

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

Climate

AMDAT Region ID	5
Sunshine Zone	2

Existing Structure

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

PCC Overlay

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

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 Estimation:
Is One-Way ADT available?

Level 2

Estimate ESALs:

Design Life (yrs):	10
Terminal Serviceability:	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

Level 3

Estimate ESALs:

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



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

map, latitude/lon: x

veloroutes.org/elevation/?location=Minneapolis&units=e

units: feet Find elevation

Elevation for Minneapolis is 859 feet

- The latitude for this location is: 44.979965
- The longitude for this location is: -93.263836
- Click [here](#) to create a route at this location.

Map Satellite Hybrid Terrain

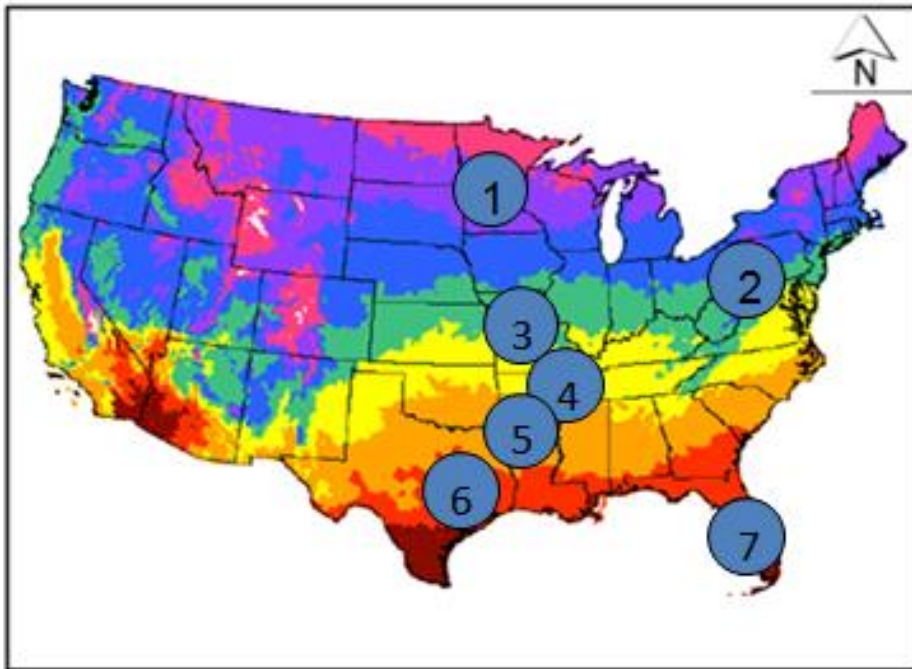
Longitude Technology
Enhanced parimutuel capabilities for the wagering industry
www.longitudate.com



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

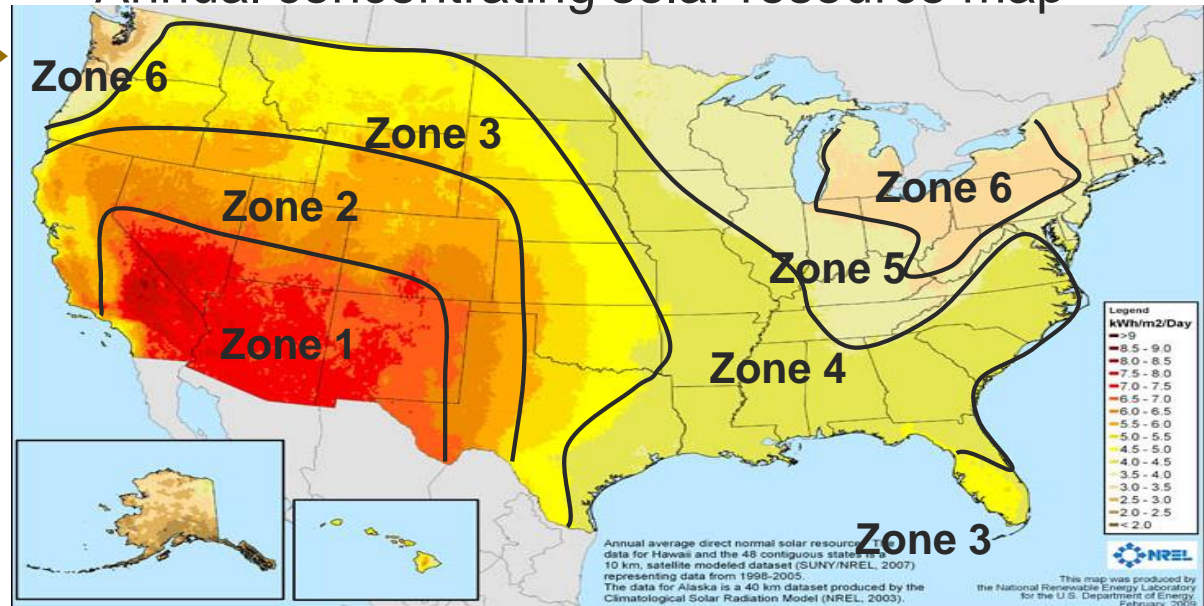
(<http://cdo.ncdc.noaa.gov/climaps/temp0313.pdf>,
accessed on January, 2010).

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

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

PCC Overlay

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

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

Subgrade k-Value Calculator

apps.acpa.org/apps/kValue.aspx

ACPA

Description

The k-Value is a commonly applied value in concrete pavement design. It estimates the composite of support of any subgrade(s) or subbase(s) layers below the concrete pavement surface course. This web applet allows you to determine the composite k-Value with consideration for up to three subgrade/subbase layers. The conversion from resilient modulus of the subgrade to k-value was updated in the fall of 2011 to better reflect published test results; the constant conversion factor of 19.4 as suggested in the AASHTO Guide for Design of Pavement Structures 1993 is no longer used. The conversion from resilient modulus of the subgrade to k-value was

Step 1 - Calculate Subgrade k-Value

Resilient Modulus of Subgrade (M_{RSG}):

[Calculate Resilient Modulus](#)

k-Value corresponding to the calculated M_{RSG} :

Step 2 - Calculate Composite k-Value

From the top down, input subgrade/subbase details

Number of subgrade/subbase layers:

Existing Structure: k-value

Whitetopping

$E = \text{HMA}$

$k_{\text{composite}} = \text{All granular layers}$



Composites

No bond @ old HMA/old PCC interface

$E = \text{HMA}$

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



Bond @ old HMA/old PCC interface

$E = \text{HMA} + \text{old PCC}$

$k_{\text{composite}} = \text{All granular layers}$



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 ³ F/in)	5.5
Fiber Type:	No Fibers
Fiber Content(lb/cu yd) (Only used when a fiber type is selected):	0

E_{pcc} 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 ³ F/in)	5.5
Fiber Type:	No Fibers
Fiber Content(lb/cu yd) (Only used when a fiber type is selected):	0

E_{pcc} Calculator
CTE Calculator



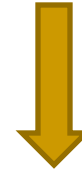
CTE

PCC Overlay

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

Ecc 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. ($10e-6/^{\circ}$ F)
Quartz	6.6
Sandstone	6.5
Gravel	6.0
Granite	5.3
Basalt	4.8
Limestone	3.8

Submit

Cancel

(AASHTO 93, pp II-29)

PCC Overlay: Fiber content

Fiber Type:	No Fibers
Fiber Content(lb/cu yd) (Only used when a fiber type is selected):	0

Fiber Type:	No Fibers
Fiber Content(lb/cu yd) (Only used when a fiber type is selected):	No Fibers Synthetic Structural Fibers Steel Fibers Low Modulus Synthetic
Joint Design	
Joint Spacing (ft):	

Select type from
drop-down list

Joint spacing

Joint Design

Joint Spacing (transverse x longitudinal, ft x ft):

2 x 2
3 x 3
4 x 4
6 x 6
7 x 7
10 x 12
12 x 12
15 x 12

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/ $^{\circ}$ F/in):	5.5
Fiber Type:	No Fibers
Fiber Content(lb/cu yd) (Only used when a fiber type is selected):	0

Epsc Calculator

CTE Calculator

Joint Design

Joint Spacing (ft):	6
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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
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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/ $^{\circ}$ F/in	4.8

Design Thickness

Design Comparisons

	BCOA-ME	CDOT
	PG58-28, LTPP	
Design h_{PCC} , in	3.0*	4.0*
Calculated h_{PCC} , in	3.0*	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: Cell 95, MnROAD
Minneapolis, MN

Traffic

Design ESALs, million	4.8
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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/ $^{\circ}$ F/in	4.8

Design Thickness

Design Comparisons

	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

Traffic

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

Existing structure

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

PCC properties

MOR, psi	650
CTE, $10^{-6}\text{in}/^{\circ}\text{F}/\text{in}$	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

Traffic

Design ESALs, million	0.81
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Existing structure

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

PCC properties

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

Design Thickness

Design Comparisons

	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
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Existing structure

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

PCC properties

MOR, psi	600
CTE, 10^{-6} in/ $^{\circ}$ 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
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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/ $^{\circ}$ F/in	6.0

Design Comparisons

Design Thickness

Design output	BCOA-ME	CDOT
	PG58-28, LTPP	
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
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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/ $^{\circ}$ 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



