

ARC Deliverables/Products Presentation and Workshop

<http://www.arc.unr.edu/>

***Western Regional Superpave Center (WRSC)
University of Nevada, Reno***

Washington, DC – January 15, 2015

ARC
Asphalt Research Consortium



www.wrsc.unr.edu ; www.arc.unr.edu

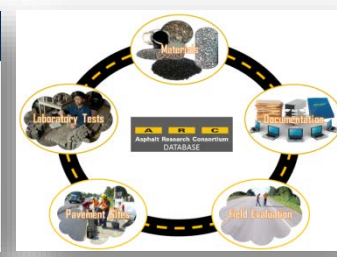
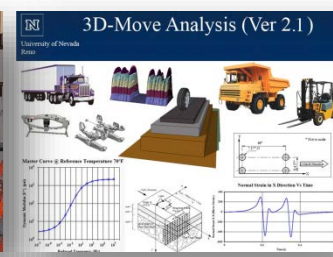
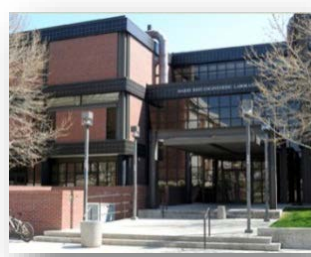


Slide No. 1

ARC Deliverables/Products Presentation and Workshop

University of Nevada, Reno

- 11:05 – 11:30:** Pavement Engineering Software: Pavement Response Model to Dynamic Loads (3D-Move).
- 11:35 – 12:00:** Rutting Performance of Asphalt Mixtures Under Critical Conditions.
- 1:00 – 1:25:** Mix Design for Cold in-Place Recycling (CIR).
- 1:30 – 1:55:** Pavement Engineering Software: Thermal Cracking Analysis Package (TCAP).



ARC Deliverables/Products Presentation and Workshop

Comprehensive Thermal Cracking Analysis Model for Asphalt Concrete Pavements

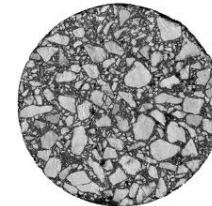
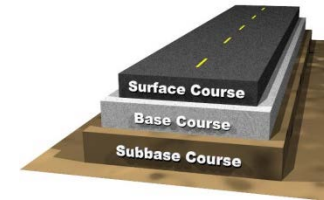
Thermal Cracking Analysis Package (TCAP)



Thermal Cracking Analysis

Influential Factors

- Pavement Structure
 - Asphalt layer thickness.
 - Interface condition.
- Environmental Conditions
 - Pavement temperatures.
 - Cooling/warming rates.
- Asphalt mixture properties
 - Viscoelastic properties
 - Thermal Volumetric properties
 - Fracture and Crack Initiation Properties
- Asphalt mixture aging
 - Property change with oxidative aging

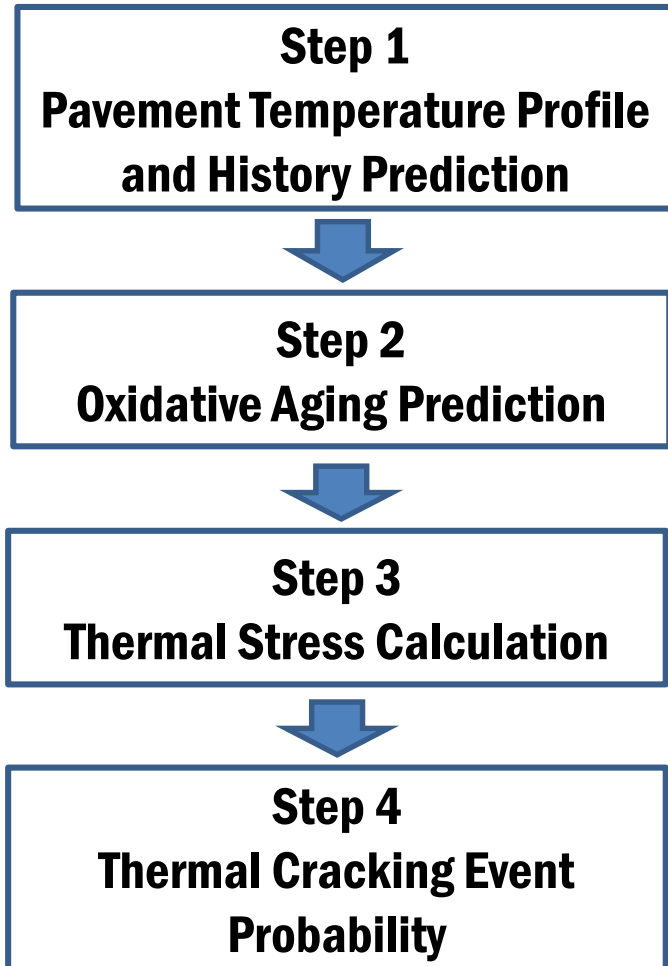


Thermal Cracking Analysis

Existing Models

- **Aging** of asphalt binder over time is **not considered**
“viscoelastic, fracture, and volumetric properties of asphalt material constant over time.”
- Thermal coefficient of contraction (CTC) is considered **constant** with temperature and usually **estimated**.
- Tensile strength is considered **constant** with temperature and time.
- Pavement temperature model (currently EICM) **can be improved**.

Thermal Cracking Analysis Proposed Model



Predicted pavement temperature (Step 1)
(over time and at depth z)

Predicted carbonyl (CA) (Step 2)
(over time and at depth z)

Asphalt mixture Relaxation modulus

- Directly from the E^* complex modulus
- based on continuous relaxation spectrum
- Age dependent

Coefficient of thermal contraction (CTC)

- Temperature dependent CTC
- Obtained from the thermal strain curve
- Age dependent

1-D Linear viscoelastic model

Thermal Cracking Analysis

Prediction of Field Aging *(Numerical solution using FCVM)*

Pavement location: **Reno, NV**
Aggregate: **Northern Nevada**
Binder type: **PG64-28 (SBS mod.)**
Binder content: **5.22%**
Air voids: **7%**

$$E_a = 72.53 \text{ kJol/mol}$$

$$AP^\alpha = 4.08 E+8 \ln(\text{CA/day})$$

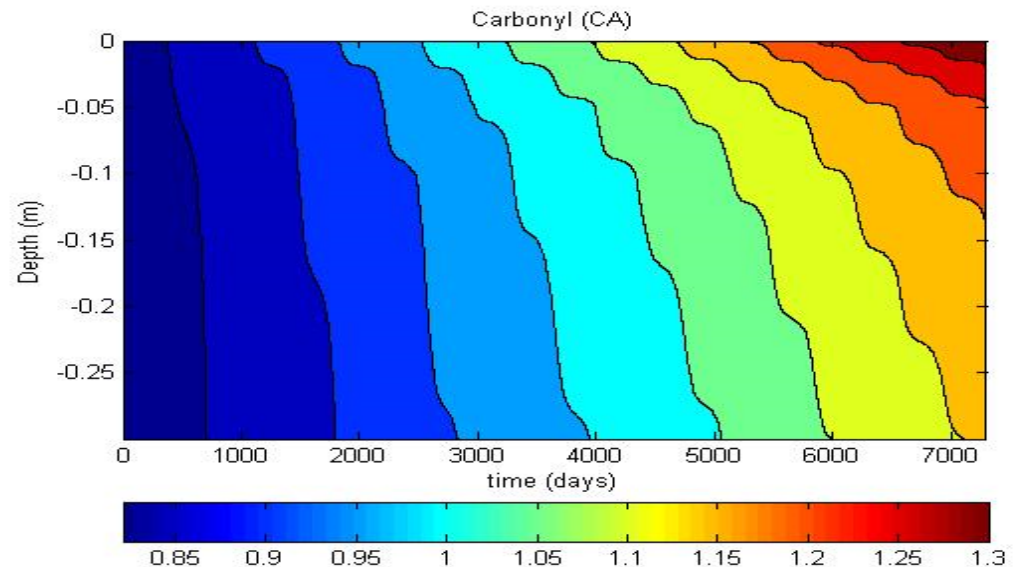
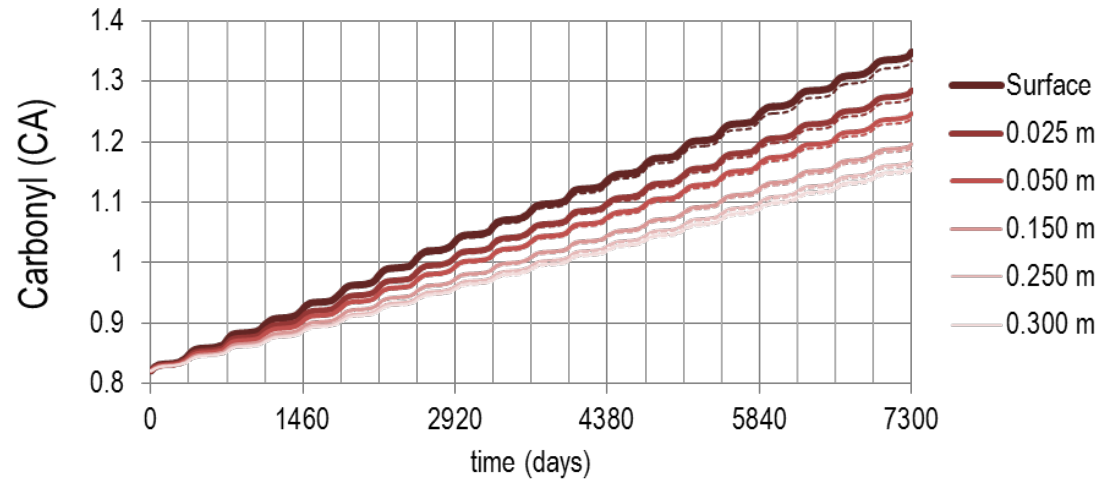
$$HS = 2.7 (1/\text{CA})$$

$$m = 9.24 \text{ (poise)}$$

$$\text{Air void diameter} = 0.5 \text{ mm}$$

$$\text{Eff. aging zone} = 1.0 \text{ mm}$$

(film thickness)



Thermal Stress Calculation

- 1D linear viscoelastic constitutive equation with oxidative aging effect.

$$\sigma_{Th}(t, CA) = \int_0^t E(\xi(t) - \xi'(t), CA) \frac{\partial \varepsilon_{Th}(t, CA)}{\partial t'} dt'$$

Relaxation Modulus
Function of time,
temperature, and aging

Thermal strain rate
Function of temperature and
age-dependent CTC

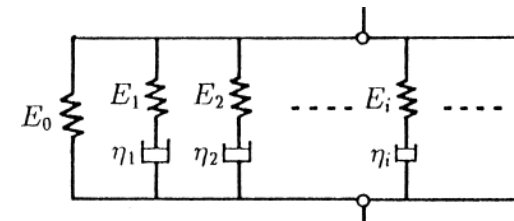
Age-Dependent Relaxation Modulus

- Relaxation modulus determined from dynamic complex modulus.
 - Continuous relaxation spectrum directly obtained by inverse Laplace Fourier Transform of complex E^* (2S2P1D, *Olard & Di Benedetto, 2003*).

$$E_r(t) = E_0 + \int_{-\infty}^{+\infty} H(\rho) \cdot e^{\left(\frac{-t}{\rho}\right)} d\ln(\rho)$$

$$H(\rho) = \pm \pi^{-1} \text{Im} E^* (\rho^{-1} \cdot e^{\pm i\pi})$$

$$E^*(i\omega) = E_0 + \frac{E_\infty - E_0}{1 + \delta(i\omega\tau)^{-k} + (i\omega\tau)^{-h} + (i\omega\beta\tau)^{-1}}$$

