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

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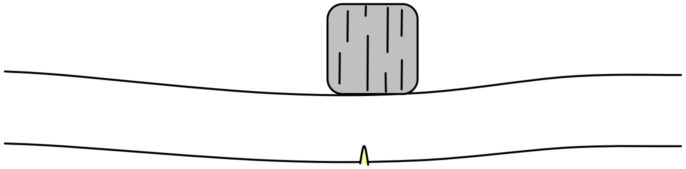
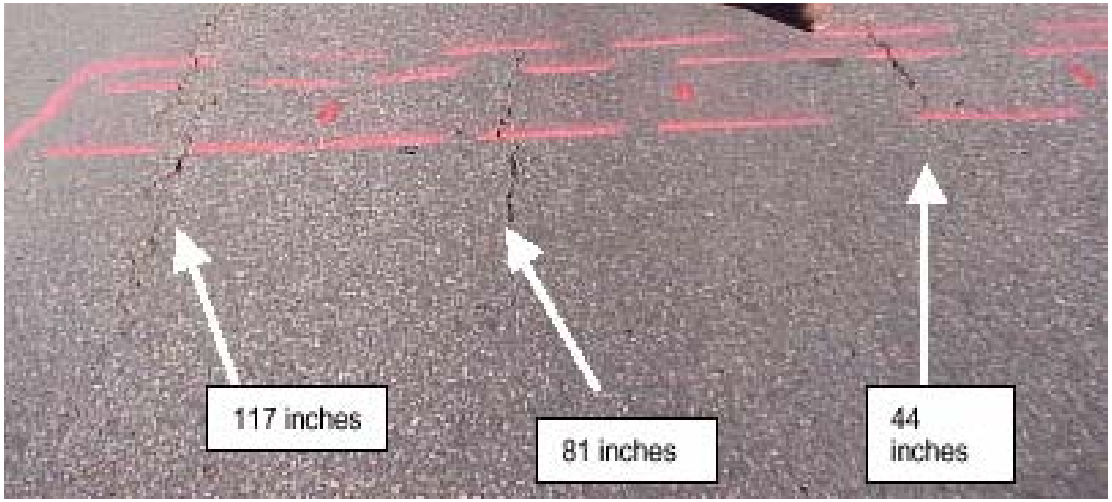
Pavement Response and Cracking

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

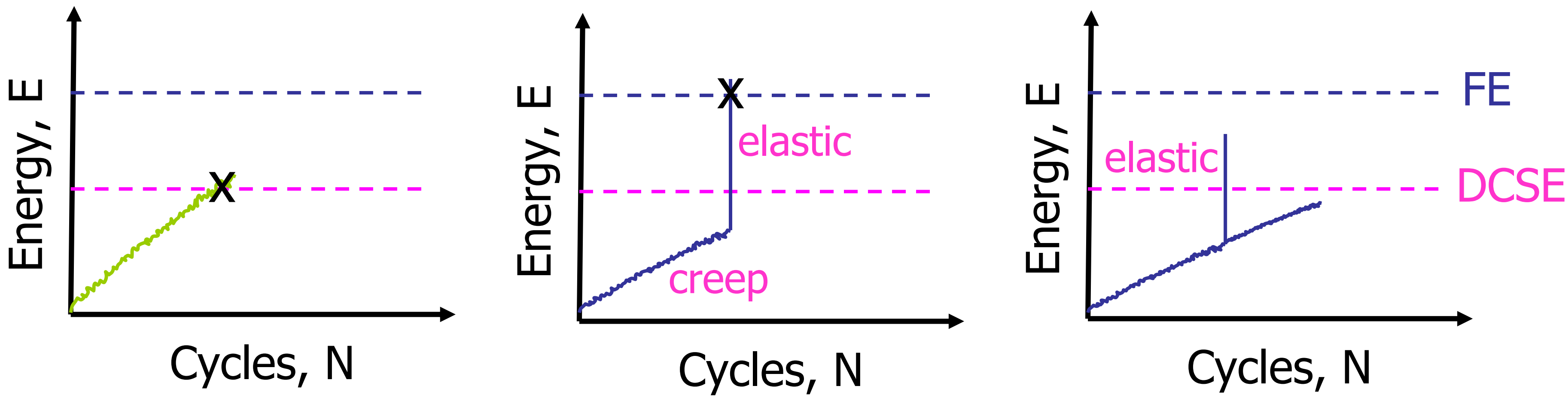
Core Extracted from Field

Florida Cracking Model – Key Features

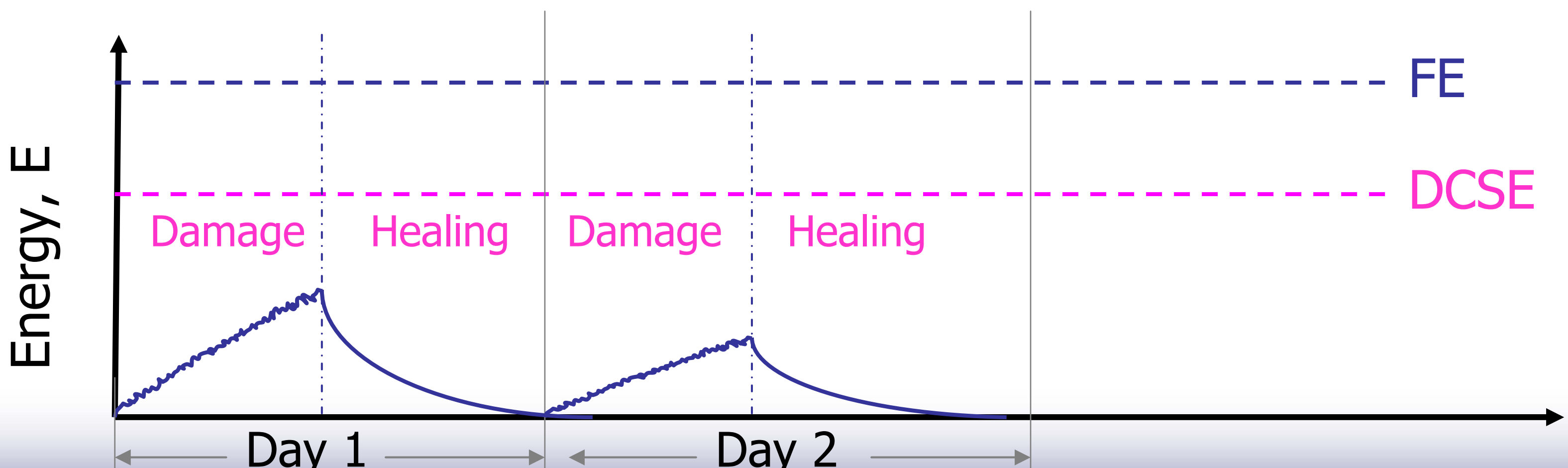
- A damage threshold exists (DCSE limit)
- Damage = Dissipated Creep Strain Energy (DCSE)
- Damage > Threshold $\rightarrow$ Macro-crack

  (DCSE) (DCSE limit)
- Macro-crack is not healable
- Damage under the cracking threshold is fully healable

