# 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.

# 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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## 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

## 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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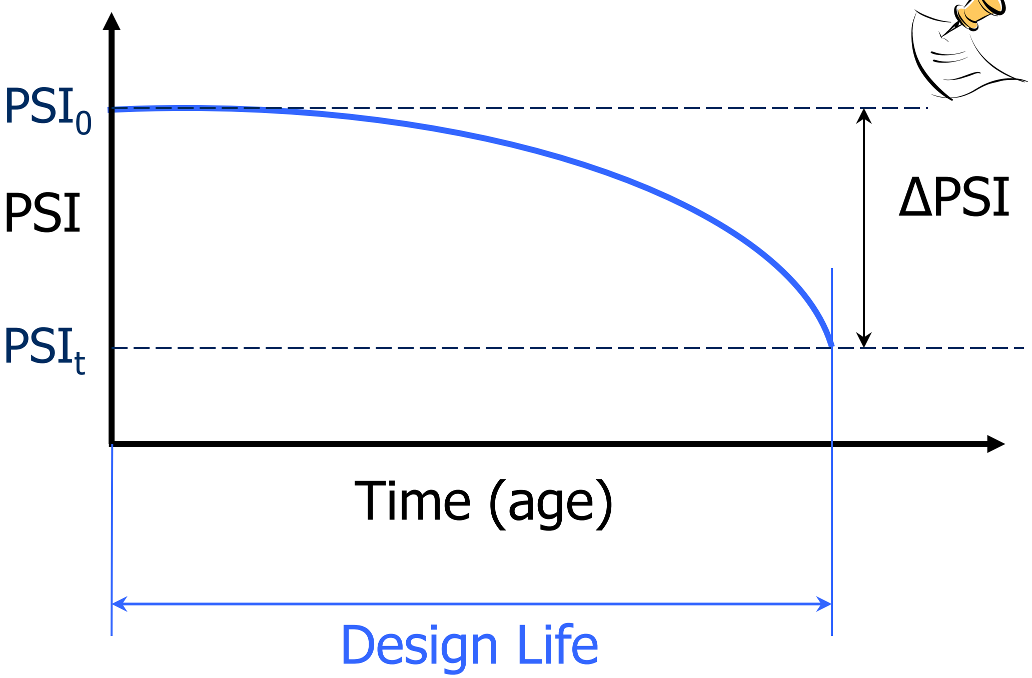
# Performance Requirements & Design Life

PSI scale: 1 (V. Poor) → 5 (V. Good)




Terminal PSI (known) → Pvt is no longer functional

**AASHTO performance requirement = $\Delta PSI$**

$\Delta PSI$ is such that $PSI_t$ is NOT reached before end of design life

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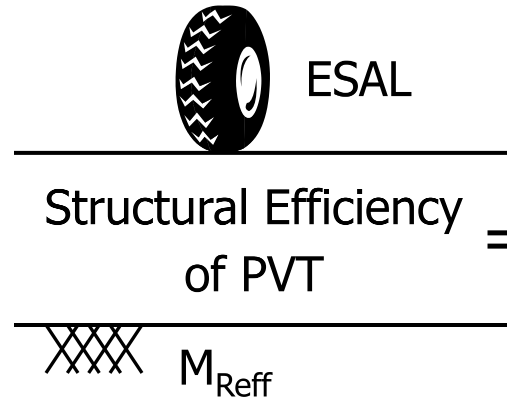
## Performance Relation

PERFORMANCE ($\Delta$PSI) $\alpha$




= Structural Number (SN)

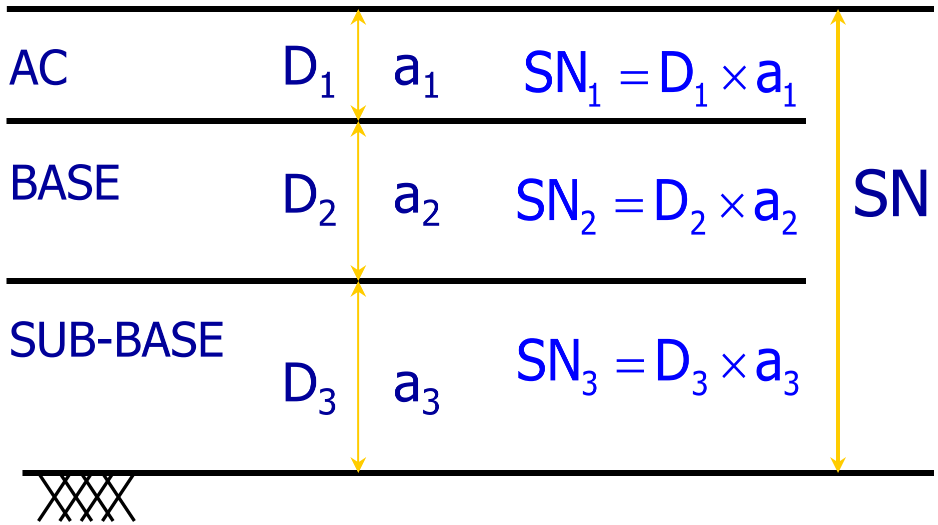
What are the three factors affecting performance ($\Delta$PSI)?

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

- $\Delta PSI$: known
- $M_{Reff}$: known
- ESAL: known
- SN: Solve for SN

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

## Definition of Structural Number




## 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 ($M_{Reff}$)

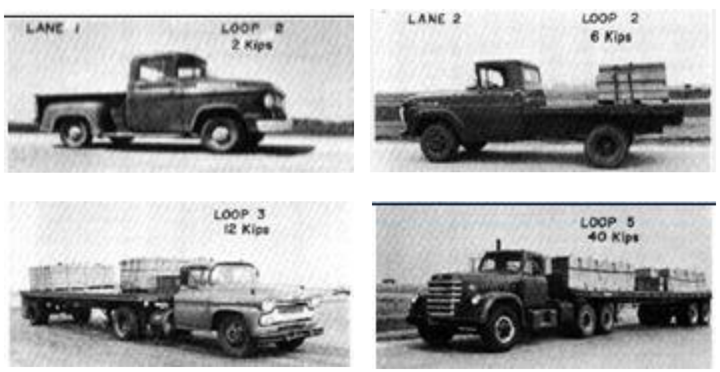
Select the performance level ($\Delta PSI$)

