Design Guide Examples and Sensitivity

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

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FHWA Pooled Fund Study TPF 5-165

BCOA-ME DESIGN GUIDE

BCOA-ME Design

Instruction:

Select from drop-down list; | Enter data; | Enter data or use calculation.

(Please enable the Macros and the Internet Explorer (not mandatory) to run the spreadsheet.)

General Information

Latitude (degree):	44.5
Longitude (degree):	93.1
Elevation (ft):	874
Estimated Design Lane ESALs:	200,000
Maximum Allowable Percent Slabs Cracked (%):	25%
Desired Reliability against Slab Cracking (%):	85%

Geographic Information

ESALs Calculator

Climate

AMDAT Region ID	5
Sunshine Zone	2

Existing Structure

Post-milling HMA Thickness (in):	6
HMA Condition:	Adequate
Composite Modulus of Subgrade Reaction, k-value (psi/in):	250
Does the existing HMA pavement have temperature cracks?	Yes

k-value Calculator

PCC Overlay

Average 28-day Flexural Strength (psi):	650
Estimated PCC Elastic Modulus (psi):	3,930,000
Coefficient of Thermal Expansion (10^{-6} in/°F/in)	5.5
Fiber Type:	No Fibers
Fiber Content(lb/cu yd) (Only used when a fiber type is selected	0

Epcc Calculator

CTE Calculator

Joint Design

Joint Spacing (ft):	6

Calculate Design

Performance Analysis

Calculated PCC Overlay Thickness (in):	3.26
Design PCC Overlay Thickness (in):	**3.5**
Is there potential for reflective cracking?	Yes

Solved.

General Information: Traffic

Level 1

Estimated Design Lane ESALs:	10,000,000	ESALs Calculator

ESALs Estimation:
Is One-Way ADT available?

Yes | No

Cancel

Level 2

Estimate ESALs:

Design Life (yrs):	10
Terminal Serviceabilty:	2
Number of Lanes in Each Direction:	1
Percent Trucks(%):	6
ADTT Growth Rate (%):	3
Traffic Growth Rate Type:	Non linear
Road Category:	Collector
One-Way Average Daily Traffic (ADT):	5,000

Submit | Cancel

Level 3

Estimate ESALs:

Design Life (yrs):	10
Terminal Serviceabilty:	2
Number of Lanes in Each Direction:	1
Percent Trucks(%):	6
ADTT Growth Rate (%):	3
Traffic Growth Rate Type:	Non linear
Road Category:	Collector

Submit | Cancel

General Information: Location

Latitude (degree):	44.5
Longitude (degree):	93.1
Elevation (ft):	874

Geographic Information

Geographic Information

Option 1

Visit Link in Internet Explorer — Open Webpage

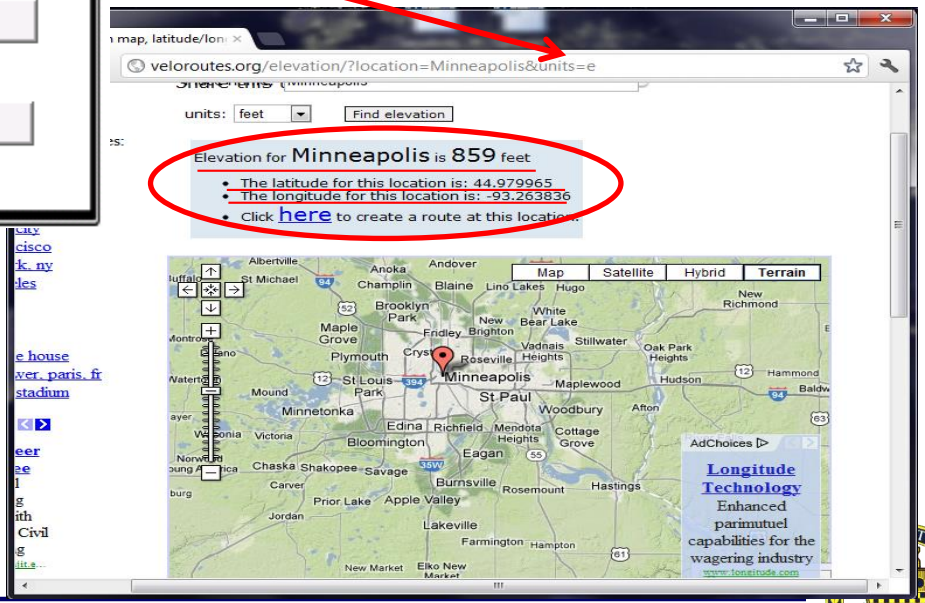
Or

Option 2 **Level 2**

Closest Location: MINNEAPOLIS, MN — Submit

Cancel

Level 1

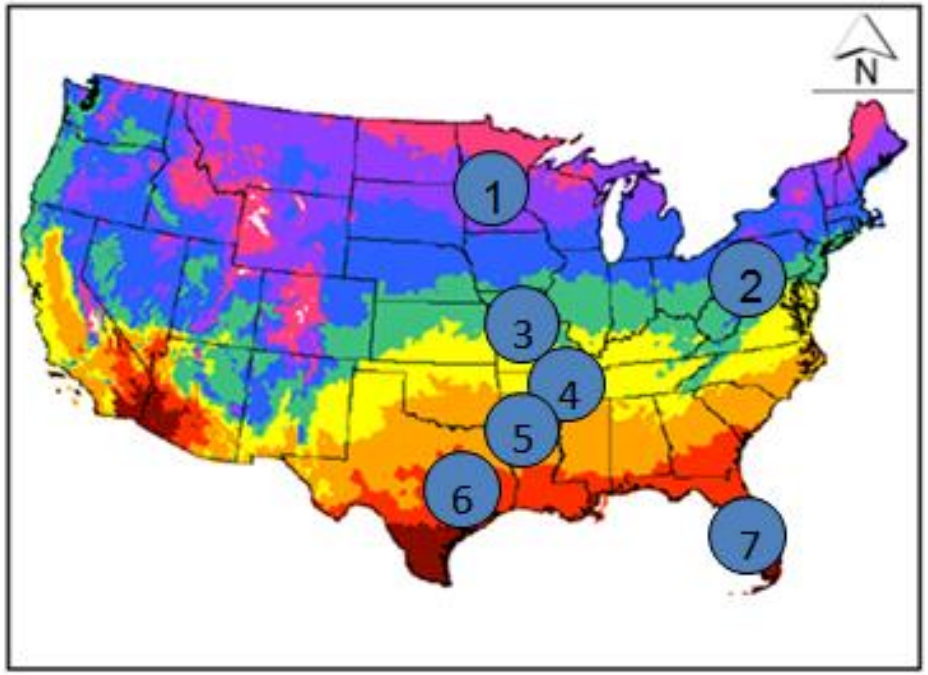


Climate: Temperature region

Climate

AMDAT Region ID	5
Sunshine Zone	2

AMDAT = Annual mean daily average temp.



Region ID	Color code	AMDAT (°F)
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

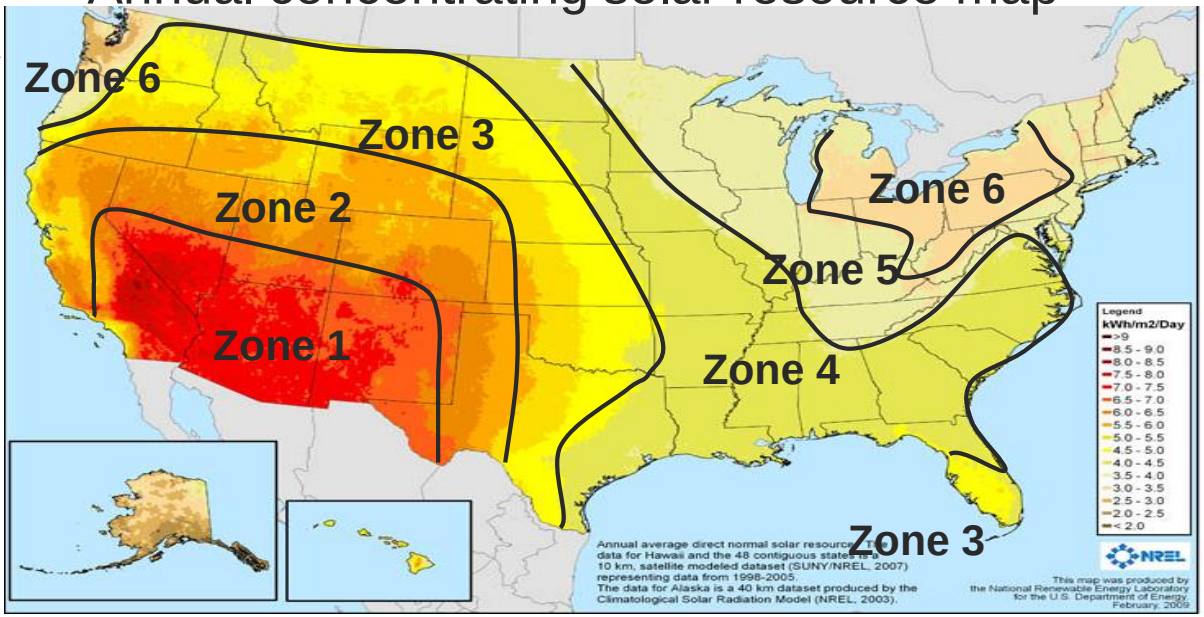
(http://cdo.ncdc.noaa.gov/climaps/temp0313.pdf, accessed on January, 2010).

Climate: Sunshine zones

Climate

AMDAT Region ID	5
Sunshine Zone	2

Annual concentrating solar resource map



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

Existing Structure: E_{HMA}

Post-milling HMA Thickness (in):	6
HMA Condition:	Adequate
Composite Modulus of Subgrade Reaction, k-value (psi/in):	150
Does the existing HMA pavement have temperature cracks?	No

PCC Overlay

Average 28-day Flexural Strength (psi):	650
Estimated PCC Elastic Modulus (psi):	4,000,000

Category	Fatigue Cracking
Adequate	0% - 8%
Marginal	8% - 20%

Epcc Calculator

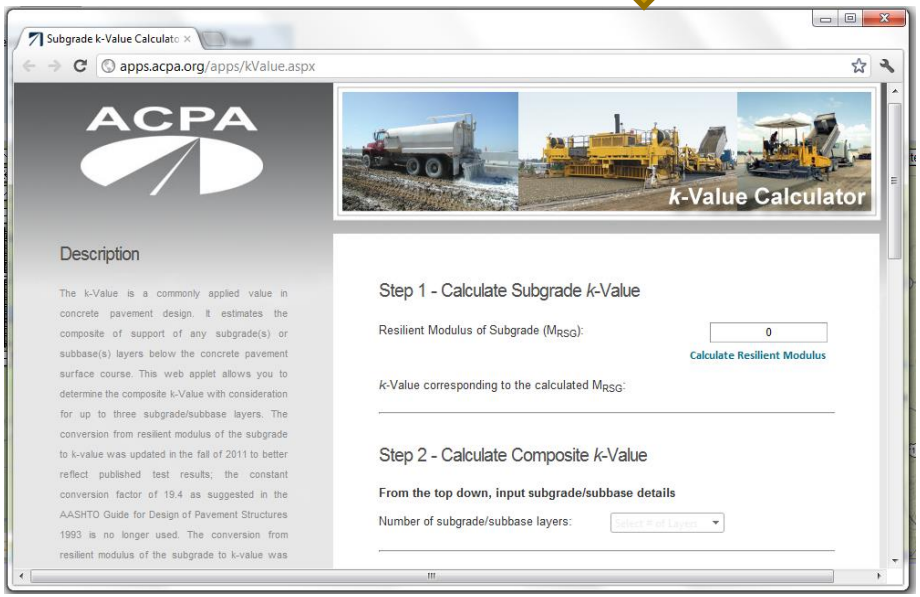
% surface area with fatigue cracking

Existing Structure: k-value

Existing Structure

Post-milling HMA Thickness (in):	6
HMA Condition:	Adequate
Composite Modulus of Subgrade Reaction, k-value (psi/in):	200
Does the existing HMA pavement have temperature cracks?	Yes

k-value Calculator



Existing Structure: k-value

Whitetopping

E= HMA

$k_{composite}$ = All granular layers

Composites

No bond @ old HMA/old PCC interface

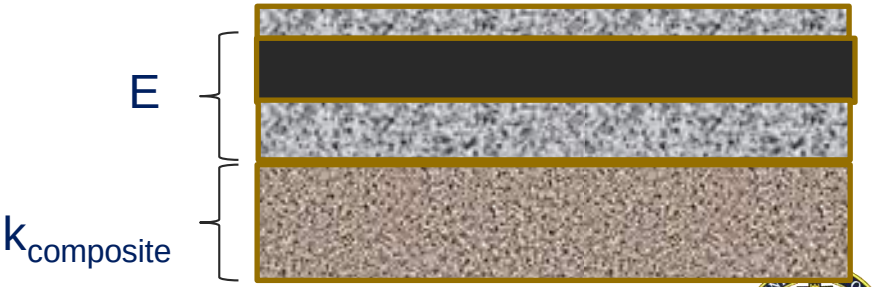
E= HMA

$k_{composite}$ = old PCC + All granular layers

Bond @ old HMA/old PCC interface

E= HMA + old PCC

$k_{composite}$ = All granular layers



PCC Overlay: Strength & stiffness

Internally estimates E_{pcc} based on either:

Compressive strength

Flexural strength

PCC Overlay

Average 28-day Flexural Strength (psi):	700
Estimated PCC Elastic Modulus (psi):	4,000,000
Coefficient of Thermal Expansion (10^{-6} in/°F/in)	5.5
Fiber Type:	No Fibers
Fiber Content(lb/cu yd) (Only used when a fiber type is selected):	0

Epcc Calculator

CTE Calculator

PCC Overlay

Average 28-day Compressive Strength (psi):	5,000
Estimated PCC Elastic Modulus (psi):	4,000,000
Coefficient of Thermal Expansion (10^{-6} in/°F/in)	5.5
Fiber Type:	No Fibers
Fiber Content(lb/cu yd) (Only used when a fiber type is selected):	0

Epcc Calculator

CTE Calculator

CTE

PCC Overlay

Average 28-day Flexural Strength (psi):	700
Estimated PCC Elastic Modulus (psi):	4,000,000
Coefficient of Thermal Expansion (10^{-6} in/°F/in)	5.5
Fiber Type:	No Fibers
Fiber Content(lb/cu yd) (Only used when a fiber type is selected):	0

Epcc Calculator

CTE Calculator

CTE Estimator:

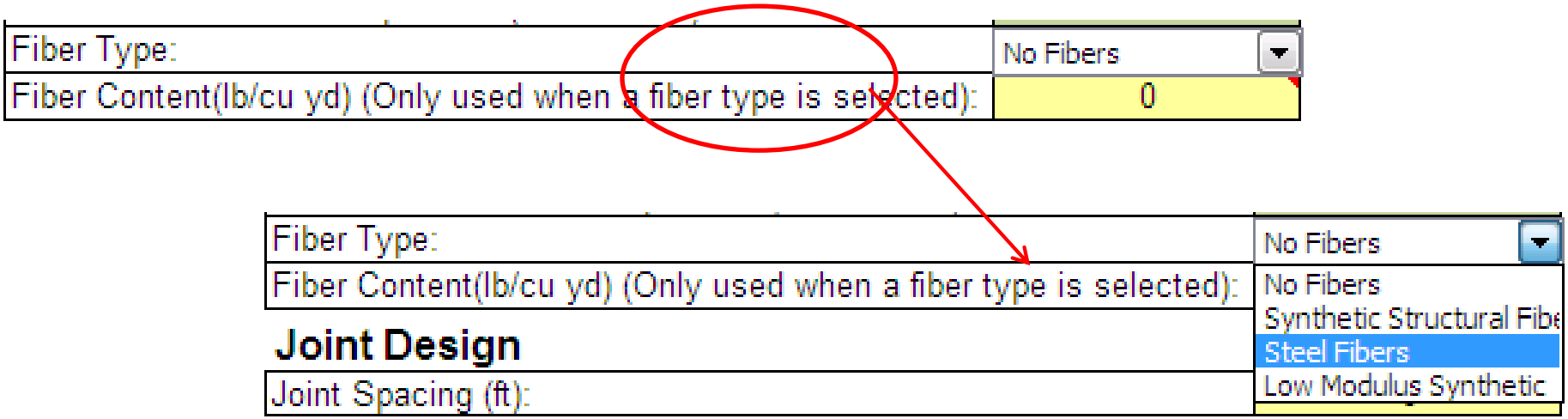
Type of Coarse Aggregate:	Gravel

Recommended Value of the Thermal Coef. of PCC as a Function of Agg. Types	
Type of Coarse Aggregate	**Concrete Thermal Coef. (10e-6/°F)**
Quartz	6.6
Sandstone	6.5
Gravel	6.0
Granite	5.3
Basalt	4.8
Limestone	3.8

(AASHTO 93, pp II-29)

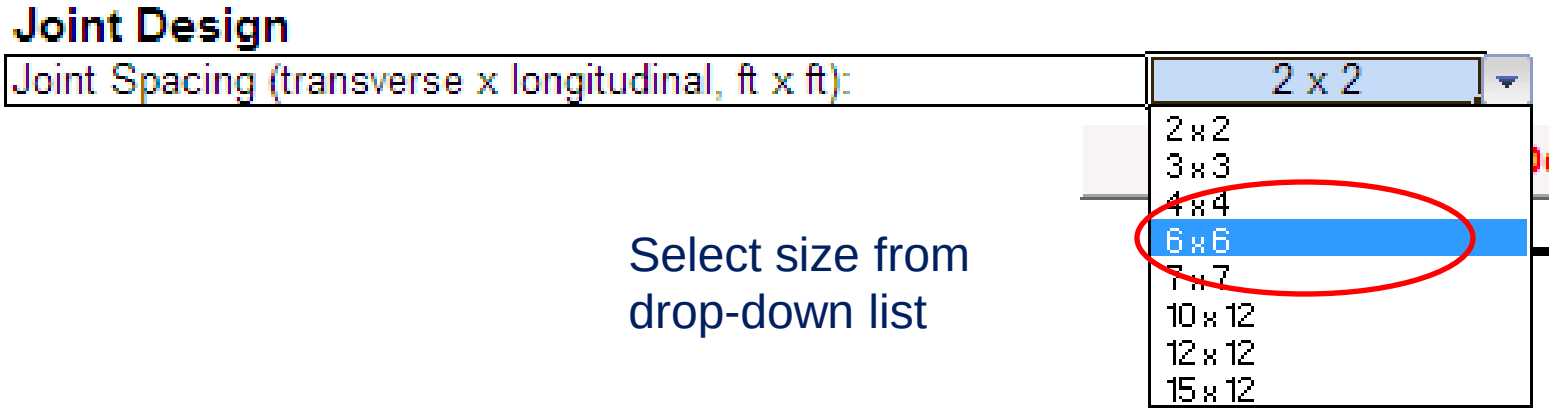
Submit Cancel

PCC Overlay: Fiber content



Select type from drop-down list

Joint spacing



Select size from drop-down list

Design thickness

PCC Overlay

Average 28-day Flexural Strength (psi):	700
Estimated PCC Elastic Modulus (psi):	4,000,000
Coefficient of Thermal Expansion (10^{-6} in/°F/in)	5.5
Fiber Type:	No Fibers
Fiber Content(lb/cu yd) (Only used when a fiber type is selected):	0

Epcc Calculator

CTE Calculator

Joint Design

Joint Spacing (ft):	6

Calculate Design

Performance Analysis

Calculated PCC Overlay Thickness (in):	3.21
Design PCC Overlay Thickness (in):	**3.5**
Is there potential for reflective cracking?	Yes

Solved.

DESIGN EXAMPLES

Design example: 6ft x 6ft

Location: Cell 95, MnROAD
Minneapolis, MN

Traffic

Design ESALs, million	4.8

Structural fiber: Polyolefin, 25lb/cy

Existing structure

h_{HMA}, in	10
HMA condition	Adequate
Comp. k- value, psi/in	150

PCC properties

MOR, psi	650
CTE, 10^{-6} in/°F/in	4.8

Design Comparisons

Design Thickness

	BCOA-ME PG58-28, LTPP	CDOT
Design h_{PCC}, in	**3.0***	4.0*
Calculated h_{PCC}, in	**3.0***	4.0*

* Indicates design minimum

Agency design and performance

As-Built h_{PCC}, in	3.0
Distress @ 7 years, 4.8 million ESALs	20% cracks

Design example: 6ft x 6ft

Location: Cell 95, MnROAD
Minneapolis, MN

Traffic

Design ESALs, million	4.8

Without structural fiber

Existing structure

h_{HMA}, in	10
HMA condition	Adequate
Comp. k- value, psi/in	150

PCC properties

MOR, psi	650
CTE, 10^{-6} in/°F/in	4.8

Design Comparisons

Design Thickness

	BCOA-ME	CDOT
Design h_{PCC}, in	**4.0**	4.0*
Calculated h_{PCC}, in	**3.92**	4.0*

Agency design and performance

As-Built h_{PCC}, in	3.0
Distress @ 7 years, 4.8 million ESALs	20% cracks

* Indicates design minimum

Design example: 6ft x 6ft

Location: Highway-2, Cumberland County, Illinois

Existing structure

h_{HMA}, in	3.5
HMA condition	Adequate
Comp. k-value, psi/in	170

Traffic

Design ESALs	0.3 million
Road cat.	Collector
One-way ADT	1,050

PCC properties

MOR, psi	650
CTE, 10^{-6}in/°F/in	3.8

Design Comparisons

Design Thickness

	BCOA-ME	CDOT
Design h_{PCC}, in	**4.5**	8.0*
Calculated h_{PCC}, in	**4.44**	8.0*

Agency design and performance

As-built h_{PCC}, in	5.75
Distress @ 3 years, 0.08 million ESALs	0.3% cracks

Design example: 4ft x 4ft

Location: NY-408 and SH-622, Rochester, NY

Existing structure

h_{HMA}, in	9.5
HMA condition	Poor
Comp. k- value, psi/in	250

Traffic

Design ESALs, million	0.81

PCC properties

Comp. Strength, psi	5,000
CTE, 10^{-6} in/°F/in	6.0

Design Comparisons

Design Thickness

	BCOA-ME	ACPA
Design h_{PCC}, in	**4.5**	2.5*
Calculated h_{PCC}, in	**4.1**	2.5*

* Indicates design minimum

Agency design and performance

As-built h_{PCC}, in	4.0
Distress @ 6 years, 0.46 million ESALs	Few corner cracks

Design example: 5.5ft x 5.5ft

Location: Highway-4,
Piatt County, IL

Traffic

Design ESALs, million	0.14

Existing structure

h_{HMA}, in	4
HMA condition	Adequate
Comp. k- value, psi/in	170

PCC properties

MOR, psi	600
CTE, 10^{-6} in/°F/in	5.3

Design Comparisons

Design Thickness

	BCOA-ME	CDOT
Design h_{PCC}, in	**4.42**	6.5
Calculated h_{PCC}, in	**4.50**	6.20

Agency design and performance

Built-in h_{PCC}, in	5.0
Distress @ 4 years, 0.04 million ESALs	0.2% cracks

Design example: 6ft x 6ft

Location: SH 121, Wadsworth Boulevard, Denver, CO

Traffic

Design ESALs, million	1.27

Existing structure

h_{HMA}, in	5.5
HMA condition	Marginal
Comp. k- value, psi/in	500

PCC properties

MOR, psi	650
CTE, 10^{-6} in/°F/in	6.0

Design Comparisons

Design Thickness

Design output	BCOA-ME PG58-28, LTPP	CDOT
Design h_{PCC}, in	**3.5**	5.0
Calculated h_{PCC}, in	**3.40**	5.03

Agency design and performance

Built-in h_{PCC}, in	4.4
Distresses	NA

Design example: 10ft x 12ft

Location: Cell 97, MnROAD
Minneapolis, MN

Traffic

Design ESALs, million	9.8

Existing structure

h_{HMA}, in	7
HMA condition	Adequate
Comp. k- value, psi/in	150

PCC properties

Compressive strength, psi	6,100
CTE, 10^{-6} in/°F/in	4.8

Design Comparisons

Design Thickness

	BCOA-ME	CDOT
Design h_{PCC}, in	**4.5***	4.0*
Calculated h_{PCC}, in	**3.28**	1.58

