A Guide to Concrete Overlays – 3rd Ed.;
PCC Overlay Design

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The National Concrete Pavement Technology Center (National CP Tech Center) at Iowa State University is a national hub for concrete pavement research and TECHNOLOGY TRANSFER.

MISSION:

• Help street and road agencies find answers to their concrete pavement-related questions.
• Identify critical concrete pavement research needs and discover sustainable solutions.
• Help agencies, industry, and businesses incorporate advanced, sustainable solutions and new technologies into their day-to-day practices.
Concrete Overlay Tech Support

- Tasked by FHWA to support state and local agencies with implementation of concrete overlays
- Involved in 30+ states since 2008
- Tech support for project scoping, PS&E and through construction

The Tech Center does not promote or sell concrete overlays, but provides unbiased technical support to agencies.
Concrete Overlays - Introduction

• 1,207 concrete overlays in 45 U.S. states from 1901 through 2014 (the database is continuing to grow)

• Includes at least 25 in Indiana!
  – 22 Unbonded
  – 18 Roads
  – Earliest: 1918 in Terre Haute
The National Concrete Overlay Explorer

1207 items

639 results out of 1207 cannot be plotted.

Special Thanks to ACPA’s Chapters and Affiliated State Paving Associations for Populating this Overlay Explorer Database
Thin (< 6 in.) Concrete Overlays in the U.S.

Square Yards, Thin Overlays

- Total by 1993: 7,000
- Total by 1999: 450,000
- Total by 2004: 1,200,000
- 2009: 5,456,100
- 2010: 3,226,700
Overlays Comprise ~14% of Concrete Surfacing Construction, Annually

Square Yards in '09 and '10

117,380,000

17,070,000

Full Depth Concrete

Concrete Overlays

[Source: Oman and ACPA]
Why Concrete Overlays?

• Benefits of Concrete Overlays
  – Provides cost effective solutions – to extend service life of existing pavements
  – Can be constructed rapidly and with effective construction traffic management
  – Can be applied to a wide variety of existing pavements exhibiting a range of performance issues
  – Most importantly: long-term service.
    – *Can be designed and constructed to achieve a service life of 15 to 40 years (or more).*
System of Concrete Overlays

Concrete Overlays

Bonded Overlay System
- Concrete Pavements
- Asphalt Pavements
- Composite Pavements

Unbonded Overlay System
- Concrete Pavements
- Asphalt Pavements
- Composite Pavements

Bond is integral to design

Old pavement is subbase
Based on over 1,000 concrete overlays from NCHRP Synthesis 99, NCHRP Synthesis 204, and ACPA’s National Overlay Explorer
... But More and More on Asphalt
Concrete Overlay Guide, *Third Edition*

Contents (145 pages)

- Overview of Overlays
- Overlay types and uses
- Evaluations & Selections
- Six Overlay Summaries
- Design Section
- Misc. Design Details
- Overlay Materials Section
- Work Zones under Traffic
- Overlay Construction
- Accelerated Construction
- Specification Considerations
- Repairs of Overlays


Full-day workshop covering all topics is available through CPTech Center
Concrete Overlay Design (Thickness and more ...)
The Principal Factors of Concrete (Overlay) Pavement Design

- Geometrics
- Thickness
- Joint Systems
- Materials
The Principal Factors of Concrete (Overlay) Pavement Design

- Geometrics
- Thickness
- Joint Systems
- Materials

Most Often Influence Cost & Selection of Projects
The Principal Factors of Concrete (Overlay) Pavement Design

- Geometrics
- Thickness
- Joint Systems
- Materials

Most Often Influence Real-world Performance
## MnROAD Whitetopping Distress (Mainline – 5 yrs service)

<table>
<thead>
<tr>
<th>Cell</th>
<th>Panels Cracked (%)</th>
<th>Corner Cracks</th>
</tr>
</thead>
<tbody>
<tr>
<td>4”-4’x4’ (93)</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>3”-4’x4’ (94)</td>
<td>40</td>
<td>165</td>
</tr>
<tr>
<td>3”-5’x6” (95)</td>
<td>8</td>
<td>17</td>
</tr>
<tr>
<td>6”-5’x6’ (96)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6”-10’x12’ (97U)</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>6”-10’x12’ (92D)</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

