TRB Webinar
Mechanisms and Mitigation Strategies for Reflective Cracking in Rehabilitated Pavements

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Organizer: TRB Standing Committee on Pavement Rehabilitation

Moderator: Bouzid Choubane

Florida Department of Transportation

August 24, 2015

Webinar Presenters

- **Mostafa Elseifi,** *Louisiana State University*
- **Imad L. Al-Qadi,** *University of Illinois at Urbana-Champaign*
- **James Greene,** *Florida Department of Transportation*

Webinar Outline

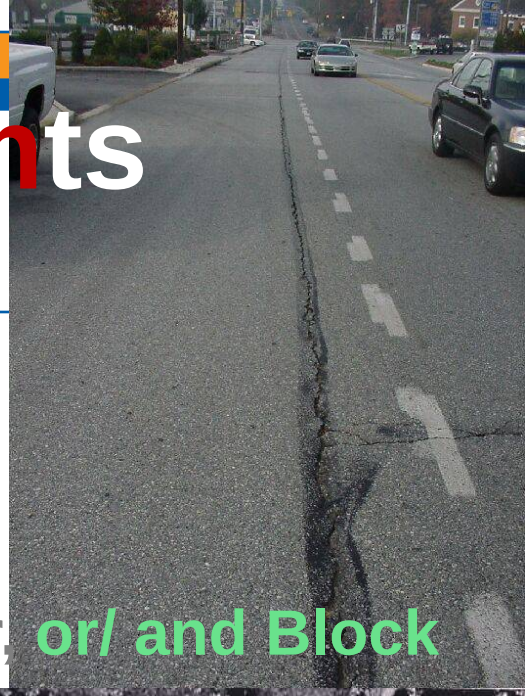
ID	Presenter	Title
1	Imad Al-Qadi	Reflective Cracking: Introduction, Mechanisms, and Testing
2	Mostafa Elseifi	Mitigation Strategies for Reflective Cracking in Pavements – Part I
3	Imad Al-Qadi	Mitigation Strategies for Reflective Cracking in Pavements – Part II
4	James Greene	Florida's experience with asphalt-rubber membrane interlayers
	Questions and Answers	

Reflective Cracking

Introduction, Mechanisms, and Testing

TRB Webinar – August 24th, 2015

Cracks in Pavements



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

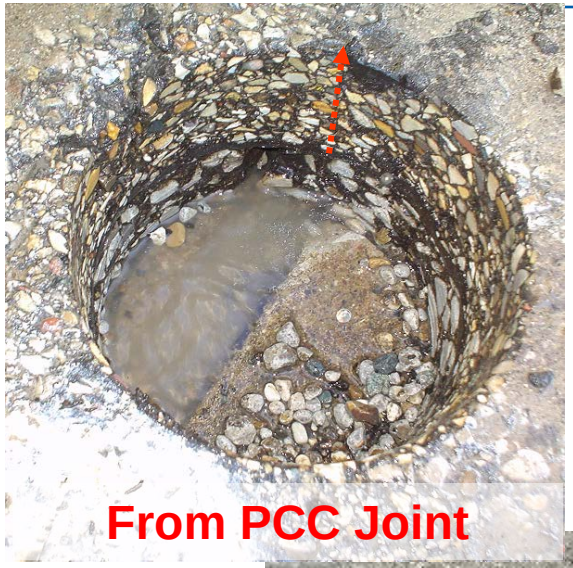
Causes of Cracks

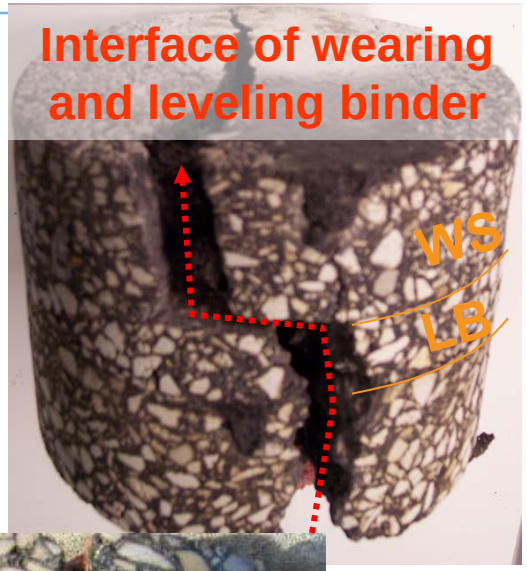
- Fatigue
- Thermal
  - Concrete, flexible, and composite pavements
- Surface stresses
- Lack of bearing support
  - Under-design, poor drainage, or settlement
- Exiting discontinuities
  - Cracks, joints, widening

Reflective Cracking

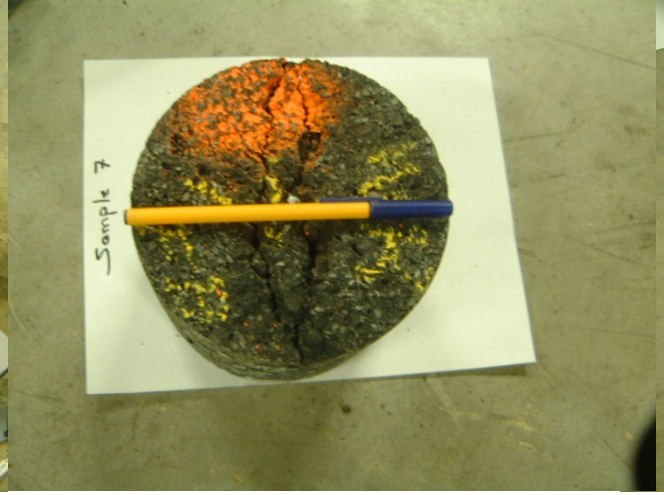
- Reflective cracking frequently develops in HMA layer constructed on jointed concrete pavements
  - Premature, unpreventable, and significantly critical
  - Induces successive deterioration to underlying pavement layers
  - Reduces structural/ functional service life of composite pavements

Various RC Propagation

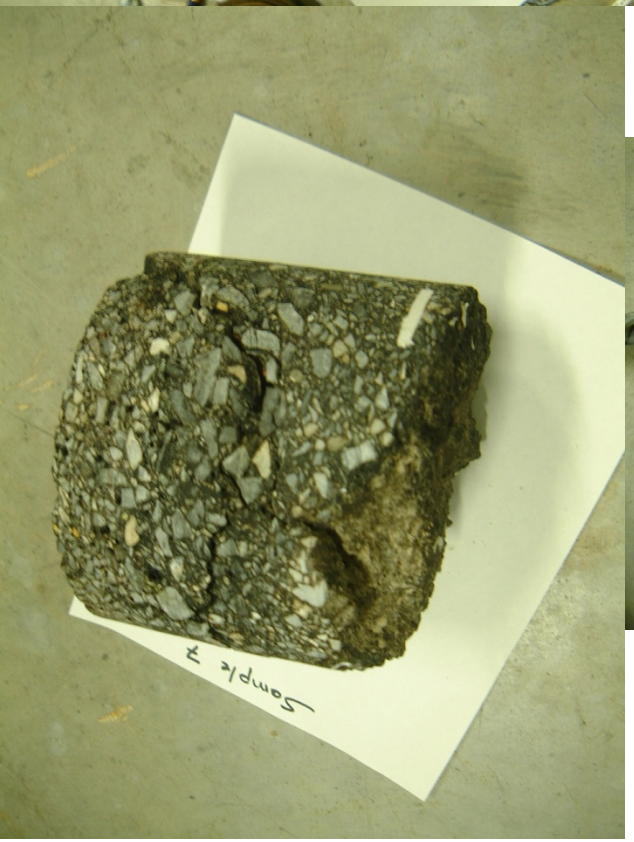





Wilson Rd
#13 WB
13

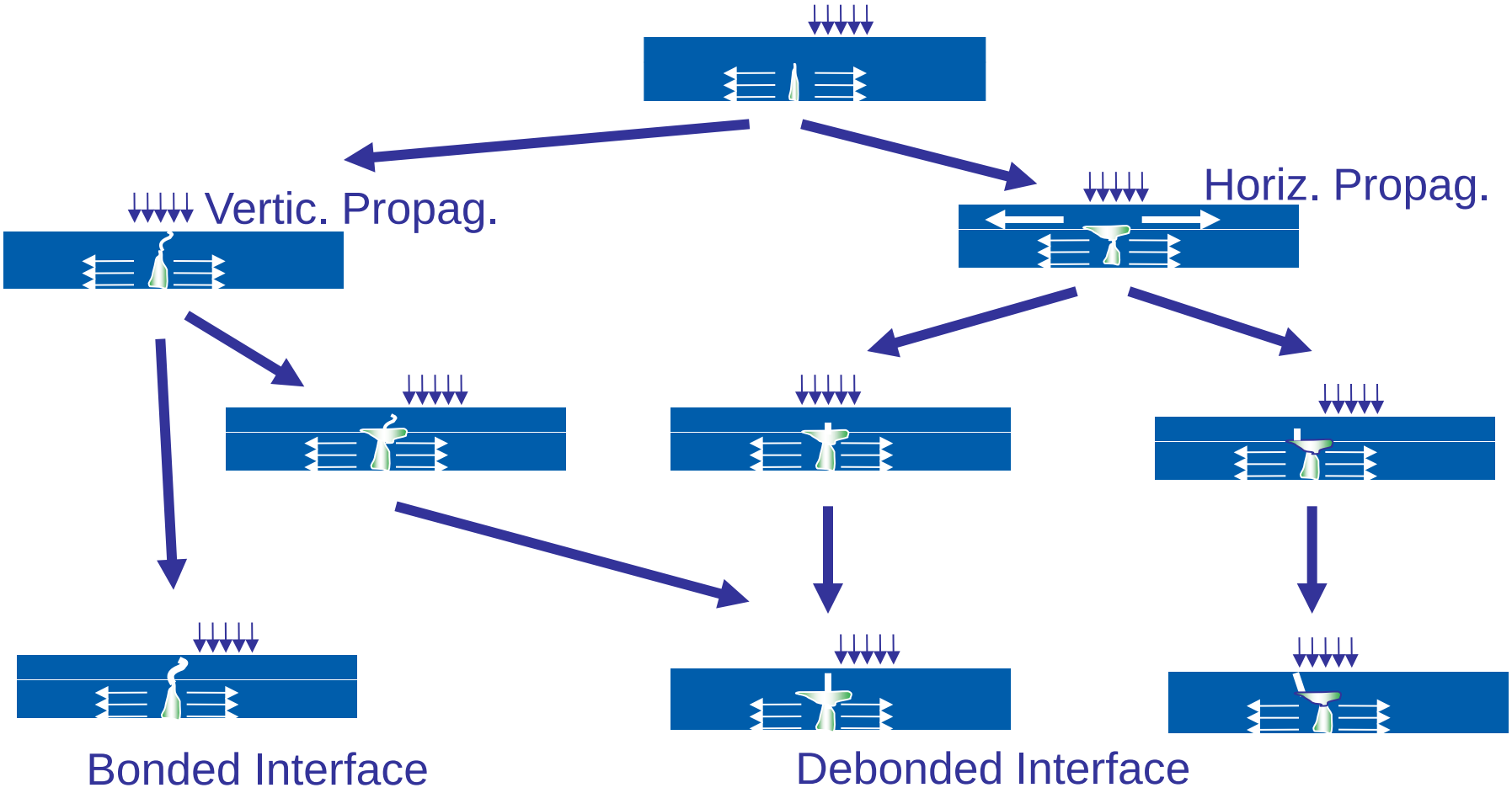

Sample 7


13
13 TURN LANE
CL. Rt. 19'


Sample 7

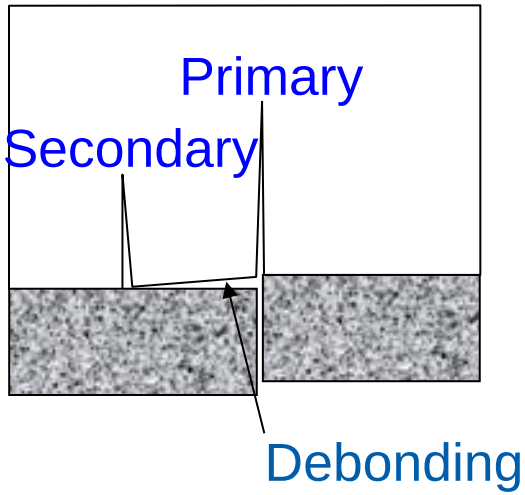

13

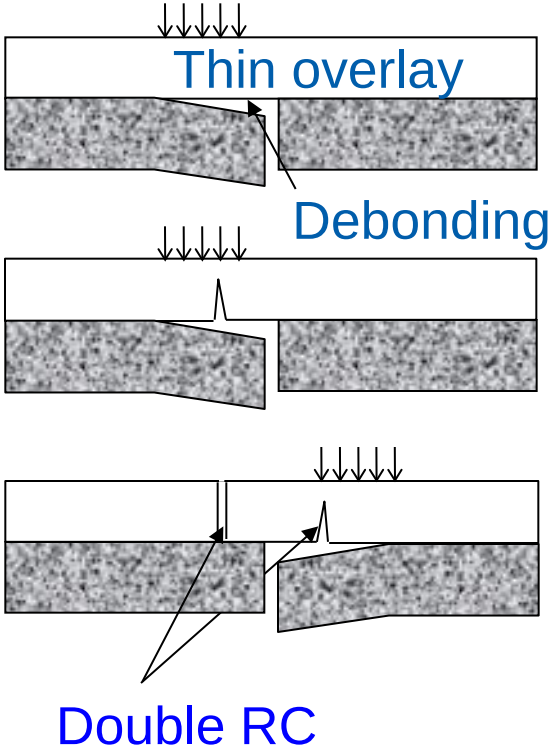
Crack Development



Reflective Cracking Pattern

- **Depends on local interface conditions**





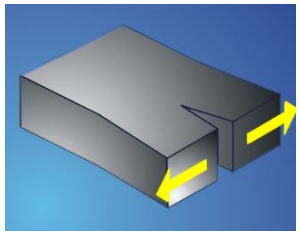
Scarpas *et al*. 2000

Zhou and Sun 2002

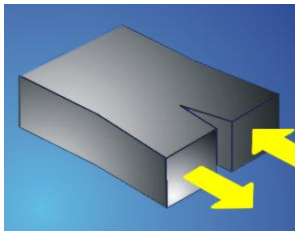
Reflective Cracking Mechanisms

Reflective Cracking Types

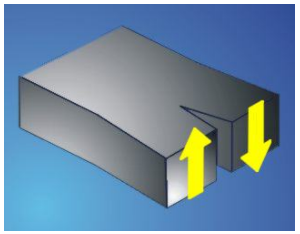
Cause	Result	Type
Vehicle Loading	Crack opening Shear failure	Mode I Mode II Mixed mode
Seasonal Variation	Crack opening	Mode I



Mode I
(Opening)

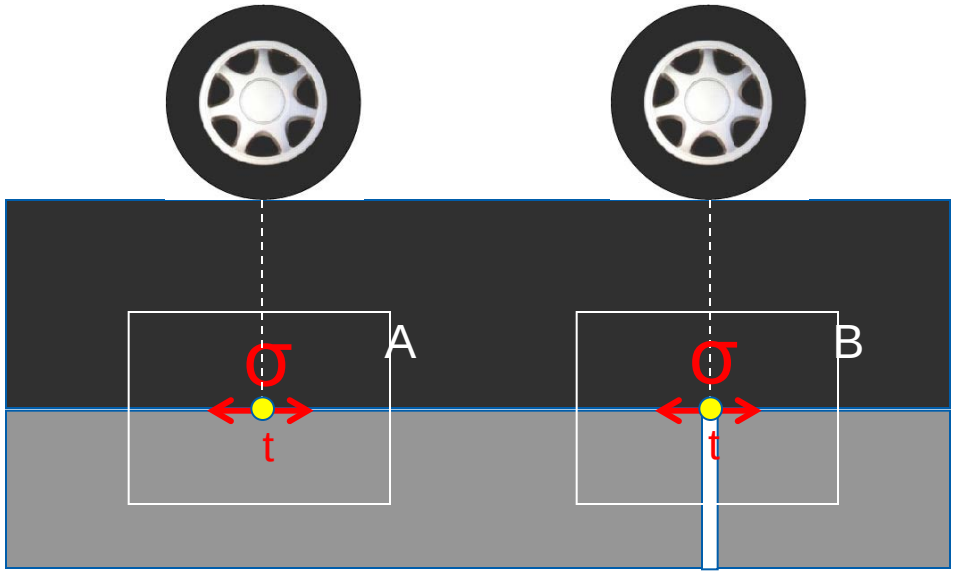


Mode II
(Sliding)



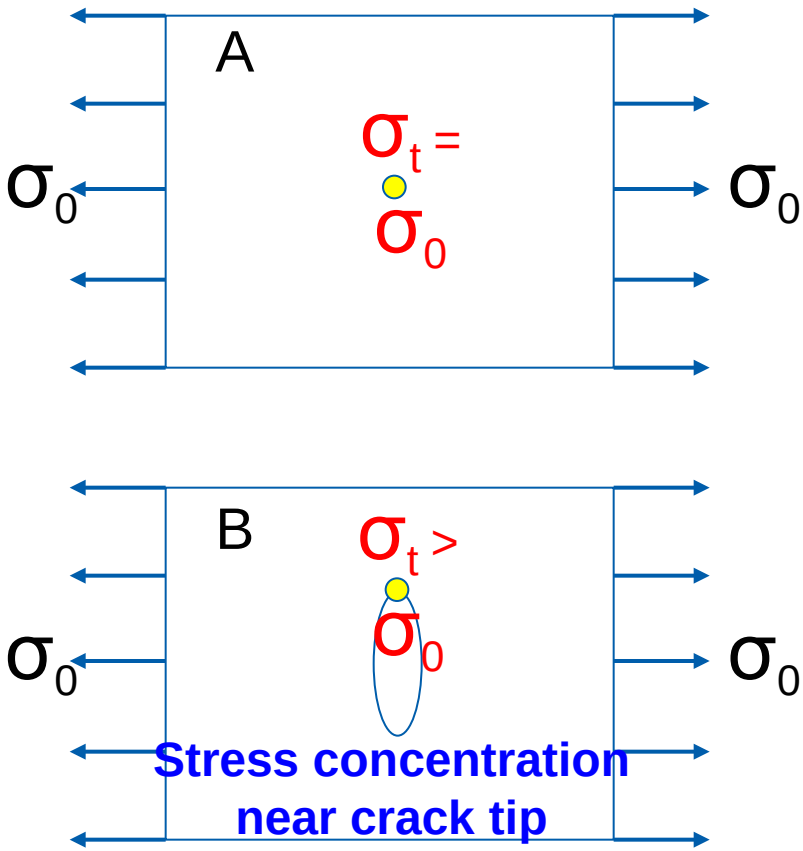
Mode III
(Tearing)

Stress Concentration



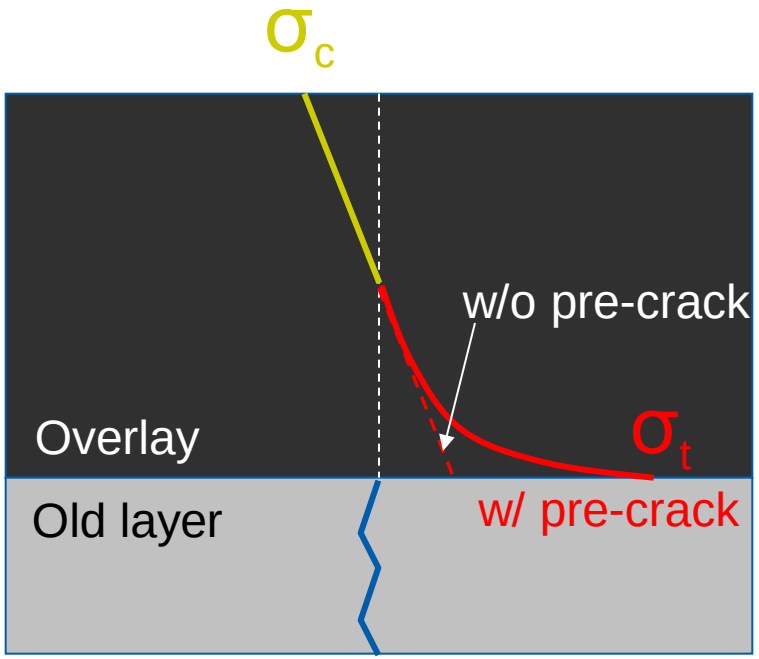
Overlay on sound surface

Overlay on cracked surface



Reflective Crack Initiation

- **Stress distribution in overlay**



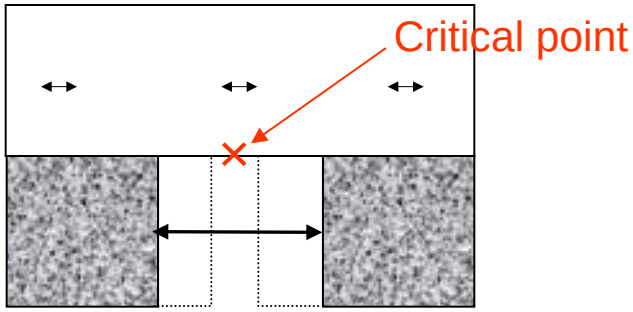
Pre-crack in old layer

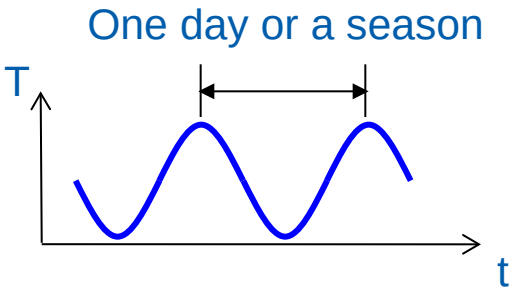
→ Stress concentration near crack tip in overlay

→ **New crack initiation**

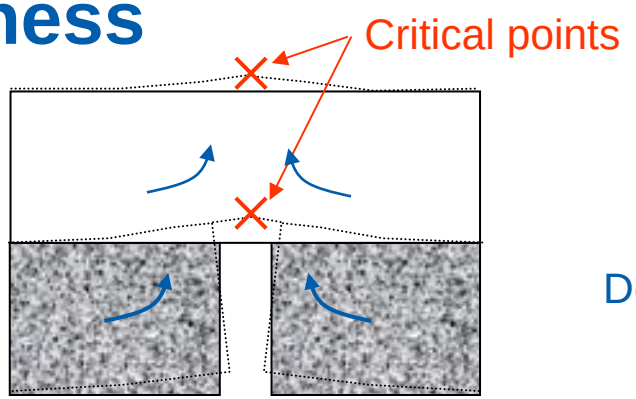
Main Causes I: Environment

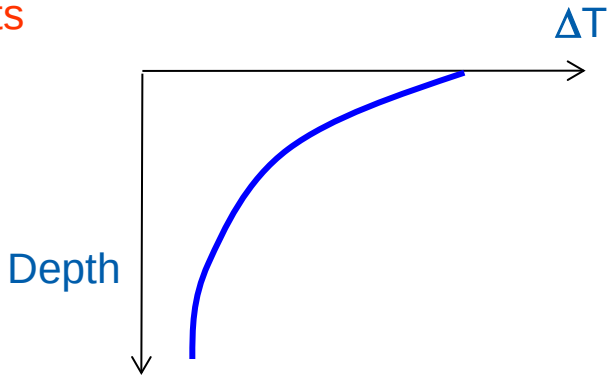
- **Contraction & expansion due to cyclic temperature variations**





