



**SE States Pavement Management & Design Conference**  
**Panama City, May 7-10, 2006**

# **Implementation of the Florida Cracking Model into the NCHRP-ME Flexible Pavement Design Framework**

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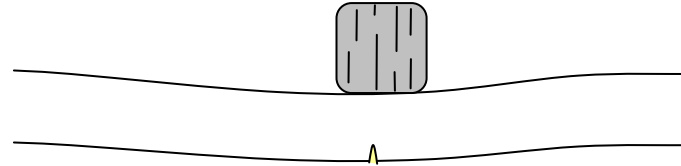
**Department of Civil & Coastal Engineering**  
**University of Florida**



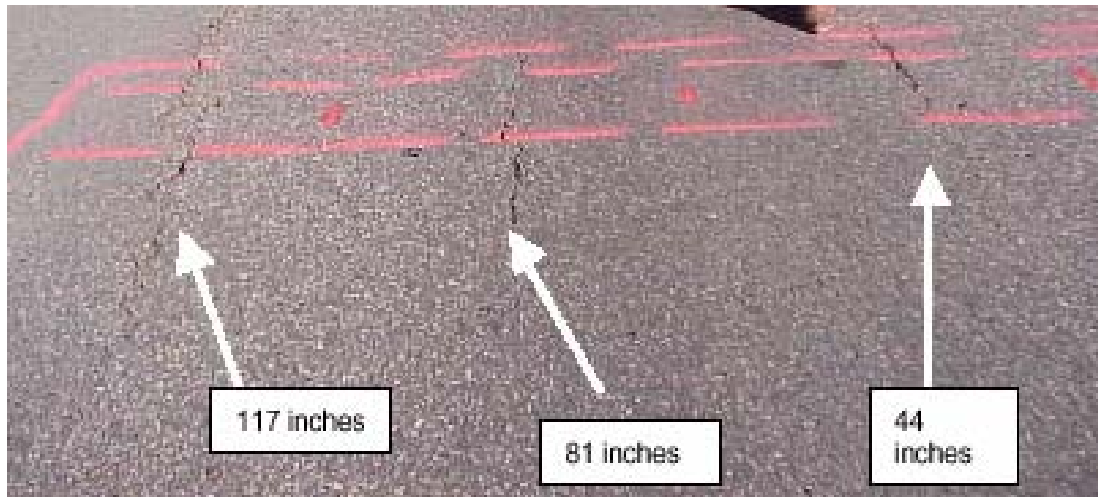
# Pavement Response and Cracking

## Bottom-up cracking

- Bending effects



## Top-down cracking



- Predominant in Florida



# FDOT Multiyear Study

## Mechanisms of Top-Down Cracking

- Stiffness Gradients (Temperature differential, Aging)
- Thermal Stresses
- Truck tire ribs induced tension, Residual viscoelastic stresses

## Cracking Models for Mixtures and Pavement

- Simpler Testing and Design Calculations



# Core Extracted from Field



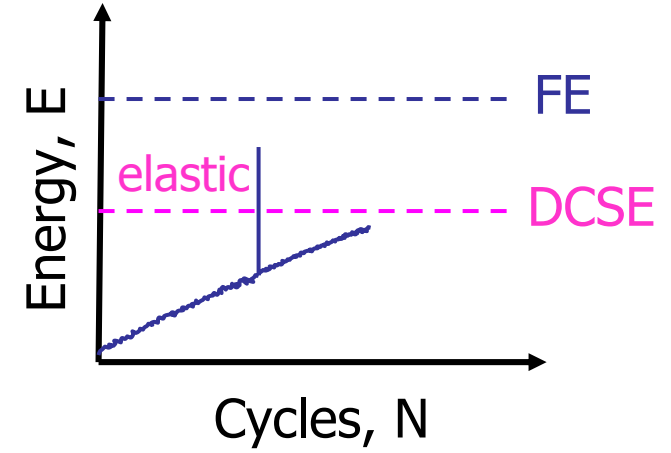
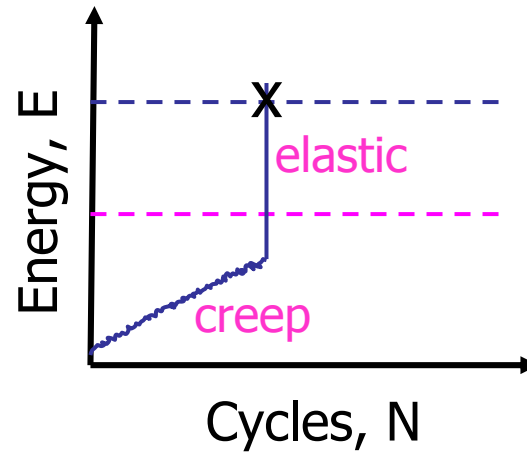
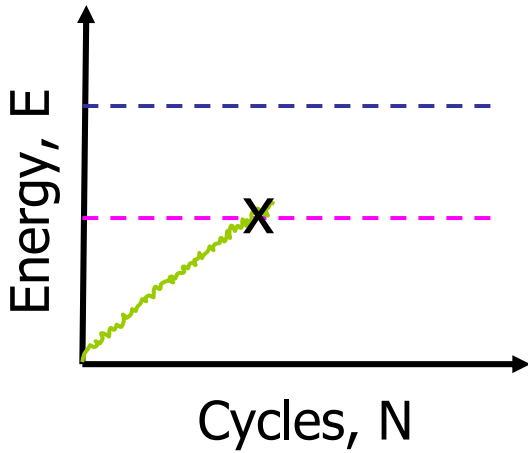


# Florida Cracking Model – Key Features

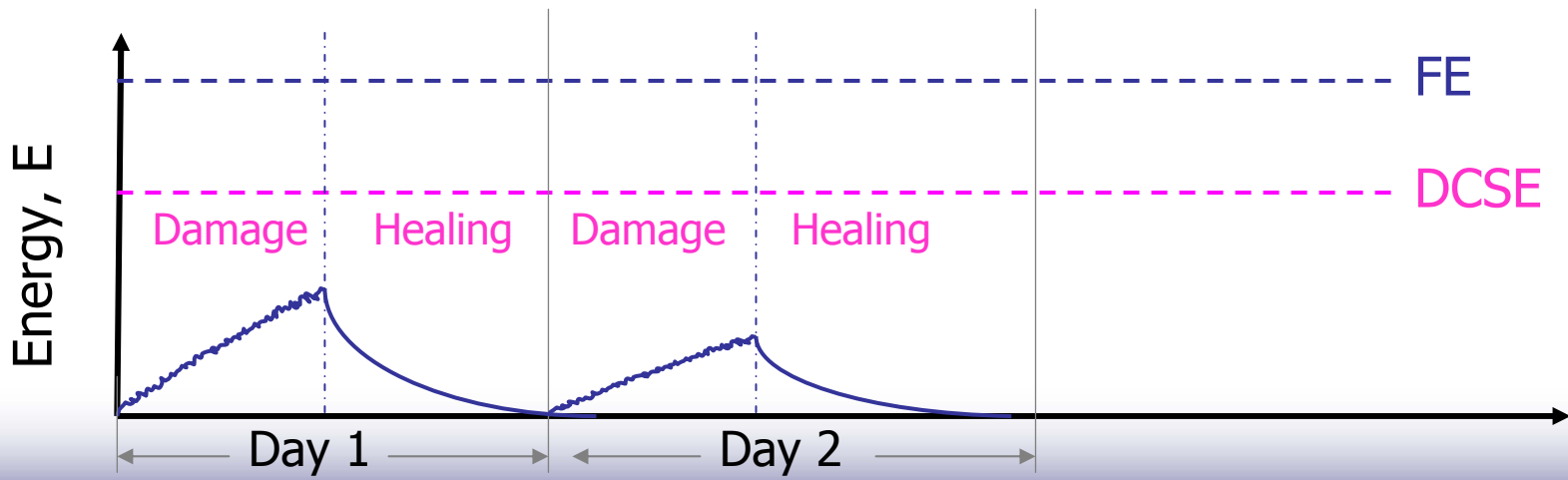
- A damage threshold exists (DCSE limit)
- Damage = Dissipated Creep Strain Energy (DCSE)
- Damage  $>$  Threshold  $\rightarrow$  Macro-crack  
(DCSE) (DCSE limit)
- Macro-crack is not healable
- Damage under the cracking threshold is fully healable



