Demo of IlliTC Software

Pooled Fund - LTC Project Close-out Meeting

September 13, 2012

Maplewood, MN

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William G. Buttlar, Glaucio Paulino

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. IlliTC

TC Model

- Stress Intensity Factor

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

C_0: *Current crack length*

σ: *Far-field stress at depth of crack*

K: *Stress Intensity Factor*

- Paris 'Law'

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

ΔK: *Change in stress intensity factor*

A, n: *Fracture parameters*

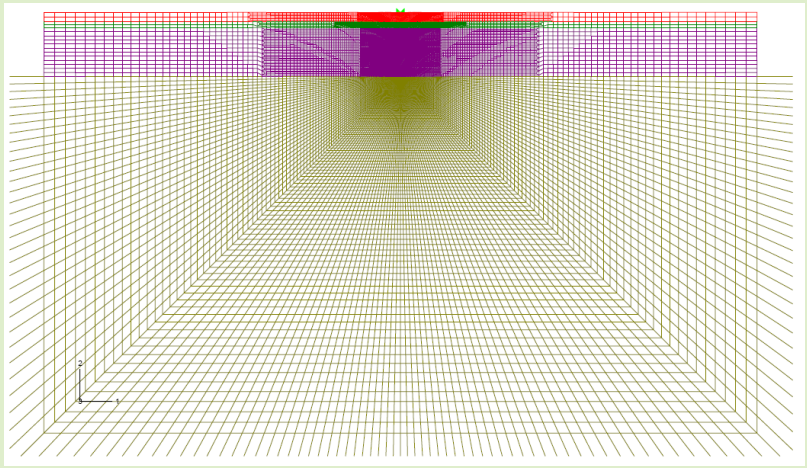
ΔC: *Change in crack depth*

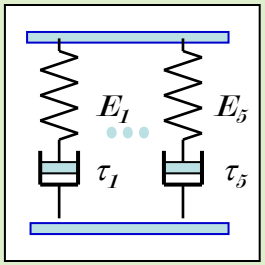
- Crack amount model

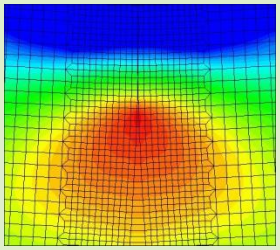
Amount of cracking is a function of the probability that the crack depth is equal to or greater the thickness of the surface layer

IlliTC

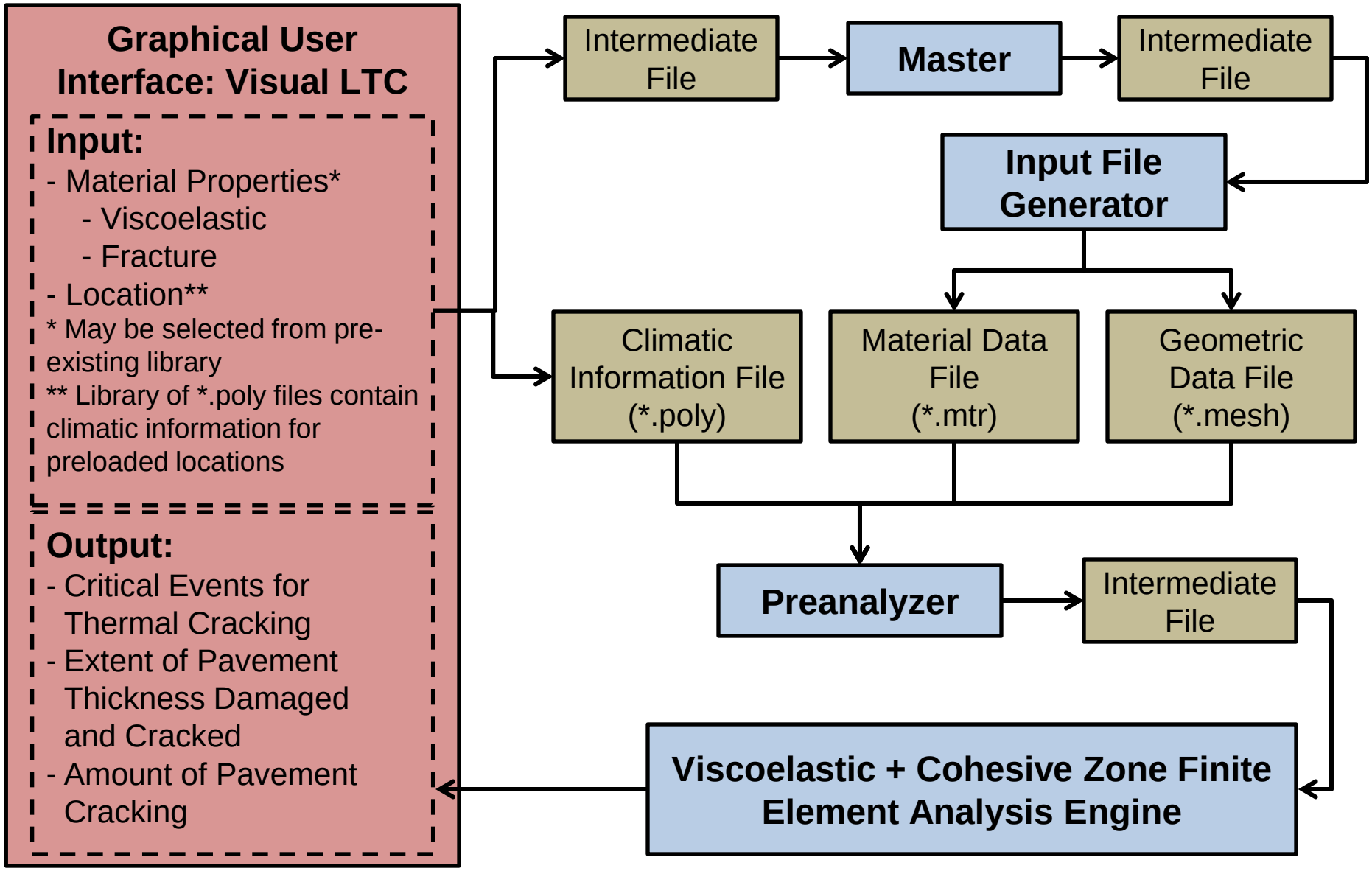
- Finite element based thermal cracking prediction model with cohesive zone modeling







IlliTC Components



Required Inputs

Property		Units	Test
Tensile strength		MPa	AASHTO T-322 or Extracted from DCT Test
Fracture energy		J/m^2	ASTM D7313 [1]
Option – 1	Unit weight	g/cm^3	AASHTO M323
	Mixture VMA [2]	%	AASHTO M323
	Aggregate coefficient of thermal expansion and contraction (CTEC) [2]	mm/mm/°C	No standardized test
Option – 2	Mixture coefficient of thermal expansion and contraction (CTEC) [3]	mm/mm/°C	No standardized test
Creep compliance test data (100 or 1000 seconds for 3 temperatures)		1/GPa	AASHTO T-322
Creep compliance test temperatures		°C	AASHTO T-322

[1] Fracture energy may be obtained with different test geometry; however the model is calibrated for the ASTM D7313 (disk-shaped compact tension, DCT) test procedure

[2] Mixture VMA and aggregate CTEC do not need to be entered if Mixture CTEC is provided

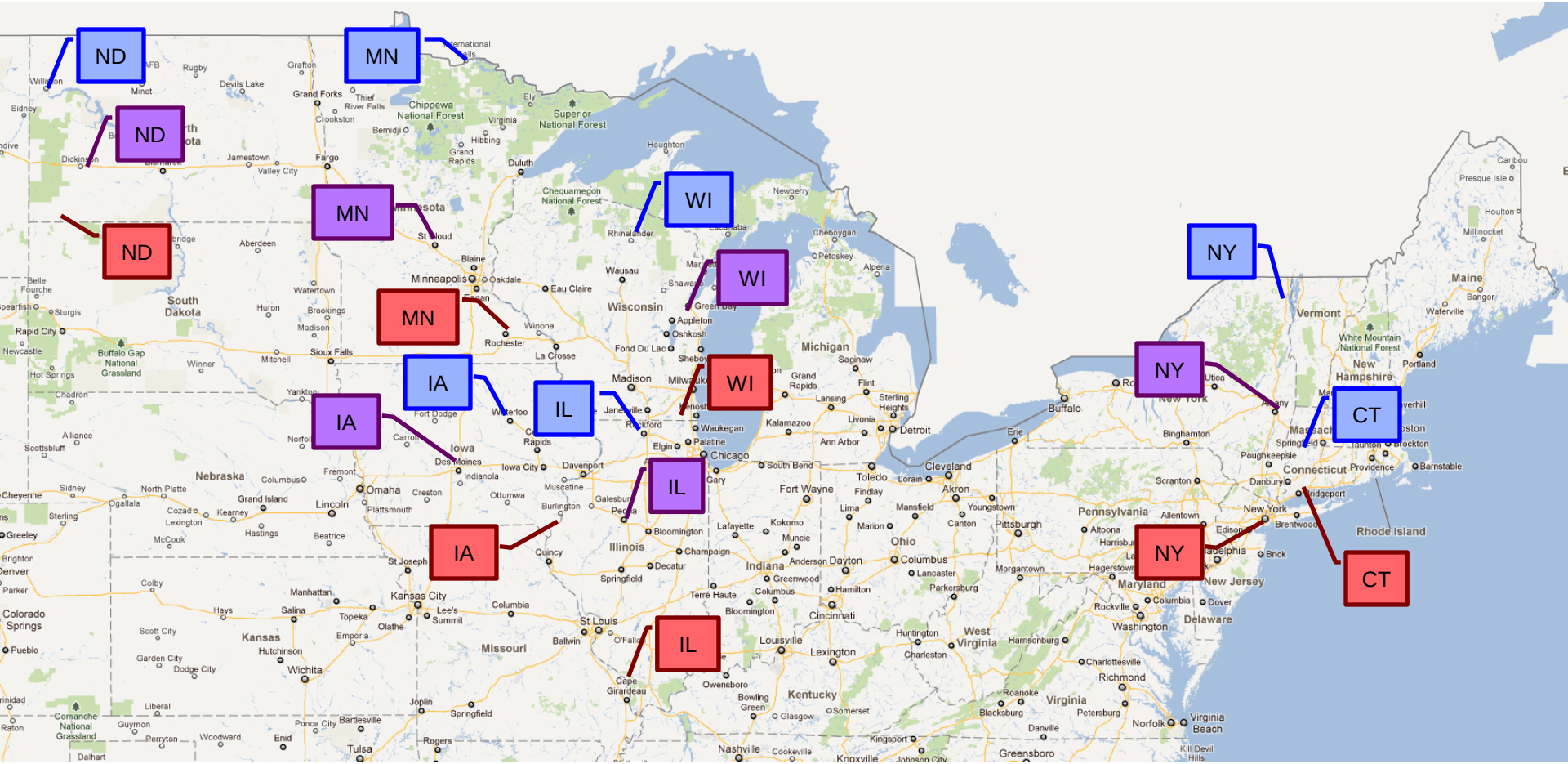
[3] Mixture CTEC will be calculated if mixture VMA and aggregate CTEC are provided

