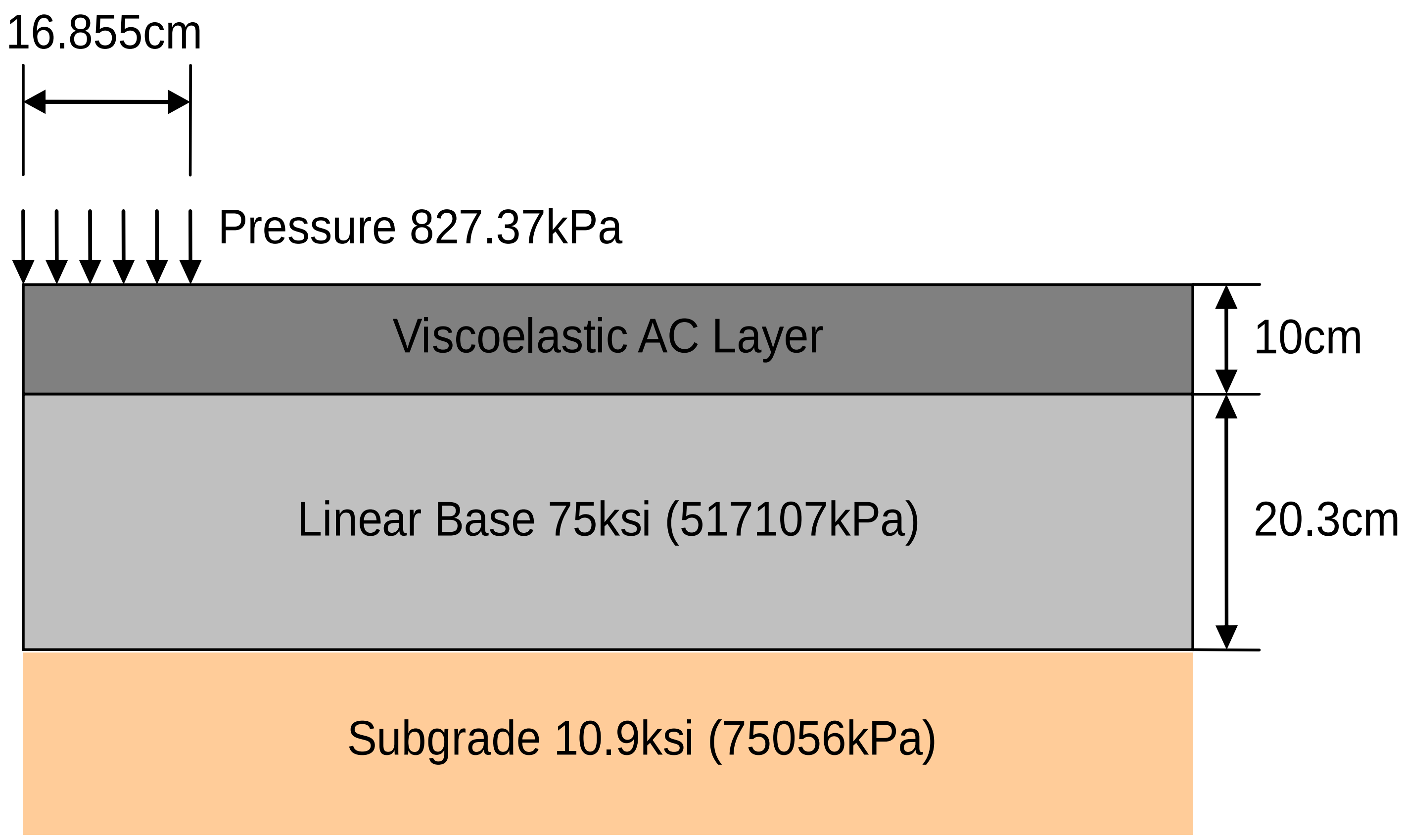


Simulation Results (Damage)