* Indicates design minimum

Agency design and performance

Built-in h_{PCC}, in	6.0
Distress @ 11.5 years, 9.8 million ESALs	21% mid-slab longitudinal cracks

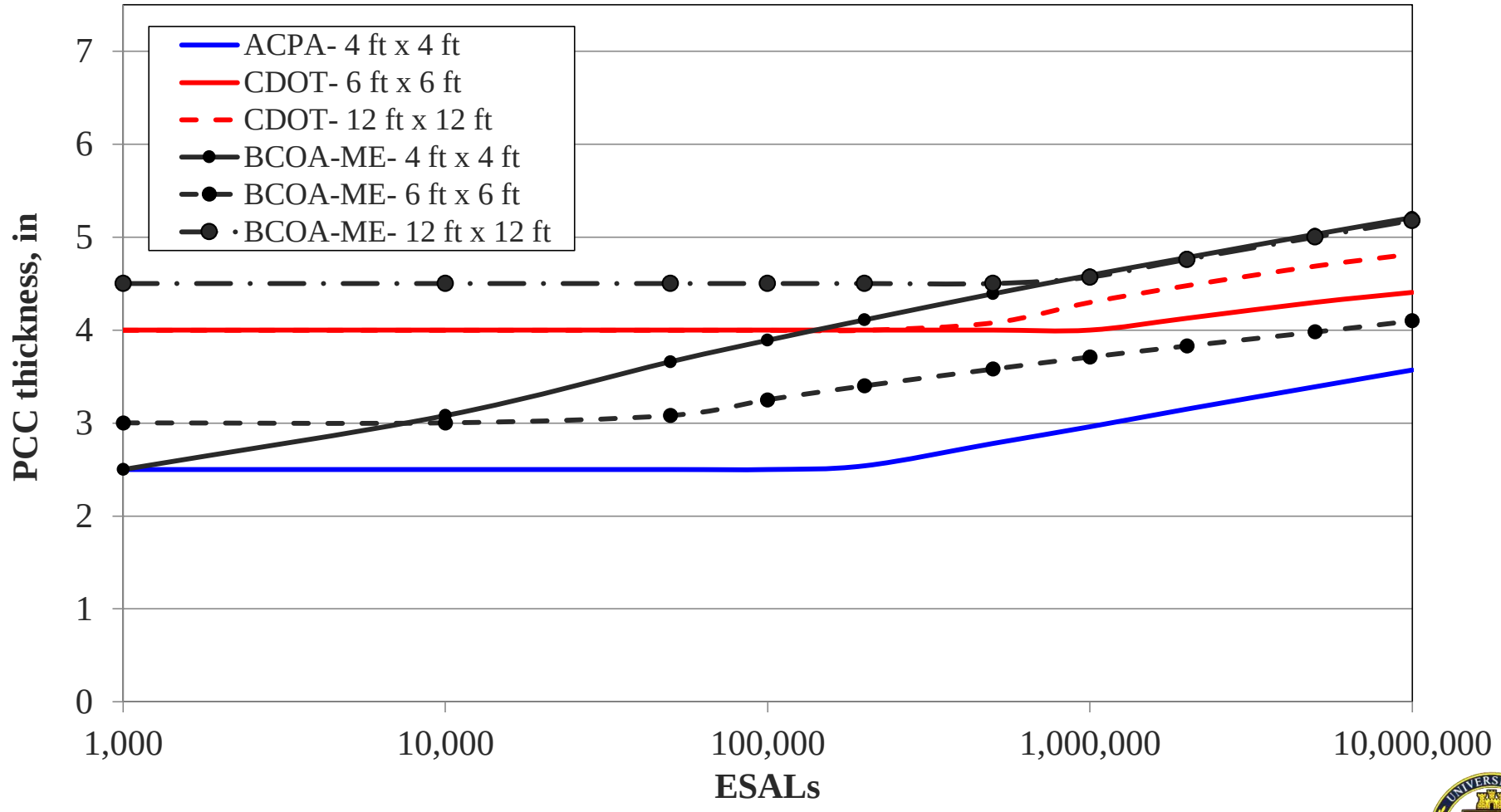
SENSITIVITY ANALYSIS

Analysis assumptions

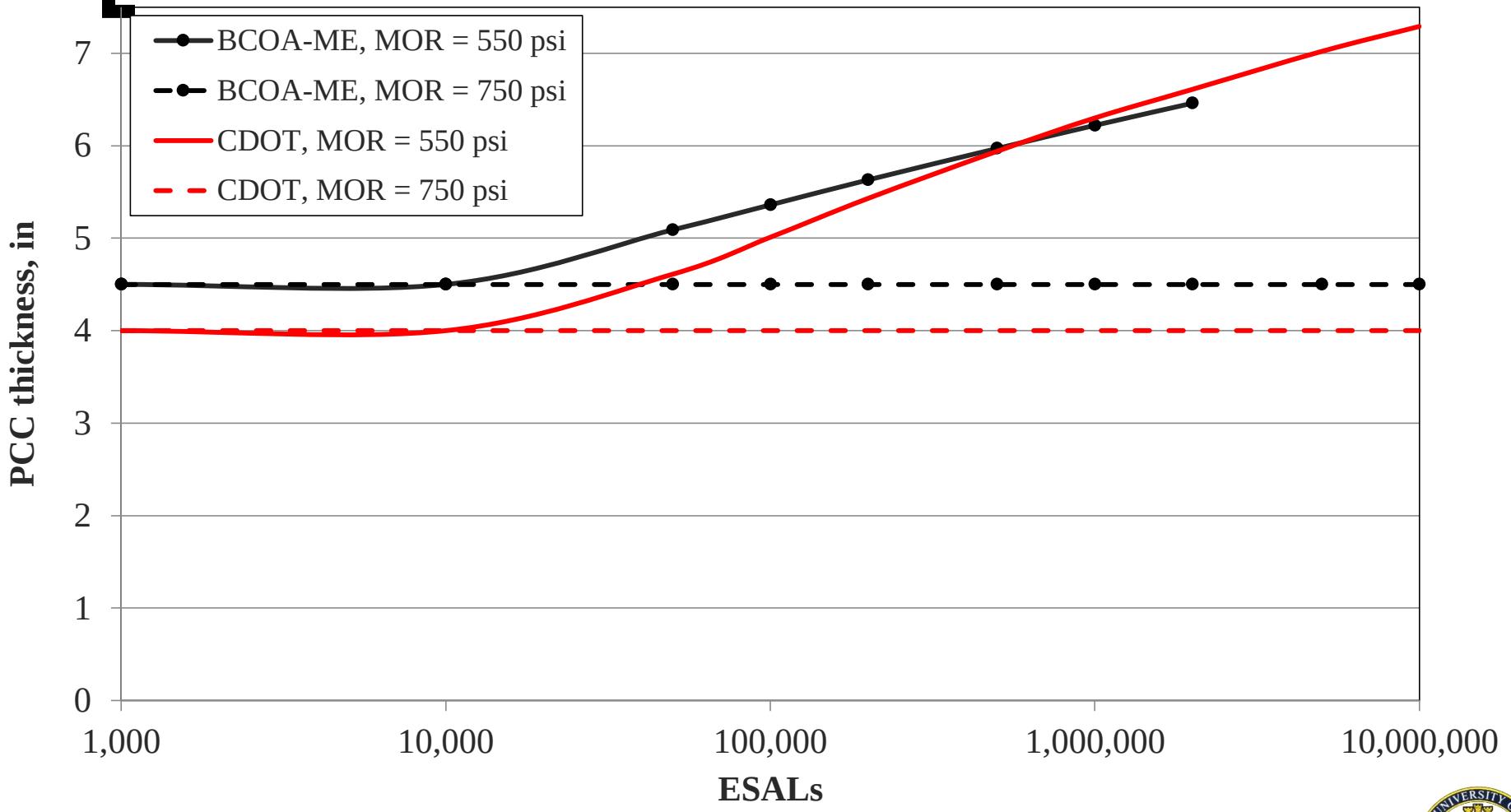
Location	Minneapolis, MN	
HMA Properties	HMA thickness	6 in
	HMA condition	Adequate*
	k-value	250 psi/in
PCC Overlay Properties	PCC strength	650 psi
	E_{PCC}	4,000,000 psi
	CTE	5.5 x 10-6 in/in/°F
Joint Design	Spacing	4ft and 6 ft

