Concrete Overlay Thickness Design

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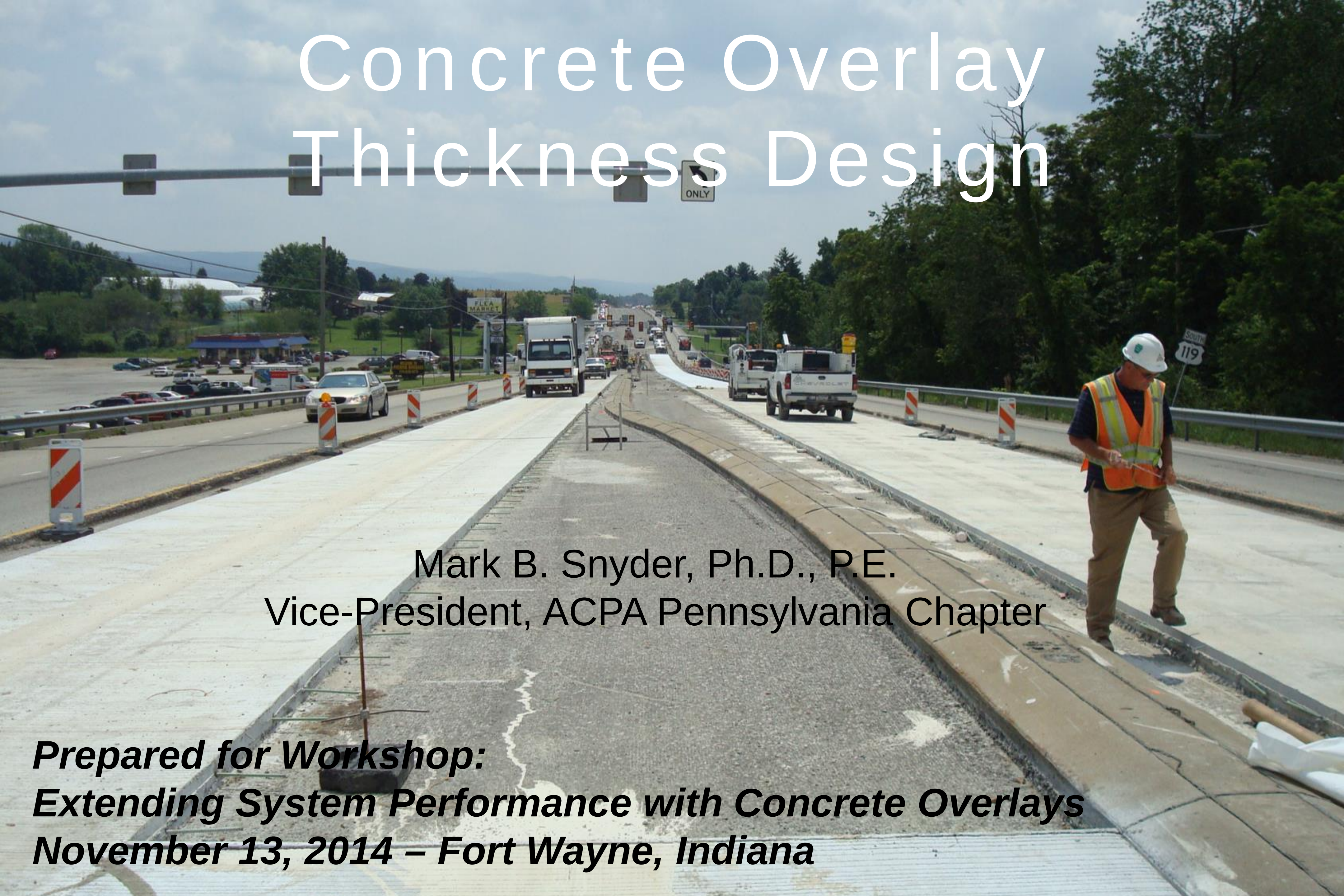
Extending System Performance with Concrete Overlays
November 13, 2014 – Fort Wayne, Indiana



The Principal Factors of Concrete (Overlay) Pavement Design

- Geometrics
- Thickness
- Joint Systems
- Materials
  (and bonding between layers of material)

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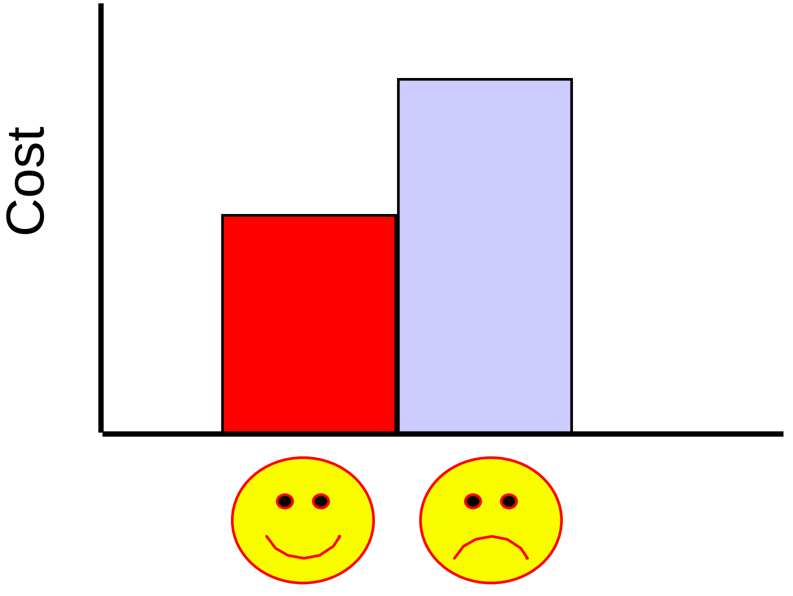
Most Often Influence Cost & Selection of Projects



The Principal Factors of Concrete (Overlay) Pavement Design

- Geometrics
- Thickness
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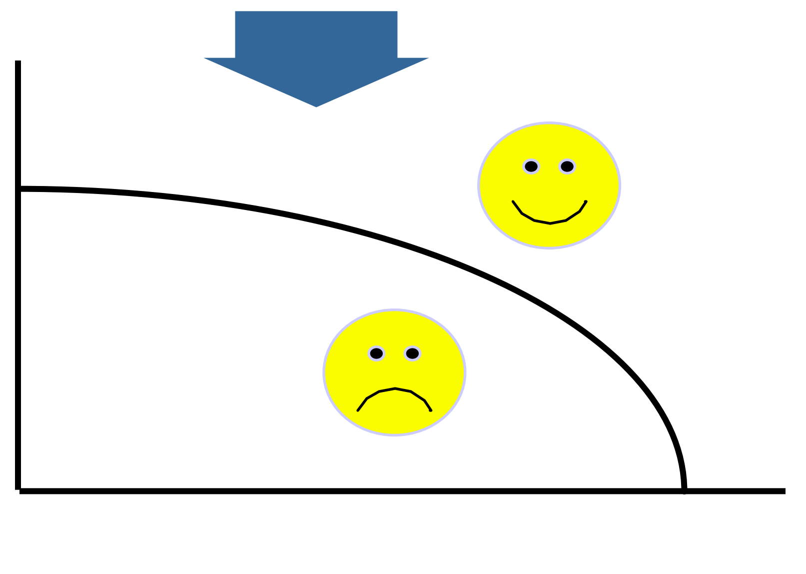
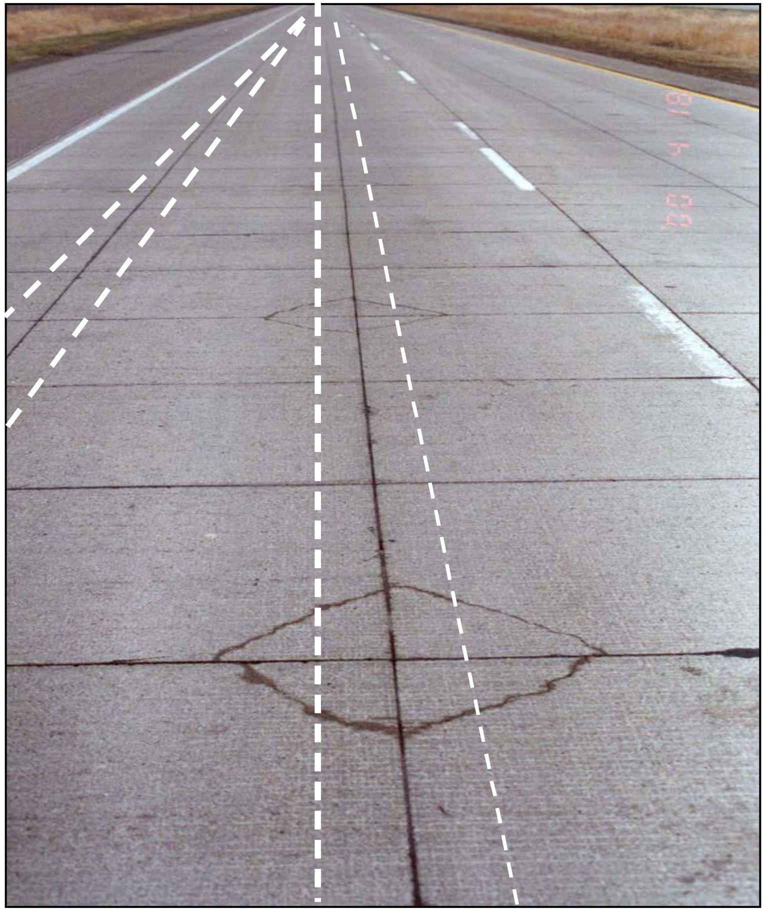
Most Often Influence Real-world Performance



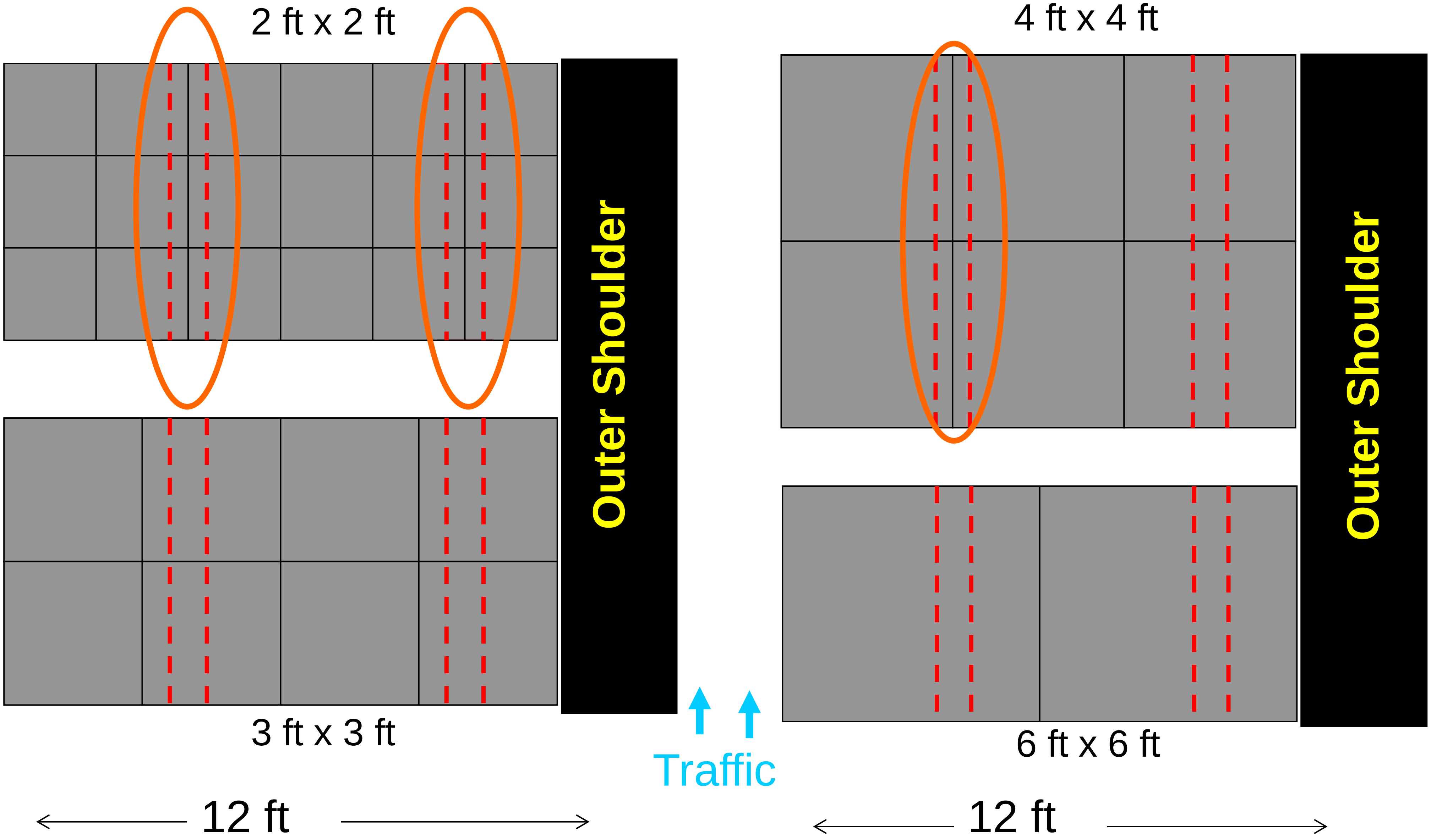
MnROAD Whitetopping Distress
(Mainline - Feb 2002)

