# University of Illinois Update

## Pooled Fund - LTC TAP Meeting

**October 5, 2011**

**Northland Inn, Minneapolis, MN**

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University of Illinois at Urbana-Champaign

# Specimens Received July 27, 2011

- 83 specimens received (3 replicates at each test temperature)
- All specimens were 50mm thick disks, 81 lab compacted and 2 from field cores

# Wisconsin samples (mostly retests)

- All samples have PGLT of $-22^{0}C$
  - 4% air voids gyratory compacted
  - 7% air voids gyratory compacted
  - 7% air void and oven conditioned
  - Field core
- Oven conditioned samples and field core tested at PGLT
- All others tested at PGLT and PGLT+10

# Validation Testing (Task 6)

- Marathon (PG58-28)
  - 12.5mm and19mm
- CITGO (PG58-28)
  - 12.5mm and 19mm
- VALERO (PG58-28)
  - 12.5mm and 19mm
- Warm mix (PG58-28)
  - Reinke's warm mix w/ RAP and antistrip
- MIF RAP (PG58-34)
  - 12.5mm and 19mm
- MIF Virgin (PG58-34)
  - 12.5mm and 19mm

TEST TEMPERATURE IS PGLT AND PGLT+10

(All tests to be completed by 10/31/11)

**Olmsted Co: *Rd104 **Rd112**

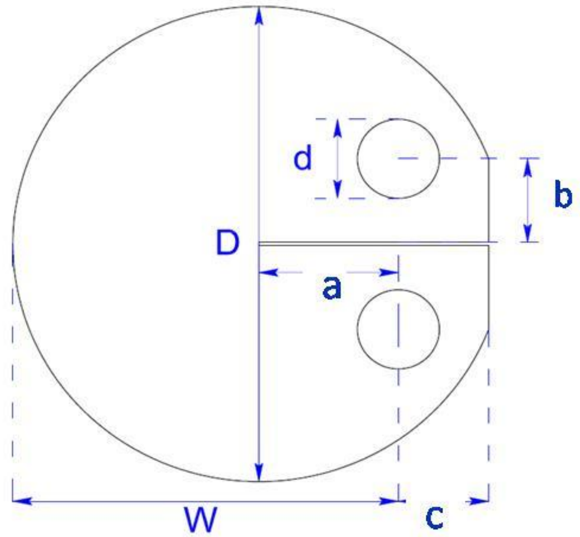
# Fabrication

**Notching and face cuts**

**Coring of loading holes**

# Testing

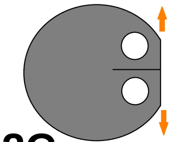
**Geometry**

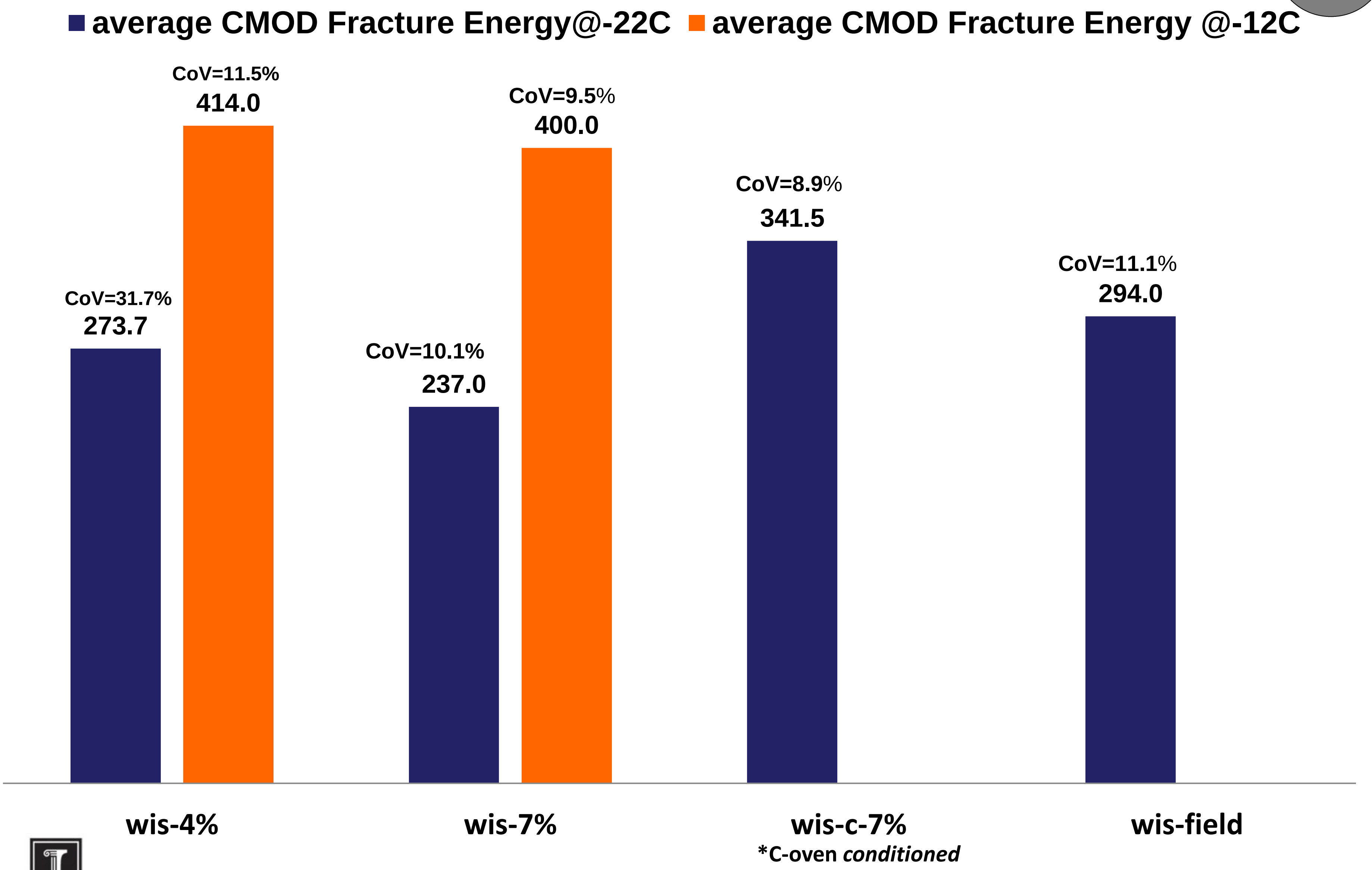



| *Recommended Dimensions (mm)* | |
|---|---|
| D | 150 |
| W | 110 |
| a | 27.5 |
| b | 25 |
| c | 35 |
| d | 25 |
| Thickness, t | 50 |

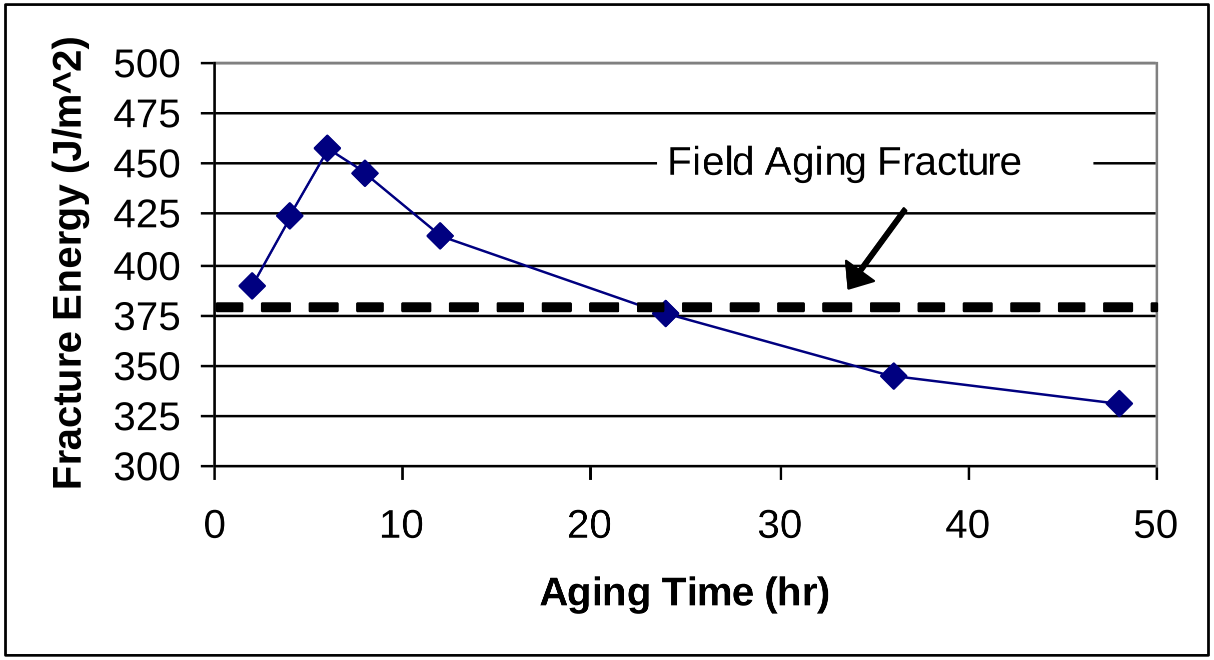
**Instron 8500 servo-hydraulic load frame with an environmental chamber capable of controlling the temperature from 30°C to -30°C**

