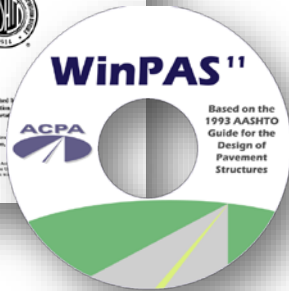
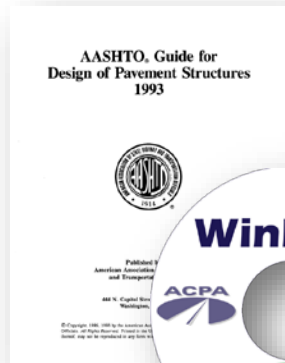


# Pavement Thickness Design Methods



**Municipal Streets Seminar  
November 12, 2014  
Ames, Iowa**



**Eric Ferrebee - ACPA**

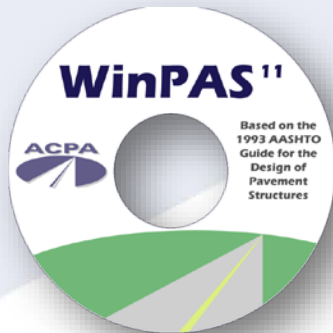
# U.S. JPCP Roadway Design Methods



**AASHTOWare  
Pavement ME**  
(previously known as  
DARWin-ME and  
MEPDG)



**ACPA  
StreetPave**



**AASHTO 93**  
(software as  
ACPA WinPAS)



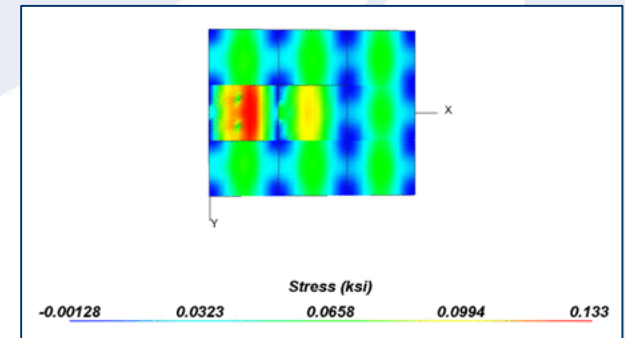
325 & 330

# Design Method Basis

- **Mechanistic** – Purely scientific and based on measured, defensible scientific rules and laws

$$\epsilon = \sigma / E$$

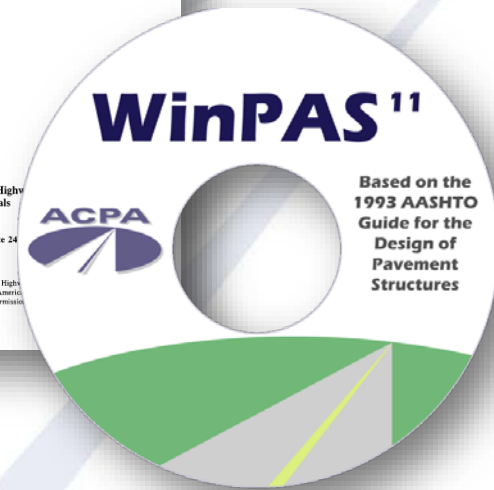
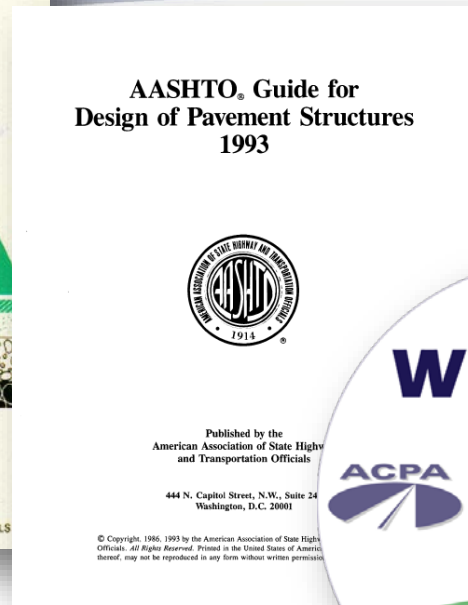
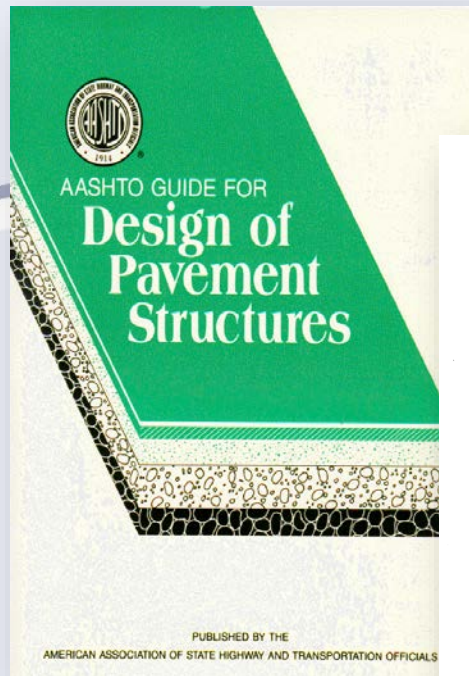
$$\Delta L = \alpha * \Delta T * L_o$$



- **Empirical** – Based on observations or experimentation and requires a lot of tests to connect all the relationships



***Cracking = loads + environment + material***

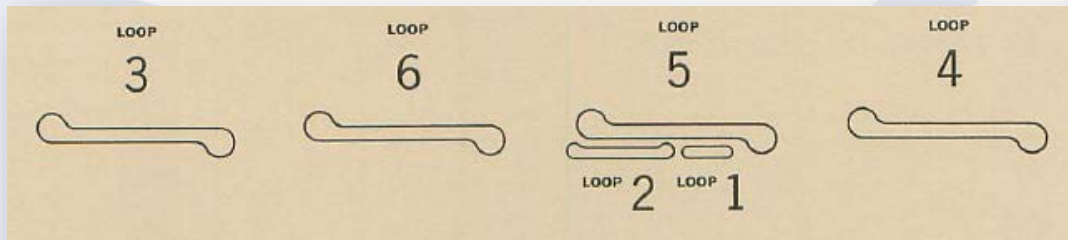
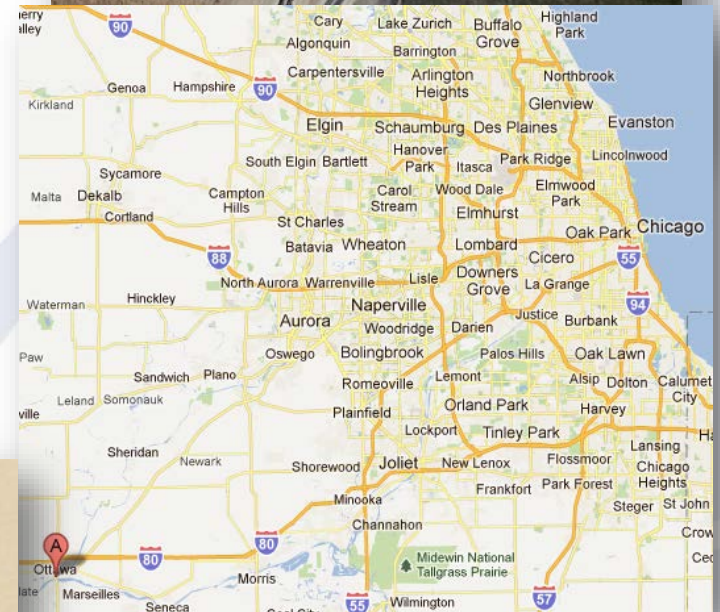
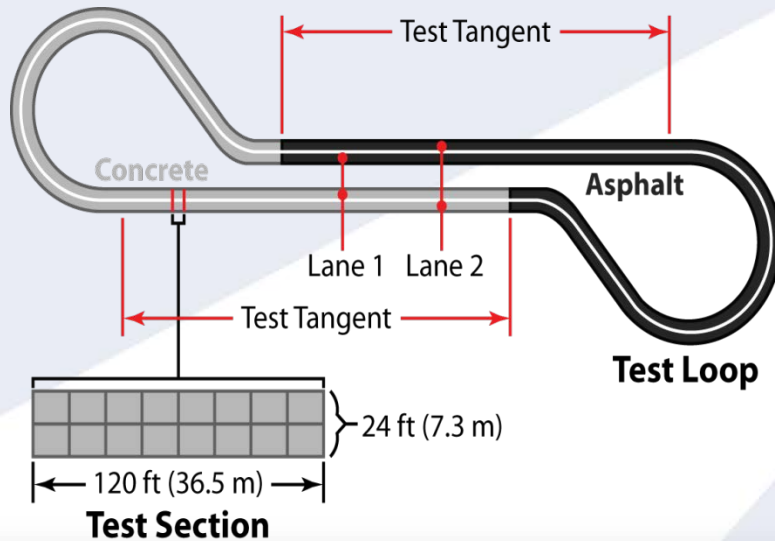


# AASHTO 93 / ACPA WinPAS

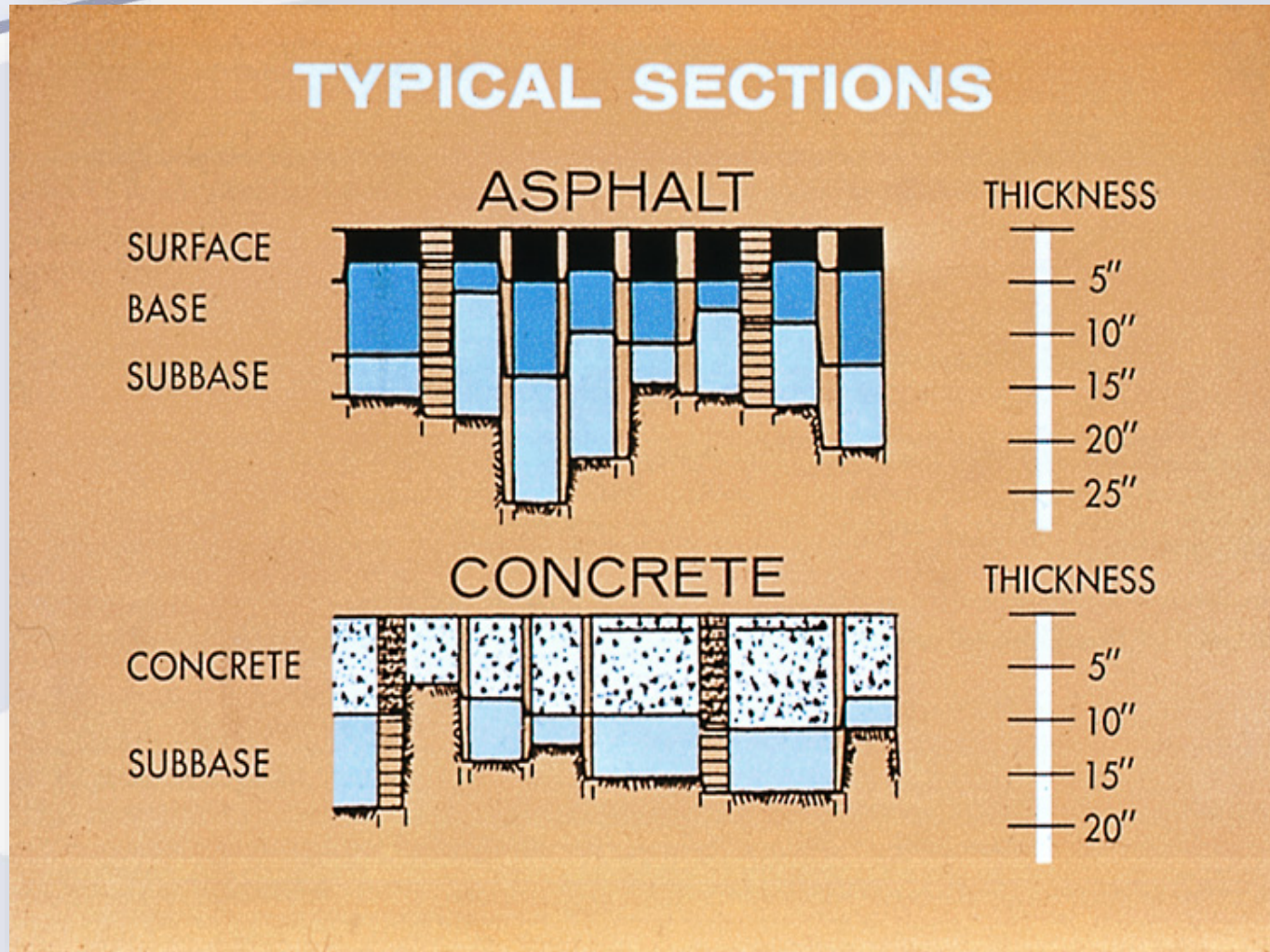
[acpa.org/winpas](http://acpa.org/winpas)

# AASHO Road Test (1958-1960)

- Wholly empirical
- Included 368 concrete and 468 asphalt sections | focus was highway pavement



# Necessary Thickness was Guessed!



**Subgrade = Clay Soil**

# Sections Loaded for 2 Yrs | 1.1 Mil Reps

**Max Single  
Axle**



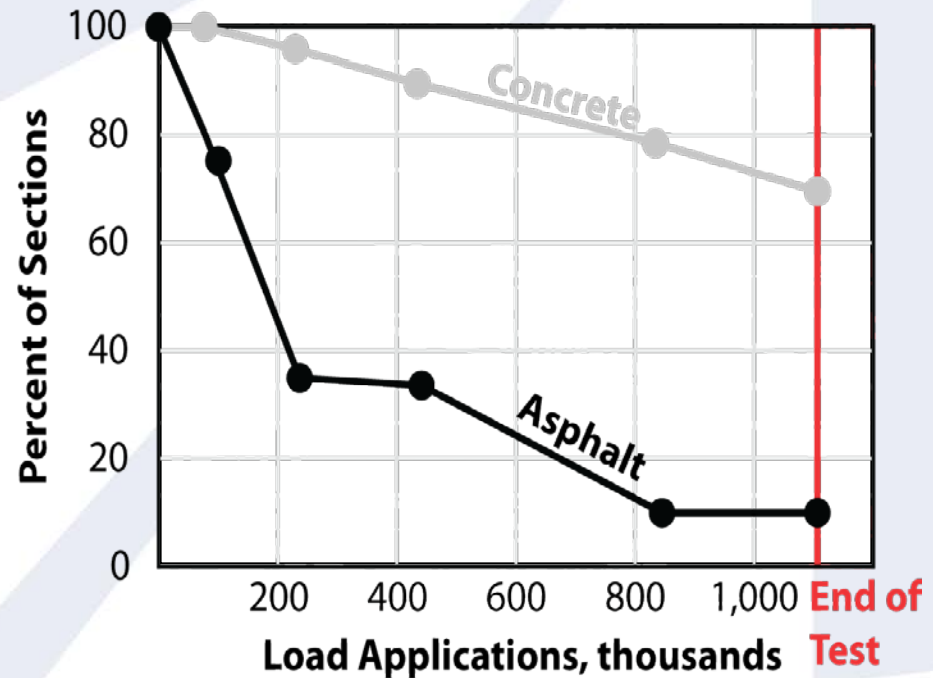
**Max Tandem  
Axle**

# Performance Estimated Subjectively

## ● Present Serviceability Index (PSI)

- 4.0 – 5.0 = Very Good
- 3.0 – 4.0 = Good
- 2.0 – 3.0 = Fair
- 1.0 – 2.0 = Poor
- 0.0 – 1.0 = Very Poor
- “Failure” at the Road Test considered @ 1.5
- Typical U.S. state agency terminal serviceability in practice = 2.5

**PERCENT SURVIVING WITH PSI ABOVE 2.5**





# Note on Inference Space of '93

The experimental design at the AASHO Road Test included a wide range of loads as previously discussed (Section 1.4.1); however, the applied loads were limited to a maximum of 1,114,000 axle applications for those sections which survived the full trafficking period. Thus, the maximum number of 18-kip equivalent single axle loads (ESAL's) applied to any test section was approximately one million. However, by applying the concept of equivalent loads to test sections subjected to only 30-kip single axle loads, for example, it

is possible to extend the findings to  $8 \times 10^6$  ESAL's. Use of any design ESAL's above  $8 \times 10^6$  requires extrapolation beyond the equations developed from the Road Test results. Such extrapolations have, how-

## AASHTO® Guide for Design of Pavement Structures 1993



Published by the  
American Association of State Highway  
and Transportation Officials

444 N. Capitol Street, N.W., Suite 249  
Washington, D.C. 20001

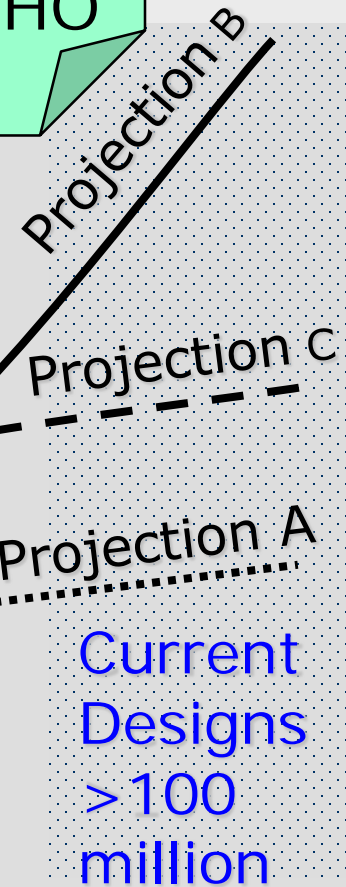
© Copyright, 1986, 1993 by the American Association of State Highway and Transportation Officials. All Rights Reserved. Printed in the United States of America. This book, or parts thereof, may not be reproduced in any form without written permission of the publishers.

