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

Organizer: TRB Standing Committee on Pavement Rehabilitation

Moderator: Bouzid Choubane
Florida Department of Transportation

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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

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<tr>
<th>ID</th>
<th>Presenter</th>
<th>Title</th>
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<td>1</td>
<td>Imad Al-Qadi</td>
<td>Reflective Cracking: Introduction, Mechanisms, and Testing</td>
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<td>2</td>
<td>Mostafa Elseifi</td>
<td>Mitigation Strategies for Reflective Cracking in Pavements – Part I</td>
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<td>Mitigation Strategies for Reflective Cracking in Pavements – Part II</td>
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<td>4</td>
<td>James Greene</td>
<td>Florida’s experience with asphalt-rubber membrane interlayers</td>
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</table>

Questions and Answers
Reflective Cracking
Introduction, Mechanisms, and Testing
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

- From PCC Joint
- Offset from a Joint
- Interface of wearing and leveling binder
- From HMA Patch
- Interface of old and new overlay
- New
- Old
Crack Development

Vertic. Propag.

Horiz. Propag.

Bonded Interface

Debonded Interface
Reflective Cracking Pattern

- Depends on local interface conditions

![Diagram showing reflective cracking patterns](image)

- Single
- Double

Scarpas et al. 2000

Zhou and Sun 2002
Reflective Cracking Mechanisms
## Reflective Cracking Types

<table>
<thead>
<tr>
<th>Cause</th>
<th>Result</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Loading</td>
<td>Crack opening</td>
<td>Mode I</td>
</tr>
<tr>
<td></td>
<td>Shear failure</td>
<td>Mode II</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mixed mode</td>
</tr>
<tr>
<td>Seasonal Variation</td>
<td>Crack opening</td>
<td>Mode I</td>
</tr>
</tbody>
</table>

- **Mode I (Opening)**
- **Mode II (Sliding)**
- **Mode III (Tearing)**
Stress Concentration

\[ \sigma_t = \frac{\sigma_0}{\sigma_0} \]

Overlay on sound surface

Overlay on cracked surface

Stress concentration near crack tip
Reflective Crack Initiation

- Stress distribution in overlay

\[ \sigma_c \]

- Pre-crack in old layer

- Stress concentration near crack tip in overlay

\[ \sigma_t \]

- New crack initiation

Old layer

Overlay

w/o pre-crack

w/ pre-crack
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)

Overlay

PCC

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)

Original crack

Separation, $\delta$

Traction, $t$

$G_c$

$\delta_{sep}$

$\delta_c$

Material crack tip

Cohesive crack tip

Extended crack into FPZ

Fracture process zone in micro cracks

Uncracked zone

Closing force

$s = f(\epsilon)$

$t = f(\delta)$

$A$

$A_1$

$A_2$

Extended crack into FPZ

Traction-free zone in a macro crack

Separation, $\delta$

Traction, $t$

$\epsilon$

$\delta$

$G_c$

$t^0$
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

<table>
<thead>
<tr>
<th>Wearing surface (38 mm)</th>
<th>Leveling binder (19 mm)</th>
<th>Concrete slab (200 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wearing surface</td>
<td>Sand mix</td>
<td>Concrete slab</td>
</tr>
<tr>
<td>Wearing surface</td>
<td>Steel netting</td>
<td>Concrete slab</td>
</tr>
</tbody>
</table>

Viewports:
1. ODB: C:/Temp671/overlay/Sand m..._cen0_coh1_30loads6_6.odb
2. ODB: C:/Temp671/overlay/Sand m...1_30loads6_6_steel1_3.odb
3. ODB: C:/DOCUME-1/ADMINB-1/LOCA...loads6_61194627307.75.odb
Traffic
Material Properties
Climate EICM
Pavement Structure

Pavement Response Model: Multi-layer elastic system

Pavement Distress Models

Pavement Performance Predictions

INPUT

Interlayer
Existing Pavement Conditions

Pavement Response Model
Stress Intensity Factor (SIF)
Artificial Neural Network (ANN)

