Concrete Overlay Design (Thickness and more …)

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The Principal Factors of Concrete (Overlay) Pavement Design

- Geometrics
- Thickness
- Joint Systems
- Materials

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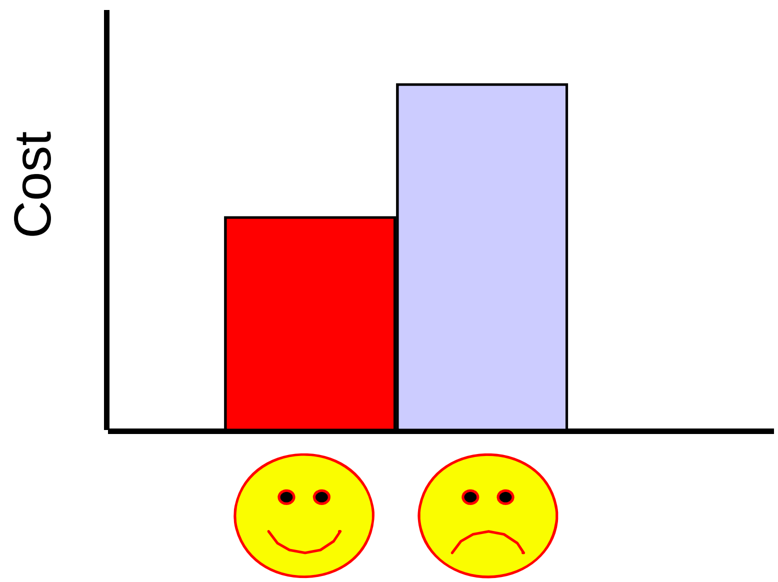
Most Often Influence Cost & Selection of Projects



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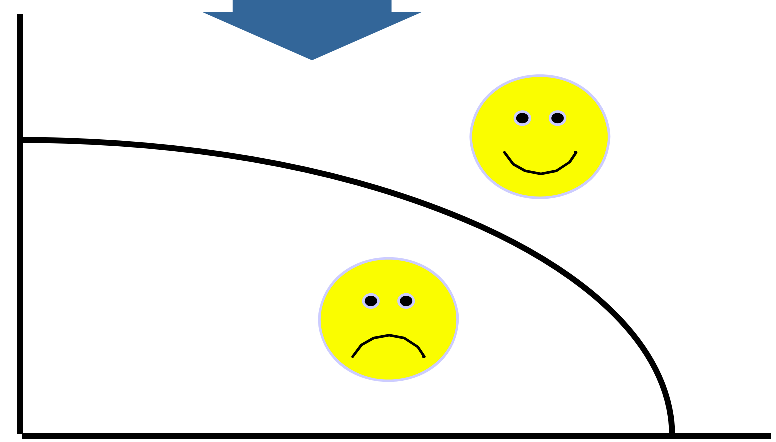
The Principal Factors of Concrete (Overlay) Pavement Design

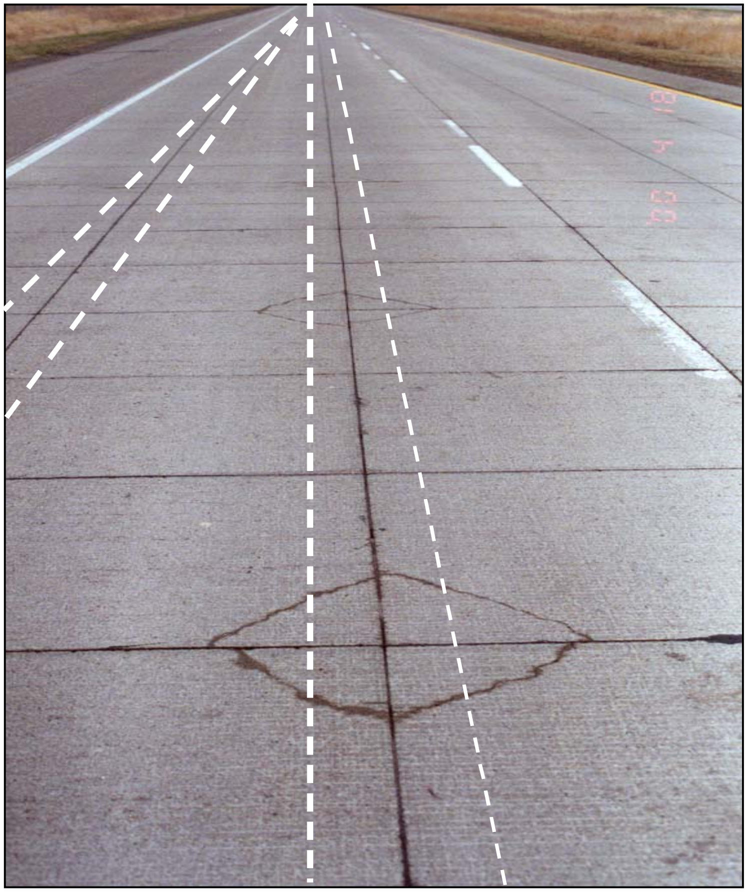
- Geometrics
- Thickness
- Joint Systems
- Materials

Most Often Influence Real-world Performance



MnROAD Whitetopping Distress
(Mainline – 5 yrs service)

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

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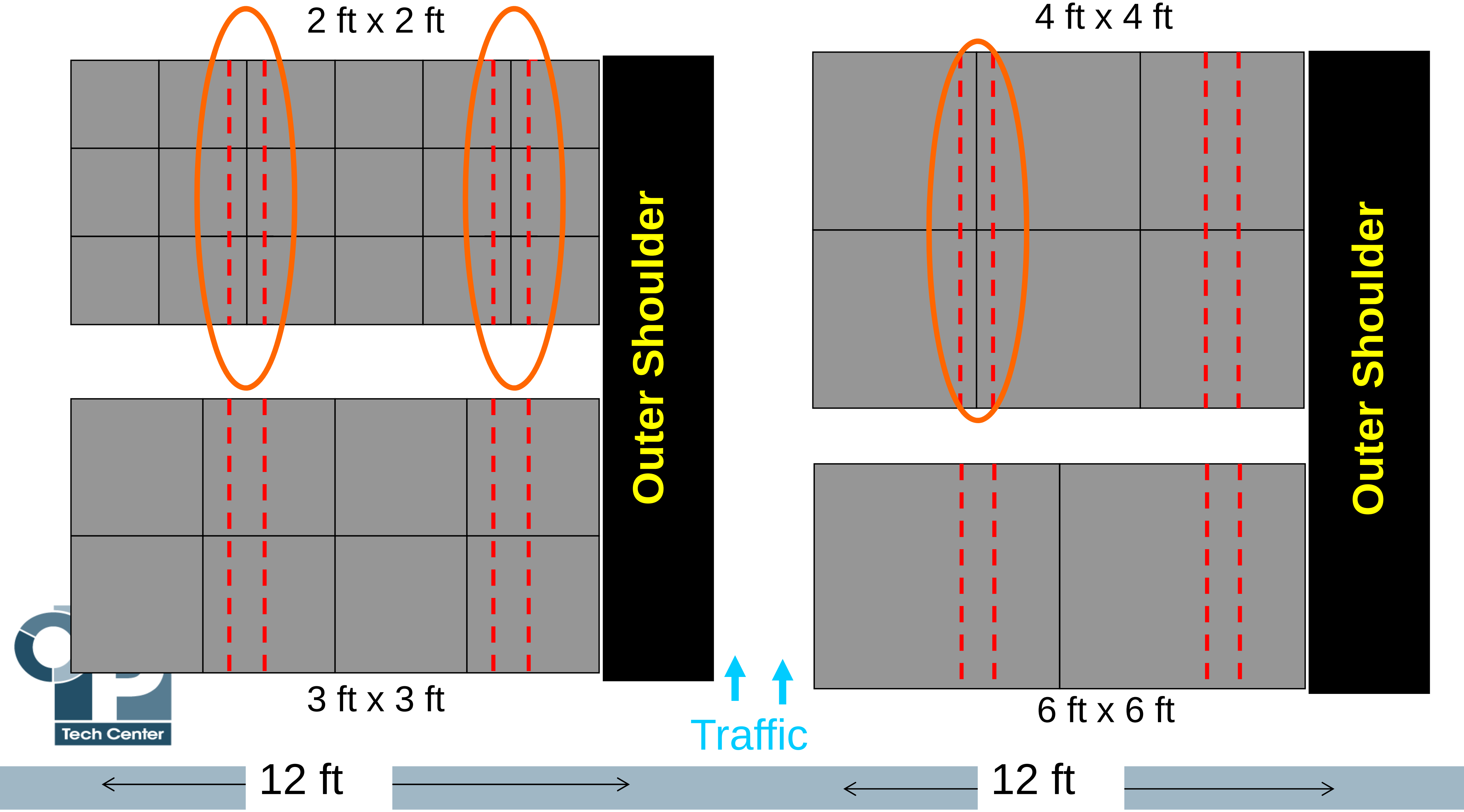
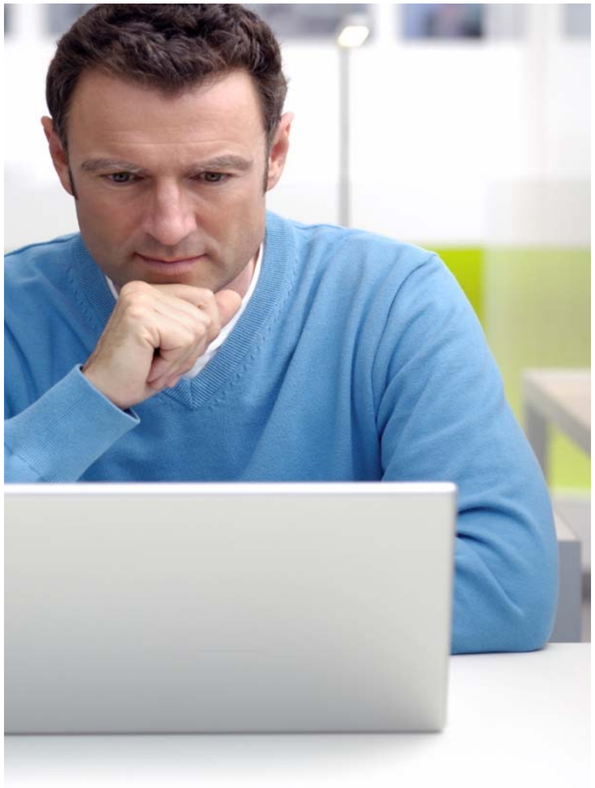
Longitudinal Joint Layout