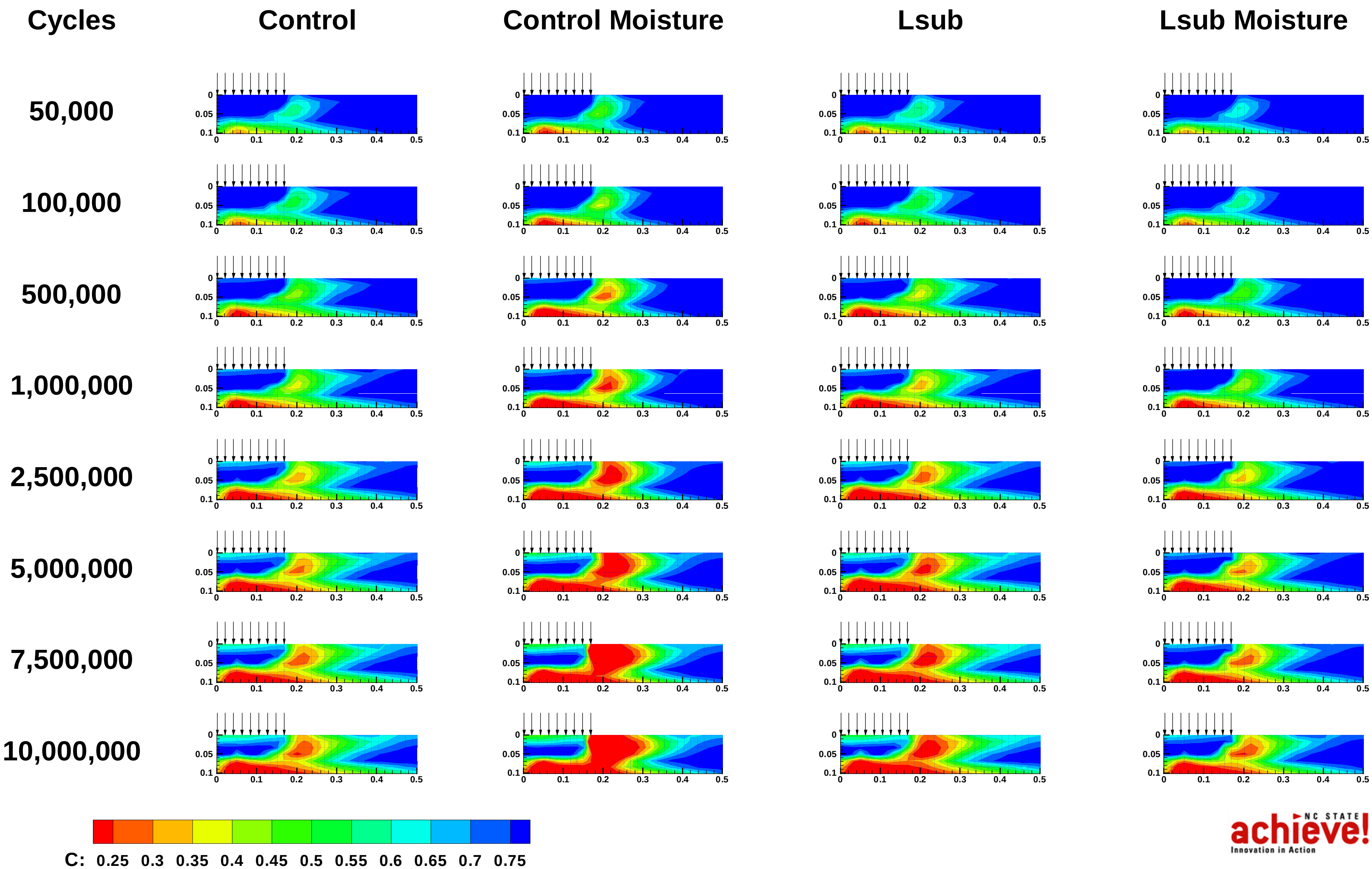
Only Mechanical Loading



Pavement Simulation for Lime-Modified Mix Evaluation