Cell	Panels Cracked (%)	Corner Cracks
4”-4’x4’ (93)	5	6
3”-4’x4’ (94)	40	165
3”-5’x6’*(95)	8	17
6”-5’x6’ (96)	0	0
6”-10’x12’(97U)	13	0
6”-10’x12’ (92D)	3	0



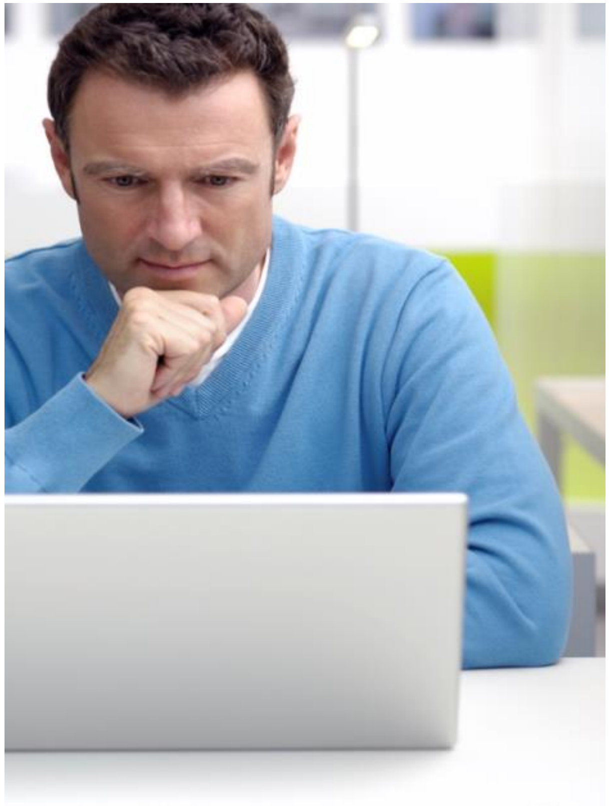
4’x4’ Panels - Corner Breaks due to Wheel Loadings

Longitudinal Joint Layout



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 <u>Causes</u>
of Functional Problems and Prevent Recurrence

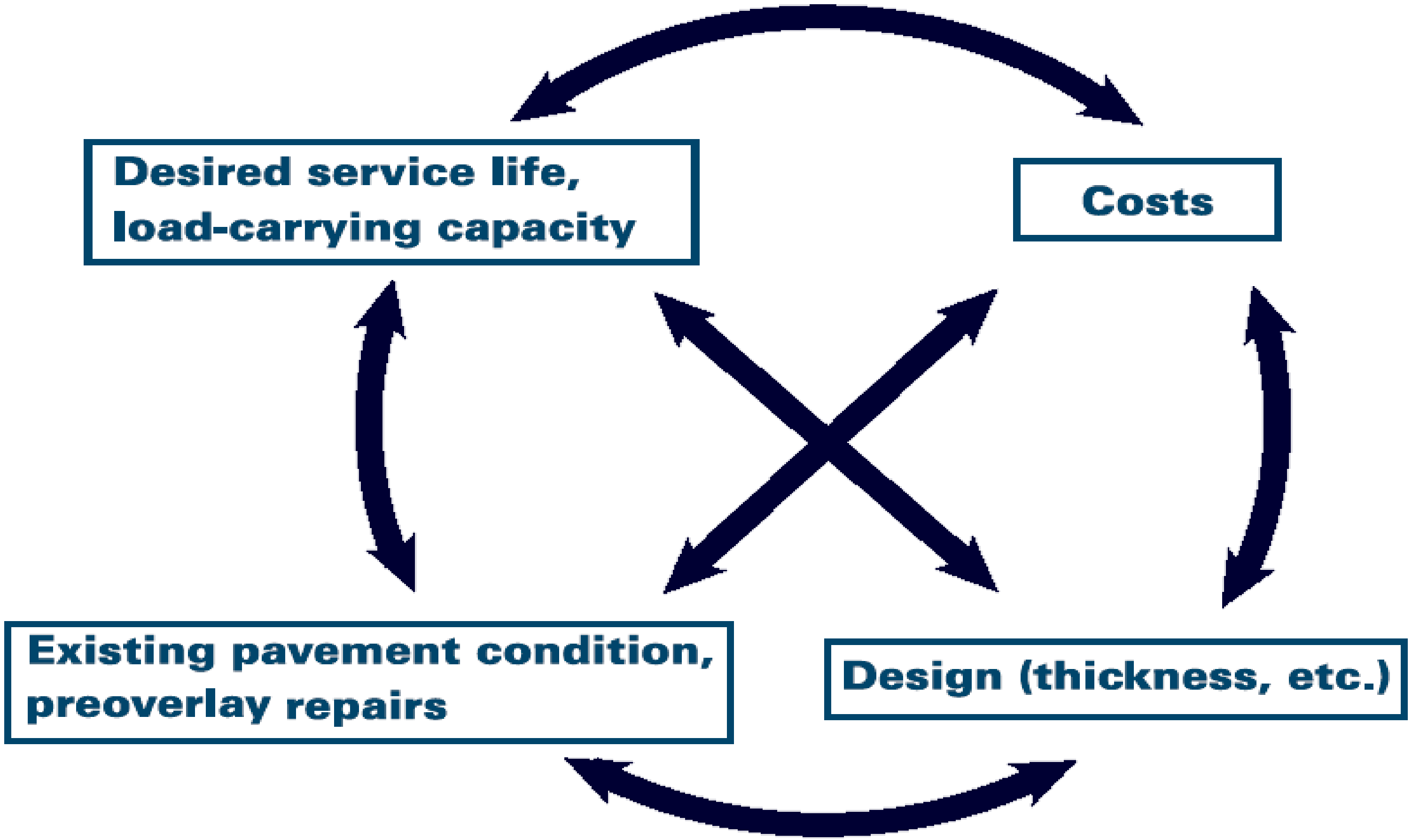
Important Considerations in Overlay Design

- 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

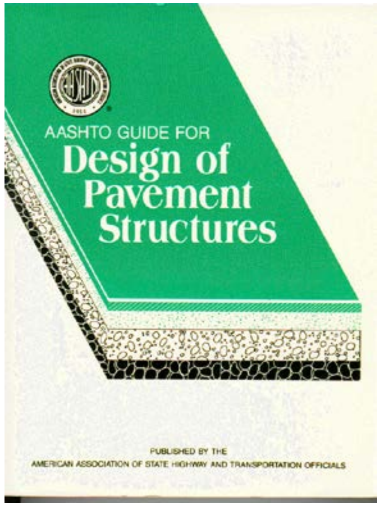


Thickness Design Procedures

- 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)

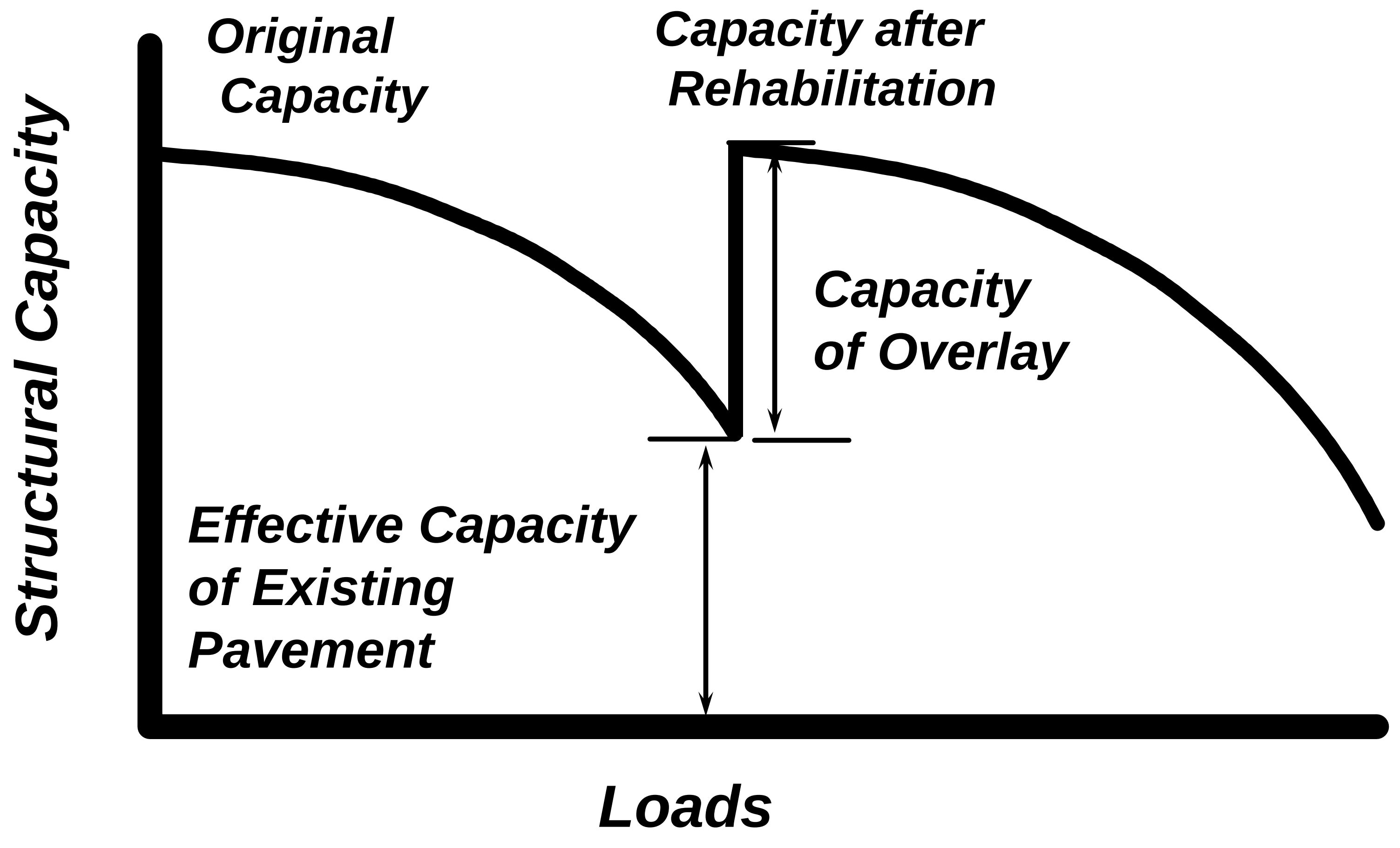
AASHO Road Test at Ottawa, Illinois (approximately 80 miles southwest of Chicago) between 1956 and 1960

1993 AASHTO Guide



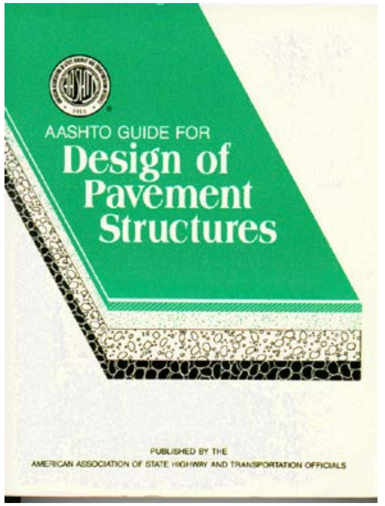
- Based on mathematical models derived from empirical data collected during the AASHO Road Test in the late 1950's.
- Procedure provides suitable bonded and unbonded concrete overlay designs.
- The AASHTO computer software for implementation of the 1993 AASHTO Guide is called DARWin. In addition, a number 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

- Uses the concepts of structural deficiency and effective structural capacity for the evaluation and characterization of the existing pavement to be overlaid.
- The structural capacity (SC) of a pavement section will decrease with traffic and time.
- Structural capacity of an overlay (SCoverlay) will restore the structural capacity of the existing pavement (SCeffective) to meet the requirements to carry the predicted future traffic (SCfuture traffic).