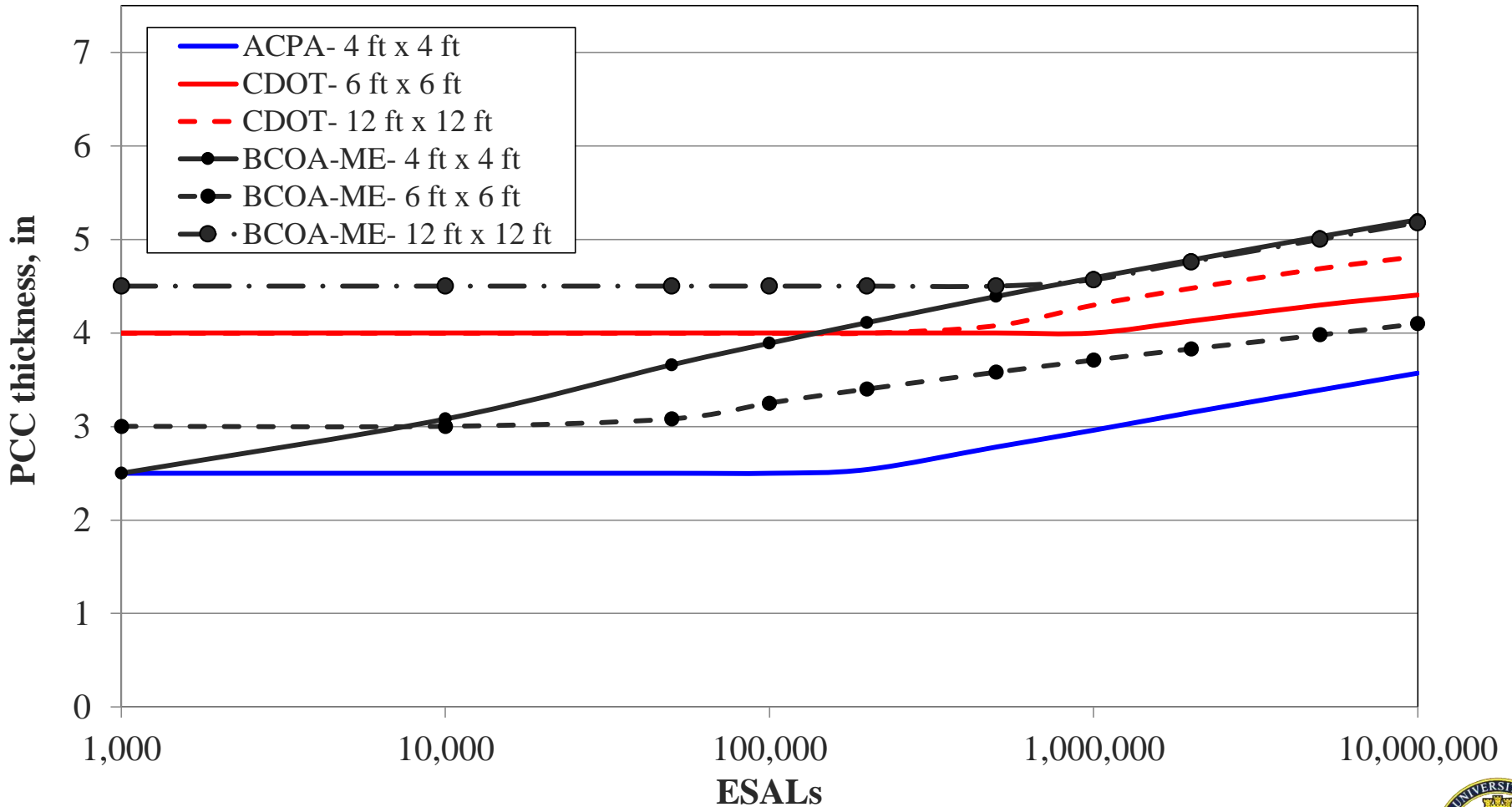
Analysis assumptions

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	5.5×10^{-6} in/in/°F
Joint Design	Spacing	4ft and 6 ft

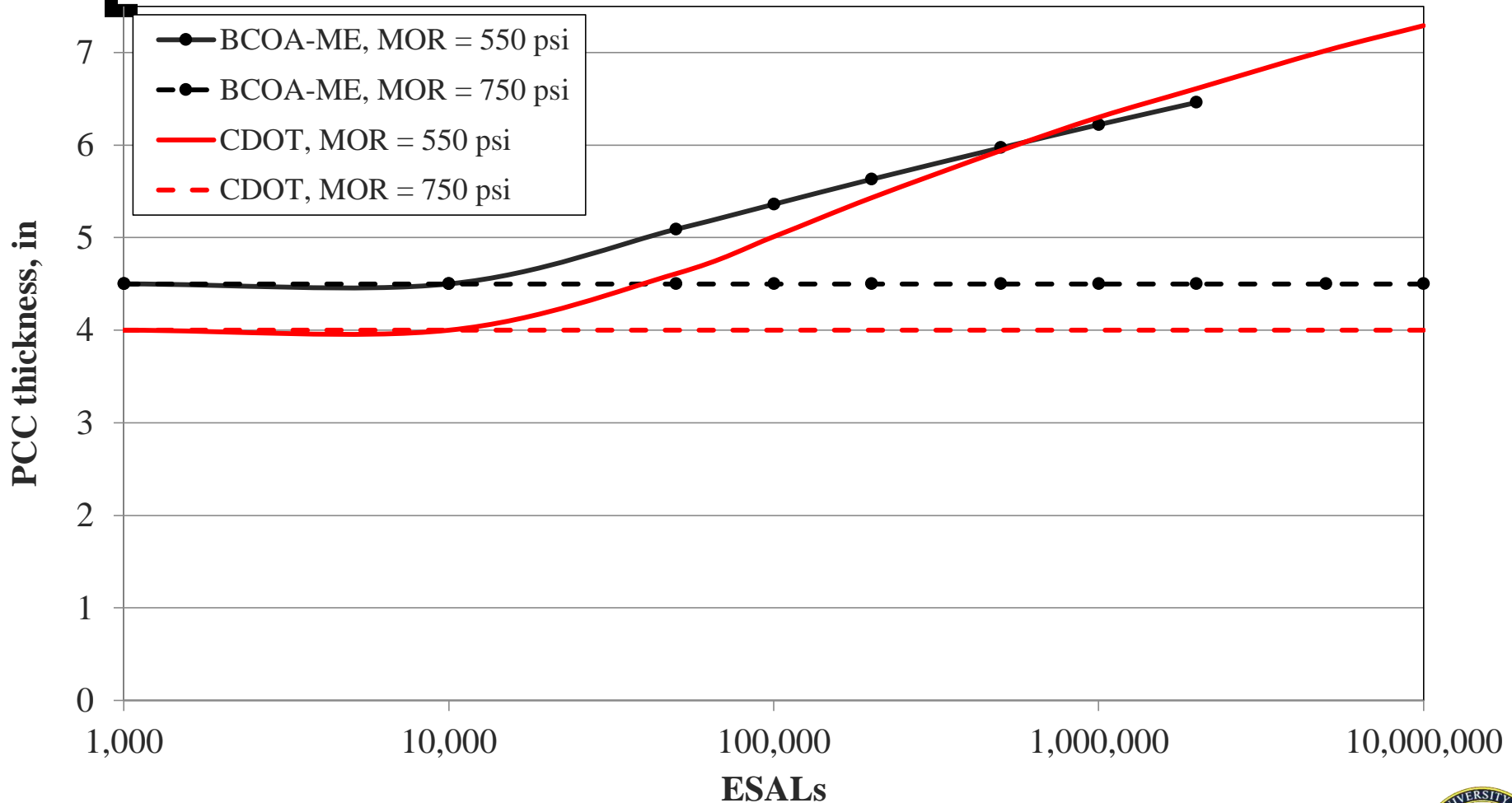
*Aged E_{HMA} @ 70°F = 860,000 psi or an effective Constant $E_{HMA} = 350,000$ psi



