### **University of Illinois Update**

#### **Pooled Fund - LTC TAP Meeting**

October 5, 2011 Northland Inn, Minneapolis, MN

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10/5/2011

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

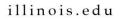


## Specimens Received July 27, 2011

- 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°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

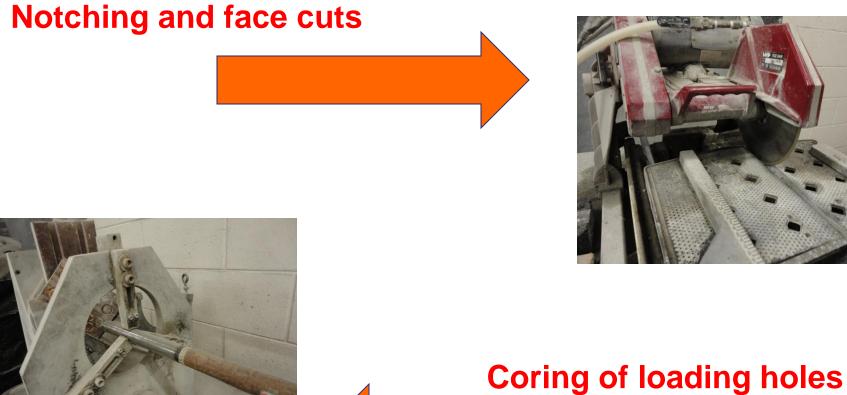
- Warm mix (PG58-28)
  - Reinke's warm mix w/ RAP and antistrip
- MIF RAP (PG58-34)
   12.5mm and 19mm
- MIF Virgin (PG58-34)
  - 12.5mm and 19mm

TEST TEMPERATURE IS PGLT AND PGLT+10 (All tests to be completed by 10/31/11)



Olmsted Co: \*Rd104 \*\*Rd112

## Fabrication



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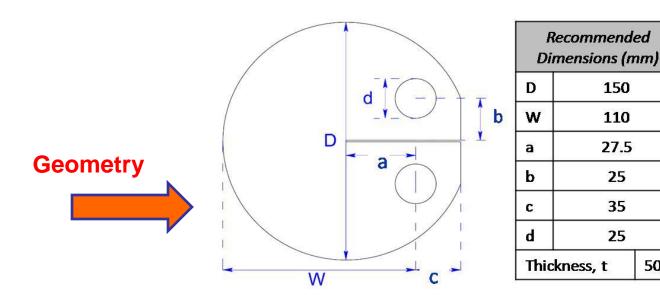
# Testing

