

Reflective Cracking: Initiation and Propagation Mechanisms



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MAIREPAV5, August 07



Outline

- Introduction: Cracking and Pavement Loading
- Reflective Cracking Mechanism
- Numerical Modeling
 - Fracture beam
 - Full-scale
- Interlayer Systems
- Reflective Cracking Assessment
- Summary

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INTRODUCTION

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Causes of Cracks

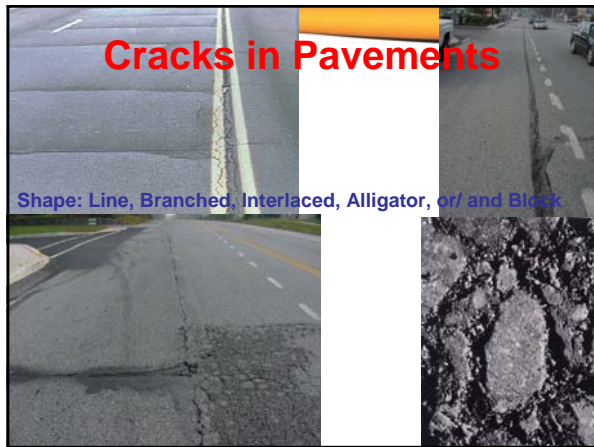
- Fatigue
- Thermal
 - Concrete, flexible, and composite pavements
- Surface stresses
- Lack of bearing support
 - Under-design, poor drainage, or settlement
- **Exiting discontinuities**
 - Cracks, joints, widening,



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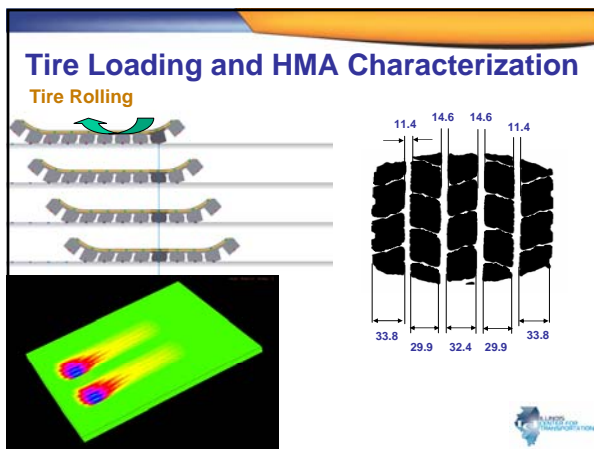
Cracks in Pavements

