

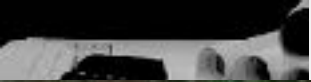
Concrete Pavement Design Tools



NWPMA 2017 Conference

Jim Powell, P.E.
Executive Director

American Concrete Pavement Association, Northwest Chapter





Concrete Pavement Longevity

- Hallmark of concrete pavements
- >50 year old pavements common...
- SR 522 in Washington
- Built 1917
- Rehab in 2001



Benefits of Longevity

- Less-frequent reconstruction
- Lower consumption of raw materials
 - Cement, aggregates, steel
- Lower energy consumption
- Congestion



Benefits of Longevity

- Reduction in pollutants
 - Manufacturing, construction, congestion
- Infrequent construction zones
- Real economic benefits...

Pavement Design !!





PAVEMENT DESIGN

The new pavement will be built in the future, on subgrades often not yet exposed or accessible; using materials not yet manufactured from sources not yet identified; by a contractor who submitted the successful "low dollar" bid, employing unidentified personnel and procedures under climatic conditions that are frequently less than ideal.

NCHRP 1-26 Phase II Final Report



Design Procedures

- Empirical Design Procedures
 - Based on observed performance
 - AASHTO 1993 Design Guide – Based on AASHO Road Test
- Mechanistic/Empirical Design Procedures
 - Based on mathematically calculated pavement responses
 - ACPA Design Procedure – StreetPave
 - AASHTO MEPDG



Concrete Pavement Design Tools

- Roadways
 - AASHTO 93 (WinPAS)
 - StreetPave
 - DarwinME
 - OptiPave
- Overlays
 - StreetPave
 - BCOA-ME
- Industrial
 - AirPave
 - PCASE (Corps of Engineers)



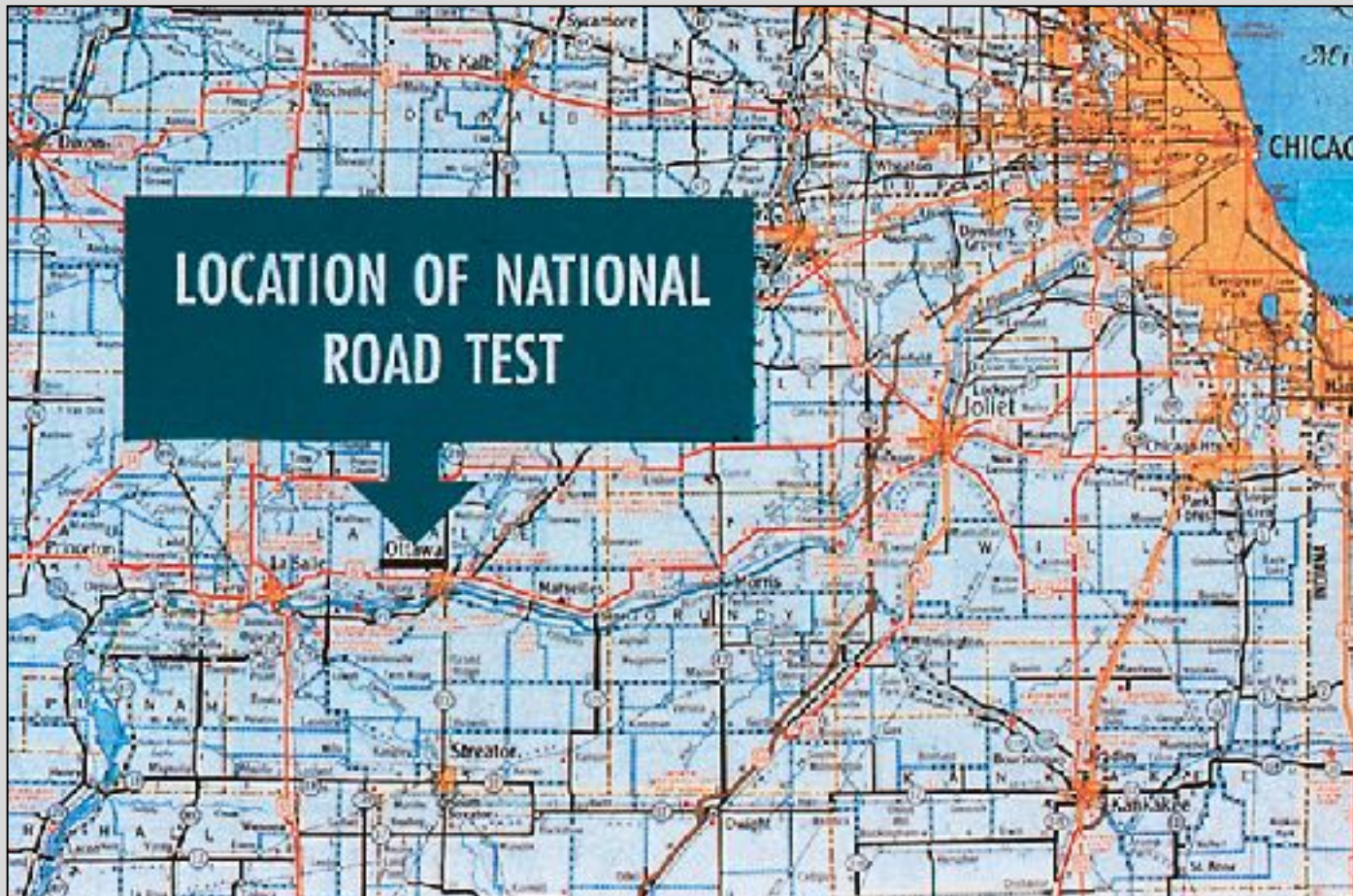
AASHTO 93 DESIGN Guide WinPAS

The AASHTO Road Test was conceived and sponsored by the American Association of State Highway Officials to study the performance of pavement structures of known thickness under moving loads of known magnitude and frequency.





AASHO Road Test Location



Typical AASHO Loop Layout

Test Tangent = 6800 ft.

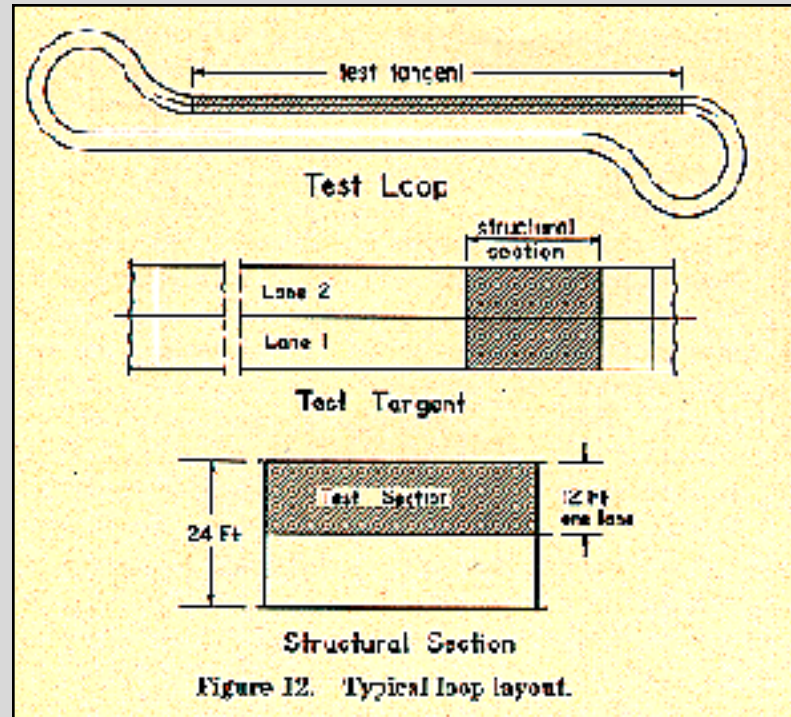
South tangents & west
turnarounds: Rigid

North tangents & east
turnarounds: Flexible

Section Length = 100 ft AC
= 240 JRCP
= 120 JPCP

368 rigid test sections

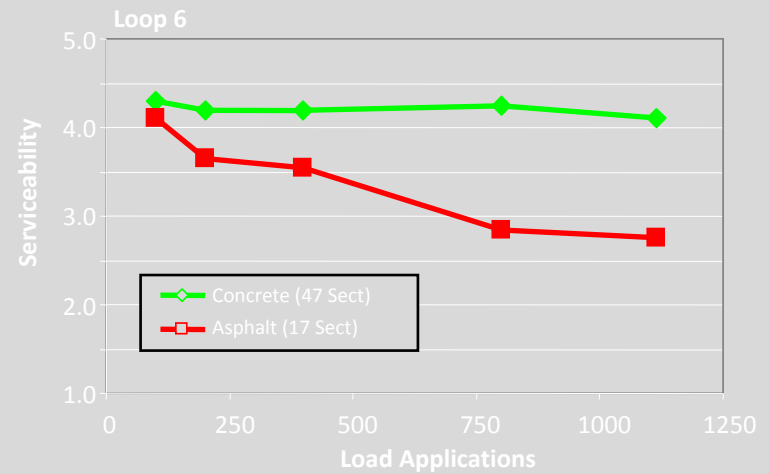
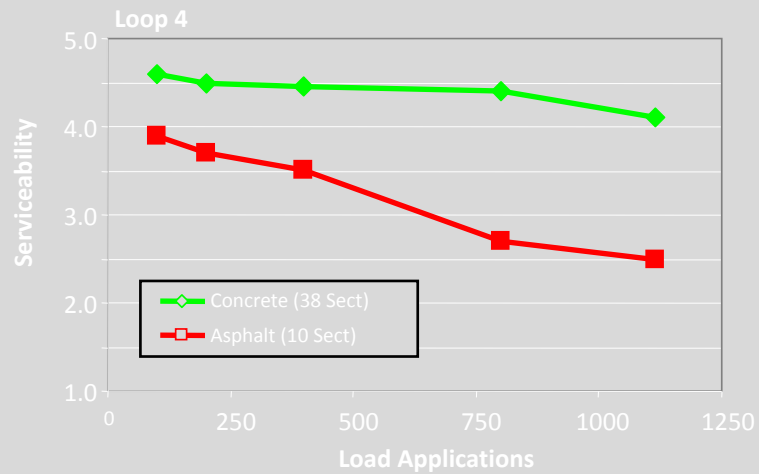
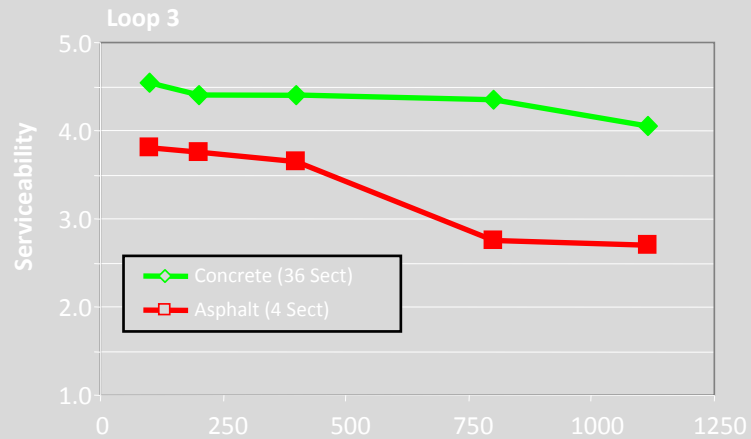
468 flexible test sections





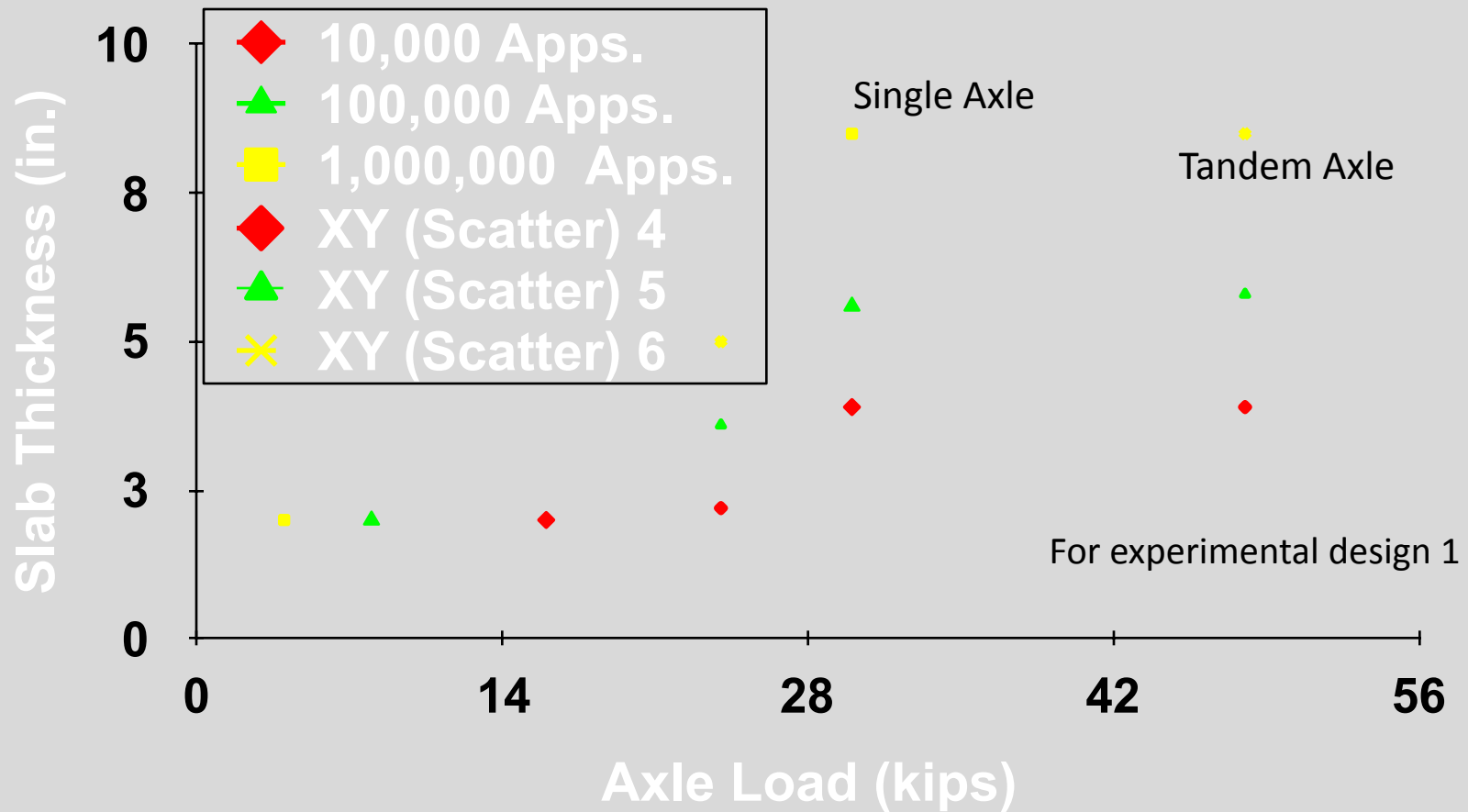
AASHO Road Test Performance

Surviving Sections





AASHO Road Test Empirical Loop Equation





AASHO Road Test Extended Design Equation

- Empirical Loop Equation only good for conditions at the AASHO Road Test
- Researchers wanted to extend equation to other sites with different:
 - Materials
 - Subgrades
 - Climates
 - Traffic Loadings



