Appendix B. M-EPDG Training Materials (UConn)
M-E PDG Training Module I

Overview

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May 2013
Evolution of Flexible Pavement Design

Empirical

WSDOT 1948
(h=f[CBR, Traffic])

AASHTO 1961

AASHTO 1972

AASHTO 1986-1993

(SN=f[Mr, h, Traffic, Reliability])

Mechanistic-Empirical

AI 1982
(Cracking/Rutting Damage = f[ε, E, Traffic, T, seasonal Mr])

AASHTO 2004 (NCHRP 1-37)

MEPDG 2008

(Distress = f[traffic parameters, pavement thickness, material properties, temperature, moisture])
Outline

- Overview of the M-E PDG
- Design Inputs
  - Traffic
  - Subgrade
  - Material Characterization
  - Reliability
  - Environmental effects
M-EPDG Objective

⇒ To provide the highway community with a state-of-the-practice tool for the design of new and rehabilitated pavement structures, based on mechanistic-empirical procedures.

M-EPDG Content

⇒ Manual of Practice
⇒ Software
Three-Stage Design Approach
M-E PDG Software Design Process (Stage 2)

**Inputs**
- Foundation Analysis
- Climate
- Materials Properties
- Traffic Analysis

**Analysis**
- Modify Design
- Trial Design
- Pavement Response Model
- Damage Accumulation Over time
- Calibrated Damage-Distress/IRI Models

**Outputs**
- Flexible Pavements (Temp Ck, Long Ck, Alligator Ck, Rut, IRI)
- Rigid Pavements (Trans Ck, Faulting)
Hierarchical Design Inputs

⇒ Level 1
  ⇒ Highest level of accuracy (lowest level of uncertainty)
  ⇒ For heavy trafficked pavements or dire safety/economic consequences of early failure
  ⇒ Require material testing data
  ⇒ Time and resource consuming

⇒ Level 2
  ⇒ Intermediate level of accuracy (closest to earlier versions of AASHTO procedure (AASHTO1986-1993)
  ⇒ Uses agency databases and empirical correlations to provide material inputs
Hierarchical Design Inputs

⇒ Level 3

⇒ Lowest level of accuracy
⇒ For pavements with minimal consequences of early failure (e.g., low-volume roads)
⇒ Typical regional average values are used

⇒ Note: Regardless the input level, the same models and procedures are used to predict distress and smoothness.
Pavement Performance Concept

⇒ **Structural Performance**
- Related to the physical condition
- Measured by predicted distresses in pavements:
  - Fatigue/Thermal cracking, and Rutting for flexible
  - Cracking and faulting for rigid pavements

⇒ **Functional Performance**
- Related to serviceability level/riding comfort
- Measured by predicted IRI
Traffic Characterization

- **Truck traffic loadings (Class 4- Class13)**
  - Full axle load spectra for 4 axle types:
    - Single (3000-41000 Lbf)
    - Tandem (6000-82000 Lbf)
    - Tridem (12000-102000 Lbf)
    - Quad (12000-102000 Lbf)
Traffic Characterization

⇒ Hierarchical levels

⇒ Level 1
  ⇒ Requires site-specific data (vehicle count by class, direction, and lane)
  ⇒ Incorporates axle weight data on project level
  ⇒ May use default tire pressure, spacing and axle spacing

⇒ Level 2
  ⇒ May use State or regional axle load spectra

⇒ Level 3
  ⇒ Provide default load spectrum data for a specific functional class of highway
Material Characterization

- **Three major groups of material parameters**
  - **Pavement response model inputs**
    - Modulus (E), Poisson’s ratio (ν) for each layer
  
  - **Material-related pavement distress criteria**
    - Measure of material strength (shear strength, compressive strength, modulus of rupture)

- **Other material properties**
  - Special properties (C.T.E of PCC and HMA)
Material Characterization

