Design Guide Framework

Bonded Concrete Overlay of Asphalt Pavements Mechanistic-Empirical Design Guide (BCOA – ME)

Julie M. Vandenbossche, P.E., Ph.D.
University of Pittsburgh

FHWA Pooled Fund Study TPF 5-165

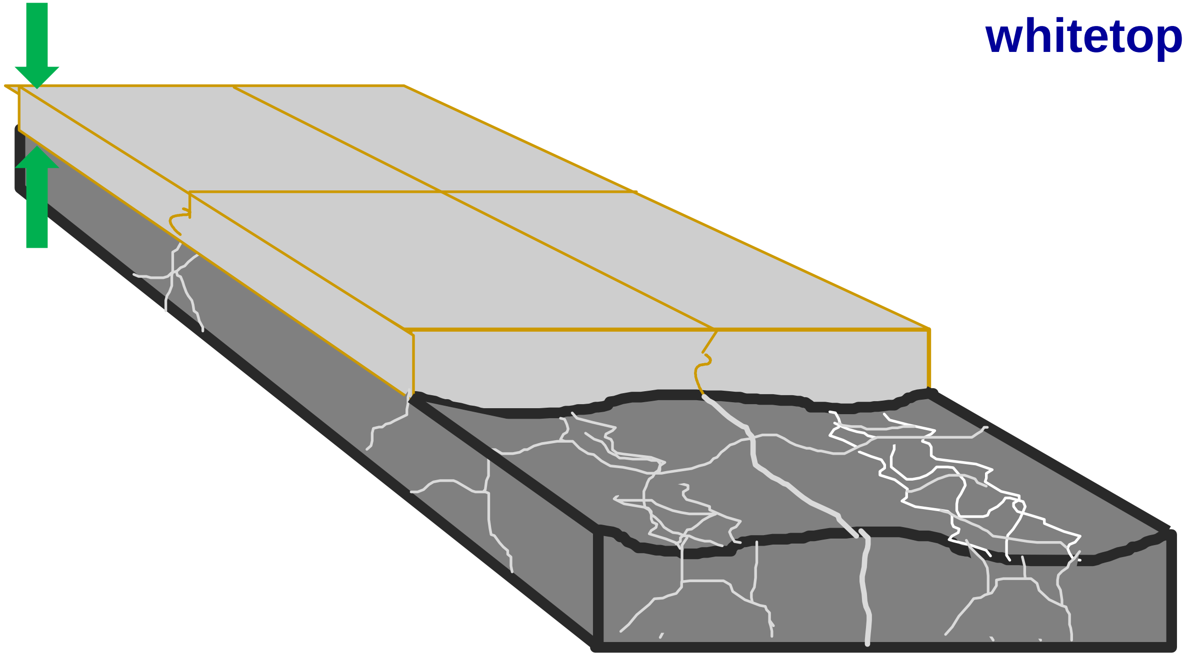
BACKGROUND & RESEARCH APPROACH

Definition

Thickness

UTW: 2”- 4” and TWT: 4.5”- 6”

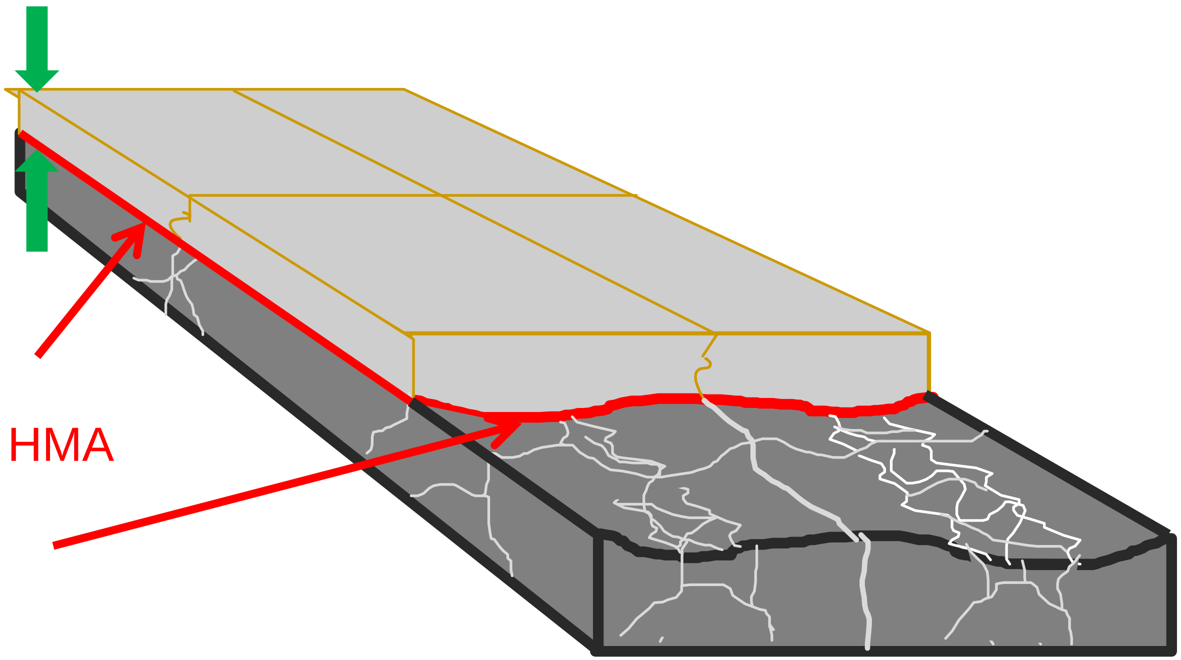
BCOA = thin & utlra-thin whitetopping



Performance- bond

Thickness

UTW: 2”- 4” and TWT: 4.5”- 6”



Bond PCC to HMA

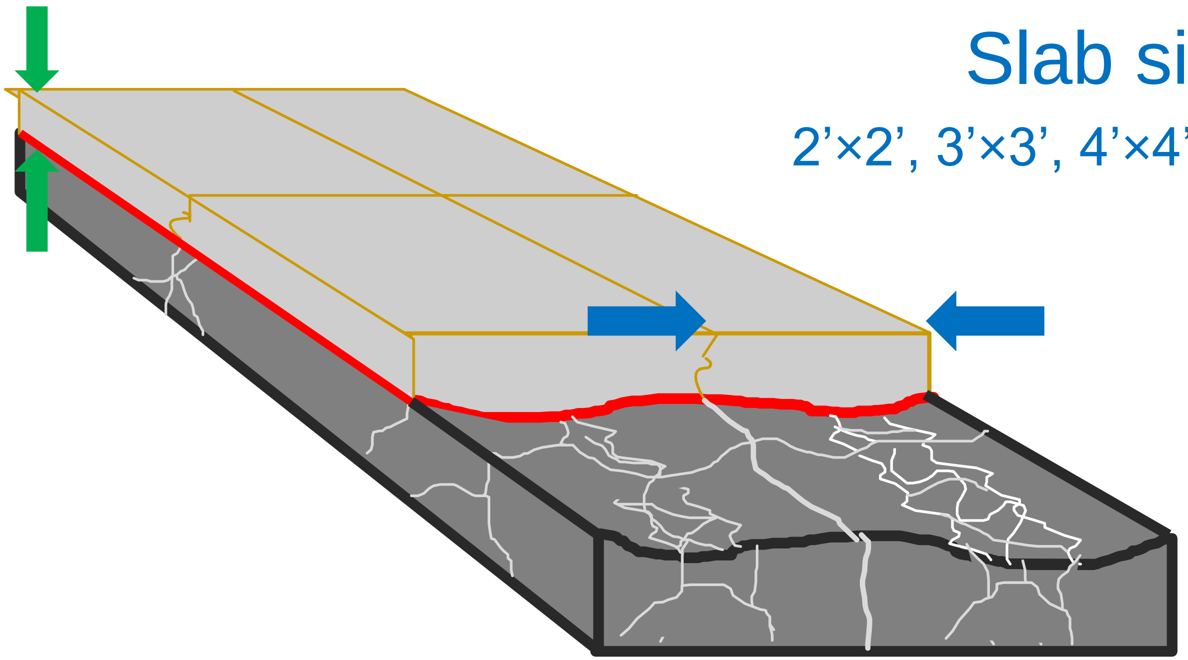
Performance – curl/warp

Thickness

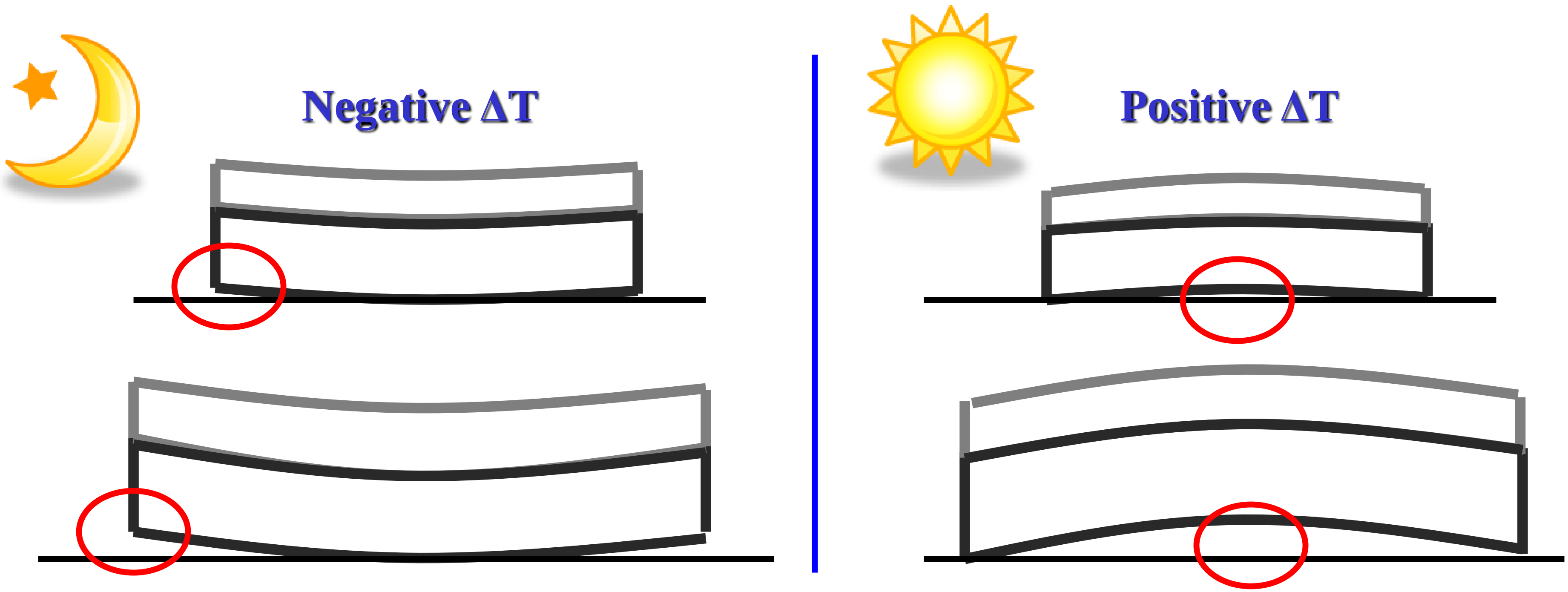
UTW: 2”- 4” and TWT: 4.5”- 6”