1986-93 Rigid Pavement Design Equation

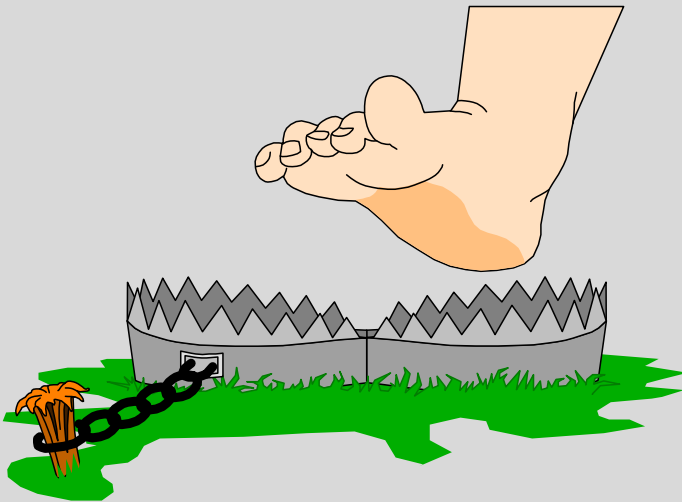
$$\begin{aligned}
 \text{Log(ESALs)} &= Z_R * s_o + 7.35 * \text{Log}(D + 1) - 0.06 + \left[\frac{\text{Log} \left[\frac{\Delta \text{PSI}}{4.5 - 1.5} \right]}{1 + \frac{1.624 * 10^7}{(D + 1)^{8.46}}} \right] \\
 &+ (4.22 - 0.32p_t) * \text{Log} \left[\frac{S'_c * C_d * [D^{0.75} - 1.132]}{215.63 * J * [D^{0.75} - \frac{18.42}{(E_c / k)^{0.25}}]} \right]
 \end{aligned}$$

Standard Normal Deviate $\rightarrow Z_R$
 Overall Standard Deviation $\rightarrow s_o$
 Depth $\rightarrow D$
 Change in Serviceability $\rightarrow \Delta \text{PSI}$
 Terminal Serviceability $\rightarrow p_t$
 Modulus of Rupture $\rightarrow S'_c$
 Drainage Coefficient $\rightarrow C_d$
 Load Transfer $\rightarrow J$
 Modulus of Elasticity $\rightarrow E_c$
 Modulus of Subgrade Reaction $\rightarrow k$

AASHTO DESIGN

Concrete Properties

Use average, in-field strength for design
(not minimum specified)



If specify minimum flexural strength at 28-day of 550 psi & allow 10% of beams to fall below minimum:

STEP 1

Estimate SDEV:

9% for typical ready mix.

$$\text{SDEV} = 550 * 0.09 = 50 \text{ psi}$$

STEP 2

$$S'c_{\text{ design }} = S'c_{\text{ minimum }} + z * \text{SDEV}$$

$$S'c_{\text{ design }} = 550 + 1.282 * 50$$

$$S'c_{\text{ design }} = 614 \text{ psi}$$

AASHTO DESIGN

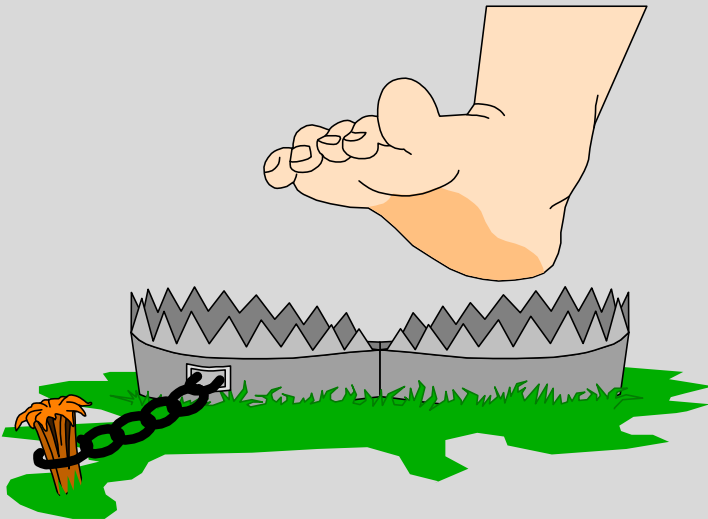
Subgrade Soil Relationships

Be careful when using
the AASHTO Subgrade
Soil Relationships

$$M_R = 1,500 * CBR$$

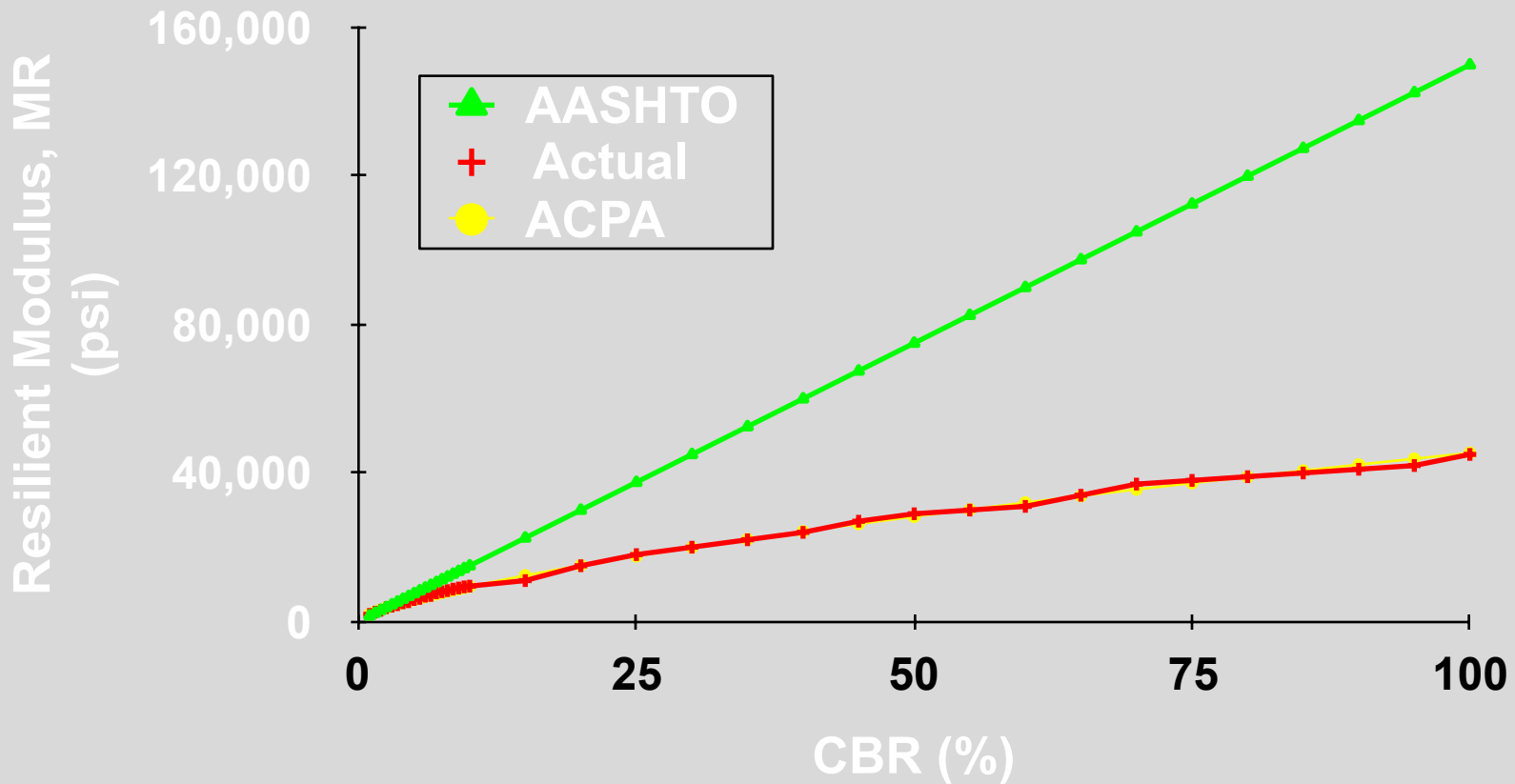
$$M_R = 1,000 + 500 * R$$

**These relationships given in the
guide between M_R and CBR and
R-values over estimates actual
 M_R values.**



AASHTO DESIGN

Subgrade Soil Relationships

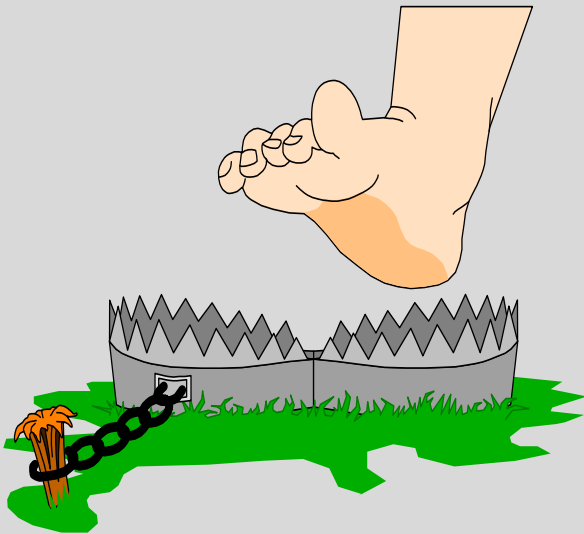


Data: NCHRP Report 128.

AASHTO DESIGN

k-Value Determination

The relationships between k and M_R (base - no base) give inconsistent results with high in-situ M_R Values.



For Example,
Assume $M_R = 12,000$ psi
with no-base
 $k = M_R / 19.4 = 619$ psi/in
with 6" granular base
 $k = 574$ psi/in (from Fig 3.3)

As the M_R value increases, the difference becomes greater.

Neither value is very realistic. Historical values are 150-250 psi/in.

AASHTO DESIGN

Loss of Support

Reduces k-value due to expected erosion of subgrade.

LOS = 0 models conditions at the AASHTO road test.

Upper 3 feet were required to be:

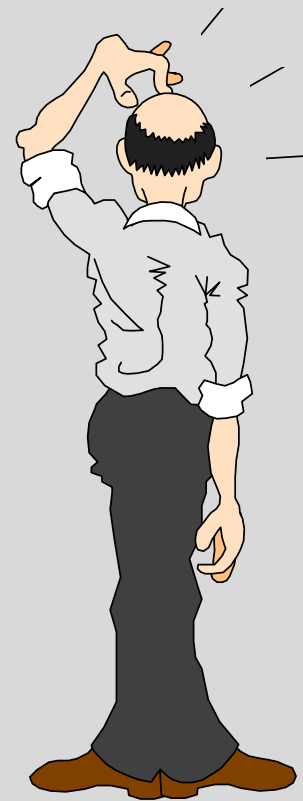
AASHTO A-6 (clay)

Group Index = 9-13

Plastic Index = 11-15

Liquid Limit 27-32

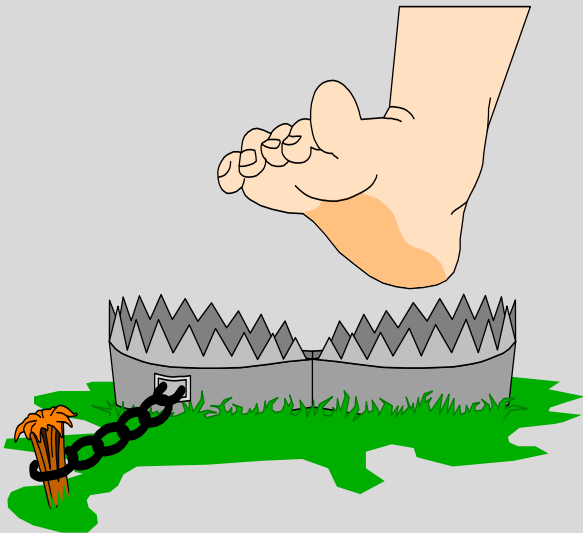
80-85% passed the #200 Sieve



AASHTO DESIGN

Subgrade Strength

Use Loss of Support = 0
(otherwise your using a
huge fudge factor)



All cracking of rigid pavements at the AASHO road test were preceded by the pumping of material from underneath the slab.

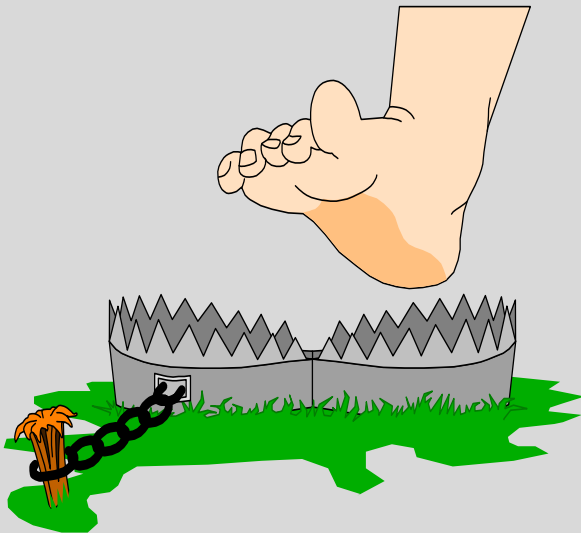
The primary mode of failure at the road test was loss of support in the poor clay soil.

Therefore, AASHTO design equations already account for support loss.

AASHTO DESIGN

Drainage Coefficient

Use Drainage Coeff > 1.0
(otherwise using a huge
fudge factor)



The subgrade soil at the AASHTO road test was a very poorly draining clay soil.

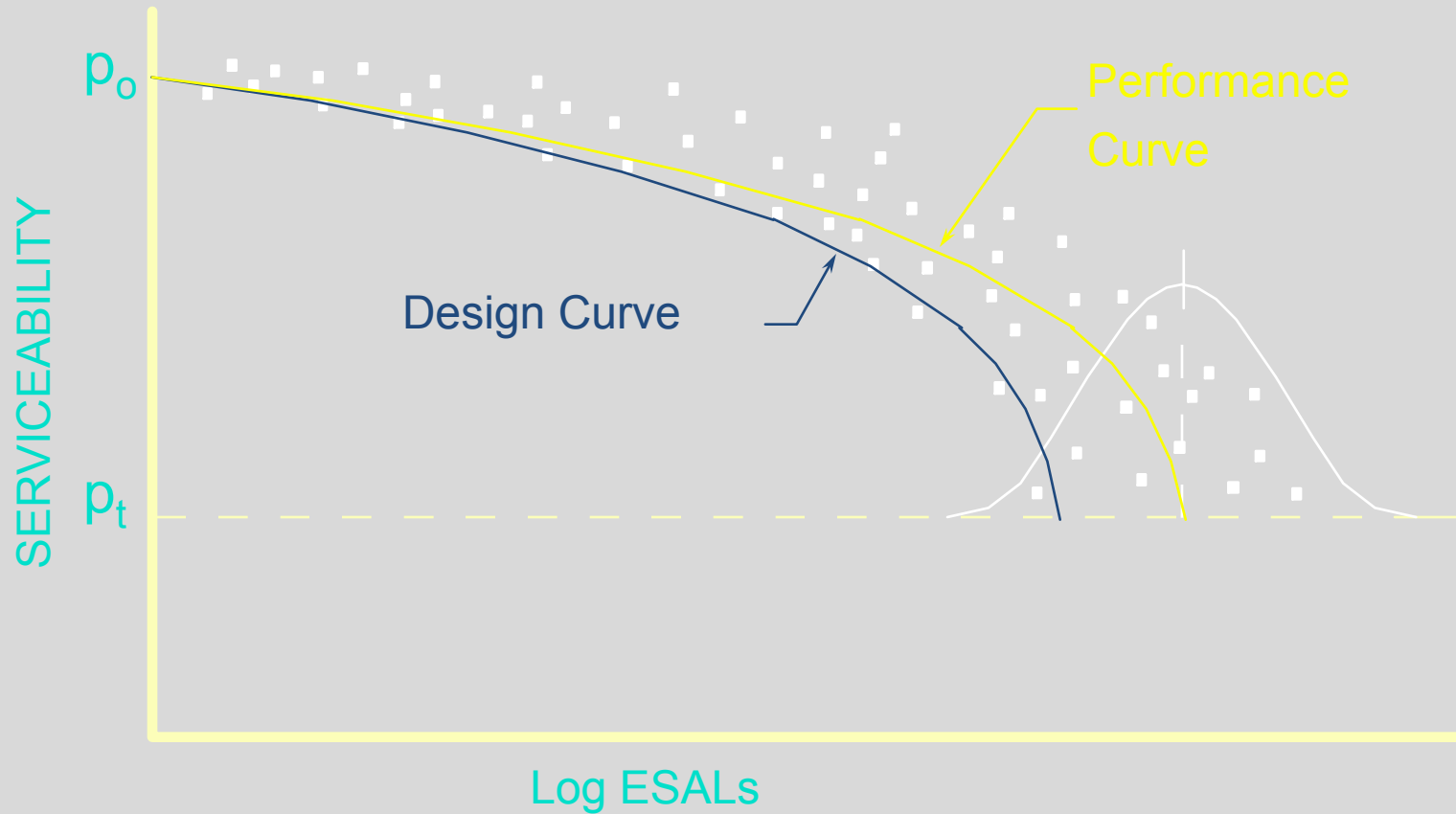
Therefore the AASHTO design equations already account for a poor drainage condition.