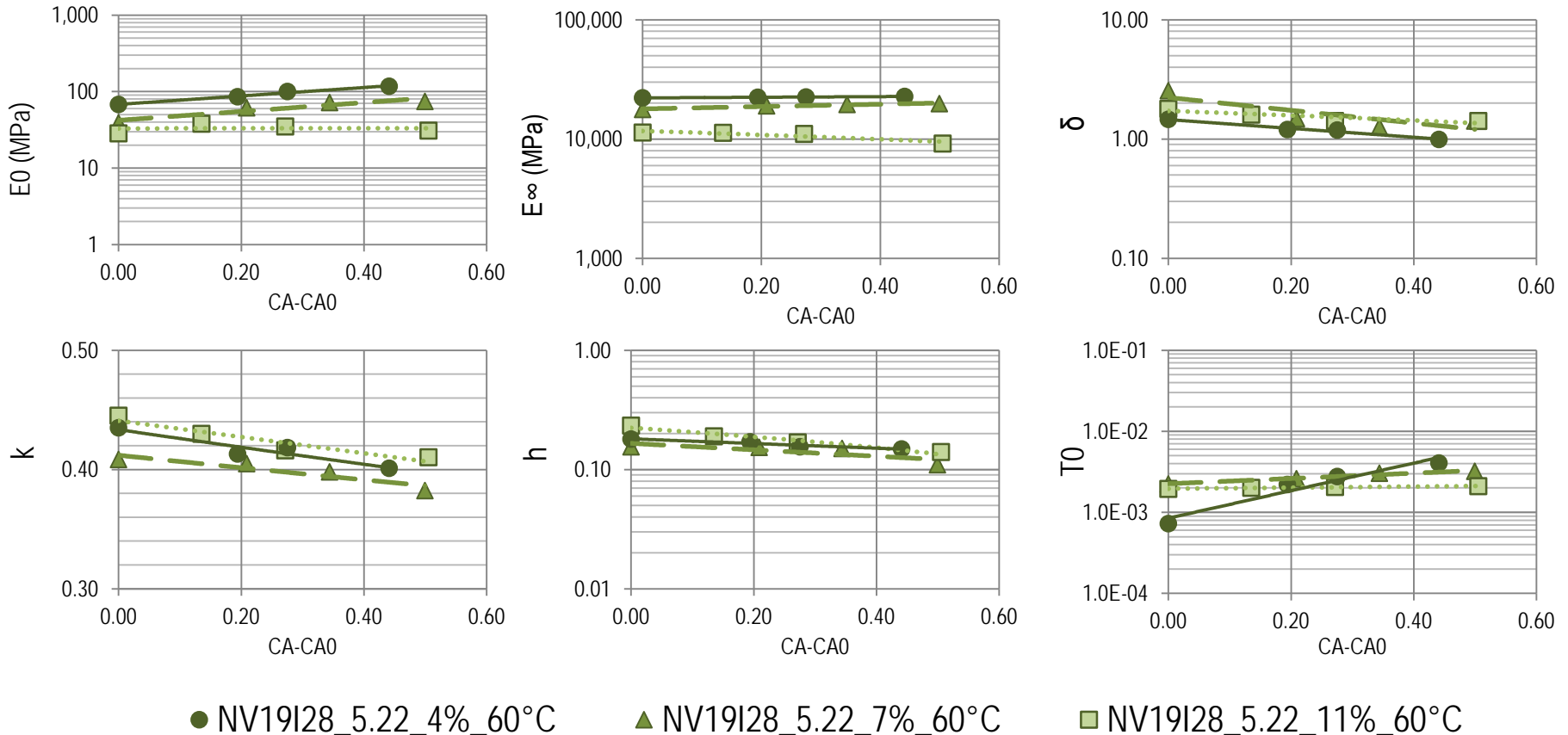


Ideal viscoelastic model

- ▶ ω : 2π *frequency, the pulsation
- ▶ E_0 : static modulus when $\omega \rightarrow 0$
- ▶ E_∞ : limit of complex modulus when $\omega \rightarrow \infty$,
- ▶ h, k : exponents such as $1 > h > k > 0$,
- ▶ δ : dimensionless constant.
- ▶ β : dimensionless constant, $\beta = \eta_i \cdot \tau^{-1} / (E_\infty - E_0)$; when $\omega \rightarrow 0$, then $E^*(i\omega\tau) \sim E_0 + i\omega\eta_i$.
- ▶ τ : characteristic time, which varies only with temperature

Thermal Cracking Analysis

Evolution of 2S2P1D Coefficient with Aging



Consistent trends were found for the evaluated mixtures!

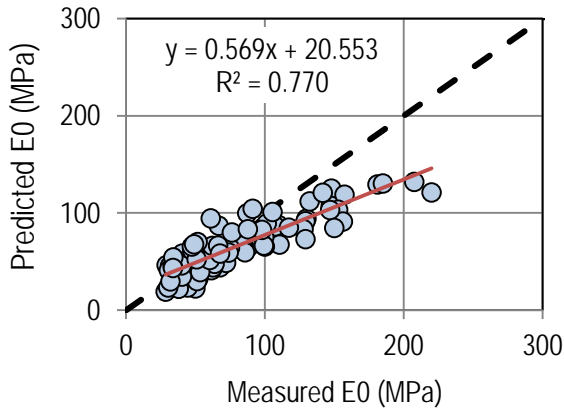
$$(2S2P1D\ coeff)_j = A_j \times e^{B_j(CA-CA_0)}$$

Evolution of 2S2P1D Coefficient with Aging

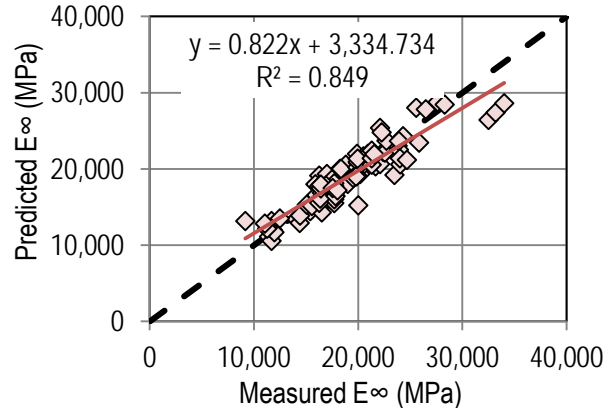
2S2P1D coeff.	Mixture variable						
	CA	V_a (%)	Abs. (%)	LSV_{Tank} (poise)	B.C. (%)	Retained # 8	Passing # 200
E_0	✓	✓	✓	✓	✓		
E_∞	✓	✓	✓	✓	✓	✓	✓
δ	✓	✓	✓	✓	✓		✓
k	✓		✓	✓			✓
h	✓			✓	✓		
T_0	✓		✓				✓

Thermal Cracking Analysis

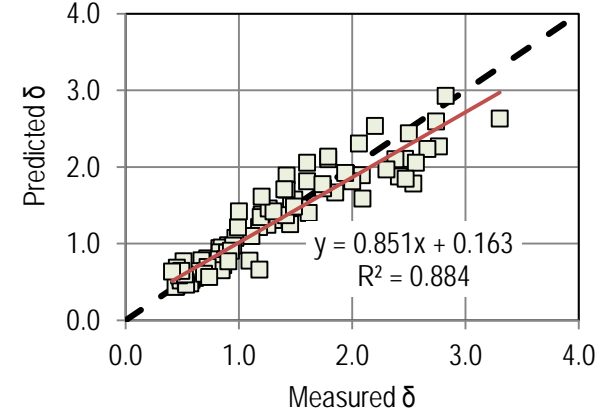
Evolution of 2S2P1D Coefficient with Aging



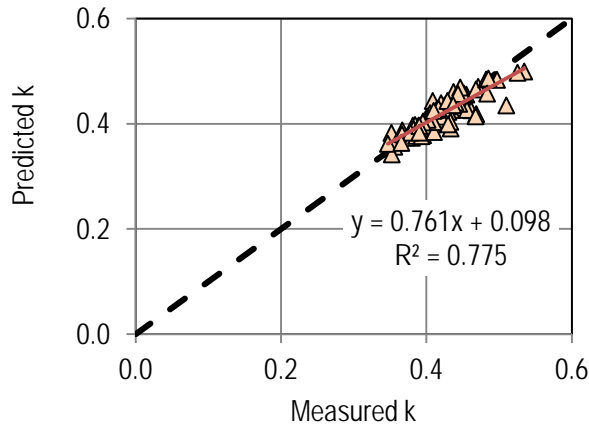
○ E_0 (MPa) — Line of Equality



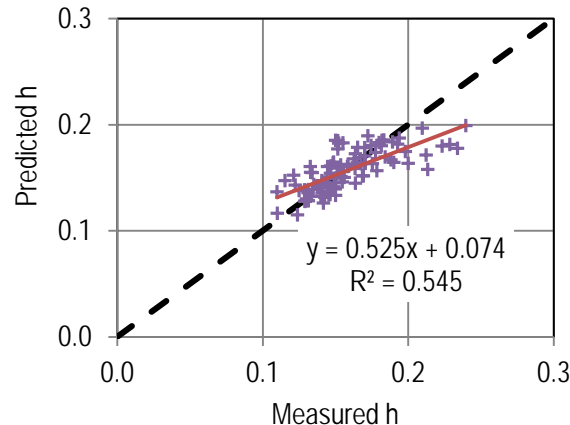
◇ E_∞ — Line of Equality



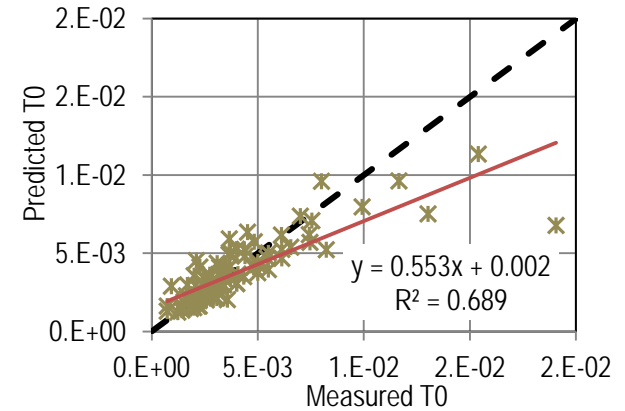
□ δ — Line of Equality



△ k — Line of Equality



+ h — Line of Equality



× T_0 — Line of Equality

Age-Dependent Properties

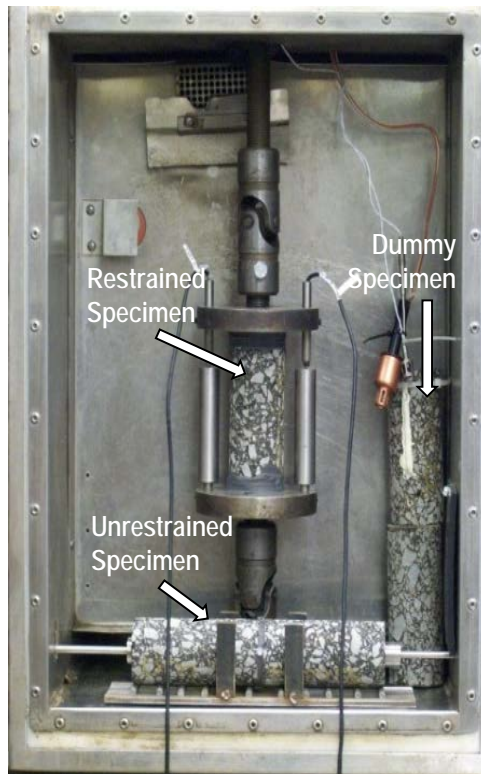
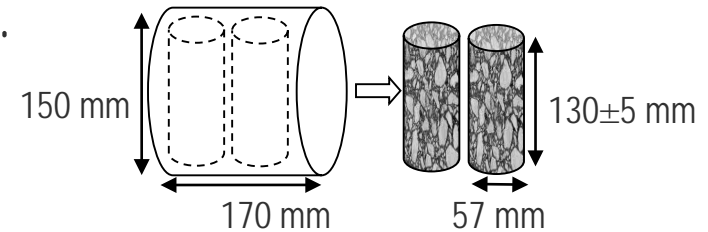
- Coefficient of thermal contraction (CTC)
 - Crack initiation stress (CIS)
- **Uniaxial Thermal Stress and Strain Test (UTSST)**

Thermal Cracking Analysis

Age-Dependent Properties

Uniaxial Thermal Stress and Strain Test (UTSST)

- Samples are cored out of a SGC specimen.



