

TRANSPORTATION RESEARCH BOARD

Introducing an Improved Design Procedure for Unbonded Concrete Overlays

October 5, 2020

2:00-3:30 PM Eastern

@NASEMTRB
#TRBwebinar

PDH Certification Information:

- 1.5 Professional Development Hours (PDH) – see follow-up email for instructions
- You must attend the entire webinar to be eligible to receive PDH credits
- Questions? Contact Reggie Gillum at RGillum@nas.edu

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Providers Program. Credit earned on completion of this program will be reported to RCEP. A certificate of completion will be issued to participants that have registered and attended the entire session. As such, it does not include content that may be deemed or construed to be an approval or endorsement by RCEP.



REGISTERED CONTINUING EDUCATION PROGRAM

#TRBwebinar

Learning Objectives

1. Describe the history, basic components, construction, and maintenance methods unique to unbonded concrete overlays of existing concrete or composite pavements.
2. Describe the important role of the interlayer system used within unbonded concrete overlays.
3. Introduce an improved procedure for the design of unbonded concrete overlays of existing concrete or composite pavements.

INTRODUCTION TO UNBONDED CONCRETE OVERLAYS



Gordon L. Smith, PE
National Concrete Pavement Technology Center

What's This All About And Why Bother?

- Our roads are getting old. We can:
 - Toss them out and start again
 - A long term solution
 - Creates a disposal headache
 - Takes energy to move them out of the way
 - Takes time = traffic delays



Why Bother?

- Our roads are getting old. We can:
 - Patch them – buy a few years
 - Limited materials usage, energy and traffic impact
 - Shorter term solution
 - Highly dependent on timing and design



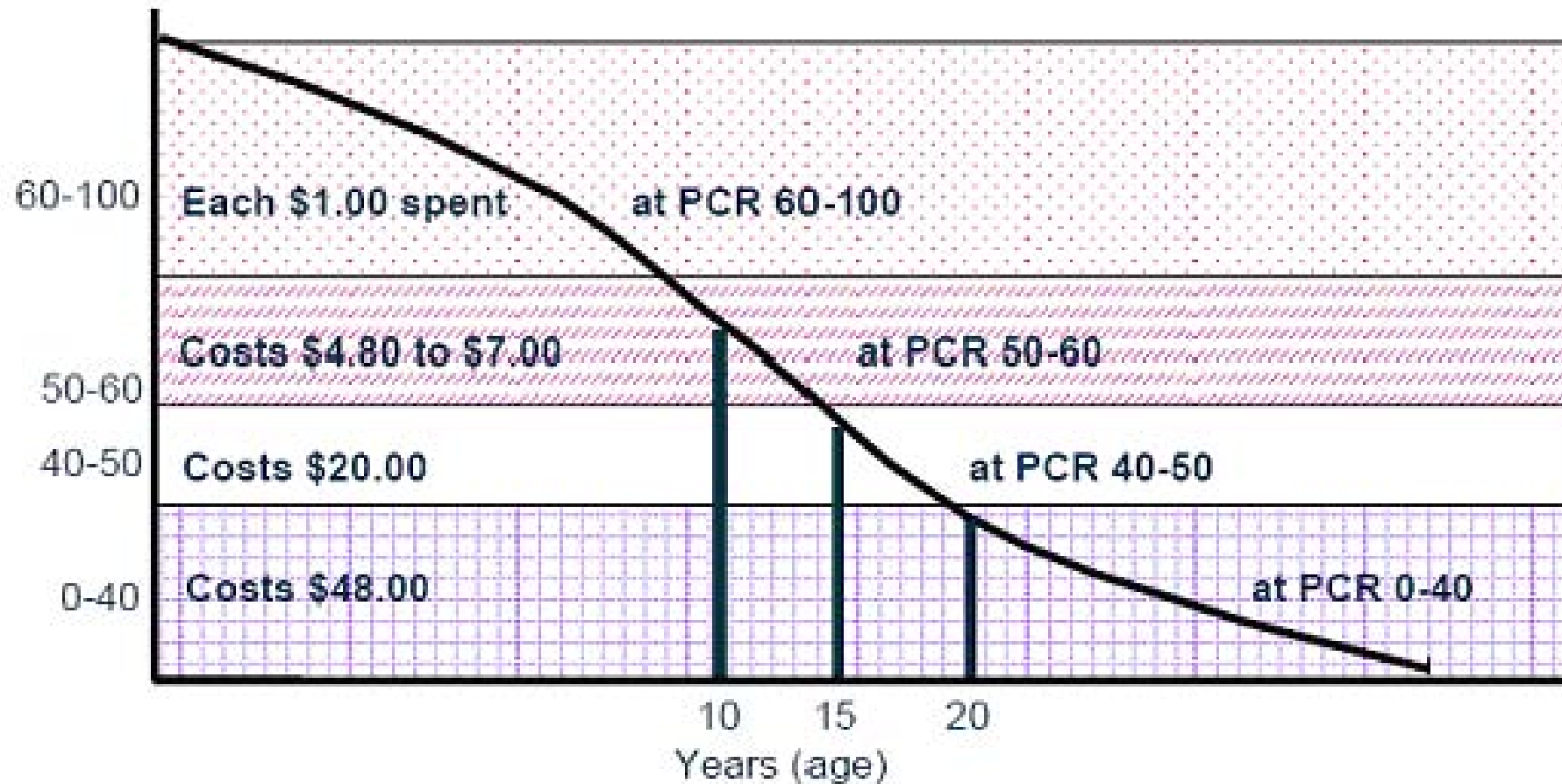
Why Bother?

- Our roads are getting old. We can:
 - Overlay them
 - Use existing equity
 - Minimize sustainability impacts
 - Longer term solution
 - Elevations / connections are tricky



The Challenge: Fix now or pay more later

Pavement Condition Rating (PCR)



Concrete Overlay Experience Around the Country

- State and local agencies in 46 States have now built concrete overlays





Unbonded Concrete Overlays

Existing concrete pavement

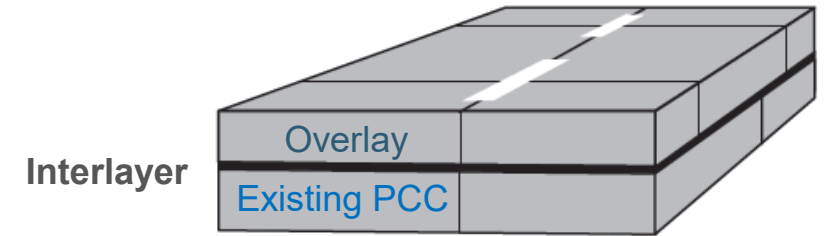
- Moderately to significantly deteriorated pavements
- Few, if any, pre-overlay repairs required
- Stable and uniform support layer

Interlayer

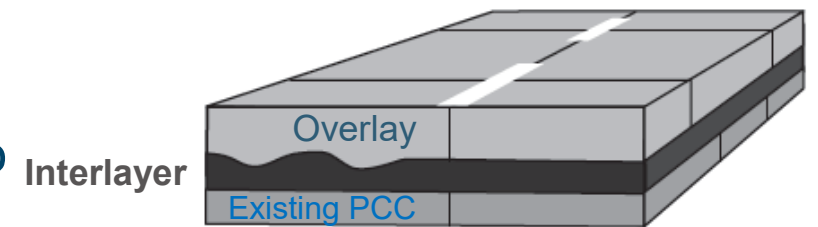
- HMA or nonwoven geotextile fabric

Overlay

- Thicker than bonded concrete overlays – typ. 6 to 8 in
- Durable surface
- Increased structural capacity



Existing concrete pavement



Composite pavement

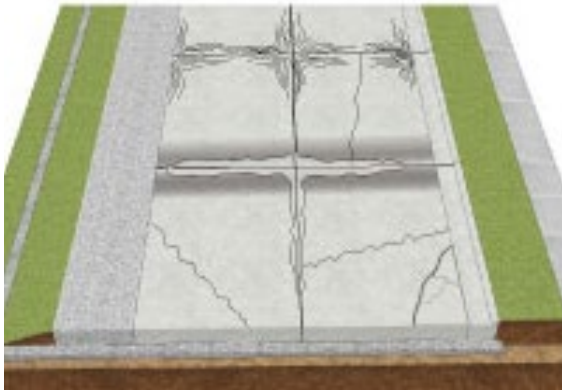
Expected Service Life

- 4 to 6 in. thick – 15 to 25 years
- > 6 in. thick – >20 years

- Assuming:
 - Sound structural design
 - Good construction practices



Overlay Selection for Existing Concrete Pavements in Fair/Poor Condition



Pavement exhibits significant surface deterioration and structural distresses

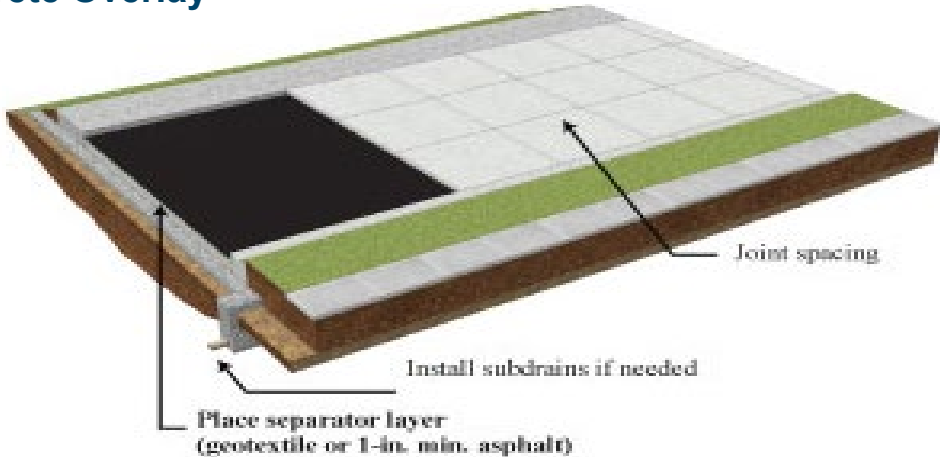
Pre-overlay Questions
Can repairs, retrofit subdrains, separation layer, etc. cost effectively provide an adequate subbase for an overlay?

NO → Non-Overlay solution

Yes ↓



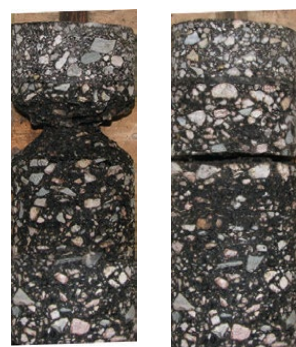
Unbonded Concrete Overlay



Overlay Selection for Existing Asphalt or Composite Pavements in Fair to Deteriorated Condition

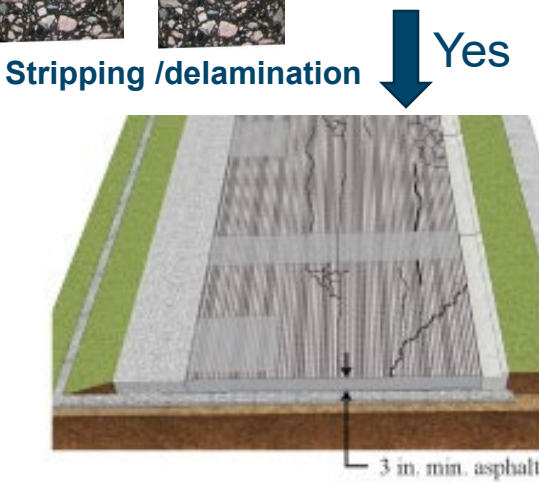


Pavement has measurable distresses such as alligator cracking, rutting, delamination, shoving, slippage, stripping, raveling thermal expansion, cracking and structural distresses.

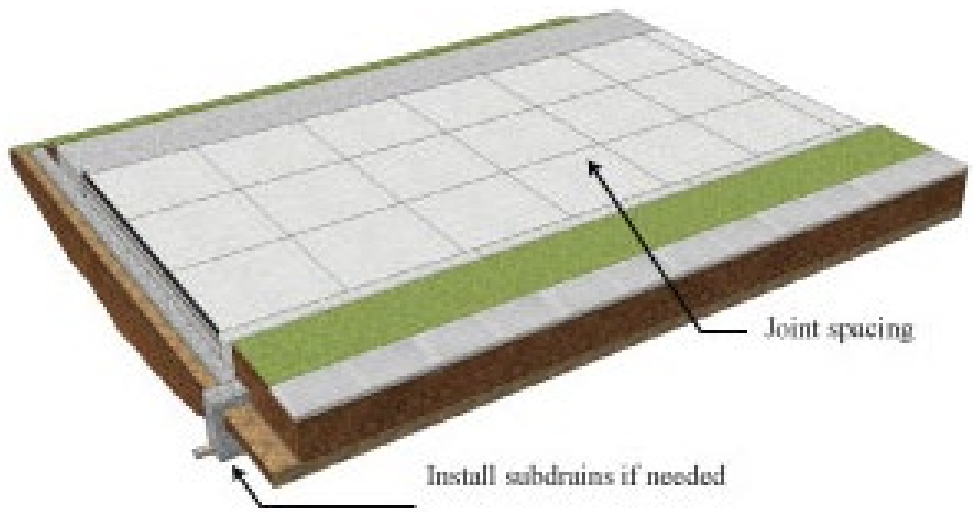


Pre-Overlay Question
Can milling and/or structural repairs cost effectively solve deficiencies, bring the existing pavement to a condition that will provide uniform support as a subbase, meet other constraints (i.e., vertical clearance, shoulders, safety rails, foreslopes, etc.), that allow for an unbonded overlay?

NO → Non-Overlay solution



Unbonded Concrete Overlay



Unbonded Concrete Overlay Thickness Design

- Today's good news! The advancement of the art and science of unbonded concrete overlay thickness design procedures.



“Moving Advancements into Practice”

MAP Brief Summer 2020

Best practices and promising technologies that can be used now to enhance concrete paving

Development of an Improved Design Procedure for Jointed Unbonded Concrete Overlays on Concrete or Composite Pavements

Summer 2020

PROJECT TITLE
Development of an Improved Design Procedure for Jointed Unbonded Concrete Overlays on Concrete or Composite Pavements

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Introduction

An unbonded concrete overlay (UBOL) is a type of rehabilitation method in which the new overlay is isolated from an existing concrete or composite pavement using a separator layer (Smith, Yu, and Peshkin 2002). The separator layer, commonly referred to as an interlayer, historically has consisted of a thin (1 in. to 2 in. thick) hot-mix asphalt (HMA) material.

Recently, non-woven geotextile fabrics have also become a popular interlayer option for UBOLs on concrete. By providing a shear plane for differential movement, the separator layer prevents the formation of reflective cracking and serves as a de-bonding layer between the two concrete layers (Torres, Rasmussen, and Harrington 2012).

The interlayer also provides a level surface for the overlay and isolates the overlay from the underlying distresses and irregularities (Smith, Yu, and Peshkin 2002). As a result, the interlayer and existing pavement serve as a stable foundation for a concrete overlay. For a composite pavement, the existing asphalt is sometimes milled to 3 in. or less so that it can serve as the interlayer.

Figure 1 illustrates a typical cross-section of a jointed UBOL placed on an existing concrete pavement.

Background

UBOLs have been used since 1916 as a successful method of rehabilitation. Still, there is a need for a design procedure that can account for the performance of the interlayer and for guidance on the design and construction features that can make UBOLs a more cost-effective solution. Even though there are many U.S. highway agencies that have routinely used this type of overlay, there are other agencies that do not even consider rehabilitation with UBOLs, citing the lack of familiarity and clear guidance.

In addition, recent design analysis and rehabilitation of concrete pavement innovations in UBOL technology have led to the introduction of new types of interlayers, such as non-woven geotextiles, as well as the design of UBOLs with panel sizes as small as 6 ft by 6 ft. The effect of these newer design features on the performance of UBOLs could not previously be accounted for when establishing the thickness of UBOLs.

The purpose of this MAP Brief is to summarize the advancements in UBOL design procedures coming from the recently completed transportation pooled fund TPF-5(269) study, which was led by the Minnesota Department of Transportation, with support from seven other states including Georgia, Iowa, Kansas, Michigan, Missouri, North Carolina, and Oklahoma.

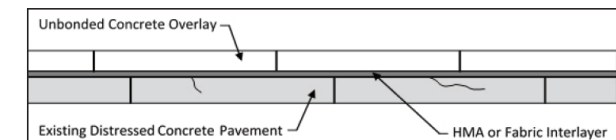


Figure 1. Typical UBOL on existing concrete pavement

How, in simple terms?

- Evaluate the pavement in place
- Consider minimal pre-overlay repair
- Prepare interface/interlayer
- Pave
- Cut joints



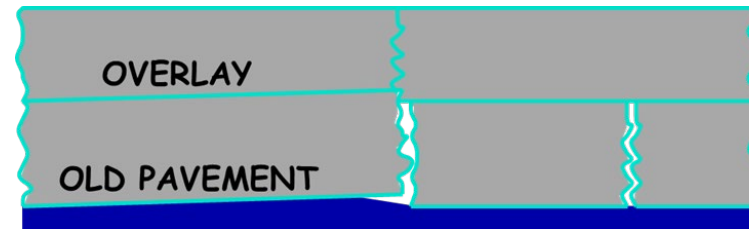
Interface

- Unbonded
 - Must not bond to concrete
 - Some bonding to asphalt is OK



Options for a Separation Layer

- HMA - A stress relief layer
- Can help prevent keying of the overlay in faulted concrete pavements
- Stripping of the asphalt binder can occur due to poor drainage and heavy truck traffic.



- Nonwoven geotextile fabric - Easy to place at less than half the cost of asphalt.
- Improved drainage, but must have outlet
- Faulting should be minimal to prevent keying of the overlay



The Concrete Mixture

- Conventional requirements:
 - w/cm
 - Air
 - SCM dose
- Consider PEM (Performance Engineered Mixture protocol - AASHTO PP84)



Placing Concrete



Texturing/Curing

- Not Optional



Joints

- Panel sizes depend on type and thickness of overlay
(4 to 15 feet square)
- Unbonded: thinner overlay = smaller panels
- Depth: $T/3$

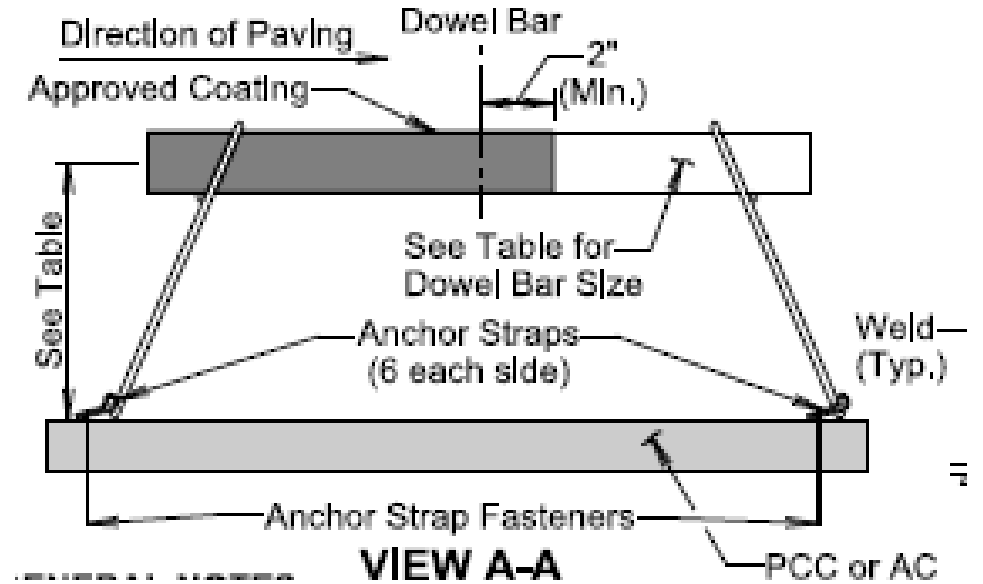


Special Sawing Facts for Concrete Overlays

- Quantity of saw cuts is increased
- Longitudinal cuts are as critical as transverse
- Increased base friction
- Base movement issues
- Base temperature control
- Mix Temperature control – set times



Dowel Basket Anchorage



Overlays Under Traffic

- Safety
- Traffic Flow
- Work Zone Space



Single Lane Paving With Through Traffic



Stringless Paving

- GPS and Total station
- Increases clearances
- Improved smoothness



Two Lane Paving With Detour



- Wide, stable shoulders – could have been completed under traffic
- However, traffic was low, so road was closed to traffic

Future of Concrete Overlays

- Thinking farther ahead...