Modern open-graded bases and more free-draining soils are design options which can be modeled with $C_d > 1.0$



AASHTO DESIGN

Reliability



AASHTO DESIGN

Reliability

Never compare designs at different reliabilities (reliability = factor of safety)



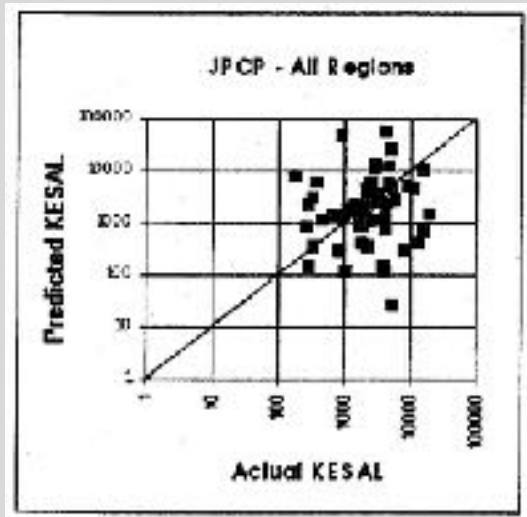
Another way to think about reliability is to consider that at 90% reliability, only 10% of the pavement will have “failed” by the end of the design period.

If you are comparing a new concrete section to a new asphalt section use the same reliability for each.

Make design evaluations at 50% reliability.



AASHTO Design Procedure Evaluation - JPCP



- The 1986-93 Equation is an “unbiased” predictor, but it is not accurate
 - Pred/Act ranged from 0.1 to over 10
- If designed with a high reliability, it will yield a conservative design

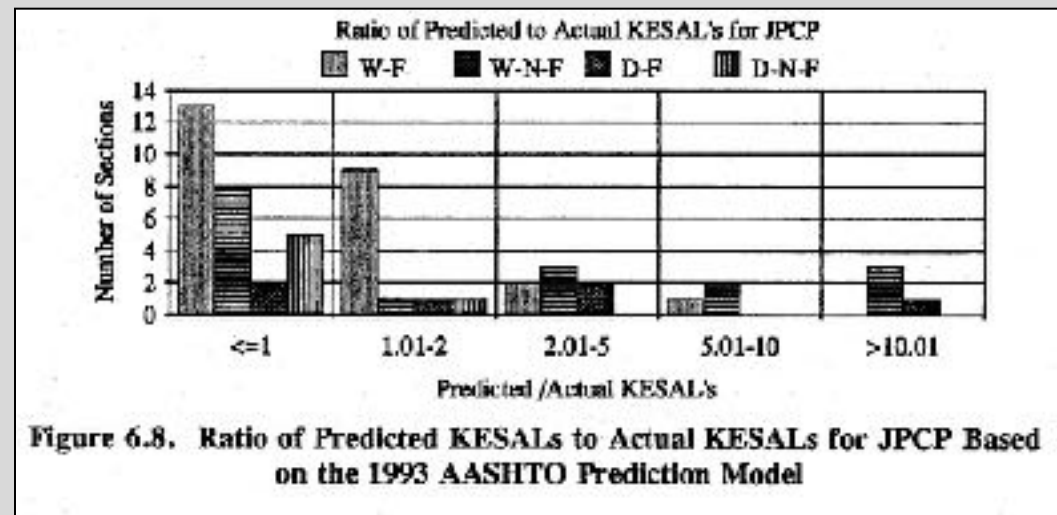


Figure 6.8. Ratio of Predicted KESALs to Actual KESALs for JPCP Based on the 1993 AASHTO Prediction Model

From: *Evaluation of the AASHTO Design Equations and Recommended Improvements*
SHRP-P-394 (1994)

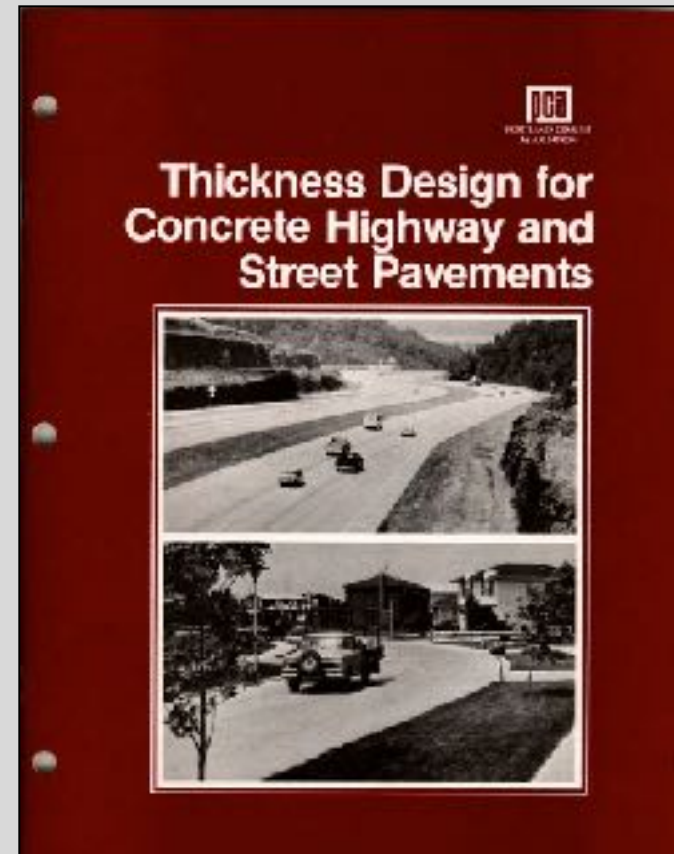


PCAPAV DESIGN PROCEDURE

PCAPAV - a mechanistic thickness design procedure.

Based on:

- Theoretical Studies
- Model & Full-scale tests
- Experimental test roads
 - i.e. AASHO Road Test
- Performance of normal pavements





StreetPave Thickness Design Procedure

- Pavement design tool geared primarily for roads & streets
- Based on the PCA's pavement thickness design methodology
- Assesses adequacy of concrete thickness using both fatigue and erosion criteria





StreetPave's Origins

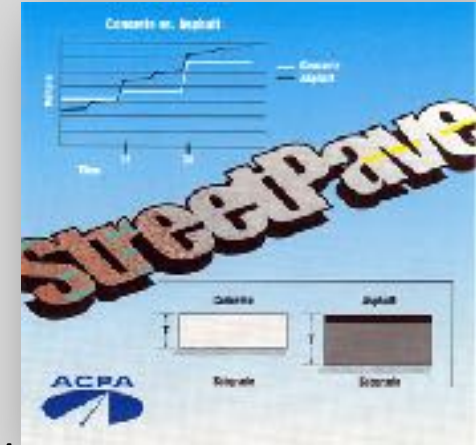
- PCA thickness design methodology for JPCP
 - first published in 1966
 - used slab stress/fatigue as the sole design criterion for determining thickness
 - updated in 1984
 - failure by erosion (pumping)
 - edge support



StreetPave's Origins



- StreetPave
 - released in 2005 by ACPA
 - tailored for streets and roads
 - improvements included:
 - enhanced concrete fatigue model w/reliability component
 - ability to analyze tridem axles in the traffic spectrum
 - new recommendations for dowel bars, joint spacing, subgrade/subbase moduli, etc.
 - side-by-side design comparison to asphalt sections





Fatigue – Total Damage

- Cumulative damage:

$$FD_{total} = FD_{single} + FD_{tandem} + FD_{tridem}$$

where,

FD_{total} = total fatigue damage, %

FD_{single} = fatigue damage from single axle loads, %

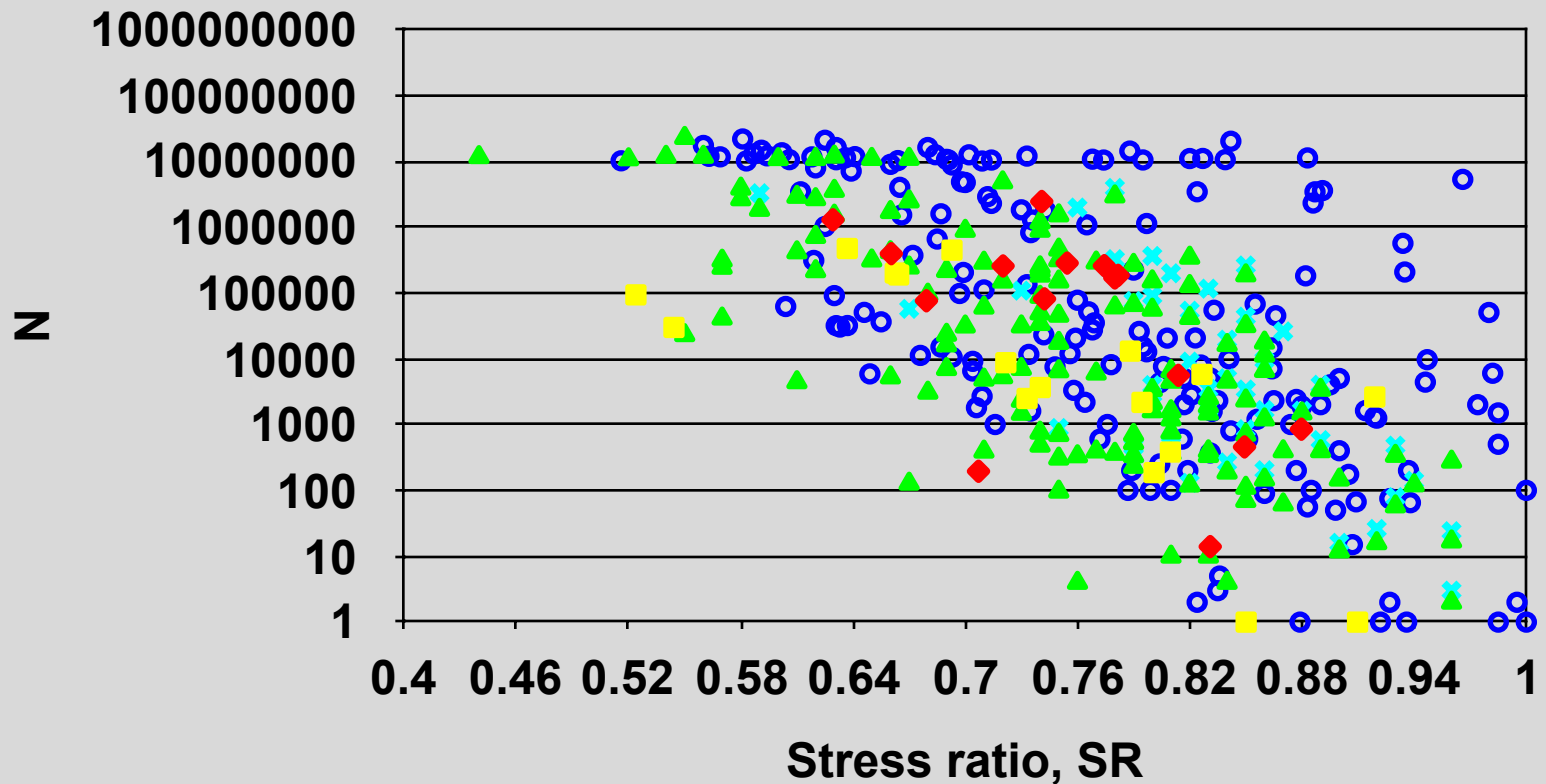
FD_{tandem} = fatigue damage from tandem axle loads, %

FD_{tridem} = fatigue damage from tridem axle loads, %

MECHANISTIC DESIGN ... but validated

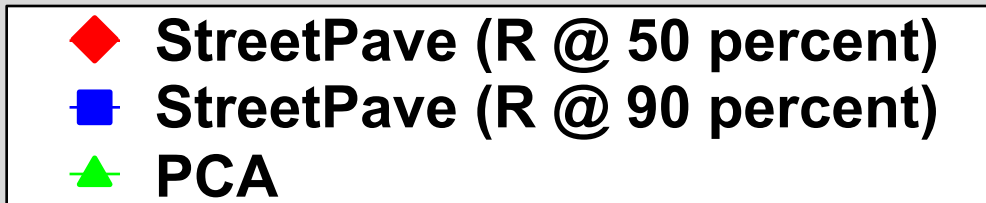
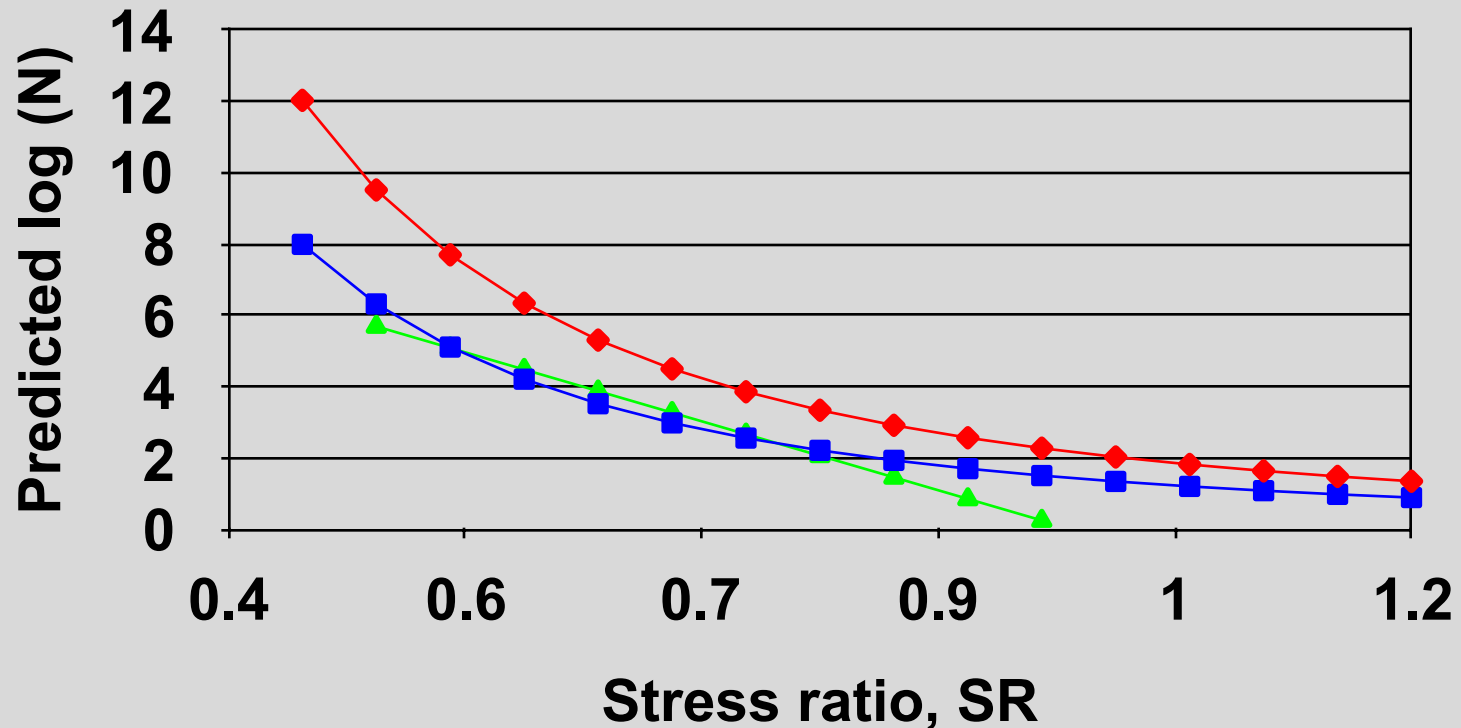