25

35

25

50

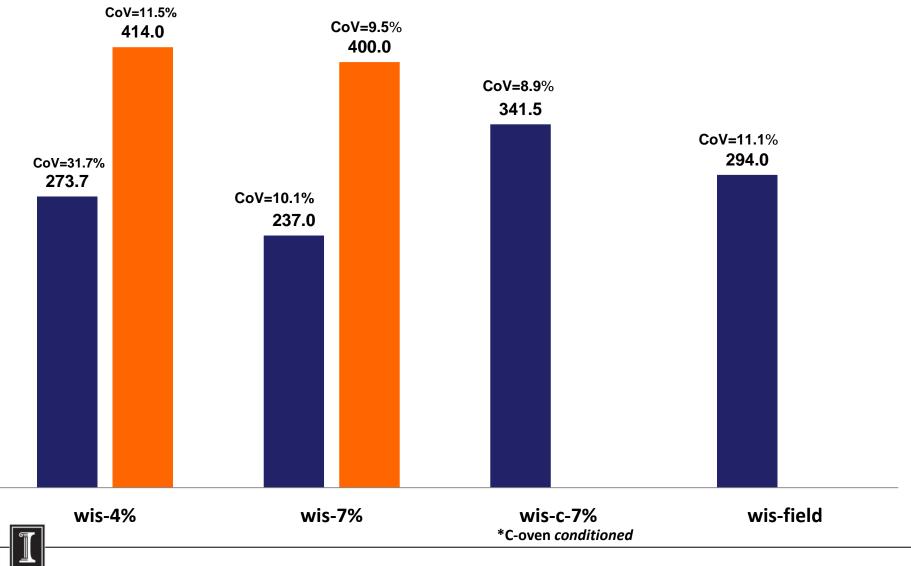




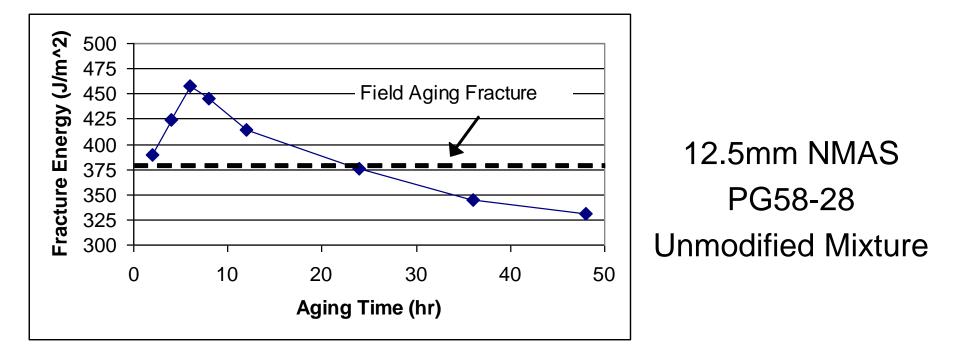
Instron 8500 servo-hydraulic load frame with an environmental chamber capable of controlling the temperature from 30°C to -30°C

#### Fracture energy of Wisconsin mix, J/m<sup>2</sup>

average CMOD Fracture Energy@-22C average CMOD Fracture Energy @-12C



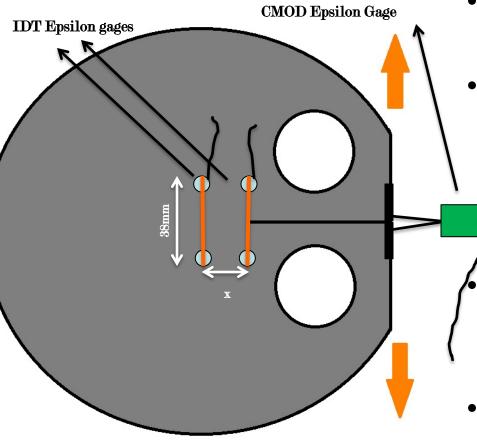
### **Influence of Aging on Mixture Fracture Energy**



Demonstrates that Fracture Energy can First Increase, then Decrease with Aging. However, Creep Compliance Simply Decreases with Aging.

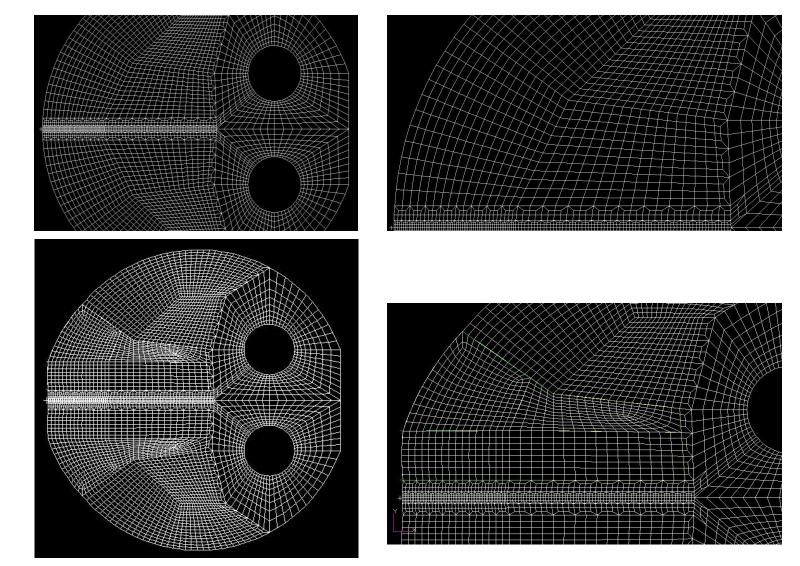
(AAPT, Braham et al., 2009)