Shape: Line, Branched, Interlaced, Alligator, or/ and Block

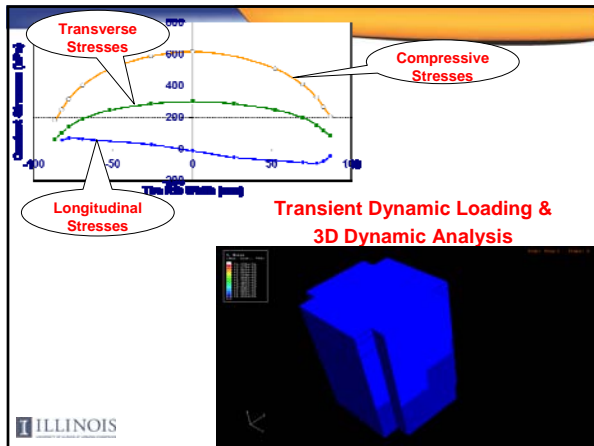


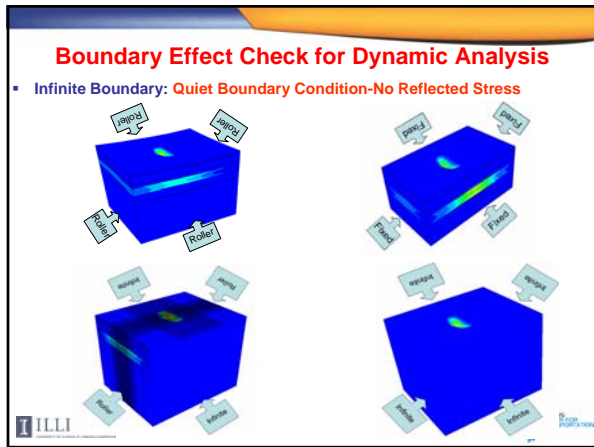
Tire Loading and HMA Characterization

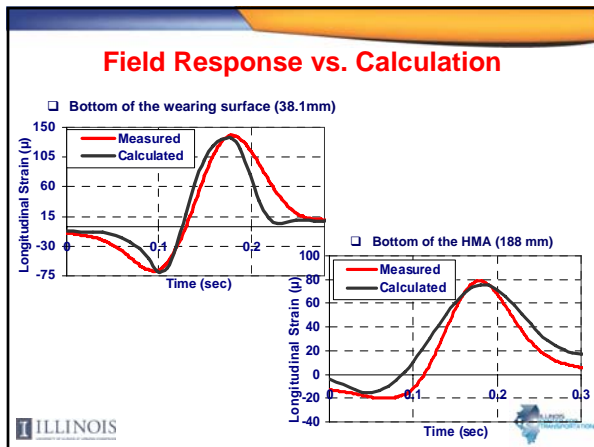
Tire Rolling

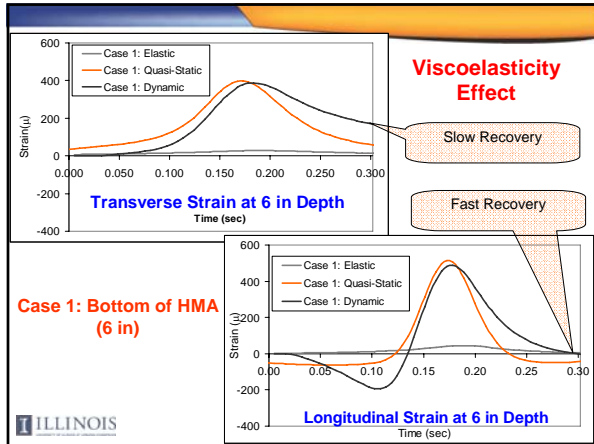


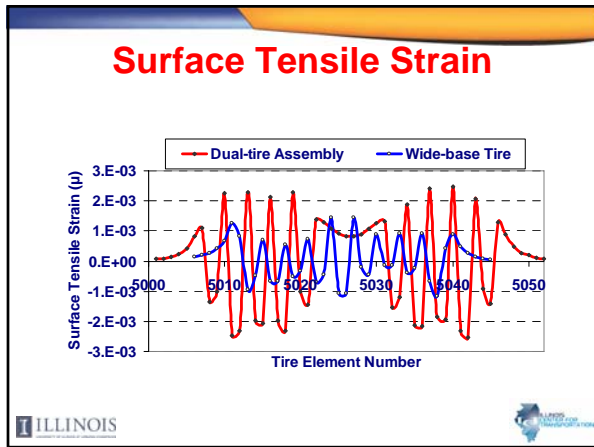
11.4	14.6	14.6	11.4	
33.8	29.9	32.4	29.9	33.8

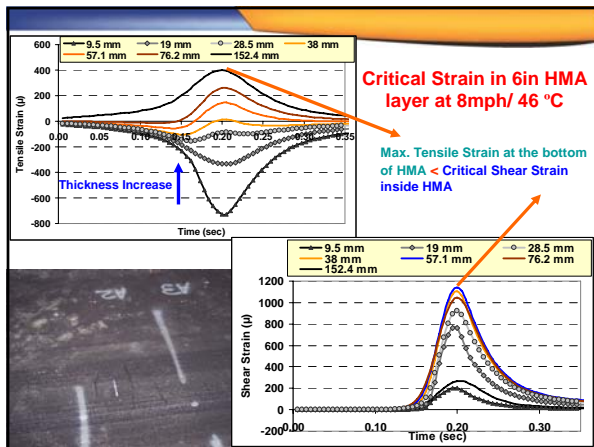















REFLECTIVE CRACKING MECHNISMS





Reflective Cracking


- Major distress in HMA overlays
- Reflection from existing discontinuities
 - Joint, crack, patch, or edge
- Environmental and vehicular loading
- Premature cracking within 2-3 years
- Transverse and longitudinal directions





Reflection from a joint



Reflection from a patch




Reflection from an edge





Reflective Cracking Mechanisms


Cause	Result	Type
Vehicle Loading	Crack opening Shear failure	Mode I Mode II Mixed mode
Seasonal Variation	Crack opening	Mode I





Mode I
(Opening)



Mode II
(Sliding)



Mode III
(Tearing)

Main Causes: Traffic

- **Crack opening (Mixed mode)**

Bending stress

Shear stress

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Thermal Cracking Test (Mode I)

Asphalt overlay
Interlayer
Concrete layer

Crack length in the overlay (mm)	Time (hours)
0	0
1	10
2	20
3	30
4	40
5	50
6	60
7	70

- 18°C
Type I
6.3 mm

0	without interlayer	3A	geogrid - plastic fibre 1
1A	surrounds bonded with an emulsion	3B	geogrid - plastic fibre 2, glass fibre 1
1B	surrounds bonded with pure bitumen	3C	geogrid - glass fibre 2
1C	surrounds bonded with polymer bitumen	4	SAMI
2	steel reinforcing netting	5	reference

Crack Development

Vertic. Propag.