Solve for the required SN needed to protect the subgrade

# AASHTO Method Limitations


One climatic zone/2 years


One type of subgrade




Vehicle types

Limited trial sections and materials

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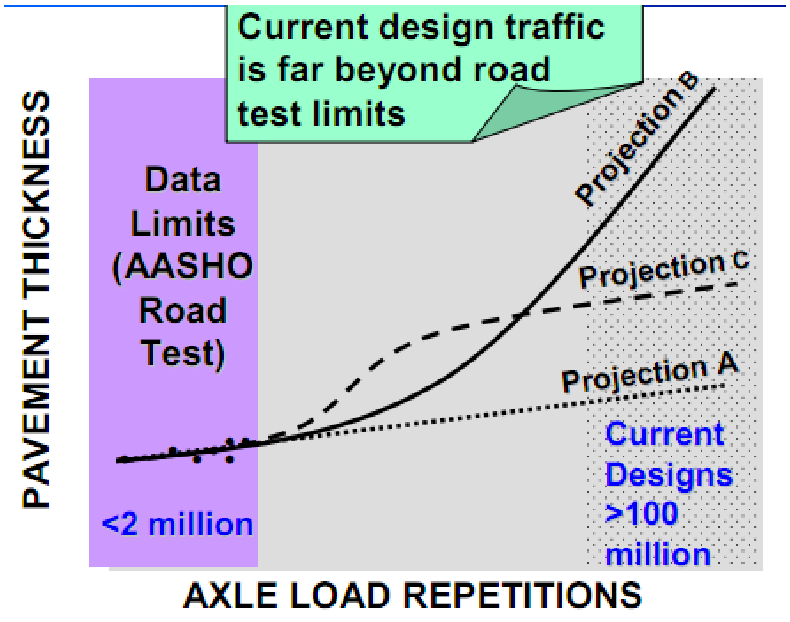
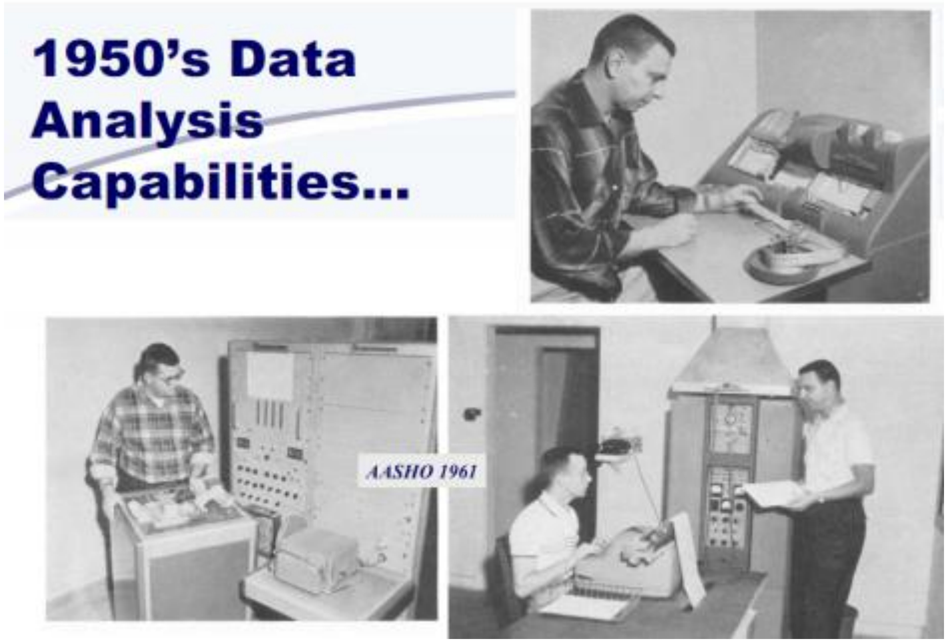
# AASHTO Method Limitations




**Number of repetitions**




**Technology**

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**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**