- Fibers
- Internal curing
- Optimum joint Spacing



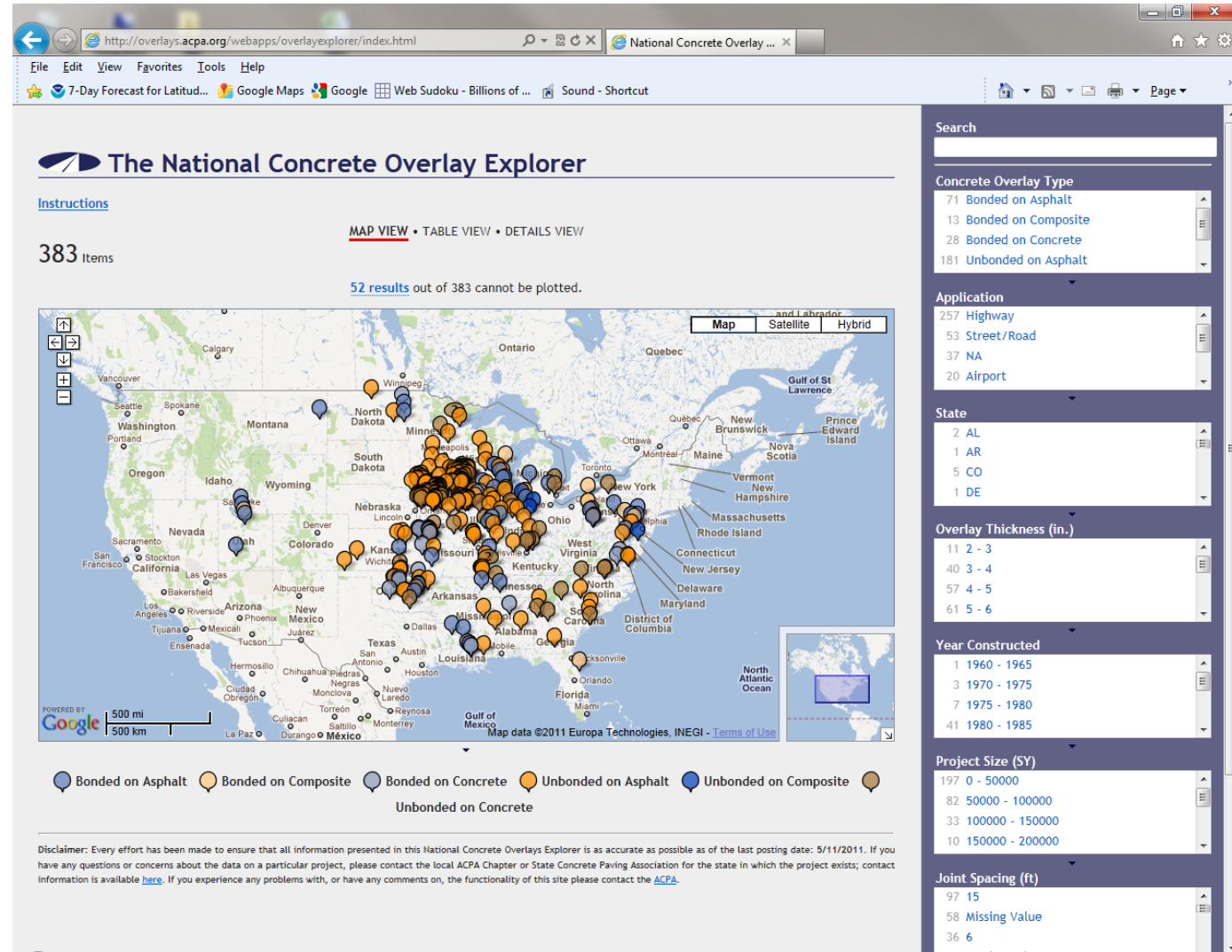
Check out where the overlays are and how they are performing.

- ACPA.org

- Resources

- Project Explorers

- Concrete Overlays



And about overlay maintenance?

Not much different than maintaining any concrete pavement - but here's a resource:

National Concrete Pavement
Technology Center 

September 2014

Second Edition

CONCRETE PAVEMENT PRESERVATION GUIDE



 U.S. Department of Transportation
Federal Highway Administration
FHWA Publication No. FHWA-HF-14-014

A long, straight road stretches into the distance under a clear blue sky. The road is flanked by green fields and utility poles. The text "Thank you" is overlaid in the center of the image.

Thank you

TPF(5)-169 - Development of an Improved Design Procedure for Unbonded Concrete Overlays: Faulting and the Role of the Interlayer

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Lev Khazanovich, PhD
Steven G. Sachs, PhD

University of Pittsburgh

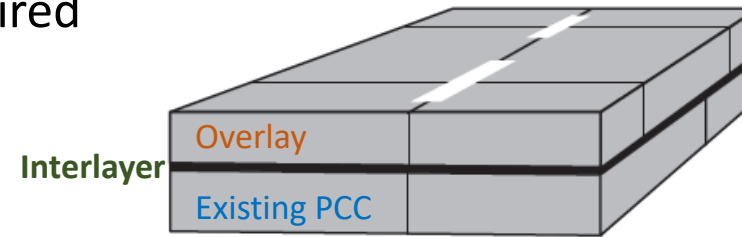
TRB Webinar
Monday Oct. 5, 2020



Unbonded concrete overlays

Existing concrete pavement

- Moderately to significantly deteriorated
 - Few, if any, pre-overlay repairs required
- Stable and uniform support layer



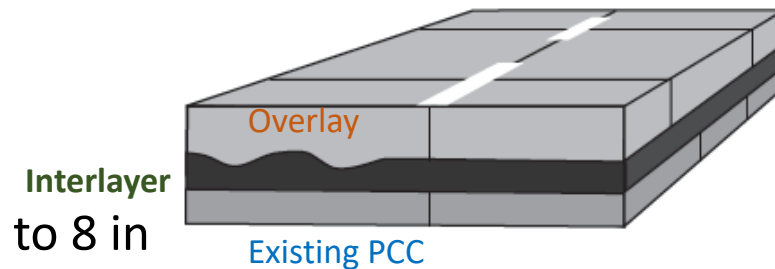
Existing concrete pavement

Interlayer

- HMA or nonwoven geotextile fabric

Overlay

- Thicker than bonded concrete overlays – typ. 6 to 8 in
- Durable surface
- Increased structural capacity



Composite pavement

Role of interlayer

- Slip plane
- Stress absorption
- Drainage



Courtesy of John Donahue MoDOT

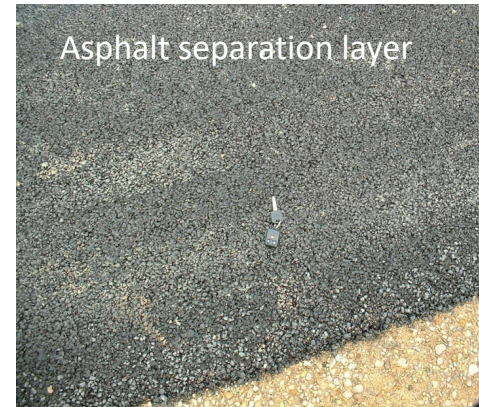
Types of interlayers

Interlayer materials:

- Nonwoven geotextile fabric
- HMA
 - New: Dense or open graded
 - Old: Milled or unmilled

Factors affecting interlayer performance:

1. Resistance to reflective cracking
2. Stiffness
3. Erosion resistant



Interlayers

5 Steps to Success

1. Balance permeability and strength
2. Erosion resistant mix (resistant to stripping)
3. Ensure proper compaction is achieved for new HMA interlayers
4. Keep moisture out of joints (seal/fill)
5. Provide a drainage path for water to exit pavement

Interlayers

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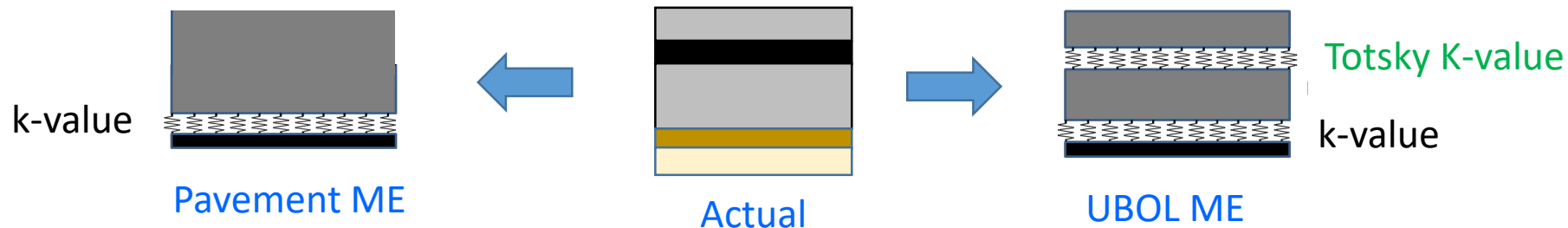
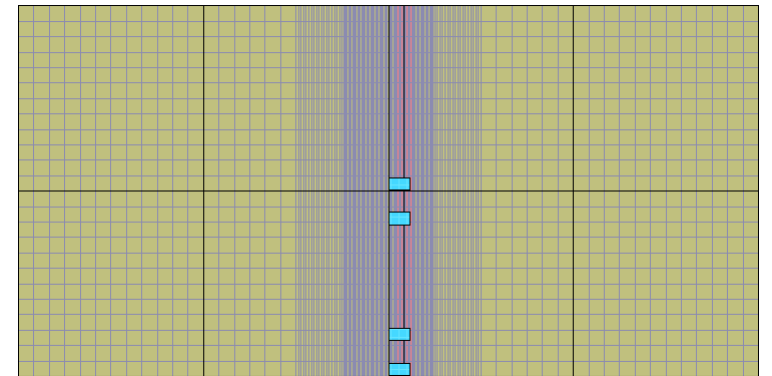
Accounted for
in **Pitt - UBOL**
ME Design
Procedure

Best Practices

- Construction
- Maintenance
- Design

Pitt UBOL-ME design procedure (FAULTING)

- Joints in overlay do not necessarily match joints in existing pavement
- Unlike Pavement M-E, structural model does not convert existing pavement and overlay into a single-layer system
 - **Totski Model** accounts for
 - overlay
 - existing slab
 - subgrade support
 - “cushioning” of the interlayer using Totski springs



Laboratory Study

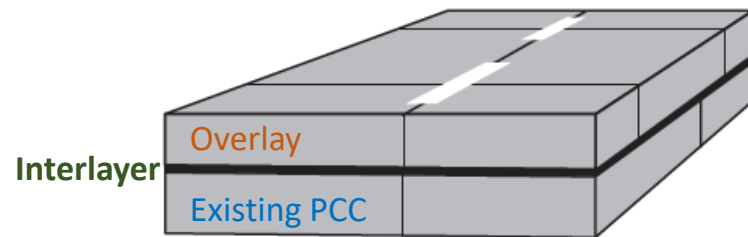
Mechanisms Investigated:

1. Ability to prevent reflective cracking
 - Structural model inputs
 - Interlayer performance
2. Stiffness of interlayer – LTE & deflections
 - Structural model inputs
 - Min. strength or stiffness criteria
3. Friction along interlayer system
 - Structural model inputs
 - Joint activation
4. Vertical resistance to uplift – pull off
 - Interlayer performance

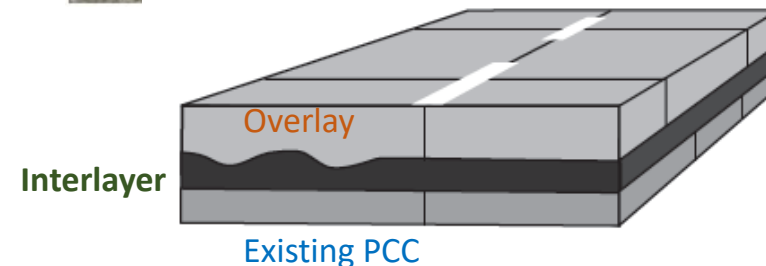
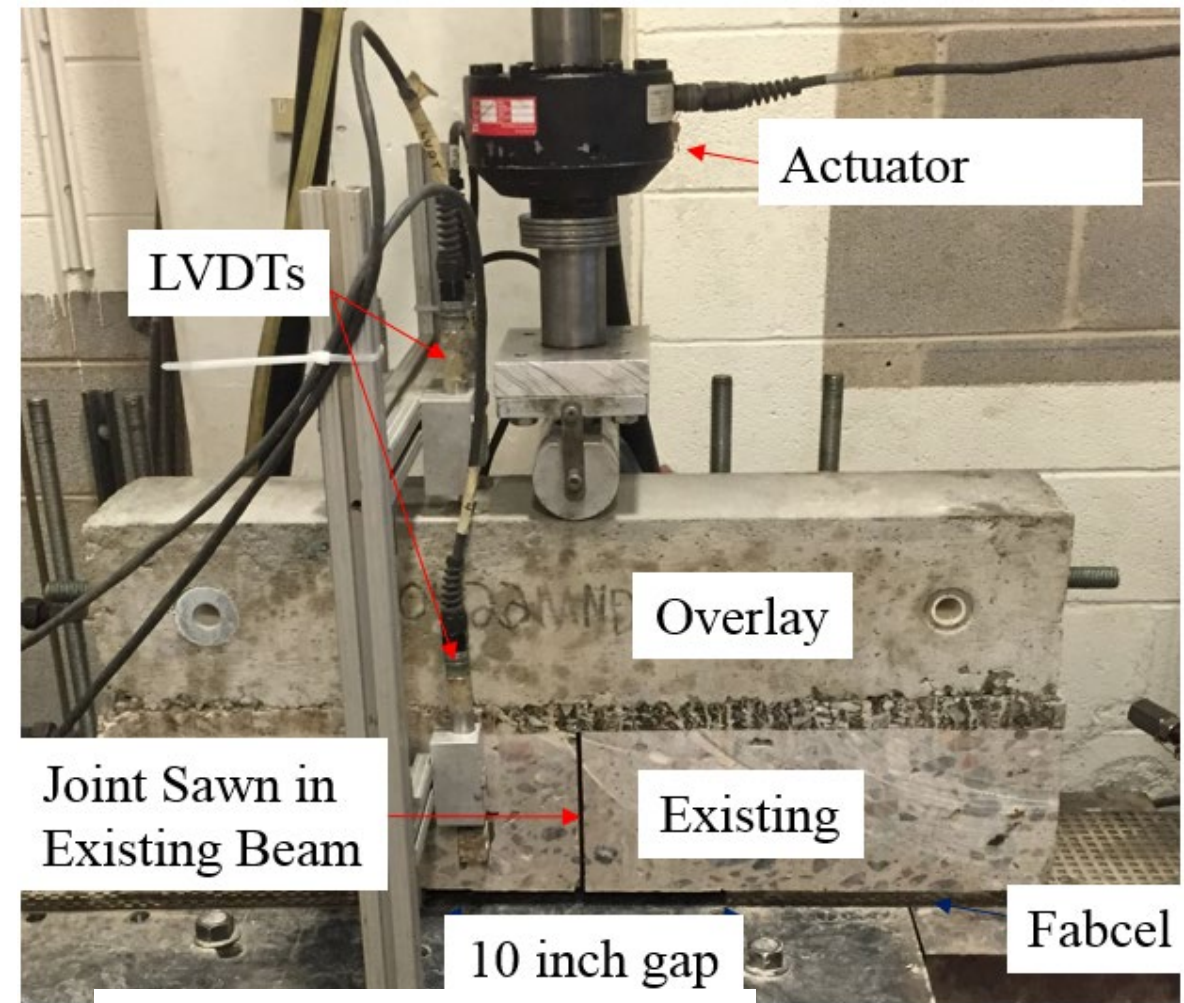
Laboratory study

Interlayer systems considered:

- Nonwoven geotextile fabric (two weights)
- HMA
 - Dense vs open graded
 - Milled vs unmilled (**composite**)
 - Old vs new



Existing concrete pavement



Composite pavement

Totski interlayer K-value

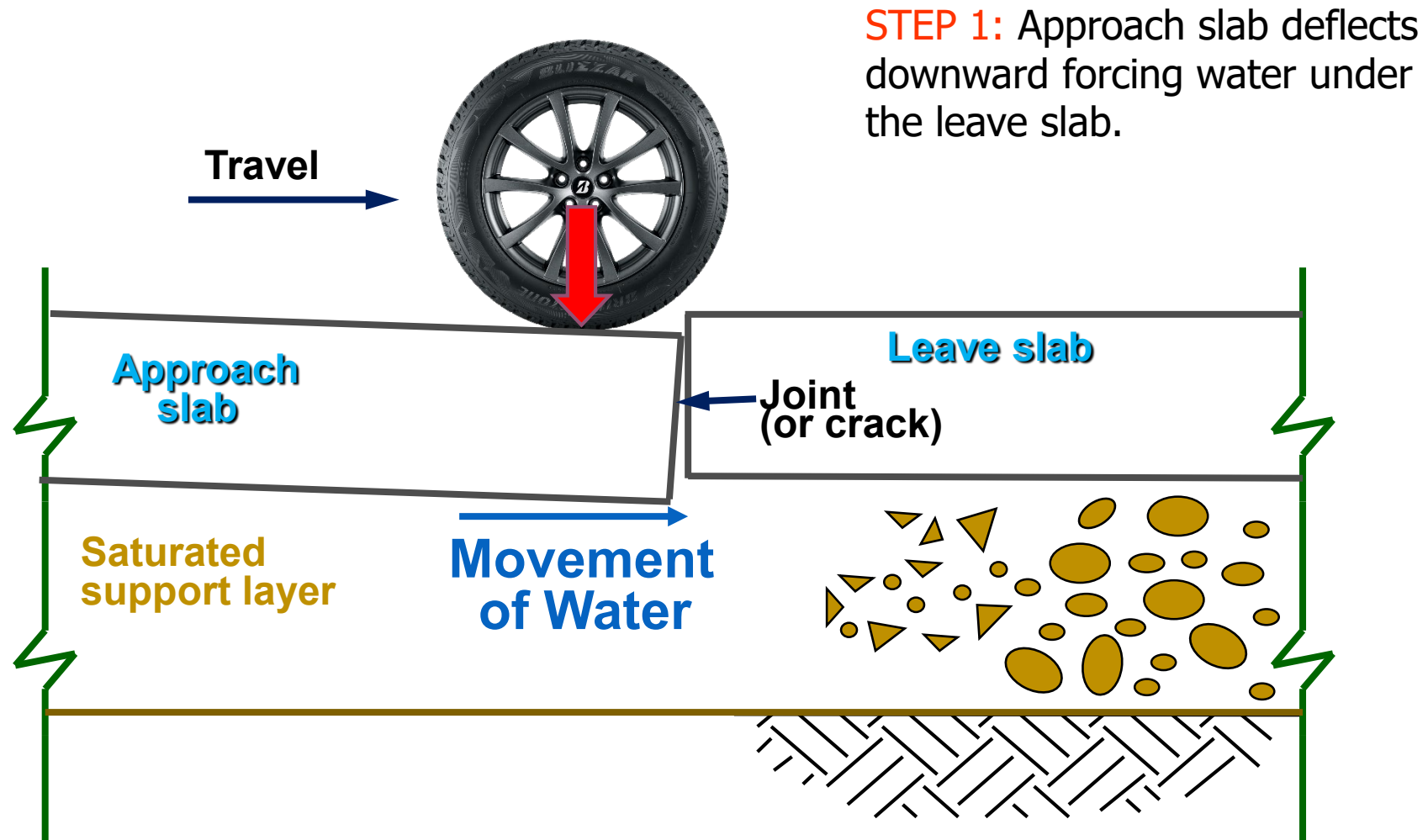
Totski K-value

Interlayer Type	Average Totski k-value (psi/in)	Standard Deviation (psi/in)
F15	337	63
F10	372	55
MNDAU	3342	1262
MNDAM	3613	1175
MNONU	2555	901
MIDAU	4046	966
MIOAU	3566	1095
PADNU	3391	1533