- **Warping due to temperature gradient through thickness**

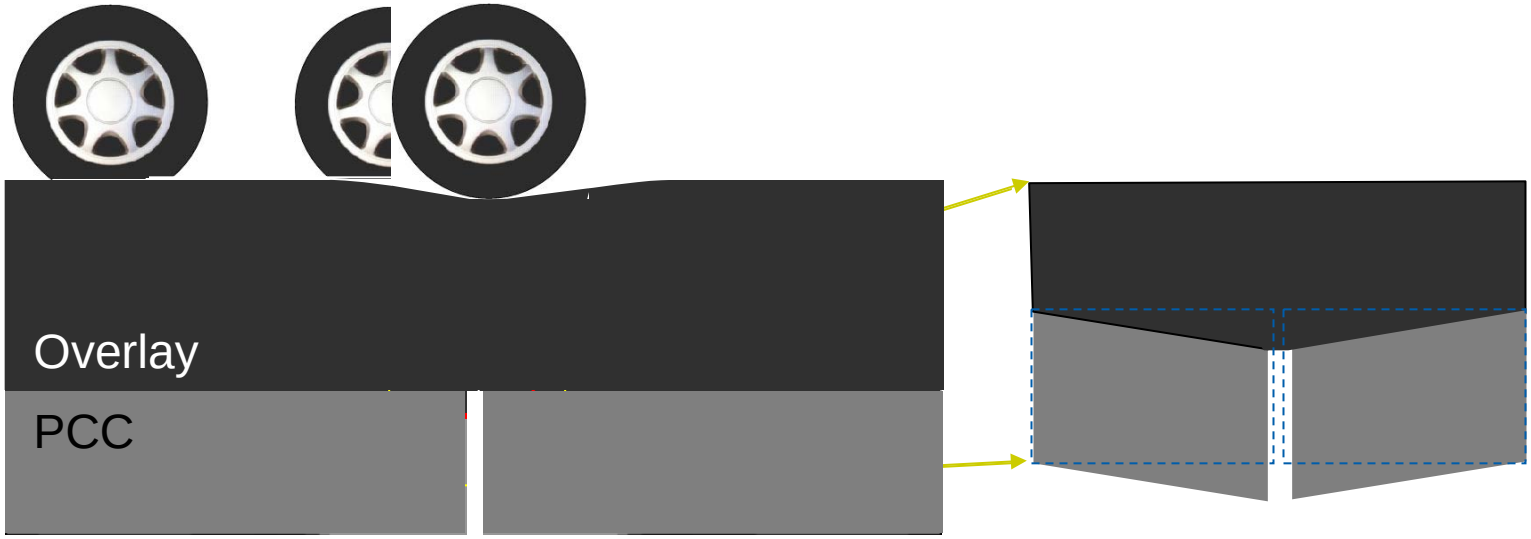




Main Causes: Traffic

- Crack opening (Mode I)

- Shear failure (Mode II, Mixed mode)

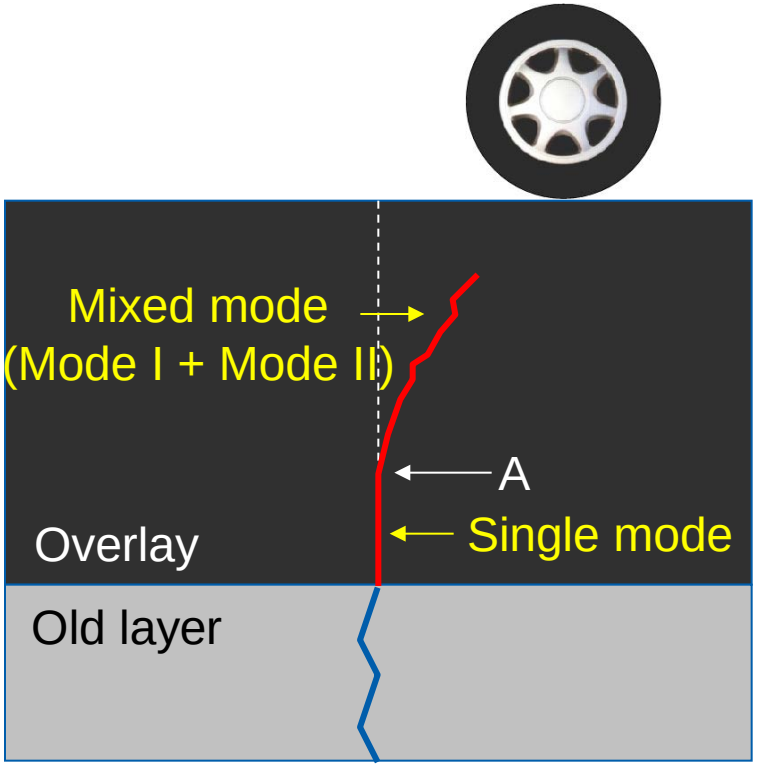


Bending stress

Shear stress

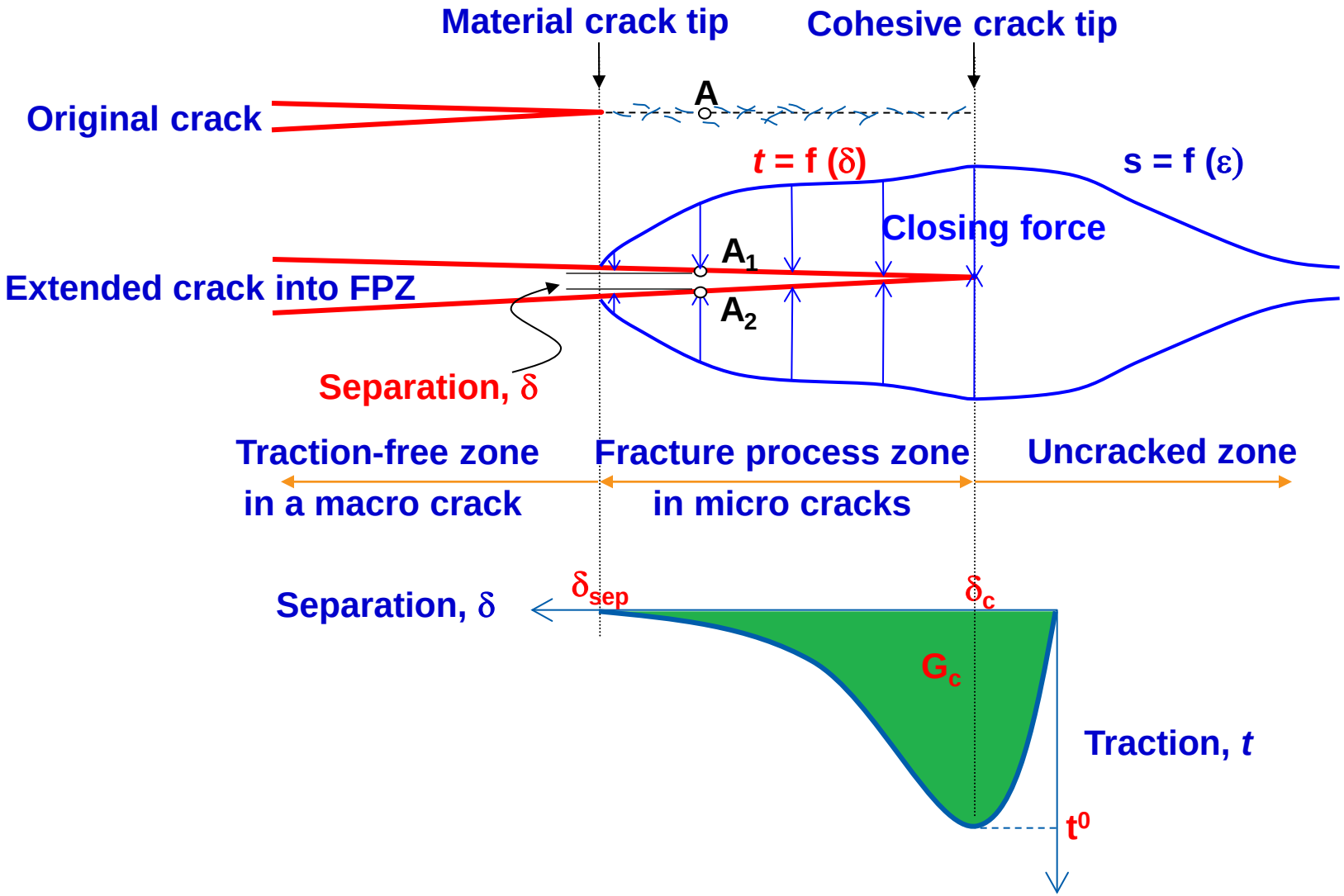
Reflective Crack Propagation

- **Mixed mode crack failure**

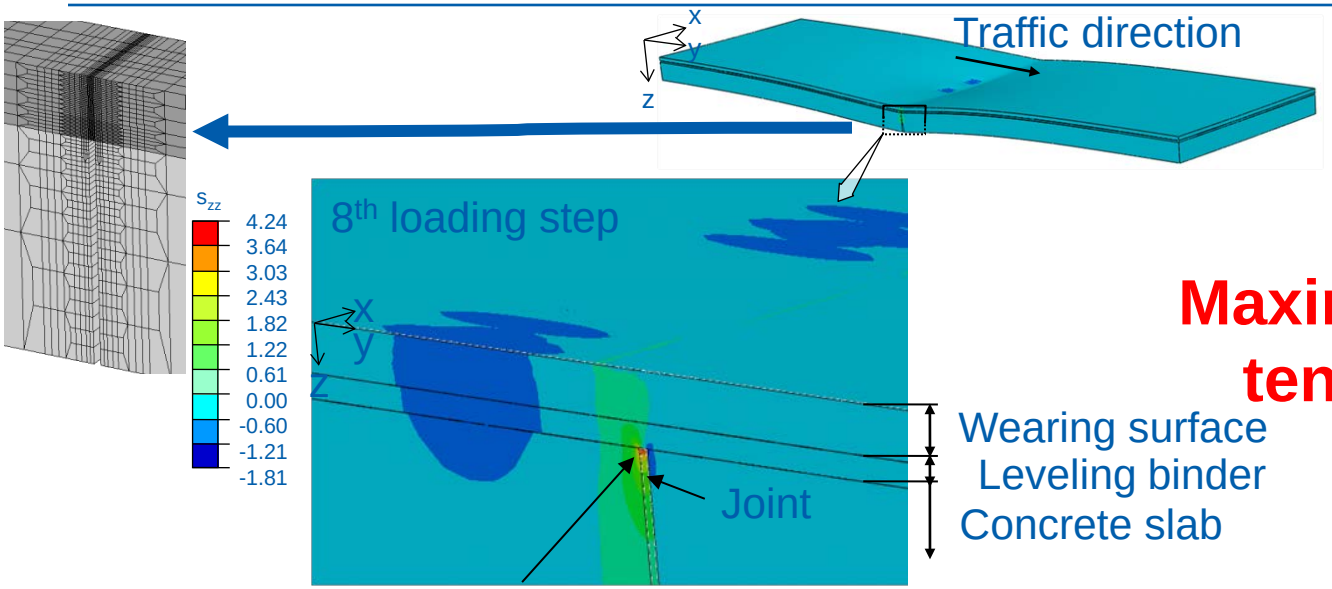


After point A, the driving force is combination of bending and shear stress due to increase in shear stress and decrease in bending stress

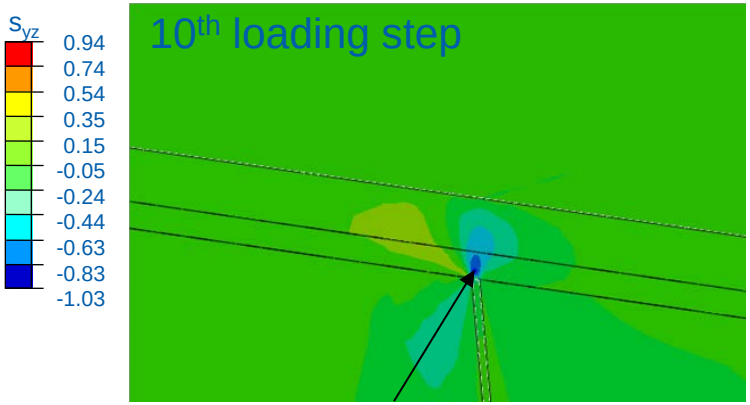
Cohesive Zone Model (CZM)