PAVEMENT THICKNESS

Data Limits (AASHO Road Test)

1.1mil

Current design traffic is far beyond AASHO road test limits



Current Designs > 100 million

AXLE LOAD REPETITIONS

# Don't Just Take My Word...

GAO

United States General Accounting Office  
Report to the Secretary of  
Transportation

November 1997

## TRANSPORTATION INFRASTRUCTURE

### Highway Pavement Design Guide Is Outdated



GAO/RCED-98-9

"The current design guide and its predecessors were largely based on design equations empirically derived from the observations AASHTO's predecessor made during road performance tests completed in 1959-60. Several transportation experts have criticized the empirical data thus derived as outdated and inadequate for today's highway system. In addition, a March 1994 DOT Office of Inspector General report concluded that the design guide was outdated and that pavement design information it relied on could not be supported and validated with systematic comparisons to actual experience or research."

**...this is why Pavement ME exists!**

# 1986-93 JPCP AASHTO 93 Equation

Change in Serviceability

Standard Normal Deviate

Overall Standard Deviation

**Thickness**

Traffic

$$\text{Log}(ESAL) = Z_R * s_o + 7.35 * \text{Log}(D + 1) - 0.06 + \left[ \frac{\text{Log} \left[ \frac{\Delta PSI}{4.5 - 1.5} \right]}{1 + \frac{1.624 * 10^7}{(D + 1)^{8.46}}} \right]$$

Terminal Serviceability

Modulus of Rupture

Drainage Coefficient

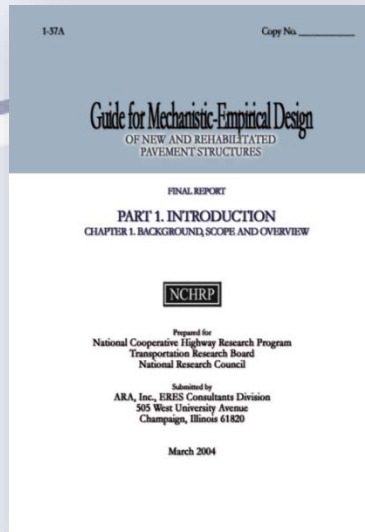
Load Transfer

Modulus of Elasticity

Modulus of Subgrade Reaction

$$+ (4.22 - 0.32 * p_t) * \text{Log} \left[ \frac{s'_c * C_d * (D^{0.75} - 1.132)}{215.63 * J * \left[ D^{0.75} - \frac{18.42}{(E_c / k)^{0.25}} \right]} \right]$$

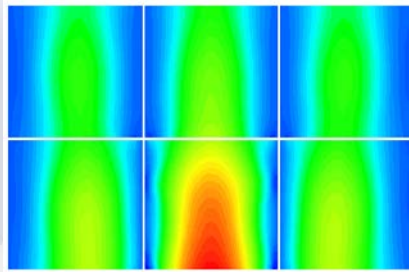
**WHAT DO DESIGNERS FOCUS ON?**



MEPDG / DARWin-ME /  
AASHTOWare Pavement ME

# Pavement ME Design

- Not “perfect” & not intended to be a “final” product
  - Complex and relatively costly
  - For highways and NOT street, road, parking lot, etc.
- 



Mechanistic  
Calculation  
of Responses

+



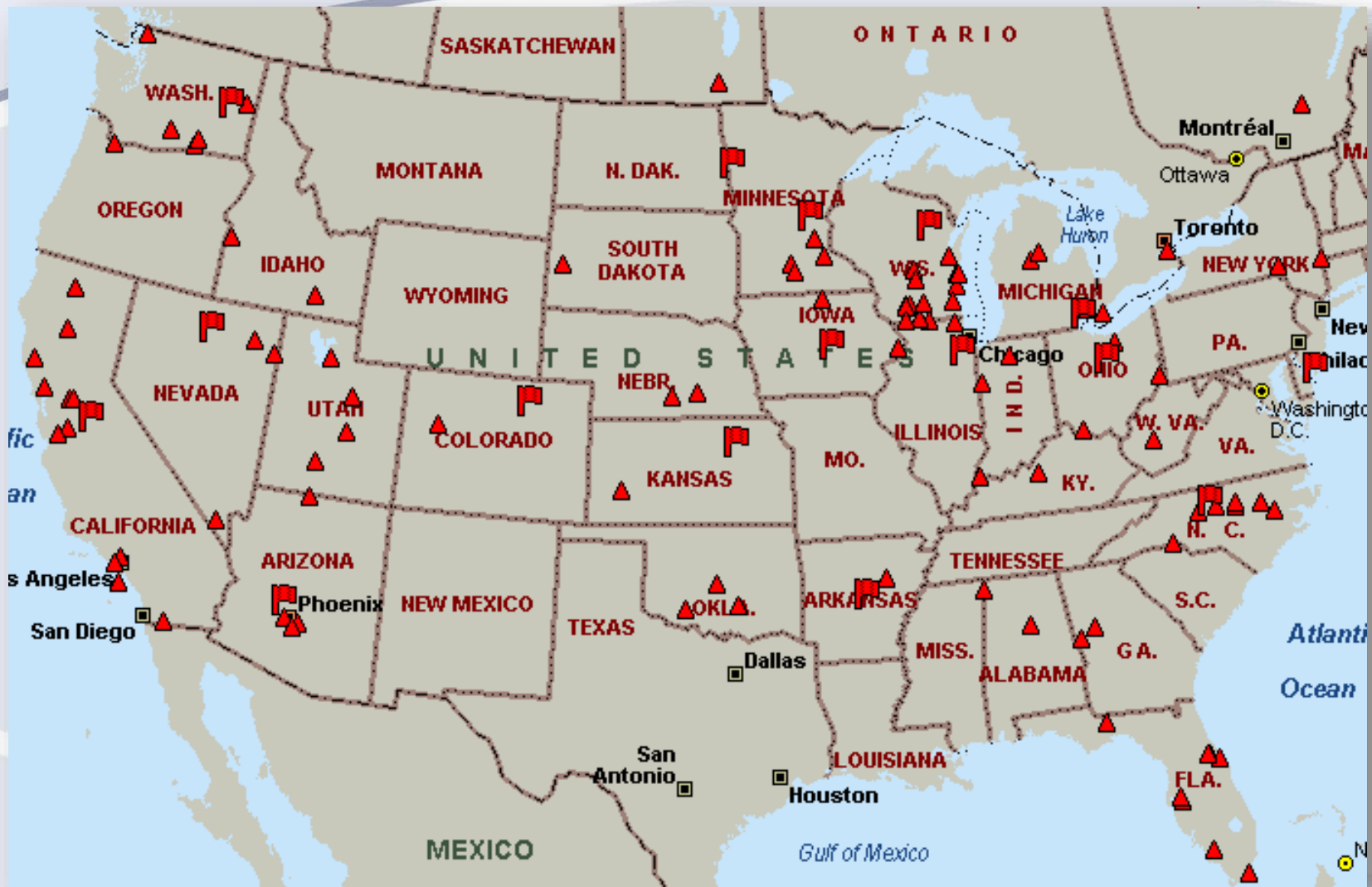
Empirical  
Tie to  
Ground

=



Pavement  
Performance  
Prediction

# JPCP Calibration – BIG INF. SPACE!



▲ LTPP GPS-3 & RPPR JPCP Sections



LTPP SPS-2, MnROAD, & AASHO JPCP Sections

# AASHTO 93 vs. ME

Wide range of structural and rehabilitation designs

design

Limited structural sections

50+ million load reps

traffic

1.1 million load reps

AASHTO 93

AASHTO Pavement ME

1 climate/2 years

climate

All climates over 20-50 years

1 set of materials

materials

New and diverse materials



# Sounds Easy Enough, Right?

$$Fault_m = \sum_{i=1}^m \Delta Fault_i$$

$$\Delta Fault_i = C_{34} * (FAULTMAX_{i-1} - Fault_{i-1})^2 * DE_i$$

$$FAULTMAX_i = FAULTMAX_0 + C_7 * \sum_{j=1}^m DE_j * \text{Log}(1 + C_5 * 5.0^{EROD})^{C_6}$$

$$FAULTMAX_0 = C_{12} * \delta_{\text{curling}} * \left[ \text{Log}(1 + C_5 * 5.0^{EROD}) * \text{Log}\left(\frac{P_{200} * \text{WetDays}}{p_s}\right) \right]^{C_6}$$

$$\sigma_0 = \frac{E_{PCC} \Delta \epsilon_{tot}}{2(1 - \mu_{PCC})}$$

$$IRI = IRI_I + C1 * CRK + C2 * SPALL + C3 * TFAULT + C4 * SF$$

$$SCF = -1400 + 350 * AIR\% * (0.5 + PREFORM) + 3.4 f'c * 0.4 - 0.2 (FTCYC * AGE) + 43 h_{PCC} - 536 WC\_Ratio$$

$$cw = \text{Max} \left( L \cdot \left( \epsilon_{shr} + \alpha_{PCC} \Delta T_c - \frac{c_2 f_\sigma}{E_{PCC}} \right) \cdot 1000 \cdot CC, 0.001 \right)$$

$n$  = traffic path.

The damage increments were discussed previously in this section.

The applied number of load applications ( $N_{i,j,k,l,m,n}$ ) is the actual number of axle type  $k$  of load level  $l$  that passed through traffic path  $n$  under each condition (age, season, and temperature difference). The allowable number of load applications is the number of load cycles at which fatigue failure is expected (corresponding to 50 percent slab cracking) and is a function of the applied stress and PCC strength. The allowable number of load applications is determined using the following fatigue model:

$$\log(N_{i,j,k,l,m,n}) = C_1 \cdot \left( \frac{MR_i}{\sigma_{i,j,k,l,m,n}} \right)^{C_2} + 0.4371 \quad (3.4.10)$$

where,

- $N_{i,j,k,l,m,n}$  = allowable number of load applications at condition  $i, j, k, l, m, n$
- $MR_i$  = PCC modulus of rupture at age  $i$ , psi
- $\sigma_{i,j,k,l,m,n}$  = applied stress at condition  $i, j, k, l, m, n$
- $C_1$  = calibration constant = 2.0
- $C_2$  = calibration constant = 1.22

The fatigue damage calculation is a simple process of summing damage from each damage increment, except that a numerical integration scheme is used to accurately determine the effects of traffic wander. The fatigue damage at the critical damage location caused by an axle load placed at any random distance away from the pavement edge (point  $j$ ) is given by the following:

$$FD_j^* = P(COV_j) \cdot FD_j \quad (3.4.11)$$

The probability of coverage is determined assuming normal distribution.

$$NORMDIST = \frac{1}{SD_{\sigma_e} \sqrt{2\pi}} e^{-\frac{1}{2} \left( \frac{x-\mu}{\sigma} \right)^2} \quad (3.4.12)$$

- = normal distribution density function.
- = wheel location - distance from pavement edge (or outside of the paint stripe for widened slab) to the outer edge of outermost wheel, in.

3.4.64

# INPUTS, INPUTS, INPUTS!!!!

AASHTO DARWin-ME Version 1.0 Build 1.0.18 (Date: 8/31/2011)

Menu

Recent Files

New Open SaveAs Save SaveAll Close Exit Run Batch Import Export Undo Redo Help

Explorer

Project1:Project Project1:Traffic

General Information

Design type: New Pavement

Pavement type: Jointed Plain Concrete f

Design life (years): 20

Pavement construction: June 2013

Traffic opening: Septeml 2013

Performance Criteria

	Limit	Reliability
Initial IRI (in./mile)	63	
Terminal IRI (in./mile)	172	90
JPCP transverse cracking (percent slabs)	15	90
Mean joint faulting (in.)	0.12	90

JPCP Design Properties

JPCP Design

- PCC surface shortwave absorptivity  0.85
- PCC joint spacing (ft) 15
- Sealant type **Preformed**
- Doweled joints **Spacing(12, Diameter(1.25))**
- Widened slab **Not widened**
- Tied shoulders **Not tied**
- Erodibility index **Very erodible (5)**
- PCC-base contact friction **Full friction with friction loss at (240) months**
- Permanent curl/warp effective temperature difference (deg F)  -10
- Identifiers **Default**

Display name/identifier

Display name of object/material/project for outputs and graphical interface

Error List

Project	Object	Property	Description

Output Error List Compare

# INPUTS, INPUTS, INPUTS!!!!

AASHTO DARWin-ME Version 1.0 Build 1.0.18 (Date: 8/31/2011)

Menu

Recent Files

New Open SaveAs Save SaveAll Close Exit Run Batch Import Export Undo Redo Help

Explorer

Project1:Project Project1:Traffic

Vehicle Class Distribution and Growth

Vehicle Class	Distribution (%)	Growth Rate (%)	Growth Function
Class 4	3.3	3	Linear
Class 5	34	3	Linear
Class 6	11.7	3	Linear
Class 7	1.6	3	Linear
Class 8	9.9	3	Linear

Hourly Adjustment

Time of Day	Percentage
12:00 am	2.3
1:00 am	2.3
2:00 am	2.3
3:00 am	2.3
4:00 am	2.3
5:00 am	2.3
6:00 am	5
7:00 am	5
8:00 am	5
9:00 am	5
10:00 am	5.9
11:00 am	5.9
12:00 pm	5.9
1:00 pm	5.9
2:00 pm	5.9
3:00 pm	5.9
4:00 pm	4.6
5:00 pm	4.6
6:00 pm	4.6
7:00 pm	4.6
8:00 pm	3.1

Monthly Adjustment

Month	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12
January	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
February	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
March	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
April	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Axes Per Truck

Vehicle Class	Single	Tandem	Tridem	Quad
Class 4	1.62	0.39	0	0
Class 5	2	0	0	0
Class 6	1.02	0.99	0	0
Class 7	1	0.26	0.83	0
Class 8	2.38	0.67	0	0
Class 9	1.12	1.82	0	0

AAADTT

- Two-way AADTT  4000
- Number of lanes  2
- Percent trucks in desi  50
- Percent trucks in desi  95
- Operational speed (m)  60

Traffic Capacity

- Traffic Capacity Cap  Not enforced

Axle Configuration

- Average axle width (ft)  8.5
- Dual tire spacing (in.)  12
- Tire pressure (psi)  120
- Tandem axle spacing  51.6
- Tridem axle spacing (in)  49.2
- Quad axle spacing (in)  49.2

Lateral Wander

- Mean wheel location (in)  18
- Traffic wander standa  10
- Design lane width (ft)  12

Wheelbase

- Average spacing of sh  12
- Average spacing of m  15
- Average spacing of lo  18
- Percent trucks with sh  33
- Percent trucks with m  33
- Percent trucks with lo  34

Traffic Capacity Cap

Error List

Project	Object	Property	Description
---------	--------	----------	-------------

Output Error List Compare

NOT ESALS!