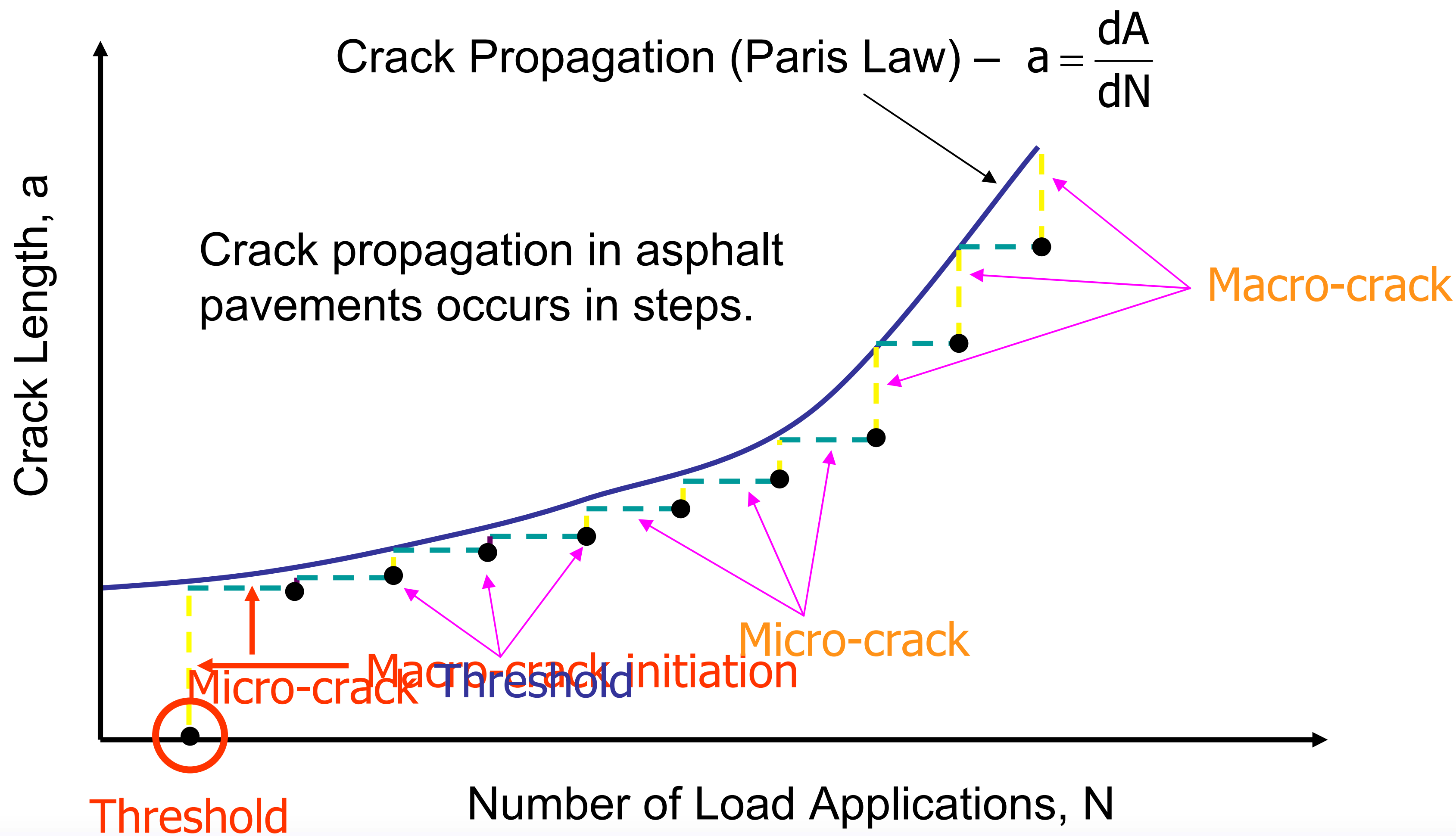
The Threshold Concept



Potential loading conditions in the field



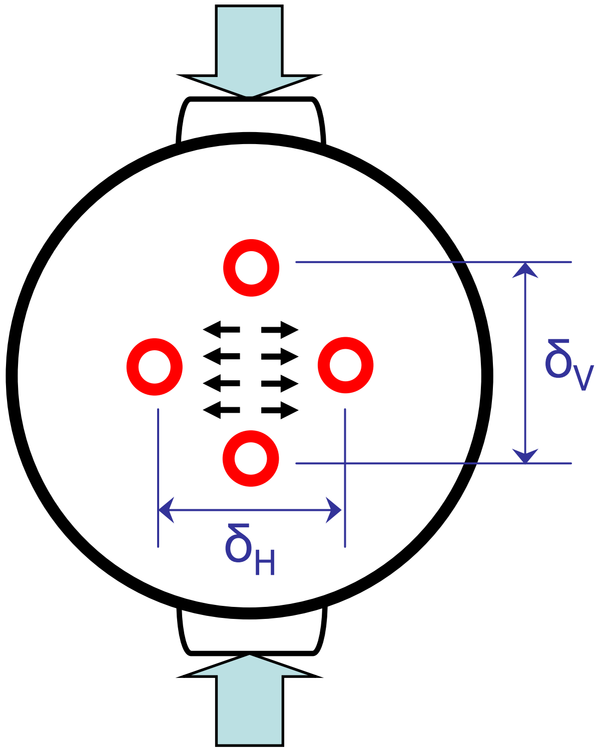
Crack Growth Model



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 – σ_{AVE} (modulus)

  to calculate the amount of dissipated energy per load cycle:

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

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

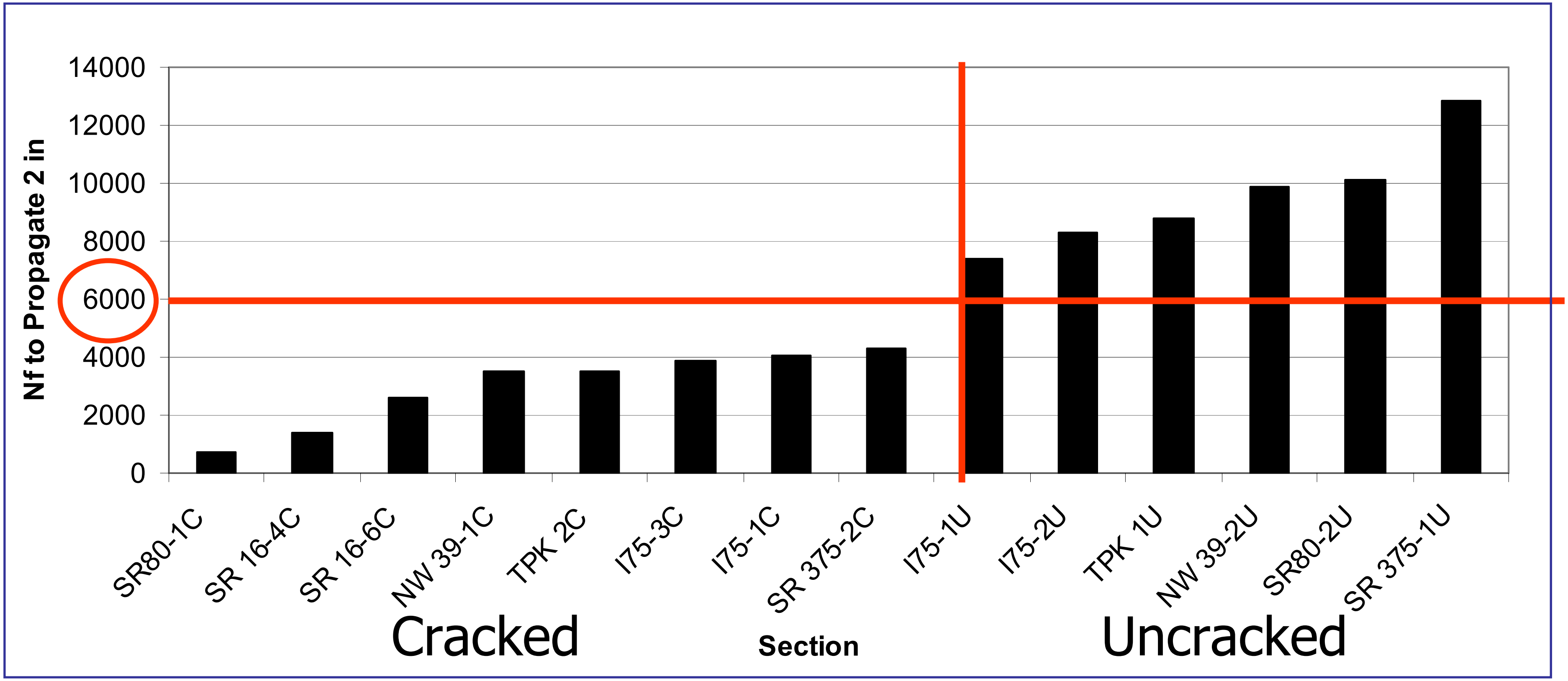
Field Test Sections

Multiple pairs of poor and good performing sections throughout Florida

- Over 18 pairs (36 sections) to date

Cycles to Failure

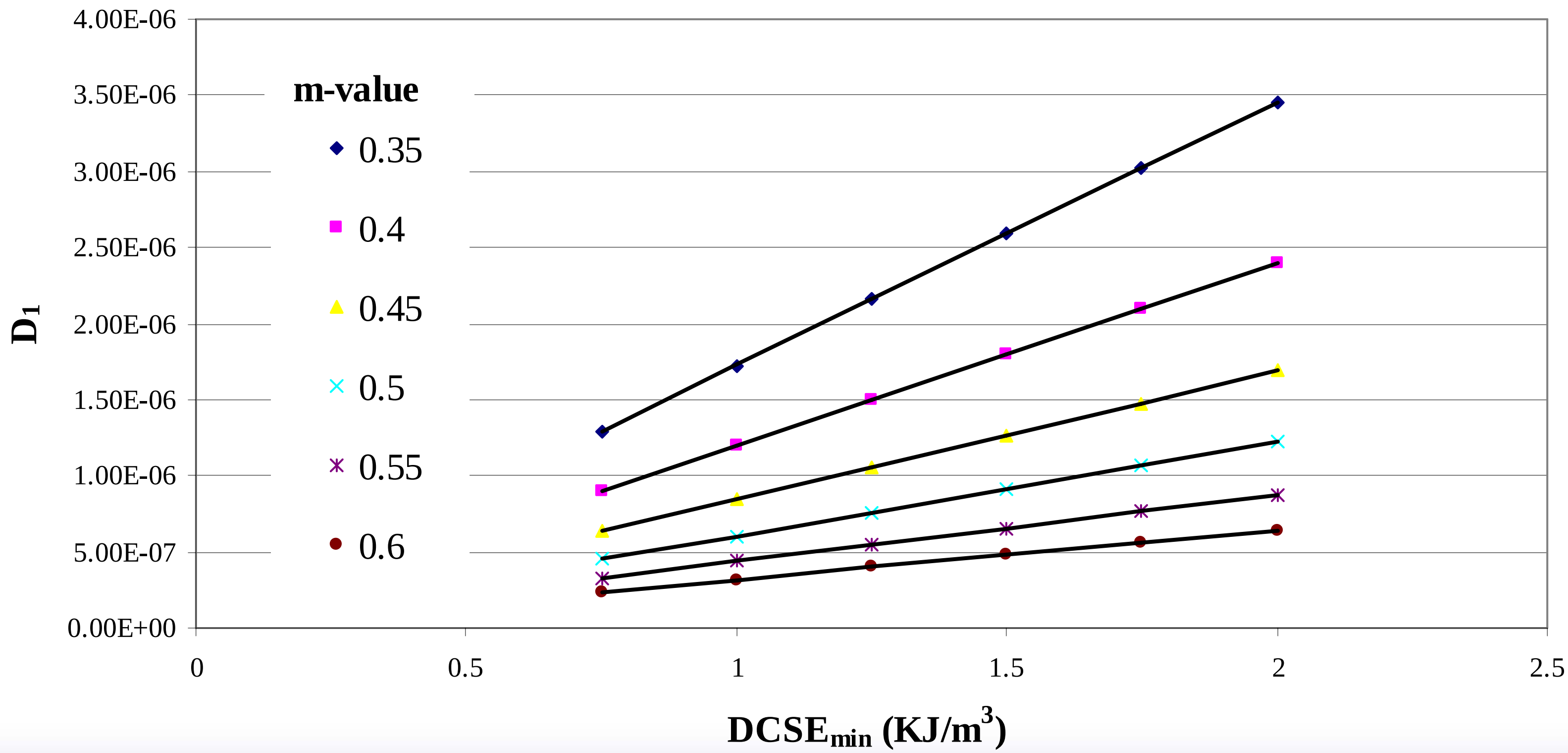
- Used the HMA Fracture Model to calculate N_f for crack to propagate 2"