Slab size

2’×2’, 3’×3’, 4’×4’ and 6’× 6’

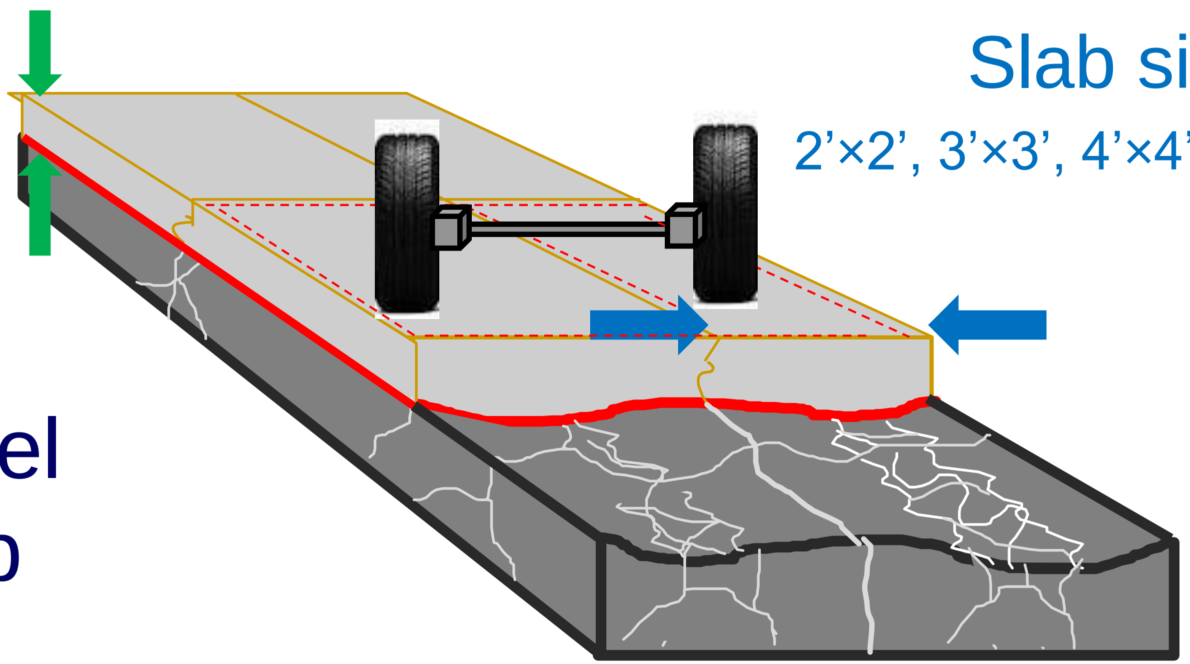


Performance – slab size



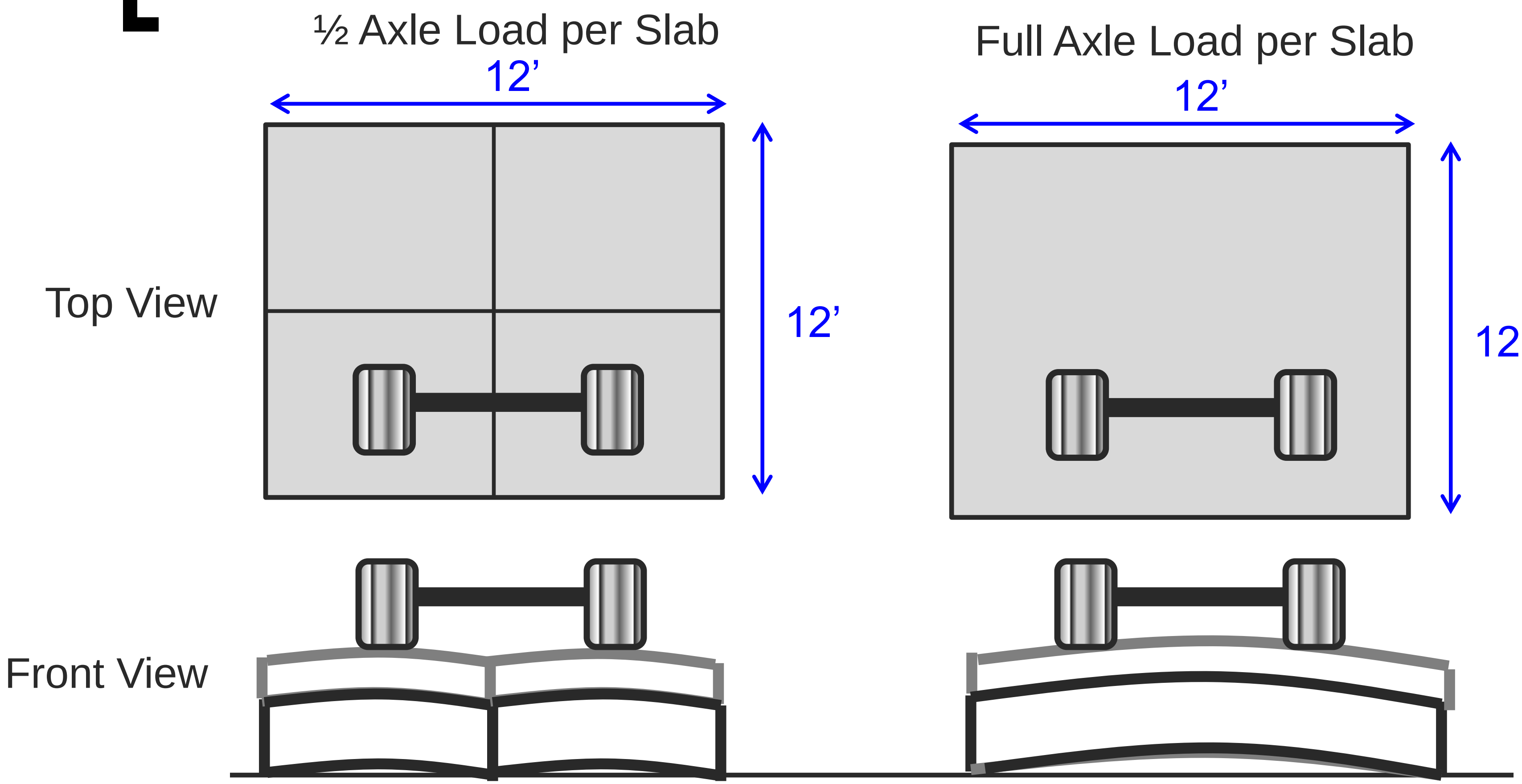
Stresses due to gradients increase with increasing slab length

Performance – one wheel per slab



One wheel per slab

Performance – slab size



More fully supported
Lower stress

Reduced support
Higher stress

Historical review

1989-1998: 181 projects in 29 states (ACPA)

1997: MnROAD instrumented sections

1998: First design procedures developed for UTW and TWT

2002: First Edition of CP Tech Center Overlay Guide

2004: Revised procedures

2004: Over 1 million syd of 6 in or thinner overlays had been placed to date (Tom Cackler)

2009-2010: Over 8 milllion syd of 6 in or thinner overlays were placed during this time (Tom Cackler)

FHWA Pooled fund study

FHWA Pooled Fundy Study 5-195: Development of Design Guide for Thin and Ultra-thin concrete Overlays of Existing Asphalt Pavements

- Minnesota – **Lead**
- Missouri
- Mississippi
- New York
- Pennsylvania
- Texas

- North Carolina, South Dakota, Iowa, Kansas

Project objectives

1. Establish field performance history & limitations of current procedures
2. Develop a design guide based on mechanistic-empirical principles
3. Create a user-friendly spreadsheet based design guide and user's manual

Project timeline

Dec. 2008: First TAP meeting

Aug. 2010: TAP members agree on supplemental work for expanding Task 3 (bond and fiber study) and Task 5

($75,000 + 6 mth extension)

Oct. 2011: Supplemental contract signed

Oct. 2011: TAP members agree on supplemental work to incorporate new structural models

(1 year extension + $100,000)

Mar. 2013: Supplemental contract signed to address new failure mode

Sept. 11, 2013: Project end date

After over 10,000 EICM and 11,000 ABAQUS runs the project is near completion!!

Projected Timeline

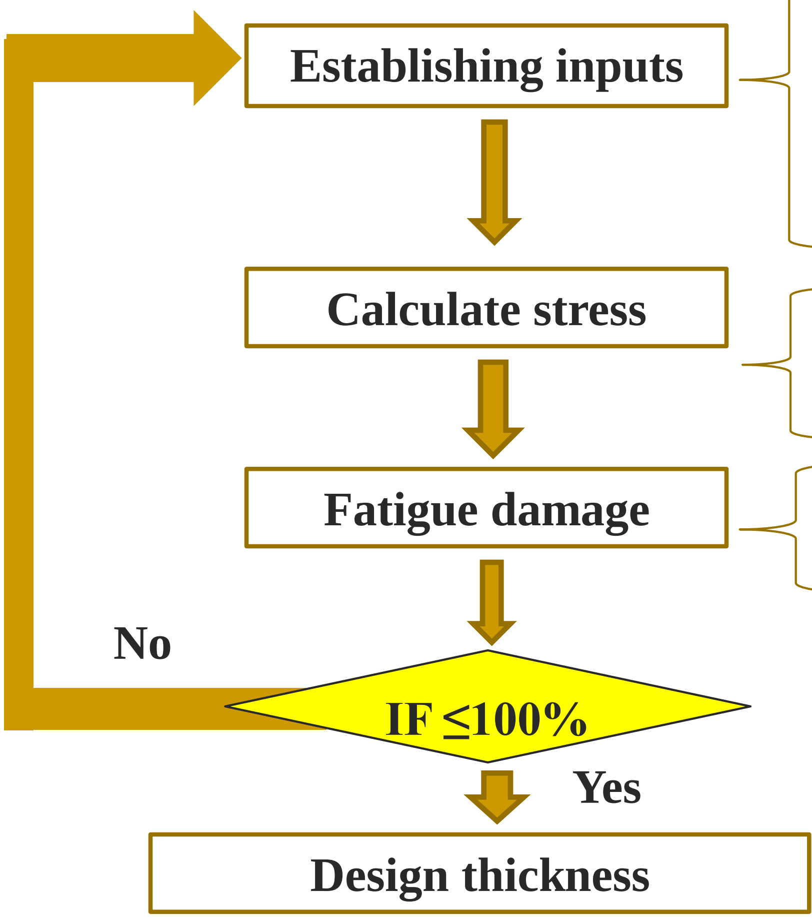
August 26, 2013: Submit remaining deliverables (Training videos, Tech Notes & Laboratory Study)

