AF2903 Road Construction and Maintenance

Mechanistic-Empirical Pavement Design Guide MEPDG (Flexible Pavements)

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Flexible Pavement Design Methods

Fundamental engineering ***mechanics*** as basis for modeling (stress, strain, deformation, fatigue, cumulative damage, etc.).

Empirical data from laboratory and field performance.

M-E Mechanics of materials coupled with observed performance.

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Mechanistic Pavement Design

- Purely scientific approach
- Relies on mechanics of structural behavior to loading
- Fundamental material properties are needed
- Geometric properties of the structure being loaded should also be known
- Example – There is no truly mechanistic pavement design procedure (much work is under way)
- Florida top down crack design tool can be taken as a representative example though much work is still needed

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AASHTO Flexible Pavement Design Review

Development

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS

AASHO Road Test

Late 50’s road test in Illinois

Objective was to determine the relationship between the number of load repetitions with the performance of various pavements

Provided data for the design criteria

Performance Measurements

Establishment of *Functional* performance criteria

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Performance Measurements (cont)

AASHO Road Test performance based on user assessment:

- Difficult to quantify (subjective)
- Highly variable
- Present Serviceability Rating (PSR)

0-1 – V. Poor
1-2 – Poor
2-3 – Fair
3-4 – Good
4-5 – V. Good

A panel of experts drove around in standard vehicles and gave a rating for the pavement

Measurable characteristics (performance indicators):

- Visible distress (cracking & rutting)
- Surface friction
- Roughness (slope variance)

Measure of how much slope varies from horizontal along the direction of traffic

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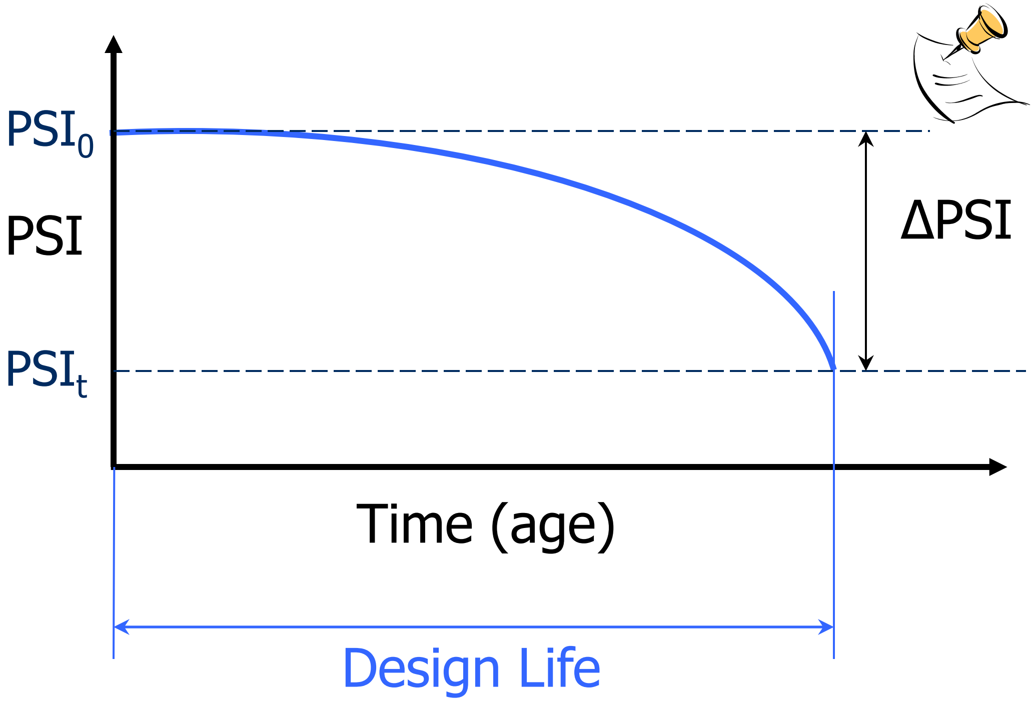
Performance Requirements & Design Life



PSI scale: 1 (V. Poor) → 5 (V. Good)

$\Delta PSI = (PSI_0 - PSI_t)$

Terminal PSI (known) → Pvt is no longer functional

AASHTO performance requirement = ΔPSI

ΔPSI is such that PSI_t is NOT reached before end of design life

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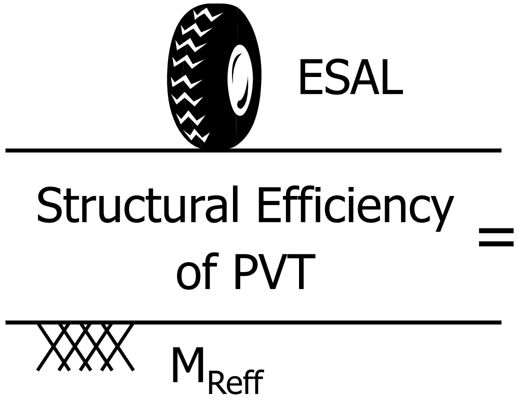
Performance Relation

PERFORMANCE
(ΔPSI)

α



= Structural Number (SN)

What are the three factors affecting performance (ΔPSI)?

$$\Delta PSI = fnc\,(M_{Reff}, SN, ESAL)$$

known known known

Solve for SN

M_{Reff}: Accounts for the environment
SN: Index relating effectiveness of PVT structure

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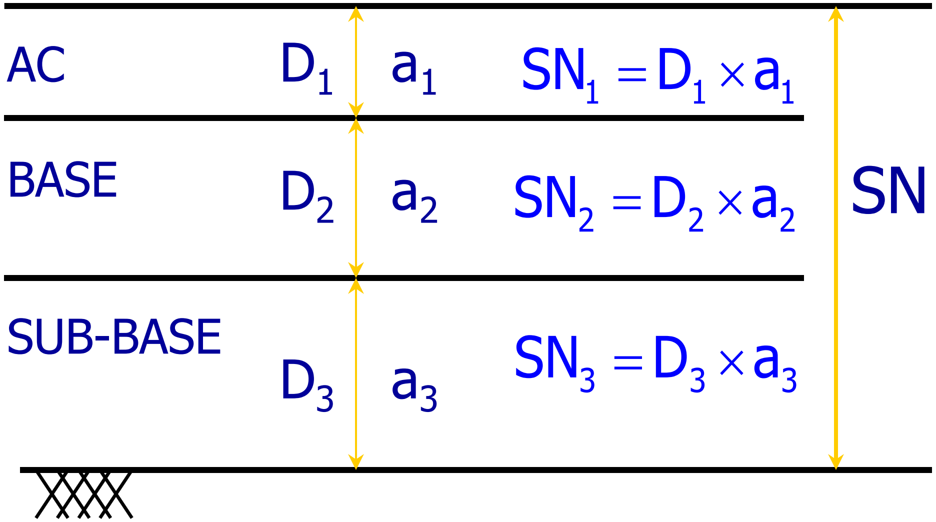
Definition of Structural Number



AC D_1 a_1 $SN_1 = D_1 \times a_1$

BASE D_2 a_2 $SN_2 = D_2 \times a_2$

SUB-BASE D_3 a_3 $SN_3 = D_3 \times a_3$

SN

Structural Coefficient (a):

a = fnc (E, position in PVT)

$$SN = SN_1 + SN_2 + SN_3$$

Basic Procedure:

Determine the traffic (ESAL)

Calculate the effective subgrade modulus (M_{Reff})

Select the performance level (ΔPSI)

Solve for the required SN needed to protect the subgrade

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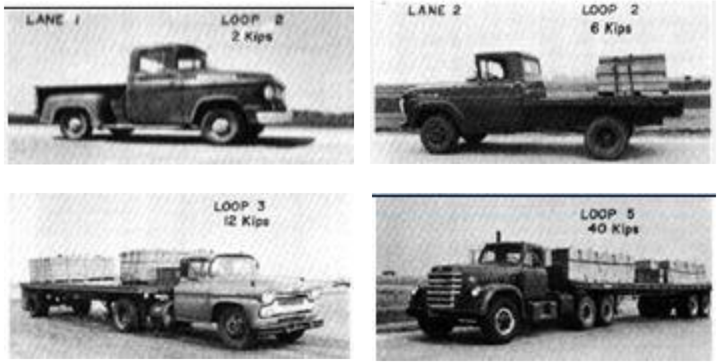
AASHTO Method Limitations

