Session 52

Bjorn Birgisson

University of Florida

Florida Top Down Cracking Pavement Design Model

Topic Description

This presentation provides an overview of a new mechanistic-empirical top down cracking design tool for Florida.

Speaker Biography

Finished B.S.C.E. in Civil Engineering and B.S. in Mathematics from the University of North Dakota, 1986. Completed M.S. in Civil Engineering from Cornell U. and a Ph.D. in Civil Engineering from the University of Minnesota in 1996. Worked as a Civil Engineering consultant for 4+ years, joined the University of Minnesota in 1997, and the University of Florida Pavement Group in 1998. Dr. Birgisson has written over 80 papers on pavements and pavement related subjects.

2006 Design Conference
Designing for More Than Bridges and Roads
July 31 – August 2, 2006

Florida Top-Down Pavement Cracking Design Model

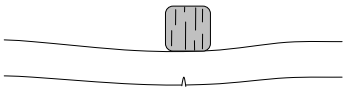
Bjorn Birgisson, Jianlin Wang, Reynaldo Roque

Department of Civil & Coastal Engineering
University of Florida

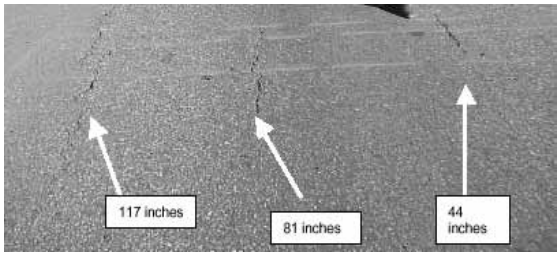
Pavement Response and Cracking

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

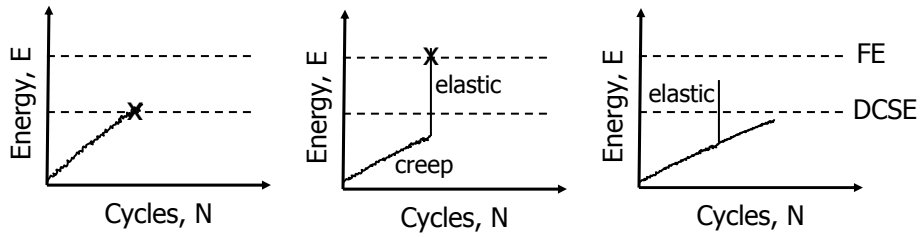
- Simpler Testing and Design Calculations