⇒ Classes of Materials

⇒ Dense-graded, hot-mix asphalt concrete (HMAC)
⇒ Open-graded, asphalt-treated permeable base (ATPB)
⇒ Cold mix asphalt (CMA)
⇒ Portland cement concrete (PCC)
⇒ Cement treated base (CTB) and lean concrete base (LCB)
⇒ Open-graded, cement-treated permeable base (CTPB)
⇒ Granular bases (aggregate base [AB], granular agg. base [GAB], coarse agg. [CA])
⇒ Lime-stabilized layers
⇒ Stabilized soils
⇒ Bedrock
Pavement Structure Modeling

⇒ **Structural Response Models**

⇒ Compute $\sigma$, $\varepsilon$, and $\delta$ due to traffic and climatic loading at critical locations

⇒ For flexible pavements
  ⇒ Multi-layer elastic analysis by JULEA (J. Usan et al.) for Level 2 and 3 (nationally calibrated on LTPP data)
  ⇒ Finite element analysis (FEA) by DSC2D for Level 1 (not calibrated)

⇒ For rigid pavements
  ⇒ 2-D finite element program ISLAB2000 (L. Khazanovich et al.)
  ⇒ Calibrated using Artificial Neural Networks (ANN)
Pavement Structure Modeling

⇒ Structural Response Model Inputs (Monthly)
  ⇒ Traffic Loading
  ⇒ Pavement Cross-Section
  ⇒ Poisson’s ratio (for each layer)
  ⇒ Elastic modulus (for each layer)
  ⇒ Thickness (for each layer)
  ⇒ Inter-layer friction (for PCC to base)
  ⇒ C.T.E. for PCC (C.T.C. for HMA)
  ⇒ Layer temperature for HMA materials
  ⇒ Temperature/moisture gradient for PCC slab
Pavement Structure Modeling

**Incremental Damage Accumulation**

- Design life is divided into time increments of:
  - 1 month for rigid pavements
  - 15 days for flexible pavements
Pavement Structure Modeling

\[ \Rightarrow \text{Incremental Damage Accumulation} \]

\[ \text{Each load application} \]

\[ \text{CTB Modulus} \]

\[ \text{Traffic} \]

\[ \text{AC Modulus} \]

\[ \text{Granular Base Modulus} \]

\[ \text{Subgrade Modulus} \]

Time, years
Pavement Structure Modeling

\[ \sum \frac{n_i}{N_i} = 1 \]

- \( n_i \) – applied traffic repetitions and i-th strain level
- \( N_i \) – allowable repetitions at i-th strain level
Pavement Structure Modeling

Incremental Damage Accumulation

\[
Fatigue\ Damage = \sum_i \sum_j \sum_k \sum_l \sum_m \sum_n \frac{n_{ijklmn}}{N_{ijklmn}}
\]

where:

\(n_{ijklmn}\) = Applied number of load applications at condition \(i,j,k,l\).

\(N_{ijklmn}\) = Allowable number of load applications at condition \(i,j\).

\(i\) = Age

\(k\) = Axle combination

\(m\) = Temperature gradient

\(j\) = Season

\(l\) = Load level

\(n\) = Traffic path
Damage Distress Models

⇒ Accumulated “damage” related to key distress types through calibrated prediction models

- Note: Models calibrated with LTPP database
Rehabilitation Design of Existing Pavements

Input Data

- Existing traffic lane condition (e.g., distress, smoothness, surface friction, deflections)
- Pavement-shoulder interface
- Pavement design features (e.g., layer thickness, structural parameters, construction requirements)
- Material properties
- Traffic parameters
- Climatic conditions
- Drainage
- Other factors (e.g., bridge clearance, safety, utilities etc.)
Rehabilitation Design of Existing Pavements

- Identification of Feasible Rehab Strategies
  - Reconstruction without lane additions
  - Reconstruction with lane additions
  - Structural overlay (with or without milling the existing layer)
  - Non-structural overlay (thin HMA layer)
  - Restoration without overlays (PCC pavements)
Design Reliability

Everything associated with pavement design is variable or uncertain in nature.