# The Threshold Concept

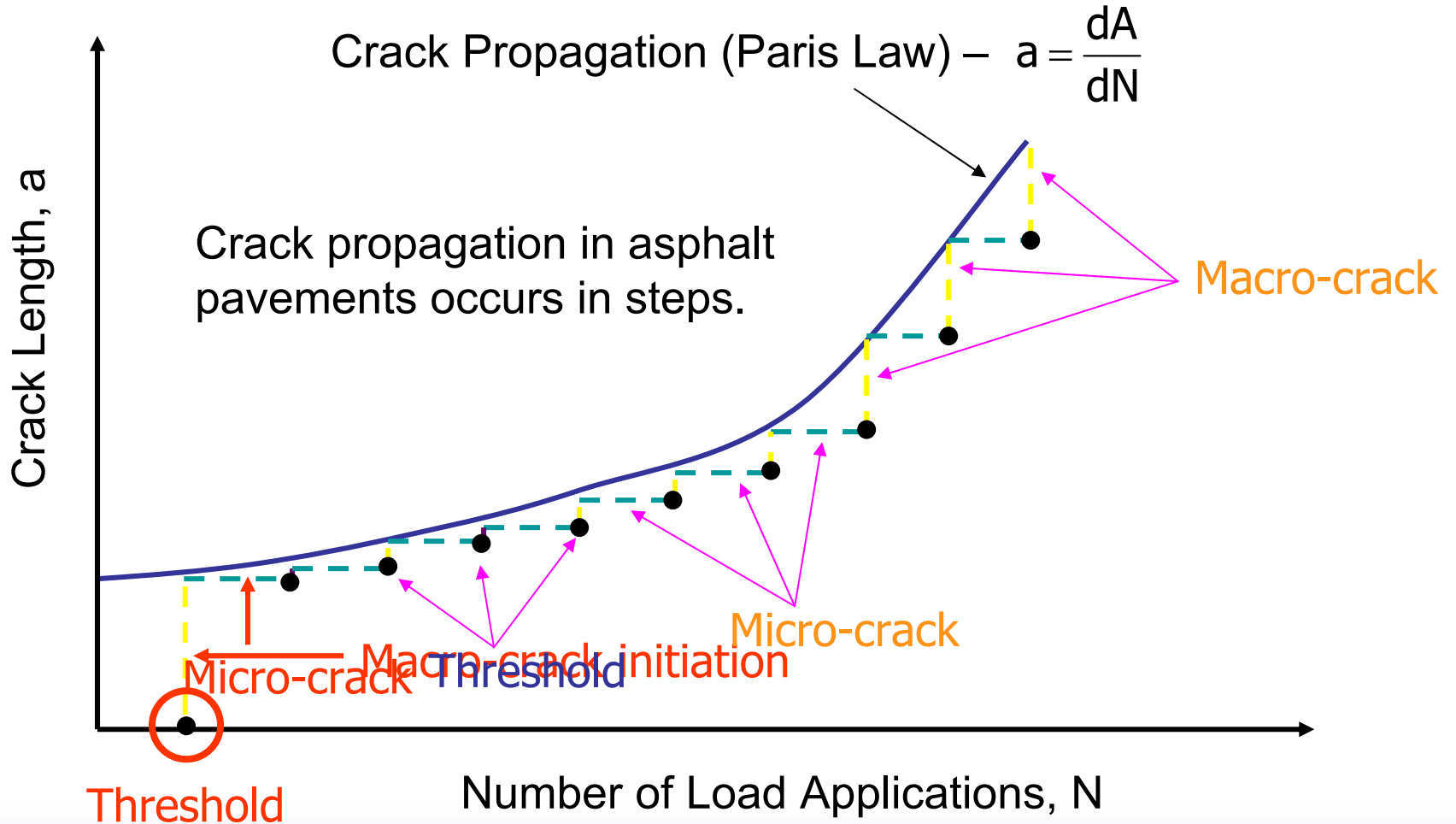


## Potential loading conditions in the field





# Crack Growth Model

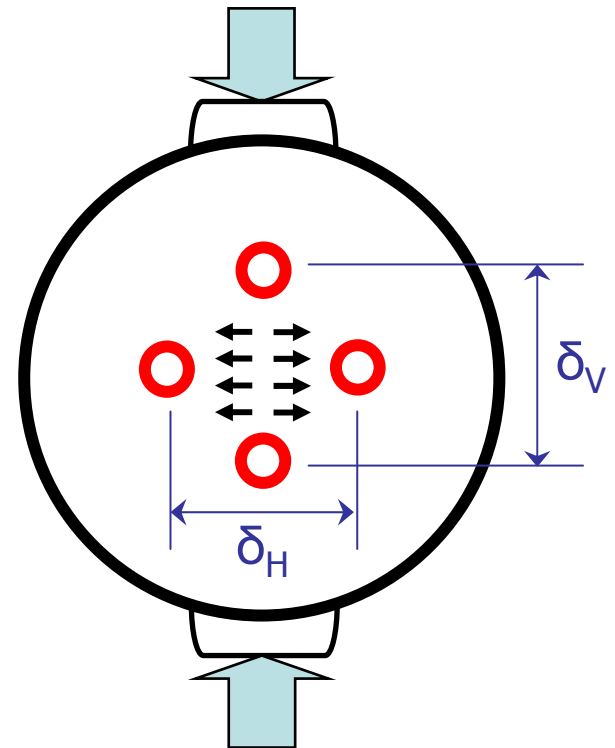




# Mixture Properties

## Superpave Indirect Tensile Test:

1. Resilient modulus (Cyclic loading)
2. Creep (Constant load with time)
  - Dissipated energy  $\propto$  creep rate
3. Strength (Increase load until fracture)
  - Energy limits







# HMA Fracture Model

- Calculate the crack growth for a given level of applied stress.
- Use
  - Material properties –  $m$ ,  $D_1$  (creep rate) &  $DCSE_f$  (energy limit)
  - Structural properties –  $\sigma_{AVE}$  (modulus)

to calculate the amount of dissipated energy per load cycle:

$$DCSE / cycle = f(\text{tensile stress, } D_1 \& m)$$

- For a given mixture with known  $DCSE_f$  we can predict  $N_f$  for initiation or propagation of cracking.



# Field Test Sections

Multiple pairs of poor and good performing sections throughout Florida

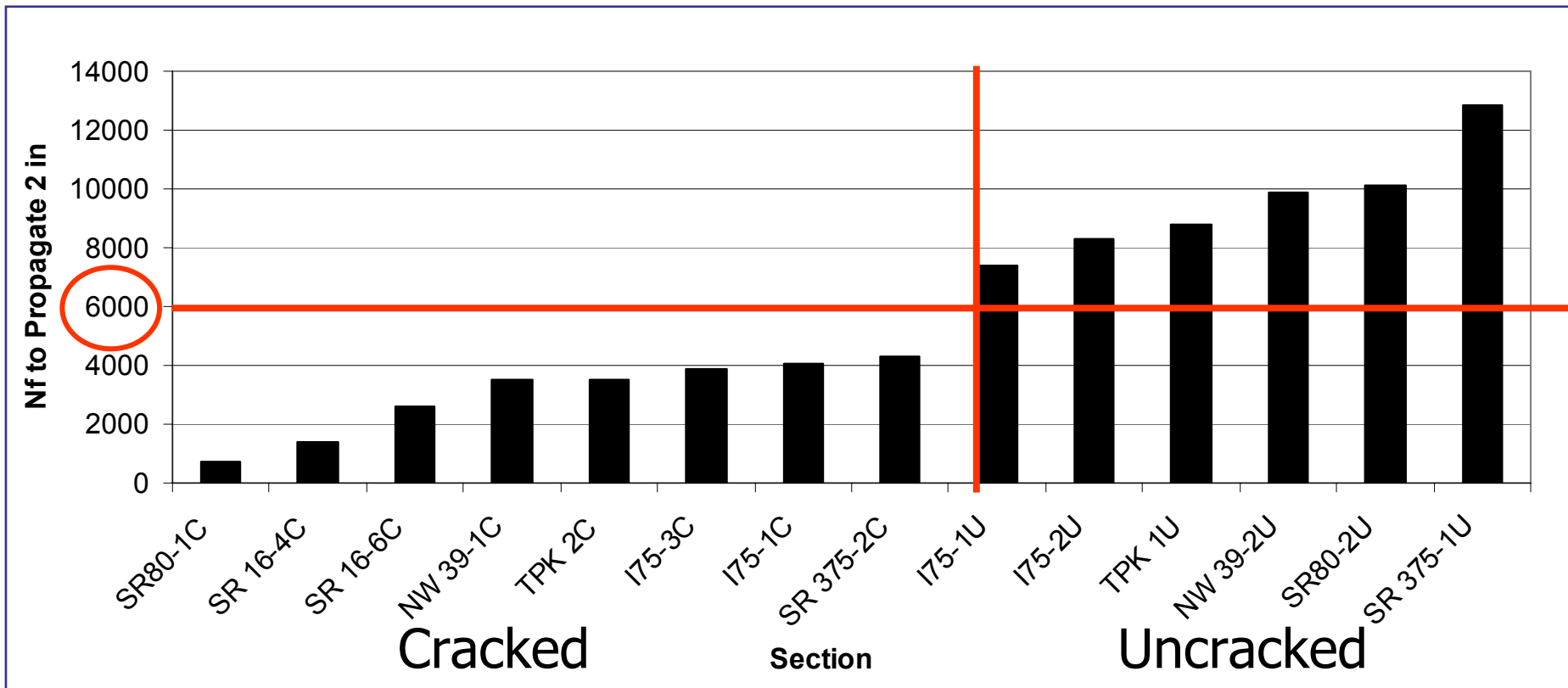
- Over 18 pairs (36 sections) to date





# Cycles to Failure

- Used the HMA Fracture Model to calculate  $N_f$  for crack to propagate 2”