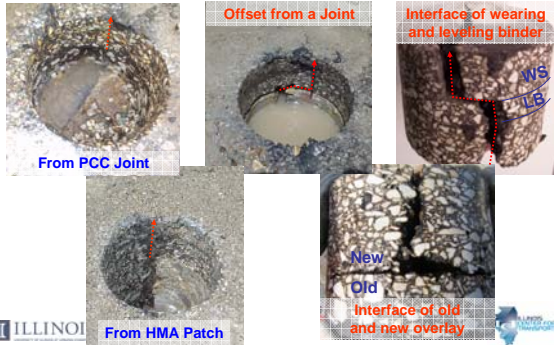
Horiz. Propag.

Bonded Interface

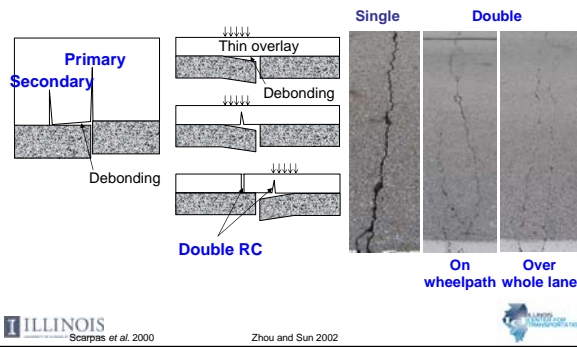
Debonded Interface

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Various RC Propagation



Single or Double RC (Thin Overlay)



REFLECTIVE CRACKING MODELING

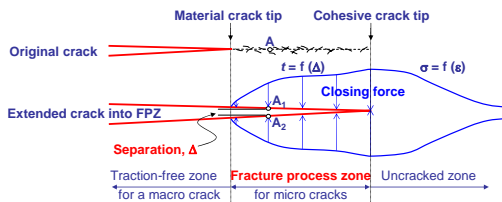
HMA Reflective Cracking Modeling

- **Beam Model**
 - Fast crack development
 - Reinforced pavement/ SAMI
- **Full-scale HMA Overlaid Pavement Model**
 - Various conditions can be considered
 - Evaluation of interlayer systems

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Cohesive Zone Model (CZM)



CZM simu.
with Tractor

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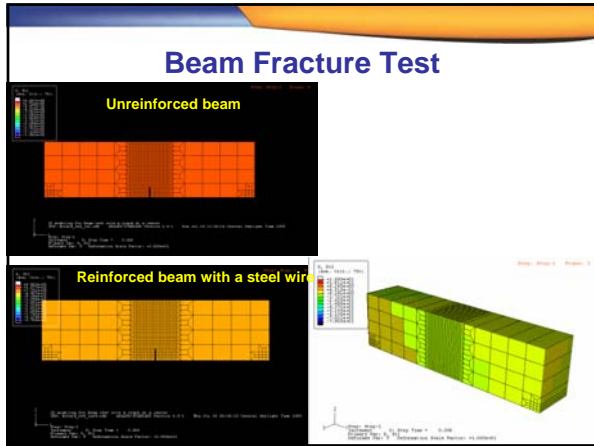


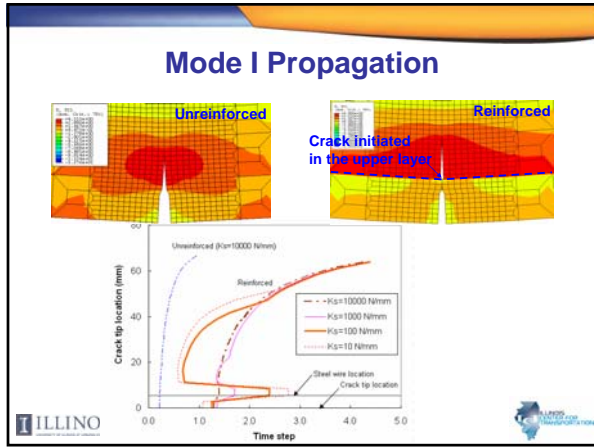
CZM in HMA Modeling

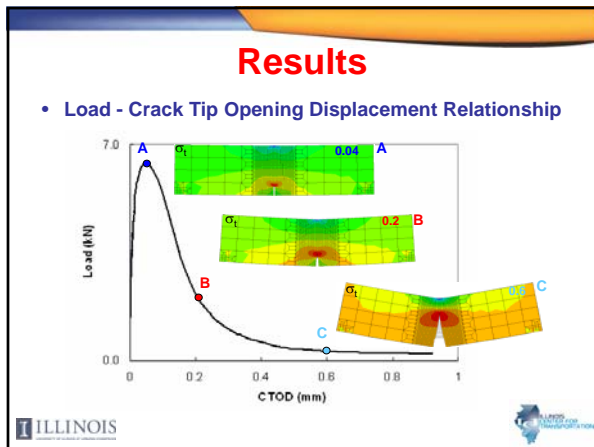
- Hillerborg *et al.* (1976): A fictitious crack model for concrete (brittle material)
- Jenq and Perng (1991): CZM for HMA as a viscoelastic material
- Soares *et al.* (2003): Extended CZM for heterogeneity
- Paulino *et al.* (2004): Intrinsic CZM in FEM
- Song *et al.* (2005): Bilinear CZM to resolve compliance problem
- Abaqus (2005): Cohesive interface element
- Baek and Al-Qadi (2006): Viscoelastic for bulk but elastic fracture property for the cohesive elements