# 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



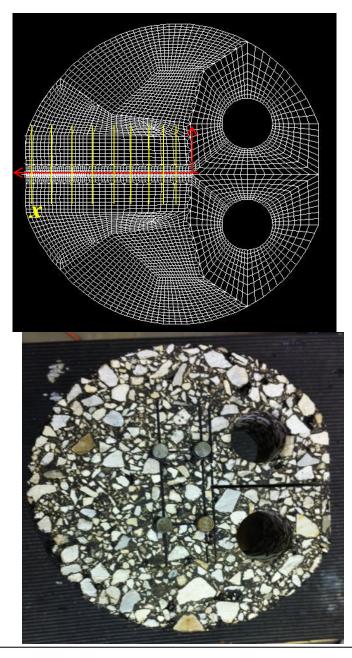
Old model

#### 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

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

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

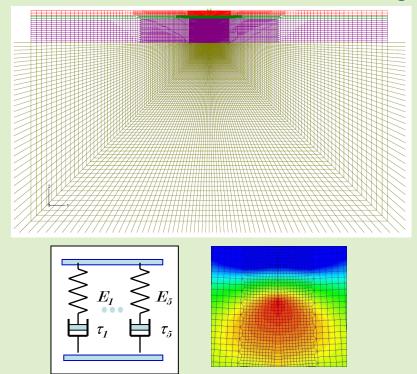
• Paris 'Law'  $\Delta C = A(\Delta K)^{n}$ • Change in stress intensity factor Fracture parameters Change in crack depth

#### 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

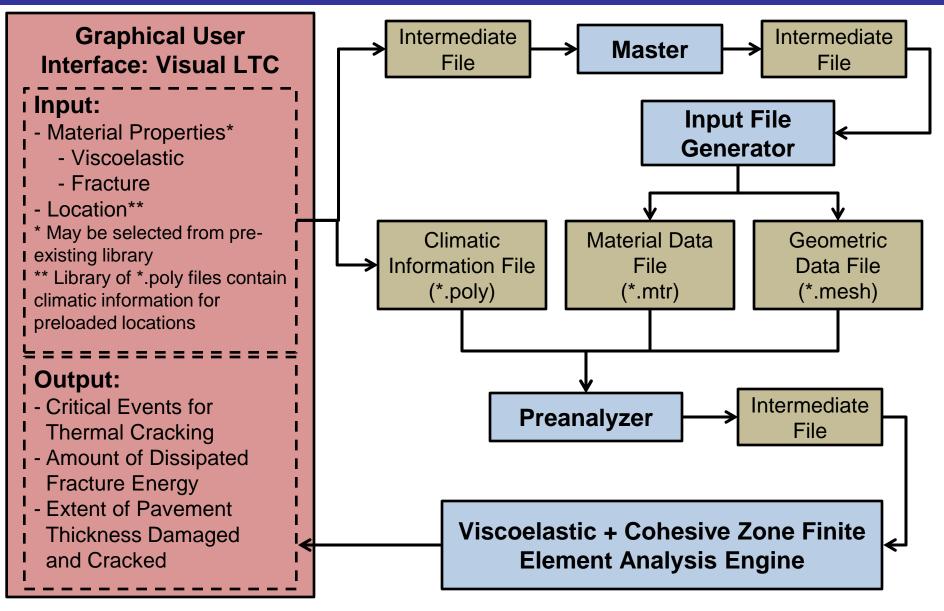
- Develop and Verify Viscoelastic Finite Element Code
- Develop and Verify Cohesive Zone Fracture FE Code
- Develop Input File Generator
- Collect and Assemble Climatic Files
- Develop and Verify Preanalysis Module
- Combine Viscoelastic and CZ FE Codes and Verify
- Develop Graphical User Interface (in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