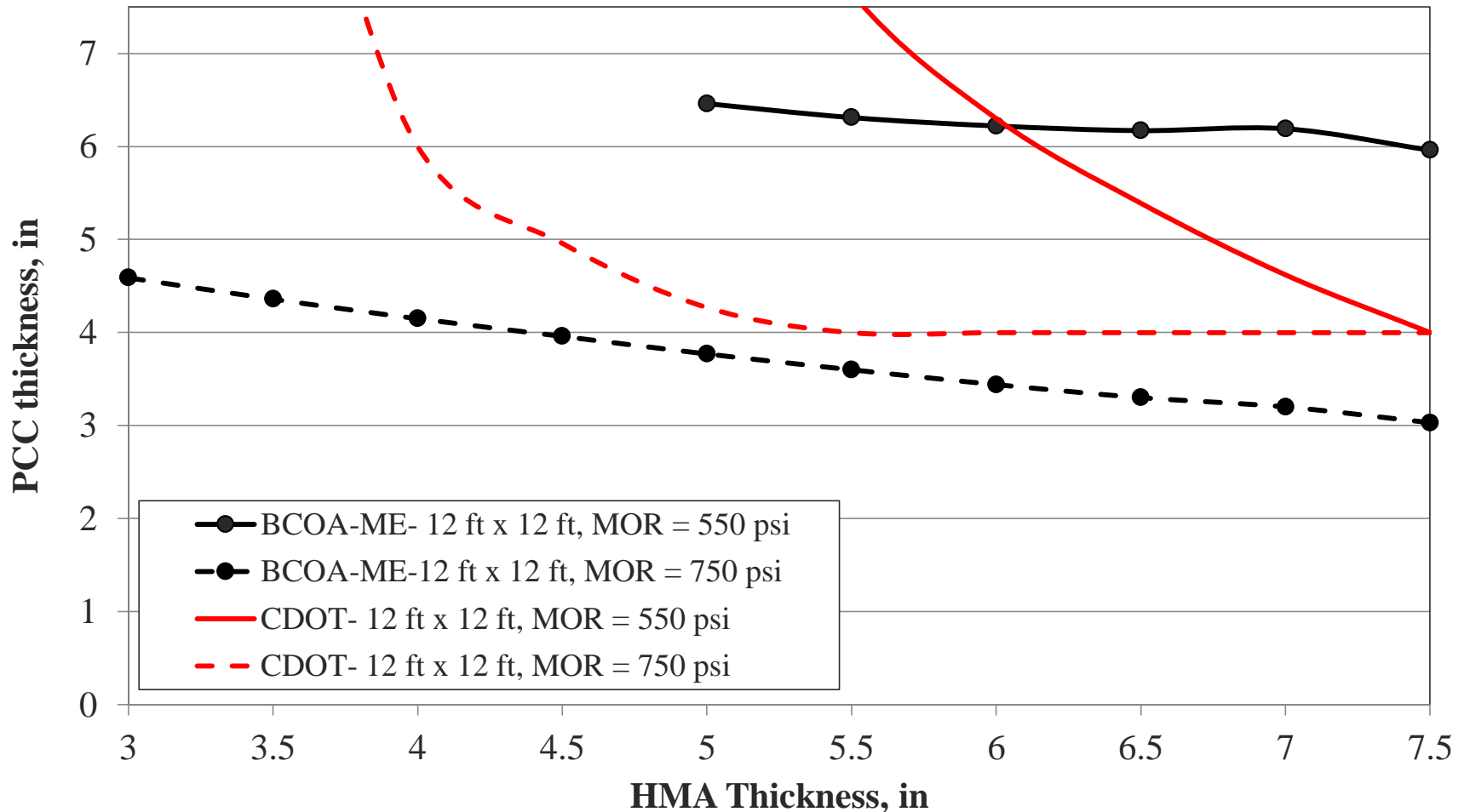
Joint spacing



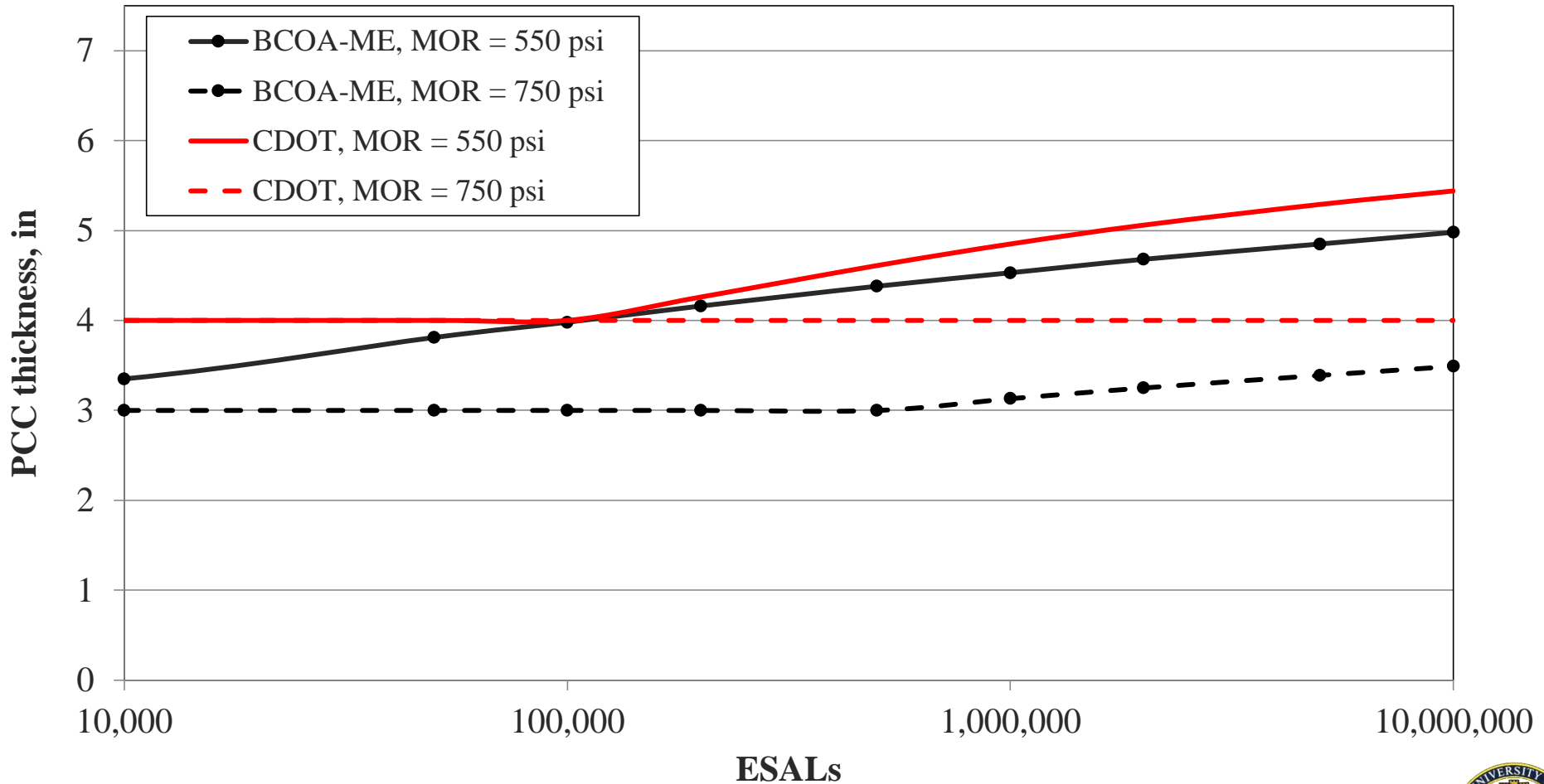
Modulus of rupture – 12 ft x 12 ft



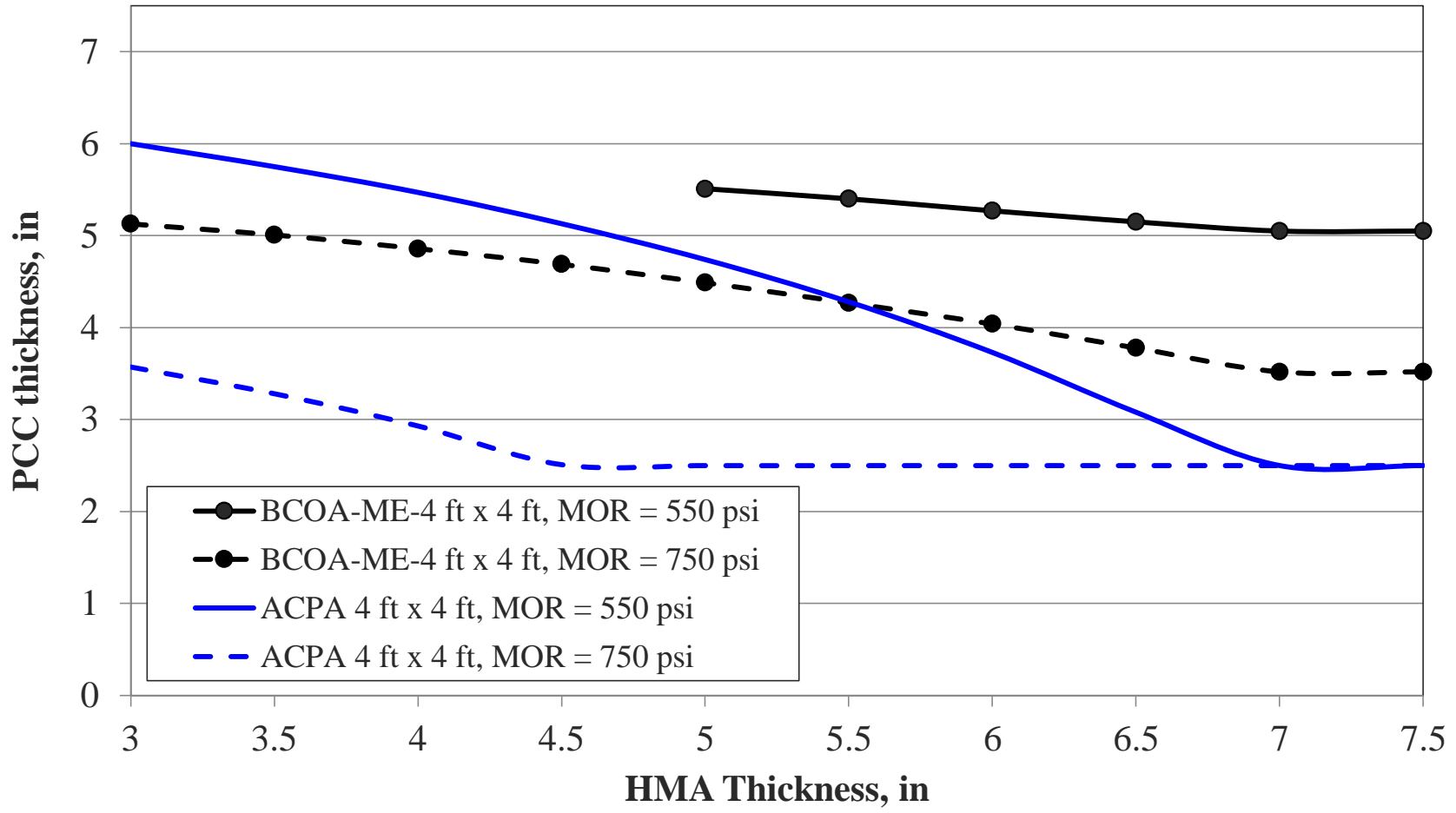
Modulus of rupture – 12 ft x 12 ft



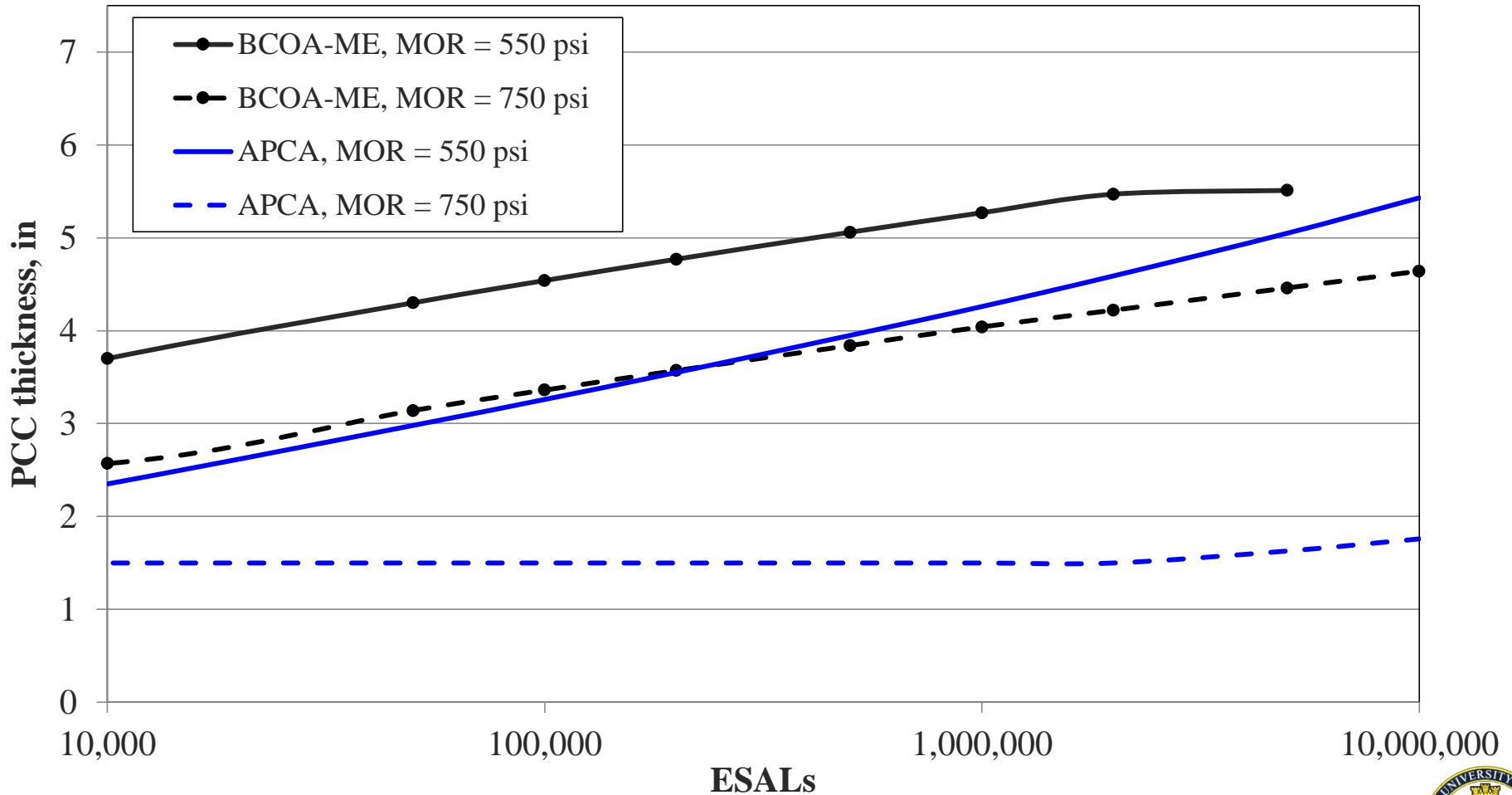