Draft Version
9/8/2014

Standard Method of Test for

Determining Thermal Cracking Properties of Asphalt Mixtures through Measurement of Thermally Induced Stress and Strain

AASHTO Designation: TP XX- (2013)

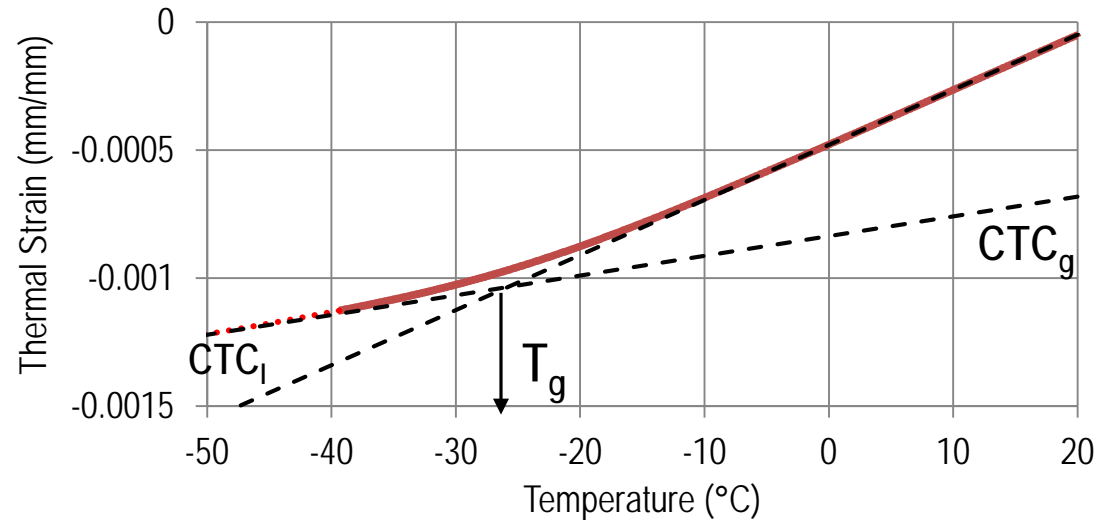
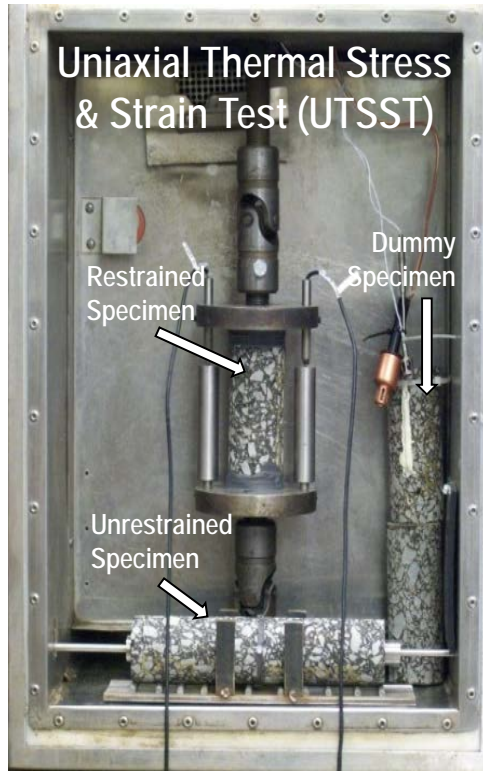
1. SCOPE

1.1. This method of test is used to determine the thermal viscoelastic and thermal volumetric properties of field cored or laboratory compacted asphalt mixture specimens by measuring the thermally induced stress and strain while being cooled at a constant rate from an initial equilibrium temperature. The Thermal stress and strain can be measured using one of the two methods.

Method A: Uniaxial Thermal Stress and Strain Test
Method B: Asphalt Thermal Cracking Test

Thermal Cracking Analysis

Temperature and Age-Dependent CTC

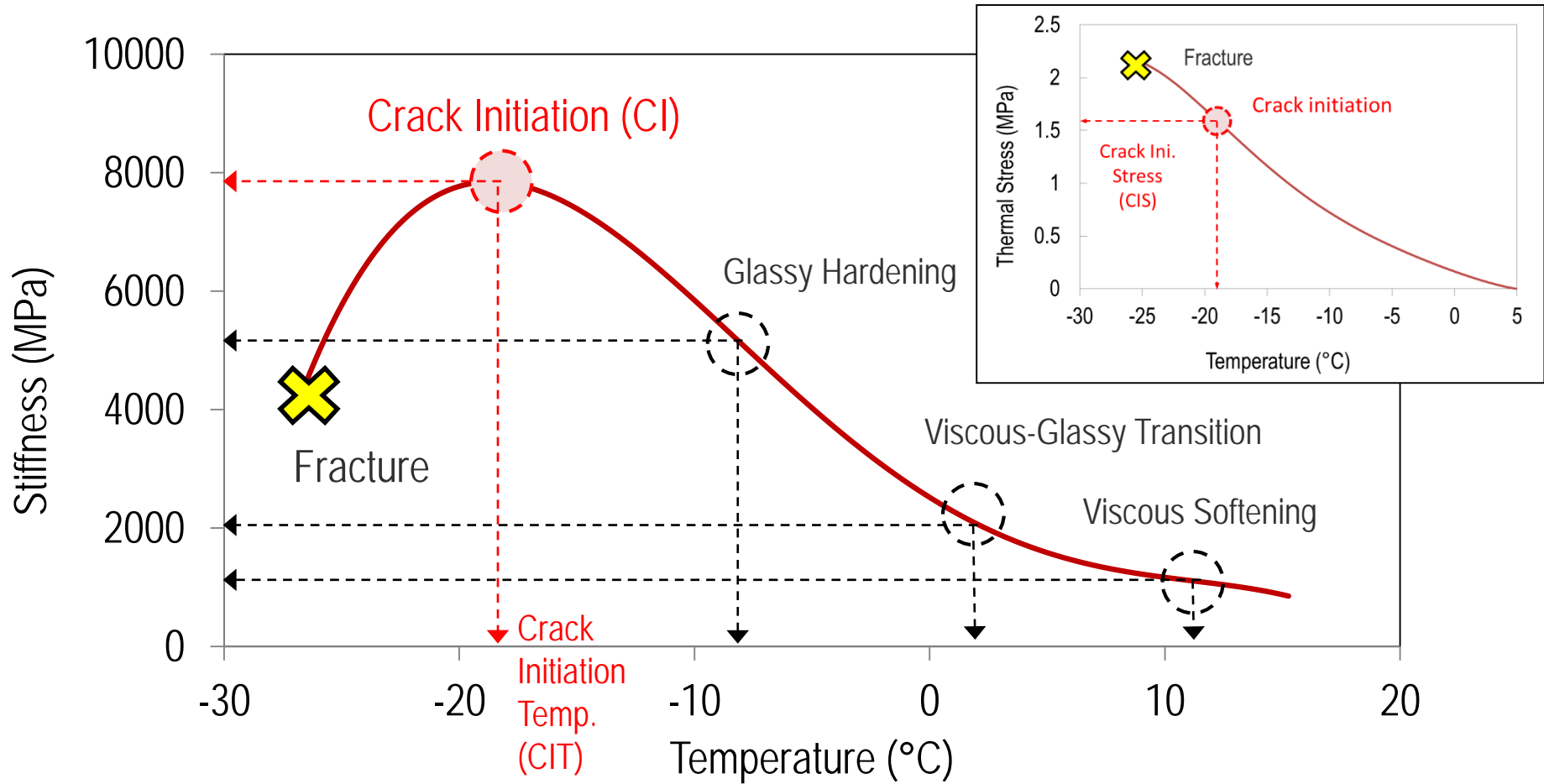


$$\varepsilon_{th} = \frac{\Delta l}{l_0} = C + CTC_g(T - T_g) + \ln \left\{ \left[1 + e^{\frac{(T-T_g)}{R}} \right]^{R(CTC_l - CTC_g)} \right\}$$

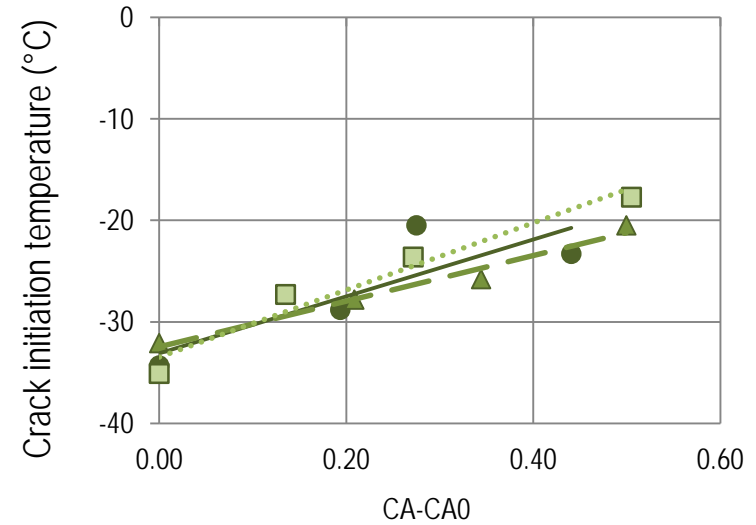
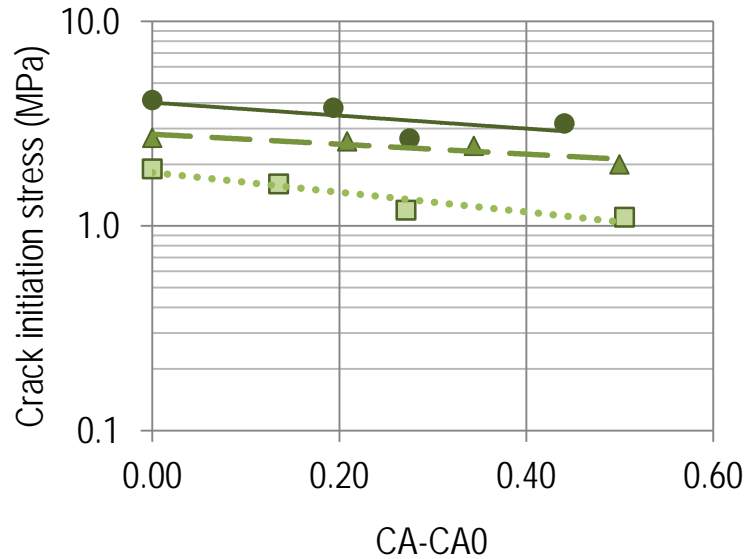
$$CTC(T) = CTC_g + \frac{(CTC_L - CTC_g) \times e^{\frac{T-T_g}{R}}}{(1 + e^{\frac{T-T_g}{R}})}$$

$$\varepsilon(T(t)) = \int_{T_0}^{T(t)} CTC(T(t)) \times dT'$$

Age-Dependent Crack Initiation Stress (CIS)



Age-Dependent Crack Initiation Stress (CIS)

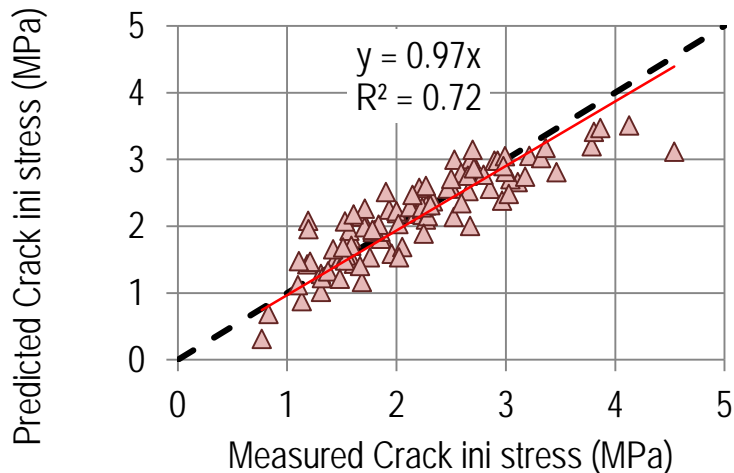


Similar trends were observed for all evaluated mixtures!