Core Extracted from Field

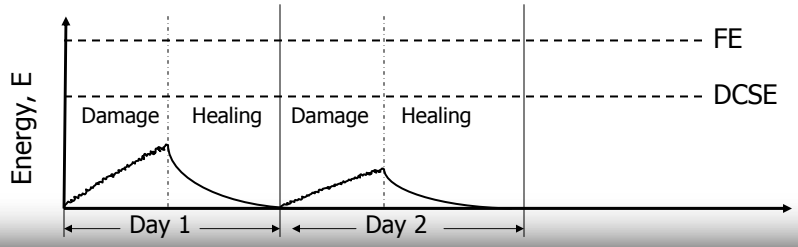
Florida Cracking Model – Key Features

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

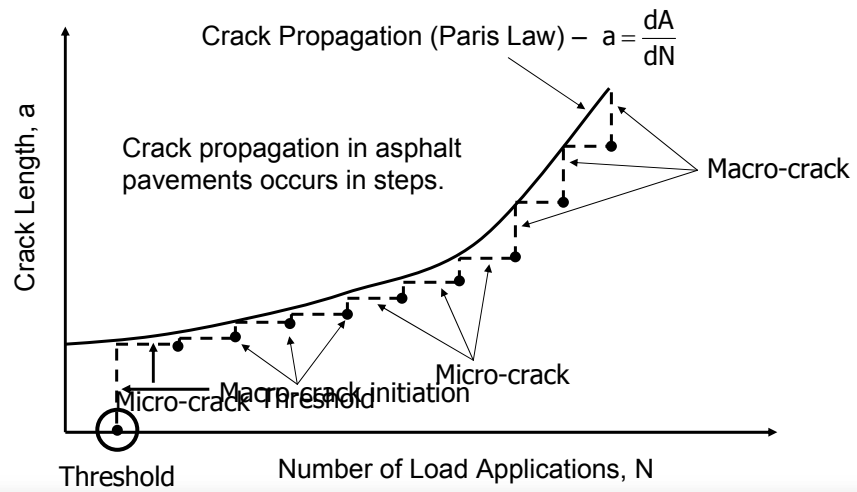
The Threshold Concept



Potential loading conditions in the field



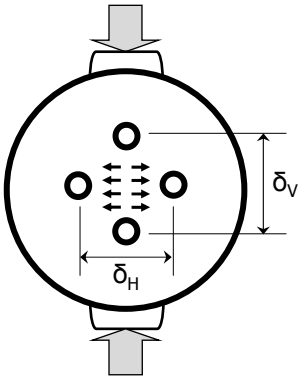
Crack Growth Model



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 – σ_{AVE} (modulus)

  to calculate the amount of dissipated energy per load cycle:

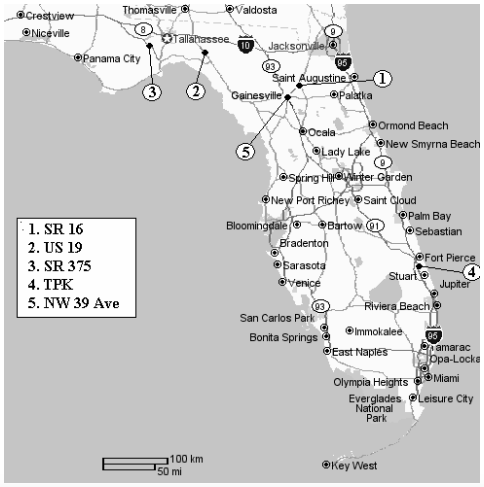
$$DCSE / cycle = f(\text{tensile stress}, D_1 \& m)$$

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

Field Test Sections

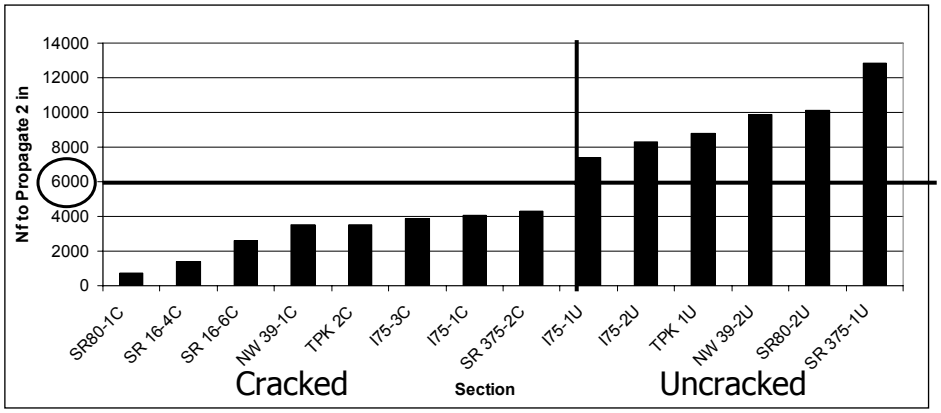
Multiple pairs of poor and good performing sections throughout Florida