Modulus of rupture – 6 ft x 6 ft



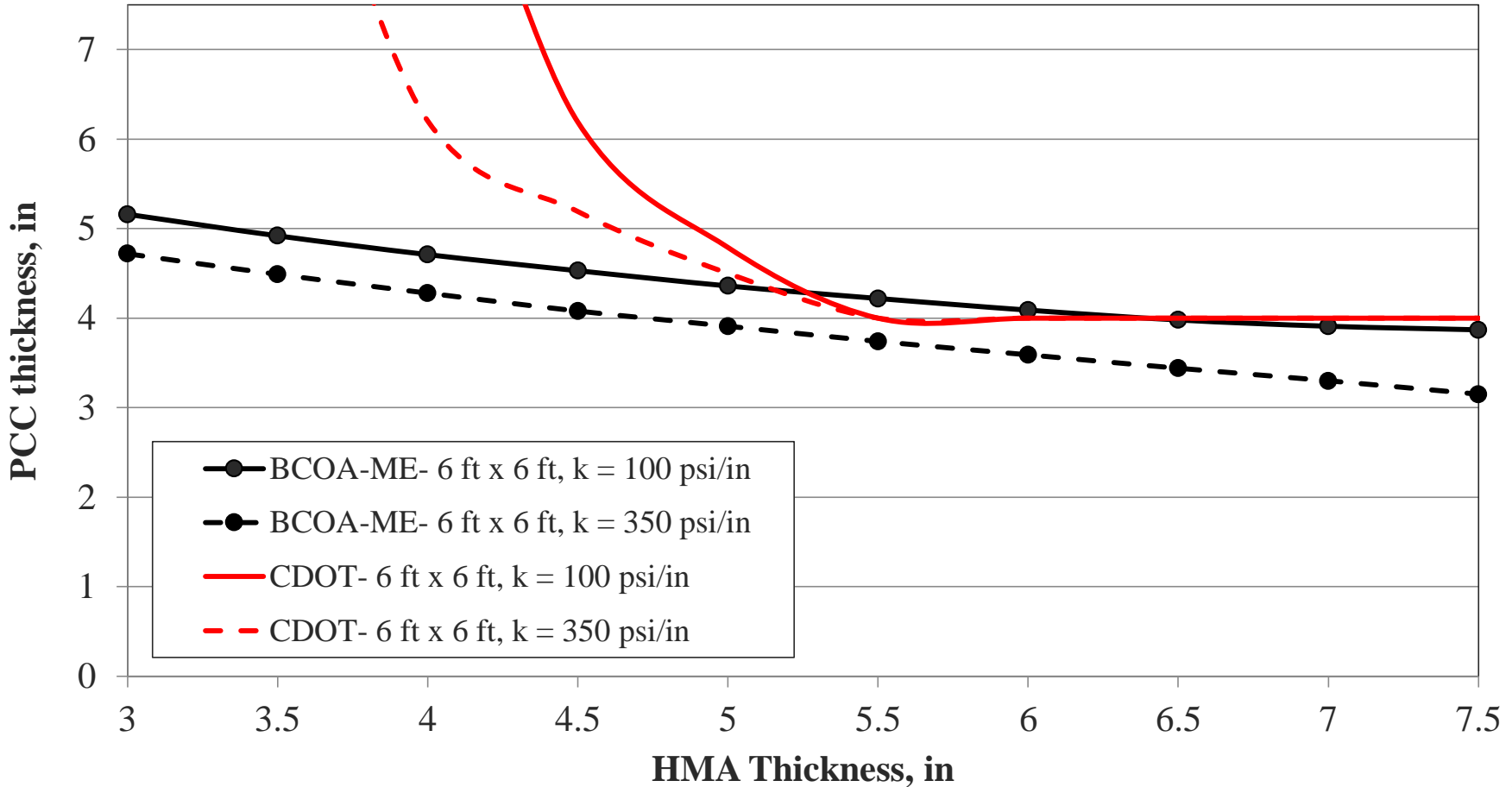
Modulus of rupture- 4 ft x 4 ft



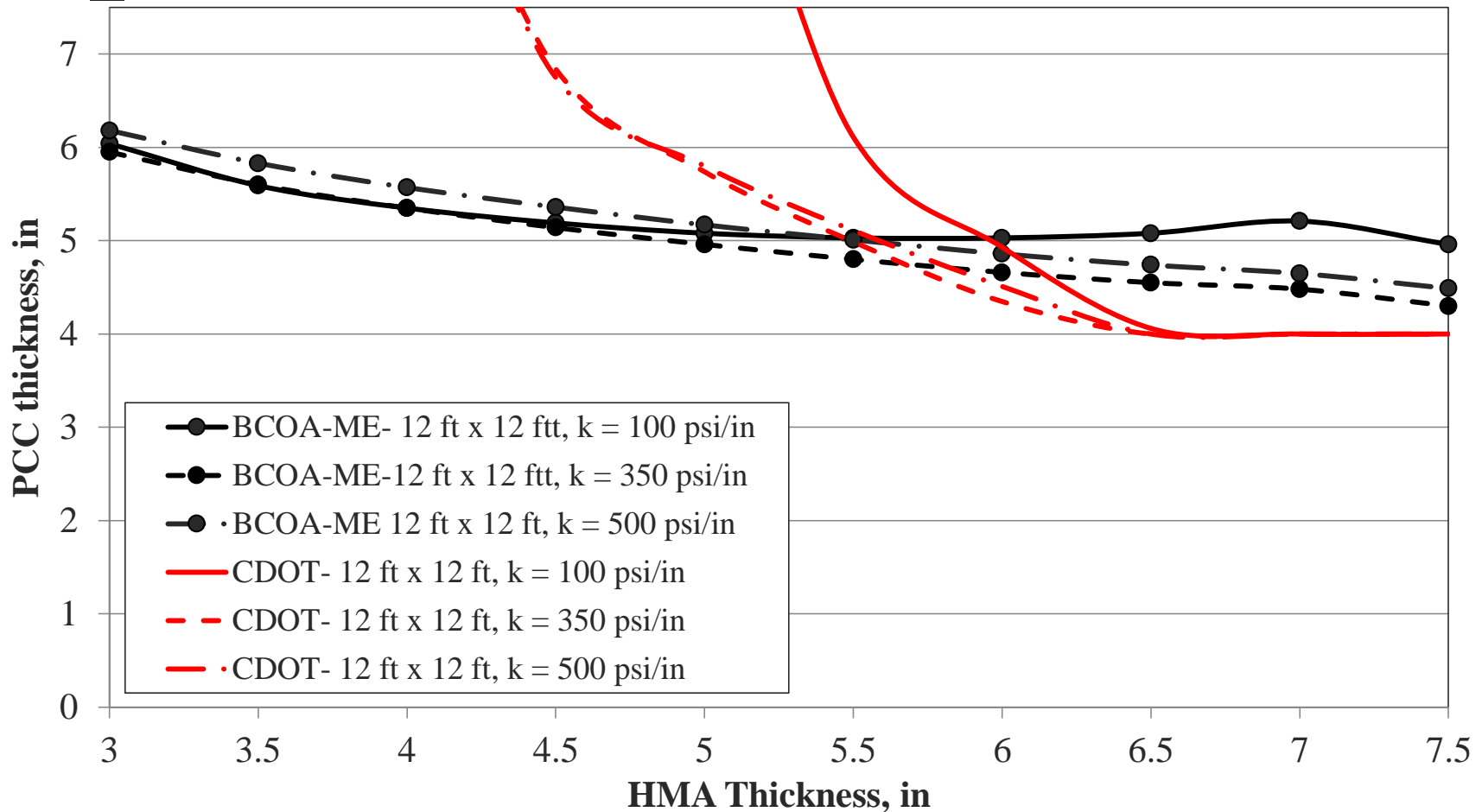
Modulus of rupture- 4 ft x 4 ft



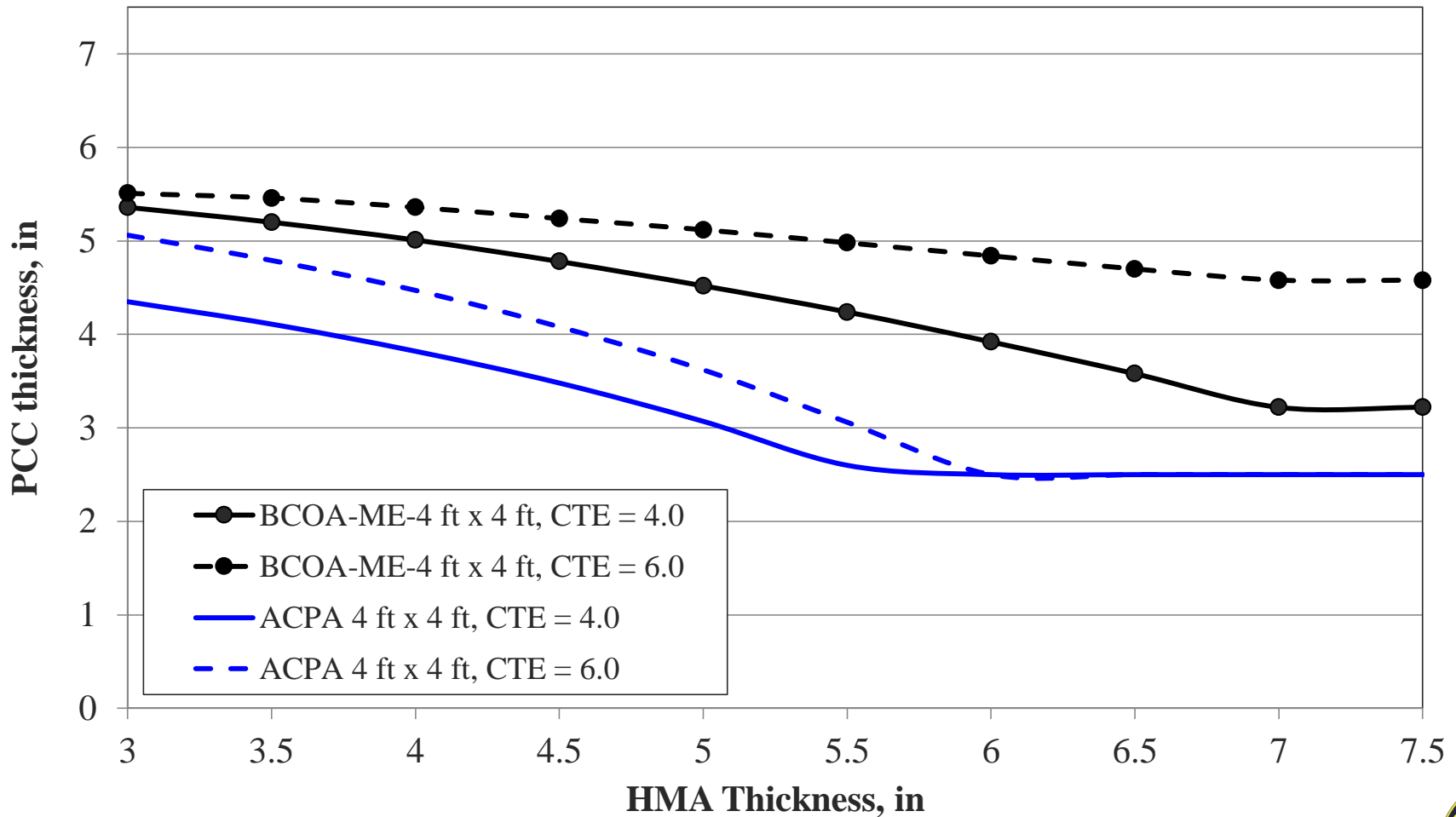
k-value – 6 ft x 6 ft



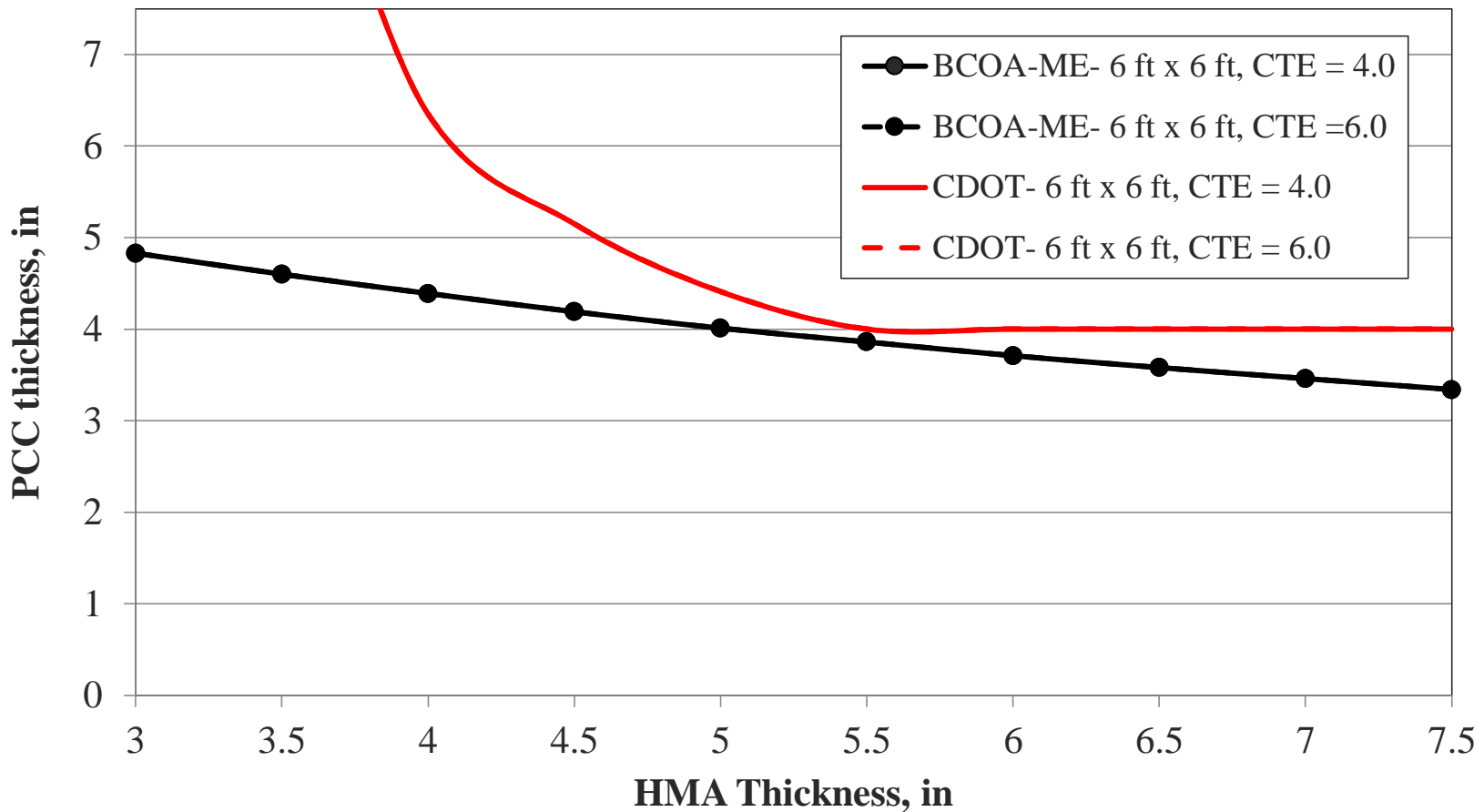