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



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

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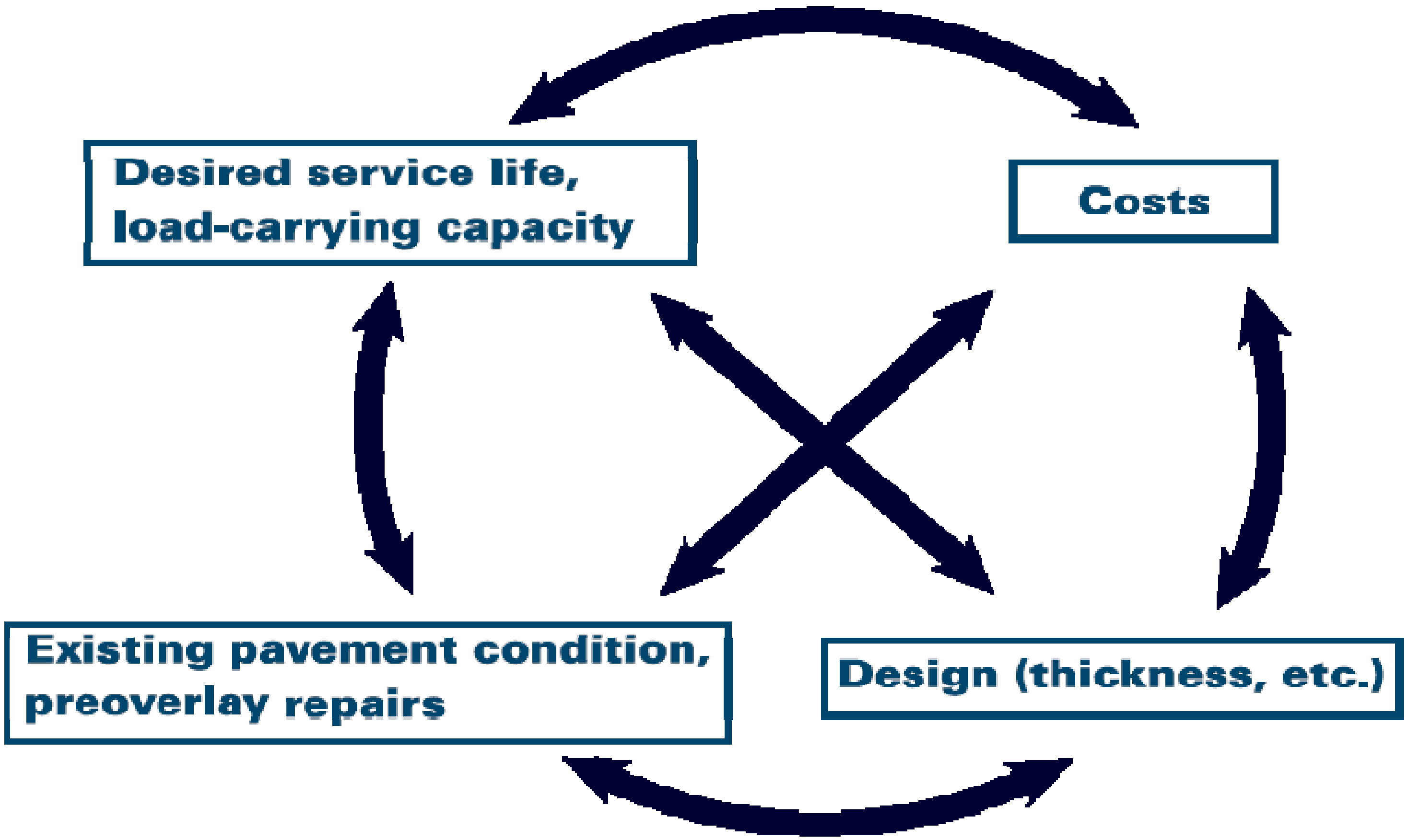
Design Balances Several Factors



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

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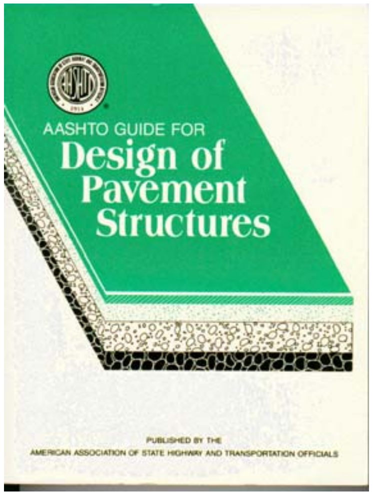
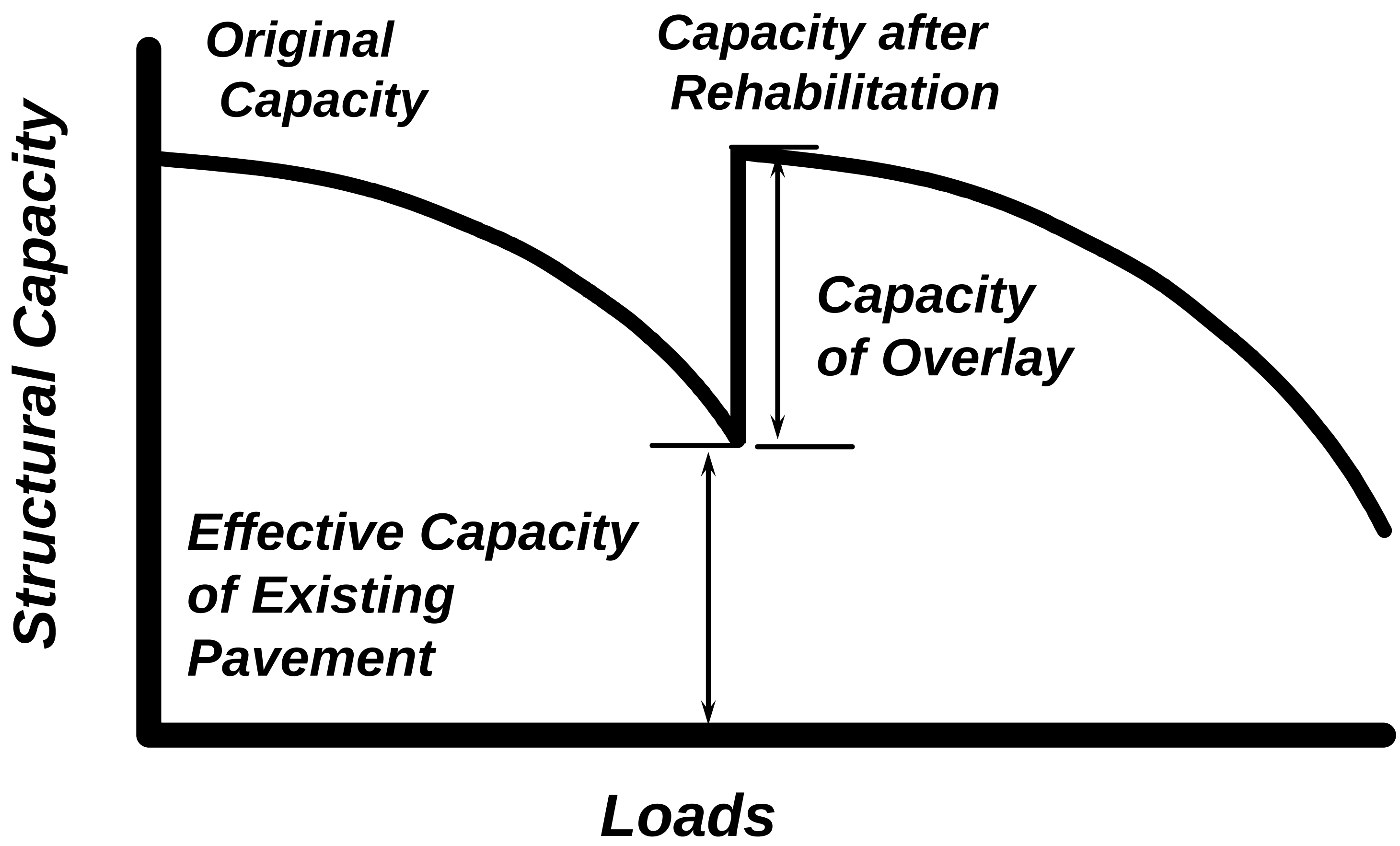
1993 AASHTO Guide



- 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)



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?