Pavement Distress Model
Reflection Cracking
(Thermal, Shearing, Bending)

Pavement Performance Prediction: Reflection Cracking Extent and Severity

OUTPUT

MODELS

After Bob Lytton
TEST METHODS FOR REFLECTIVE CRACKING
Testing for RC

DCT

SCB

Texas Overlay Test
Thermal Cracking Test (Mode I)

Asphalt overlay

Interlayer

Concrete layer

Crack length in the overlay (cm)

-10°C
Type 1
6.5 cm

0 3A 1A 5 1B 3B 4 1C

0 6 12 18 24 30 36 42 48

without interlayer
woven bonded with an emulsion
woven bonded with pure bitumen
woven bonded with polymer-bitumen
sheet reinforcing netting

3A geogrid - plastic fibre 1
3B geogrid - plastic fibre 2, glass fibre 1
3C geogrid - glass fibre 2
4 SAMI
5 woven
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

![Graph showing load vs. CMOD (mm)](image)
Fracture Zone - Digital Image Correlation (DIC)
SCB Fracture Results

N90 lab mix design (30% ABR)
Fracture Energy = 1780 J/m²
Slope = -2.87 kN/mm
Critical displacement = 2.19 mm

N90 lab mix design (control)
Fracture Energy = 1790 J/m²
Slope = -1.59 kN/mm
Critical displacement = 2.84 mm
SCB Test Parameters

Flexibility Index (FI) = A × \( G_F \times \frac{1}{|m|} \)

- Peak Load
- Slope at inflection point (m)
- Critical Displacement \((w_1)\)
- Opening at Peak Load \((w_0)\)
FI: Field Cores

Flexibility Index (FI) - Field Cores

Increasing cracking potential

Type I
Type II
Type III
## Draft Categorization of Mixes Using Flexibility Index and Threshold

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

*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
(Google)
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

Air-coupled antenna

Dowel bar

30.5m joint spacing

Ground-coupled antenna

Video camera
GPR Survey

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

Diagram showing layered materials and reflections.
Interlayer Detection

ISAC identification/accurate width measurement (0.9m)

Joint-associated reflective cracking

Joint

PCC surface

Dowel bar

STA. 135+00

STA. 140+00
Presentation 2: Mitigation Strategies for Reflective Cracking in Pavements – Part I
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
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
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

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Picture</th>
<th>Functions</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galvanized Steel Netting</td>
<td><img src="image" alt="Netting" /></td>
<td>Reinforcement</td>
<td>3.00 – 5.00 $/yd²</td>
</tr>
<tr>
<td>Geogrid</td>
<td><img src="image" alt="Geogrid" /></td>
<td>Reinforcement</td>
<td>1.80 – 4.00 $/yd²</td>
</tr>
<tr>
<td>Geonet</td>
<td><img src="image" alt="Geonet" /></td>
<td>Reinforcement</td>
<td>3.00 – 4.00 $/yd²</td>
</tr>
<tr>
<td>Glass-Grid</td>
<td><img src="image" alt="Glass-Grid" /></td>
<td>Reinforcement</td>
<td>4.00 – 7.00 $/yd²</td>
</tr>
<tr>
<td>Paving Fabric</td>
<td><img src="image" alt="Paving Fabric" /></td>
<td>Stress Relief</td>
<td>0.60 – 1.05 $/yd²</td>
</tr>
<tr>
<td>Geocomposite</td>
<td><img src="image" alt="Geocomposite" /></td>
<td>Stress Relief</td>
<td>8.00 – 9.20 $/yd²</td>
</tr>
</tbody>
</table>
## Crack Control Treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Picture</th>
<th>Functions</th>
<th>Estimated Cost</th>
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</thead>
<tbody>
<tr>
<td>SAMI</td>
<td></td>
<td>Stress Relief</td>
<td>5.00 – 6.00 $/yd²</td>
</tr>
<tr>
<td>Rubblization</td>
<td></td>
<td>Eliminates movement in concrete layer</td>
<td>5.00 – 6.00 $/yd²</td>
</tr>
<tr>
<td>NovaChip</td>
<td></td>
<td>Stress Relief</td>
<td>3.00 – 4.00 $/yd²</td>
</tr>
<tr>
<td>Strata</td>
<td></td>
<td>Stress Relief</td>
<td>4.00 – 5.00 $/yd²</td>
</tr>
<tr>
<td>Saw and Seal</td>
<td></td>
<td>Control reflective cracking by sawing overlay</td>
<td>1.00 - 2.00 $/ft.</td>
</tr>
</tbody>
</table>