- Over 18 pairs (36 sections) to date



Cycles to Failure

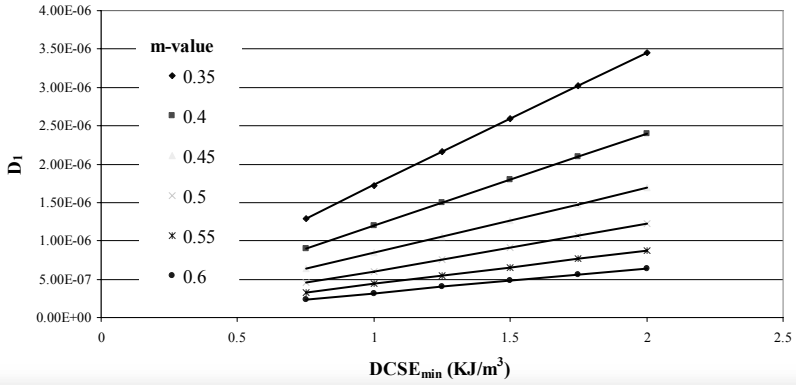
- Used the HMA Fracture Model to calculate N_f for crack to propagate 2”



- 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

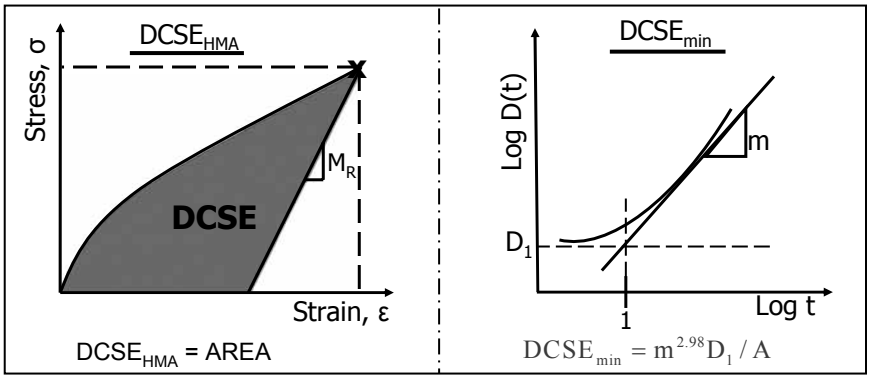
- $DCSE_{min}$ is the minimum energy required to produce N_f=6000
- Express the $DCSE_{min}$, D_1 & m-value relation in a single function:
  - $DCSE_{min} = \frac{m^{2.98} D_1}{A}$
  - $A = \frac{(6.36 - S_t)}{33.44 \times \sigma_t^{3.1}} + 2.46 \times 10^{-8}$

Tensile Strength

Tensile Stress

Energy Ratio Concept

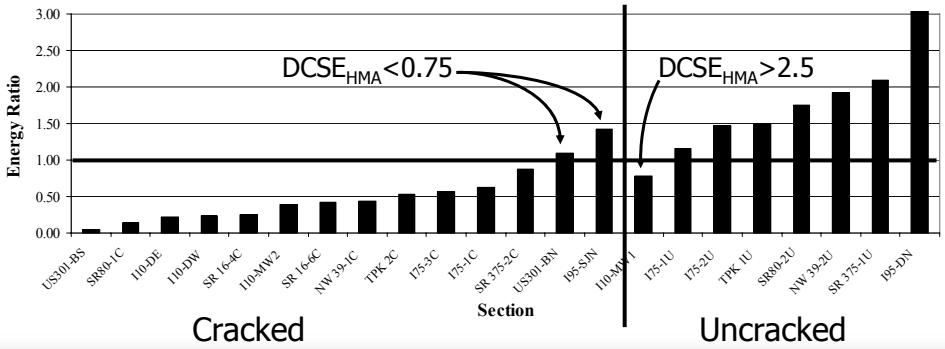
- The $DCSE_{HMA}$ has to be greater than the $DCSE_{min}$ for good cracking performance:



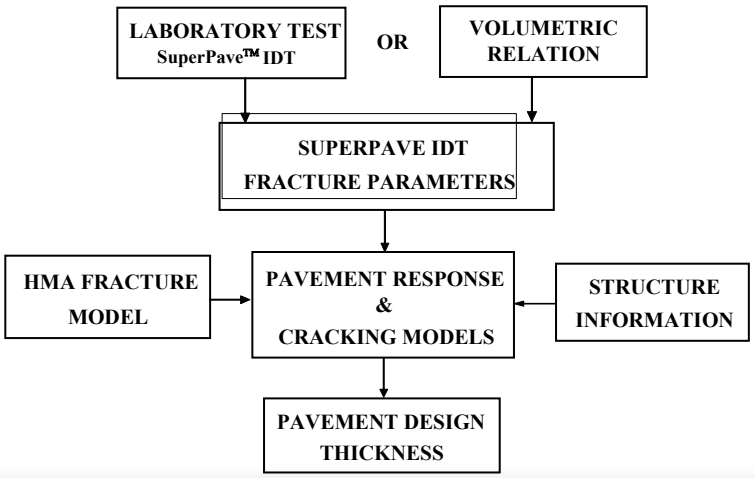
$$\text{ENERGY RATIO} = \frac{DCSE_{HMA}}{DCSE_{min}} > 1$$