# OUTPUTS, OUTPUTS, OUTPUTS!!!



## Project1

File Name: C:\Users\rodhen.apel\Documents\My Darwin\ME\Projects\Project1.dgw



### Design Inputs

Design Life: 20 years Existing construction: - Climate Data: 41.986, -87.914  
 Design Type: Jointed Plain Concrete Pavement (JPCP) Pavement construction: June, 2013 Sources (Lat/Lon)  
 Traffic opening: September, 2013

### Design Structure

Layer type	Material Type	Thickness (in.)	Joint Design:	Age (year)	Heavy Truck (cumulative)
PCC	JPCP Default	10.0	Joint spacing (ft)	2013 (Initial)	4,000
NonStabilized aggregate	Permeable aggregate	10.0	Dowel diameter (in.)	2023 (10 years)	7,876,620
Subgrade	A-6	Semi-Infinite	Slab width (ft)	2033 (20 years)	17,835,200

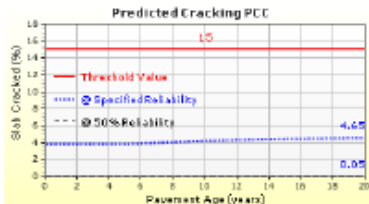
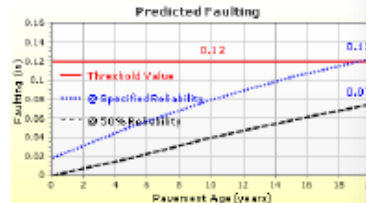
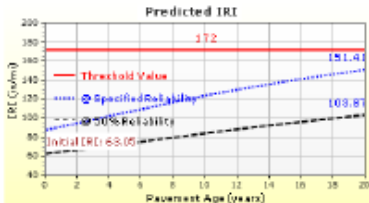
### Traffic

### Design Outputs

#### Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (In./mile)	172.00	151.41	90.00	96.69	Pass
Mean joint faulting (in.)	0.12	0.12	90.00	88.42	Fail
JPCP transverse cracking (percent slabs)	15.00	4.65	90.00	100.00	Pass

#### Distress Charts



## Project1

File Name: C:\Users\rodhen.apel\Documents\My Darwin\ME\Projects\Project1.dgw



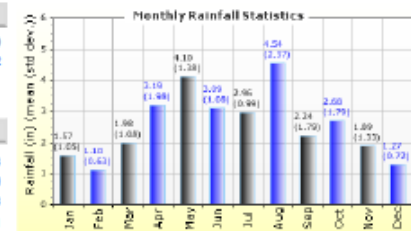
### Climate Inputs

#### Climate Data Sources:

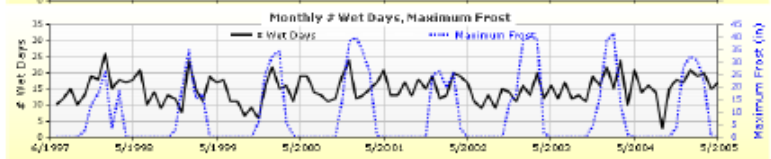
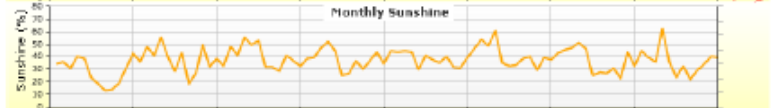
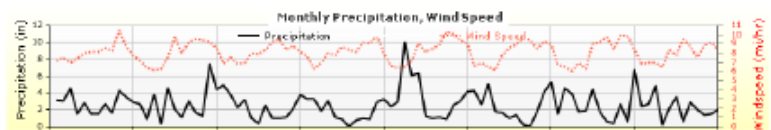
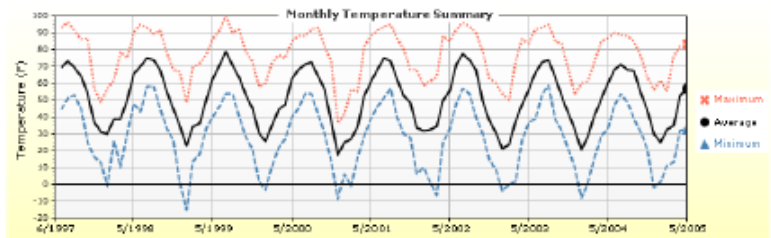
Climate Station Cities: Location (lat lon elevation(ft))  
 CHICAGO, IL 41.98600 -87.91400 662

#### Annual Statistics:

Mean annual air temperature (°F) 51.03  
 Mean annual precipitation (in.) 30.60  
 Freezing index (°F - days) 649.68  
 Average annual number of freeze/thaw cycles: 56.11



#### Monthly Climate Summary:



# Some Agencies Trying to Simplify

MnDOT M-E Design for Rigid Pavements

Main | Design Values | User Guide | About | Defaults

Project name: **Rodden Example** [Load from \*.txt file]

\*.txt file path: C:\Users\rrodden.acpa\Documents\Work\mndot [Edit]

Project notes: Just a test run for a presentation slide

Design life, years: 30      Climate (by district): D4

Initial traffic, HCADT: 5000      Linear yearly growth, %: 3

Axle load spectra: MEPDG Default

Widened outer lane? Yes      Joint spacing, feet: 15

Shoulder type: Tied PCC

Thickness: **8.70**      [Exit]      [Run]

**Note the inputs that have been deemed worth varying...**

**...designers have a new idea of "what matters"!**

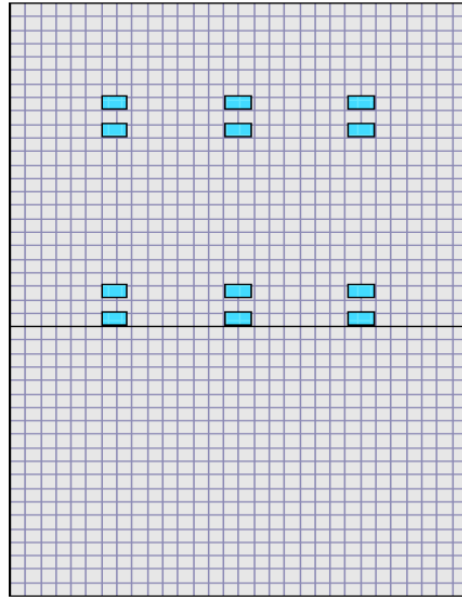
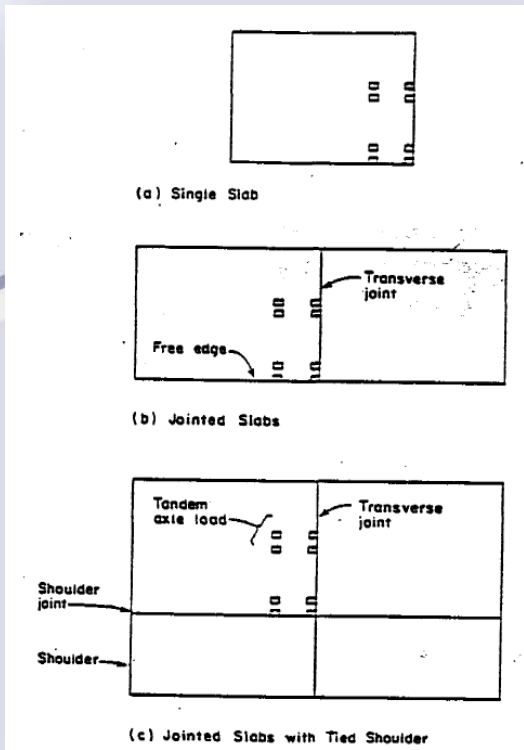


Figure 7. FE model of tridem axle edge loading (lane with tied concrete shoulders).



# ACPA StreetPave

# ACPA StreetPave

- Roots date back to the 1960s PCA Method
- Tailored for streets and roads
- Failure modes are cracking and faulting



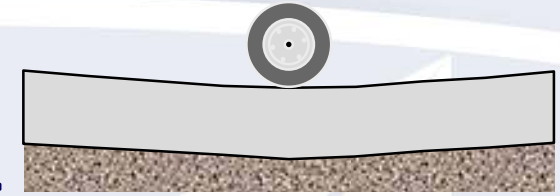
# Traffic Spectrum + Counts

Single Axles		Tandem Axles	
Axle Load (kip)	Axles/1,000 Trucks	Axle Load (kip)	Axles/1,000 Trucks
34	0.19	60	0.57
32	0.54	56	1.07
30	0.63	52	1.79
28	1.78	48	3.03
26	3.52	44	3.52
24	4.16	40	20.31
22	9.69	36	78.19
20	41.82	32	109.54
18	68.27	28	95.79
16	57.07	24	71.16

- Total trucks in design lane over the design life...  
calculated from trucks/day (2-way), traffic growth rate (%/yr), design life (yrs), directional distribution (%) and design lane distribution (%)



# Traffic Loads Generate Stresses



- Equivalent stress at the slab edge:

$$\sigma_{eq} = \frac{6 * M_e}{h_c^2} * f_1 * f_2 * f_3 * f_4$$

$M_e$  = equivalent moment, psi; different for single, tandem, and tridem axles, with and without edge support - func on radius of relative stiffness, which depends on concrete modulus, Poisson's ratio, and thickness and the k-value

$h_c$  = pavement thickness, in.

$f_1$  = adjustment for the effect of axle loads and contact area

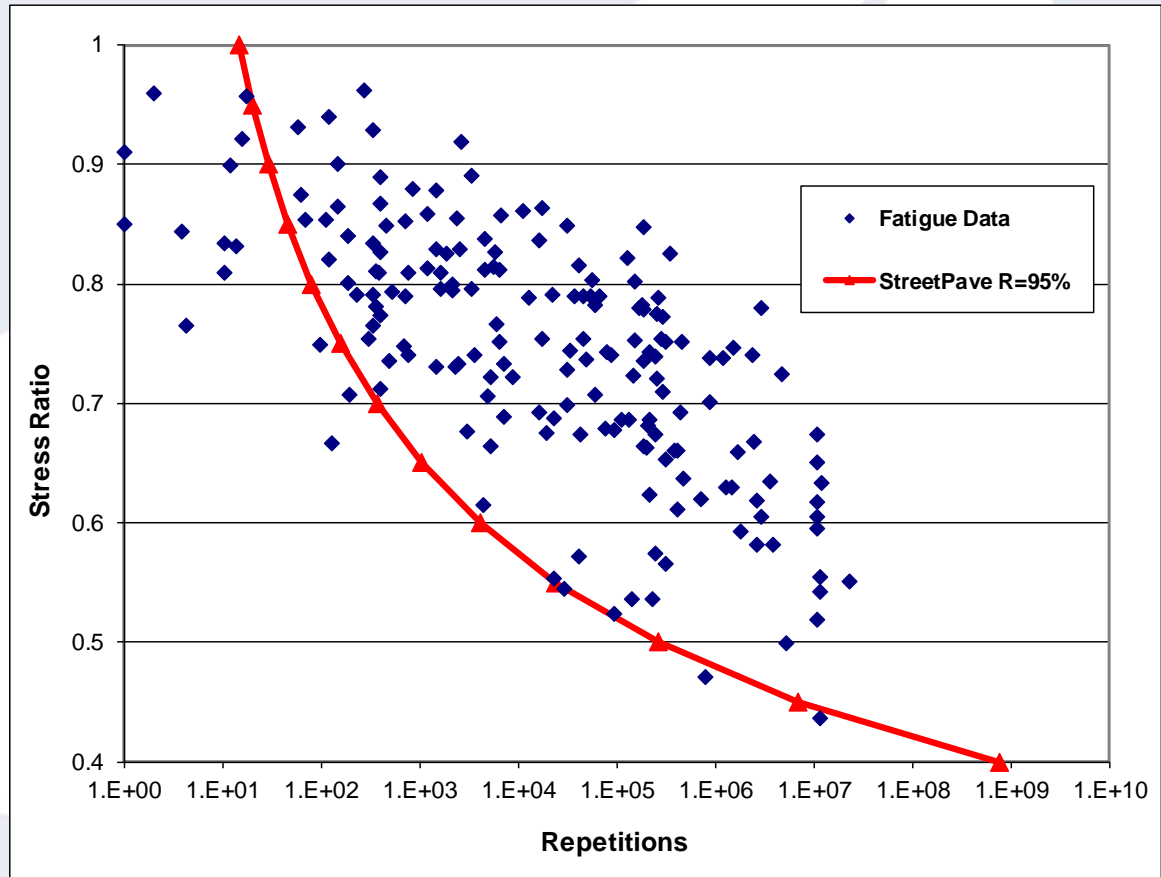
$f_2$  = adjustment for a slab with no concrete shoulder

$f_3$  = adjustment to account for the effect of truck (wheel) placement at the slab edge

$f_4$  = adjustment to account for approximately 23.5% increase in concrete strength with age after the 28<sup>th</sup> day and reduction of one coefficient of variation (COV) to account for materials variability

# Limit Stress Ratio to Allow Design Reps

- Stress Ratio (SR) = Stress / Concrete Strength
- StreetPave makes slab thicker to limit stress ratio low enough to achieve the design traffic repetitions

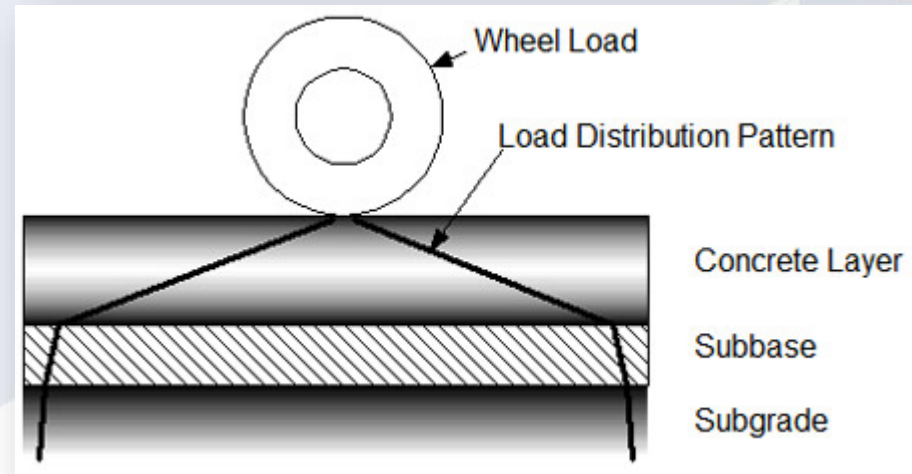


**Inference space normalized to SR**

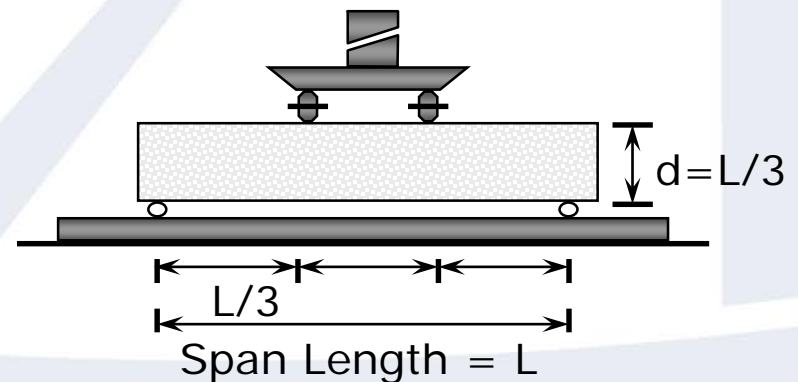
# A Conservative Approach!

- StreetPave fatigue calculation should be conservative relative to ME Design because:

- **Size Effects** – Slabs have a greater fatigue capacity than beams
- **Support** – The beam test has a k-value for support of 0 psi/in.!



...versus...



# Faulting Design in StreetPave

- If dowels used, faulting mitigated & fails by cracks
- No faulting data collected at the AASHO road test so model developed in 1980s using field performance data from WI, MN, ND, GA, and CA
- Similar to cracking models, the pavement is made thicker, as necessary, until faulting model predicts that the pavement will not fail by faulting during the design life
- StreetPave's weak point




# StreetPave Accepted in MN



MINNESOTA DEPARTMENT OF TRANSPORTATION  
State Aid Division  
Technical Memorandum No. 12-SA-03  
October 09, 2012

To: County Engineers  
City Engineers  
MnDOT District State Aid Engineers  
MnDOT District Materials Engineers  
FHWA

From:   
Julie Skallman, P.E.  
State Aid Engineer

Subject: State Aid for Local Transportation (SALT)  
Use of ACPA StreetPave Software for Design of Concrete Pavements for  
Cities and Counties

#### Expiration

This Technical Memorandum will remain in effect until October 09, 2017, unless superseded prior to this date, or the information provided in this Technical Memorandum is incorporated into the State Aid Manual.

#### Implementation

This Technical Memorandum, which allows the use of the American Concrete Pavement Association's (ACPA) StreetPave software for jointed concrete pavement design as an alternative to the MnDOT RigidPave software, is effective immediately. In deciding which software program to use, several factors, including those mentioned in this Technical Memorandum, shall be considered by the Engineer. City, county and consultant engineers working on State Aid and Federal-aid concrete pavement projects are allowed to use the ACPA StreetPave software program as an alternative to the MnDOT RigidPave software program. However, concrete pavement projects within Trunk Highway right-of-way must continue to implement the MnDOT RigidPave design software.

StreetPave Equivalent Bituminous Design and the Life Cycle Cost Module are not approved by SALT.

#### Introduction

In an effort to stay abreast of new technology and design methods, State Aid for Local Transportation (SALT) has recently completed a comparison of the ACPA StreetPave concrete pavement design software and the MnDOT RigidPave concrete pavement design software (previously the only concrete pavement design software approved for State Aid and Federal-aid projects).