- **SAMI**: Stress Relief
- **Rubblization**: Eliminates movement in concrete layer
- **NovaChip**: Stress Relief
- **Strata**: Stress Relief
- **Saw and Seal**: Control reflective cracking by sawing overlay
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 interlayer
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

<table>
<thead>
<tr>
<th>Rehabilitation Type</th>
<th>Estimated Time Between Treatments (yrs.)</th>
<th>Annual Worth ($/Lane Mile)</th>
<th>Annual Worth ($/Square Yard)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BST</td>
<td>6</td>
<td>2,700</td>
<td>0.28</td>
</tr>
<tr>
<td>HMA Class G</td>
<td>7</td>
<td>8,300</td>
<td>0.89</td>
</tr>
<tr>
<td>NovaChip</td>
<td>8 to 9</td>
<td>7,800 - 8,600</td>
<td>0.83 - 0.92</td>
</tr>
<tr>
<td>HMA Class A or ½ in Superpave</td>
<td>10</td>
<td>11,100</td>
<td>1.18</td>
</tr>
</tbody>
</table>
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
A polymer-rich dense fine aggregate mixture placed on the existing pavement and is then overlaid.

Recommended on structurally-sound pavement.
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/yd² for cold climate.
  - 0.25 and 0.30 gal/yd² 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

- Cut Joints
- Clean Joints
- Seal Joints
- Mark Joint Locations
- Asphalt Paving

Within 3 days of Overlay

Rubberized asphalt sealant

3mm wide by 25mm deep
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

Difference in Cost between Untreated and Sawed and Sealed sections
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
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
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

<table>
<thead>
<tr>
<th></th>
<th>Reinf.</th>
<th>Resistance High Strain</th>
<th>Waterproof</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand Asphalt</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>SAMI (*)</td>
<td></td>
<td>XX</td>
<td>XX</td>
</tr>
<tr>
<td>Impregnated Nonwoven</td>
<td></td>
<td>X</td>
<td>XX</td>
</tr>
<tr>
<td>Grid Composite</td>
<td>X/XX</td>
<td>X</td>
<td>X/XX*</td>
</tr>
<tr>
<td>Steel Netting</td>
<td>XX</td>
<td>X*</td>
<td>X*</td>
</tr>
<tr>
<td>3D Grids</td>
<td>XX</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tri-planar</td>
<td></td>
<td>X</td>
<td>XX</td>
</tr>
<tr>
<td>Strain Tolerant Layer</td>
<td></td>
<td>XX</td>
<td>XX</td>
</tr>
</tbody>
</table>

* 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

![Graph showing increased flexibility with distance and deflection](image-url)
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

Steel Reinforcing Nettings

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/m²

- **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: 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/yd²
- **No. 6 stone**
  - Placed at approximately 0.3 ft³/yd² 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

<table>
<thead>
<tr>
<th>County</th>
<th>Years Until First Crack</th>
<th>Rut Depth after 10 years, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jefferson</td>
<td>7</td>
<td>11.4*</td>
</tr>
<tr>
<td>Leon-1</td>
<td>6</td>
<td>8.3</td>
</tr>
<tr>
<td>Leon-2</td>
<td>7</td>
<td>11.3*</td>
</tr>
<tr>
<td>Gadsden</td>
<td>5</td>
<td>7.2</td>
</tr>
<tr>
<td>Jackson-1</td>
<td>7</td>
<td>4.7</td>
</tr>
<tr>
<td>Jackson-2</td>
<td>7</td>
<td>7.2</td>
</tr>
<tr>
<td>Walton</td>
<td>7</td>
<td>5.1</td>
</tr>
</tbody>
</table>