One climatic zone/2 years


A-6 / A-7-6 (Clay)
Poor Drainage

AASHO 1961

One type of subgrade



Vehicle types

Limited trial sections and materials

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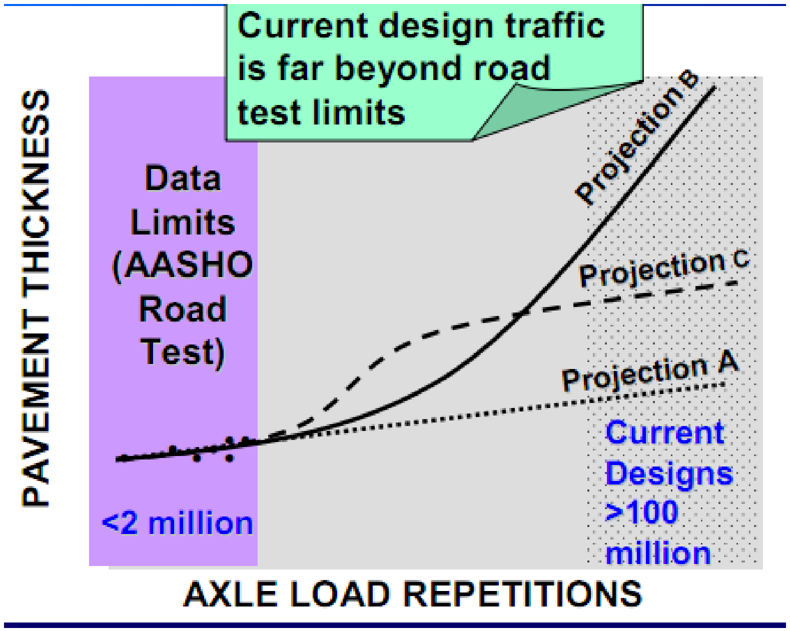
AASHTO Method Limitations

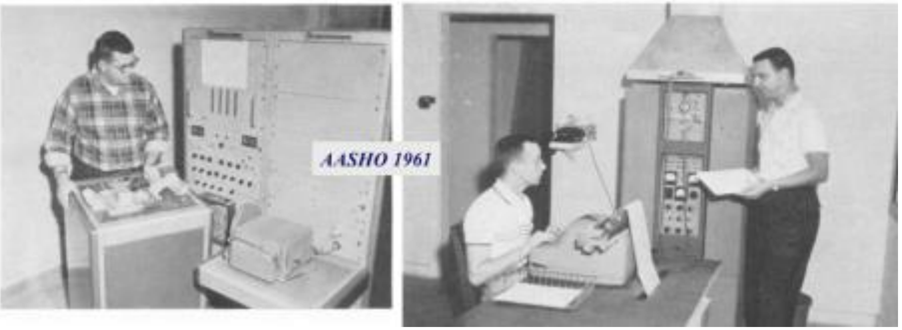


Current design traffic is far beyond road test limits

Number of repetitions

1950's Data Analysis Capabilities...

Technology



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MEPDG Flexible Pavement


NCHRP

M-E PDG

Mechanistic-Empirical Pavement Design Guide

This software is for review only and should not be used for design.
This software was developed under NCHRP 1-37A and 1-40D.
Distribution of this software must be approved by NCHRP.

developed by
APPLIED RESEARCH ASSOCIATES, INC
TRANSPORTATION
ASU

State-Of-The-Art design Guide based on:

- **Fundamental pavement engineering principles**
- **Climatic conditions**
- **Traffic characteristics**
- **Material properties**

It has been calibrated using over 250 pavement sites throughout the US

http://www.trb.org/mepdg/guide.htm

Trial & Error: Propose a trial design, run MEPDG, review performance, & revise as necessary.
Understanding **MEPDG Output tables** & graphs is critical to this process.

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MEPDG Major Advantages

- More robust (better understanding of mechanics of materials)
- Predicts types of distress
- Modular system that allows for incremental enhancement
- Produces a more reliable design
- No longer dependent on the extrapolation of empirical relationships
- Excellent for forensic analysis
- Answers “What if….” questions
- Calibrate to Local Materials, Traffic, Climate….

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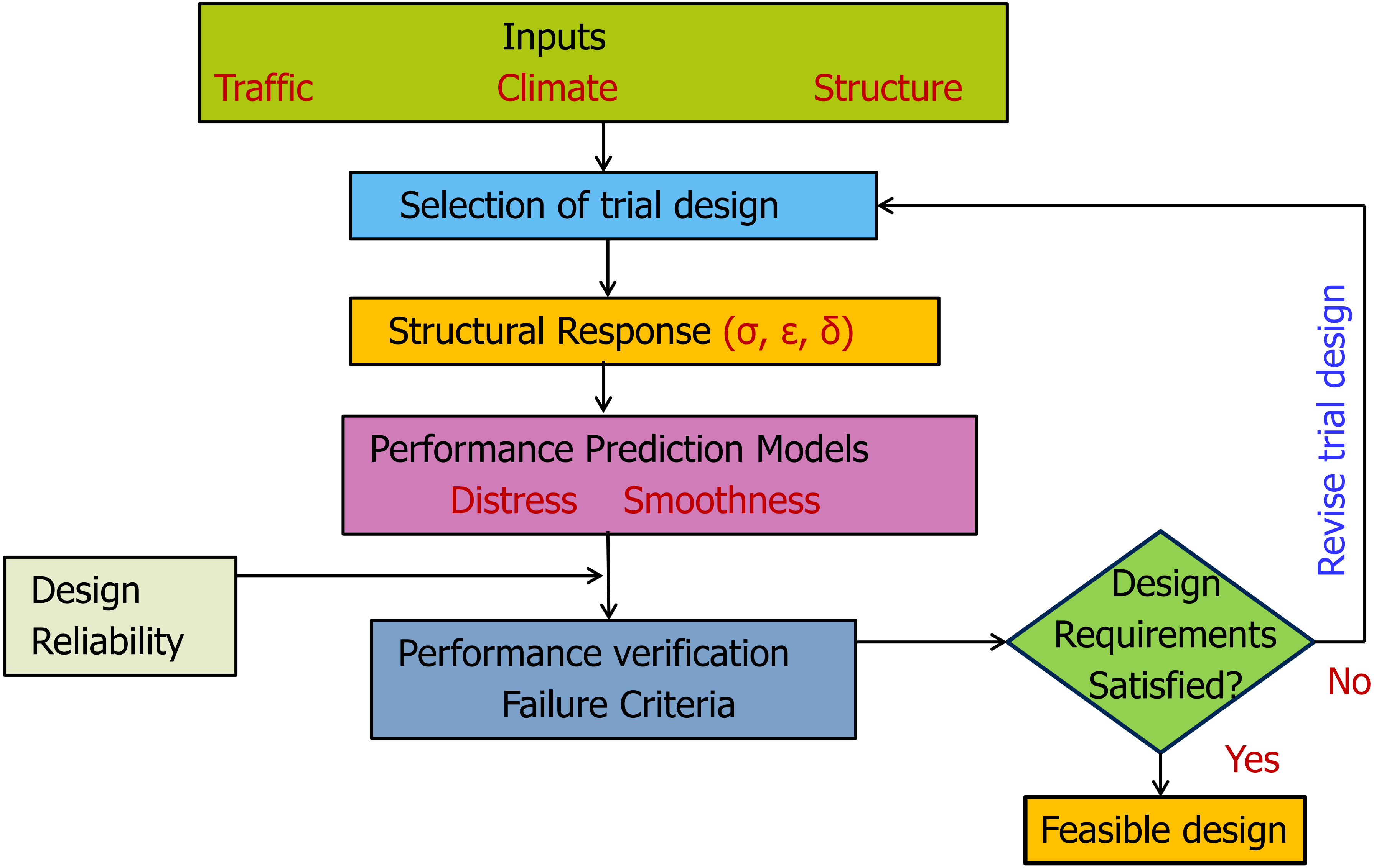
Basic Procedure for M-E Pavement Design



Inputs

Traffic Climate Structure

Selection of trial design

Structural Response (σ, ε, δ)

Performance Prediction Models

Distress Smoothness

Design Reliability

Performance verification

Failure Criteria

Design Requirements Satisfied?