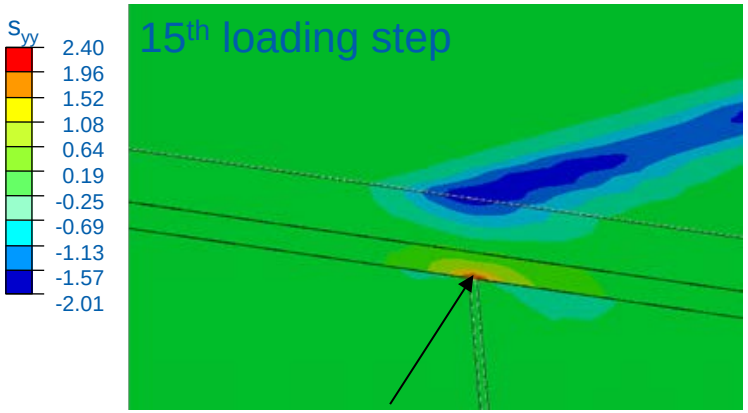
Critical Stresses at the Joint



Maximum vertical tensile stress



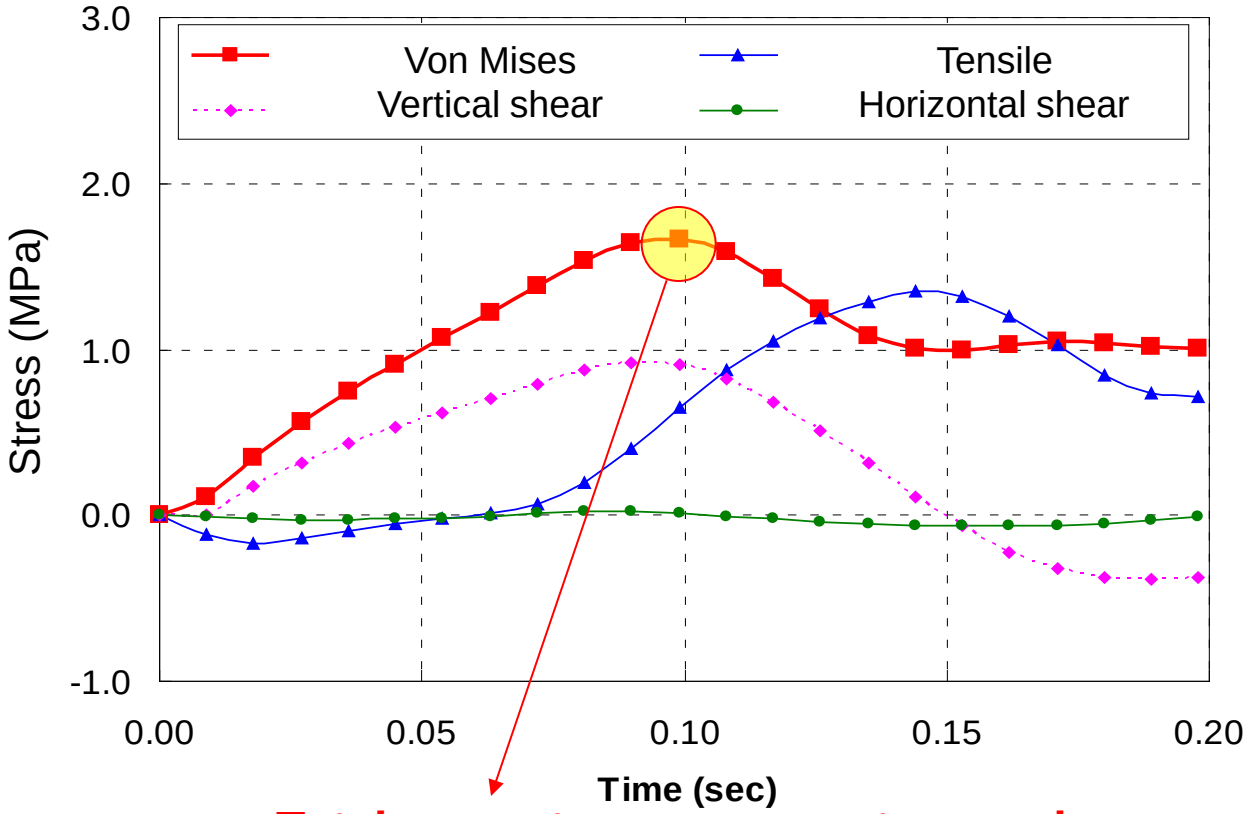
Max. vert. shear stress



Max. horiz. tensile stress

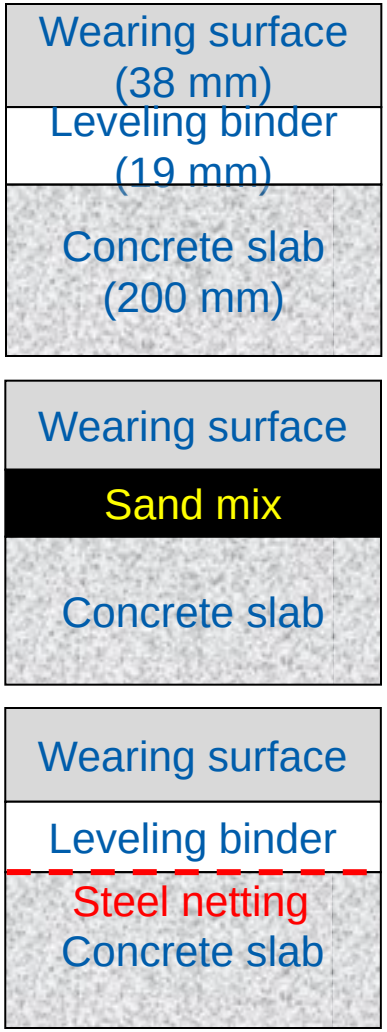
Multi-phase Stresses

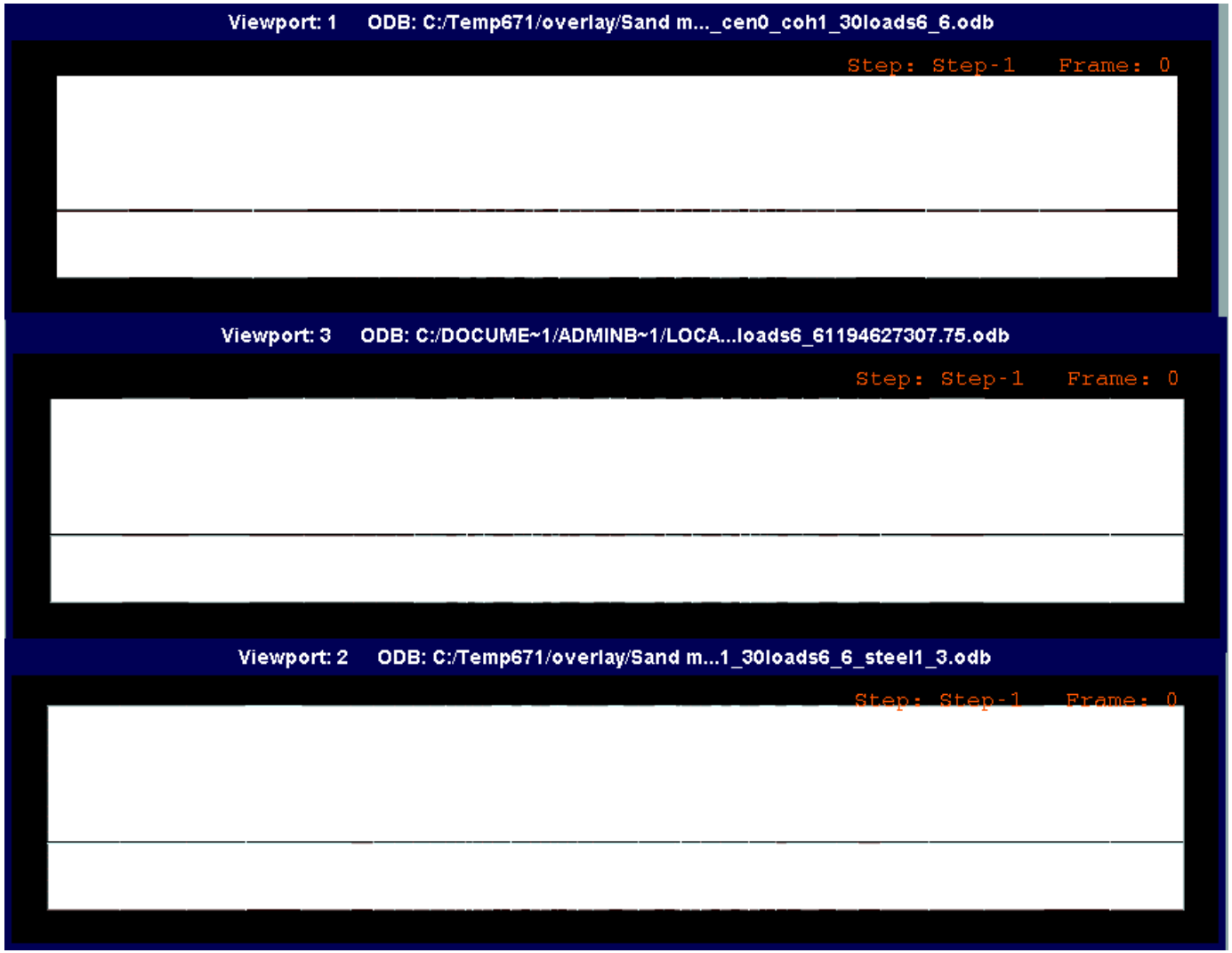
- By one pass of vehicular loading

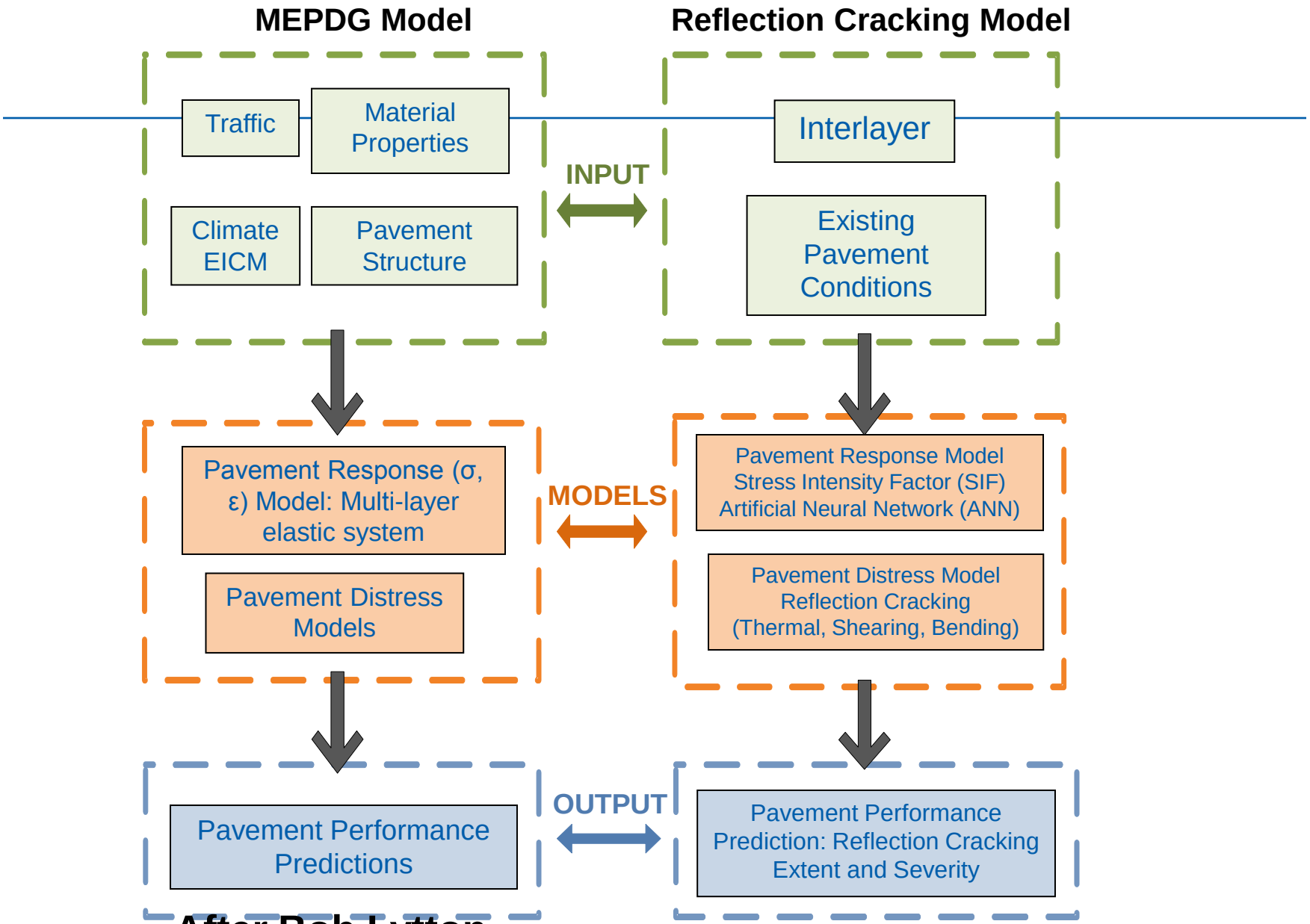


Total max. stress occurs at max. shear

Comparison of Three HMA Designs



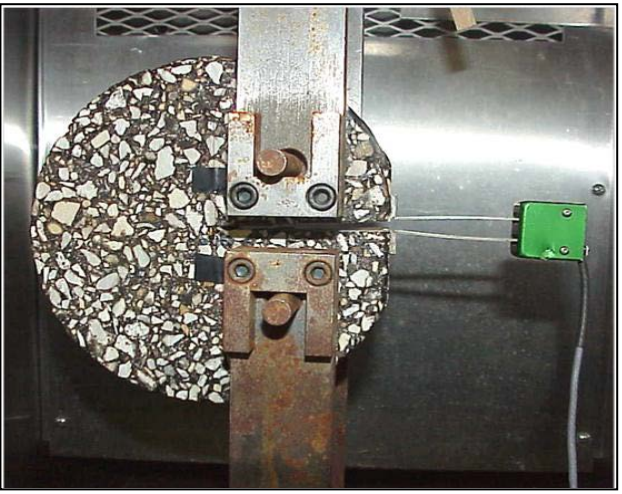




After Bob Lytton

TEST METHODS FOR REFLECTIVE CRACKING

Testing for RC

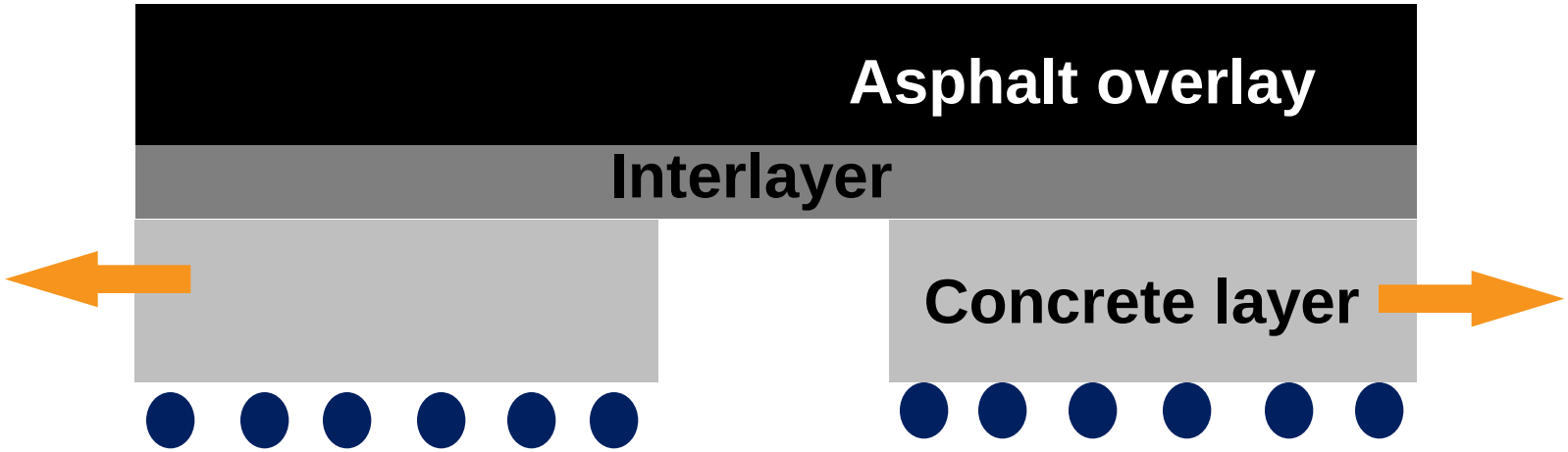


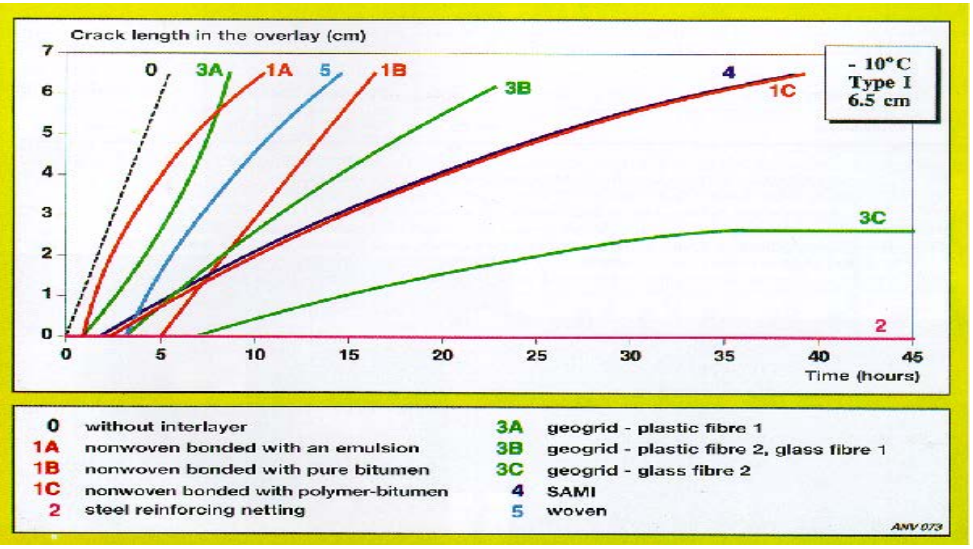
DCT

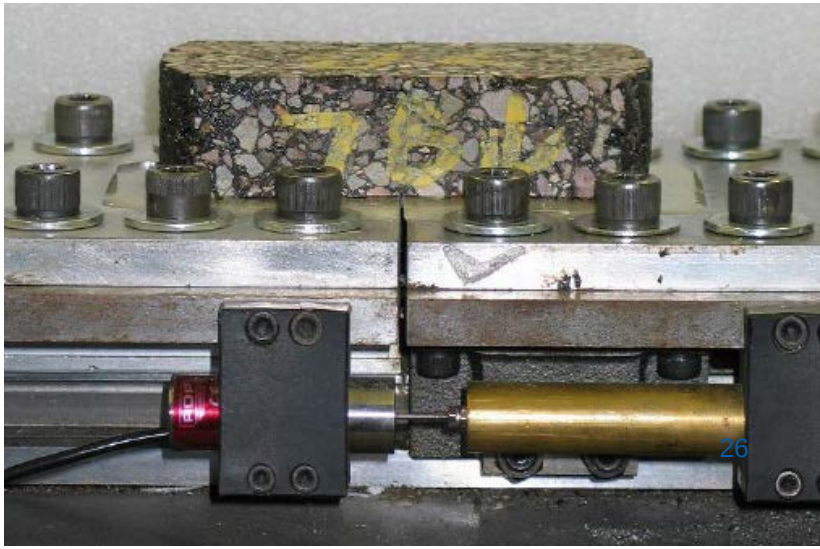
SCB

Texas Overlay Test

Thermal Cracking Test (Mode I)







Test Method Selection Criteria

- Significant and meaningful spread in test output
- Correlation to independent tests and engineering intuition
- Correlation to field performance
- Applicability and seamless implementation

Video

In YouTube: ICT SCB

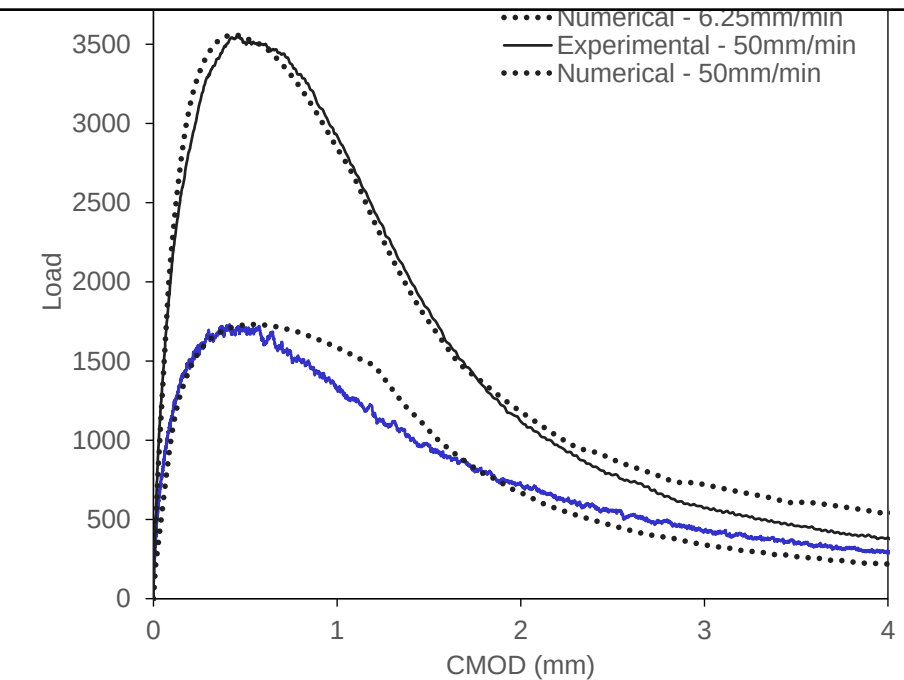
https://www.youtube.com/watch?v=EcUsAt-Esz4

Semi-Circular Bending Test

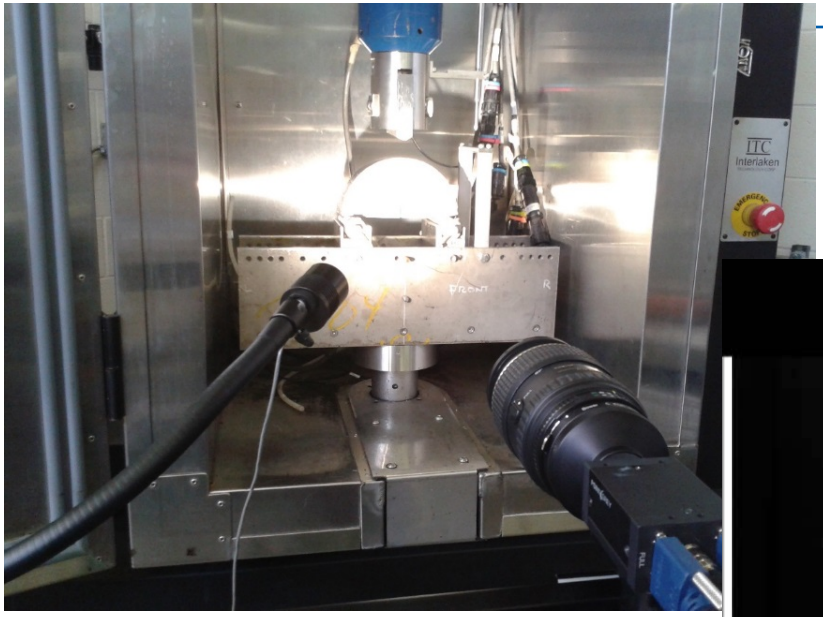
- Relies on simple three point bending
- Easy specimen preparation
- Can use AASHTO T283 equipment
- Repeatability

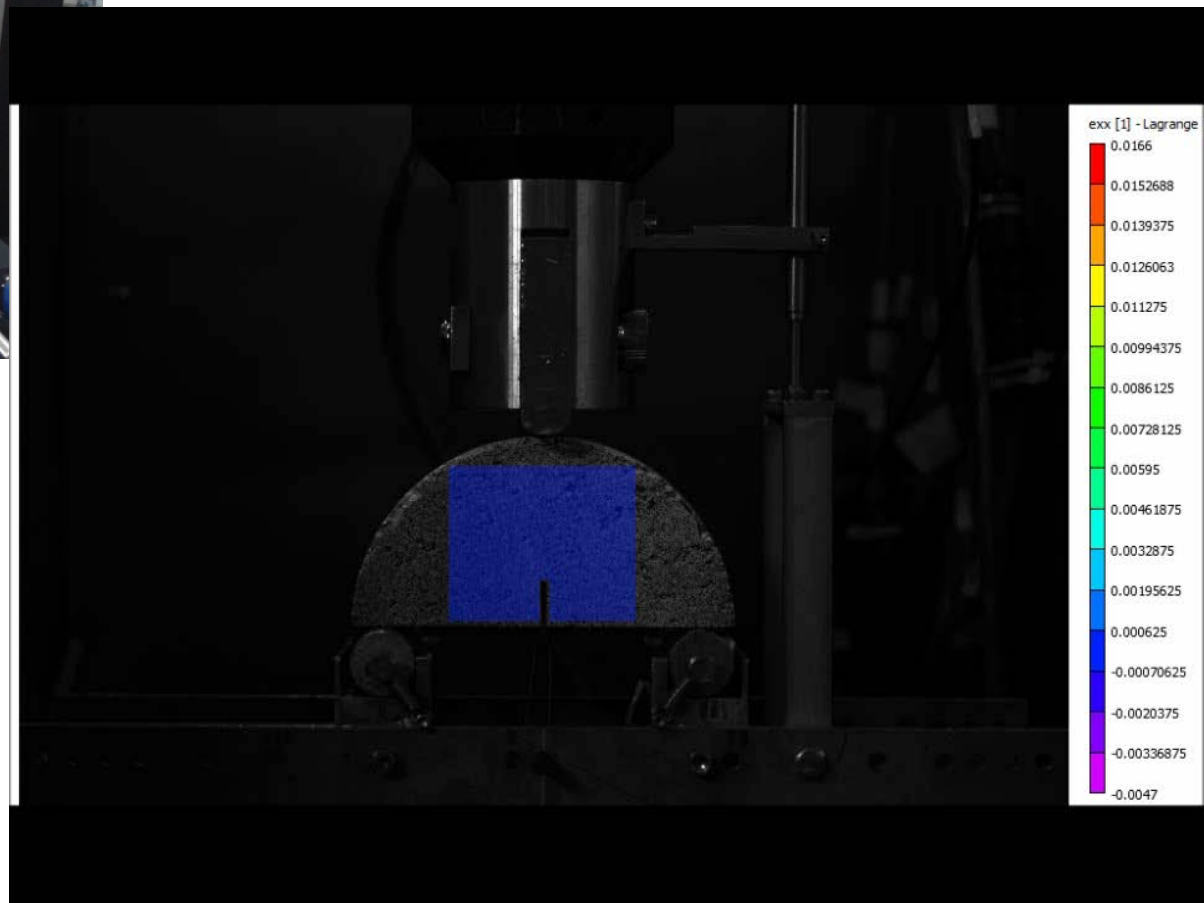
FEM Results

- FEM simulations of N80-25 mix

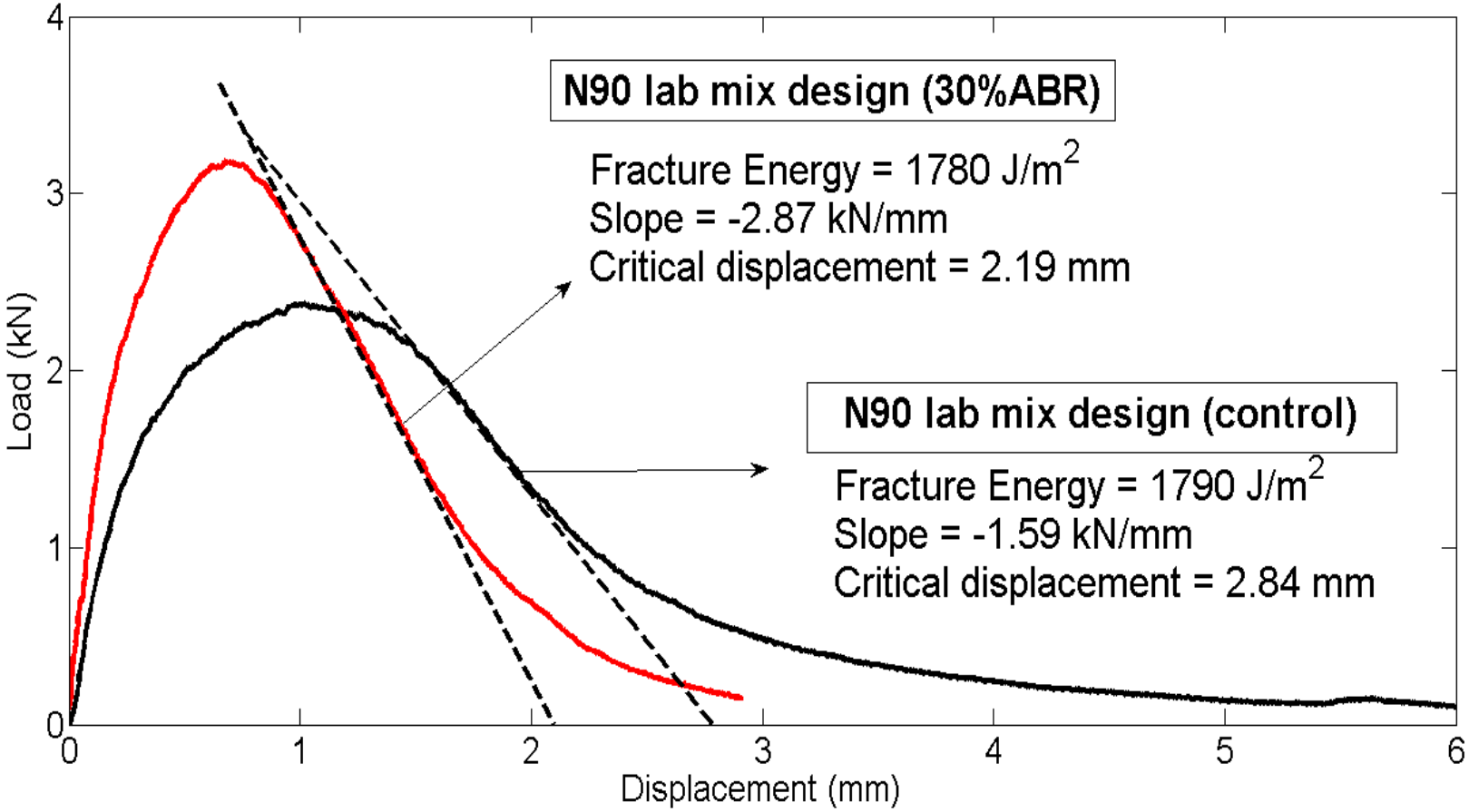


Fracture Zone - Digital Image Correlation (DIC)