## Use of StreetPave for Design of Concrete Pavements for Cities and Counties in Minnesota

Minnesota  
Department of  
Transportation

**RESEARCH  
SERVICES**

Office of  
Policy Analysis,  
Research &  
Innovation

Matthew Oman, Primary Author  
Braun Intertec Corporation

March 2012

Research Project  
Final Report 2012-10



*Your Destination...Our Priority*



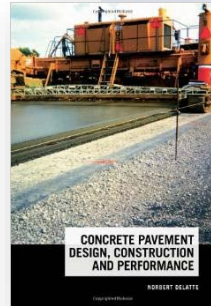
<http://www.dot.state.mn.us/stateaid/admin/memos/12-sa-03.pdf>

<http://www.dot.state.mn.us/research/documents/201210.pdf>

# And Its Use is Growing!



- Also “approved” in VA and many other state, city, and county engineers are using it in the U.S.
- StreetPave used in design tables in:
  - ACI 325 and 330 documents
  - Dr. Norb Delatte’s textbook *Concrete Pavement Design, Construction, and Performance*
- Internationally, used in Australia, Portugal, Mexico, Uruguay, Argentina, Chile, etc.



# StreetPave | Project Details

The screenshot displays the 'StreetPave 12' application window. At the top, there is a menu bar with 'File', 'Units', 'About', and 'Check for Updates'. Below the menu bar are four tabs: 'Project', 'Traffic', 'Design Details', and 'New Pavement Design'. The 'Project' tab is currently selected. The main content area is divided into two sections: 'Project Information' and 'Software Use'. The 'Project Information' section contains five input fields: 'Project Name' (StreetPave Example), 'Route' (Kane St), 'Location' (Anywhere, USA), 'Owner / Agency' (The City), and 'Design Engineer' (Rodden, P.E.). To the right of these fields is a 'Project Description' text area containing the text 'This is just an example to illustrate the key features of StreetPave'. A 'Next' button is located in the top right corner of the 'Project Information' section. The 'Software Use' section contains a dropdown menu with the selected option 'Design a new jointed plain concrete pavement', a 'Help' button, and two questions with 'Option Off' buttons: 'Determine a comparable new asphalt pavement thickness?' and 'Conduct a life cycle cost analysis (LCCA)?'.

StreetPave 12

File Units About Check for Updates

Project Traffic Design Details New Pavement Design

**Project Information** Next

Project Name  Project Description

Route

Location

Owner / Agency

Design Engineer

**Software Use**

Determine a comparable new asphalt pavement thickness?

Conduct a life cycle cost analysis (LCCA)?

# StreetPave | Traffic Details

StreetPave 12

File Units About Check for Updates

Project Traffic Design Details New Pavement Design

### Traffic Category / Load Spectrum

**Typical Traffic Spectrums**    **ACI 330 Traffic Spectrums**    [Help](#)

Residential                       Category A

Collector                               Category B    [Custom Traffic Spectrum](#)

Minor Arterial                       Category C

Major Arterial                       Category D

### Truck Traffic over the Pavement Design Life

Trucks per Day (two-way, at time of construction)  [Calculate](#)

Traffic Growth Rate  % per year [Help](#)

Design Life  years [Help](#)

Directional Distribution  % [Help](#)

Design Lane Distribution  % [Help](#)

Average Trucks per Day in Design Lane over the Design Life                      **162**

Total Trucks in Design Lane over the Design Life    **1,778,099**

Traffic Category: Major Arterial	
Axle load, kips	Axes / 1000 trucks
<b>Single Axles</b>	
34	0.19
32	0.54
30	0.63
28	1.78
26	3.52
24	4.16
22	9.69
20	41.82
18	68.27
16	57.07
<b>Tandem Axles</b>	
60	0.57
56	1.07
52	1.79
48	3.03
44	3.52
40	20.31
36	78.19
32	109.54
28	95.79
24	71.16
<b>Tridem Axles (User Defined Only)</b>	
78	0
72	0
66	0
60	0
54	0
48	0
42	0
36	0
30	0
24	0

[Next](#)



# StreetPave | Design Details | General

The screenshot shows the 'StreetPave 12' software interface. The window title is 'StreetPave 12'. The menu bar includes 'File', 'Units', 'About', and 'Check for Updates'. Below the menu bar are four tabs: 'Project', 'Traffic', 'Design Details', and 'New Pavement Design'. The 'Design Details' tab is active, and within it, the 'Global' sub-tab is selected. The main content area is titled 'General Design Inputs' and contains the following fields and controls:

- Terminal Serviceability:** A text input field containing the value '2' and a 'Help' button.
- Reliability:** A text input field containing the value '85' followed by a '%' symbol, and a 'Help' button.
- Resilient Modulus of the Subgrade:** A section with two radio button options:
  - Convert CBR or R-value to MRSG: Includes a 'Calculate' button and a text field displaying '4,118 psi'.
  - Input a known MRSG: Includes a 'Help' button and a text field containing '4,118 psi'.

A 'Next' button is located in the top right corner of the main content area.

# StreetPave | Design Details | Concrete

StreetPave 12

File Units About Check for Updates

Project Traffic Design Details New Pavement Design

Global Concrete Asphalt

**Percent of Slabs Cracked at End of Design Life** Next

Slabs Cracked  % Help

**Composite Modulus of Subgrade Reaction (Static k-Value)** Help

Use calculated composite static k-value  Enter a known static k-value

Calculate  psi/in.  psi/in.

**Concrete Material Properties**

28-Day Flexural Strength (MR)  psi Calculate Help Modulus of Elasticity (E)  psi Help

Macrofibers in Concrete?  Help

**Edge Support**

Edge support (e.g., tied concrete shoulder, curb and gutter, or widened lane) provided?  yes  no Help

# StreetPave | Design Results

StreetPave 12

File Units About Check for Updates

Project Traffic Design Details New Pavement Design

Run Design

**CONCRETE PAVEMENT DESIGN**

Rigid ESALs = 1,331,869

Composite Modulus of Subgrade Reaction (Static k-Value) = 100 psi/in.

Save Project As

View/Print Design Summary

Sensitivity Analysis of Concrete Pavement Design

k-value  Reliability

Concrete Strength  % Slabs Cracked

Design Life

	Min. Required Thickness	Design Thickness	Max Joint Spacing	Failure Controlled By
	in.	in.	ft	
*Doweled	7.80	8.00	15	Cracking
Undoweled	7.80	8.00	15	Cracking

Load Transfer Rec. Jointing Rec.

Cracking/Faulting Table Rounding Considerations

\*Because the doweled thickness is less than 8 in. and cracking is the predicted cause of failure, dowel bars typically would not be recommended for the design details you provided.

# StreetPave | Design Report

9/29/2014 5:37:00PM Engineer: Rodden, P.E. Page 1 of 3

Dowel/Condition  
**StreetPave 12**

**Report for Concrete Pavement Design**

Project Name: StreetPave Example  
 Route: Kane St  
 Location: Anywhere, USA  
 Project Description: This is just an example to illustrate the key feat  
 Owner/Agency: The City  
 Design Engineer: Rodden, P.E.

**Recommended Concrete Pavement Design**

Min. Required Thickness = 7.8 in  
 Design Thickness = 8.00 in  
 Max. Joint Spacing = 15 ft  
 Failure Controlled By = Cracking

\*Because the doweled thickness is less than 8 in. and cracking is the predicted cause of failure, dowel bars typically would not be recommended for the design details you provided.

Thickness Adjustment	Thickness (in.)	Reliability at Specified Design Life (%)	Theoretical Life at Specified Reliability (yrs)
Rounded-Down	7.50	99.9	14
None (As-Designed)	7.8	85	30
Rounded-Up (Recommended)	8.00	99.9	47

**Inputs**

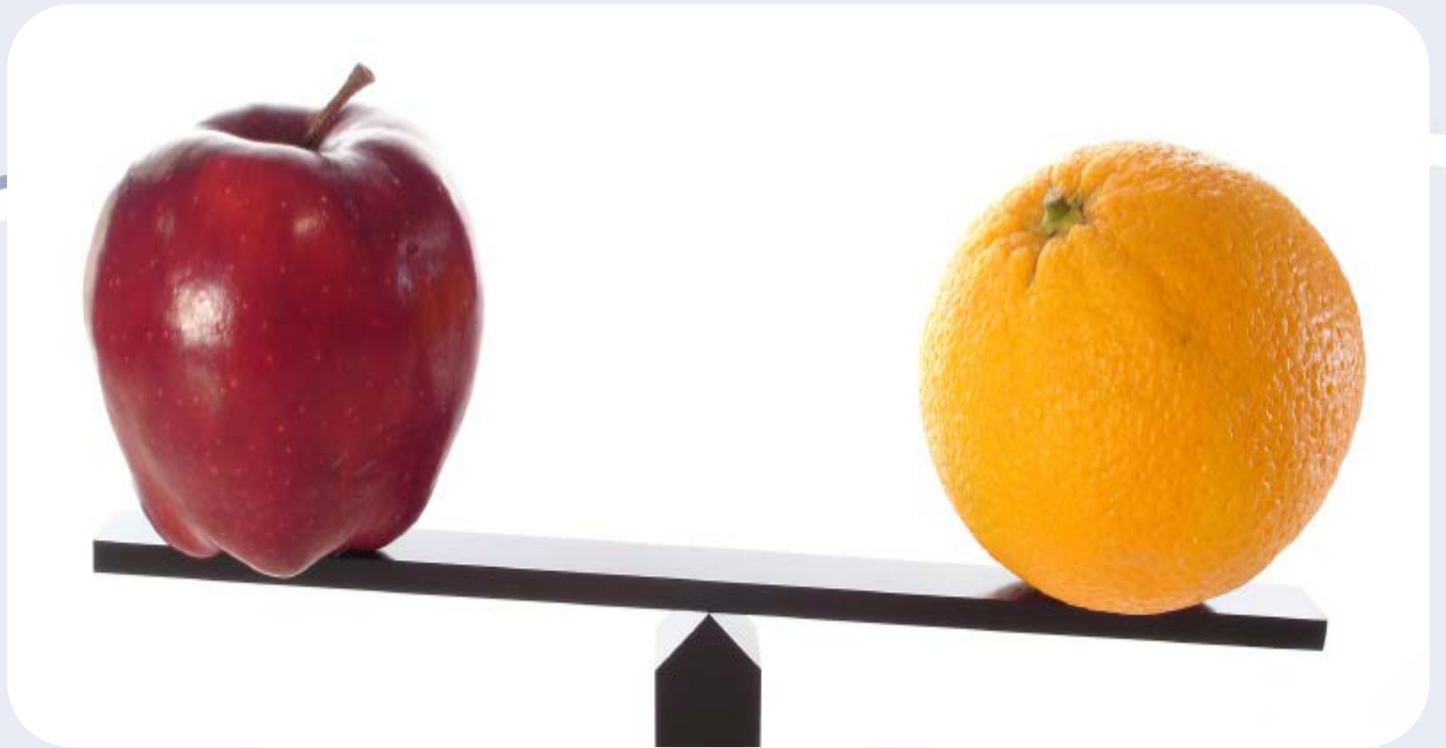
Design Life: 30 years  
 Reliability: 85 %  
 Reliability: 15 %  
 Percent of Slabs Cracked at End of Design Life: Major Arterial

**Traffic**

Traffic Category: 50  
 Direction Distribution: 100  
 Design Lane Distribution: 240 per day  
 Trucks per Day (two-way, at time of construction): 2 % per year  
 Truck Traffic Growth: 1,331,869  
 Rigid ESALs =

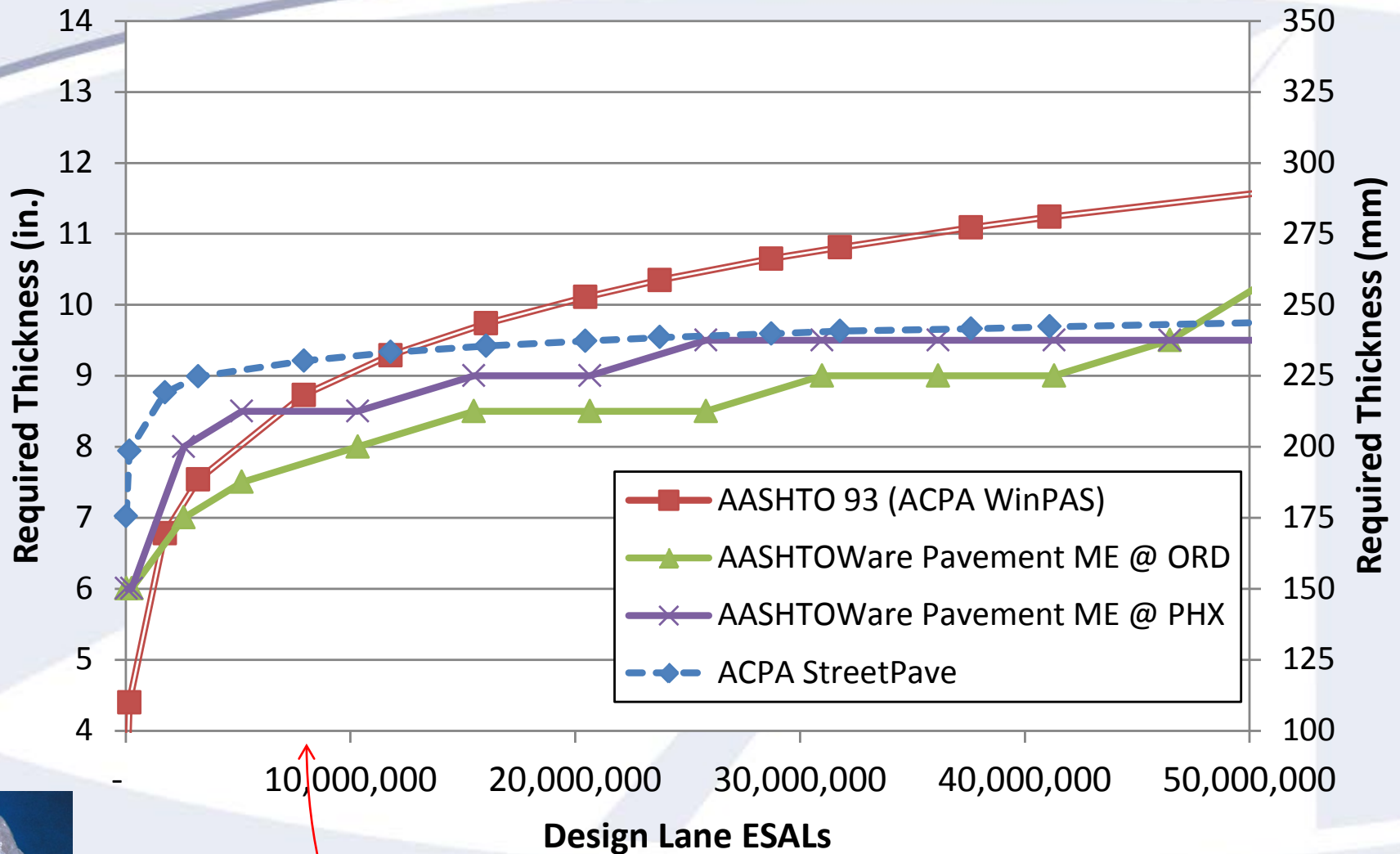
American Concrete Pavement Association  
[www.acpa.org](http://www.acpa.org) || [apps.acpa.org](http://apps.acpa.org)

Traffic Category: Major Arterial			Cracking Analysis		
Axle Load, kips	Axes per 1000 Trucks	Expected Repetitions	Stress Ratio	Allowable Repetitions	Fatigue Consumed
<b>Single Axles</b>					
34	0.19	338	0.699	1018	33.18
32	0.54	960	0.661	2593	37.02
30	0.63	1120	0.622	8064	13.89
28	1.78	3165	0.583	32514	9.73
26	3.52	6259	0.544	185111	3.38
24	4.16	7397	0.504	1682478	0.44
22	9.69	17230	0.465	29293913	0.06
20	41.82	74360	0.425	unlimited	0.01
18	68.27	121391	0.385	unlimited	0
16	57.07	101476	0.344	unlimited	0
<b>Tandem Axles</b>					
60	0.57	1014	0.546	167538	0.6
56	1.07	1903	0.511	1081193	0.18
52	1.79	3183	0.477	11068268	0.03
48	3.03	5388	0.442	211811503	0
44	3.52	6259	0.408	unlimited	0
40	20.31	36113	0.373	unlimited	0
36	78.19	139030	0.338	unlimited	0
32	109.54	194773	0.302	unlimited	0
28	95.79	170324	0.266	unlimited	0
24	71.16	126530	0.231	unlimited	0
<b>Total Fatigue Used %:</b>					<b>98.53</b>



# Comparison of Results and U.S. Trends

# Doweled JPCP Thickness Comparison

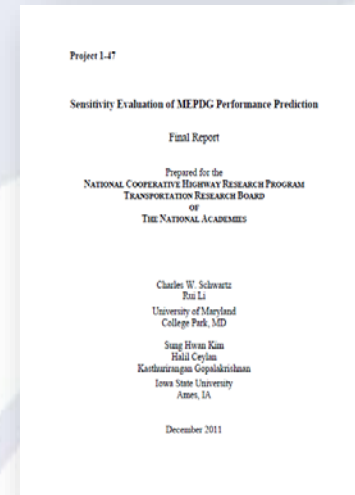


remember AASHTO 93 limit?