- 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

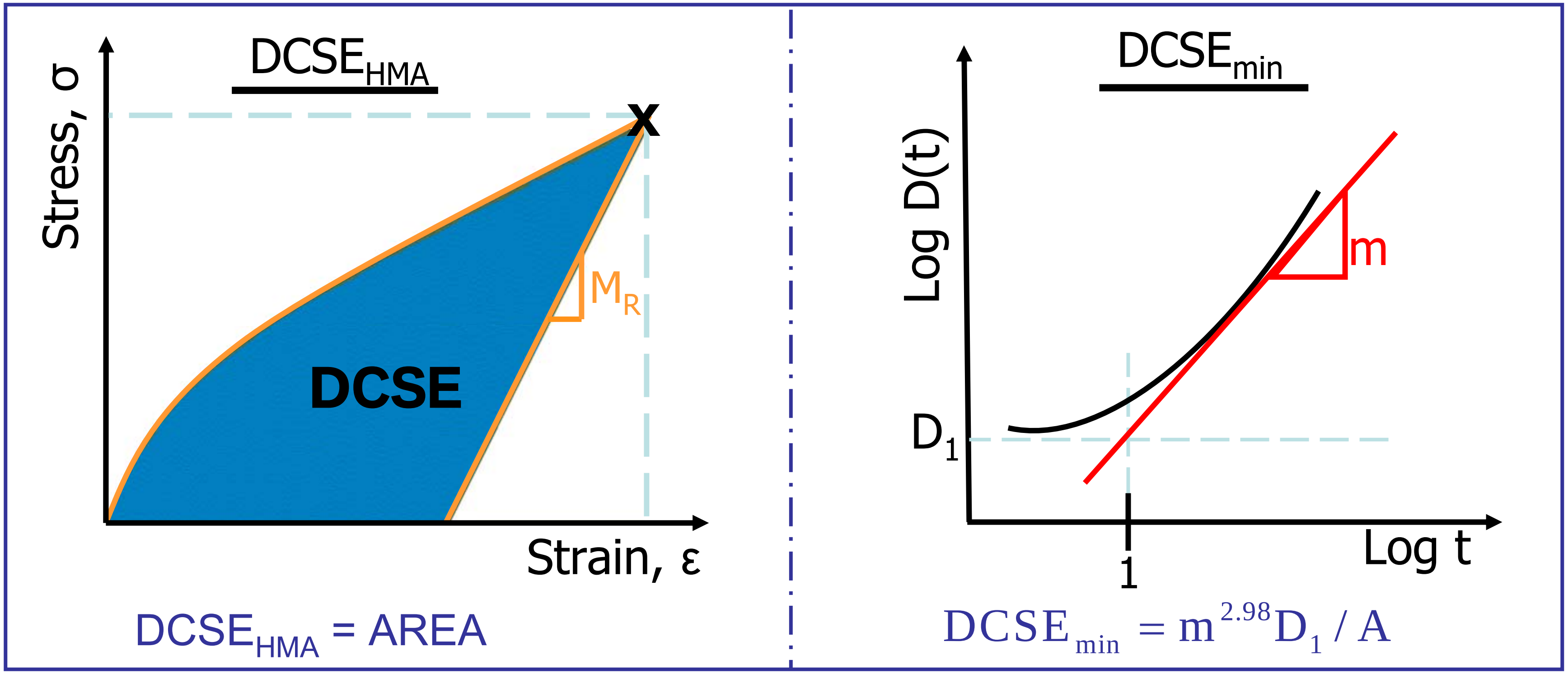
- $DCSE_{min}$ is the minimum energy required to produce N_f=6000
- Express the $DCSE_{min}$, D_1 & m-value relation in a single function:
  - $$DCSE_{min} = \frac{m^{2.98} D_1}{A}$$
  - $$A = \frac{(6.36 - S_t)}{33.44 \times \sigma_t^{3.1}} + 2.46 \times 10^{-8}$$

S_t → Tensile Strength

σ_t → Tensile Stress

Energy Ratio Concept

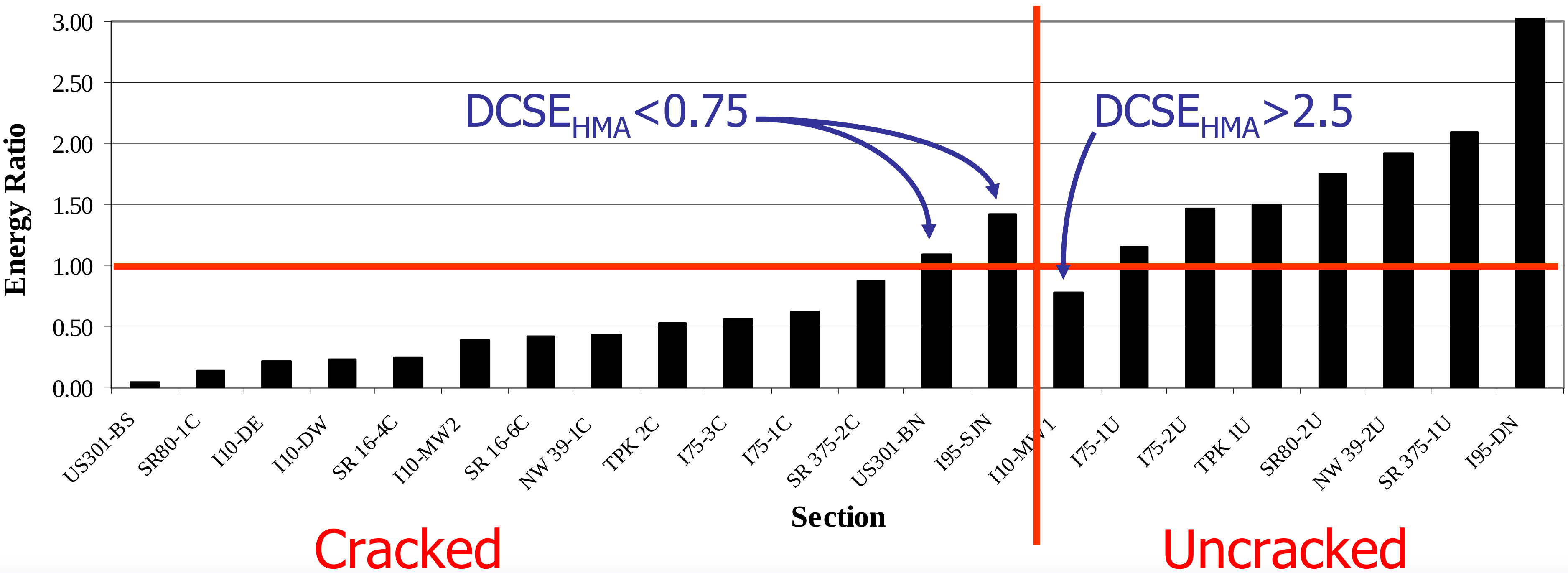
- The $DCSE_{HMA}$ has to be greater than the $DCSE_{min}$ for good cracking performance:



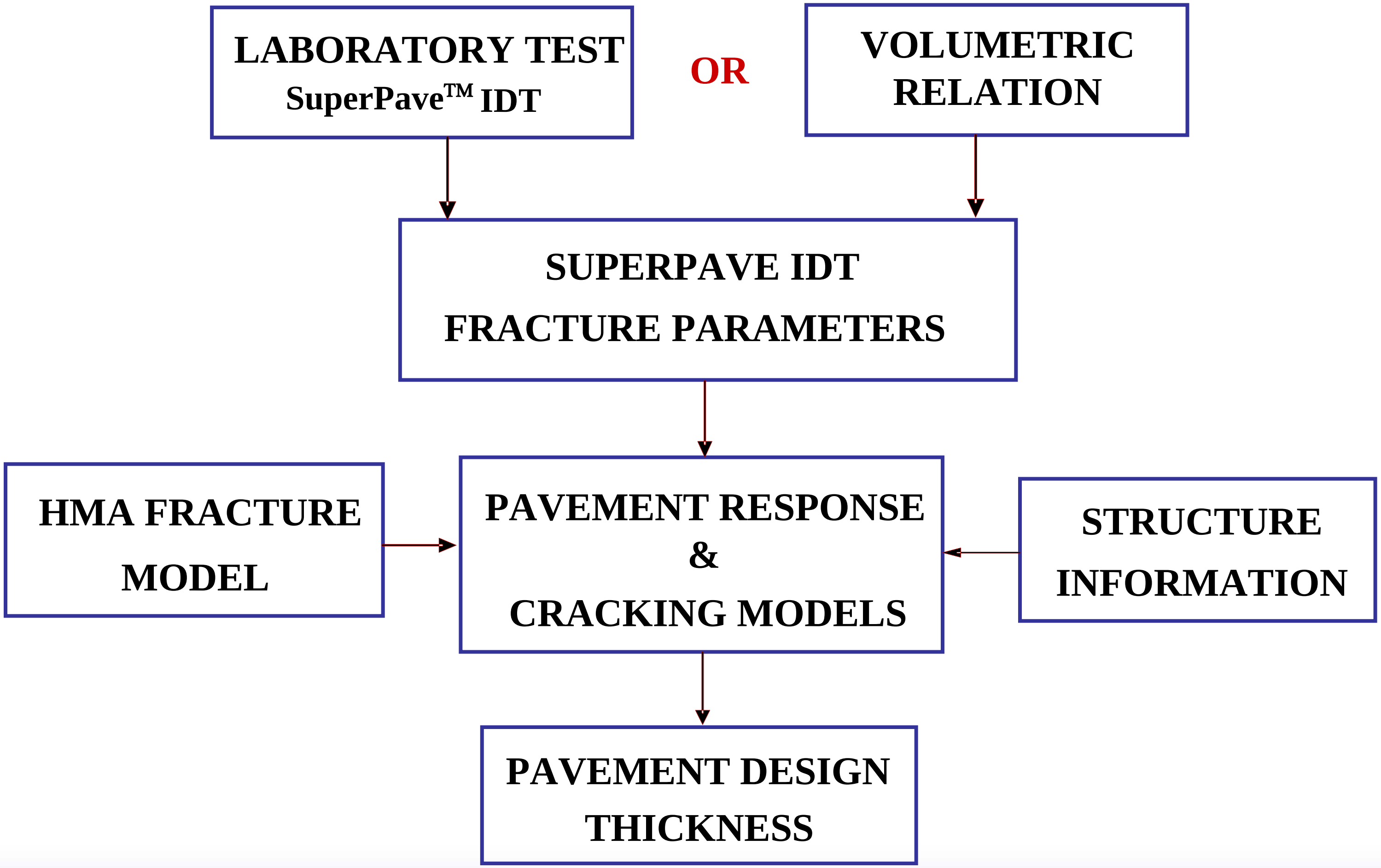
$$\text{ENERGY RATIO} = \frac{DCSE_{HMA}}{DCSE_{min}} > 1$$