No

Revise trial design

Yes

Feasible design

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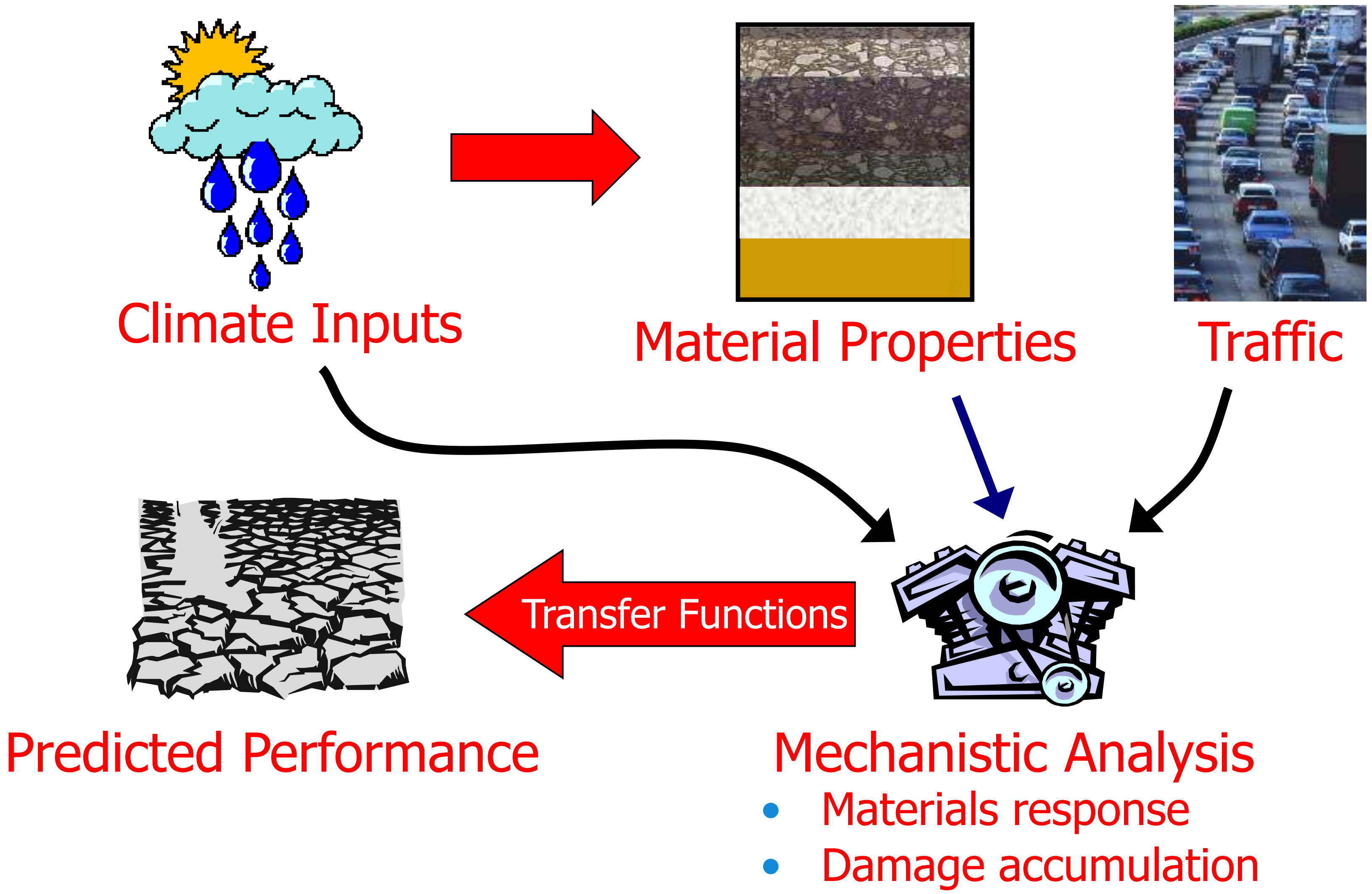
Design Procedure



Climate Inputs

Material Properties

Traffic

Transfer Functions

Predicted Performance

Mechanistic Analysis

- Materials response
- Damage accumulation

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Overview

- Objective
- Justification
- Flexible Pavement Design Process
- Input Levels and Selection
- Required Inputs
- Design Procedure
- Pavement Response Models
- Current Status

MEPDG Objective

"The overall objective of the Guide for the Mechanistic-Empirical Design for New and Rehabilitated Pavement Structures is to provide the highway community with a state-of-the-practice tool for the design and rehabilitated pavement structures, based on mechanistic-empirical principles."

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Justification for a New Design Guide

- Rehabilitation
- Climate
- Soils
- Surface Material – HMA & PCC
- Truck Characteristics
- Design Life – short duration of road test
- Performance
- Reliability – AASHTO 1986 guide

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MEPDG Flexible Pavement

Flexible Pavements

- Conventional
- Deep Strength
- Full Depth
- “Semi-Rigid”
- Inverted

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Input Level Selection

- Sensitivity of the pavement performance to a given input
- Criticality of the project
- Information available at the time of design
- Resources and time available to the designer to obtain the inputs

Inputs

- General information
- Site/Project Identification
- Analysis Parameters
- Traffic
- Climate
- Drainage and Surface Properties
- Pavement Structure

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Inputs - General Information

- Design Life
- Base/subgrade construction month
- Pavement construction month
- Traffic opening month

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Inputs - Site/Project Identification

- Project Location
- Project Identification
- Functional Class
  - Principal Arterial – Interstate & Defense routes
  - Principal Arterial – Other
  - Minor Arterial
  - Major Collector
  - Minor Collector
  - Local Routes & Streets

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Inputs - Analysis Parameters

- Initial IRI
- Performance Criteria
  - Surface-down fatigue cracking
  - Bottom-up fatigue cracking
  - Thermal cracking
  - Fatigue fracture of chemically stabilized layers
  - Total permanent deformation
  - Smoothness

Input - Traffic Input Levels

- Level 1
  - Site specific vehicle classification & axle weight data
- Level 2
  - Site specific vehicle classification & regional axle weight data
- Level 3
  - Regional vehicle classification & axle weight data
- Level 4
  - Default vehicle classification & axle load distribution

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Input - Traffic Module Data Analysis

- Weigh in Motion (WIM)
- Automatic Vehicle Classification (AVC)
- Vehicle counts
- Two-way AADT
- Percentage of trucks in design lane
- Operational speed
- Monthly adjustment factors
- Reasonable assumptions about number of axles & axle spacing for each truck class
- Tire inflation pressure & wheel wander data

Input - Truck Traffic Classification

Functional Classification

Distribution of trucks

- TTC 1 – Major Single-Trailer Truck Route (Type I)
- TTC 2 – Major Single-Trailer Truck Route (Type II)
- TTC 3 – Major Single- and Multi- Trailer Truck Route (Type I)
- TTC 4 – Major Single-Trailer Truck Route (Type III)
- TTC 5 – Major Single- and Multi- Trailer Truck Route (Type II)
- TTC 6 – Intermediate Light and Single-Trailer Truck Route (I)
- TTC 7 – Major Mixed Truck Route (Type I)
- TTC 8 – Major Multi-Trailer Truck Route (Type I)
- TTC 9 – Intermediate Light and Single-Trailer Truck Route (II)
- TTC 10 – Major Mixed Truck Route (Type II)
- TTC 11 – Major Multi-Trailer Truck Route (Type II)
- TTC 12 – Intermediate Light and Single-Trailer Truck Route (III)
- TTC 13 – Major Mixed Truck Route (Type III)
- TTC 14 – Major Light Truck Route (Type I)
- TTC 15 – Major Light Truck Route (Type II)
- TTC 16 – Major Light and Multi-Trailer Truck Route
- TTC 17 – Major Bus Route

Input - Traffic Module Data Analysis

Loading details

- Tire pressures
- Tire & axle load
- Axle & tire spacing
- Average number of axles
- per vehicle classification

Traffic factors

- Time distribution factors
- Weekday & Weekend truck factors
- Directional Distribution
- Lane Distribution
- Lateral Distribution
- Traffic growth function