# Fracture energy of Wisconsin mix, J/m$^2$





# Influence of Aging on Mixture Fracture Energy




12.5mm NMAS

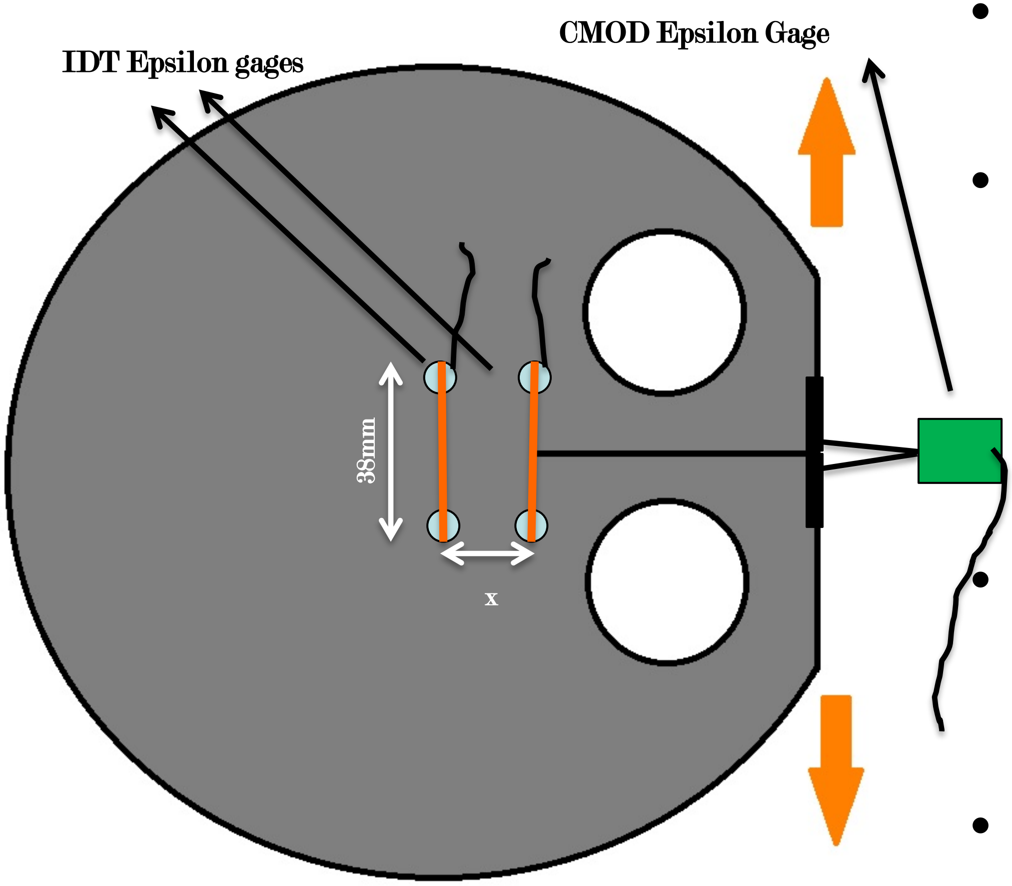
PG58-28

Unmodified Mixture

Demonstrates that Fracture Energy can First Increase, then Decrease with Aging.

However, Creep Compliance Simply Decreases with Aging. (*AAPT, Braham et al., 2009)*

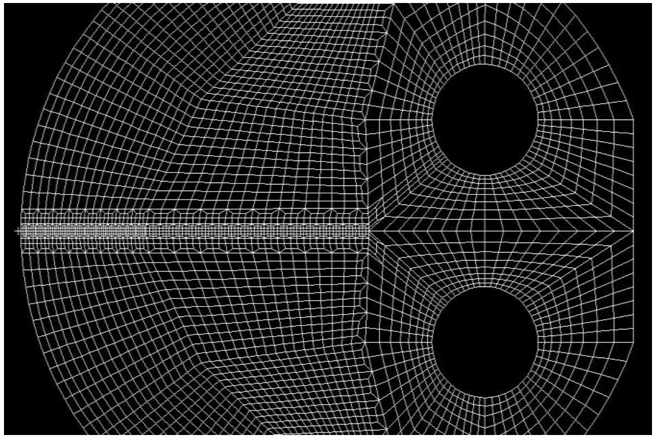
# Creep Compliance from DC(T)

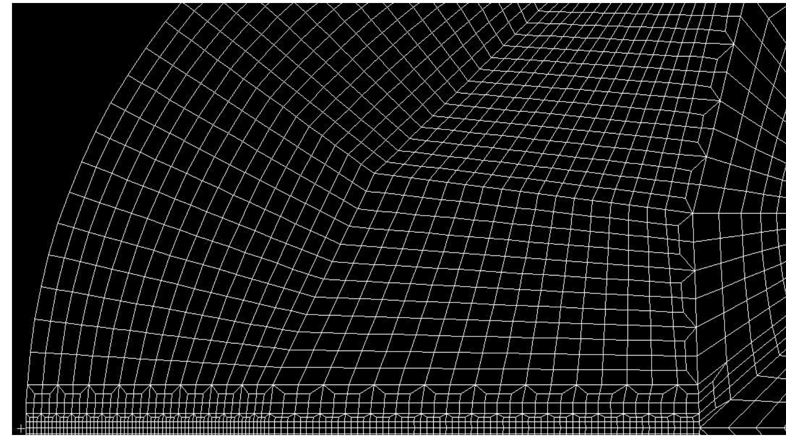



- Apply a tensile creep load and collect deflections
- Creep load should be high enough to induce measurable deflection but it should not create damage at notch tip
- 'x' is optimized using experimental and modeling correlation
- Results will be compared to IDT Creep compliance