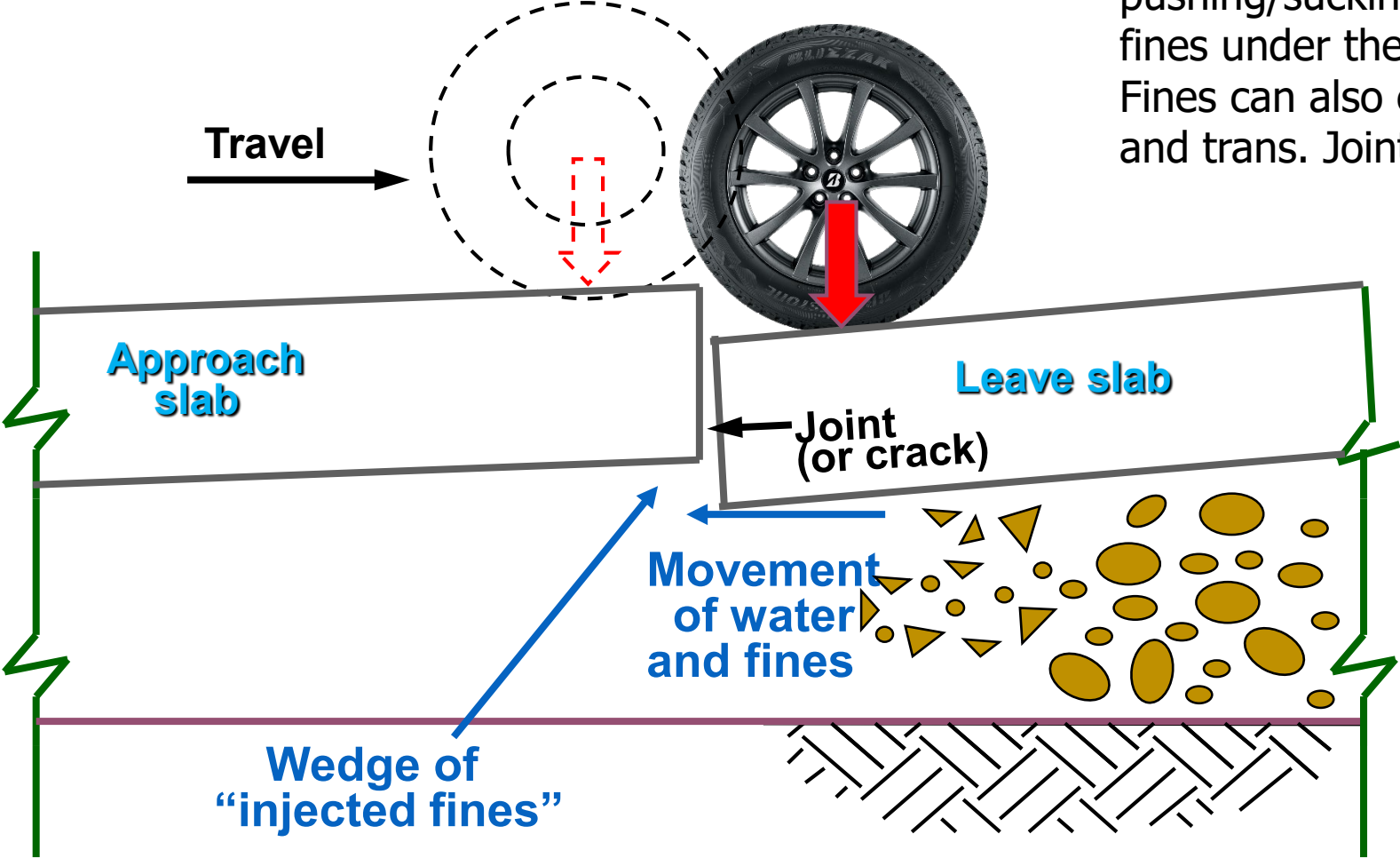
Ave. based on Lab and Field (FWD):

- Asphalt = 3500 psi/in
- Nonwoven geotextile fabric = 425 psi/in

Faulting

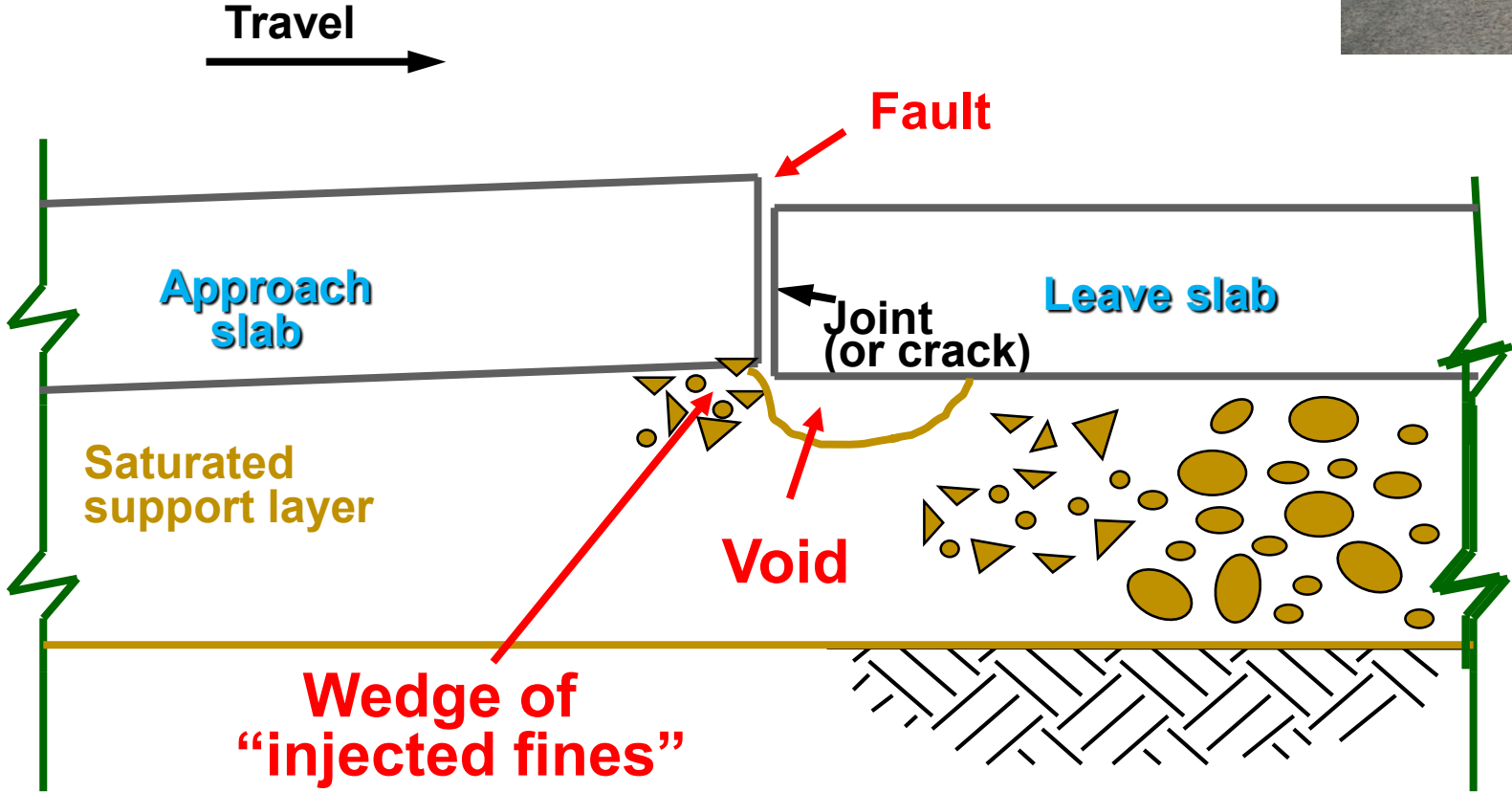


Faulting



STEP 2: Approach slab rebounds upward and leave slab is forced downward pushing/sucking water and fines under the approach slab. Fines can also eject out long. and trans. Joints.

Faulting



Pavement Interactive

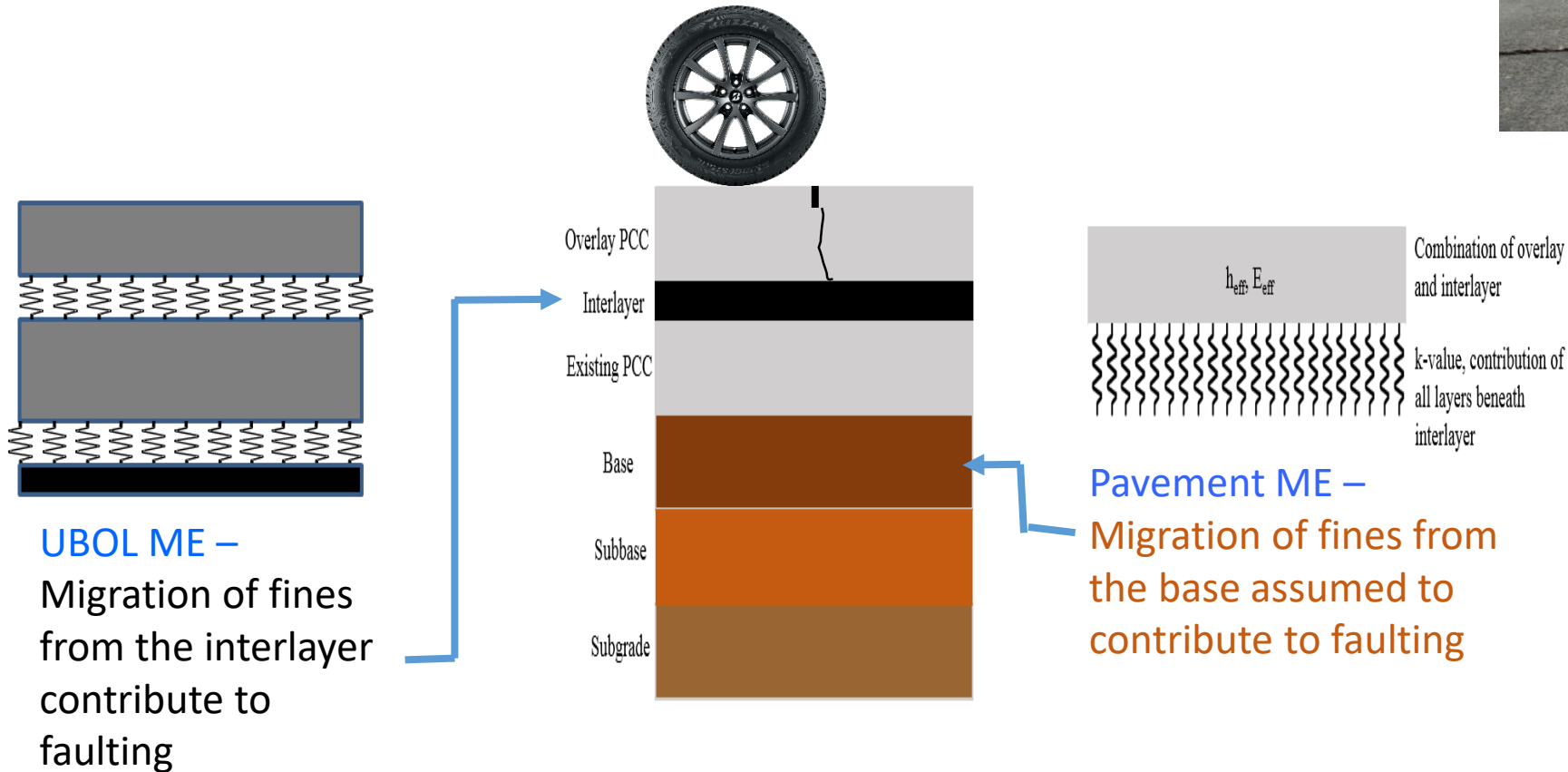
<http://pavementinteractive.org/index.php?title=Faulting>

UBOL Design: Faulting

UBOL ME: Accounting for interlayer in the development of faulting (Source of fines)



Pavement Interactive



UBOL Design: Faulting

$$F_0 = (C_1 + C_2 * FR^{0.25}) * \delta_{curl} * [C_5 * E]^{C_6} * \log(WETDAYS * P_{200})$$

$$F_i = F_{i-1} + C_7 * C_8 * DE_i * [C_5 * E]^{C_6}$$

$$\Delta Fault_i = (C_3 + C_4 * FR^{0.25}) * (F_{i-1} - Fault_{i-1}) * C_8 * DE_i$$

$$Fault_i = Fault_{i-1} + \Delta Fault_i$$

F_0 = initial maximum mean transverse joint faulting (in)

FR = base freezing index (% time that the top of the base is below freezing (<32°F))

δ_{curl} = max mean monthly PCC upward slab deflection due to curling

E = erosion potential of interlayer: f(% binder content, % air voids, P_{200})

P_{200} = Percent of interlayer aggregate passing No. 200 sieve

$WETDAYS$ = Average number of annual wet days (> 0.1 in of rainfall)

F_i = maximum mean transverse joint faulting for month i (in)

F_{i-1} = maximum mean transverse joint faulting for month i-1 (in)

DE_i = Differential energy density of accumulated during month i

$\Delta Fault_i$ = incremental monthly change in mean transverse joint faulting during month i (in)

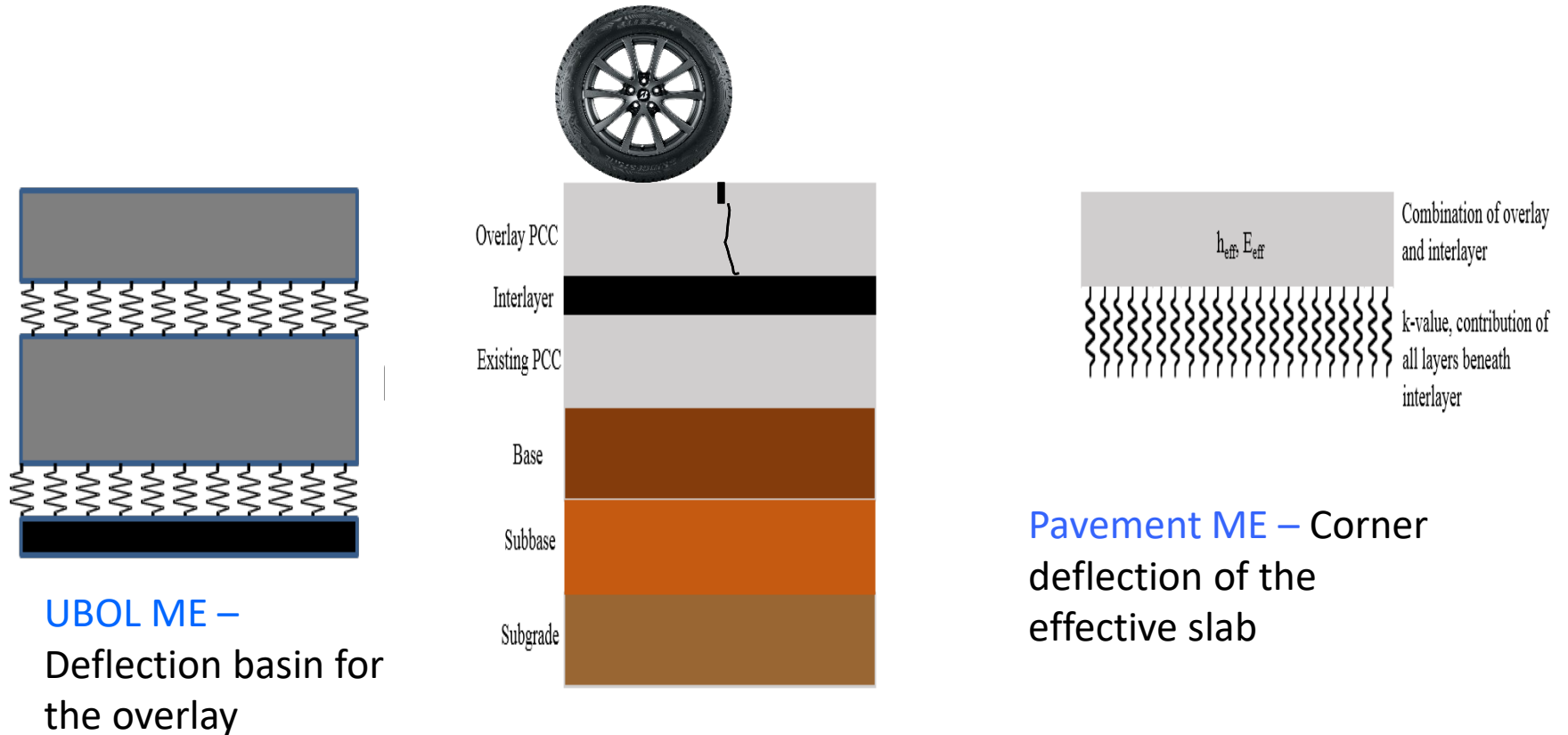
$C_1 \dots C_8$ = Calibration coefficients

$Fault_{i-1}$ = mean joint faulting at the beginning of month i (0 if i = 1)

$Fault_i$ = mean joint faulting at the end of month i (in)