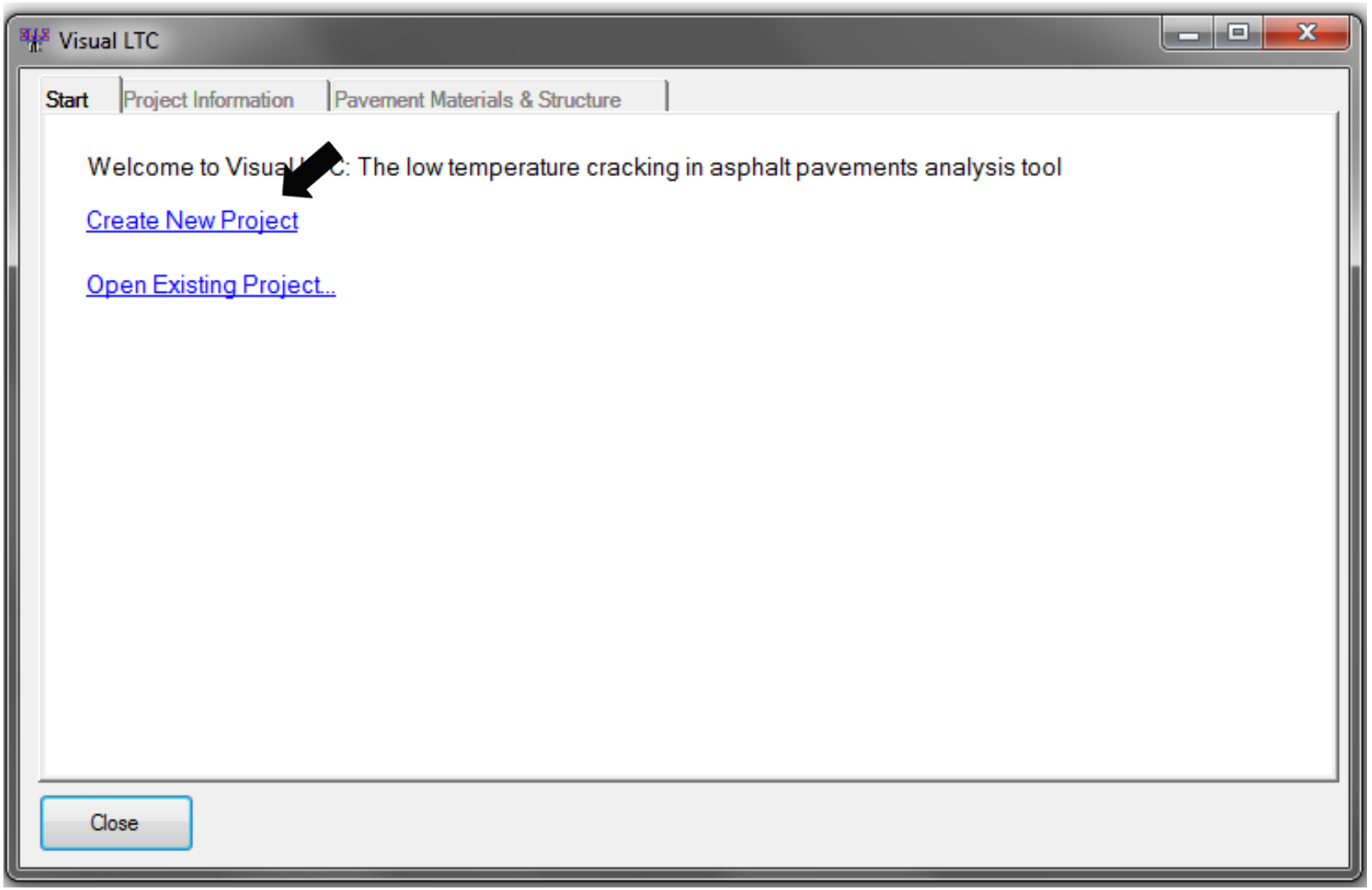
Map of US Showing Climatic Locations

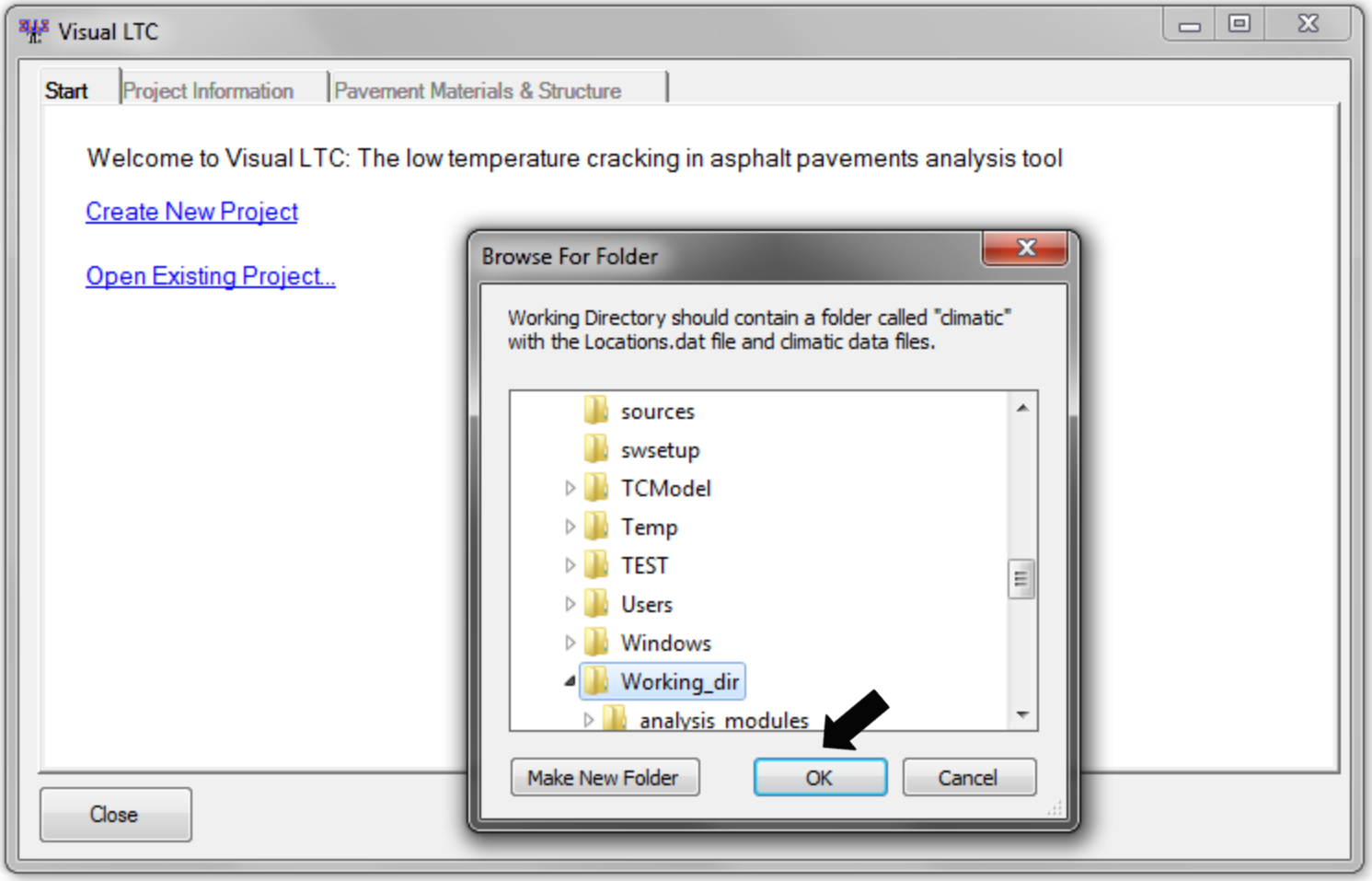
Cold Climate

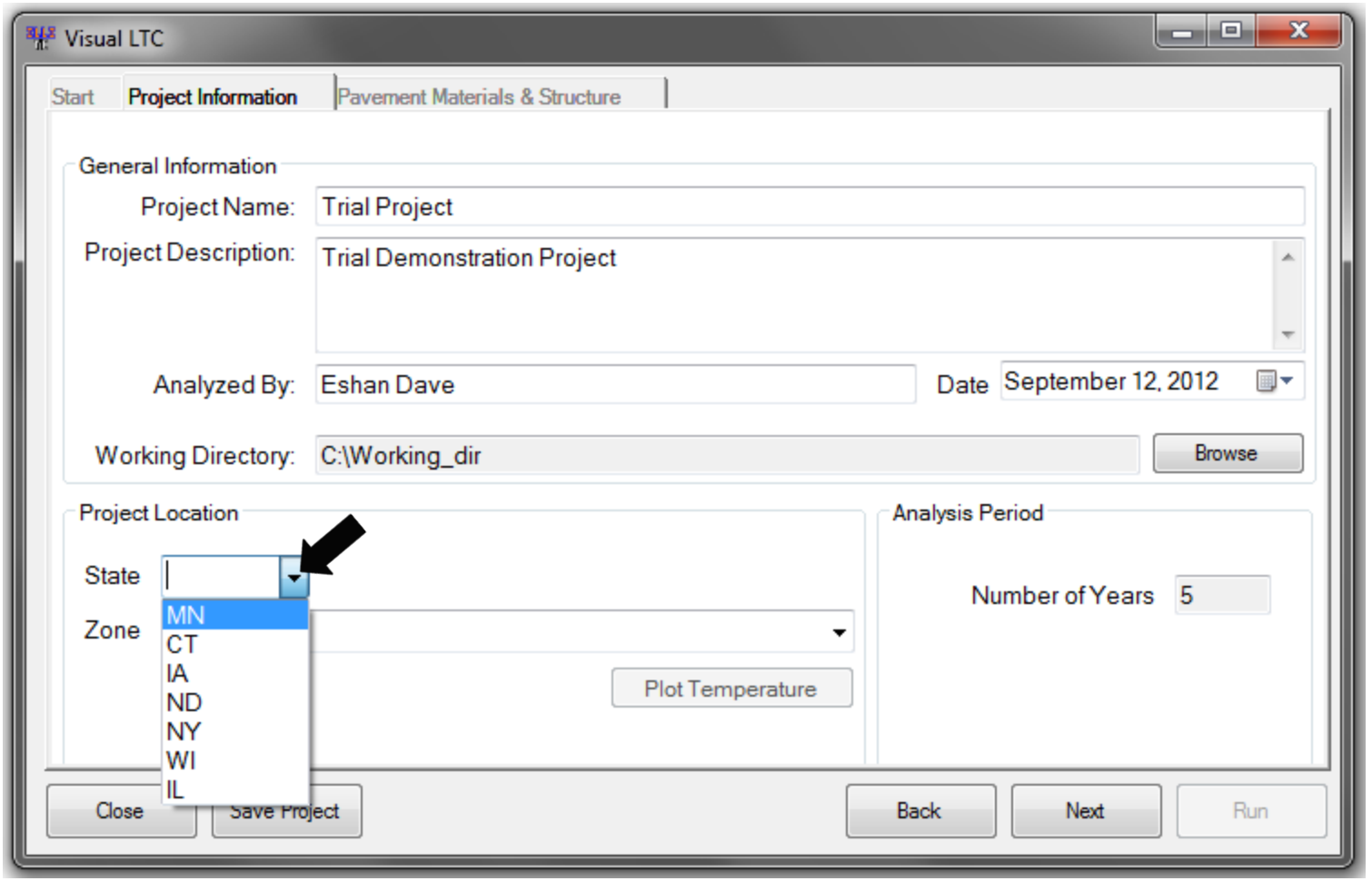
Intermediate Climate

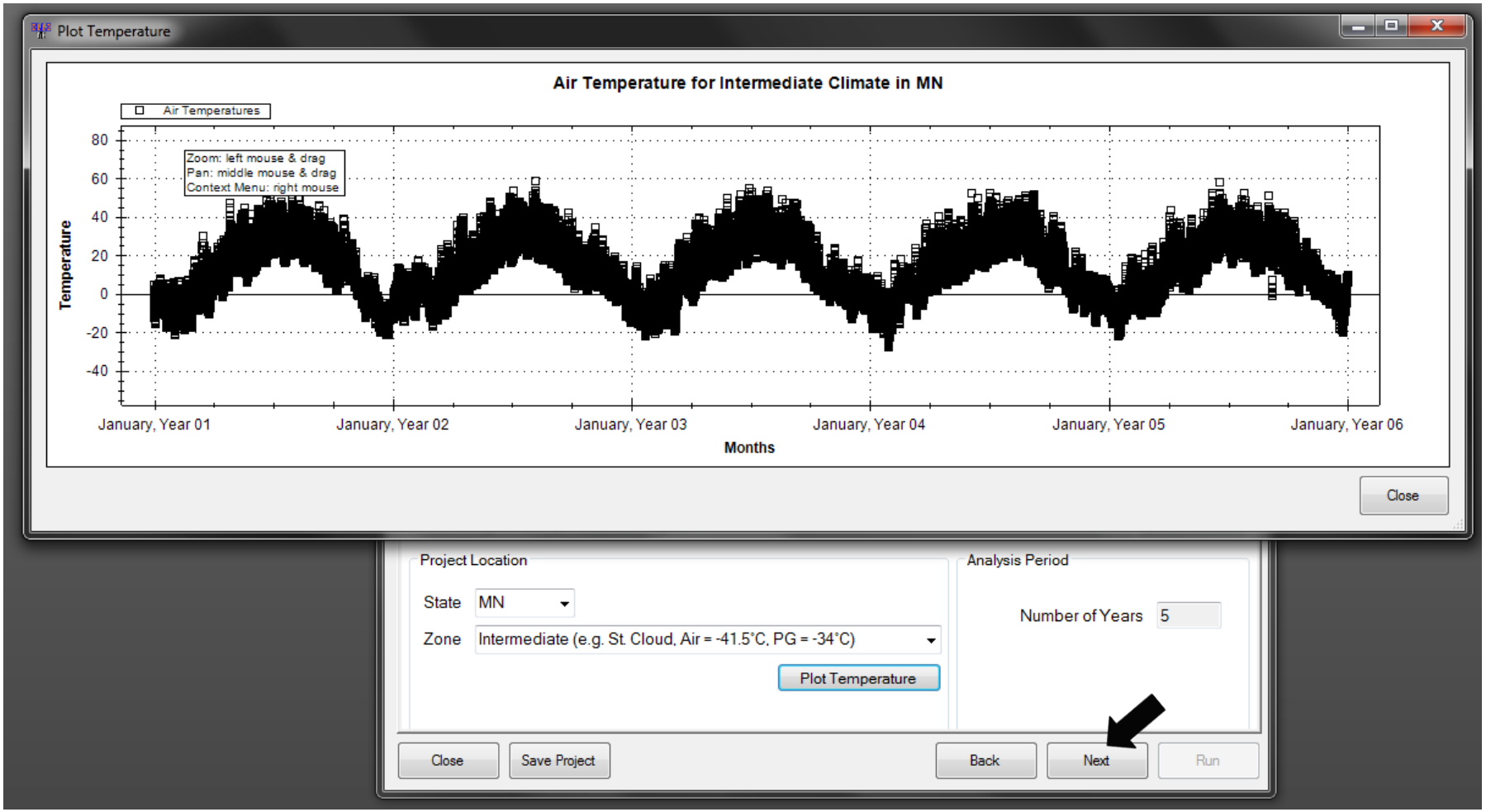
Warm Climate

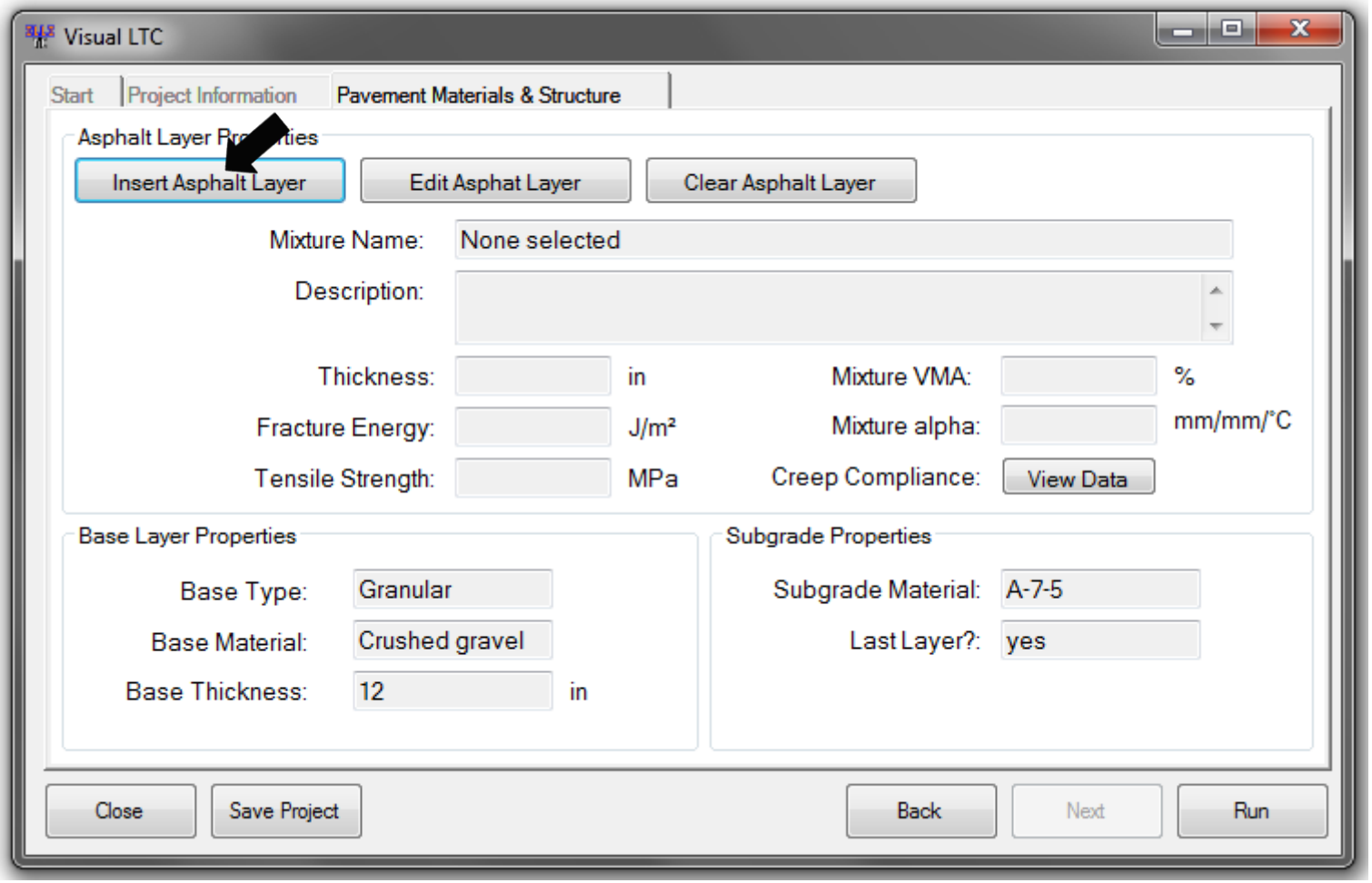


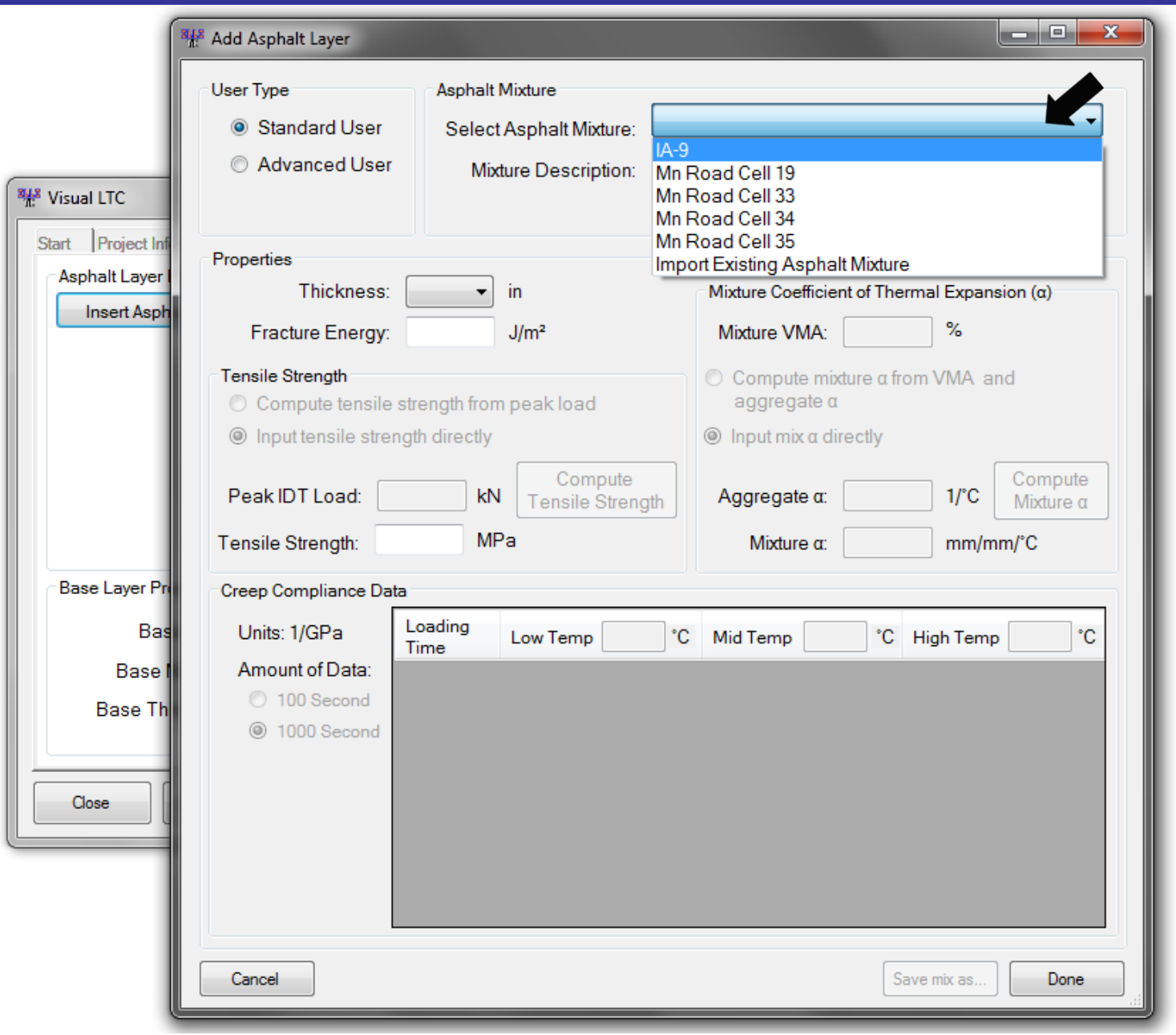

Visual LTC
Start
Project Information
Pavement Materials & Structure
Welcome to Visual LTC: The low temperature cracking in asphalt pavements analysis tool