Overlay Design - Basic Steps
1993 AASHTO

1. **Determine Existing Pavement Information**
2. **Predict Future Traffic / ESALs**
3. **Determine Required Future Structural Capacity**
4. **Perform Condition Survey**
5. **Perform Deflection Testing**
6. **Perform Coring / Materials Testing**
7. **Determine Existing Structural Capacity**
8. **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

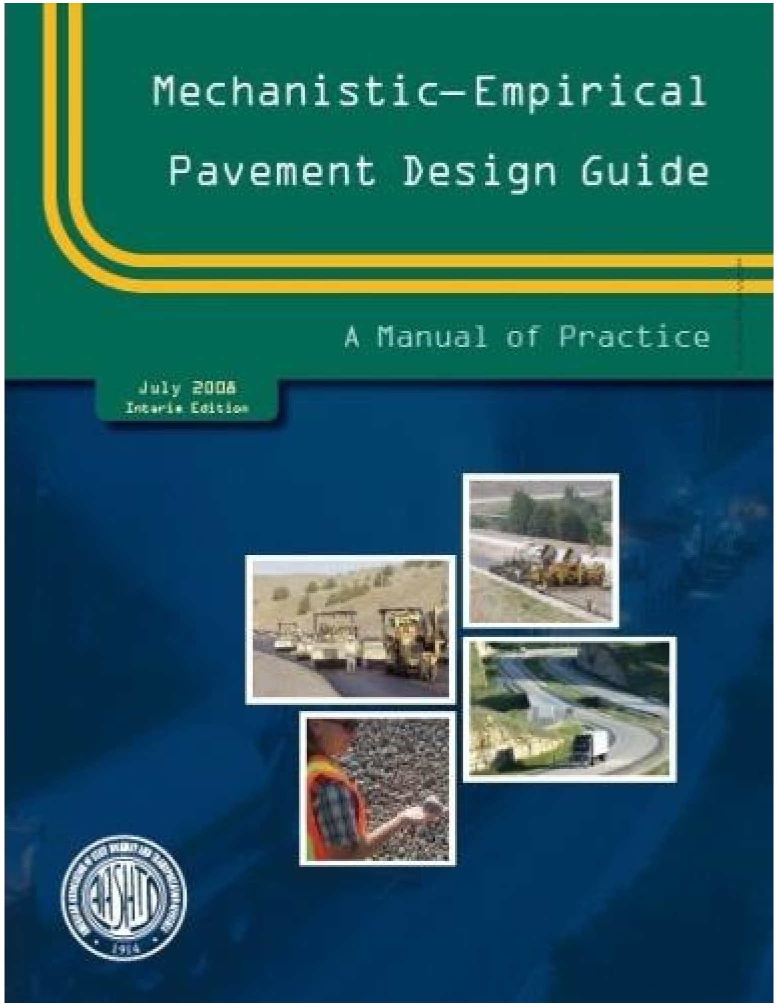
Allows consideration of new designs and design features – INNOVATION!

Examples:

smaller panels or widened lanes (w/reduced slab thickness)

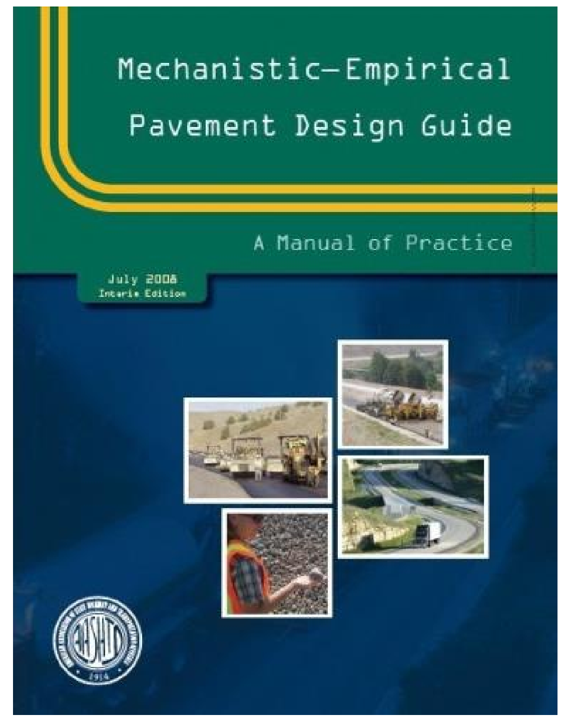
AASHTO Interim
M-E Pavement Design Guide 2007

- MEPDG provides models and design tools for JPCP & CRCP overlays of existing HMA, JPCP & CRCP
- MEPDG used to analyze impact of existing pavement condition on performance and design of concrete overlay.

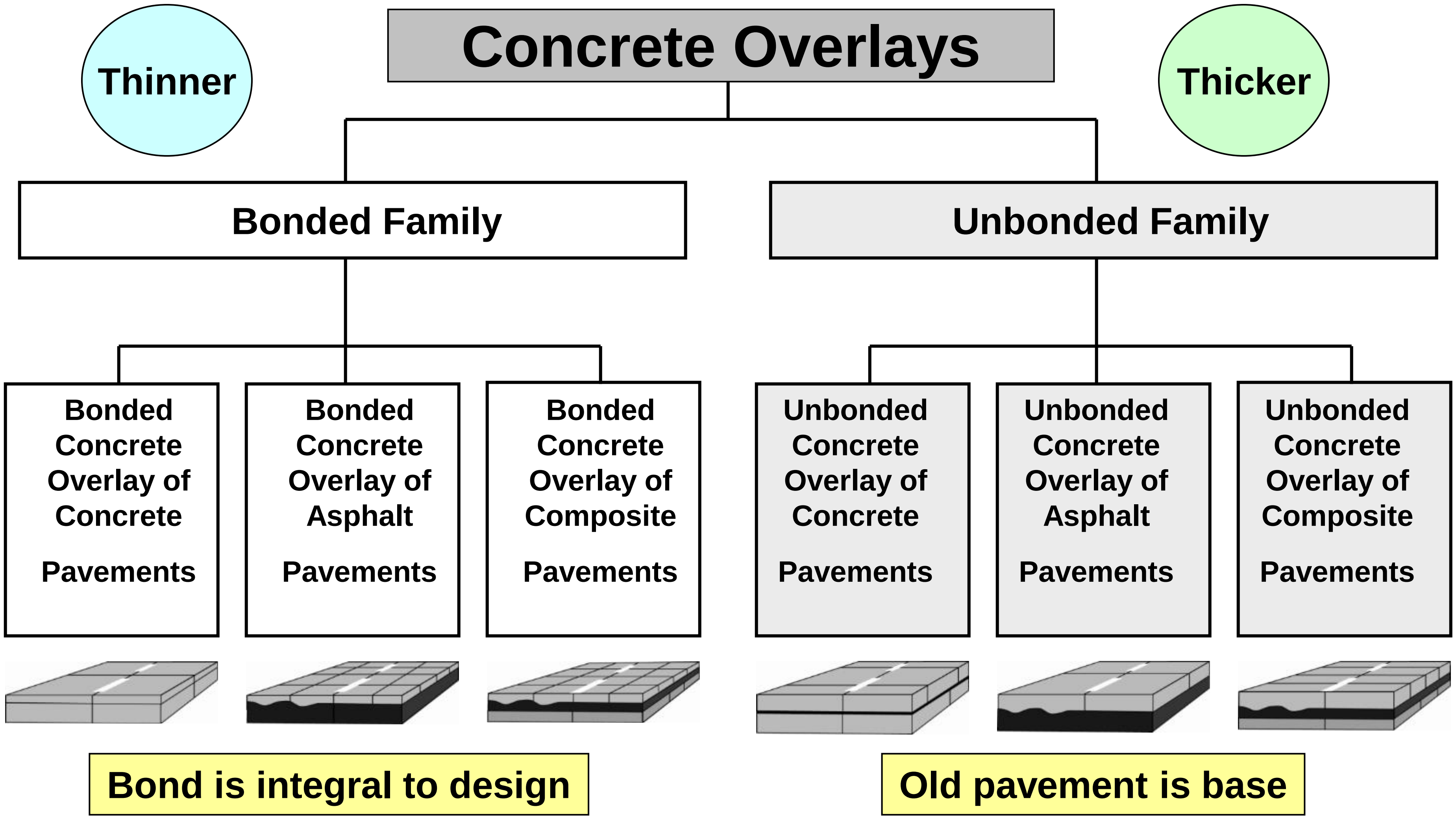


M-E PDG

- 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
- 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)
  - Support conditions, local climatic factors, and concrete material and support layer properties.



Family of Concrete Overlays



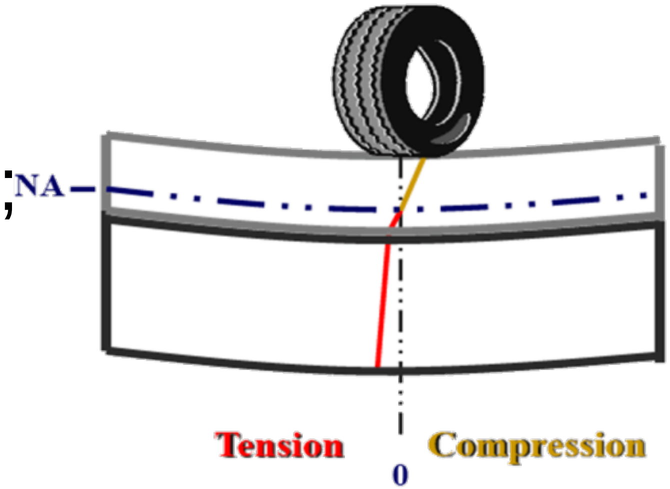
Typical PCC Overlay Service Lives

Concrete Overlay Type	Typical Life
Bonded on Concrete	15-25 years
Unbonded on Concrete	20-30 years
Bonded on Asphalt/Composite	5-15 years
Unbonded on Asphalt/Composite	20-30 years

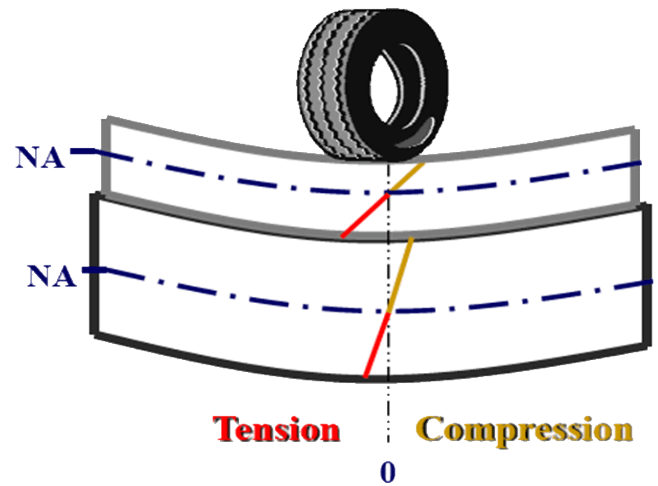
Based on FHWA's "Portland Cement Concrete Overlays – State of the Technology Synthesis" (FHWA-IF-02-045)

Bonded versus Unbonded (intent)