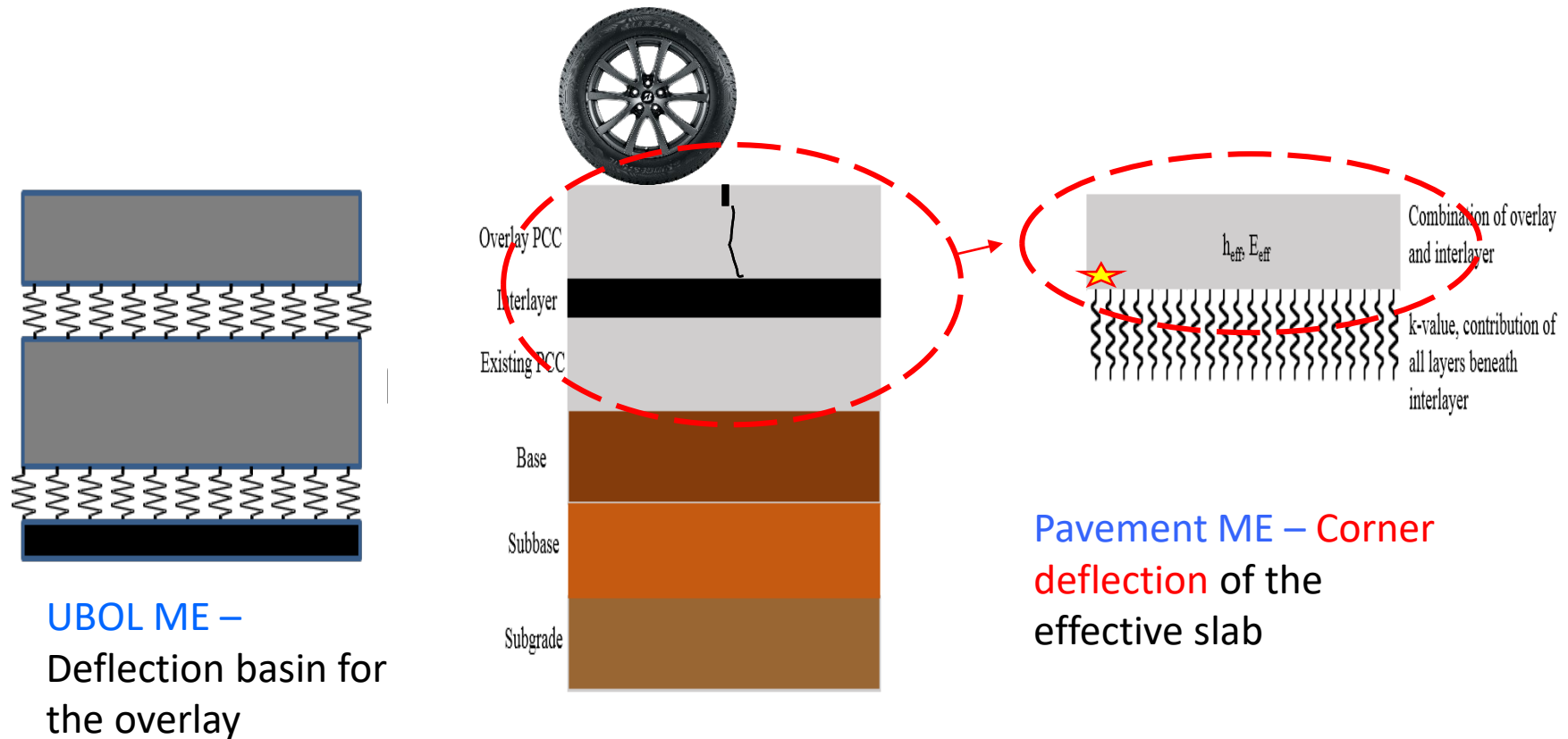
UBOL Design: Faulting

Accounting for interlayer in the development of faulting (**Deflections**)



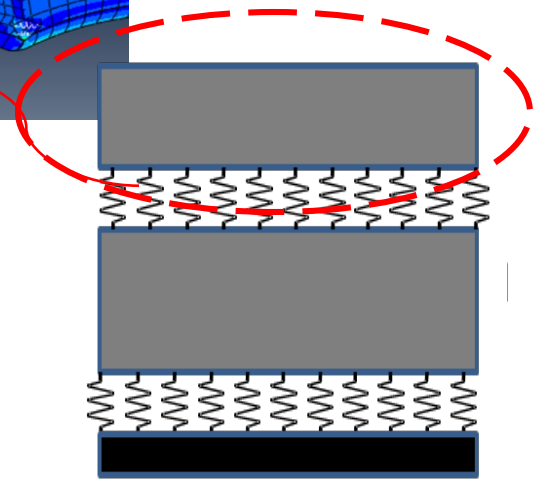
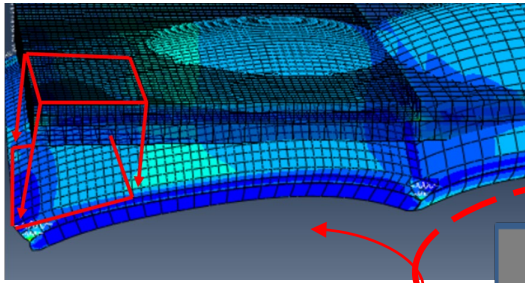
UBOL Design: Faulting

Accounting for interlayer in the development of faulting (Deflections)

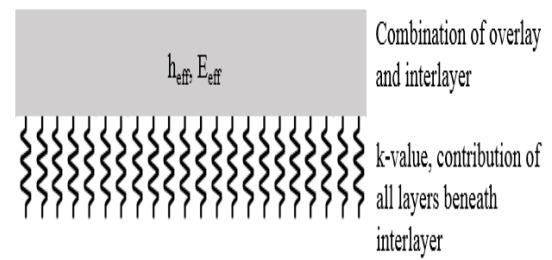
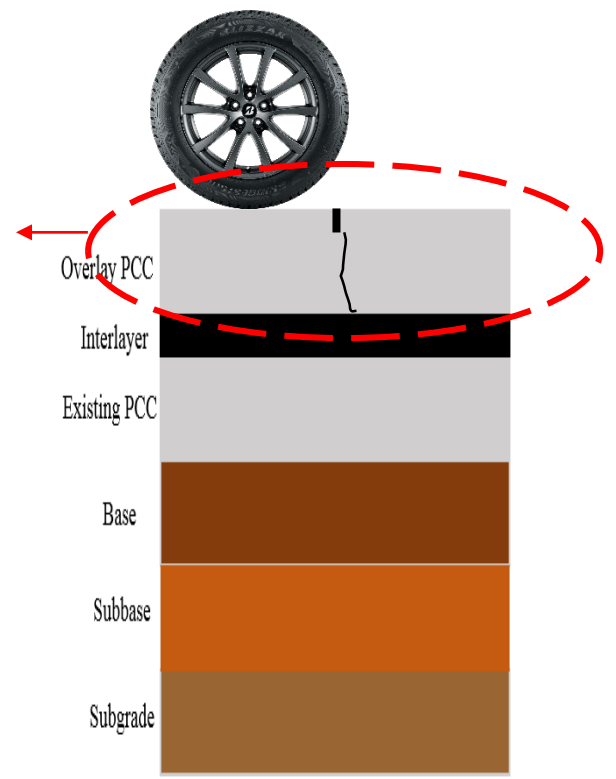


UBOL Design: Faulting

Accounting for interlayer in the development of faulting (Deflections)



UBOL ME – Deflection basin for the overlay



Pavement ME – Corner deflection of the effective slab

Calibration coefficients

Coefficient	UBOL ME– 11/16/2019	Current Pavement ME (Pitt)	Original Pavement ME
CDOWEL	0.25		-
C1	1.25	0.595	1.29
C2	1.5	1.636	1.1
C3	0.8	0.00217	0.001725
C4	0.015	0.00444	0.0008
C5 ¹	0.01	250	250
C6	1.46	0.47	0.4
C7	0.62	7.3	1.2
C8 ²	$1/(4 \times 10^6)^a,$ $-3.5 \times 10^{-7} + 6.25 \times 10^{-8} \times JtSpace^b$	400	400

¹Different Erosion model

²Previous model used C8 as dowel damage coefficient
not used for calibration

^aJtSpace ≤ 12 ft

^bJtSpace > 12 ft

Calibration coefficients

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CDOWEL	0.25		-
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¹Erosion model developed

²Previous model used C8 as dowel damage coefficient
not used for calibration

^aJtSpace ≤ 12 ft

^bJtSpace > 12 ft

Faulting

Pavement ME Approach: Modeled as newly constructed JPCP

MEPDG Documentation Appendix JJ

Erodibility index

Assigned integer value based upon base type

$\alpha = 1$ – extremely erosion resistant

to

$\alpha = 5$ – very erodible

UBOL EROD = 1 for all interlayer types

Erodibility Class	Material Description and Testing
1	<p>(a) Lean concrete with approximately 8 percent cement; or with long-term compressive strength > 2,500 psi (>2,000 psi at 28-days) and a granular subbase layer or a stabilized soil layer, or a geotextile fabric is placed between the treated base and subgrade, otherwise class 2.</p> <p>(b) Hot mixed asphalt concrete with 6 percent asphalt cement that passes appropriate stripping tests and aggregate tests and a granular subbase layer or a stabilized soil layer (otherwise class 2).</p> <p>(c) Permeable drainage layer (asphalt treated aggregate or cement treated aggregate and with an appropriate granular or geotextile separation layer placed between the treated permeable base and subgrade.</p>
2	<p>(a) Cement treated granular material with 5 percent cement manufactured in plant, or long-term compressive strength 2,000 to 2,500 psi (1,500 to 2,000 psi at 28-days) and a granular subbase layer or a stabilized soil layer, or a geotextile fabric is placed between the treated base and subgrade; otherwise class 3.</p> <p>(b) Asphalt treated granular material with 4 percent asphalt cement that passes appropriate stripping test and a granular subbase layer or a treated soil layer or a geotextile fabric is placed between the treated base and subgrade; otherwise class 3.</p>
3	<p>(a) Cement-treated granular material with 3.5 percent cement manufactured in plant, or with long-term compressive strength 1,000 to 2,000 psi (750 psi to 1,500 at 28-days).</p> <p>(b) Asphalt treated granular material with 3 percent asphalt cement that passes appropriate stripping test.</p>
4	Unbound crushed granular material having dense gradation and high quality aggregates.
5	Untreated soils (PCC slab placed on prepared/compacted subgrade)

Faulting

New Approach: Erosion Model

$$\alpha = \log(1 + a(5 - \%Binder) + b(10 - \%AV) + c * P_{200})$$

α = Erodibility index

$\%Binder$ = Percent binder in asphalt interlayer

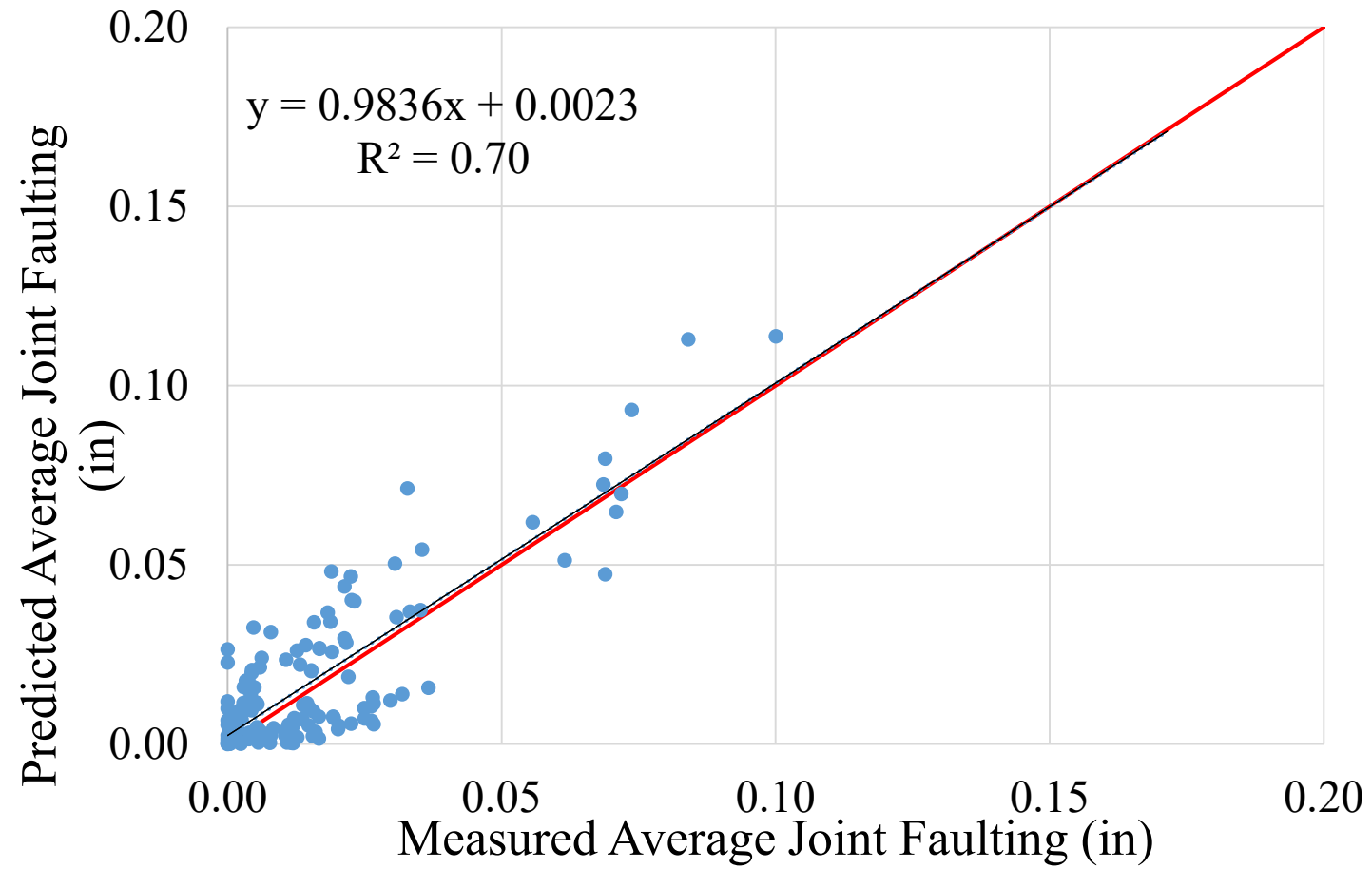
$\%AV$ = Percent air voids in asphalt interlayer

P_{200} = Percent passing No. 200 sieve in interlayer

a, b, c = Calibration coefficients (0.14 0.14, 0.05)

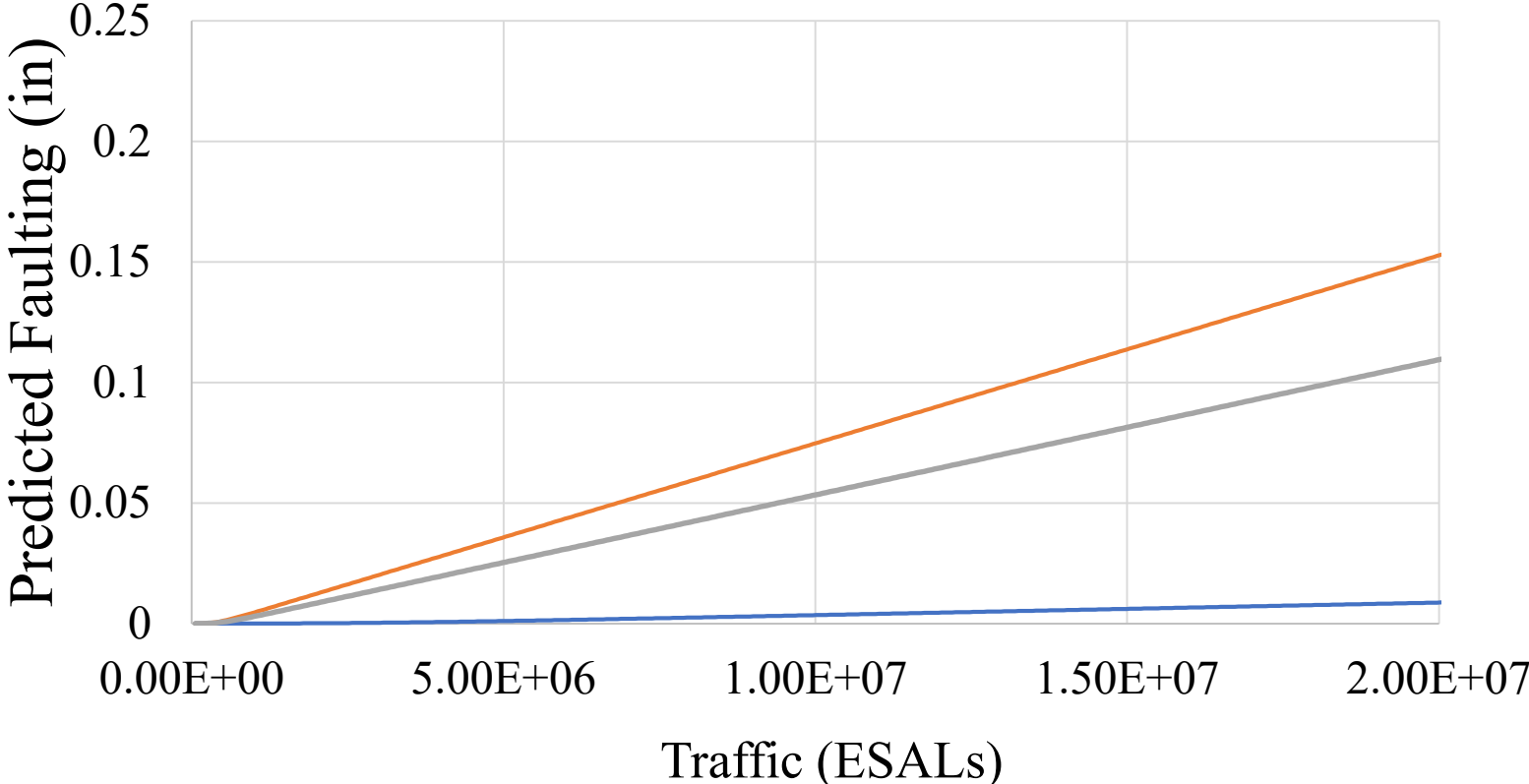
$$E = \begin{cases} (1.8483 * \alpha^2 - 0.8179 * \alpha + 0.1123) & \text{Undoweled, Doweled pavements} \\ 0.02 & \text{NWGF sections} \end{cases}$$

Faulting



Faulting

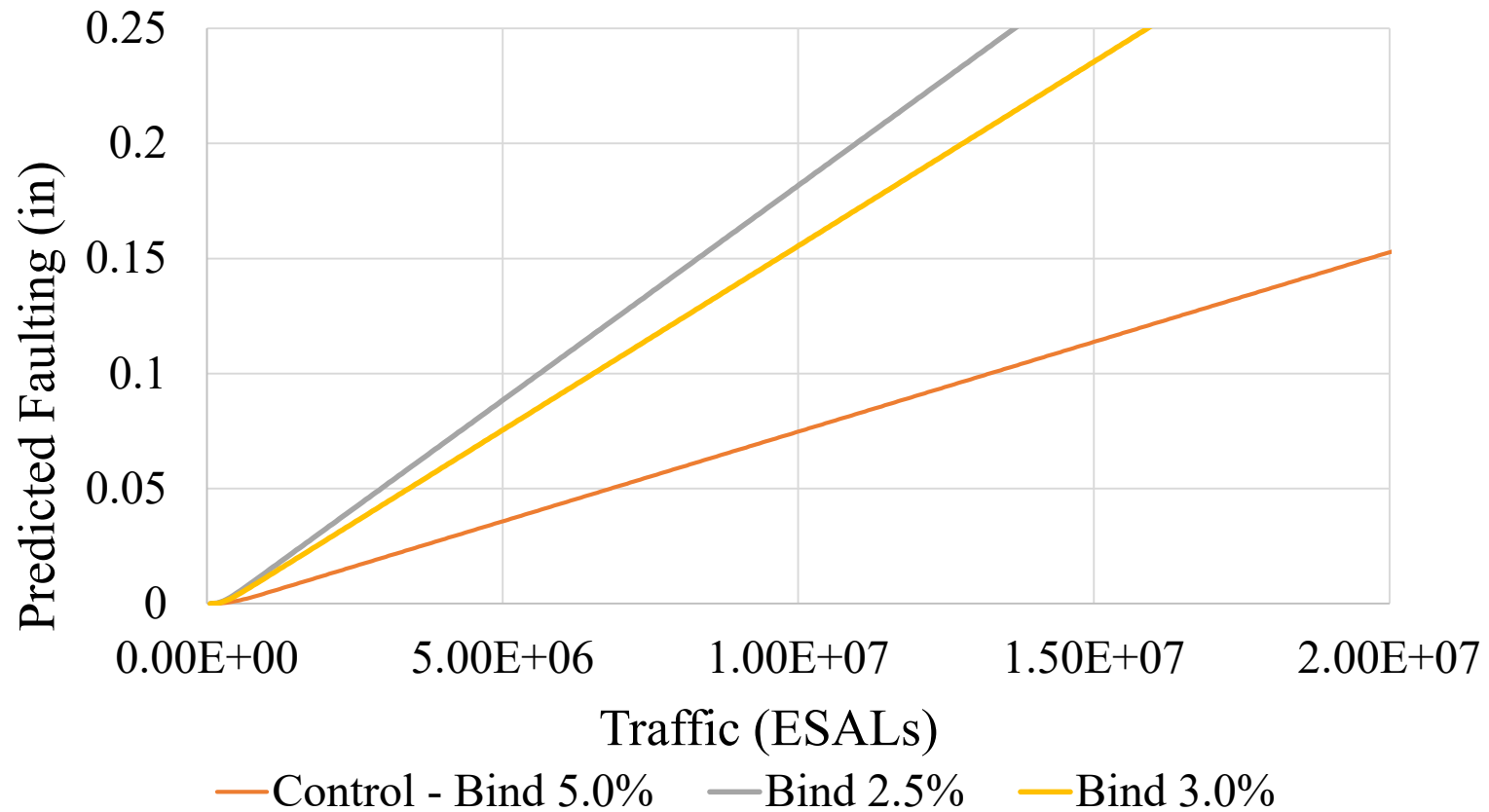
Interlayer type



- Control - Dense Graded Asphalt
- Open Graded Asphalt
- Fabric Interlayer

Faulting

Interlayer effective binder content



Thank You



Any Questions?