Sept 2, 2013: Receive all comments

Sept. 11, 2013: All comments addressed and deliverables submitted

FRAMEWORK & ENHANCEMENTS

Design flow chart



Enhancements

- Traffic
  - Wheel wander
- Establish HMA stiffness
- Climate consideration
  - HMA stiffness
  - Effective temp gradients
- PCC properties: structural fibers

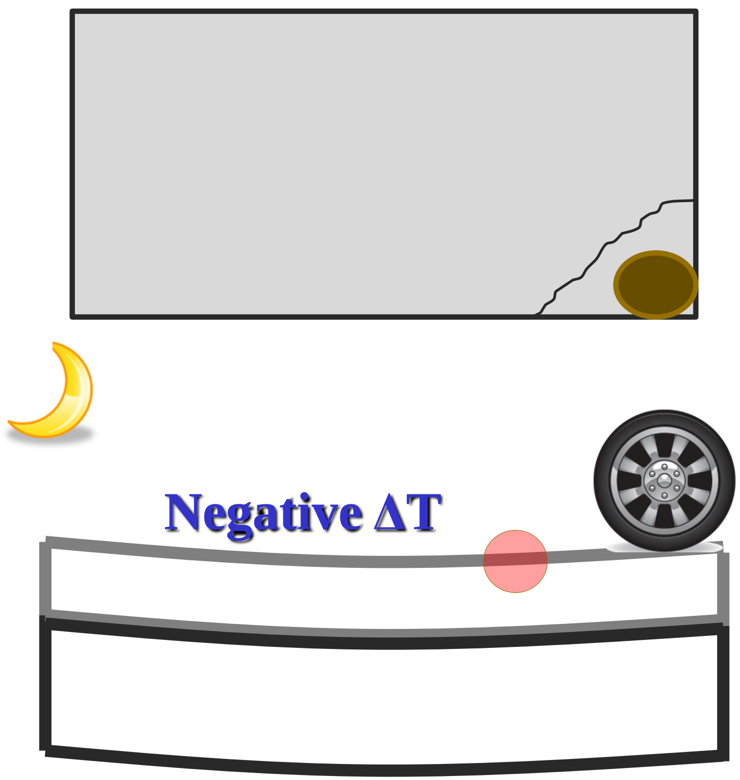
- Identifies correct failure mode
- Structural response models
- Interface debonding

- Calibration

Design history

PCA (1998)

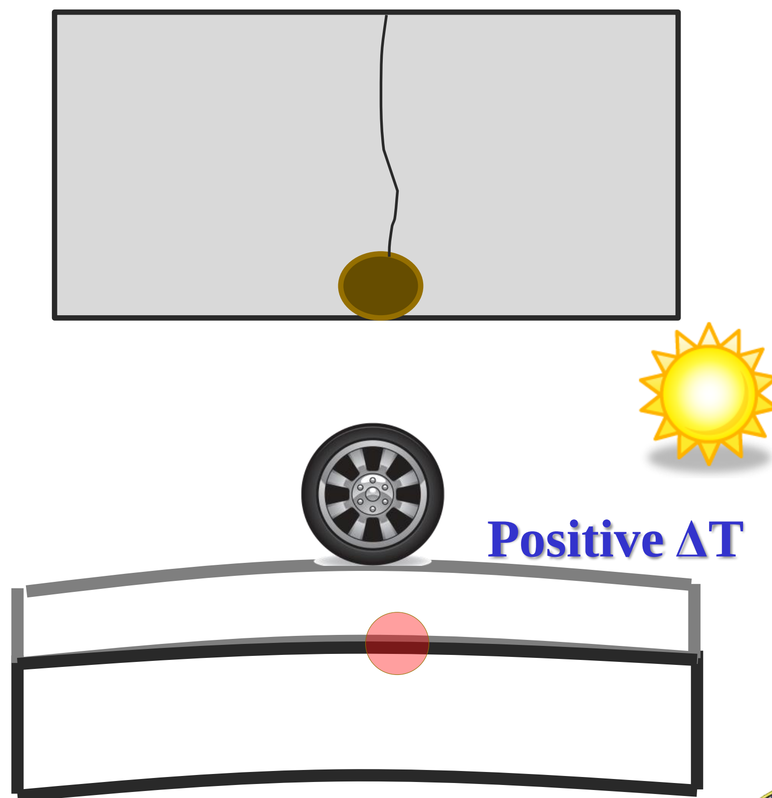
UTW (≤ 4in): Corner crck



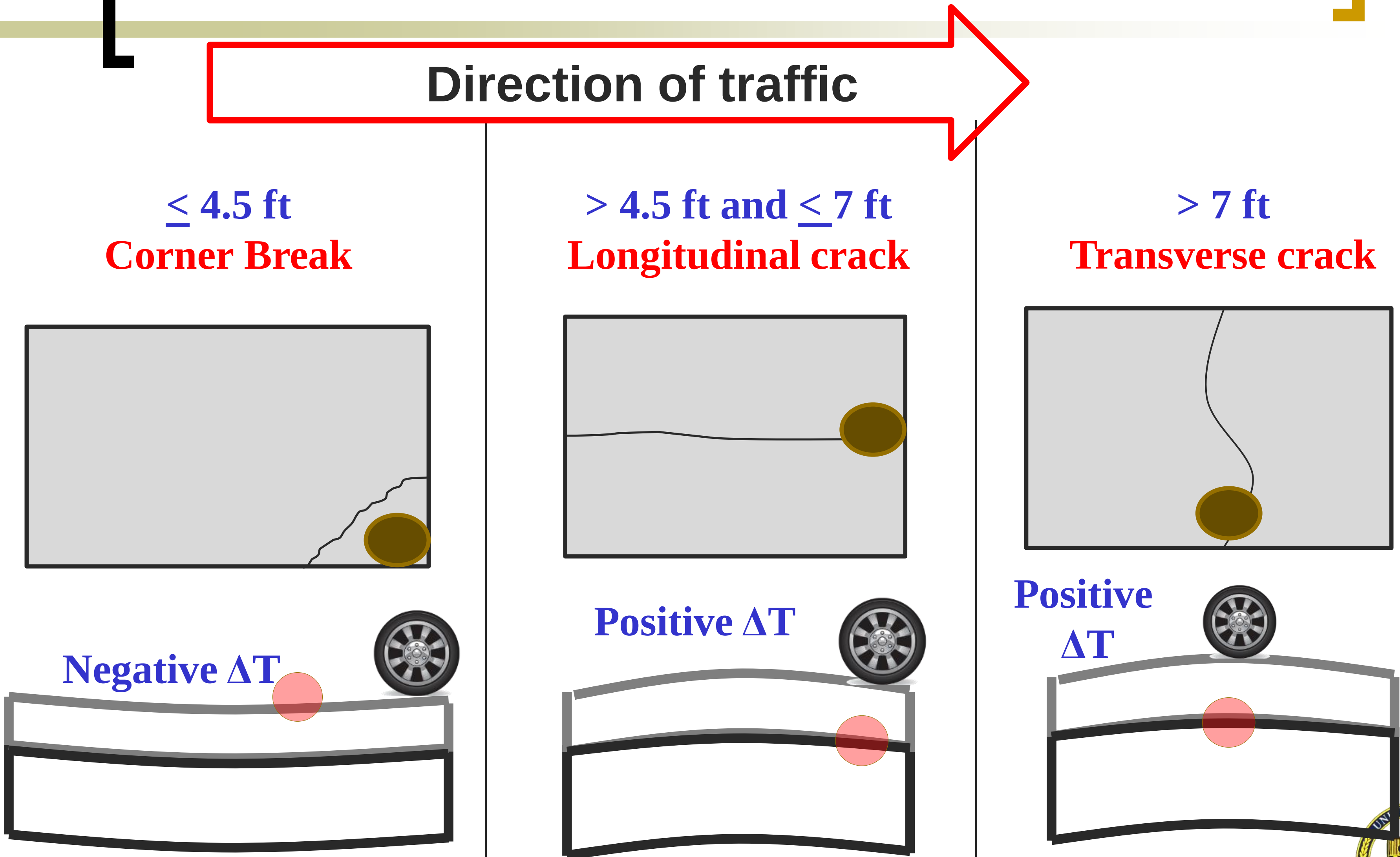
Assumed failure mode for ACPA BCOA app

CDOT (1998; rev. 2004)

TWT(< 4 in to ≤ 6in): Trans. crck

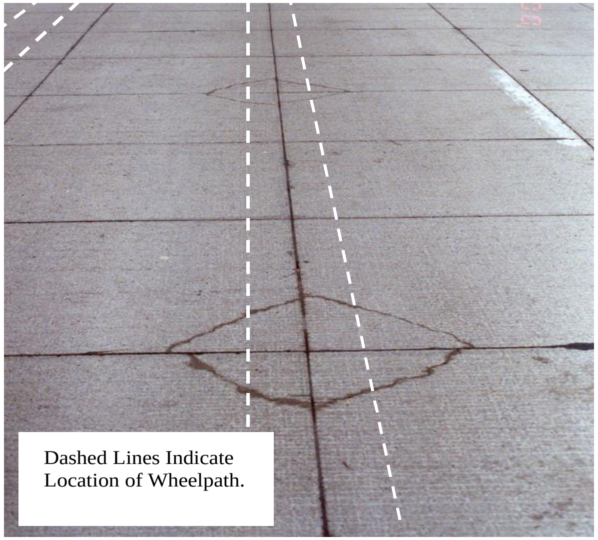


Actual failure modes

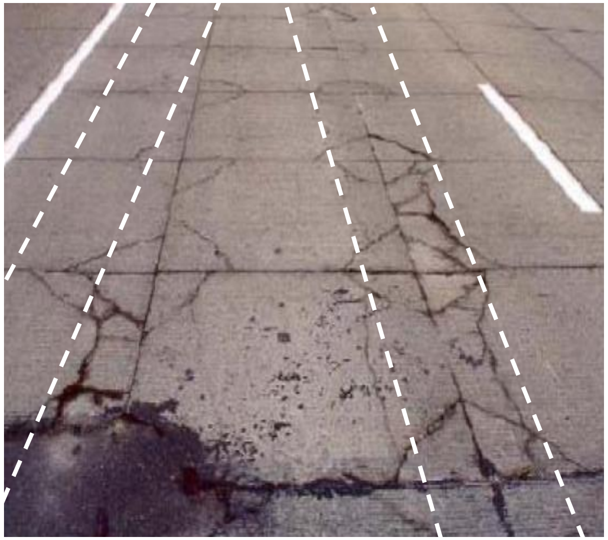


BCOA-ME Failure modes

corner breaks



(a) Cell 94 (2001)



(b) Cell 94 (2003)