Energy Ratio Results

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



Florida Framework for Cracking Evaluation of HMA Pavements

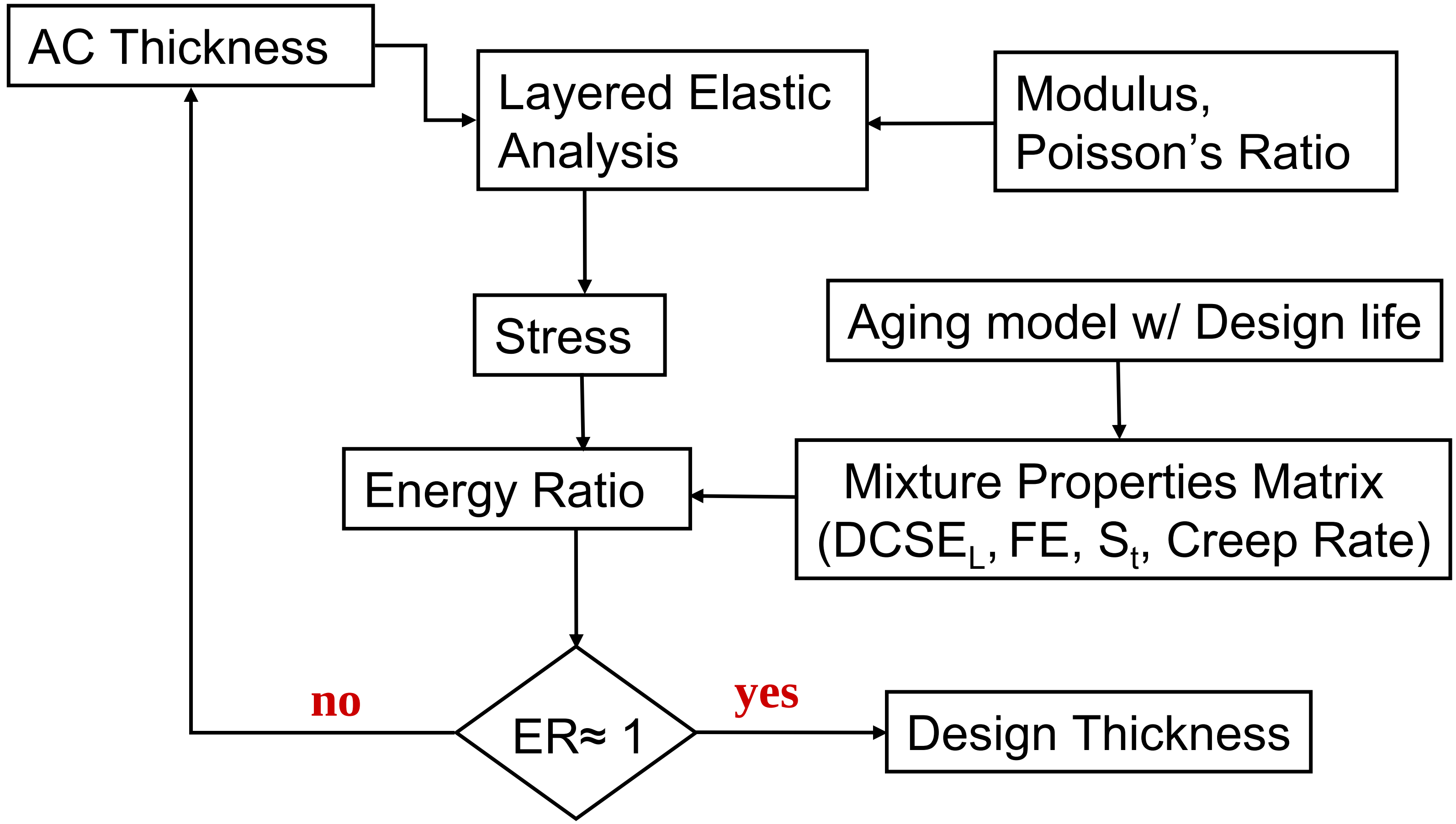


Top-Down Cracking Design

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

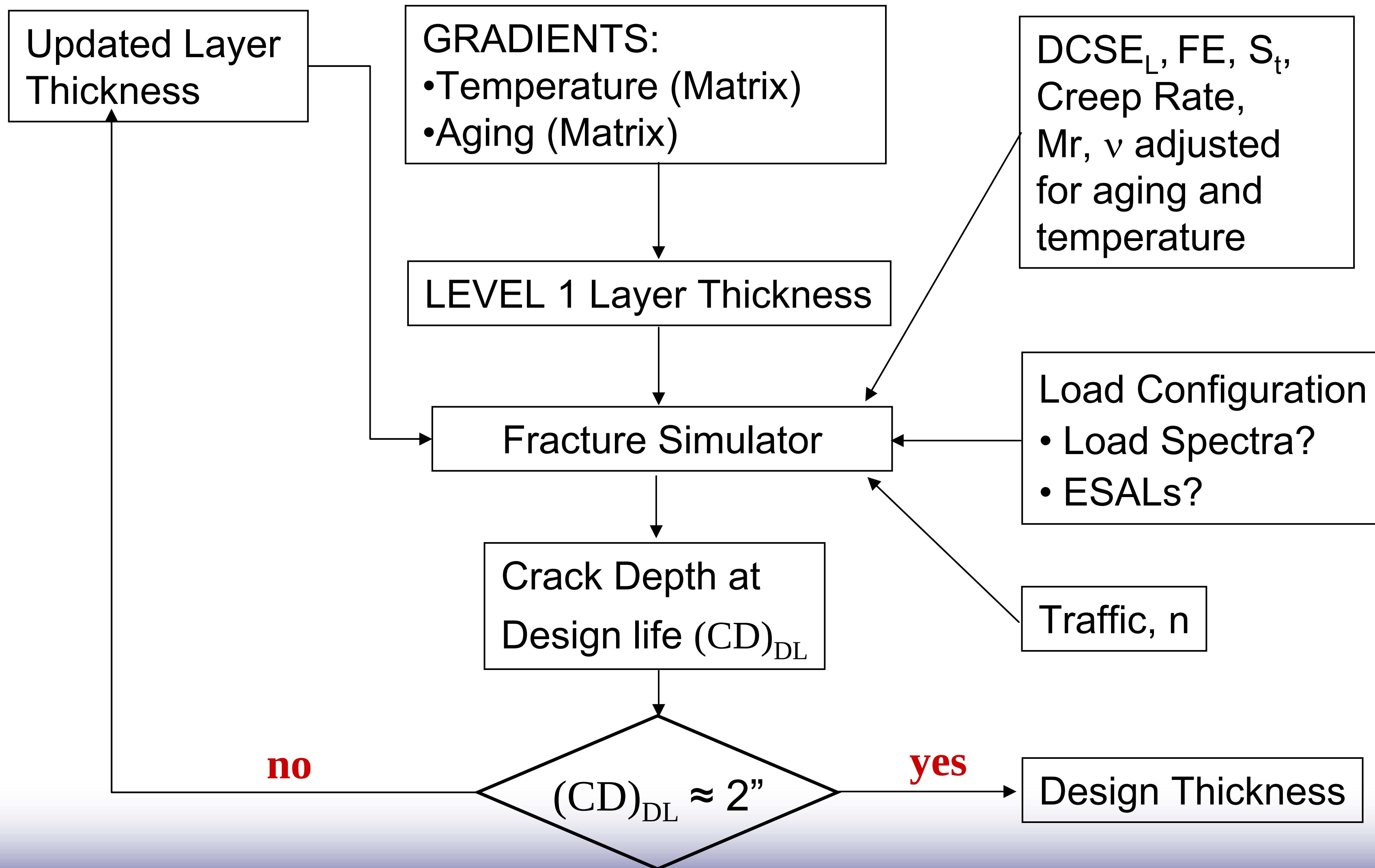
M-E Design Flowchart – Level 3



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

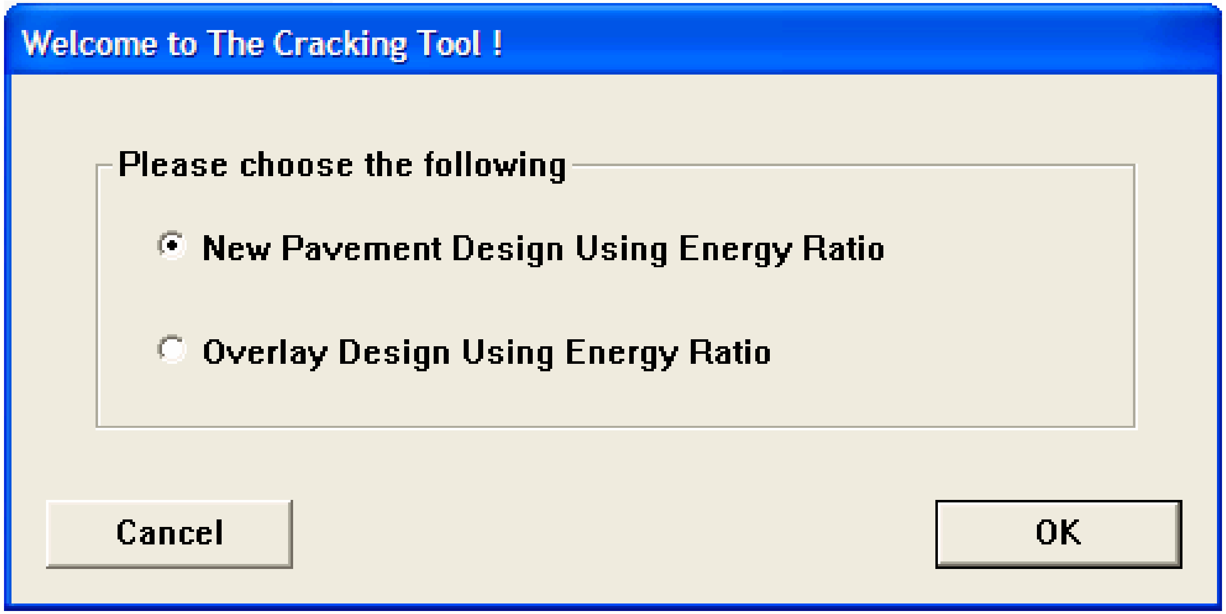
- Uses a fast pavement fracture simulator to predict depth of cracking after x years (Design life), and account for the effects of:
  - Mixture & Structure
  - Temperature/aging gradients
  - Load Configuration
  - Traffic
- Level 1:
  - Measured properties from IDT
- Level 2:
  - Estimated properties