TPF(5)-169: Development of an Improved Design Procedure for Unbonded Concrete Overlays

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TRB Webinar

Monday Oct. 5, 2020



Existing Design Procedures for Unbonded Concrete Overlays

- Empirical

- Corps of Engineers (Departments of the Army and the Air Force 1979; Army Corps of Engineers 2001)
- AASHTO (1993)

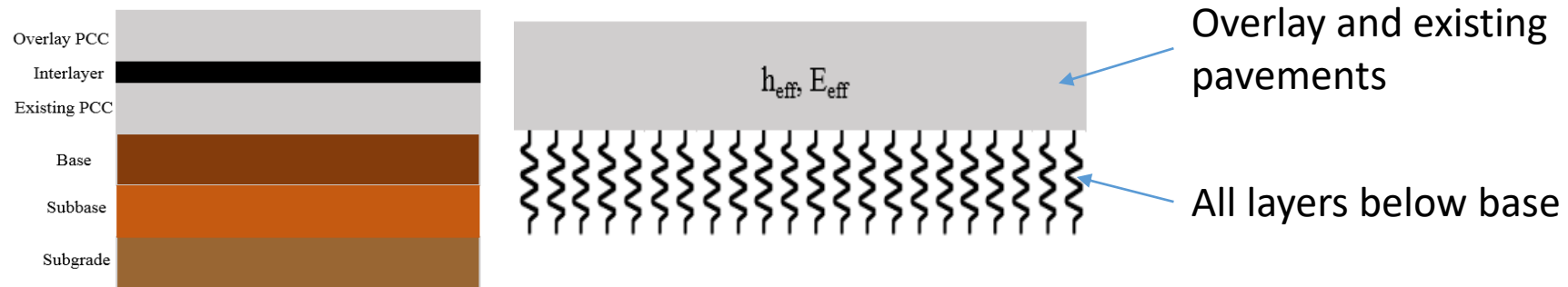
$$h_{OL} = \sqrt{h_{new}^2 - C h_{old}^2}$$

- Mechanistic-Empirical

- FAA (Rollings 1988)
- Portland Cement Association (PCA) (Tayabji and Okamoto 1985)
- MEPDG (NCHRP 2004)

M-E PDG Procedure for Unbonded Overlays

- Adopts the MEPDG structural and performance prediction models for new concrete pavements
- Structural model:
 - Equivalent plate on Winkler foundation

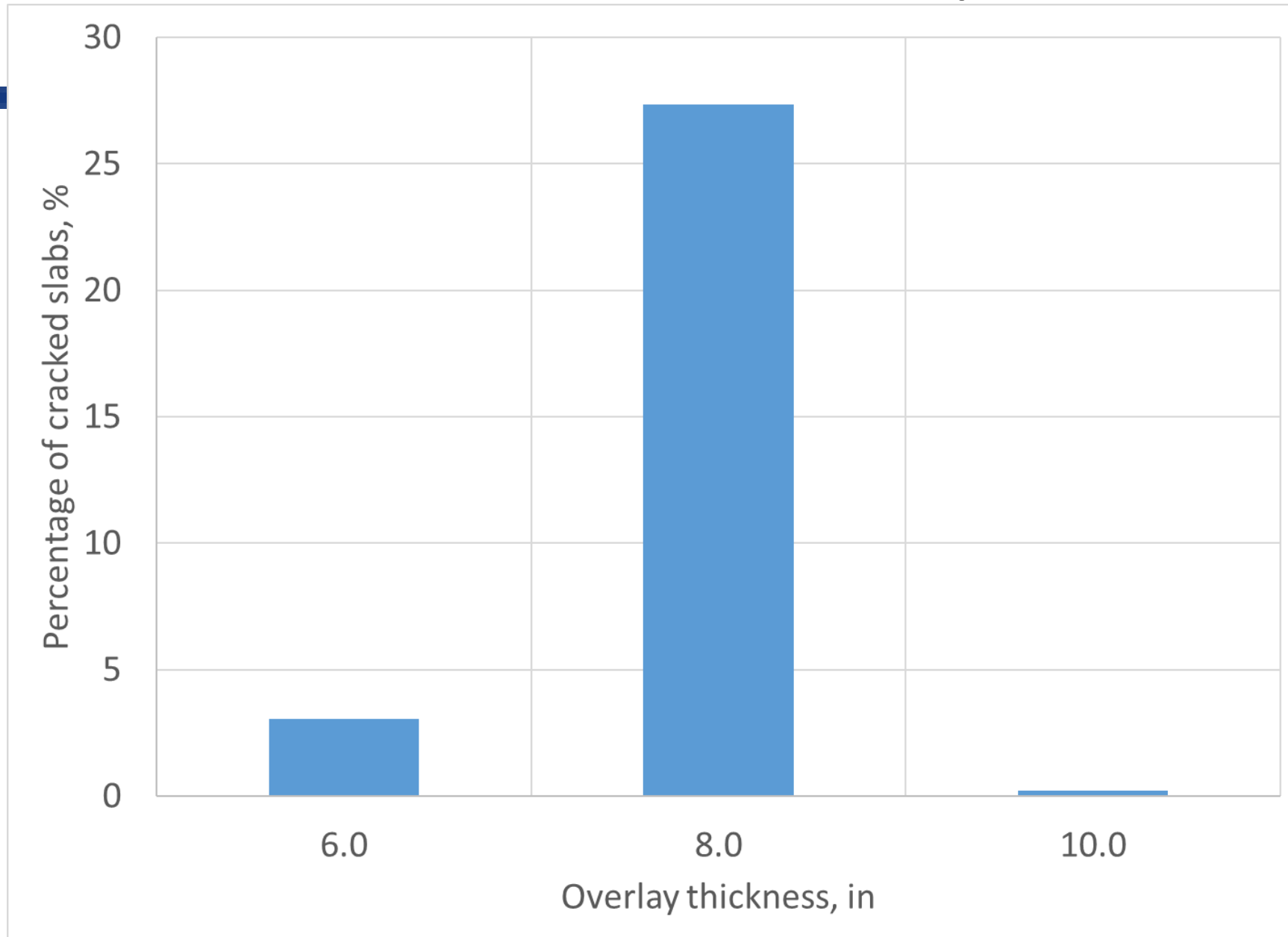


- Existing pavement stiffness is reduced using an empirical stiffness reduction factor
- Joints in the overlay match joints in the existing slab
- Deflection basins of the overlay and the existing pavements are the same

Pavement ME Example

- Location: Rochester, MN
- Design life: 20 years
- Traffic:
 - Two-way initial AADTT: 8,000
 - Linear yearly increase: 3.0%
 - Axle spectrum: Pavement ME default
- Existing pavement:
 - Thickness: 8 in
 - Modulus of elasticity: 4,000,000 psi
- Interlayer thickness: 1 in
- Overlay joint spacing: 15 ft
- Untied PCC shoulder
- Unbonded overlay flexural strength: 650 psi.

Pavement ME Example



TPF-5(269) Pooled Fund Design Procedure

- MEPDG framework
 - Incremental damage approach
 - Axle load spectrum for traffic characterization
 - Use of EICM
 - ...
- Pavement performance modeling
 - Cracking model
 - Transverse cracking model
 - Transverse joint damage model (corner/longitudinal cracking)
 - Faulting model

Cracking Model Framework

- Pavement ME (MEPDG) framework:
 - Effect of PCC age on concrete strength and stiffness
 - Axle load spectrum
 - Curling analysis
 - Effect of built-in curling
- Significant modifications
 - Interlayer stiffness and degradation are accounted for
 - Short slabs (6 ft x 6 ft) are included
 - Other modifications

Traffic Analysis

- MEPDG default axle spectrum distribution
- AADTT for the first year
- Linear traffic volume growth model

Curling Analysis

EICM is used to predict hourly temperature profile through PCC based on historical hourly climatic data

- 59 weather stations
- Overlay thicknesses 4, 6, 8, and 10 in
- Temperature profiles are approximated by quadratic functions
- Frequency tables generated for each case
- Interpolation for other thicknesses

Temperature Distributions Frequency

ΔT_L	C									
	-0.4	-0.3	-0.2	-0.1	0	0.1	0.2	0.3	0.4	0.5
-24.8994	0	0	0.00117	0.00223	0	0	0	0	0	0
-23.0144	0	0.00106	0.00493	0.01397	0.00023	0	0	0	0	0
-21.1352	0	0.00376	0.01725	0.0493	0.00141	0	0	0	0	0
-19.2559	0.00141	0.0061	0.01878	0.08462	0.00622	0	0	0	0	0
-17.371	0.00282	0.00681	0.01526	0.07418	0.01514	0.00399	0	0	0	0
-15.4917	0.00106	0.00634	0.01291	0.05692	0.0311	0.00481	0.00258	0	0	0
-13.6124	0.00129	0.00552	0.00939	0.03263	0.03474	0.0061	0.00587	0	0	0
-11.7275	0.00117	0.00552	0.00669	0.01068	0.00657	0.00599	0.00692	0	0	0
-9.8482	0	0.00329	0.00599	0.00646	0.0027	0.00716	0.00646	0.00305	0	0
-7.9689	0	0.00211	0.00692	0.00681	0.00493	0.00669	0.00458	0.00552	0	0
-6.084	0	0.00117	0.00469	0.00751	0.00716	0.00634	0.00317	0.0088	0	0
-4.2047	0	0	0.0054	0.00704	0.00505	0.0054	0.0027	0.00892	0.00176	0
-2.3255	0	0	0.00305	0.00857	0.00505	0.00458	0.00282	0.00599	0.00376	0
-0.4405	0	0	0	0.00751	0.00493	0.00411	0.00399	0.00552	0.00411	0
1.4387	0	0	0	0.00516	0.00786	0.00481	0.00282	0.00657	0.00552	0.00106
3.318	0	0	0	0.00246	0.00634	0.00587	0.00364	0.00751	0.00775	0
5.2029	0	0	0	0	0.0061	0.00704	0.00657	0.00716	0.00528	0
7.0822	0	0	0	0	0.00364	0.00516	0.00869	0.00845	0.0054	0.00188
8.9615	0	0	0	0	0.00094	0.00481	0.00493	0.00505	0.00563	0.00141
10.8464	0	0	0	0	0.00047	0.00235	0.00634	0.00681	0.00399	0.00211
12.7257	0	0	0	0	0	0.00188	0.00246	0.00376	0.00293	0.00141
14.605	0	0	0	0	0.00023	0	0.00176	0.00293	0.00235	0
16.4899	0	0	0	0	0.00059	0	0	0.00117	0.00188	0
18.3692	0	0	0	0	0.00059	0	0	0	0.00129	0

*Adjusted for built-in curling

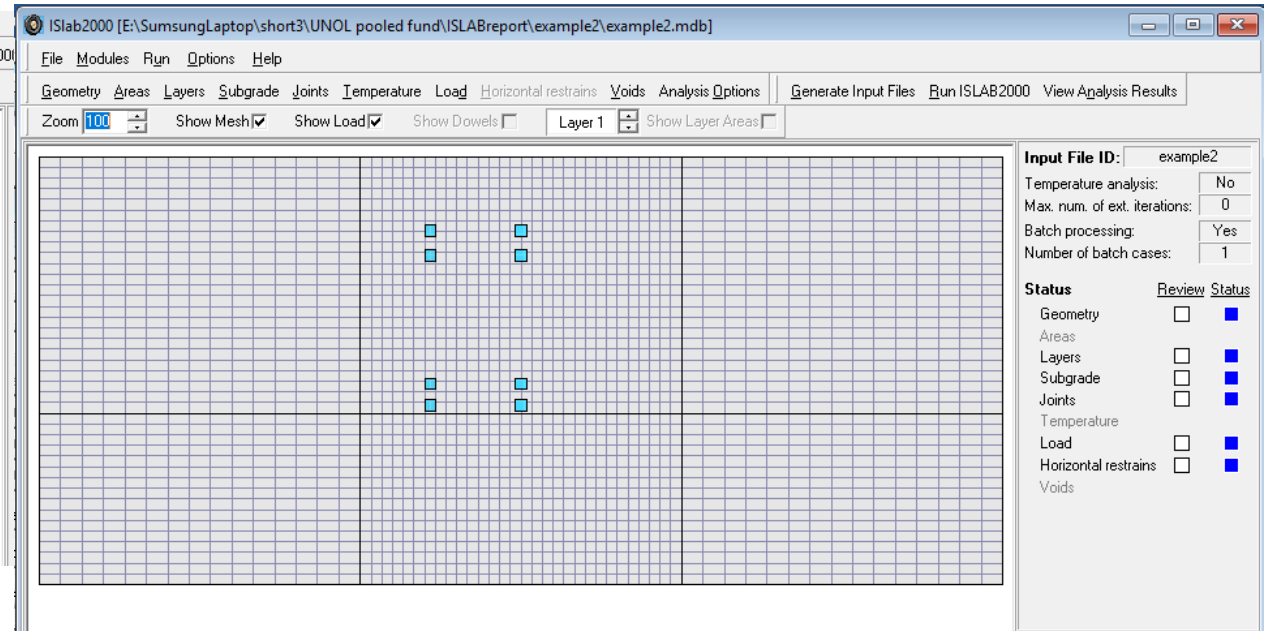
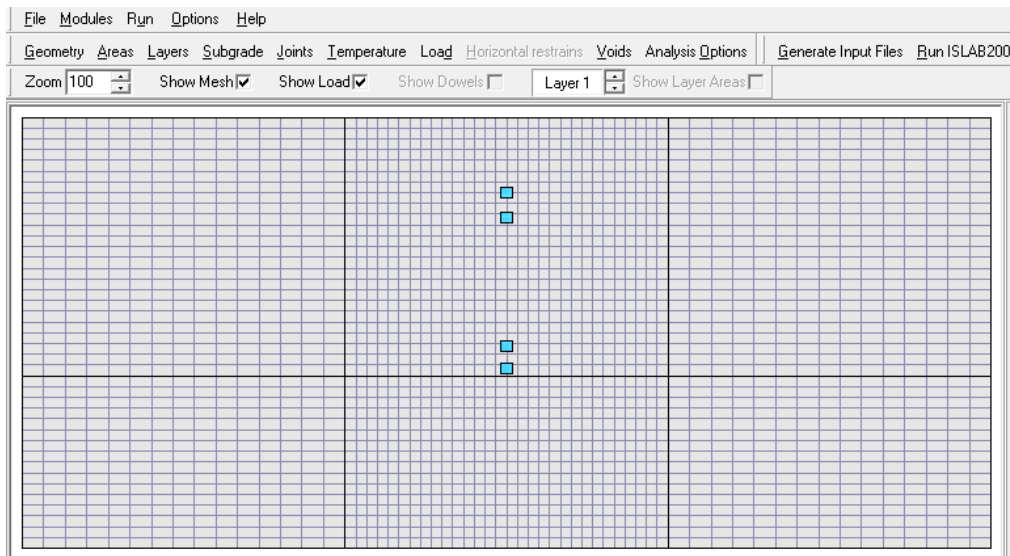
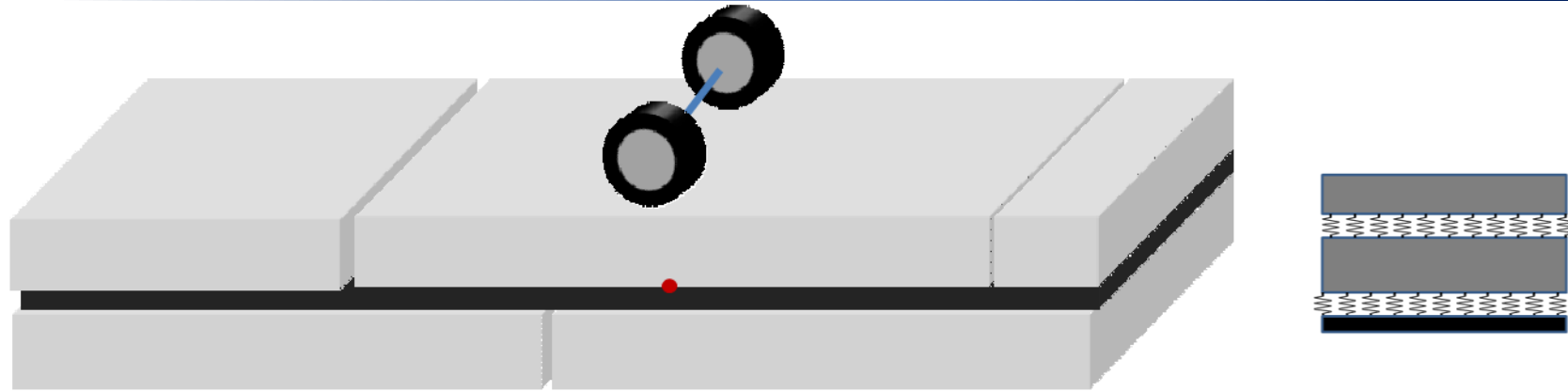
Hiller and Roesler (2010)