BCOA-ME Failure modes

Initiation point

Longitudinal cracks in the wheelpath

March, 2009

Failure mode not considered

Midslab Longitudinal cracks

Structural models

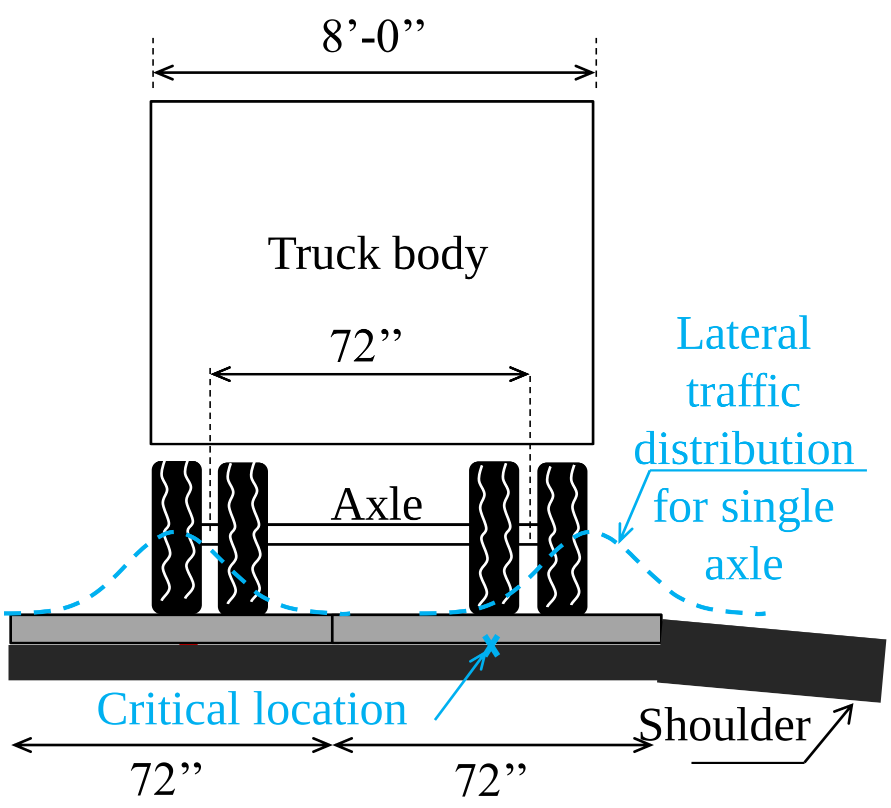
Parameters	ACPA	PITT	CDOT
Failure	Corner break	Longitudinal crack	Transverse crack
L, ft	2x2, 4x4	6x6	4x4, 6x6, 12x12
h_{PCC}, in	2-4	3, 4, 5, 6	4-7
E_{PCC}, million psi	4	4	4
h_{HMA}, in	3-9	3, 5, 7, 9	3, 6, 9
E_{HMA}, million psi	0.05-2	0.2, 0.4, 0.6, 0.8, 1.0, 1.5, 2.0, 3.0, 4.0	0.05, 0.25,0.5,0.75, 1
k-value, psi/in	75-800	50, 150, 300, 500	50, 150, 300, 500

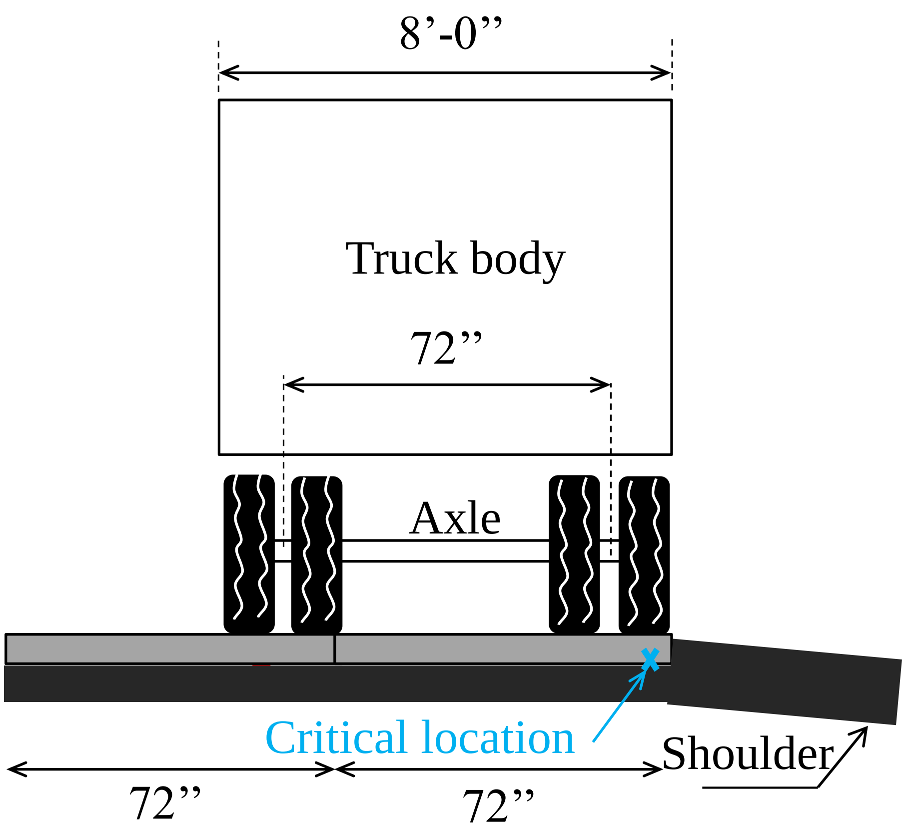
Structural models

ACPA BCOA app

Parameters	ACPA	PITT	CDOT
Failure	Corner break	Longitudinal crack	Transverse crack
L, ft	2x2, 4x4	6x6	4x4, 6x6, 12x12
h_{PCC}, in	2-4	3, 4, 5, 6	4-7
E_{PCC}, million psi	4	4	4
h_{HMA}, in	3-9	3, 5, 7, 9	3, 6, 9
E_{HMA}, million psi	0.05-2	0.2, 0.4, 0.6, 0.8, 1.0, 1.5, 2.0, 3.0, 4.0	0.05, 0.25,0.5,0.75, 1
k-value, psi/in	75-800	50, 150, 300, 500	50, 150, 300, 500

Wheel wander





HMA stiffness

Establish E_{HMA}

1. Estimated E_{HMA} for new mix
   - Binder selected based on geographical location & LTPP Bind
   - Typ. agg. gradation
2. Adjust E_{HMA}
   - Aging
   - Fatigue - % HMA fatigue cracking

HMA condition	Fatigue cracking (%)	Damage factor	E_{HMA} reduction (%)
Adequate	0 – 10%	0.4	10
Marginal	10 – 15%	0.6	20

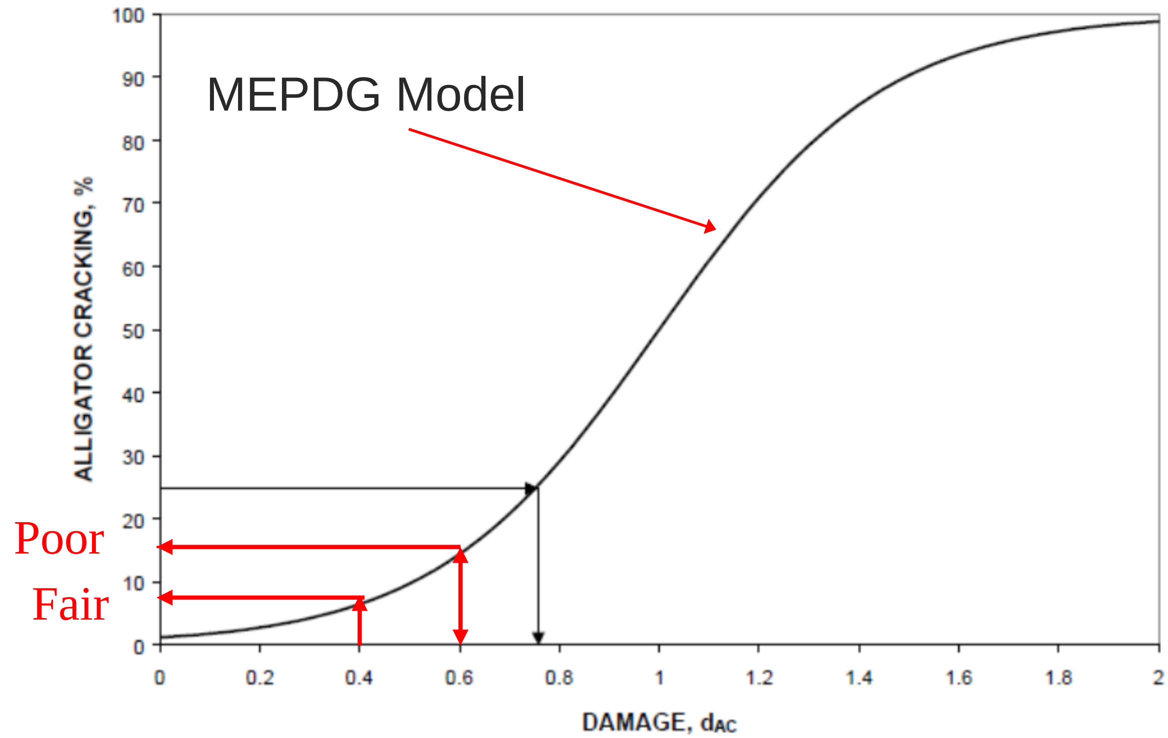
Reduction of HMA modulus

Table 13. Distress types and levels recommended for assessing asphalt and composite pavement structural adequacy

Distress Type	Highway Classification	Distress Level		
		Adequate	Marginal	Inadequate
Fatigue cracking (% of wheel path area)	Interstate/Freeway	<5	5 to 20	>20
	Primary	<10	10 to 45	>45
	Secondary	<10	10 to 45	>45
Longitudinal cracking in wheel path (ft/mi)	Interstate/Freeway	<265 (50.2 m/km)	265 to 1060 (50.2 to 200.8 m/km)	>1060 (200.8 m/km)
	Primary	<530 (100.4 m/km)	530 to 2650 (100.4 to 501.9 m/km)	>2650 (501.9 m/km)
	Secondary	<530 (100.4 m/km)	530 to 2650 (100.4 to 501.9 m/km)	>2650 (501.9 m/km)
Composite pavement reflection cracking crack width (in.)	Interstate/Freeway	<0.50 (12.7 mm)	0.25 to 0.50 (6.4 to 12.7 mm)	>0.50 (12.7 mm)
	Primary	<0.50 (12.7 mm)	0.50 to 0.75 (12.7 to 19.1 mm)	>0.75 (19.1 mm)
	Secondary	<0.50 (12.7 mm)	0.50 to 0.75 (12.7 to 19.1 mm)	>0.75 (19.1 mm)
Transverse crack spacing (ft)	Interstate/Freeway	>200 (61.0 m)	100 to 200 (30.5 to 61.0 m)	<100 (30.5 m)
	Primary	>120 (36.6 m)	60 to 120 (18.3 to 36.6 m)	<60 (18.3 m)
	Secondary	>120 (36.6 m)	60 to 120 (18.3 to 36.6 m)	<60 (18.3 m)
Mean depth of rutting in both wheel paths (in.)	Interstate/Freeway	<0.25 (6.4 mm)	0.25 to 0.40 (6.4 to 10.2 mm)	>0.40 (10.2 mm)
	Primary	<0.35 (8.9 mm)	0.35 to 0.60 (8.9 to 15.2 mm)	>0.60 (15.2 mm)
	Secondary	<0.40 (10.2 mm)	0.40 to 0.80 (10.2 to 20.3 mm)	>0.80 (20.3 mm)
Shoving (% of wheel path area)	Interstate/Freeway	None	1 to 10	>10
	Primary	<10	10 to 20	>20
	Secondary	<20	20 to 45	>45
Applicability of Bonded Concrete Overlays				
Applicability of Unbonded Concrete Overlays				