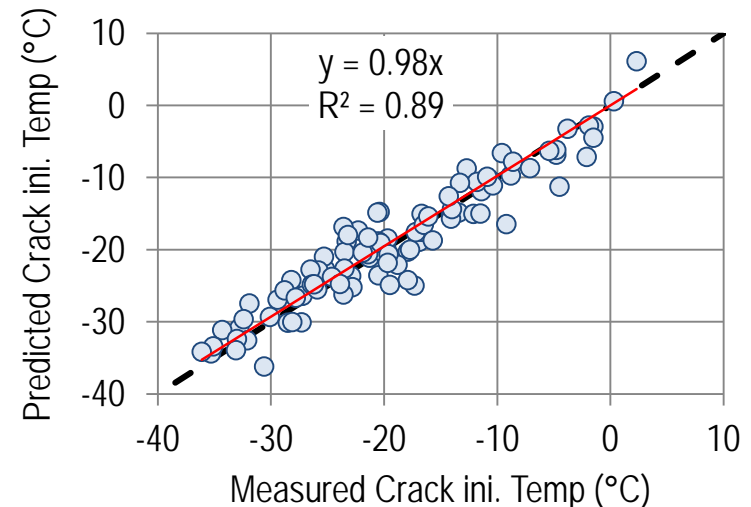
$$CIS = E \times e^{F(CA-CA_0)}$$

Age-Dependent Crack Initiation Stress (CIS)

	Mixture variable						
	CA	Va (%)	Abs. (%)	LSV _{Tank} (poise)	B.C. (%)	Retained # 8	Passing # 200
CIS	✓	✓	✓	✓			✓
CIT	✓	✓		✓	✓	✓	✓



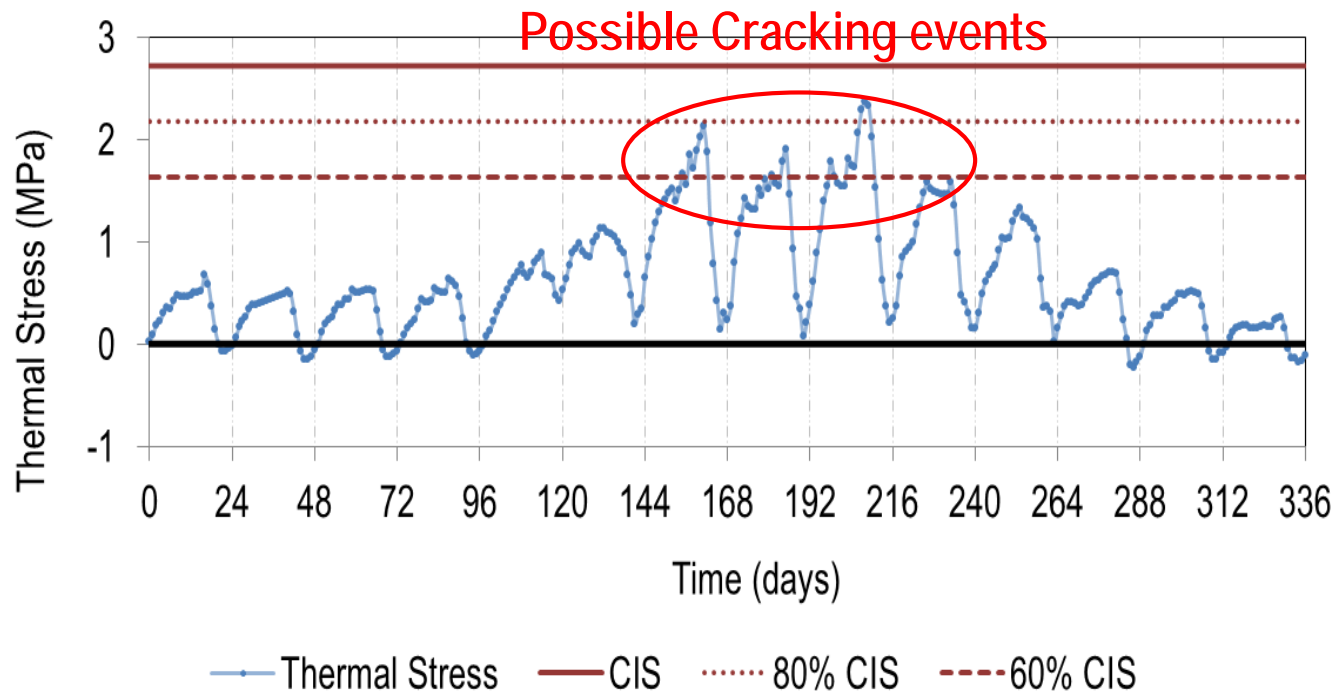
△ Crack initiation stress - - Line of equality



○ Crack initiation temperature - - Line of equality

Thermal Cracking Event Probability

- The accumulative events during which thermal stress reaches a defined percentage of the asphalt mixture Crack Initiation Stress (CIS) over the analysis period!



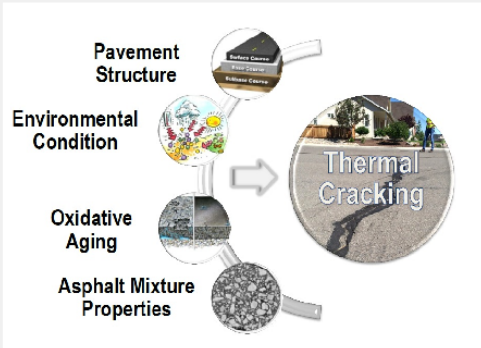
MATLAB Graphical User Interface (GUI) Thermal Cracking Analysis Package (TCAP)



Thermal Cracking Analysis Package Ver Alfa 1.0

About TCAP

Analysis Steps



- General Information
- Pavement Structure
- Pavement Temperature
- Oxidative Aging (Carbo
- Asphalt Materials Prop
- Thermal Cracking Anal

General Information

Project Name: NV28-4%-Reno

Analysis Period: 20

Construction Date: month: August, Days: 1, year: 2000

Project Discription

Example of calculation

Refresh Accept



Thermal Cracking Analysis Package Ver Alfa 1.0

About TCAP

Analysis Steps

- General Information
- Pavement Structure
- Pavement Temperature
- Oxidative Aging (Carbo
- Asphalt Materials Prop
- Thermal Cracking Anal

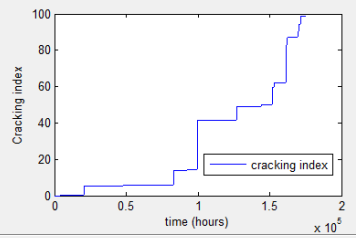
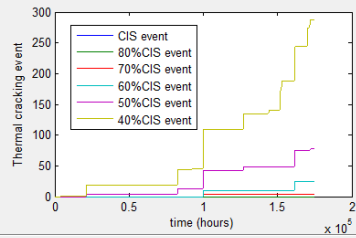
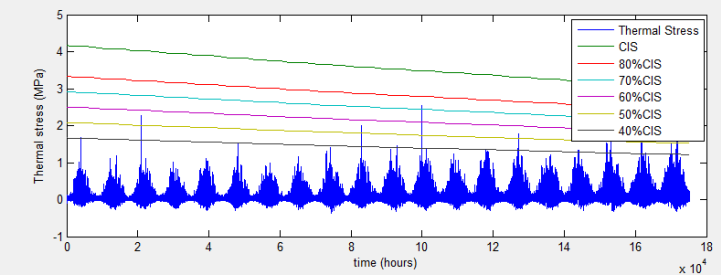
Import CA predictions

C:\TCAP software\July2014\TCAP-Newcode\WV284air.csv

Run Analysis

Aging interval: 1

output file name: Results



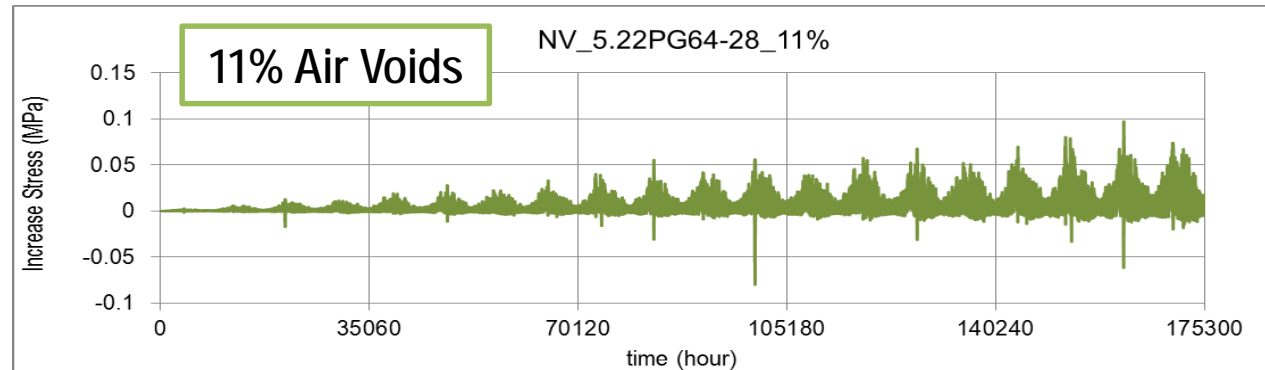
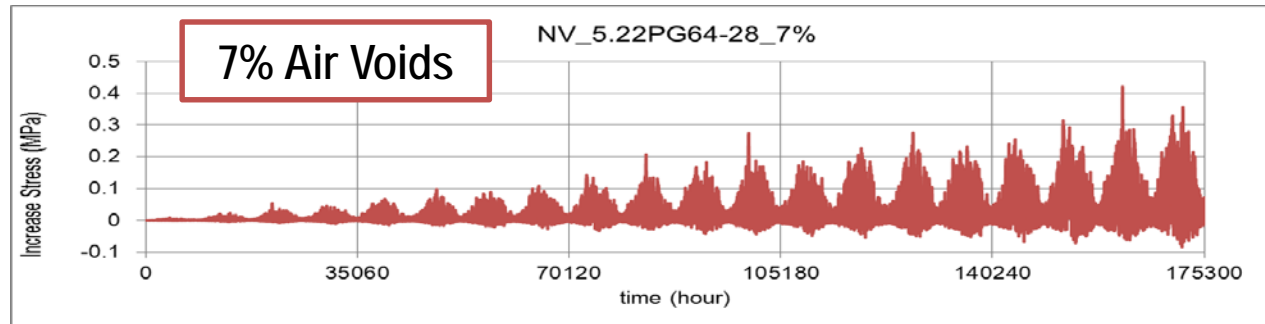
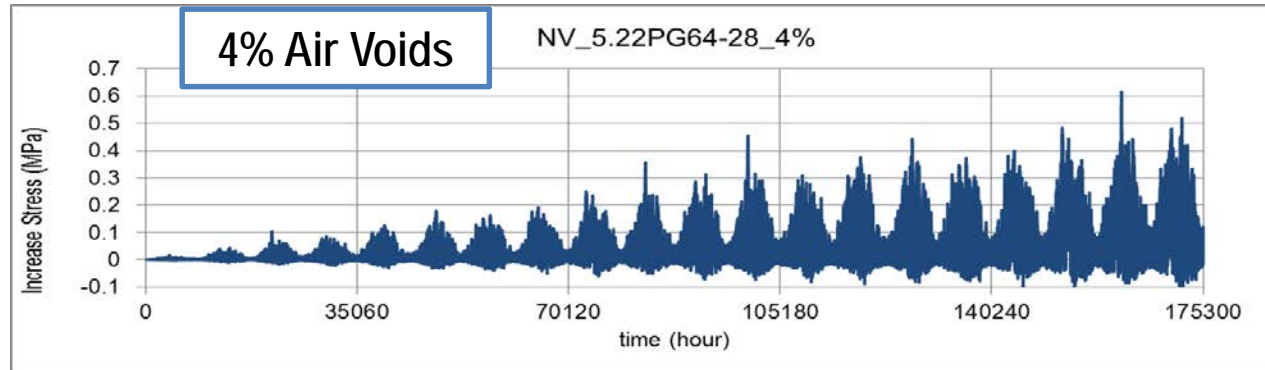
Examples: TCAP Analysis