4’x4’ Panels - Corner Breaks due to Wheel Loadings
Longitudinal Joint Layout

- 2 ft x 2 ft
- 3 ft x 3 ft
- 6 ft x 6 ft

Traffic

Outer Shoulder
How Are Pavements (and Overlays) Designed

- Today, we have data-driven methods to design major elements of concrete pavements
  - Thickness
  - Joint Spacing
  - Edge Support
  - Load Transfer
  - Flexural Strength
  - Subgrade Support
  - Subbase
  - And more
Pavement Evaluation for Overlay Design

Functional Evaluation of Existing Pavement

- Surface Friction Problems/Polishing
  - Use Diamond Grinding or Grooving to Restore Skid Resistance
- Surface Roughness
  - Use CPR and Diamond Grinding or Thin Bonded Overlay to Restore Structure

Overlay Designs Must Address the Causes of Functional Problems and Prevent Recurrence
Important Considerations in Overlay Design

• Required Future Design Life of the Overlay
• Traffic Loading (ESALs)
• Pre-overlay Repair
• Reflective Crack Control
• Subdrainage
• Structural vs Functional Overlays
• Recycling Existing Pavement (PCC & AC)
• Durability of aggregate for new concrete
Important Considerations in Overlay Design (cont.)

- Shoulders
- Existing PCC Slab Durability
- PCC Overlay Joints
- PCC Overlay Reinforcement
- PCC Overlays Bonding / Separation Layers
- Overlay Design Reliability Level & Overall Standard Deviation
- Pavement Widening
- Traffic Disruptions and User Delay Costs
Design Balances Several Factors

- Desired service life, load-carrying capacity
- Existing pavement condition, preoverlay repairs
- Costs
- Design (thickness, etc.)
Thickness Design Procedures

• Empirical Design Procedures
  – Based on observed performance
    ▪ ‘72, ‘86/’93 AASHTO Design Procedures

• Mechanistic-Empirical Design Procedures
  – Based on mathematically calculated pavement responses
    ▪ Pavement-ME (MEPDG)
    ▪ PCA Design Procedure (PCAPAV)
    ▪ ACPA Ultrathin Whitetopping Design Procedure
    ▪ StreetPave (ACPA Design Method)
    ▪ BCOA-ME (Univ. of Pittsburgh, 2013)
1993 AASHTO Guide

• Based on mathematical models derived from empirical data collected during the AASHO Road Test in the late 1950’s.

• Procedure provides suitable bonded and unbonded concrete overlay designs.

• The AASHTO computer software for implementation of the 1993 AASHTO Guide is called DARWin. In addition, a number of agencies and State Departments of Transportation have developed custom software and spreadsheets to apply this procedure.
Structural Deficiency Approach to Overlay Design (1993 AASHTO Guide)

- Original Capacity
- Capacity after Rehabilitation
- Effective Capacity of Existing Pavement
- Capacity of Overlay

Loads vs. Structural Capacity
Overlay Design - Basic Steps
1993 AASHTO

1. Determine Existing Pavement Information
2. Determine Required Future Structural Capacity
   - Predict Future Traffic / ESALs
3. Determine Existing Structural Capacity
   - Perform Condition Survey
   - Perform Deflection Testing
   - Perform Coring / Materials Testing
4. Determine Overlay Structural Capacity and Thicknesses

Overlay Designs Must Address the Causes of Functional & Structural Problems and Prevent Recurrence

Limitations?
Mechanistic-Empirical Design

• The Mechanistic Part:
  ➢ Structural models predict responses of pavement (stresses, strains, deflections) to loads and environment

• The Empirical Part:
  ➢ Data-based models predict pavement performance (IRI, cracking, faulting, etc.) for given pavement stress/strain/deflection

Allows consideration of new designs and design features – INNOVATION!

Examples:
smaller panels or widened lanes (w/reduced slab thickness)
M-E PDG (and PavementME)

• M-E PDG combines a mechanistic-based analysis approach with field performance data in order to enable the engineer to confidently predict the performance of pavement systems.

• MEPDG provides models and design tools for JPCP & CRCP overlays of existing HMA, JPCP & CRCP.