(From the “Guide to Concrete Overlays” -by CP Tech Center)

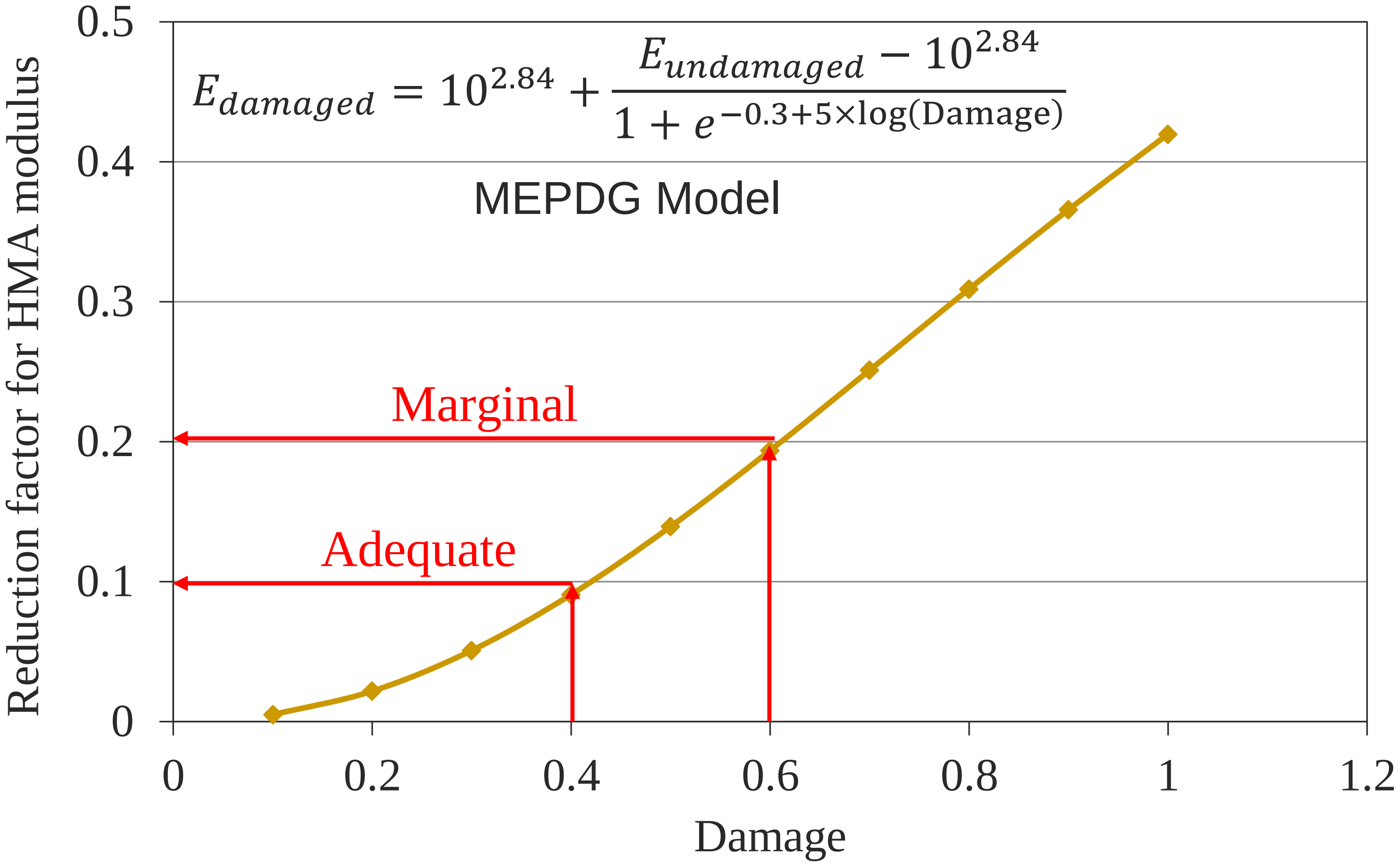
HMA stiffness reduction-Fatigue



CP Tech Center condition criteria for BOCA candidates

Condition	**% Fatigue crack**	**Damage**
Adequate	0-7.5	0.4
Marginal	7.5-15	0.6

HMA stiffness reduction-Fatigue

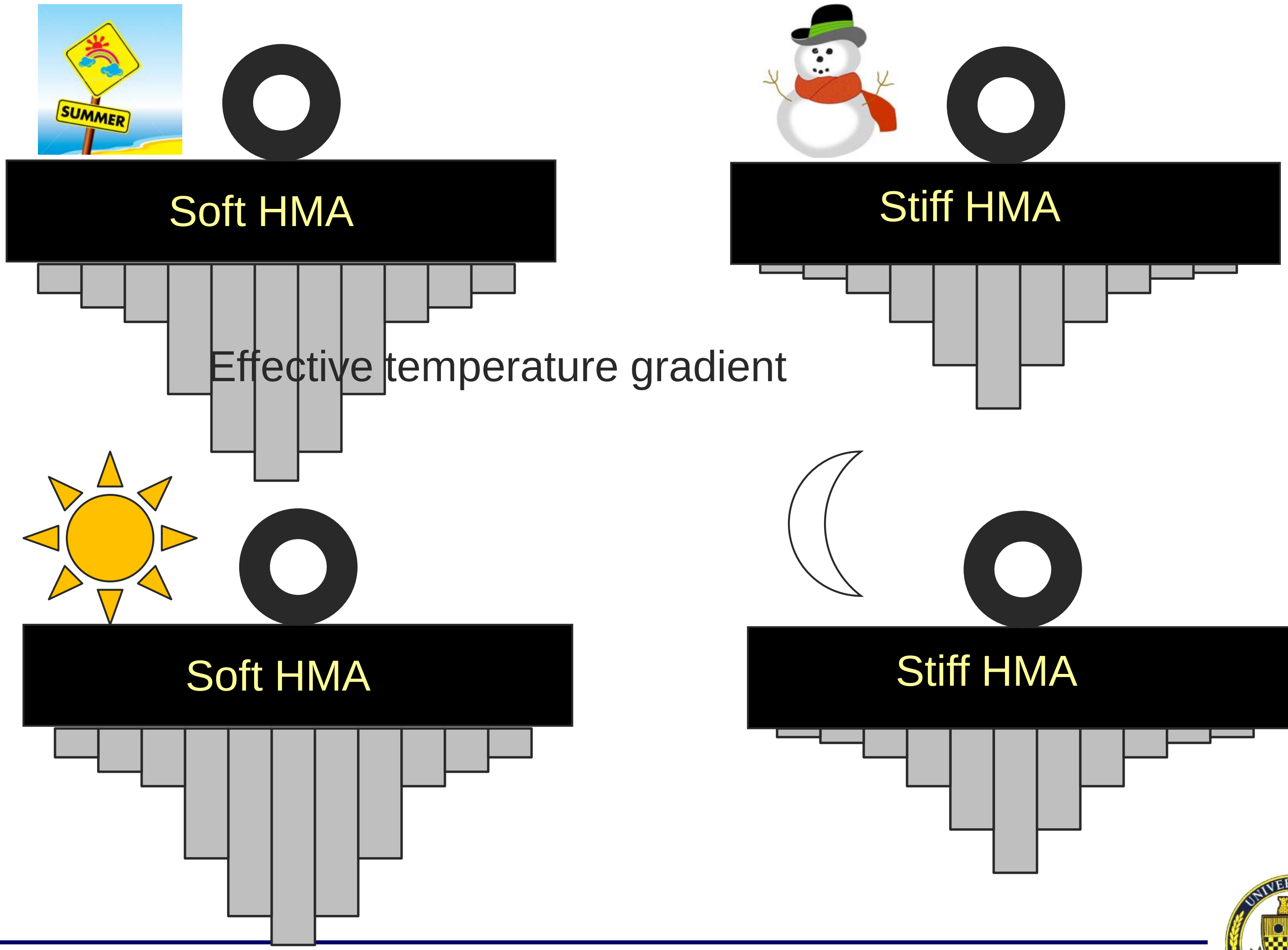


TEMPERATURE EFFECTS ON HMA STIFFNESS

Temp. dependence of E_{HMA}

Seasonal variation

Daily variation



Populating database: Climate

194 weather stations

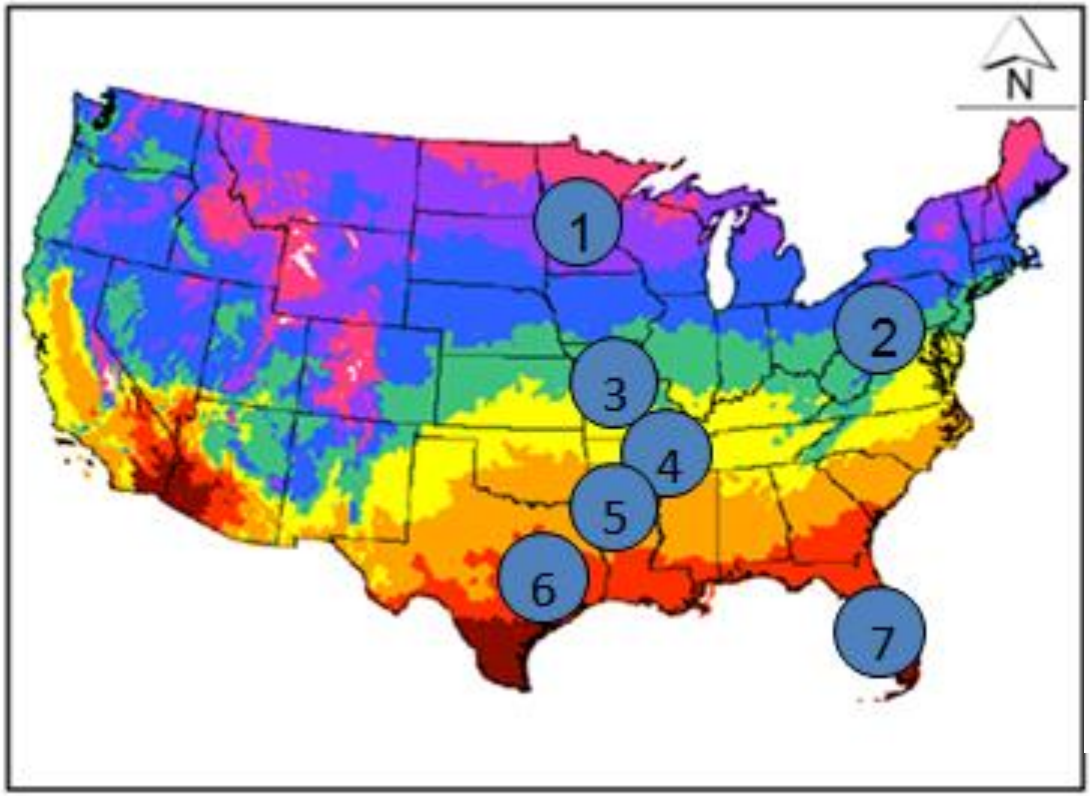
(Google map of continental US as in June, 2010)

Projects at each station

Parameters	Joint spacing ≤ 4.5 ft	4.5 ft<Joint spacing ≤ 6.5 ft	Slab is full lane width
L, ft	3 4	6	10
h_{PCC}, in	3 4	3 4 6	5 6
MOR_{PCC}, psi	550 650 750	550 650 750	550 650 750
h_{HMA}, in	4 8	4 8	4 6 8
Number of cases	24	18	18

Seven zones based on AMDAT

AMDAT = Annual mean daily average temp.