#### Completed/Reported

Completed

**Underway** 

### **ILLI-TC Components**



#### 10/7/2011

#### Low Temperature Cracking

#### **1. Collection and Assembly of Climatic Files**

#### Climatic data from participating states was collected

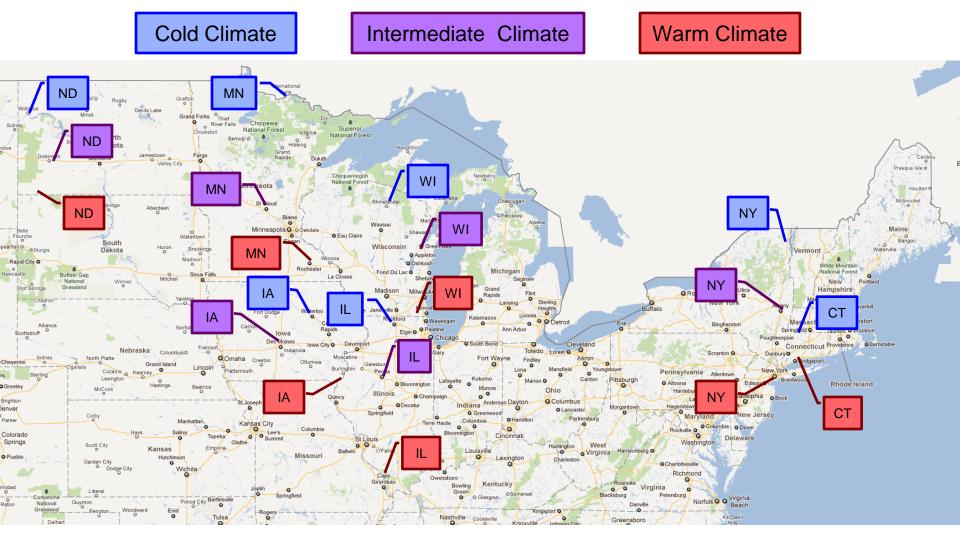
- Climatic data file repository for AASHTO MEPDG
- Two or Three locations for each of the participating states
  - Cold, Intermediate and Warm
  - Two locations for Connecticut, three for all other states
  - 7 States = 21 Climatic Conditions