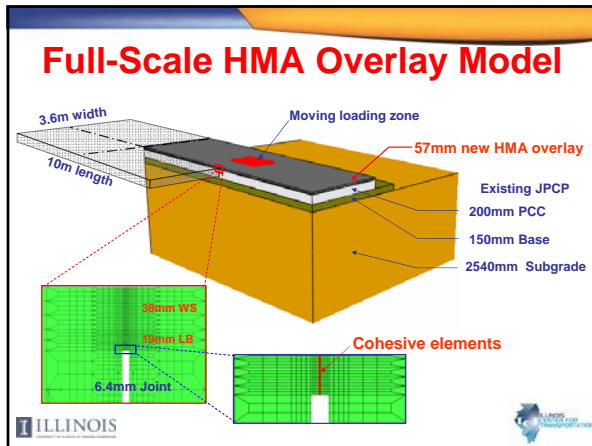
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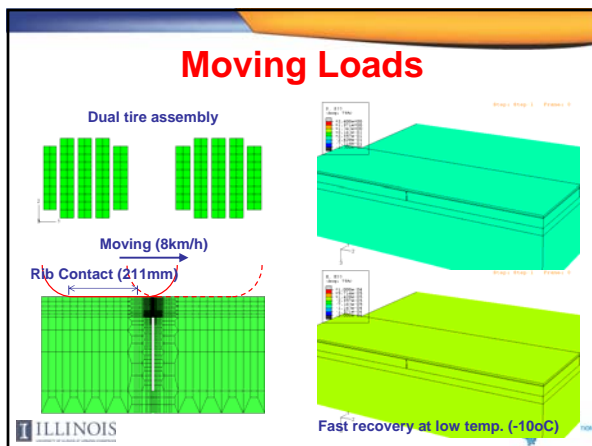