Structural Modeling

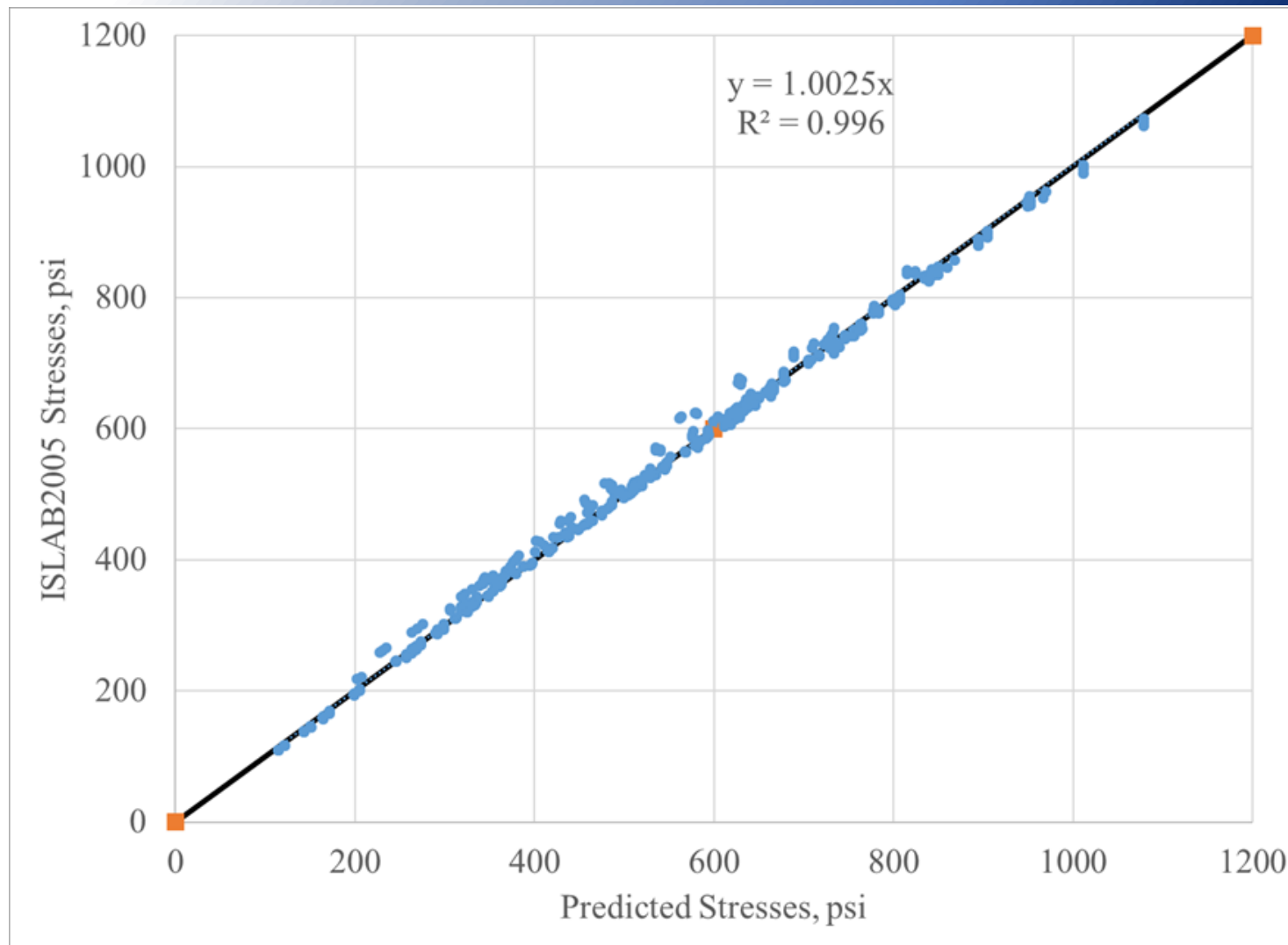
- Totski model for structural responses
 - Independent curling of the overlay and existing pavement
 - Composite bending behavior
 - Mismatched joints in the overlay and existing pavements
 - Totski spring stiffness depending on the interlayer type
 - Interlayer deterioration
- Several factorials of ISLAB2000 Totski model runs (more than 100,000 cases) were performed to develop NNs