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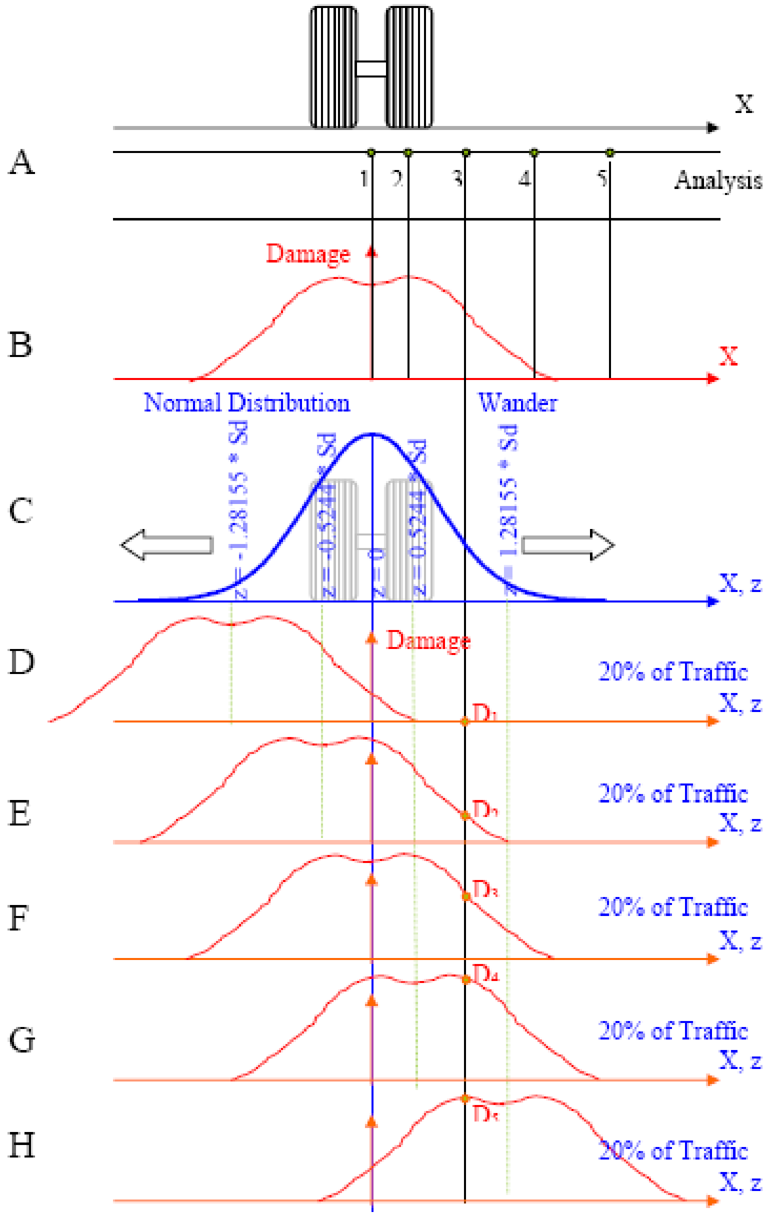
Input - Traffic Module Data Analysis

Accounts for the wander of trucks across one lane of traffic



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Input - Climate

- Weather information
  - Hourly air temperature
  - Hourly precipitation
  - Hourly wind speed
  - Hourly percentage of sunshine
  - Hourly ambient relative humidity
  - Seasonal or constant water table depth

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Input - Drainage & Surface Properties

- Pavement shortwave absorptivity
  - Ratio of the amount of solar energy absorbed by the pavement surface
  - Typical values
    - 0.80-0.90 for weathered
    - 0.90-0.98 for new pavement
- Potential for Infiltration
  - Recommend subdrainage
- Pavement cross slope
- Length of drainage path

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Input - Pavement Structure

Layer Properties

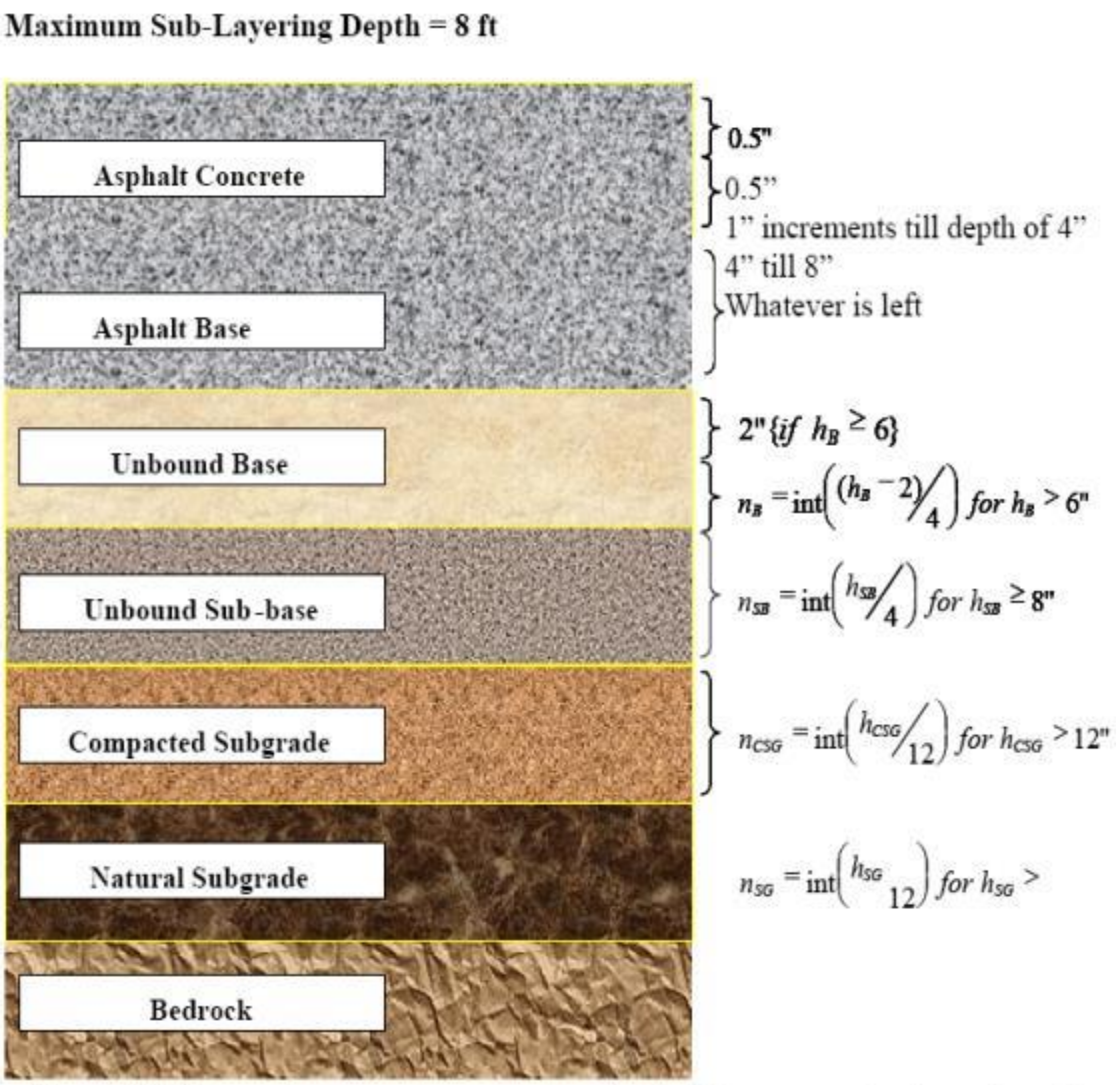
- Defined by user

  4-6 layers

  Maximum of 10 is recommended

- Subdivide layers

  12-15 sub layers



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Input - Pavement Structure

- Asphalt Concrete & Asphalt Stabilized layers
  - Specify maximum of 3 HMA layers
  - Asphalt aging modeled only for top sub layer
  - Layer inputs
    - Layer thickness
    - Poisson's ratio
    - Thermal conductivity
    - Heat capacity
    - Total unit weight

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Input - Pavement Structure

- Dynamic Modulus, E*
  - *Stiffness*
  - Property function of:
    - Temperature
    - rate of loading
    - Age
    - binder stiffness
    - aggregate gradation
    - binder content
    - air voids

- *Inputs*
  - Asphalt mixture properties
  - Asphalt binder
  - Air voids

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Input - Pavement Structure

- Bedrock
  - Presence within 10 feet of the pavement surface influences the structural response of the pavement layers
  - *Inputs*
    - Layer thickness (infinite)
    - Unit weight
    - Poisson’s ratio
    - Layer modulus

Design Procedure

Predict a variety of distress types

- Asphalt fatigue facture
- Permanent deformation
- HMA thermal fracture
- Load associated fatigue fracture of chemically
- stabilized layers

Design Procedure

Performance criteria

Rutting

Cracking

Roughness (IRI)

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Design Procedure

- Select an initial trial pavement structure
- Identify pavement cross section
- Specify layer material types & thickness
- Is Seasonal Analysis required?