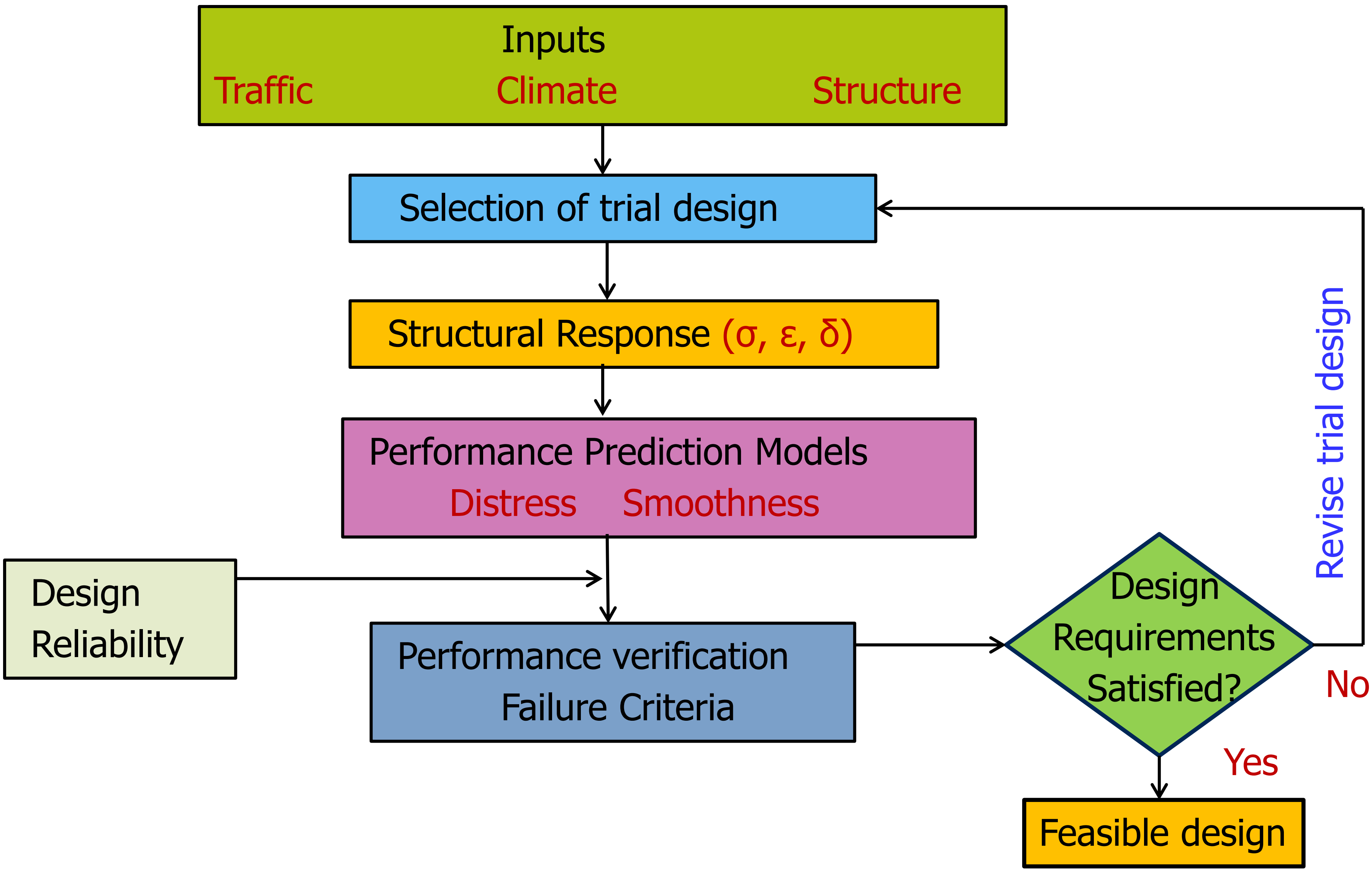
http://www.trb.org/mepdg/guide.htm

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

# 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….

# Basic Procedure for M-E Pavement Design

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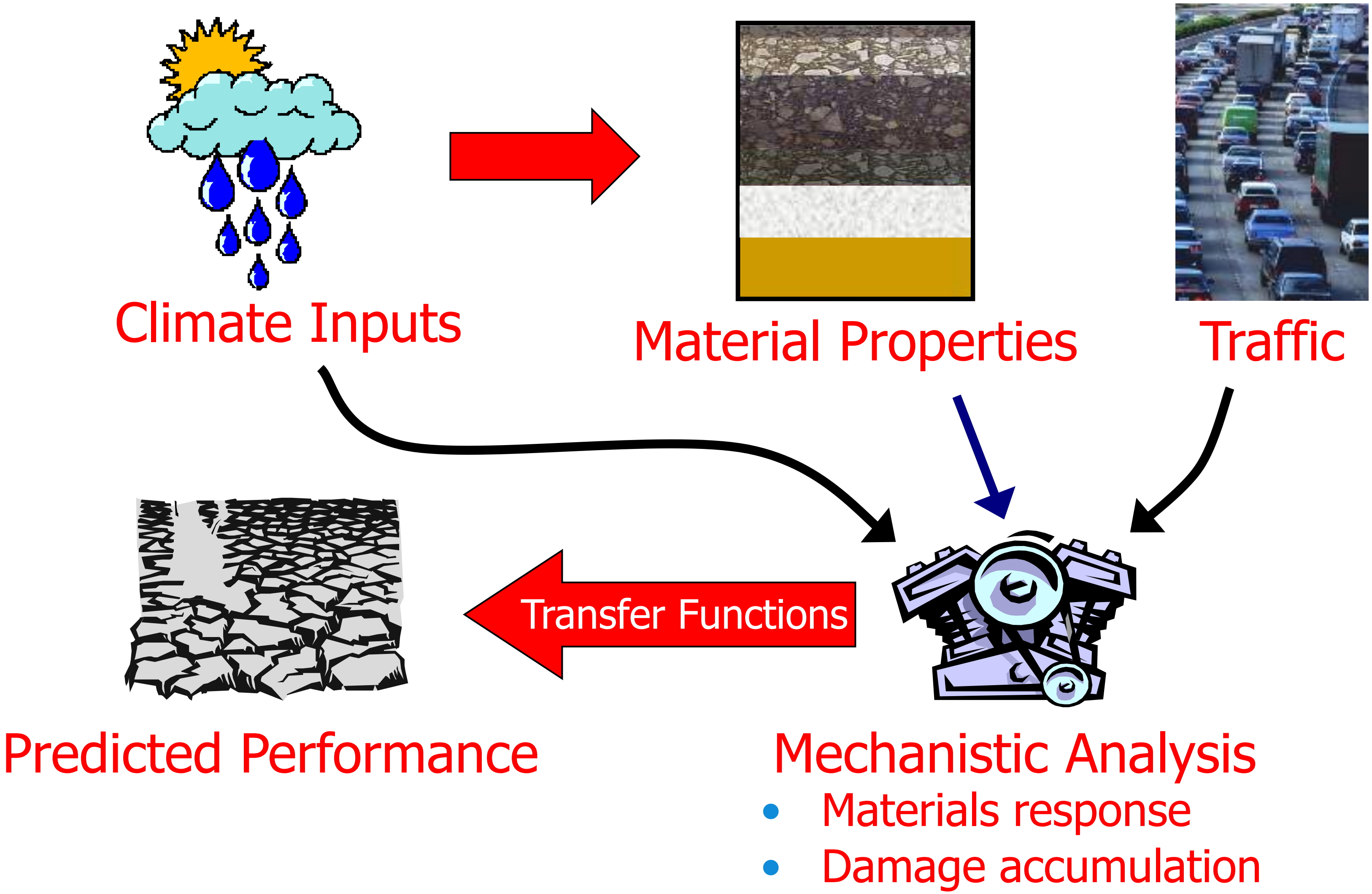
# Design Procedure



# Overview

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

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# 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."