*Aged E_{HMA} @ 70°F =860,000 psi or an effective Constant E_{HMA} = 350,000 psi

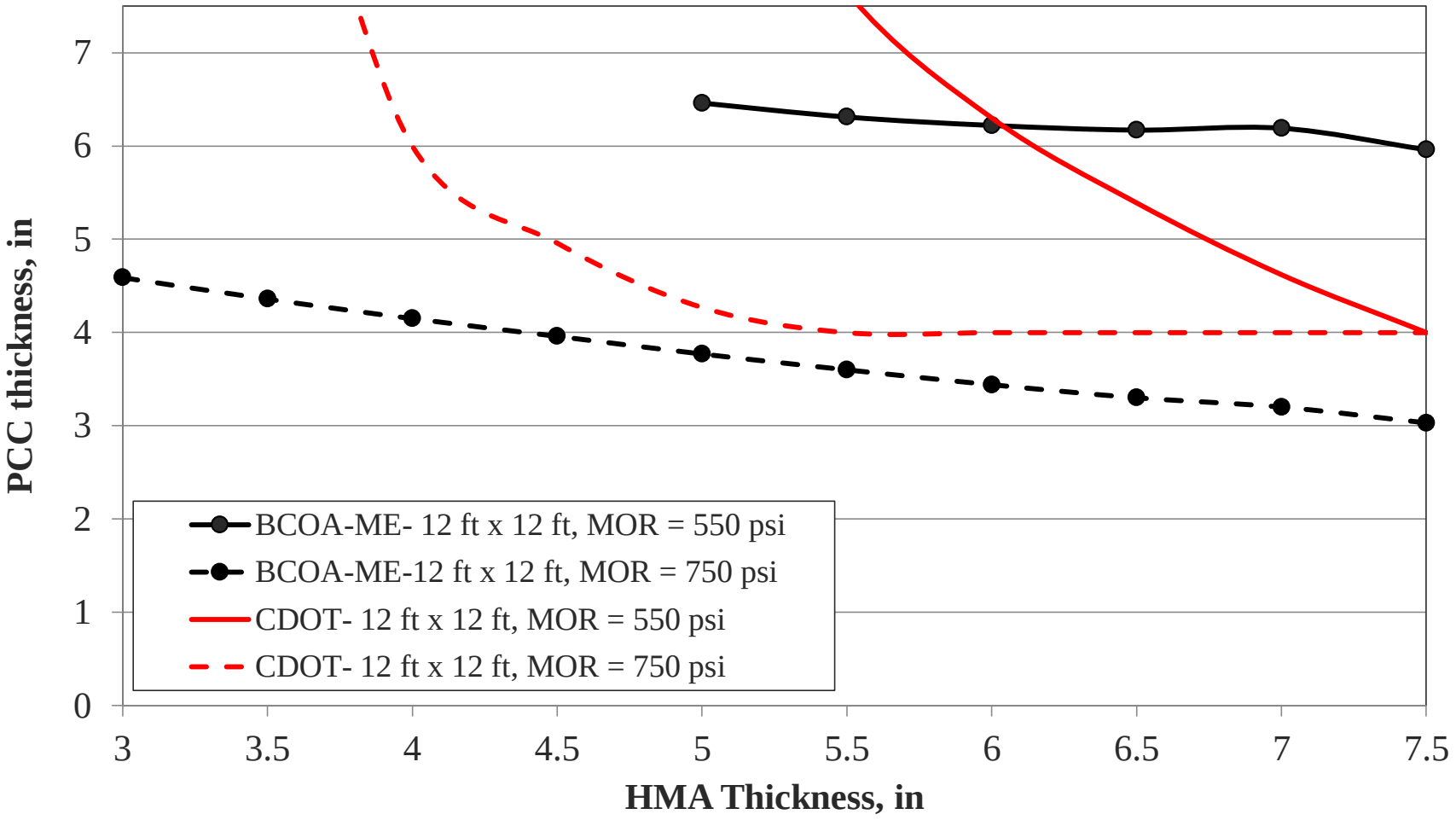
Joint spacing



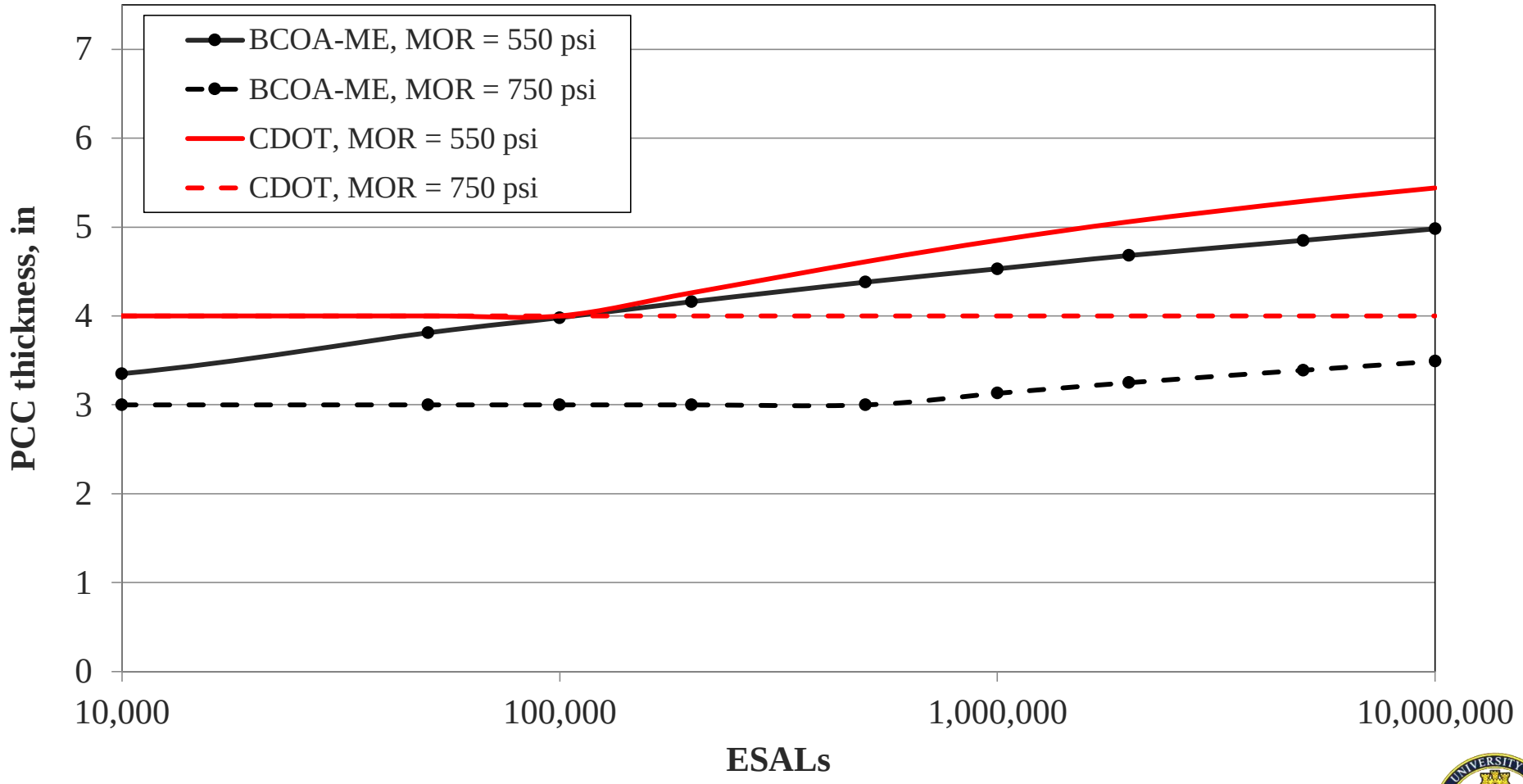
Modulus of rupture – 12 ft x 12 ft



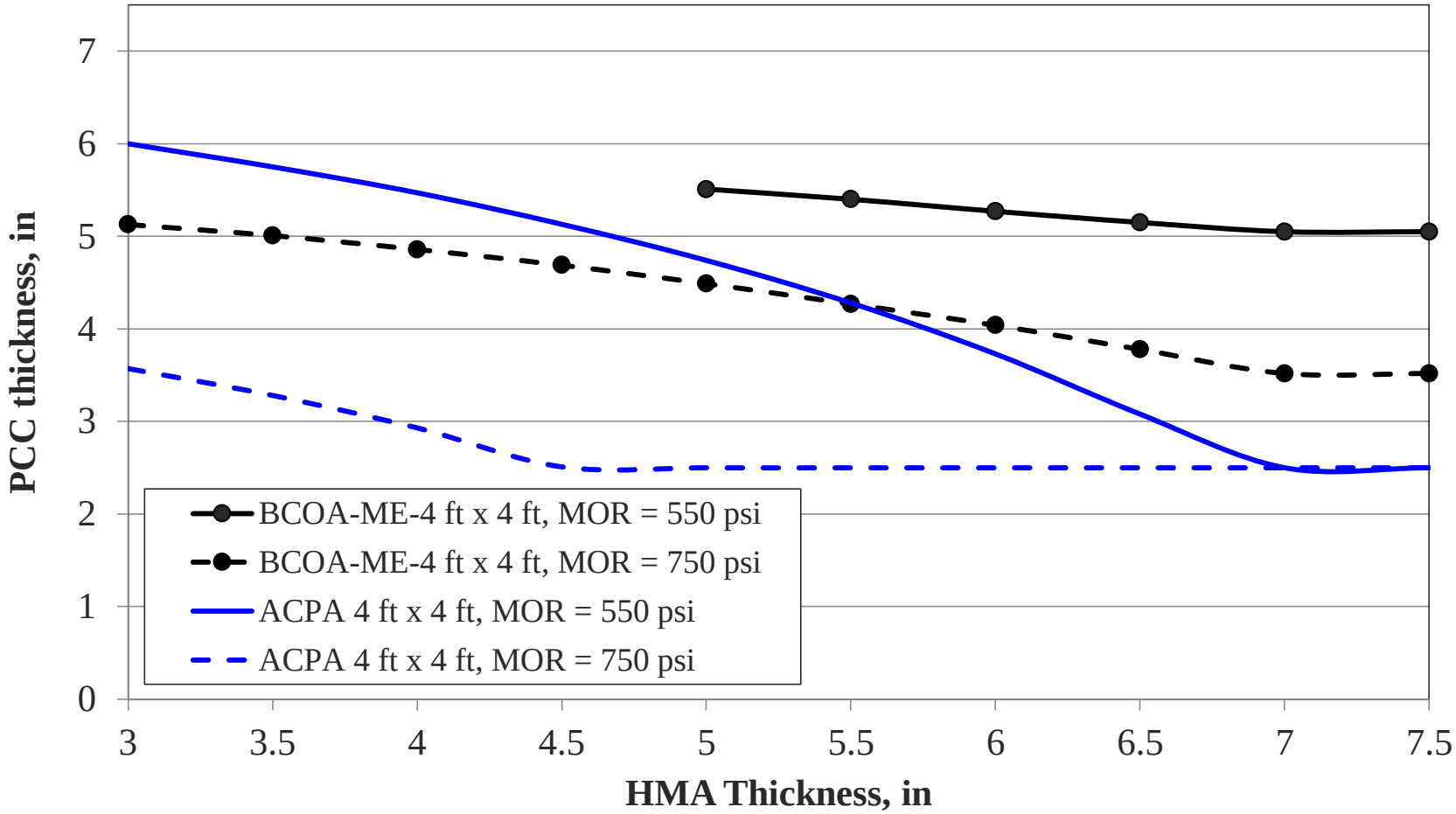
Modulus of rupture – 12 ft x 12 ft



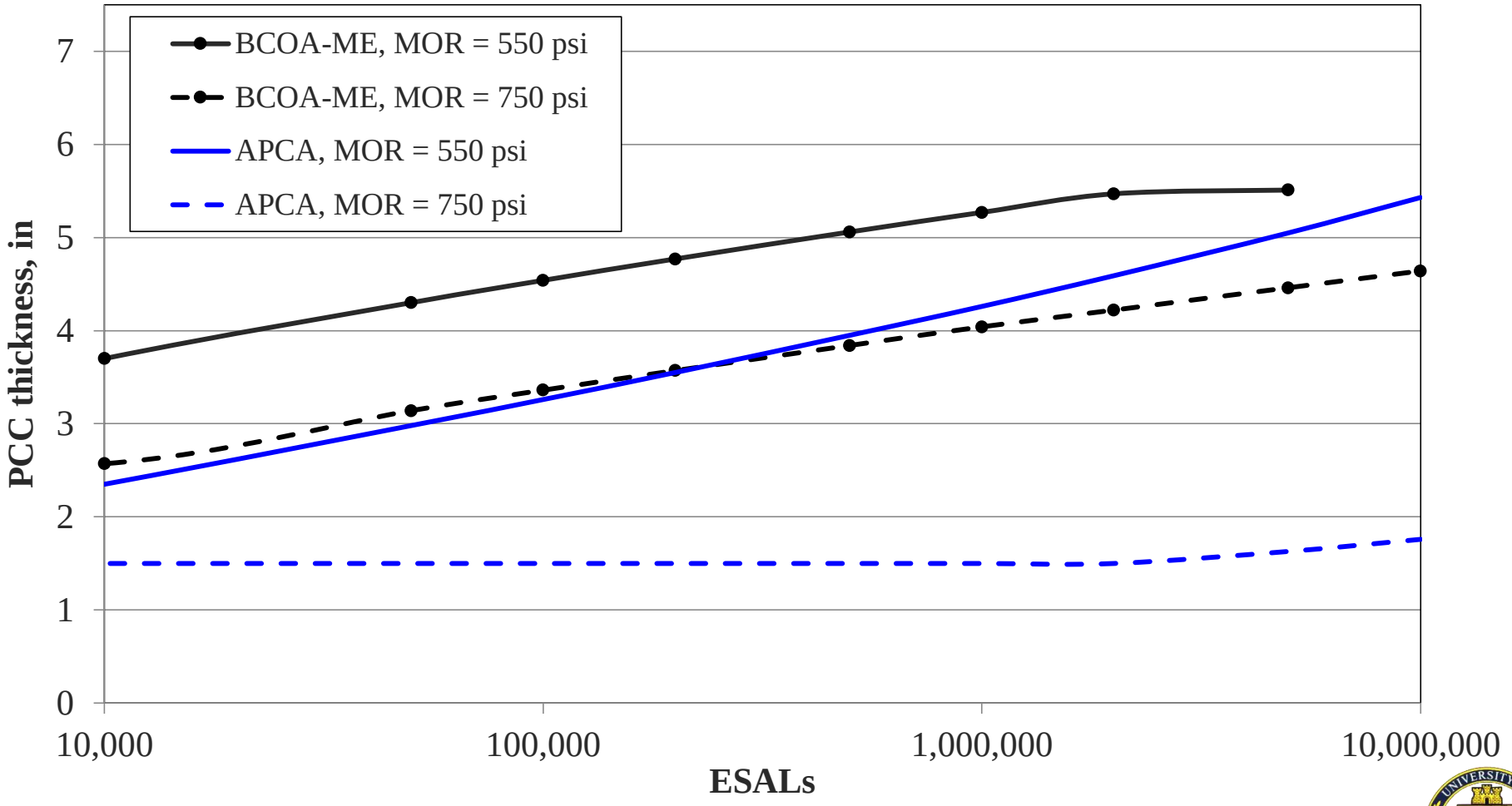
Modulus of rupture – 6 ft x 6 ft



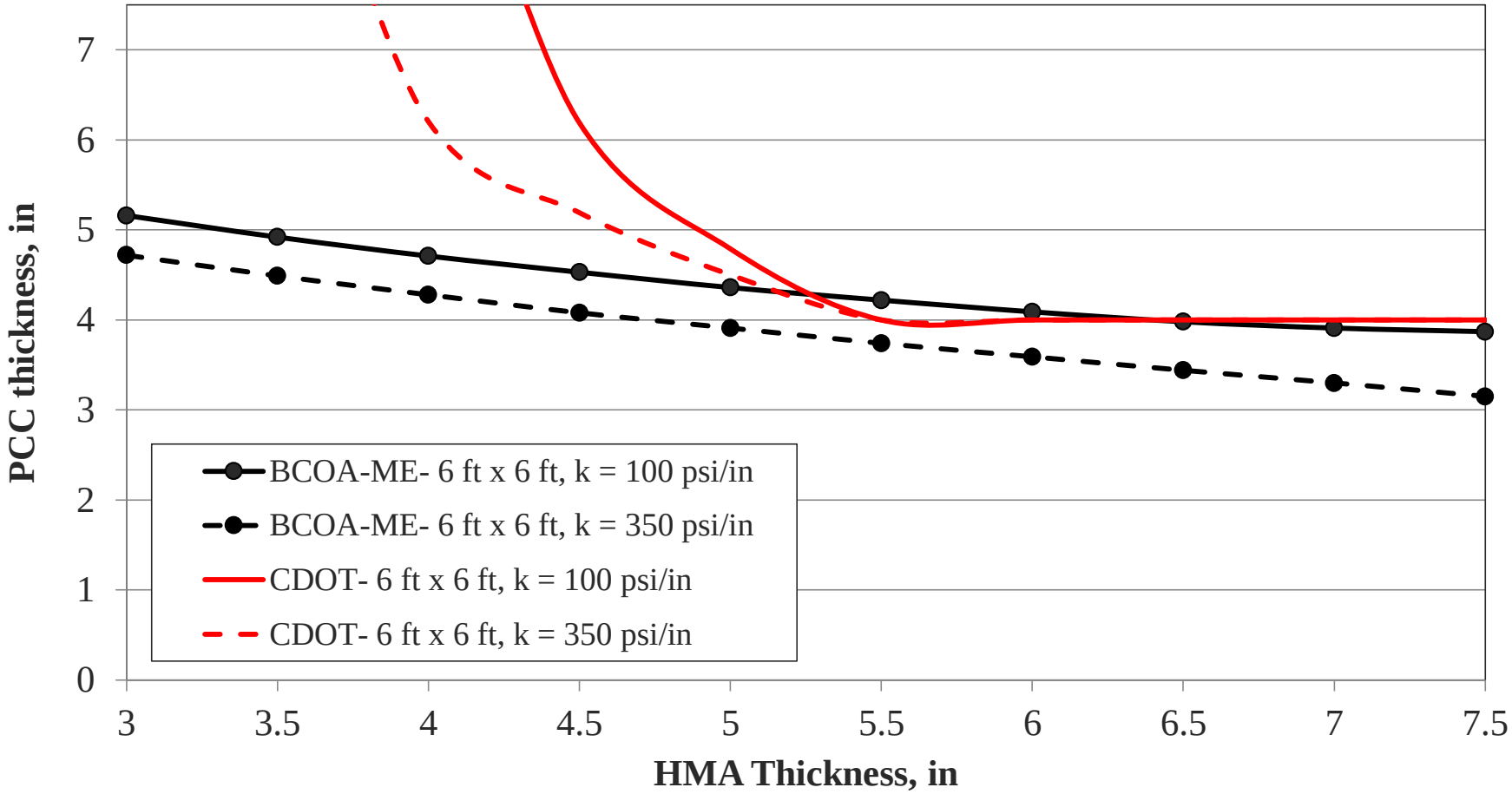