#### 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.



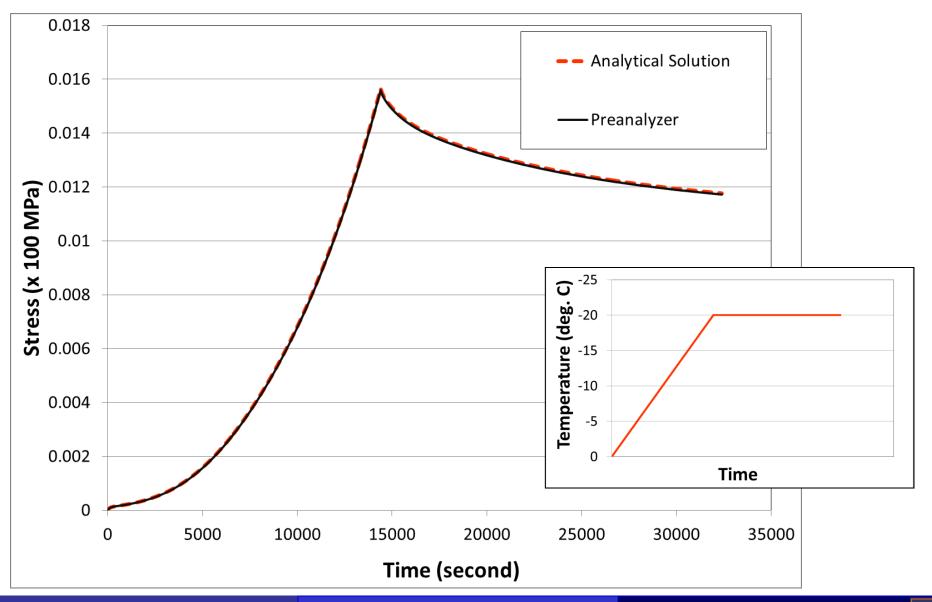
#### 10/7/2011

#### Low Temperature Cracking

### 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

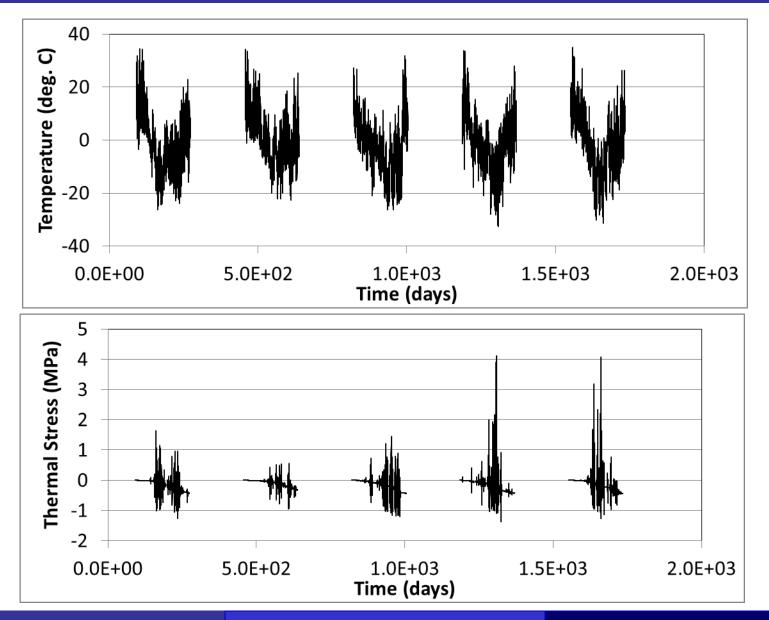
### 2. Preanalysis Module: Verification



10/7/2011

Low Temperature Cracking

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



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### 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)

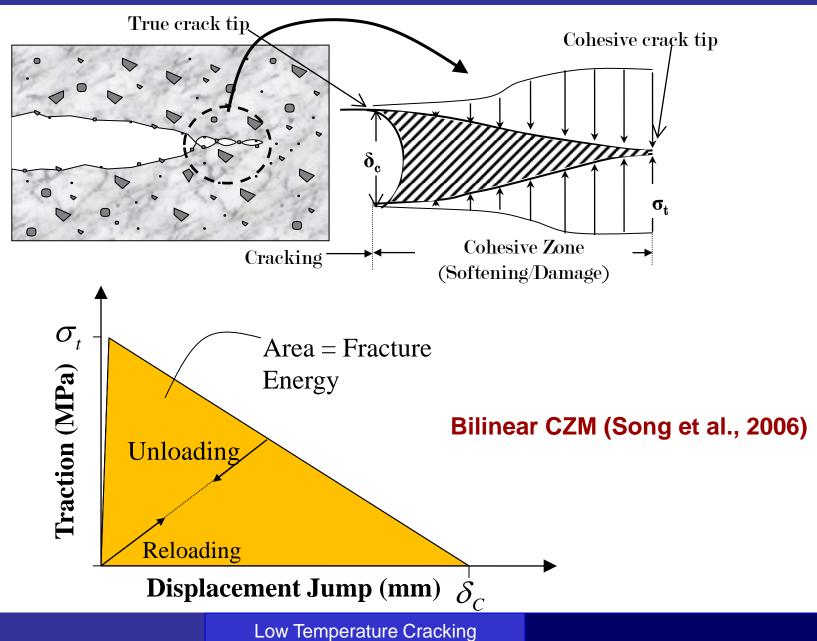
# Individual components have been implemented and verified