# 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

# 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

# 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

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# 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

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# 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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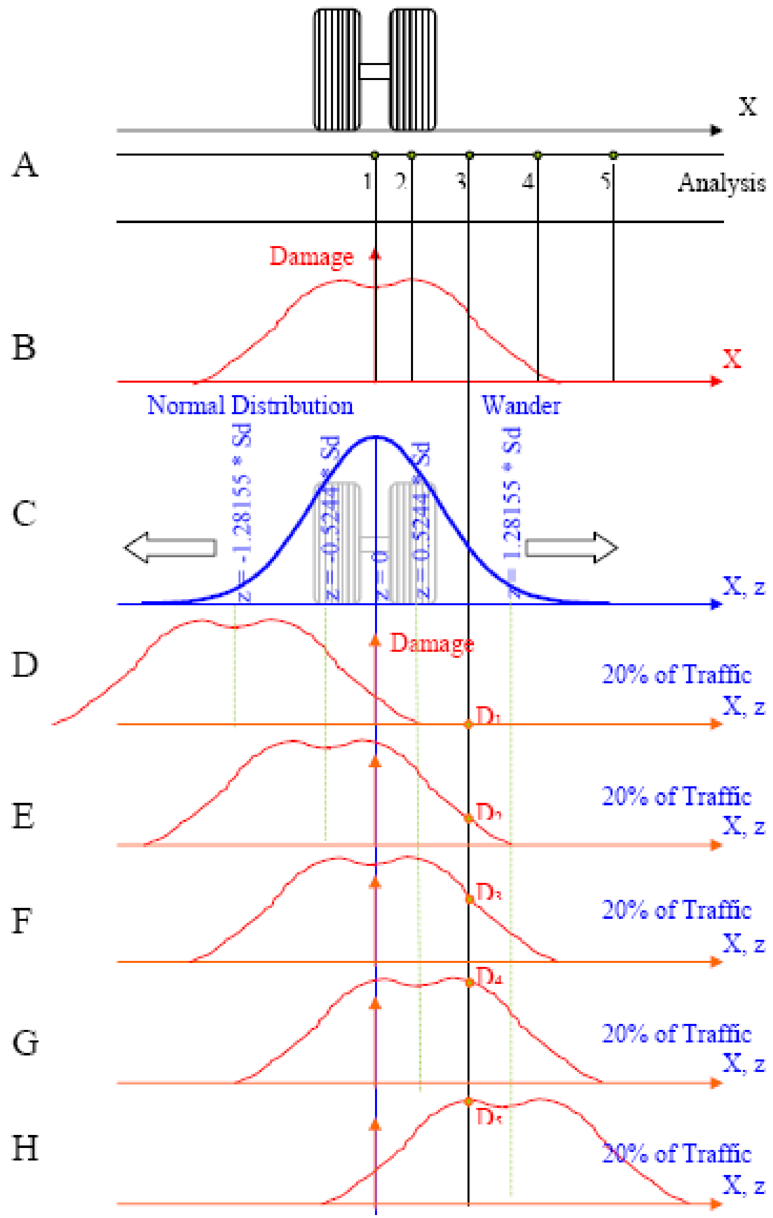
# Input - Traffic Module Data Analysis

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

# 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

# Input - Pavement Structure

## Layer Properties

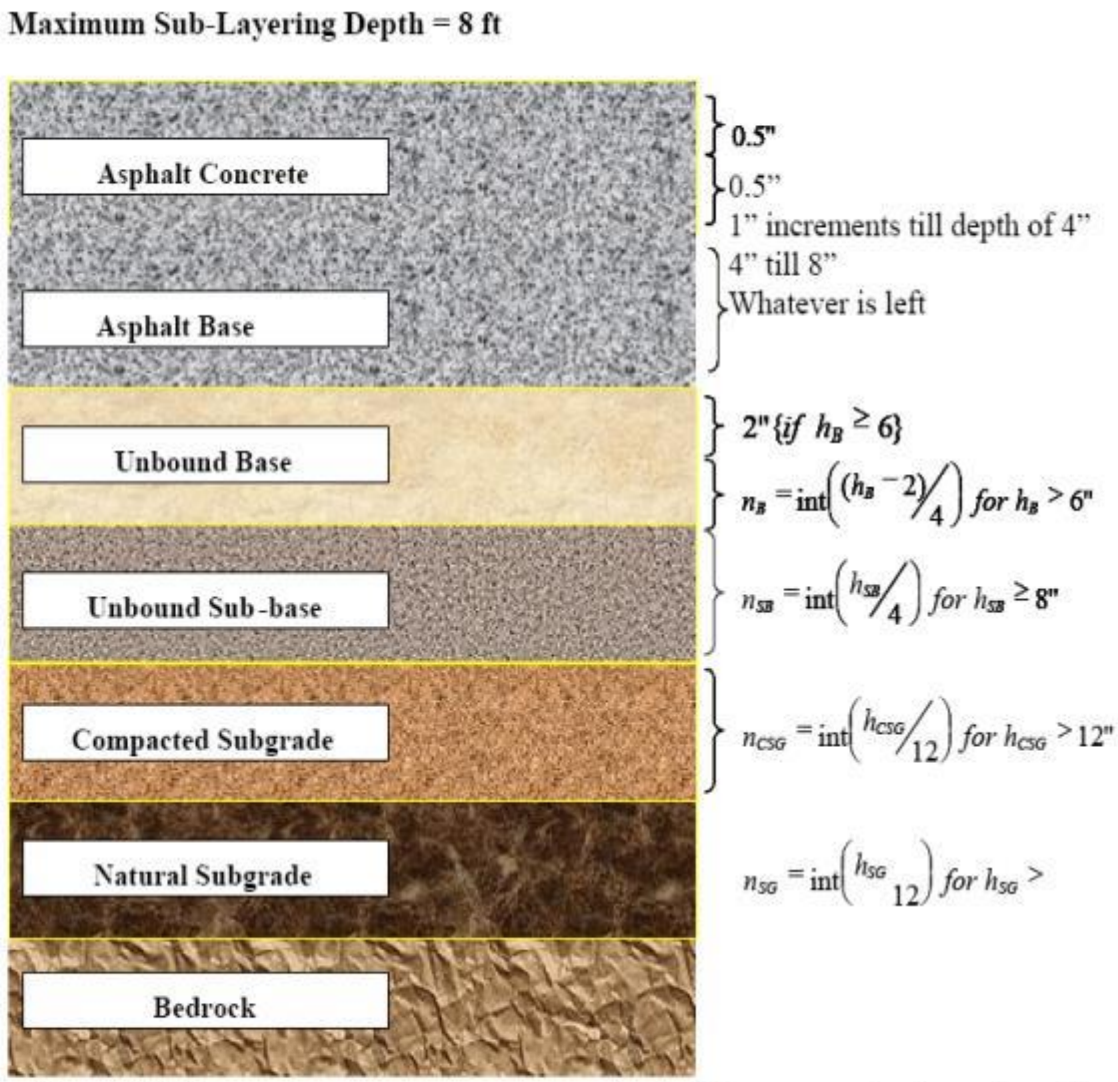
- Defined by user

  4-6 layers

  Maximum of 10 is recommended

- Subdivide layers

  12-15 sub layers



# 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

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# 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