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

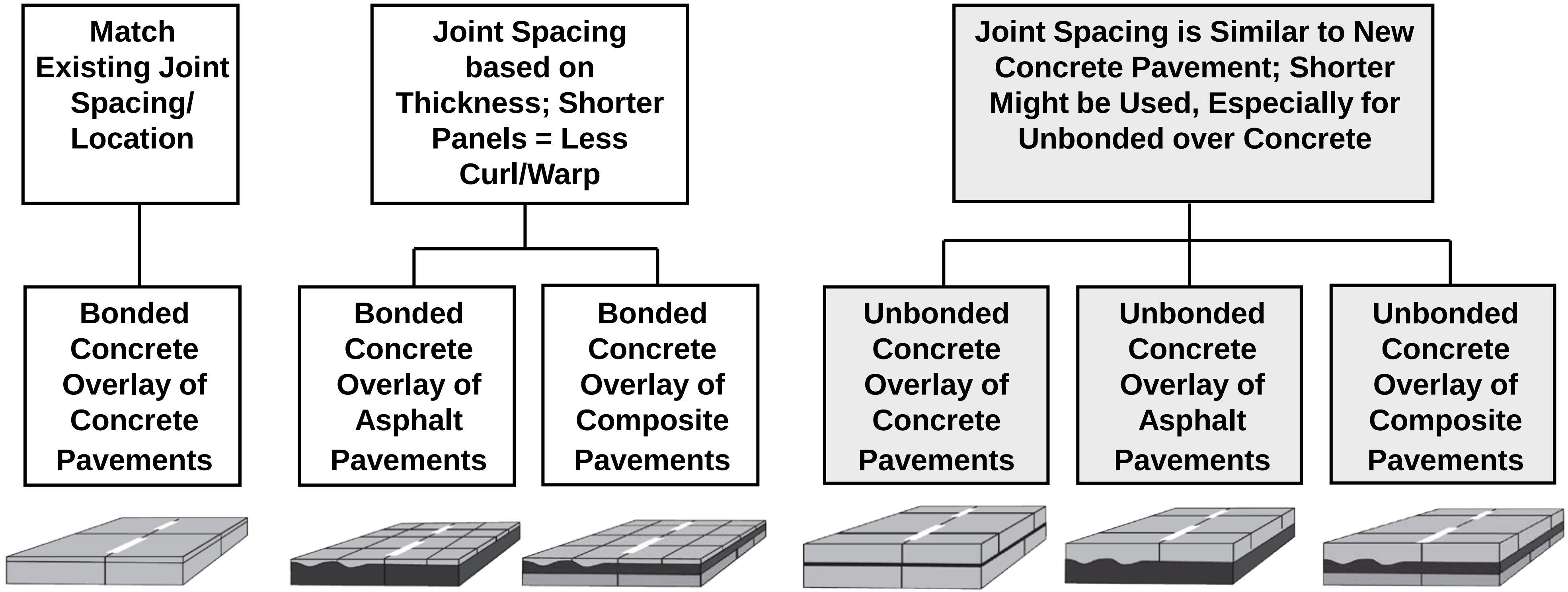


- **Unbonded:** Use to restore structural capacity and increase pavement life equivalent to full-depth pavement. Also results in improved surface friction, noise, and rideability



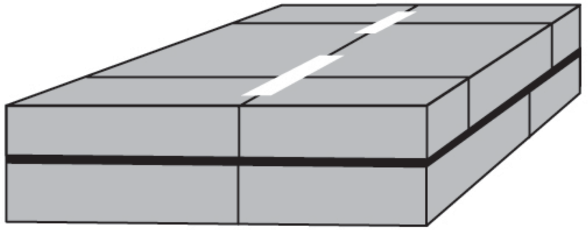
Jointing Patterns Vary

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

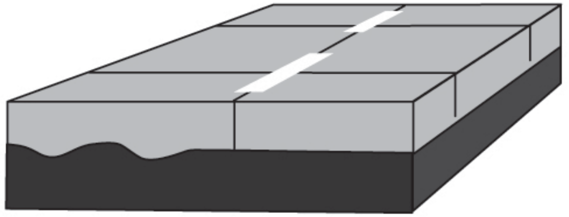


Unbonded Concrete Overlays

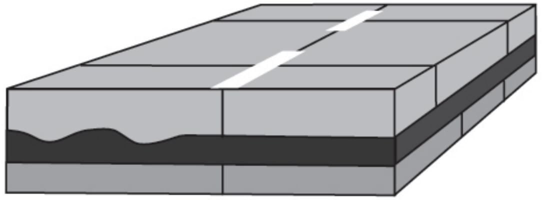
Unbonded Concrete Overlays of Concrete Pavements
–previously called unbonded overlays–



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:

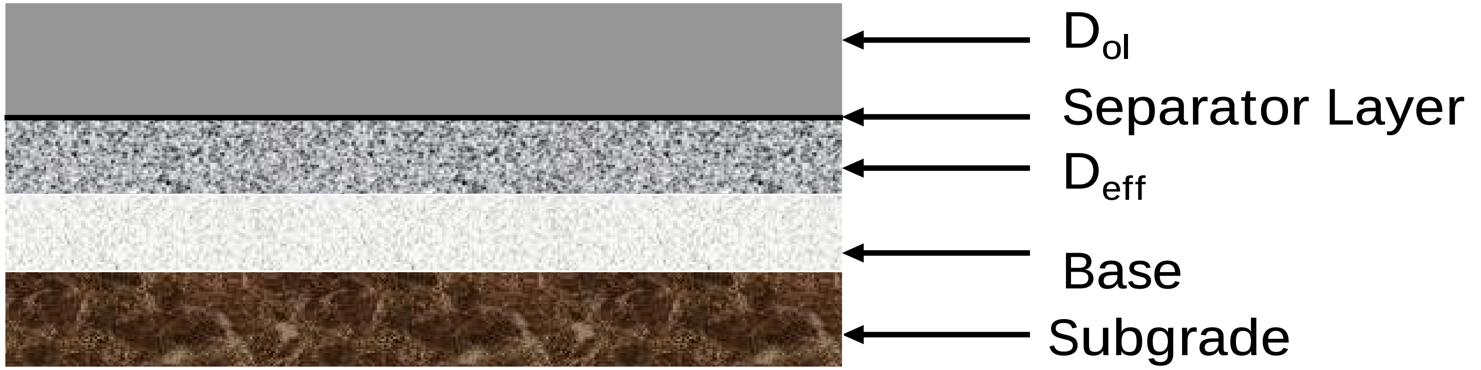
$$D_{ol} = \sqrt{D_f^2 - D_{eff}^2}$$

where:

D_{ol} = *Required PCC overlay thickness*

D_f = *Thickness of new PCC pavement for design conditions*

D_{eff} = *Effective thickness of existing PCC*



Unbonded on Concrete / Composite
1993 AASHTO

Determination Of Effective Slab Thickness (D_{eff})

$$D_{eff} = F_{jcu} * D$$

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})

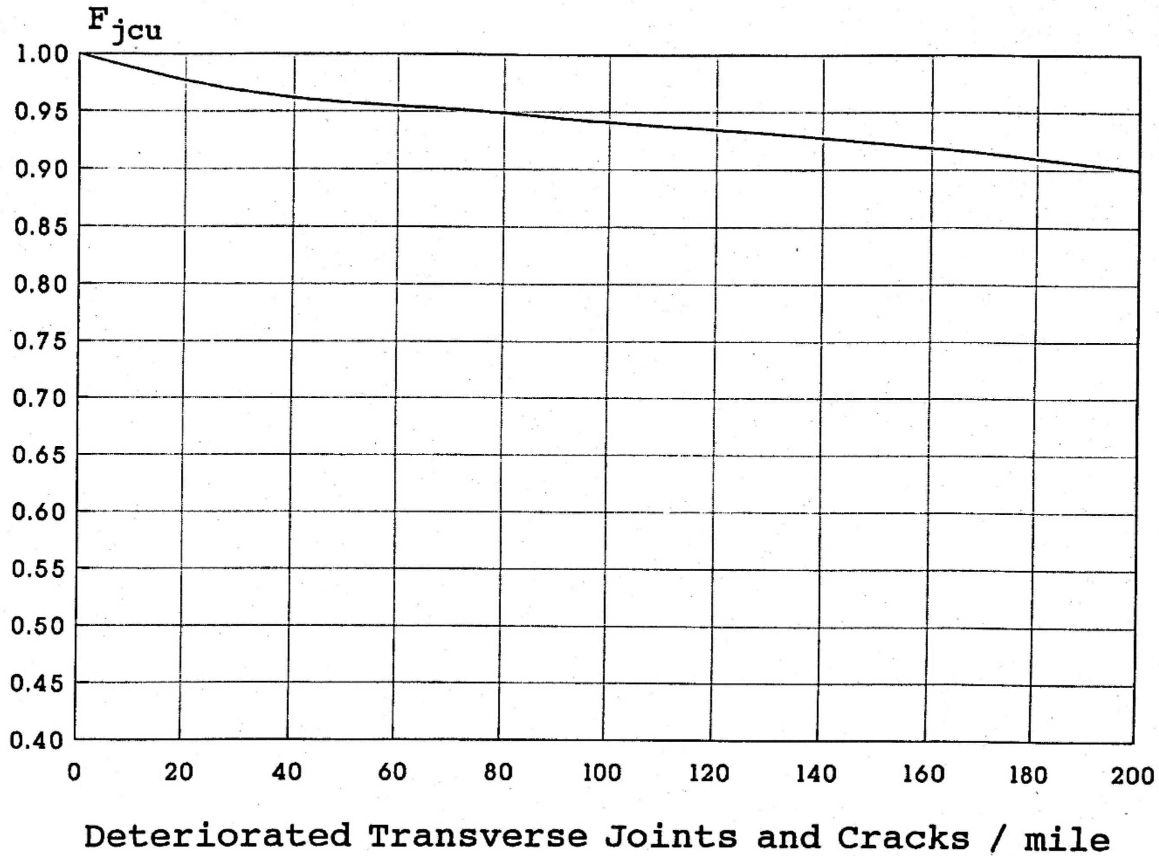


Figure 5.13. F_{jcu} **Adjustment Factor for Unbonded JPCP, JRCP, and CRCP Overlays**

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 Fabrics are now 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.

Proposed Interim Specifications for Geotextile Interlayer Material

Property	Requirements	Test Procedure
Geotextile Type	Nonwoven, needle-punched, no thermal treatment to include calendaring	EN 13249, Annex F (Certification)
Color	Uniform/nominally same color fibers	(Visual Inspection)
Mass per unit area	≥ 500 g/m² (14.7 oz/sq.yd) ≤ 550 g/m² (16.2 oz/sq.yd)	ISO 9864 (ASTM D 5261)
Thickness under load (pressure)	[a] At 2 kPa (0.29 psi): ≥ 3.0 mm (0.12 in.) [b] At 20 kPa (2.9 psi): ≥ 2.5 mm (0.10 in.) [c] At 200 kPa (29 psi): ≥ 1.0 mm (0.04 in.)	ISO 9863-1 (ASTM D 5199)
Wide-width tensile strength	≥ 10 kN/m (685 lb/ft)	ISO 10319 (ASTM D 4595)
Wide-width maximum elongation	≤ 130%	ISO 10319 (ASTM D 4595)
Water permeability in normal direction under load (pressure)	≥ 1×10-4 m/s (3.3×10-4 ft/s) at 20 kPa (2.9 psi)	DIN 60500-4 (modified ASTM D 5493)
In-plane water permeability (transmissivity) under load (pressure)	[a] ≥ 5×10-4 m/s (1.6×10-3 ft/s) at 20 kPa (2.9 psi) [b] ≥2×10-4 m/s (6.6×10-4 ft/s) at 200 kPa (2.9 psi)	ISO 12958 (modified ASTM D 4716)
Weather resistance	Retained Strength ≥ 60%	EN 12224 (ASTM D 4355 @ 500 hrs. exposure

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.**

Unbonded Concrete Overlay of Asphalt
1993 AASHTO

- Thickness
  - Designed as new pavement on asphalt base
    - Need to adjust "k-value" in design procedure
  - Assumes no bonding to the existing asphalt
- Jointing
  - Spacing - same as new concrete pavement
  - Depth - adjust for AC distortion
  - Reinforcing & dowels - same as new pavement

Unbonded Overlay of Asphalt
AASHTO 93 Design

- Figure 3.3 - nomograph for determining k-value using
  - Roadbed soil modulus
  - Subbase modulus-use AC modulus
  - Subbase thickness-use AC thickness
- Typical Value
  - k = 300 – 400 psi/in

Example:

D_{SB} = 6 inches

E_{SB} = 20,000 psi

M_R = 7,000 psi

Solution: k_∞ = 400 pci

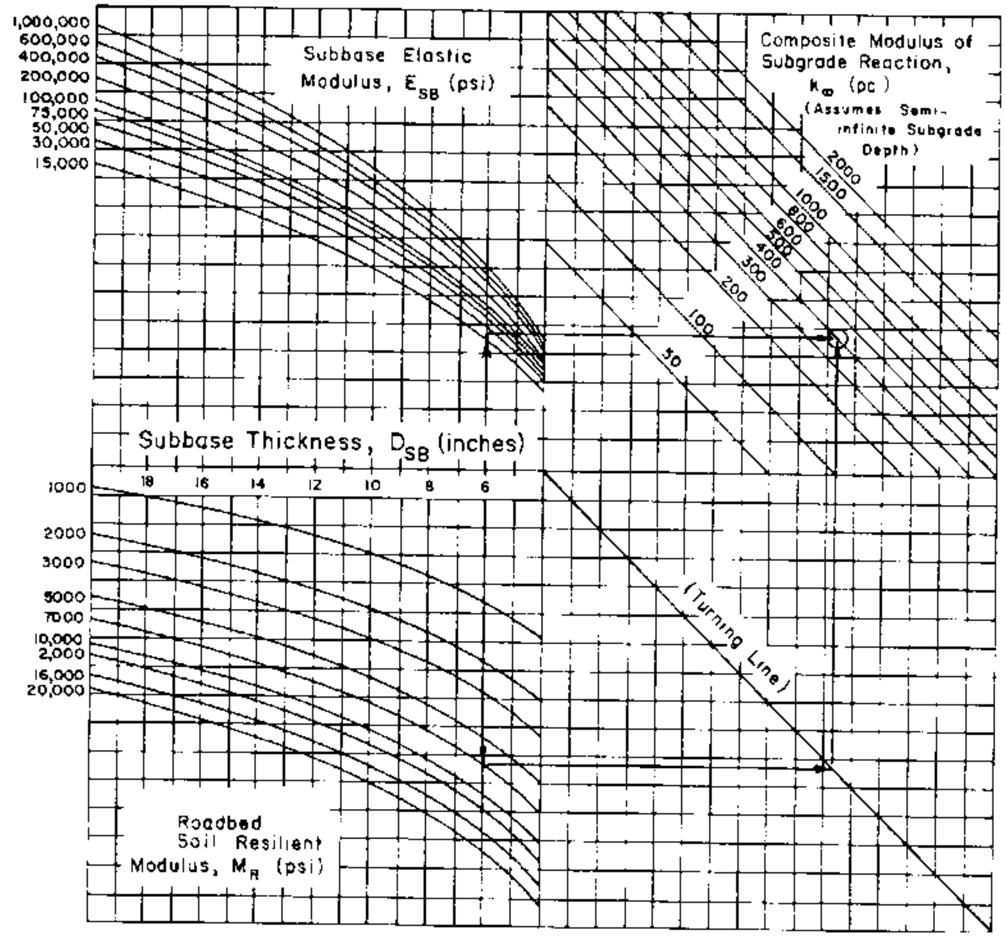


Figure 3.3. Chart for Estimating Composite Modulus of Subgrade Reaction, k_∞, Assuming a Semi-Infinite Subgrade Depth. (For practical purposes, a semi-infinite depth is considered to be greater than 10 feet below the surface of the subgrade.)

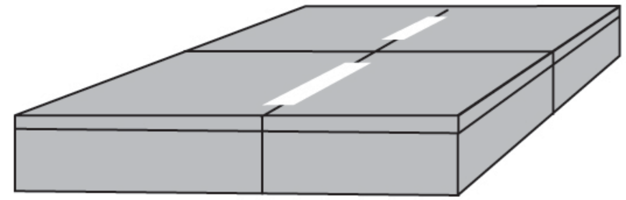
Design-Relevant Assumptions for Unbonded Overlays on Concrete

Design Method	Design Assumptions, Deficiencies / Strengths and/or Items to Note
1993 AASHTO Guide	• This procedure assumes no friction between the concrete overlay and the existing HMA pavement or interlayer, uses a composite k-value, and consequently yields conservative thickness designs. • The effective structural capacity of existing concrete and composite pavements is based on the condition survey or the remaining life methods. These two methods have different limitations and may yield inconsistent or unreasonable results.
M-E PDG	• Integrates slab geometry, climatic factors, concrete material and support layer properties compared to the 1993 AASHTO Guide. • The HMA and concrete are treated as unbonded structural layers without any frictional consideration with the concrete overlay. • This method is still under evaluation, calibration, and implementation by State Highway Agencies.

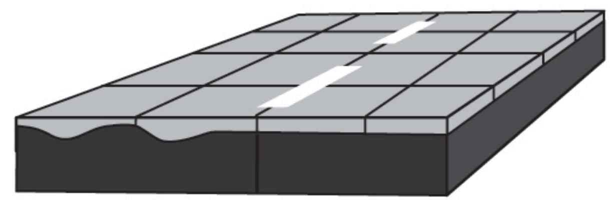
Lots of Guidance Available…

Bonded Concrete Overlays

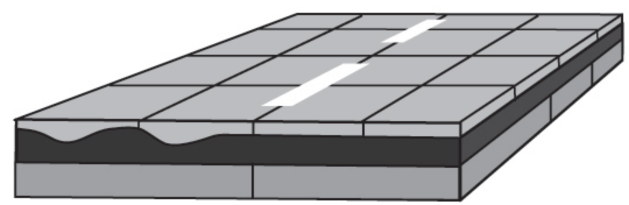
Bonded Concrete Overlays of Concrete Pavements
–previously called bonded overlays–



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



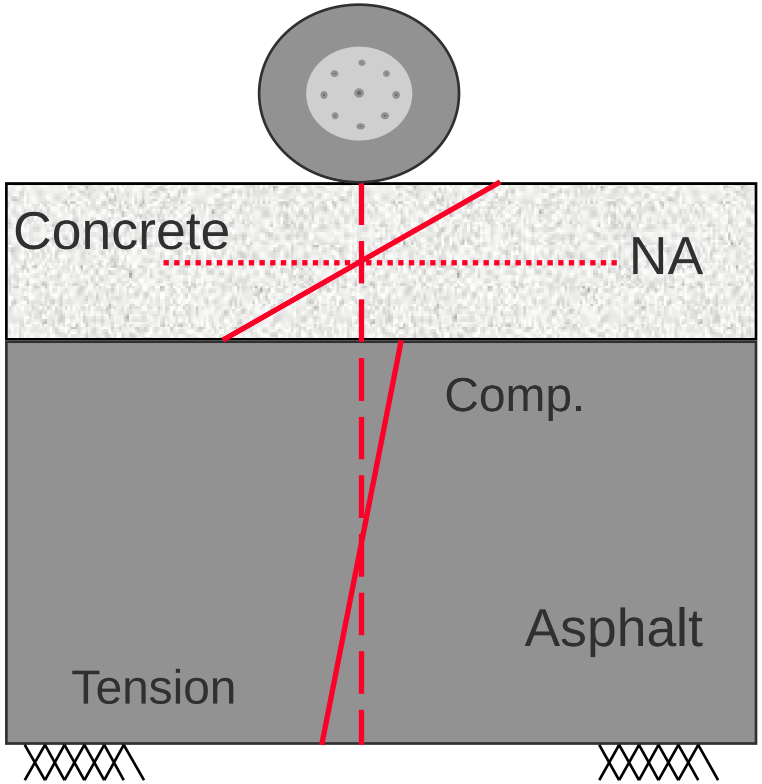
Bonded Concrete Overlays of Composite Pavements



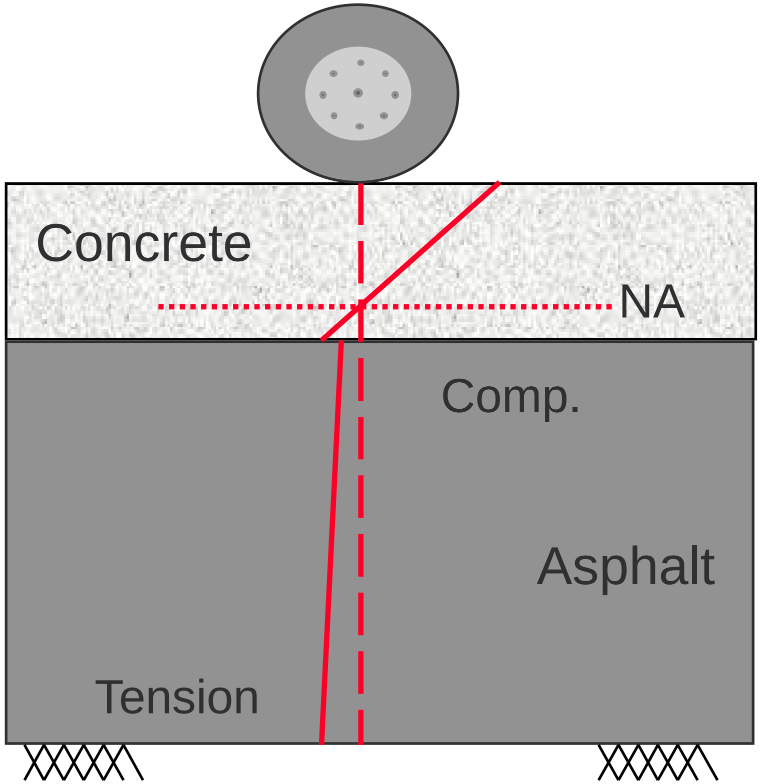
How Do Bonded Overlays over Asphalt Work?