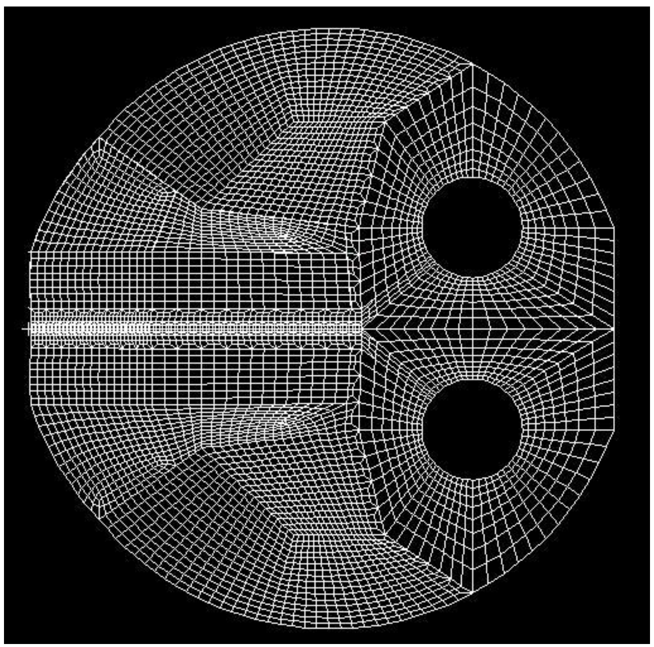
# DC(T) + IDT

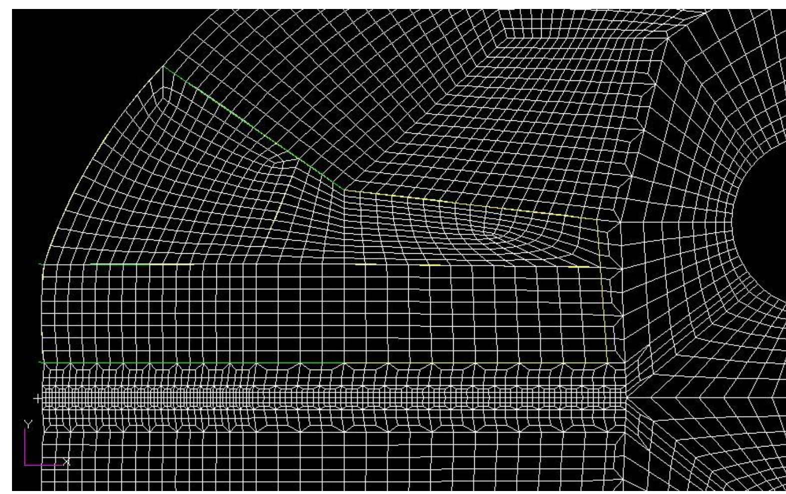
**Old model**





**New model**





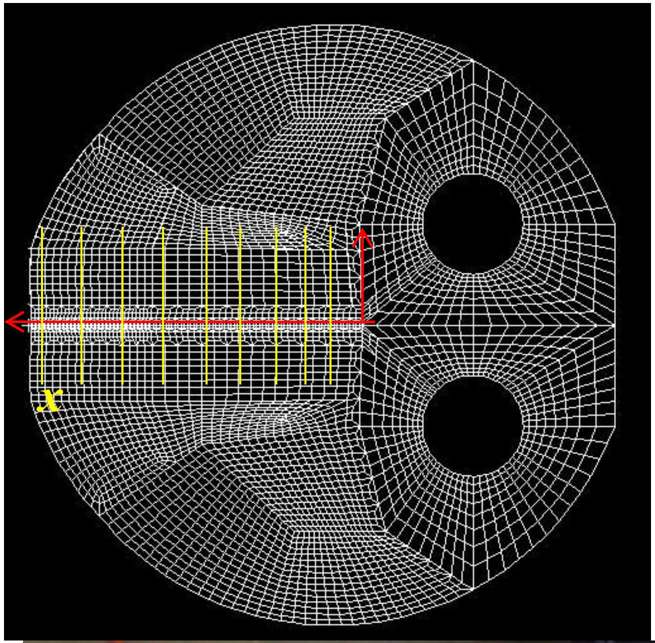
# DCT+IDT model

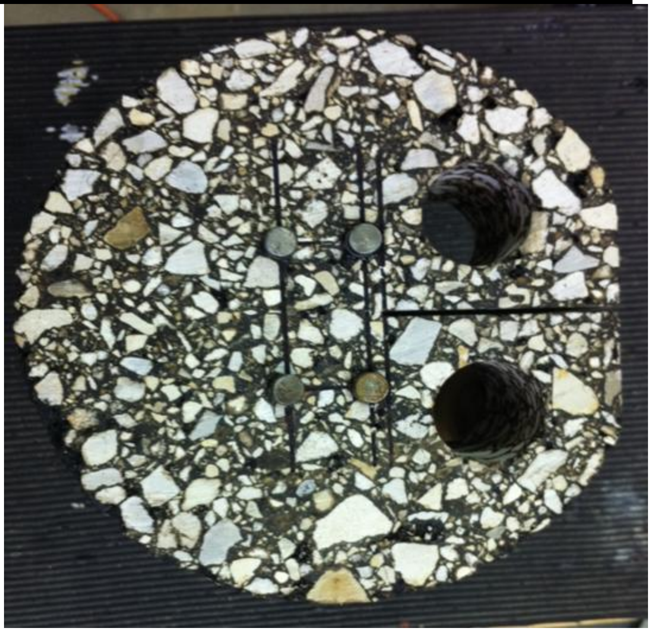
- **Four Different FEM Models :**

**- DCT specimen with notch(Elastic)**
**- DCT specimen with notch(Viscoelastic)**
**- DCT specimen without notch(Elastic)**
**- DCT specimen without notch(Viscoelastic)**

- **9 Nodesets along the X axis:**

**X (mm): 2, 10, 20, 30, 40, 50, 60, 70, 80**



# Update on Low Temperature Cracking Model for Asphalt Concrete

# "ILLI-TC"

Department of Civil & Environmental Engineering
University of Illinois at Urbana-Champaign

# Why do we Need a Thermal Cracking Model?

- **Binder important, but does not completely control:**
  - Aggregate/mastic effects on mixture creep/fracture properties
  - Effects of RAP, WMA, fibers, and other additives
  - Final, constructed mixture volumetrics – voids, agg structure
  - Plant/field aging
  - Structural effects of temperature profile, fracture process
- **Modeling can provide:**
  - True performance prediction (cracking vs. time)
  - Input for maintenance decisions
  - Insight for policy decisions

# Old TC Model vs. New TC Model

## TC Model

- Stress Intensity Factor

$$K = \sigma(0.45 + 1.99 C_0^{0.56})$$

*Current crack length*
*Far-field stress at depth of crack*
*Stress Intensity Factor*

- Paris 'Law'

$$\Delta C = A(\Delta K)^n$$

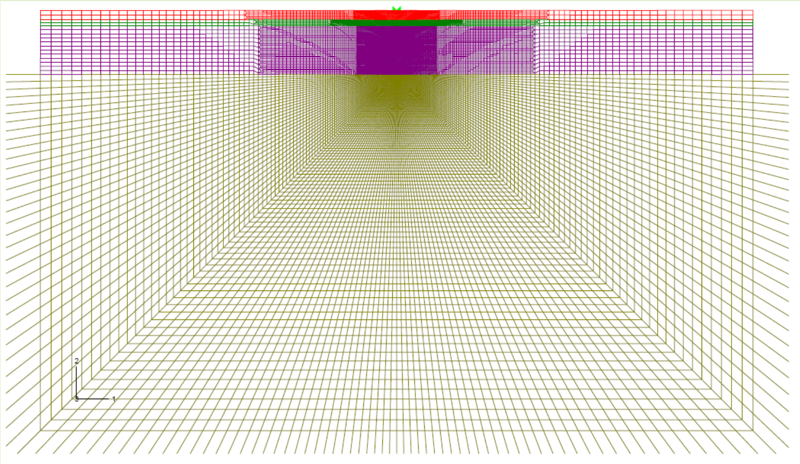
*Change in stress intensity factor*
*Fracture parameters*
*Change in crack depth*

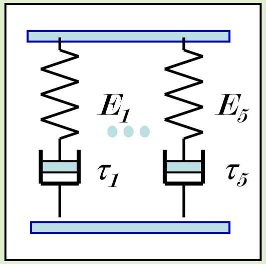
- Crack amount model

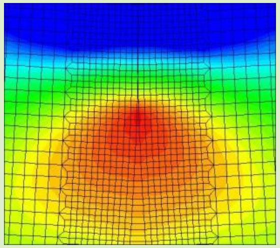
Amount of cracking is a function of the probability that the crack depth is equal to or greater the thickness of the surface layer

## New TC Model

- Finite element based thermal cracking prediction model with cohesive zone modeling





# Modeling Tasks

- Develop and Verify Viscoelastic Finite Element Code
- Develop and Verify Cohesive Zone Fracture FE Code
- Develop Input File Generator
- Collect and Assemble Climatic Files
- Develop and Verify Preanalysis Module
- Combine Viscoelastic and CZ FE Codes and Verify
- Develop Graphical User Interface (in Conjunction with NexTrans University Transportation Center)
- Calibrate Code
- Validate Code

**Completed/Reported** **Completed** **Underway**

# ILLI-TC Components

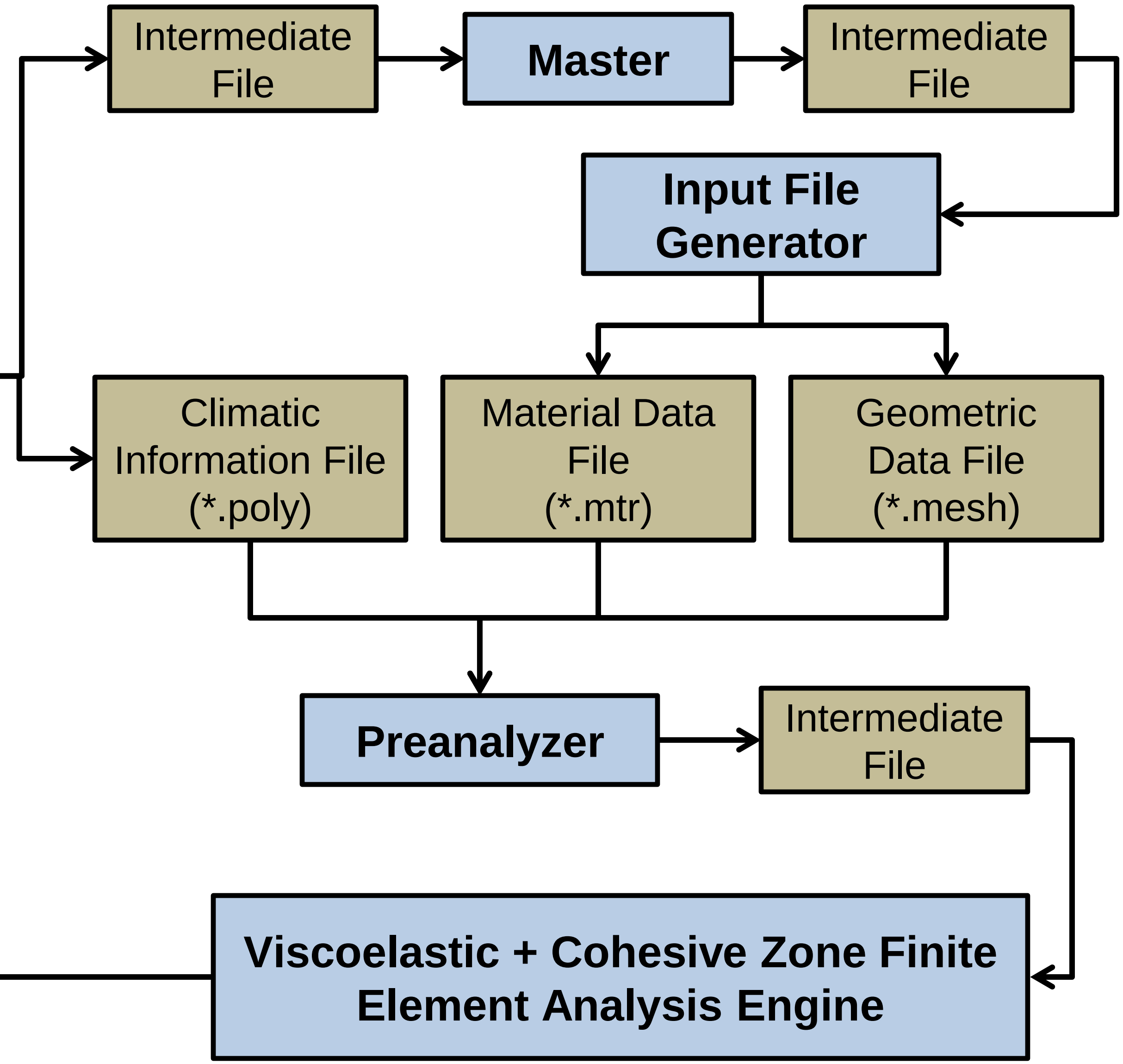
**Graphical User Interface: Visual LTC**