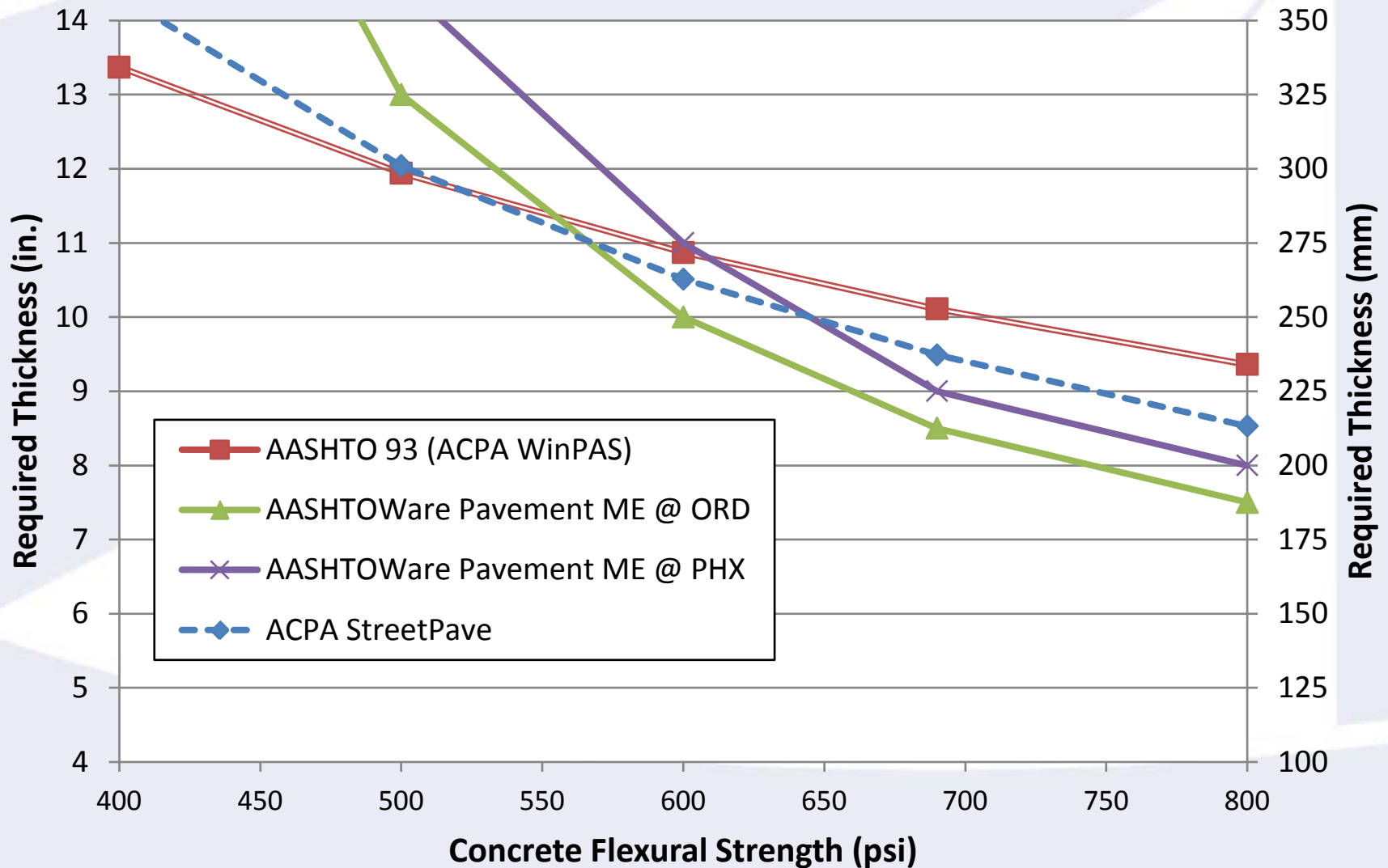
# Top 10 ME Design Most Sensitive

1. **Concrete Flexural Strength at 28-Days**
2. Concrete Thickness
3. Surface Shortwave Absorptivity (SSA)
4. Joint Spacing
5. **Concrete Modulus of Elasticity at 28-Days**
6. Design Lane Width with a 14 ft (4.3 m) Widened Slab
7. **Edge Support via Widened Slab**
8. Concrete Thermal Conductivity
9. Concrete Coefficient of Thermal Expansion (CTE)
10. Concrete Unit Weight



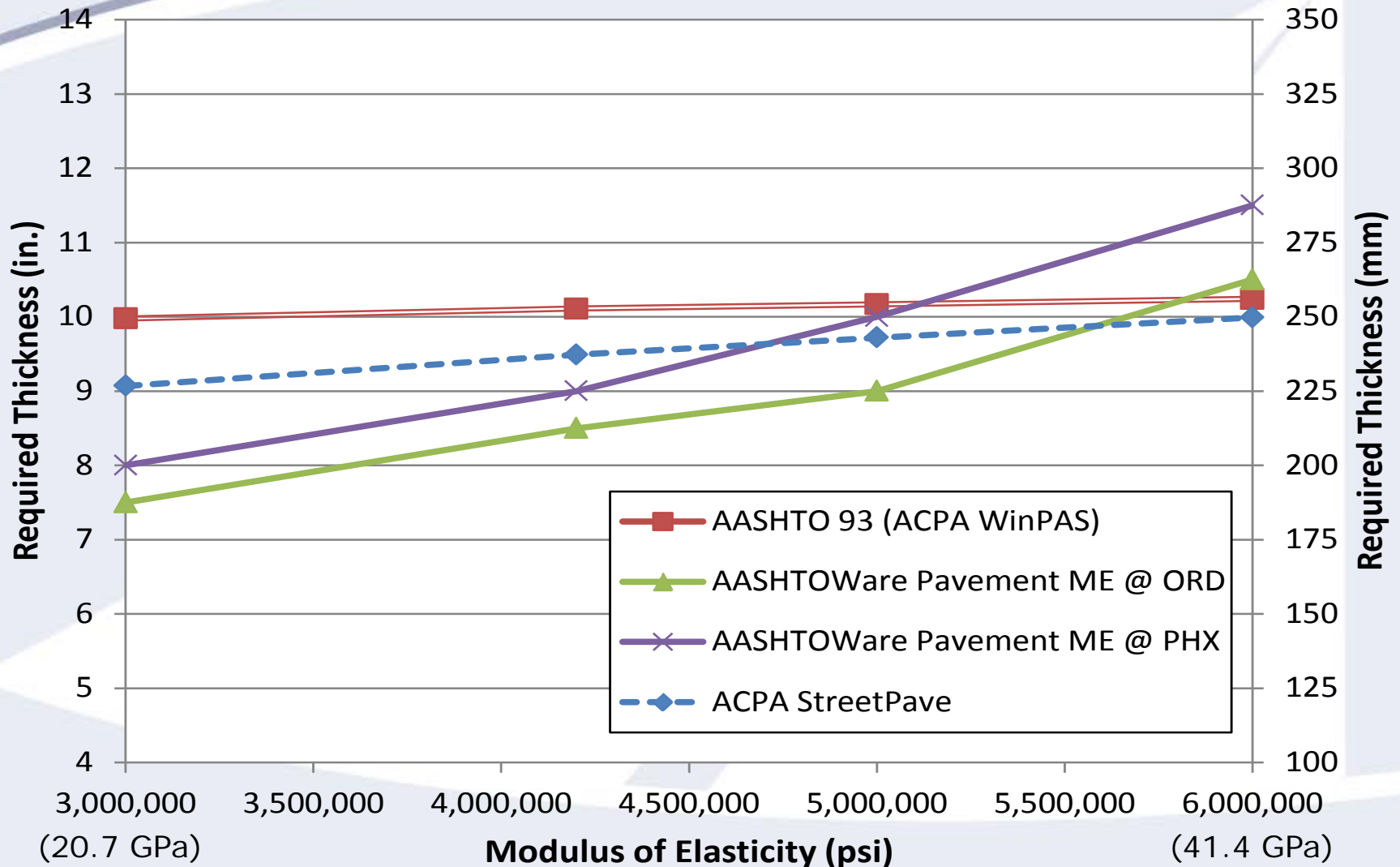
Red = only ME Design input... the **VALUE** of the software!  
Blue + Bold = common for all