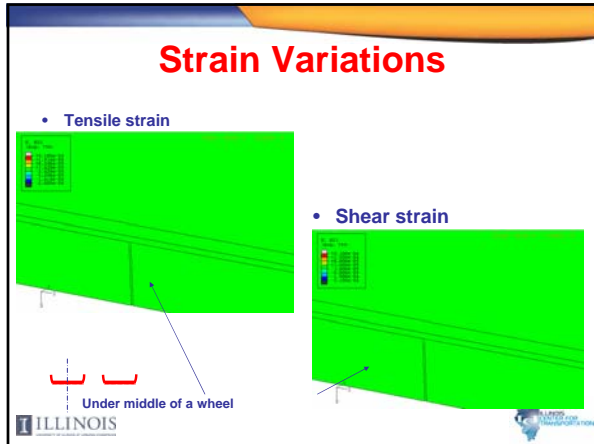


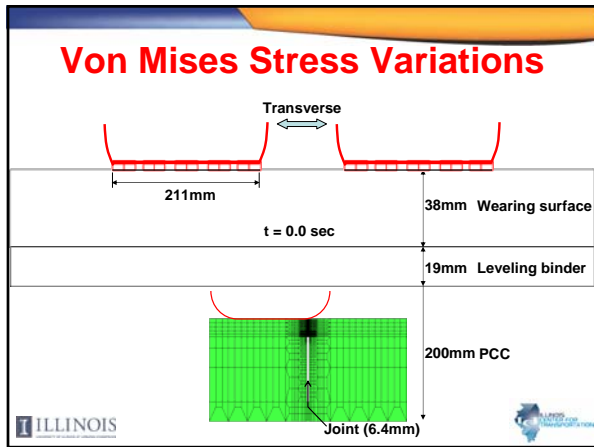


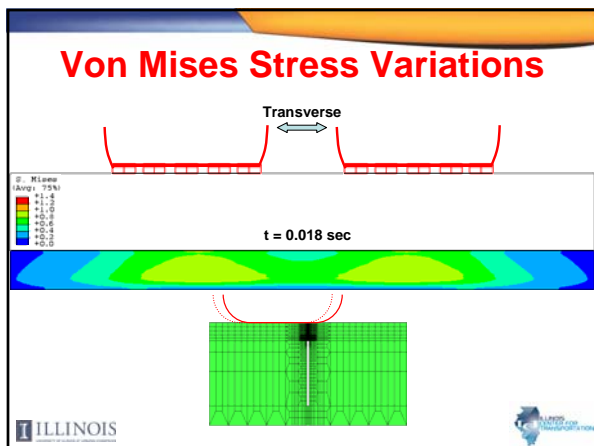


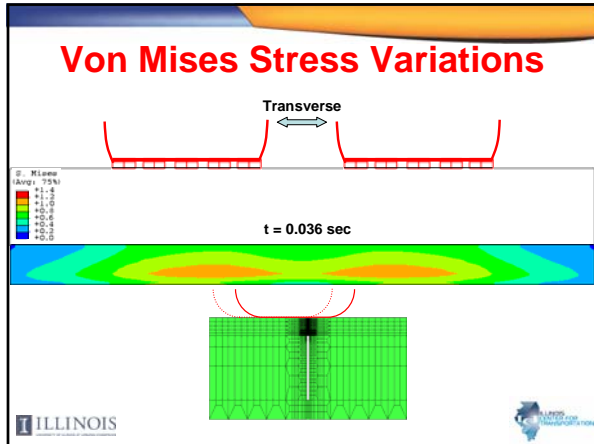
- ### Material Characteristics
- Bulk Property
 - HMA: The Prony series converted from E^*
 - PCC, base, and subgrade: Elastic
 - HMA fracture property in CZM
 - Fracture energy, tensile strength
 - Interface Property
 - HMA/PCC, PCC/base, base/subgrade
 - Friction, elastic slip
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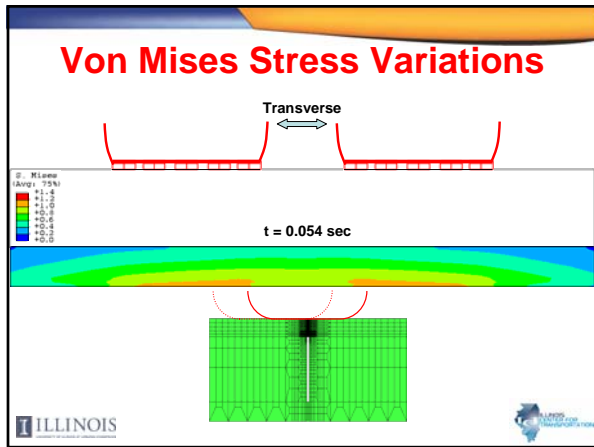