## 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

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

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

# 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 $i$.

## 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. |
| $\beta_1$ | = | Regression coefficient determined through field calibration. |
| $N(z)$ | = | Standard normal distribution evaluated at (z). |
| $\sigma$ | = | 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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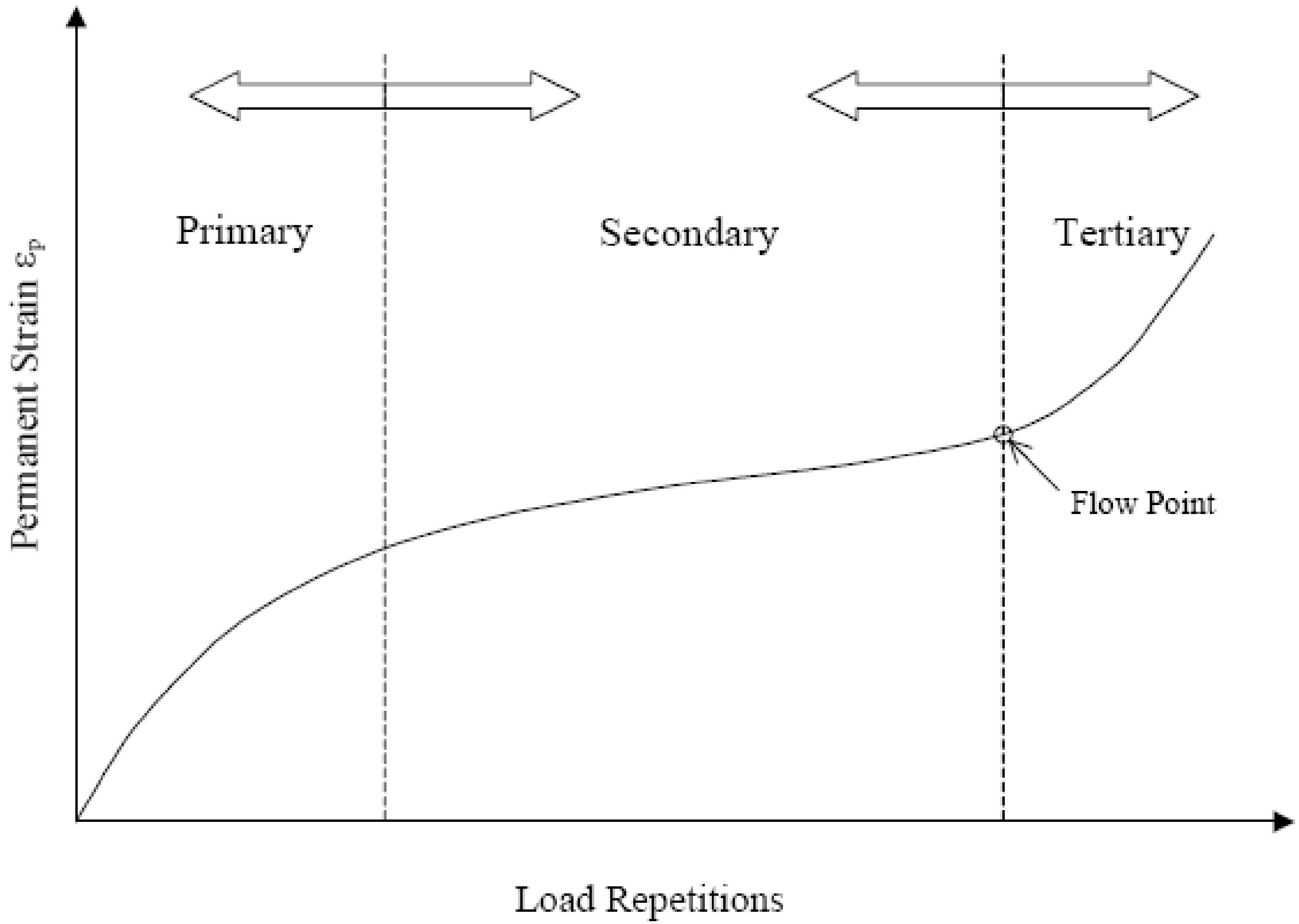
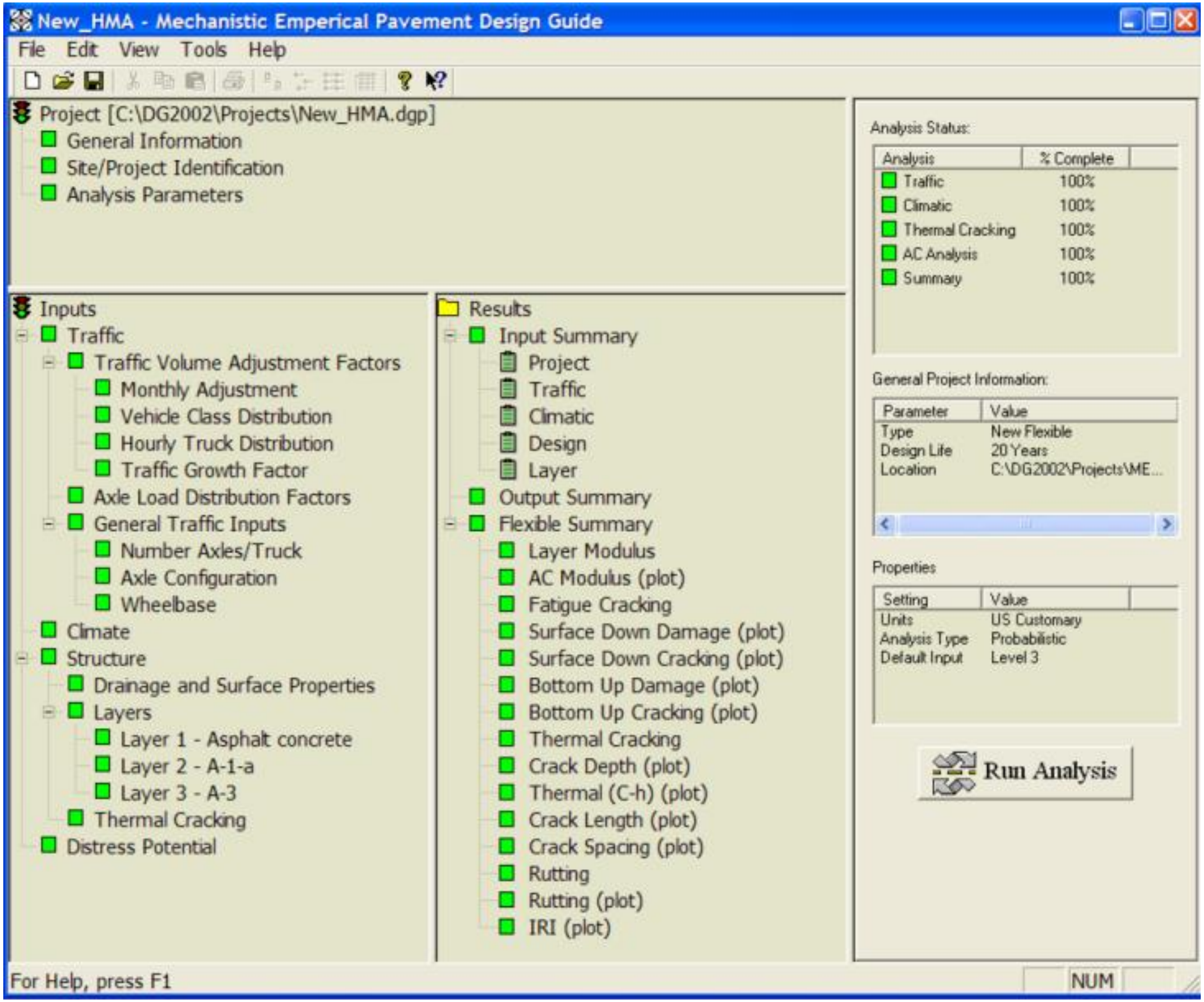
# Pavement Response Models