• Method adopts an integrated pavement design approach which allows:
  - Designer to determine the overlay thickness based on the interaction between the pavement geometry (slab size, shoulder type, load transfer, steel reinforcement).
  - Consideration of support conditions, local climatic factors, and concrete material and support layer properties.
Family of Concrete Overlays

Concrete Overlays

- Bonded Family
  - Bonded Concrete Overlay of Concrete Pavements
  - Bonded Concrete Overlay of Asphalt Pavements
  - Bonded Concrete Overlay of Composite Pavements
- Unbonded Family
  - Unbonded Concrete Overlay of Concrete Pavements
  - Unbonded Concrete Overlay of Asphalt Pavements
  - Unbonded Concrete Overlay of Composite Pavements

Bond is integral to design
Old pavement is base
## Typical PCC Overlay Service Lives

<table>
<thead>
<tr>
<th>Concrete Overlay Type</th>
<th>Typical Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonded on Concrete</td>
<td>15-25 years</td>
</tr>
<tr>
<td>Unbonded on Concrete</td>
<td>20-30 years</td>
</tr>
<tr>
<td>Bonded on Asphalt/Composite</td>
<td>5-15 years</td>
</tr>
<tr>
<td>Unbonded on Asphalt/Composite</td>
<td>20-30 years</td>
</tr>
</tbody>
</table>

Based on FHWA’s “Portland Cement Concrete Overlays – State of the Technology Synthesis” (FHWA-IF-02-045)
Bonded versus Unbonded (intent)

• **Bonded**: Use to eliminate surface defects; increase structural capacity; and improve surface friction, noise, and rideability

• **Unbonded**: Use to restore structural capacity and increase pavement life equivalent to full-depth pavement. Also results in improved surface friction, noise, and rideability
Jointing Patterns Vary

- Joint spacing depends on bond, stiffness of support, etc.

Match Existing Joint Spacing/Location
- Bonded Concrete Overlay of Concrete Pavements
- Bonded Concrete Overlay of Asphalt Pavements
- Bonded Concrete Overlay of Composite Pavements

Joint Spacing based on Thickness; Shorter Panels = Less Curl/Warp
- Unbonded Concrete Overlay of Concrete Pavements
- Unbonded Concrete Overlay of Asphalt Pavements
- Unbonded Concrete Overlay of Composite Pavements

Joint Spacing is Similar to New Concrete Pavement; Shorter Might be Used, Especially for Unbonded over Concrete
Bonded Concrete Overlays

Bonded Concrete Overlays of Concrete Pavements
—previously called bonded overlays—

Bonded Concrete Overlays of Asphalt Pavements
—previously called ultra-thin whitetopping—

Bonded Concrete Overlays of Composite Pavements
Bonded Overlays of ACP

- **Thickness – 4 to 6 in.** *(moderately loaded)*
  - State/county highways
  - Secondary routes
  - Collectors

- **Thickness – 2 to 4 in.** *(lightly loaded)*
  - City streets
  - Urban intersections
  - Parking lots
How Do Bonded Overlays over Asphalt Work?

• Concrete bonds to the asphalt
  – Lowers the neutral axis
  – Decreases stresses in the concrete
• Short joint spacing
  – Controls cracking
  – Slabs act as paver-blocks
• Fibers improve concrete toughness
Bonding Effects on Edge Stress

Unbonded

Bonded
Effects of AC Thickness

Concrete

Tension

Comp.

Asphalt

\[ x \]

Concrete

Tension

Comp.

Asphalt

\[ 2x \]
Effects of Joint Spacing – Load Stress

3.0 ft 3.0 ft 3.0 ft

Short Slabs Deflect
Very little flexural stress

10.0 ft

Standard Slabs Bend
Higher flexural stress
Short Panels Improve Performance By Decreasing Curling And Warping

Effect of Slab Length on Shrinkage Force

- Curling & warping is produced by the shrinkage force at the slab surface.
  - Due to drying and thermal differential shrinkage on the surface of the concrete.
- The magnitude of this force is dependent on the length of the surface.
  - Shorter slabs have less length, which means that shorter slabs have reduced curling.