- 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

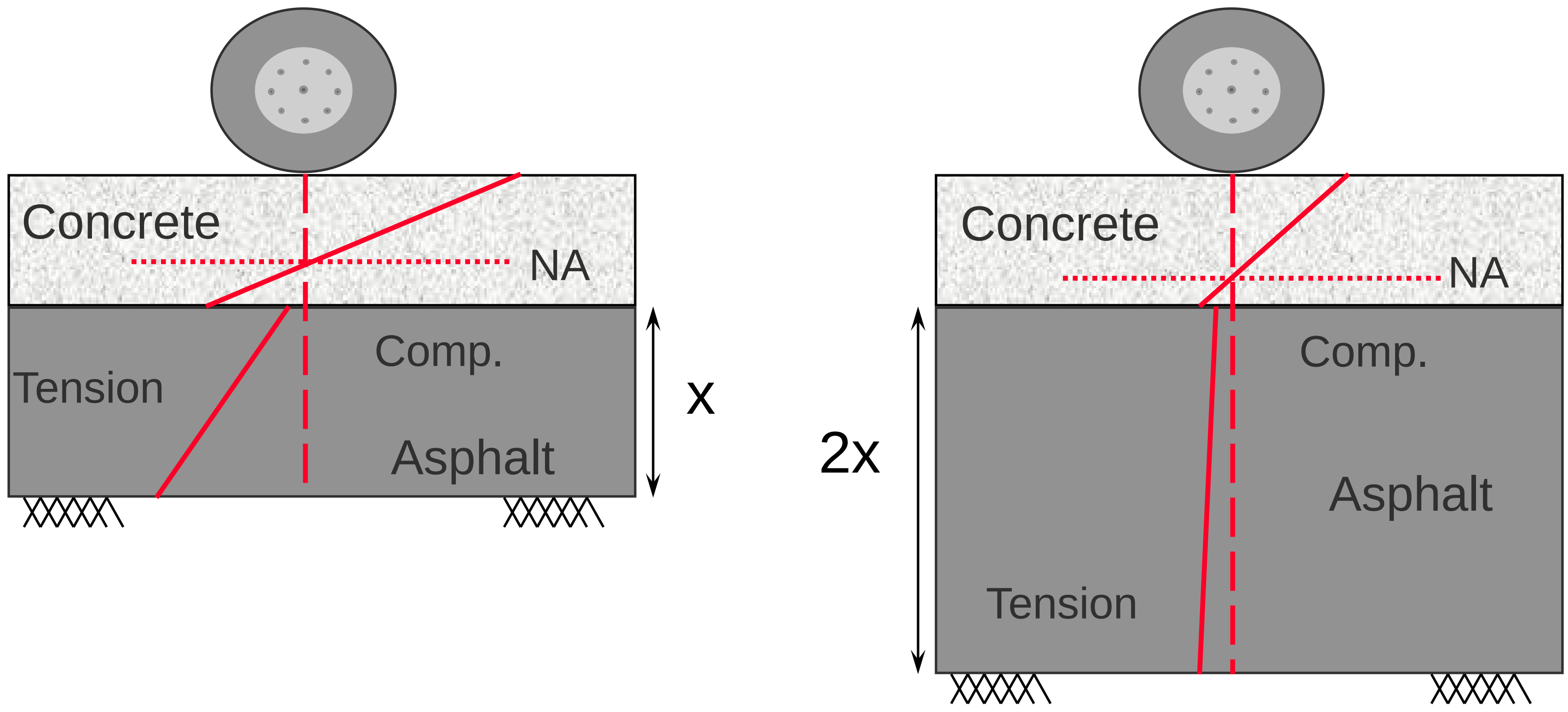


Unbonded

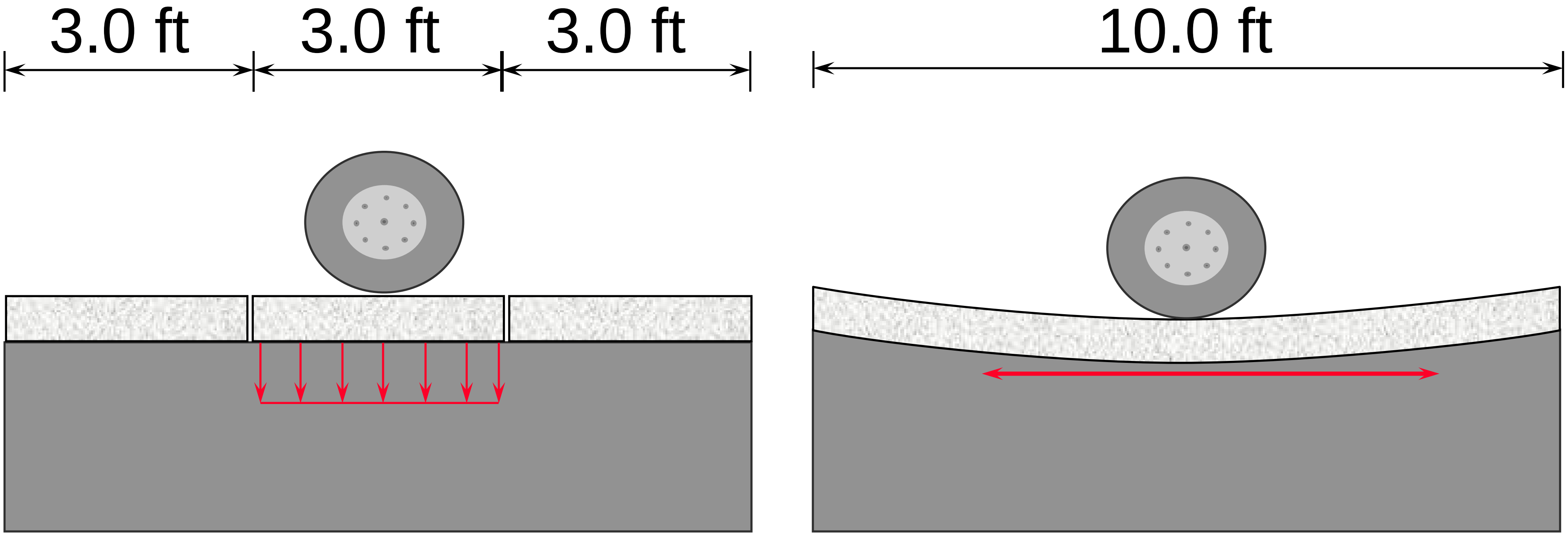


Bonded

Effects of AC Thickness



Effects of Joint Spacing



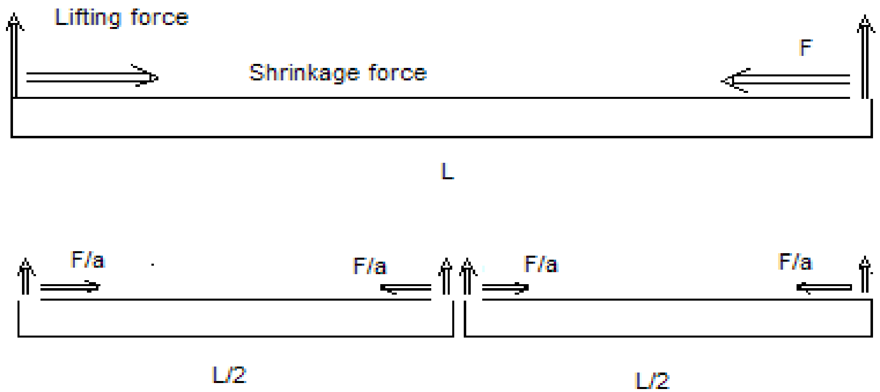
Short Slabs Deflect
Very little flexural stress

Standard Slabs Bend
Higher flexural stress

Short Panels Improve Performance By Decreasing Curling And Warping

Effect of Slab Length on Shrinkage Force

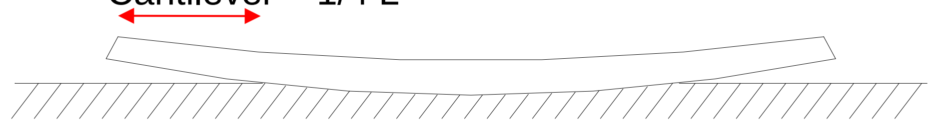
- **Curling & warping is produced by the shrinkage force at the slab surface.**
  - **Due to drying and thermal differential shrinkage on the surface of the concrete.**
- **The magnitude of this force is dependent on the length of the surface.**
  - **Shorter slabs have less length, which means that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



Effect of Slab Length on Curling/Warping

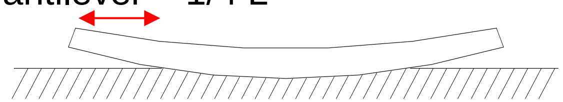
- **All concrete slabs curl / warp so that approximately 1/4 of the slab length is lifted of the subgrade / subbase support**
- **By reducing slab length, the amount lifted, and the height of the lift is greatly reduced**

Cantilever = 1/4 L



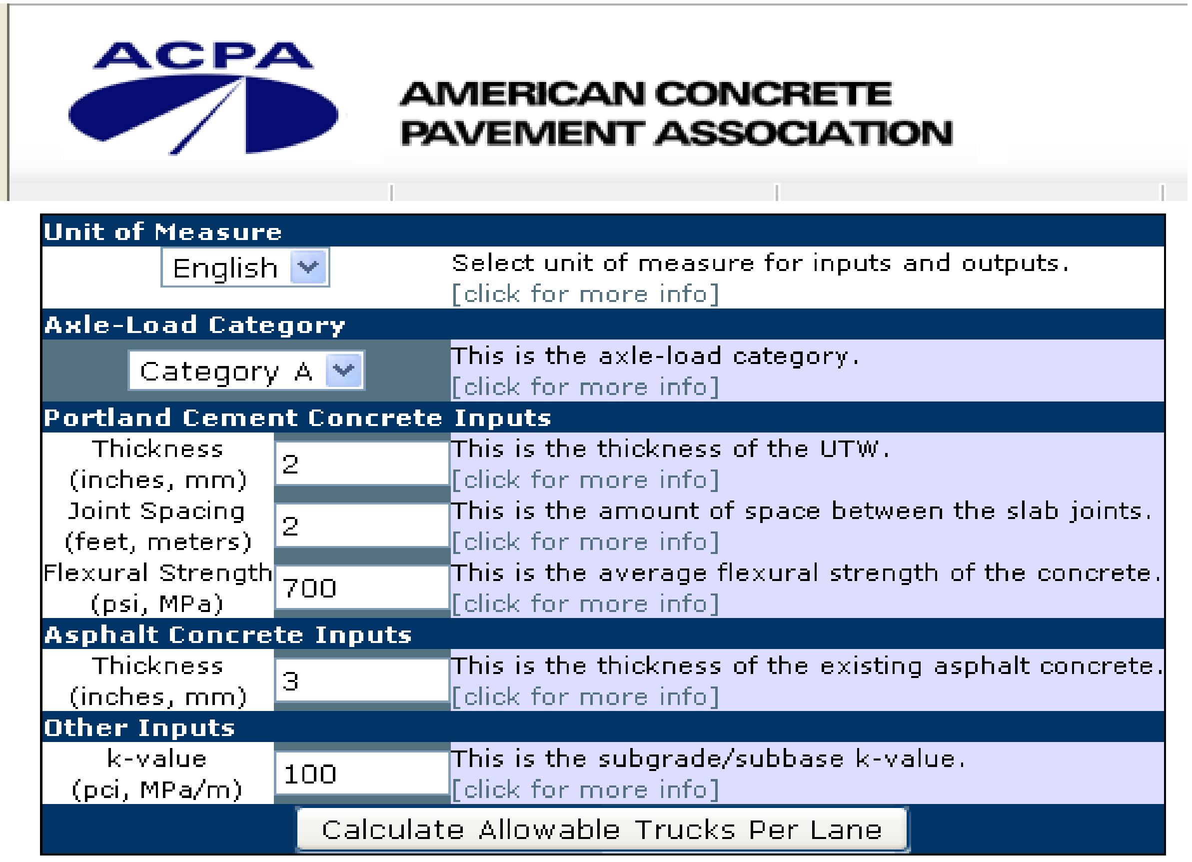
Length 12 to 15 ft., cantilever = 3 to 3.75 ft

Cantilever = 1/4 L



Length 6 ft., cantilever = 1.5 ft

Bonded on HMA/Composite: Original ACPA Method



- Web-based
- Mechanistic-empirical
  - Fatigue failure (corner loading)
  - New fatigue model with reliability input
  - Better fatigue characterization of HMA
- Fibers -Improved flexural ductility, toughness, fatigue capacity
- Models bond failure

Bonded on HMA/Composite: Modified ACPA Method

- Improved by:
  - Randell Riley, Illinois Chapter, ACPA
  - Dr. Jeff Roesler, University of Illinois (sponsored by Illinois DOT)
- Improvements made to modified include:
  - New fatigue model with reliability input
  - Better fatigue characterization of HMA
- Fibers -Improved flexural ductility, toughness, fatigue capacity
- Models bond failure

Bonded Overlay on Asphalt/Composite:
Bonded Concrete Overlay on Asphalt (BCOA)

- Web-based
- Mechanistic-empirical
  - Fatigue model with reliability input (corner loading)
  - Better fatigue characterization of HMA
  - Fibers -Improved flexural ductility, toughness, fatigue capacity
- Models bond failure

Web App:
http://apps.acpa.org/apps/bcoa.aspx

Bonded On Asphalt/Composite (BCOA) Inputs

General Design Details

Design Lane ESALs: [Estimate ESALs]	0
Slabs Cracked at End of Design Life (%):	20 %
Reliability (%):	85 %
Effective Temperature Gradient (°F/in.):	-1.4
Time at Effective Temperature Gradient (%):	58 %

Existing Pavement Structure Details

Remaining Asphalt Thickness (in.):	4
Asphalt Modulus of Elasticity (psi):	700,000
Modulus of Subgrade Reaction (pci):	150 (Calculate *k*-Value)

Concrete Material Details

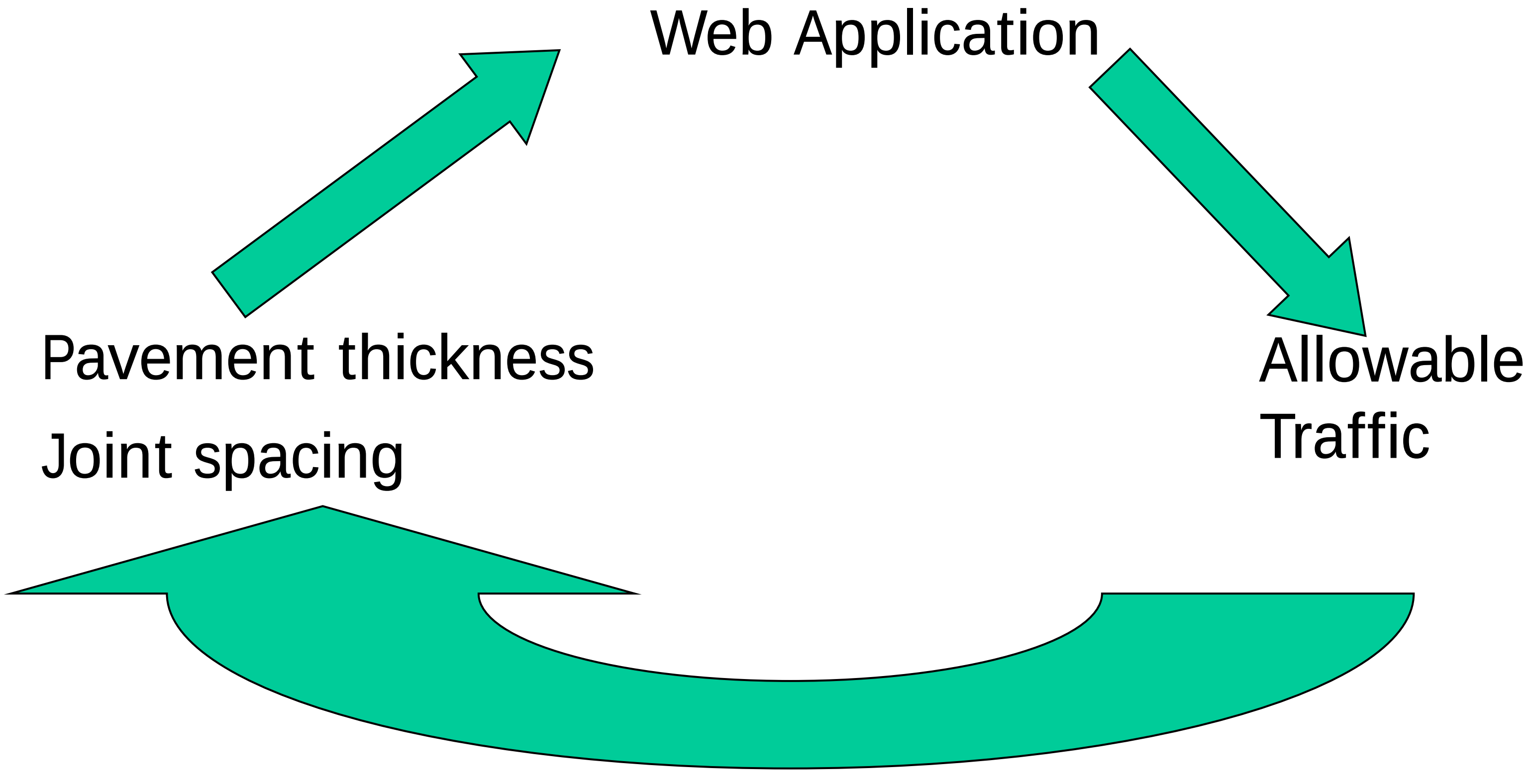
28-Day Flexural Strength (psi):	750
Fibers Used In Concrete:	No Fibers
Concrete Modulus of Elasticity (psi):	3,600,000
Coefficient of Thermal Expansion (10^{-6}/°F):	5.5