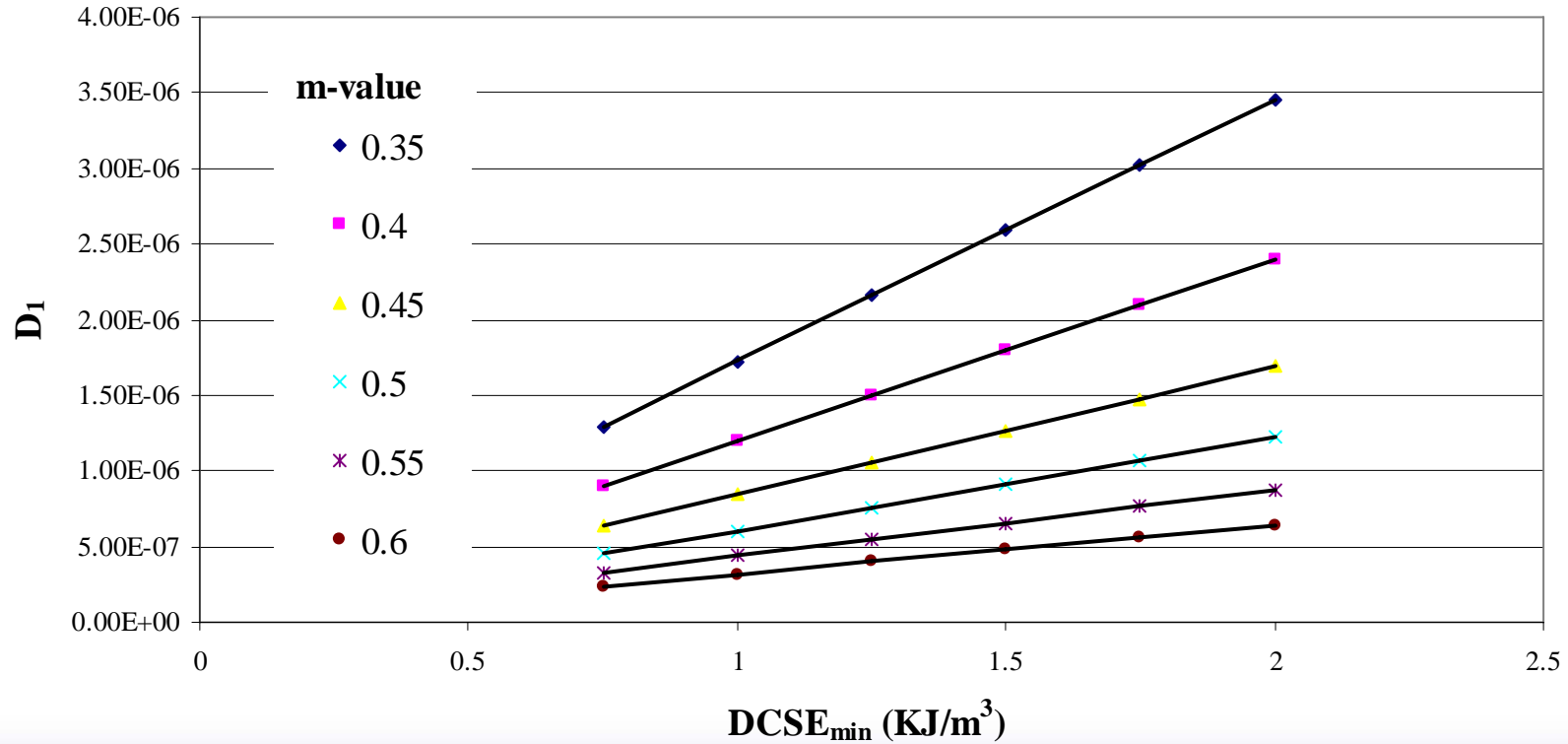


- Mixtures with  $N_f < 6000$  performed poorly



# Critical $N_f$

- Set  $N_f=6000$  as the critical value that distinguishes mixture performance
- Calculate  $DCSE_{min}$  that produced  $N_f=6000$  for various  $D_1$  &  $m$ -values





# Minimum Energy

- $DCSE_{\min}$  is the minimum energy required to produce  $N_f=6000$
- Express the  $DCSE_{\min}$ ,  $D_1$  & m-value relation in a single function:

$$- DCSE_{\min} = \frac{m^{2.98} D_1}{A}$$

Tensile Strength

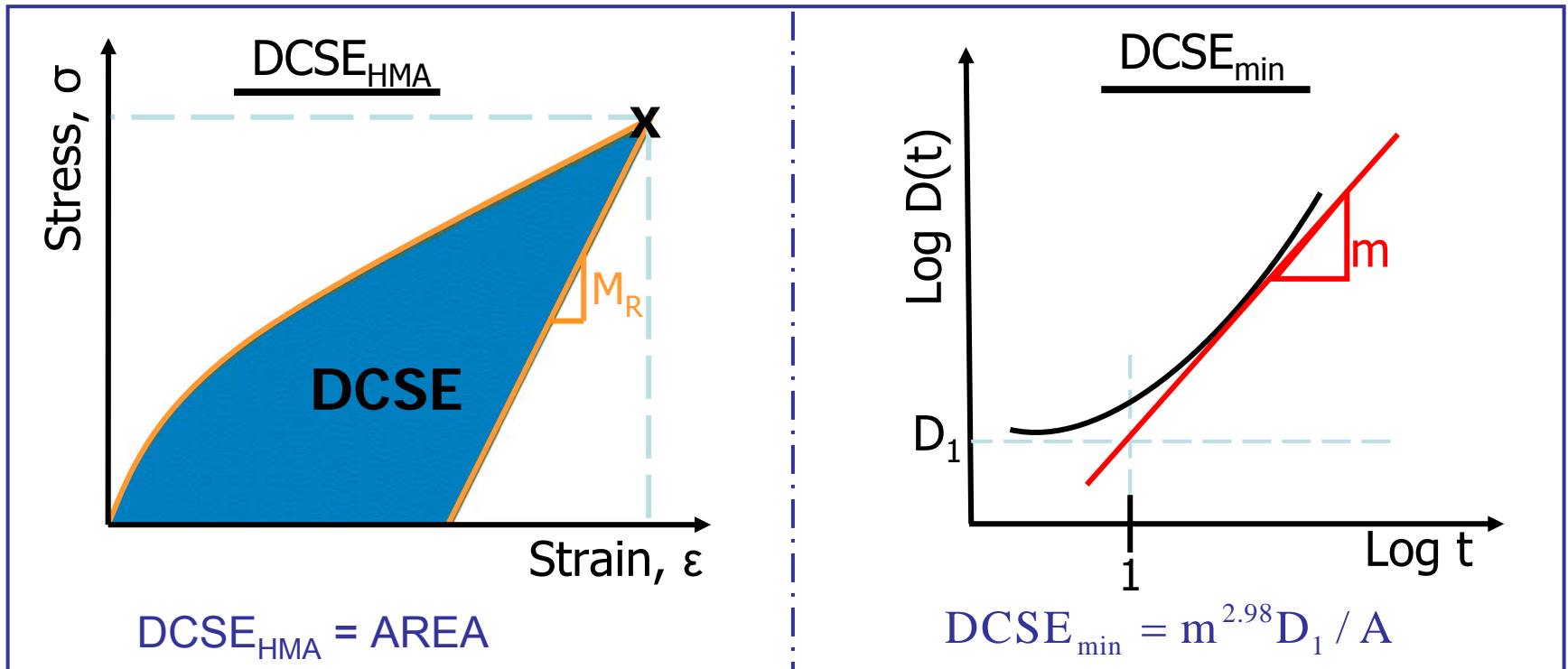
$$- A = \frac{(6.36 - S_t)}{33.44 \times \sigma_t^{3.1}} + 2.46 \times 10^{-8}$$