Stress Analysis

Bottom-up transverse cracking

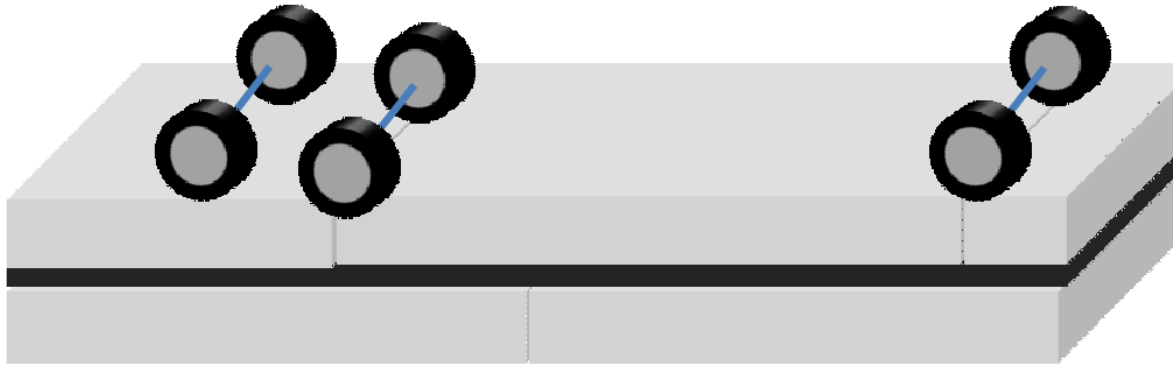


NNs for Bottom of the Overlay Edge Stresses

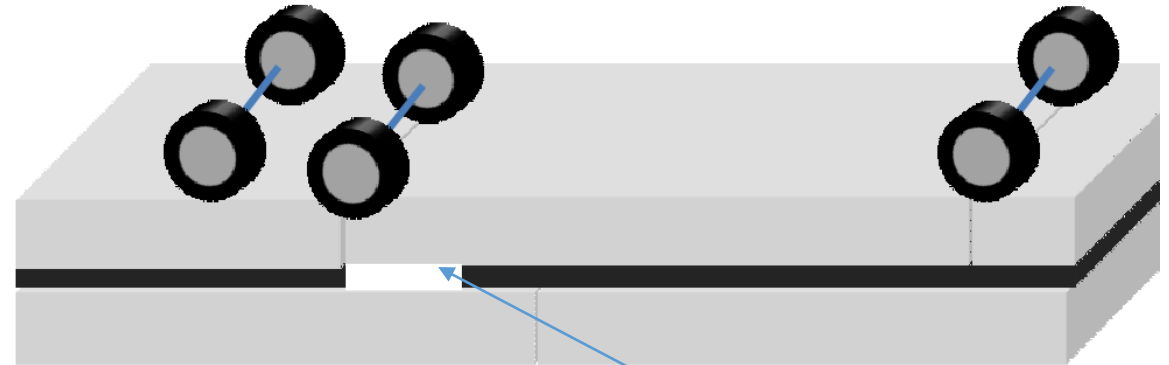


Stress Analysis

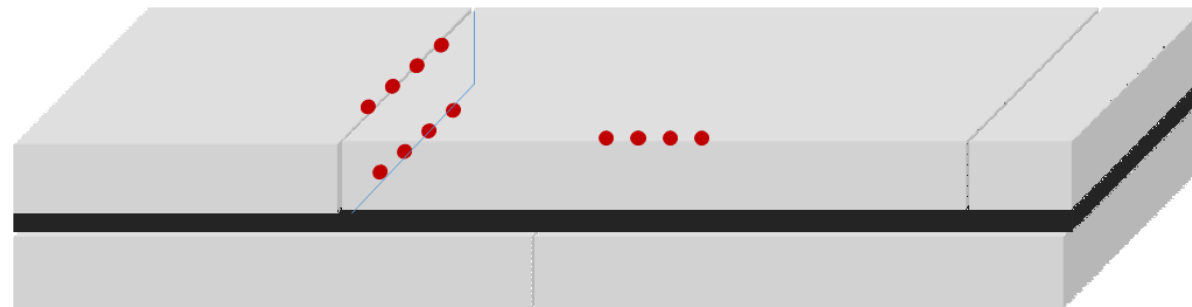
Top-down and joint damage



No voids

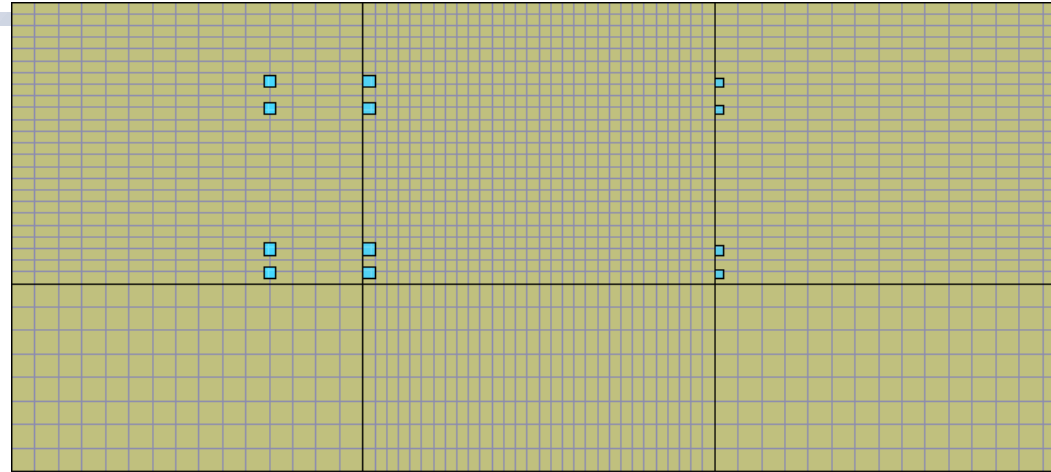


24-in long, lane-wide void simulating erosion in the interlayer

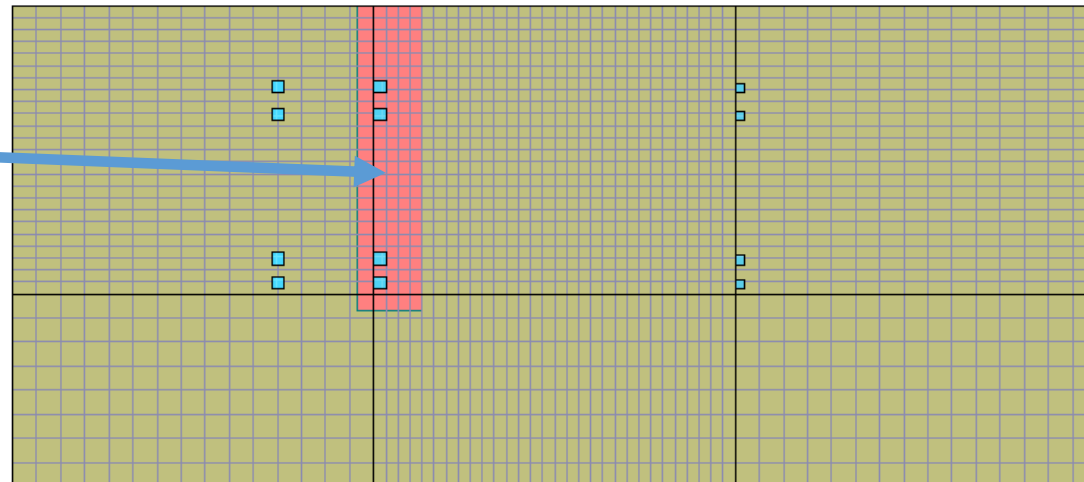


ISLAB2000 Models for Conventional Overlays

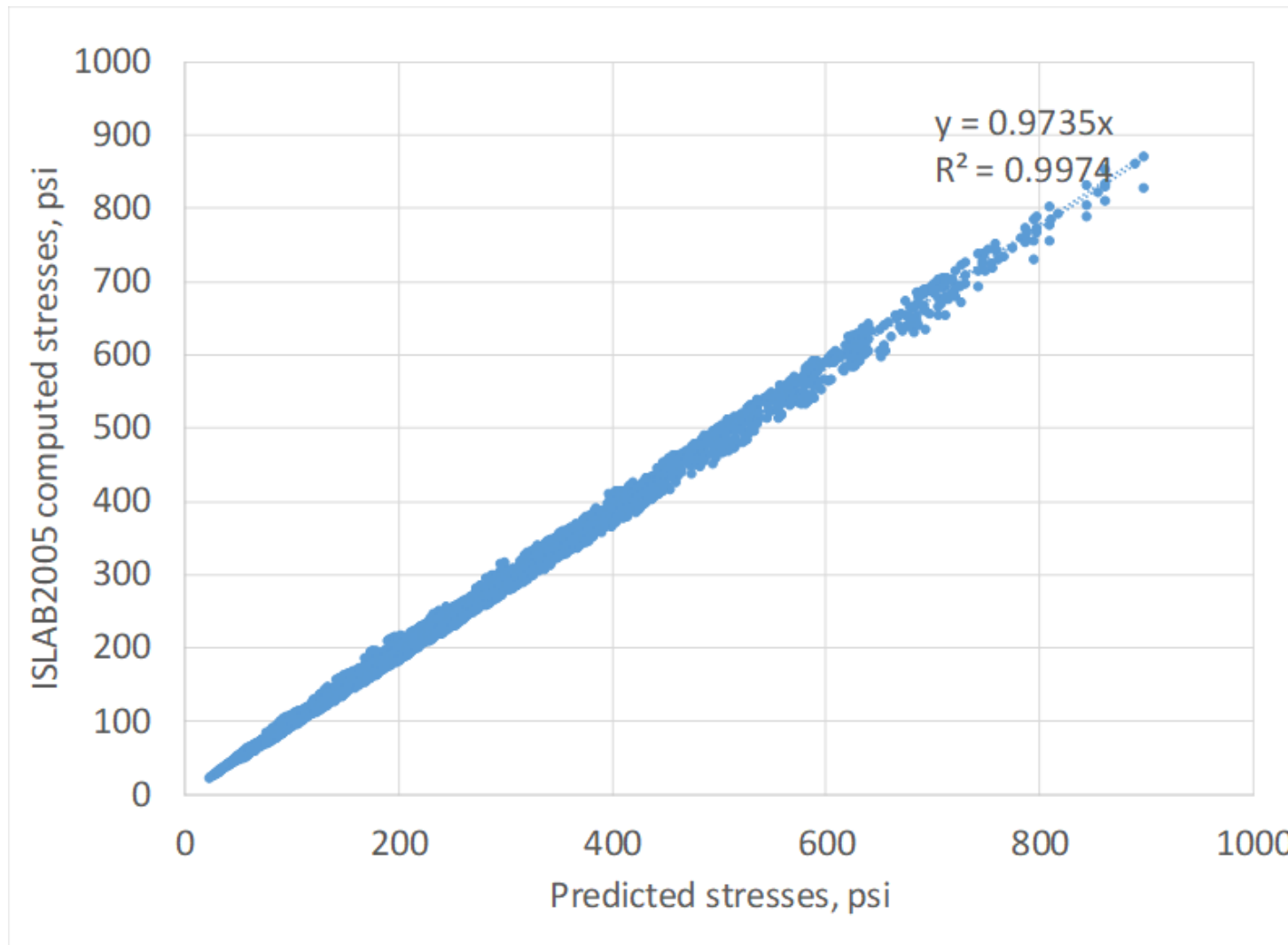
No voids



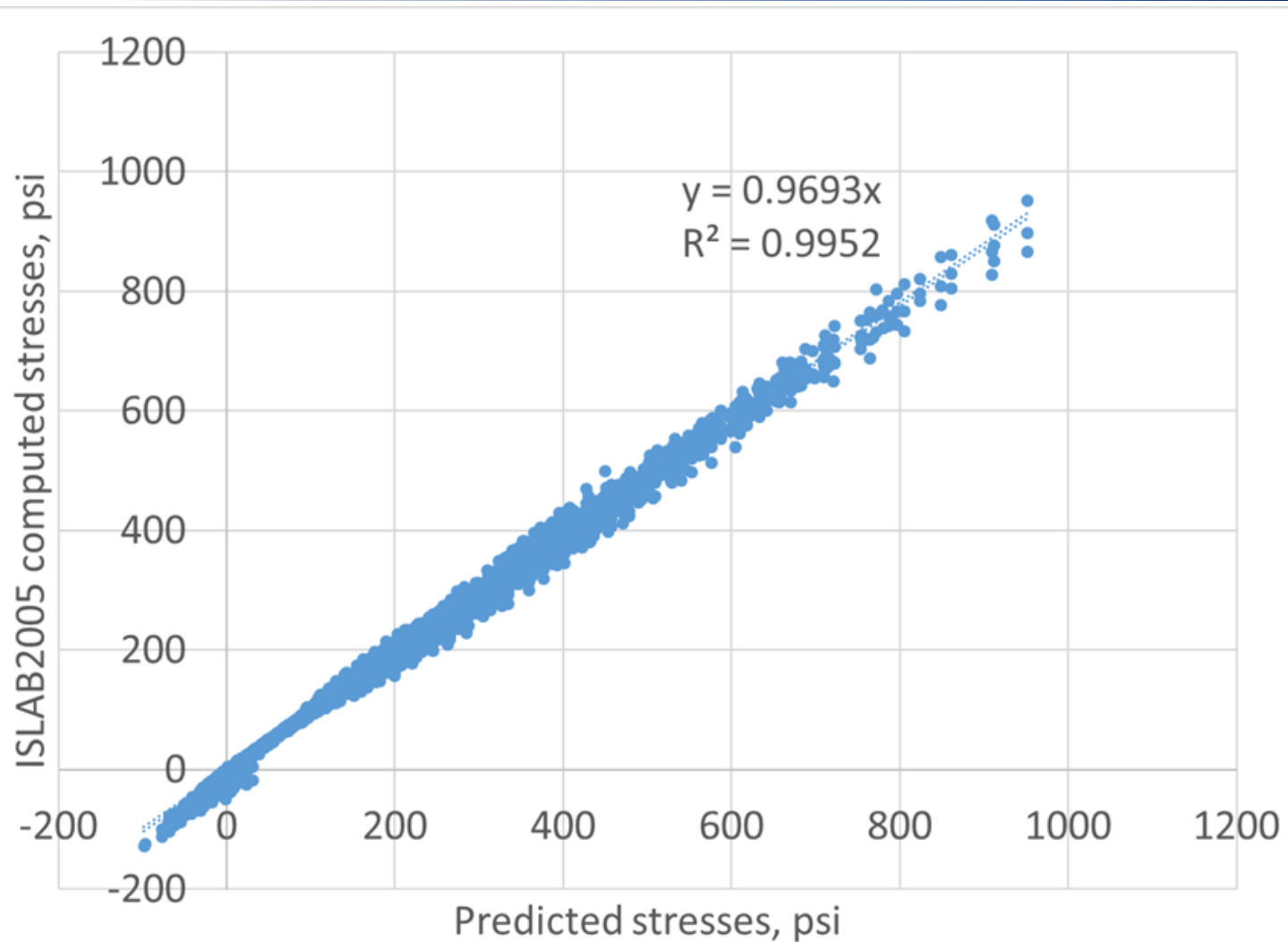
Void in
the interlayer



NNs for Stresses at the Bottom Surface of the Transverse Joint



NNs for Stresses at the Top Surface of the Transverse Joint



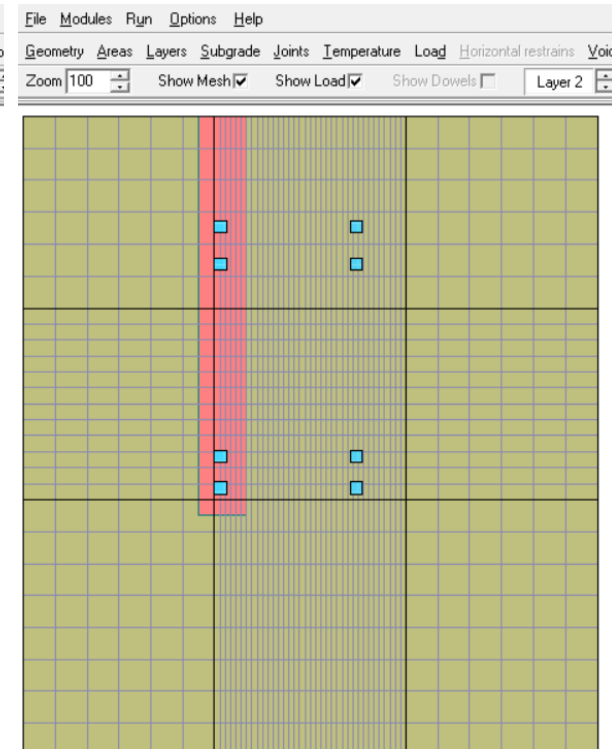
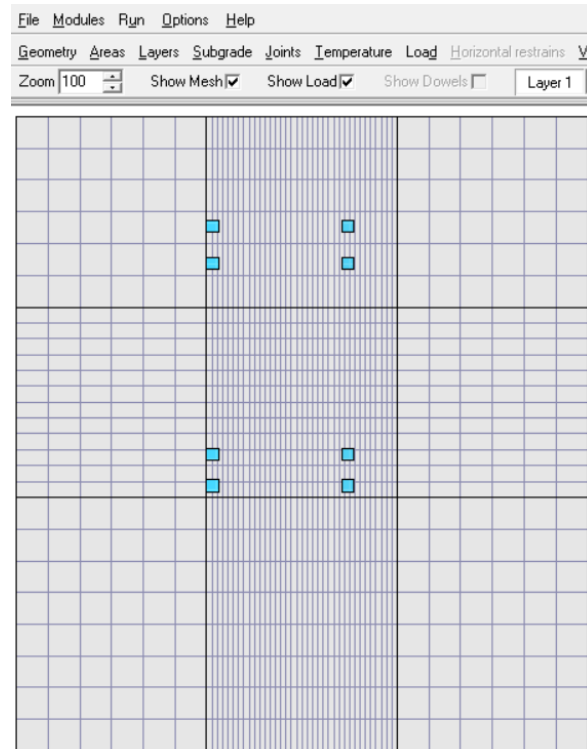
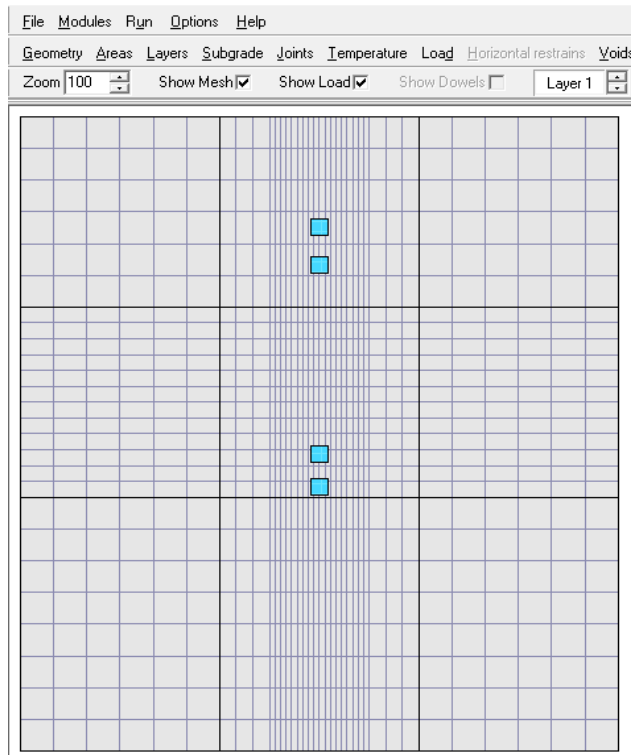
ISLAB2000 Models for Short Slab Overlay

Bottom of Overlay Edge

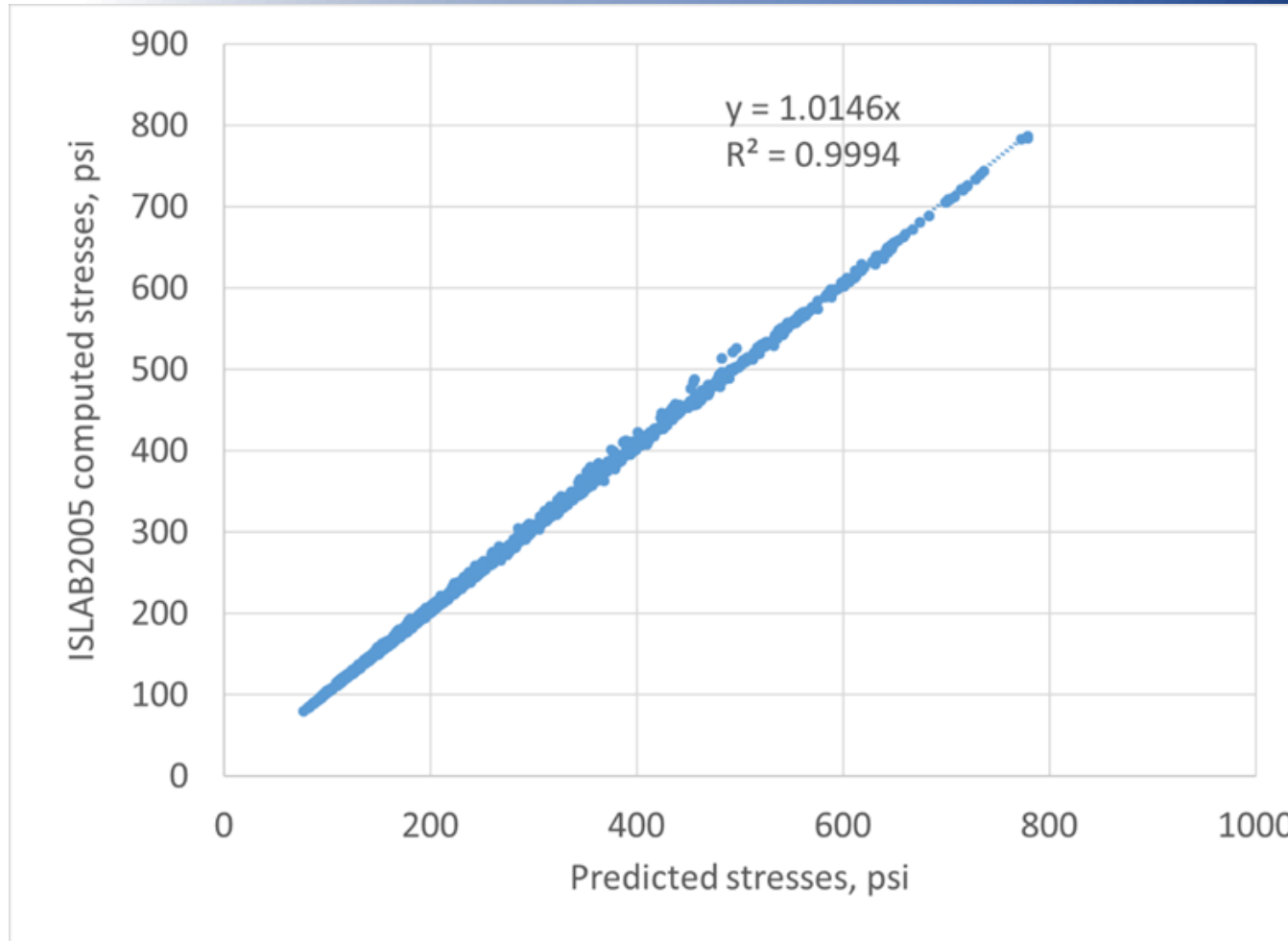
Top of Overlay Edge or Transverse Joint

No void

Void



NNs for Stresses at the Top Surface of the Short Slab/Shoulder Joint



TPF(5)-169 Cracking Model

- Modified built-in curling analysis (NCHRP 1-51 approach)

$$\Delta T_{built-in} = \Delta T_{input} \left(1 \pm \left(1 - \exp\left[-0.001 \frac{\ell_{OL}}{L}\right]^4 \right) \left(1 - \exp\left[-10^{-6} \frac{\ell_{eff}}{L}\right]^4 \right) \right)$$

- Longitudinal edge and transverse cracking analysis
- Monte Carlo-based reliability analysis (MnPAVE Rigid-based approach [Tompkins , Johanneck, and Khazanovich 2019])

Incremental Damage Calculation

- Increment: 1 year
- Frequencies for linear and non-linear temperature gradients
- Stress and damage computations with and w/o void

$$\text{Fatigue Damage} = \sum_i \sum_j \sum_k \sum_l \sum_m \sum_n \frac{n_{ijklmn}}{N_{ijklmn}} \quad \text{Log}(N) = 2.0 * \left(\frac{M_r}{\sigma_{total}} \right)^{1.22} + 0.4371$$

- Four types of fatigue damage
 - Longitudinal edge, bottom overlay surface (transverse bottom-up cracking)
 - Longitudinal edge, top overlay surface (transverse top-down cracking)
 - Transverse joint, top overlay surface (longitudinal/corner cracking)
 - Transvers joint, bottom overlay surface (longitudinal cracking)

Incremental Damage Calculation

- Damage computation for the increment

$$DAM_i = (1 - \Lambda_i) DAM_{i,w/o \text{ void}} + \Lambda_i DAM_{i,w \text{ void}}$$

Λ_i : interlayer deterioration index for the increment i .

Depends on the interlayer age and properties

Cracking Analysis

$$\% \text{ of Cracked Slabs} = \frac{100\%}{1 + C_3 DAM^{C_4}}$$

- Step 1. Compute:
 - Top-down transverse cracking
 - Bottom-up transverse cracking
 - Top-down longitudinal cracking
 - Bottom-up longitudinal cracking

Cracking Analysis

- Step 2. Determine:
 - Transverse cracking

$$TRCRACK = (TCRK_{\text{Bottom_up}} + TCRK_{\text{top-down}} - TCRK_{\text{Bottom_up}} * TCRK_{\text{top-down}})100\%$$

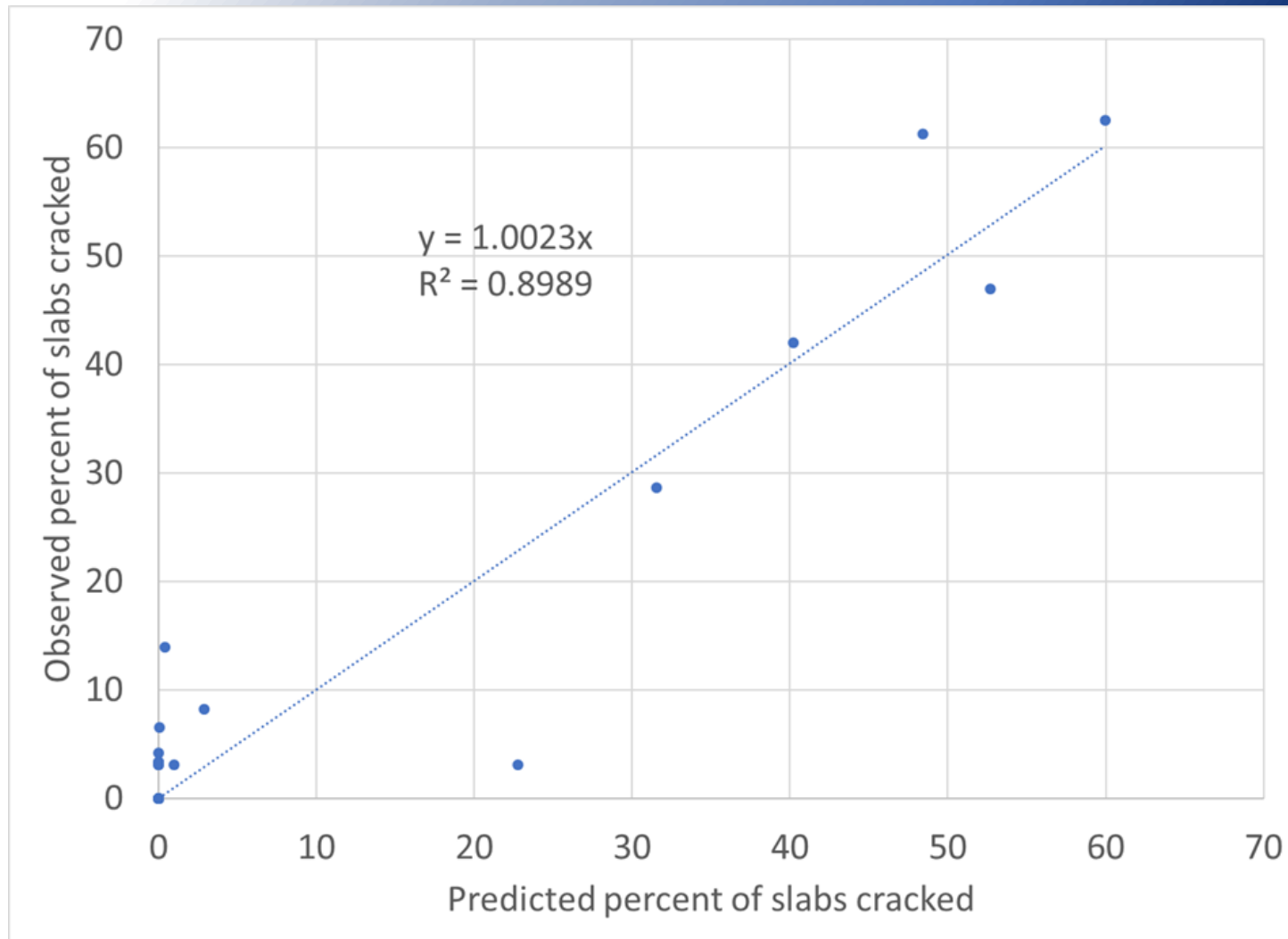
- Longitudinal cracking

$$LCRACK = (LCRK_{\text{Bottom_up}} + LCRK_{\text{top-down}} - LCRK_{\text{Bottom_up}} * LCRK_{\text{top-down}})100\%$$

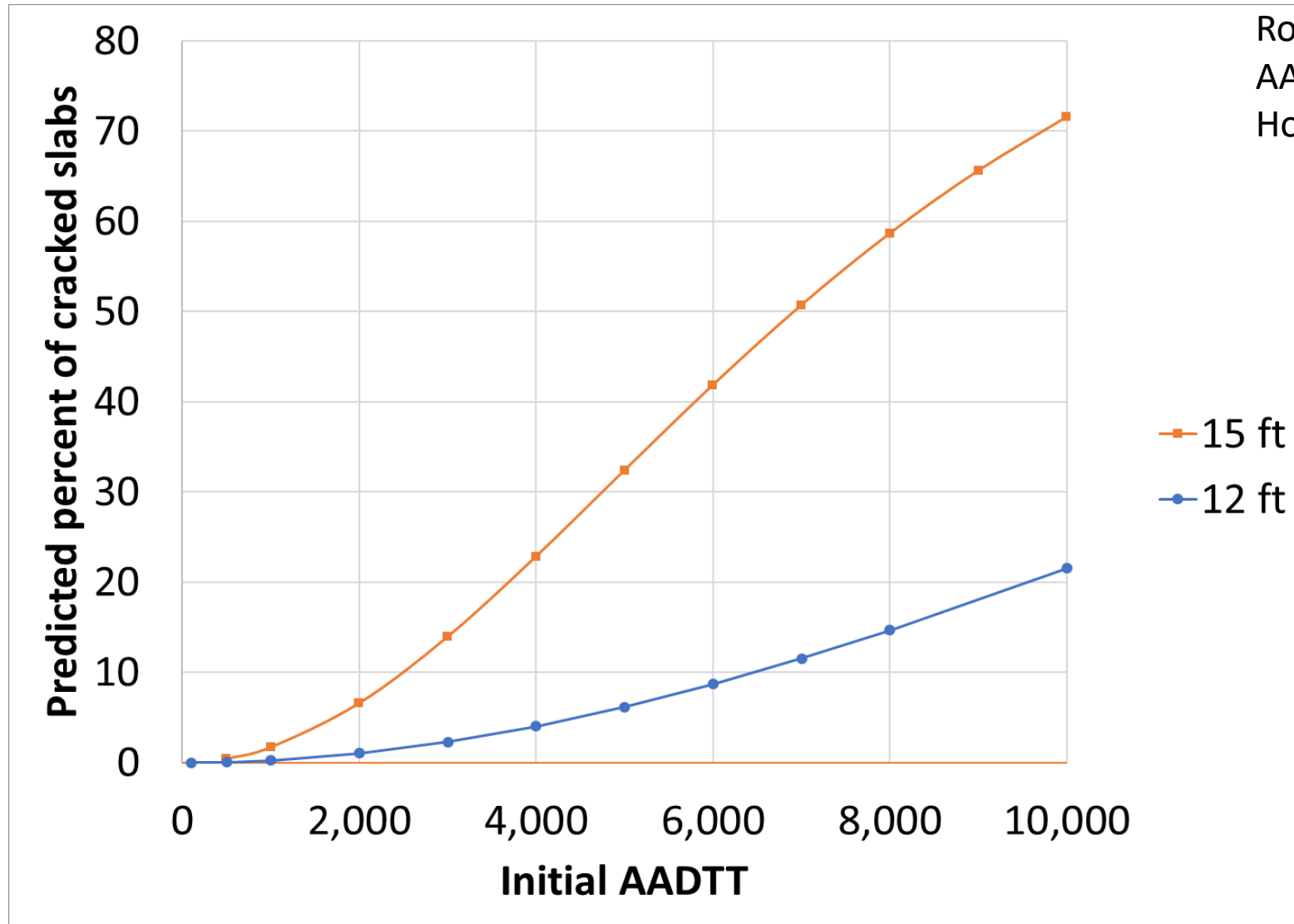
- Step 3. Compute total cracking:

$$CRACK = (TRCRACK + LCRACK - TRCRACK * LCRACK) * 100\%$$

Cracking Model Calibration



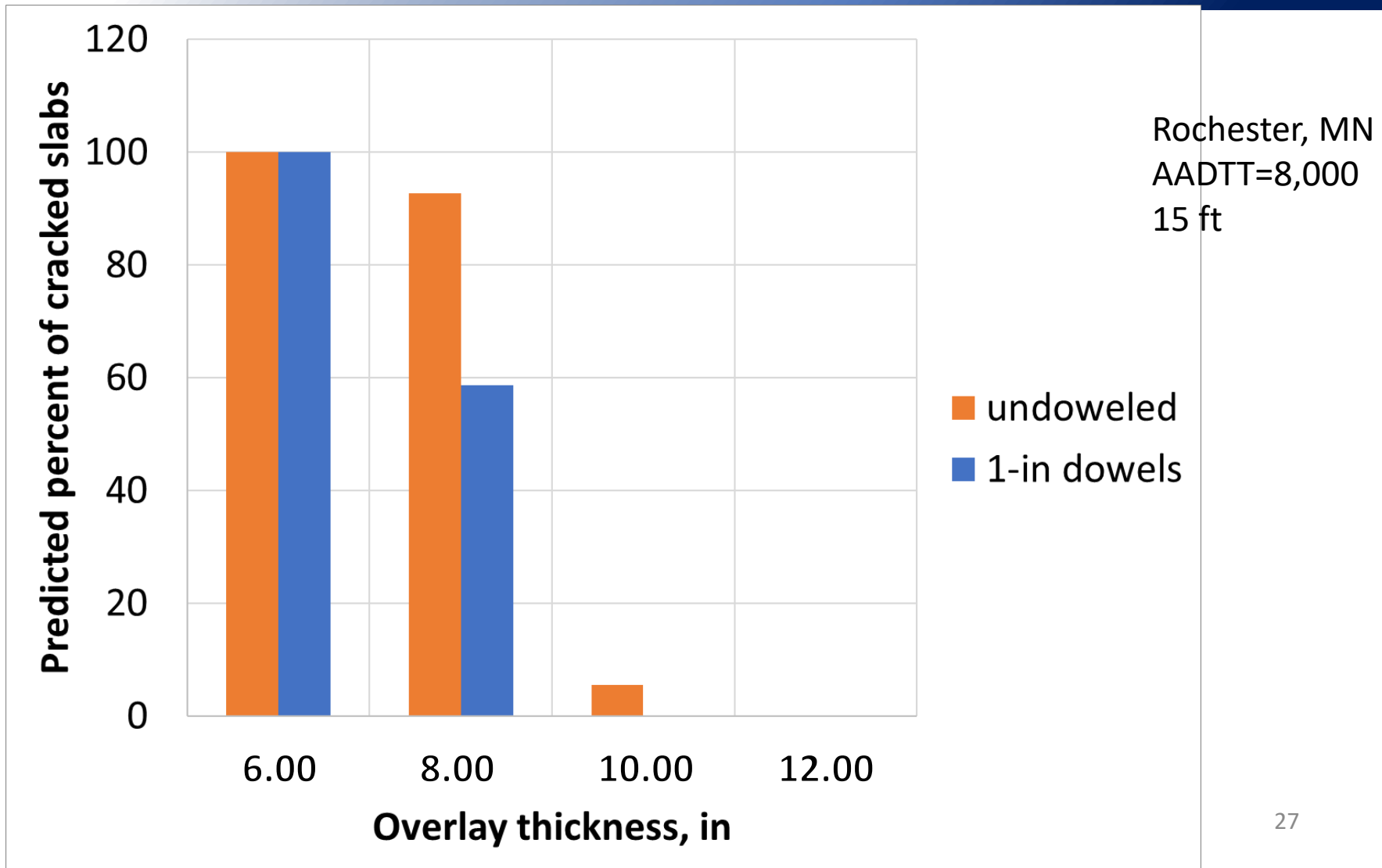
Effect of Joint Spacing



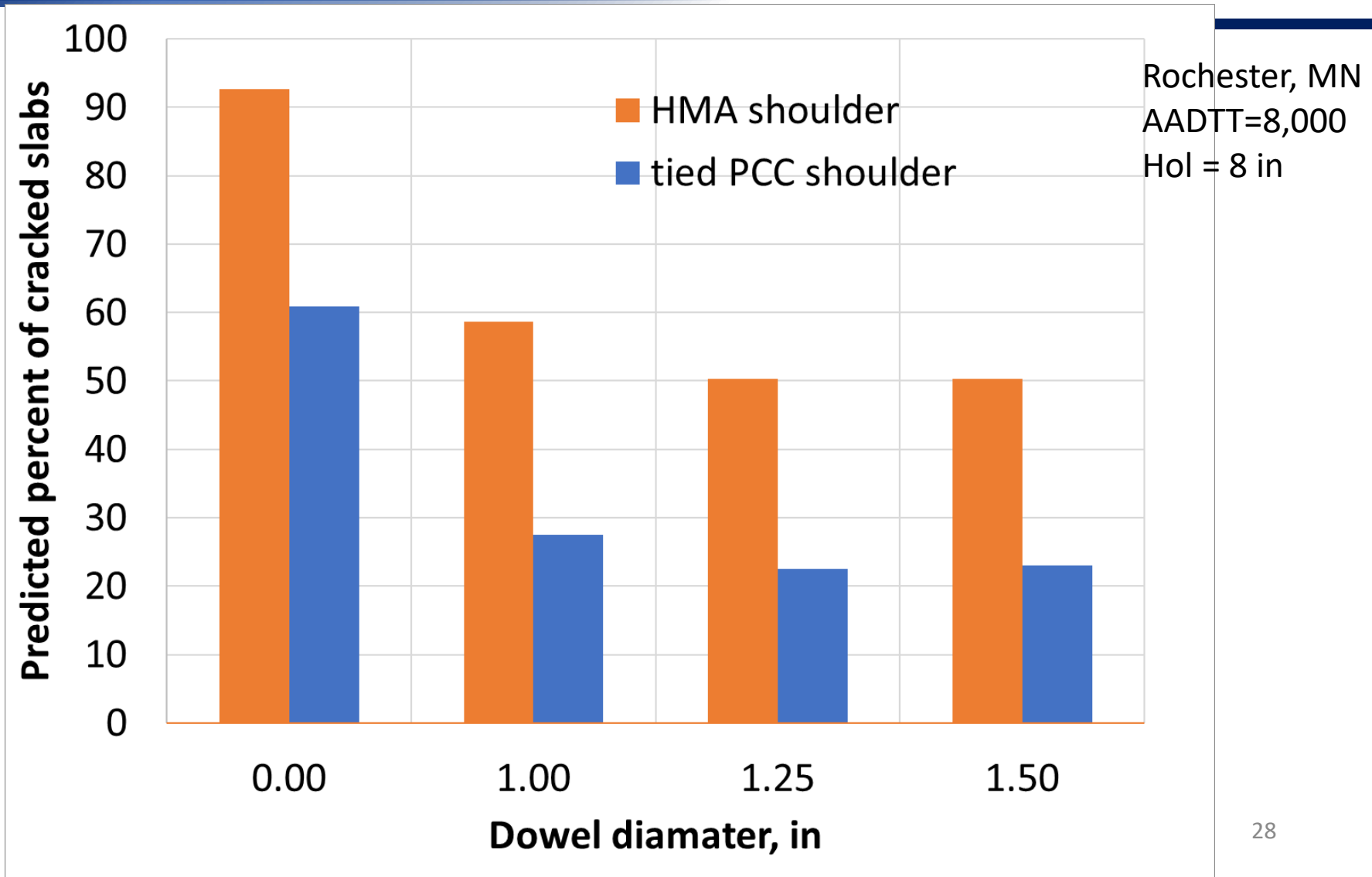
Rochester, MN
AADTT=10,000
Hol = 8 in

—■— 15 ft
—●— 12 ft

Effect of Overlay Thickness on Predicted Cracking



Effect of Dowel Diameter on Predicted Cracking



Software

<https://uboldesign3.azurewebsites.net/>

The screenshot shows a web browser window with the URL <https://uboldesign3.azurewebsites.net/>. The page title is "TPF-5(269) UBOL Design". Below the title, there are "Show" and "Hide" buttons, and a link to "Open a PDF file with the project report." The main form contains several input fields and dropdown menus for design parameters:

Reliability analysis	Climate station
Yes	MOBILE AL

Design Life, years:	Cracking Reliability, %	Faulting Reliability, %:
20	90	90

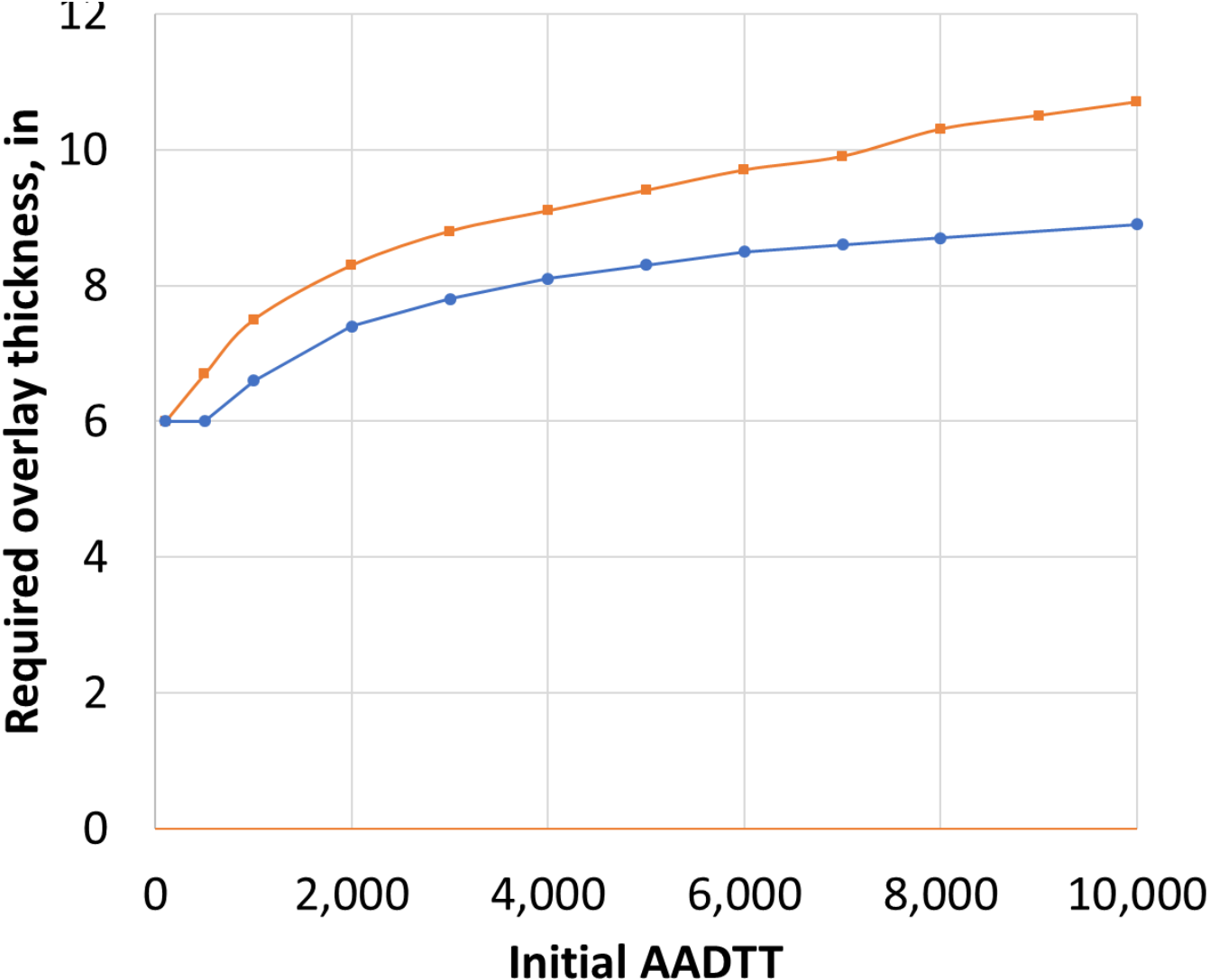
Two-way AADTT Year 1:	Linear Yearly Growth, %	Number of Lanes
1000	3	2

Joint Spacing, ft	Dowel Diameter, in	Shoulder Type
13.5	0	Tied PCC

PCC Flexural Strength, psi:	Existing PCC Thickness, in:	Existing PCC modulus, psi:	Interlayer Type
631.0	10.0	4000000.0	Fabric

At the bottom of the form, there are "Submit" and "Settings" buttons. The Windows taskbar at the bottom shows the time as 8:03 AM on 9/25/2020.

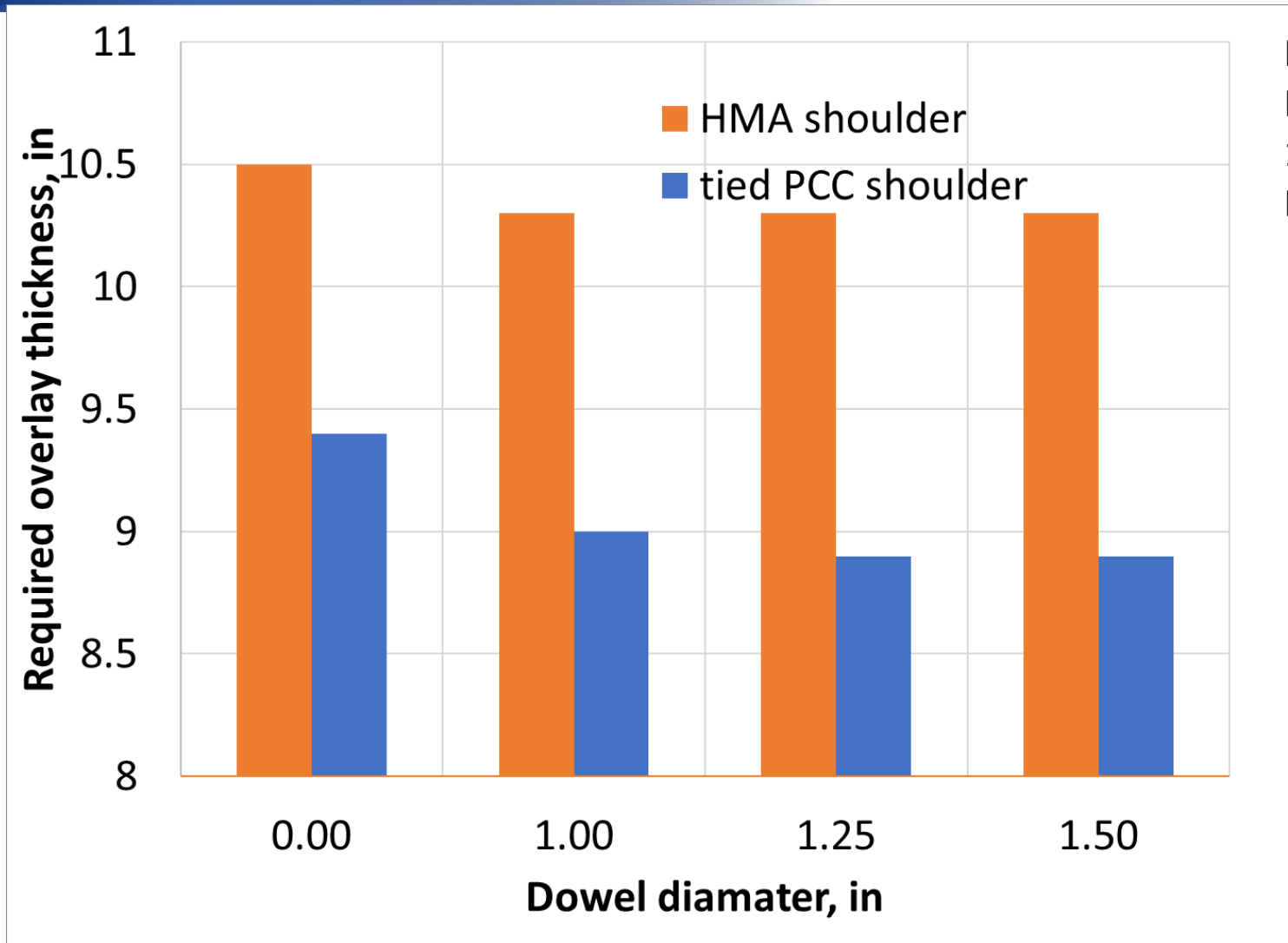
Required Overlay Thickness



Rochester, MN
HMA interlayer
Dowel: 1in
AC shoulder
15% cracked slabs
Reliability: 90%

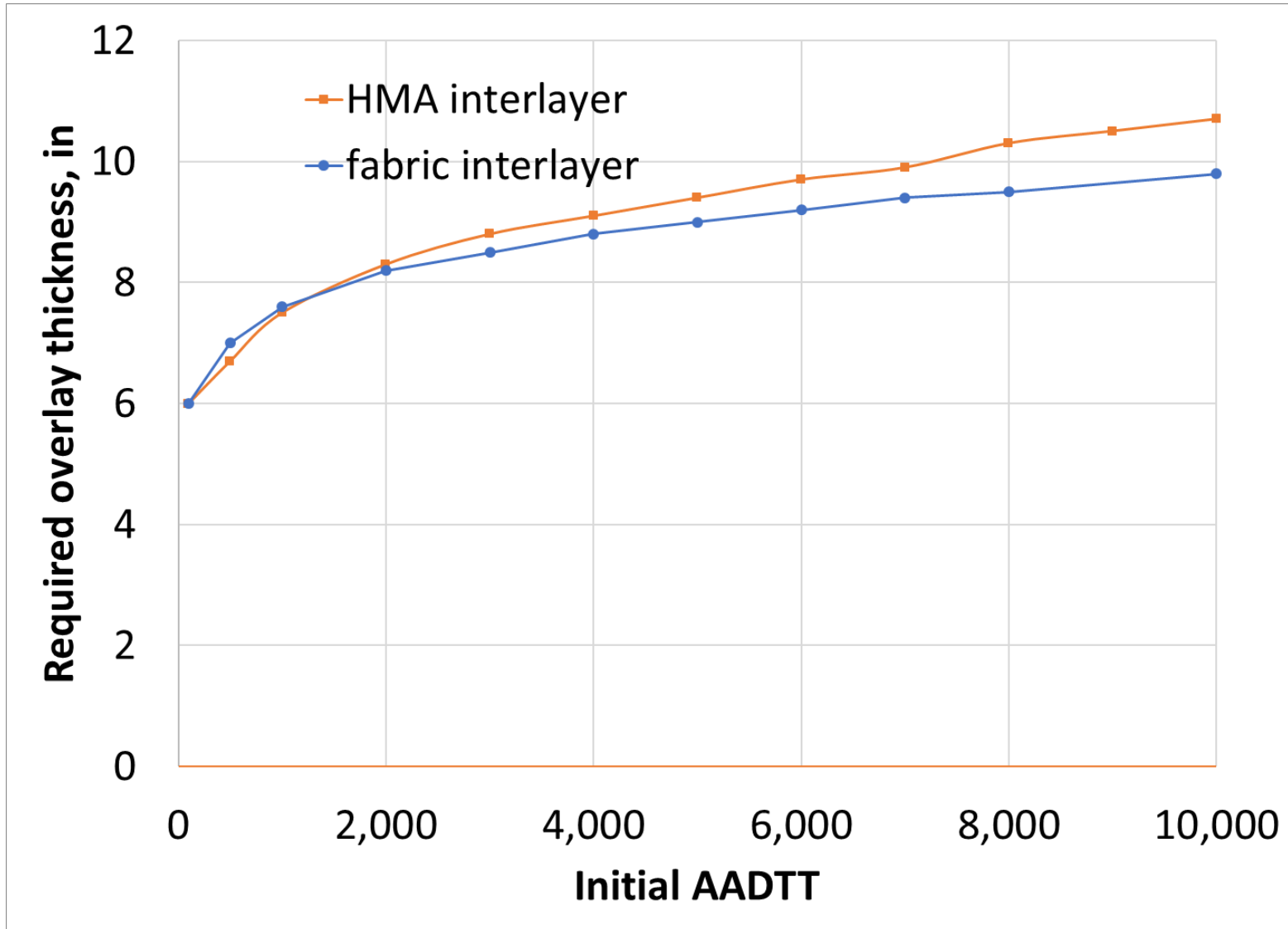
—■— 15 ft
—●— 12 ft

Effect of Edge Support



Rochester, MN
HMA interlayer
15 ft
Reliability: 90%

Effect of Interlayer Type



Conclusions

- Design of unbonded PCC overlays is a challenging problem
- Proper accounting for structural contribution of the interlayer is an important step toward improvement of ME procedure for this type of overlays
- Totski model provides a simple yet robust approach for modeling of interlayer
- Significant progress have been made toward development of improved faulting and cracking models
- The procedure has been implemented into a web-based software

<https://uboldesign3.azurewebsites.net/>

Acknowledgements

- Dr. Derek Tompkins, former postdoc at the University of Minnesota
- U of Pittsburgh students
- U of Minnesota students
- Tom Burnham, MnDOT – project Technical Liaison
- TPF-5(269)-participating state DOTs

<https://uboldesign3.azurewebsites.net/>

Thank You



Any Questions?

<http://uboldesign3.azurewebsites.net/>



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MnDOT



Other TRB events for you

- *October 19:* [Where Are We Now with Performance-Based Pavement Warranties?](#)

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- *Jan 13 - 15:* [International Symposium on Pavement Life Cycle Assessment](#)
- *May 28 - 30:* [International Conference on Resource Sustainability: Sustainable Pavement Technologies](#)

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2020

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