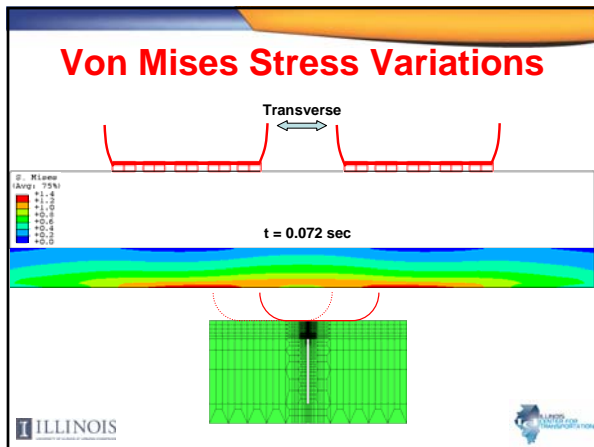


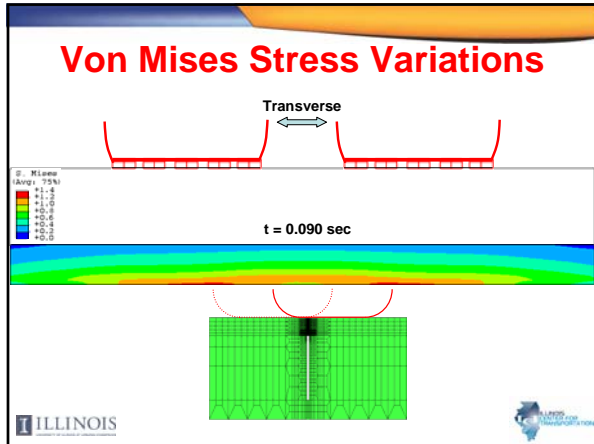


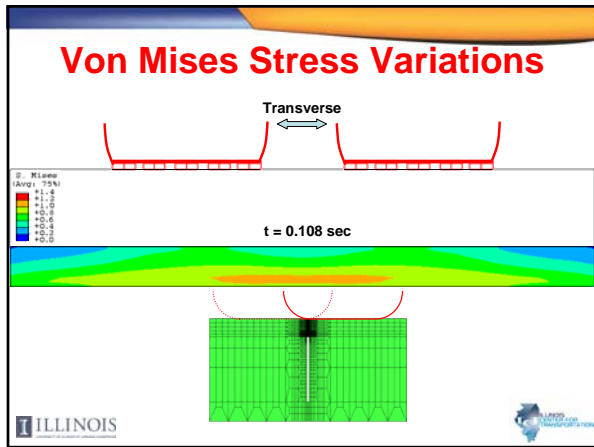


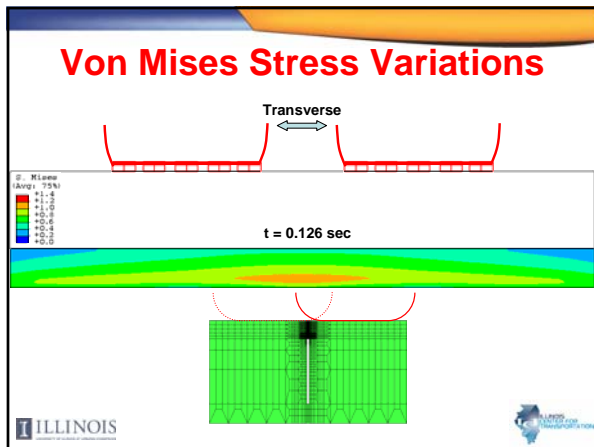


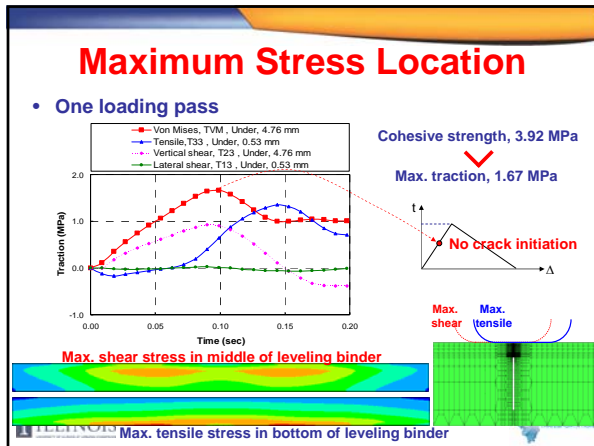


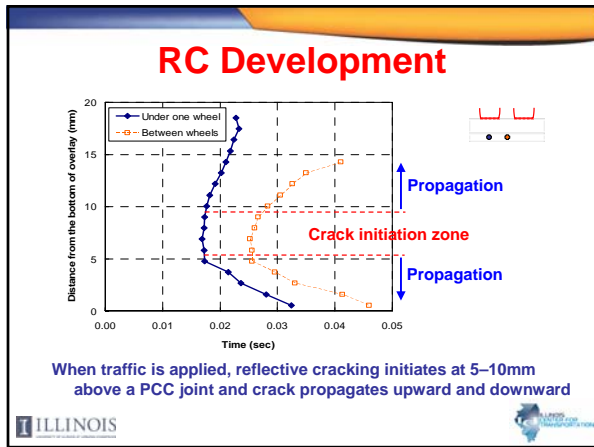


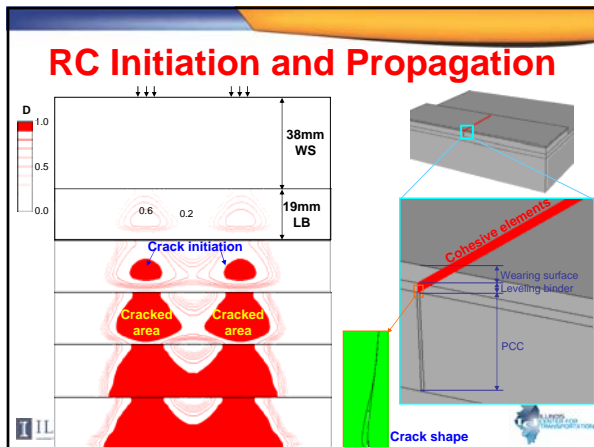












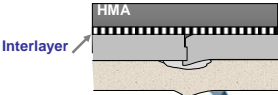




INTERLAYER SYSTEMS






Control Measures

- Existing Condition
 - Pumping, Slab rocking/ faulting,
- Typical Solution
 - Pre-Overlay Treatment:
 - Crack and seat, Break and seat, Rubblization
 - Slab stabilization/ load transfer restoration
 - Sawing and sealing joints
 - HMA Overlay
 - Overlay Systems
 - Improved mix
 - Joint filling/ stabilization
 - Leveling course
 - Interlayer systems:



Crack Control Expectation

- Delay cracking occurrence
- Reduce number of cracks
- Control crack severity
- Provide other benefits:
 - Reduce overlay thickness
 - Enhance waterproofing capabilities



Interlayer Systems

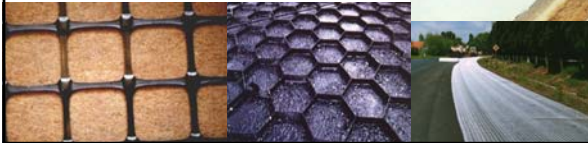
- Cost-effective technique
- Reinforcement:
 - Stiff materials to compensate lack of HMA's tensile strength
- Strain tolerant (Stress relief):
 - Soft materials to dissipate strain energy by deforming itself
- Modified HMA:
 - “Tough” materials to resist cracking