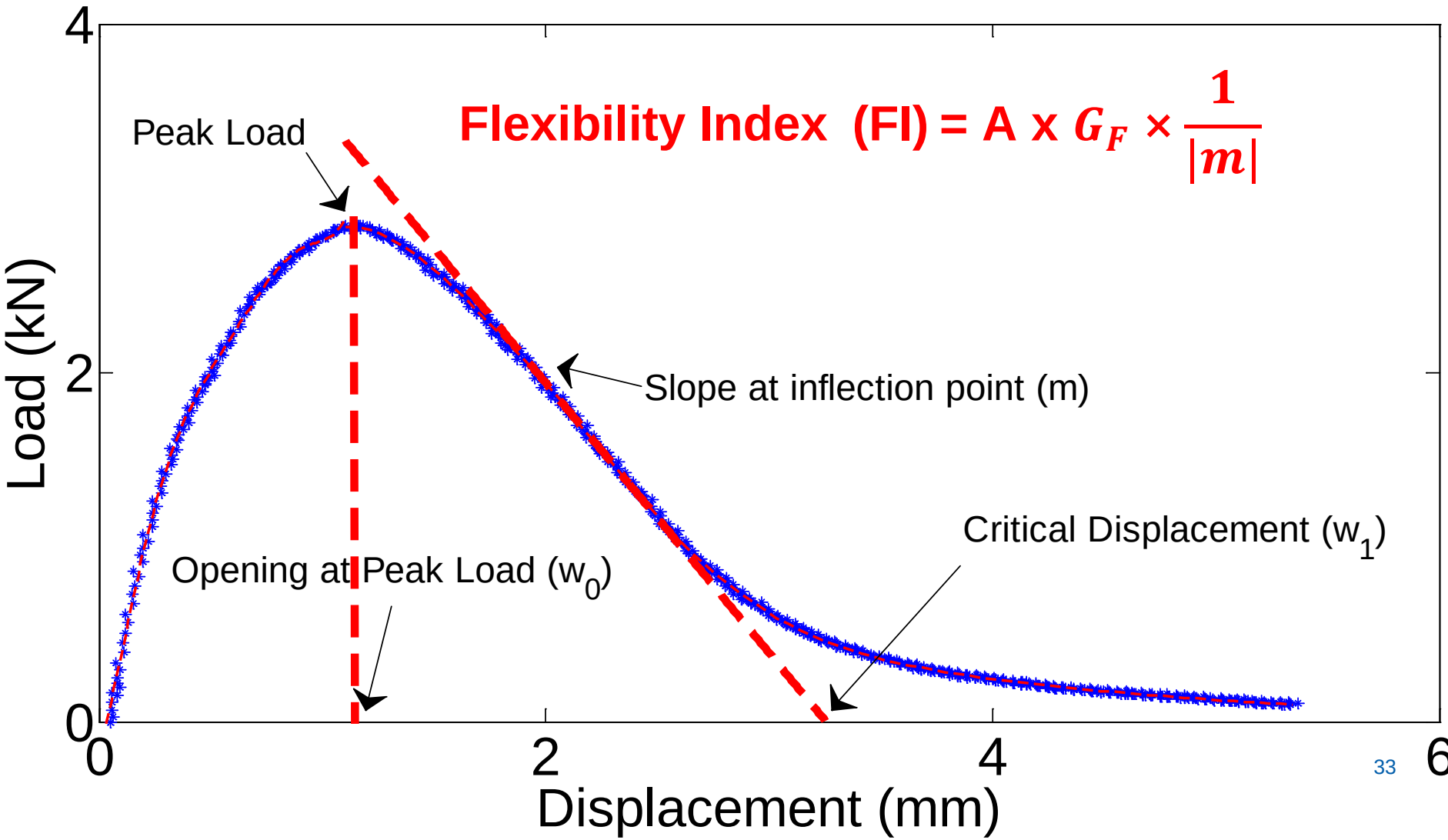




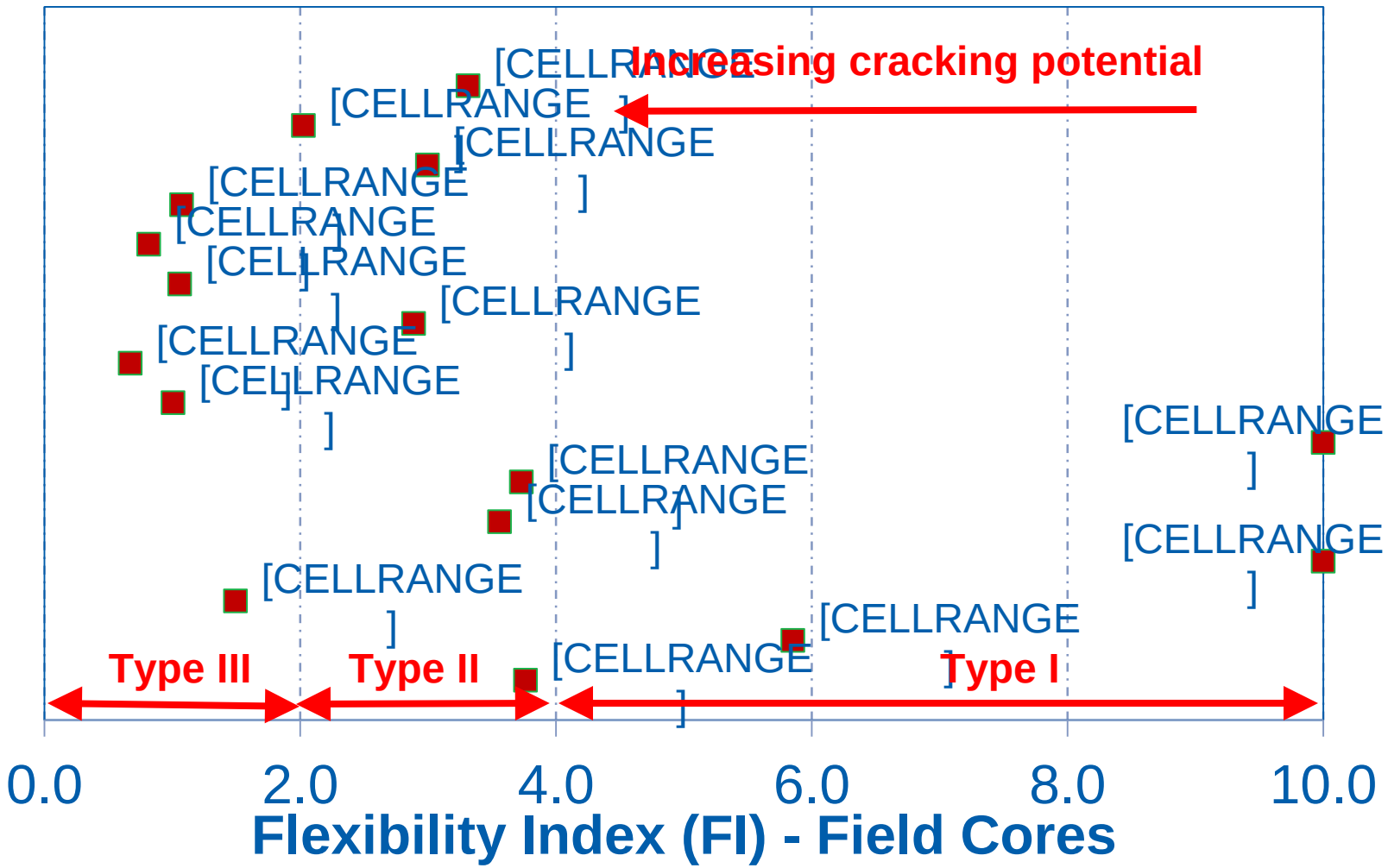
SCB Fracture Results



SCB Test Parameters



FI: Field Cores



FI Categorization & Implementation

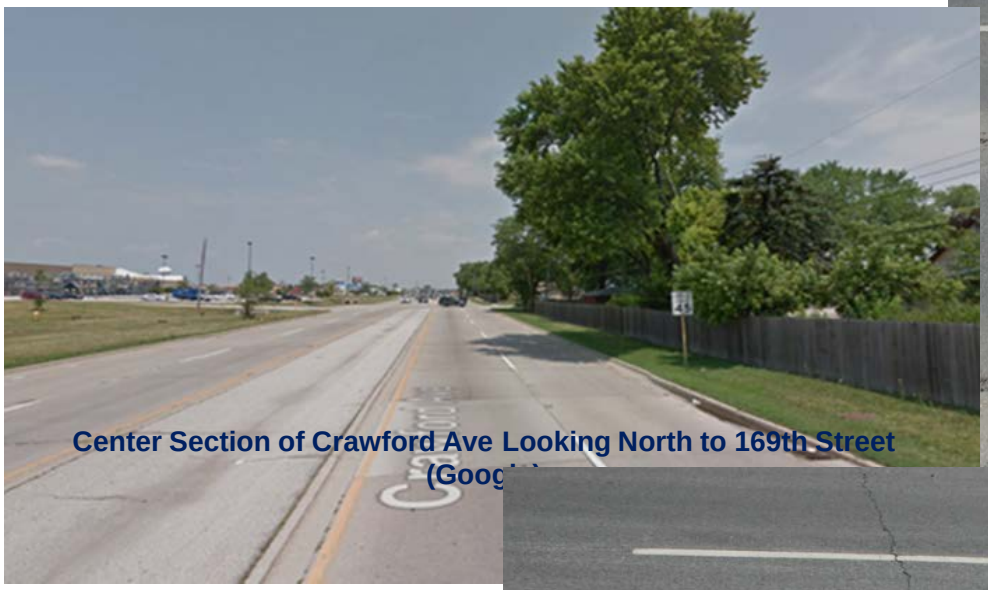
- **Draft Categorization of Mixes Using Flexibility Index and Threshold**

Mix Category	Mix Type Based on Flexibility Index (FI)	Potential Actions and Remedies
Unacceptable Mix	Type III (<2.0)	Reject mix due to high early cracking potential. Redesign the mix.
Inferior Mix	Type II (≤2.0-4.0)	Mix susceptible to cracking. Use the mix only in temporary application or redesign.
Acceptable Mix	Type I (≤4.0-10.0[1])	Accept the mix. Mix is expected to perform adequately. Use the mix in surface overlay or typical pavement applications.

***Lab-compacted mix having FI > 10 is considered high performance mix.**

Crawford/Pulaski

2014 HMA Overlay



Center Section of Crawford Ave Looking North to 169th Street
(Goog

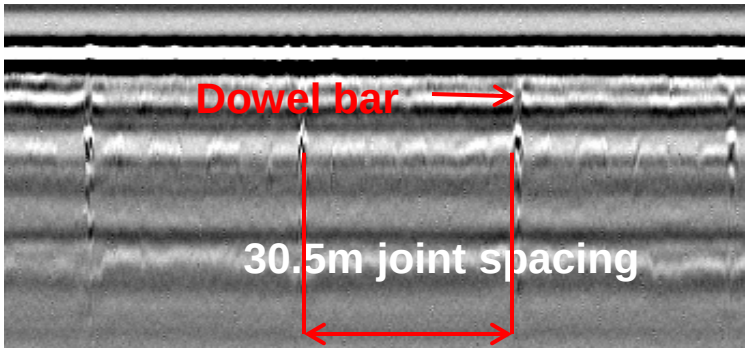
FIELD TESTING OF REFLECTIVE CRACKING

Reflective Cracking Survey

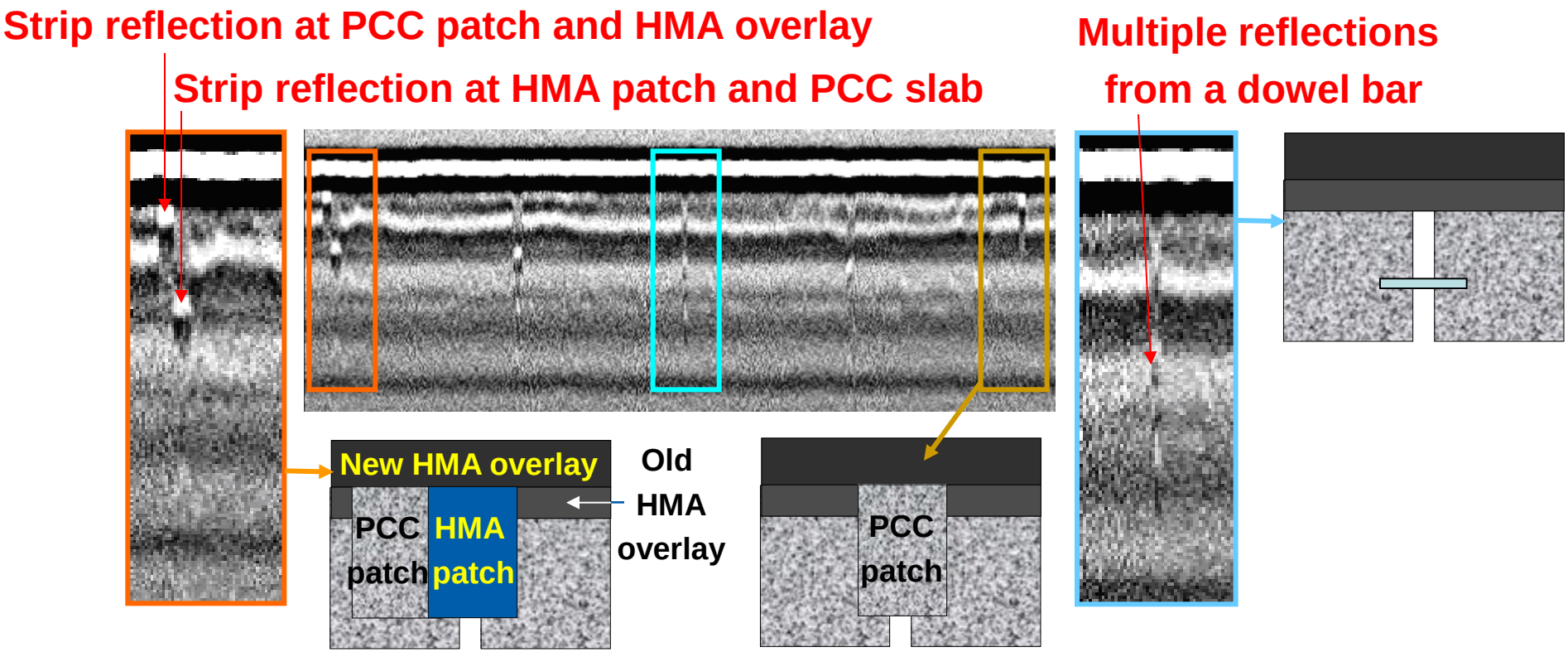
- Surface Survey
  - Visual (Walk-on/ Windshield) survey
    - Severity (starting, low, medium, and high)
    - Extent (0.0 - 1.0)
  - Video survey
    - Faster and safer operation
    - Link to other distress survey
- Nondestructive Testing:
  - Ground penetrating Radar (GPR) survey
    - Overlay thickness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

Reflective Crack Survey System

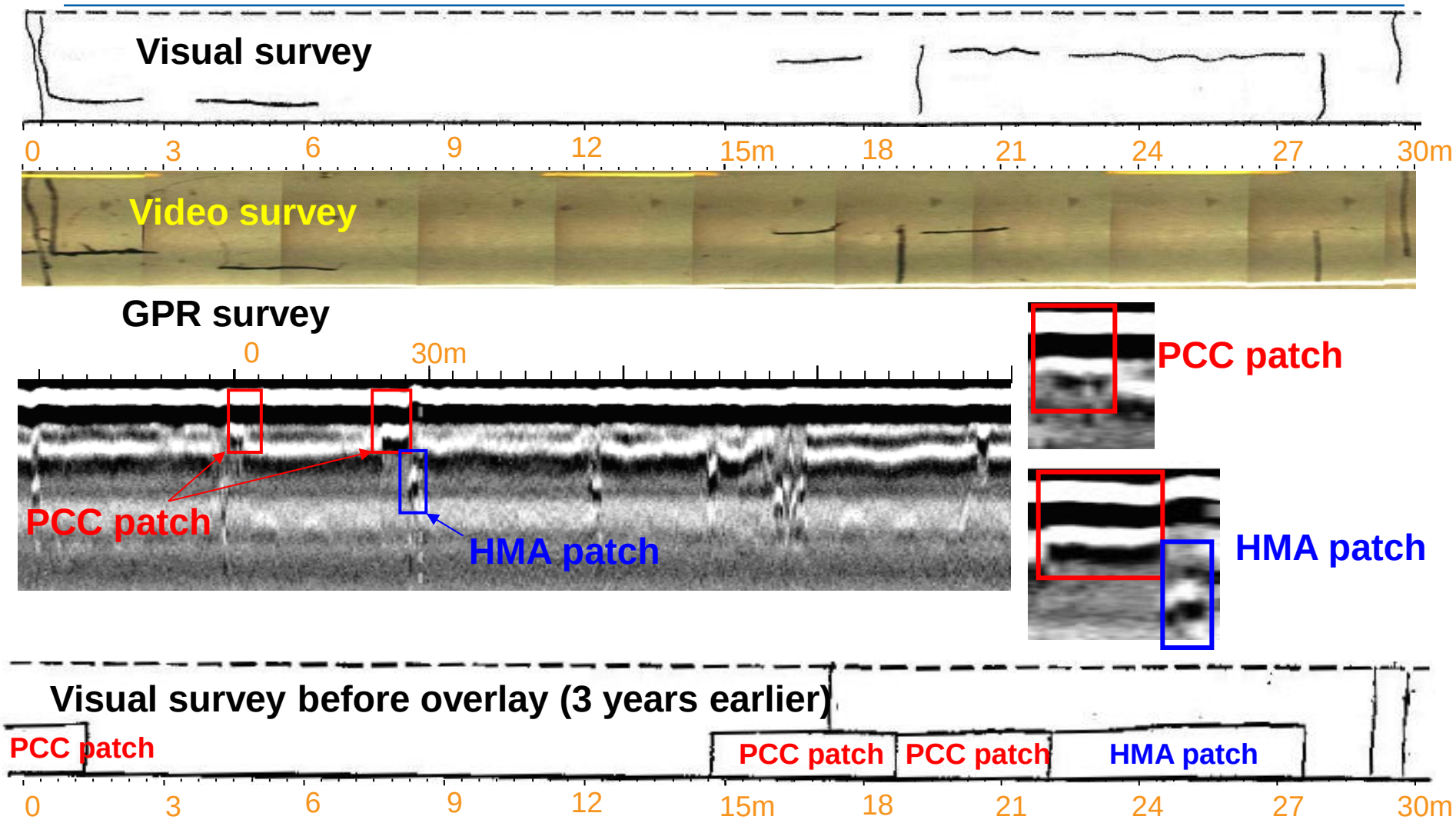
- **GPR and Video Integration System (GaVIS)**
  - **GPR: Joint/ patch location and overlay thickness**
    - **Video: Surface cracks**



GPR Survey

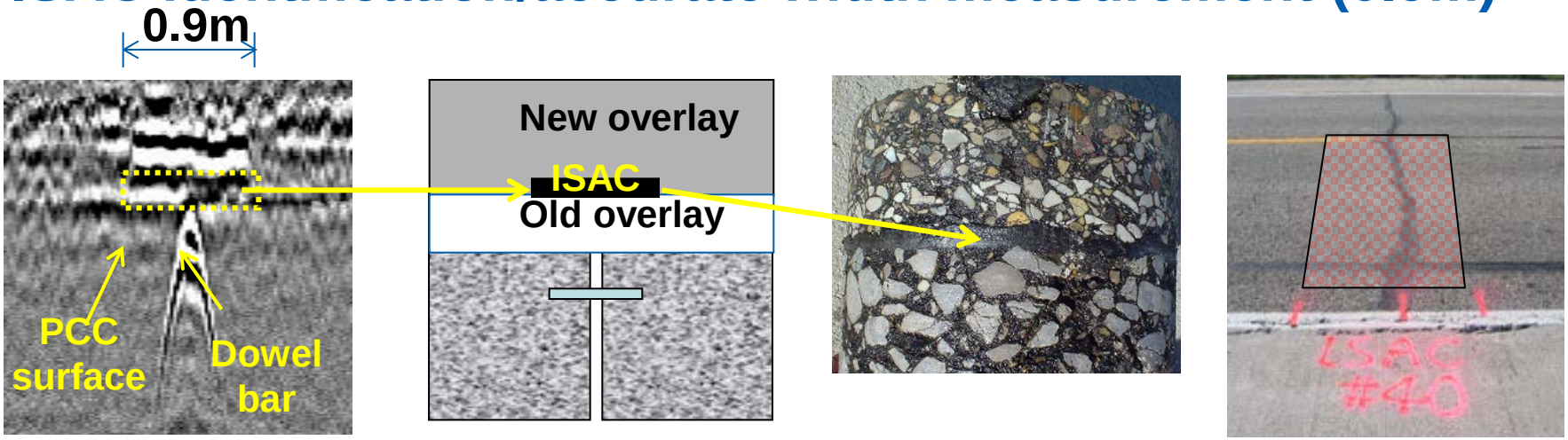

Strip reflection at PCC patch and HMA overlay
Strip reflection at HMA patch and PCC slab
Multiple reflections from a dowel bar
New HMA overlay
PCC patch
HMA patch
Old HMA overlay
PCC patch

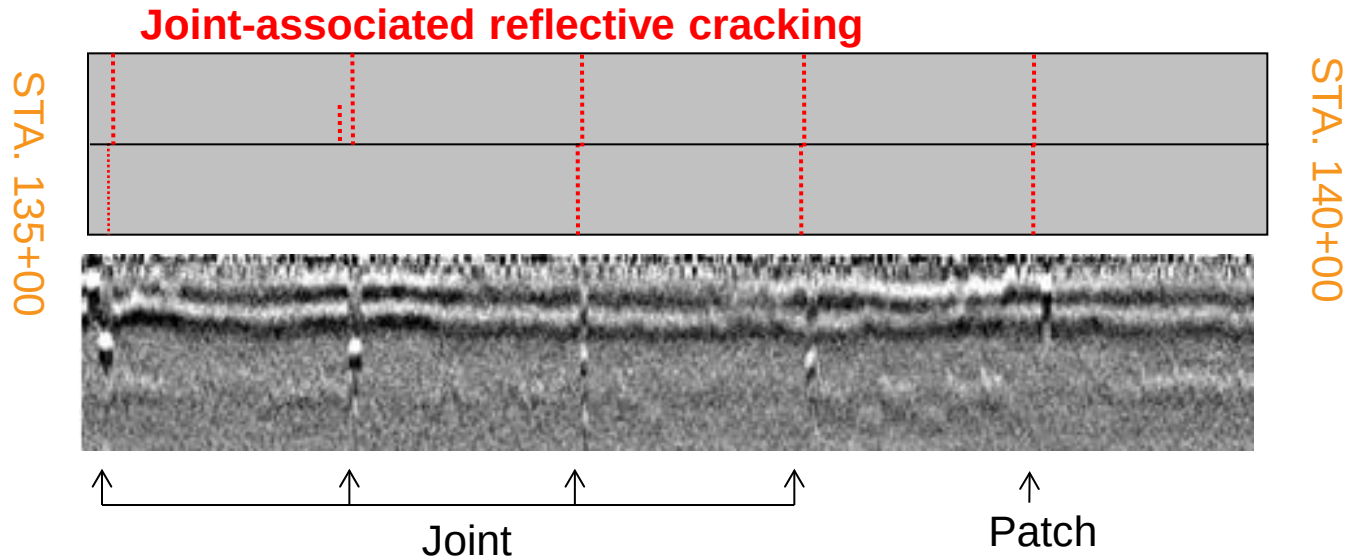
Example (IL130 Section 6)



Interlayer Detection

ISAC identification/accurate width measurement (0.9m)





Presentation 2:
Mitigation Strategies for Reflective Cracking in Pavements – Part I

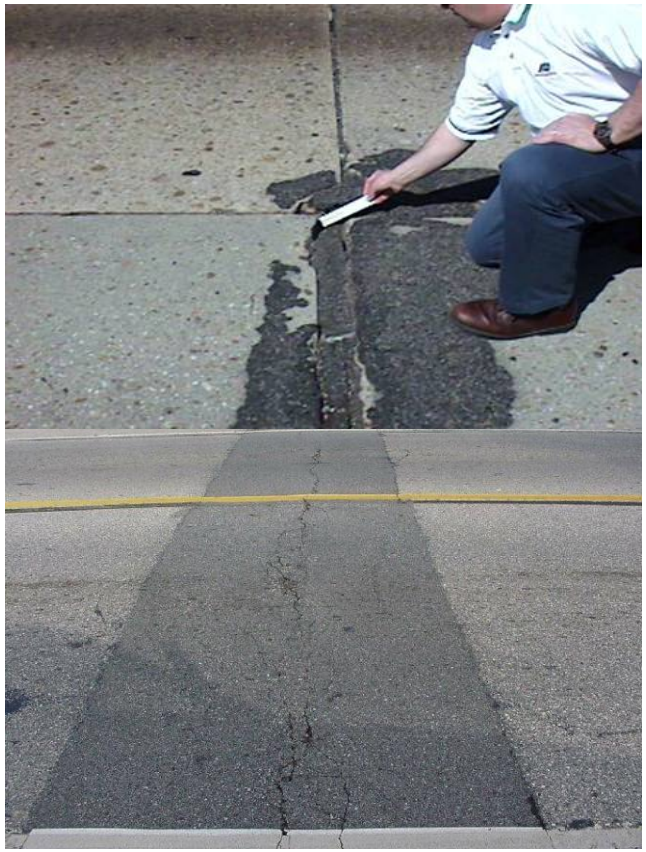
TRB Webinar – August 24th, 2015

Introduction

- Reflective cracking is the major modes of failure in rehabilitated pavements
- HMA overlays are not cost-effective against reflective cracking
- Various crack control methods have been introduced since 1960s → Mixed experiences

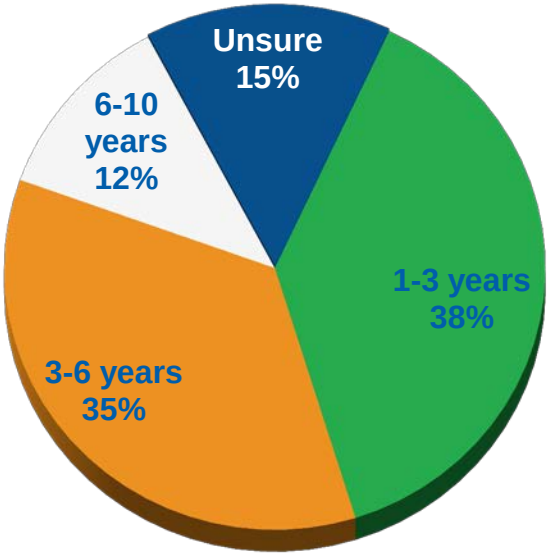
Crack Control Expectation

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



States of Practice

- **What is the average service life in years of a regular 1.5 to 2in HMA overlay against reflective cracking (i.e., time for the reflection of 50% of joints or cracks)?**
  - 1 to 6 years service life in majority of states
  - Greater service live in proactive states against RC
  - Shorter service life noticed for states in Northern Region



Average Service Life of a 2in HMA Overlay

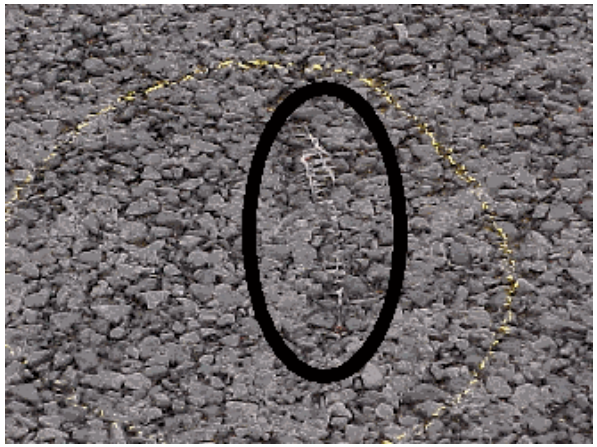
Regular Actions

- **Does your state take regular actions to address reflective cracking in HMA overlay?**

- Majority (63%) of states take regular actions
- 37% of highway agencies do not take specific regular actions to address reflective cracking

After 50 years of Experience

- A clear gap exists between in-situ performance and the understanding of the contributing mechanisms
- Performance of crack control treatments has been mixed



Crack Control Treatments

Treatment	Picture	Functions	Estimated Cost
Galvanized Steel Netting		Reinforcement	3.00 – 5.00 $/yd^2
Geogrid		Reinforcement	1.80 – 4.00 $/yd^2
Geonet		Reinforcement	3.00 – 4.00 $/yd^2
Glass-Grid		Reinforcement	4.00 – 7.00 $/yd^2
Paving Fabric		Stress Relief	0.60 – 1.05 $/yd^2
Geocomposite		Stress Relief	8.00 – 9.20 $/yd^2

Crack Control Treatments

Treatment	Picture	Functions	Estimated Cost
SAMI		Stress Relief	
Rubblization		Eliminates movement in concrete layer	5.00 – 6.00 $/yd^2
NovaChip		Stress Relief	3.00 – 4.00 $/yd^2
Strata		Stress Relief	4.00 – 5.00 $/yd^2
Saw and Seal		Control reflective cracking by sawing overlay	1.00 - 2.00 $/ft.