## Permanent Deformation

3 distinct stages of rutting behavior



# MEPDG Software

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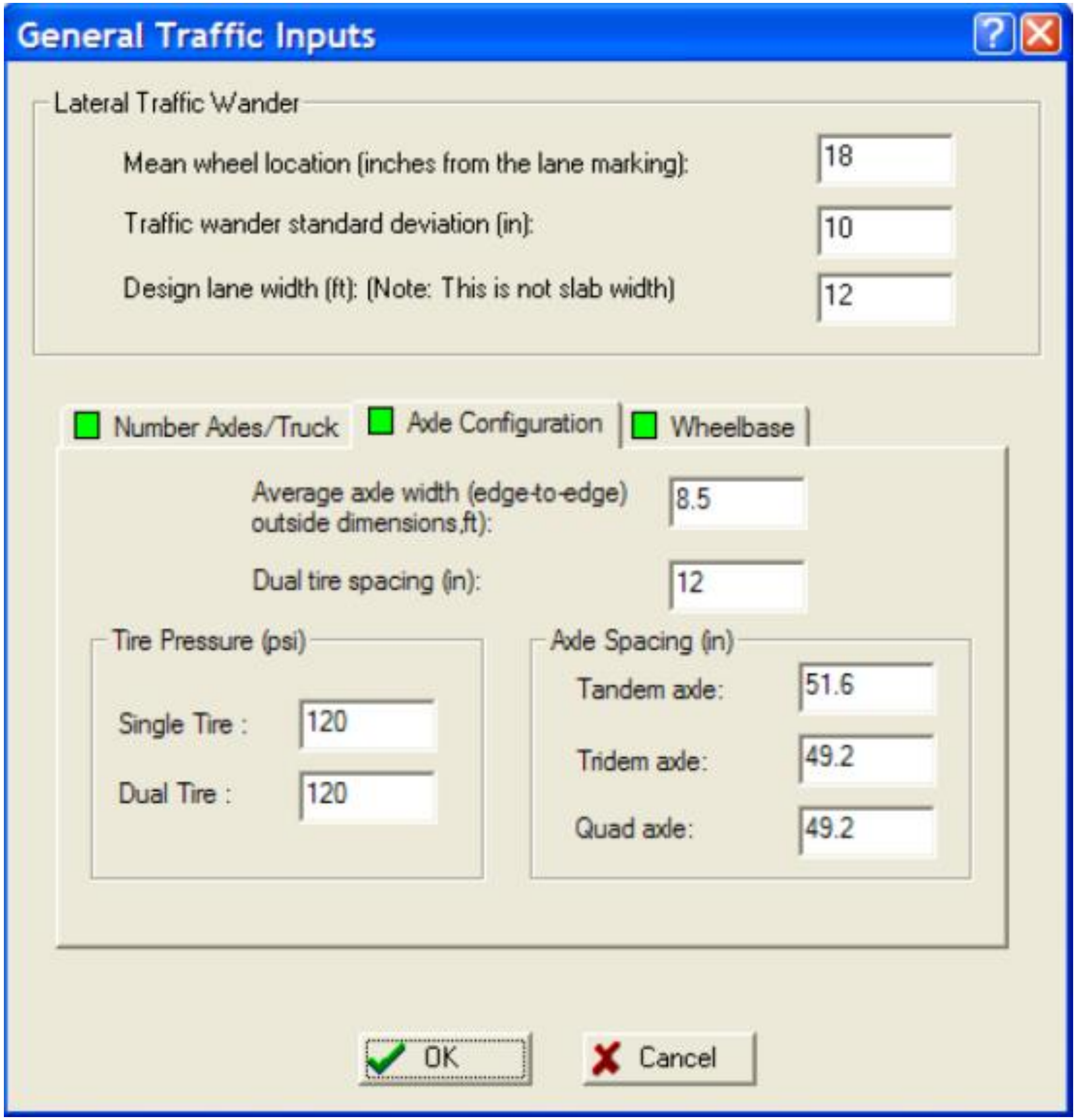