Fatigue – Test Data





Fatigue - Model Comparison





Faulting – Total Erosion

- Cumulative erosion:

$$ED_{total} = ED_{single} + ED_{tandem} + ED_{tridem}$$

where,

ED_{total} = total erosion damage, %

ED_{single} = erosion damage from single axle loads, %

ED_{tandem} = erosion damage from tandem axle loads, %

ED_{tridem} = erosion damage from tridem axle loads, %





Faulting – Erosion per Load Group

- Erosion damage (ED) for each load group is computed per Miner's damage hypothesis:

$$ED = \sum \frac{n_i}{N_{e_i}}$$

where,

n = number of load appl

N_e = allowable
applications

to **erosion** failure





Faulting – Power

- Rate or work or power:

$$P = 268.7 \left(\frac{M^{1.27} S^2}{k} \right)$$

where,

δ_{eq} = equivalent corner deflection, in.

k = composite k-value of subgrade/subbase

- Idea is that, for a unit area, a thinner pavement with a shorter deflection basin (e.g., smaller radius of relative stiffness) will receive a faster punch





Faulting – Erosion Failure

- Pavement thickness incrementally increased





StreetPave – Design Inputs

- Design Life
- Reliability
- % Slabs Cracked
- Traffic
 - Volume
 - Load
 - Growth
 - Distribution
- K-value
 - Subgrade & Subbase(s)
 - Thickness
 - Modulus
 - Edge Support
 - Dowel Bars
 - Concrete
 - Strength
 - Modulus of Elasticity

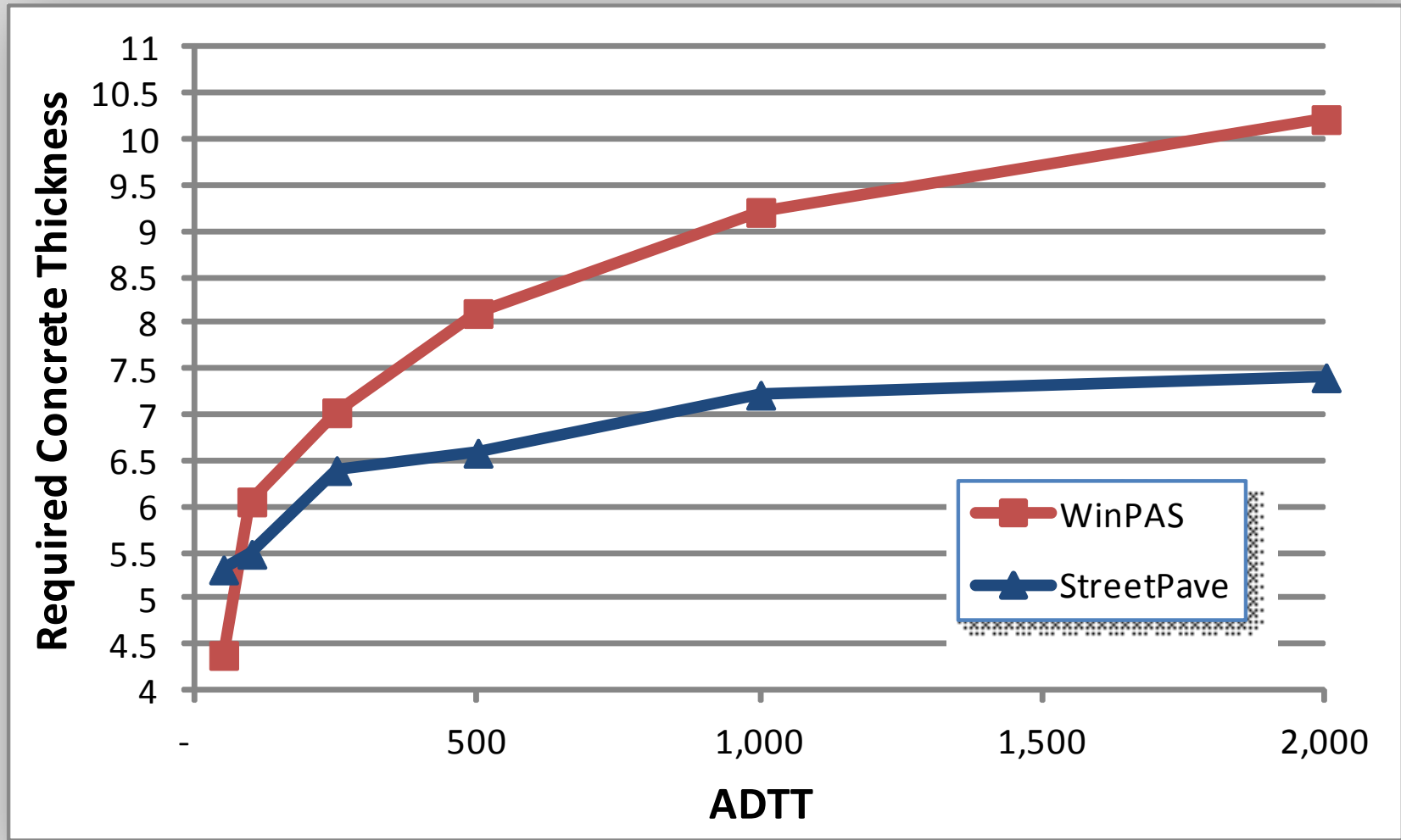


Controlling Factors

- Fatigue usually controls design of light-traffic pavements
 - Single-axles usually cause more fatigue damage
- Erosion usually controls design of undoweled medium- and heavy-traffic pavements
 - Tandem and tridem axles usually cause more erosion damage



AASHTO 93 vs. StreetPave

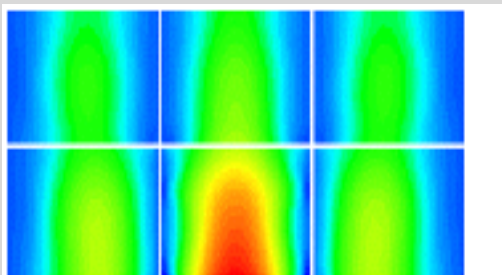


- Traffic spectrum factors in – not just ESALs!

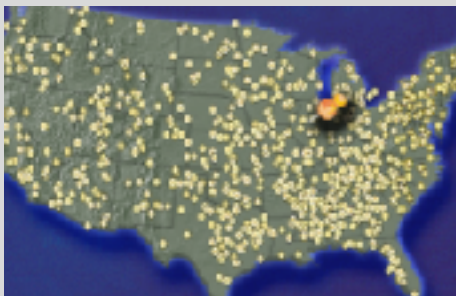


DARWIN ME

Mechanistic-Empirical Design



Mechanistic Elements



Empirical Elements



Pavement Performance
Prediction



M-E Design Basics

- Mechanistically:
 - Calculate critical pavement response (i.e., stresses, strains, and deflections) due to:
 - Traffic loading.
 - Environmental conditions.
 - Accumulate damage over time.
- Empirically:
 - Relate damage over time to pavement distresses through calibrated models, e.g.:
 - Cracking, Faulting, Roughness in JPCP.
 - Punchouts, Crack Width, Roughness in CRCP.
 - Accumulate damage over time.

MECHANISTIC + EMPIRICAL DESIGN

INPUTS, INPUTS, INPUTS!!!!

ASHTO DARWin-ME Version 1.0 Build 1.0.10 (Date: 8/31/2011)

Menu Recent Files - New Open Save Save All Close Exit Run Batch Import Export Undo Redo Help

Explorer Project1 Project1 Traffic

General Information
Design type: New Pavement
Pavement type: Jointed Plain Concrete P
Design life (years): 20
Pavement construction: June 2013
Traffic opening: Section 2013

Performance Criteria

	Unit	Flexibility
Initial IRI (m/km)	60	
Terminal IRI (m/km)	77	80
JCI Transverse cracking (percent slab)	75	50
Maximum faulting (m)	0.12	80

JRCF Design Properties

F JRCF Design
FCC subbase strength (flexibility) 0.85
F FCC joint spacing (m) 15
Swallow type Preformed
E Doweled joints Spacing(12), Diameter(1.25)
L Widened slab Not widened
L Tied shoulders Not tied
L Eroded by index Very erodible (5)
L FCC base contact friction Full friction with friction loss at (240) months
L Permanent CUL Design of edgewise temperature difference (deg F) 10
F Infiltration
Display name Infiltration Default

Display name **nonchicken**
Display name of object/material project for output and graphical interface

From List

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

Output Error Log Compare

INPUTS, INPUTS, INPUTS!!!!

ANSITO DARWin-ME Version 1.0 Build 1.0.13 (Date: 8/31/2011)

Menu: Recent Files: New, Open, Save, Save As, Close, Exit, Run, Batch, Import, Export, Undo, Redo, Help

Explore: Project 1 > Traffic

MDTT

- Two-way AADT: 4000
- Number of lanes: 2
- Percent trucks in flow: 50
- Percent trucks in flow: 95
- Operational speed (in): 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: 51.5
- Tridem axle spacing (ft): 49.7
- Quad axle spacing (ft): 49.7

External Wander

- Mean wheel location (ft): 16
- Frame wander stands: 10
- Design lane width (ft): 12

Wheelbase

- Average spacing of axles: 12
- Average spacing of tires: 15
- Average spacing of tires: 18
- Percent trucks with 4 axles: 20
- Percent trucks with 3 axles: 30
- Percent trucks with 2 axles: 34

Traffic Capacity Cap

Vehicle Class Distribution and Growth

Vehicle Class	Distribution (%)	Growth Rate (%)	Growth Function
Class 1	3.3	3	Linear
Class 2	34	3	Linear
Class 3	11.7	3	Linear
Class 4	1.6	3	Linear
Class 5	5.0	5	Linear

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

Hourly Adjustment

Time of Day	Percentage
12:00 am	2.9
1:00 am	2.9
2:00 am	2.9
3:00 am	2.9
4:00 am	2.9
5:00 am	2.0
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

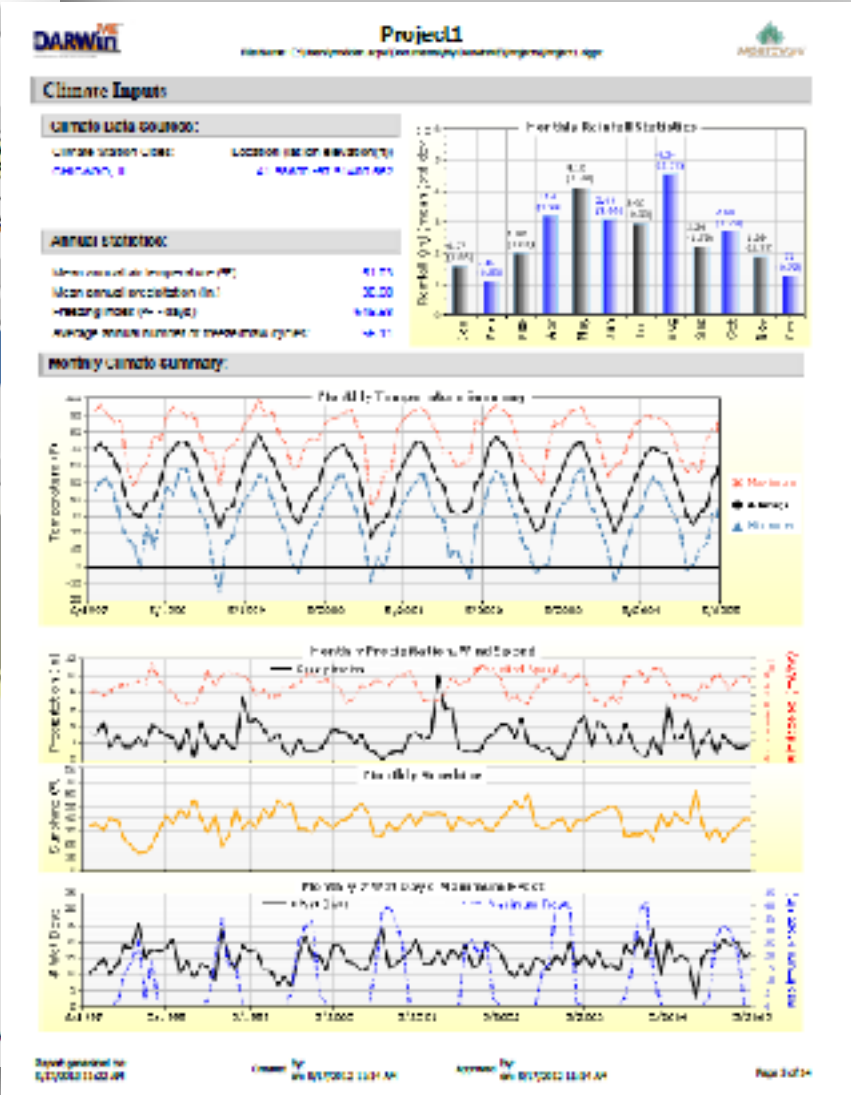
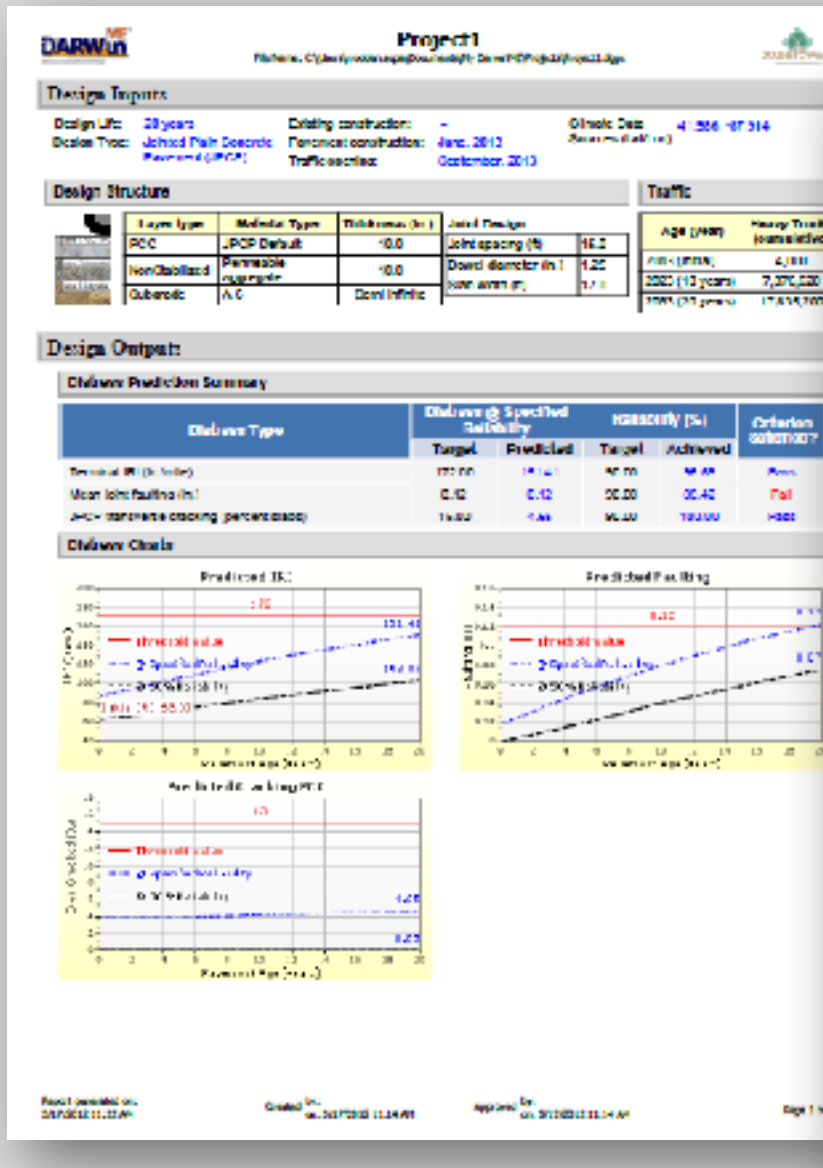
Axles Per Truck

Vehicle Class	Single	Tandem	Tridem	Quad
Class 1	1.02	0.00	0	0
Class 2	2	0	0	0
Class 3	1.02	0.99	0	0
Class 4	1	0.76	0.83	0
Class 5	2.30	0.67	0	0
Class 6	1.02	1.83	0	0