M-E Design Flowchart – Level 2

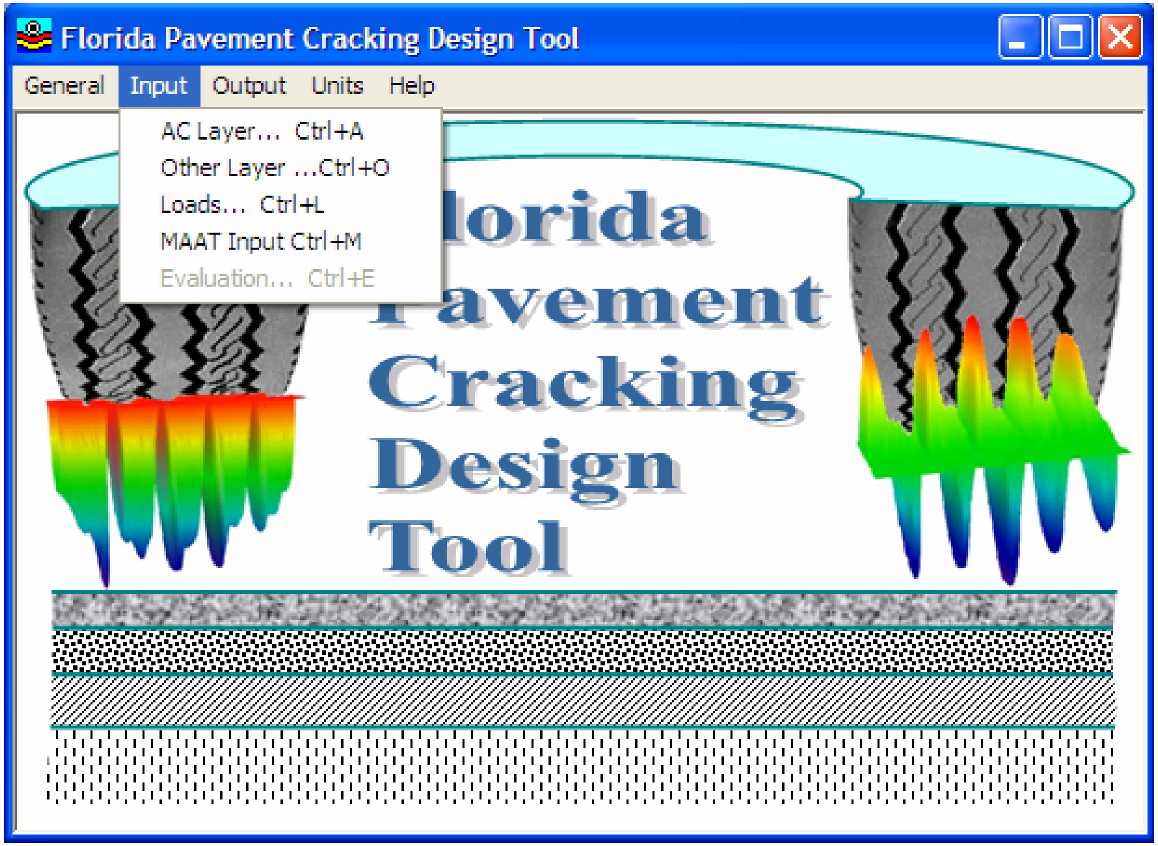


Design Studio

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

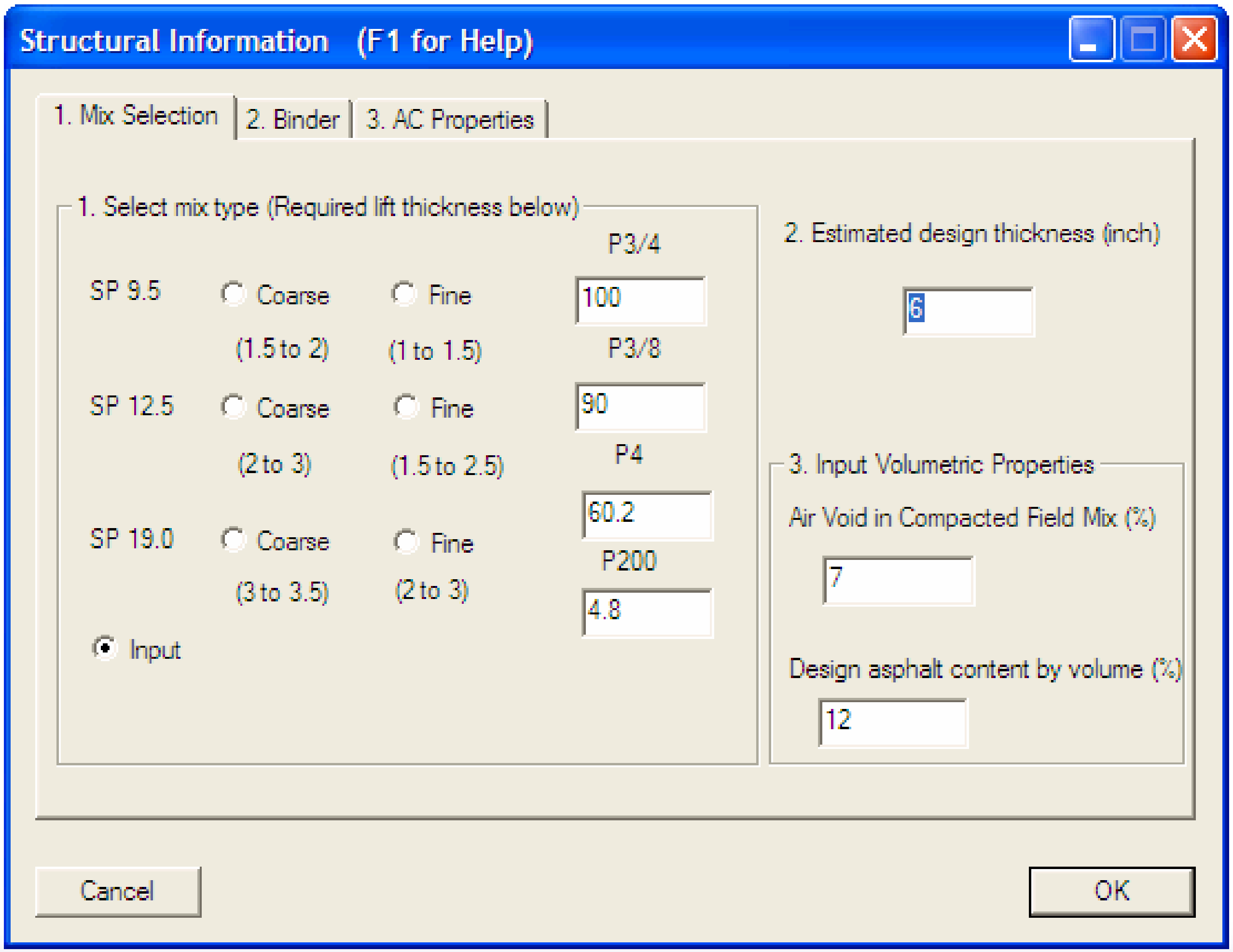


Input Menu



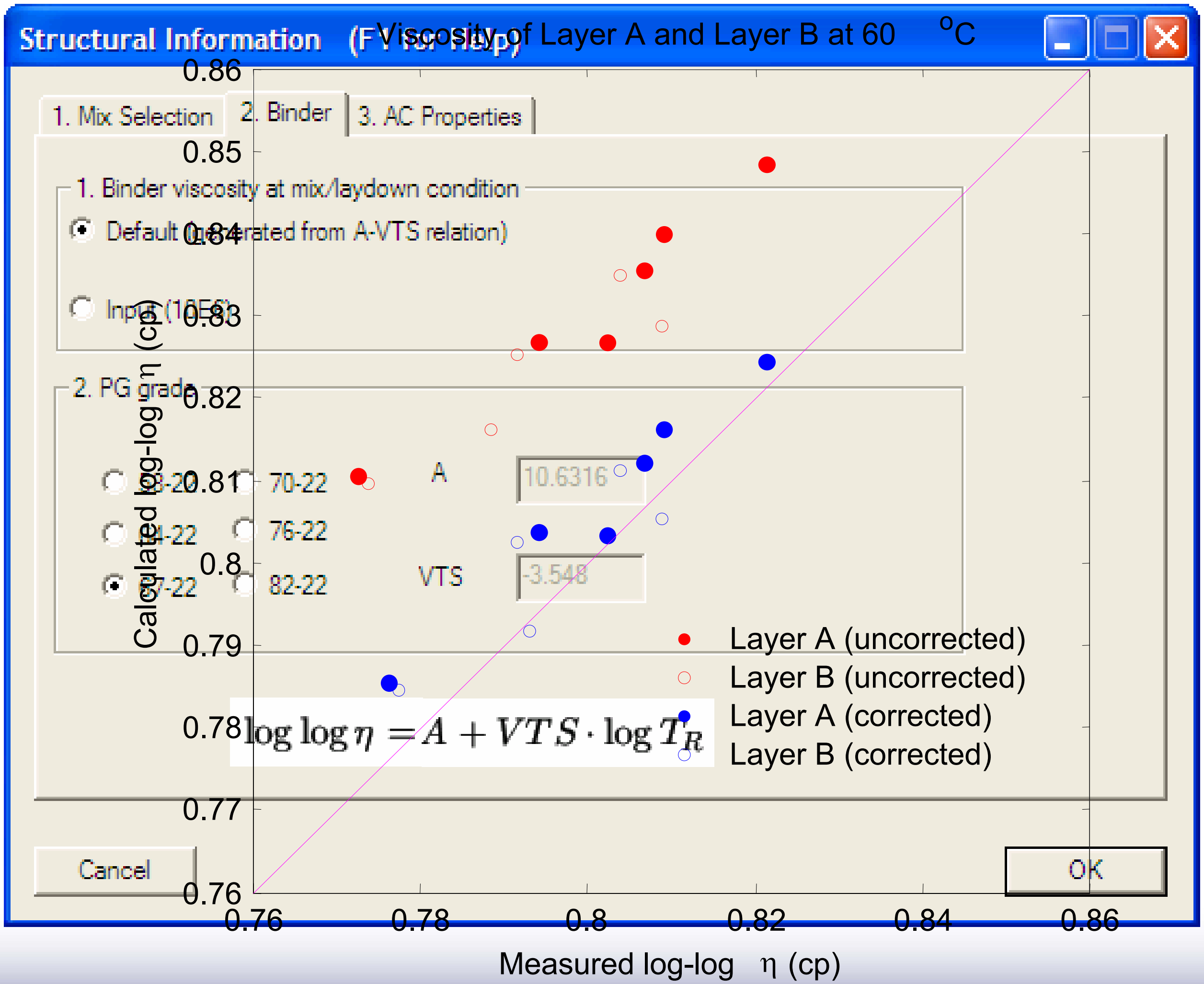
- Structure
  - AC Layer
  - Other Layers
- Loads
- MAAT