NO – constant values for modulus & Poisson's ratio

YES – Two options

  - Enhanced Integrated Climatic Model (EICM)
  - Monthly Seasonal values

Pavement Response Models

- Determines structural responses of the pavement system
- Outputs are the stresses, strains and displacements within the pavement layers
  - Tensile horizontal strain at the bottom of the HMA layer
  - Compressive vertical stresses/strains within the HMA layer
  - Compressive vertical stresses/strains within the base/subbase layers
  - Compressive vertical stresses/strains at the top of the subgrade

Pavement Response Models

Fatigue life prediction based on horizontal strain at the bottom of AC layer

$$N_f = f_1 (\varepsilon_t)^{-f_2} (E_1)^{-f_3}$$

f_1 = Laboratory to field shift factor
f_2 & f_3 = Determined from fatigue tests on lab specimen

Rutting life prediction based on vertical strain at the top of subgrade

$$N_f = f_4 (\varepsilon_c)^{-f_5}$$

f_4 & f_5 = Determined from fatigue tests on lab specimen

Asphalt Institute equation

$$N_f = 0.0796 (\varepsilon_t)^{-3.291} (E_1)^{-0.854}$$

$$N_d = 1.365 * 10^{-9} (\varepsilon_c)^{4.477}$$

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Pavement Response Models

Fatigue Cracking

- Both top-down & bottom-up
- Based on calculating the fatigue damage at the surface & at the bottom of each asphalt layer
- Based upon Miner's Law

$$D = \sum_{i=1}^{T} \frac{n_i}{N_i}$$

where:

D = damage.
T = total number of periods.
n_i = actual traffic for period i.
N_i = traffic allowed under conditions prevailing in i.

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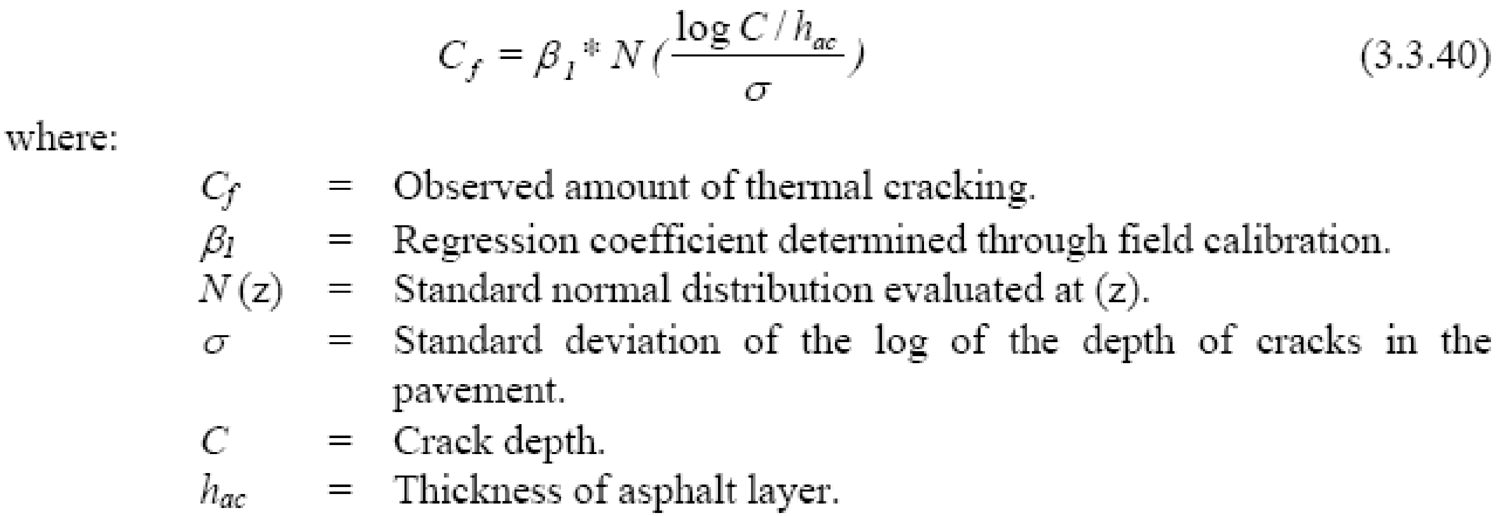
Pavement Response Models

Thermal Fracture

Amount of transverse cracking expected is predicted by relating the crack depth to the amount of cracking present.

Enhanced version of model developed by the SHRP A-005 research contract.



$$C_f = \beta_1 * N\left(\frac{\log C / h_{ac}}{\sigma}\right) \qquad (3.3.40)$$

where:

C_f = Observed amount of thermal cracking.
β_1 = Regression coefficient determined through field calibration.
$N(z)$ = Standard normal distribution evaluated at (z).
σ = Standard deviation of the log of the depth of cracks in the pavement.
C = Crack depth.
h_{ac} = Thickness of asphalt layer.

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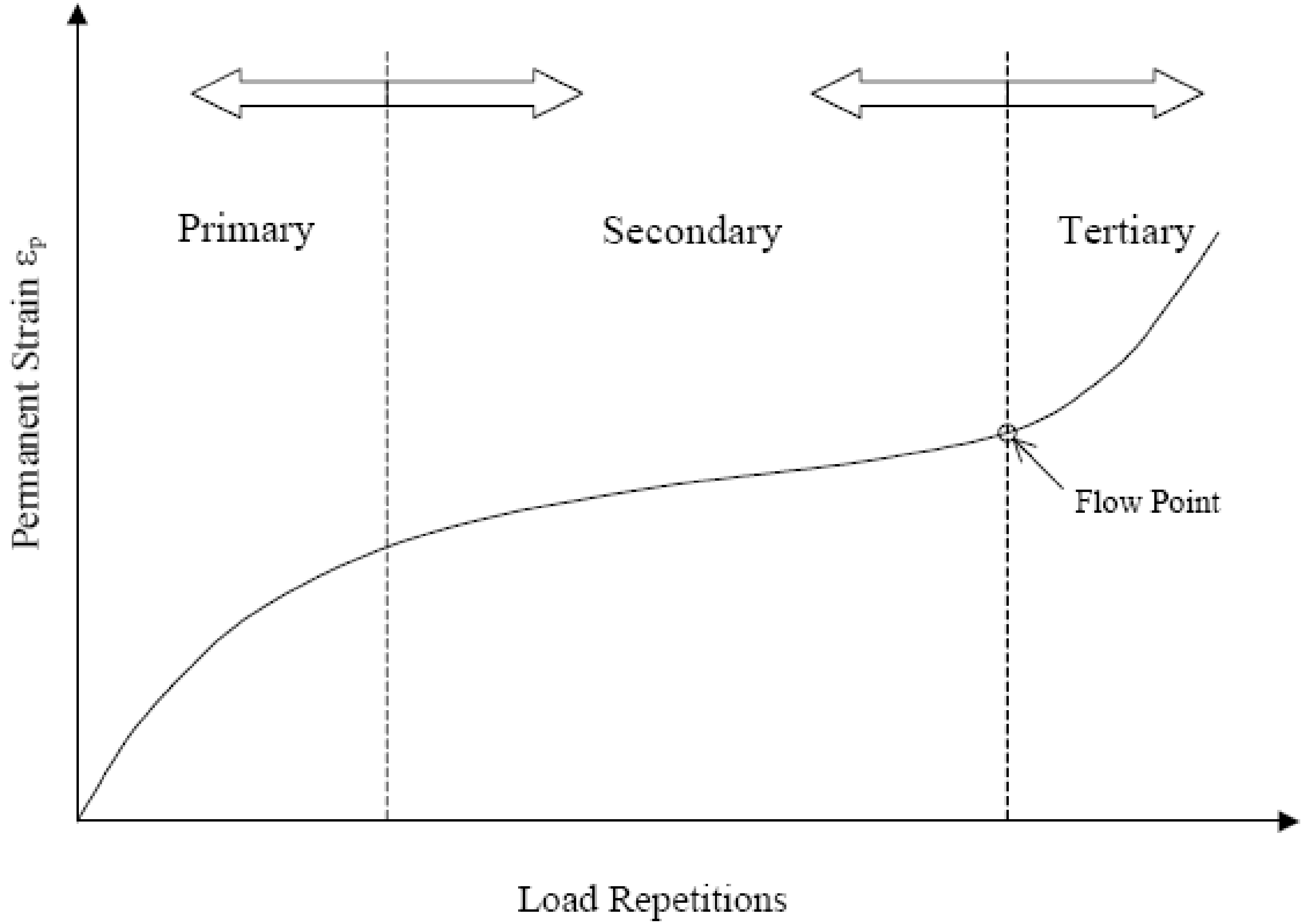
Pavement Response Models