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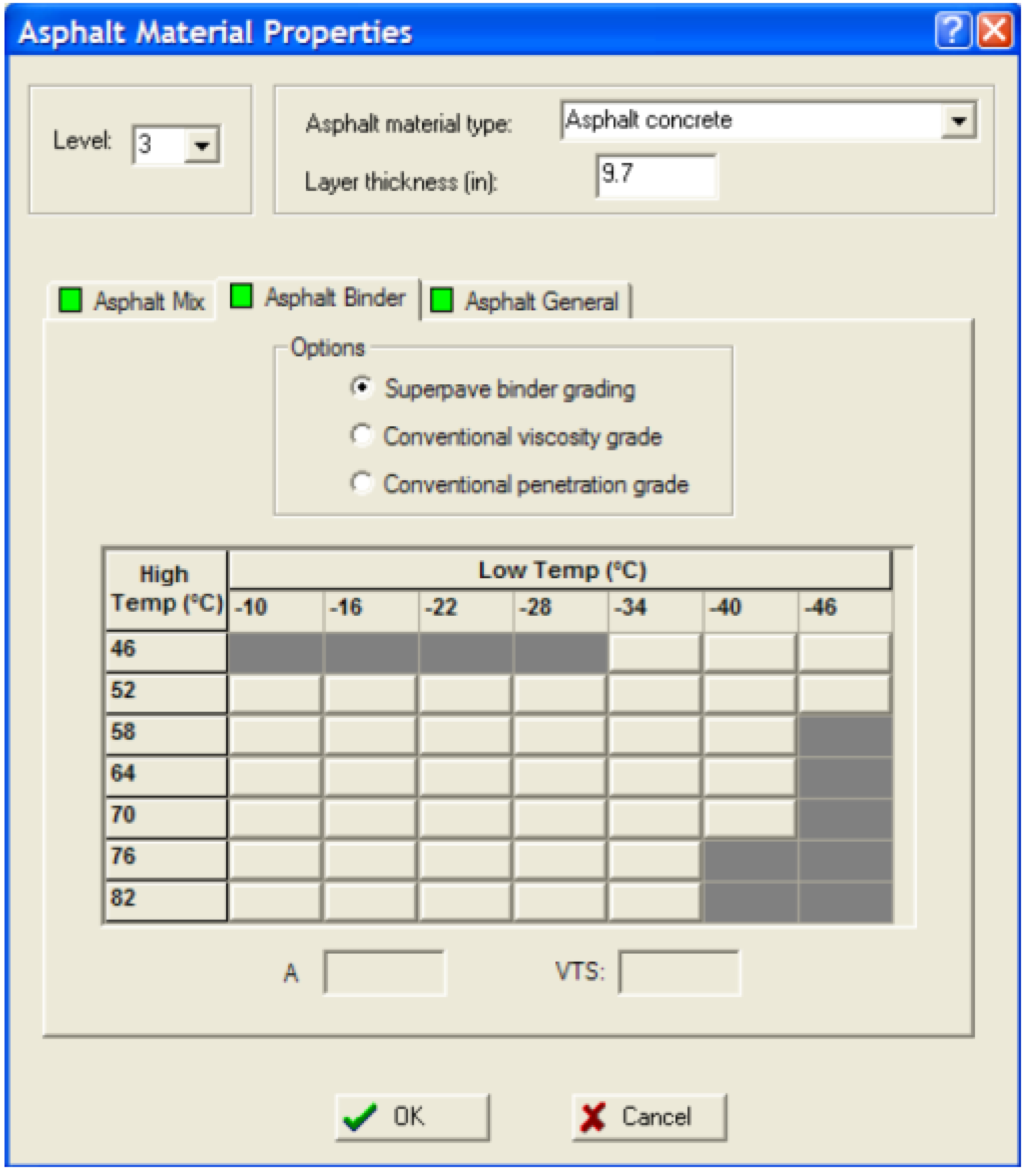


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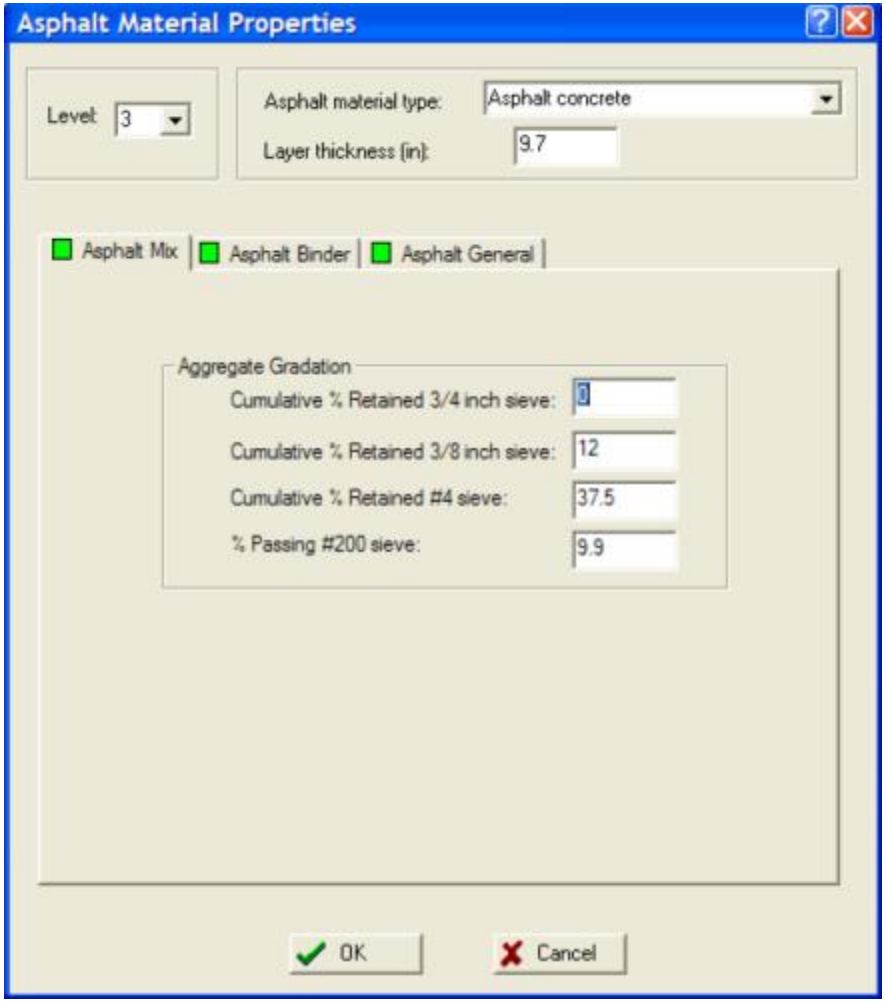