**Input:**
- Material Properties*
  - Viscoelastic
  - Fracture
- Location**

* May be selected from pre-existing library

** Library of *.poly files contain climatic information for preloaded locations

**Output:**
- Critical Events for Thermal Cracking
- Amount of Dissipated Fracture Energy
- Extent of Pavement Thickness Damaged and Cracked



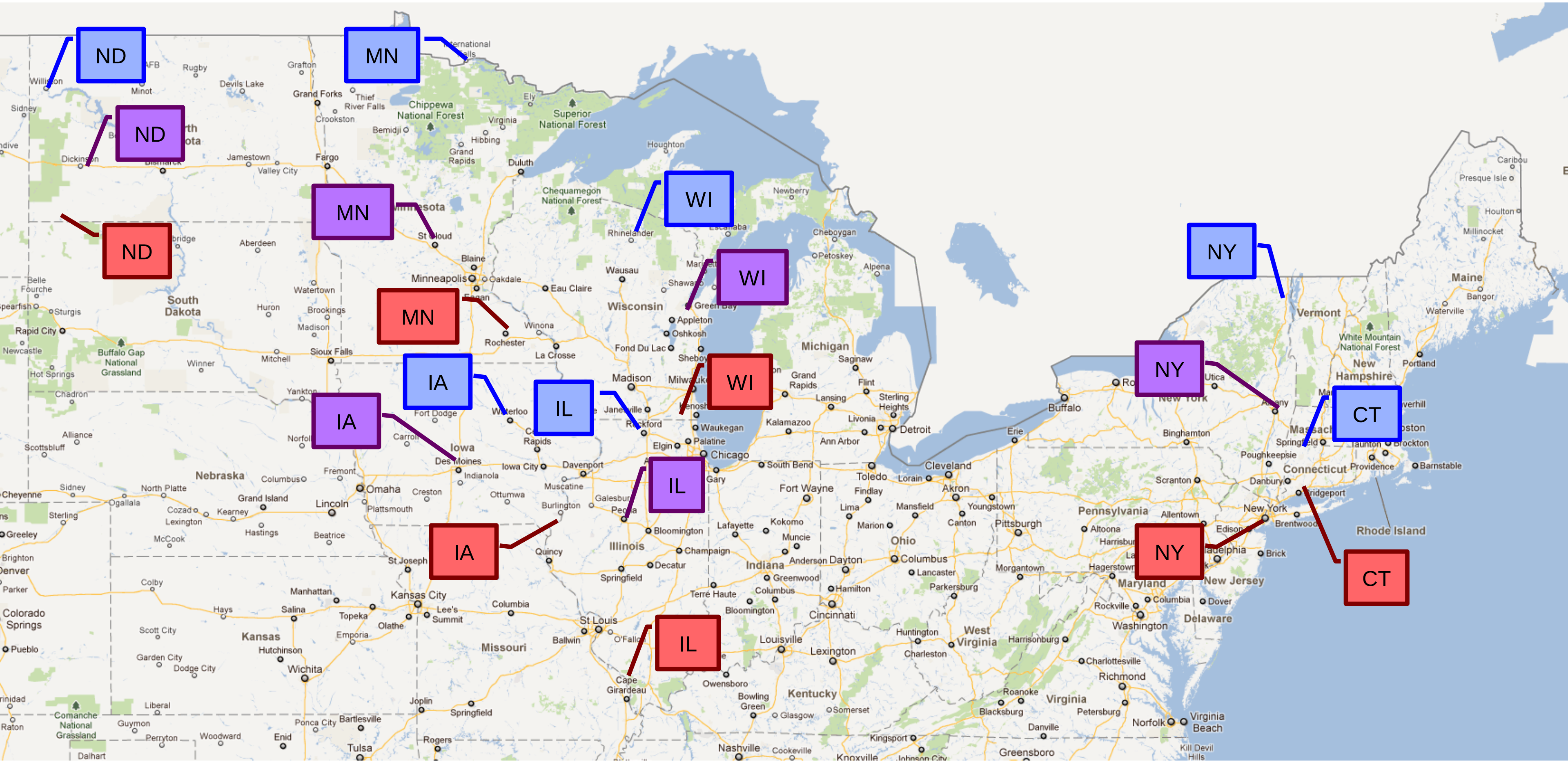
# 1. Collection and Assembly of Climatic Files

- **Climatic data from participating states was collected**
  - Climatic data file repository for AASHTO MEPDG
  - Two or Three locations for each of the participating states
    - Cold, Intermediate and Warm
    - Two locations for Connecticut, three for all other states
    - 7 States = 21 Climatic Conditions
- **Integrated Climatic Model analyses were conducted**
  - 11 AC Thicknesses (3" – 16")
- **Total of 220 files**

# 1. Collection and Assembly of Climatic Files

- Map of US showing climatic locations.

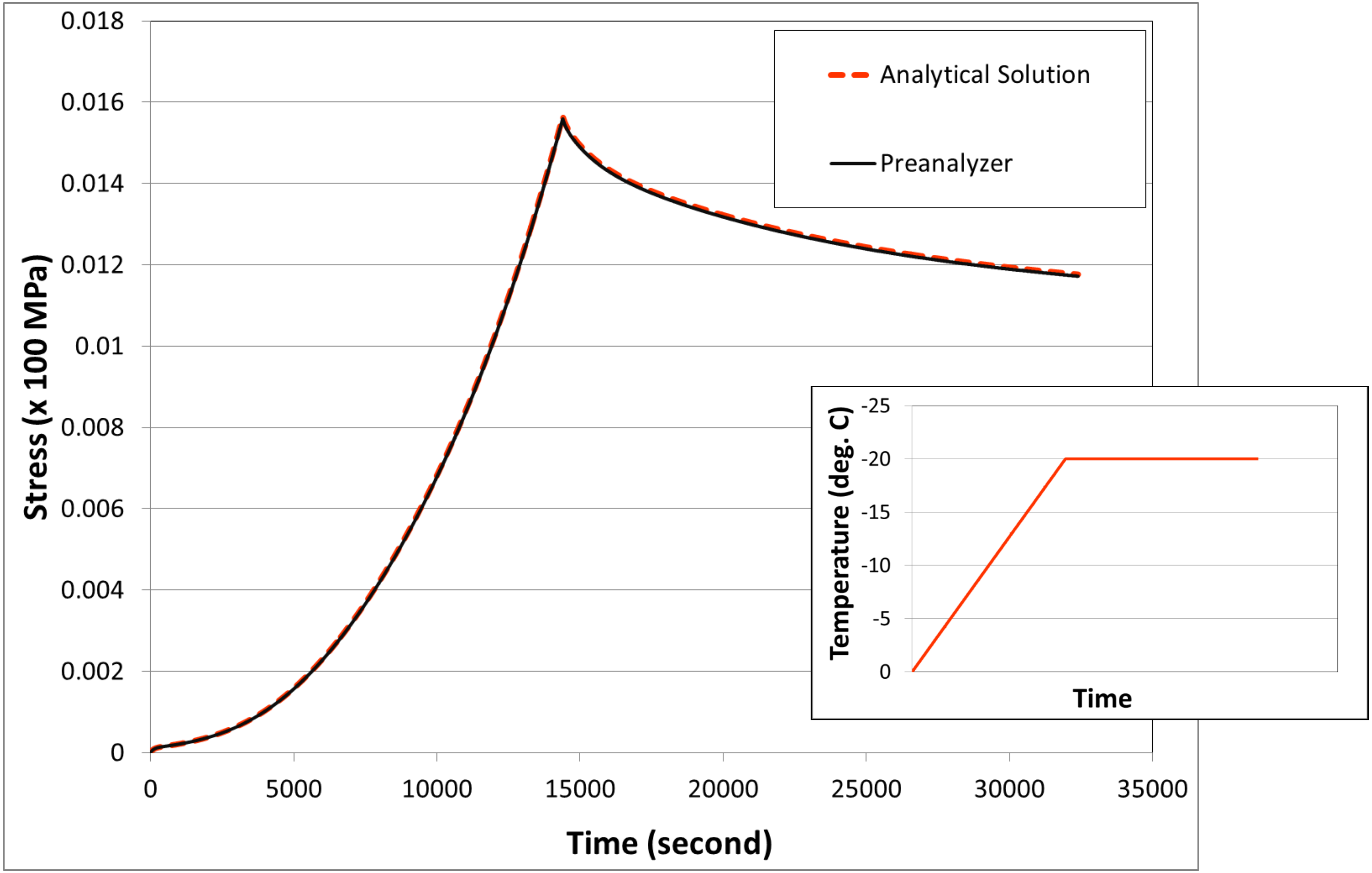
Cold Climate | Intermediate Climate | Warm Climate