Interlayer Systems

- **Reinforcement:**
  - **Stiff materials to compensate lack of HMA's tensile strength**
- **Strain tolerant (Strain-energy relief):**
  - **Soft materials to dissipate strain energy by deforming itself**
- **Modified HMA:**
  - **Polymer-modified or crumb-rubber modified mixes to resist cracking**

Group 1: Asphalt-Based Interlayer Systems

- Stress-Absorbing Membrane Interlayer (SAMI)
- NovaChip®
- STRATA® reflective crack relief system
- Asphaltic surface treatment (chip seal)
- Open-graded AC interlay

Group 2: Geosynthetics and Steel Nettings

- Geosynthetics:
  - Paving fabric
    - Strip and area application
  - Geogrid
  - Glass-grid
  - Geocomposite
  - Geonet
  - Composite systems (e.g., Interlayer Stress Absorbing Composite [ISAC])
- Steel reinforcing mesh

Group 3: Other Methods

- Other methods:
  - Special purposes HMA mixtures (SMA, rubberized HMA, OGFC)
  - Saw and seal
  - Crack sealing + Overlay
  - Fractured slab approaches:
    - Crack and seat
    - Break and seat
    - Rubblization
  - Cold-in place recycling

GROUP 1: ASPHALT-BASED INTERLAYER SYSTEMS

NovaChip®

- Ultrathin bonded wearing course - NovaChip
- A thin (3/8 to 3/4in) gap graded HMA layer placed on top of a Novabond® membrane, which is a polymer-modified asphalt emulsion
- Pretreatment of existing joints is recommended (crack sealing)

Benefits:

- Experience has been mostly positive (e.g., North Carolina)
- Does not require grading adjustment
- Does not require adjustment to supporting structures (e.g., guardrails)

NovaChip® (Russel at al. 2008)

- Conducted a field study in Washington State
- NovaChip used instead of 1-in dense HMA on top of a deteriorated flexible pavement
- NovaChip performed well for about six years
  - Service life around 8 to 9 years

NovaChip (Russel et al. 2008)

- Evaluated cost effectiveness of NovaChip compared to HMA Class G:
  - Evaluated for low volume roads
  - Cost ranges from $3.00 to $4.00 per square yard
  - Cost of NovaChip ® was comparable to dense HMA

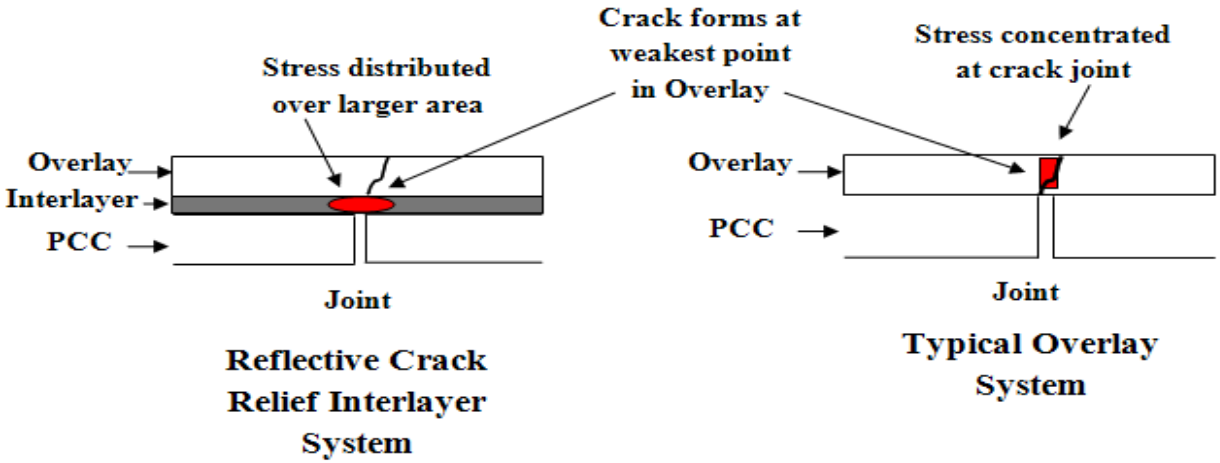
Rehabilitation Type	Estimated Time Between Treatments (yrs.)	Annual Worth ($/Lane Mile)	Annual Worth ($/Square Yard)
BST	6	2,700	0.28
HMA Class G	7	8,300	0.89
NovaChip	8 to 9	7,800 - 8,600	0.83 - 0.92
HMA Class A or ½ in Superpave	10	11,100	1.18

NovaChip (Cooper and Mohammad 2004)

- Reported Louisiana's first experience with NovaChip® :
  - Three sections were constructed and evaluated for 6 years
- Evaluated the performance of the technique:
  - Satisfactory performance with respect to rutting, roughness and cracking
  - Recommended further evaluations in concrete pavements

STRATA®

- A polymer-rich dense fine aggregate mixture placed on the existing pavement and is then overlaid
- Recommended on structurally-sound pavement

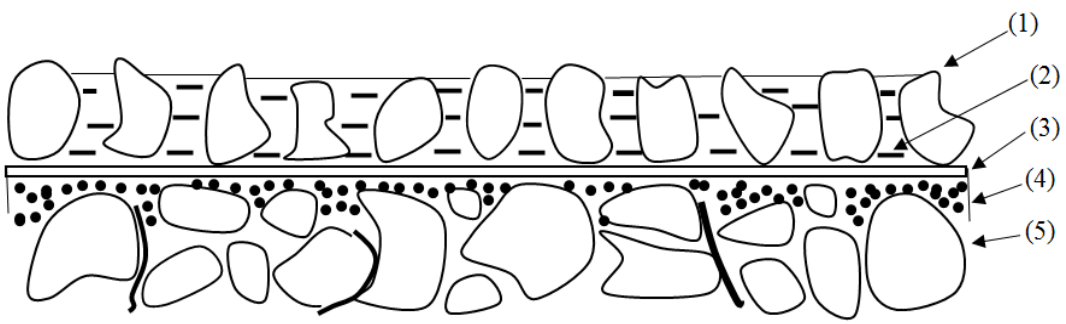


STRATA® - (Bischoff 2007)

- Two sections on I94 were evaluated in Wisconsin:
- First section:
  - One subsection with STRATA performed similar to control subsection
  - STRATA subsection performed best with only 6% reflective after 4 years
- Second section:
  - One of the control subsection performed good
- Bischoff recommended not using STRATA system in Wisconsin

Chip Seal/Paving Fabric (Davis and Miner 2010)

- Evaluated the use of nonwoven paving fabrics under chip seal
- 33 field projects were analyzed



Legend:
(1) Sealing aggregate
(2) Main Binder application
(3) Geotextile
(4) First Binder application (tack or bond coat)
(5) Weak or cracked base

Chip Seal (Davis and Miner 2010)

- **Results:**
  - **In warm climates (e.g., Texas and California), incorporation of fabric improved life of chip seal by 50-70%**
  - **In Michigan, test section with chip seal and paving fabric performed well compared to control section**
- **Shall not be used for roads with:**
  - **Vertical grades greater than 10%**
  - **ADT greater than 10,000**
  - **Severe freeze-thaw cycles**
  - **Poor drainage conditions**
- **Binder application rates:**
  - **0.30 and 0.35 gal/yd^2 for cold climate**
  - **0.25 and 0.30 gal/yd^2 for hot climate**

FRACTURED SLAB APPROACHES

Fractured Slab Techniques

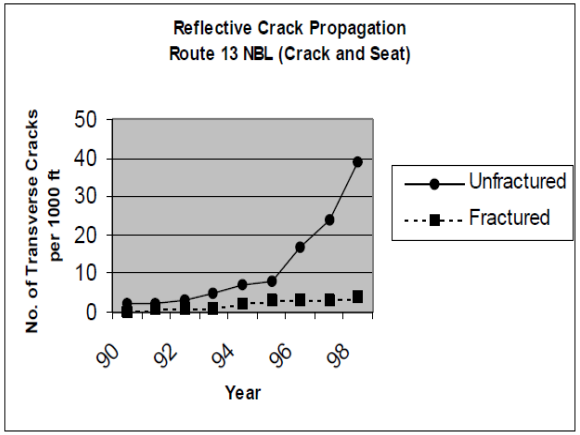
- Crack and seat (JPCP)
- Break and seat (JRCP)
- Rubblize (JPCP, JRCP, CRCP)

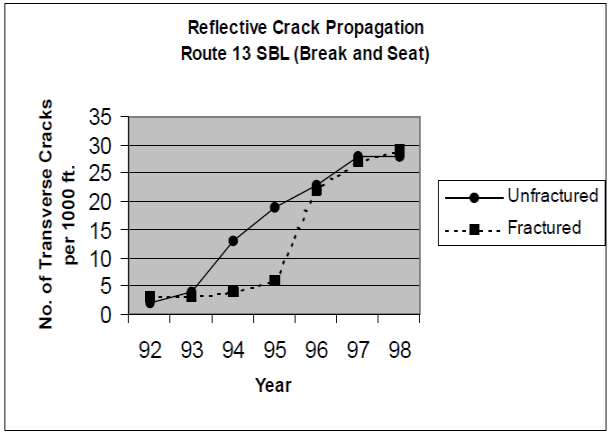
Crack and Seat (Freeman 2002)

- Evaluated performance of crack and seat:
  - Evaluated five projects for 8 years:
    - Two JPCP and three JRCP
  - Guillotine drop hammer and 50-ton pneumatic tire roller
- Movements prior to rehabilitation:
  - Vertical displacements (¼ to ¾ in.) were measured across the transverse joints
  - Patched slabs representing 8 to 15% of the total number of slabs were recorded

Crack and Seat (Freeman 2002)

- Crack and seat was effective in case of JPCP
- Less effective in case of JRCP (effective up to three years of construction)
- Effective technique given the nominal cost of operation





Crack and Seat (Choubane et al. 2010)

- Evaluated performance of crack and seat to retard reflective cracking:
  - 14 sections were selected on I-10 in Florida
  - Rideability, rutting and cracking data were collected for 7 years after construction.
- Crack and seat was effective in conjunction with ARMI
  - Provided good ride characteristics
  - Rutting performance was effective (less than 6mm rutting)
  - Reflective cracks were insignificant

Rubblization (Timm and Warren 2004)

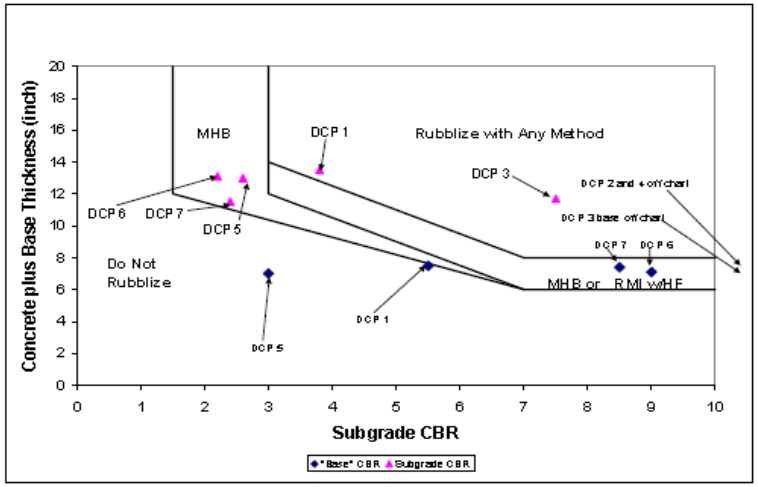
- Evaluated the performance of rubblization in Alabama for JPCP and CRCP
  - Nine projects with 2.5 to 11 years of service
- Rubblization improved pavement performance
- Higher levels of distress in CRCP
  - Incomplete debonding between concrete and steel reinforcement

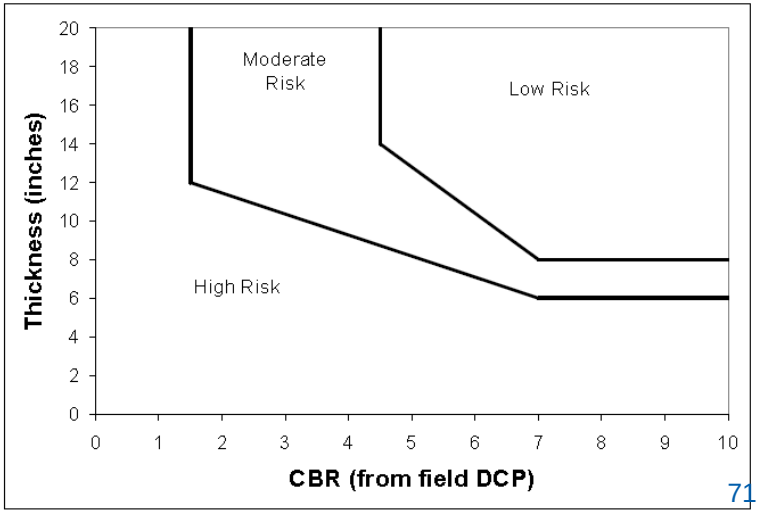
Rubblization (Sebasta and Scullion 2007)

- Evaluated the performance of rubblization for concrete pavements:
  - Five field projects were evaluated and monitored
  - Prior and after construction evaluation was performed using GPR, FWD and DCP
  - Tests performed to identify areas of moisture accumulation and weak support beneath the slab

Rubblization (Sebasta and Scullion 2007)

- Two factors to consider in selecting rubblization:
  - Drainage conditions
  - Subgrade support beneath the slab
- Modulus of rubblized layer increased with age (from 114 to 323 ksi)
- The Illinois rubblization selection chart and a modified chart version were presented





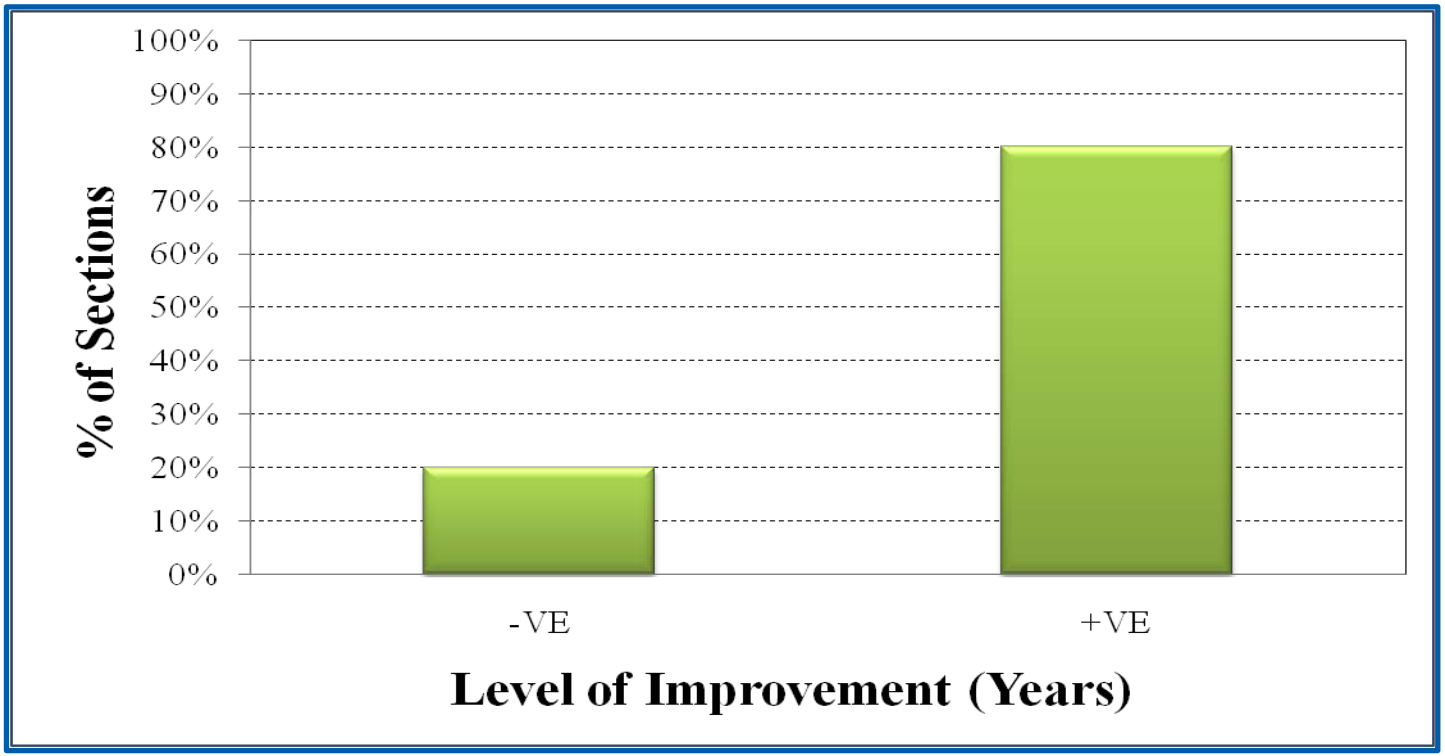
Saw and Seal


Mark Joint Locations
Asphalt Paving
Within 3 days of Overlay
Cut Joints
3mm wide by 25mm deep
Clean Joints
Seal Joints
Rubberized asphalt sealant

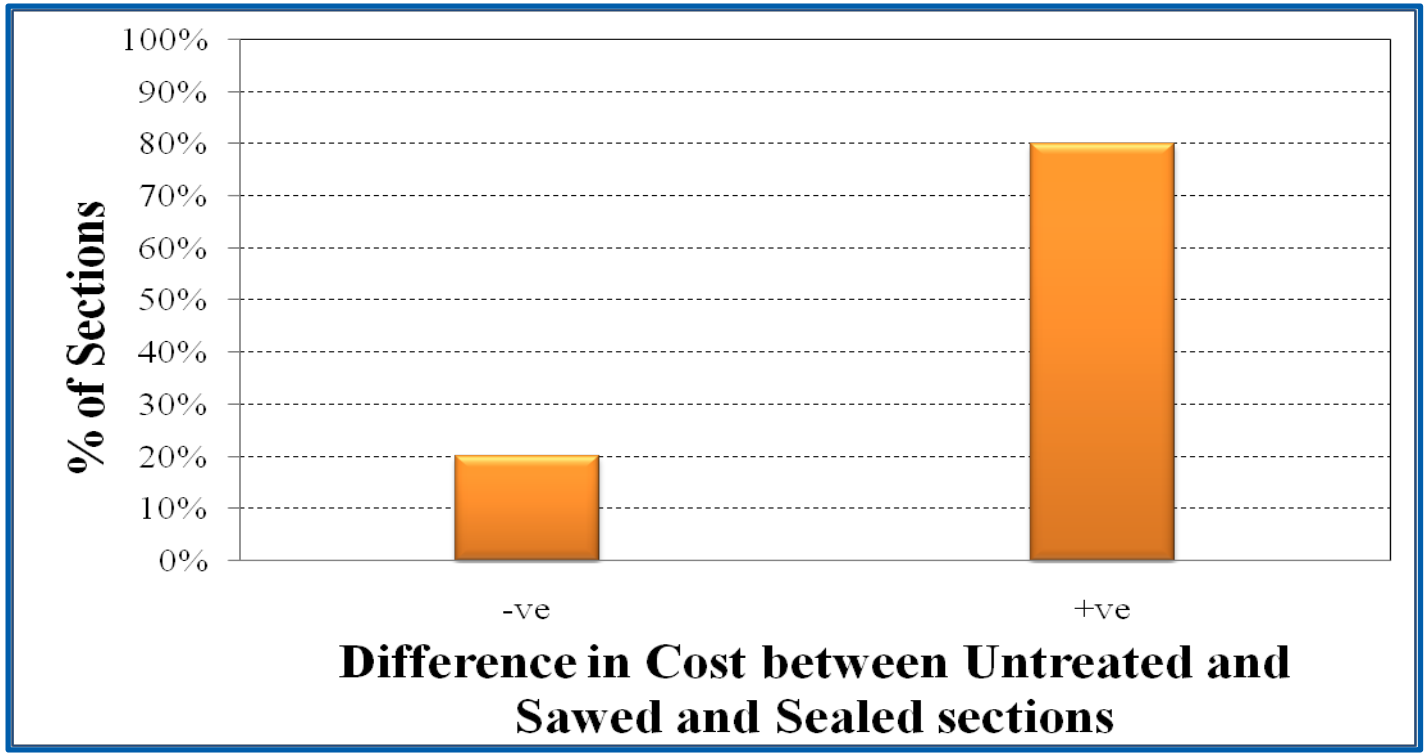
Saw and Seal (Elseifi et al. 2011)

- Evaluated the field performance of saw and seal treatment method to control reflective cracking
  - 15 in-service pavements with a service life of 6 to 14 years
- Assessed performance and cost-effectiveness of saw and seal treatment method

Results: Levels of Improvement



Results: Cost Analysis



Saw and Seal (Farina et al. 2008)

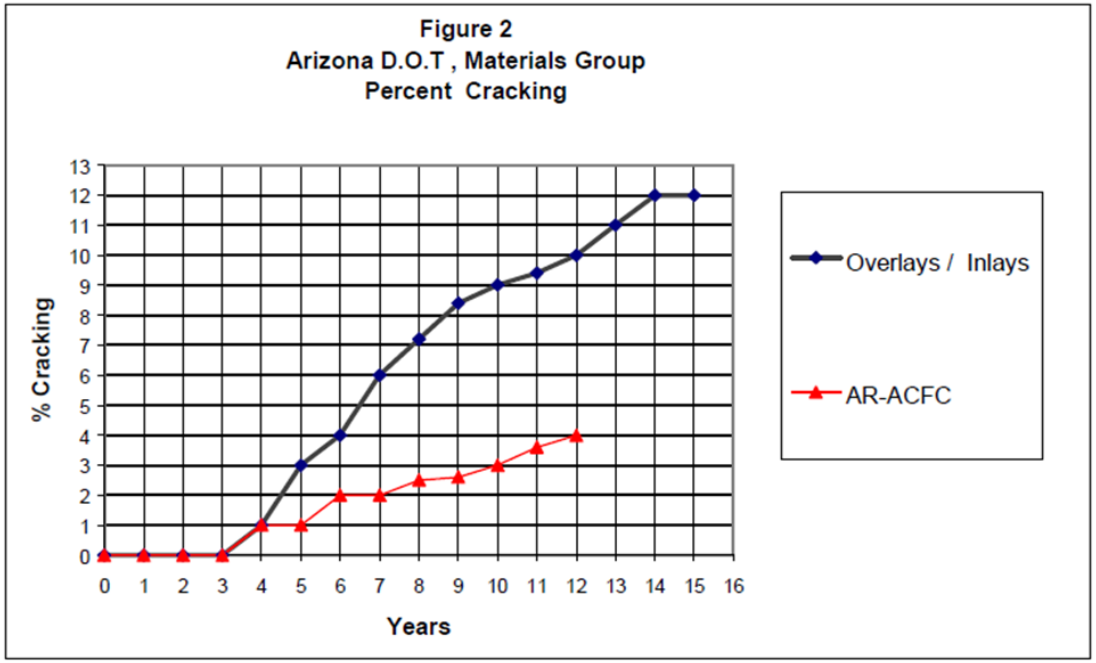
- Evaluated the field performance of saw and seal treatment method (fabrics, etc.)
  - Sections with two joint spacing were built on top of concrete pavement
  - Visual surveys, deflection testing, coring for seven years
- Determined saw and seal to be the best performer
  - Joint spacing of 15ft reduces severity compared to joint spacing of 20ft