Effect of Slab Length on Curling/Warping

- All concrete slabs curl / warp so that approximately 1/4 of the slab length is lifted of the subgrade / subbase support.
- By reducing slab length, the amount lifted, and the height of the lift is greatly reduced.

Cantilever = 1/4 L

Length 12 to 15 ft., cantilever = 3 to 3.75 ft

Cantilever = 1/4 L

Length 6 ft., cantilever = 1.5 ft
Summary of Best Overlay Jointing Practices

- Joint spacing (max = 18-to-24 x thickness)
  - For <3 in. overlay, use 3 by 3 ft
  - For 3 to 6 in. overlay, use 6 by 6 ft
  - For > 6 in. use full width and conventional spacing

- Aspect ratio < 1.5

- Adjust depth of saw cut for actual slab thickness
  - Full depth plus ½” for bonded over concrete
  - T/3 for bonded on asphalt/composite and unbonded

- Dowel & tie bar use
  - Dowels not necessary for overlay thickness < 8 in.
  - For unbonded overlays > 4 in., may use tie bars at longitudinal joints
Longitudinal Joint Layout

- 2 ft x 2 ft
- 3 ft x 3 ft
- 4 ft x 4 ft
- 6 ft x 6 ft

Traffic

12 ft
Source: Burnham (MnDOT)
(Last site update Sept. 2013/Last guide update Sept. 2013)

The bonded concrete overlays of asphalt mechanistic-empirical design procedure (BCOA-ME) was developed at the University of Pittsburgh under the FHWA Pooled Fund Study TFF 5-165. This pavement structure has been referred to as thin and ultra-thin whitetopping. This site is a repository for all information relating to the BCOA-ME. The information has been sorted based on its intended use and can be retrieved by clicking on the appropriate tab below. The BCOA-ME can be run directly from this site by clicking on the “Design Guide” tab below.

http://www.engineering.pitt.edu/Vandenbossche/BCOA-ME/
Project Goal

- Rational mechanistic-empirical design procedure
  - Stand alone design procedure
  - Easily incorporated into Pavement ME
  - Address actual failure modes
  - Account for climatic effects
### BCOA-ME Design

**General Information**
- **Latitude (degree):** 44.5
- **Longitude (degree):** 93.1
- **Elevation (ft):** 874
- **Estimated Design Lane ESALs:** 200,000
- **Maximum Allowable Percent Slabs Cracked (%):** 25%
- **Desired Reliability against Slab Cracking (%):** 85%

**Climate**
- **AMDAT Region ID:** 5
- **Sunshine Zone:** 2

**Existing Structure**
- **Post-milling HMA Thickness (in):** 6
- **HMA Condition:** Adequate
- **Composite Modulus of Subgrade Reaction, k-value (psi/in):** 250
- **Does the existing HMA pavement have temperature cracks?** Yes

**PCC Overlay**
- **Average 28-day Flexural Strength (psi):** 650
- **Estimated PCC Elastic Modulus (psi):** 3,930,000
- **Coefficient of Thermal Expansion (10^-3 in/°F/in):** 5.5
- **Fiber Type:** No Fibers
- **Fiber Content (lb/cu yd):** 0

**Joint Design**
- **Joint Spacing (ft):** 6

### Performance Analysis
- **Calculated PCC Overlay Thickness (in):** 3.26
- **Design PCC Overlay Thickness (in):** 3.5
- **Is there potential for reflective cracking?** Yes

**Solved.**
**Structural Fibers Considerations**

- Does not increase the concrete’s strength
- Increases toughness
- Increases post-crack integrity
  - Helps control plastic shrinkage cracking
  - Steel fibers not recommended where deicing salts may be used.
Con Expo Demo
March 2002, Las Vegas
Structural Fibers

Straight synthetic: Strux 90/40

Crimped synthetic: Enduro 600

Residual strength ratio = 24%
Unbonded Concrete Overlays

Unbonded Concrete Overlays of Concrete Pavements
—previously called unbonded overlays—

Unbonded Concrete Overlays of Asphalt Pavements
—previously called conventional whitetopping—

Unbonded Concrete Overlays of Composite Pavements
Unbonded on Concrete / Composite 1993 AASHTO