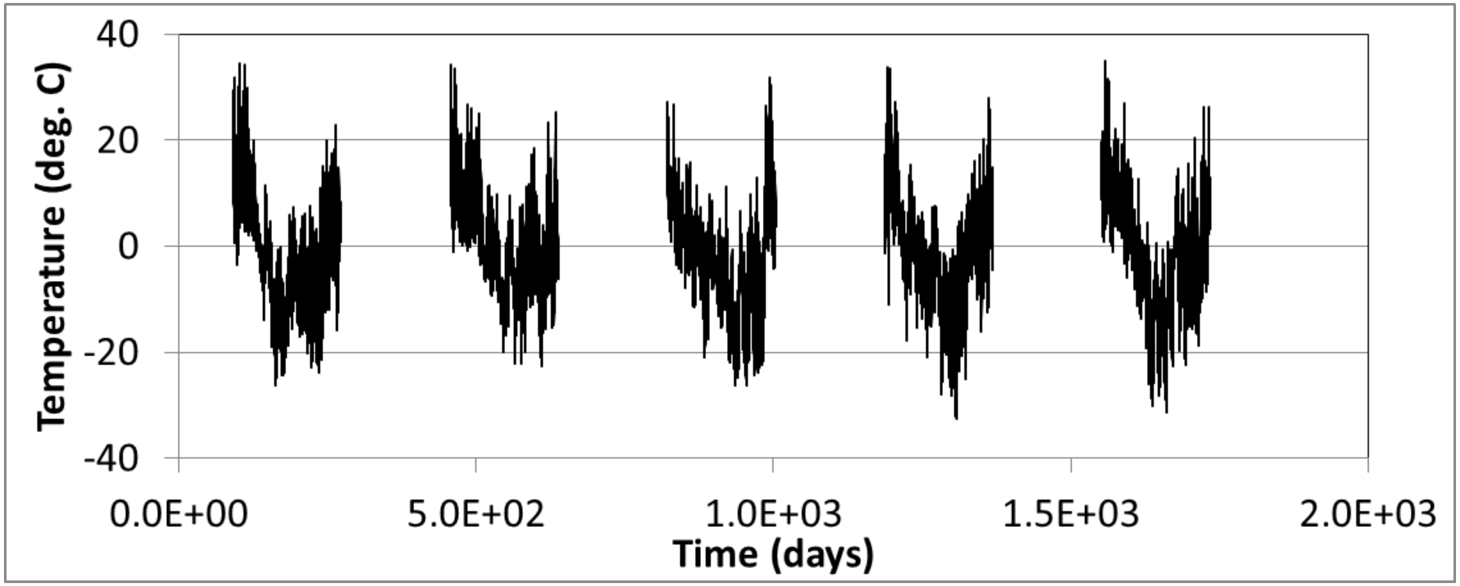
# 2. Preanalysis Module

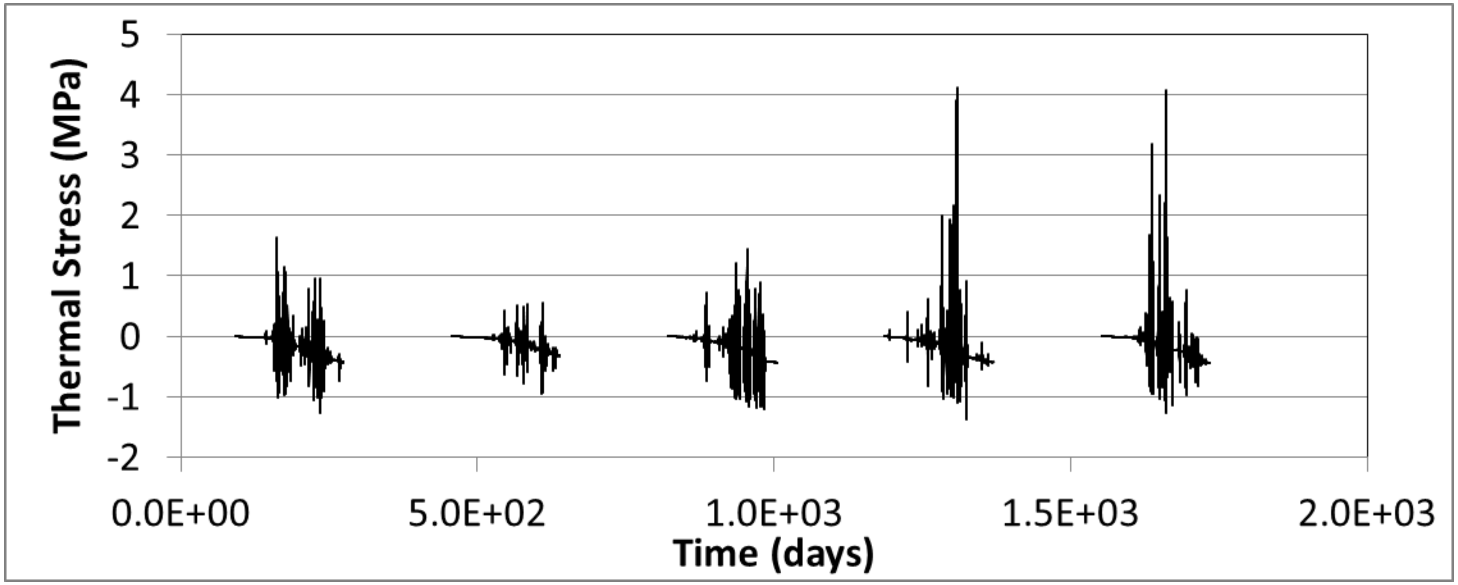
- **Motivation: Optimize analysis times for the finite element analysis**
- **Purpose: Presolve simplified problem to identify critical cooling events**
- **Approach: Use 1-dimensional viscoelastic solution using surface temperatures and asphalt properties as input to predict thermally induced stresses**
  - Related to thermal stress on surface of pavement
- **Implementation and verification has been completed**

# 2. Preanalysis Module: Verification



# 2. Preanalysis Module: Result (Intl. Falls, MN)



# 2. Preanalysis Module: What's Next

- **Determining suitable thermal stress threshold**
  - Use these to determine finite element model start and end points
- **This is done in conjunction with full scale verification**
- **Stress threshold determination is linked to model calibration and validation process**

# 3. Finite Element Analysis Engine (FEAE)

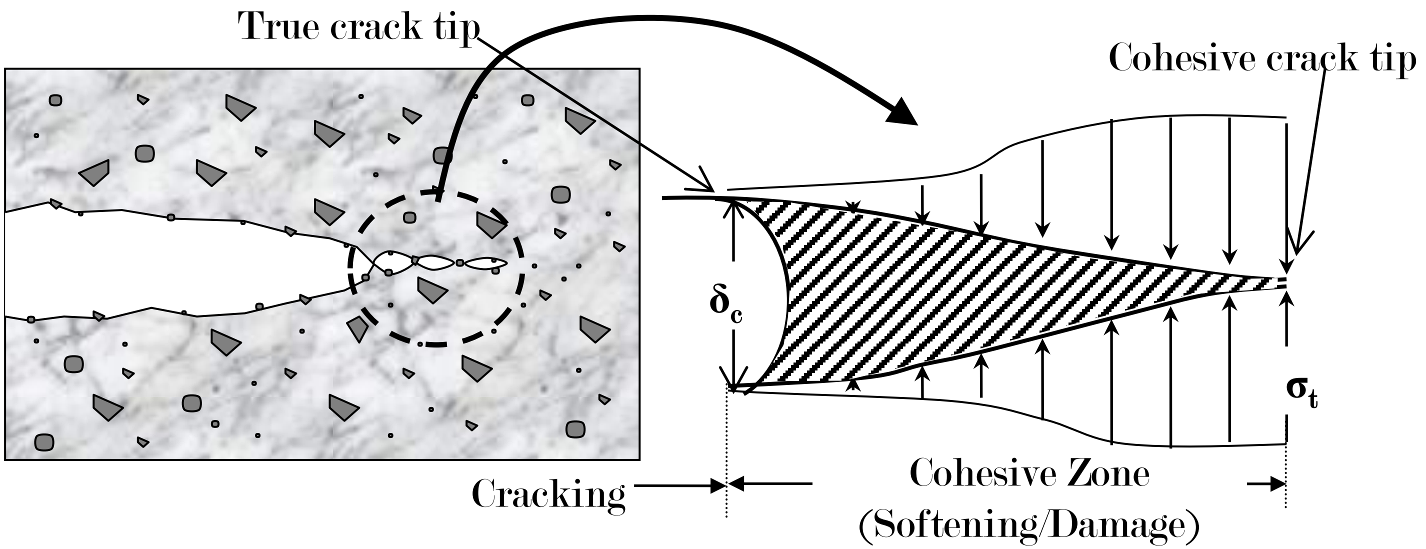
- **Individual components have been implemented and verified**
  - Viscoelastic bulk elements
  - Cohesive zone fracture elements
- **Final code has been generated through combination of above**
- **Code has been linked to other components of ILLI-TC**
- **Preliminary verification has been conducted**