Asphalt Rubber (Way 2000)

- Presented Arizona DOT experience with AR to delay reflective cracking:
  - Used in open-graded and gap-graded mixes (0.5 to 1 in. and 1 to 2.0 in)
  - AR binder from 9 to 10% in open-graded and 7.5 to 8.5% in gap-graded
  - Base asphalt is PG 58-22, PG 64-16
  - Rubber-modified asphalt is PG 70-22 to PG 82-28

Asphalt Rubber (Way 2000)

- Performance of AR has been excellent against reflective cracking on I19



Asphalt Rubber (Brown et al. 1991)

- Evaluated the performance of asphalt rubber in Georgia
  - 6% crumb rubber was added using the wet process
  - Field performance was evaluated for four years
- Crumb rubber caused the mix to become very brittle→ large amount of reflective cracking
- Crumb rubber did not reduce reflective cracking → expensive to produce and install

Collective Evaluation (Chen et al. 2006)

- Evaluated the field performance of different treatment methods for JPCP:
  - Grid
  - Strata
  - Petromat fabric
  - Crumb rubber asphalt mix
  - Flexible base
  - Arkansas mix (open-graded AC interlayer)
  - Full-depth repair
  - Break and seat
  - Crushed stone base interlayer

Collective Evaluation (Chen et al. 2006)

- **Main Findings:**
  - **Strata costs 10 to 20 times the cost of Petromat**
  - **After two years, 3% in section with Strata and 10% in section with Petromat**
  - **Crack retarding grid did not perform well – Debonding**
  - **Full-depth repair was not successful and the most expensive**
  - **Best performing sections were the ones with Arkansas mix and the crushed stone base interlayer**

Collective Evaluation (Von Quintus et al. 2010)

- Evaluated the field performance of various treatments in airport pavements
- Most effective methods:
  - Rubblization for PCC pavements
  - Full-depth reclamation for flexible pavements
  - Paving fabrics are effective with small cracks
  - Saw and seal

Collective Evaluation (Powell 2012)

- Evaluated the field performance of pavement preservation treatments:
  - fog seals, crack seals, chip seals, overlay, ultra-thin bonded wearing course
- Crack sealing stopped the development of interconnected cracks observed in the control section

Presentation 3:
Mitigation Strategies for Reflective Cracking in Pavements – Part II

TRB Webinar – August 24th, 2015

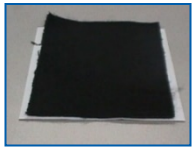
Group 2: Geosynthetics and Steel Nettings

- Geosynthetics:
  - Paving fabric
    - Strip and area application
  - Geogrid
  - Glass-grid
  - Geocomposite
  - Geonet
  - Composite systems (e.g., Interlayer Stress Absorbing Composite [ISAC])
- Steel reinforcing mesh

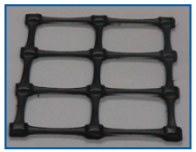
Interlayer Systems – Group 2

Geosynthetics

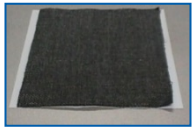
Geotextile



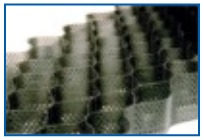
Geogrid



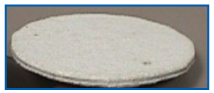
Geomembrane



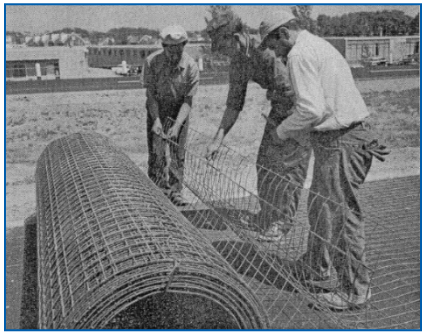
Geocell



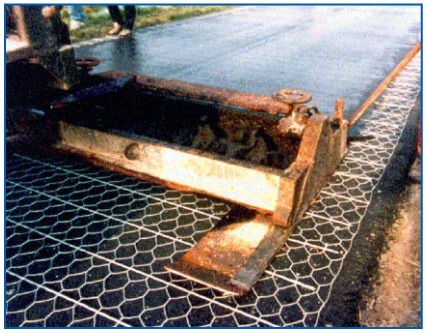
Geocomposite



Steel Reinforcement



1960



1990

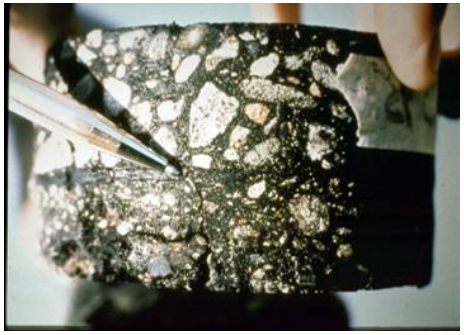
Overlay Interlayer Functions

	Reinf.	Resistance 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

* Smoothness & Recycling!!

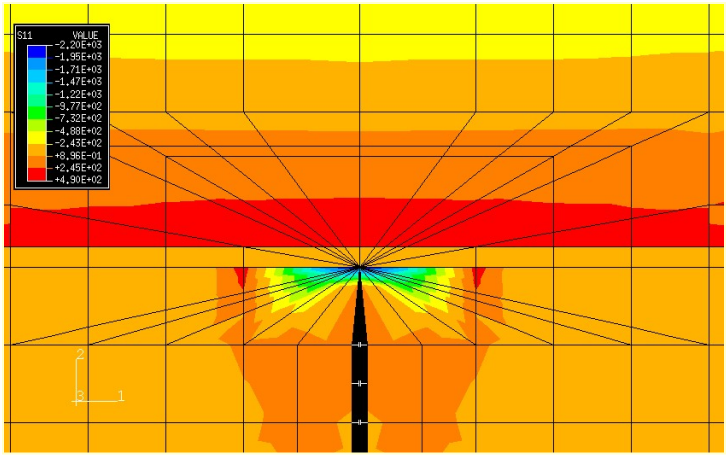
Band-Aid

Fabric Interlayer



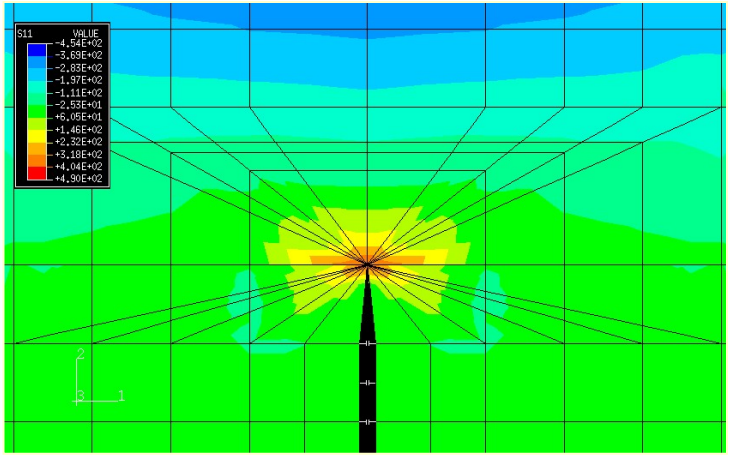
Geocomposite - Installation

Crack Initiation: Mode I

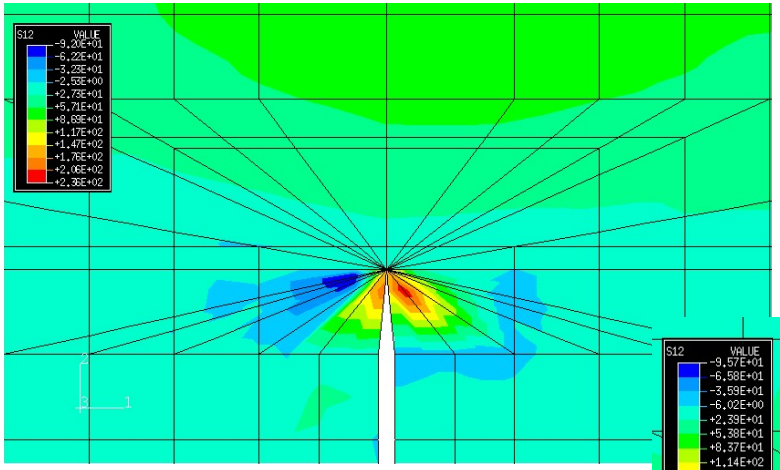


Horizontal Stress With Strain Energy Reliever

Horizontal Stress without Interlayer

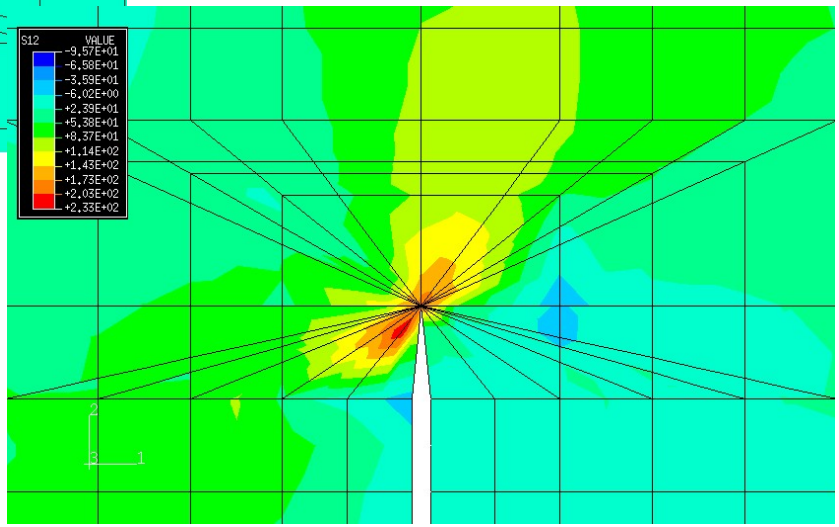


Crack Initiation: Mode II



Shear Stress with Strain Energy Reliever

Shear Stress without Strain Energy Reliever

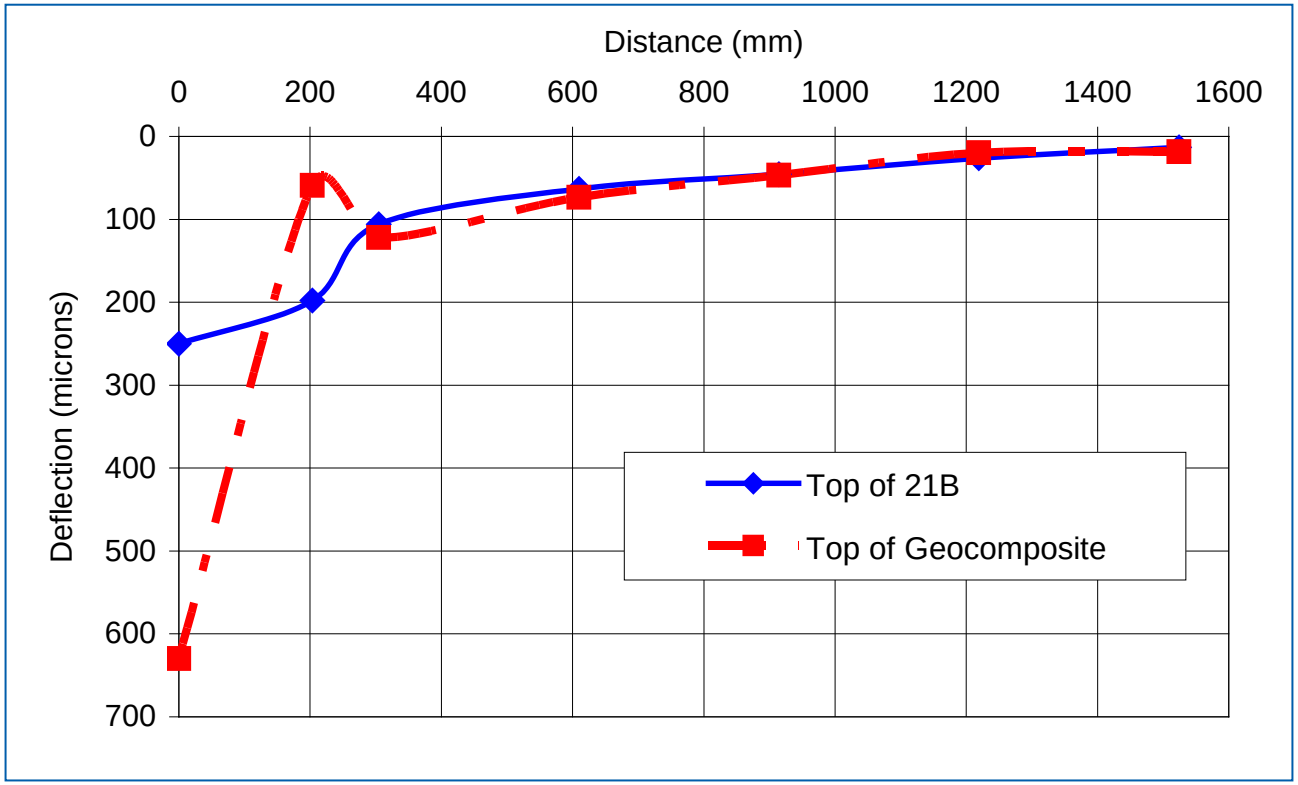


Crack Propagation

- Strain-energy reliever is only effective in the crack propagation phase if the crack does not propagate through the interlayer

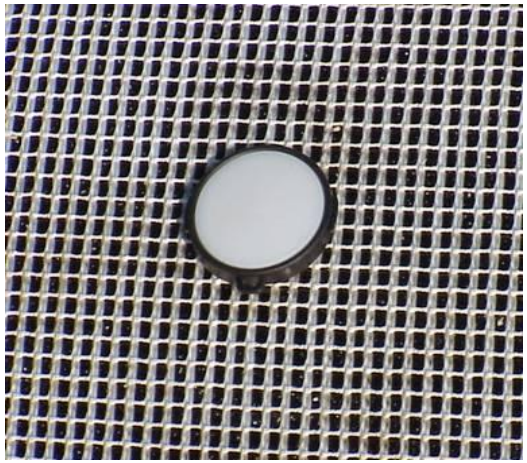
Increased Flexibility

- The use of soft interlayer system would cause an increase in pavement surface deflection

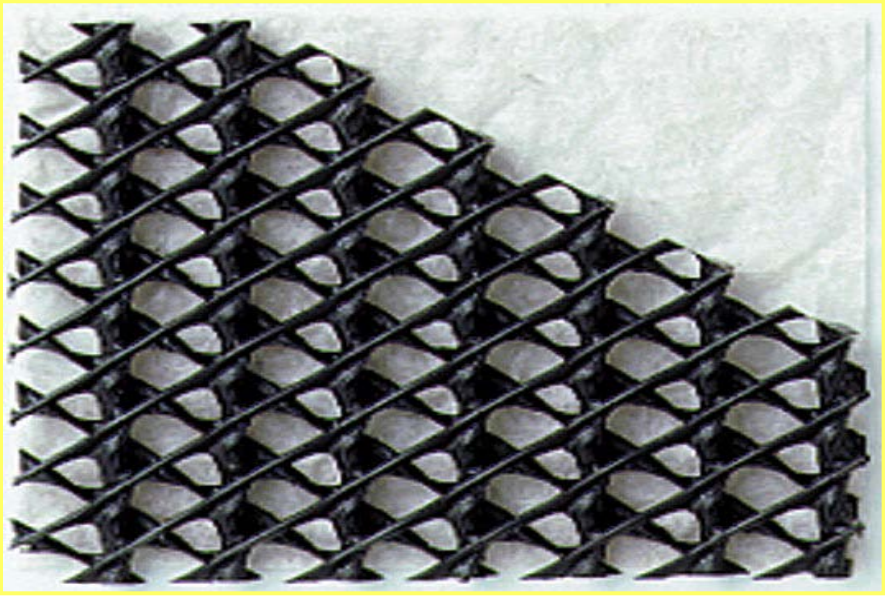


Reinforcing Composite

Interlayer Stress Absorbing Composite, ISAC



TenDrain



VDOT-Route 58 Rehabilitation Project

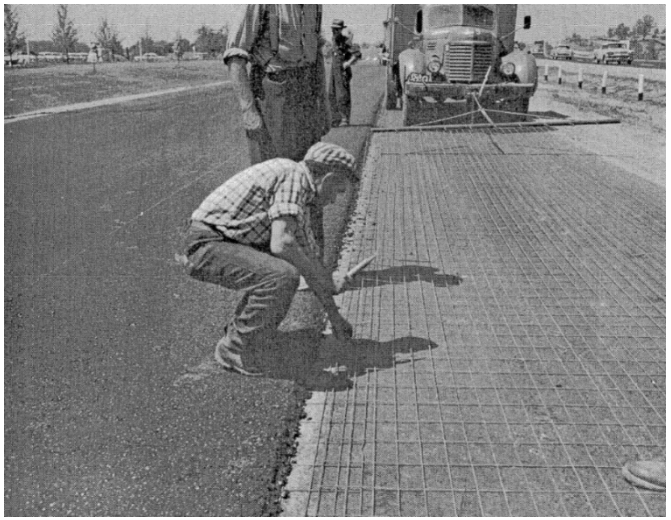
Factors Influencing Geosynthetic Performance

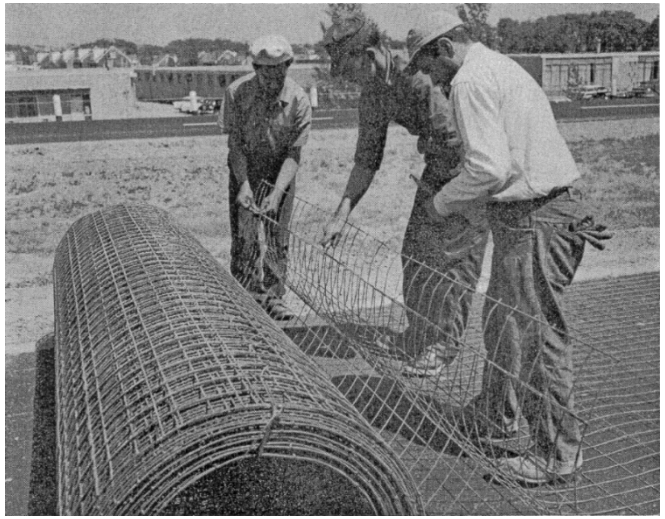
- Existing pavements
  - More successful with rehabilitated flexible pavements
- Movement at the joints
  - More successful with stable joints
- Traffic
  - More successful with light to medium traffic
- Construction
  - Good bonding key to good performance (tack coat,…)

STEEL REINFORCING NETTINGS

Welded Steel Wire

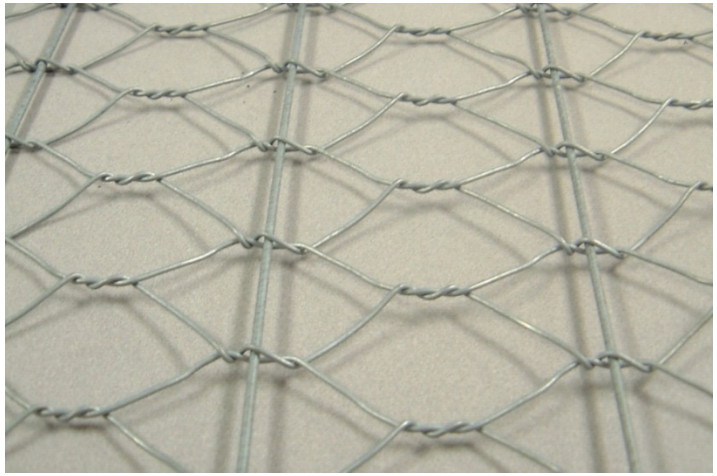
- Technology Emerged in the Early 1950s in the US and Canada (Brownridge et al. 1964, Bushing et al. 1970)





Steel Reinforcing Nettings

- Technology Reemerged in the Early 1990s in Europe (Francken 1992; Veys 1996).



Experiences with Steel Reinforcement - EU

1989

70mm
HMA

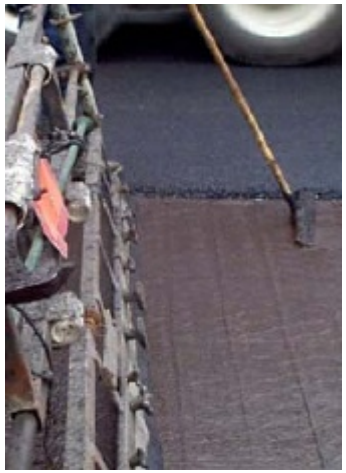
11 years

2000

Steel Reinforcement Nettings

- First application in the US was in 1999 at the Virginia Smart Road
- Several states installed trials sections and some are being monitored for long-term performance



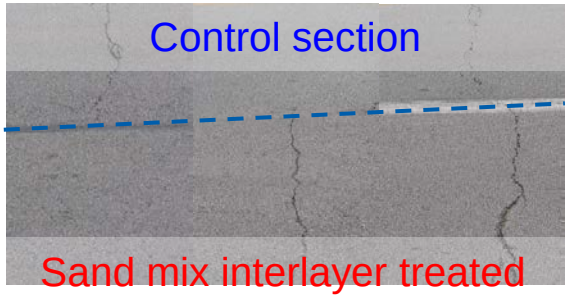


Steel Reinforcing Nettings (Al-Qadi et al. 2003)

- **Installation:**
  - **Nailing**
  - **Intermediate Layer: Slurry Seal 17kg/m^2**
- **Field performance in the US:**
  - **Installation procedure should be more systematic**
  - **Performance is installation dependent**

Interlayer Performance Challenges!

- No improvement or not cost effective!!
- Causes:
  - Lack of understanding interlayer system mechanisms
  - Inappropriate interlayer installation
  - Interlayer material properties and characteristics
  - Interface condition



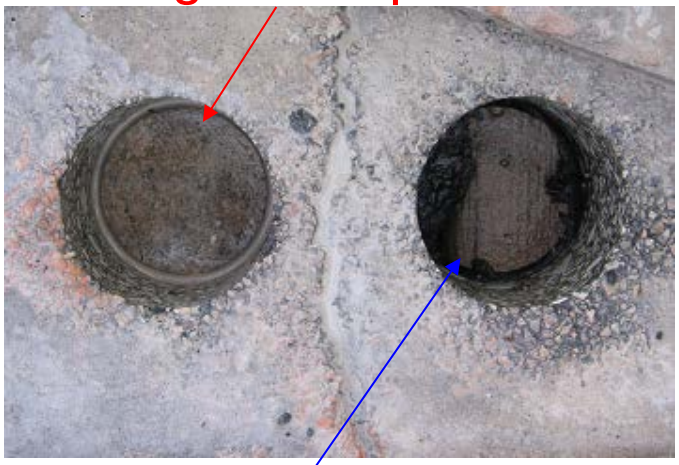
In Less Than a Year!

Bad Practice!