- 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**

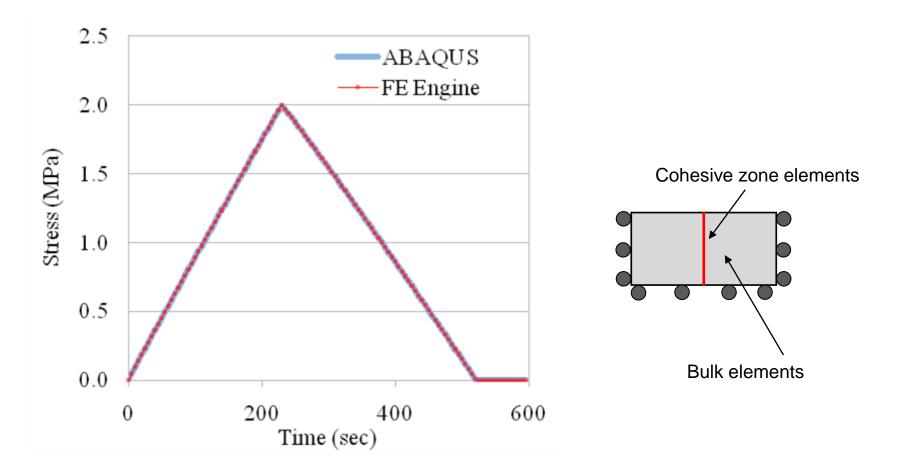
- Cohesive zone model (CZM) is a computationally efficient and effective way of modeling damage and cracking in asphalt concrete
- CZM Capabilities:
  - Softening (damage)
  - Complete separation (difficult with continuum type models)
  - Captures the length scale associated with fracture process

### 3. FEAE: Bilinear Cohesive Zone Model



### **3. FEAE: Verification Example**

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



#### □ Start

• Visual LTC	
Start Project Information Pavement Materials & Structure Welcome to Visual LTC: The low temperature crackin	g in asphalt pavements analysis tool
Create New Project	
Open Existing Project	Browse For Folder
Close	Working Directory should contain a folder called "hcd" with dimatic data files and a folder called "files" to hold the ICM output files. <ul> <li>Desktop</li> <li>Libraries</li> <li>Administrator</li> <li>Administrator</li> <li>Computer</li> <li>Network</li> <li>Control Panel</li> <li>Recycle Bin</li> <li>ILLI-TC</li> <li>Test Directory_v2</li> <li>climatic</li> </ul> Make New Folder OK



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# Start Project Information

🖳 Visual LTC		
Start Project Information	Pavement Materials & Structure	
General Information Project Name: Project Description:	MN lintermediate Analysis Comparison - Mix 1	
Analyzed By:	SL Date October 05, 20	11 💵
Working Directory:	C:\Users\Administrator\Desktop\Test Directory_v2	Browse
Project Location State MN - Zone Intermediate	Analysis Period	
Close Save Pro	oject Back Next	Run



Start	🖳 Visual LTC		
<ul> <li>Project</li> <li>Information</li> <li>Plot</li> </ul>	Start Project Information General Information Project Name: Project Description:	MN lintermediate	
temperatur	Analyzed By:	SL	Date October 05, 2011
Plot Temperatures 70 60 50 Pan: middle mouse & drag Context Menu: right mouse 40 9 10 -10 -20 -40 January, Year 02	Air Tempe 6°C at 6 AM on Feb 04, Year 02 January, Year 0	erature for Intermediate Climate in MN	January, Year 05
			Close

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 Start
 Project Information
 Plot temperature
 Pavement