Create New Project
Open Existing Project...
Close

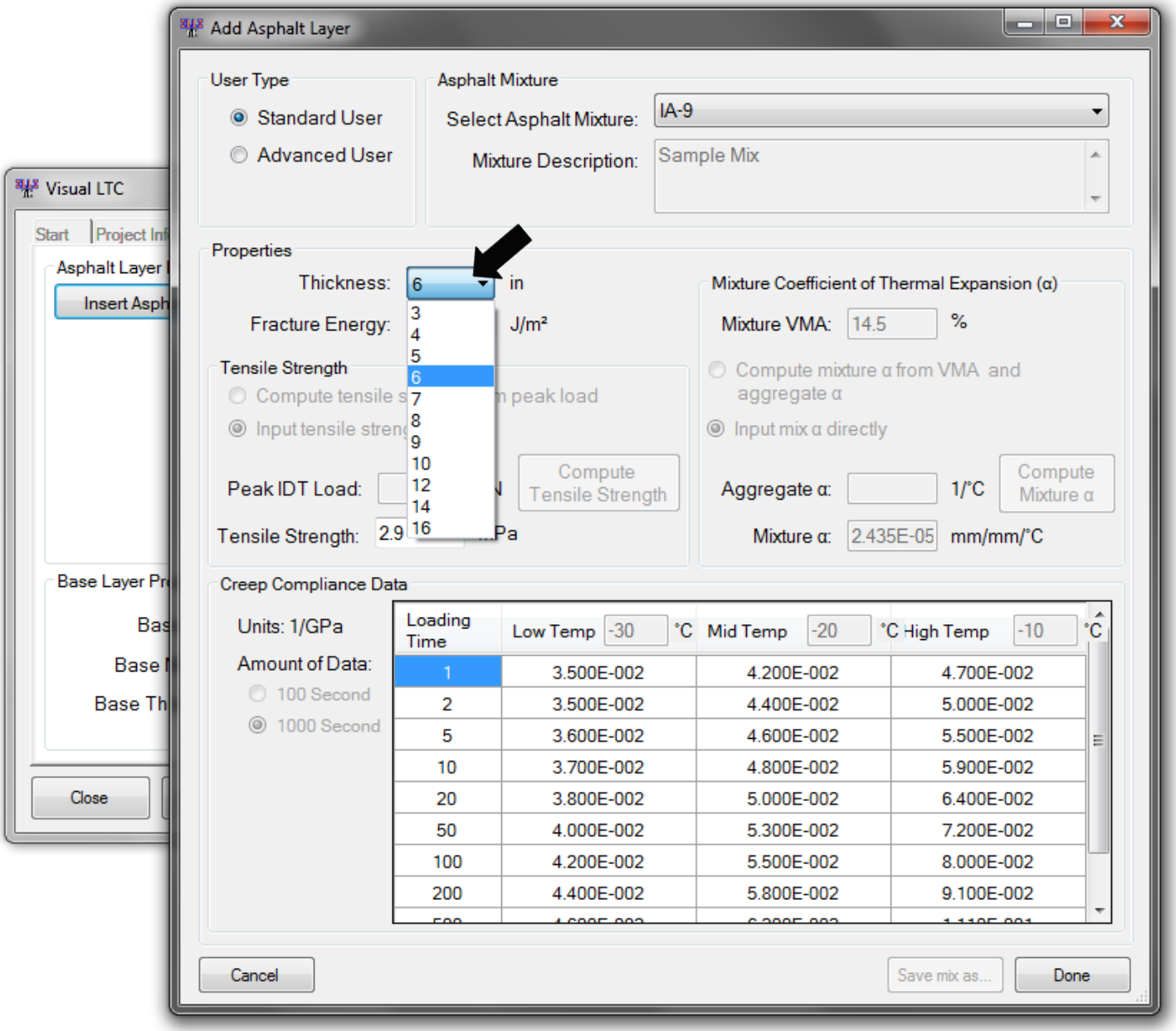

Visual LTC
Start
Project Information
Pavement Materials & Structure
Welcome to Visual LTC: The low temperature cracking in asphalt pavements analysis tool
Create New Project
Open Existing Project..
Close
Browse For Folder
Working Directory should contain a folder called "climatic" with the Locations.dat file and climatic data files.
sources
swsetup
TCModel
Temp
TEST
Users
Windows