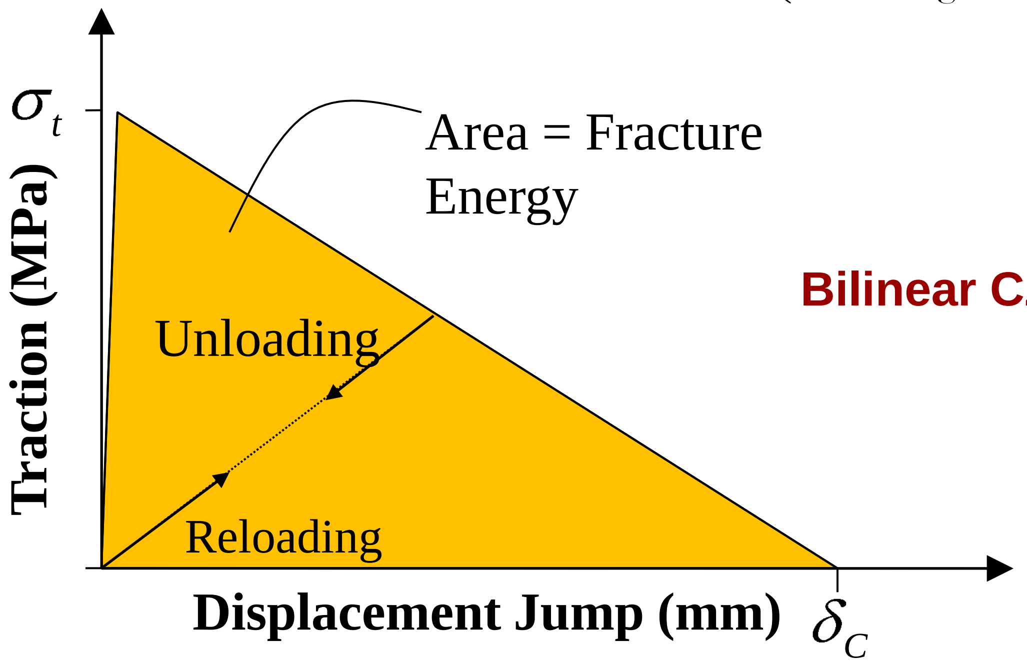
# 3. FEAE: Cohesive Zone Model

- **Cohesive zone model (CZM) is a computationally efficient and effective way of modeling damage and cracking in asphalt concrete**

- **CZM Capabilities:**
  - Softening (damage)
  - Complete separation (difficult with continuum type models)
  - Captures the length scale associated with fracture process

# 3. FEAE: Bilinear Cohesive Zone Model

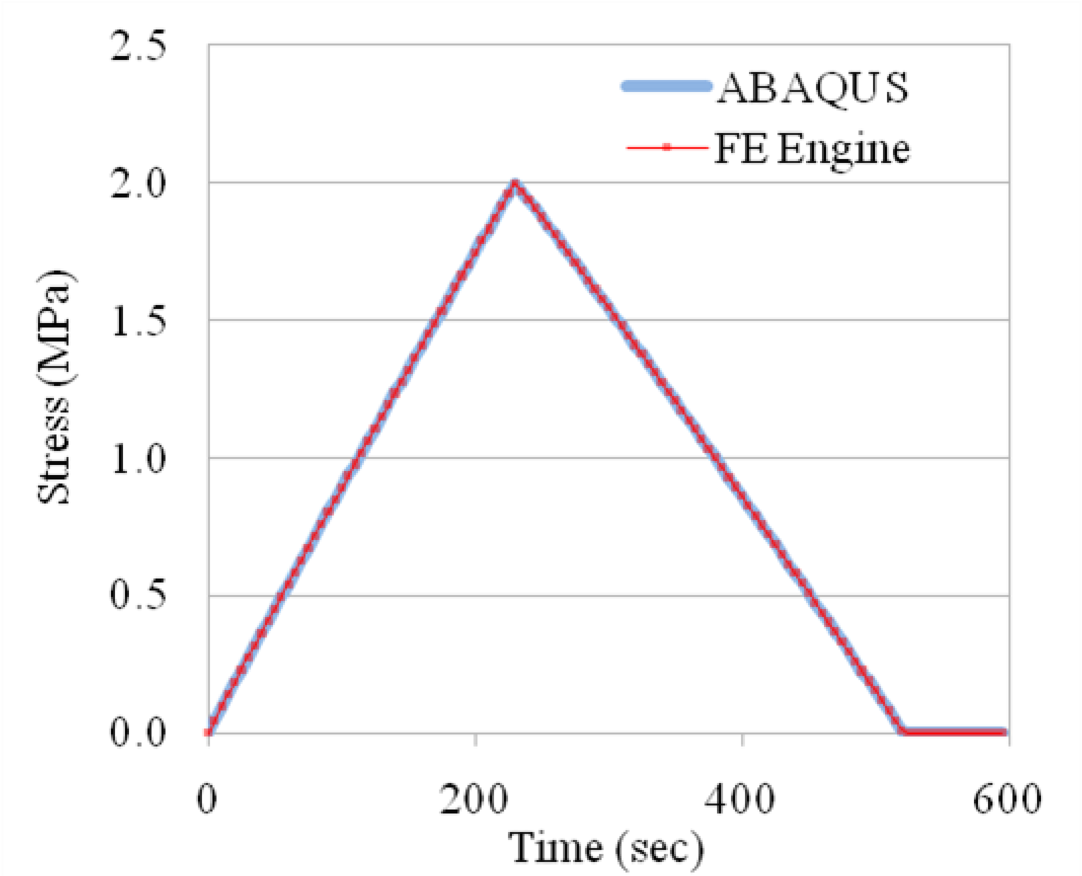


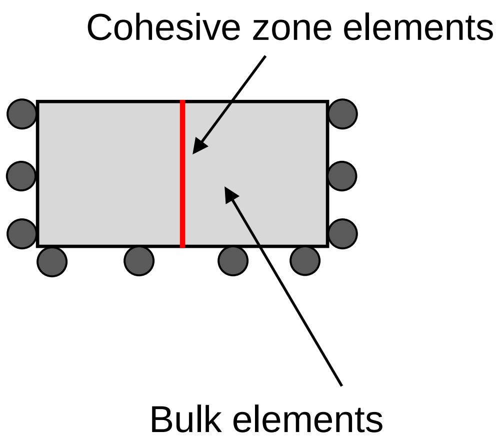




**Bilinear CZM (Song et al., 2006)**

# 3. FEAE: Verification Example

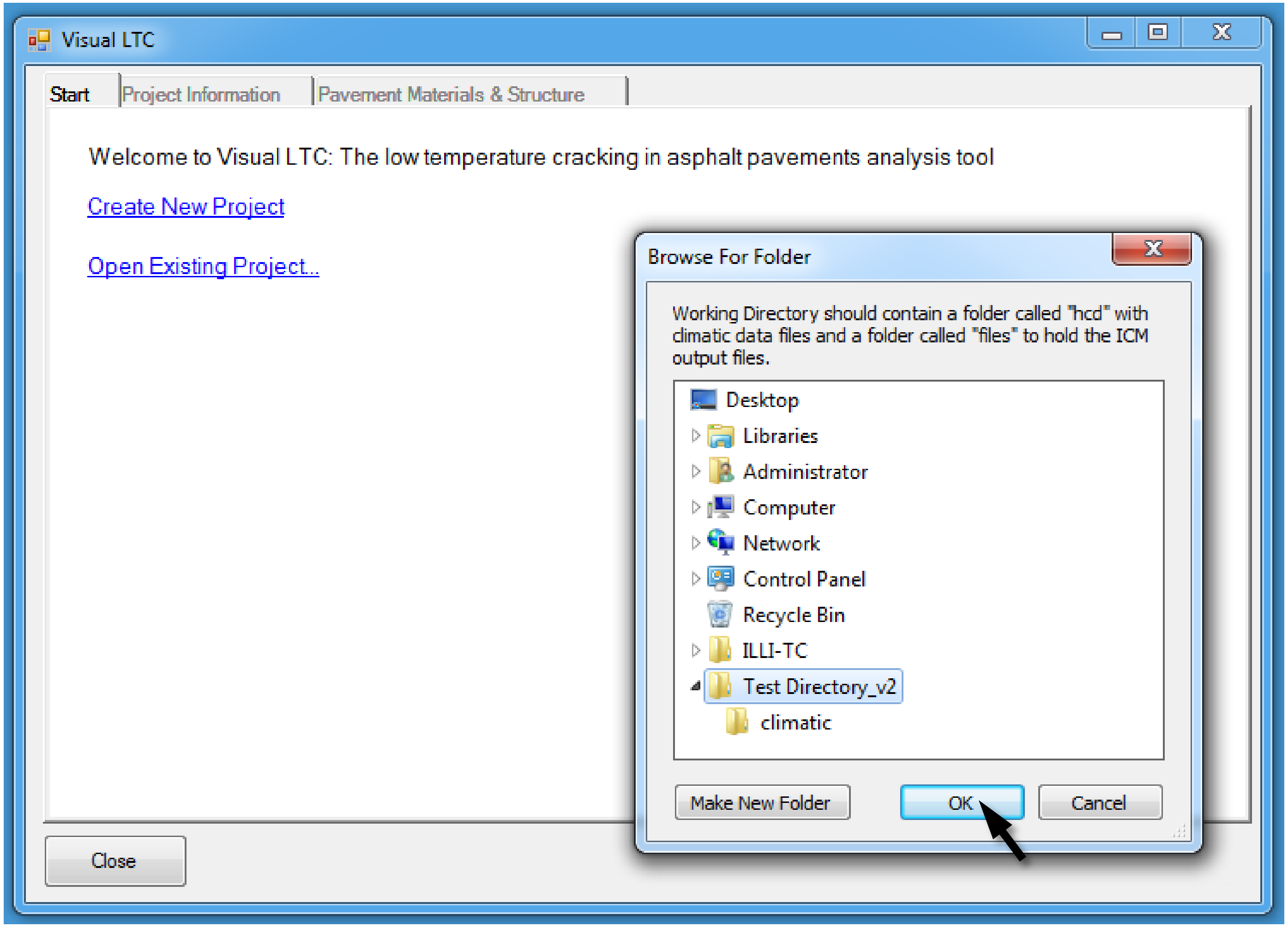
- Temperature drop 0° to -10°C over 600 sec