Modulus of rupture- 4 ft x 4 ft



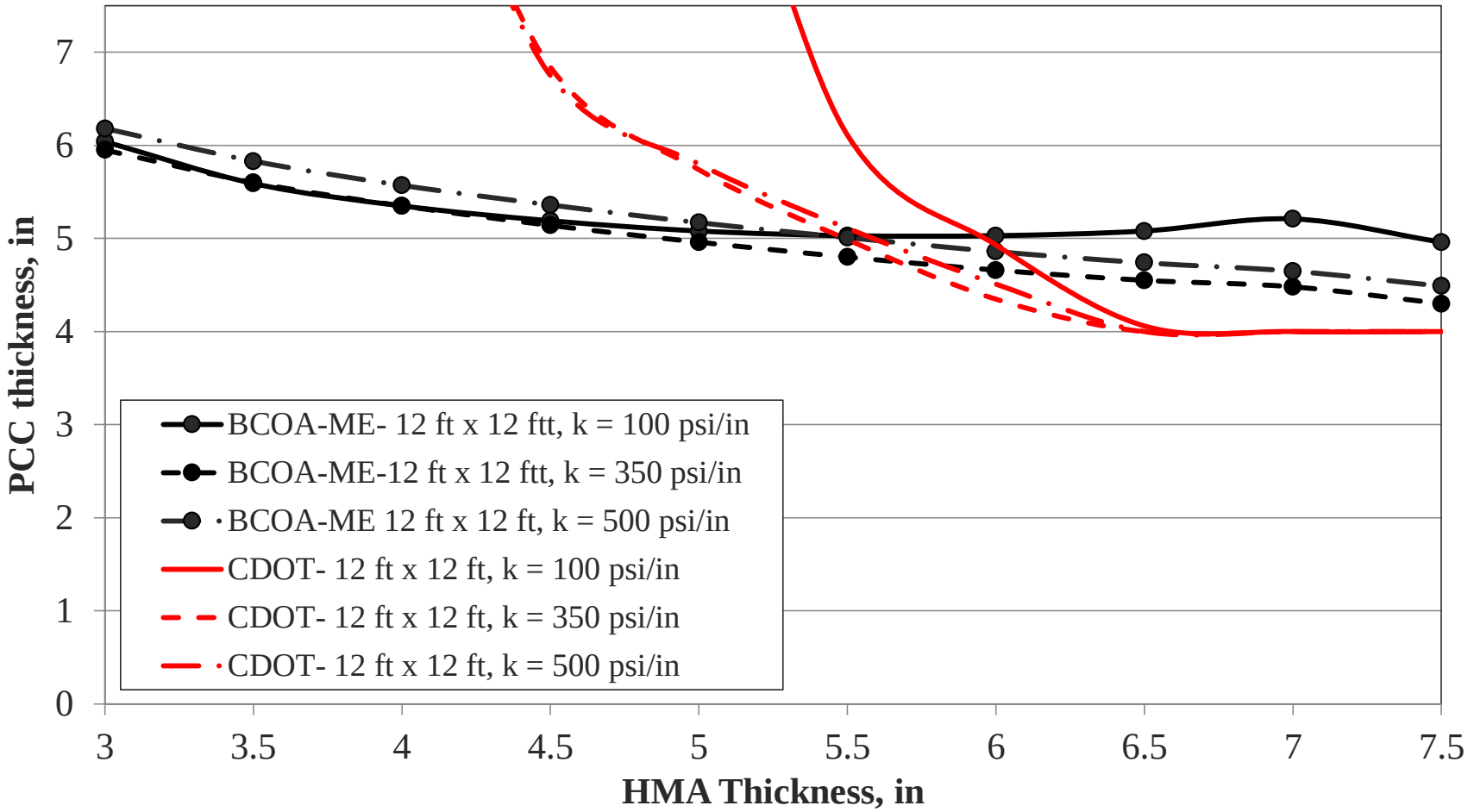
Modulus of rupture- 4 ft x 4 ft



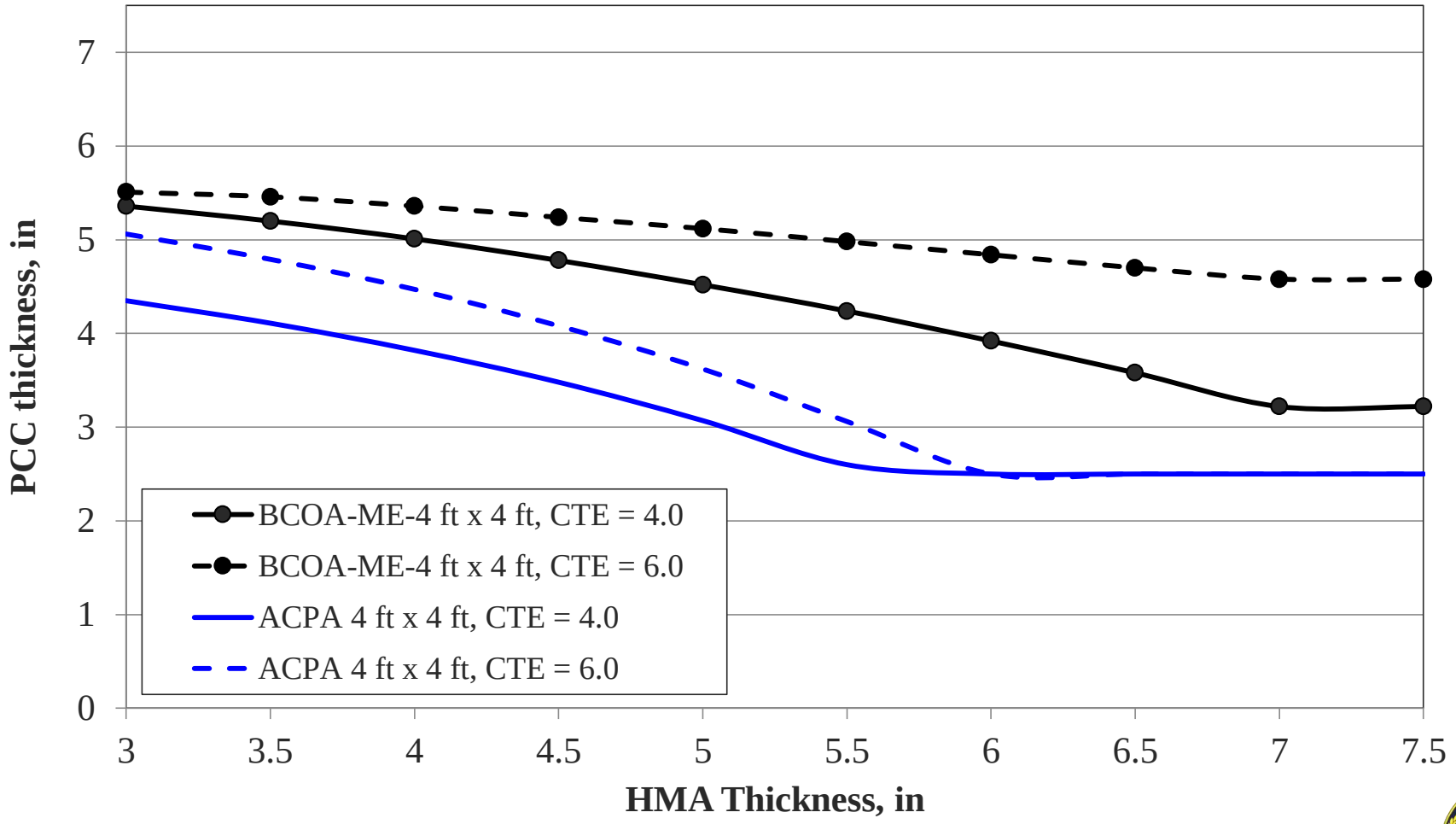
k-value – 6 ft x 6 ft



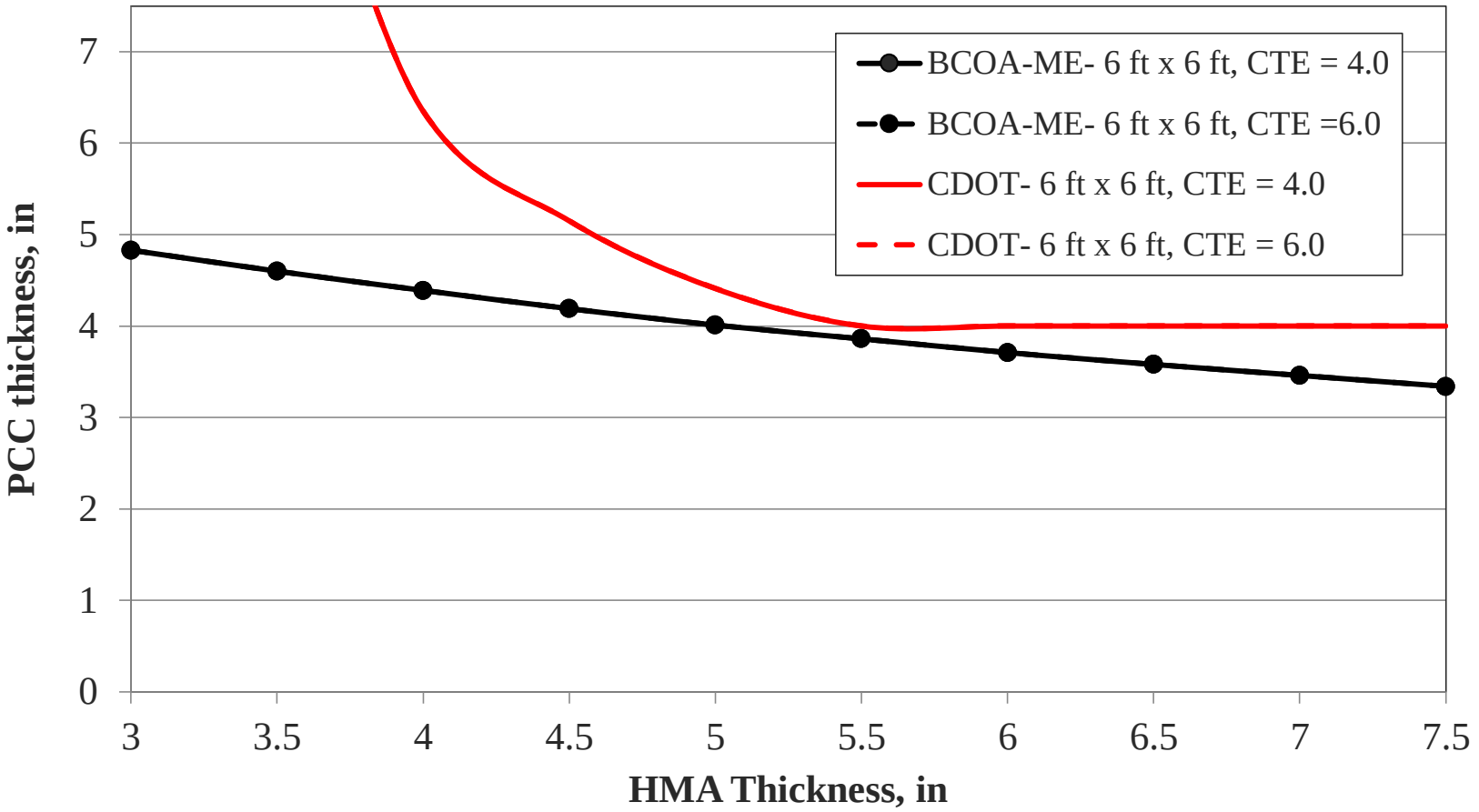
k-value – 12 ft x 12 ft



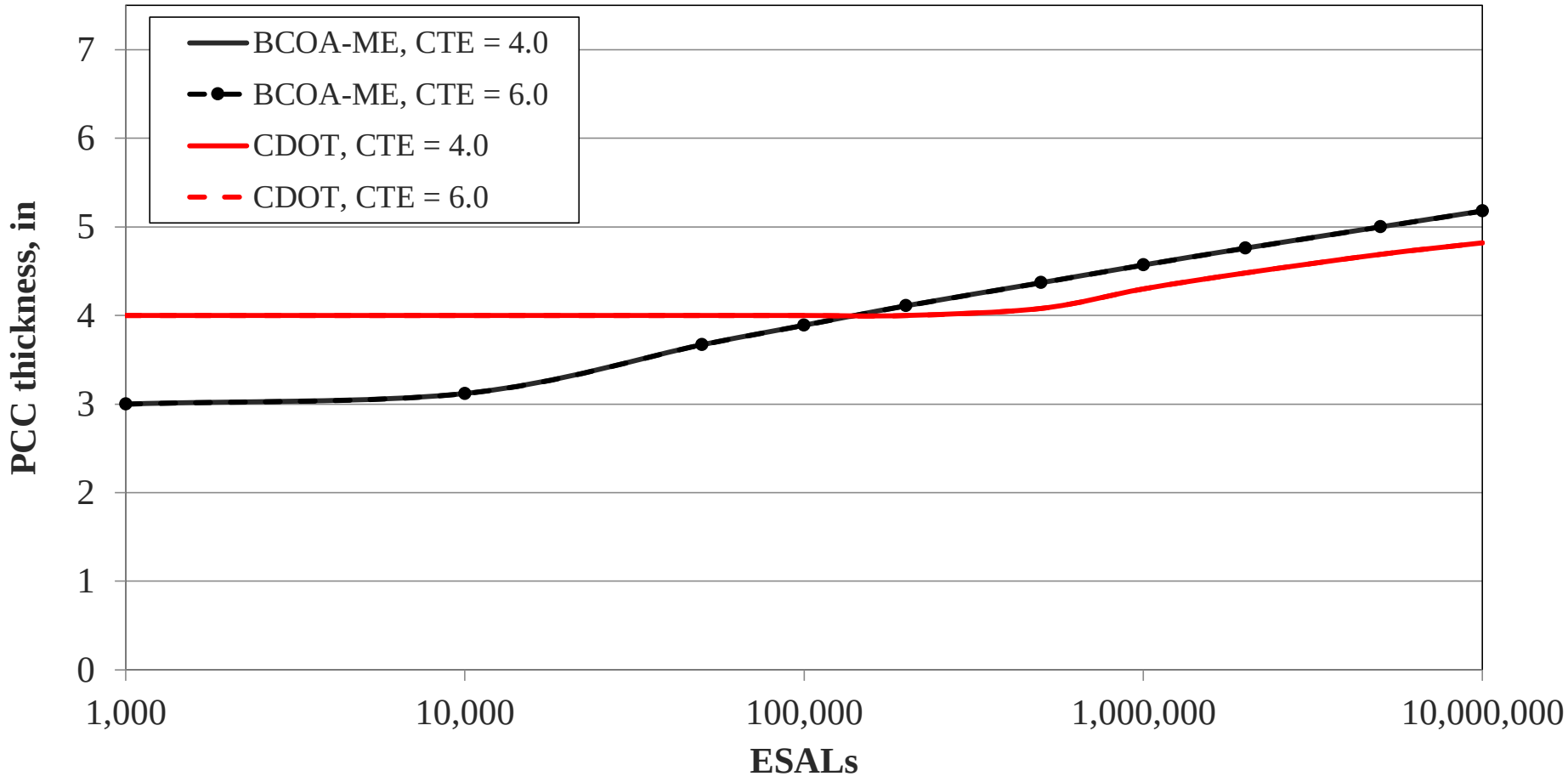
CTE – 4 ft x 4 ft


PCC thickness, in
HMA Thickness, in
0
1
2
3
4
5
6
7
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