Working_dir
analysis_modules
Make New Folder
OK
Cancel

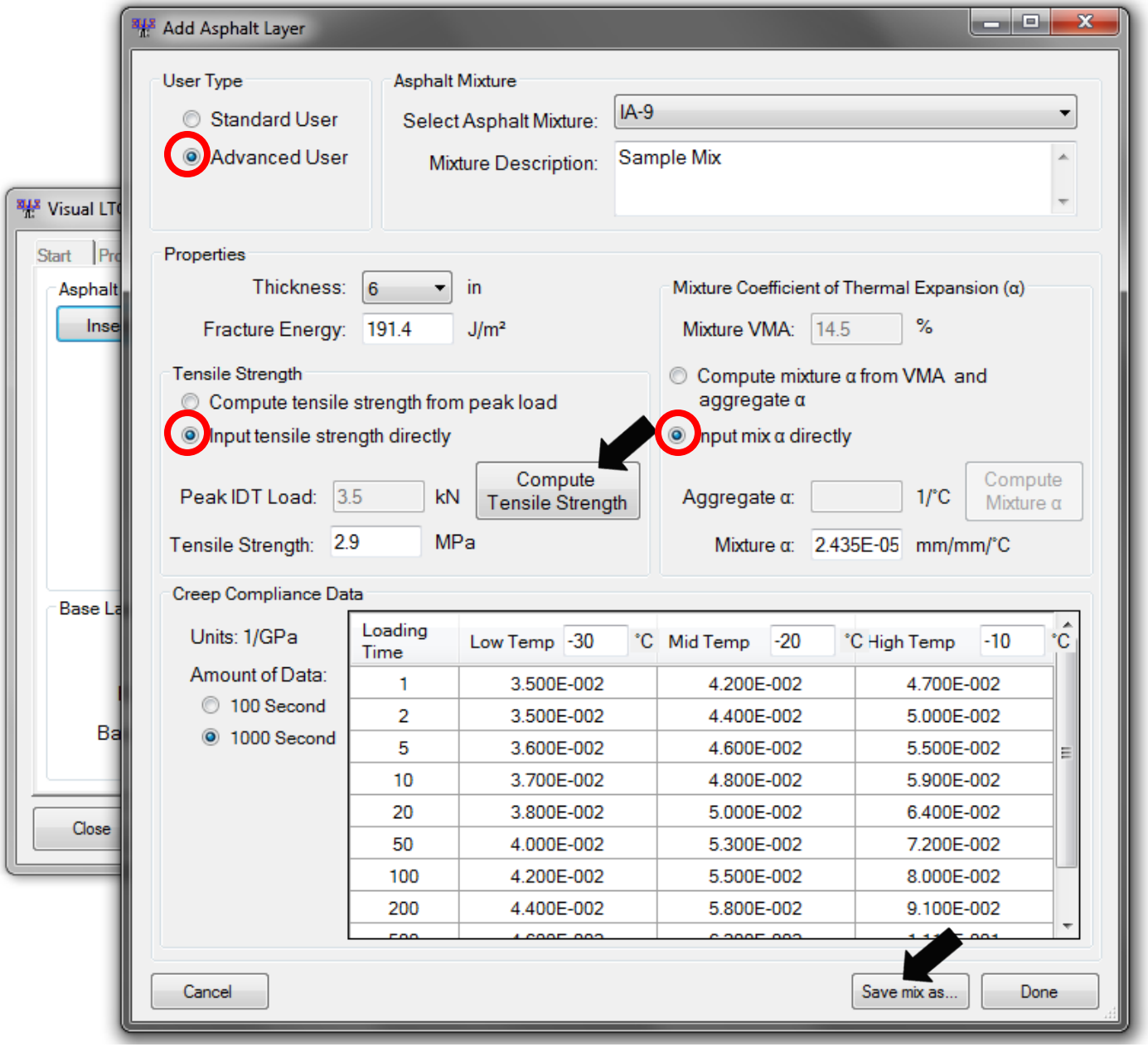

Visual LTC
Start
Project Information
Pavement Materials & Structure
General Information
Project Name:
Trial Project
Project Description:
Trial Demonstration Project
Analyzed By:
Eshan Dave
Date
September 12, 2012
Working Directory:
C:\Working_dir
Browse
Project Location
State
Zone
MN
CT
IA
ND
NY
WI
IL
Plot Temperature
Analysis Period
Number of Years
5
Close
Save Project
Back
Next
Run