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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

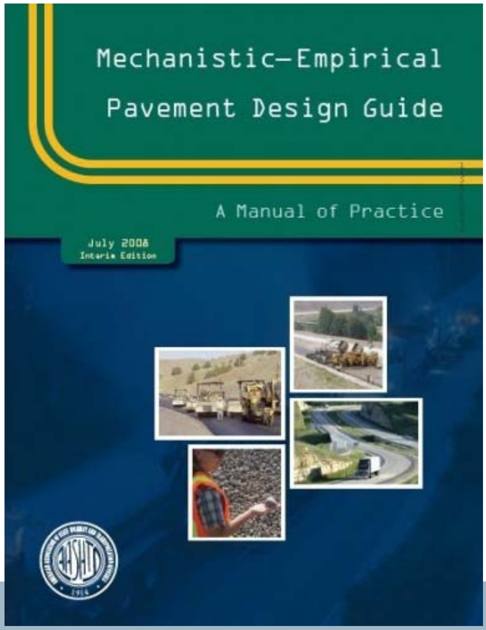
Allows consideration of new designs and design features – INNOVATION!

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.



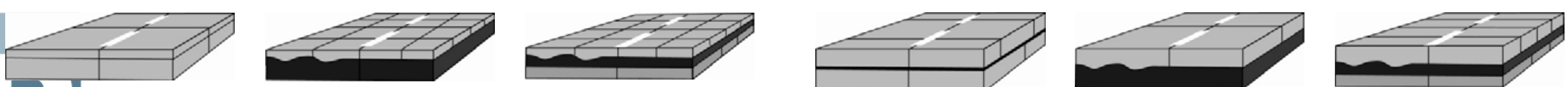
Family of Concrete Overlays

Thinner

Concrete Overlays

Thicker

- **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

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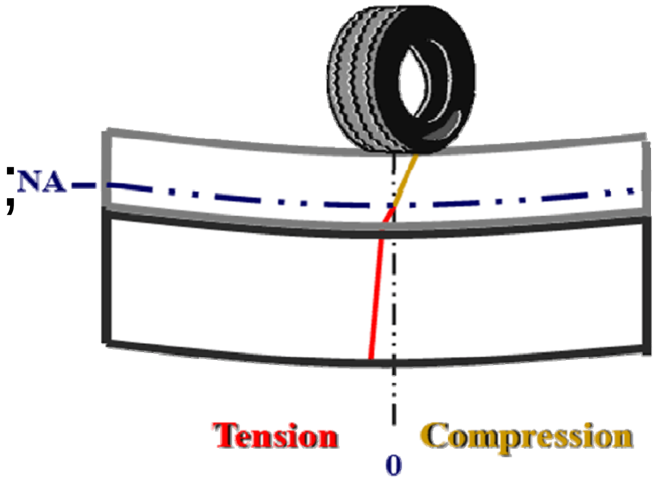
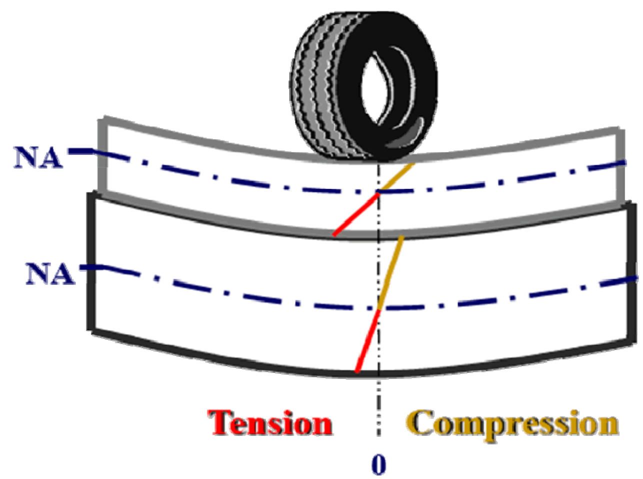
Bonded versus Unbonded (intent)

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

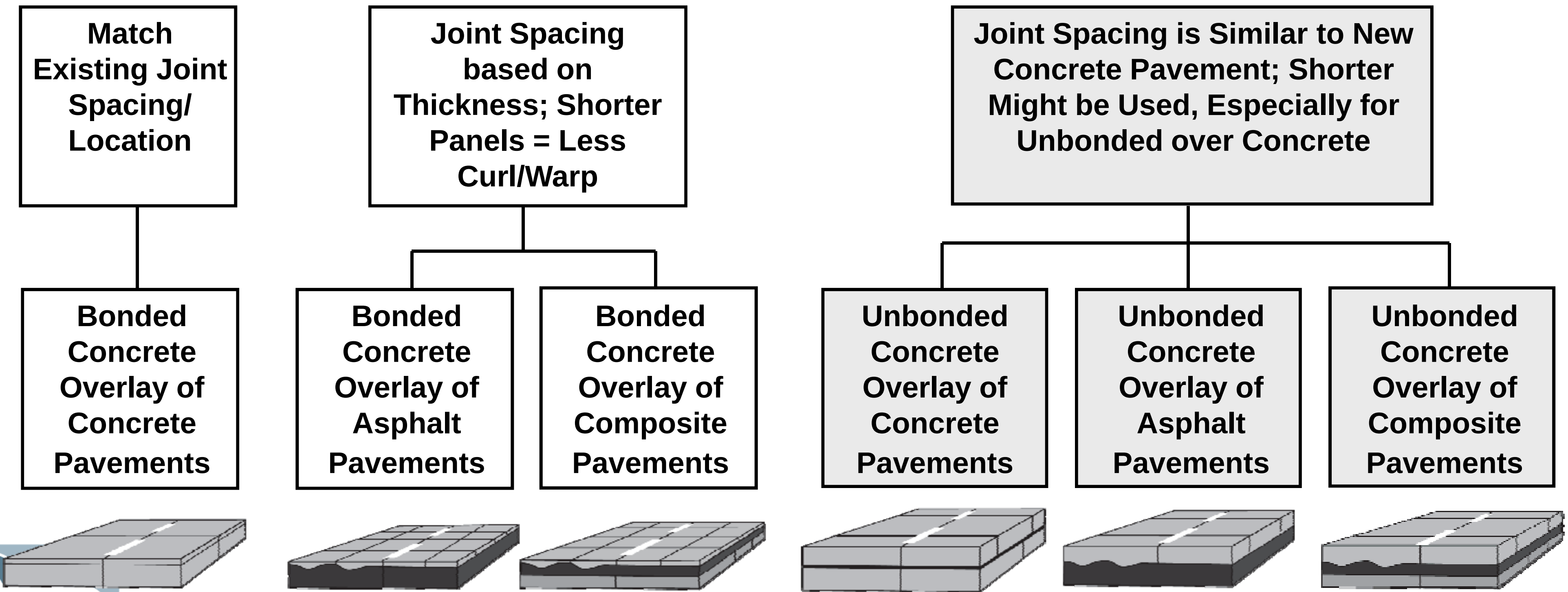


- **Unbonded:** Use to restore structural capacity and increase pavement life equivalent to full-depth pavement. Also results in improved surface friction, noise, and rideability



Jointing Patterns Vary

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



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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)

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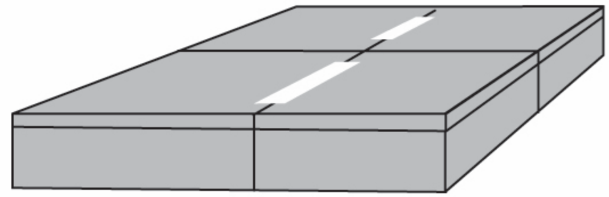
Bonded Concrete Overlays

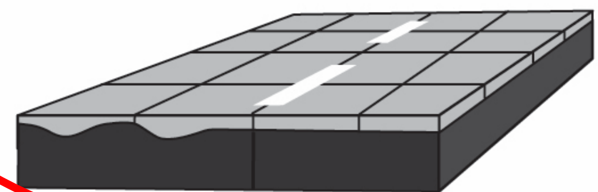
Bonded Concrete Overlays of Concrete Pavements

–previously called bonded overlays–

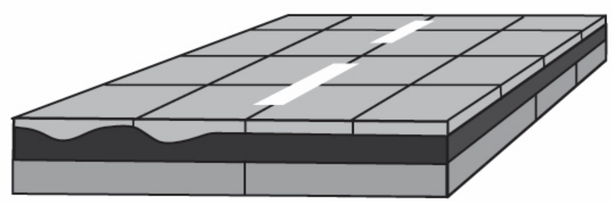


Bonded Concrete Overlays of Asphalt Pavements

–previously called ultra-thin whitetopping–



Bonded Concrete Overlays of Composite Pavements



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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

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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