- Pavement Location
 - Reno, Nevada
- Asphalt Mixtures:
 - Polymer-modified PG64-28; 3 air void levels:
 - NV_5.22PG64-28_4%; NV_5.22PG64-28_7%; NV_5.22PG64-28_11%
- Design Period
 - 20 years

Examples: TCAP analysis

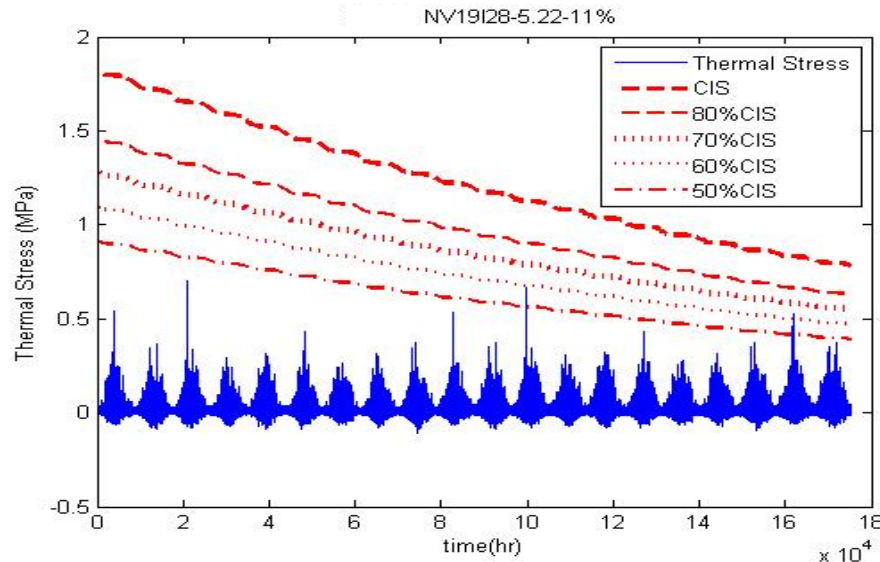
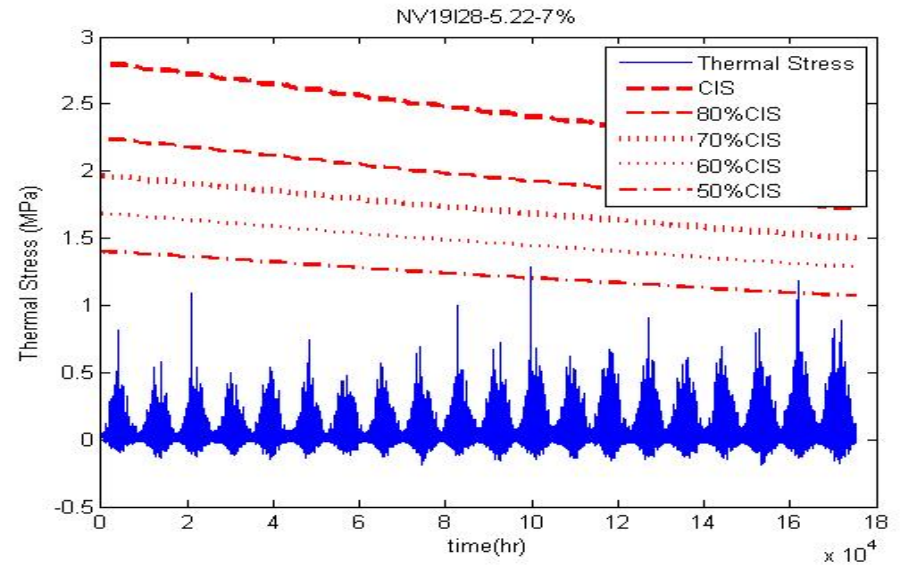
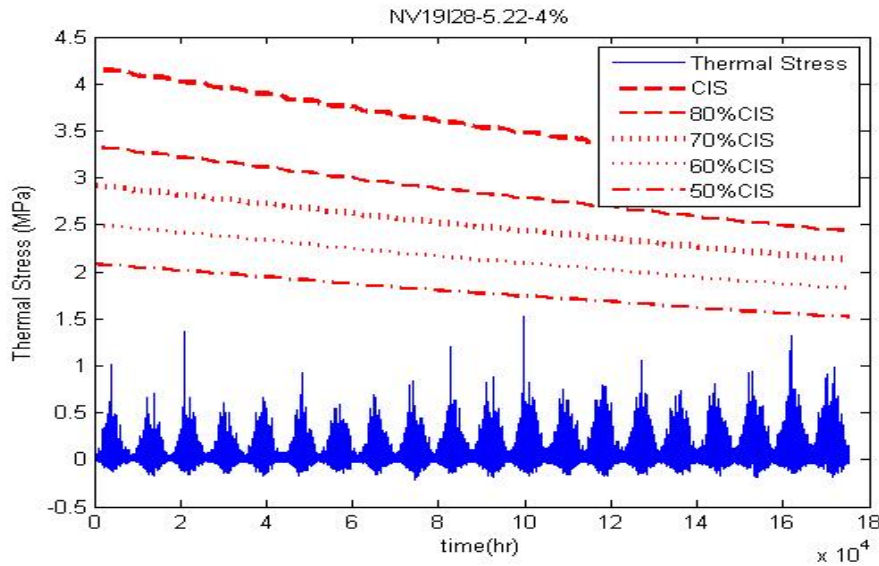
Effect of Oxidative Aging on Thermal Stresses

Difference in predicted thermal stresses between aging and no-aging effect analyses.

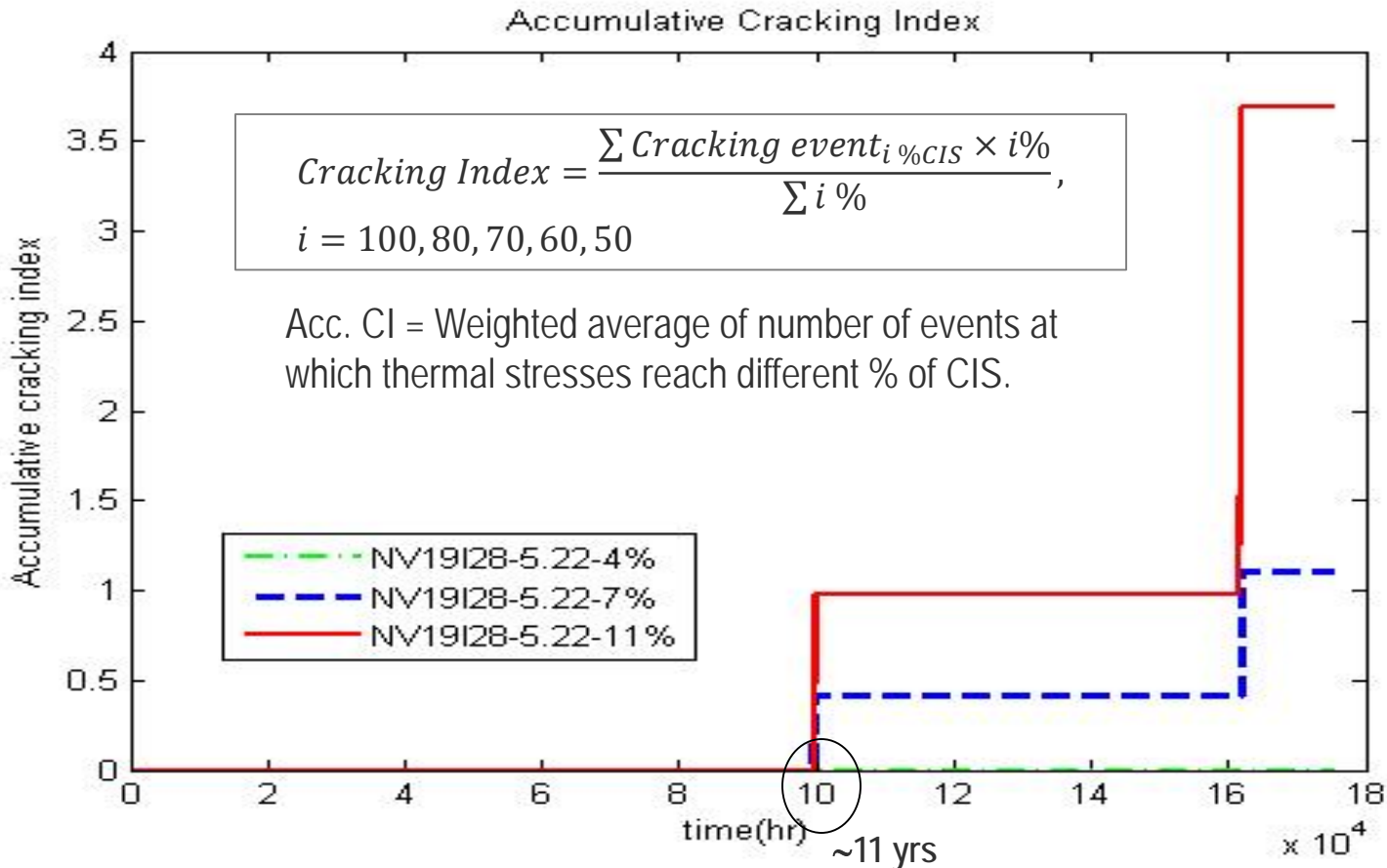


Examples: TCAP analysis

Thermal Stress vs. Crack Initiation Stress (CIS)



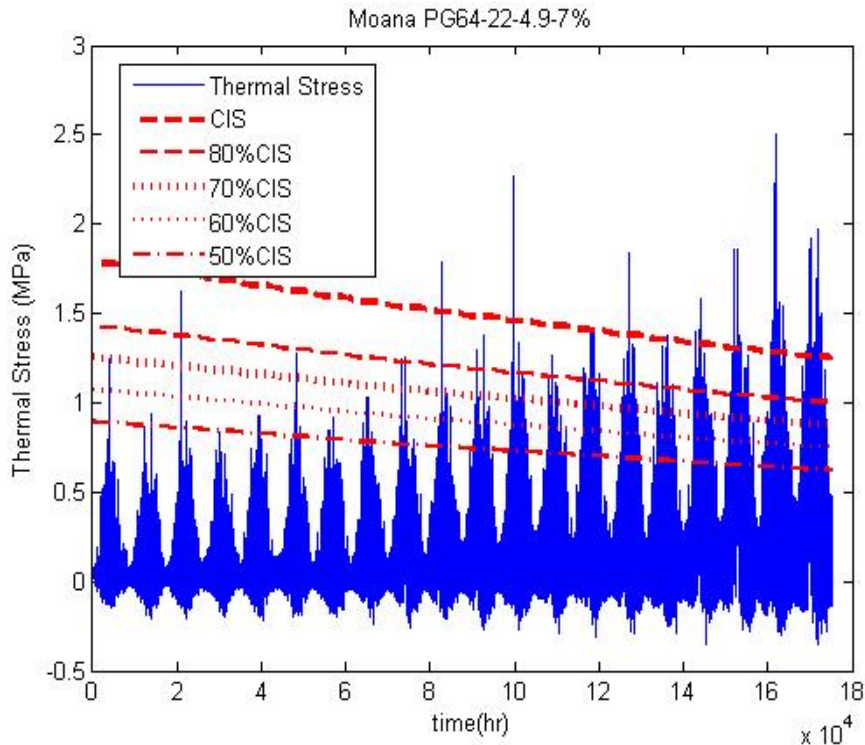
Effect of Mixtures Air Voids



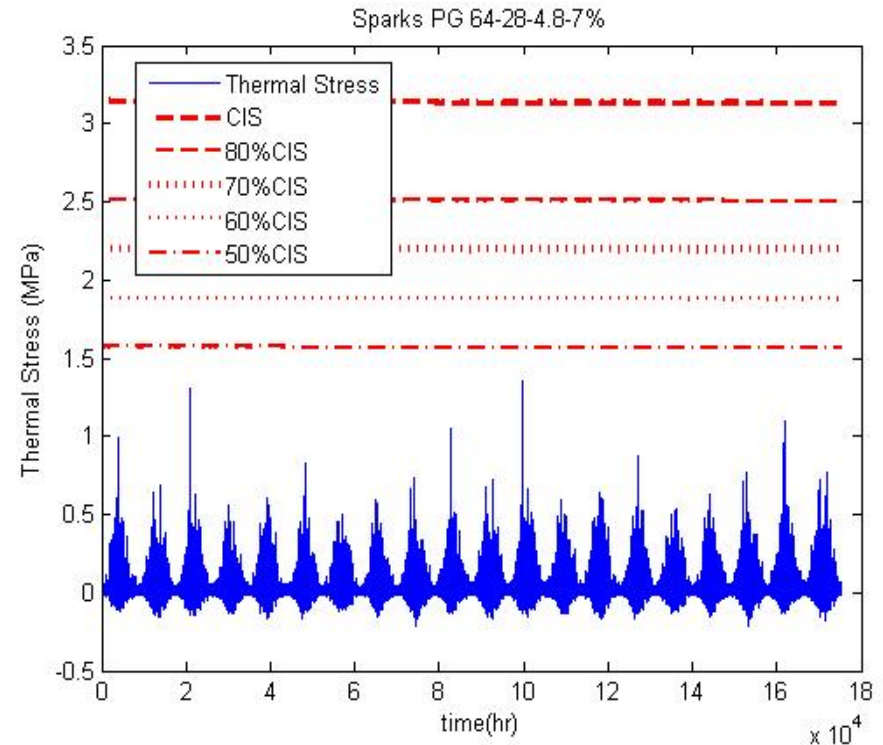
Cracking likelihoods increase for mixture with higher air voids level....