Permanent Deformation

3 distinct stages of rutting behavior



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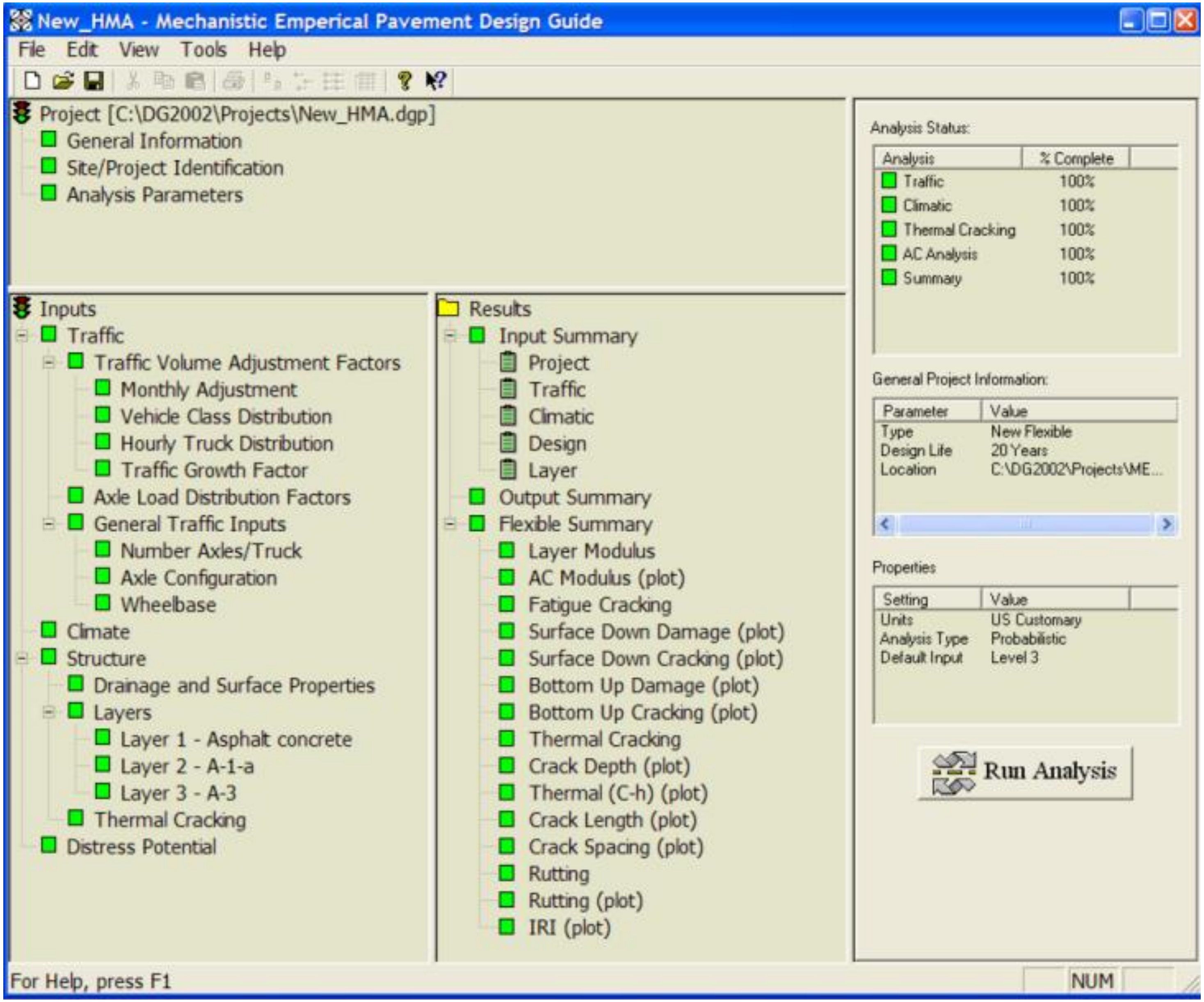
MEPDG Software



Analysis Status:

Analysis	% Complete
🟩 Traffic	100%
🟩 Climatic	100%
🟩 Thermal Cracking	100%
🟩 AC Analysis	100%
🟩 Summary	100%

General Project Information:

Parameter	Value
Type	New Flexible
Design Life	20 Years
Location	C:\DG2002\Projects\ME...

Properties

Setting	Value
Units	US Customary
Analysis Type	Probabilistic
Default Input	Level 3

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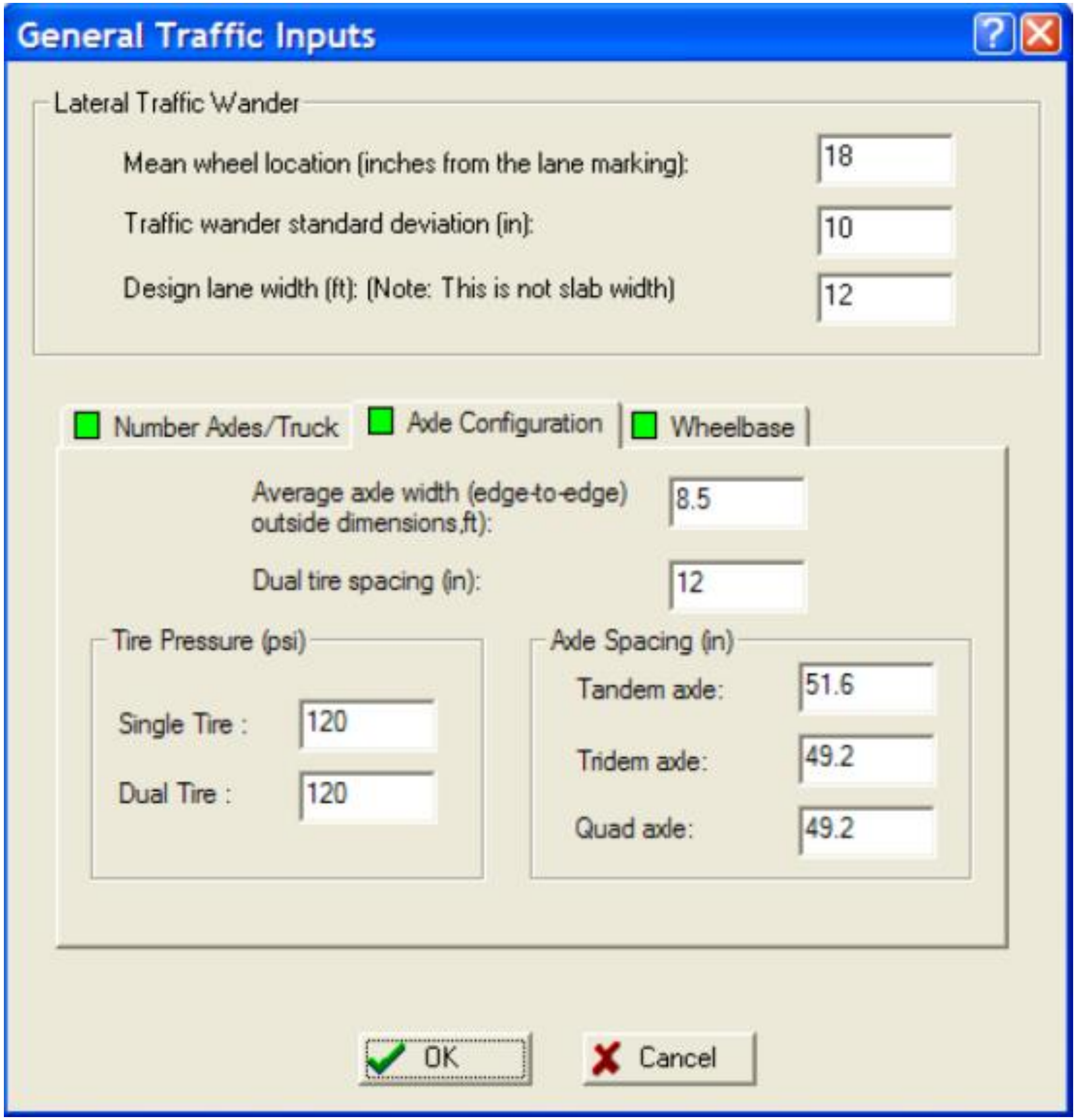