k-value – 12 ft x 12 ft



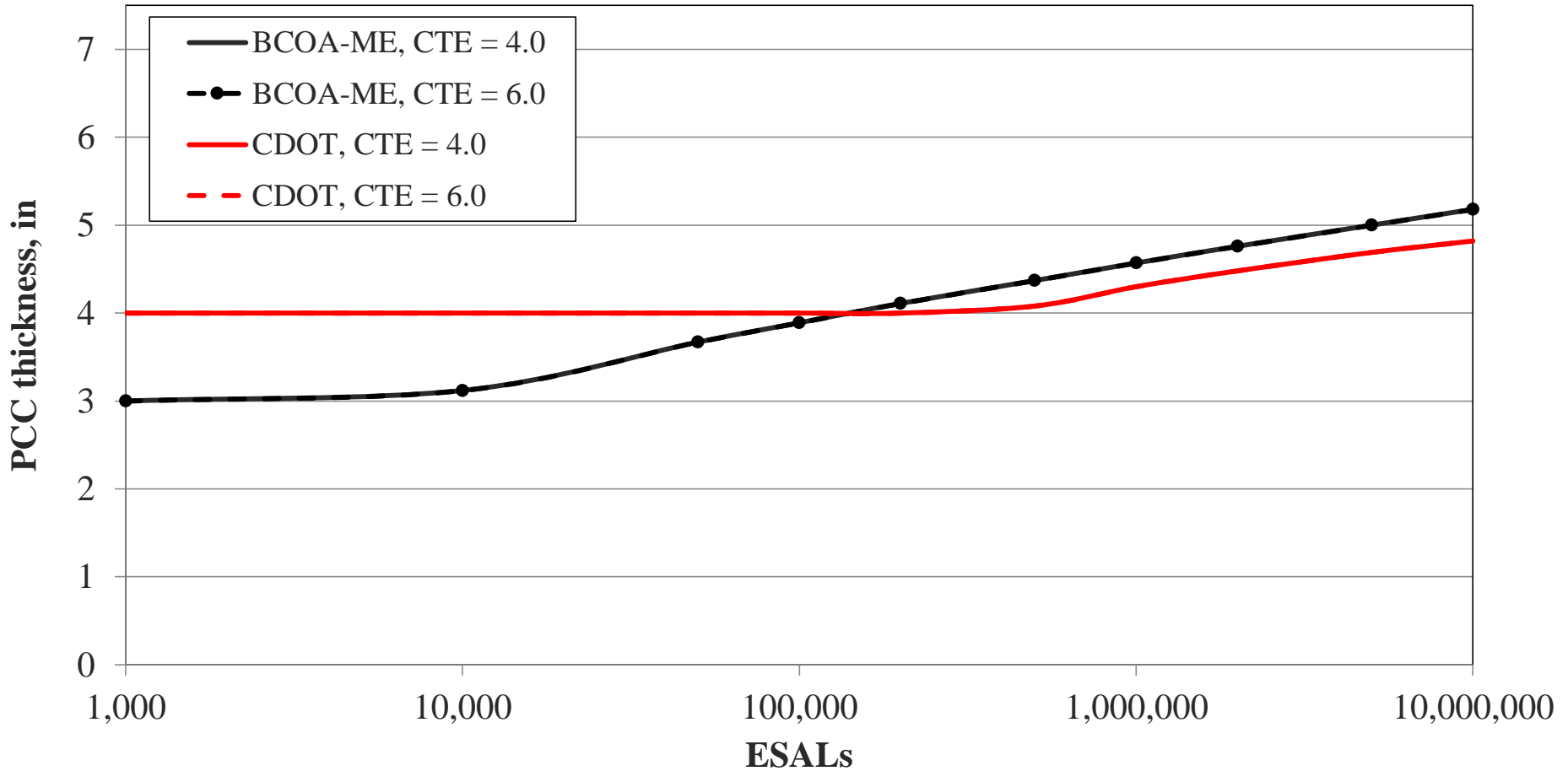
CTE – 4 ft x 4 ft



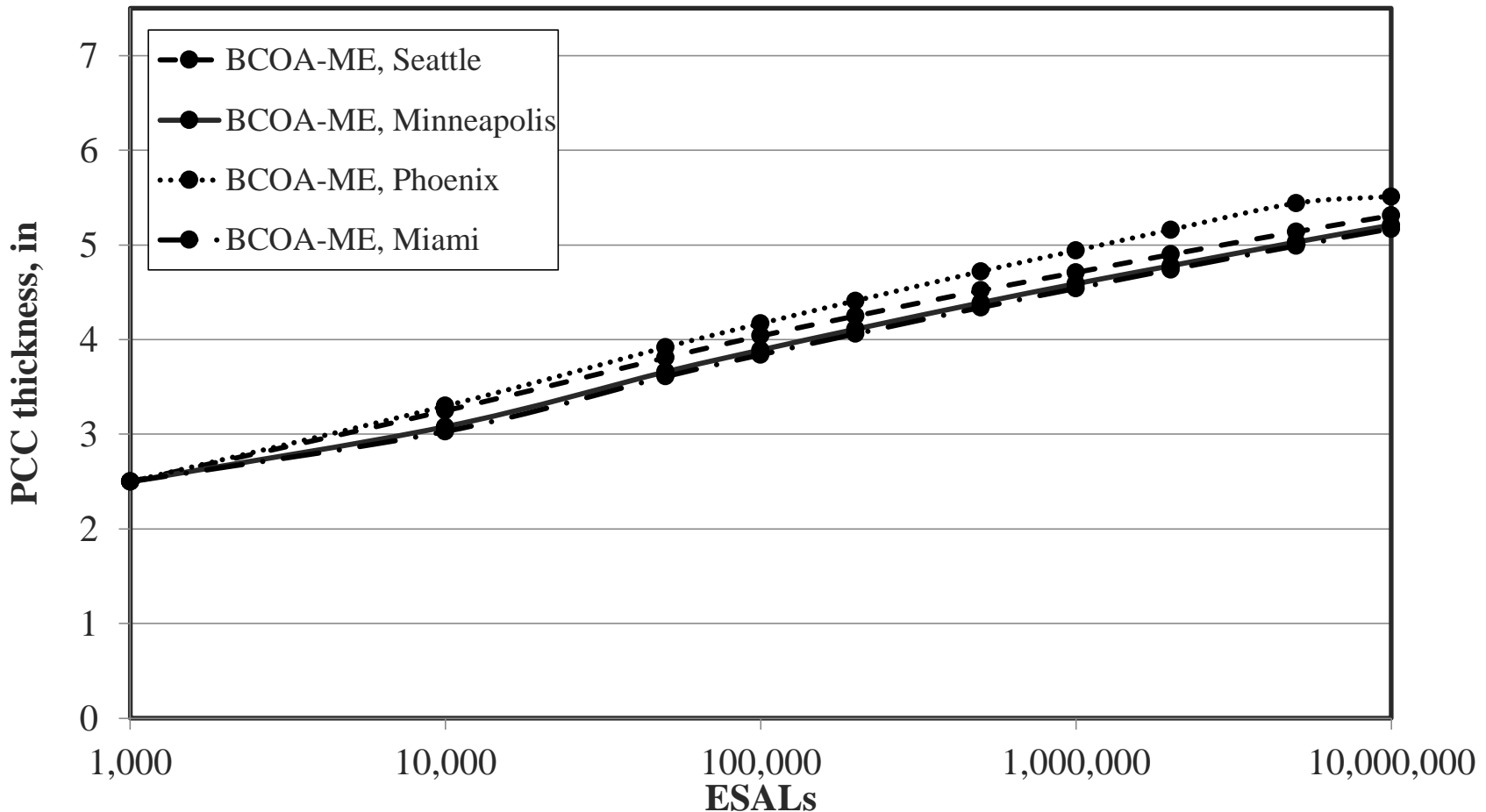
CTE – 6 ft x 6 ft



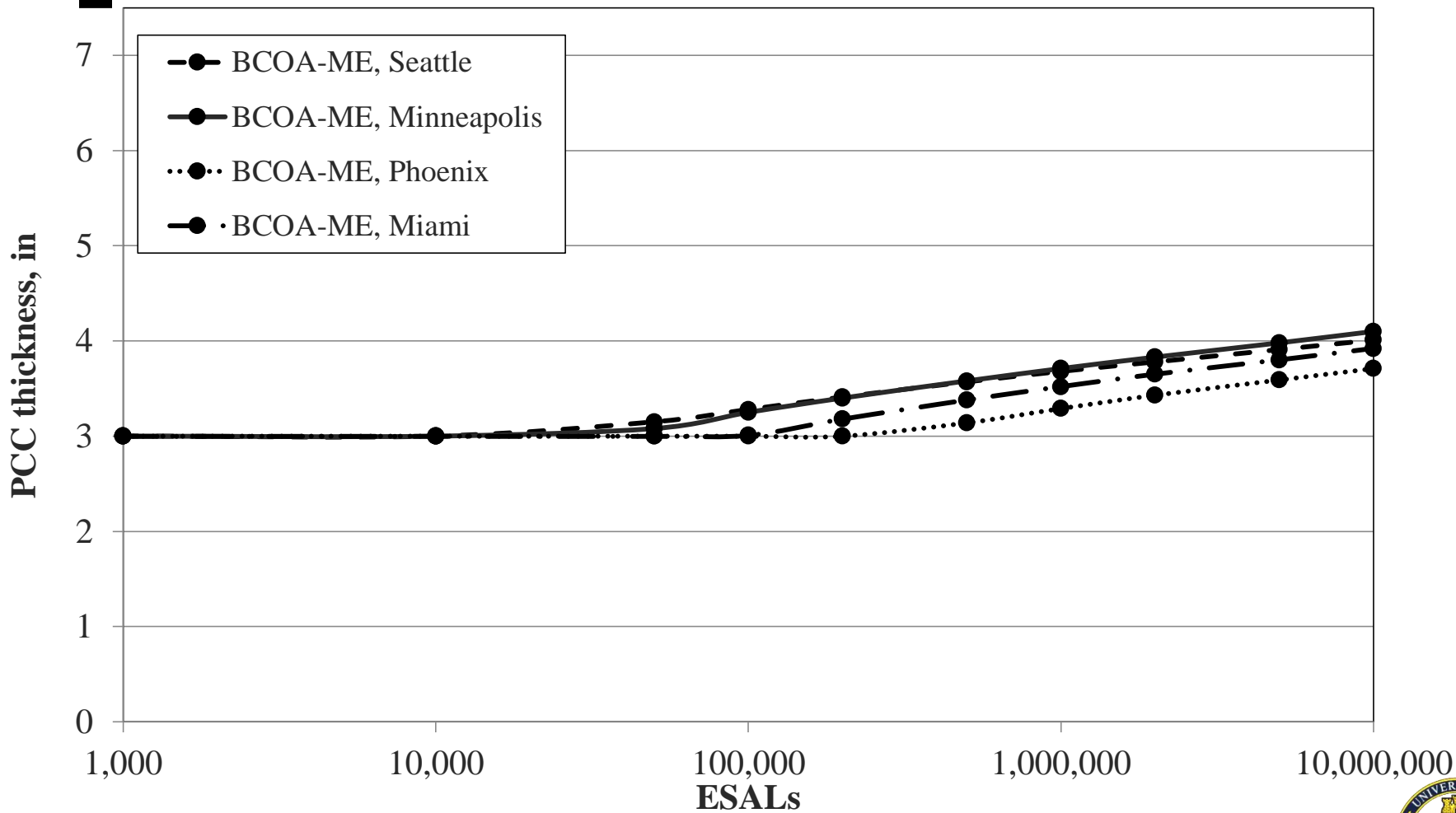
CTE – 12 ft x 12 ft



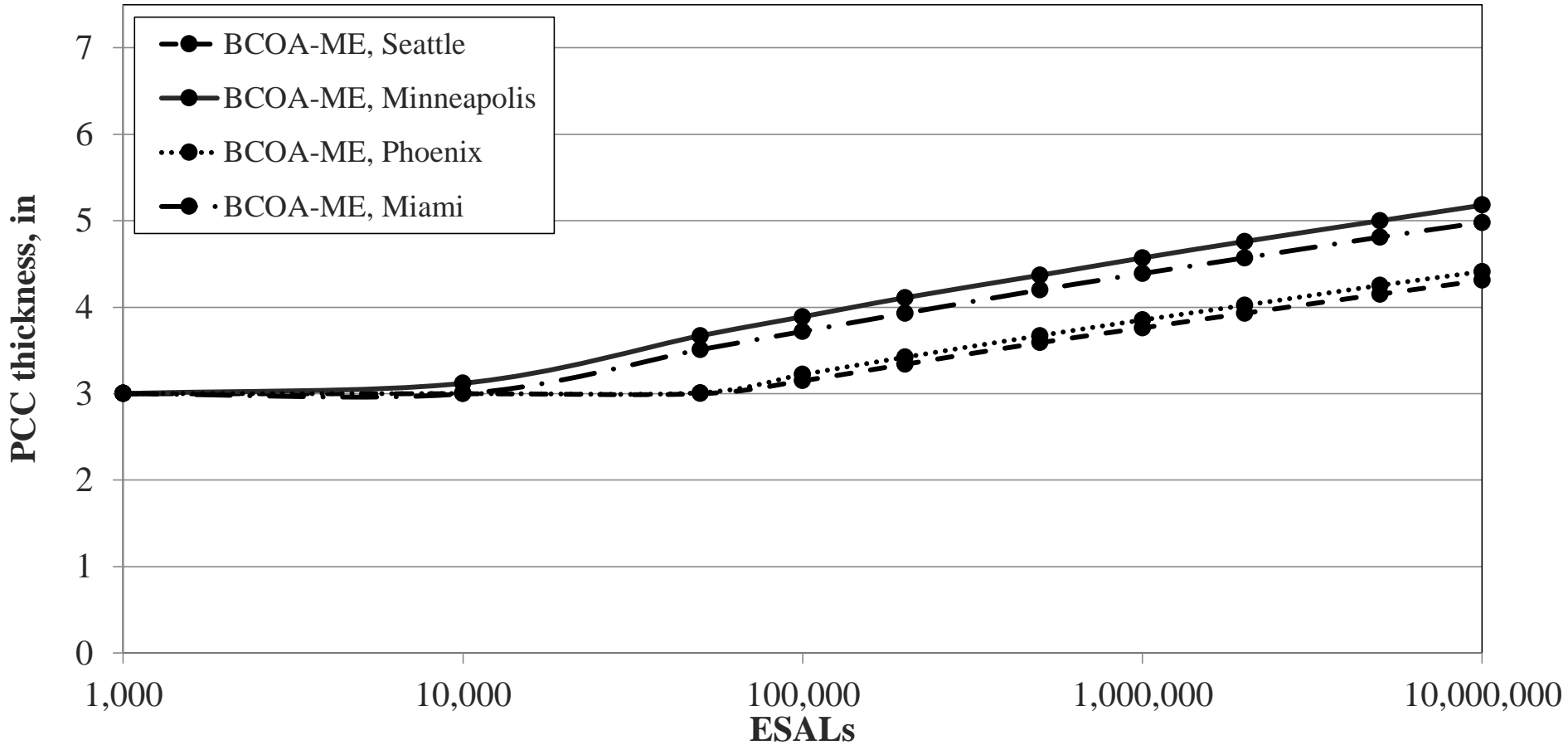