AC Layer – Basic Design



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

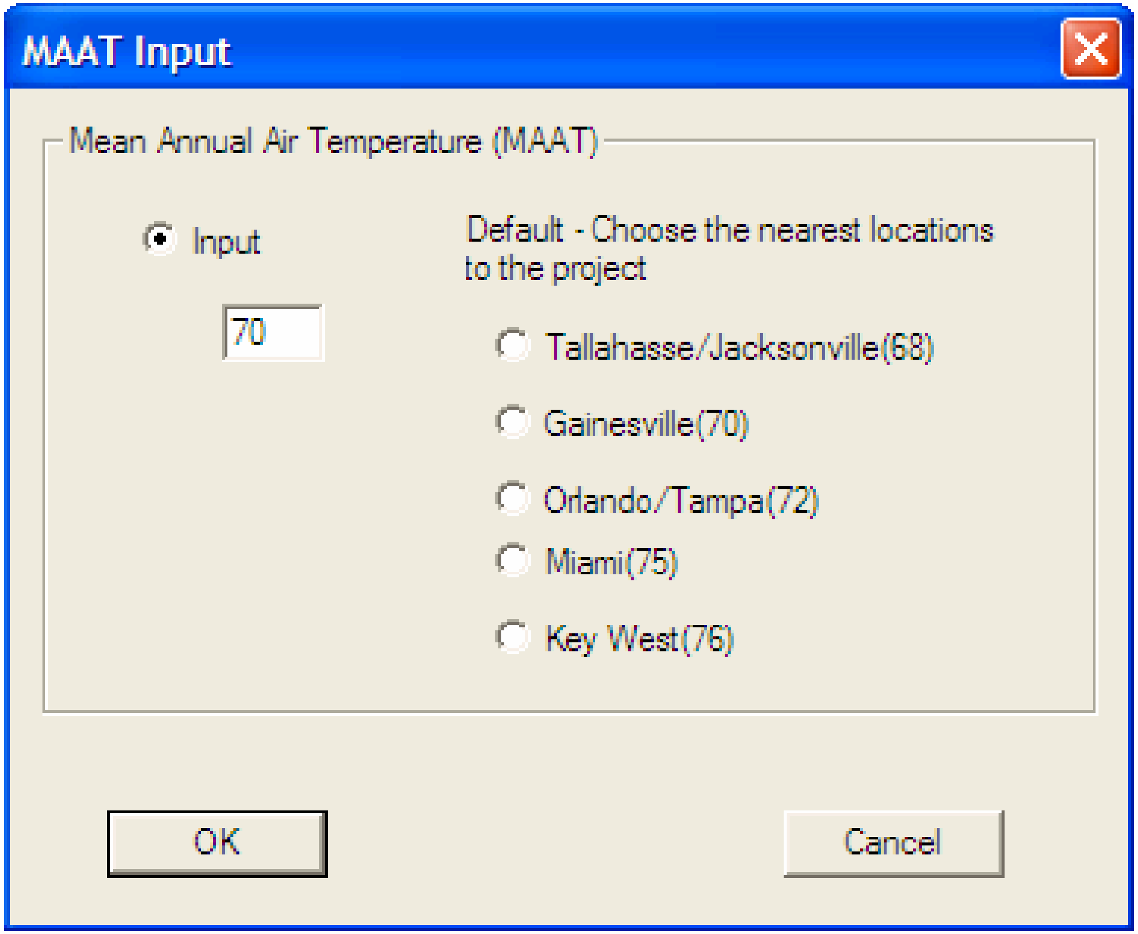
Binder Selection



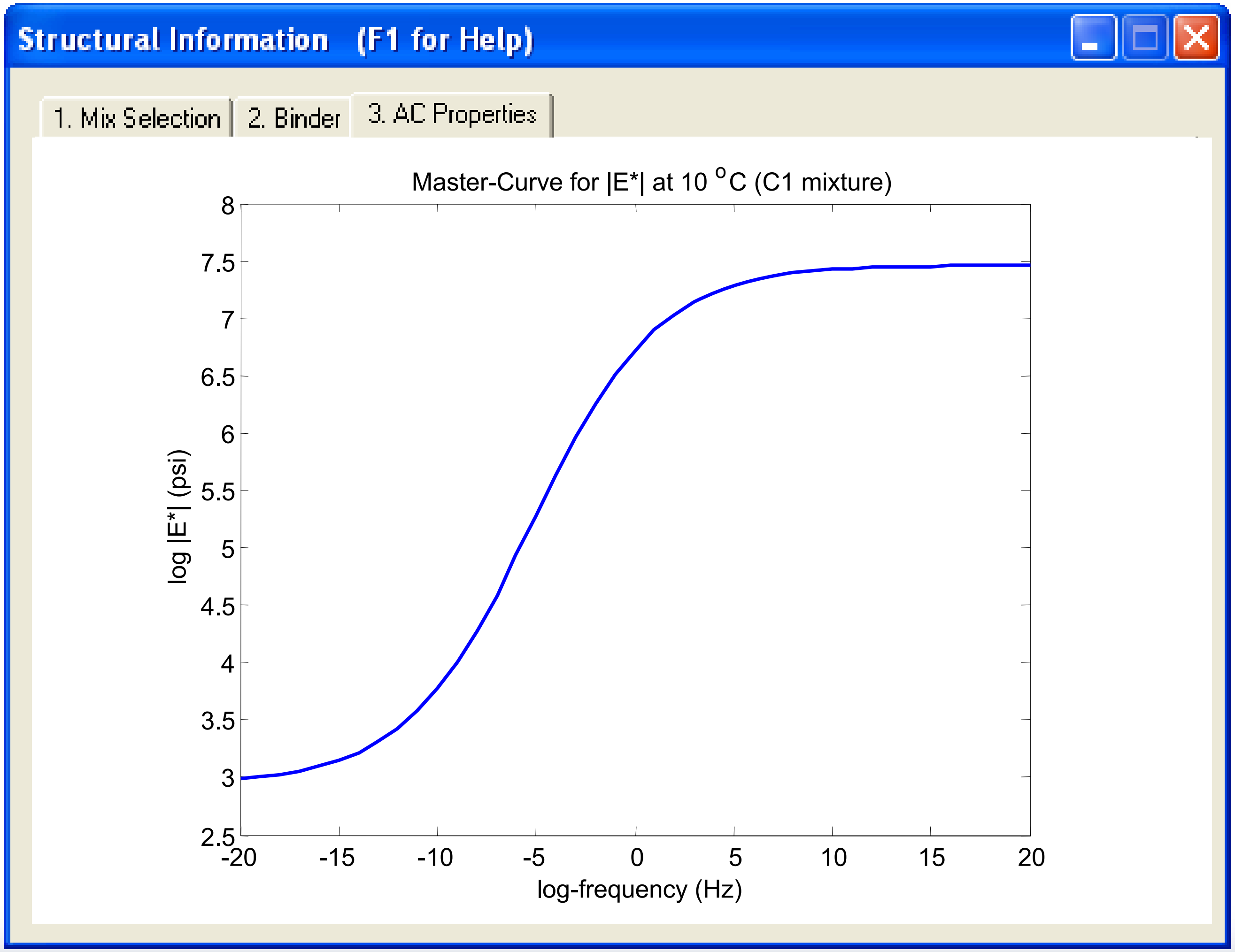
- Estimate the binder viscosity at mix/laydown condition
- Predict the in-service viscosity based on the global aging model
- Correction