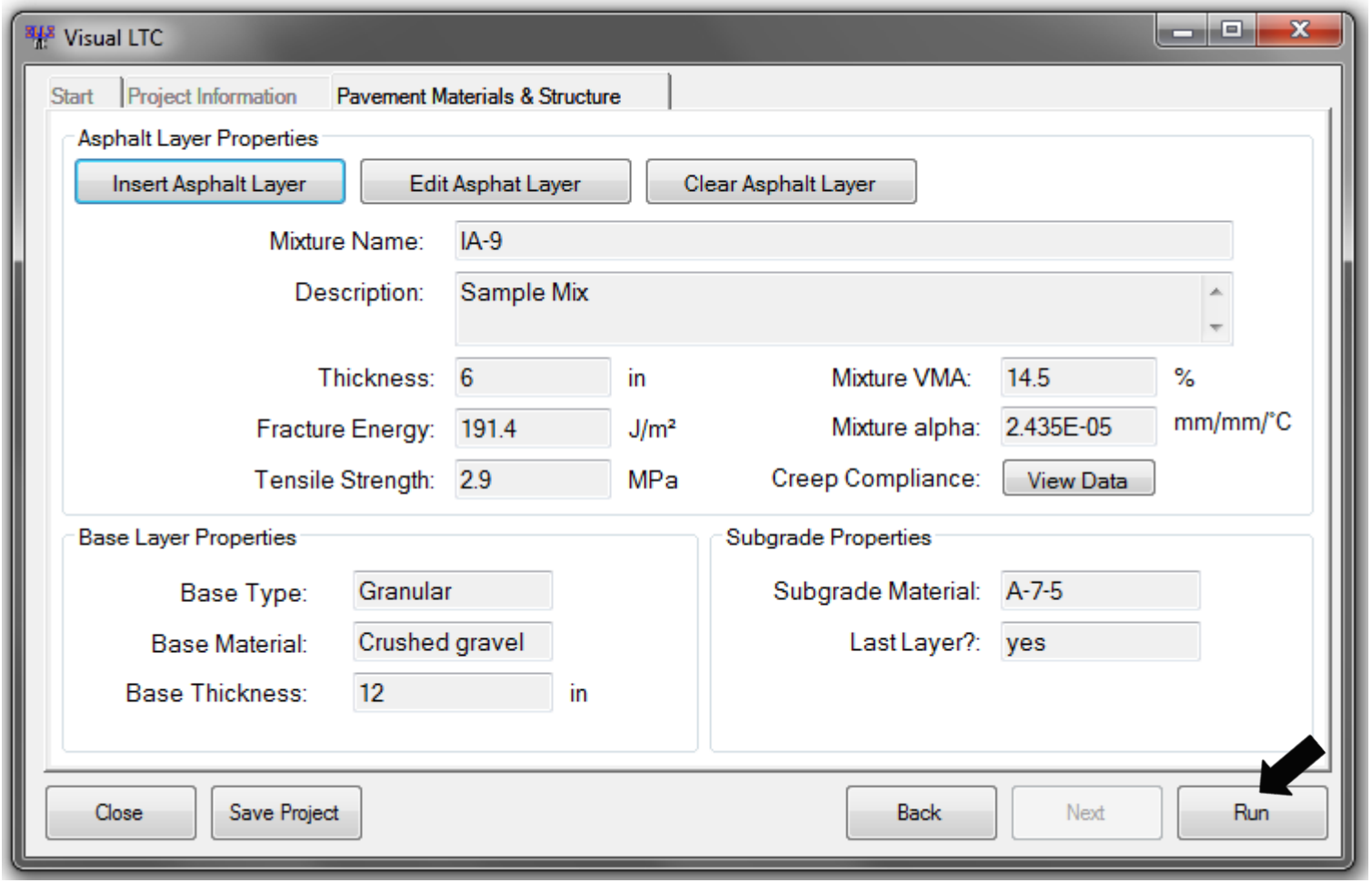

Plot Temperature
Air Temperature for Intermediate Climate in MN
Air Temperatures
Zoom: left mouse & drag
Pan: middle mouse & drag
Context Menu: right mouse
Temperature
80
60
40
20
0
-20
-40
January, Year 01
January, Year 02
January, Year 03
January, Year 04
January, Year 05
January, Year 06
Months
Close
Project Location
State
MN
Zone
Intermediate (e.g. St. Cloud, Air = -41.5°C, PG = -34°C)
Plot Temperature
Analysis Period
Number of Years
5
Close
Save Project
Back
Next
Run

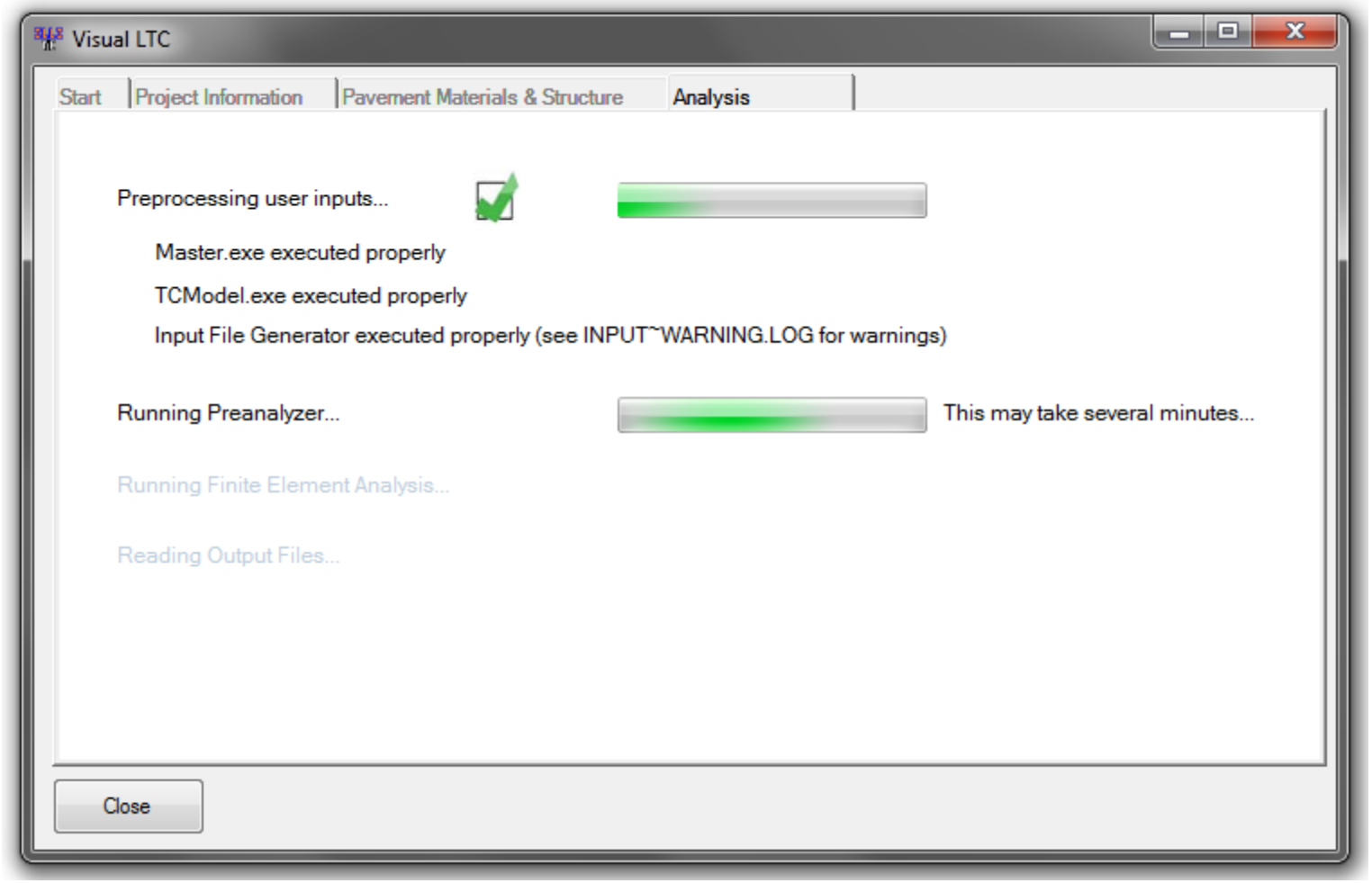

Visual LTC
Start
Project Information
Pavement Materials & Structure
Asphalt Layer Properties
Insert Asphalt Layer
Edit Asphat Layer
Clear Asphalt Layer
Mixture Name:
None selected
Description:
Thickness:
in
Mixture VMA:
%
Fracture Energy:
J/m²
Mixture alpha:
mm/mm/°C
Tensile Strength:
MPa
Creep Compliance:
View Data
Base Layer Properties
Base Type:
Granular
Base Material:
Crushed gravel
Base Thickness:
12
in
Subgrade Properties
Subgrade Material:
A-7-5
Last Layer?:
yes
Close
Save Project
Back
Next
Run