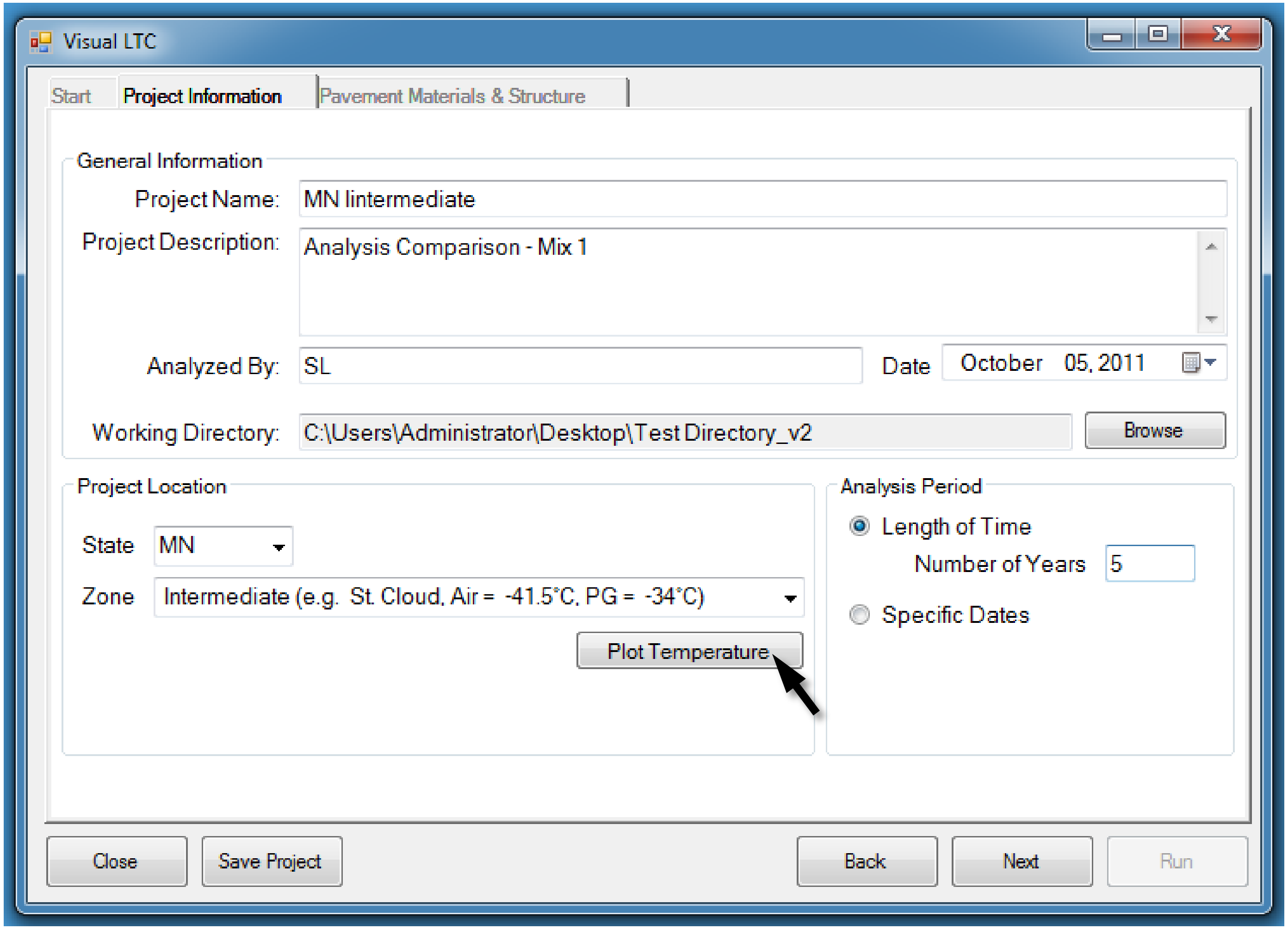
# 4. Graphical User Interface: Visual LTC

- **Start**



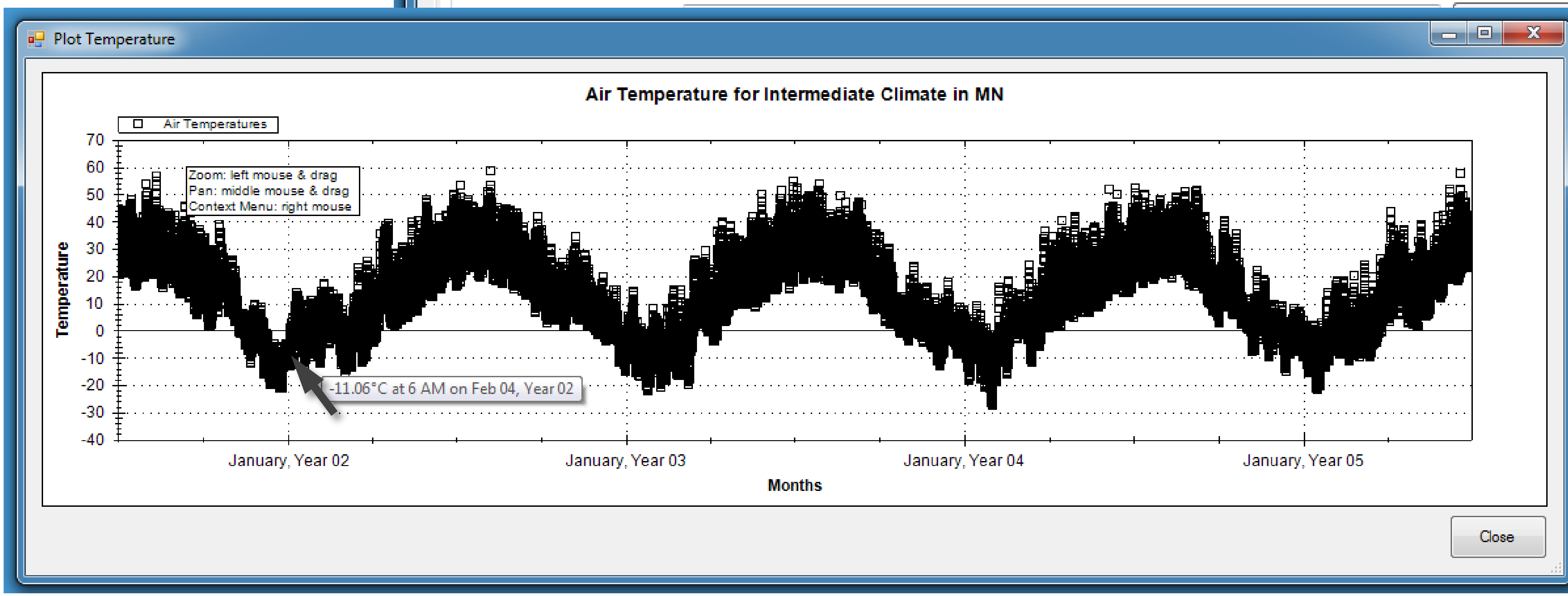
# 4. Graphical User Interface: Visual LTC