Tensile Stress



# Energy Ratio Concept

- The  $DCSE_{HMA}$  has to be greater than the  $DCSE_{min}$  for good cracking performance:

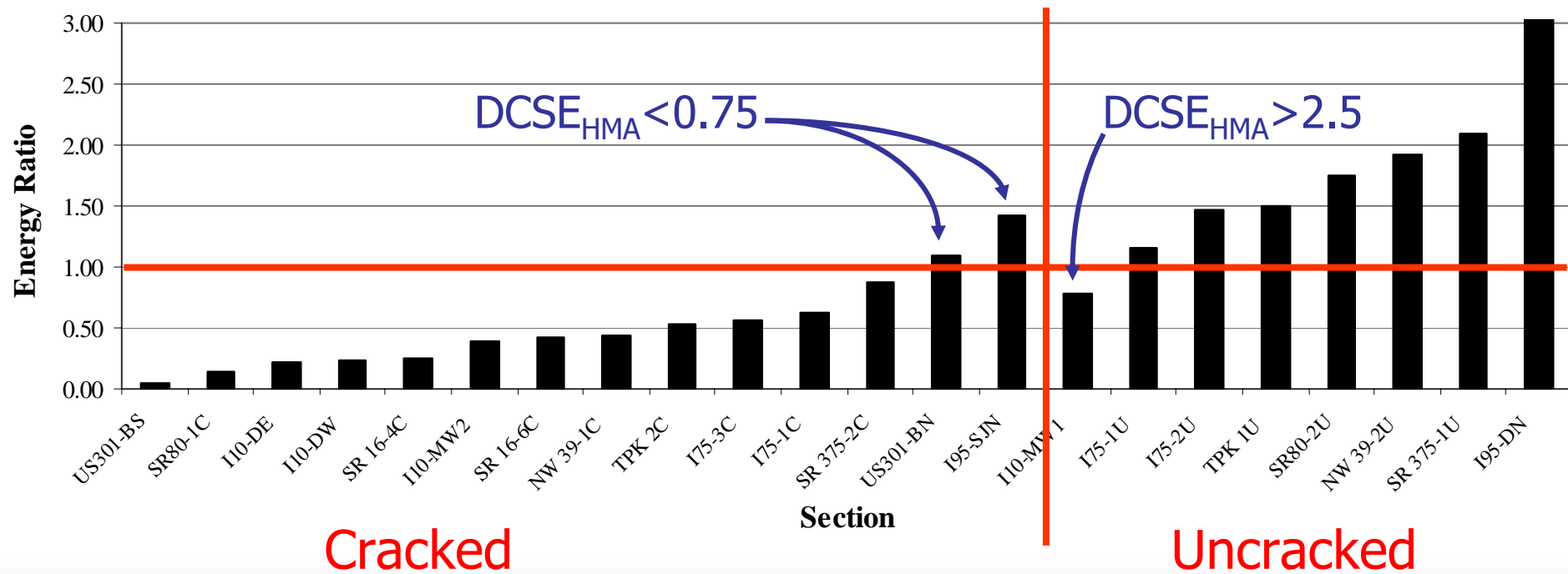


$$ENERGY \ RATIO = \frac{DCSE_{HMA}}{DCSE_{min}} > 1$$



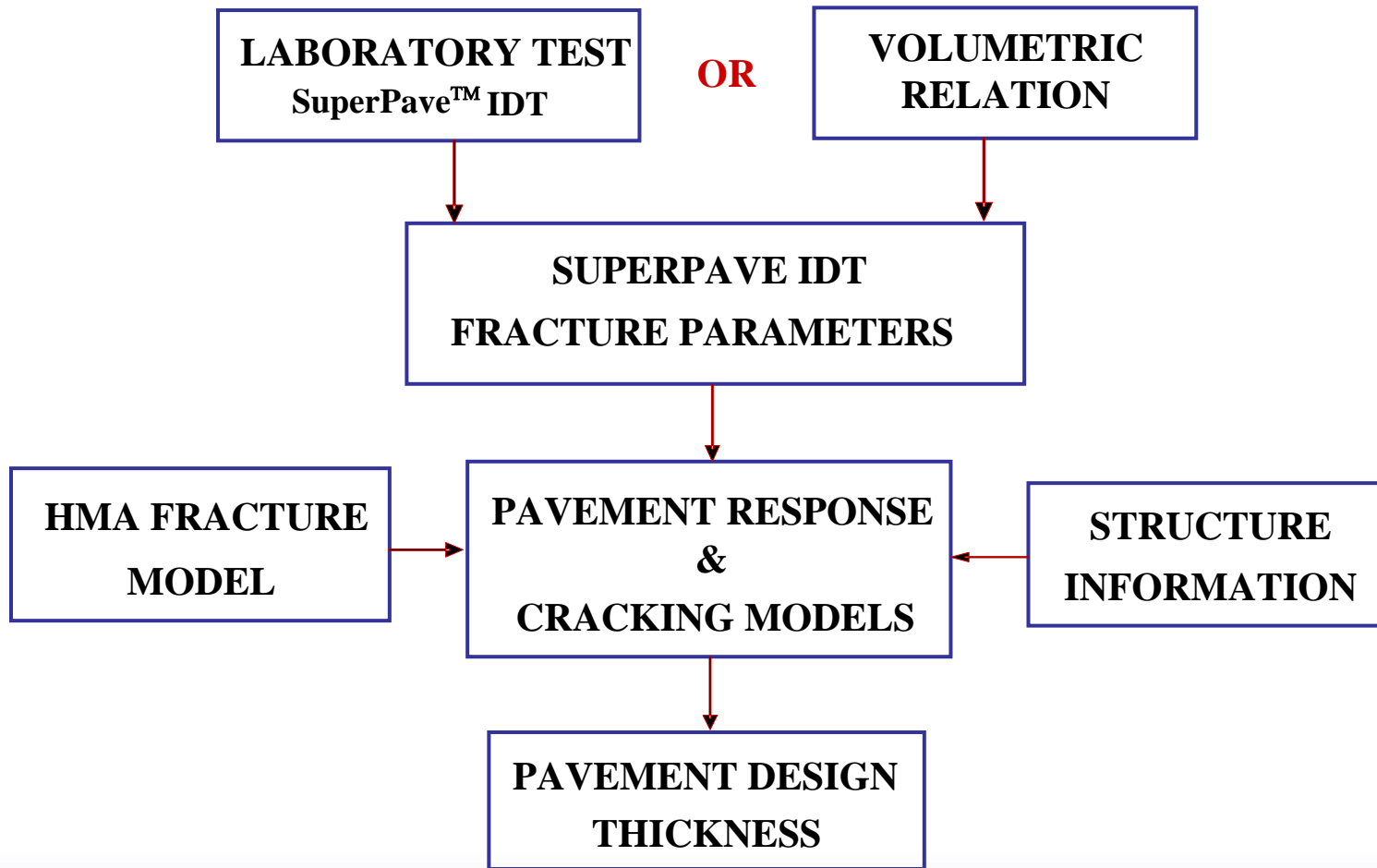
# Energy Ratio Results

- Examined all sections
- Performance criteria:  $ER > 1$  ;  $DCSE_{HMA} > 0.75$