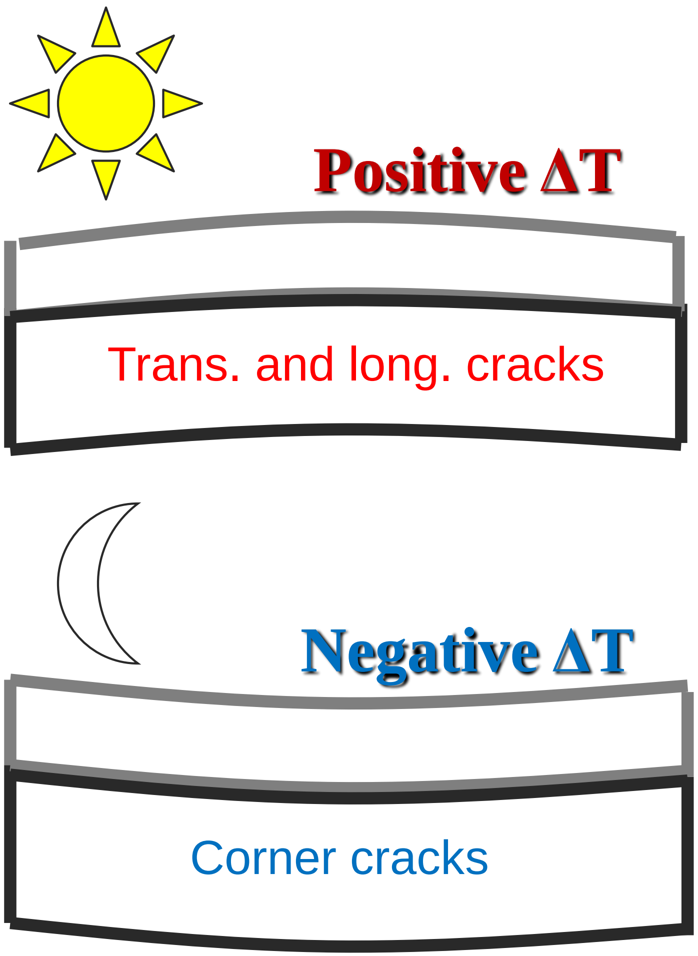


Region ID	Color code	AMDAT (ºF)
1		32.0-45.0
2		45.1-50.0
3		50.1-55.0
4		55.1-60.0
5		60.1-65.0
6		65.1-70.0
7		>70.0

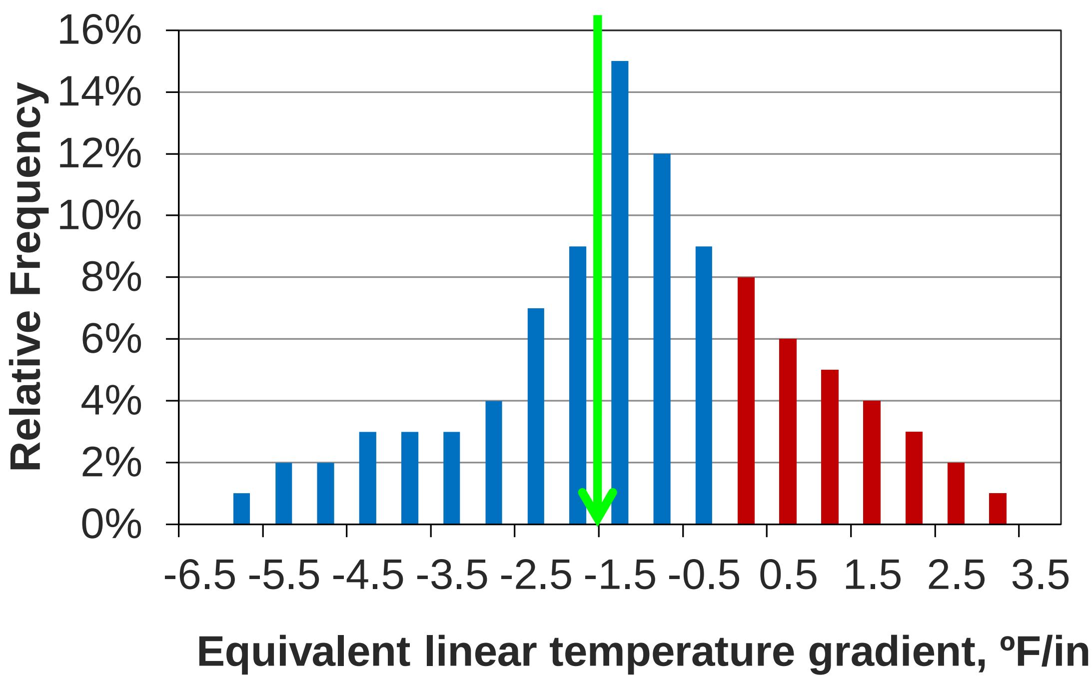
(http://cdo.ncdc.noaa.gov/climaps/temp0313.pdf, accessed on January, 2010).

EFFECTIVE TEMPERATURE GRADIENTS

Effective temp. gradient



Design input:
Effective temp. gradient (ETG)



Populating database: Climate

194 weather stations

(Google map of continental US as in June, 2010)

Projects at each station

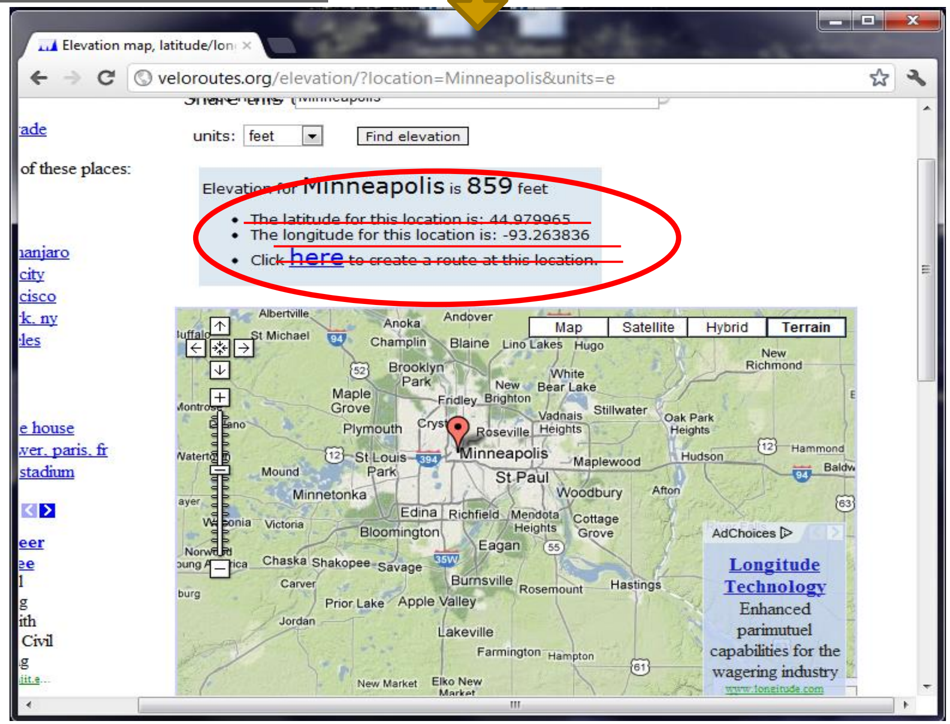
Parameters	Joint spacing ≤ 4.5 ft	4.5 ft<Joint spacing ≤ 6.5 ft	Slab is full lane width
L, ft	3 4	6	10
h_{PCC}, in	3 4	3 4 6	5 6
MOR_{PCC}, psi	550 650 750	550 650 750	550 650 750
h_{HMA}, in	4 8	4 8	4 6 8
Number of cases	24	18	18

Inputs: Geographical information

Climatic Consideration

Latitude (degree):	44.6
Longitude (degree):	-93.77
Elevation (ft):	856
AMDAT Region ID	1
Map of Sunshine Zone	5

Geographic Information



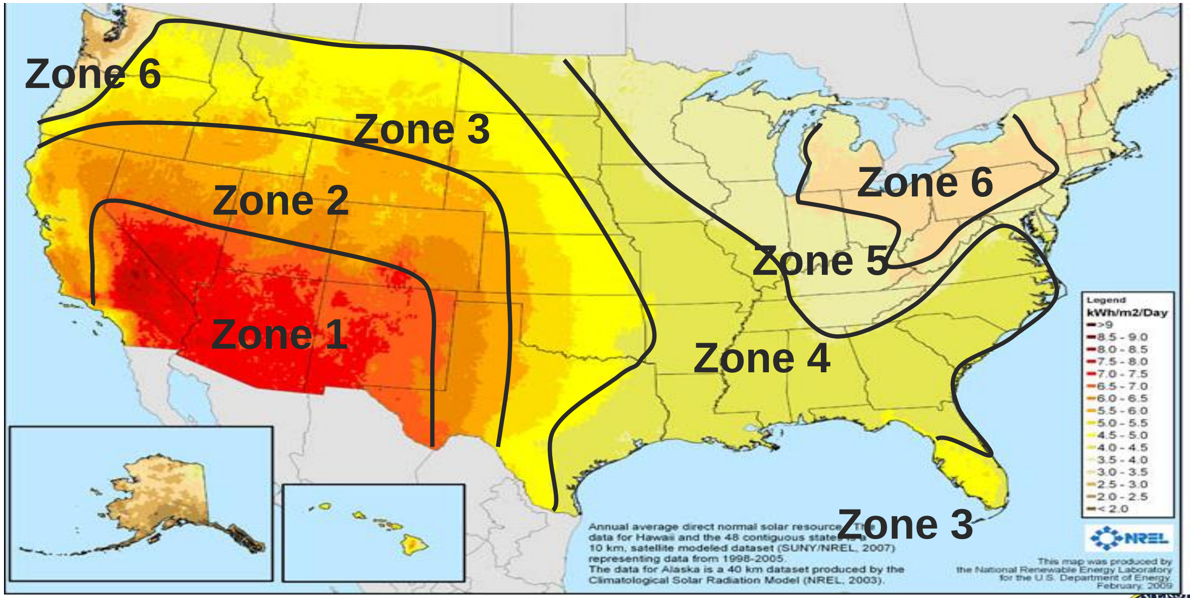
Inputs: sunshine

Climatic Consideration

Latitude (degree):	44.6
Longitude (degree):	-93.77
Elevation (ft):	856
AMDAT Region ID	1
Map of Sunshine Zone	5