Concrete Overlay Details

Joint Spacing (in.):	72
Preoverlay Surface Preparation:	Old Asphalt, Cleaned

Bonded On Asphalt/Composite (BCOA) Inputs

- BCOA is a thickness calculator, but you can adjust design thickness and joint spacing to determine allowable trucks.



BCOA ME

University of Pittsburgh

(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 TPF 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.

Design Guide

Practitioner's Information | **Training Tools** | **Technical Documentation** | **Sponsoring Agencies**

User's Feedback

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

Instruction:

Select from drop-down list;	Enter data;	Enter data or use calculation.

(Please enable the Macros and the Internet Explorer (not mandatory) to run the spreadsheet.)

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%

Geographic Information

ESALs Calculator

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

k-value Calculator

PCC Overlay

Average 28-day Flexural Strength (psi):	650
Estimated PCC Elastic Modulus (psi):	3,930,000
Coefficient of Thermal Expansion (10^{-6} in/°F/in)	5.5
Fiber Type:	No Fibers
Fiber Content(lb/cu yd) (Only used when a fiber type is selected	0

Epcc Calculator

CTE Calculator

Joint Design

Joint Spacing (ft):	6

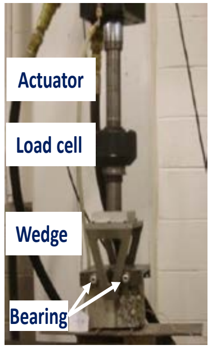
Calculate Design

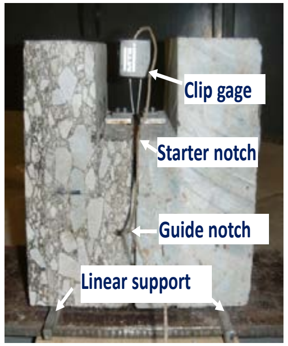
Performance Analysis

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

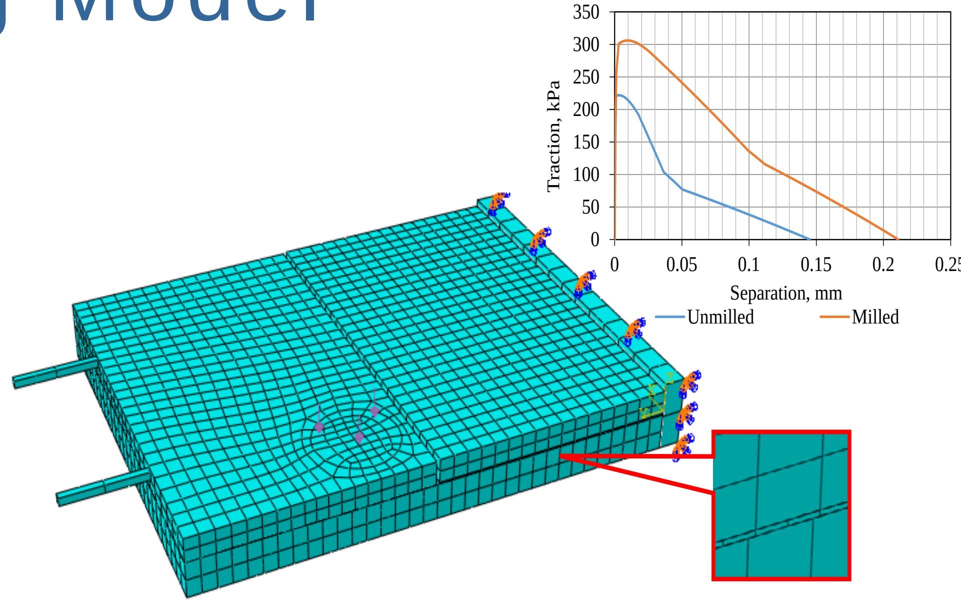
Solved.

Debonding Model

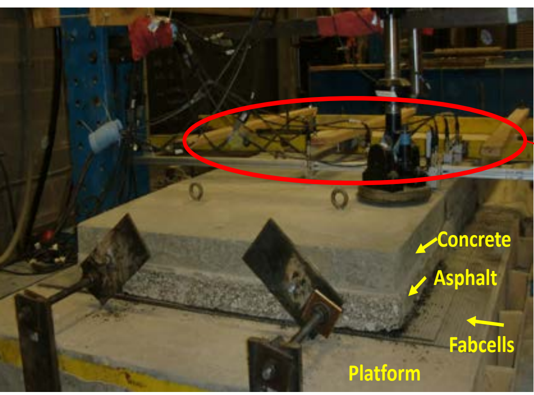


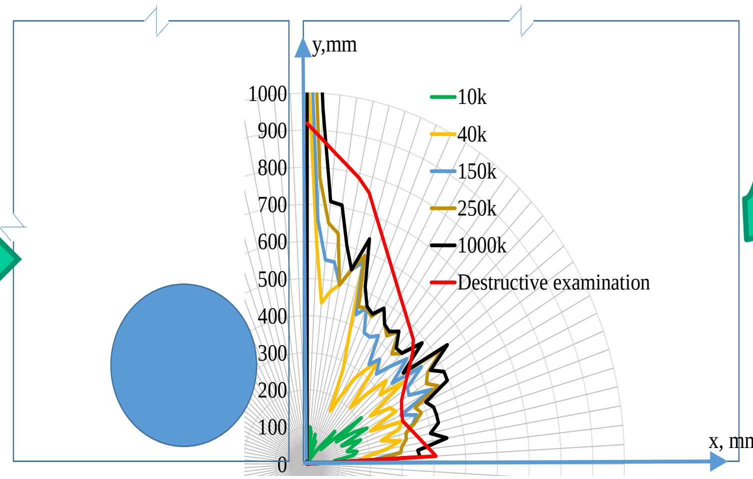


Split wedge: Material property at the interface = f(load rate, temp., surface texture)



FEM: Evaluation of actual BCOA designs





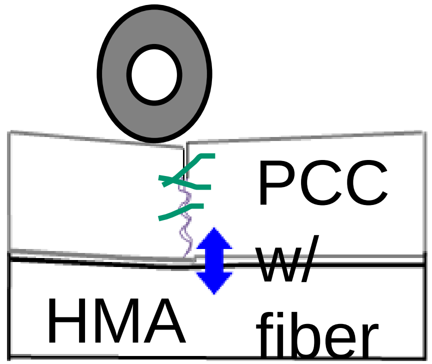
ALF testing: Energy required for delamination

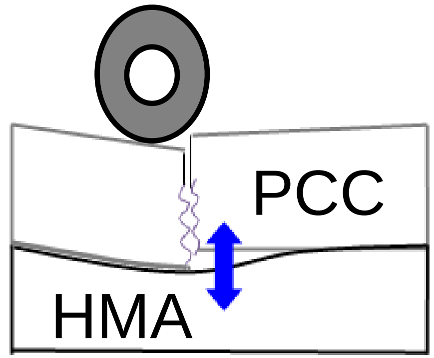
Area of delamination as a function of load applications

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.