# Florida Framework for Cracking Evaluation of HMA Pavements







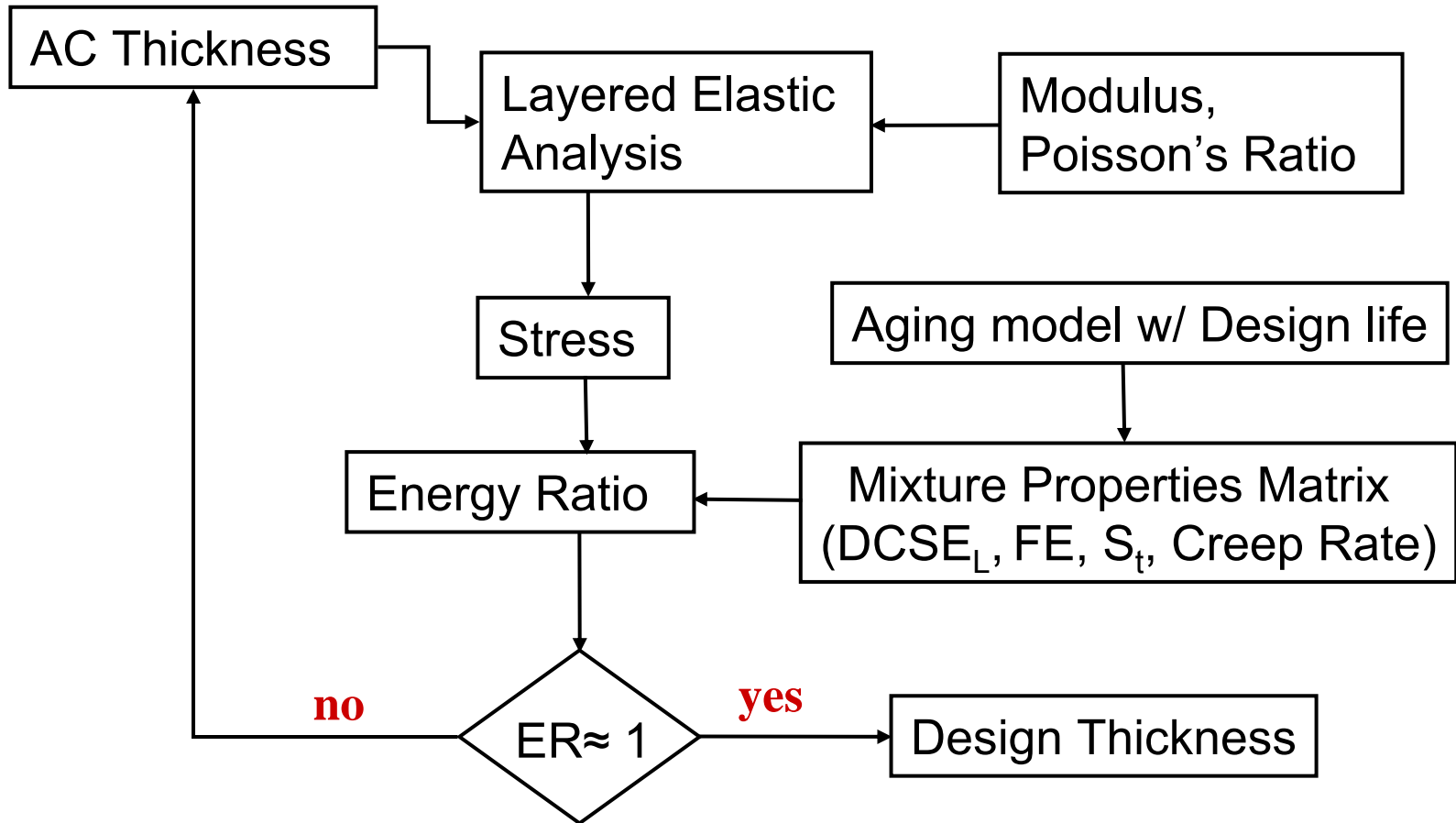
# Top-Down Cracking Design

## **Level 3: Use Energy Ratio for M-E Top-Down Cracking Design**

- Accounts for structure and mixture for “averaged” environmental conditions
- Design Premise: ensure a reasonable predicted crack depth after  $x$  number of years (Design Life)
  - Determine thickness for ER=1 @ design life



# M-E Design Flowchart – Level 3



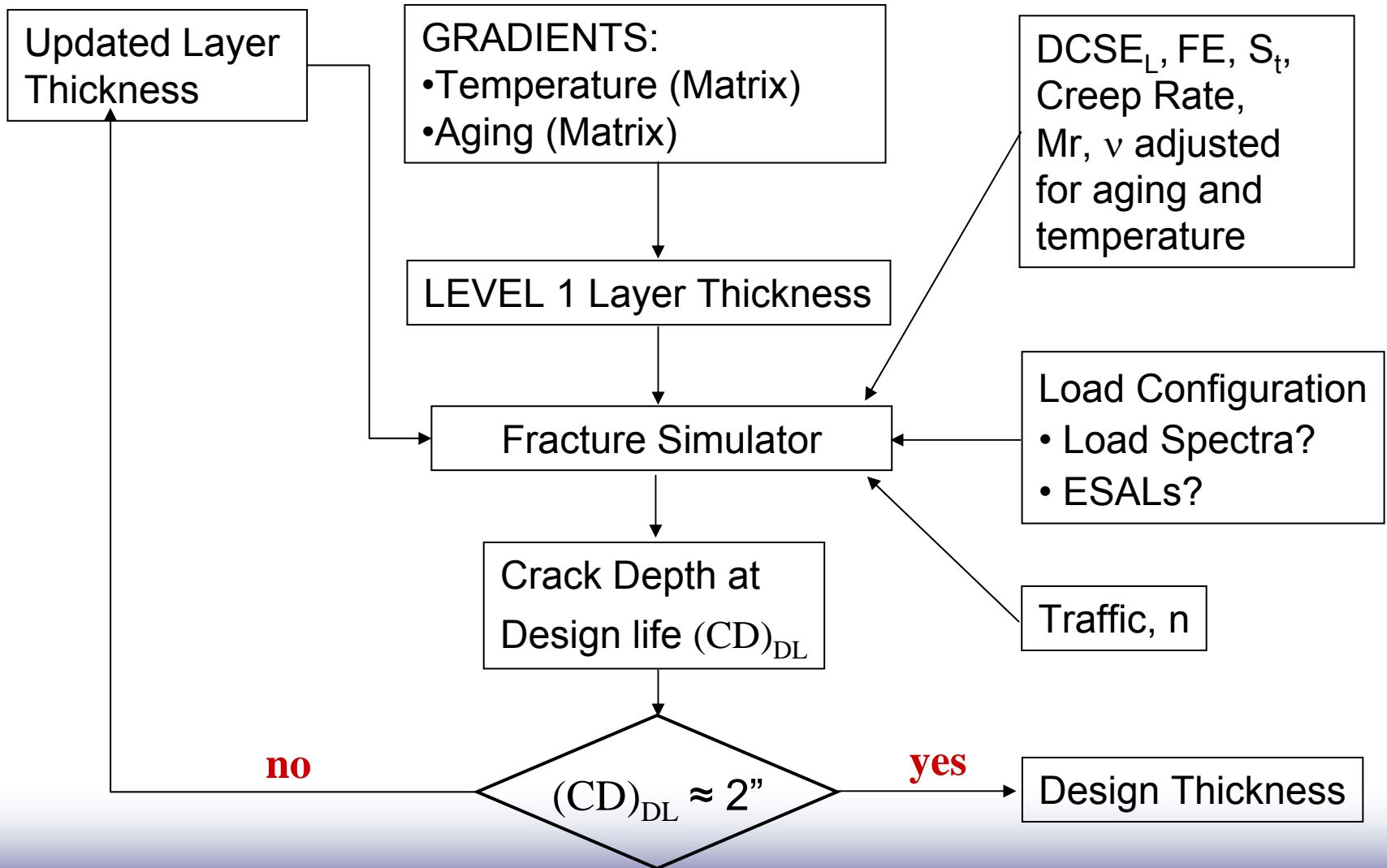


# M-E Top Down Cracking Design– Level 1 & 2

- Uses a fast pavement fracture simulator to predict depth of cracking after x years (Design life), and account for the effects of:
  - Mixture & Structure
  - Temperature/aging gradients
  - Load Configuration
  - Traffic
- Level 1:
  - Measured properties from IDT
- Level 2:
  - Estimated properties