Effect of Moisture Conditioning



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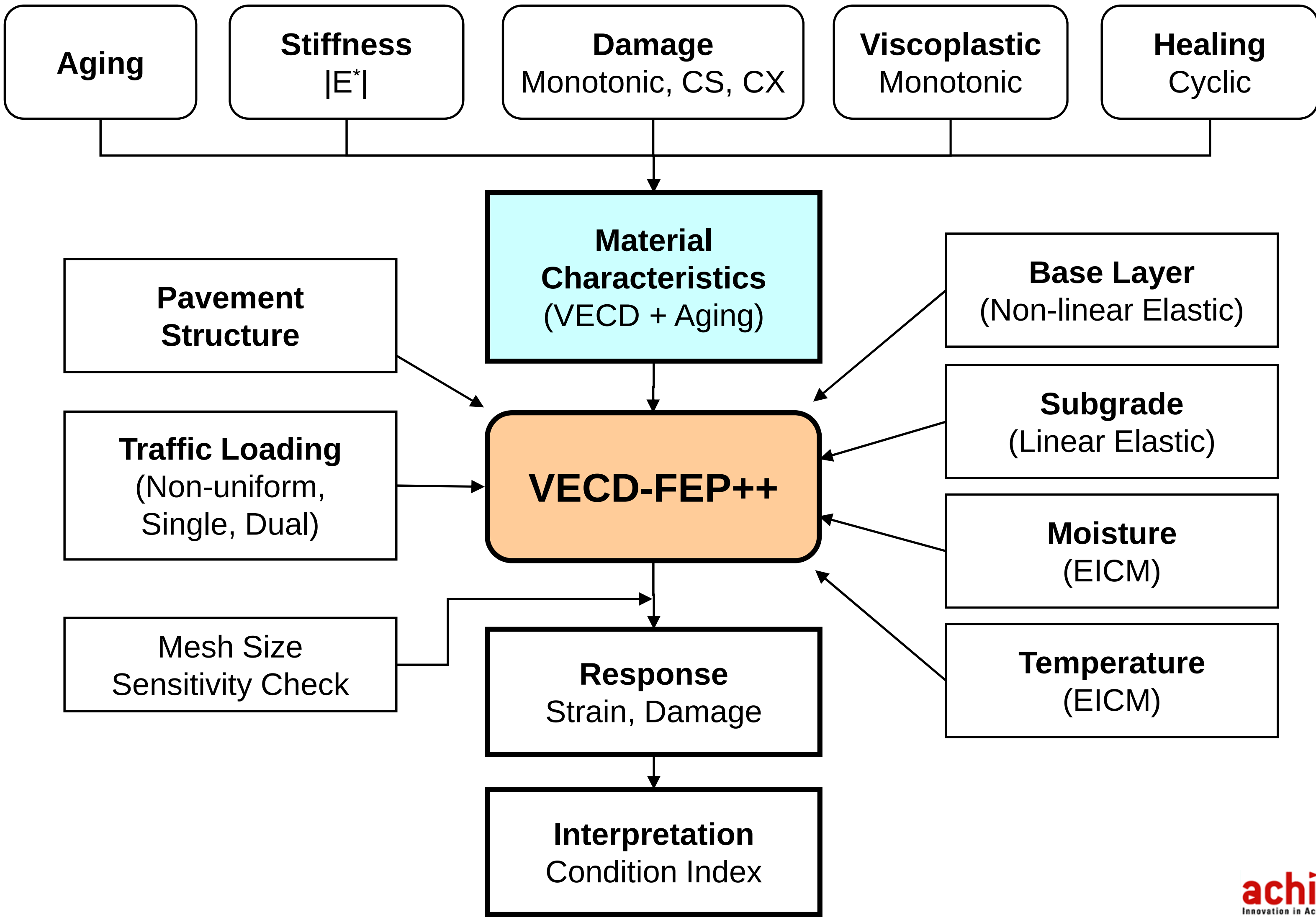