Energy Ratio Results

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



Florida Framework for Cracking Evaluation of HMA Pavements

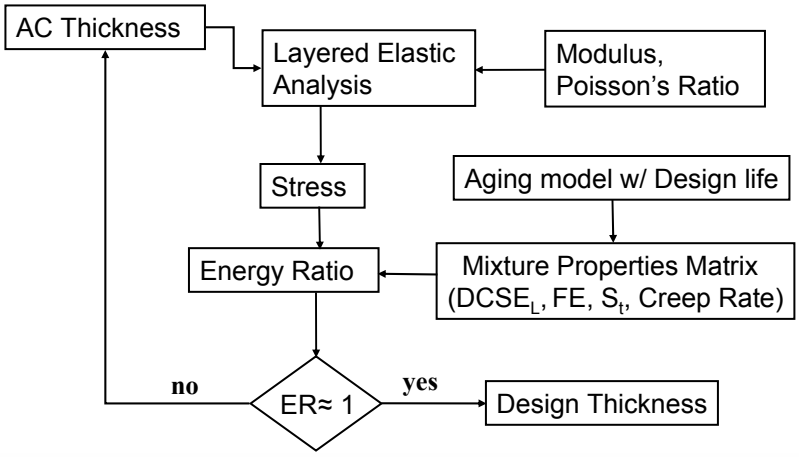


Top-Down Cracking Design

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

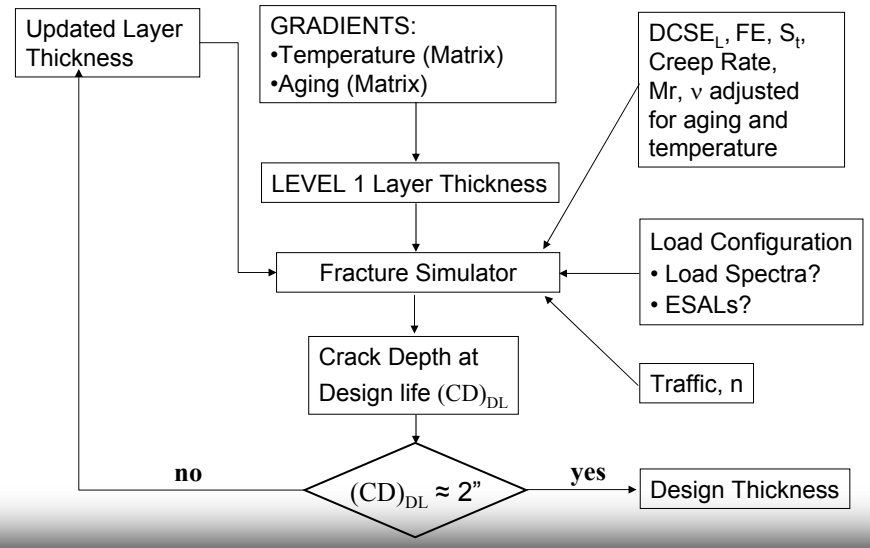
M-E Design Flowchart – Level 3



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

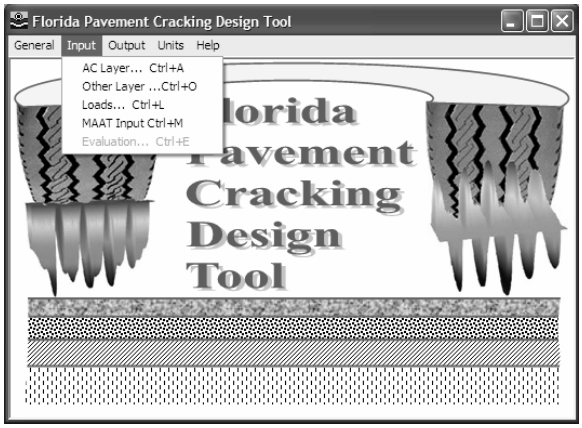
M-E Design Flowchart – Level 2



Design Studio

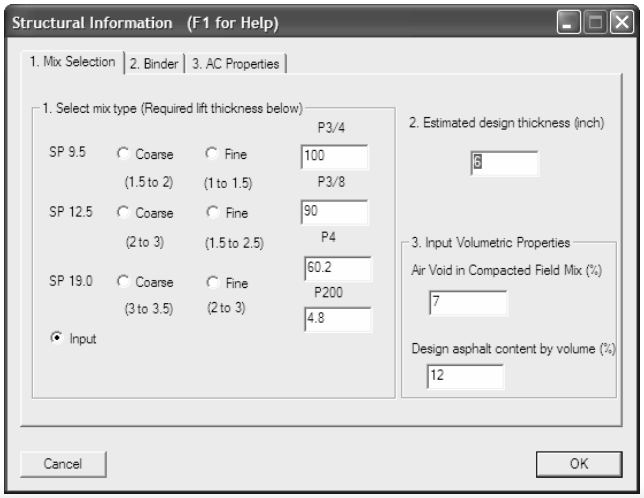
- New Pavement Design using Energy Ratio
- Overlay Design using Energy Ratio

Input Menu



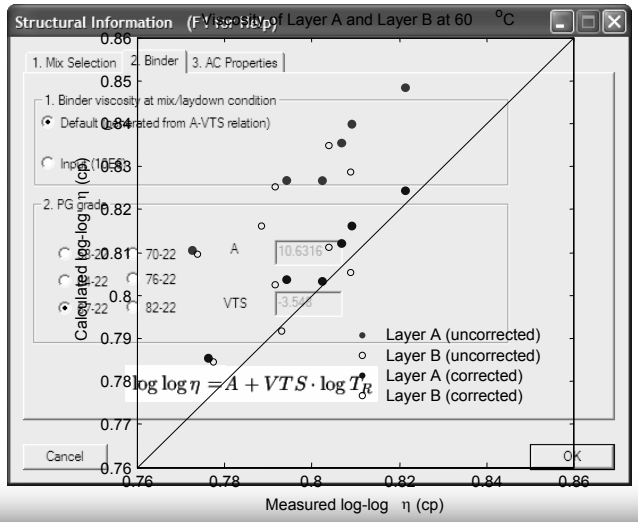
- Structure
  - AC Layer
  - Other Layers
- Loads
- MAAT