BCOA-ME-4 ft x 4 ft, CTE = 4.0
BCOA-ME-4 ft x 4 ft, CTE = 6.0
ACPA 4 ft x 4 ft, CTE = 4.0
ACPA 4 ft x 4 ft, CTE = 6.0

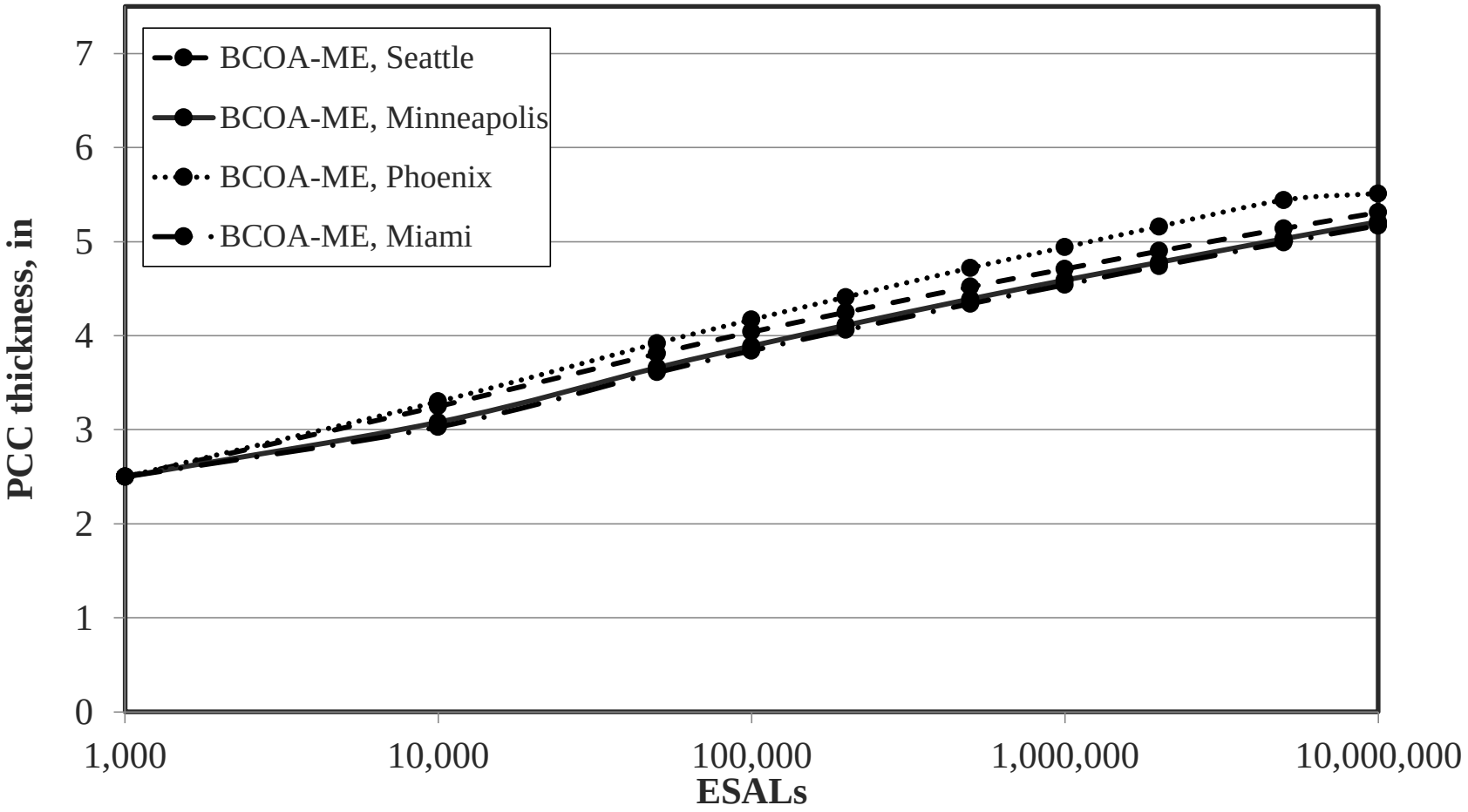
CTE – 6 ft x 6 ft


PCC thickness, in
HMA Thickness, in
0
1
2
3
4
5
6
7
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
BCOA-ME- 6 ft x 6 ft, CTE = 4.0
BCOA-ME- 6 ft x 6 ft, CTE =6.0
CDOT- 6 ft x 6 ft, CTE = 4.0
CDOT- 6 ft x 6 ft, CTE = 6.0