File List: Project, Object, Property, Description

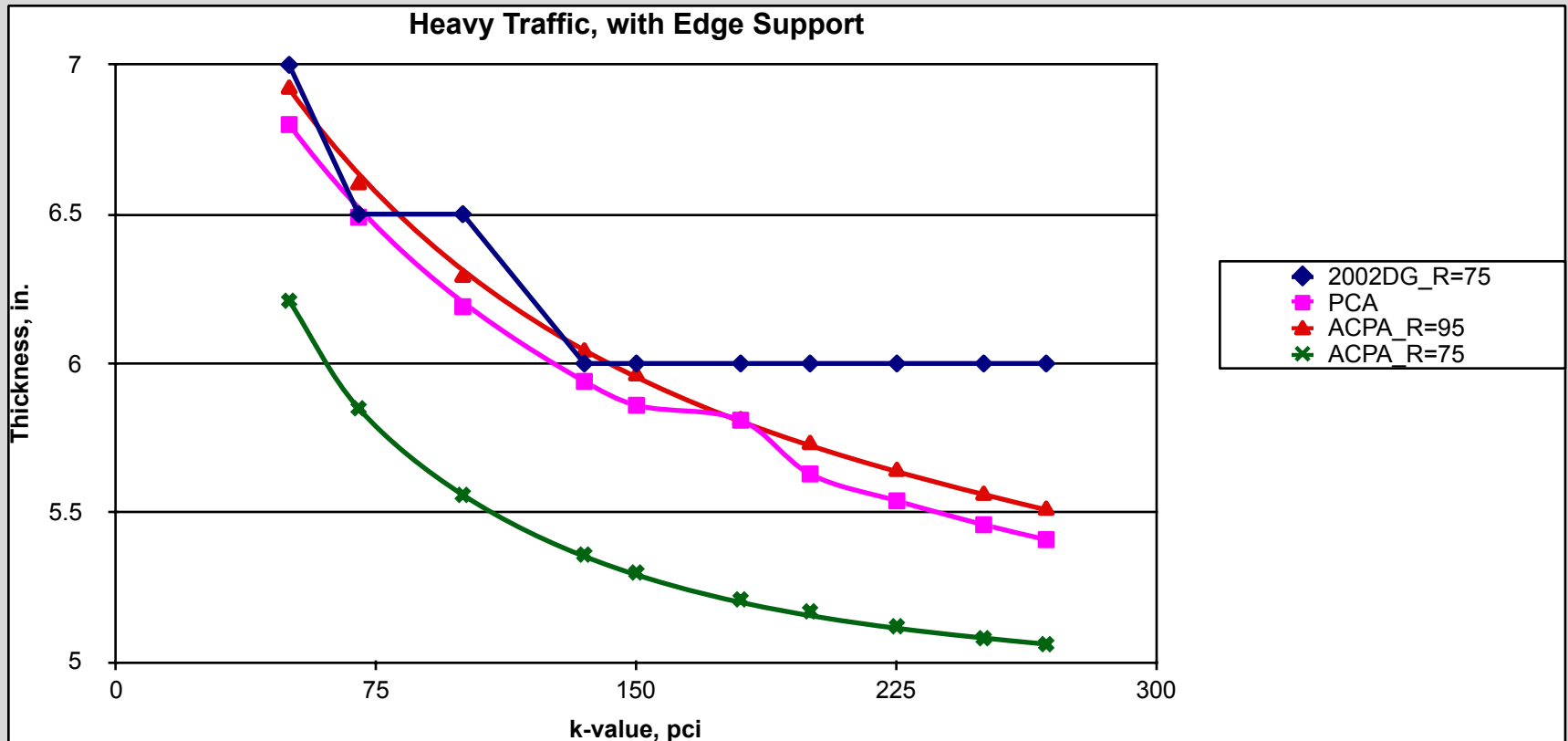
Output, Error List, Compare

OUTPUTS, OUTPUTS, OUTPUTS!!!



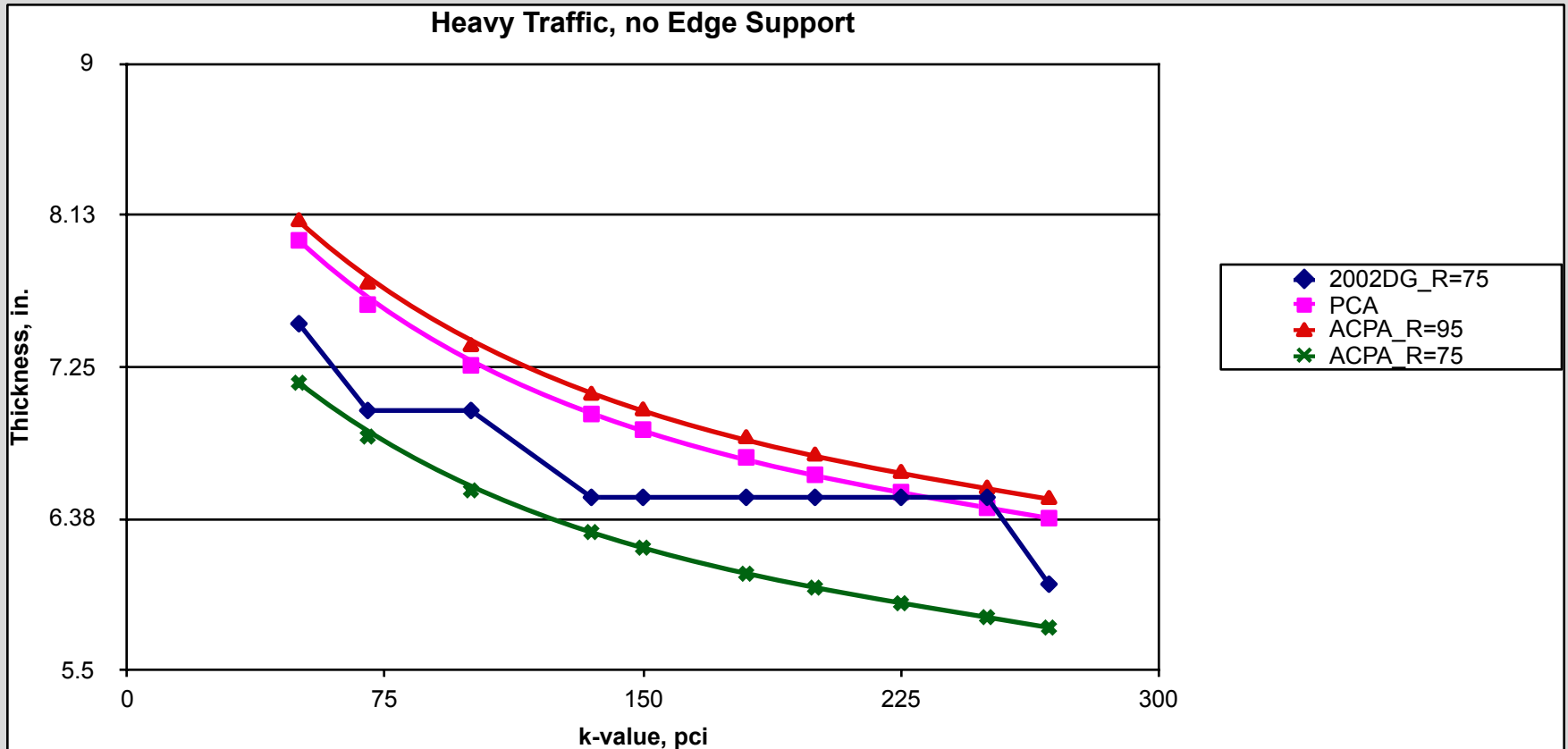


Heavy Traffic, w/ Edge Support





Heavy Traffic, no Edge Support



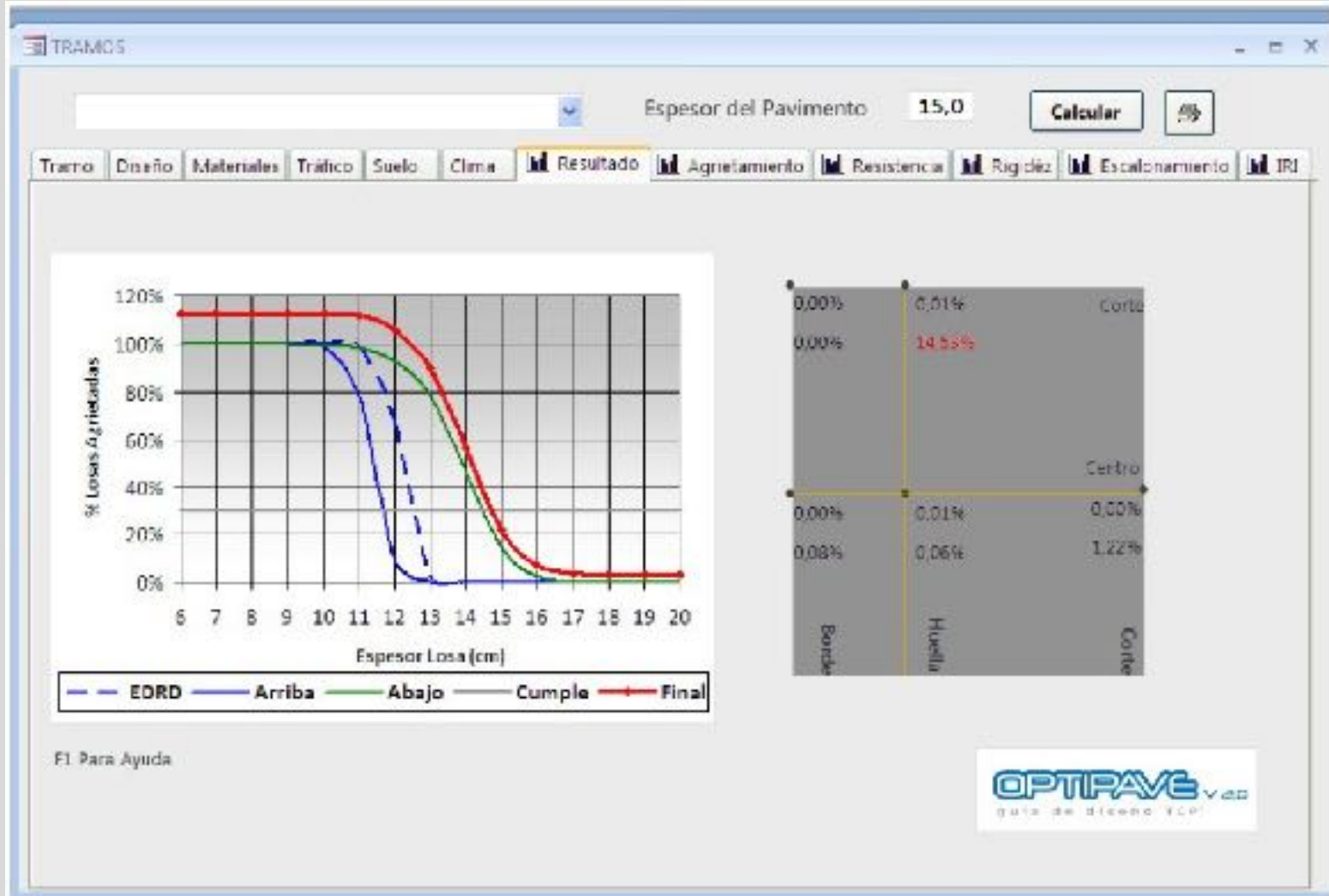


Summary / Conclusions

- At **heavy** traffic levels:
 - ME Design Guide is still fairly close to PCA and ACPA at 95% reliability
 - ME Design Guide not as sensitive to edge support condition

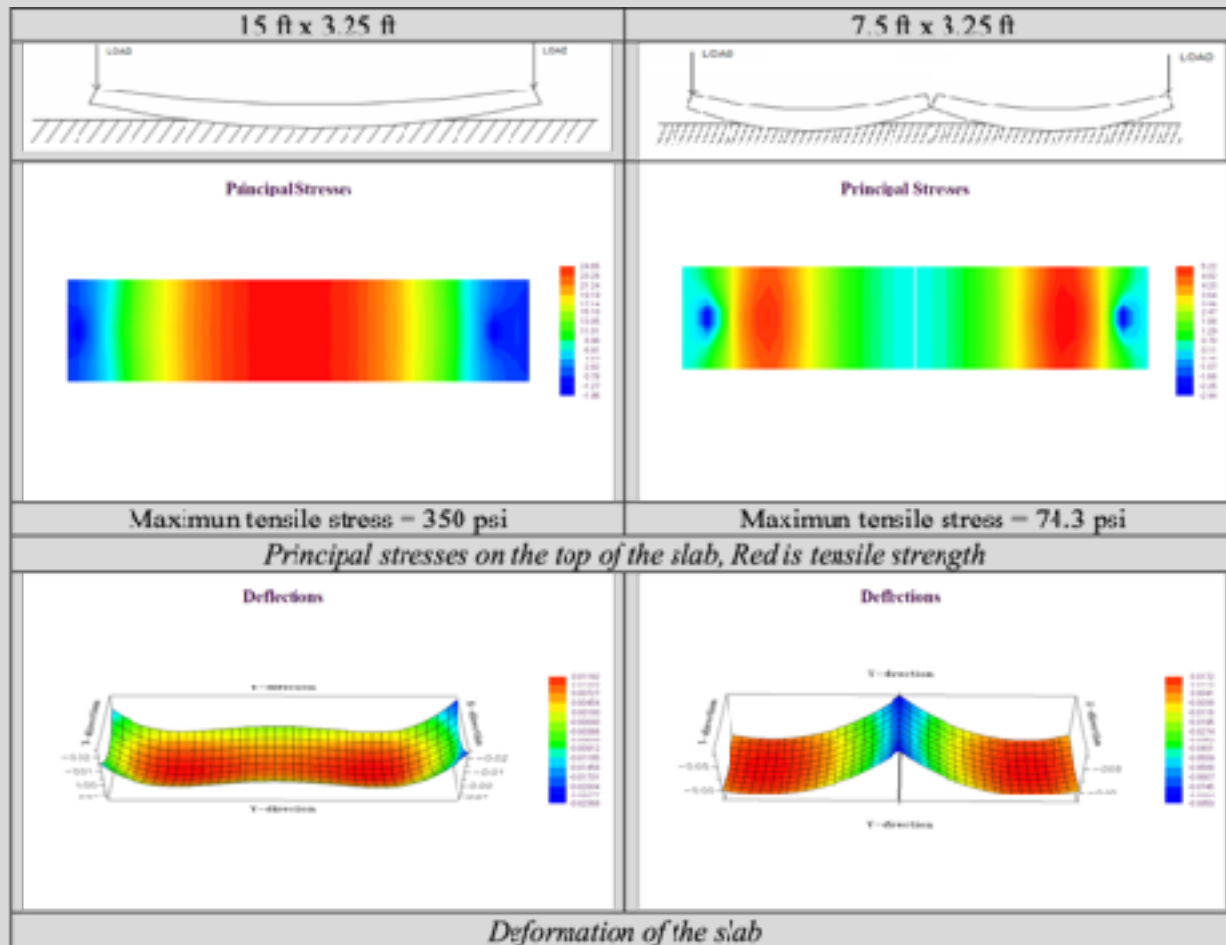


Thin Concrete Pavements





Influence of Slab Geometry on Stresses





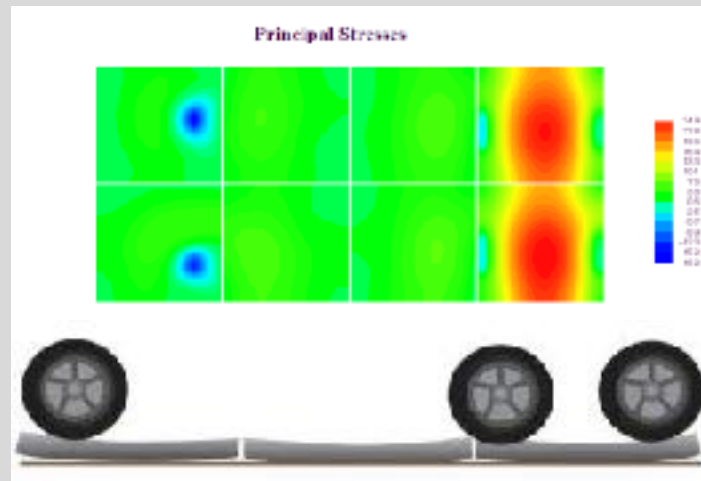
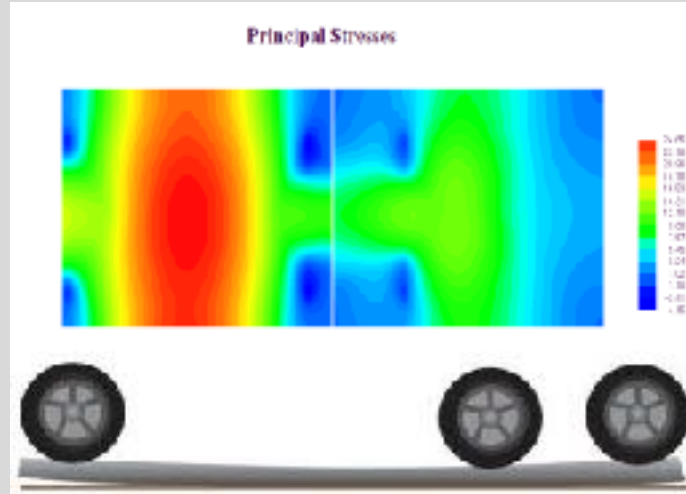
Position of the Loads and Dimension of the Slabs