- Slab Thickness Design

Unbonded overlay design equation:

\[ D_{ol} = \sqrt{D_f^2 - D_{eff}^2} \]

where:

- \( D_{ol} \) = Required PCC overlay thickness
- \( D_f \) = Thickness of new PCC pavement for design conditions
- \( D_{eff} \) = Effective thickness of existing PCC
Determination Of Effective Slab Thickness ($D_{eff}$)

$$D_{eff} = F_{jcu} \times D$$

Where

$F_{jcu} =$ Joints and Cracks Adjustment Factor

$D =$ Thickness of Existing Slab, in.
Unbonded Concrete Overlay
Joints & Cracks Adjustment Factor, \((F_{jcu})\)

Adjusts for PSI loss due to unrepaired joints, cracks, and other discontinuities
- Number of deteriorated transverse joints per mile
- Number of deteriorated transverse cracks per mile
- Number of existing expansion joints, exceptionally wide joints (>1 in.), or AC full-depth patches

Very little reflective cracking has been observed in unbonded overlays
Can use thicker interlayer instead of repairs
Unbonded Concrete Overlay
Joints & Cracks Adjustment Factor, \( (F_{jcu}) \)

Figure 5.13. \( F_{jcu} \) Adjustment Factor for Unbonded JPCP, JRCP, and CRCP Overlays

Deteriorated Transverse Joints and Cracks / mile
Unbonded on Concrete: 1993 AASHTO

- Separator layer (interlayer)
  - Can significantly affect performance
  - Functions
    - Isolate overlay from underlying pavement
    - Allow differential horizontal movement
    - Provide a level surface for the overlay construction
  - Types
    - Dense- or open graded HMA, typ. 1-2 in.
    - Nonwoven Geotextile
    - Other materials have been used with varying success
Nonwoven Geotextile Interlayer are being used as the Separator Interlayer

“Non-woven fabrics are defined as a web or sheet of fibers bonded together by entangling fiber or filaments mechanically, thermally or chemically. They are flat, porous sheets that are made directly from separate fibers.

Missouri DOT
- Completed about 25 projects utilizing the fabric to include interstate highways, state routes, lower volume roads, and airports
- All fabrics have been placed between existing old concrete and the new unbonded overlay
- The existing concrete was bare or was milled to remove asphalt overlays
- To date, no issues have arisen with performance, and the first project (2007) is performing well
- Missouri DOT currently has three approved fabrics (see Missouri DOT website for specifications)

Core from Germany showing non-woven geotextile interlayer between surface concrete and cement-treated base. Fabric bonds to PCC but not CTB or LCB.
<table>
<thead>
<tr>
<th>Property</th>
<th>Requirements</th>
<th>Test Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geotextile Type</td>
<td>Nonwoven, needle-punched, no thermal treatment to include calendaring</td>
<td>EN 13249, Annex F (Certification)</td>
</tr>
<tr>
<td>Color</td>
<td>Uniform/nominally same color fibers</td>
<td>(Visual Inspection)</td>
</tr>
<tr>
<td>Mass per unit area</td>
<td>≥ 500 g/m² (14.7 oz/sq.yd)</td>
<td>ISO 9864 (ASTM D 5261)</td>
</tr>
<tr>
<td></td>
<td>≤ 550 g/m² (16.2 oz/sq.yd)</td>
<td></td>
</tr>
<tr>
<td>Thickness under load (pressure)</td>
<td>[a] At 2 kPa (0.29 psi): ≥ 3.0 mm (0.12 in.)</td>
<td>ISO 9863-1 (ASTM D 5199)</td>
</tr>
<tr>
<td></td>
<td>[b] At 20 kPa (2.9 psi): ≥ 2.5 mm (0.10 in.)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[c] At 200 kPa (29 psi): ≥ 1.0 mm (0.04 in.)</td>
<td></td>
</tr>
<tr>
<td>Wide-width tensile strength</td>
<td>≥ 10 kN/m (685 lb/ft)</td>
<td>ISO 10319 (ASTM D 4595)</td>
</tr>
<tr>
<td>Wide-width maximum elongation</td>
<td>≤ 130%</td>
<td>ISO 10319 (ASTM D 4595)</td>
</tr>
<tr>
<td>Water permeability in normal direction</td>
<td>≥ 1×10⁻⁴ m/s (3.3×10⁻⁴ ft/s) at 20 kPa (2.9 psi)</td>
<td>DIN 60500-4 (modified ASTM D 5493)</td>
</tr>
<tr>
<td>under load (pressure)</td>
<td>[a] ≥ 5×10⁻⁴ m/s (1.6×10⁻³ ft/s) at 20 kPa (2.9 psi)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[b] ≥2×10⁻⁴ m/s (6.6×10⁻⁴ ft/s) at 200 kPa (2.9 psi)</td>
<td>ISO 12958 (modified ASTM D 4716)</td>
</tr>
<tr>
<td>In-plane water permeability (transmissivity)</td>
<td>Retained Strength ≥ 60%</td>
<td>EN 12224 (ASTM D 4355 @ 500 hrs. exposure for grey, white, or black material only)</td>
</tr>
<tr>
<td>Weather resistance</td>
<td>≥ 96% Polypropylene/Polyethylene</td>
<td>EN 13249, Annex B (Certification)</td>
</tr>
<tr>
<td>Alkali resistance</td>
<td>≥ 96% Polypropylene/Polyethylene</td>
<td></td>
</tr>
</tbody>
</table>
Unbonded on Concrete: 1993 AASHTO