MAAT Input

- Input MAAT to predict aging



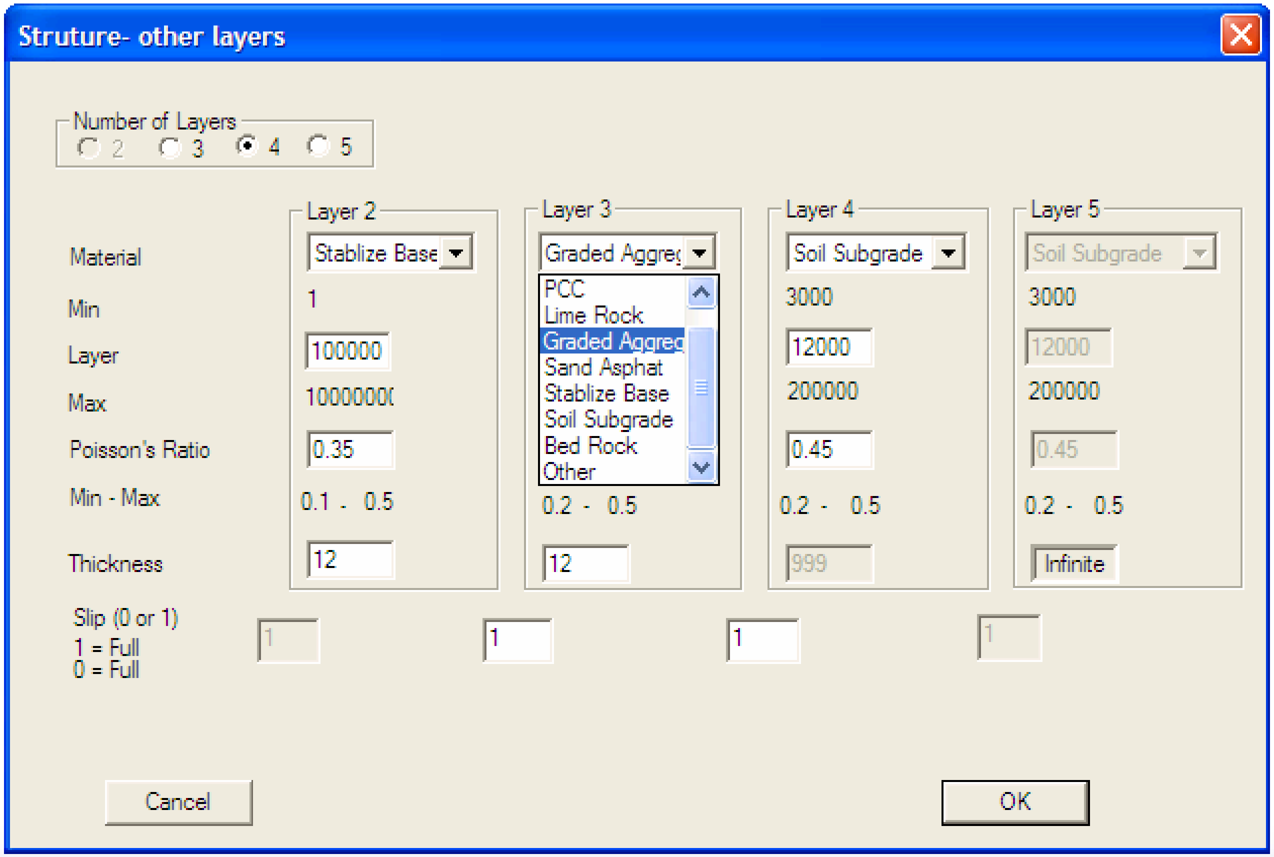
Mixture Properties



- 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)



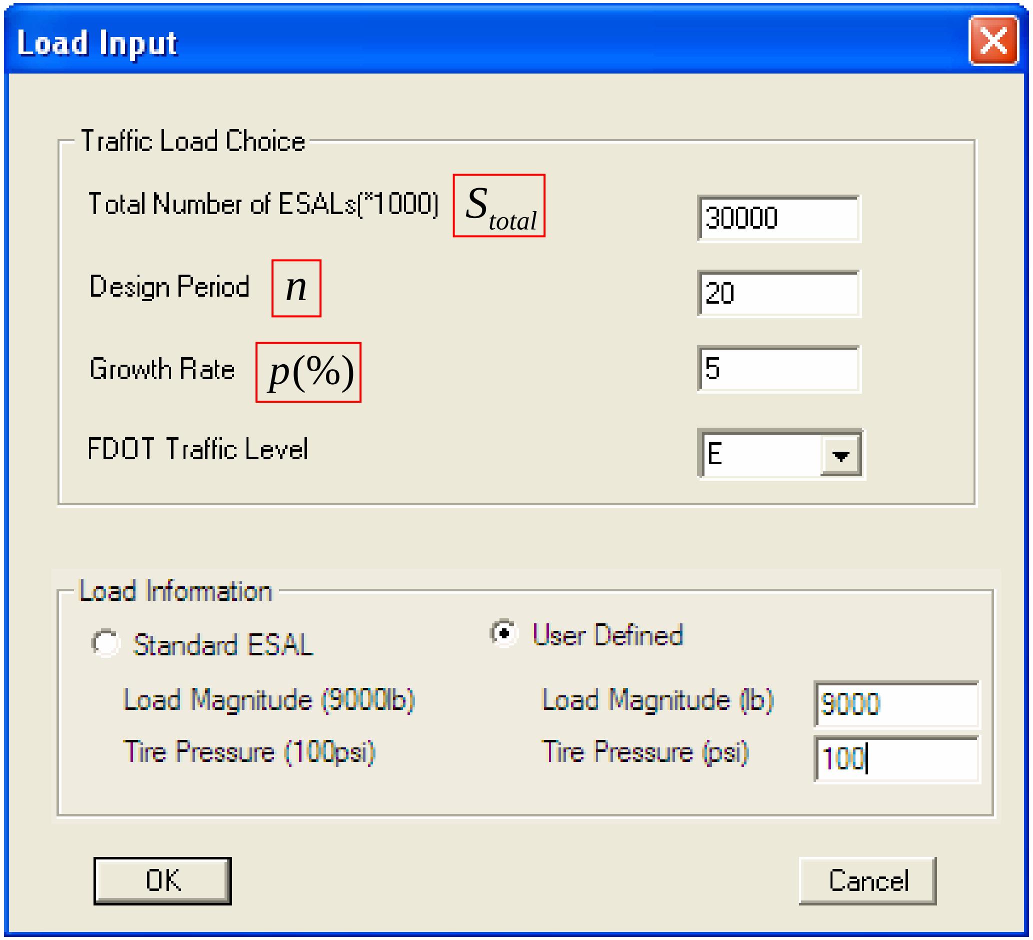
- User can determine the number of layers
- Default properties suggested for selected materials
- User can also define the material properties

Loads Input

- Simplified load information

The maximum number of ESALs/year:

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



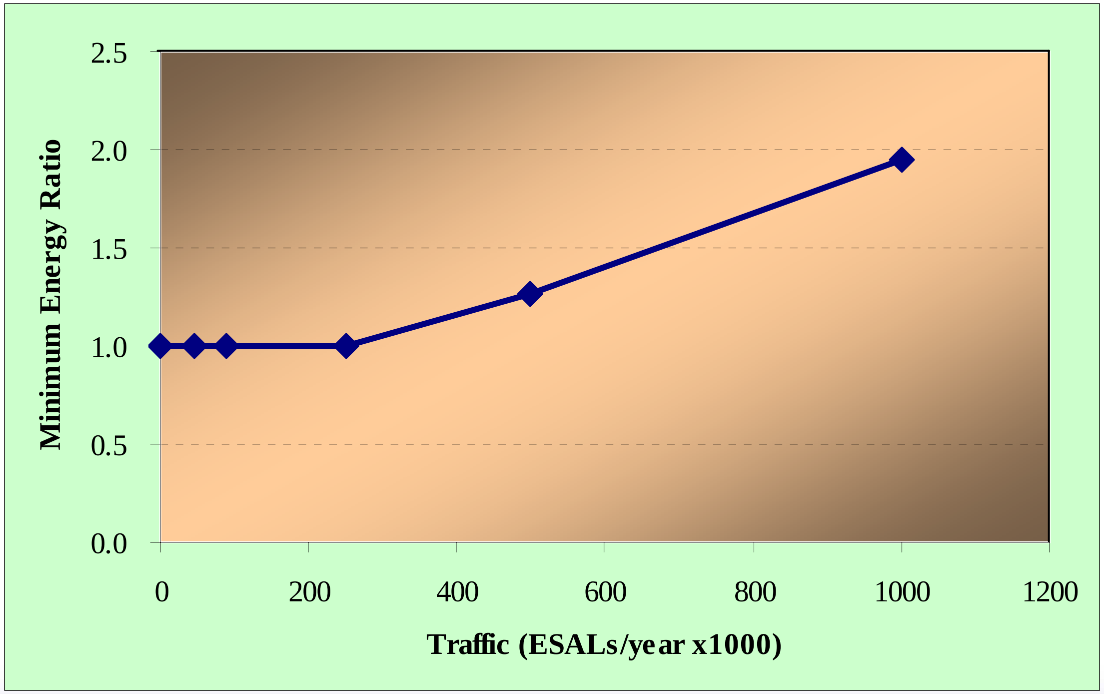
ER Calculation

- ER formula

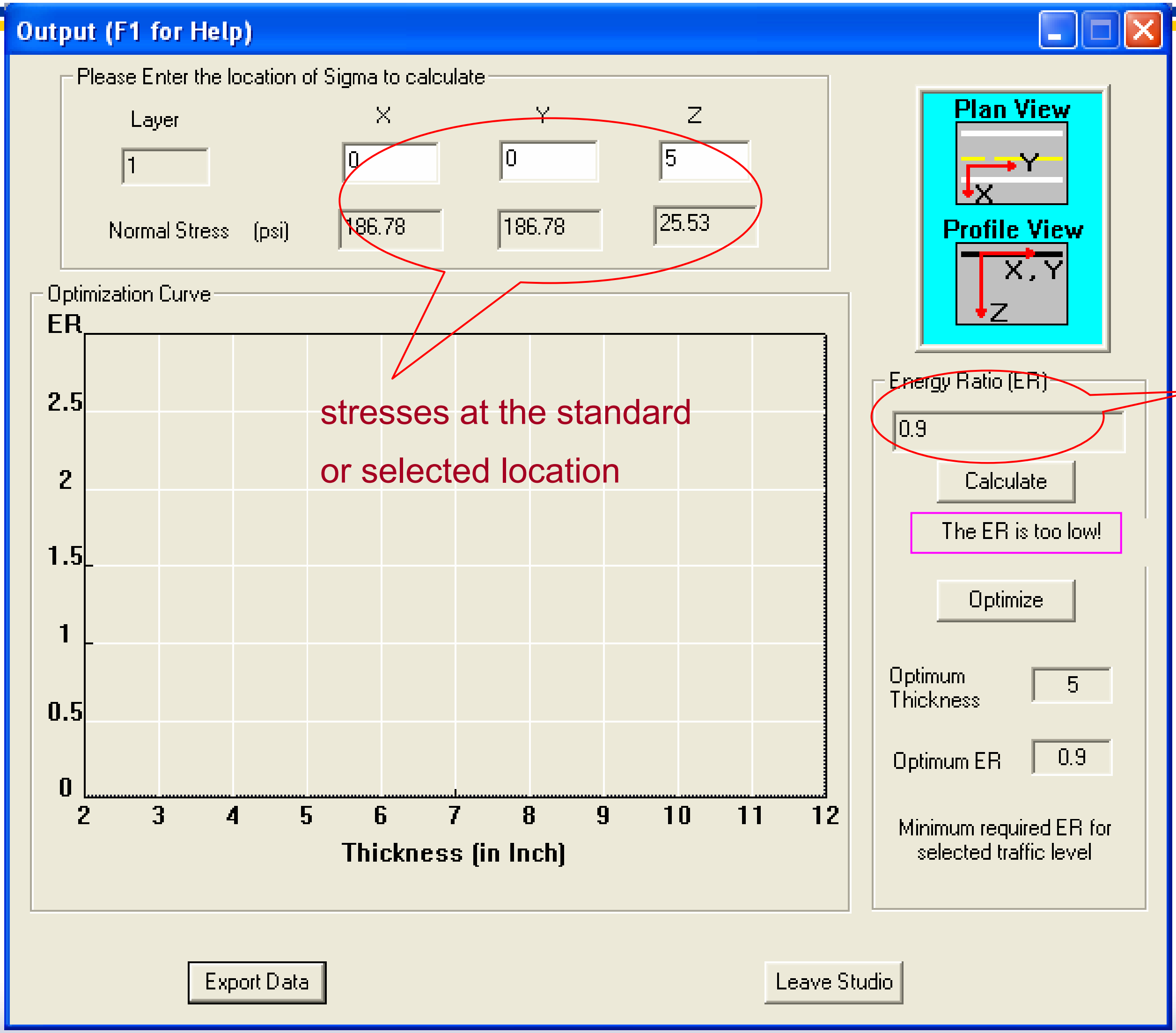
$$ER = \frac{\text{DCSE}_f}{\text{DCSE}_{\min}} = \frac{\text{DCSE}_f}{D_1 \cdot m^{2.98}} \cdot A \;, \text{ where } A = \frac{0.0299 \cdot (6.36 - S_t)}{\sigma_t^{3.1}} + 2.46 \times 10^{-8}$$