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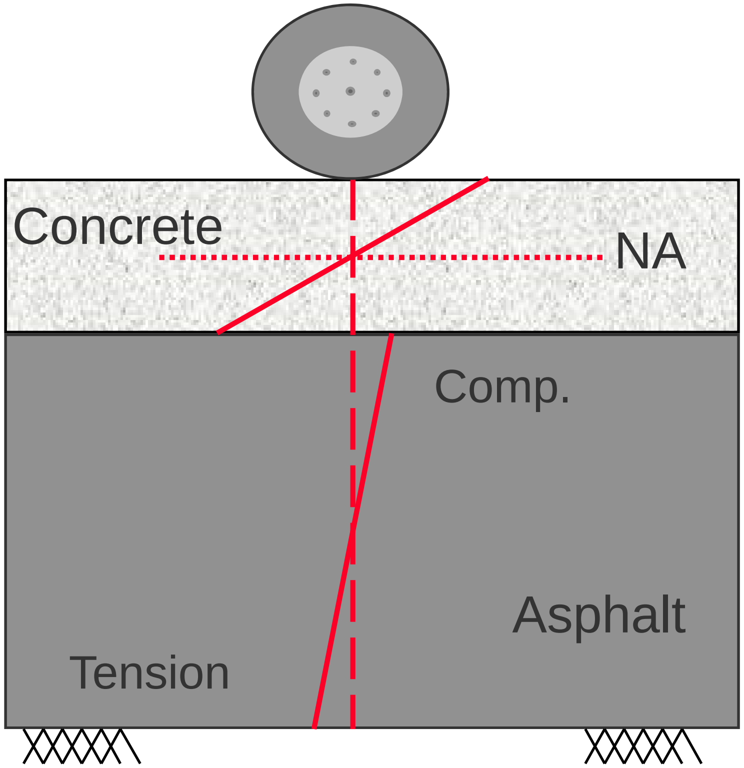
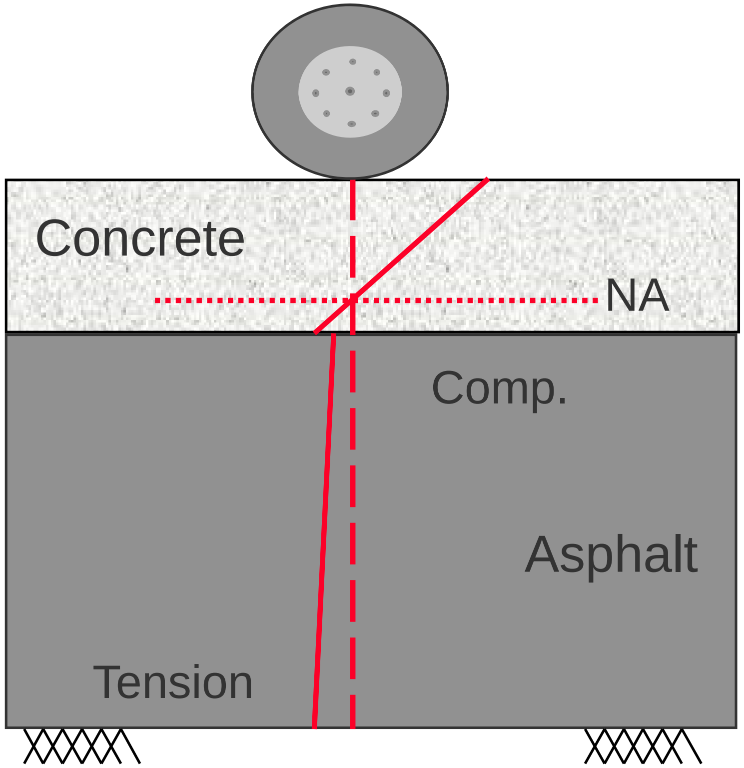
Bonding Effects on Edge Stress

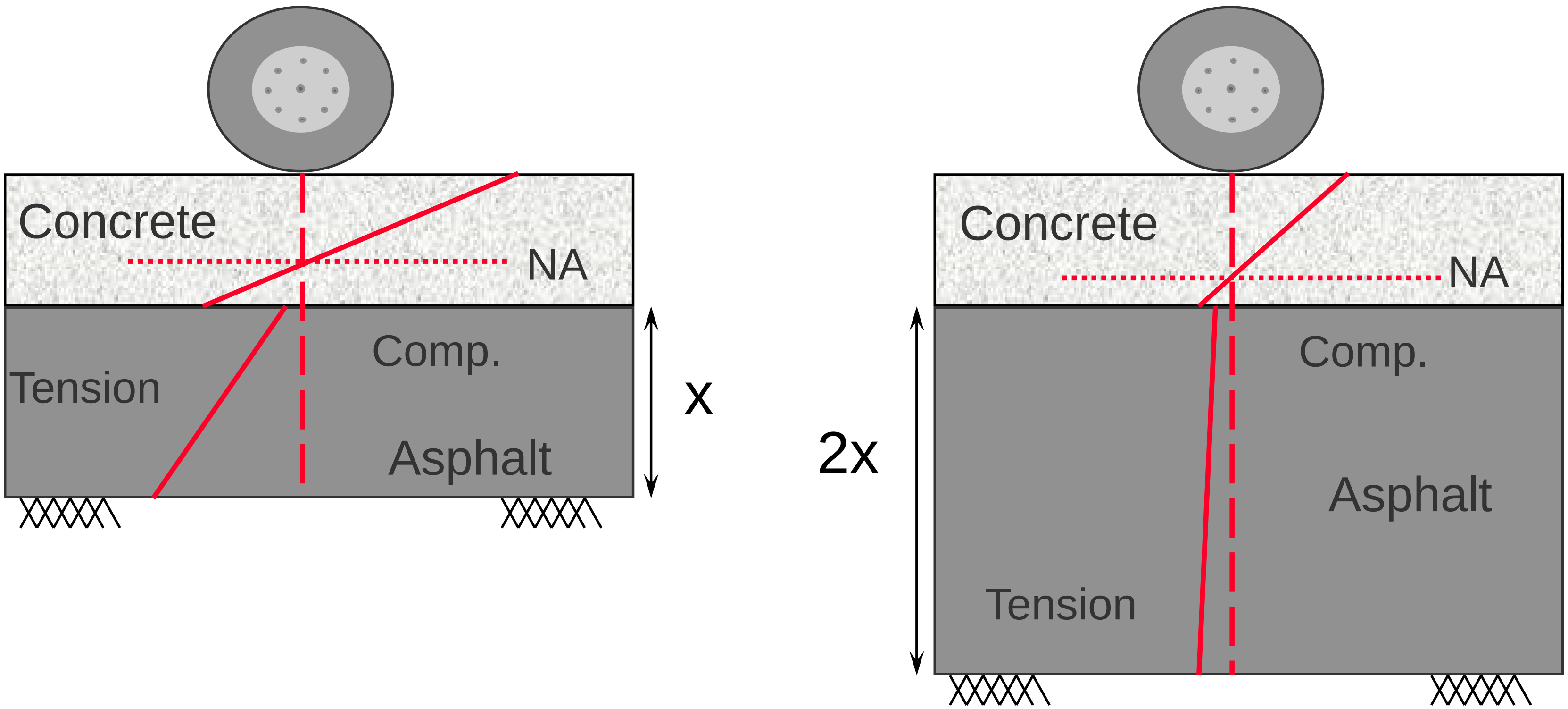


Unbonded



Bonded

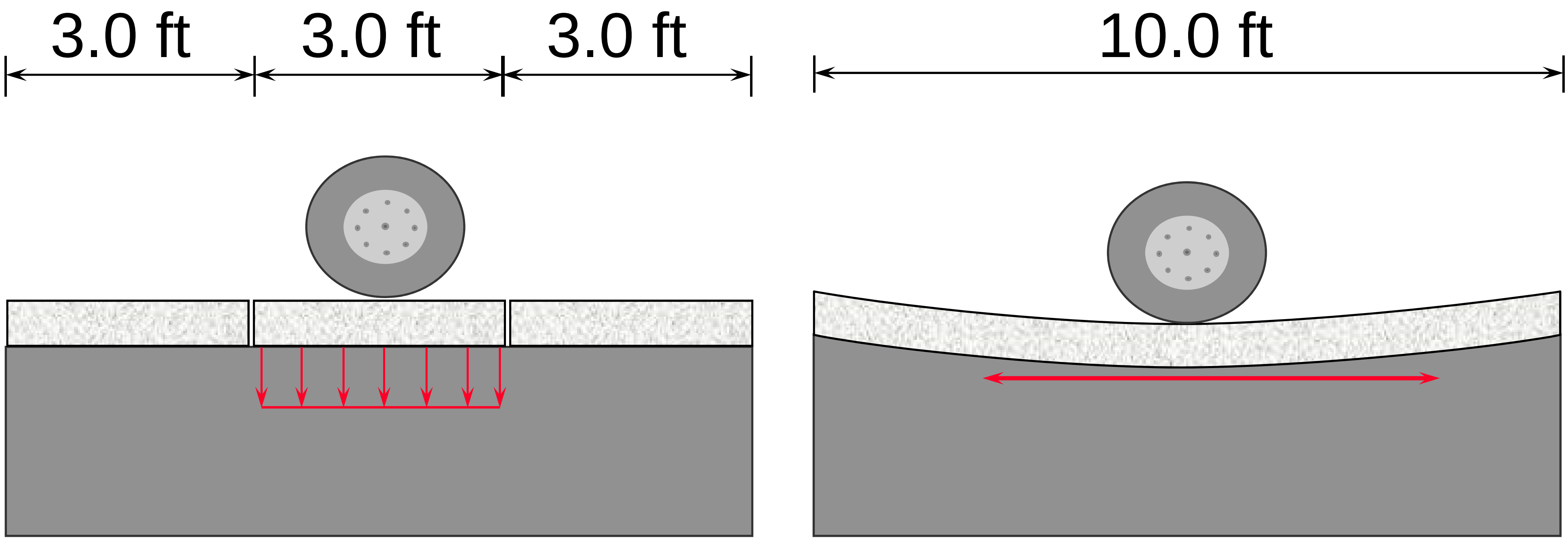
Effects of AC Thickness



Need for Joints

- Designed crack
- Why crack control
  - Shrinkage cracks
  - Thermal cracks
- Minimize impact of cracks