# Flexural Strength Sensitivity



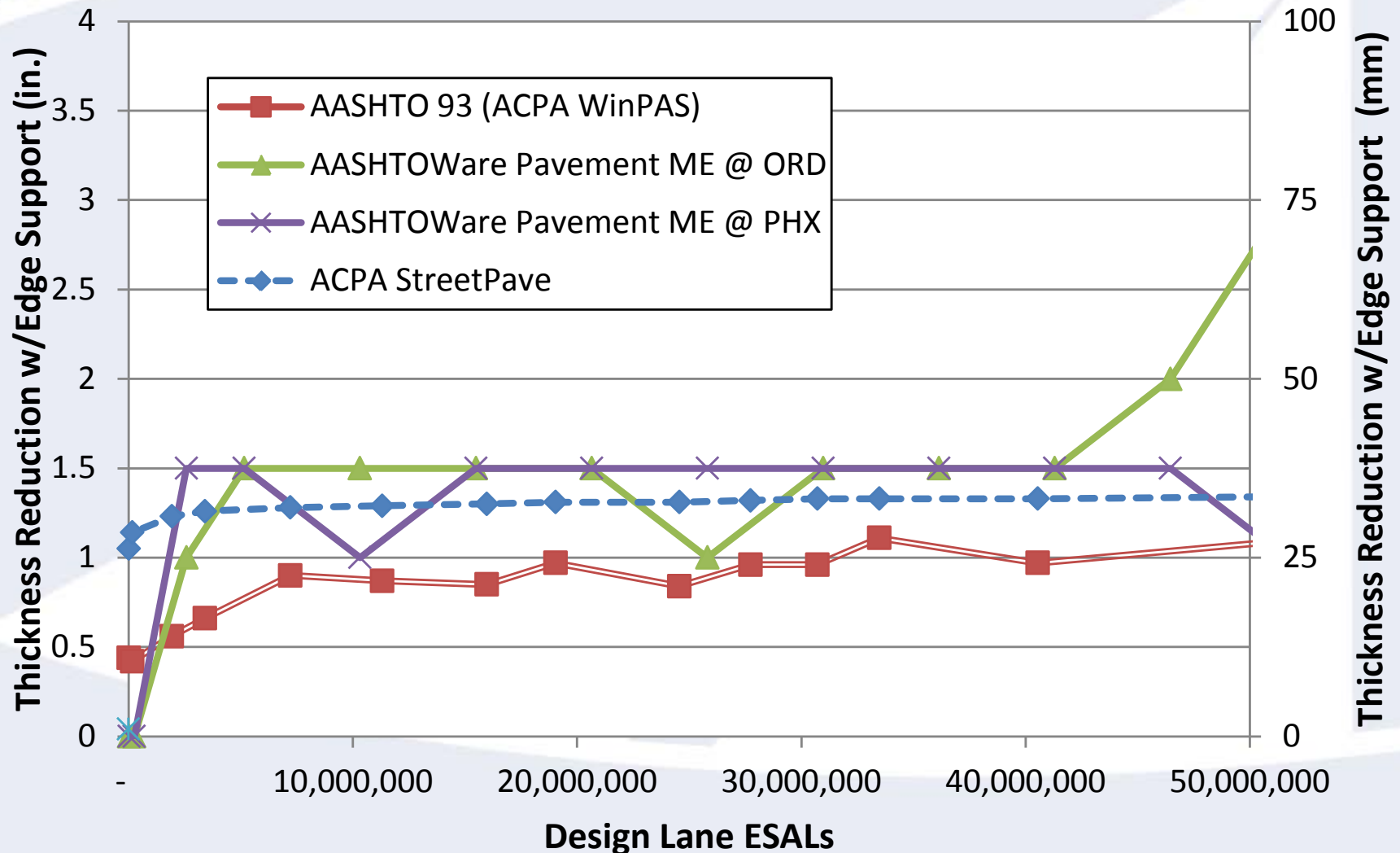


# Modulus of Elasticity Sensitivity

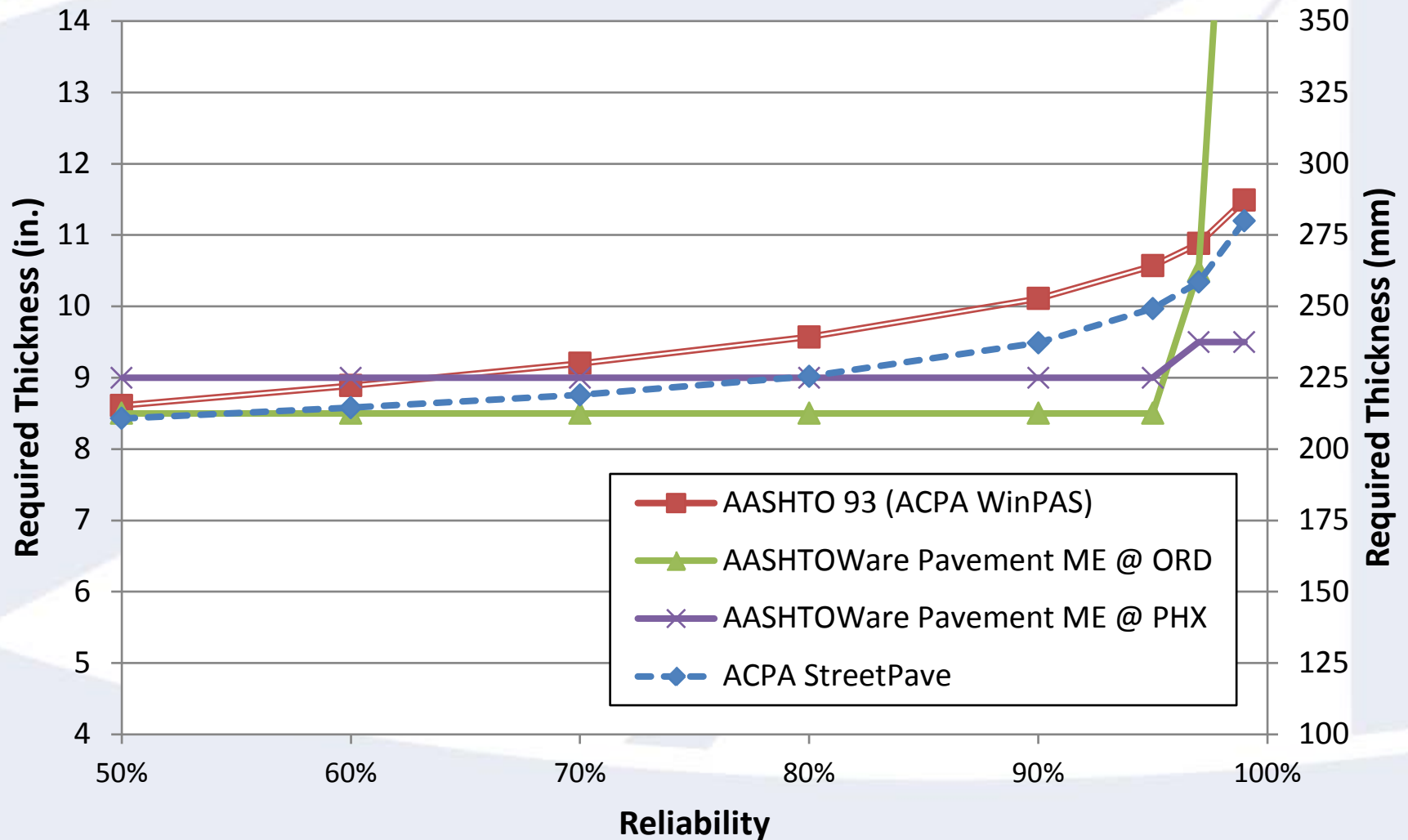


**... in reality, need to change strength too...**

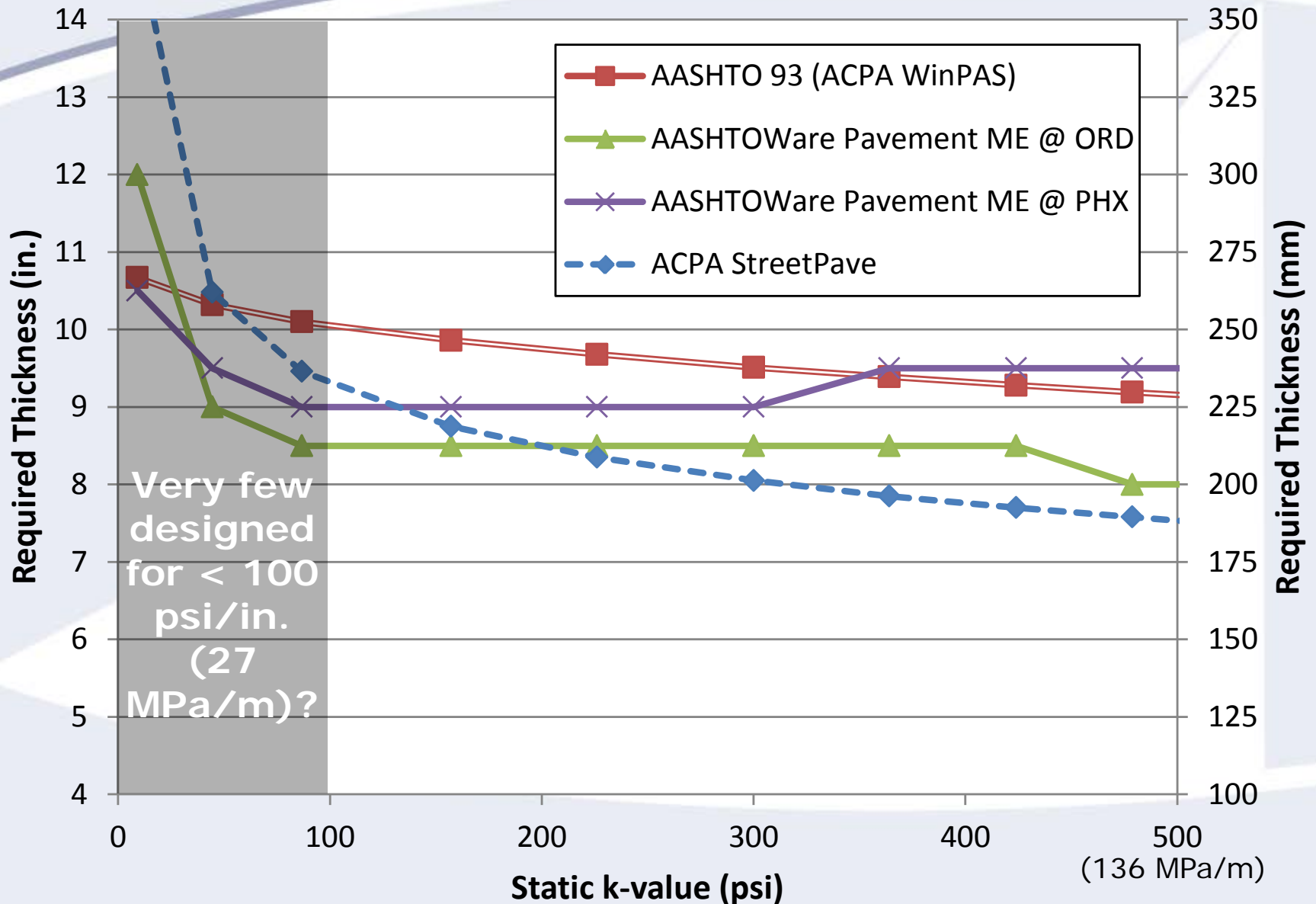
# Thickness Reduction w/ Edge Support



# Reliability Sensitivity



# k-value Sensitivity



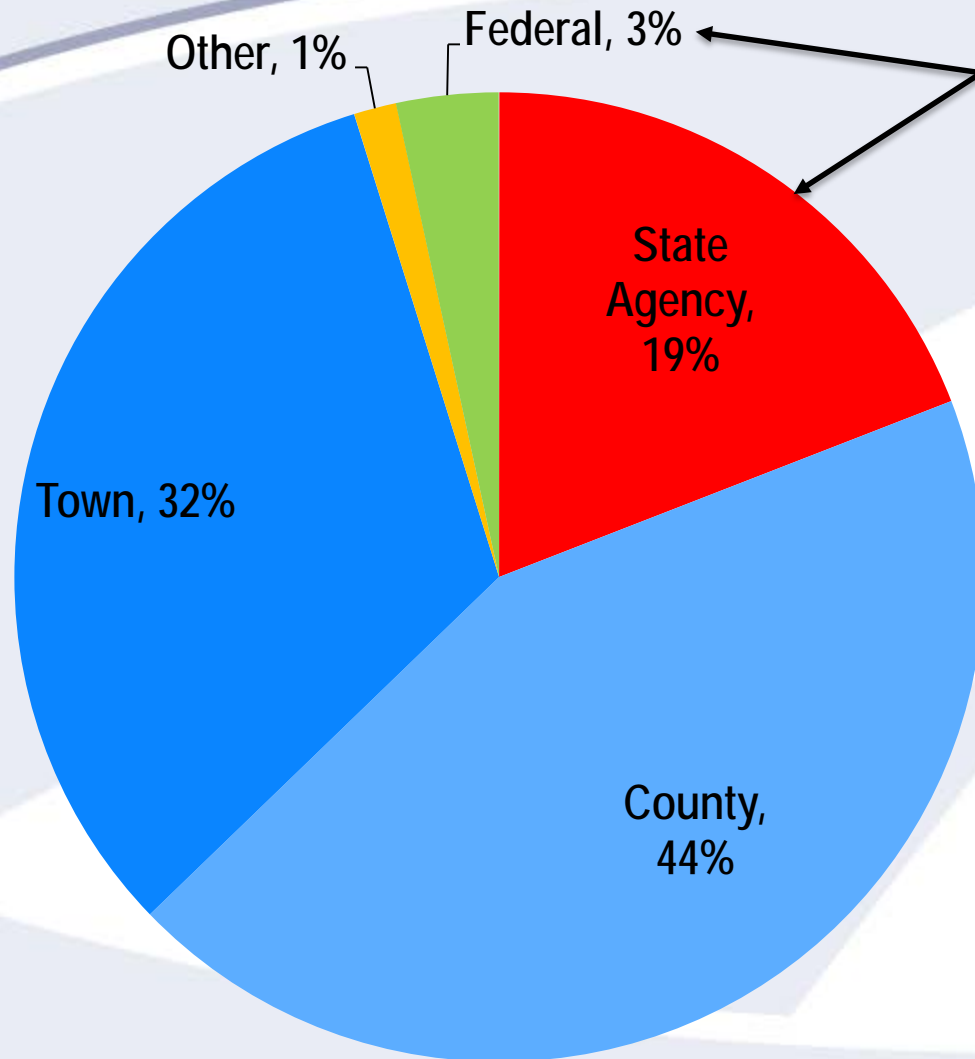
# U.S. Agencies Quickly Changing

- Summary of State Agency practice in 2005:

Design Method Used	Percent of Responding Agencies	State Agency
AASHTO 72/86/93	85%	AR, AZ, DE, FL, ID, IN, IA, KS, MD, MI, NV, NC, OH, OK, SC, SD, TN, UT, VA, WA, WV, WI, WY
AASHTO MEPDG	4%	MO
PCA Method	11%	HI, IN, IA
State-Developed	7%	IL, MT

- At the end of 2013, 41 state agencies had performed ME Design calibration and implementation efforts, indicating a relatively quick shift from AASHTO 93.

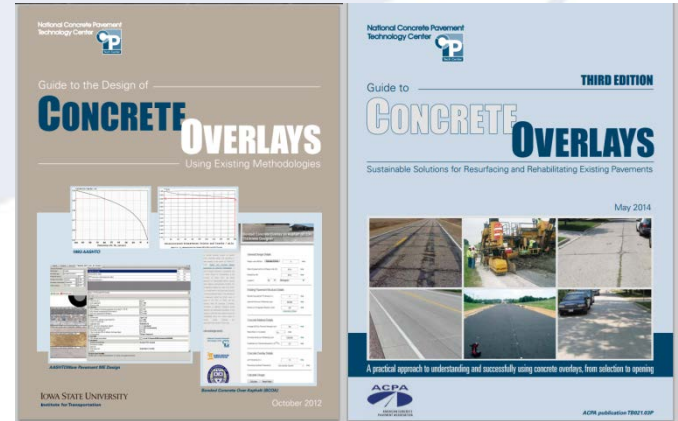
# U.S. Roadway Length (lane miles)



AASHTO tools are being developed for these owners...

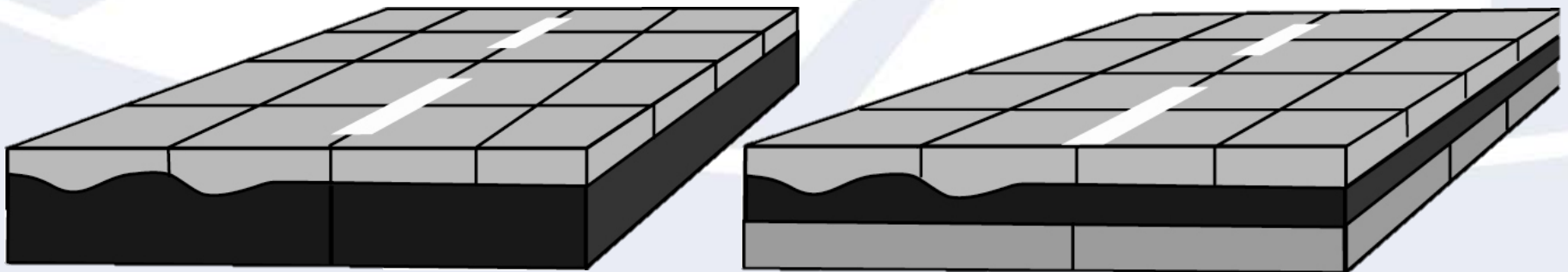
City, county, and other local engineers need to decide what to use locally because Pavement ME will not trickle down due to its cost and complexity!

# Overlay Design - Bonded Concrete on Asphalt



# Bonded over Asphalt/Composite

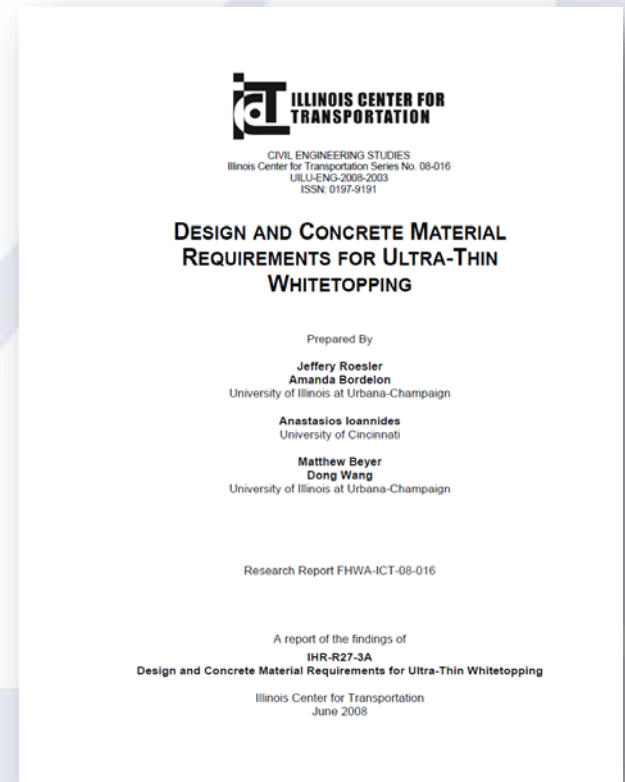
- AASHTO 93: not applicable
- AASHTO ME: limited to a joint spacing  $> 10$  ft (3 m) and not applicable to thinner (2-6 in. [50-150 mm]) concrete overlays; refers people to ACPA
- ACPA BCOA and StreetPave: account for bond to asphalt and short slab size, fibers, etc.





# Bonded over Asphalt/Composite

- Not an extension of an existing design method; a completely custom-built design method
- For ACPA BCOA and StreetPave based primarily on FHWA-ICT-08-016
- Other methods include CDOT 6x6x6 and recently released FHWA pooled fund TPF-5(165)



# FHWA pooled fund TPF-5(165)



BONDED CONCRETE OVERLAY OF ASPHALT PAVEMENTS  
MECHANISTIC-EMPIRICAL DESIGN GUIDE (BCOA-ME)



VALIDATION STUDIES

University of Pittsburgh  
Department of Civil and Environmental Engineering  
Pittsburgh, Pennsylvania 15261

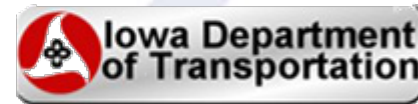


Prepared by:  
Nicole Dufalla  
Julie M. Vandenbossche, Ph.D., P.E.