Strip Interlayer System Installation

Due to lack of compaction at the end of strip-type interlayer,
reflective cracking can develop along the edges

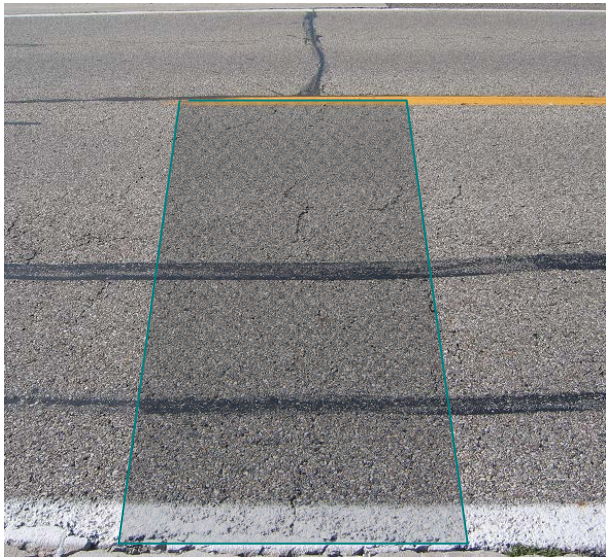
Edge of strip treatment



Strip type fabric interlayer

SAF

ISAC



SAF: Sand Anti-Fracture mixture

ISAC: Interlayer stress absorbing composite

Due to proper installation of ISAC,
severe reflective cracking is successfully controlled

Considerations for Interlayer Systems

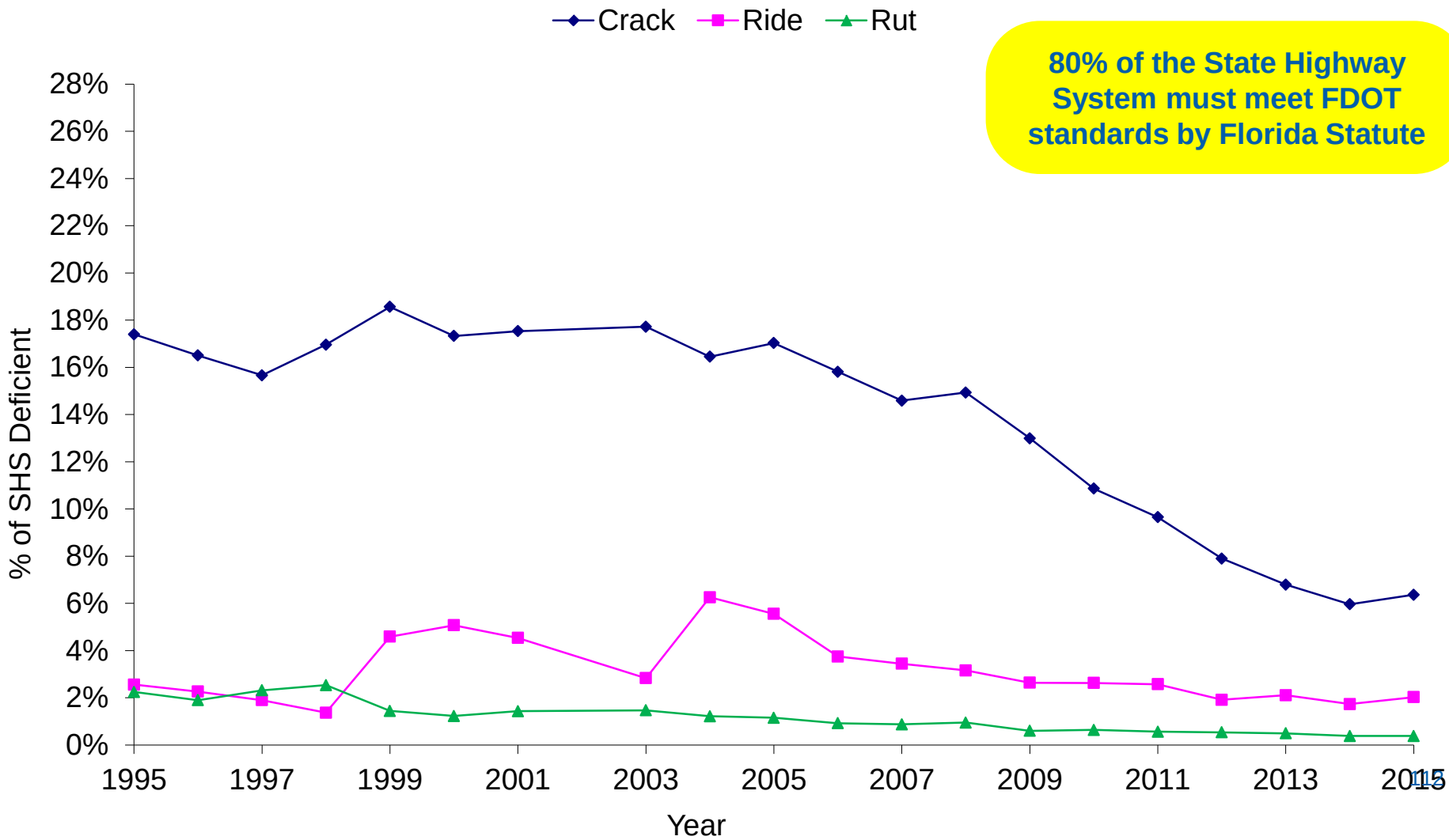
- Interlayer systems MAY NOT prevent crack movement
- Not all interlayer systems are the same! (reinforcement, strain tolerant, moisture barriers)
- Joints/cracks must be stable (Prepare Pavement!)
- Minimum overlay thickness needs to be identified
- Successful installation is a key for proper performance: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

Presentation 4:
Florida's Experience with Asphalt Rubber Membrane Interlayers

FDOT's Resurfacing Program

- Approximately 2,000 lanes miles are resurfaced annually
- Bottom-up fatigue cracking & base/subgrade damage is uncommon
- Primary asphalt distresses
  - Top-down & reflective cracking
  - Raveling

Historical Statewide Performance



80% of the State Highway System must meet FDOT standards by Florida Statute

Background

- It is often not practical to mill deep enough to remove all surface cracks
- FDOT's primary reflection crack mitigation strategy has been an ARMI
- Pavements treated with an ARMI often have mixed performance
- Districts have observed increased rutting; particularly at intersections

ARMI

- Asphalt binder with 20% GTR (ARB-20)
  - PG 64-22 base binder & 20, 40, or 80 mesh GTR
  - Placed at 0.6 to 0.8 gal/yd^2
- No. 6 stone
  - Placed at approximately 0.3 ft^3/yd^2 and seated with a rubber tire roller
- Min 1.5 in. overlay to provide sufficient heat to properly bond ARMI and overlay

Observations & Experience

- Florida's first ARMI experiment conducted in 1978 (SR 60 Hillsborough County)
- Informal survey of District Bituminous Engineers
  - Wide range of experience
  - Many roadways already have an ARMI in place
  - Construction quality is a concern among all districts
  - Some districts have observed instability rutting in thin overlays with an ARMI
  - Perceived benefit does not always justify the cost

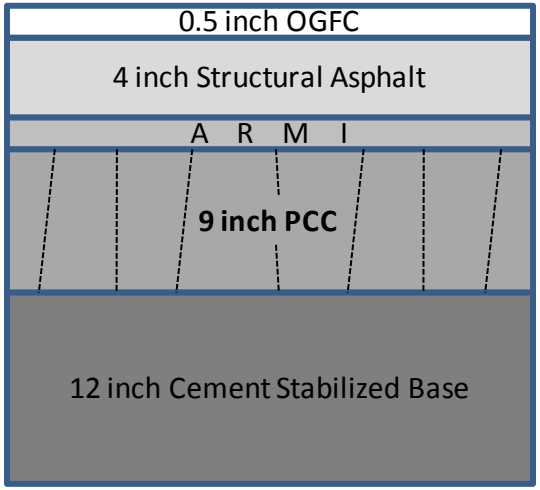
I-10 Concrete Rehabilitation

- Evaluation of 7 PCC sections rehabilitated from 1993 - 1995
- Cracked & seated PCC pavement into 36 in. max size pieces

Considered to have good overall performance

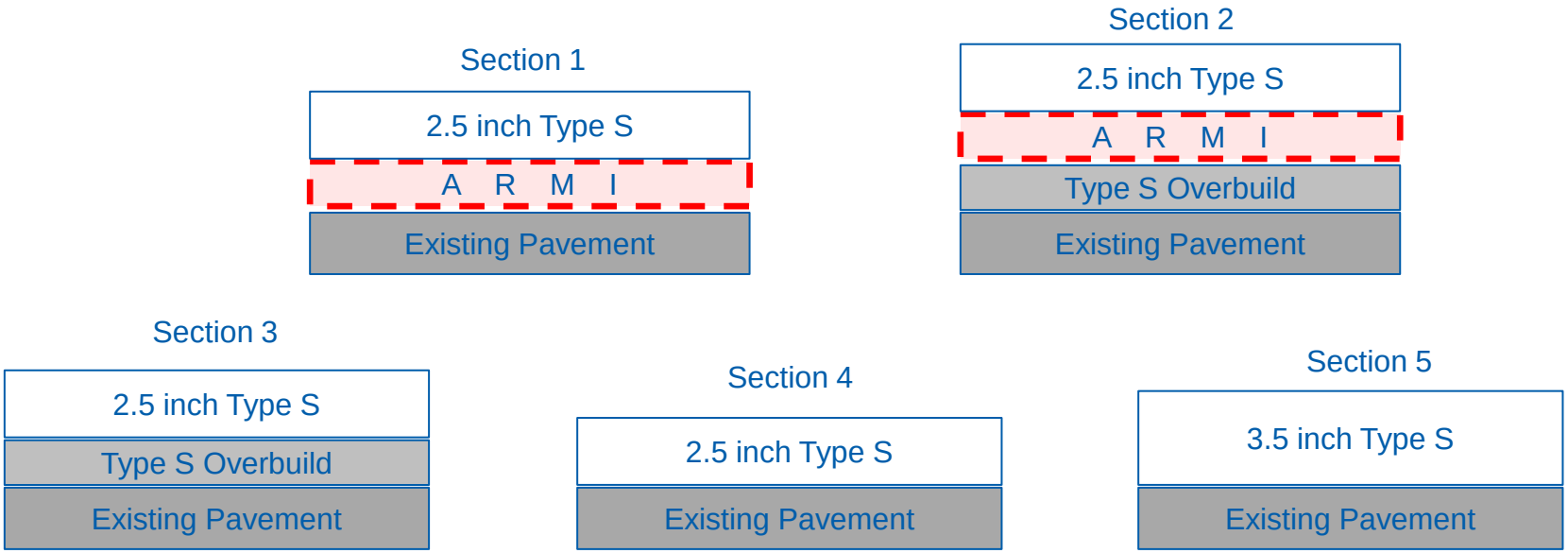
County	Years Until First Crack	Rut Depth after 10 years, mm
Jefferson	7	11.4*
Leon-1	6	8.3
Leon-2	7	11.3*
Gadsden	5	7.2
Jackson-1	7	4.7
Jackson-2	7	7.2
Walton	7	5.1

* Replaced after less than 7 years. Construction and mix design issues thought to be reasons for premature failure.



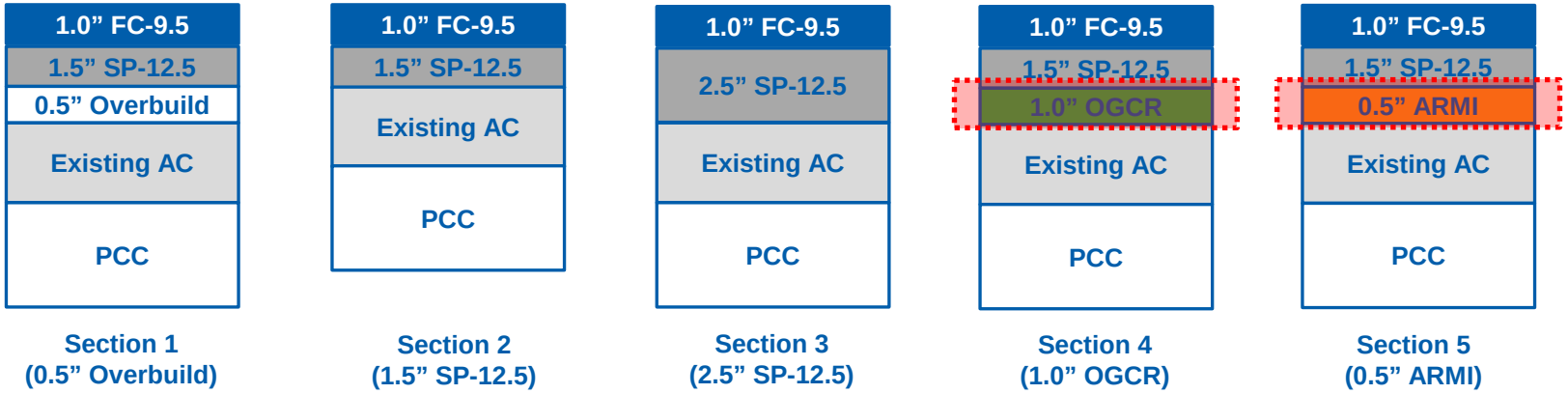
SR-2 Experimental Project

- Five experimental sections monitored from 1998 to 2011
- Both sections with an ARMI had more cracking than prior to rehab



US-90 Experimental Project

- Five experimental sections monitored since 2010
- ARMI section had minor reflection cracking after first year
- After 5 years, ARMI section has most reflection cracking



Forensic Investigations

- Several forensic investigations have found an ARMI may be a contributing factor to excessive rutting
  - SR 37 & Sheperd Rd intersection, Polk County
  - US 27 & SR 540 intersection, Polk County
  - I-10, Okaloosa & Washington Counties
- Many District field personnel have observed construction issues
  - Excessive ARB-20
  - Insufficient No. 6 stone

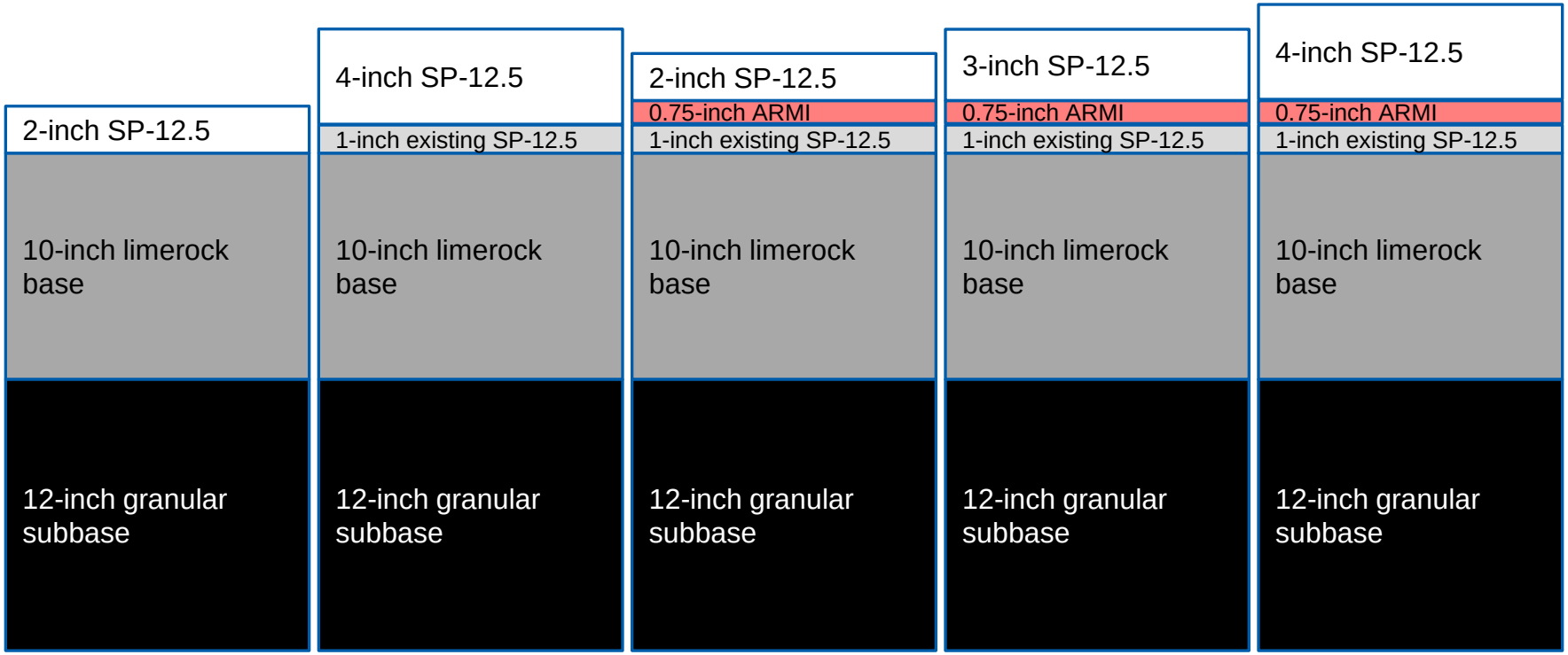
APT Experiment Design

- Five test lanes
  - SP-12.5 mm
  - PG 76-22 binder
- Overlays of 2, 3 and 4 inch with an ARMI
- Control sections
  - 4 inch overlay without an ARMI
  - New 2 inch thick asphalt pavement

Pavement Structure

Control Sections

Experimental Sections



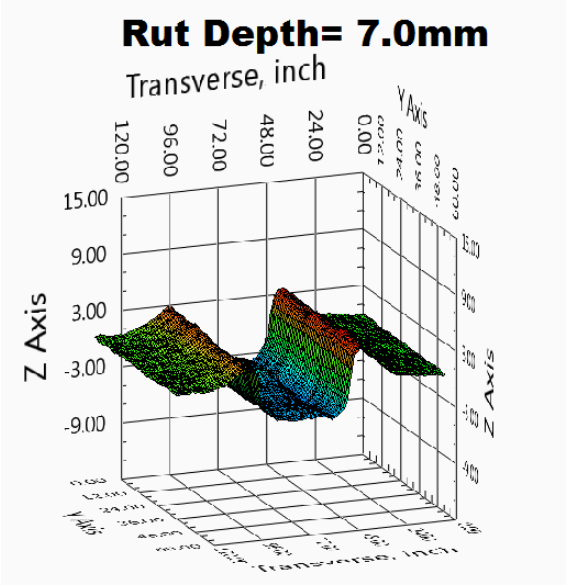
HVS Basics

- Dynatest HVS, Mark IV
- Wheel speed up to 8 mph
- Loading: 7 to 24 kips
- Wander from 0 to 30 inches

Rut Measurement

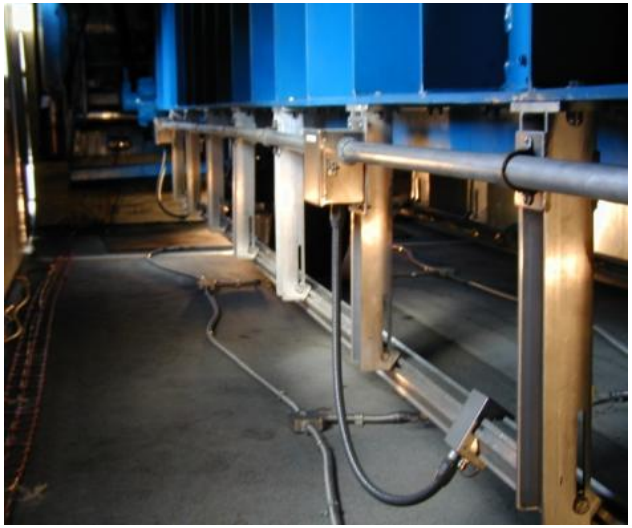
- Two 16 kHz Lasers
- Unloaded wheel carriage travels at 2.5 mph
- Profile time is approximately 15 minutes
- Profiles collected throughout test

Laser profiler



Heating System

- Radiant heaters attached to both sides of HVS test beam
- Insulated panels enclose test area
- Pavement temperature monitored and controlled by thermocouple measurements



APT Loading Conditions

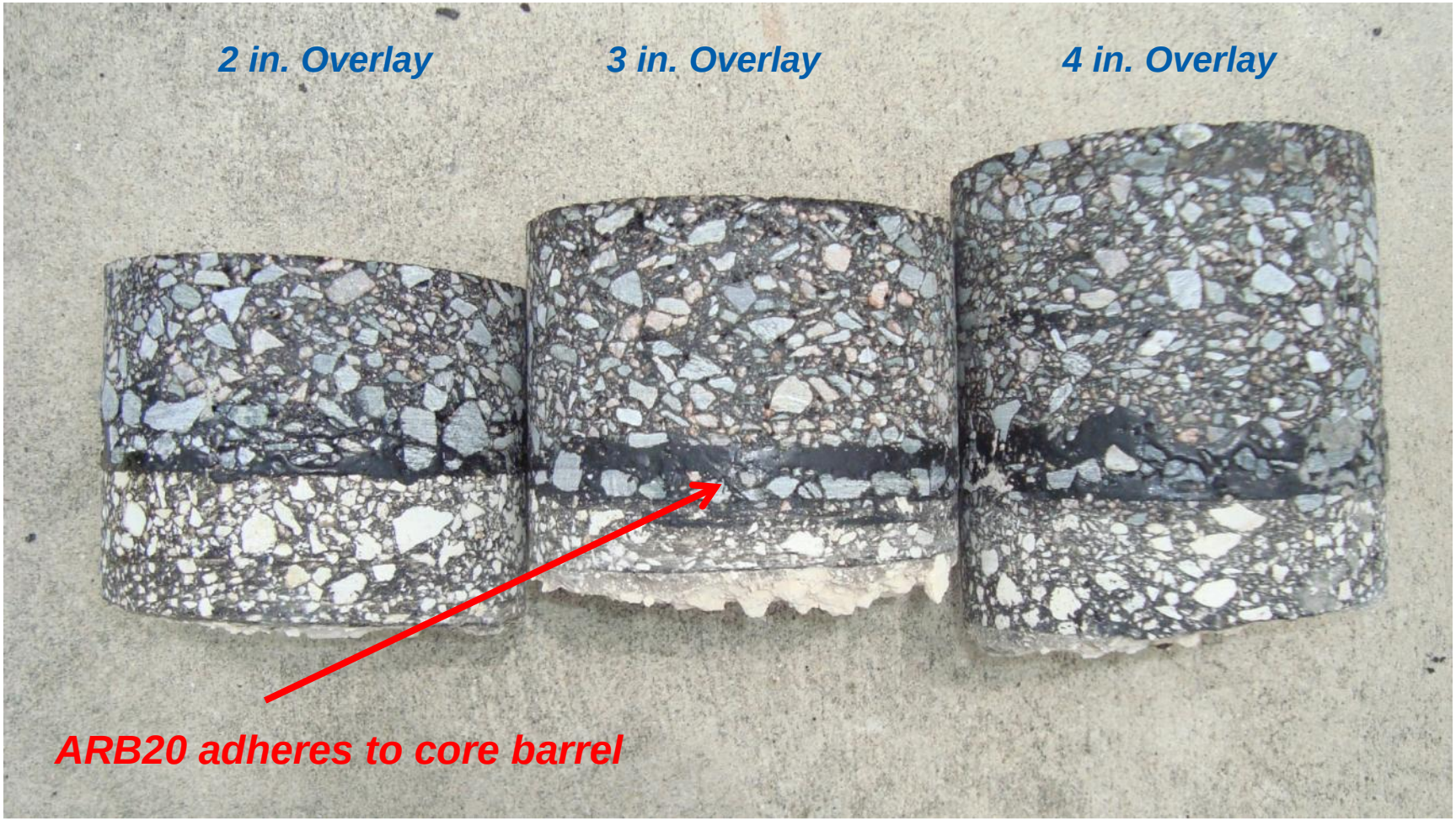
- 455mm wide-base tire
  - Michelin X One XDA-HT Plus, 455/55R22.5
- 9 kip load
- 4-inch wander
- Constant temperature maintained at 120ºF