Effects of Joint Spacing – Load Stress



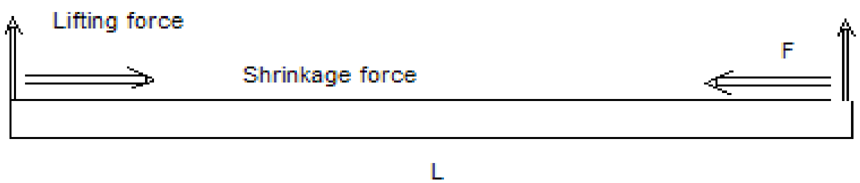
Short Slabs Deflect
Very little flexural stress

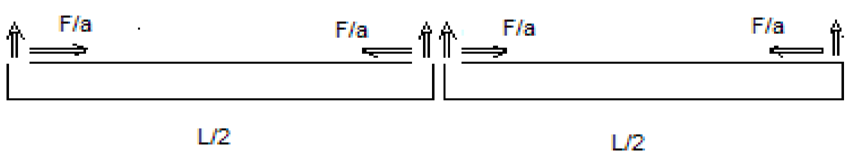
Standard Slabs Bend
Higher flexural stress

Effects of Panel Length: Shrinkage and Curl/Warp Stresses

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**

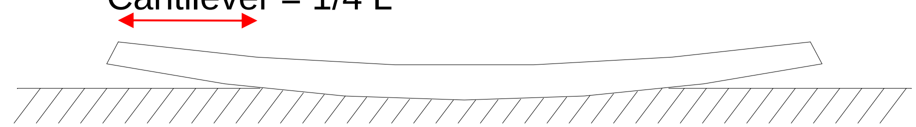




Effect of Slab Length on Curling/Warping

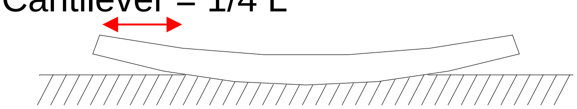
- **All concrete slabs curl / warp so that approximately 1/4 of the slab length is lifted of the subgrade / subbase support**
- **By reducing slab length, the amount lifted, and the height of the lift is greatly reduced**

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

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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
- Adjust depth of saw cut for actual slab thickness
  - Full depth plus ½" for bonded over concrete
  - T/3 for 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

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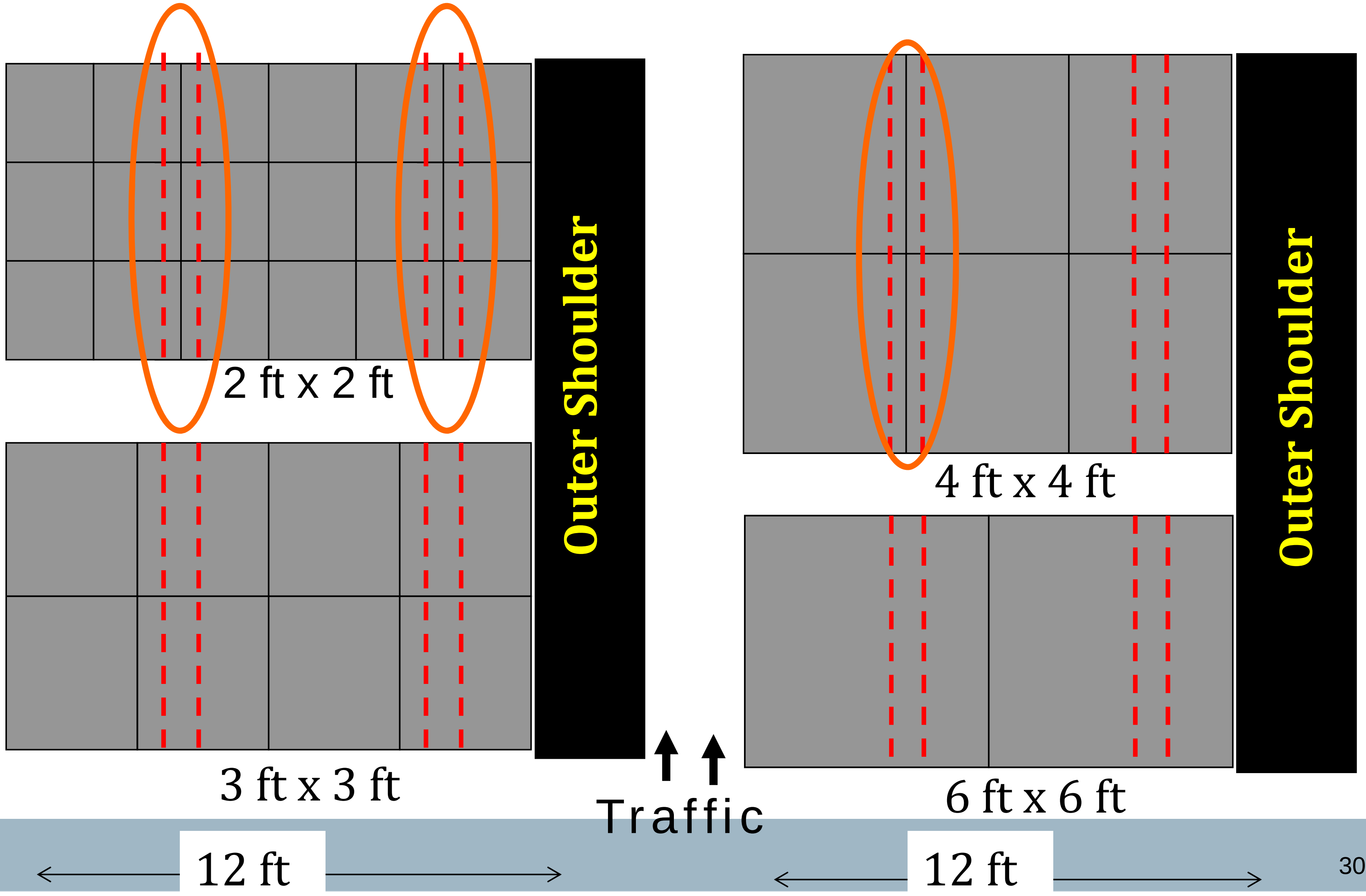
Longitudinal Joint Layout



Source: Burnham (MnDOT)

Source: Burnham (MnDOT)

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

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.

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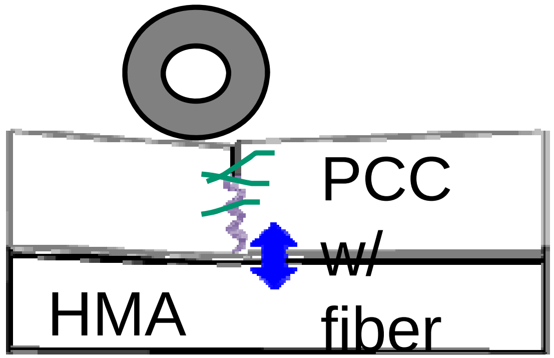
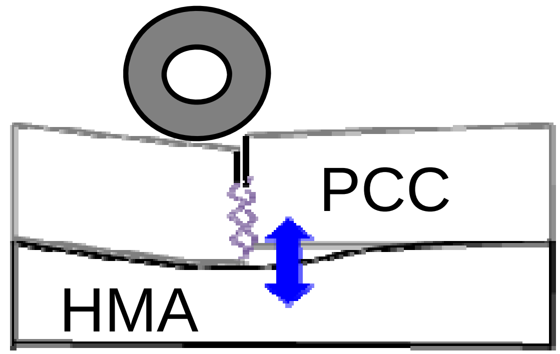
Structural Fibers Considerations

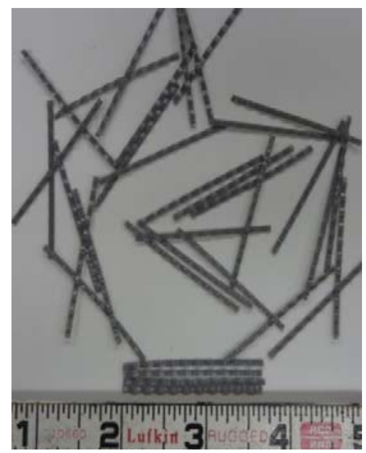
- Does not increase the concrete's strength
- Increases toughness
- Increases post-crack integrity
  - Helps control plastic shrinkage cracking
  - steel fibers not recommended where deicing salts may be used.