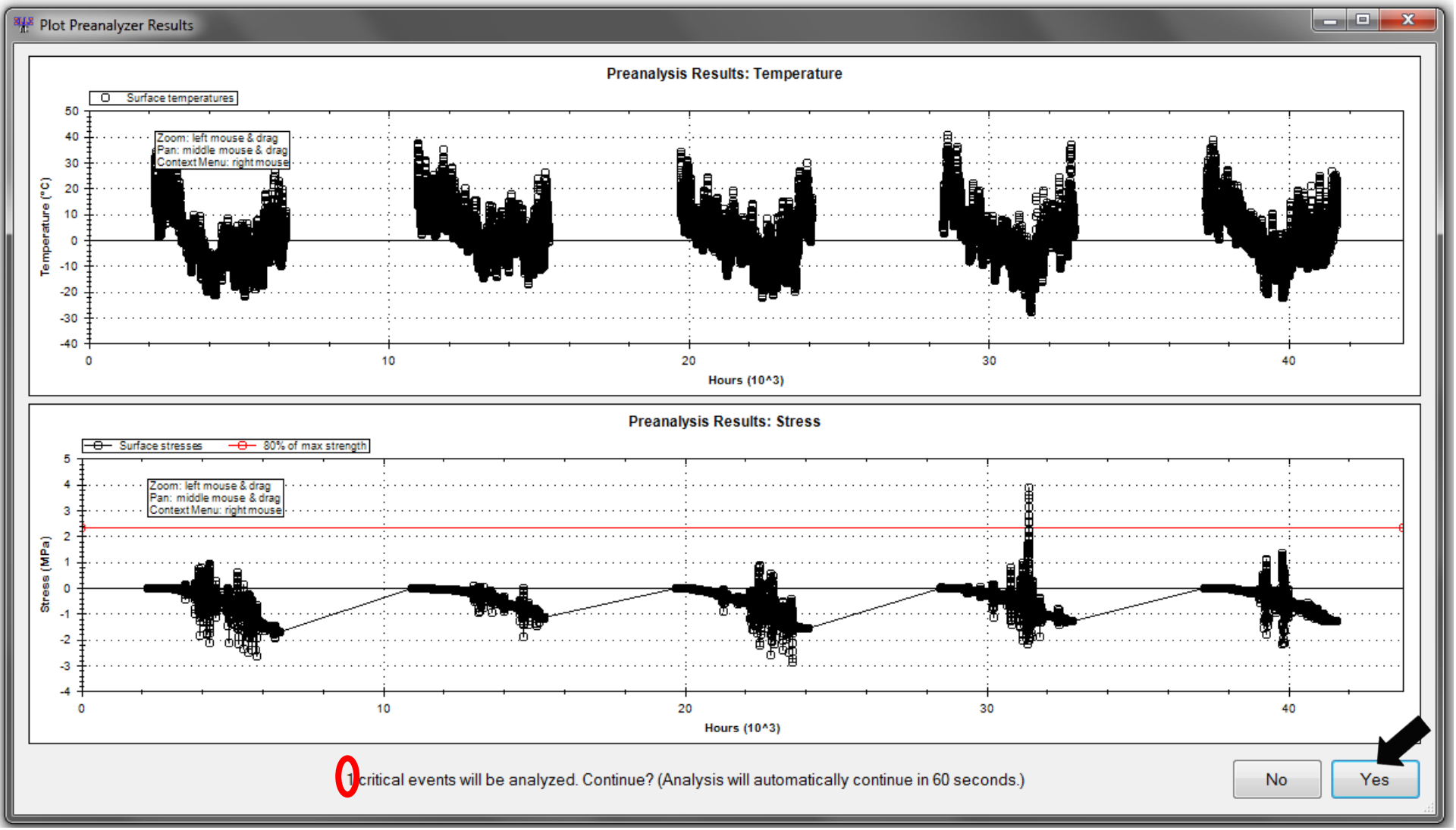

Visual LTC
Start
Project Inf
Asphalt Layer
Insert Asph
Base Layer Pr
Bas
Base
Base Th
Close
Add Asphalt Layer
User Type
Standard User
Advanced User
Asphalt Mixture
Select Asphalt Mixture:
Mixture Description:
IA-9
Mn Road Cell 19
Mn Road Cell 33
Mn Road Cell 34
Mn Road Cell 35
Import Existing Asphalt Mixture
Properties
Thickness:
in
Fracture Energy:
J/m²
Tensile Strength
Compute tensile strength from peak load
Input tensile strength directly
Peak IDT Load:
kN
Compute Tensile Strength
Tensile Strength:
MPa
Mixture Coefficient of Thermal Expansion (α)
Mixture VMA:
%
Compute mixture α from VMA and aggregate α
Input mix α directly
Aggregate α:
1/°C
Compute Mixture α
Mixture α:
mm/mm/°C
Creep Compliance Data
Units: 1/GPa
Amount of Data:
100 Second
1000 Second
Loading Time
Low Temp
°C
Mid Temp
°C
High Temp
°C
Cancel
Save mix as...
Done

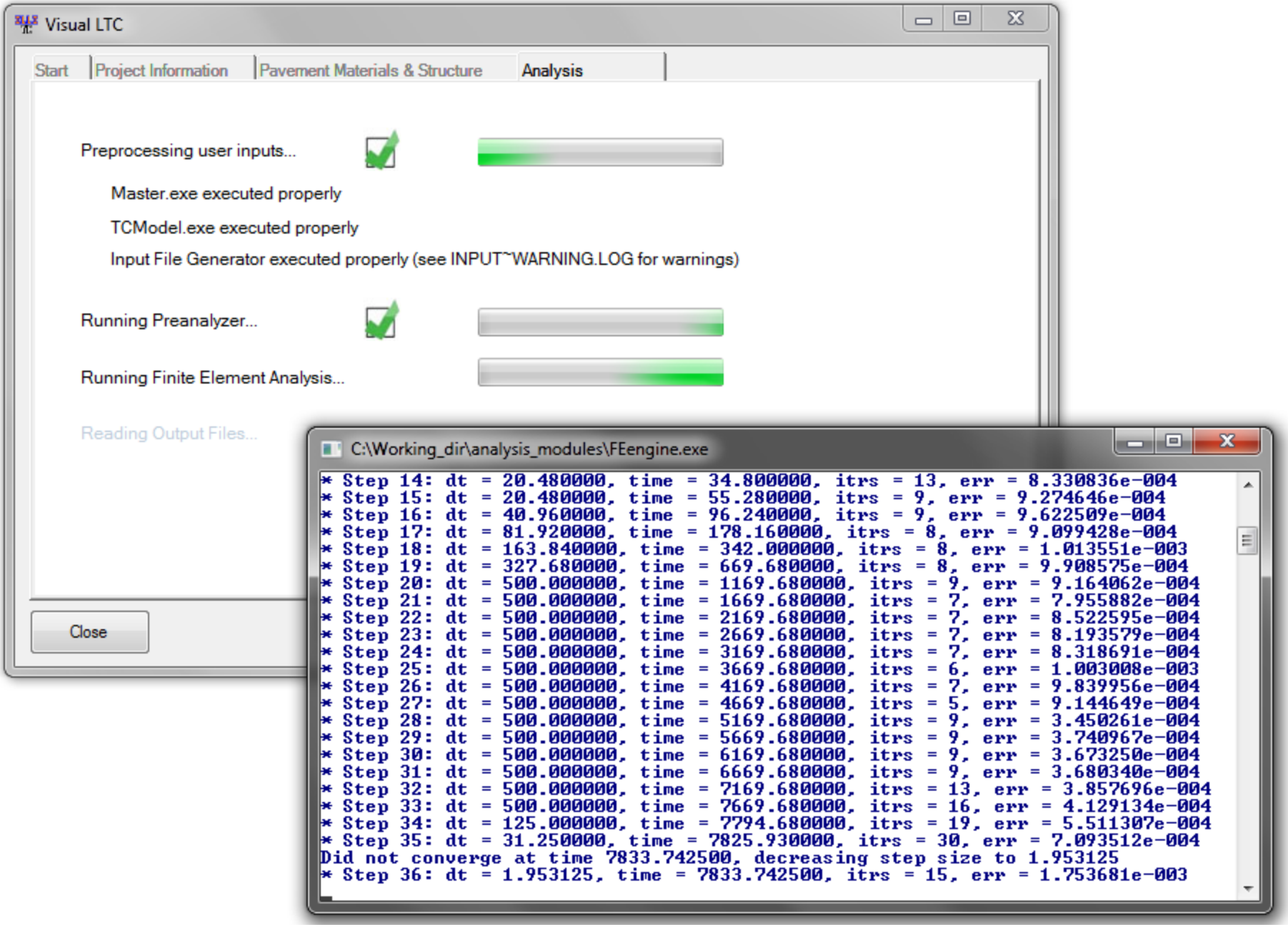

Visual LTC
Start
Project Inf
Asphalt Layer
Insert Asph
Base Layer Pr
Bas
Base
Base Th
Close
Add Asphalt Layer
User Type
Standard User
Advanced User
Asphalt Mixture
Select Asphalt Mixture:
IA-9
Mixture Description:
Sample Mix
Properties
Thickness:
6
in
3
4
5
6
7
8
9
10
12
14
16
Fracture Energy:
J/m²
Tensile Strength
Compute tensile s
peak load
Input tensile stren
Peak IDT Load:
Compute Tensile Strength
Tensile Strength:
2.9
Pa
Mixture Coefficient of Thermal Expansion (α)
Mixture VMA:
14.5
%
Compute mixture α from VMA and aggregate α
Input mix α directly
Aggregate α:
1/°C
Compute Mixture α
Mixture α:
2.435E-05
mm/mm/°C
Creep Compliance Data
Units: 1/GPa
Amount of Data:
100 Second
1000 Second
Loading Time
Low Temp -30 °C
Mid Temp -20 °C
High Temp -10 °C
1 3.500E-002 4.200E-002 4.700E-002
2 3.500E-002 4.400E-002 5.000E-002
5 3.600E-002 4.600E-002 5.500E-002
10 3.700E-002 4.800E-002 5.900E-002
20 3.800E-002 5.000E-002 6.400E-002
50 4.000E-002 5.300E-002 7.200E-002
100 4.200E-002 5.500E-002 8.000E-002
200 4.400E-002 5.800E-002 9.100E-002
Cancel
Save mix as...
Done