General Traffic Inputs

Lateral Traffic Wander

Mean wheel location (inches from the lane marking): 18

Traffic wander standard deviation (in): 10

Design lane width (ft): (Note: This is not slab width) 12

Average axle width (edge-to-edge) outside dimensions,ft): 8.5

Dual tire spacing (in): 12

Tire Pressure (psi)

Single Tire : 120

Dual Tire : 120

Axle Spacing (in)

Tandem axle: 51.6

Tridem axle: 49.2

Quad axle: 49.2

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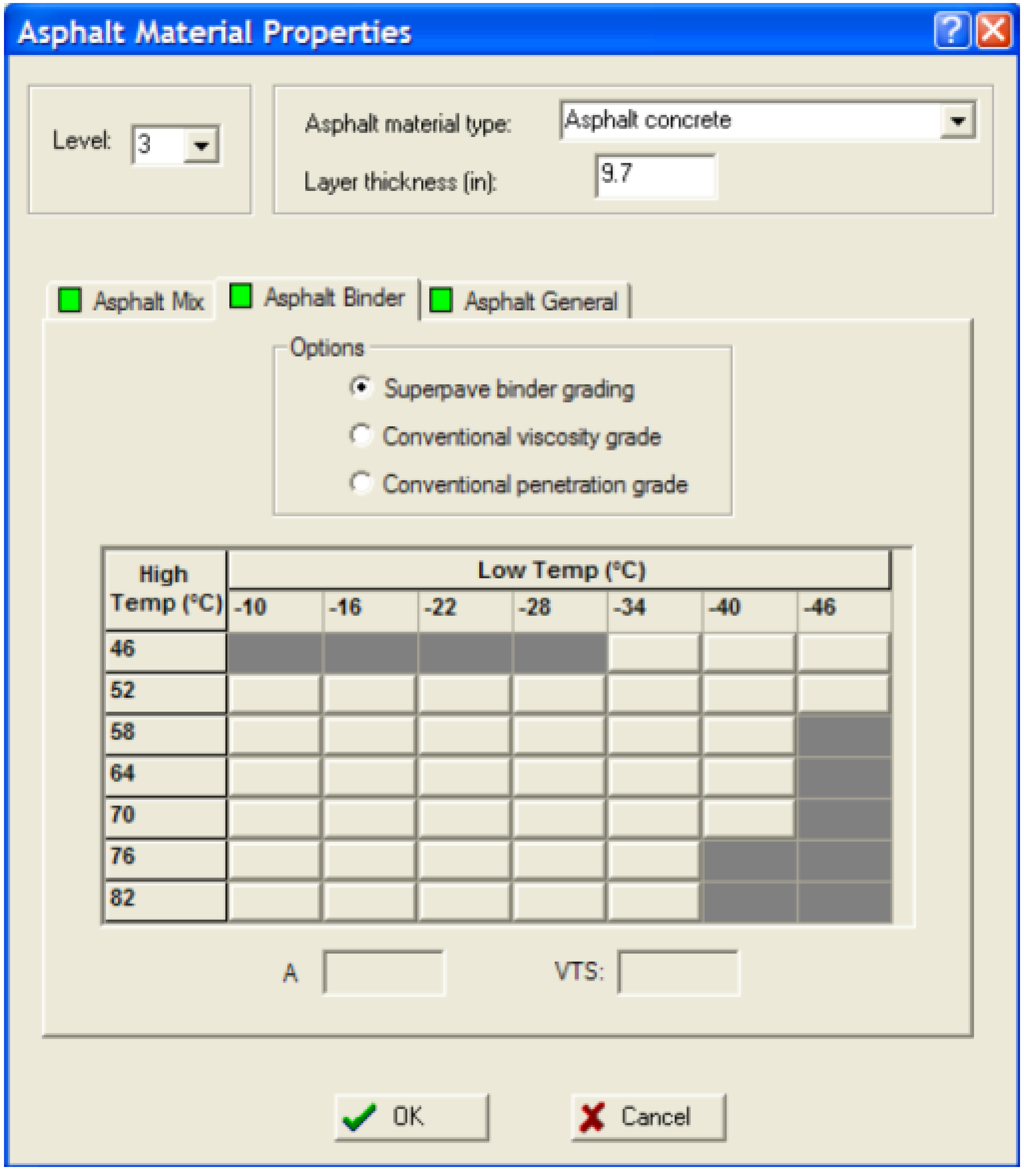

Asphalt Material Properties

Level: 3

Asphalt material type: Asphalt concrete

Layer thickness (in): 9.7

Options

● Superpave binder grading

○ Conventional viscosity grade

○ Conventional penetration grade

High Temp (°C)	Low Temp (°C)						
	-10	-16	-22	-28	-34	-40	-46
46	▨	▨	▨	▨			
52							
58							▨
64							▨
70							▨
76						▨	▨
82						▨	▨

A

VTS:

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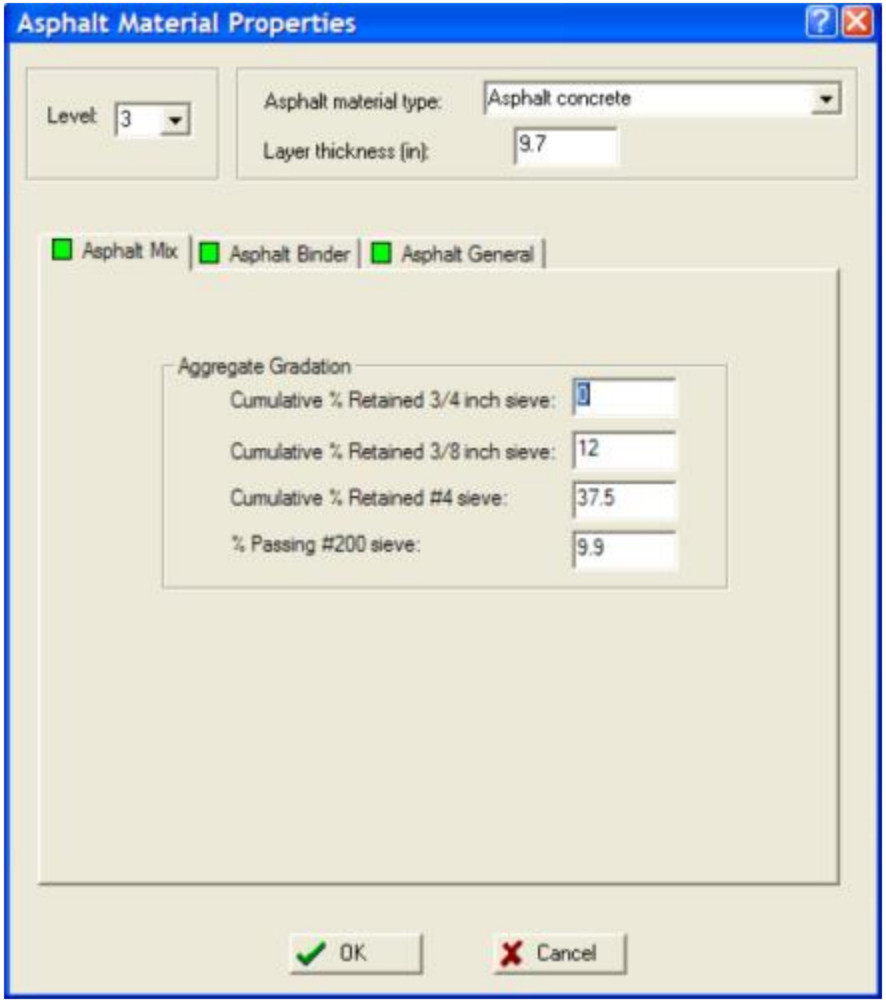