Structural Fibers





Residual strength ratio = 24%



Straight synthetic: Strux 90/40

Crimped synthetic: Enduro 600

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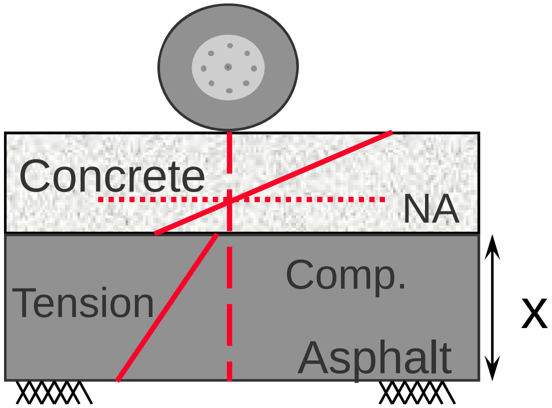
Concrete Overlay Design: Comparing BCOA-ME and SJPCP Module in Pavement-ME

Authors:
Dr. Julie Vandenbossche, University of Pittsburgh
Kevin Alland, University of Pittsburgh
Dr. Mark Snyder, University of Pittsburgh - PRESENTER



Prepared for:
ACPA Colorado/Wyoming Chapter Annual Workshop
Denver, CO
March 16, 2017

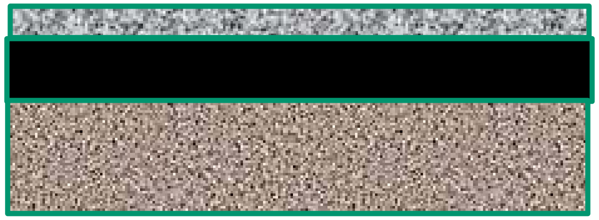
Comparing BCOA-ME and SJPCP Pavement ME
Limitations and Capabilities

Midsize slabs	1. Long. Cracks 2. Diagonal Cracks

Design Procedure	Panel Thickness	Panel size
1. BCOA-ME	3 to 6.5 in	4.5 to 8 ft
2. Pavement ME	4 to 8 in	4.5 to 8 ft

Note: BCOA-ME also handles smaller panels (to 2 x 2, 2” thick)
and larger panels (up to 12 ft). PavementME Design SJPCP dc

Structural Design Consideration of HMA



HMA thickness > 8 in is considered to be 8 in for both BCOA-ME and Pavement ME

(Additional HMA thickness *is* considered in BCOA-ME for prediction of reflective cracking; Pavement ME does not have capability to predict reflective cracking.)

Source: Vandenbossche et al, 2017

Joint Faulting

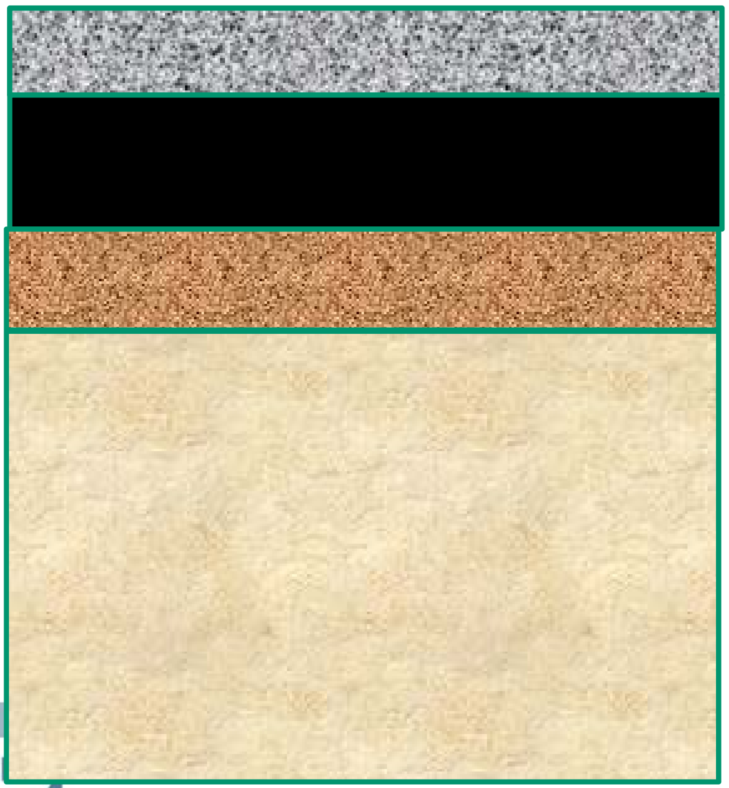
- Neither Pavement ME or BCOA ME currently predict faulting, but …

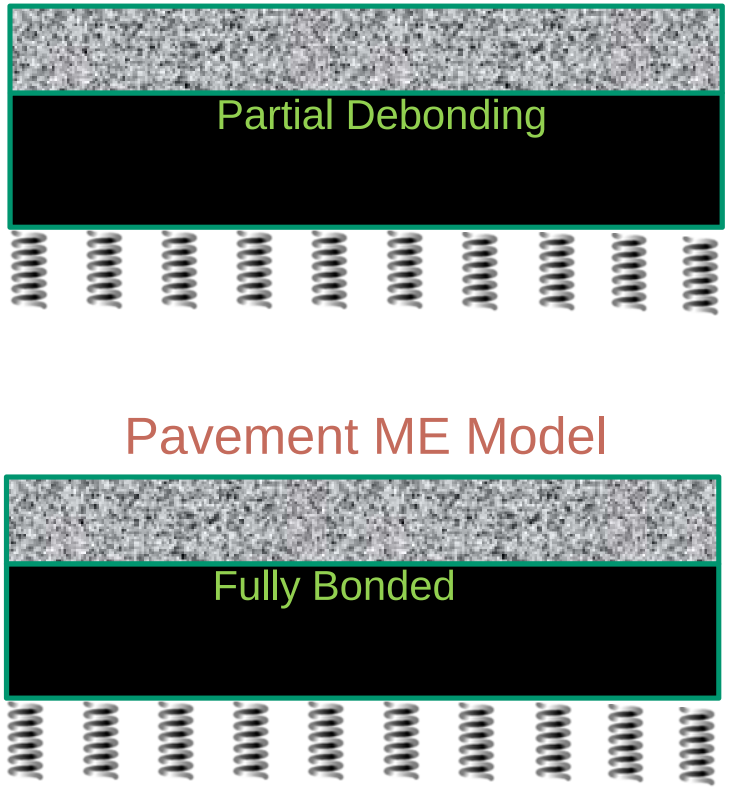
- Faulting model currently being developed for BCOA-ME at U-Pitt

Source: Vandenbossche et al, 2017

Primary Analytical Differences Between BCOA-ME and Pavement ME

Concrete/Asphalt Interaction





Source: Vandenbossche et al, 2017

HMA stiffness-fatigue reduction

HMA condition	Fatigue cracking (%)	Damage factor	E_{HMA} reduction (%)
BCOA-ME			
Adequate	0 – 8%	0.4	10
Marginal	8 – 15%	0.6	20
Pavement-ME			
All	65%	1.1	48

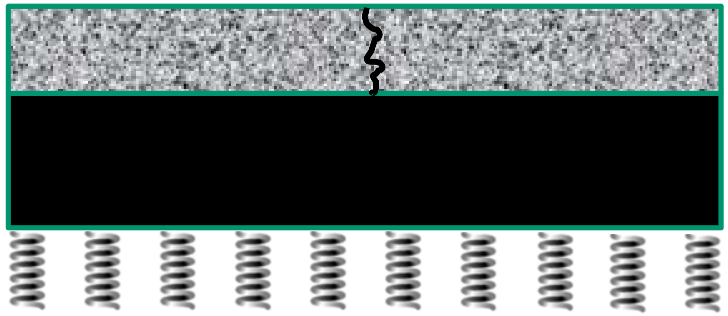
Pavement ME

- Does not account for different levels of distress in HMA
- Unrealistic level of HMA fatigue cracking (65%) required because HMA and overlay are modeled as fully bonded

Source: Vandenbossche et al, 2017

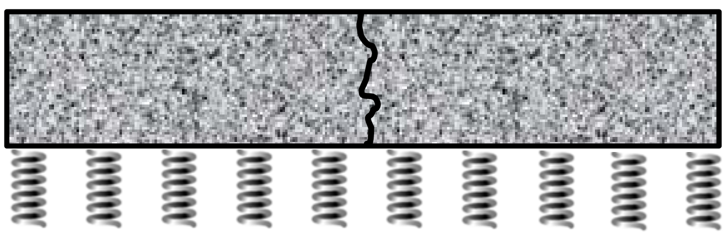
Joint Behavior

BCOA-ME



HMA layer is continuous

Pavement ME



Joint extends through entire equivalent layer

Source: Vandenbossche et al, 2017

HMA stiffness

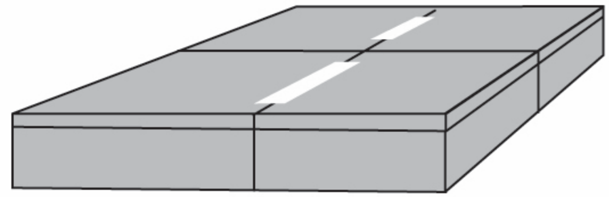
BCOA-ME	Pavement ME
Step 1. Estimate E_{HMA} for new mix	
• Binder selected from LTPP bind • Typical gradation, voids, effective binder	• Select binder grade • Select gradation, voids, effective binder (standard values used for calibration)
Step 2. Adjust E_{HMA}	
• Aging • Damage factor based on observed distress	• Aging • Constant damage factor • Includes the effect of debonding