Climate sensitivity- 4ft x 4ft



Climate sensitivity – 6 ft x 6 ft



Climate sensitivity – 12 ft x 12 ft



Thank You



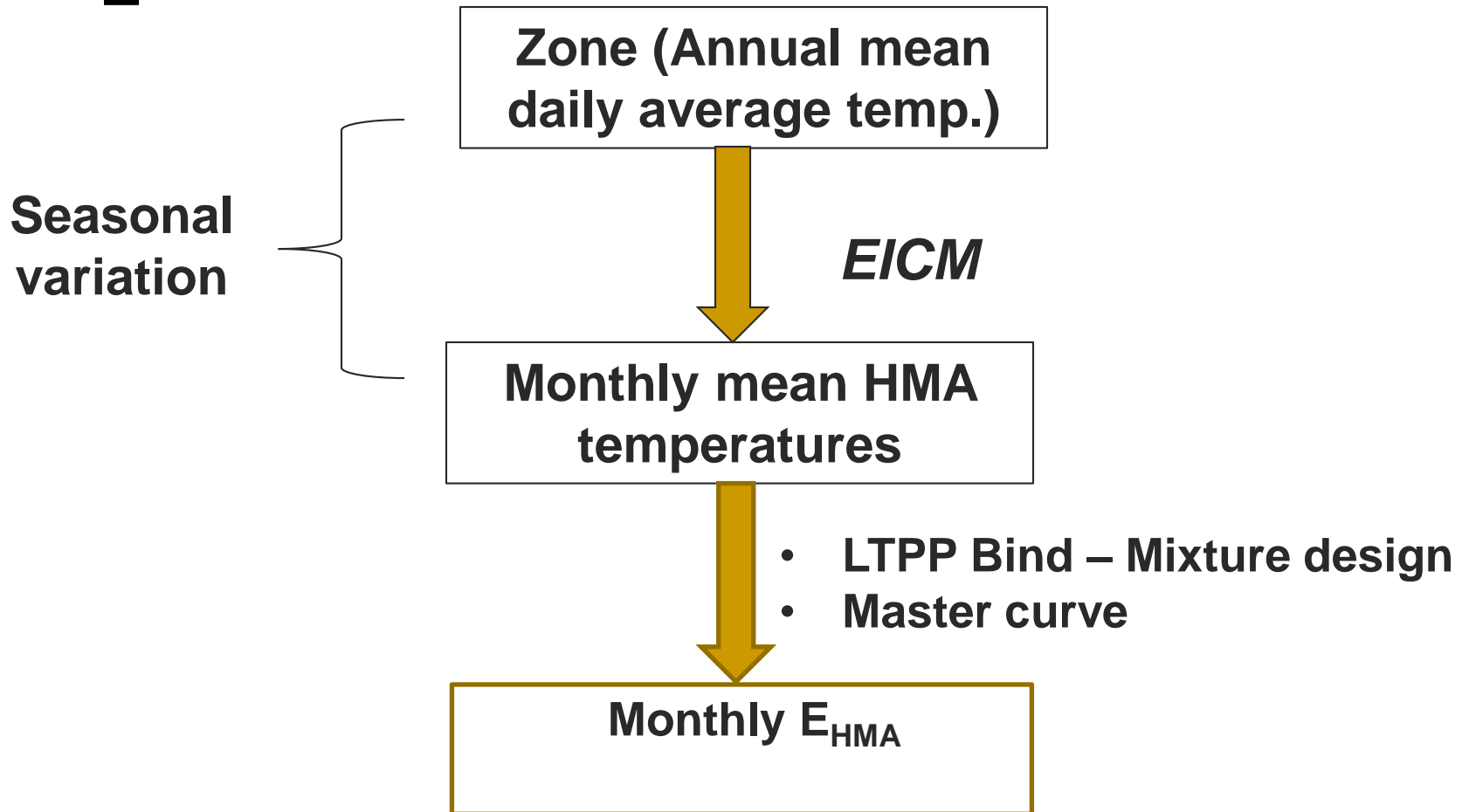
Any Questions?

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 - Section 1	