- Start
- Project Information



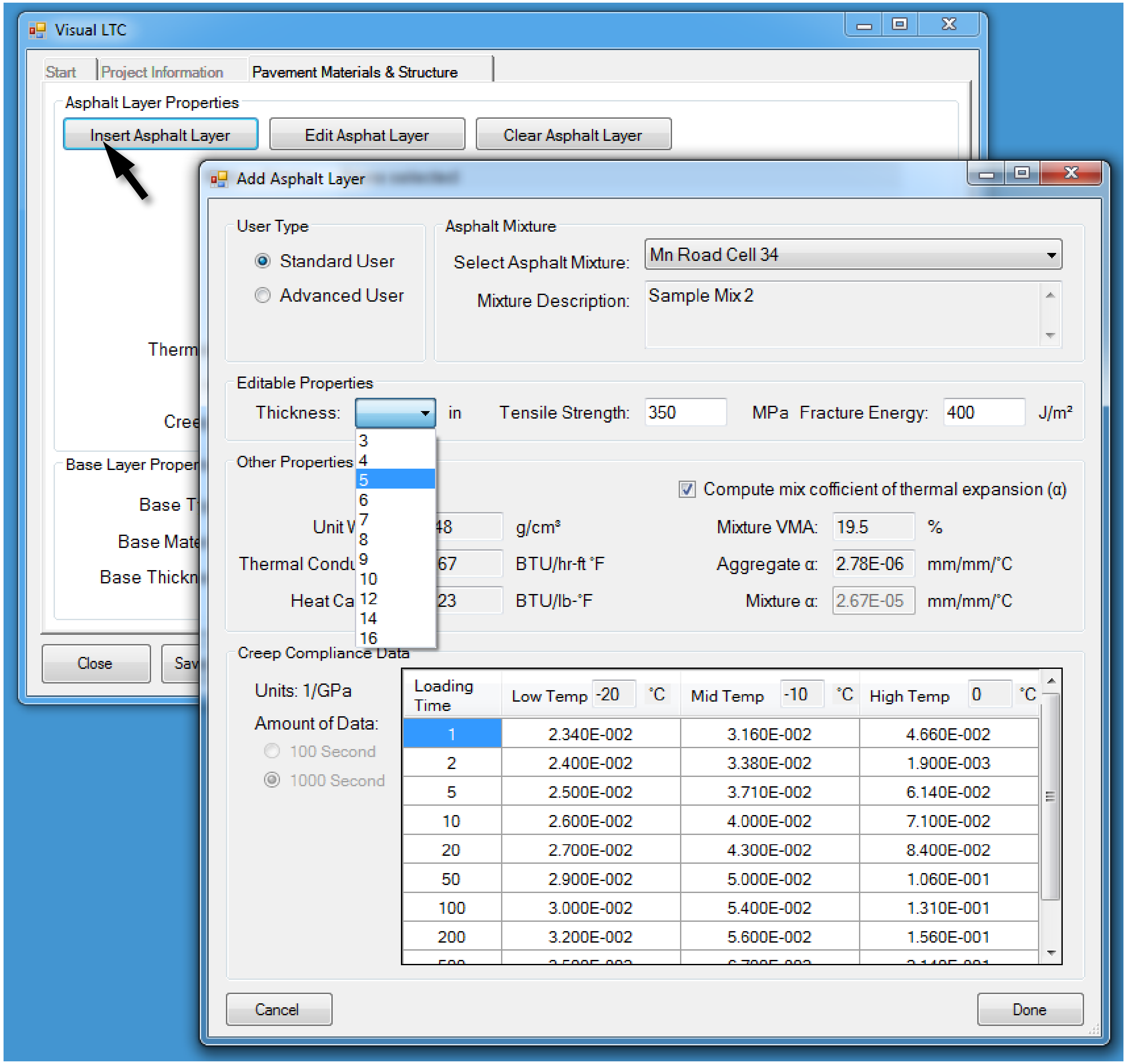
# 4. Graphical User Interface: Visual LTC

- **Start**
- **Project Information**
  - Plot temperature

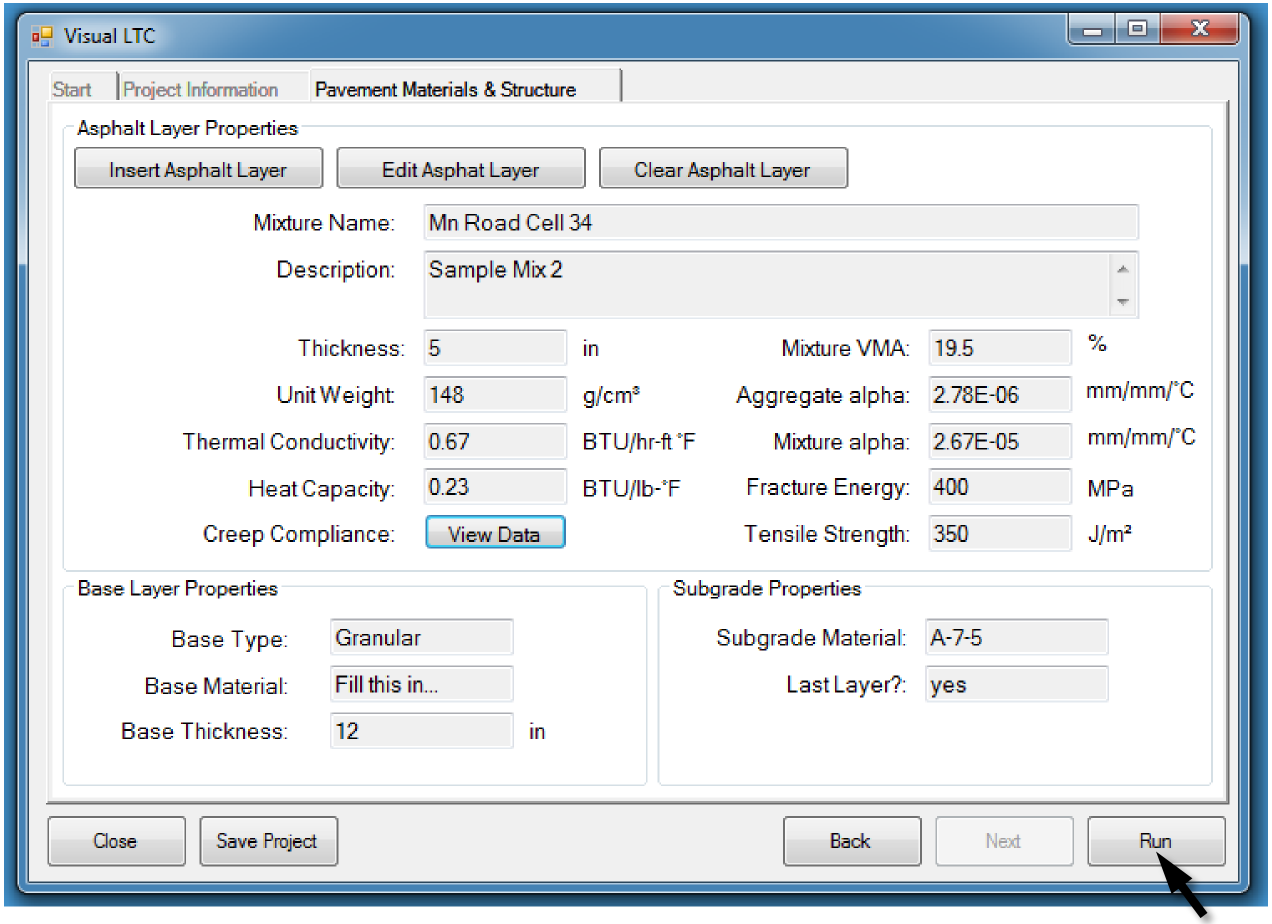
# 4. Graphical User Interface: Visual LTC

- **Start**
- **Project Information**
  - Plot temperature
- **Pavement materials & structure**
  - Insert Asphalt Layer



# 4. Graphical User Interface: Visual LTC

- Start
- Project Information
  - Plot temperature
- Pavement materials & structure
- Run



# Modeling – Remaining Tasks

- **Verify Combined Code for Full Scale Pavement Models – Sept-Oct 2011**
- **Calibrate Code – Oct - Nov 2011**
- **Validate Code – Nov 2011 - Jan 2012**
  - Pavement performance data from Phase-II

# APPENDIX

# "User Type"

- **Similar to existing MEPDG layout**
- **User can easily switch between user types**

- **Standard User**
  - Practitioners
  - Access to all existing mixes
  - Default mix properties can be viewed but not changed

- **Advanced User**
  - Researchers/Developers
  - Access to all existing mixes
  - Default mix properties can be viewed and changed
  - Modify existing mixes and add new mixes

# 3. FEAE: Viscoelastic Formulation

- **Recursive-incremental time integration scheme**

$$\sigma(x,t) = \int_{t'=-\infty}^{t'=t} C(x, \xi - \xi') \frac{\partial \varepsilon(x,t')}{\partial t'} dt' \qquad d\boldsymbol{\sigma}(\xi) = \mathbf{K}(\mathbf{x},\xi) \times d\boldsymbol{\varepsilon}(\xi) + d\boldsymbol{\sigma}^R(\xi)$$