Asphalt Rubber Binder

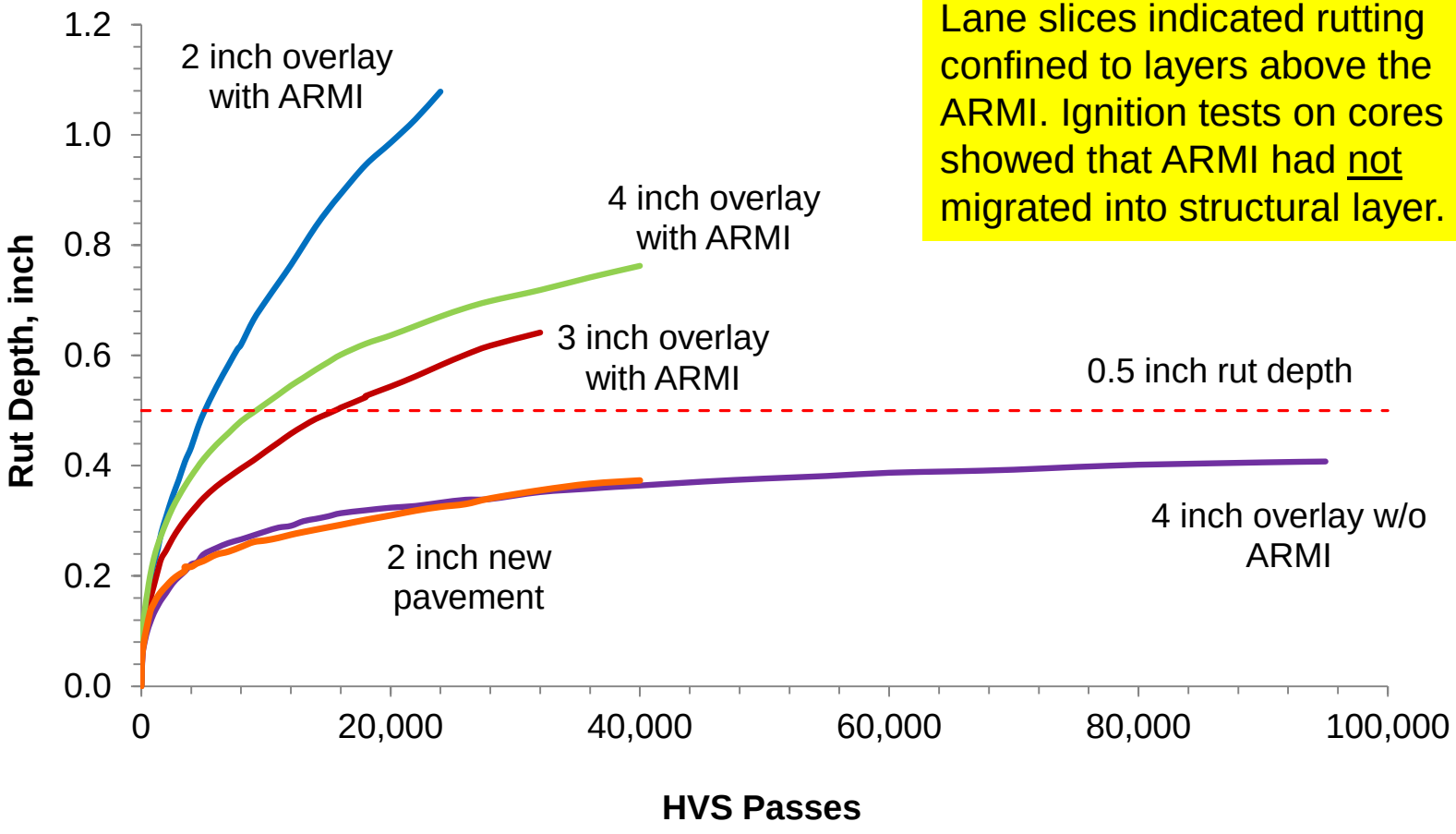
Spreading No. 6 Stone

Seating Stone

Cores

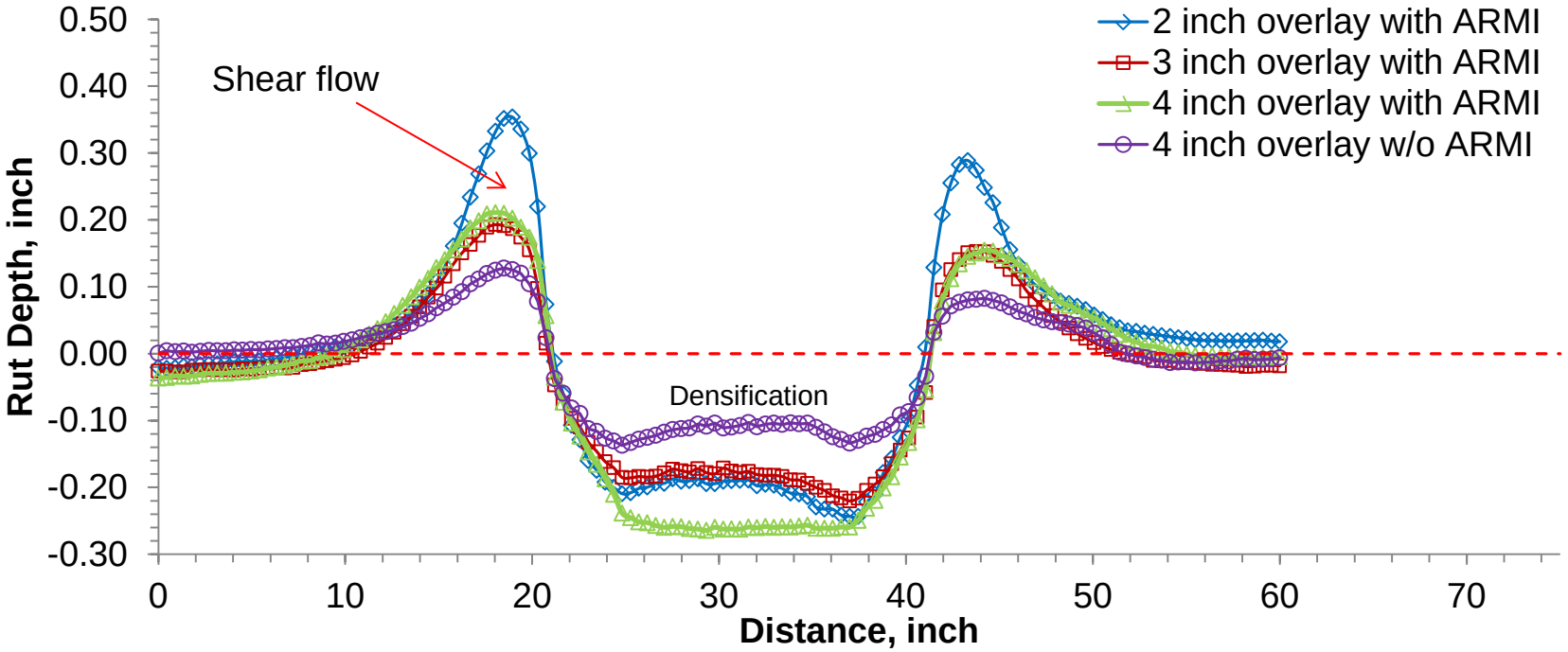

2 in. Overlay
3 in. Overlay
4 in. Overlay
ARB20 adheres to core barrel

Rutting History



Lane slices indicated rutting confined to layers above the ARMI. Ignition tests on cores showed that ARMI had not migrated into structural layer.

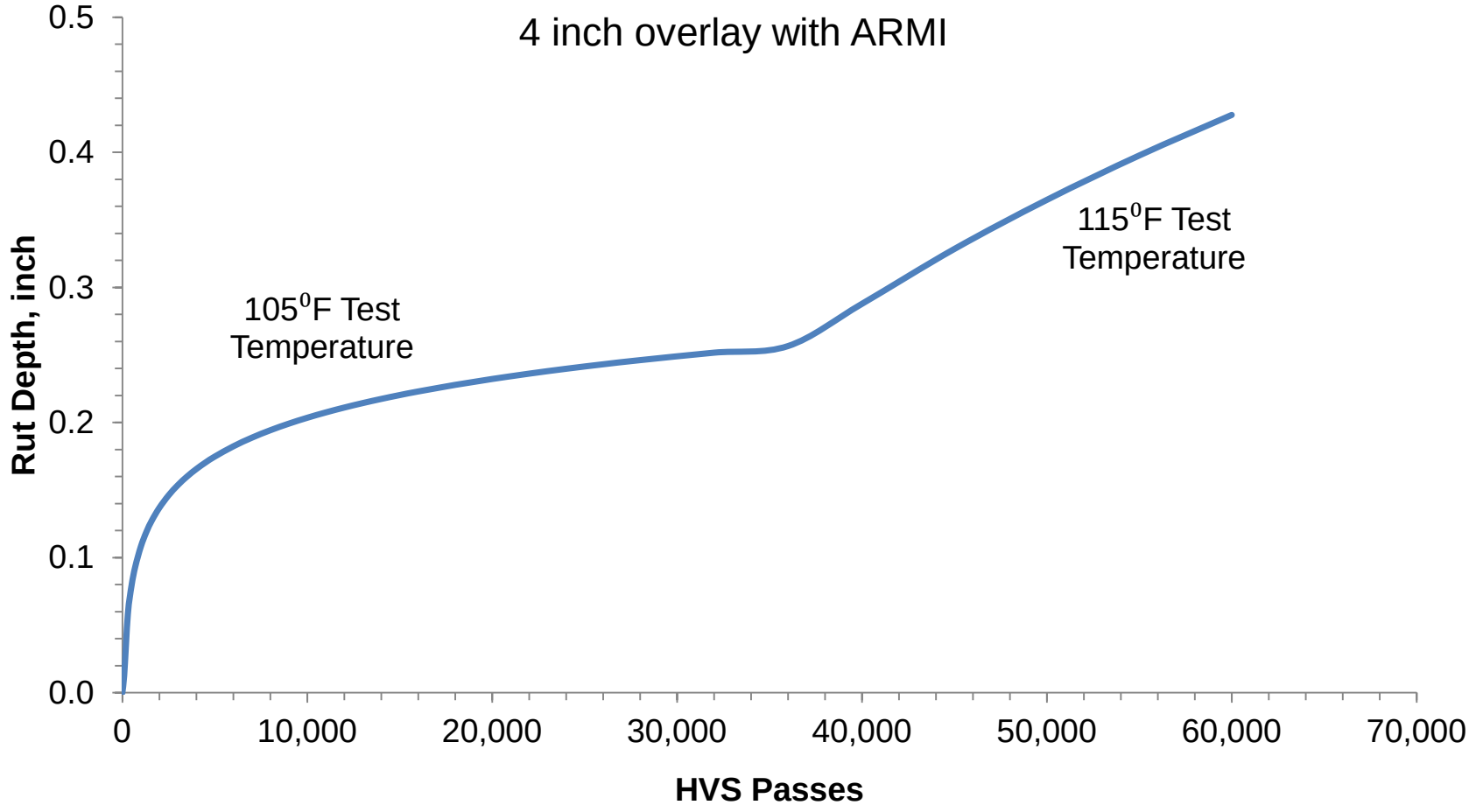
Rut Depth & Shear Flow @ 10,000 Passes



Profile Data	2 in. overlay with ARMI	3 in. overlay with ARMI	4 in. overlay with ARMI	4 in. overlay w/o ARMI
Rut Depth, inch	0.70	0.43	0.51	0.28
Shear Area/WP Area	1.00	0.82	0.77	0.63

Shear increases with decreased ARMI depth

Temperature Sensitivity



Pavement Temperature

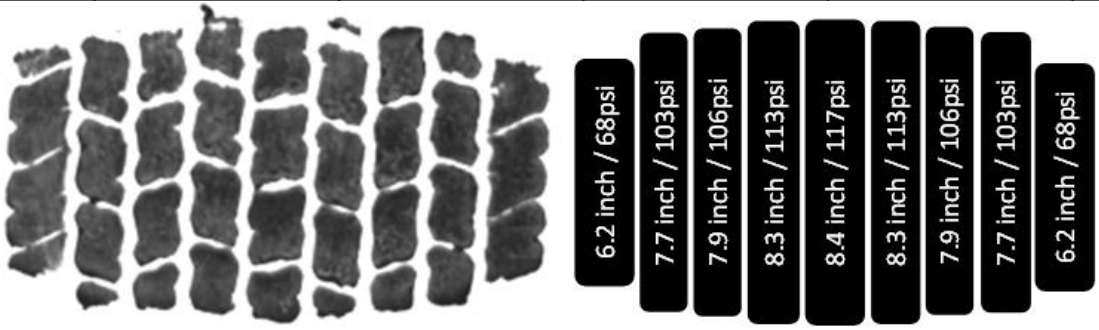
- Instability rutting greatly increased when asphalt temperature increased to 115°F
- Realistic summer asphalt temperatures

Summer Asphalt Temperature	Percent of time	
	4 inch depth	2 inch depth
>125°F	8	19
>115°F	25	30
>105°F	42	41

Finite Element Analysis

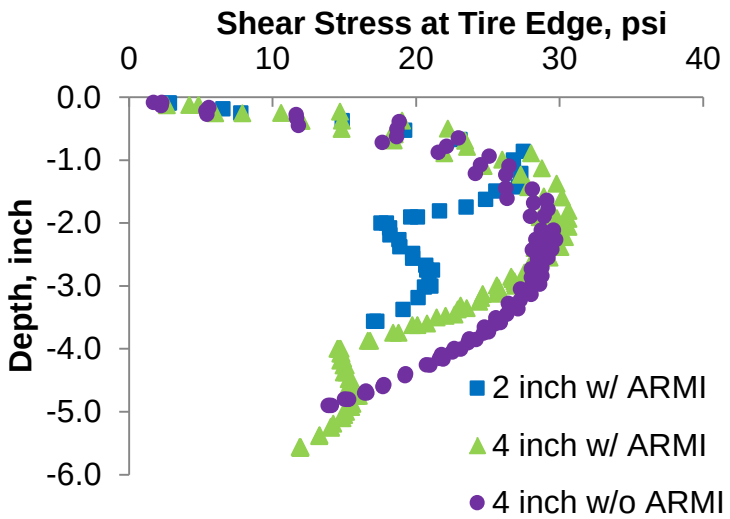
- **Objective: Determine the location and magnitude of critical stresses/strains**

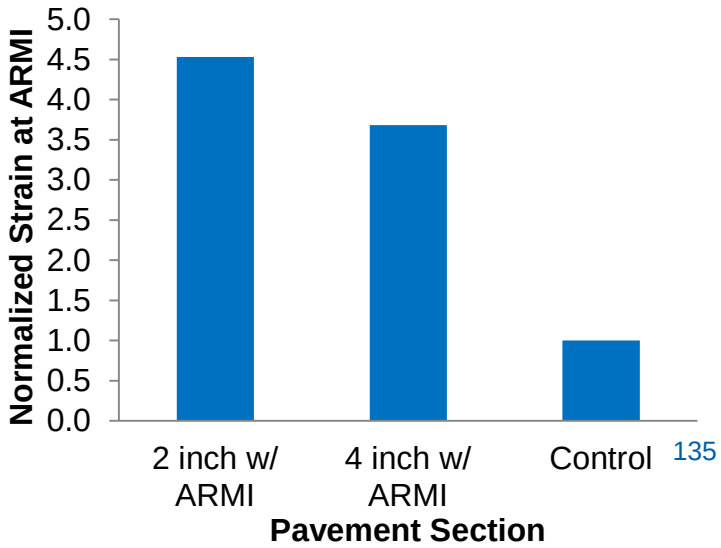
Layer	Thickness, inch			Modulus, ksi	
	2 inch overlay with ARMI	4 inch overlay with ARMI	4 inch overlay w/o ARMI (control)	70^0F	120^0F
Structural Asphalt	2	4	4	1,100	280
ARMI	0.75	0.75	NA	170	40
Existing Structural Asphalt	1	1	1	1,100	280
Base	10	10	10	80	80
Subgrade	36	36	36	40	40



Predicted Shear & Strain

- Max shear stresses/strains occurred just above the ARMI and below the tire edge
- Transverse strain at top of ARMI was found to be 3.7 to 4.5 times the control





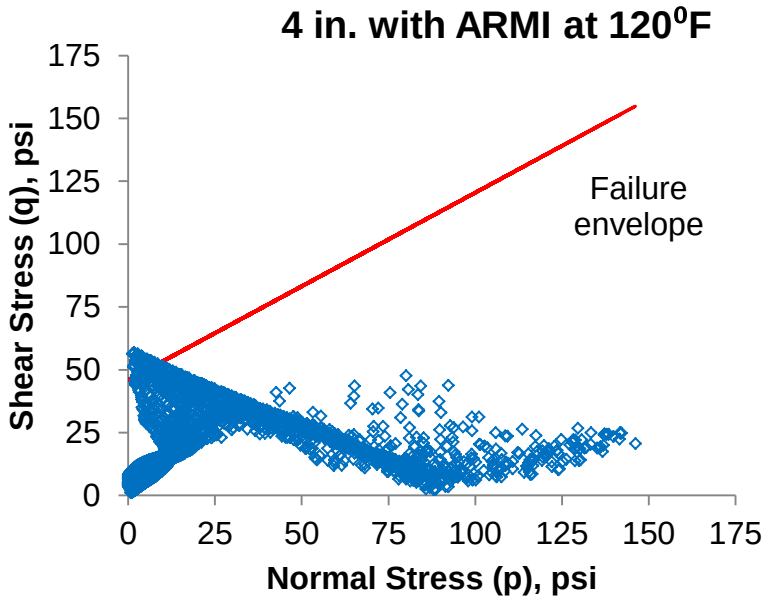
p-q Space

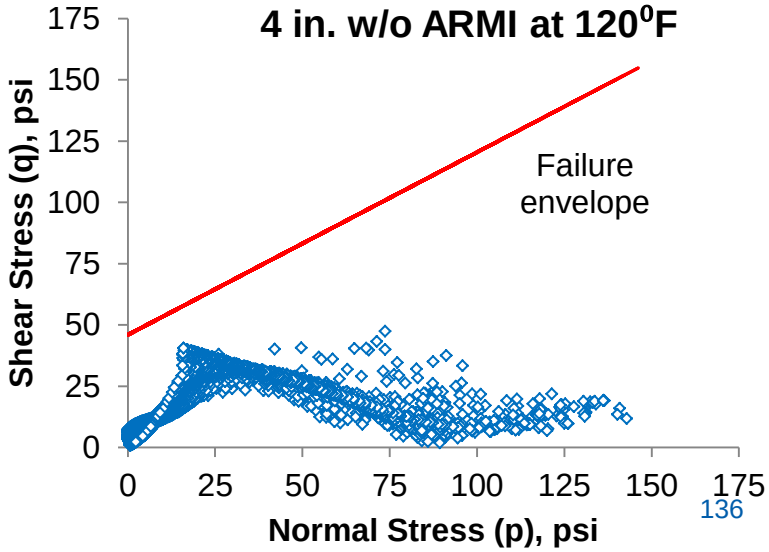
- **Assumptions**
  - **Friction angle (α) = 40°**
  - **Cohesion (c) = 60 psi at 120°F**

$$p = (\sigma_1 + \sigma_3)/2$$
$$q = (\sigma_1 - \sigma_3)/2$$
$$q_{failure} = a + p \tan\alpha$$

where,

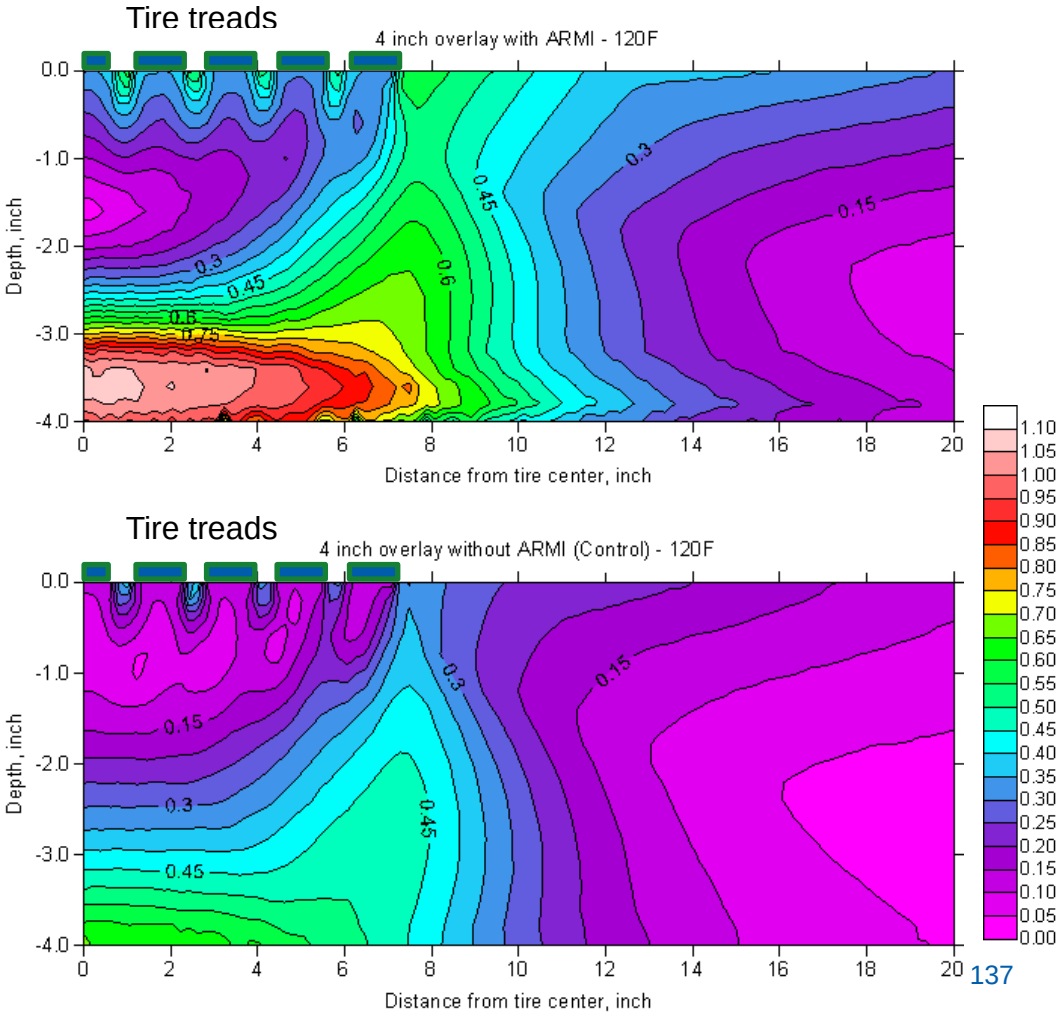
$$a = c \cos\varphi$$
$$\sin\varphi = \tan\alpha$$





Stress Ratios ($q/q_{failure}$)

- Critical stress states above ARMI and at tire edge
- Elevated temp. increases instability above ARMI



Instability Rutting Summary

- An ARMI as deep as 4 inches contributed to instability rutting
  - Pavements with an ARMI rutted 20 to 50 times faster than those without an ARMI
  - FEA indicated critical stress states above ARMI and at the tire edge
- Other contributing factors include slow moving heavy loads and summer like pavement temperature

What Now?

- Searching for alternatives
- Evaluating Florida asphalt mixes and potential interlayer alternatives for crack resistant properties
- New experimental section with open-graded crack relief layer
- Looking for a candidate project for a 4.75-mm mix with polymer modified asphalt as crack relief interlayer

Controlling Reflective Cracking

- Evaluate pavement condition (structural and functional)
- Predict existing crack movement
- Understand reflective cracking mechanism
- Evaluate potential reflective cracking control alternative approaches (How they work, experience, field application, service life, …)
- Select the optimized technique: durability, efficiency, effectives, cost, sustainability (e.g., environment, recycling,..)
- Proper installation!

Questions and Answers