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,

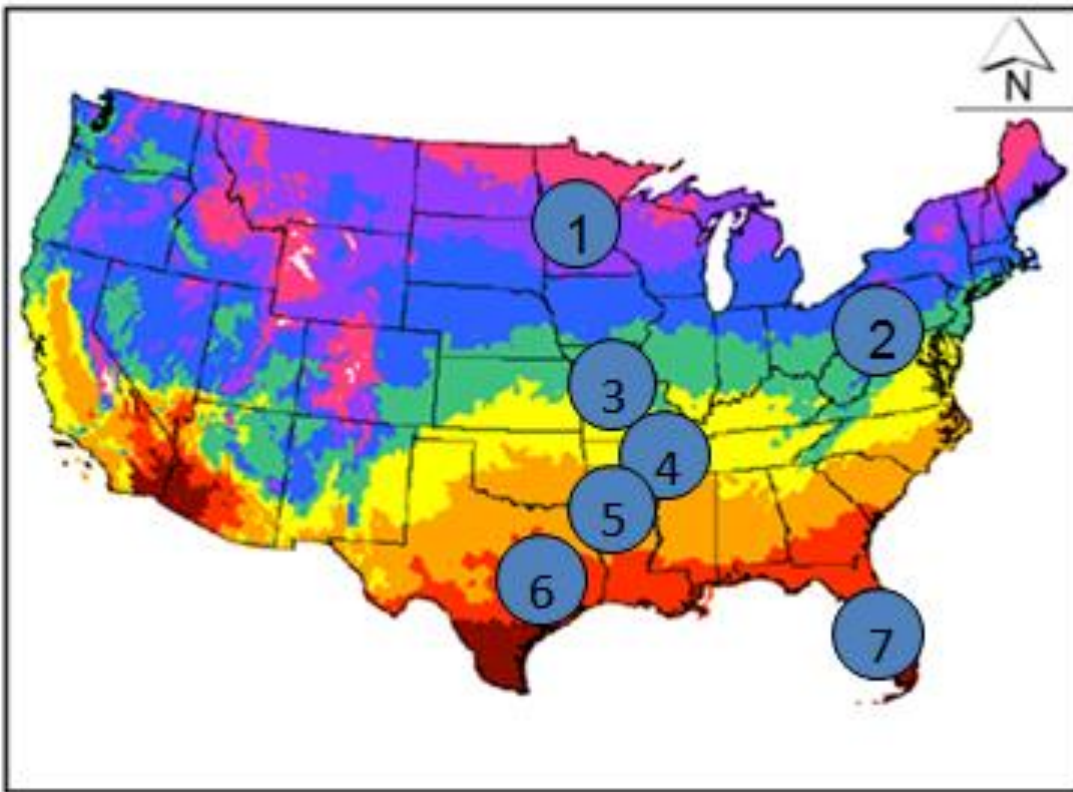
F_m = monthly adjustment factor,

F_h = hourly adjustment factor.



Seven zones based on AMDAT

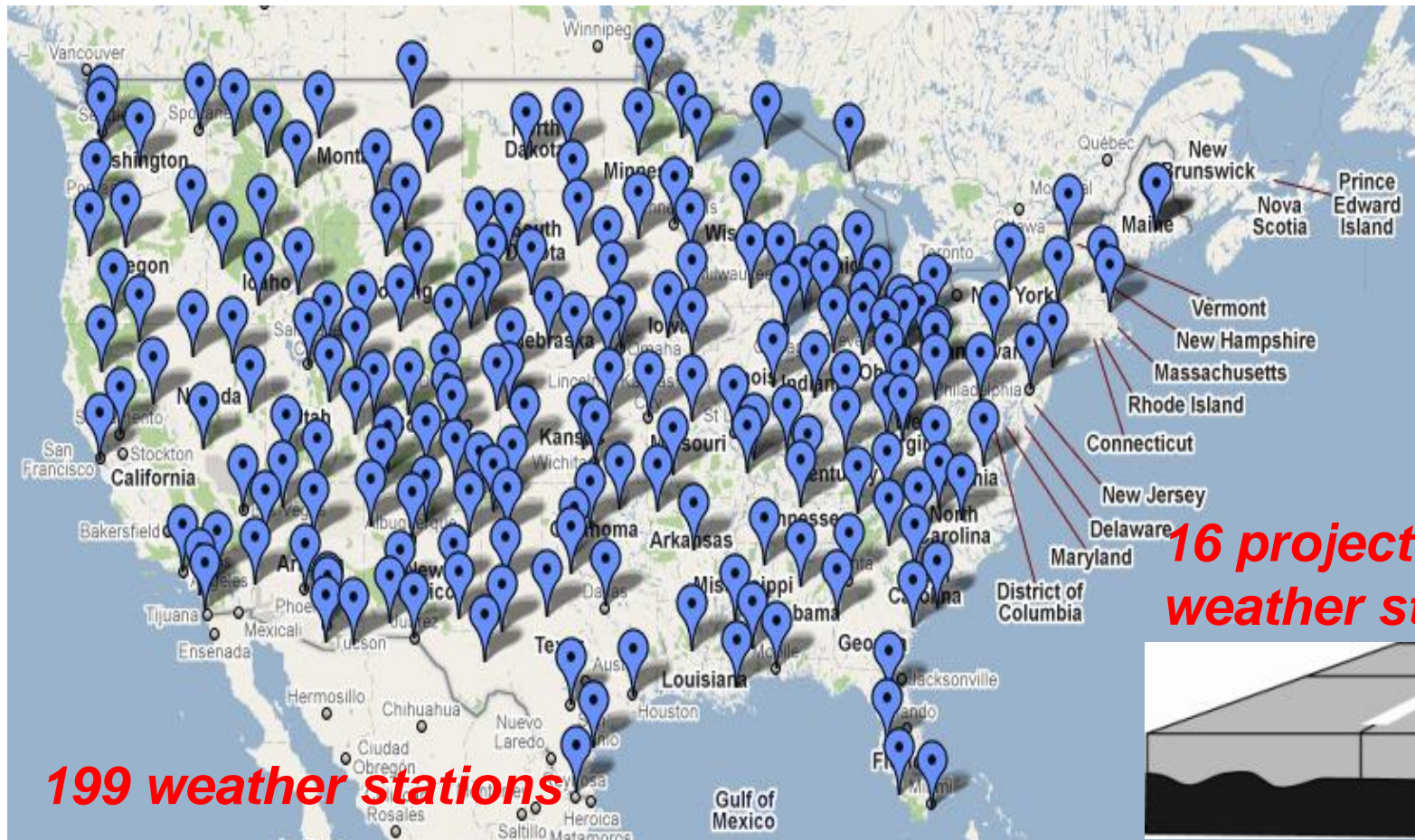
AMDAT = Annual mean daily average temp.