# M-E Design Flowchart – Level 2





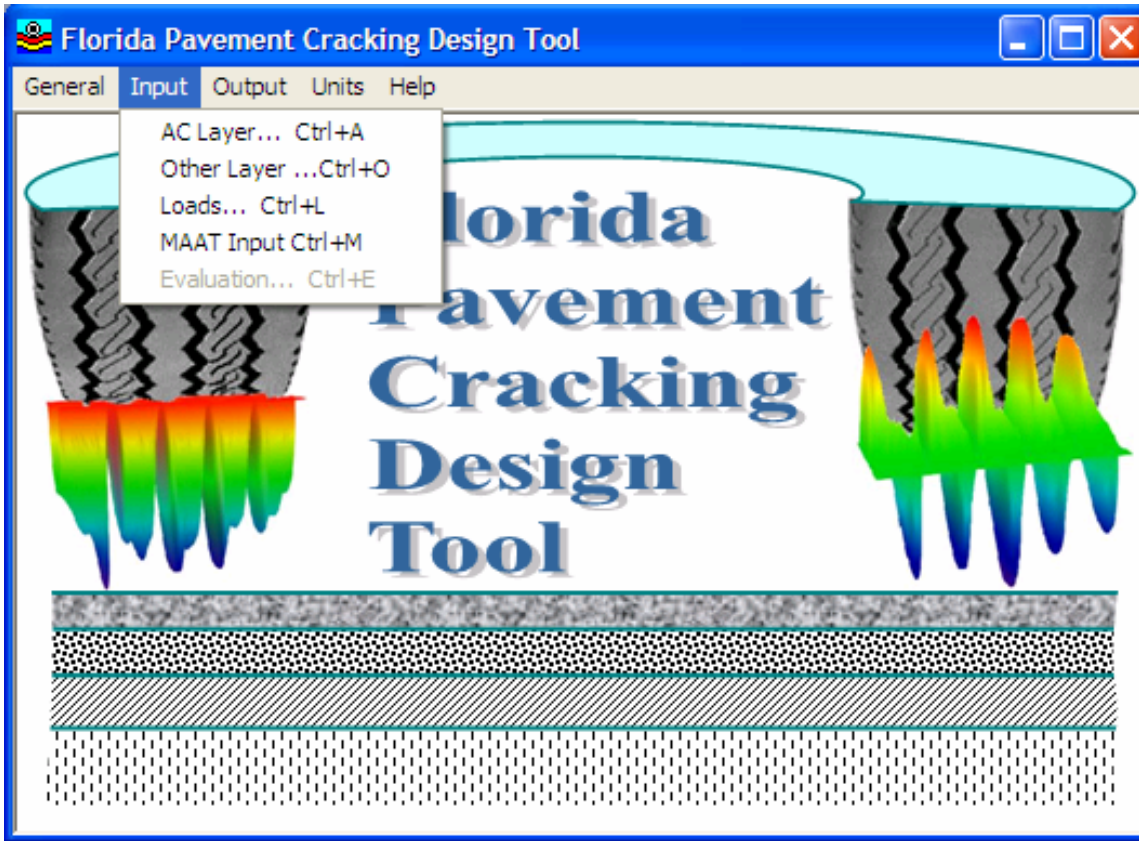
# Design Studio

- New Pavement Design using Energy Ratio
- Overlay Design using Energy Ratio





# Input Menu



- Structure
  - AC Layer
  - Other Layers
- Loads
- MAAT



# AC Layer – Basic Design

Structural Information (F1 for Help)

1. Mix Selection | 2. Binder | 3. AC Properties

1. Select mix type (Required lift thickness below)

SP 9.5	<input type="radio"/> Coarse (1.5 to 2)	<input type="radio"/> Fine (1 to 1.5)	P3/4 100
SP 12.5	<input type="radio"/> Coarse (2 to 3)	<input type="radio"/> Fine (1.5 to 2.5)	P3/8 90
SP 19.0	<input type="radio"/> Coarse (3 to 3.5)	<input type="radio"/> Fine (2 to 3)	P4 60.2
<input checked="" type="radio"/> Input			P200 4.8

2. Estimated design thickness (inch)  
6

3. Input Volumetric Properties

Air Void in Compacted Field Mix (%)  
7

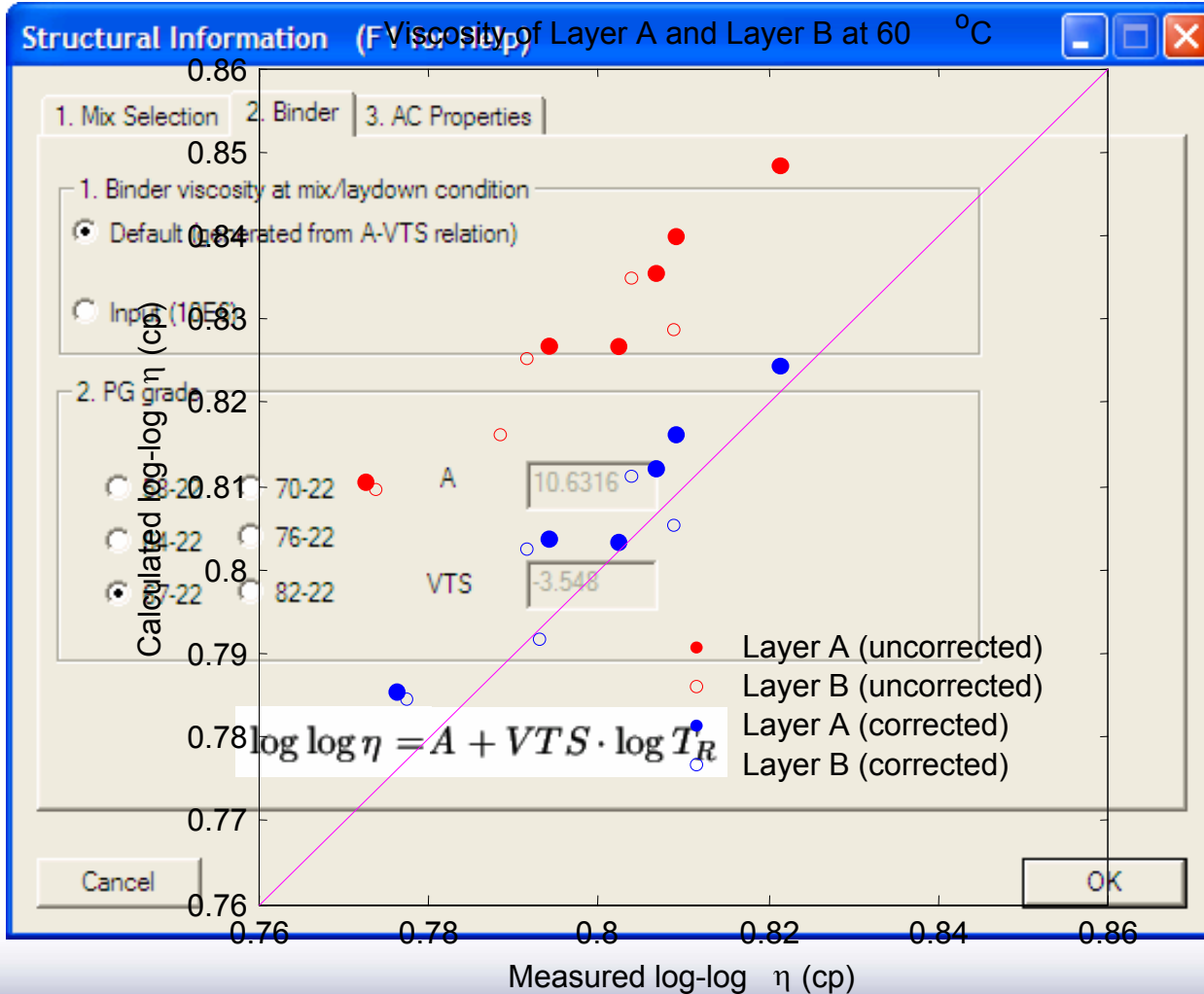
Design asphalt content by volume (%)  
12

Cancel OK

- Suggested gradation or input your own
- Estimate an initial design thickness (will be optimized)
- Input Design AV and  $V_b$



# Binder Selection



- Estimate the binder viscosity at mix/laydown condition
- Predict the in-service viscosity based on the global aging model
- Correction





# MAAT Input

- Input MAAT to predict aging

**MAAT Input** ✕

Mean Annual Air Temperature (MAAT)

Input

Default - Choose the nearest locations to the project

Tallahassee/Jacksonville(68)

Gainesville(70)