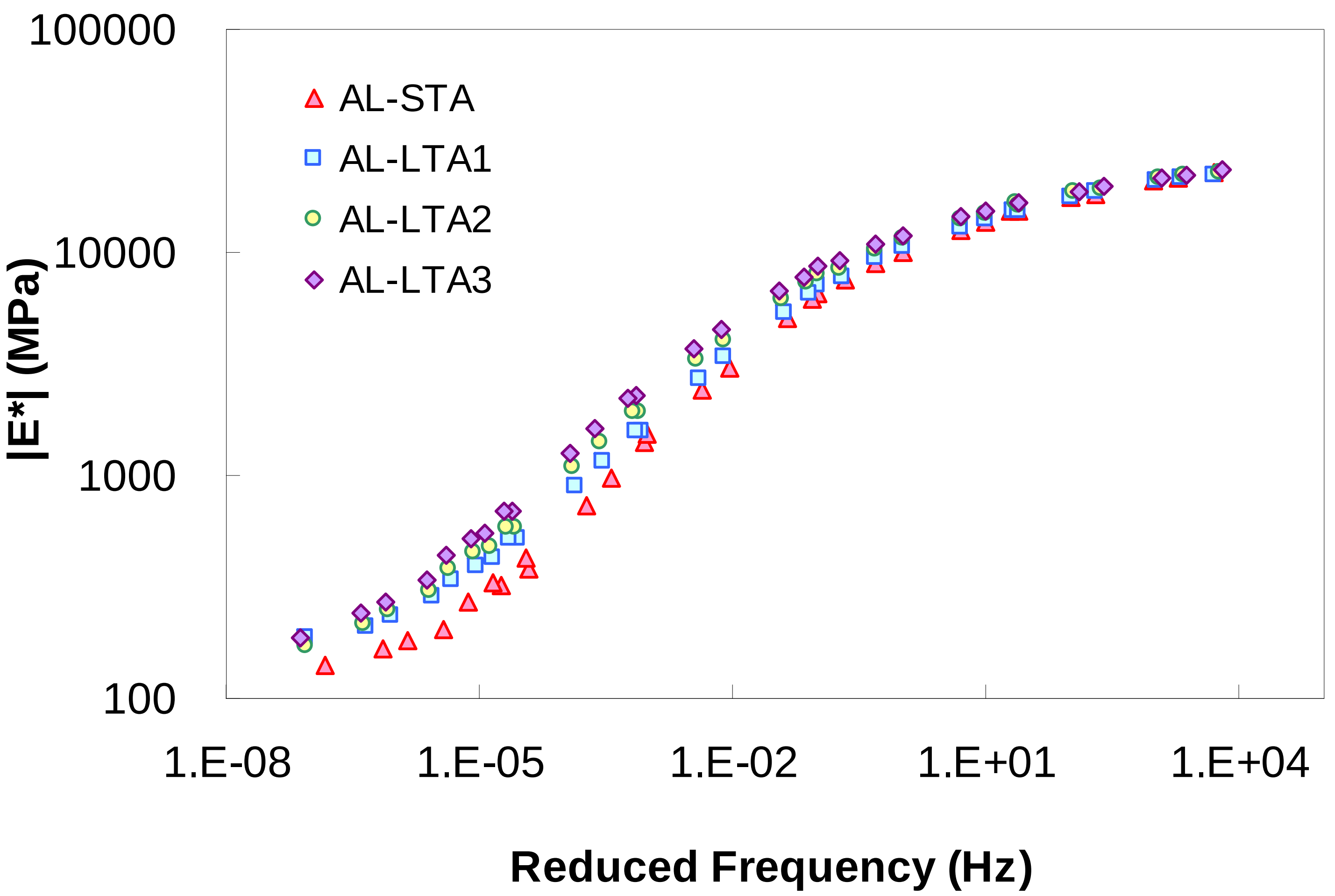
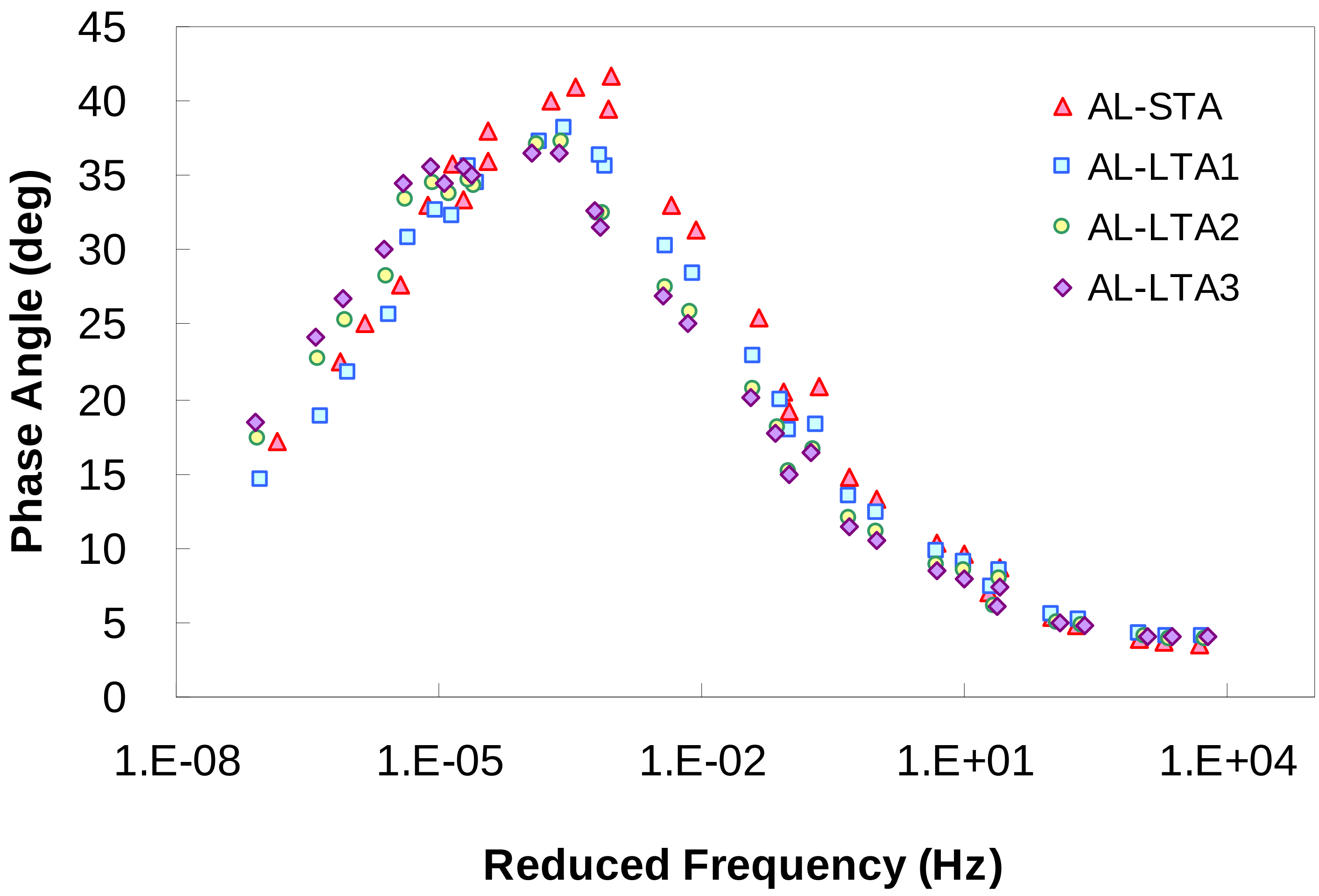
NCHRP 1-42A VECD-FEP++