Examples: TCAP analysis

Effect of Modification (Two field projects from Reno, NV)

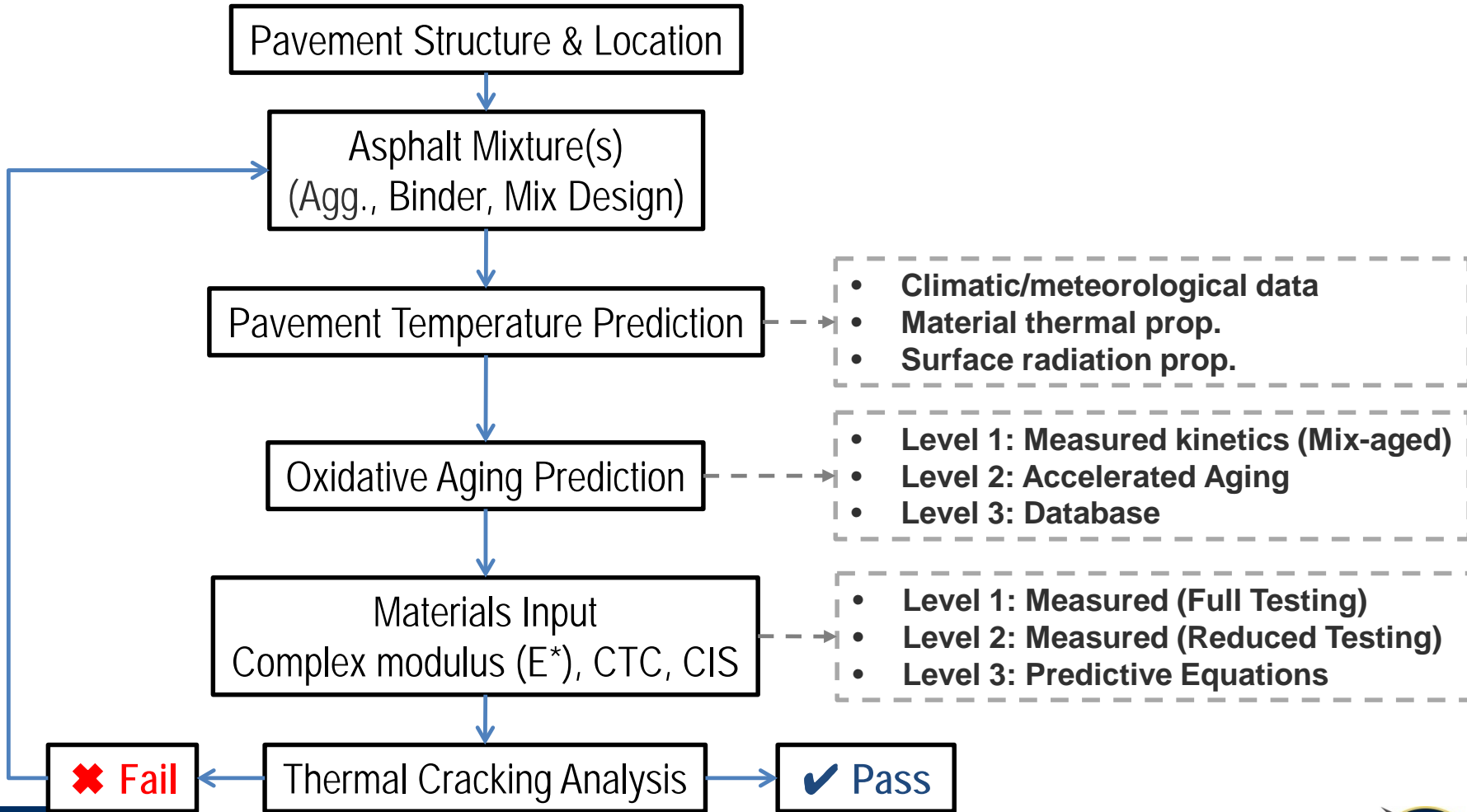


Un-modified
PG64-22 (Moana, 2006)



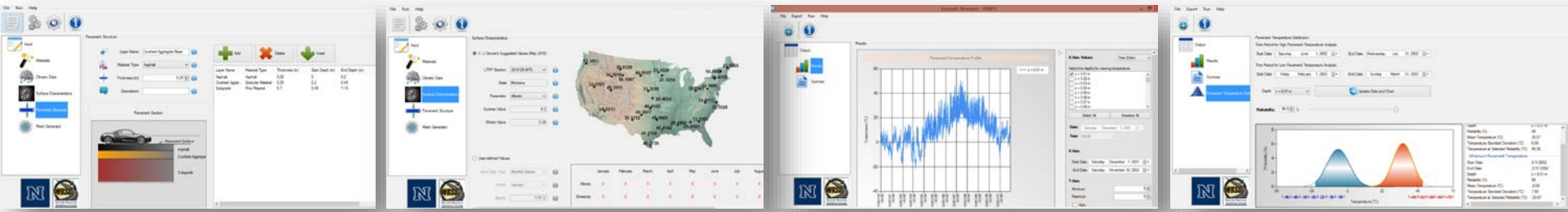
SBS polymer-modified
PG64-28 (Sparks, 2008)

TCAP Implementation



Future Research and Improvements

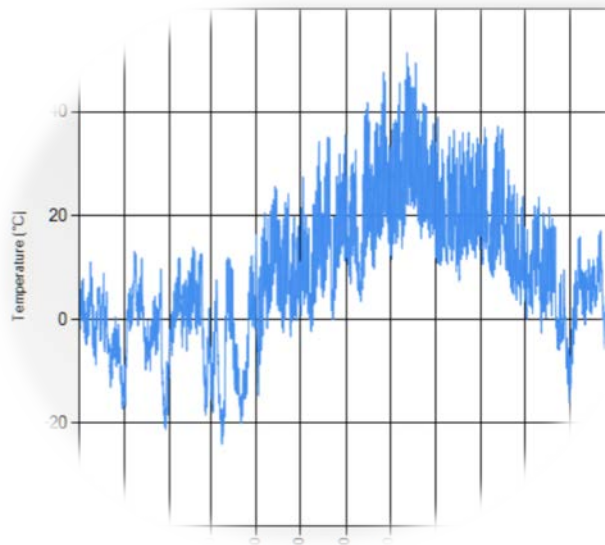
- Field validation of TCAP model.
- Sensitivity analysis of TCAP model.
- Level 3 material input:
 - Regression models for materials oxidative aging, viscoelastic, and crack initiation properties.
- Development of a stand-alone TCAP software.



Pavement Temperature Profile Prediction

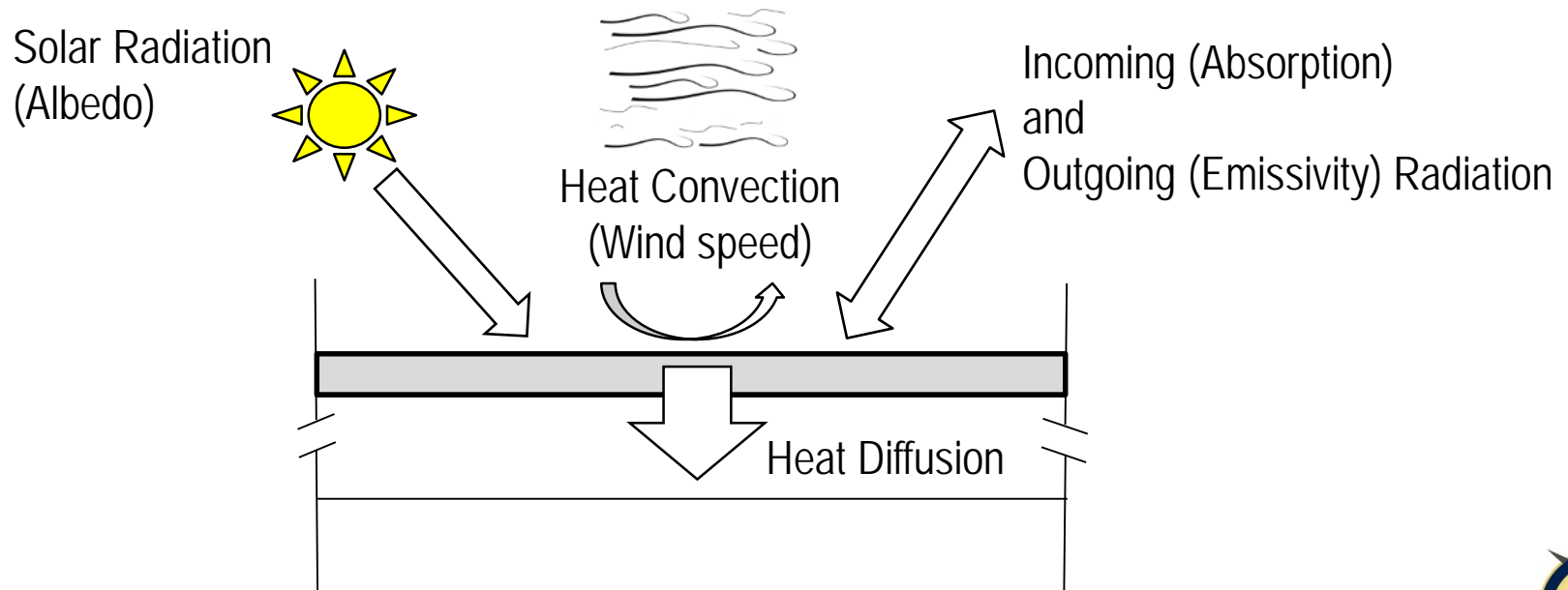
Temperature Estimate Model for Pavement Structures -- TEMPS --

<http://www.arc.unr.edu/Software.html>



Pavement Temperature Profile Prediction

- ⑩ Improvement of the *Heat Transfer* model [Han et al., 2011 (TAMU)]
 - Enhanced boundary conditions.
 - Variable pavement surface radiation properties.
- ⑩ Application of Finite Control Volume method (FCV) with Implicit Scheme [Zia et al., 2014 (UNR)]



Heat Transfer Balance Between Pavement Structure & Surrounding Environment

Pavement Temperature Profile Prediction Standalone Software: TEMPS (Alpha Version 0.0.1)

www.arc.unr.edu/Software.html

Asphalt Research Consortium

Home Outreach Project Team Software Publications Workshops Newsletters

Software

- 3D-Move Analysis
- PANDA Model
- TEMPS

Free Softwares

TEMPS Software (Version 0.0.1)

Release Date: December 2014

Version
TEMPS
(Temperature Estimate Model for Pavement Structures)
Version 0.0.1 (Alpha Version)

Contact
Homepage: <http://wrsc.unr.edu/>
Email: eleh@unr.edu

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The research team at the University of Nevada, Reno has developed a new time-efficient software program that predicts the hourly temperature history at any depth in the asphalt pavement for any location in the United States. The software, called **Temperature Estimate Model for Pavement Structures (TEMPS)**, make use of the Finite Control Volume Method (FCVM) with the fully implicit scheme to remedy some of the known limitations in the current pavement temperature profile models. TEMPS suggests the use of meteorological data such as solar radiation and considers monthly variation in pavement surface radiation properties (albedo, emissivity, and absorption coefficients). The implemented improvements led to good agreement between the predicted pavement temperature profiles and selected LTPP SMP sites. The TEMPS model is a unique software and can have numerous applications in pavement engineering. For instance, accurate prediction of pavement temperatures, over time and with depth, is critical particularly in mechanistic modeling of thermal cracking.