AC Layer – Basic Design



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

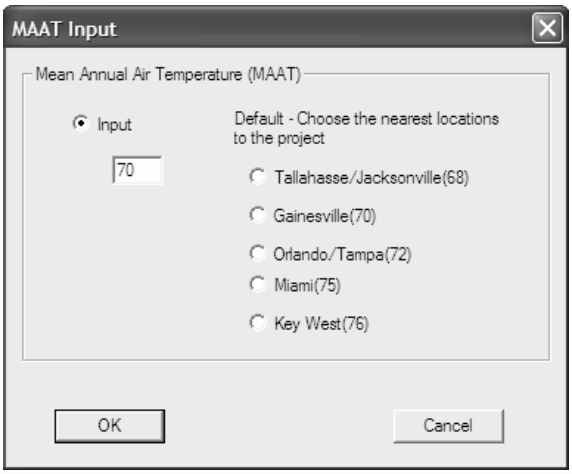
Binder Selection



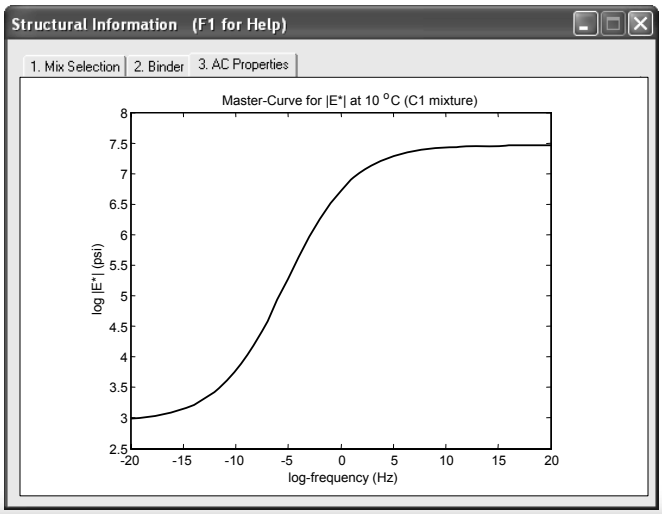
- Estimate the binder viscosity at mix/laydown condition
- Predict the in-service viscosity based on the global aging model
- Correction

MAAT Input

- Input MAAT to predict aging



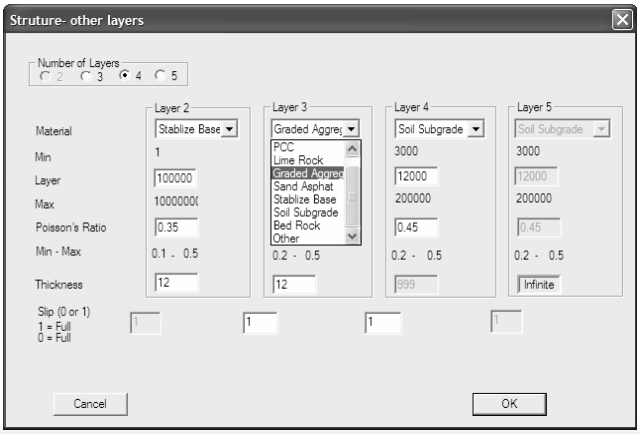
Mixture Properties



- 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)



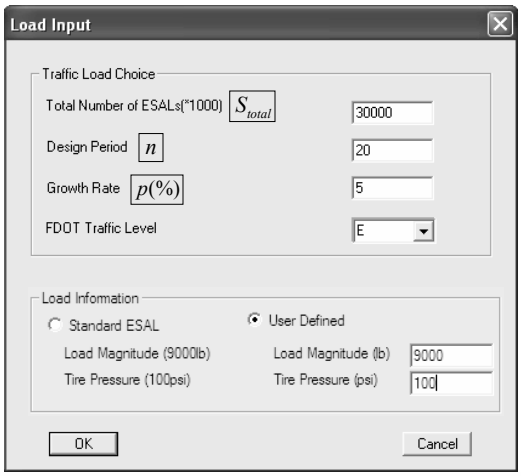
- User can determine the number of layers
- Default properties suggested for selected materials
- User can also define the material properties

Loads Input

- Simplified load information

The maximum number of ESALs/year:

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



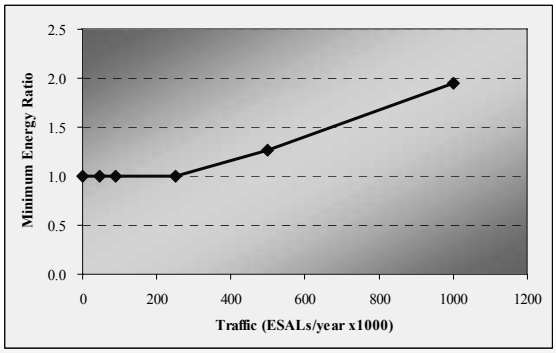
ER Calculation

- ER formula

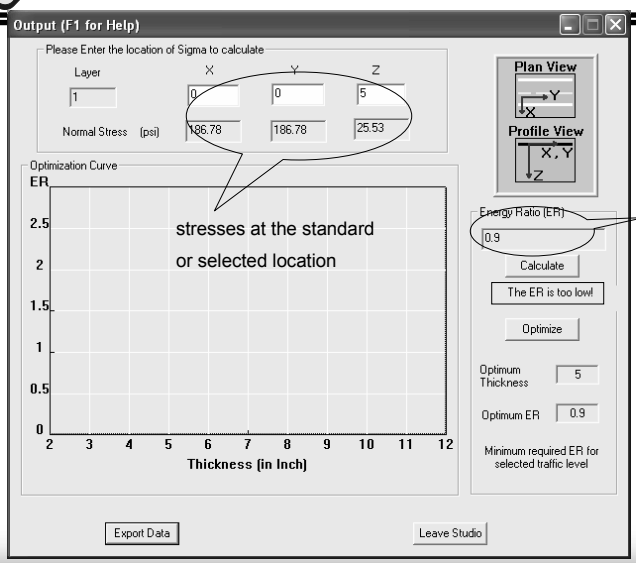
$$ER = \frac{\mathrm{DCSE}_f}{\mathrm{DCSE}_{\min}} = \frac{\mathrm{DCSE}_f}{D_1 \cdot m^{2.98}} \cdot A \text{ , where } A = \frac{0.0299 \cdot (6.36 - S_t)}{\sigma_t^{3.1}} + 2.46 \times 10^{-8}$$

- Minimum ER adjusted for traffic level

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



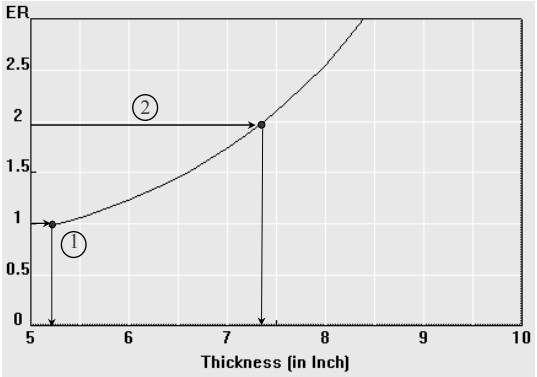
ER Output



ER value

Thickness Optimization

- Search for the thickness that gives the minimum required ER

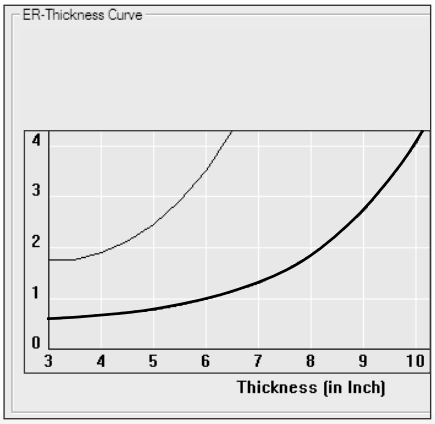


2 Optimum Thickness 7.4
Optimum ER 1.95
Minimum required ER for selected traffic level

1 Optimum Thickness 5.2
Optimum ER 1
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

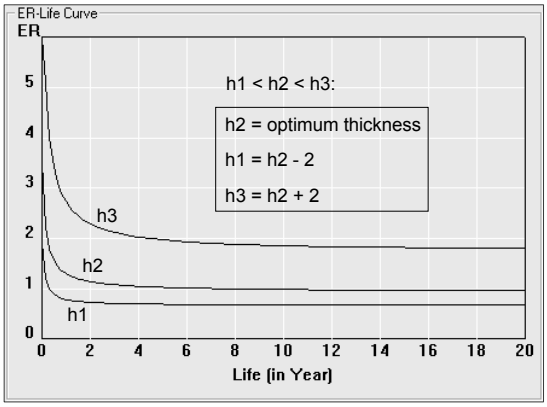


Pavement Life Curve

- 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