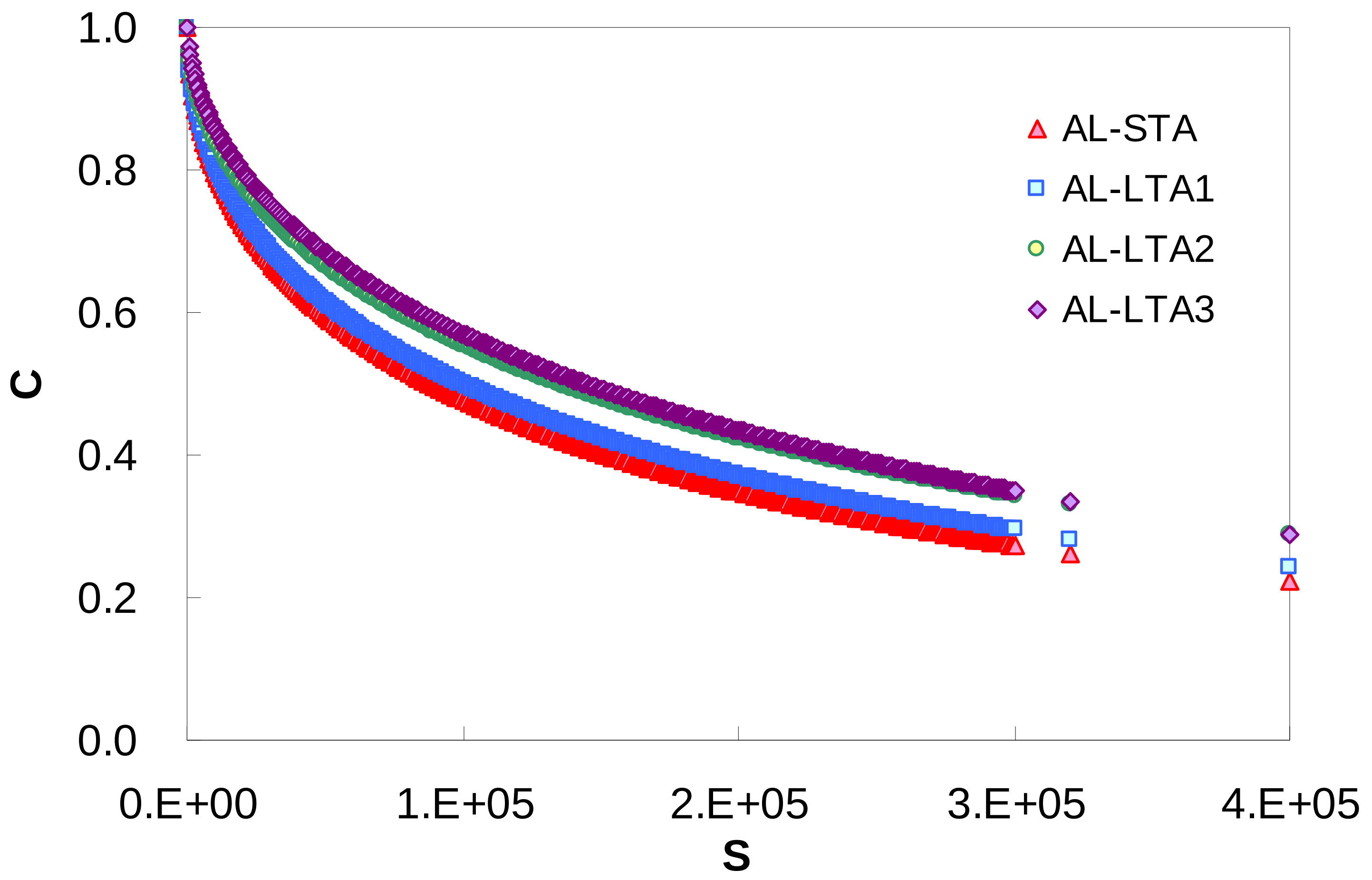
Effect of Aging on |E*|



Effect of Aging on Phase Angle

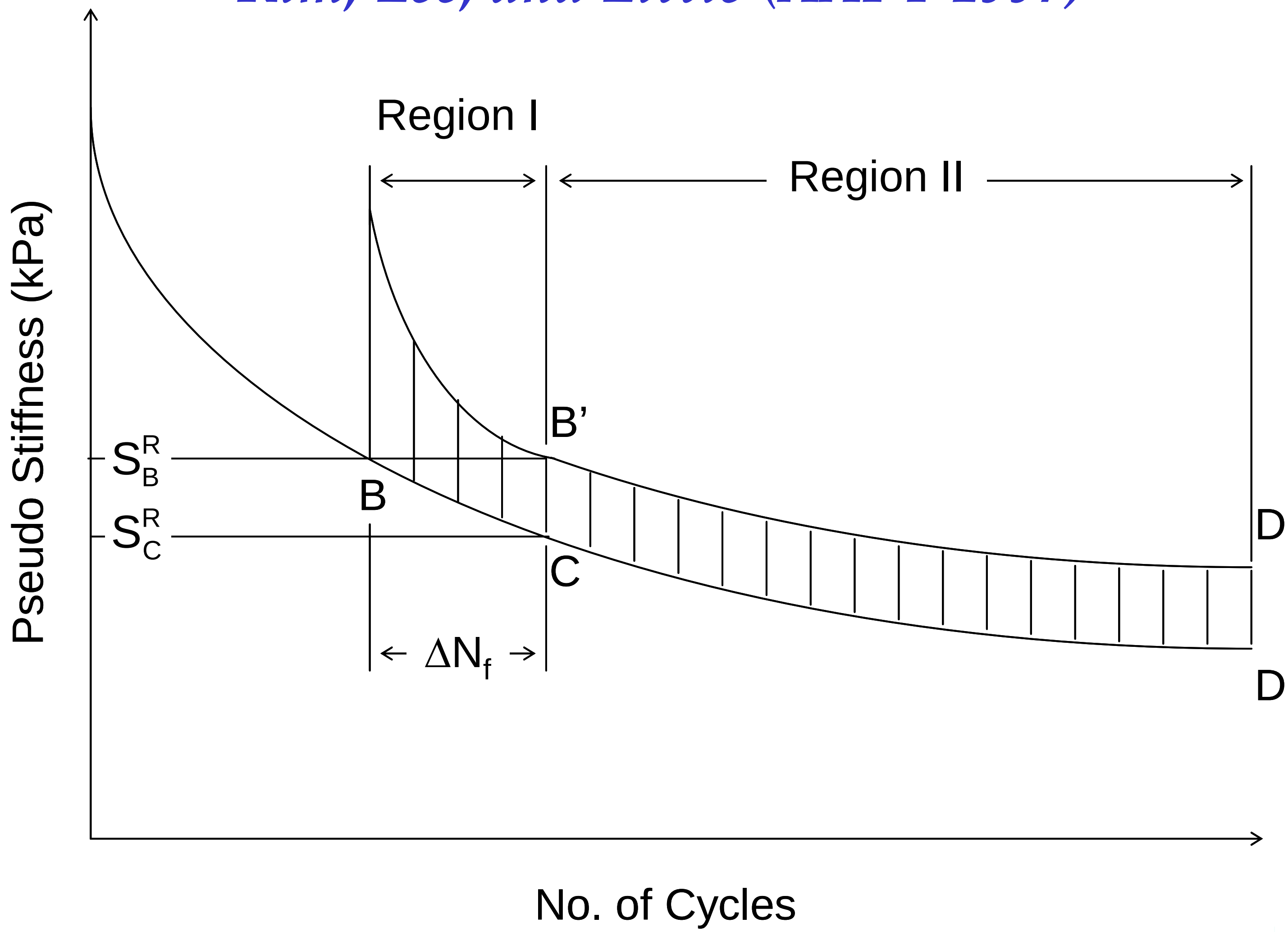


Effect of Aging on VECD Model



Healing Model

Kim, Lee, and Little (AAPT 1997)