Geographic Information

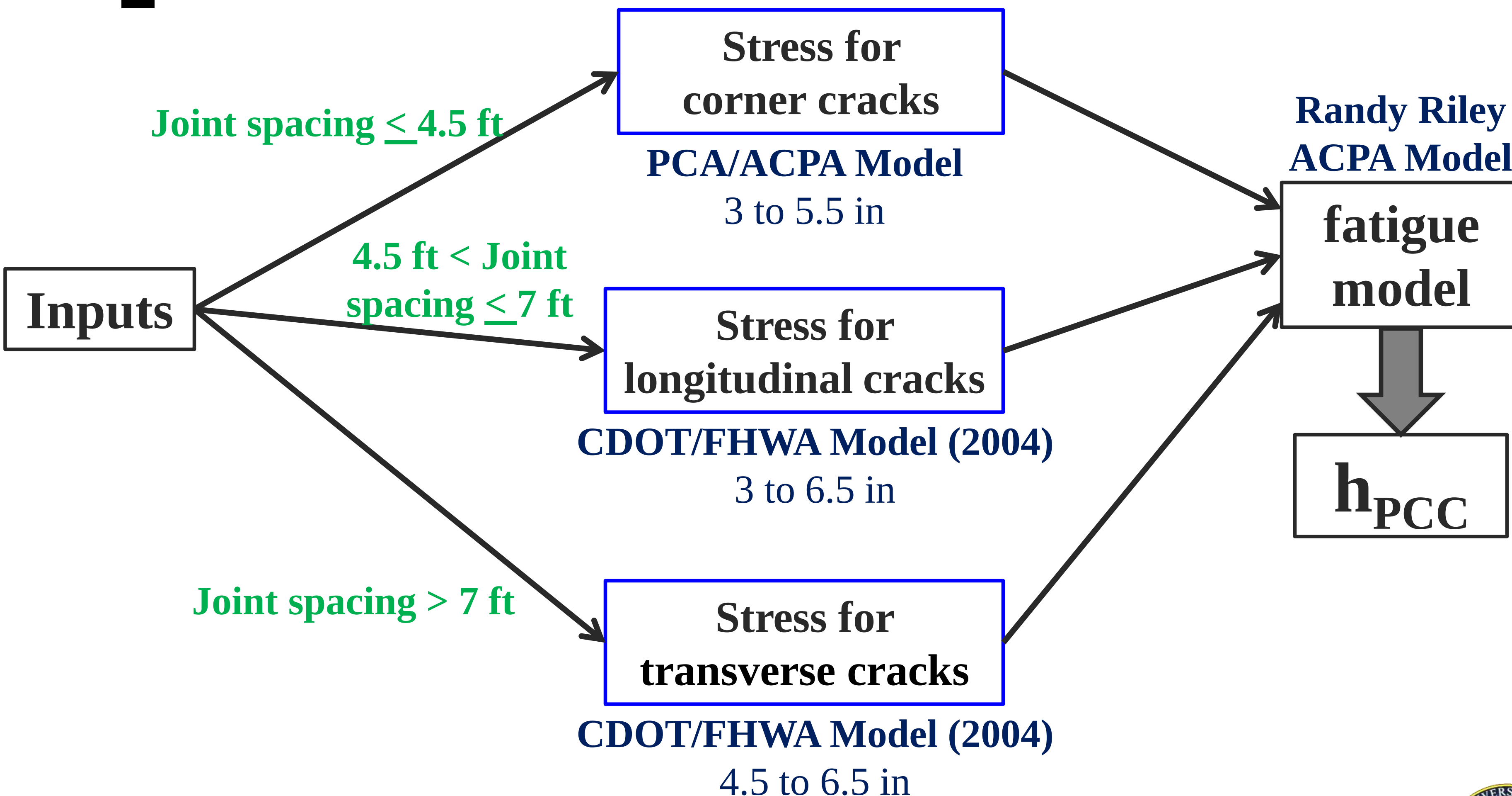
Annual concentrating solar resource map



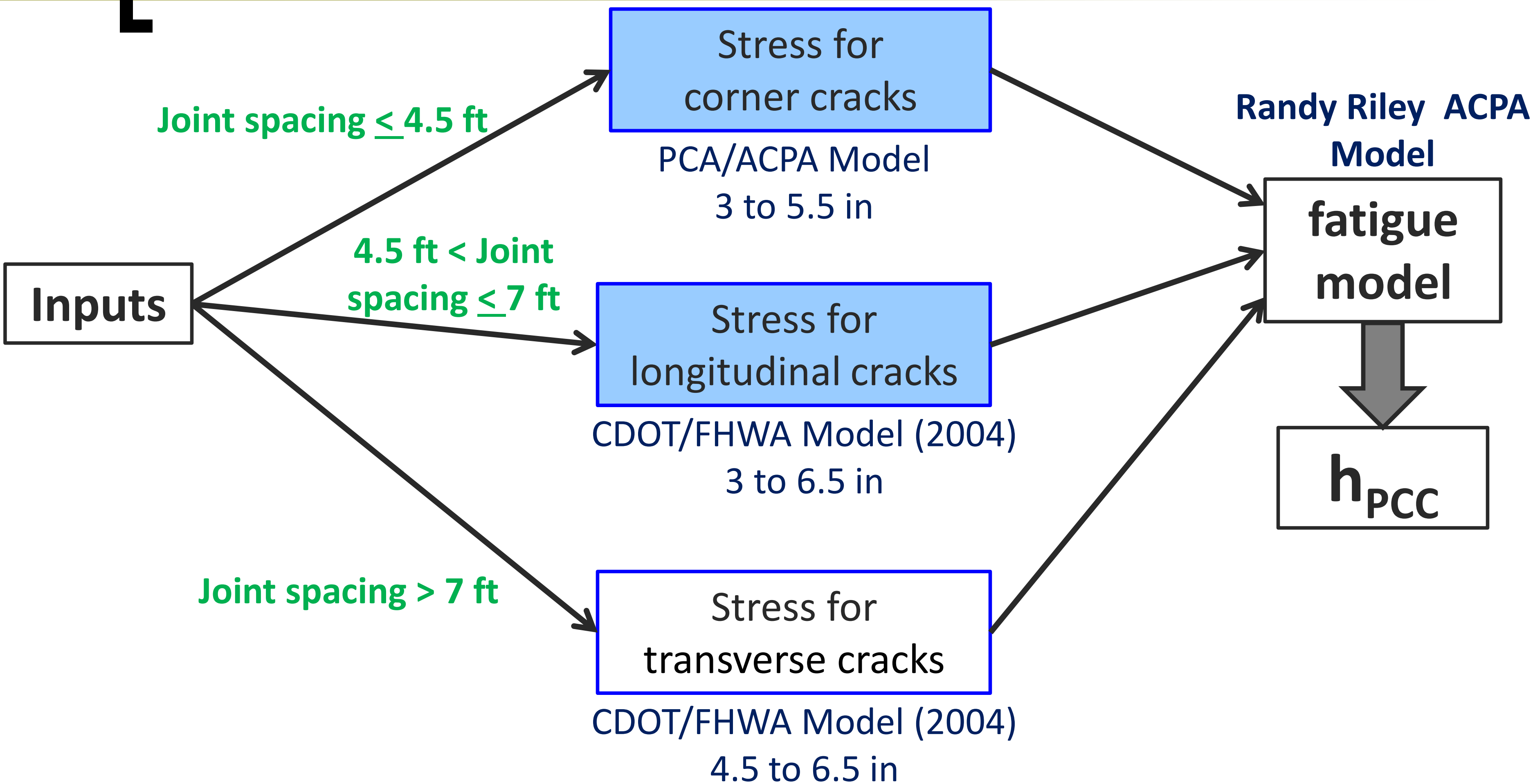
(http://www.nrel.gov/gis/solar.html, as in May 2010)

DESIGN FRAMEWORK

BCOA-ME design framework



BCOA-ME design framework



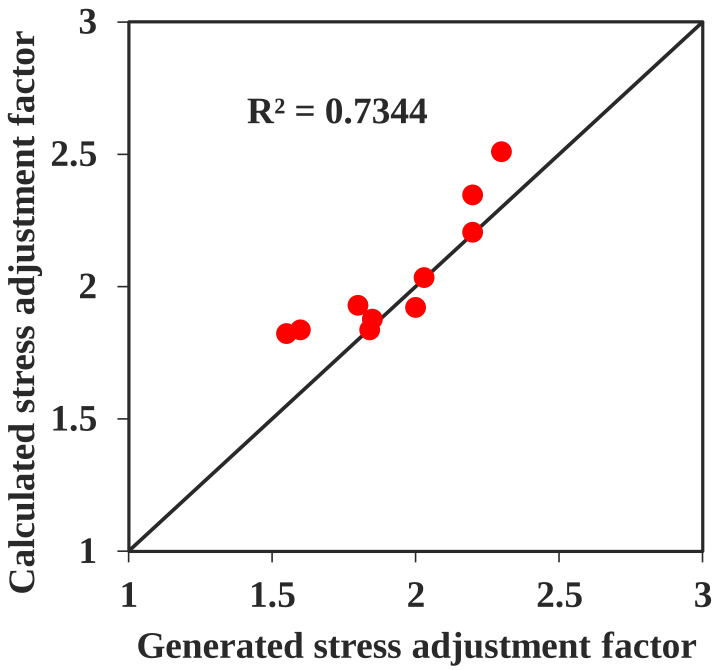
Shading indicates prediction model was calibrated with performance data.