Level: 3

Asphalt material type: Asphalt concrete

Layer thickness (in): 9.7

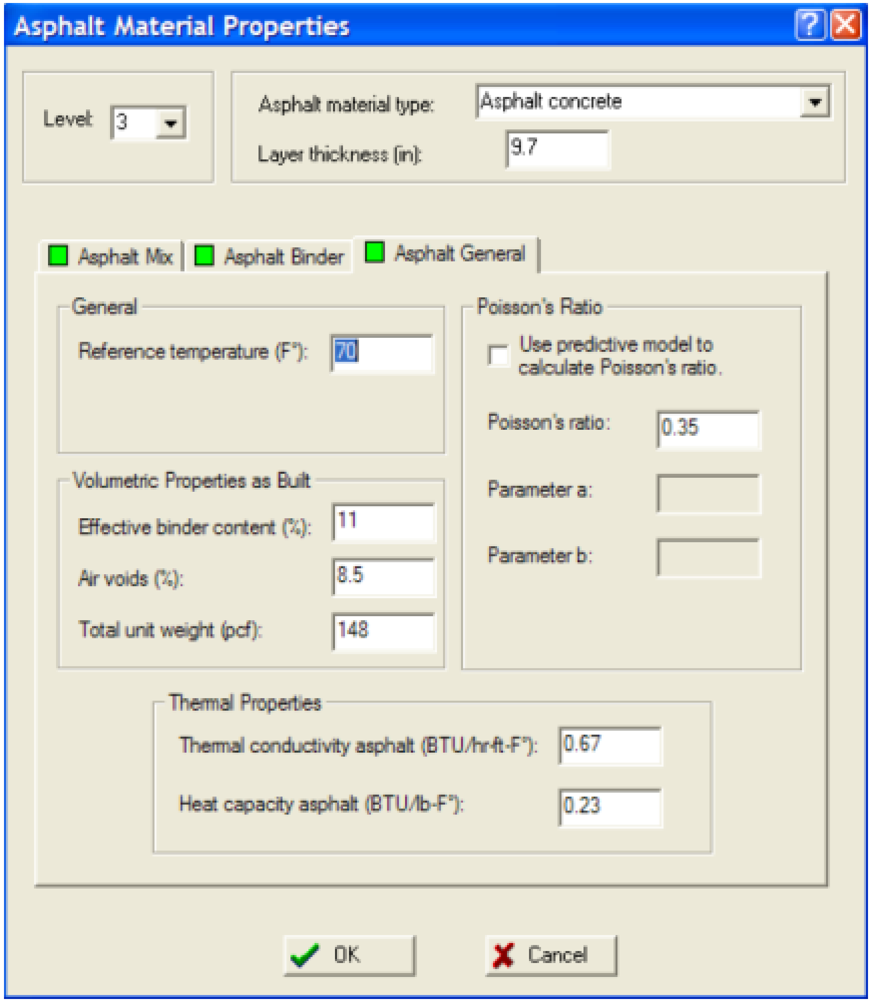
Aggregate Gradation

Cumulative % Retained 3/4 inch sieve: 0

Cumulative % Retained 3/8 inch sieve: 12

Cumulative % Retained #4 sieve: 37.5

% Passing #200 sieve: 9.9



Level: 3

Asphalt material type: Asphalt concrete

Layer thickness (in): 9.7

General

Reference temperature (F°): 70

Volumetric Properties as Built

Effective binder content (%): 11

Air voids (%): 8.5

Total unit weight (pcf): 148

Poisson's Ratio

☐ Use predictive model to calculate Poisson's ratio.

Poisson's ratio: 0.35

Parameter a:

Parameter b:

Thermal Properties

Thermal conductivity asphalt (BTU/hr-ft-F°): 0.67

Heat capacity asphalt (BTU/lb-F°): 0.23

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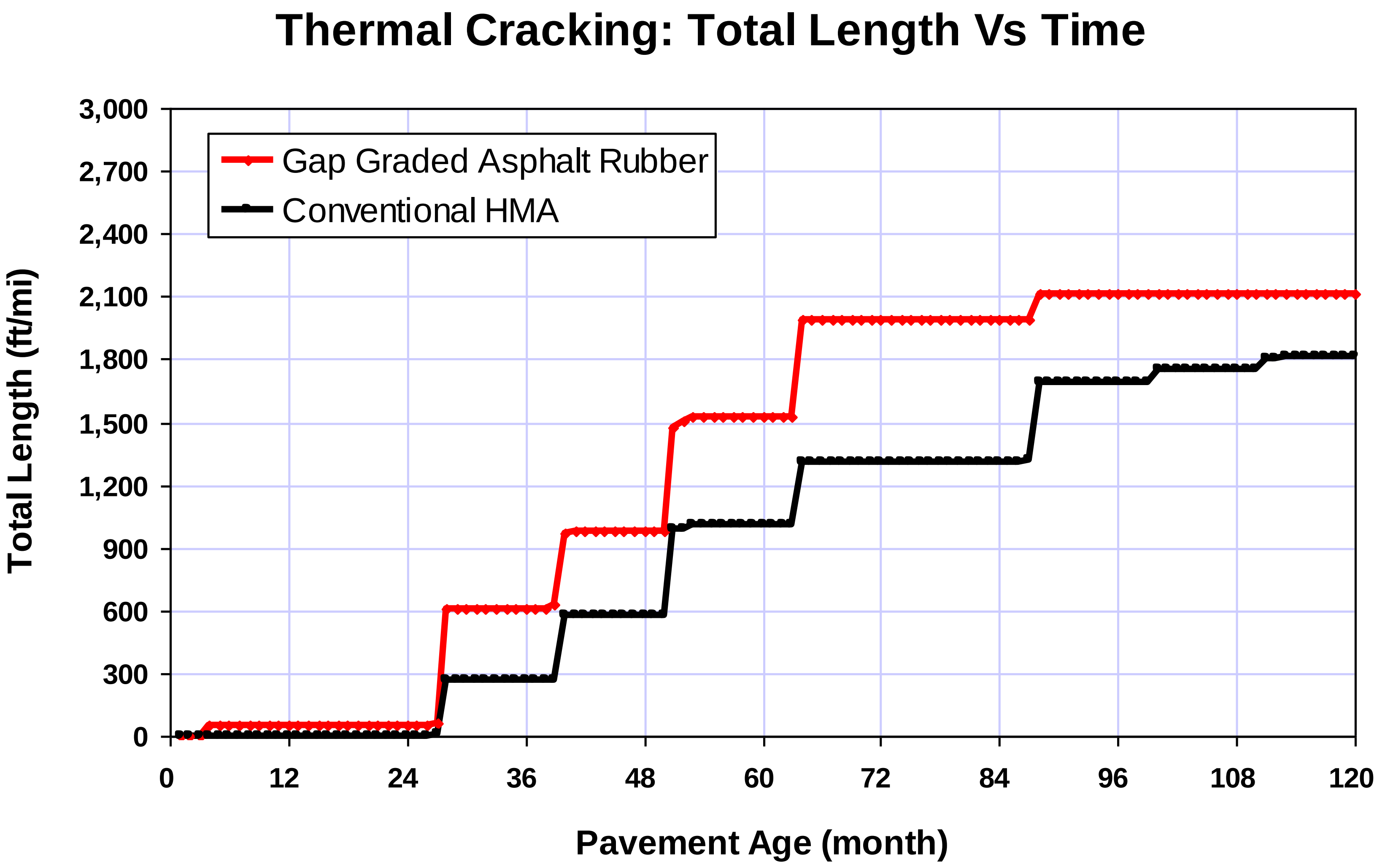
MEPDG Prediction Models



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MEPDG Prediction Models

QUESTIONS

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