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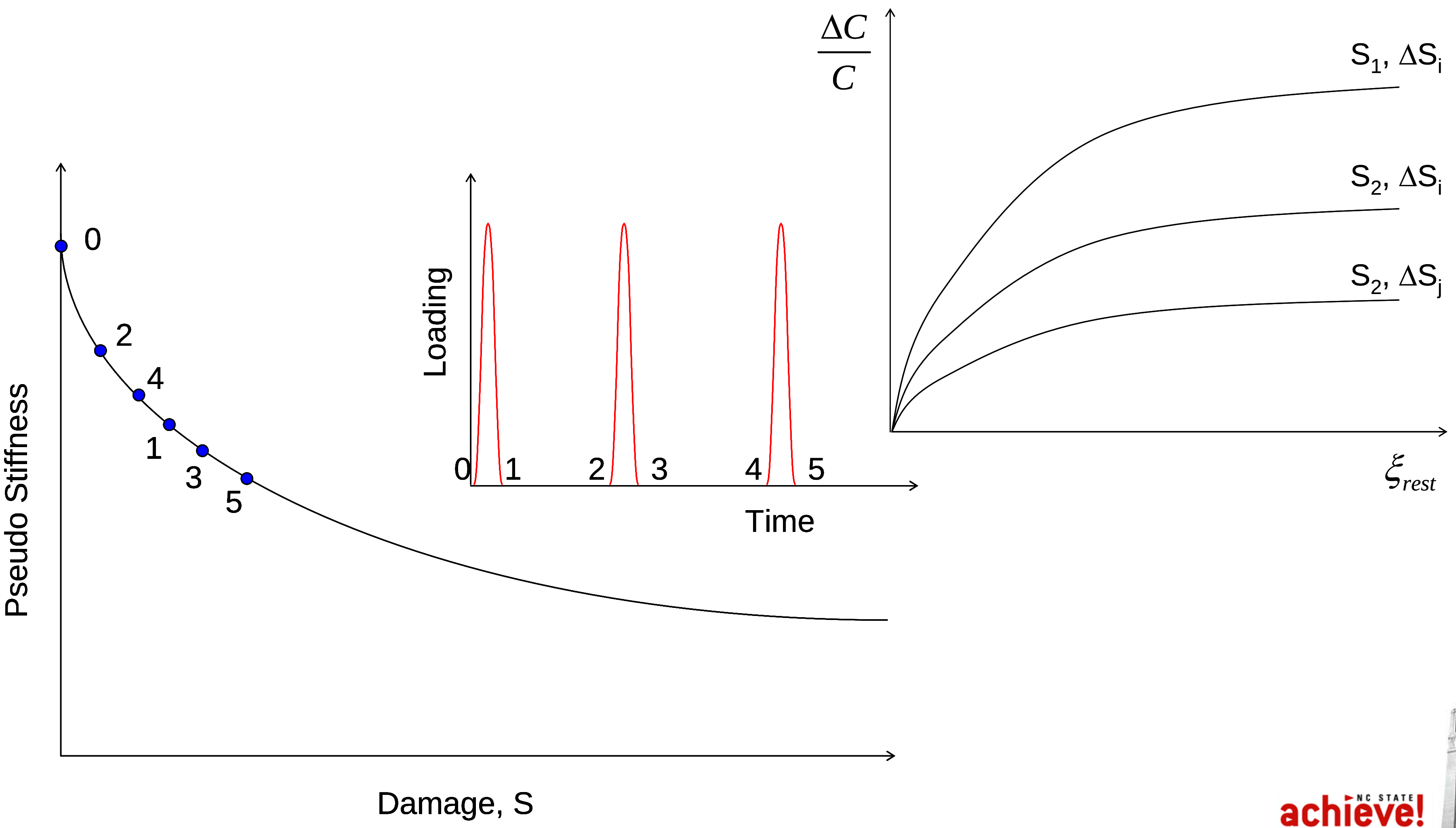
Modified Healing Model

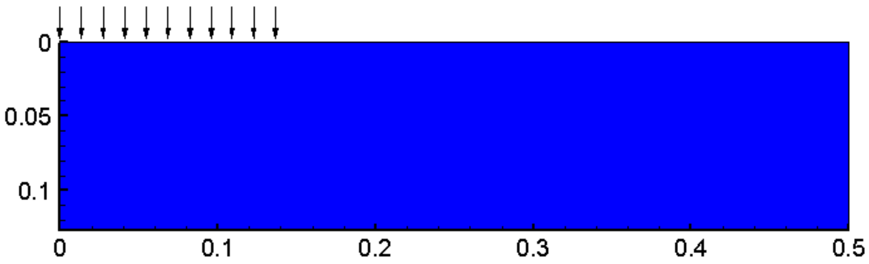
NCHRP 1-42A



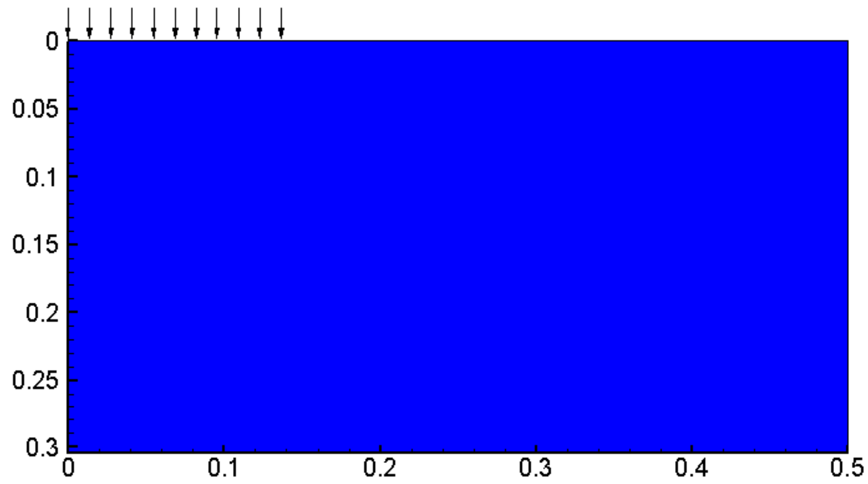
Simulation Results (Cracking Index)