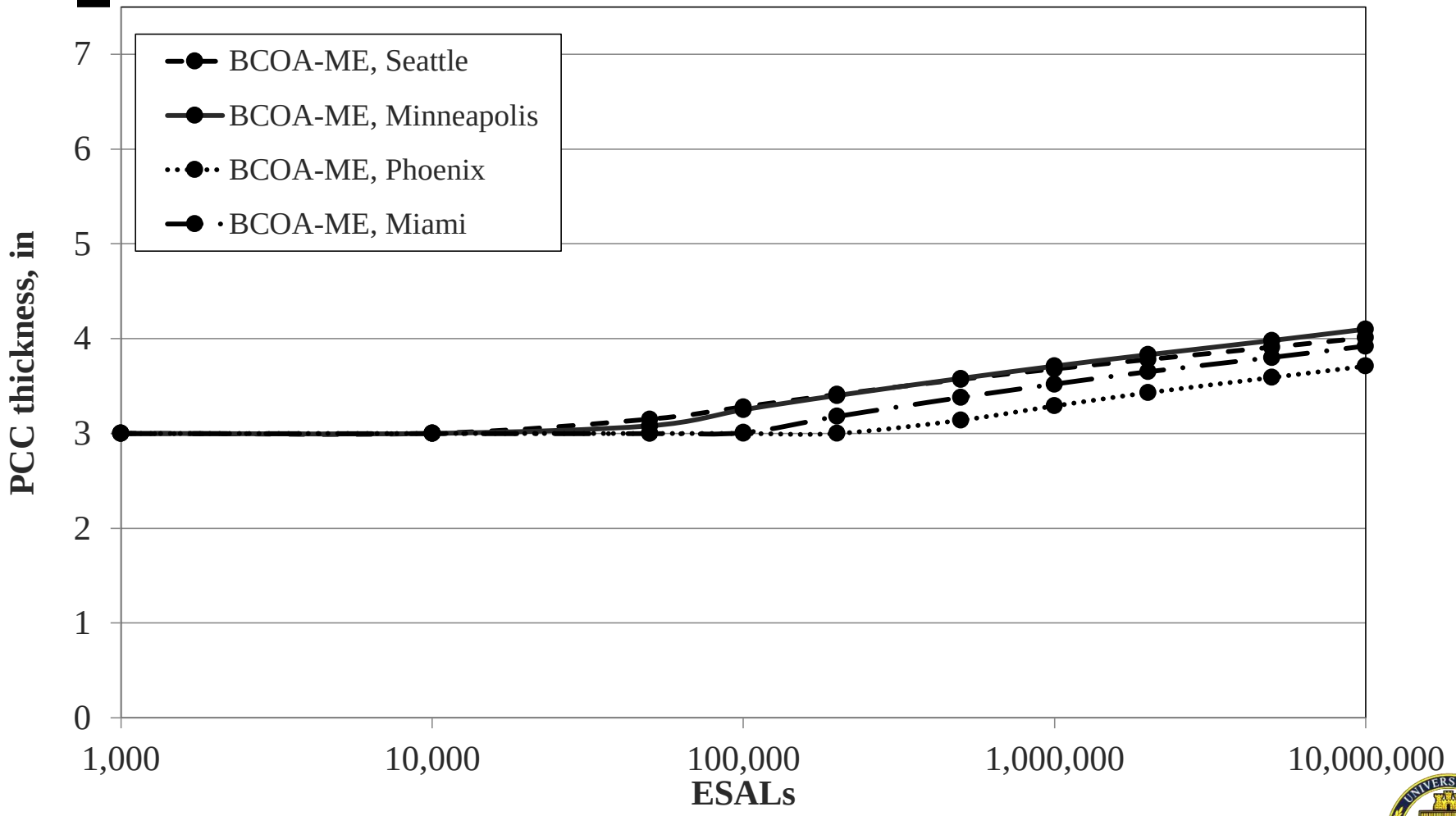
CTE – 12 ft x 12 ft



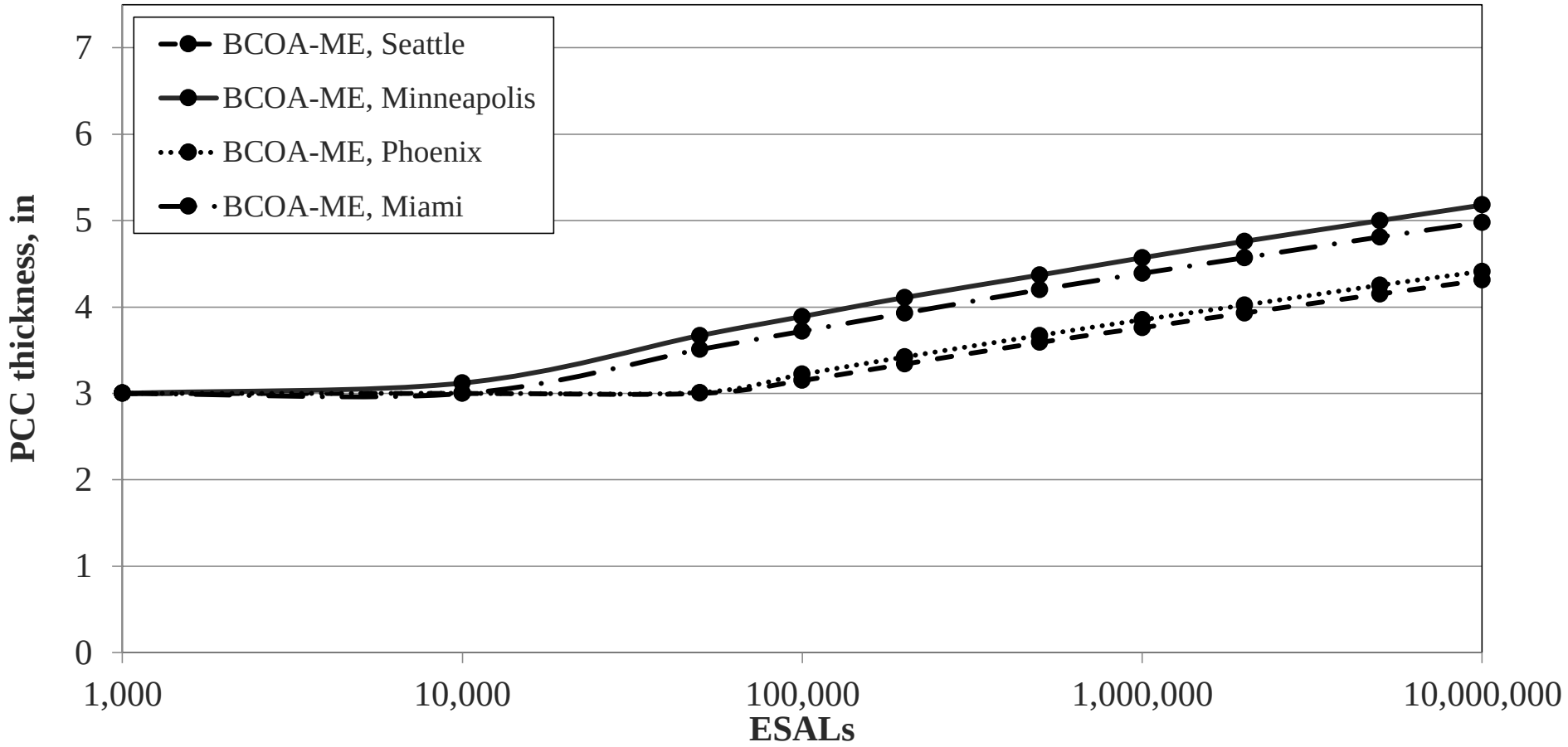
Climate sensitivity- 4ft x 4ft



Climate sensitivity – 6 ft x 6 ft



Climate sensitivity – 12 ft x 12 ft



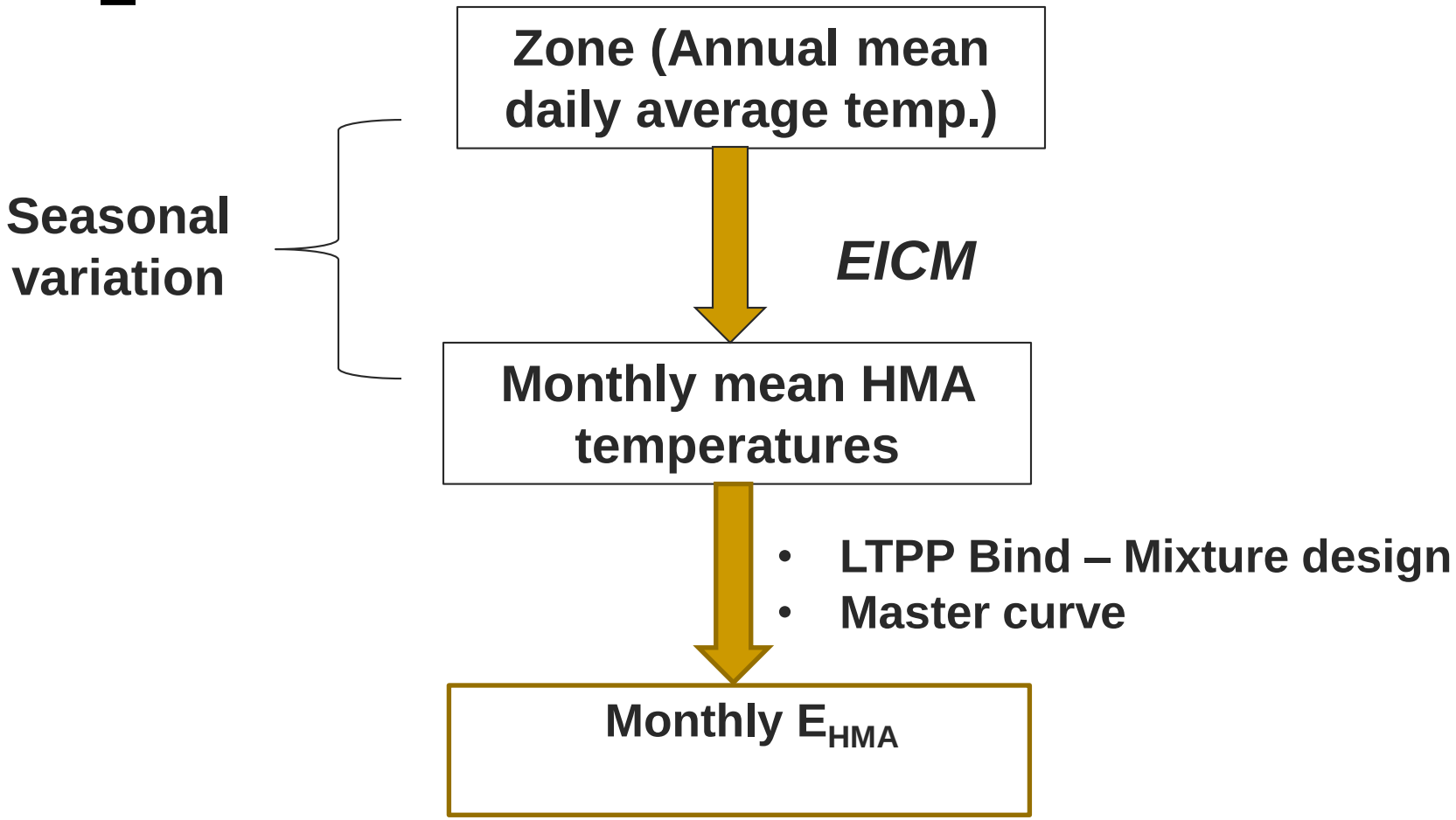
Thank You

Any Questions?

Calibration sites (Stress adjustment factors)

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 93, MnROAD	4	9	4 × 4
	Cell 94, MnROAD	3	10	4 × 4
Illinois	Highway 4, Piatt County	5	4	5.5 × 5.5
	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
	SH 119 - Section 4	7.3	3.4	6 × 6

Adjustment for seasonal variation of E_{HMA}



Composite adjustment factor

$$F = F_m \times F_h$$

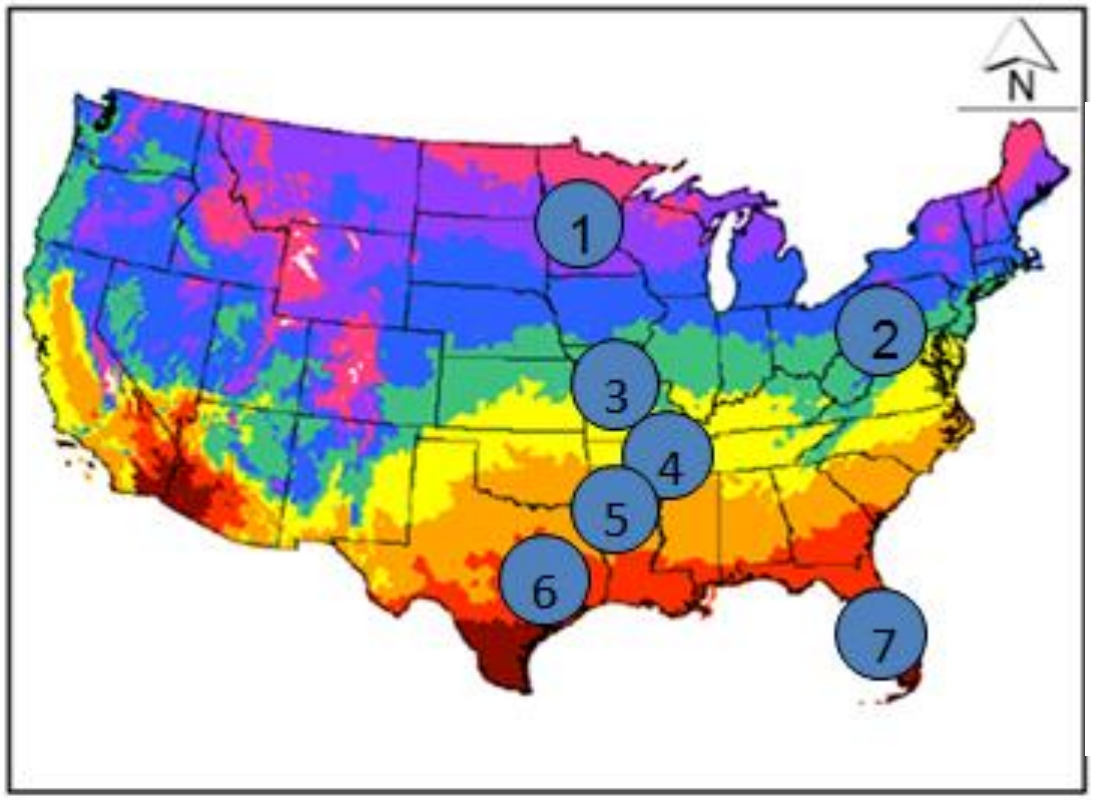
where,

F_m= monthly adjustment factor,

F_h = hourly adjustment factor.