To install the software:

1. [Download](#) the TEMPS Windows Installer Package;
2. Run Setup.exe file associated with the TEMPS program.

Simply follow the on-screen directions to install *TEMPS (Version 0.0.1)*. Click *Next* to start the installation on the Welcome screen.



Pavement Temperature Profile Prediction

TEMPS – Input

- Materials
- Climatic Data
- Surface Characteristics
- Pavement Structure
- Mesh Generator



Pavement Temperature Profile Prediction

TEMPS – Materials

Materials

Material Type:

Identifier Color:

Specific Heat Capacity (J/kg*K):

Conductivity (W/m*K):

Density (kg/m³):

Description:

Material Type	Identifier Color	Specific Heat Capacity (J/kg*K)	Conductivity (W/m*K)	Density (kg/m³)	Description
Asphalt	Black	920	1.21	2250	
Granular Mat...	Orange	835	0.2	1600	
Fine Material	Brown	835	0.20	1500	

Pavement Temperature Profile Prediction

TEMPS – Climatic Data

Example-Montana - TEMPS

File Run Help

Input
Materials
Climatic Data
Surface Characteristics
Pavement Structure
Mesh Generator

Climatic Data

Year	Day	Month	Hour	Air Temperature(°C)	Wind Speed(m/s)	Solar Radiation
2001	1	12	0	-1	19	0
2001	1	12	1	-1	16	0
2001	1	12	2	-1	15	0
2001	1	12	3	0	22	0
2001	1	12	4	-1	19	0
2001	1	12	5	-1	18	0
2001	1	12	6	0	21	0

Plot: Air Temperature
Type: Line

X-Axis: Start Date: Saturday, December 1, 2001; End Date: Saturday, November 30, 2002

Y-Axis: Minimum: 0

Climatic Data Sources

- 1. National Climate Data Center (NCDC)**
The following website provides free hourly temperature data:
<http://gis.ncdc.noaa.gov/>
- 2. National Solar Radiation Data Base (NSRDB)**
The following website provides you with a good source for hourly air temperature, hourly solar radiation and hourly wind speed data which are available mostly for airports:
http://redc.nrel.gov/solar/old_data/nsrdb/
- 3. Long Term Pavement Performance (LTPP)**
The following website provides LTPP data, which are monitored on pavement sections in the United States over years:
<http://www.infopave.com/>

Pavement Temperature Profile Prediction

TEMPS – Surface Characteristics

Example-Montana - TEMPS

File Run Help

Input
Materials
Climatic Data
Surface Characteristics
Pavement Structure
Mesh Generator

Surface Characteristics

C. J. Glover's Suggested Values (May 2010)

LTPP Section: 30-8129

State: Montana

Parameter: Albedo

Summer Value: 0.2

Winter Value: 0.35

User-defined Values

Input Data Type: Monthly Values

Month: January

Albedo: 0.00

	January	February	March	April	May	June	July	August	September
Albedo	0	0	0	0	0	0	0	0	0
Emissivity	0	0	0	0	0	0	0	0	0
Albedo	0	0	0	0	0	0	0	0	0

Pavement Temperature Profile Prediction

TEMPS – Pavement Structure

File Run Help

Input
Materials
Climatic Data
Surface Characteristics
Pavement Structure
Mesh Generator

Pavement Structure

Layer Name:

Material Type:

Thickness (m):

Description:

+ Add X Delete ↓ Insert

Layer Name	Material Type	Thickness (m)	Start Depth (m)	End Depth (m)	Description
Asphalt	Asphalt	0.20	0	0.2	
Crushed Aggre...	Granular Material	0.25	0.2	0.45	
Subgrade	Fine Material	0.70	0.45	1.15	

Pavement Section

Western Regional Superpave Center

Pavement Temperature Profile Prediction TEMPS – Mesh Generator

File Run Help

Input
Materials
Climatic Data
Surface Characteristics
Pavement Structure
Mesh Generator

Pavement Structure

Mesh Type: Non-Uniform

Spacing (m): 0.01

Generate Mesh

Node View

Pavement Surface

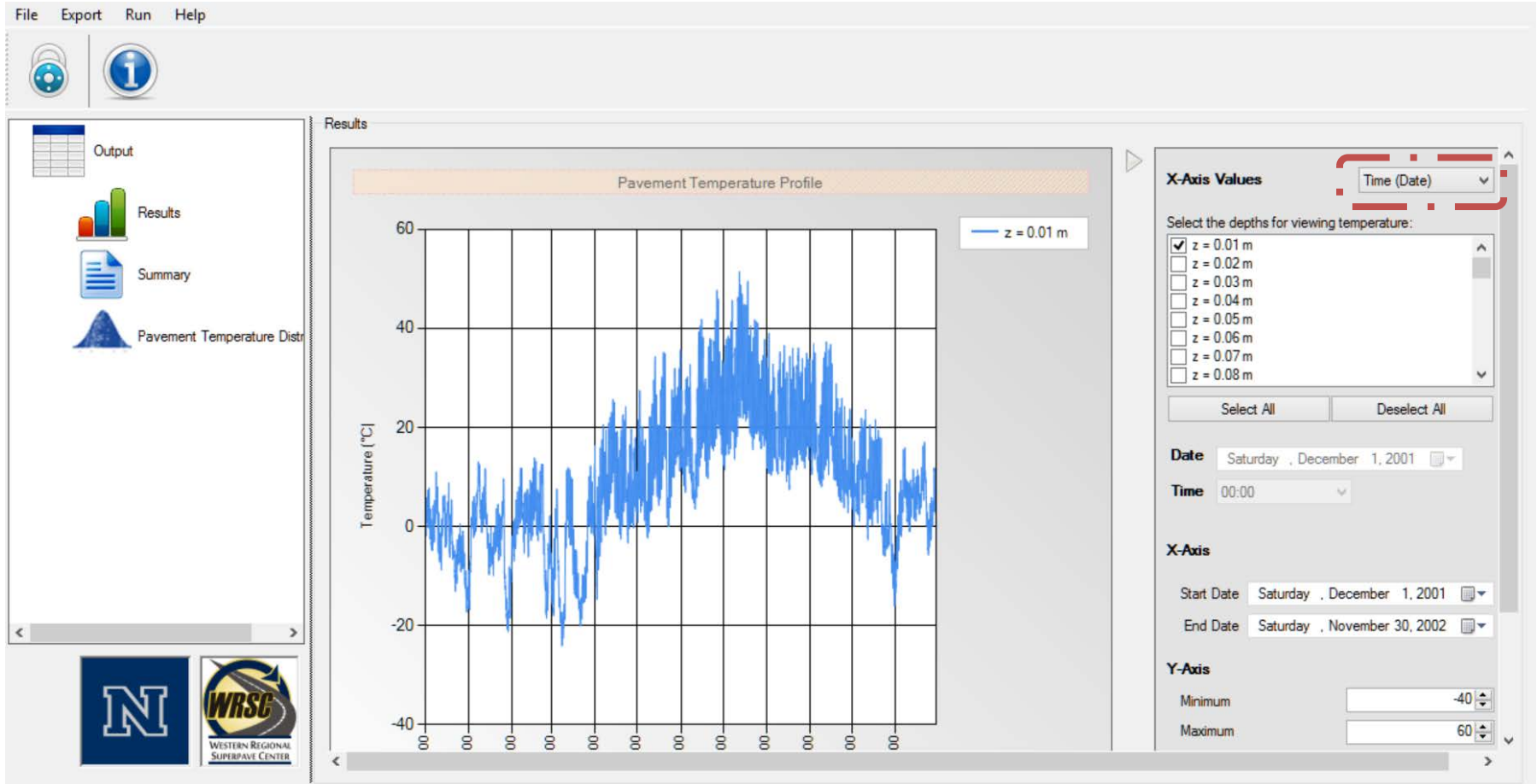
Asphalt

Crushed Aggregate

N
WRSC
WESTERN REGIONAL
SUPERPAVE CENTER

Pavement Temperature Profile Prediction

TEMPS – Output Results



Pavement Temperature Profile Prediction

TEMPS – Output Summary

File Export Run Help

Pavement Temperature Profile Summary

Date-Time ↓	Depth →	z = 0.01 m	z = 0.02 m	z = 0.03 m	z = 0.04 m	z = 0.05 m	z = 0.06 m	z = 0.07 m	z = 0.08 m	z = 0.09 m	z = 0.1 m
12/1/2001 - 0:00		-1.13°C	-1.16°C	-1.19°C	-1.22°C	-1.25°C	-1.28°C	-1.31°C	-1.34°C	-1.37°C	-1.4°C
12/1/2001 - 1:00		-1.74°C	-1.65°C	-1.58°C	-1.53°C	-1.5°C	-1.48°C	-1.47°C	-1.46°C	-1.47°C	-1.47°C
12/1/2001 - 2:00		-1.92°C	-1.85°C	-1.78°C	-1.73°C	-1.68°C	-1.65°C	-1.62°C	-1.6°C	-1.58°C	-1.57°C
12/1/2001 - 3:00		-1.83°C	-1.81°C	-1.78°C	-1.75°C	-1.73°C	-1.7°C	-1.68°C	-1.66°C	-1.65°C	-1.64°C
12/1/2001 - 4:00		-1.5°C	-1.54°C	-1.57°C	-1.6°C	-1.61°C	-1.62°C	-1.63°C	-1.63°C	-1.63°C	-1.63°C
12/1/2001 - 5:00		-1.71°C	-1.69°C	-1.67°C	-1.66°C	-1.66°C	-1.65°C	-1.65°C	-1.65°C	-1.64°C	-1.64°C
12/1/2001 - 6:00		-1.76°C	-1.74°C	-1.73°C	-1.71°C	-1.7°C	-1.69°C	-1.68°C	-1.68°C	-1.67°C	-1.67°C
12/1/2001 - 7:00		-1.49°C	-1.54°C	-1.57°C	-1.59°C	-1.57°C	-1.62°C	-1.63°C	-1.64°C	-1.64°C	-1.65°C
12/1/2001 - 8:00		-1.46°C	-1.49°C	-1.51°C	-1.53°C	-1.56°C	-1.57°C	-1.59°C	-1.6°C	-1.61°C	-1.62°C
12/1/2001 - 9:00		-1.15°C	-1.23°C	-1.3°C	-1.35°C	-1.4°C	-1.44°C	-1.48°C	-1.51°C	-1.54°C	-1.56°C
12/1/2001 - 10:00		-0.07°C	-0.33°C	-0.55°C	-0.73°C	-0.88°C	-1.01°C	-1.12°C	-1.21°C	-1.29°C	-1.35°C

General Summary Detailed Summary

Overall Minimum Pavement Temperature: -24.04°C Occured On: 3/8/2002 - 8:00, At the Depth of: 0.01 m

Overall Maximum Pavement Temperature: 51.42°C Occured On: 7/12/2002 - 16:00, At the Depth of: 0.01 m