Region ID	Color code	AMDAT (°F)
1	Pink	32.0-45.0
2	Purple	45.1-50.0
3	Blue	50.1-55.0
4	Green	55.1-60.0
5	Yellow	60.1-65.0
6	Orange	65.1-70.0
7	Dark Red	>70.0

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

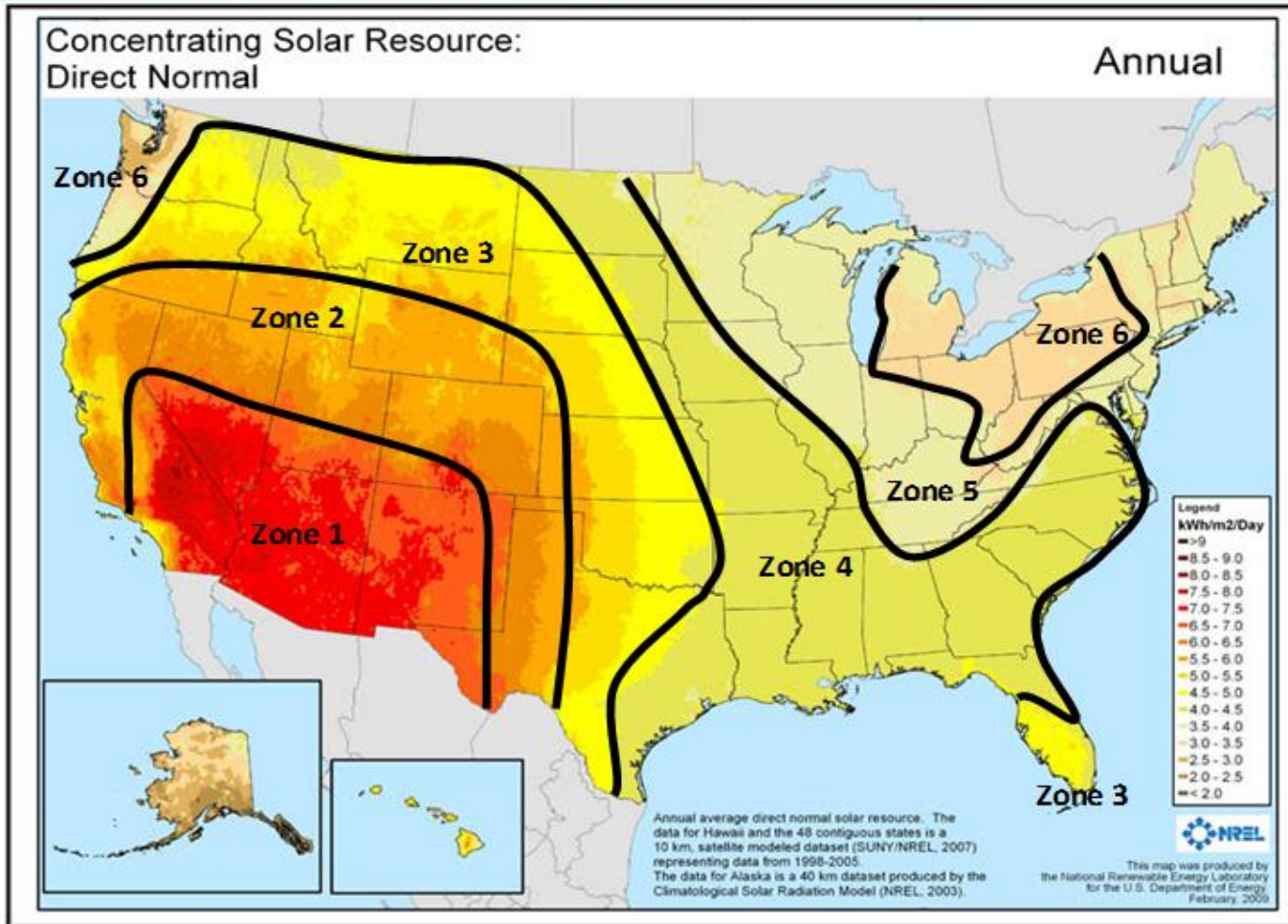
Populating database: Climate



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

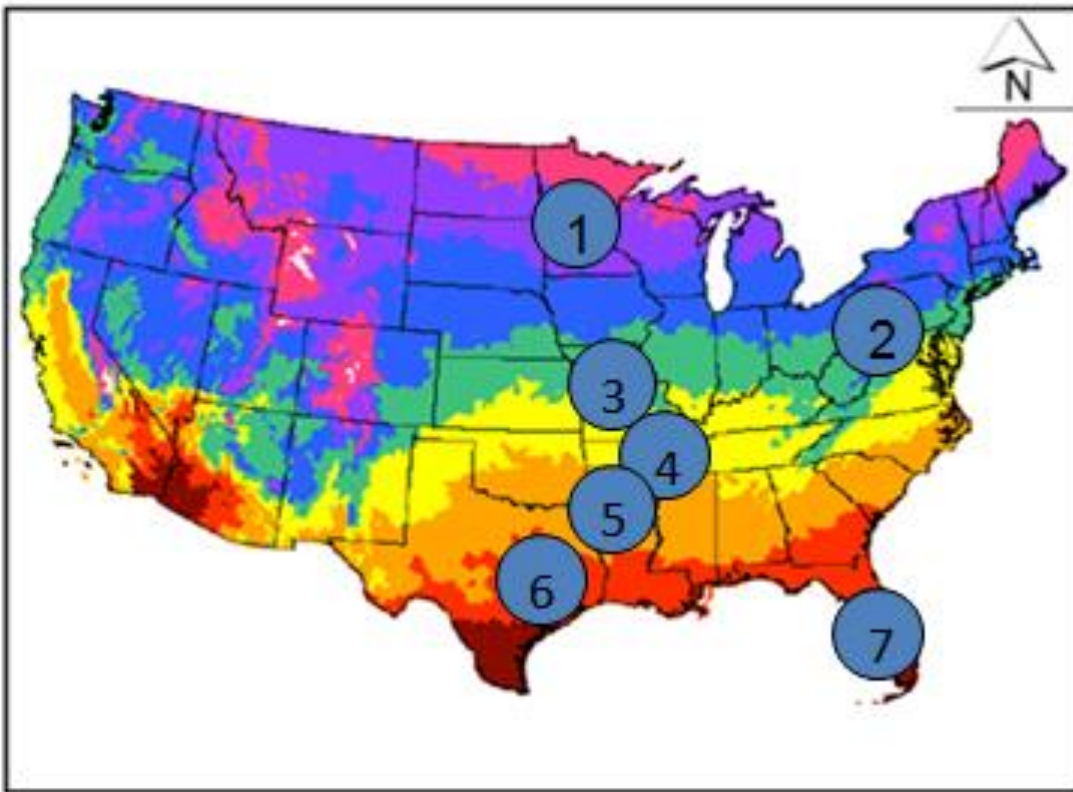
Sunshine



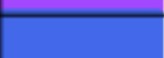




Fig. 2: Annual concentrating solar resource map of USA.



Seven zones based on AMDAT

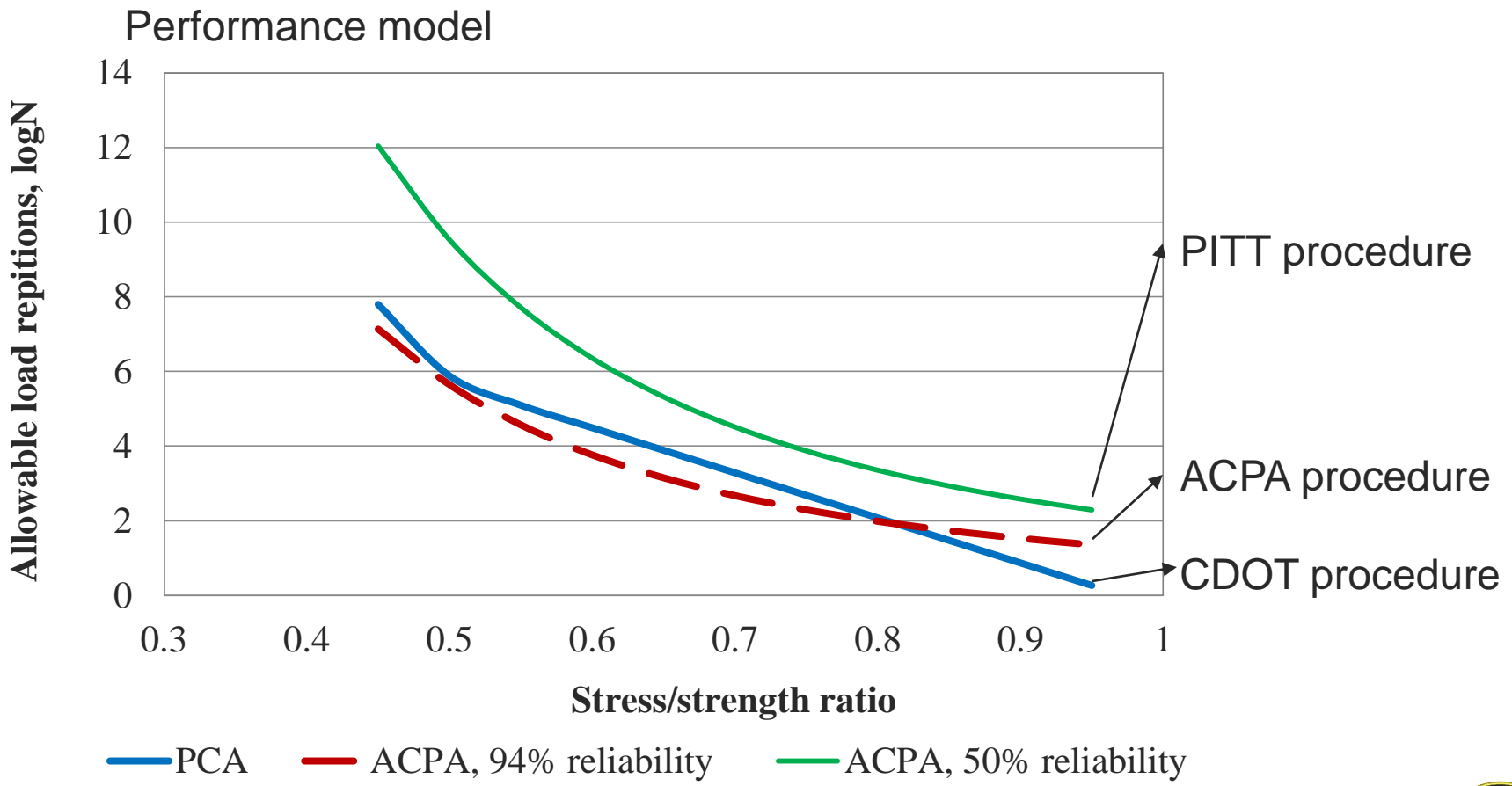
AMDAT = Annual mean daily average temp.



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	Epc Calculator
Coefficient of Thermal Expansion (10^{-6} in/ $^{\circ}$ F/in)		5.5	CTE Calculator

A decorative graphic at the top of the slide consists of a horizontal line with a light-to-dark green gradient. On the left side, a large black bracket '[' is positioned above the line. On the right side, a large yellow bracket ']' is positioned above the line.

REDUCTION FACTOR FOR HMA MODULUS