Calibration sites

State	Project	h_{PCC}, in	h_{HMA}, in	Slab size, ft × ft
Minnesota	Cell 95, MnROAD	3	10	6 × 6
	Cell 62, MnROAD	4	8	6 × 5
	Cell 60, MnROAD	5	7	6 × 5
	Cell 94, MnROAD	3	10	4 × 4
Missouri	Intersection of SR 291 and SR 78	4	4	4 × 4
	US-60 between US 71 and US 71 near Neosho	5	4.5	4 × 4
New York State	NY-408 and SH-622	4	9.5 (7)	4 × 4
Illinois	Highway 2- Cumberland County	5.75	6.5	5.5 × 6
Colorado	US85- Section1	4.7	4.5	5 × 5
	US85- Section 2	5.8	5.9	5 × 5
	US85- Section 3	6	5.4	5 × 5
	SH 119- Section 1	5.1	3.3	6 × 6
	SH 119- Section 3	6.3	3.4	6 × 6

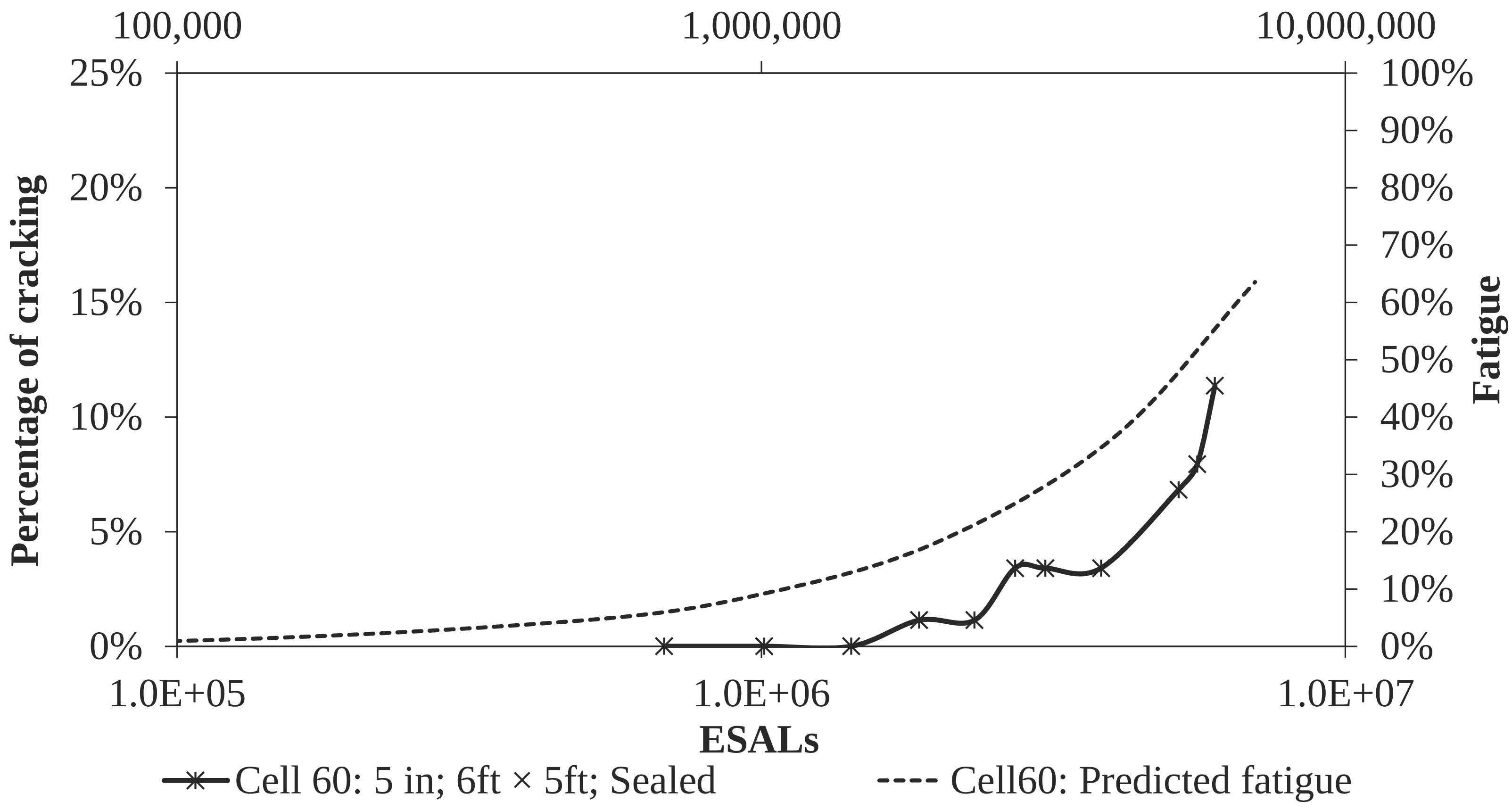
Calibration: Stress Adjustment Factors- Longitudinal cracking

4.5 ft > slab size < 7ft



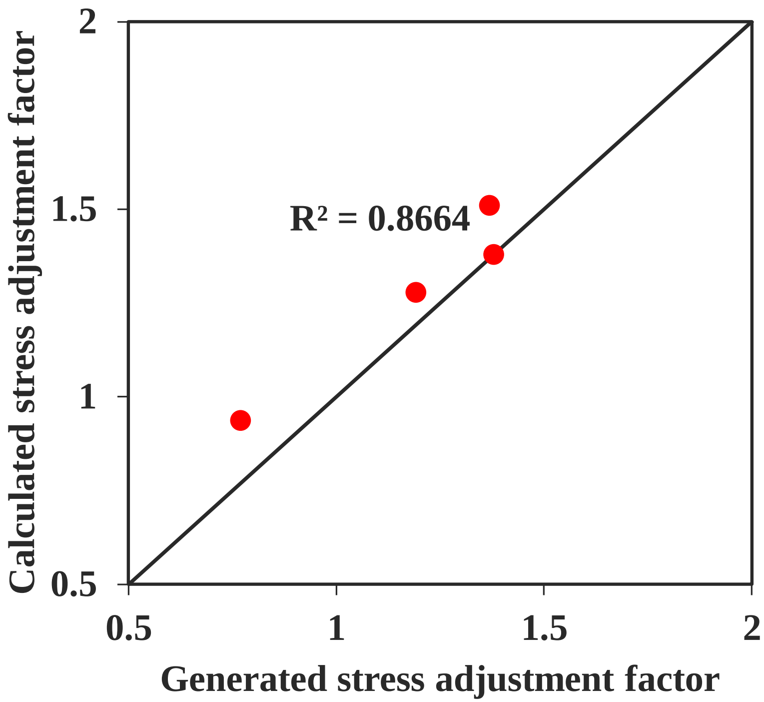
$$F_{stress} = (1.70815412 - 0.03953861 \cdot \min(4, h_{pcc}) + 0.03623689 \cdot h_{HMA} - 0.01942344 \cdot h_{HMA}^2 + 0.00091517 \cdot h_{HMA}^3) \cdot \left(\frac{MOR}{650}\right)^{0.35}$$

Predicted vs observed performance



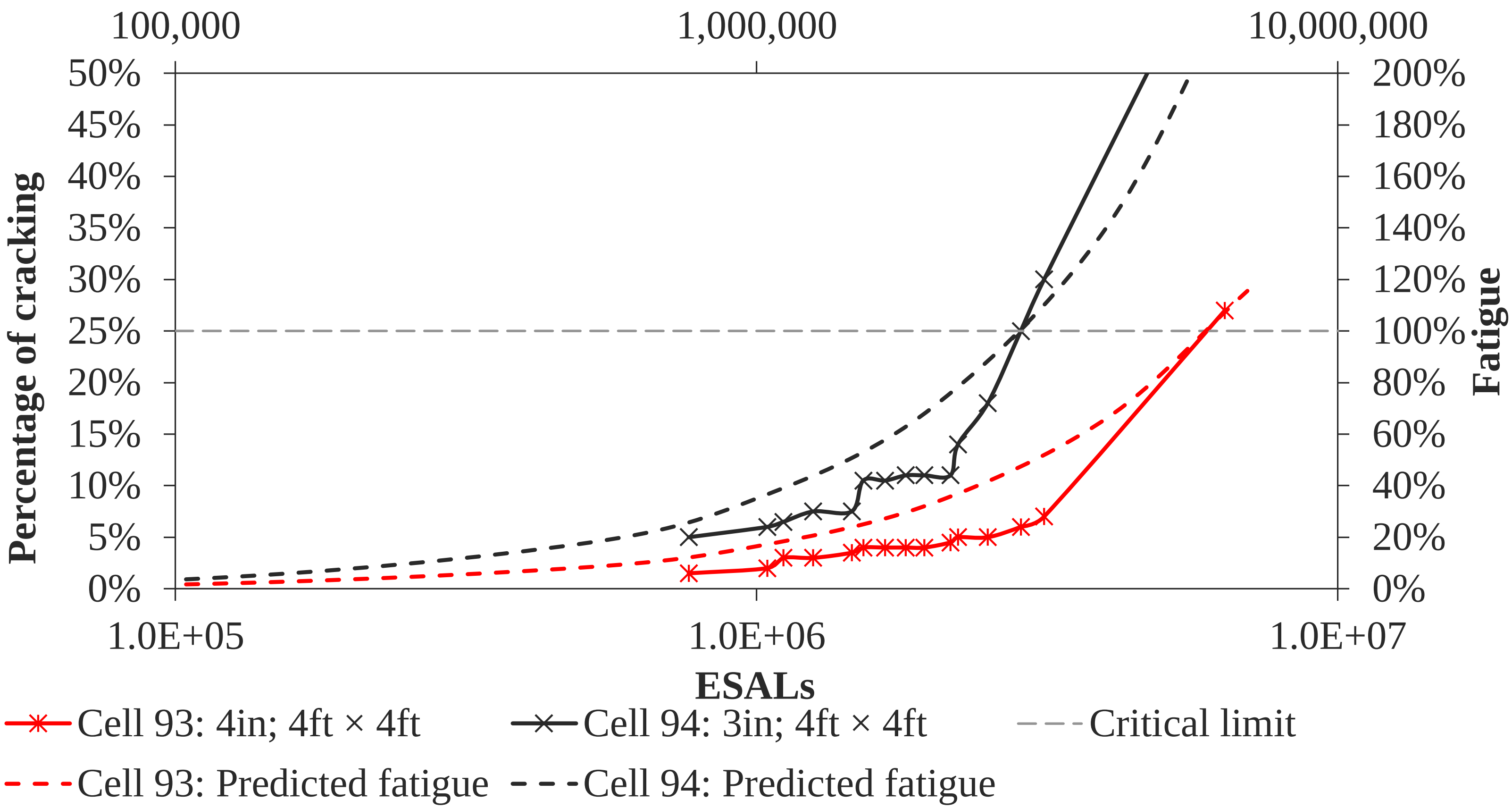
Calibration: Stress Adjustment Factors - corner breaks

Slab size $\leq$ 4.5 ft



$$F_{stress} = 10^{\left[0.61073 - 0.1066 \cdot \log(h_{pcc}) - 0.705 \cdot \log\left(h_{HMA}\right) + 0.00861 \cdot h_{HMA}^2\right]} \cdot \left(\frac{650}{MOR}\right)^{0.5}$$

Predicted vs observed performance



Predicted vs observed performance