- Minimum ER adjusted for traffic level

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



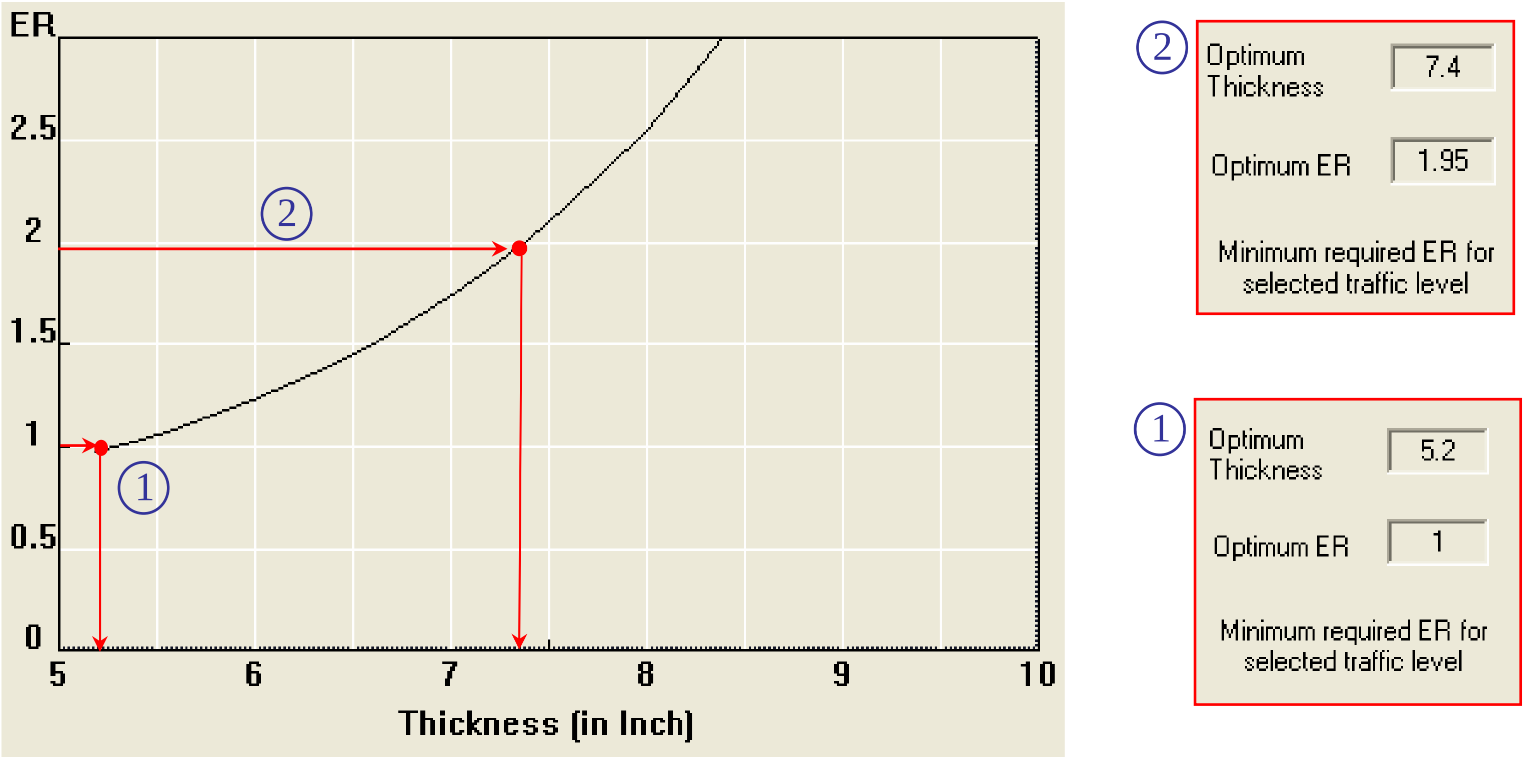
ER Output



ER value

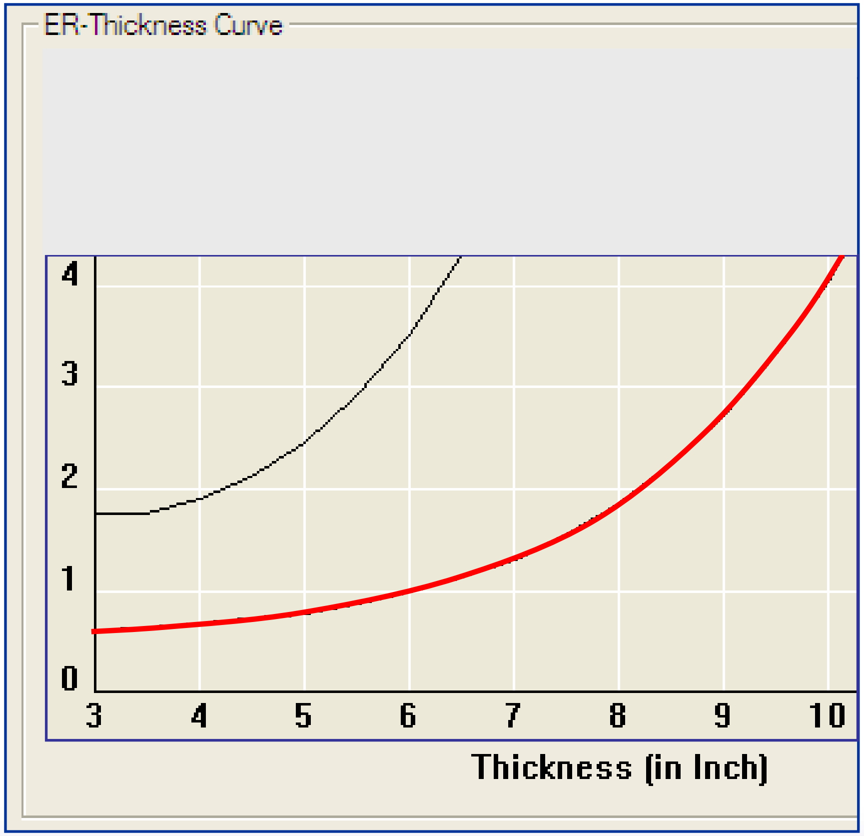
Thickness Optimization

- Search for the thickness that gives the minimum required ER



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

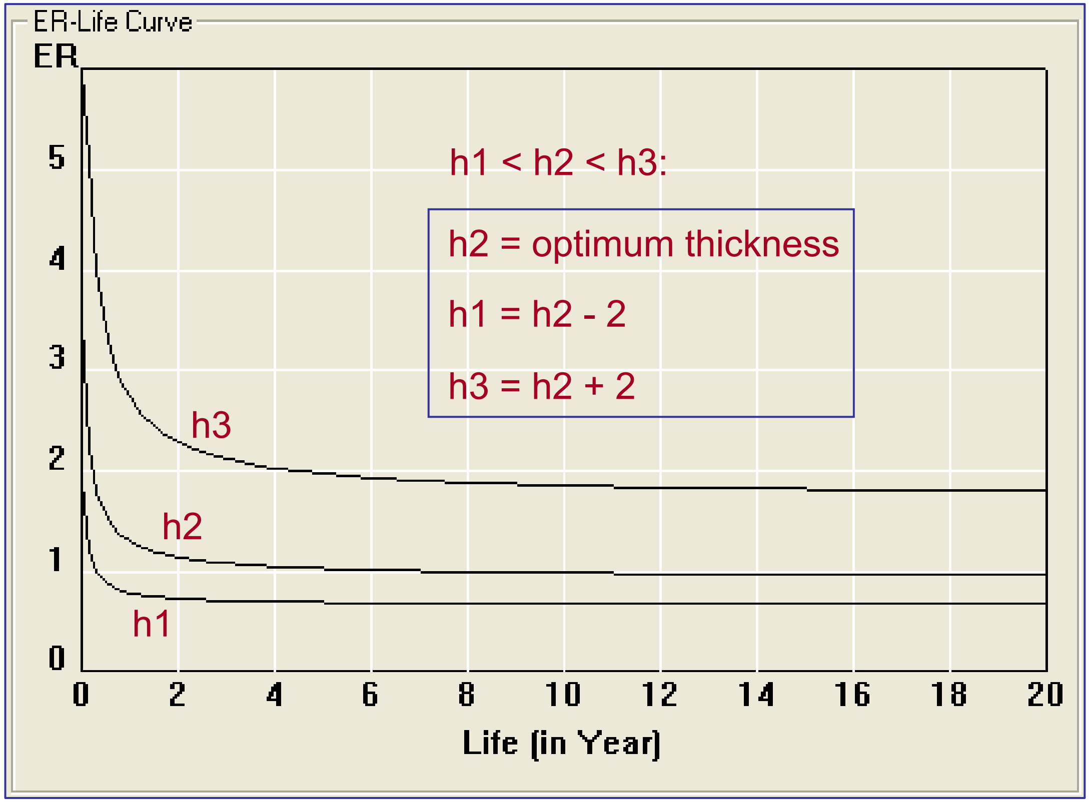


Pavement Life Curve

- 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