- Nonwoven Geotextile Interlayer

www.ConcreteOnTop.com

It is recommended that the design thickness calculated using the 1993 AASHTO Guide be increased by 0.5 in. when a nonwoven geotextile interlayer is used in lieu of HMA.
Pavement-ME Unbonded Concrete Overlays
(Uses the same process as new pavements...)

- Determine basic design parameters (traffic, soil conditions, etc.)
- Develop preliminary designs (thickness, base designs, joint spacing, and other design features)
- Evaluate the predicted performance from Pavement-ME over the analysis period (e.g., 50 years) to determine the life-cycle activity profiles describing “when” and “what” rehabilitation activates will be performed.
- Calculate the Initial and Life Cycle Costs for each pavement design over the analysis period.
- Evaluate designs and modify as needed to develop a pavement section that meets or exceed the required initial performance period and has the lowest life cycle cost.
Guide for the Design of Concrete Overlays using Existing Methodologies

- Background of recommended overlay design techniques
  - 1992 AASHTO Overlay procedure
  - Pavement-ME/MEPDG
  - ACPA Bonded Concrete Overlay of Asphalt pavements
  - (BCOA-ME background on host website)

- Detailed examples of how to use the existing design methodology

- Learn by example – then apply for your situation!

Available online: http://www.cptechcenter.org/
### Which Overlay Design Method(s)?

<table>
<thead>
<tr>
<th>Concrete Overlay Type</th>
<th>Design Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unbonded</strong> on Asphalt, Composite, or Concrete</td>
<td>AASHTO ME, ACPA StreetPave 12, AASHTO 93, OptiPave 2.0</td>
</tr>
<tr>
<td><strong>Bonded</strong> on Asphalt or Composite</td>
<td>ACPA BCOA, ACPA StreetPave 12, BCOA ME, CO 6x6x6</td>
</tr>
<tr>
<td><strong>Bonded</strong> on Concrete</td>
<td>AASHTO ME, ACPA StreetPave 12, AASHTO 93</td>
</tr>
</tbody>
</table>

[apps.acpa.org]
Lots of Guidance Available...
Plan Development

• For agencies that are inexperienced with the design of concrete overlays, the approach should be similar to that of designing an asphalt overlay.

• The location, geometrics and maintenance of traffic requirements should dictate the level of design detail that is required in the plans.
Plan Development

- Oklahoma example
- 5 mile county road – 5” concrete overlay
- 12 plan sheets (4 are structure details)
Variable Cross-Slope

- Matching existing features demands flexibility
- Cross-slope should be labeled as variable

2% where possible (variable to match existing conditions)
Acknowledgments

- Dale Harrington and Gary Fick, National Concrete Pavement Technology Center
- U.S. FHWA
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- American Concrete Pavement Association
- Randy Riley, ACPA-Illinois
Thank You For Your Attention!