TCP[®] Design
AASHTO Design





Slabs Sizes and Thickness For Same Top Stress (363 psi)





Characteristics of TCP Design

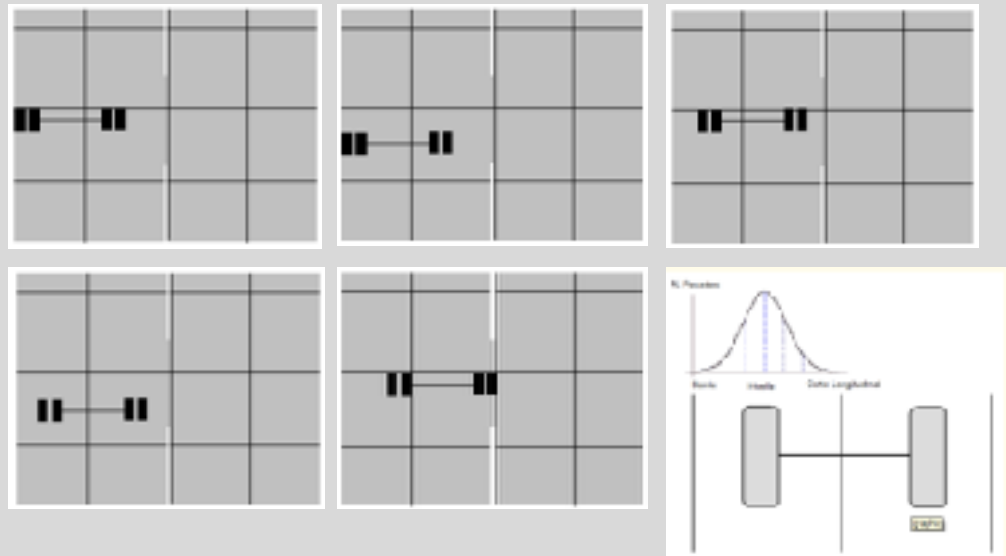
- Small slabs (1.4 to 2.4) meters long (5ft-8ft)
 - Less curl/warp; smaller crack width
- Granular base (fines < 8%) 15 cm thick
 - Less pumping/faulting potential
- Normal or fiber reinforced concrete
- Geotextile between the subgrade and base, if needed
- Thin joint cut (<2.5 mm wide)
- No joints sealing
- Optimized dowel bar system or no dowels
- Lateral confinement with curb, shoulder , vertical steel pins or FRC
- Widened outer lane



TCP Design

- Cumulative fatigue damage, like StreetPave
 - Islab 2000 runs for stresses; NCHRP 1-37 for fatigue
- ESALs used for simplicity
- Environment considered in calculations

**MECHANISTIC
DESIGN
... but validated**





Non-Standard Loads

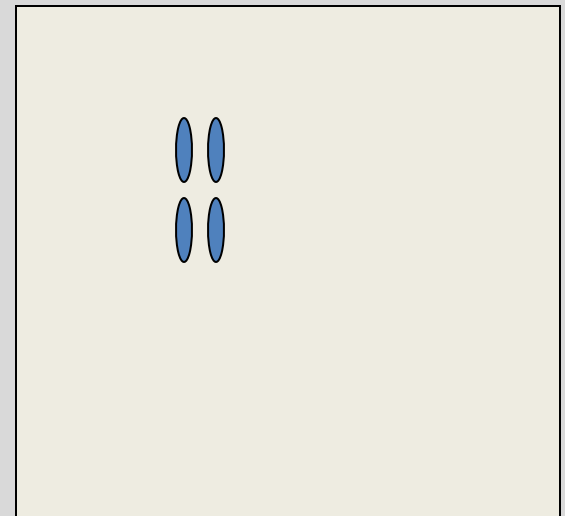




ACPA AirPave Procedure

- Westergaard Analysis
- Center Loading
- Gear Rotation
- Gear Configuration
- Number of wheels
- Tire contact area
- Tire pressure

Loading Condition





AirPave

ACTA AirPave

General Project Information

Project ID: Project 1

Run Date:

Operator:

Operation Guide

ANALYSIS TYPE

1. Pavement Evaluation: When you want to calculate a stress ratio and allowable repetitions for aircraft(s)/vehicle(s).
2. Pavement Design: When you want to calculate a design thickness.

LOADING CONDITION

1. Interior Loading: When tires are away from slab edges.
2. Edge Loading: When one set of tires are on the longitudinal edge of the slab.

UNITS

1. US Units: When US unit system is to be used.

Operation Command Buttons

Compute View Sensitivity

Help Exit

Note: Sensitivity analysis is only available after completing an evaluation analysis for a single aircraft/vehicle.

Airport Pavement Evaluation

Loading Condition

Interior Loading

Edge Loading

Units

US Units

SI Units

Analysis Type

Pavement Evaluation: Calculate Stress Ratio

Slab Thickness (inches)

Pavement Design: Calculate Design Thickness

Design Stress Ratio

User Defined Input

Aircraft/Vehicles Selected

Modulus of Elasticity, E (million psi)

Modulus of Rupture, MR (psi)

Modulus of Subgrade Reaction, k (pci)

Aircraft Loading

Modulus of Elasticity (E)

Modulus of Rupture (MR)

Modulus of Subgrade Reaction (k)



AirPave

Airpave (US Unit)

Airpave

Vehicle/Aircraft Name	Selected
Andy Test	<input type="checkbox"/>
Test Aircraft 1	<input type="checkbox"/>
Test Aircraft 2	<input type="checkbox"/>
Kalmar Ottawa 4x2	<input type="checkbox"/>
Kalmar Ottawa 4x2 2	<input type="checkbox"/>
Ottawa	<input type="checkbox"/>
Tractor Trailer	<input type="checkbox"/>
Tractor Trailer 2	<input type="checkbox"/>
Taylor Container Handler	<input type="checkbox"/>
Taylor Container Handler 2	<input checked="" type="checkbox"/>
Test Aircraft	<input type="checkbox"/>
Stacker	<input type="checkbox"/>

Gear Configuration

Number of Wheels	2
Contact Area (in ²)	400
Contact Pressure (psi)	100
Gear Configuration	0000
Gross Weight (lb)	210947

Coordinates of Wheels

Point	X (in)	Y (in)
1	0	0
2	0	23.1

Operation Guide

Your operation options:

1. Select a gear from the list and click the "OK" button to accept the selection.
2. Click the "User Defined" button to input your user defined gear.
3. Click the "Cancel" button to cancel this operation.

Note: X is along the longitudinal axis.



AirPave

Stress* ratio	Allowable repetitions	Stress ratio	Allowable repetitions
0.51**	400,000	0.63	14,000
0.52	300,000	0.64	11,000
0.53	240,000	0.65	8,000
0.54	180,000	0.66	6,000
0.55	130,000	0.67	4,500
0.56	100,000	0.68	3,500
0.57	75,000	0.69	2,500
0.58	57,000	0.70	2,000
0.59	42,000	0.71	1,500
0.60	32,000	0.72	1,100
0.61	24,000	0.73	850
0.62	18,000	0.74	650

* Load stress divided by modulus of rupture.

** Unlimited repetitions for stress ratios of 0.50 or less.



AirPave

ACPA AirPave Pavement Evaluation Report

Summary Information

GENERAL DESIGN INFORMATION

Project ID: Project 1

Operator: Blank

Run Date: 11/5/2014

GENERAL DESIGN INPUT

Slab Thickness: 15.00in

Unit: US Units

Aircraft/Vehicle Summary Table

<u>Aircraft/Vehicle Name</u>	<u>X Max</u> in	<u>Y Max</u> in	<u>Maximum</u> <u>Angle</u>	<u>Maximum</u> <u>Stress</u> ps	<u>Stress</u> <u>Ratio</u>	<u>Allowable Total</u> <u>Repetitions</u>
Taylor Container Handler 2	0.00	-11.34	0.00	431.23	0.52	20,693

AirPave

ACPA AirPave

Pavement Evaluation Report

Detailed Aircraft/Vehicle Report

USER DEFINED INPUT

Design Vehicle/Aircraft:	Taylor Commuter Handler 2		
Gear Configuration:	12nd	Pavement Type:	PCB
Modulus of Elasticity(E):	5 million psi		
Modulus of Resilience(MR):	700 psi		
Modulus of Subgrade Reaction(k):	200 pci		
Computation Method:	W/O Axle Rotation	Loading Condition:	Initial Loading
Number of Wheels:	2	Contact Area:	400 in ²
Contact Pressure:	150 psi		
Total Load:	100,000 lb		

WHEEL COORDINATES in

x = 0.0 0.0
y = 0.0 20.0

COMPUTATION RESULT

X Max:	0.00	in
Y Max:	11.04	in
Maximum Angle:	0.0	Degrees
Maximum Stress:	431.23	psi
Stress Ratio:	0.616	

OUTPUT

Allowable Total Deflection: 20.633

NOTE

A stress ratio (stress divided by design strength) greater than 0.75 may be too high to satisfy routine pavement design requirements (low thickness or inadequate) but may be used to estimate the effect of unexpected heavy loads on an existing pavement.



EverFE

7.6 EverFE 2.25 Unit System: english Current Project: UP_Intermodel_Vard (No Solution)

7M Out 0000 7M In FILE SOLVE VISUALIZE HELP

Geometry Material Loading Dowel Interlock Meshing

Slab:
 F (lb) 4700
 n 0.2
 alpha (per cent) 65.116
 density (lb/ft³) 0.78-005

Dowels and Ties:
 F (lb) 19000
 n 13

Base:
 E (ksi) 750
 nu 0.2
 density (lb/ft³) 0.45

Slab/Base interface:
 Dropped Edge
 Initial Slip (in) 0.25
 Slip Displacement (in) 0.02

Dense Liquid Subgrades:
 Transverse
 C (lb/ft) 0



EverFE

EverFE 2.25 Unit System: english Current Project: UP_Intermodal_Vend (No Solution)

ZM Out ZM In FILE SOLVE VISUALIZE HELP

Geometry Material Loading Dowel Interlock Meshing

State Layout

- 1 row, 1 column
- 2 rows, 1 column
- 3 rows, 1 column
- 1 row, 2 columns
- 2 rows, 2 columns
- 3 rows, 2 columns
- 1 row, 3 columns
- 2 rows, 3 columns
- 3 rows, 3 columns

Column 1 Length (mm): 120

Column 2 Length (mm): 120

Row 1 Width (mm): 120

Row 2 Width (mm): 120

Row 3 Width (mm): 120

Soil Thickness (mm): 12

First Skew angle (deg): 1

Second Skew angle (deg): 0

Third Skew angle (deg): 1

Dose and Subgrade

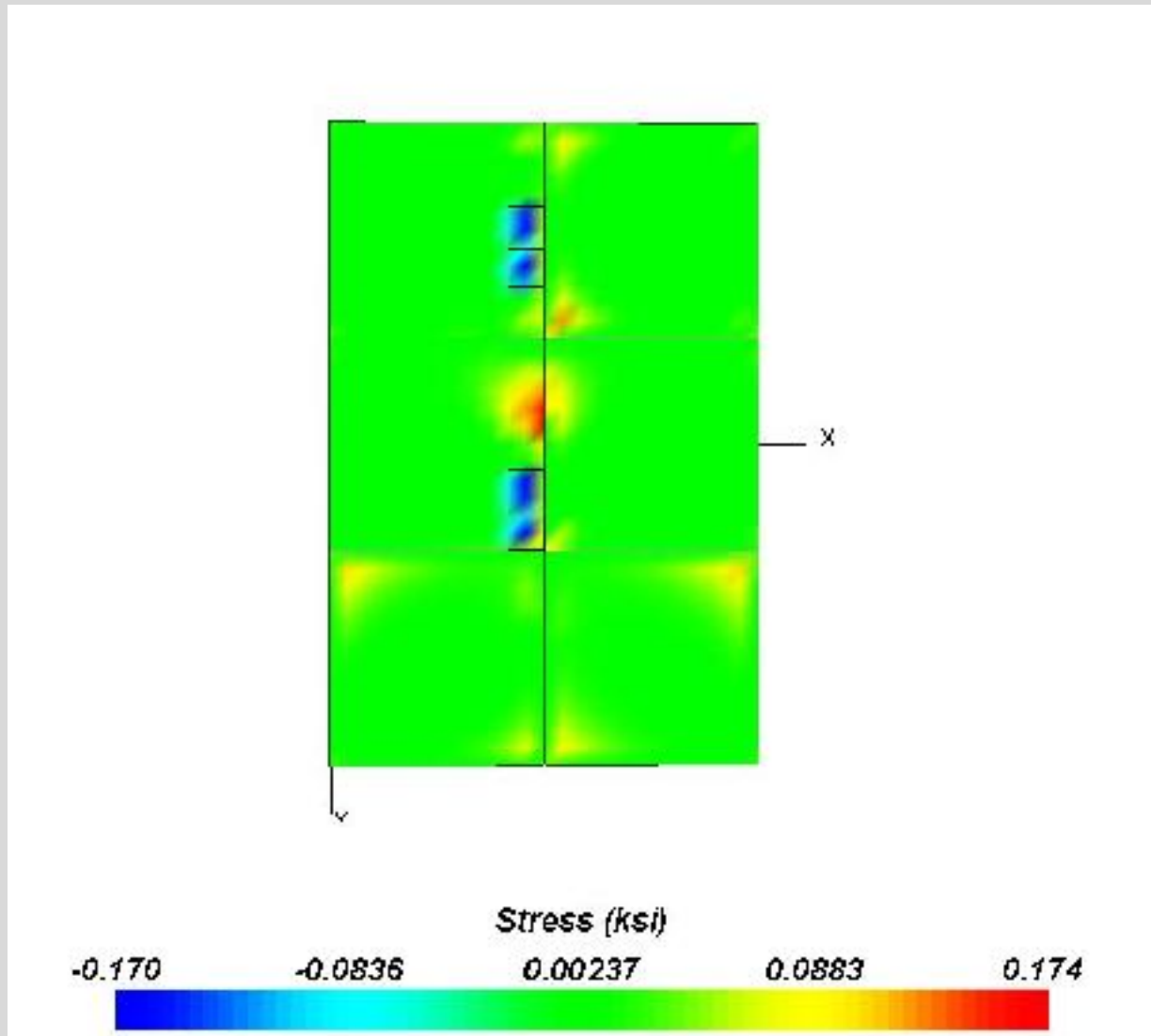
- No Layer
- 1 Layer
- 2 Layer
- 3 Layer

Layer Depth (mm): 12

The screenshot displays the EverFE software interface. The main window is titled 'EverFE 2.25' and shows a project named 'UP_Intermodal_Vend (No Solution)'. The interface includes a menu bar with 'ZM Out', 'ZM In', 'FILE', 'SOLVE', 'VISUALIZE', and 'HELP'. Below the menu bar are tabs for 'Geometry', 'Material', 'Loading', 'Dowel', 'Interlock', and 'Meshing'. The 'State Layout' section contains a list of grid configurations, with '3 rows, 2 columns' selected. To the right of this list are input fields for 'Column 1 Length (mm)', 'Column 2 Length (mm)', 'Row 1 Width (mm)', 'Row 2 Width (mm)', 'Row 3 Width (mm)', 'Soil Thickness (mm)', 'First Skew angle (deg)', 'Second Skew angle (deg)', and 'Third Skew angle (deg)'. The 'Dose and Subgrade' section has radio buttons for 'No Layer', '1 Layer', '2 Layer', and '3 Layer', with '1 Layer' selected, and an input field for 'Layer Depth (mm)' set to 12. The main workspace shows a top-down view of a 3x2 grid of columns and rows, with a cross-section view below it showing a column and a subgrade layer.