Mechanical and Thermal Loading, Aging, Healing, and Viscoplasticity

Thin Pavement



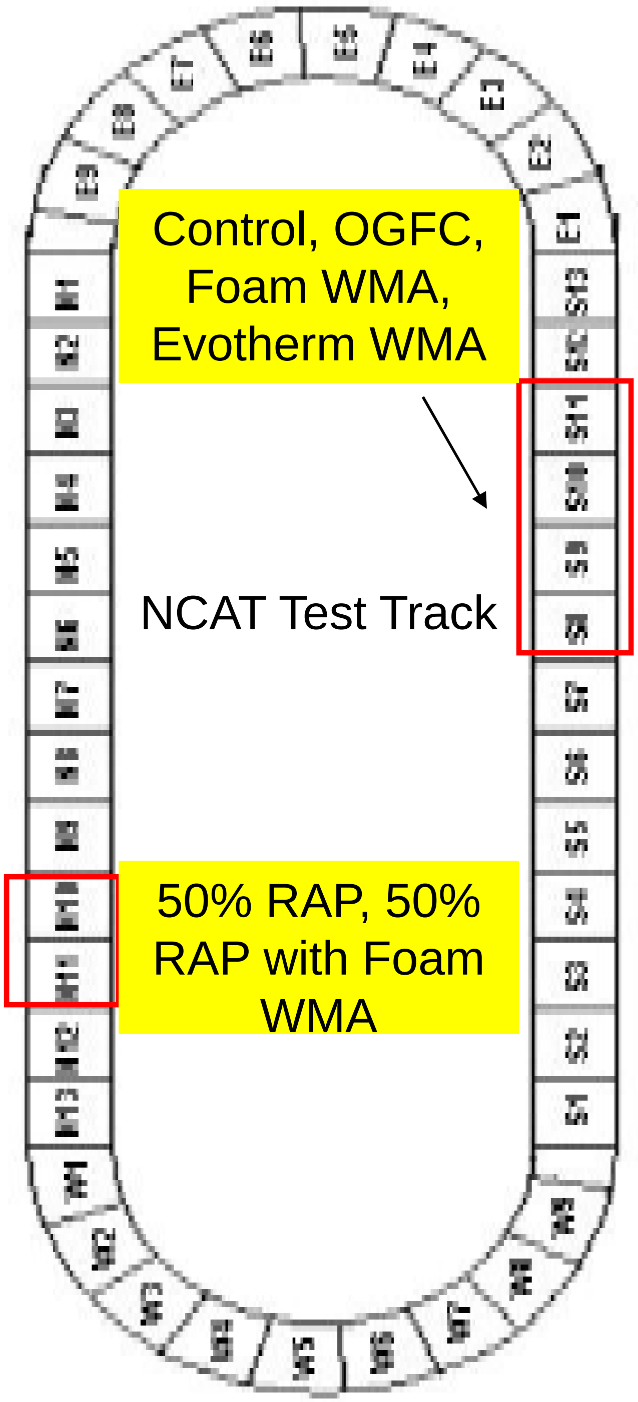
Thick Pavement



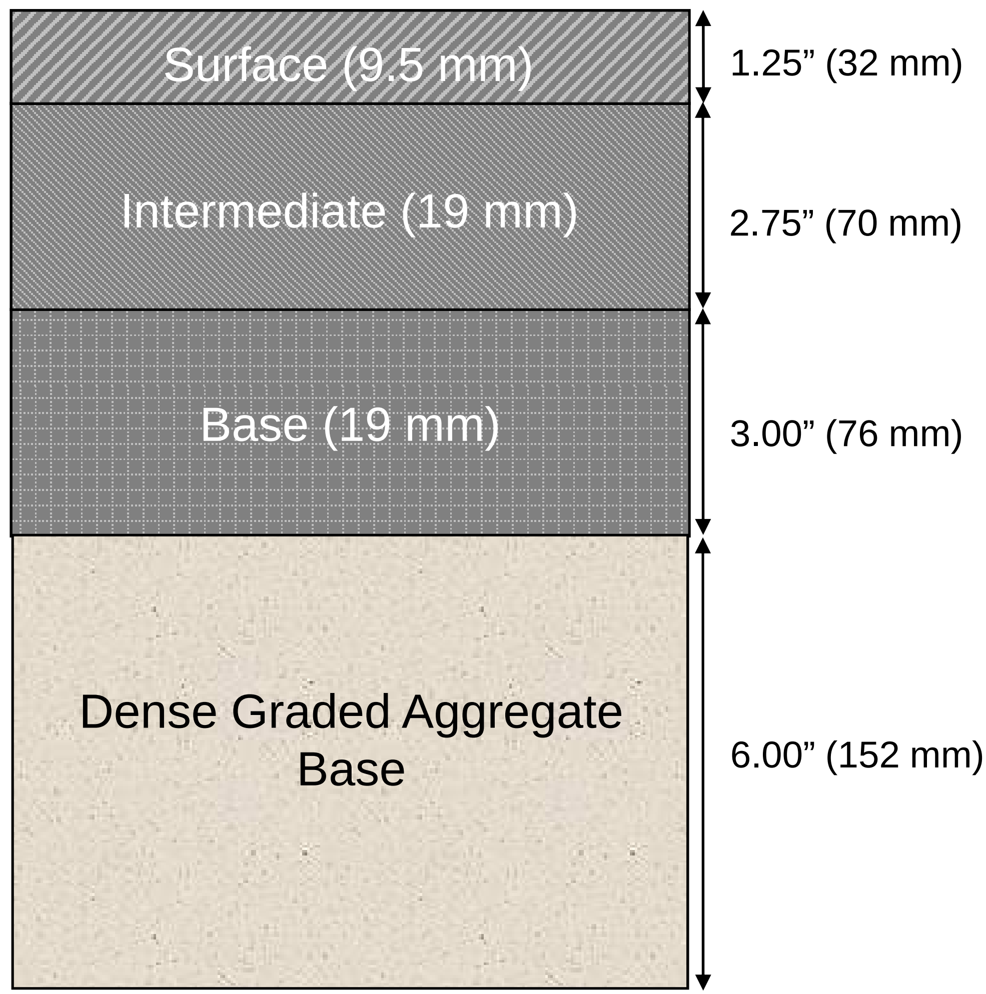
Summary

- VEPCD model's ability to predict material's behavior at a wide range of conditions
- Cracking simulation of VECD-FEP++ does not need to know the crack location a priori.
- Thermal stress, aging, healing, viscoplasticity models implemented into VECD-FEP++
- VECD-FEP++ as a tool to investigate and model WMA materials and pavements

Thank you!



NCAT Test Track Cross Section



Stiff Subgrade

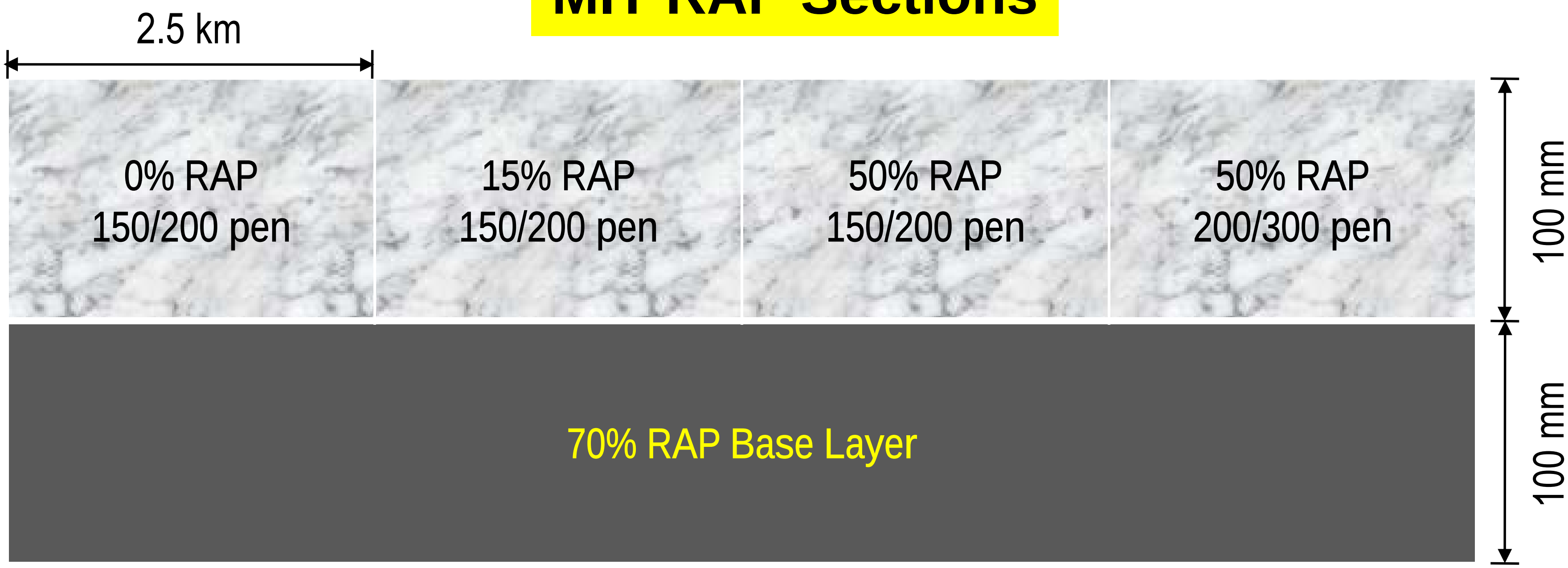
Summary of NCAT Mixtures

- HMA Mixtures
  - Control, OGFC (15% RAP)
  - High RAP (50%), High RAP + WMA
- WMA
  - Evotherm (additive), Advera (foam)
- RAP
  - 0, 15, 50% RAP
- Binder Grades
  - Surface/Intermediate layers
    - ✓ No RAP – PG 76-22
    - ✓ With High RAP – PG 67-22
  - Base layer
    - ✓ PG 67-22

Summary of MIT Mixtures

- WMA Project
  - WMA Additives
    - ✓ Advera, Sasobit, Evotherm
  - Layer Properties
    - ✓ Surface layer – 0% RAP, 150/200 pen
    - ✓ Intermediate layer – 30% RAP, 200/300 pen
- RAP Project
  - RAP
    - ✓ 0, 15, 50%
  - Binder
    - ✓ 150/200 pen for all % RAP, also 200/300 pen for 50% RAP
  - Base Materials (not sampled)
    - ✓ 70% RAP

MIT RAP Sections



MIT WMA Sections