Prepared for:  
FHWA Pooled Fund Project: TPF-5-165

# Pitt BCOA ME

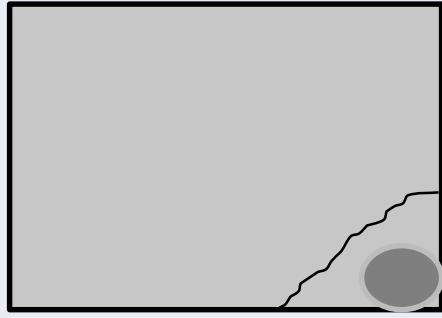
- FHWA Pooled Fund Study TPF 5-165



# BCOA ME failure modes

$\leq 4.5$  ft

**Corner Break**

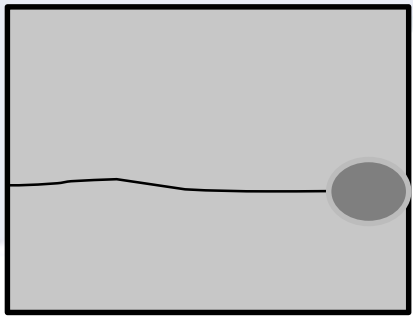


**Negative  $\Delta T$**

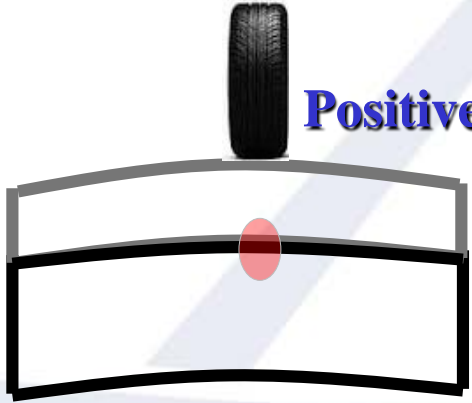


5 to 7 ft

**Long. & Diag Crack**



**Positive  $\Delta T$**

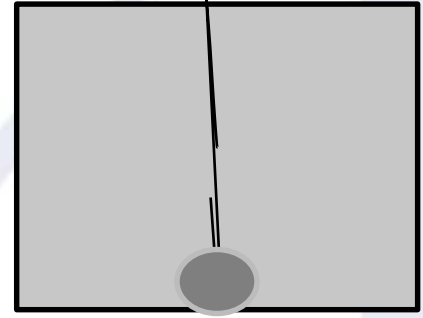


10 x 12 ft

12 x 12 ft

12 x 15 ft

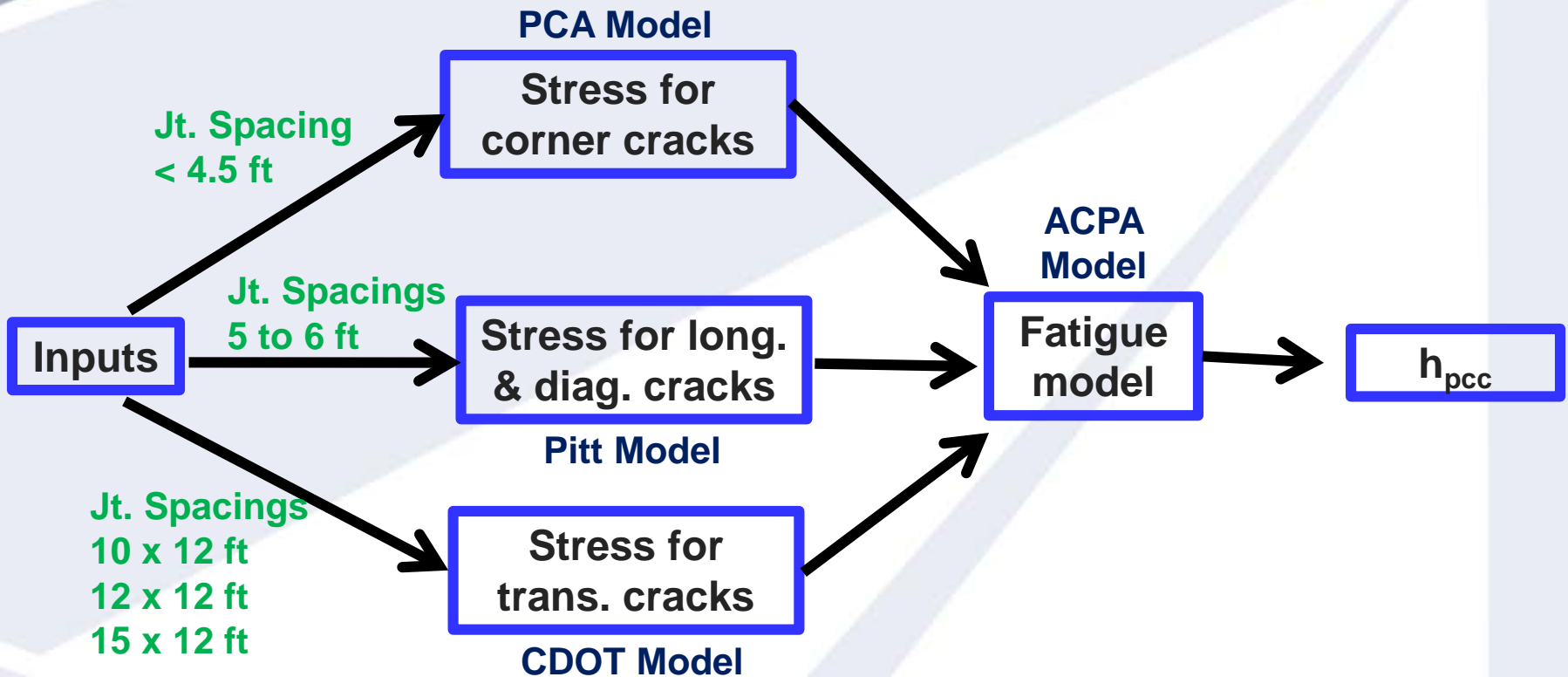
**Trans. Crack**



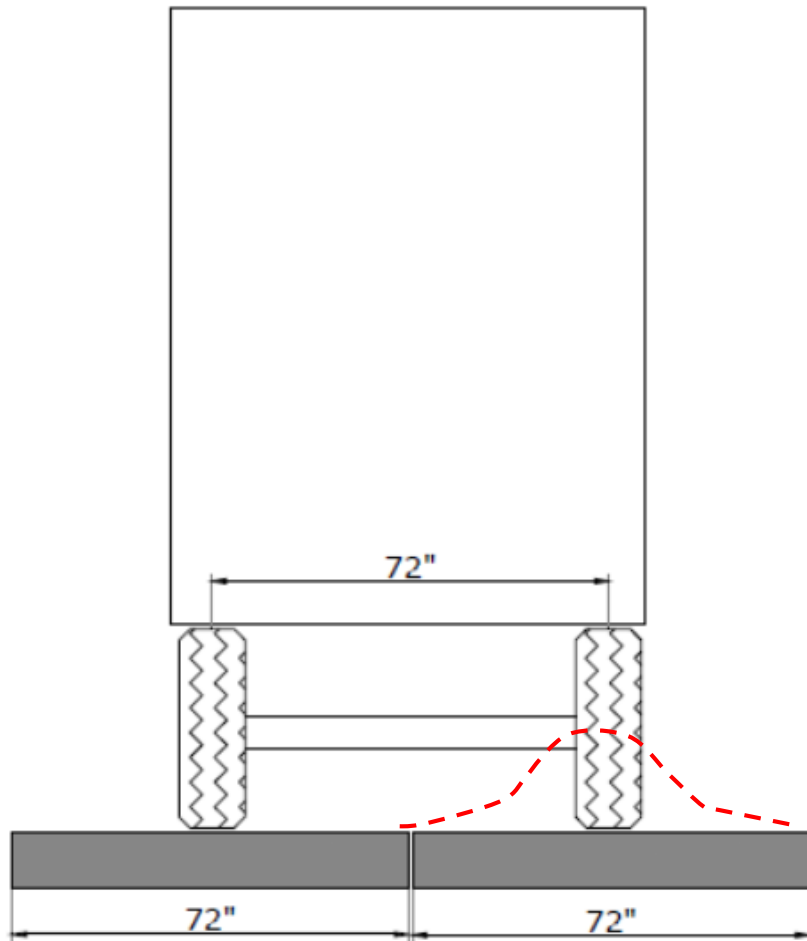
**Positive  $\Delta T$**



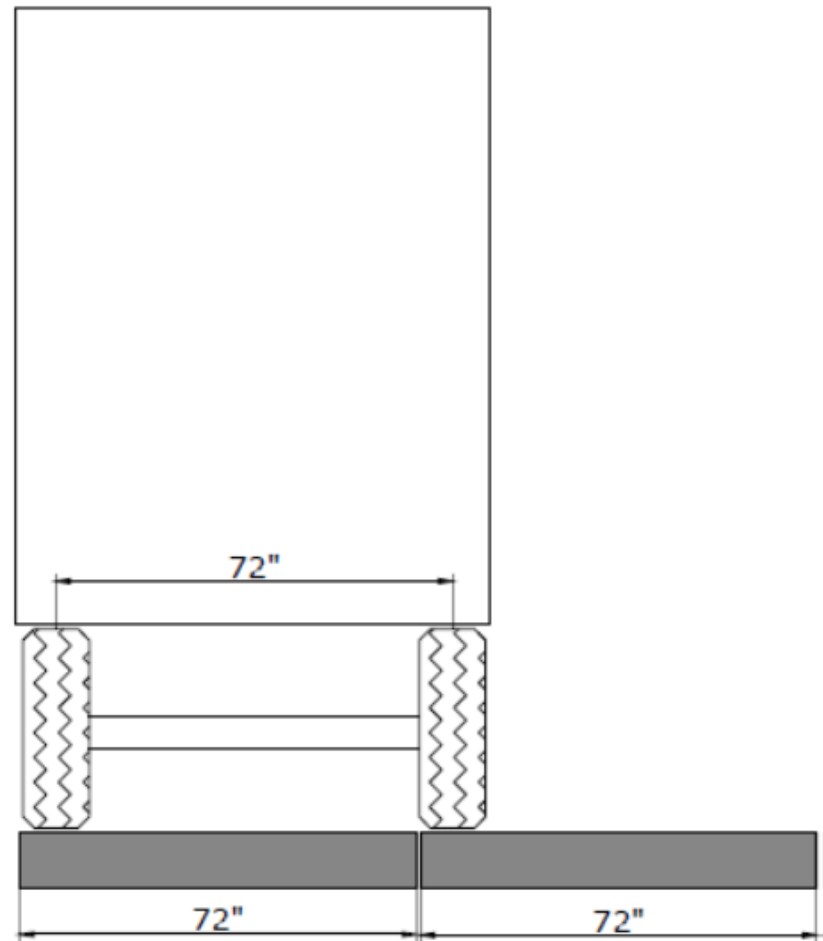
# BCOA-ME



# Wheel wander considered



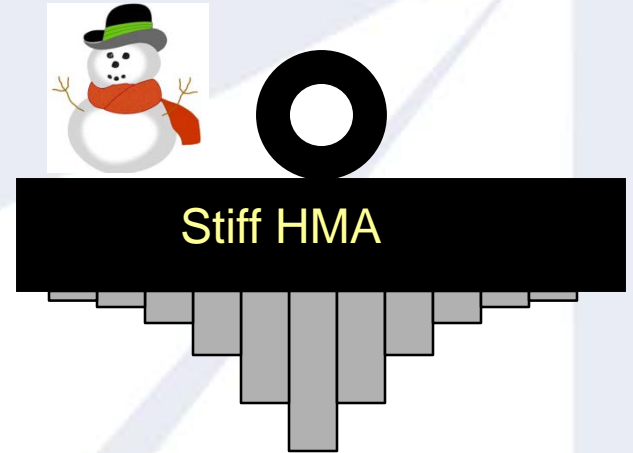
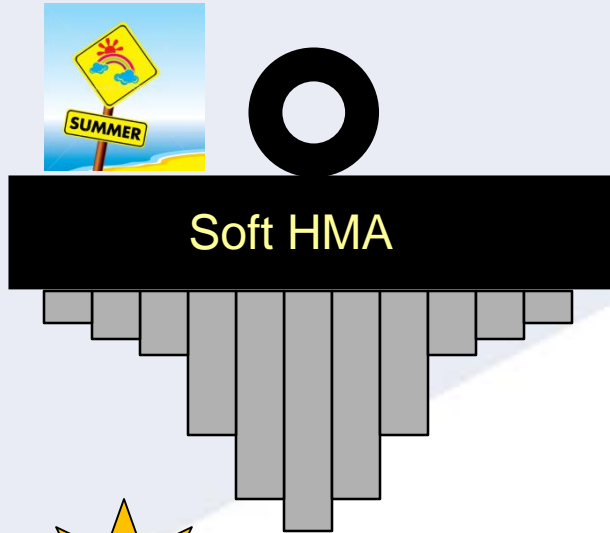
(a) Real Situation in the Road



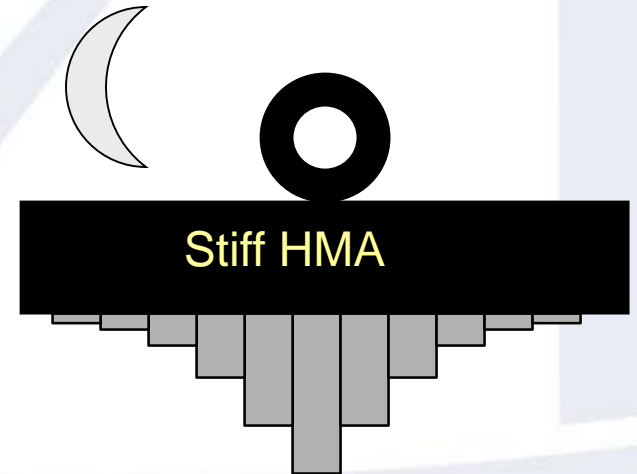
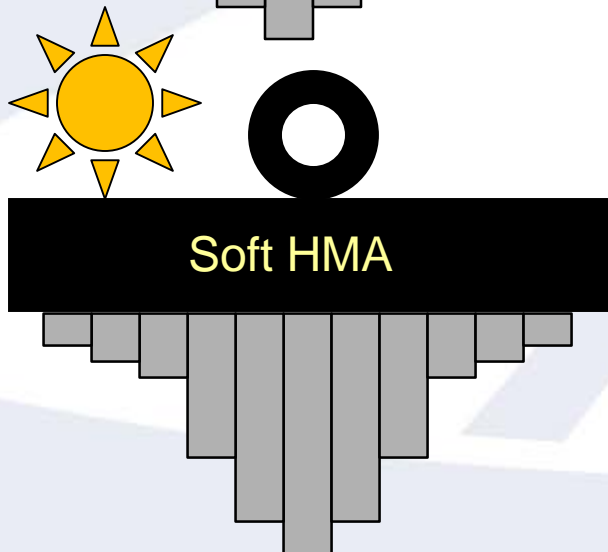
(b) Critical condition

# Variation in HMA stiffness

Seasonal  
variation



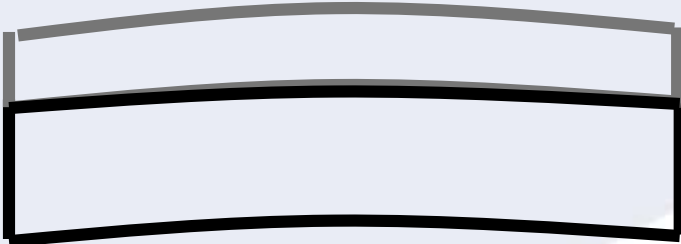
Daily  
variation



# Effective temp. gradient



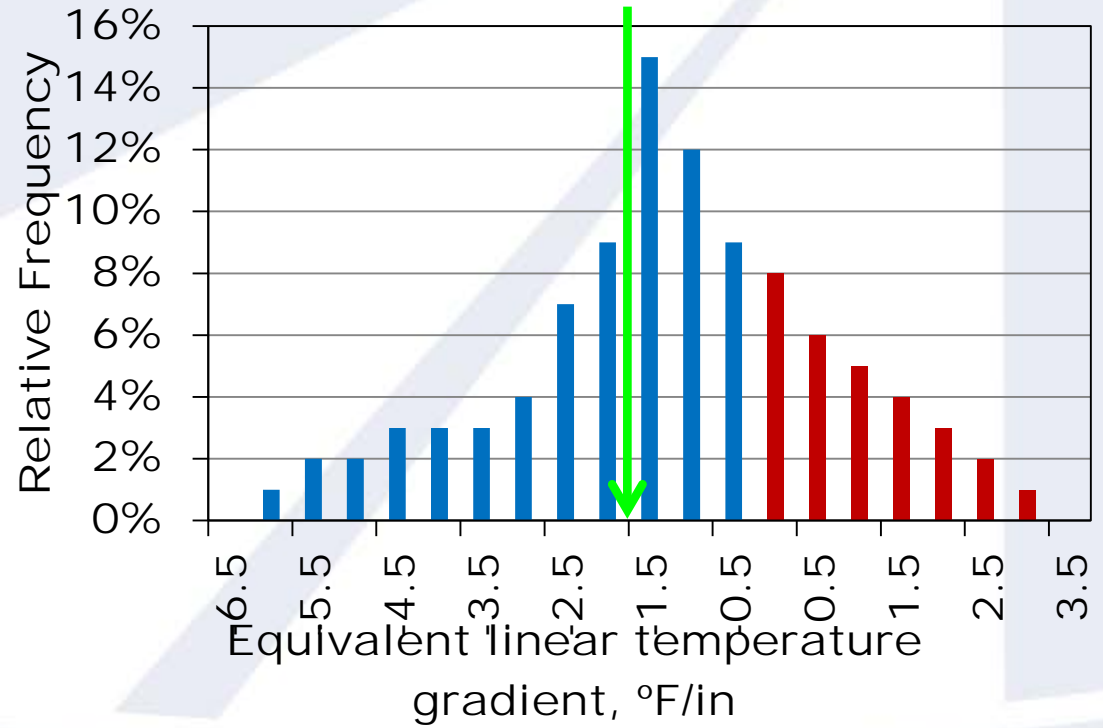
**Positive  $\Delta T$**



**Negative  $\Delta T$**

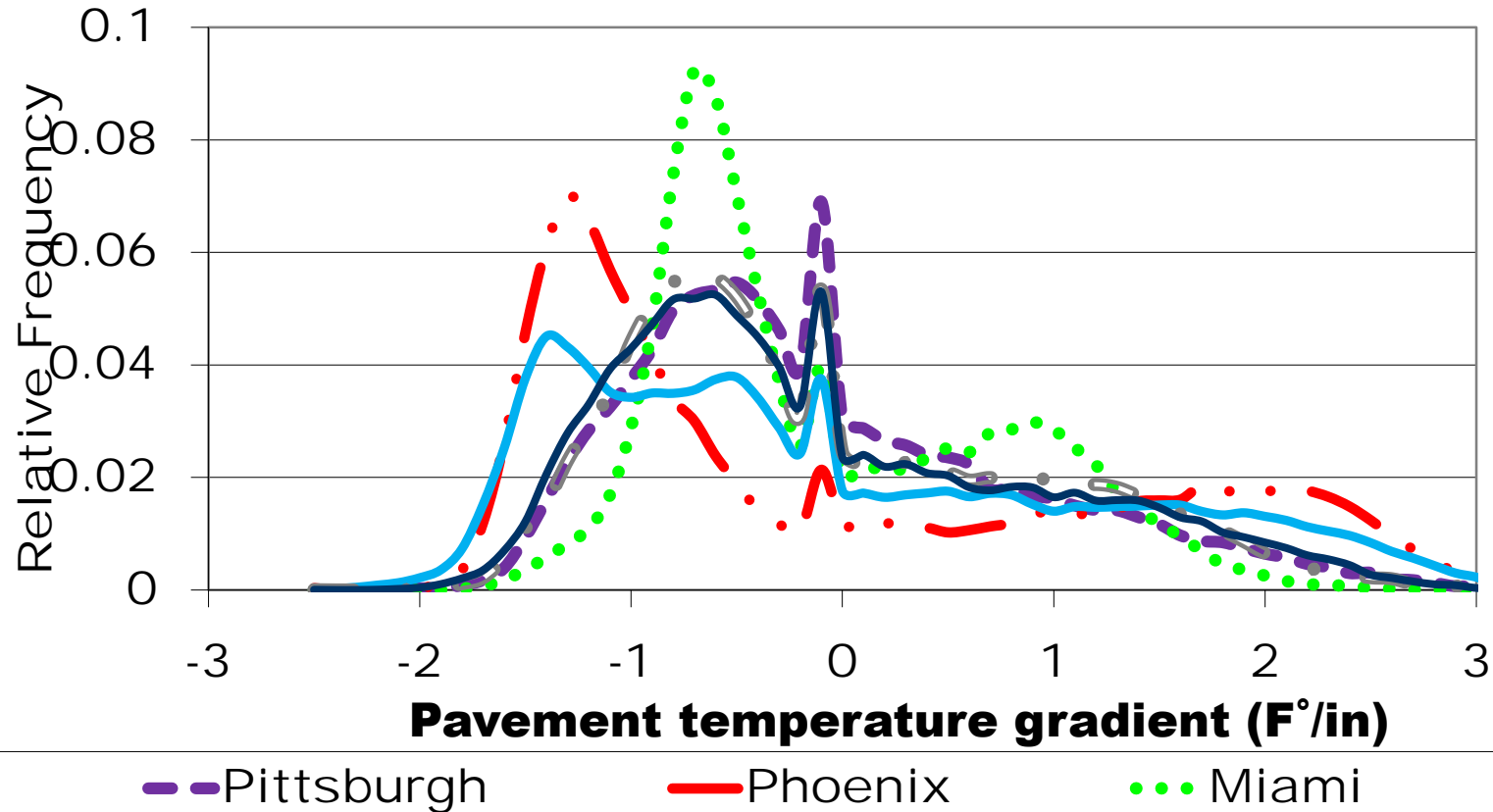


Design input required:  
Effective temp. gradient (ETG)