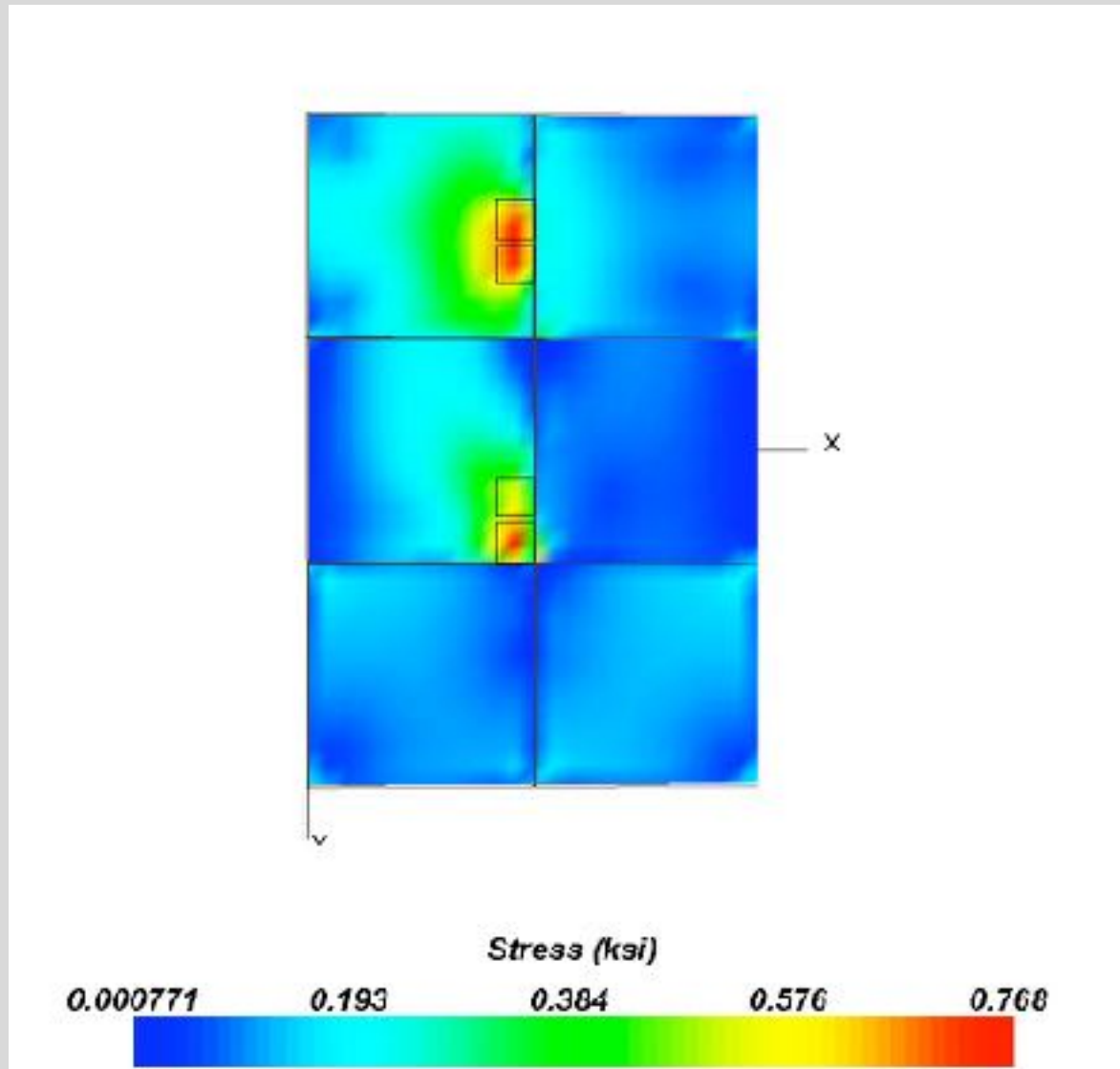


EverFE





EverFE





PCASE

PCASE 14900

File Parameters Add-ins Window Help

Go Traffic | Design | Evaluation | 3D | Details | Edit | Core Features | Vehicle Edit | Help | Utilities | 3D Reports | 3D/Fax Set | GIS Assignment Tool

Inventory | List Set | Vehicle TOASC GO

Vehicle

STACER

Auto in Title: None | Design Type: Road | English | License: 14900-14900-3000

Vehicle	Weight (lb)	Power
STACER	20000	5000
TEPEX 46 XLS PER STACER W/3P LDMC	28295	100

Apply | Edit | Del

PCASE Design Vehicle

Design	Length (in)	Paralel (in)	Head (in)	Wheel (in)	Analysis (in)	Length (in)	Seasons	Traffic
STACER	Round	Feasible	Feasible	Flat	R	COD	ANNUAL	STACER
STACER 12	Round	Feasible	Feasible	Flat	Left	COD	ANNUAL	STACER 12
TEPEX	Round	Feasible	Feasible	Flat	R	COD	ANNUAL	STACER 2
TEPEX 464	Round	Feasible	Feasible	Flat	LED	COD	ANNUAL	STACER 2

ADD | EDIT | DELETE | BACK | FORWARD | COPY | PASTE

Multiple Usage Rules | Material List

Layer	Material	Thickness (in)	Analysis	Non-Fatigue Thickness (in)	Layer Strength
LEFT FLOOR	MARBLE 100		ANALYSIS	1.000	
DECK	S.A.	0.500	Concrete	1.700	3.00
WHEEL	STEEL W/REINFORCED	1.500	STEEL	0.500	3.00
Natural Slope	Concrete (1)		C.S.A.	0.000	250.00

ADD | EDIT | DELETE | BACK | FORWARD | COPY | PASTE | CONNECTION | ADD | REMOVE

Layer Details | View Materials | Sensitivity | Subgrade Prep | Reports | Save and Calculate | Exit

Vehicle Edit Vehicle

Vehicle: JACO-TS 1122-44

Ref Load (lb): 7000 | Custom

Type of Vehicle: Vehicle Ground

Mass (lb): 12000

Minimum Load (lb): 6000

W Load on Rear Gear: 100

OUTSIDE RICHES LINES: 1

Rear Thrust Line: 7

Type of Ground Vehicle: ANALYSIS

Box Shape 1

#	S (in)	T (in)	S Load	Paralel (in)	Design Area (sq in)	Shape
1	35.00	32.00	6.000	100.00	35.00	1.000
2	36.00	34.00	11.111	100.00	60.00	1.000
3	35.00	34.00	11.111	100.00	60.00	1.000
4	32.00	34.00	11.111	100.00	60.00	1.000
5	35.00	34.00	11.111	100.00	60.00	1.000

Setup | View Report | Add | Copy | Edit | Save | Cancel | Delete | Exit

Non-Linear | Characteristics

Gear Plot

Legend: Torque (Add, Remove, Move, Flip, Rotate, Copy, Paste)

OK | Cancel



Overlay Experiences

- Spokane, WA
 - 3 sections on I-90, 3", 4", 5"
 - Constructed in 2004
 - Eastbound AADT 40,000
 - Excellent performance in 4" and 5" sections
 - Reconstructed in 2011







BCOA - ME



VANDENBOSSCHE

BACKGROUND

COURSES

RESEARCH

LAB TOUR

BCOA-ME

[ADMISSIONS](#) [ACADEMICS](#) [RESEARCH](#) [STUDENTS](#) [ALUMNI & GIVING](#) [RESOURCES](#)

IAM

BCOA-ME



(Last site update Jan. 2016/Last guide update April 2015)

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

[DESIGN GUIDE](#)

[PRACTITIONER'S INFO](#)

[TRAINING TOOLS](#)

[TECHNICAL DOCS](#)

[SPONSORING AGENCIES](#)



BCOA ME Sponsors

- VANDENBOSSCHE
- BALDWIN
- COUNCILS
- DISPATCH
- LAD TOUR
- BCOA ME
 - BCOA ME Home
 - Design Guide
 - Practitioner's Information
 - Training
 - Technical Discussions
 - Submittals



SPONSORS





BCOA ME Main Screen

GENERAL INFORMATION

Latitude (degree):	<input type="text" value="45.95"/>	Geographic Information
Longitude (degree):	<input type="text" value="-109.98"/>	
Elevation (ft):	<input type="text" value="223"/>	
Estimated Design Lane LSPLs:	<input type="text" value="17987000"/>	ESPLs Calculator
Maximum Allowable Percent Slabs Cracked (%):	<input type="text" value="15"/>	
Desired Reliability against Slab Cracking (%):	<input type="text" value="90"/>	

CLIMATE

ANALM Region ID:	<input type="text" value="3"/>
Map of Sunshine Zone:	<input type="text" value="0"/>

EXISTING STRUCTURE

Post-curing HMA Thickness (in):	<input type="text" value="4"/>	
HMA Fatigue:	<input type="text" value="Adequate"/>	Fatigue Cracking Example
Composite Modulus of Subgrade Reaction, k value (pci/in):	<input type="text" value="150"/>	k-value Calculator
Does the existing HMA pavement have transverse	<input type="radio"/> Yes <input checked="" type="radio"/> No	Transverse Cracking



BCOA ME Traffic

ESALS ESTIMATION:

Is One-Way ADT Available?

Yes

No

ESTIMATE ESALS:

Design Life (yrs):

30

Terminal Serviceability:

2.5 ▼

Number of Lanes in Each Direction:

2 ▼

Percent Trucks(%):

8

ADTT Growth Rate (%):

2

Traffic Growth Rate Type:

Non-linear ▼

Road Category:

Major arterial ▼

One Way Average Daily Traffic (ADT):

15000

CANCEL

SUBMIT



BCOA ME Environment

GEOGRAPHIC INFORMATION

Option 1

Open webpage to estimate climate information.

[Open Webpage](#)

or

Option 2

Choose closest city with a similar climate:

OR ▼ PORTLAND ▼

[CANCEL](#)

[SUBMIT](#)



BCOA ME Main Screen

PCC OVERLAY PROPERTIES

Average 28-day Flexural Strength (lb/in² beam):

550

Estimated PCC Elastic Modulus (psi):

2930000

E-mod Calculator

Coefficient of Thermal Expansion (10⁻⁶ in./°F/in):

8

CTE Calculator

Fiber Type:

No fibers

JOINT DESIGN

Joint Spacing (ft):

0 x 0

CALCULATE DESIGN

PERFORMANCE ANALYSIS

Calculated PCC Overlay Thickness (in)

5.13

Design PCC Overlay Thickness (in)

5

Is there potential for reflective cracking?

No

Solved.

Macro Fibers

Table 1. Concrete Mix Proportions and Fresh and Mechanical Concrete Properties

	Plain concrete	0.32% synthetic macrofibers	0.48% synthetic macrofibers	0.35% hooked end steel fibers	0.50% crimped steel fibers
Materials (kg/m ³)					
Coarse aggregate	995	975	976	965	983
Fine aggregate	823	806	807	796	813
Cement	363	360	360	347	363
Water	178	182	183	163	172
Daracem (mL/100 kg)	925	1,116	1,117	868	1,328
Water-to-cement ratio	0.49	0.51	0.51	0.49	0.47
Air content (%)	1.8	2.9	2.8	6	3.2
Slump (mm)	200	150	115	110	190
Compressive (MPa)	41.1	36.1	31.8	34	37.2
Flexural strength (MPa)	4.73	4.69	4.82	4.68	5.28
^a R _{0.3} values (%)	2	24	39	43	35
Slab thickness (mm)	139.7	131.8	131.8	131.8	131.8

^aR_{0.3} = equivalent flexural strength ratio at 3-mm deformation.



BCOA ME

Design w/ Fibers

PCC OVERLAY PROPERTIES

Average 28 day Flexural Strength (three point bend) ▾	<input type="text" value="650"/>	
Estimated PCC Elastic Modulus (psi):	<input type="text" value="2900000"/>	Eps Calculator
Coefficient of Thermal Expansion (10 ⁻⁶ in./°F./in)	<input type="text" value="6"/>	CTE Calculator
Fiber Type:	<input type="text" value="Synthetic Strand and fibers ▾"/>	
Fiber Content (lb/yds):	<input type="text" value="3"/>	

JOINT DESIGN

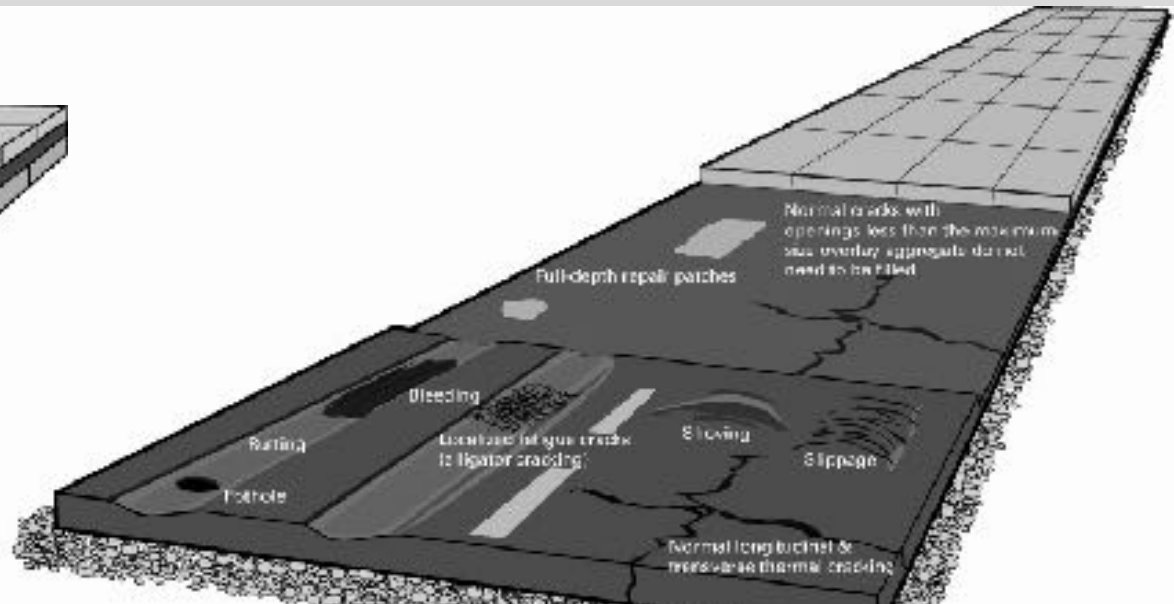
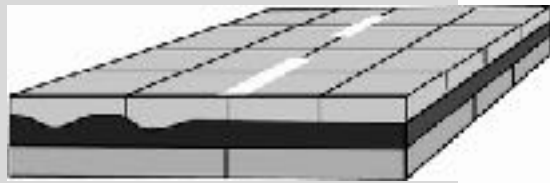
Joint Spacing (ft):	<input type="text" value="6 x 6 ▾"/>
---------------------	--------------------------------------

CALCULATE DESIGN

PERFORMANCE ANALYSIS

Calculated PCC Overlay Thickness (in)	4.16
Design PCC Overlay Thickness (in)	4.5
Is there potential for reflective cracking?	No
	Solved.

Repairs-Bonded Resurfacing of Asphalt or Composite Pavement



Existing pavement distress	Spot repairs to consider
Fatigue cracking	Full-depth repair patch
Pothole	Full-depth repair patch
Deep rutting	Milling
Shoving, slippage	Milling
Thermal cracking	None



Milling: Bonded Resurfacing of Asphalt or Composite Pavements

The three main objectives of milling:

1. to remove significant surface distortions that contain soft asphalt material, resulting in an inadequate bonding surface
2. to reduce high spots to help ensure minimum resurfacing depth and reduce the quantity of concrete needed to fill low spots; and
3. to roughen a portion of the surface to enhance bond development between the new concrete overlay and the existing asphalt.
(don't leave a thin lift)

Milling: Bonded Resurfacing of Asphalt or Composite Pavements

- Complete removal of ruts is not needed when rutting in the existing asphalt pavement does not exceed 2".
- Any ruts in the existing pavement are filled with concrete, resulting in a thicker concrete overlay above the ruts.
- A minimum of 3"–4" of asphalt should be left after milling because of the reliance on the asphalt pavement to carry a portion of the load.