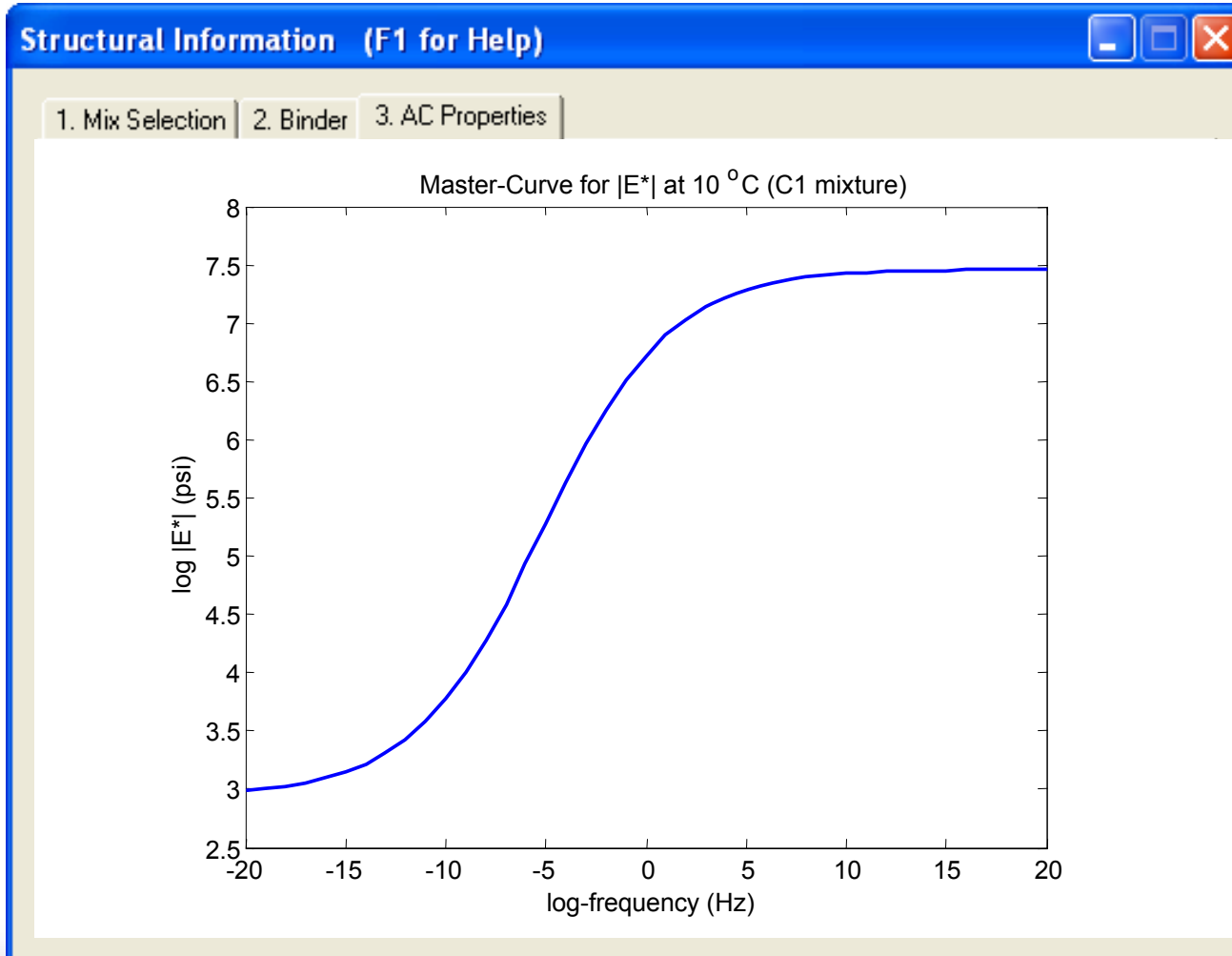
Orlando/Tampa(72)

Miami(75)

Key West(76)



# Mixture Properties



- Layer modulus estimate from  $|E^*|$  master curve
- Poisson's ratio estimated from  $E_{AC}$
- IDT parameters estimated from some basic relations



# Pavement Structure – Other Layers

- Base, sub-base and subgrade layers (**elastic**)

The screenshot shows a dialog box titled "Structure- other layers" with a close button (X) in the top right corner. The dialog is used to define the properties of pavement layers. At the top, there is a "Number of Layers" section with radio buttons for 2, 3, 4, and 5, where 4 is selected. Below this, there are four columns representing Layer 2, Layer 3, Layer 4, and Layer 5. Each column has a "Material" dropdown menu, a "Min" value, a "Layer" value, a "Max" value, a "Poisson's Ratio" value, a "Min - Max" range, and a "Thickness" value. Layer 2 is set to "Stabilize Base" with a thickness of 12. Layer 3 is set to "Graded Aggregate" with a thickness of 12. Layer 4 is set to "Soil Subgrade" with a thickness of 999. Layer 5 is set to "Soil Subgrade" with a thickness of "Infinite". At the bottom, there are "Cancel" and "OK" buttons. A legend at the bottom left indicates "Slip (0 or 1)" where 1 = Full and 0 = Full, with the value 1 entered in the input boxes for each layer.

Property	Layer 2	Layer 3	Layer 4	Layer 5
Material	Stabilize Base	Graded Aggregate	Soil Subgrade	Soil Subgrade
Min	1		3000	3000
Layer	100000		12000	12000
Max	1000000		200000	200000
Poisson's Ratio	0.35		0.45	0.45
Min - Max	0.1 - 0.5	0.2 - 0.5	0.2 - 0.5	0.2 - 0.5
Thickness	12	12	999	Infinite
Slip (0 or 1)	1	1	1	1

- User can determine the number of layers
- Default properties suggested for selected materials
- User can also define the material properties



# Loads Input

- Simplified load information

The maximum number of ESALs/year:

$$S_n = S_{total} \times \frac{p(1+p)^{n-1}}{(1+p)^n - 1}$$

**Load Input**

Traffic Load Choice

Total Number of ESALs(\*1000)  $S_{total}$  30000

Design Period  $n$  20

Growth Rate  $p(\%)$  5

FDOT Traffic Level E

Load Information

Standard ESAL  User Defined

Load Magnitude (9000lb) Load Magnitude (lb) 9000

Tire Pressure (100psi) Tire Pressure (psi) 100

OK Cancel



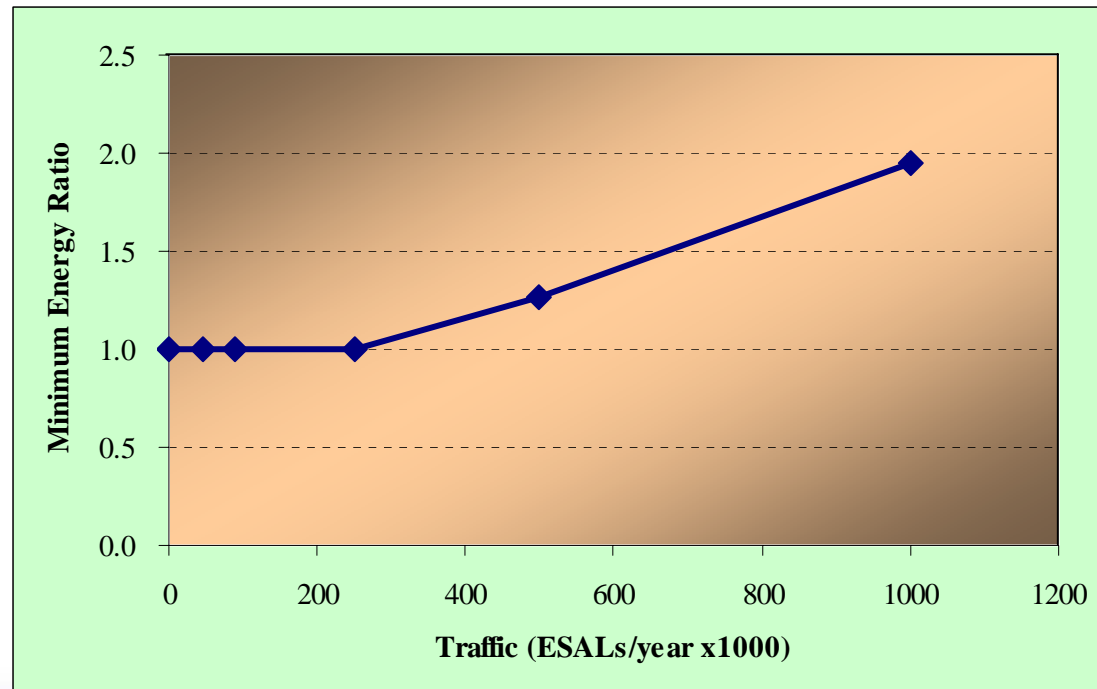
# ER Calculation

- ER formula

$$ER = \frac{DCSE_f}{DCSE_{min}} = \frac{DCSE_f}{D_1 \cdot m^{2.98}} \cdot A, \text{ where } A = \frac{0.0299 \cdot (6.36 - S_t)}{\sigma_t^{3.1}} + 2.46 \times 10^{-8}$$

- Minimum ER adjusted for traffic level

According to the traffic load input, select the minimum (optimum) ER corresponding to the traffic level





# ER Output

Output (F1 for Help)

Please Enter the location of Sigma to calculate

Layer	X	Y	Z
1	0	0	5

Normal Stress (psi)

186.78	186.78	25.53
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Optimization Curve

ER

Thickness (in Inch)

Plan View

Profile View

Energy Ratio (ER)

0.9

Calculate

The ER is too low!