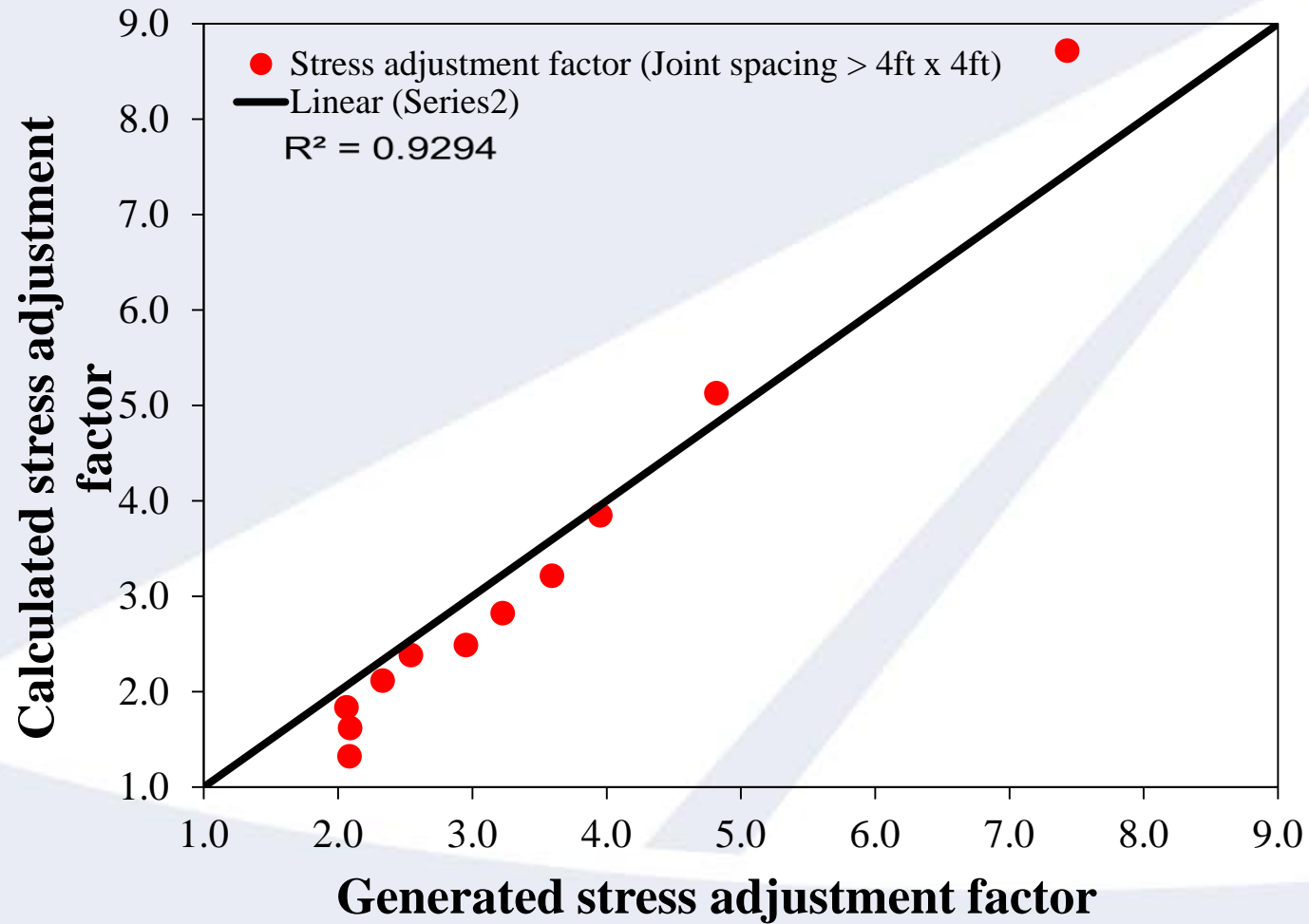
# Regional variation in temp. grad.



Vandenbossche and Mu (2010)



# Calibration - Stress Adj. Factors



# Pitt BCOA-ME Web App

The screenshot displays a web browser window with the URL [www.engineering.pitt.edu/Vandenbossche/BCOA-ME\\_DesignGuide/](http://www.engineering.pitt.edu/Vandenbossche/BCOA-ME_DesignGuide/). The page header features the University of Pittsburgh logo and the text "SWANSON school of engineering". Navigation links include "About", "Departments & Programs", "Centers & Institutes", "Future Students", "Corporate Partners", "Research", "Alumni & Friends", "Faculty & Staff", and "Current Students".

A sidebar on the left is titled "J. Vandebossche PhD" and contains buttons for "Home", "Background", "Publications", "Courses", "Research", "Lab Tour", and "BCOA-ME".

The main content area features a large "BCOA-ME" logo with the University of Pittsburgh seal below it. Below the logo, it states "(Last updated: 9/9/2013)".

The "General Information" section contains the following data:

Field	Value	Tool
Latitude (degree):	44.53	Geographic Information
Longitude (degree):	-93.14	
Elevation (ft):	874	
Estimated Design Lane ESALs:	1000000	ESALs Calculator
Maximum Allowable Percent Slabs Cracked (%):	25	

The Windows taskbar at the bottom shows the time as 10:01 AM.

# Pitt BCOA-ME Web App

The screenshot displays the Pitt BCOA-ME Web App interface. The browser address bar shows the URL: [www.engineering.pitt.edu/Vandenbossche/BCOA-ME\\_DesignGuide/](http://www.engineering.pitt.edu/Vandenbossche/BCOA-ME_DesignGuide/). The interface is organized into sections with blue underlined headers: **Climate**, **Existing Structure**, **PCC Overlay Properties**, and **Joint Design**.

Input fields and their values are as follows:

- Desired Reliability against Slab Cracking (%): 85
- AMDAT Region ID: 5
- Map of Sunshine Zone: 2
- Post-milling HMA Thickness (in): 6
- HMA Fatigue: Adequate
- Composite Modulus of Subgrade Reaction, k-value (psi/in): 150
- Does the existing HMA pavement have transverse cracks?: Yes (selected)
- Average 28-day Flexural Strength (three-point bendir): 650
- Estimated PCC Elastic Modulus (psi): 4000000
- Coefficient of Thermal Expansion (10-6 in<sup>2</sup>/F/in): 5.5
- Fiber Type: No Fibers
- Joint Spacing (ft): 6 x 6

Buttons and links include: "Example of Fatigue Cracking", "k-value Calculator", "Transverse Cracking", "Epsc Calculator", "CTE Calculator", and a prominent "Calculate Design" button at the bottom.

Annotations on the right side of the interface include:

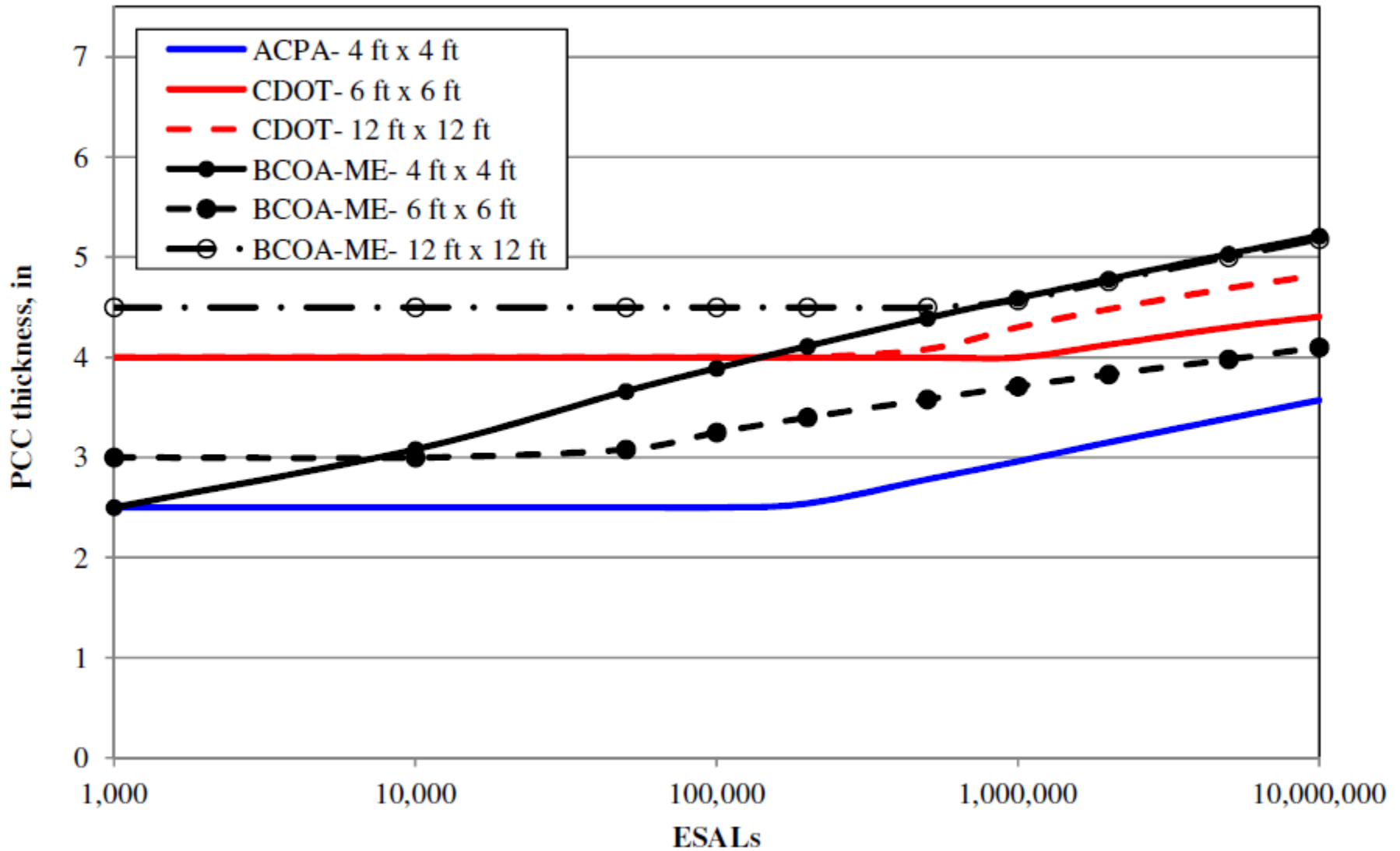
- "Annual Mean Daily Average Temp" with a white arrow pointing to the AMDAT Region ID field.
- "ACPA k-value web app" with a white arrow pointing to the "k-value Calculator" button.

The Windows taskbar at the bottom shows the time as 10:01 AM and includes icons for various applications and system utilities.

# Results of the BCOA-ME

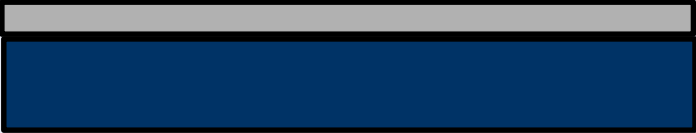
- BCOA ME is  $<1/3$  ACPA BCOA app,  $<1/3$  CDOT procedure and the remainder was developed at Pitt
- Comparison to ACPA BCOA app:
  - $JS \leq 4.5$  ft, the model is similar but thicknesses possibly greater because BCOA ME was calibrated to field performance, accounting for loading directly in the wheel path
  - $JS > 4.5$  ft, it will not compare because failure mode changes (e.g., no longer corner cracking); BCOA ME will almost always be thinner than ACPA BCOA for a 6' x 6' JS
- Comparison to CDOT design procedure:
  - Depends on failure mode

# Bonded over Asphalt/Composite



# Design considerations

PCC = 4 in or less  
**HMA**



PCC = 5 in or more  
**PCC**



Overlay thickness

PCC = 4 in or less

**HMA**

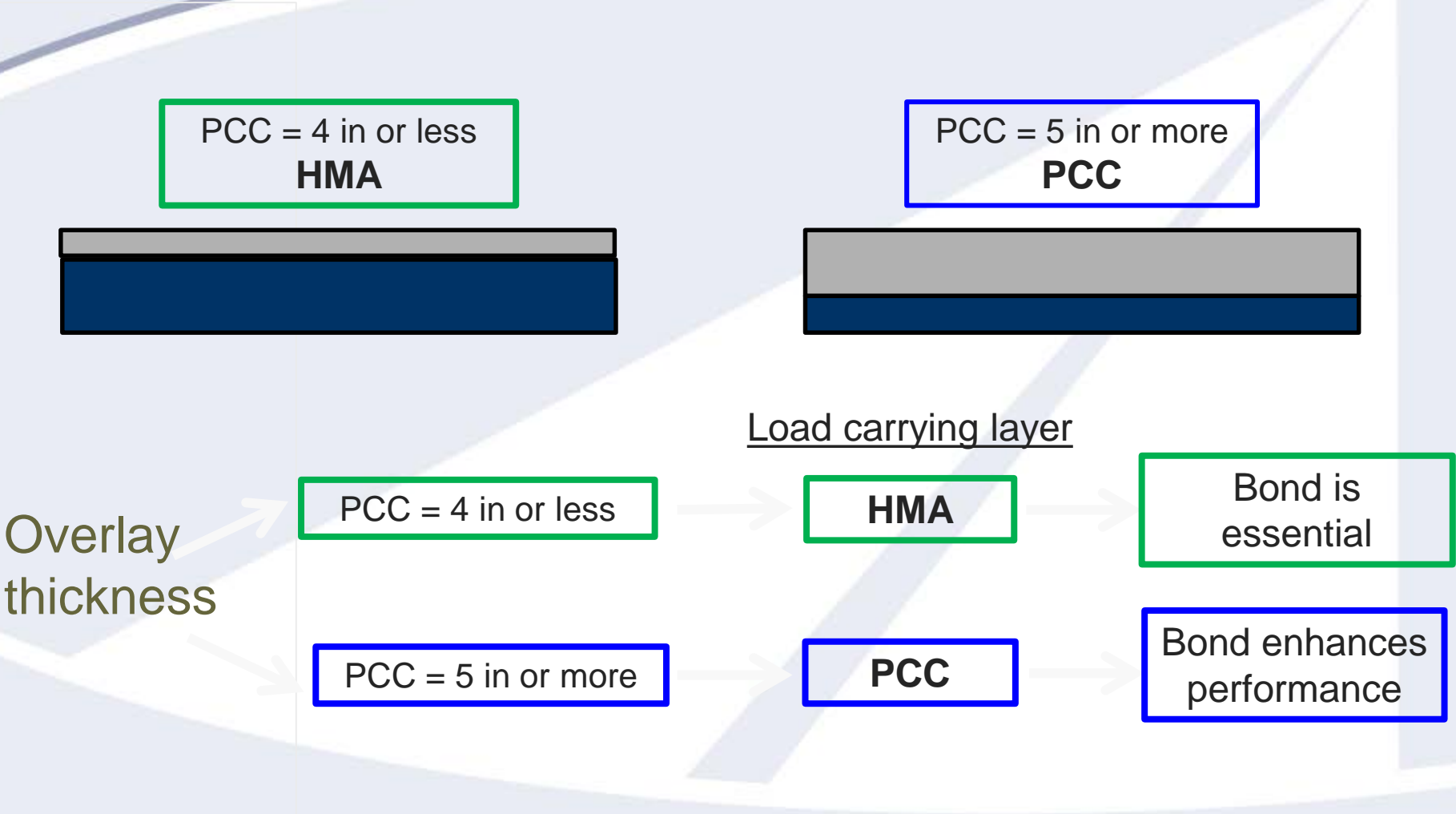
Bond is essential

PCC = 5 in or more

**PCC**

Bond enhances performance

Load carrying layer



# Design considerations

10 in HMA



4 in PCC  
6 in HMA

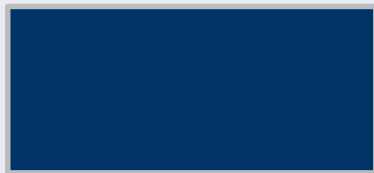


6 in PCC  
4 in HMA



# Design considerations

10 in HMA



4 in PCC  
6 in HMA



6 in PCC  
4 in HMA

Critical Stress for 6ft x 6ft slab, psi			
PCC Thickness	3 in	4 in	6 in
HMA Thickness			
4 in	352	339	274
6 in	246	234	211
8 in	198	191	177

# Thank you.

## Questions? FEEDBACK!

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Download StreetPave:  
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