Pre-Paving



- Surface cleaning
 - Power sweeping
 - Air blasting





Construction



- Place concrete when surface temperature is $<120^{\circ}\text{F}$.
- Conventional fixed-form or slip form placement used.
- Shotblast or mill (if needed) and clean surface thoroughly.
- Grout or epoxy bonding agents are not required (however local conditions and experience will dictate).
- Texture Pavement for friction.
- Curing material must be placed as soon as possible (<30 minutes). Full coverage is essential.
- Begin sawing as soon as possible (use of early entry saw is recommended).
- Test mix throughout placement for QC.



Paving



- Maintenance of traffic
 - Depends on concrete overlay thickness
 - If edge drop-off criteria is exceeded, then MOT is just like full depth PCC reconstruction
 - Otherwise, similar to MOT for asphalt projects
 - Options include:
 - Construction adjacent to traffic (lane at a time)
 - Positive separation or cones
 - Pilot car operation for two lane roadways
 - Crossovers and construct full width
 - Staged intersections or full closure with accelerated opening (48 to 72 hr)
 - All concrete overlays are accelerated construction!



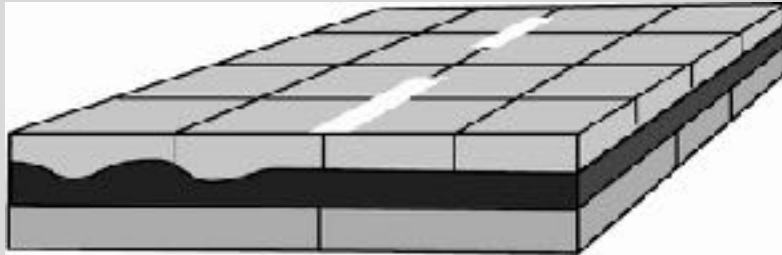
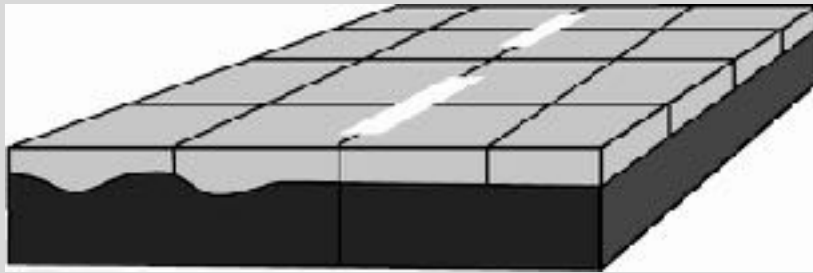
Curing of Overlays

- Cure as soon as practical
- Even and complete coverage
- Consistent operating speed
- Edge covered also
- Even and complete cover
- Adjust for dry and/or wind
- Clean/adjust nozzles
- Keep it wet, keep it warm: for durability





Important Elements-Bonded Resurfacing of Asphalt/Composite Pavement



- Clean Surface/Bond is important for good performance
- Thin milling may be required to eliminate significant surface distortions of 2" or more and provide good bond.
- Leave at least 3" remaining asphalt after milling.

- Control surface temperature of existing asphalt to below 120°F.
- Try to keep joints out of wheel paths.
- Curing should be timely and adequate.
- Small joint spacing to minimize bonding shear stress



Unbonded on Concrete

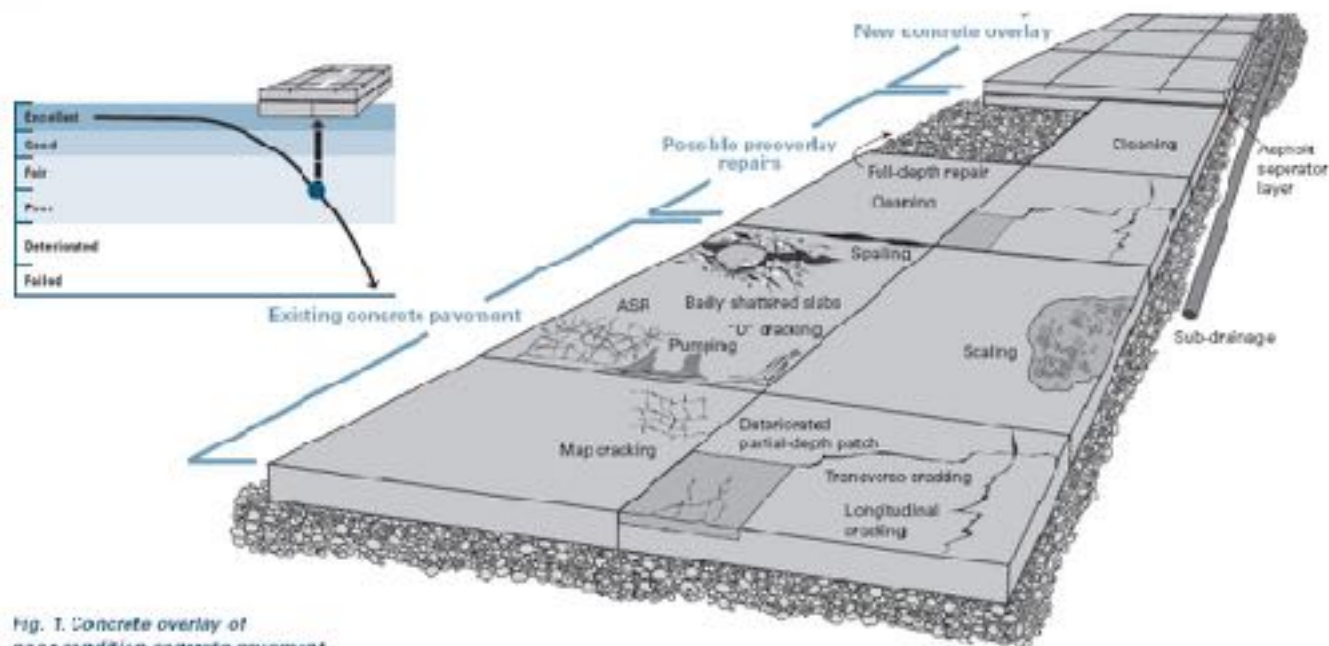


Fig. 1. Concrete overlay of poor condition concrete pavement

- If the movement is confined to isolated areas, full depth repairs can solve the problem.
- For faulted pavements, if the subgrade is stable, the overlay has proven to be adequate.
- Minor faulting is generally not a concern when a separator layer of 1" or greater is used.



Separation for Unbonded Overlays

- Separation required for good performance.
 - Isolate overlay from existing pavement:
 - Prevent reflection cracking.
 - Prevent bonding/mechanical interlocking.
 - Provide level surface for overlay construction.
 - Traditional – 1 in dense HMA.
 - New – Nonwoven Geotextile fabric (MO, ND, VA, KS...)





Nonwoven Fabric Interlayer





Nonwoven Fabric Interlayer





Nonwoven Fabric Interlayer





Benefits of Geotextile Interlayer

- Provides adequate separation
- Avoids another paving operation:
 - Saves on mobilization
 - Avoids materials availability/cost issues
- Reduces overhead clearance issues
- Reduces materials for shoulder fills
- Reduces project costs



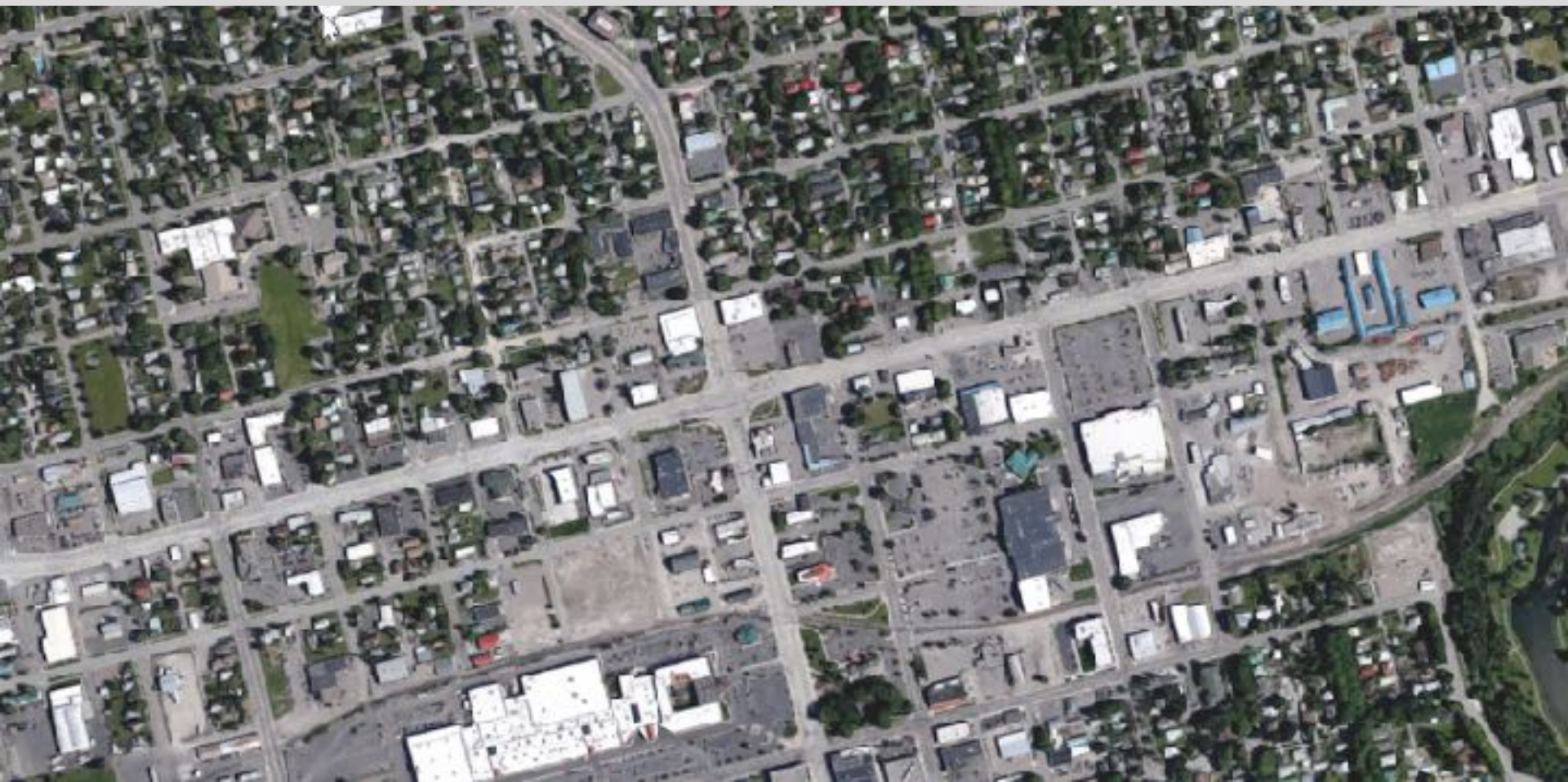
Overlay Experiences

- Kalispell
 - 5" on 5" of HMA
 - 6' joint spacing
 - 18,000 ADT in 2000
 - 30% Trucks
 - Built in 2000
 - Performing very well











Overlay Experiences

- Bellevue
 - 3” PCC on 3” AC
 - Built 1998
 - Still in service
 - Cracking in edge panels due to lack of support. Edge panels have been replaced.





Overlay Experiences

- US 20/26 & Middleton Road
- Built in 2005
- 4" on 4"
- Still in service
- Excellent performance





Other NW Projects

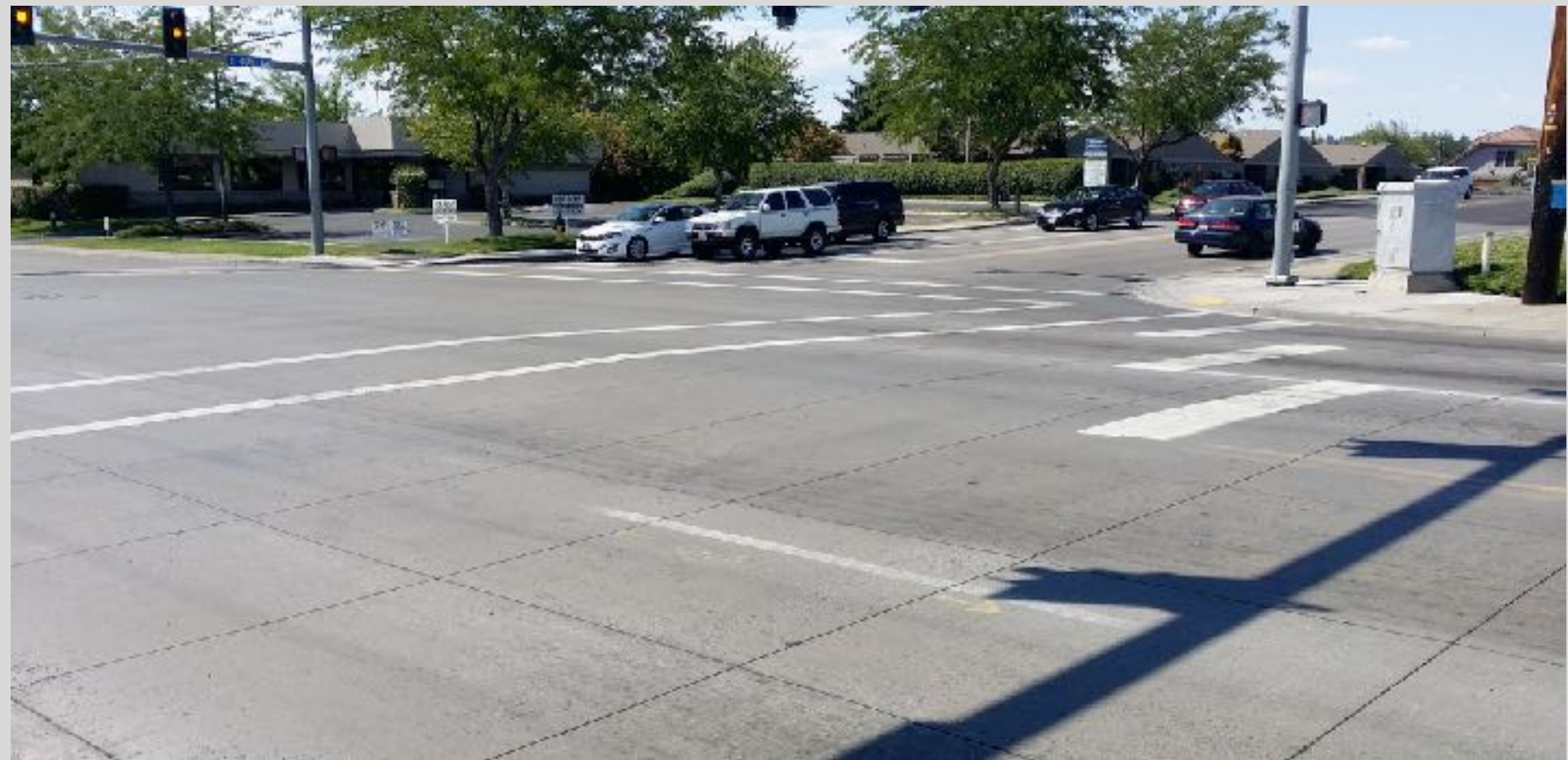
- Portland
 - NE Columbia Blvd.
 - 4" – 6" PCC on 0" – 4" Asphalt
 - N. Denver Avenue
 - 2.5" PCC on Variable Sections
- Eugene
 - Coburg Rd.
 - 6" PCC on 4" Asphalt
- Yakima
 - 40th and Knob Hill
 - 6" PCC on 2" – 4" Asphalt

Portland





Yakima





QUESTIONS?