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.

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
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
AASHTO Flexible Pavement Design Review

Performance Measurements (cont)

AASHTO Road Test performance based on user assessment:
- Difficult to quantify (subjective)
  - Highly variable
  - Present Serviceability Rating (PSR)

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>V. Poor</td>
</tr>
<tr>
<td>1-2</td>
<td>Poor</td>
</tr>
<tr>
<td>2-3</td>
<td>Fair</td>
</tr>
<tr>
<td>3-4</td>
<td>Good</td>
</tr>
<tr>
<td>4-5</td>
<td>V. Good</td>
</tr>
</tbody>
</table>

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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AASHTO Flexible Pavement Design Review

Performance Requirements & Design Life

PSI scale: 1 (V. Poor) → 5 (V. Good)

\[ \Delta \text{PSI} = (\text{PSI}_0 - \text{PSI}_t) \]

Terminal PSI (known) → Pvt is no longer functional

AASHTO performance requirement = \( \Delta \text{PSI} \)
\( \Delta \text{PSI} \) is such that \( \text{PSI}_t \) is NOT reached before end of design life

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

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

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

Solve for $SN$
### Definition of Structural Number

<table>
<thead>
<tr>
<th>Layer</th>
<th>Depth</th>
<th>Structural Number Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>$D_1$</td>
<td>$SN_1 = D_1 \times a_1$</td>
</tr>
<tr>
<td>BASE</td>
<td>$D_2$</td>
<td>$SN_2 = D_2 \times a_2$</td>
</tr>
<tr>
<td>SUB-BASE</td>
<td>$D_3$</td>
<td>$SN_3 = D_3 \times a_3$</td>
</tr>
</tbody>
</table>

#### Structural Coefficient ($a$): $a = fnc (E, \text{position in PVT})$

#### SN Calculation

$$SN = SN_1 + SN_2 + SN_3$$

### Basic Procedure:

1. Determine the traffic (ESAL)
2. Calculate the effective subgrade modulus ($M_{Reff}$)
3. Select the performance level ($\Delta\text{PSI}$)
4. 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

Current design traffic is far beyond road test limits

Number of repetitions

Technology

1950’s Data Analysis Capabilities...
MEPDG Flexible Pavement

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....
Basic Procedure for M-E Pavement Design

1. Inputs
   - Traffic
   - Climate
   - Structure

2. Selection of trial design

3. Structural Response \((\sigma, \varepsilon, \delta)\)

4. Performance Prediction Models
   - Distress
   - Smoothness

5. Performance verification
   - Failure Criteria

6. Design
   - Reliability

7. Design Requirements Satisfied?
   - Yes
   - No

8. Feasible design

Revise trial design as necessary.
Design Procedure

Climate Inputs → Material Properties → Traffic

Predicted Performance → Transfer Functions → Mechanistic Analysis

- Materials response
- Damage accumulation
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.”
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
Flexible Pavements

- Conventional
- Deep Strength
- Full Depth
- "Semi-Rigid"
- Inverted
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
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
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
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
Input - Traffic Module Data Analysis

Accounts for the wander of trucks across one lane of traffic
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
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
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
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 fracture
- Permanent deformation
- HMA thermal fracture
- Load associated fatigue fracture of chemically stabilized layers
Design Procedure

Performance criteria

Cracking

Rutting

Roughness (IRI)
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
Fatigue life prediction based on horizontal strain at the bottom of AC layer

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

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

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

Asphalt Institute equation

\[ N_f = 0.0796(\varepsilon_t)^{-3.291}(E_1)^{-0.854} \]
\[ N_d = 1.365 \times 10^{-9}(\varepsilon_c)^{4.477} \]

- \( f_1 \) = Laboratory to field shift factor
- \( f_2 \) & \( f_3 \) = Determined from fatigue tests on lab specimen
- \( f_4 \) & \( f_5 \) = Determined from fatigue tests on lab specimen
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 \( i \).
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.

\[ C_f = \beta_1 \cdot N \left( \frac{\log C / h_{ac}}{\sigma} \right) \]  

(3.3.40)

where:
- \( C_f \) = Observed amount of thermal cracking.
- \( \beta_i \) = 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.
Pavement Response Models

Permanent Deformation

3 distinct stages of rutting behavior

![Diagram showing the three stages of rutting behavior: Primary, Secondary, and Tertiary, with a flow point.](image)
MEPDG Software

New_HMA - Mechanistic Empirical Pavement Design Guide

Project [C:\DG2002\Projects\New_HMA.dgp]
- General Information
- Site/Project Identification
- Analysis Parameters

Inputs
- Traffic
  - Traffic Volume Adjustment Factors
    - Monthly Adjustment
    - Vehicle Class Distribution
    - Hourly Truck Distribution
    - Traffic Growth Factor
  - General Traffic Inputs
    - Number Axles/Truck
    - Axle Configuration
  - Wheelbase

- Climate
- Structure
  - Drainage and Surface Properties

- Layers
  - Layer 1 - Asphalt concrete
  - Layer 2 - A-1-a
  - Layer 3 - A-3
  - Thermal Cracking
- Distress Potential

Results
- Input Summary
  - Project
    - Traffic
    - Climatic
    - Design
    - Layer
  - Output Summary
  - Flexible Summary
    - Layer Modulus
    - AC Modulus (plot)
    - Fatigue Cracking
    - Surface Down Damage (plot)
    - Surface Down Cracking (plot)
    - Bottom Up Damage (plot)
    - Bottom Up Cracking (plot)
    - Thermal Cracking
    - Crack Depth (plot)
    - Thermal (C-h) (plot)
    - Crack Length (plot)
    - Crack Spacing (plot)
    - Rutting
    - Rutting (plot)
    - IRI (plot)

Analysis Status:
- Traffic: 100%
- Climatic: 100%
- Thermal Cracking: 100%
- AC Analysis: 100%
- Summary: 100%

General Project Information:
- Type: New Flexible
- Design Life: 20 Years
- Location: C:\DG2002\Projects\ME...

Properties
- Setting: US Customary
- Units: US Customary
- Analysis Type: Probabilistic
- Default Input: Level 3

Run Analysis

For Help, press F1

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MEPDG Software

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

Number Axles/Truck
- Average axle width (edge-to-edge) outside dimensions (ft): 8.5
- Dual tire spacing (in): 12

Axle Pressure (psi)
- Single Tire: 120
- Dual Tire: 120

Axle Spacing (in)
- Tandem axle: 51.6
- Tridem axle: 49.2
- Quad axle: 49.2
MEPDG Software

Asphalt Material Properties

Asphalt material type: Asphalt concrete
Layer thickness (in): 9.7

Options
- Superpave binder grading
- Conventional viscosity grade
- Conventional penetration grade

High Temp (°C):
46
52
58
64
70
76
82

Low Temp (°C):
-10
-16
-22
-28
-34
-40
-46

A
VTS:─
Thermal Cracking: Total Length Vs Time

- **Gap Graded Asphalt Rubber**
- **Conventional HMA**

Pavement Age (month) vs Total Length (ft/mi) graph.
QUESTIONS