Sources of variability: traffic, materials, construction, performance

Design Reliability for Distresses:

\[ R = P[\text{Distress over Design period} < \text{Critical Distress Level}] \]

Design Reliability for smoothness (IRI):

\[ R = P[\text{IRI over Design period} < \text{Critical IRI Level}] \]
Design Reliability

- **AASHTO1993** has different definition

\[ R = P(N < n) \]

where \( N \) = predicted ESALs; \( n \) = actual ESALs

- **AASHTO approach**: thicker pavement => higher \( R \)
- **MEPDG approach**: other design features can be considered to improve \( R \) (e.g., HMA mix design, dowel bars, subgrade improvement)
Design Reliability

CRK_{\text{crit.}} = 10\%
Design Reliability

- **Prediction of variability (Standard Deviation):**

- **Calculation of design reliability**

![Graph showing prediction of variability and calculation of design reliability](image)
Design Reliability

Calculation of design reliability

1. Using the Design Guide cracking model, predict the cracking level over the design period using mean inputs to the model. This corresponds approximately to a “mean” slab cracking due to symmetry of residuals.

2. Estimate cracking at the desired reliability level using the following relationship:

\[
\text{CRACK}_P = \text{CRACK\_mean} + \text{STDmeas} \times Z_p
\]  

(1.1.9)

where,

- \( \text{CRACK}_P \) = cracking level corresponding to the reliability level \( p \).
- \( \text{CRACK\_mean} \) = cracking predicted using the deterministic model with mean inputs (corresponding to 50 percent reliability).
- \( \text{STDmeas} \) = standard deviation of cracking corresponding to cracking predicted using the deterministic model with mean inputs.
- \( Z_p \) = standardized normal deviate (mean 0 and standard deviation 1) corresponding to reliability level \( p \).
**Design Reliability**

⇒ *Recommended levels of reliability*

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<th>Functional Classification</th>
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Enhanced Integrated Climate Model (EICM)

EICM Module predicts:

- Environmental effects adjustment factors for unbound Resilient modulus
  - **Finite Element/Linear Elastic Analysis Modules**
- Hourly temperature profile through AC layers
  - **Thermal Cracking Module**
- Temperature Frequency Distribution at mid-depth of bound sublayers
  - **Fatigue/Permanent Deformation Modules**
- Average moisture content for unbound materials
  - **Unbound Permanent Deformation Module**
EICM Analysis

- Records the user supplied resilient modulus, $MR$, of all unbound layer materials.
- Evaluates equilibrium moisture condition and the seasonal changes in moisture contents.
- Evaluates the effect of changes in soil moisture the user entered resilient modulus, $MR$.
- Evaluates the effect of freezing on the layer $MR$.
- Evaluates the effect of thawing and recovery from the frozen $MR$ condition.
- Evaluates changes in temperature as a function of time for all asphalt bound layers.
Environmental Effects
Adjustment Factors

EICM computes climatic adjustment factors for the Resilient modulus for:

- Frozen material
- Recovering material
- Unfrozen or fully recovered material
- Environmental effect through composite adjustment factor

\[ M_R = F_{env} \cdot M_{Ropt} \]
Soil Moisture Adjustment

\[
\log\frac{M_R}{M_{Ropt}} = a + \frac{b-a}{1 + \exp\left(\ln\frac{-b}{a} + k_m \cdot \theta - S_{opt}\right)}
\]

\(M_R/M_{Ropt}\) = Resilient modulus ratio; \(M_R\) is the resilient modulus at a given time and \(M_{Ropt}\) is the resilient modulus at a reference condition.

\(a\) = Minimum of \(\log(M_R/M_{Ropt})\).

\(b\) = Maximum of \(\log(M_R/M_{Ropt})\).

\(k_m\) = Regression parameter.

\((S - S_{opt})\) = Variation in degree of saturation expressed in decimal.
Resilient Moduli for Thawed Unbound Materials

\[ RF = \text{modulus reduction factor} = \frac{MR_{\text{min}}}{\min(MR_{\text{unfrz}}, MR_{\text{opt}})} \]

Recommended values of \( RF \) for fine-grained materials (\( P_{200} > 50\% \)).