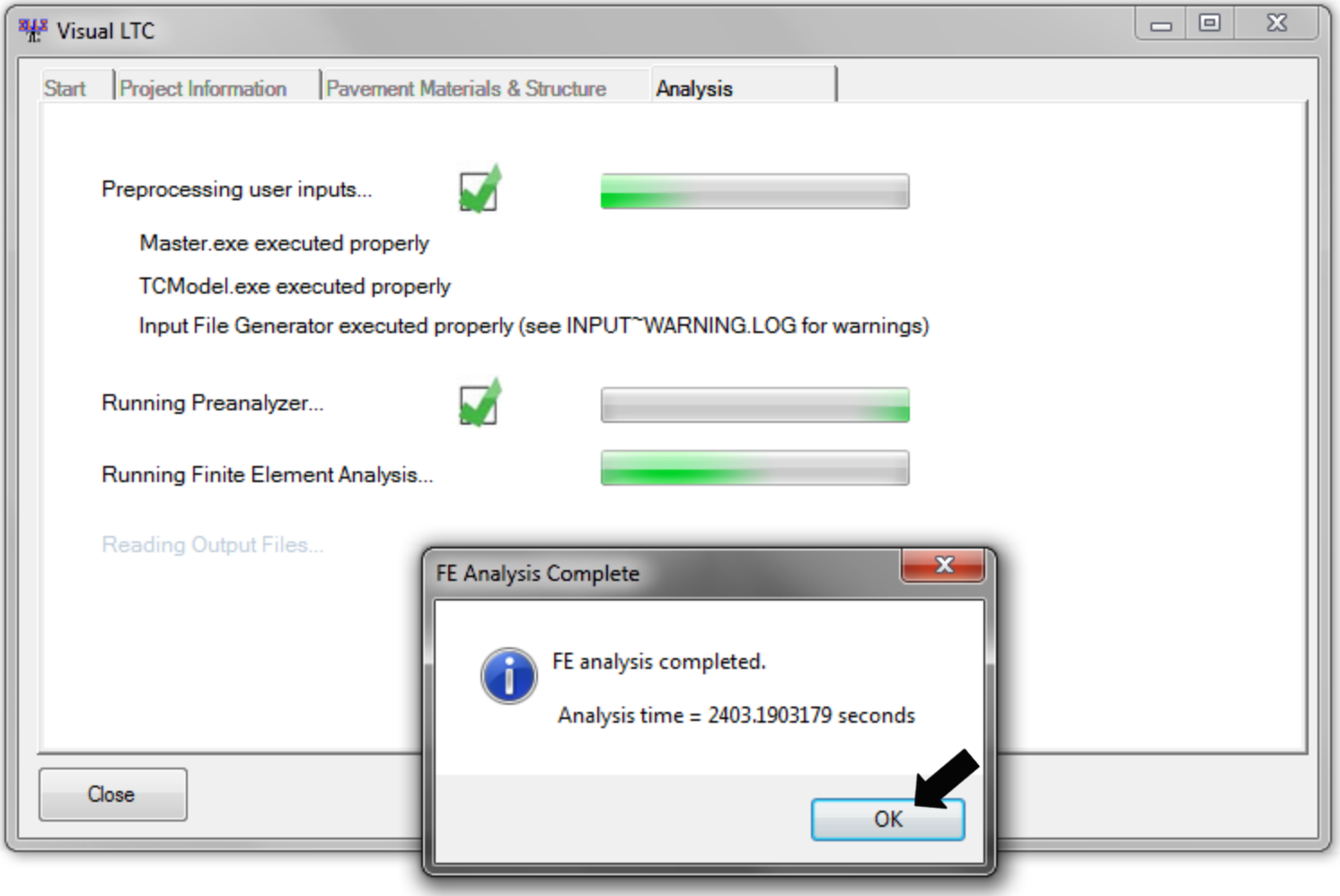

Add Asphalt Layer
User Type
Standard User
Advanced User
Asphalt Mixture
Select Asphalt Mixture:
IA-9
Mixture Description:
Sample Mix
Properties
Thickness:
6
in
Fracture Energy:
191.4
J/m²
Tensile Strength
Compute tensile strength from peak load
Input tensile strength directly
Peak IDT Load:
3.5
kN
Compute Tensile Strength
Tensile Strength:
2.9
MPa
Mixture Coefficient of Thermal Expansion (α)
Mixture VMA:
14.5
%
Compute mixture α from VMA and aggregate α
Input mix α directly
Aggregate α:
1/°C
Compute Mixture α
Mixture α:
2.435E-05
mm/mm/°C
Creep Compliance Data
Units: 1/GPa
Amount of Data:
100 Second
1000 Second
Loading Time
Low Temp -30 °C
Mid Temp -20 °C
High Temp -10 °C
1 3.500E-002 4.200E-002 4.700E-002
2 3.500E-002 4.400E-002 5.000E-002
5 3.600E-002 4.600E-002 5.500E-002
10 3.700E-002 4.800E-002 5.900E-002
20 3.800E-002 5.000E-002 6.400E-002
50 4.000E-002 5.300E-002 7.200E-002
100 4.200E-002 5.500E-002 8.000E-002
200 4.400E-002 5.800E-002 9.100E-002
Cancel
Save mix as...
Done
Visual LT
Start
Asphalt
Base La
Close

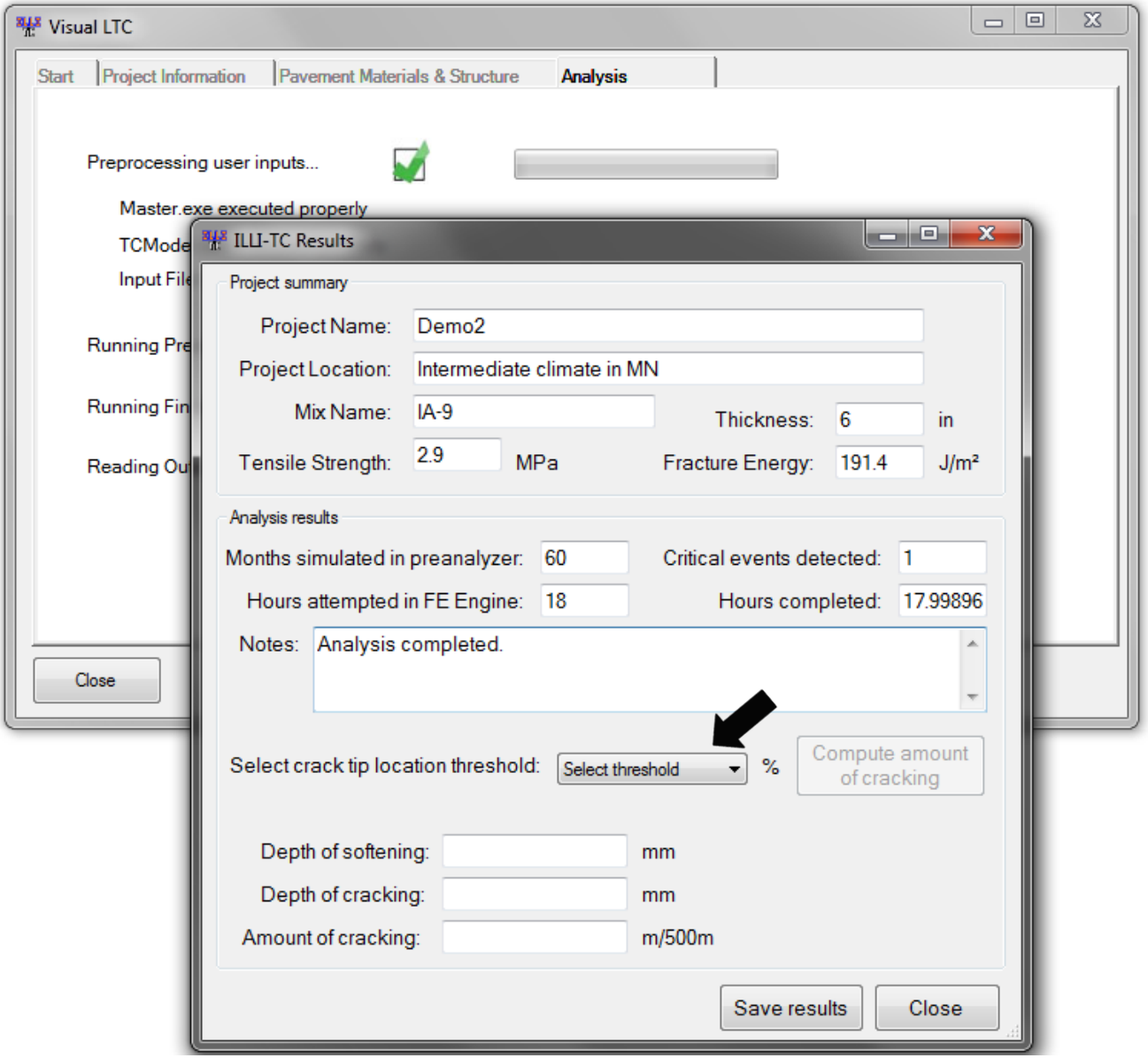

Visual LTC
Start
Project Information
Pavement Materials & Structure
Asphalt Layer Properties
Insert Asphalt Layer
Edit Asphat Layer
Clear Asphalt Layer
Mixture Name:
IA-9
Description:
Sample Mix
Thickness:
6
in
Mixture VMA:
14.5
%
Fracture Energy:
191.4
J/m²
Mixture alpha:
2.435E-05
mm/mm/°C
Tensile Strength:
2.9
MPa
Creep Compliance:
View Data
Base Layer Properties
Base Type:
Granular
Base Material:
Crushed gravel
Base Thickness:
12
in
Subgrade Properties
Subgrade Material:
A-7-5
Last Layer?:
yes
Close
Save Project
Back
Next
Run

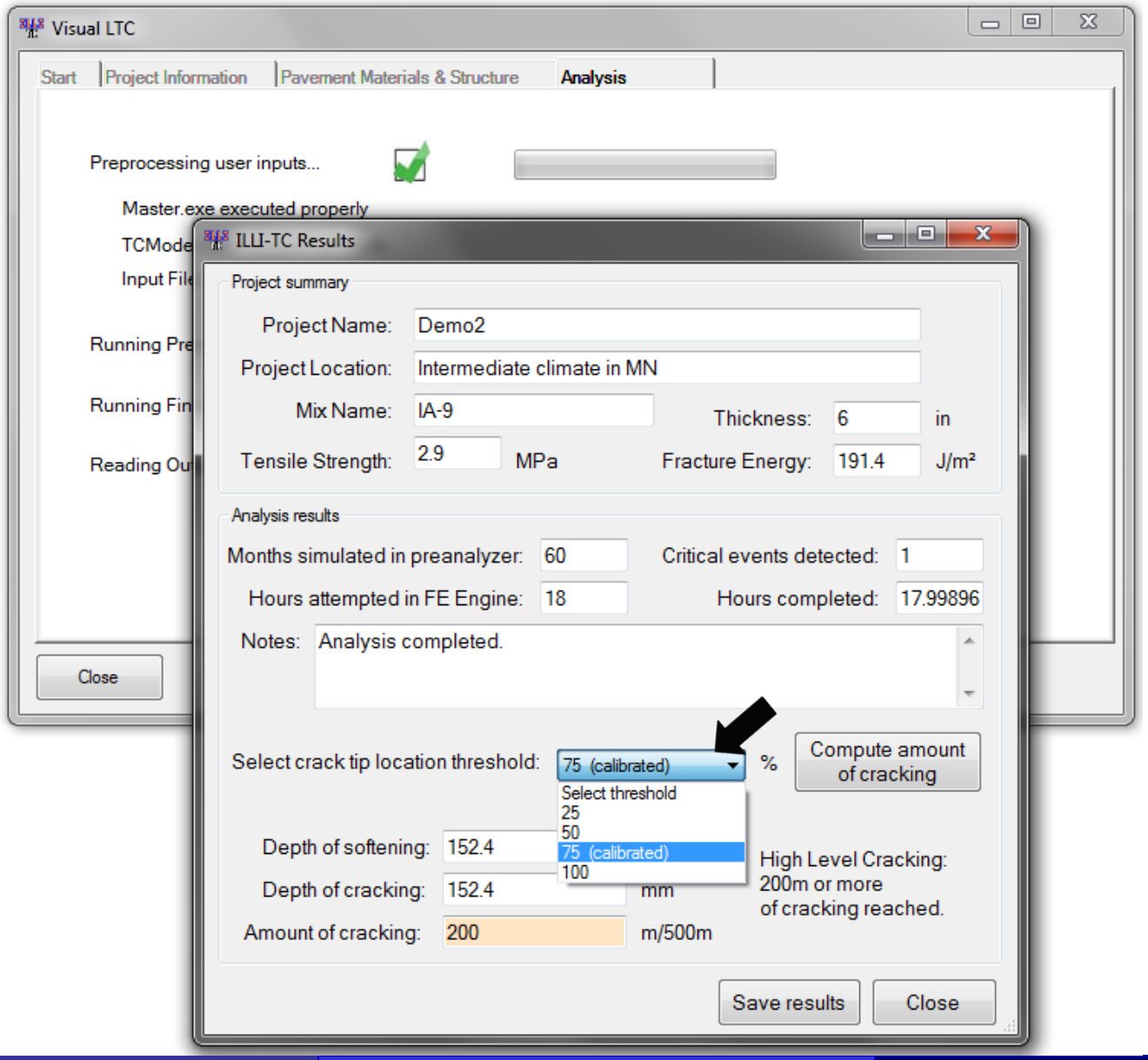

Visual LTC
Start
Project Information
Pavement Materials & Structure
Analysis
Preprocessing user inputs...
Master.exe executed properly
TCModel.exe executed properly
Input File Generator executed properly (see INPUT~WARNING.LOG for warnings)
Running Preanalyzer...
This may take several minutes...
Running Finite Element Analysis...
Reading Output Files...
Close