Export General Summary

Pavement Temperature Profile Prediction

TEMPS – Output Summary

File Export Run Help

Pavement Temperature Profile Summary

Date-Time ↓	Depth →	z = 0.01 m	z = 0.02 m	z = 0.03 m	z = 0.04 m	z = 0.05 m	z = 0.06 m	z = 0.07 m	z = 0.08 m	z = 0.09 m	z = 0.1 m
12/1/2001 - 0:00		-1.13°C	-1.16°C	-1.19°C	-1.22°C	-1.25°C	-1.28°C	-1.31°C	-1.34°C	-1.37°C	-1.4°C
12/1/2001 - 1:00		-1.74°C	-1.65°C	-1.58°C	-1.53°C	-1.5°C	-1.48°C	-1.47°C	-1.46°C	-1.47°C	-1.47°C
12/1/2001 - 2:00		-1.92°C	-1.85°C	-1.78°C	-1.73°C	-1.68°C	-1.65°C	-1.62°C	-1.6°C	-1.58°C	-1.57°C
12/1/2001 - 3:00		-1.83°C	-1.81°C	-1.78°C	-1.75°C	-1.73°C	-1.7°C	-1.68°C	-1.66°C	-1.65°C	-1.64°C
12/1/2001 - 4:00		-1.5°C	-1.54°C	-1.57°C	-1.6°C	-1.61°C	-1.62°C	-1.63°C	-1.63°C	-1.63°C	-1.63°C
12/1/2001 - 5:00		-1.71°C	-1.69°C	-1.67°C	-1.66°C	-1.66°C	-1.65°C	-1.65°C	-1.65°C	-1.64°C	-1.64°C
12/1/2001 - 6:00		-1.76°C	-1.74°C	-1.73°C	-1.71°C	-1.7°C	-1.69°C	-1.68°C	-1.68°C	-1.67°C	-1.67°C
12/1/2001 - 7:00		-1.49°C	-1.54°C	-1.57°C	-1.59°C	-1.61°C	-1.62°C	-1.63°C	-1.64°C	-1.64°C	-1.65°C
12/1/2001 - 8:00		-1.46°C	-1.49°C	-1.51°C	-1.53°C	-1.56°C	-1.57°C	-1.59°C	-1.6°C	-1.61°C	-1.62°C
12/1/2001 - 9:00		-1.15°C	-1.23°C	-1.3°C	-1.35°C	-1.4°C	-1.44°C	-1.48°C	-1.51°C	-1.54°C	-1.56°C
12/1/2001 - 10:00		-0.07°C	-0.33°C	-0.55°C	-0.73°C	-0.88°C	-1.01°C	-1.12°C	-1.21°C	-1.29°C	-1.35°C

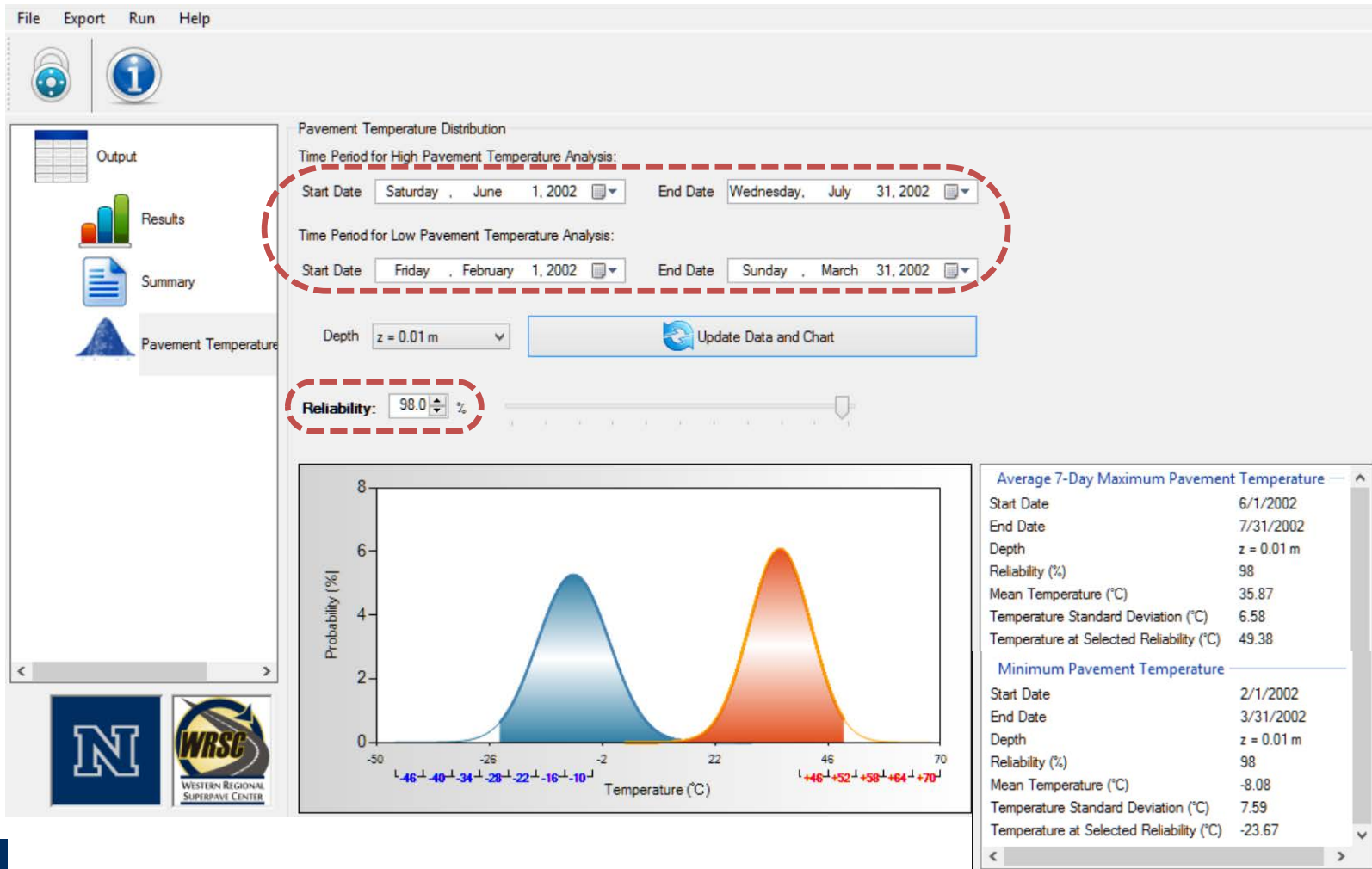
General Summary Detailed Summary

Start Date: Saturday, December 1, 2001 End Date: Saturday, November 30, 2002 Depth: z = 0.01 m [Update] [Export]

Date	Average Pavement Temperature (°C)	Minimum Pavement Temperature (°C)	Maximum Pavement Temperature (°C)	Pavement Temperature Standard Deviation (°C)
12/1/2001	1.02	-1.92	5.85	2.66
12/2/2001	3.17	0.7	7.35	2.28
12/3/2001	2.6	-0.19	7.83	2.54
12/4/2001	-0.41	-3.07	3.56	2.12
12/5/2001	-2.92	-4.85	1.37	1.78
12/6/2001	-0.92	-4.08	4.27	2.67
12/7/2001	0.34	-3.08	5.28	2.69
12/8/2001	5.32	0.89	11.02	3.37
12/9/2001	3.66	-2.77	8.03	2.92

Pavement Temperature Profile Prediction

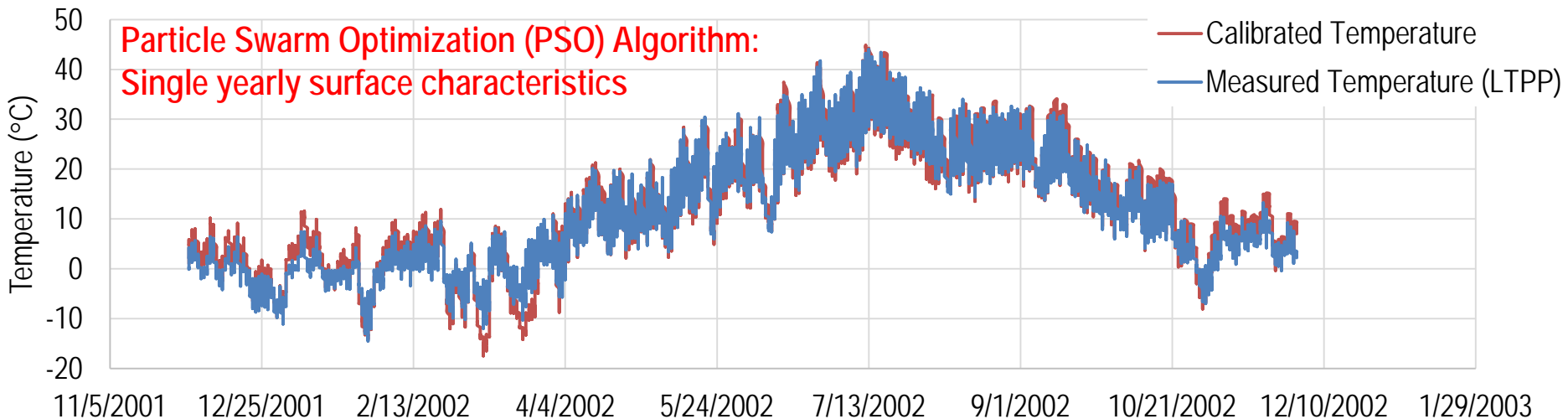
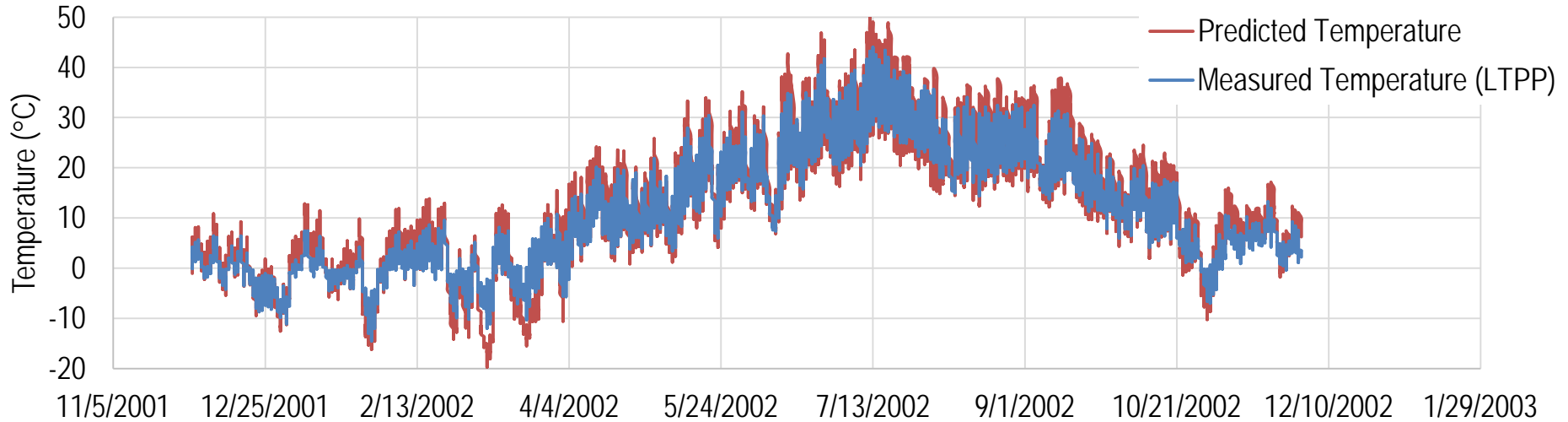
TEMPS – Pavement Temperature Distribution



Pavement Temperature Profile Prediction

TEMPS – Predicted versus Measured

Great Falls, MT at depth of 0.09 m (3.5 inch)



TEMPS – Additional Improvements

- Calibration: Optimize the surface characteristics (Albedo, Emissivity, Absorption) using Particle Swarm Optimization (PSO) Algorithm
 - Monthly or seasonal values.
- Create/Include input files for LTPP SMP sections.
- Provide a summary of pavement cooling/warming rates

Thank You!



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Thank You!