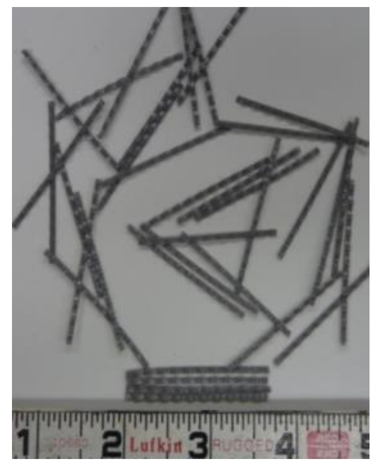
Structural Fibers





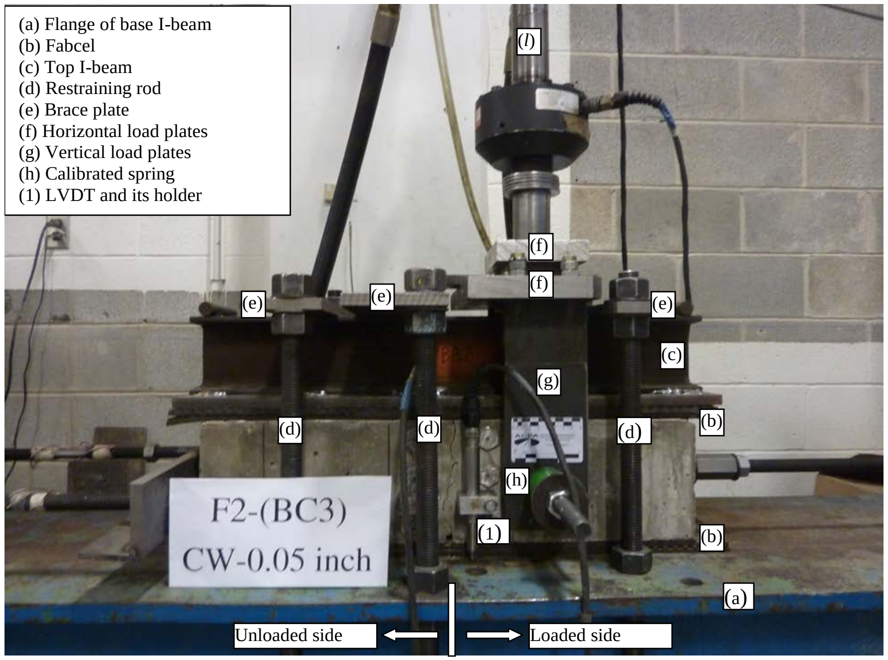
Straight synthetic:
Strux 90/40

Residual strength ratio = 24%

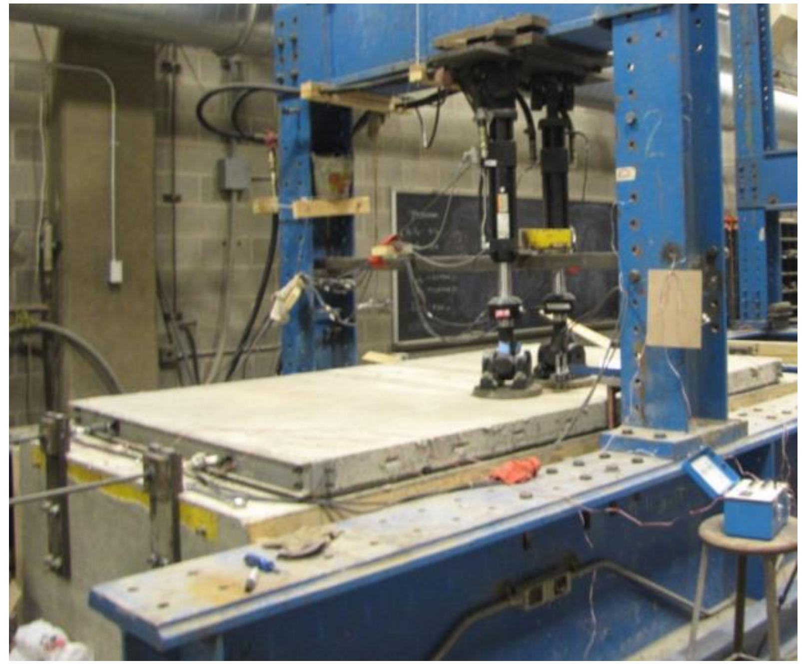


Crimped synthetic:
Enduro 600

Structural Fibers



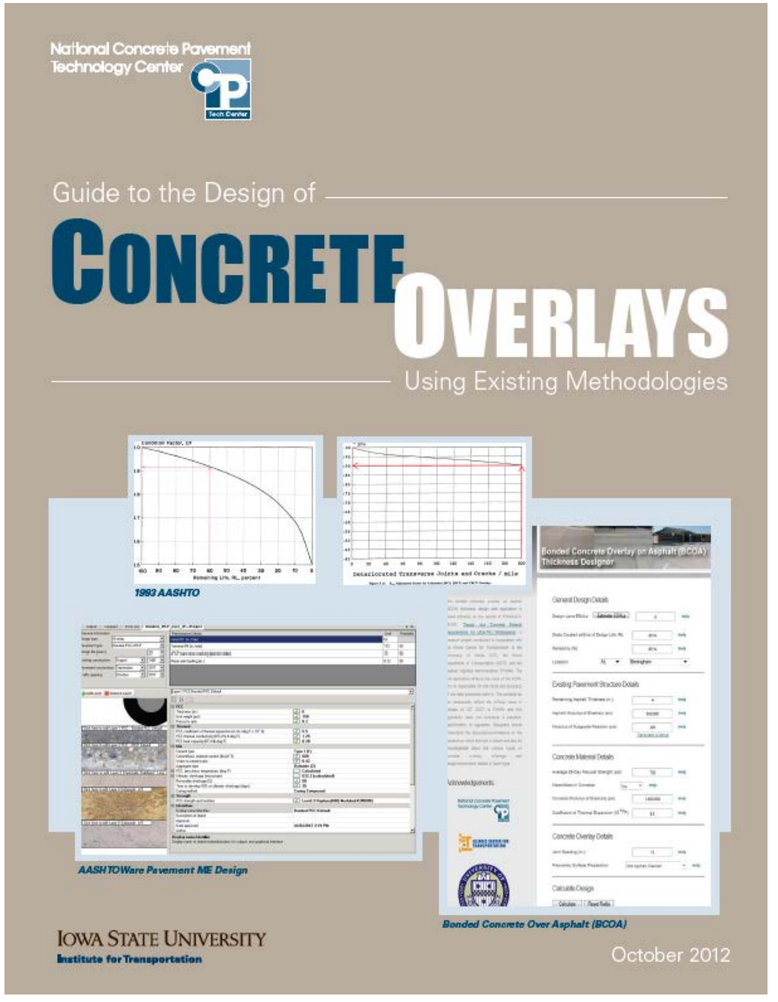
Beam ALF



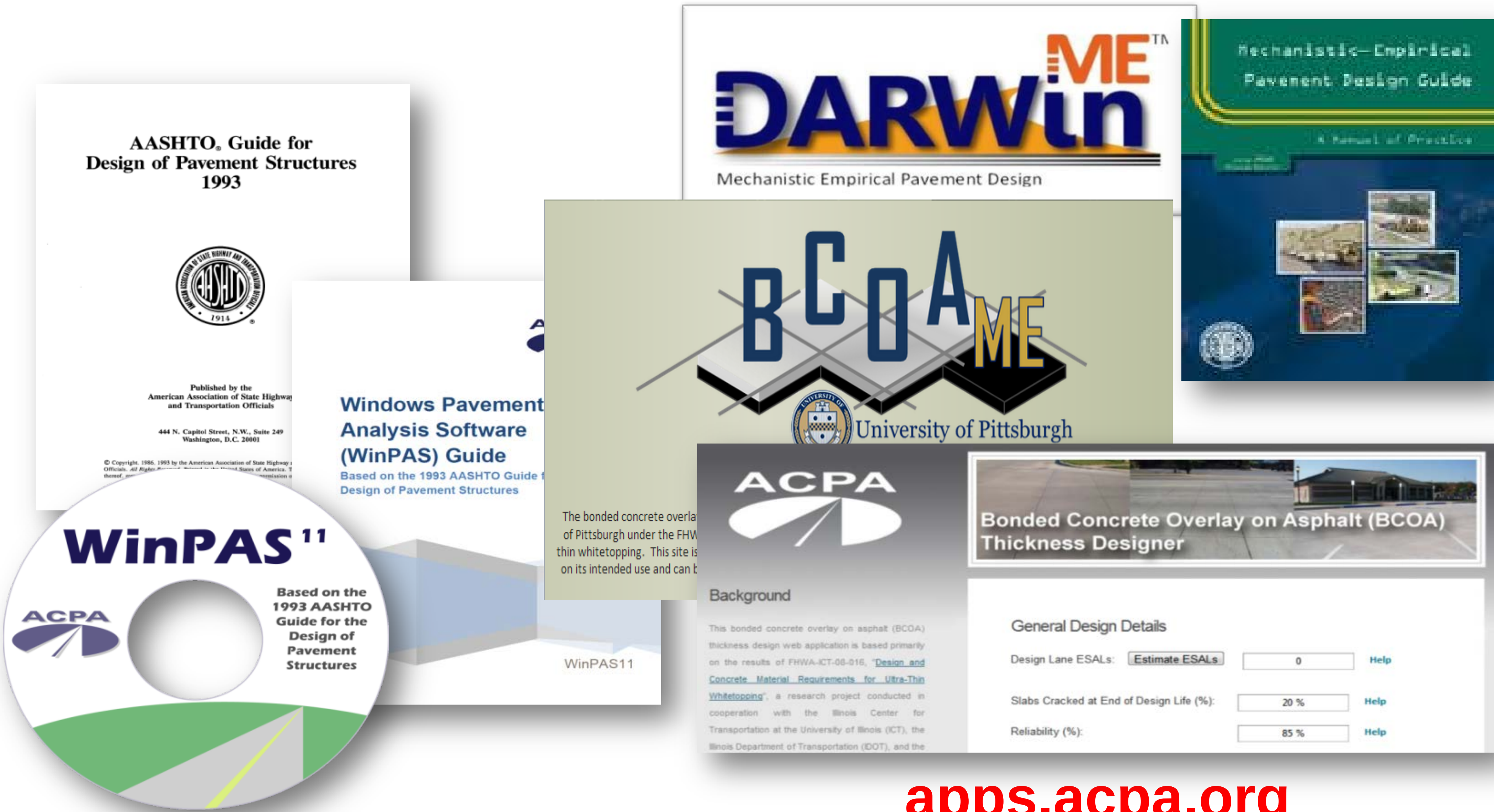
Full scale ALF

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!



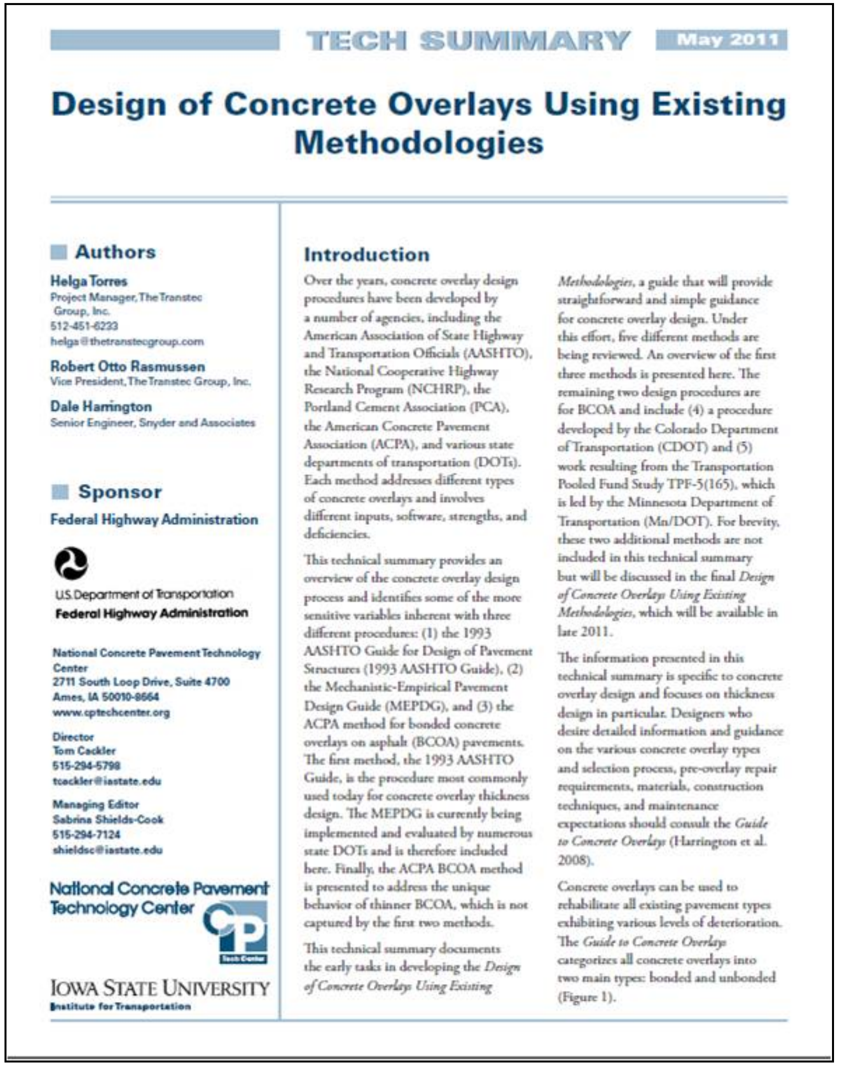
Design Methods Recommended



apps.acpa.org

Guide for the Design of Concrete Overlays using Existing Methodologies

- Tech Summary
  - Interim Guidance
  - Background of recommended overlay design techniques
- Available online:
  - http://www.cptechcenter.org/



TECH SUMMARY May 2011

Design of Concrete Overlays Using Existing Methodologies

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Introduction

Over the years, concrete overlay design procedures have been developed by a number of agencies, including the American Association of State Highway and Transportation Officials (AASHTO), the National Cooperative Highway Research Program (NCHRP), the Portland Cement Association (PCA), the American Concrete Pavement Association (ACPA), and various state departments of transportation (DOTs). Each method addresses different types of concrete overlays and involves different inputs, software, strengths, and deficiencies.

This technical summary provides an overview of the concrete overlay design process and identifies some of the more sensitive variables inherent with three different procedures: (1) the 1993 AASHTO Guide for Design of Pavement Structures (1993 AASHTO Guide), (2) the Mechanistic-Empirical Pavement Design Guide (MEPDG), and (3) the ACPA method for bonded concrete overlays on asphalt (BCOA) pavements. The first method, the 1993 AASHTO Guide, is the procedure most commonly used today for concrete overlay thickness design. The MEPDG is currently being implemented and evaluated by numerous state DOTs and is therefore included here. Finally, the ACPA BCOA method is presented to address the unique behavior of thinner BCOA, which is not captured by the first two methods.

This technical summary documents the early tasks in developing the *Design of Concrete Overlays Using Existing Methodologies*, a guide that will provide straightforward and simple guidance for concrete overlay design. Under this effort, five different methods are being reviewed. An overview of the first three methods is presented here. The remaining two design procedures are for BCOA and include (4) a procedure developed by the Colorado Department of Transportation (CDOT) and (5) work resulting from the Transportation Pooled Fund Study TPF-5(165), which is led by the Minnesota Department of Transportation (Mn/DOT). For brevity, these two additional methods are not included in this technical summary but will be discussed in the final *Design of Concrete Overlays Using Existing Methodologies*, which will be available in late 2011.

The information presented in this technical summary is specific to concrete overlay design and focuses on thickness design in particular. Designers who desire detailed information and guidance on the various concrete overlay types and selection process, pre-overlay repair requirements, materials, construction techniques, and maintenance expectations should consult the *Guide to Concrete Overlays* (Harrington et al. 2008).

Concrete overlays can be used to rehabilitate all existing pavement types exhibiting various levels of deterioration. The *Guide to Concrete Overlays* categorizes all concrete overlays into two main types: bonded and unbonded (Figure 1).

Thank You For Your Attention!