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<thead>
<tr>
<th>( P_{200} ) (%)</th>
<th>( PI &lt; 12% )</th>
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<th>( PI &gt; 35% )</th>
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Resilient Moduli for Recovering Unbound Materials

• $T_R = 90$ days for sands/gravels with $P_{200}PI < 0.1$.
• $T_R = 120$ days for silts/clays with $0.1 < P_{200}PI < 10$.
• $T_R = 150$ days for clays with $P_{200}PI > 10$. 

Recovery ratio

\[ \begin{align*}
0 & \quad 1 \\
0 & \quad T_R
\end{align*} \]
Time-depth diagram and matrix of adjustment coefficients

**LEGEND:**
- **FROZEN**
- **RECOVERING**
- **UNFROZEN**

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Matrix of adjustment coefficients

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</table>
Quintile temperature distribution

If the mean monthly temperature ($\mu$) reported is $50^\circ F$ and has a standard deviation ($\sigma$) of $15^\circ F$

<table>
<thead>
<tr>
<th>Sub-Season</th>
<th>z-value</th>
<th>Temperature, $^\circ F$</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>-1.2816</td>
<td>30.8</td>
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<tr>
<td>2</td>
<td>-0.5244</td>
<td>44.8</td>
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<td>50.0</td>
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<td>4</td>
<td>0.5244</td>
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</tr>
<tr>
<td>5</td>
<td>1.2816</td>
<td>69.2</td>
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</tbody>
</table>
Connecticut Department of Transportation

M-E PDG Training Module II

Flexible Pavement Design

Prepared by Dr. Iliya Yut
Department of Civil Engineering, UConn
May 2013
M-E PDG models for flexible pavements

- Overview of the M-E PDG
- Load Related Cracking
- Rutting Models
- Thermal Cracking
- Roughness models
M-E PDG Design Process

Foundation Analysis → Climate → Materials Properties → Traffic Analysis

Inputs

Trial Design → Pavement Response Model → Damage Accumulation Over time

Analysis

Calibrated Damage-Distress/IRI Models

Modify Design

No → Decision: Meet Performance Criteria?

Yes → Temp Ck, Long Ck, Alligator Ck, Rut, IRI

Outputs
Possible Asphalt Pavement Systems

Conventional
- Asphalt Concrete
- Unbound Base
- Unbound Sub-Base
- Compacted Subgrade
- Natural Subgrade

Deep Strength
- Asphalt Concrete
- Unbound Base
- Compacted Subgrade
- Natural Subgrade

Full Depth
- Asphalt Surface
- Asphalt Binder
- Asphalt Base
- Compacted Subgrade
- Natural Subgrade

Semi-Rigid with ATB
- Asphalt Concrete
- Asphalt Treated Base
- Unbound Sub-Base
- Compacted Subgrade
- Natural Subgrade

Semi-Rigid with CTB
- Asphalt Concrete
- Cement Treated Base
- Unbound Sub-Base
- Compacted Subgrade
- Natural Subgrade

Inverted Section
- Asphalt Concrete
- Unbound Base
- Asphalt Treated or Cement Treated Layer
- Compacted Subgrade
- Natural Subgrade
Damage Accumulation - Incremental Damage Concept

⇒ Design life is divided into time increments of:
  ⇒ 1 month for rigid pavements
  ⇒ 15 days for flexible pavements
Incremental Changes Over Pavement Life

- Each load application
- CTB Modulus
- Traffic
- AC Modulus
- Granular Base Modulus
- Subgrade Modulus

Time, years
Rules of Simulation

↩ Simulate the pavement structure and foundation as detailed as possible; divide the subgrade or foundation soils into two layers especially when bedrock and other hard soils are not encountered.