Source: Vandenbossche et al, 2017

Bonded Concrete Overlays

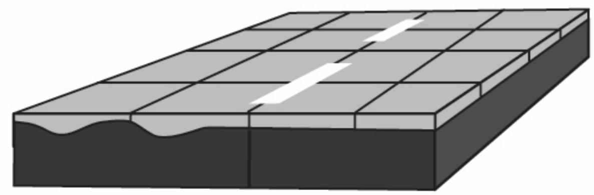
Bonded Concrete Overlays of Concrete Pavements

–previously called bonded overlays–

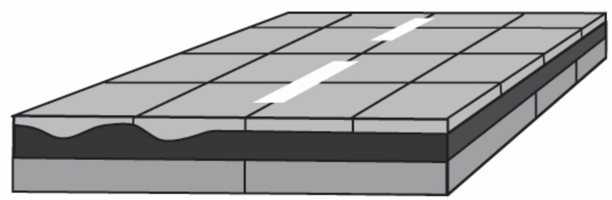


Bonded Concrete Overlays of Asphalt Pavements

–previously called ultra-thin whitetopping–



Bonded Concrete Overlays of Composite Pavements



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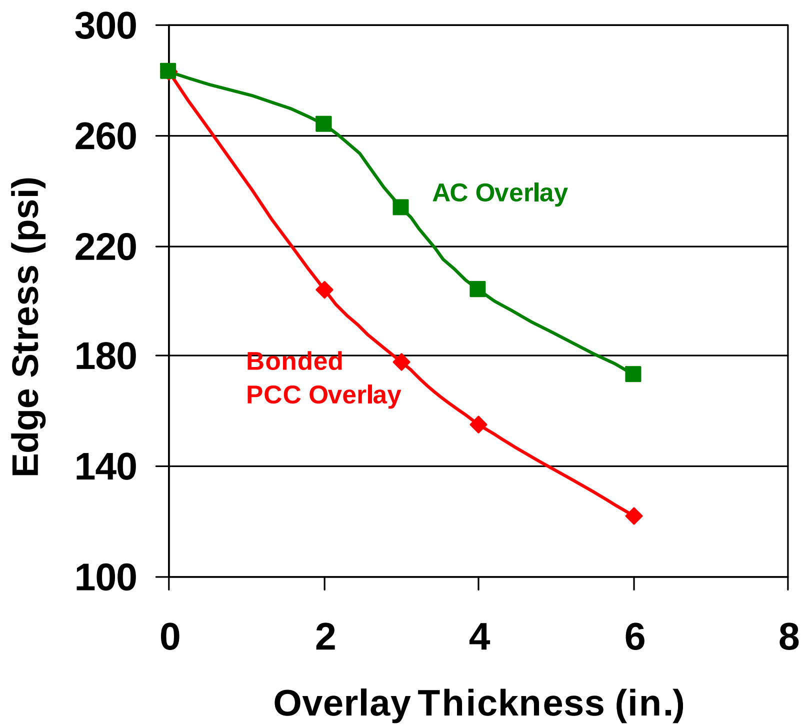
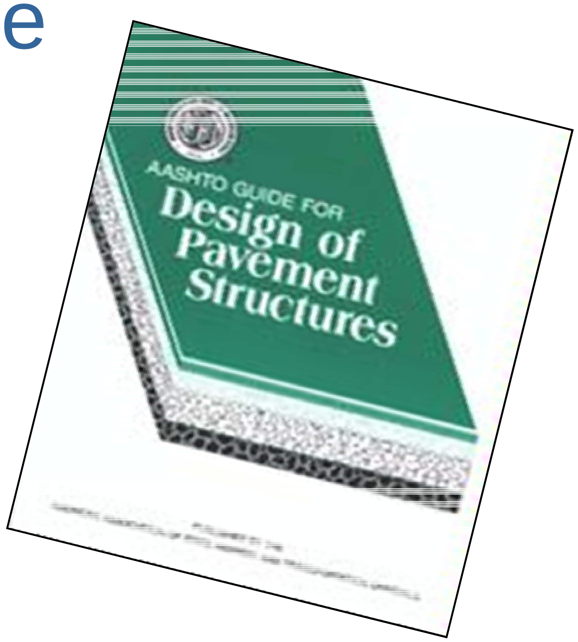
Bonded Concrete over Concrete – Advantages

- Increase structural capacity.
  - More efficient than AC.
    - 1 in. of PCC ~ 2 in. of AC
  - Critical edge stresses are about 35% lower than an equivalent asphalt overlay.
- Long service life
  - High PSI.
- Lower user & engineering costs.
- Rut free



Bonded Concrete on Concrete
1993 AASHTO



- Slab Thickness Design

  Bonded overlay design equation:

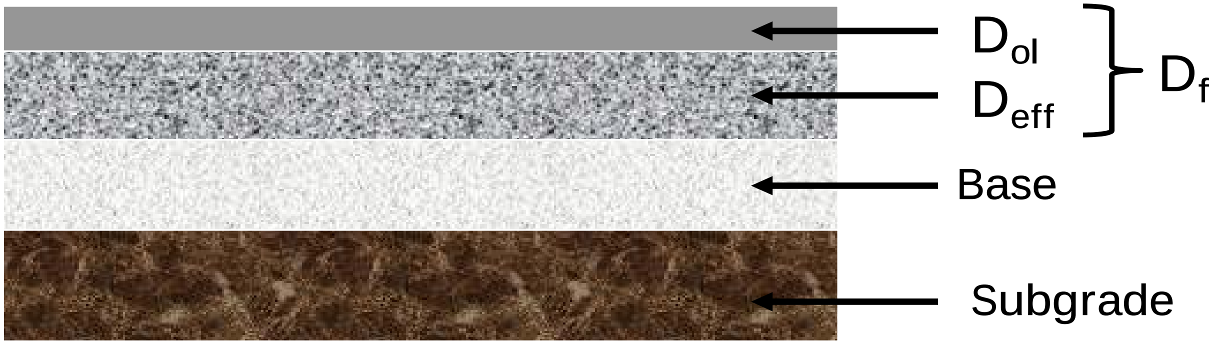
$$D_{ol} = D_f - D_{eff}$$

where:

D_{ol} = *Required concrete overlay thickness*

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

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



Note: Effects of panel size on bonding are not considered!

Bonded Concrete on Concrete
1993 AASHTO

Determination Of Effective Slab Thickness (D_{eff})

$$D_{eff} = F_{jc} * F_{dur} * F_{fat} * D$$

Where:

F_{jc} = Joints and Cracks Adjustment Factor
F_{dur} =Durability Adjustment Factor
F_{fat} = Fatigue Adjustment Factor
D = Effective Thickness of Existing Slab, in.

Design-relevant Assumptions for Bonded Concrete Methodologies

Design Method	Design Assumptions, Deficiencies / Strengths and/or Items to Note
1993 AASHTO Guide	• Assumes complete bond for entire life of the overlay. • Effective structural capacity of the existing pavement is based on the condition survey or the remaining life methods. These two methods have different limitations and may yield inconsistent or unreasonable results. • Pavement designers are familiar with this design process and variables for almost 20 years.
M-E PDG	• Integrates slab geometry, climatic factors, concrete material and layer properties into thickness design compared to the 1993 AASHTO Guide. • Assumes complete bond for entire life of the overlay. • This method is still under evaluation, calibration, and implementation by State Highway Agencies.

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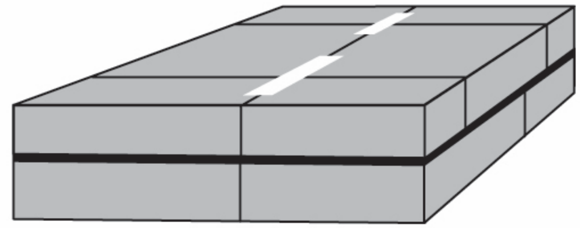
Unbonded Concrete Overlays

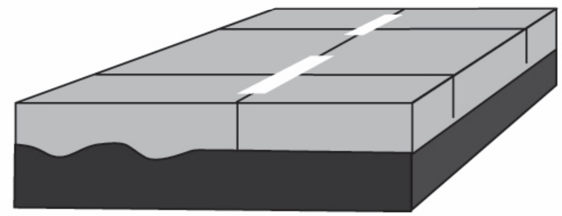
Unbonded Concrete Overlays of Concrete Pavements

–previously called unbonded overlays–

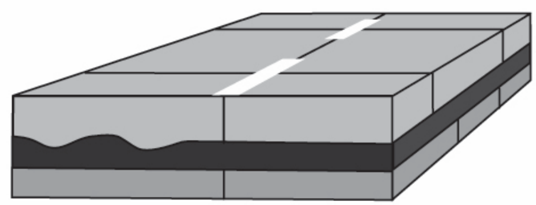


Unbonded Concrete Overlays of Asphalt Pavements

–previously called conventional whitetopping–



Unbonded Concrete Overlays of Composite Pavements



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Unbonded on Concrete / Composite
1993 AASHTO