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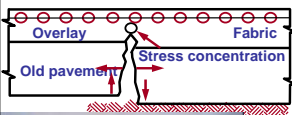


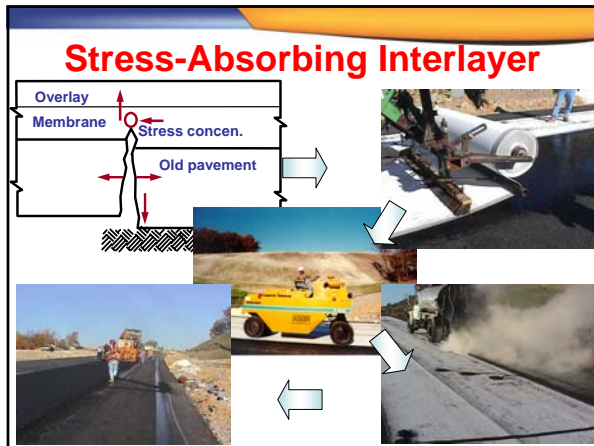
Interlayer Systems

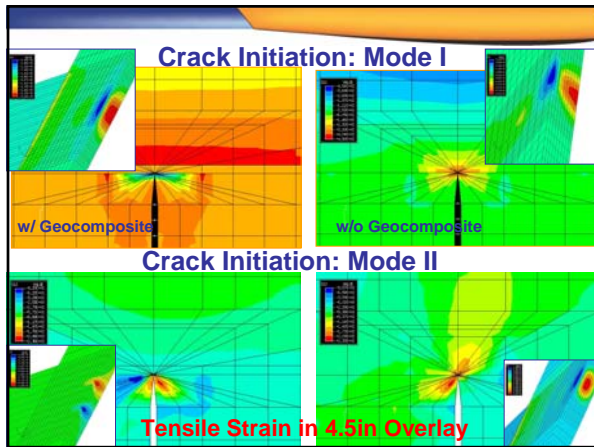
- Sand Asphalt
- SAMI
- Geotextile
- Geomembrane/ Geocomposite
- Grid/ Steel Netting
- 3D Grid

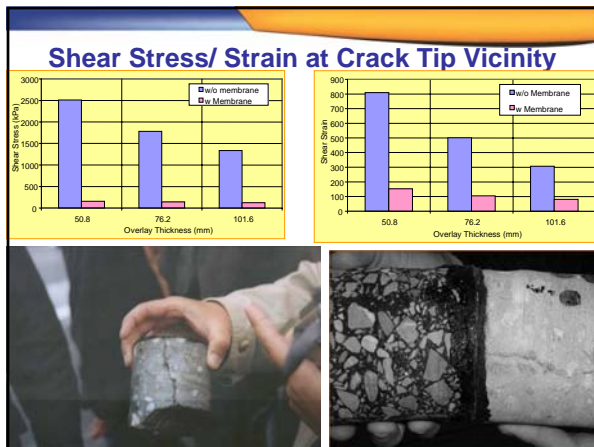


Fabric Interlayer









Steel Reinforcing Netting

Technology emerged in the early 1950s in the US and Canada, and was re-introduced in the early 1980s in Europe.

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Steel Reinforcement Netting

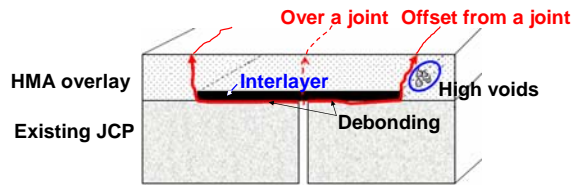
- The first application in the US was in 1999 by Al-Qadi et. al
- Several states installed trials sections and some are monitored for long-term performance