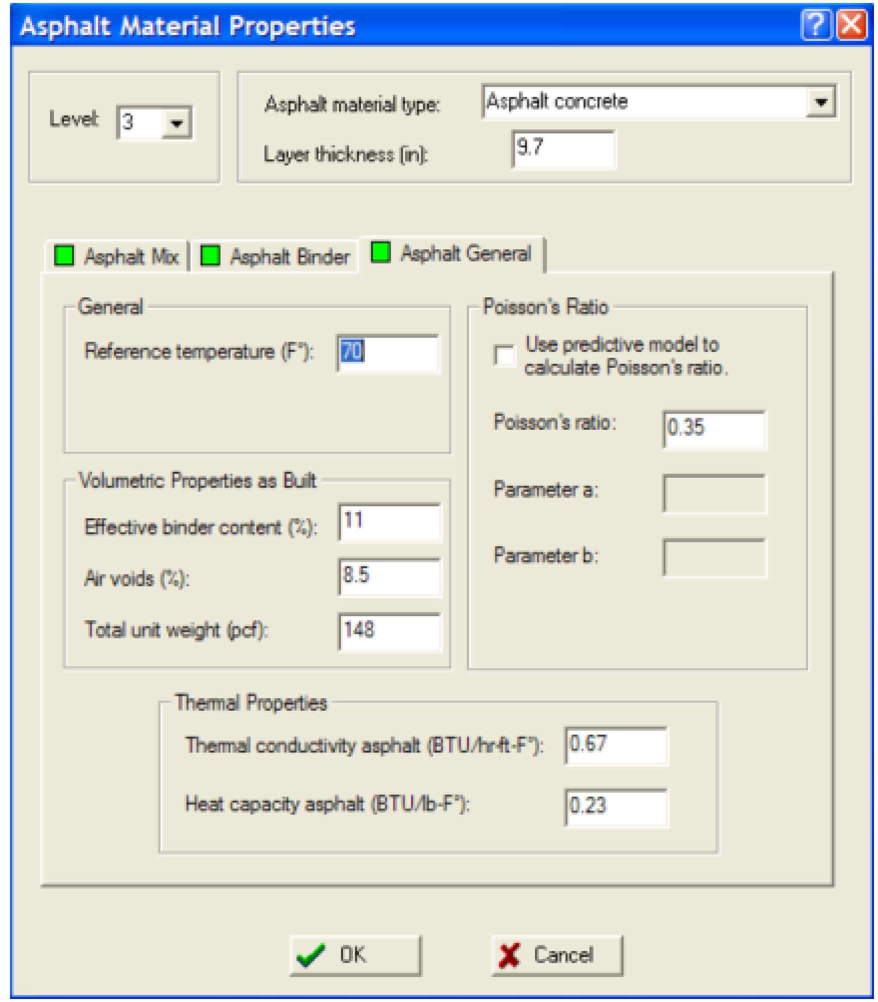


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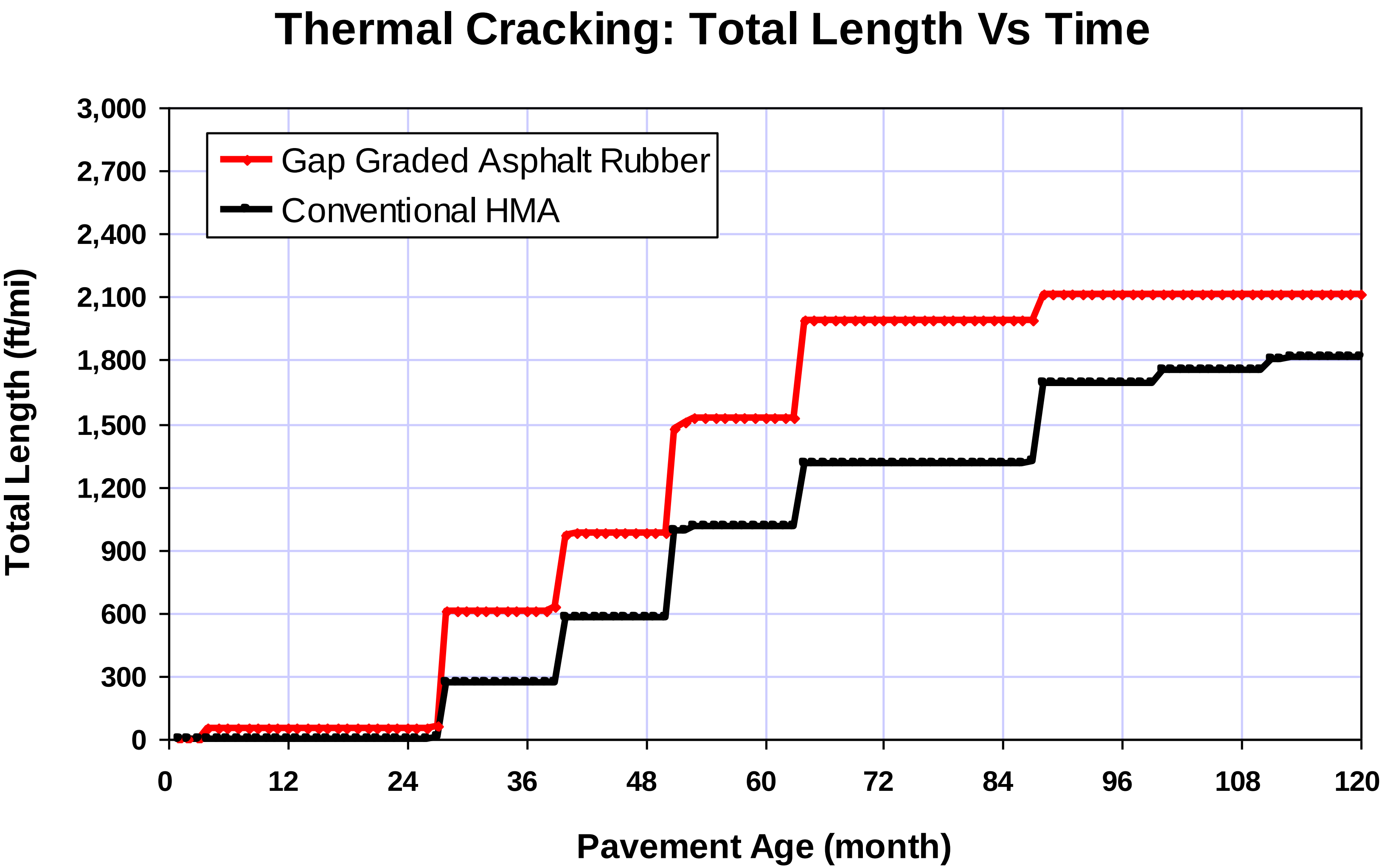
# MEPDG Prediction Models

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# MEPDG Prediction Models

# QUESTIONS

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