Optimize

Optimum Thickness 5

Optimum ER 0.9

Minimum required ER for selected traffic level

Export Data

Leave Studio

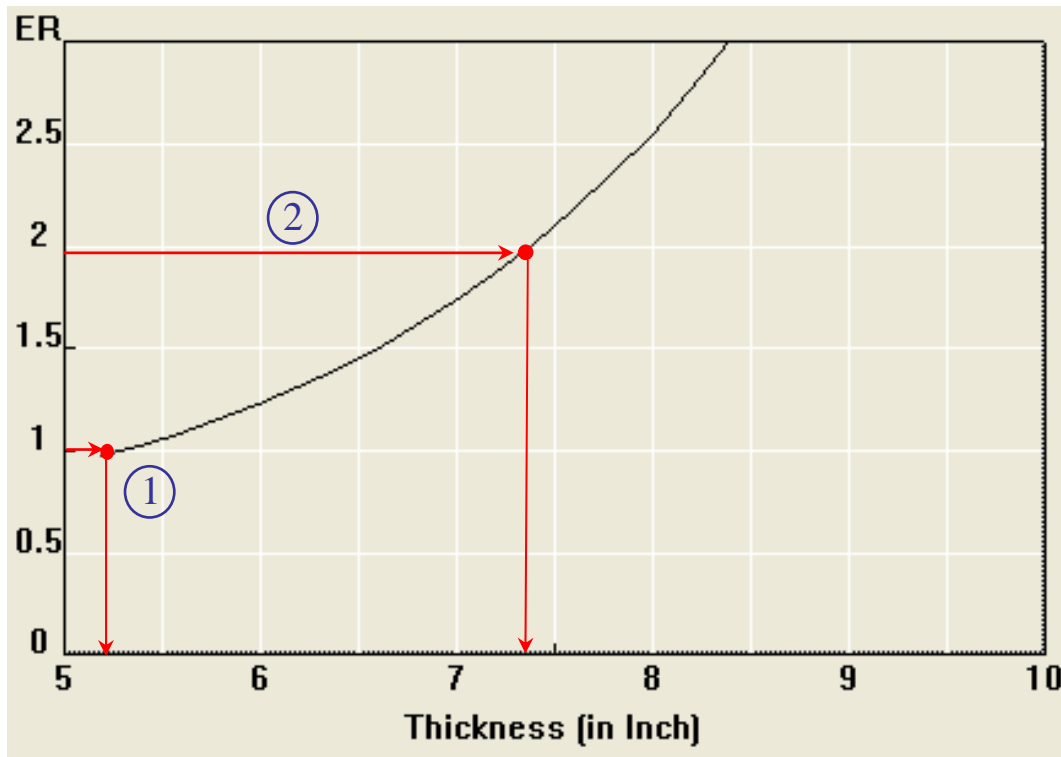
stresses at the standard or selected location

ER value



# Thickness Optimization

- Search for the thickness that gives the minimum required ER



② Optimum Thickness

Optimum ER

Minimum required ER for selected traffic level

① Optimum Thickness

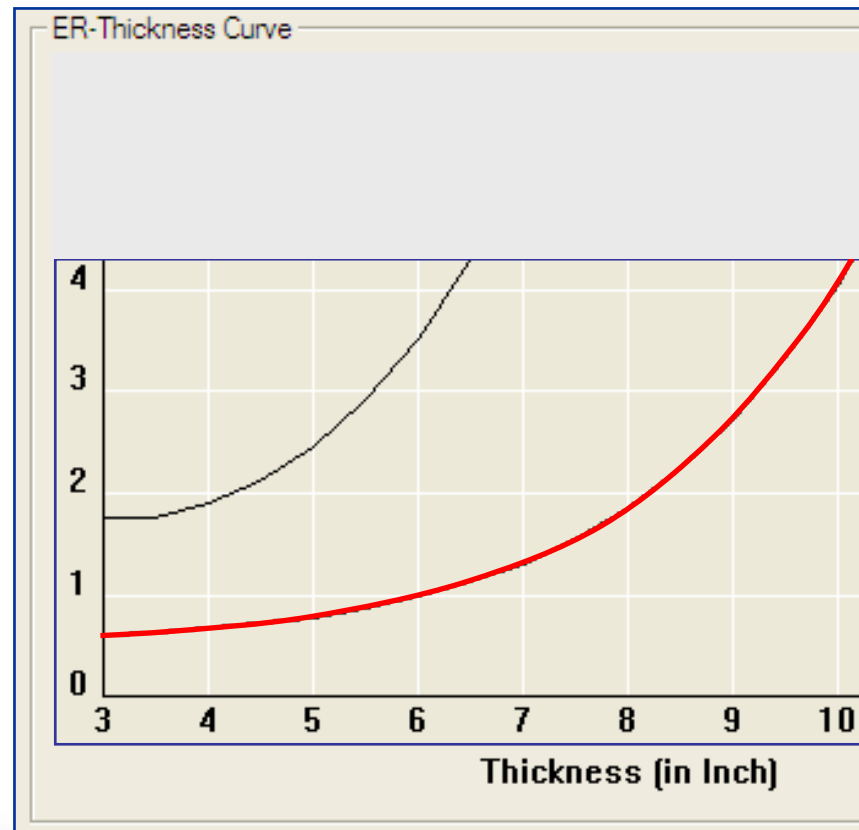
Optimum ER

Minimum required ER for selected traffic level



# ER-Thickness Curve

- Plot ER-thickness curves at different pavement ages
  - ER increases as the pavement thickness increase if the pavement is not too thin
  - The ER values for new and aged pavements differ significantly, especially for thick pavements



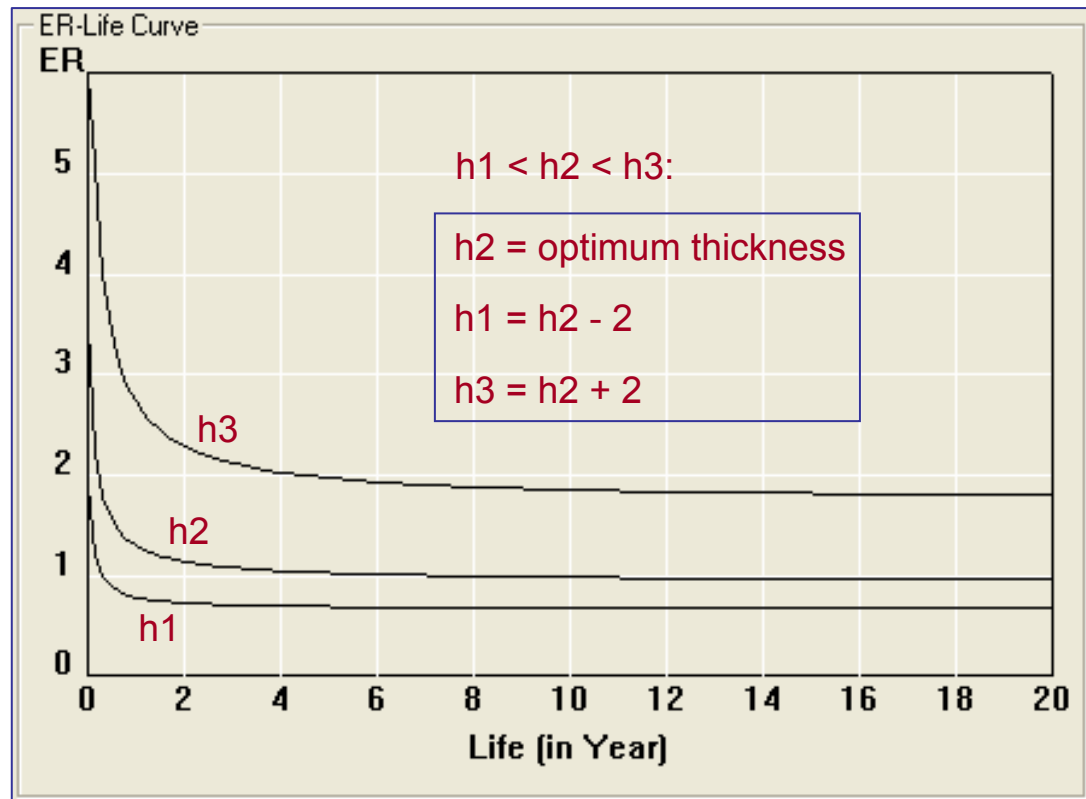




# Pavement Life Curve

- Plot pavement life curves for different thicknesses

- ER drops down significantly in the first couple of years
- Sensitivity of ER to thickness is shown in the graph





# Summary

- A new M-E pavement design tool for top down cracking based on Energy Ratio
  - Validated on more than 30 field sections
  - Thickness design optimized for
    - traffic level
    - mixture type
    - binder type
  - The optimization is an automated process



# Summary (Cont'd)

- Level 1 and 2 pavement design tool being developed
  - Frame work complete
    - fast fracture simulator
- NCHRP 1-42A:
  - Models for top-down cracking
    - Awarded to UF on May 1, 2006



# Questions