* 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

<table>
<thead>
<tr>
<th>Section</th>
<th>Layer 1</th>
<th>Layer 2</th>
<th>Layer 3</th>
<th>Layer 4</th>
<th>Layer 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.0” FC-9.5</td>
<td>1.5” SP-12.5</td>
<td></td>
<td>1.0” OGCR</td>
<td></td>
</tr>
<tr>
<td>Section 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.5” Overbuild)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1.5” SP-12.5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2.5” SP-12.5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1.0” OGCR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.5” ARMI)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>2-inch SP-12.5</th>
<th>4-inch SP-12.5</th>
<th>2-inch SP-12.5</th>
<th>3-inch SP-12.5</th>
<th>4-inch SP-12.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10-inch limerock base</td>
<td>1-inch existing SP-12.5</td>
<td>1-inch existing SP-12.5</td>
<td>10-inch limerock base</td>
</tr>
<tr>
<td></td>
<td>12-inch granular subbase</td>
<td>12-inch granular subbase</td>
<td>12-inch granular subbase</td>
<td>12-inch granular subbase</td>
</tr>
</tbody>
</table>

### Experimental Sections

<table>
<thead>
<tr>
<th>2-inch SP-12.5</th>
<th>4-inch SP-12.5</th>
<th>2-inch SP-12.5</th>
<th>3-inch SP-12.5</th>
<th>4-inch SP-12.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.75-inch ARMI</td>
<td>1-inch existing SP-12.5</td>
<td>0.75-inch ARMI</td>
<td>0.75-inch ARMI</td>
</tr>
<tr>
<td></td>
<td>10-inch limerock base</td>
<td>1-inch existing SP-12.5</td>
<td>1-inch existing SP-12.5</td>
<td>10-inch limerock base</td>
</tr>
<tr>
<td></td>
<td>12-inch granular subbase</td>
<td>12-inch granular subbase</td>
<td>12-inch granular subbase</td>
<td>12-inch granular subbase</td>
</tr>
</tbody>
</table>
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
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 120°F
Asphalt Rubber Binder
Spreading No. 6 Stone
Seating Stone
ARB20 adheres to core barrel
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

Shear increases with decreased ARMI depth
Temperature Sensitivity

4 inch overlay with ARMI

105°F Test Temperature

115°F Test Temperature

Rut Depth, inch

HVS Passes

0 10,000 20,000 30,000 40,000 50,000 60,000 70,000

0 0.1 0.2 0.3 0.4 0.5

132
Pavement Temperature

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

<table>
<thead>
<tr>
<th>Summer Asphalt Temperature</th>
<th>Percent of time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 inch depth</td>
</tr>
<tr>
<td>&gt;125°F</td>
<td>8</td>
</tr>
<tr>
<td>&gt;115°F</td>
<td>25</td>
</tr>
<tr>
<td>&gt;105°F</td>
<td>42</td>
</tr>
</tbody>
</table>
Finite Element Analysis

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

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness, inch</th>
<th>Modulus, ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 inch overlay with ARMI</td>
<td>4 inch overlay with ARMI</td>
</tr>
<tr>
<td>Structural Asphalt</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>ARMI</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>Existing Structural Asphalt</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Base</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Subgrade</td>
<td>36</td>
<td>36</td>
</tr>
</tbody>
</table>
- 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** ($\alpha$) = 40°
- **Cohesion** ($c$) = 60 psi at 120°F

$$p = \frac{(\sigma_1 + \sigma_3)}{2}$$

$$q = \frac{(\sigma_1 - \sigma_3)}{2}$$

$$q_{\text{failure}} = a + p \tan \alpha$$

where,

$$a = c \cos \phi$$

$$\sin \phi = \tan \alpha$$
Stress Ratios \((q/q_{\text{failure}})\)

- 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