Seven zones based on AMDAT

AMDAT = Annual mean daily average temp.



Region ID	Color code	AMDAT (°F)
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).

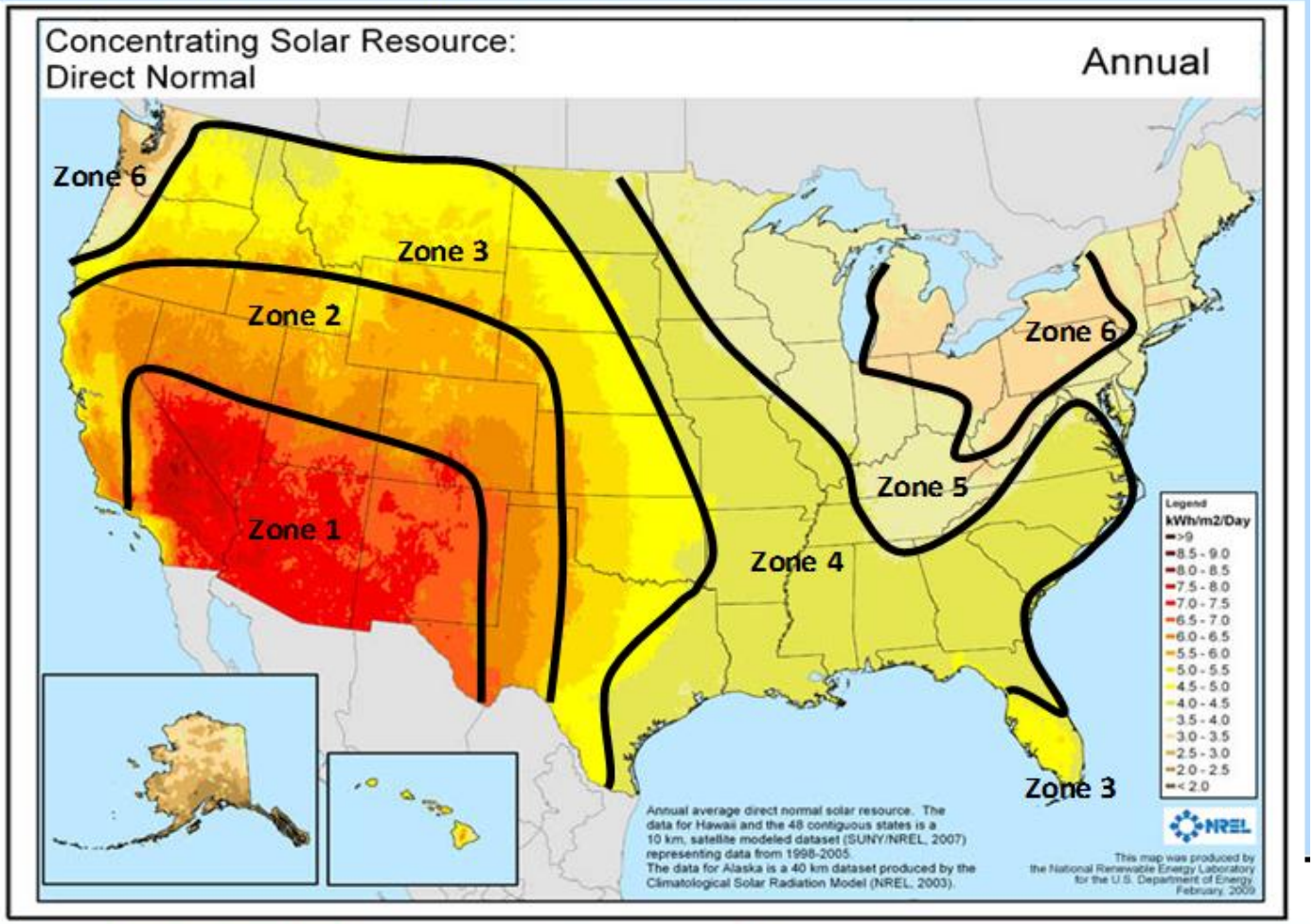
Populating database: Climate

16 projects for each weather station

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

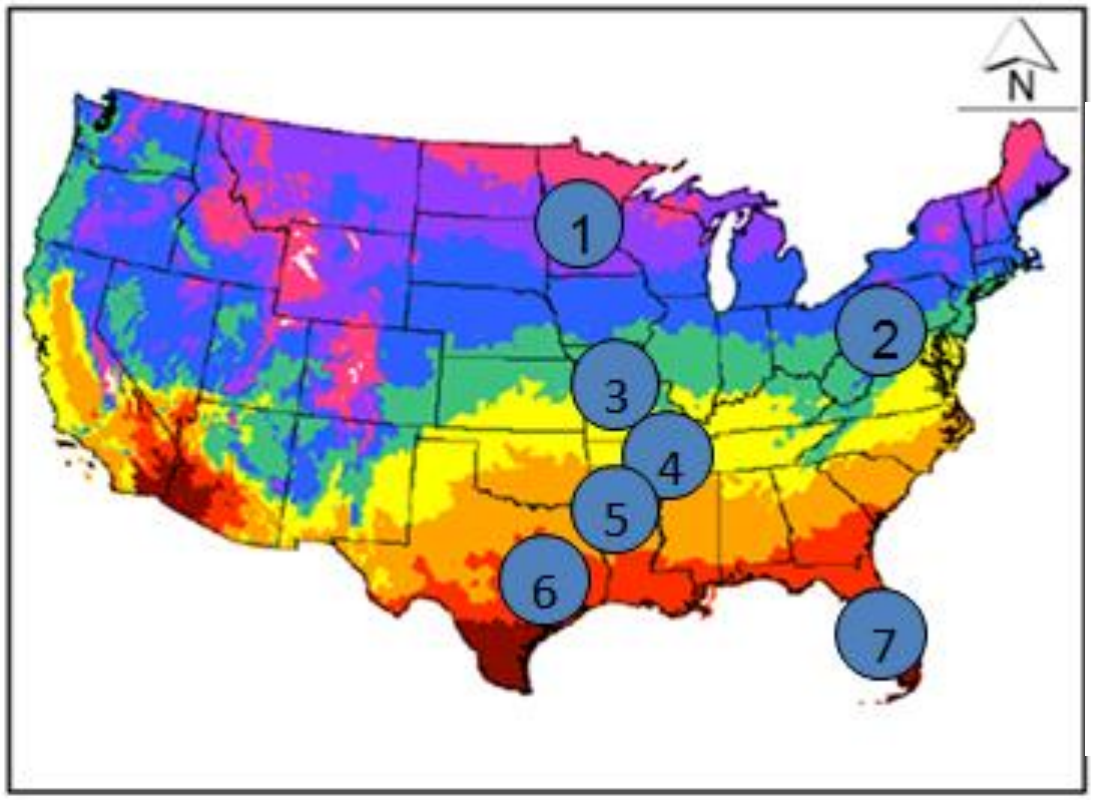
Sunshine

Fig. 2: Annual concentrating solar resource map of USA.



Seven zones based on AMDAT

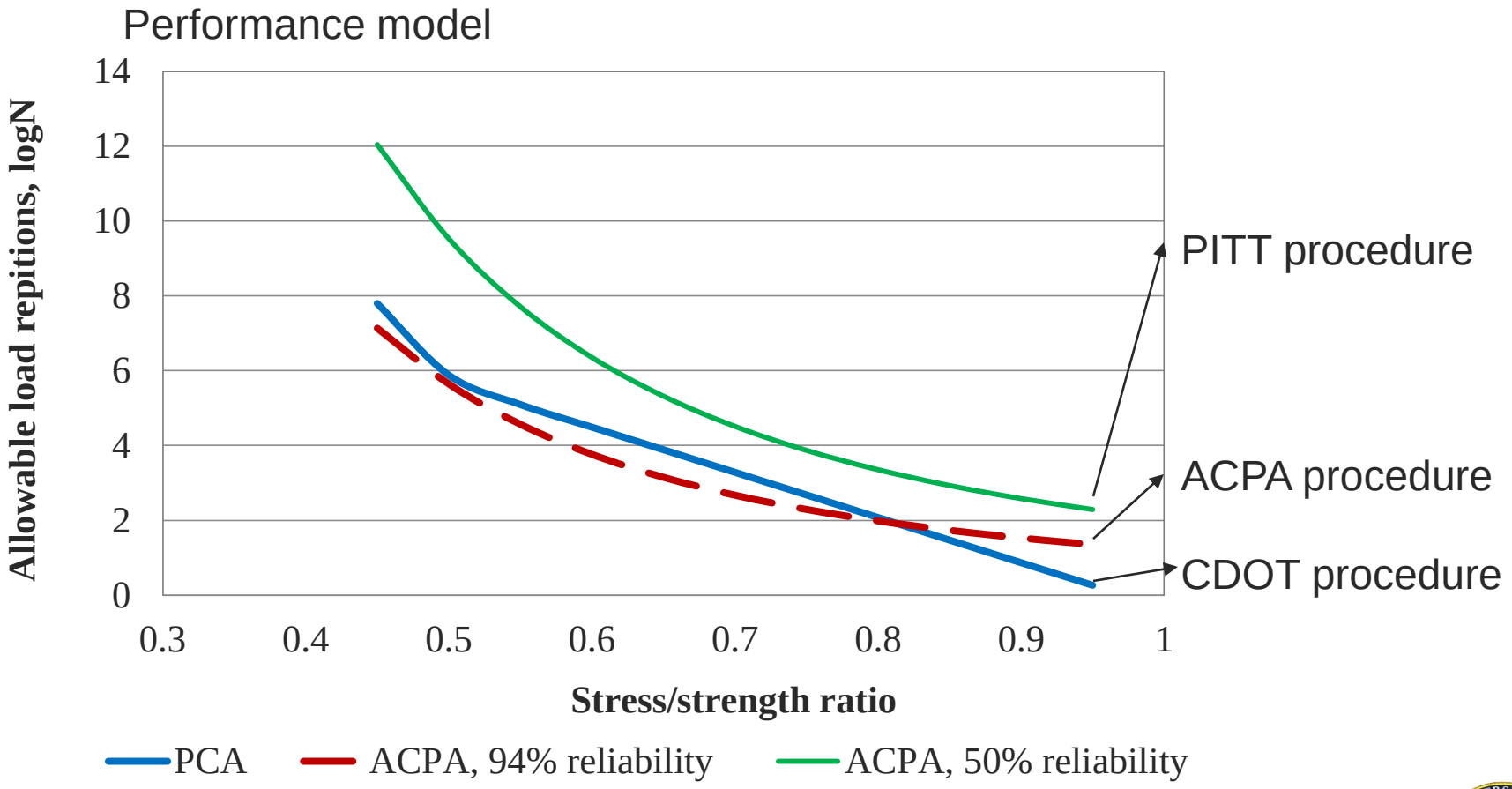
AMDAT = Annual mean daily average temp.



Region ID	Color code	AMDAT (°F)
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).

Inference space



E_{PCC} calculator

PCC Overlay Properties

Average 28-day Flexural Strength (psi):	650
Estimated PCC Elastic Modulus (psi):	3,600,000
Coefficient of Thermal Expansion (10^{-6} in/°F/in)	5.5

Epcc Calculator

CTE Calculator

REDUCTION FACTOR FOR HMA MODULUS