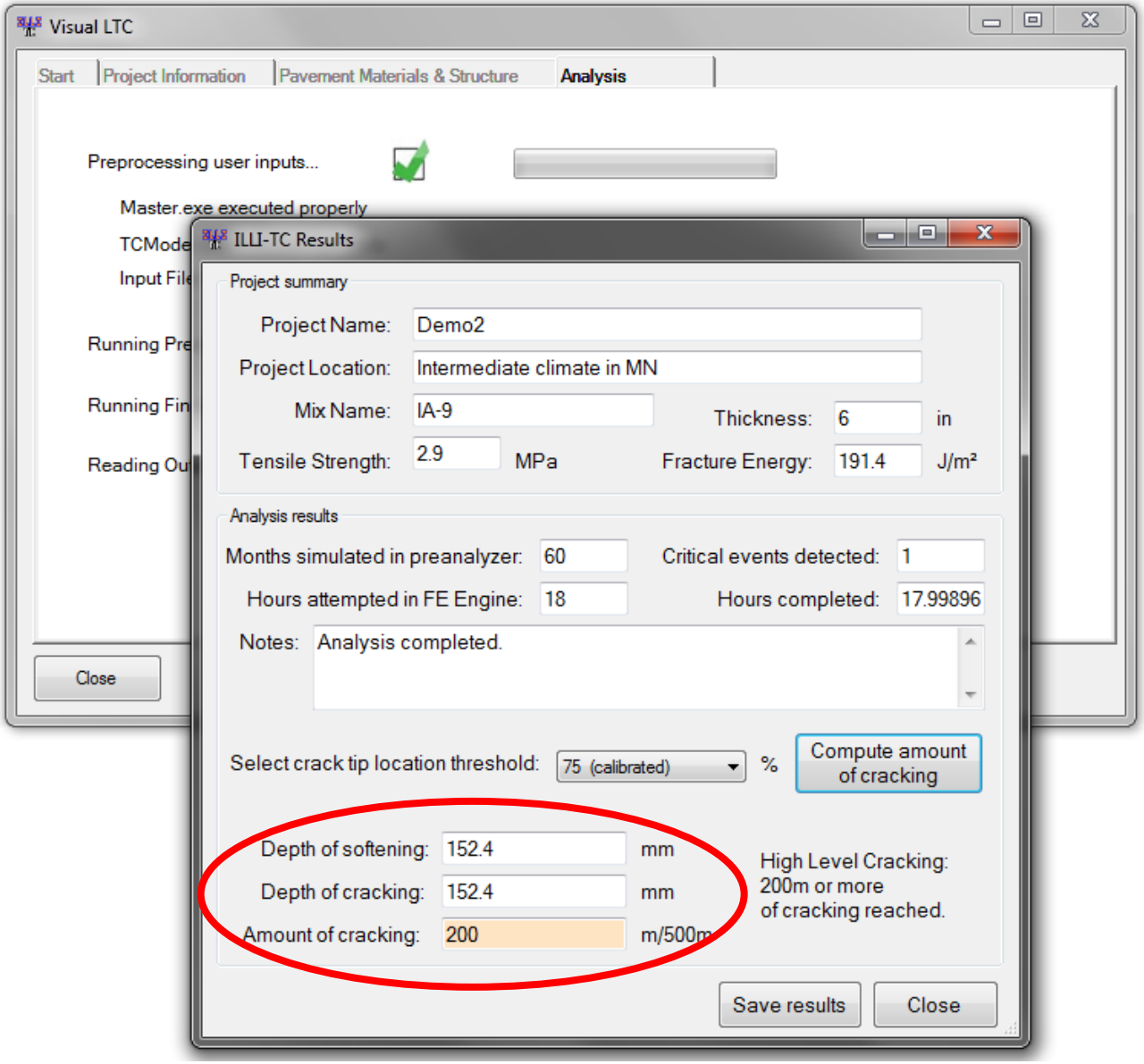

Plot Preanalyzer Results
Preanalysis Results: Temperature
Surface temperatures
Zoom: left mouse & drag
Pan: middle mouse & drag
Context Menu: right mouse
Temperature (°C)
Hours (10^3)
Preanalysis Results: Stress
Surface stresses
80% of max strength
Zoom: left mouse & drag
Pan: middle mouse & drag
Context Menu: right mouse
Stress (MPa)
Hours (10^3)
critical events will be analyzed. Continue? (Analysis will automatically continue in 60 seconds.)
No
Yes


Visual LTC
Start
Project Information
Pavement Materials & Structure
Analysis
Preprocessing user inputs...
Master.exe executed properly
TCModel.exe executed properly
Input File Generator executed properly (see INPUT~WARNING.LOG for warnings)
Running Preanalyzer...
Running Finite Element Analysis...
Reading Output Files...
Close
C:\Working_dir\analysis_modules\FEengine.exe
* Step 14: dt = 20.480000, time = 34.800000, itrs = 13, err = 8.330836e-004
* Step 15: dt = 20.480000, time = 55.280000, itrs = 9, err = 9.274646e-004
* Step 16: dt = 40.960000, time = 96.240000, itrs = 9, err = 9.622509e-004
* Step 17: dt = 81.920000, time = 178.160000, itrs = 8, err = 9.099428e-004
* Step 18: dt = 163.840000, time = 342.000000, itrs = 8, err = 1.013551e-003
* Step 19: dt = 327.680000, time = 669.680000, itrs = 8, err = 9.908575e-004
* Step 20: dt = 500.000000, time = 1169.680000, itrs = 9, err = 9.164062e-004
* Step 21: dt = 500.000000, time = 1669.680000, itrs = 7, err = 7.955882e-004
* Step 22: dt = 500.000000, time = 2169.680000, itrs = 7, err = 8.522595e-004
* Step 23: dt = 500.000000, time = 2669.680000, itrs = 7, err = 8.193579e-004
* Step 24: dt = 500.000000, time = 3169.680000, itrs = 7, err = 8.318691e-004
* Step 25: dt = 500.000000, time = 3669.680000, itrs = 6, err = 1.003008e-003
* Step 26: dt = 500.000000, time = 4169.680000, itrs = 7, err = 9.839956e-004
* Step 27: dt = 500.000000, time = 4669.680000, itrs = 5, err = 9.144649e-004
* Step 28: dt = 500.000000, time = 5169.680000, itrs = 9, err = 3.450261e-004
* Step 29: dt = 500.000000, time = 5669.680000, itrs = 9, err = 3.740967e-004
* Step 30: dt = 500.000000, time = 6169.680000, itrs = 9, err = 3.673250e-004
* Step 31: dt = 500.000000, time = 6669.680000, itrs = 9, err = 3.680340e-004
* Step 32: dt = 500.000000, time = 7169.680000, itrs = 13, err = 3.857696e-004
* Step 33: dt = 500.000000, time = 7669.680000, itrs = 16, err = 4.129134e-004
* Step 34: dt = 125.000000, time = 7794.680000, itrs = 19, err = 5.511307e-004
* Step 35: dt = 31.250000, time = 7825.930000, itrs = 30, err = 7.093512e-004
Did not converge at time 7833.742500, decreasing step size to 1.953125
* Step 36: dt = 1.953125, time = 7833.742500, itrs = 15, err = 1.753681e-003


Visual LTC
Start
Project Information
Pavement Materials & Structure
Analysis
Preprocessing user inputs...
Master.exe executed properly
TCModel.exe executed properly
Input File Generator executed properly (see INPUT~WARNING.LOG for warnings)
Running Preanalyzer...
Running Finite Element Analysis...
Reading Output Files...
Close
FE Analysis Complete
FE analysis completed.
Analysis time = 2403.1903179 seconds
OK


Visual LTC
Start
Project Information
Pavement Materials & Structure
Analysis
Preprocessing user inputs...
Master.exe executed properly
TCMode
Input File
Running Pre
Running Fin
Reading Ou
Close
ILLI-TC Results
Project summary
Project Name: Demo2
Project Location: Intermediate climate in MN
Mix Name: IA-9
Thickness: 6 in
Tensile Strength: 2.9 MPa
Fracture Energy: 191.4 J/m²
Analysis results
Months simulated in preanalyzer: 60
Critical events detected: 1
Hours attempted in FE Engine: 18
Hours completed: 17.99896
Notes: Analysis completed.
Select crack tip location threshold: Select threshold %
Compute amount of cracking
Depth of softening: mm
Depth of cracking: mm
Amount of cracking: m/500m
Save results
Close


Visual LTC
Start
Project Information
Pavement Materials & Structure
Analysis
Preprocessing user inputs...
Master.exe executed properly
TCMode
Input File
Running Pre
Running Fin
Reading Ou
Close
ILLI-TC Results
Project summary
Project Name: Demo2
Project Location: Intermediate climate in MN
Mix Name: IA-9
Thickness: 6 in
Tensile Strength: 2.9 MPa
Fracture Energy: 191.4 J/m²
Analysis results
Months simulated in preanalyzer: 60
Critical events detected: 1
Hours attempted in FE Engine: 18
Hours completed: 17.99896
Notes: Analysis completed.
Select crack tip location threshold: 75 (calibrated) %
Compute amount of cracking
Select threshold
25
50
75 (calibrated)
100
Depth of softening: 152.4
Depth of cracking: 152.4 mm
Amount of cracking: 200 m/500m
High Level Cracking: 200m or more of cracking reached.
Save results
Close


Visual LTC
Start
Project Information
Pavement Materials & Structure
Analysis
Preprocessing user inputs...
Master.exe executed properly
TCMode
Input File
Running Pre
Running Fin
Reading Ou
Close
ILLI-TC Results
Project summary
Project Name: Demo2
Project Location: Intermediate climate in MN
Mix Name: IA-9
Thickness: 6 in
Tensile Strength: 2.9 MPa
Fracture Energy: 191.4 J/m²
Analysis results
Months simulated in preanalyzer: 60
Critical events detected: 1
Hours attempted in FE Engine: 18
Hours completed: 17.99896
Notes: Analysis completed.
Select crack tip location threshold: 75 (calibrated) %
Compute amount of cracking
Depth of softening: 152.4 mm
Depth of cracking: 152.4 mm
Amount of cracking: 200 m/500m
High Level Cracking: 200m or more of cracking reached.
Save results
Close

Thank you for your attention

- **Questions?**

- **Acknowledgements**
  - Kyoungsoo Park
  - Huiming Yin
  - Behzad Behnia
  - Steven Gresk