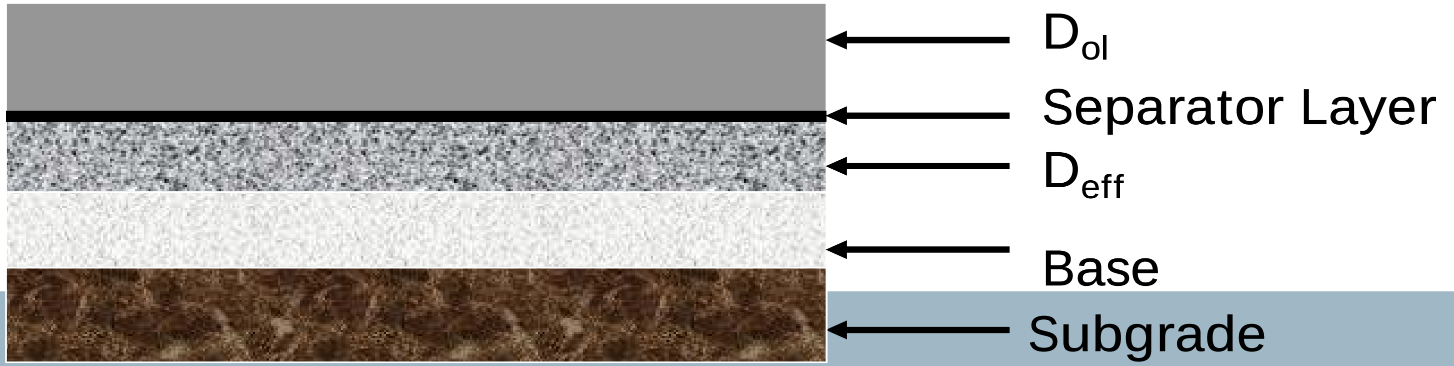
- Slab Thickness Design

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})

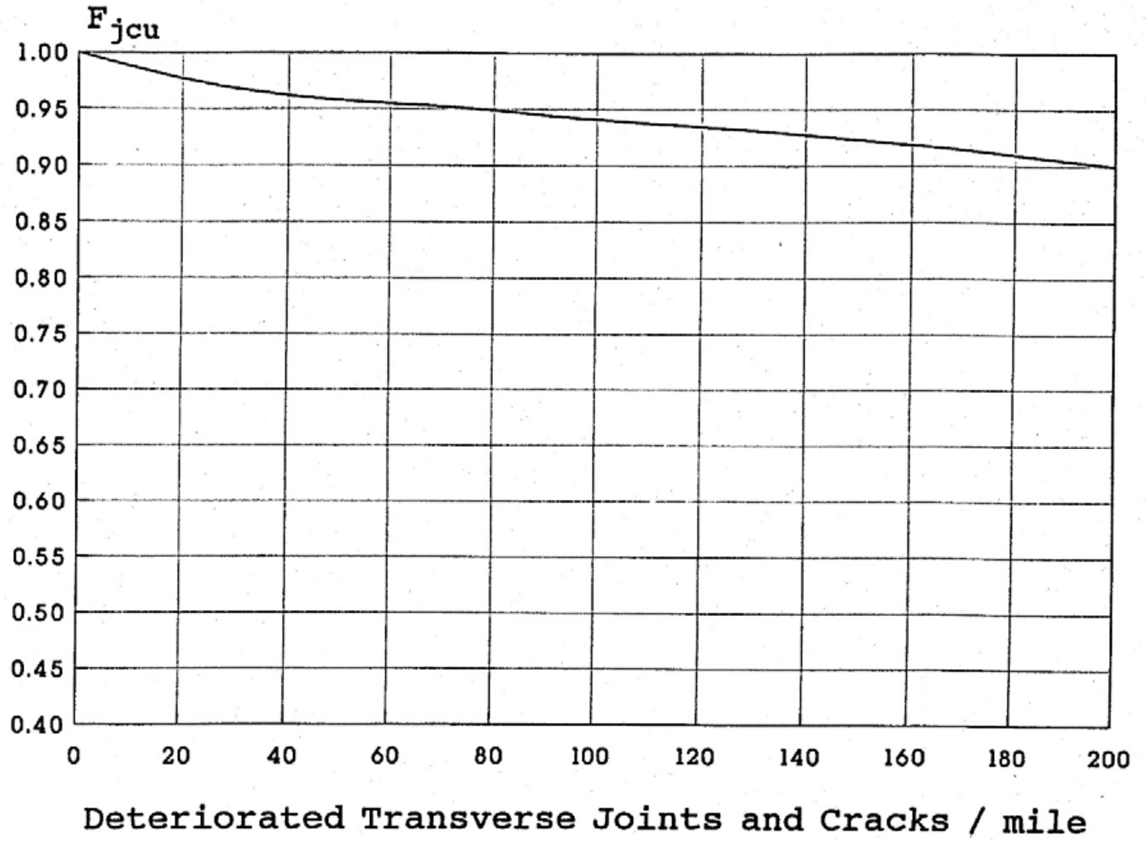


Figure 5.13. F_{jcu} Adjustment Factor for Unbonded JPCP, JRCP, and CRCP Overlays

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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

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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.

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Typical Fabric Specs

Property	**Requirement (95% PWL)**
Fabric Type	• **Non-woven** Geotextile • Uniform color
Mass per unit area	≥ 13.3 oz/sq.yd ≤ **16.2** oz/sq.yd
Thickness under pressure	0.29 psi: ≥ **0.12 in.** 2.9 psi: ≥ **0.10 in.** 29 psi: ≥ **0.04 in.**
Tensile strength	≥ 685 lb/ft
Maximum elongation	≤ 130% (≤ 60% recommended as best practice)
Water permeability in normal direction under pressure	≥ 3.3×10^{-4} ft/s) [under pressure of 2.9 psi]
Alkali resistance	≥ 96% Polypropylene/Polyethylene

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.

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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.**

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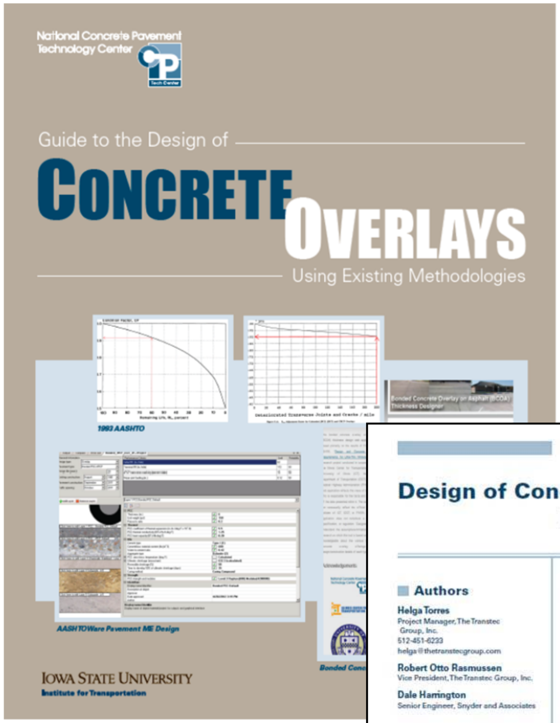
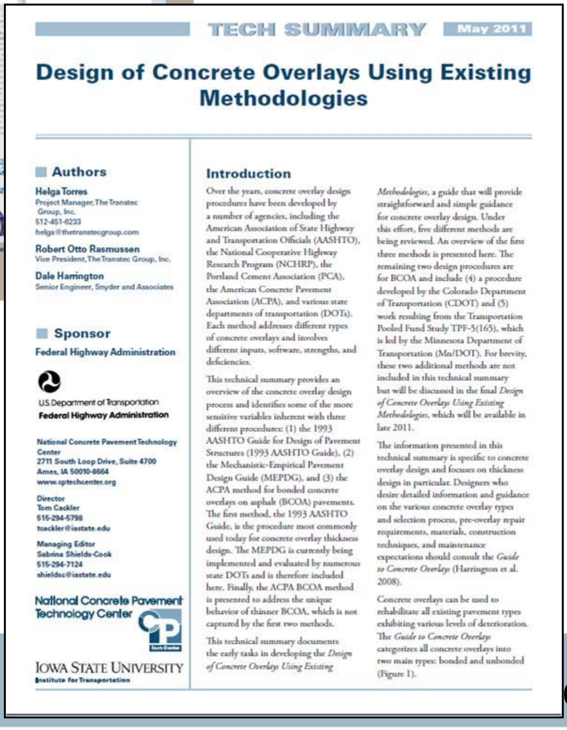
Guide for the Design of Concrete Overlays using Existing Methodologies

- 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!





TECH SUMMARY May 2011

Design of Concrete Overlays Using Existing Methodologies

Authors

Helga Torres
Project Manager, The Transtec Group, Inc.
512-451-6233
helga@thetranstecgroup.com

Robert Otto Rasmussen
Vice President, The Transtec Group, Inc.

Dale Harrington
Senior Engineer, Snyder and Associates

Sponsor

Federal Highway Administration

U.S. Department of Transportation
Federal Highway Administration

National Concrete Pavement Technology Center
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
www.cptechcenter.org

Director
Tom Cackler
515-294-5798
tcackler@iastate.edu

Managing Editor
Sabrina Shields-Cook
515-294-7124
shieldsc@iastate.edu

National Concrete Pavement Technology Center

IOWA STATE UNIVERSITY
Institute for Transportation

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).

Available online:

http://www.cptechcenter.org/

Which Overlay Design Method(s)?

Concrete Overlay Type	Design Methods
Unbonded on Asphalt, Composite, or Concrete	AASHTO ME, ACPA StreetPave 12, AASHTO 93, OptiPave 2.0
Bonded on Asphalt or Composite	ACPA BCOA, ACPA StreetPave 12, BCOA ME, CO 6x6x6
Bonded on Concrete	AASHTO ME, ACPA StreetPave 12, AASHTO 93

apps.acpa.org

Lots of Guidance Available…

Thank You For Your Attention!

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