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Band-Aid

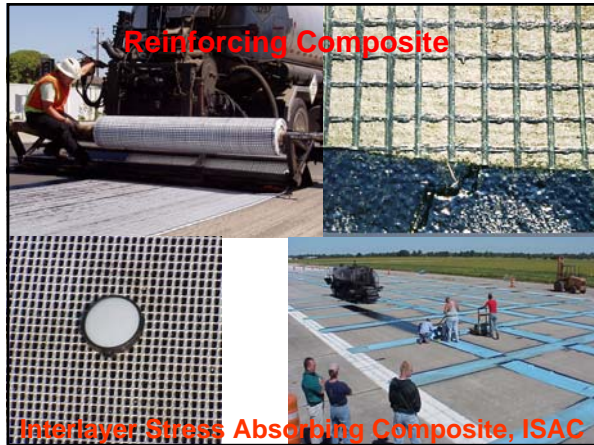
Bad Practice! **In Less than a Year**

Optimum Thickness of Band-Aid



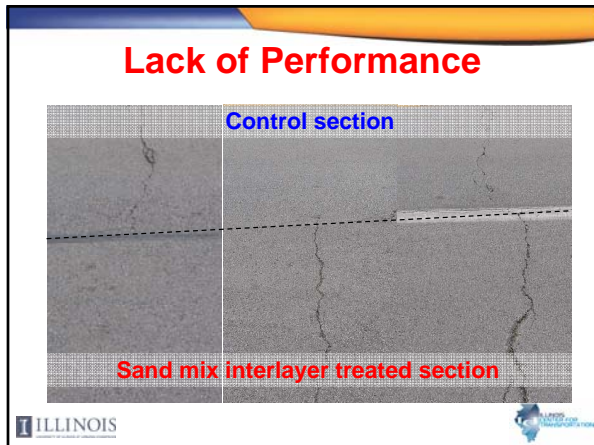
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Overlay Interlayer Functions

	Reinf.	Resist High Strain	Waterproof
Sand Asphalt		X	X
SAMI (*)		XX	XX
Impregnated Nonwoven		X	XX
Grid Composite	X/XX	X	X/XX*
Steel Netting	XX	X*	X*
3D Grids	XX		
Tri-planar		X	XX
Strain Tolerant Layer		XX	XX

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Considerations When Using Interlayer Systems to Abate Reflective Cracking

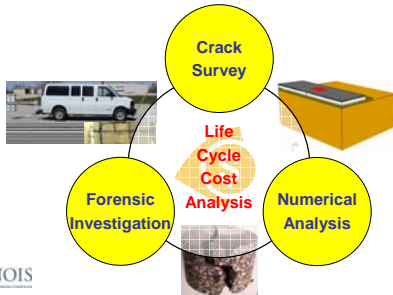
- Interlayer systems **MAY NOT** prevent crack movement
- Not all interlayer systems are the same! (reinforcement, strain tolerant, moisture barriers)
- Joints/cracks must be stable (Prepare Pavement!)
- Minimum overlay thickness needs to be identified
- Successful installation is a key for good performance:
 - No wrinkles
 - Pretensioning/ fixation
 - Interlayer system joints
 - Bonding issues
 - Overlay characteristics

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Interlayer Assessment

- Cost-effectiveness and overlay performance



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RC Survey: A Suggested Approach!

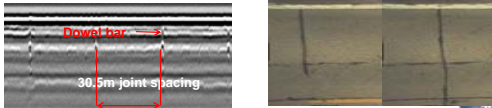
- **Surface Survey**
 - Visual (Walk-on/ Windshield) survey
 - Severity (starting, low, medium, and high)
 - Extent (0.0 - 1.0)
 - Video survey
 - Faster and safer operation
 - Link to other distress survey
- **Nondestructive Testing:**
 - Ground penetrating Radar (GPR) survey
 - Overlay thickness
 - Joint/patch location

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Reflective Crack Survey System

- GPR and Video Integration System (GaVIS)
 - GPR: Joint/ patch location and overlay thickness
 - Video: Surface cracks

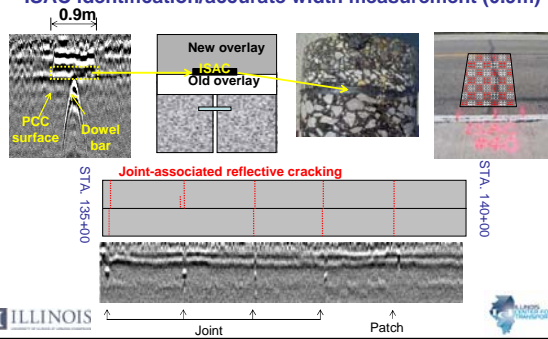


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Interlayer Detection

- ISAC identification/accurate width measurement (0.9m)



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Crack Assessment

- Moving Load
- FWD




Summary

- Reflective cracking is a complex phenomena and requires appropriate modeling
- VE FE modeling can successfully be used to quantify reflective cracking:
 - Continuous loading to simulate field loading conditions
 - Surface shear should be considered
 - Interface stresses should be appropriately modeled
 - Dynamic analysis enhances model prediction
 - CZM should be appropriately utilized

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Summary

- Pavement interlayer systems can be effective
 - *Identify current (or potential) distress*
 - *Select proper interlayer system type and application*
 - *Debonding and interface shear must be considered*
 - *Proper installation is very important!*
- Any overlay design method should address reflective cracking
 - NCHRP 1-41: Models for Predicting Reflection Cracking of HMA Overlays (2008?)

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**Sixth RILEM International Conference on
CRACKING IN PAVEMENTS**



Chicago, Illinois
June 16-18, 2008
www.ict.uiuc.edu/RILEM