materials & structure

 Insert Asphalt Layer

🖳 Visual LTC								1
Start Project Informa	tion Pavement Materials &	Structure	]					
Asphalt Layer Properties								
Insert Asphalt L	ayer Edit Asphat La	ayer	Clear Asphalt Laye	r )				
	🖳 Add Asphalt Layer	and a						- 0 <b>x</b>
•	User Type	Aspha	It Mixture					
	Ma Decid Call 24					•		
	<ul> <li>Standard Oser</li> <li>Advanced User</li> </ul>		ct Asphalt Mixture:		mala Mix 2			
	Advanced User	N	lixture Description:	Sar	mple Mix 2			<u> </u>
Therm								<b>T</b>
	Editable Properties							
Cree	Thickness:	→ in	Tensile Strength:	350	MPa Fra	cture Ene	ergy: 400	J/m²
Base Layer Proper	-							
Base T	6				Compute mix co	officiento	f thermal ex	cpansion (α)
Base Mate	Unit V 7	48	g/cm³		Mixture VMA:	19.5	%	
Base Thickn	Thermal Condi 9	67	BTU/hr-ft °F		Aggregate α:	2.78E-0	6 mm/m	m/°C
Buse minim	Heat Ca 12	23	BTU/Ib-°F		Mixture α:	2.67E-0	5 mm/m	m/°C
	Creep Compliance Dat							
Close Sav		Loading		_			_	
	Units: 1/GPa	Time	Low Temp -20	°C	Mid Temp -10	°C Hig	h Temp (	- 0° (
	Amount of Data: 100 Second	1	2.340E-002		3.160E-002		4.660E-00	02
	<ul> <li>100 Second</li> <li>1000 Second</li> </ul>	2	2.400E-002		3.380E-002		1.900E-00	03
	I 1000 Second	5	2.500E-002		3.710E-002		6.140E-00	02 ≡
		10	2.600E-002		4.000E-002		7.100E-00	02
		20	2.700E-002		4.300E-002		8.400E-00	02
		50	2.900E-002		5.000E-002		1.060E-00	01
		100	3.000E-002		5.400E-002		1.310E-00	01
		200	3.200E-002		5.600E-002		1.560E-00	01 +
		F00	2 5005 002		0 7005 000		2 1 405 00	
	Cancel							Done
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- □ Start
- Project Information
  - Plot temperature
- Pavement
   materials &
   structure
- Run

🖳 Visual LTC					- • ×		
Start Project Information Pavement Materials & Structure							
Asphalt Layer Properties							
Insert Asphalt Layer Edit Asphat Layer Clear Asphalt Layer							
Mixture Name:	34						
Description: Sample Mix 2					*		
Thickness:	5	in	Mixture VMA:	19.5	%		
Unit Weight	148	g/cm³	Aggregate alpha:	2.78E-06	mm/mm/°C		
Thermal Conductivity: 0.67		BTU/hr-ft °F	Mixture alpha:	2.67E-05	mm/mm/°C		
Heat Capacity: 0.23		BTU/lb-°F	Fracture Energy:	400	MPa		
Creep Compliance: View Da			Tensile Strength:	350	J/m²		
Base Layer Properties		Sub	grade Properties		1		
Base Type: Granula	r		Subgrade Material: A-7-5				
Base Material: Fill this i	n		Last Layer?:	yes			
Base Thickness: 12	in						
Close Save Project			Back	Next	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

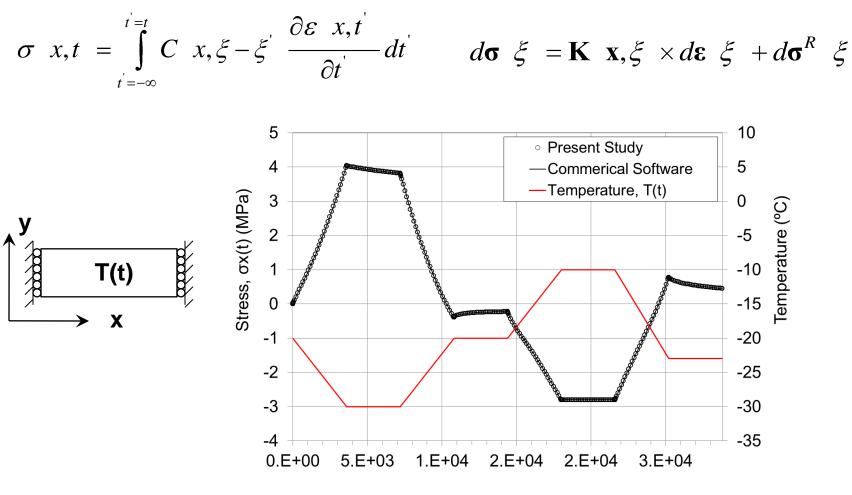
- Practitioners
- Access to all existing mixes
- Default mix properties can be viewed but not changed

#### 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



Time (sec)