↩ Combine layers as needed

- Try to combine the lower layers first and treat the upper layers in more detail, if at all possible.
- Thin non-structural layers should be combined with other layers
- Any layer that is less than 1-inch in thickness should be combined with the supporting layer
- Similar materials of adjacent layers should be combined into one layer
- Filter fabrics used for drainage purposes between a fine-grained soil and aggregate base material should be ignored
Sub-Layering for Structural Analysis (cont)

- AC surface layer
  
  - 0.5 in top sub-layer
  
  - Remaining parts: from 1 in

- AC binder – no sublayering

- AC base – no sublayering

- CTB – no sublayering

- AGG base (1-st unbound layer)
  
  - no sublayering if <4”
  
  - 4” top sub-layer and remaining are >4”

- AGG subbase
  
  - Sublayers >4”

- Subgrade
  
  - 12” first 8’, infinite subgrade after that

- Bedrock – no sublayering

- Maximum number of sublayers – 20

- Maximum number of evaluation points - 26
Sub-Layering for Structural Analysis

- Asphalt
- Asphalt
- Unbound
- Unbound
- Compacted
- Natural
- Bedrock
Global Aging System

- Original to mix/lay-down model.
- Surface aging model.
- Air void adjustment.
- Viscosity-depth model
Surface Aging Model

\[
\log\log(\eta_{\text{aged}}) = \frac{\log\log(\eta_{t=0}) + At}{1 + Bt}
\]

A depends on mean annual temperature and reduced time

B depends on reduced time
Air Void Adjustment

\[ \log \log (\eta_{aged})' = F_v \log \log (\eta_{aged}) \]

\[ F_v = \frac{1 + 1.0367 \times 10^{-4} (VA)(t)}{1 + 6.1798 \times 10^{-4} (t)} \]

\[ VA = \frac{VA_{orig} + 0.011(t) - 2}{1 + 4.24 \times 10^{-4} (t)(Maat) + 1.169 \times 10^{-3} \left( \frac{t}{\eta_{orig,77}} \right)} + 2 \]
Viscosity-Depth Model

\[ \eta_{t,z} = \frac{\eta_t (4 + E) - E(\eta_{t=0})(1 - 4z)}{4(1 + Ez)} \]

- \( \eta_{t,z} \) = Aged viscosity at time \( t \), and depth \( z \)
- \( \eta_t \) = Aged surface viscosity
- \( z \) = Depth, in
- \( E \) = 23.83e\((-0.0308 \text{ Maat})\)
- \( \text{Maat} \) = Mean annual air temperature, °F
Enhanced Integrated Climate Model (EICM)

EICM Module predicts:

- Environmental effects adjustment factors for unbound Resilient modulus

  **Finite Element/Linear Elastic Analysis Modules**

- Hourly temperature profile through AC layers

  **Thermal Cracking Module**

- Temperature Frequency Distribution at mid-depth of bound sublayers

  **Fatigue/Permanent Deformation Modules**

- Average moisture content for unbound materials

  **Unbound Permanent Deformation Module**
EICM Analysis

- Records the user supplied resilient modulus, $MR$, of all unbound layer materials.
- Evaluates equilibrium moisture condition and the seasonal changes in moisture contents.
- Evaluates the effect of changes in soil moisture the user entered resilient modulus, $MR$.
- Evaluates the effect of freezing on the layer $MR$.
- Evaluates the effect of thawing and recovery from the frozen $MR$ condition.
- Evaluates changes in temperature as a function of time for all asphalt bound layers.
Environmental Effects
Adjustment Factors

EICM computes climatic adjustment factors for the Resilient modulus for:

- Frozen material
- Recovering material
- Unfrozen or fully recovered material
- Environmental effect through composite adjustment factor

\[ M_R = F_{env} \cdot M_{R_{opt}} \]
Soil Moisture Adjustment

\[ \log \frac{M_R}{M_{Ropt}} = a + \frac{b - a}{1 + \exp \left( \ln \frac{-b}{a} + k_m \cdot (S - S_{opt}) \right)} \]

\[ M_{R/Ropt} = \text{Resilient modulus ratio; } M_R \text{ is the resilient modulus at a given time and } M_{Ropt} \text{ is the resilient modulus at a reference condition.} \]

\( a = \) Minimum of log\((M_R/M_{Ropt})\).

\( b = \) Maximum of log\((M_R/M_{Ropt})\).

\( k_m = \) Regression parameter.

\( (S - S_{opt}) = \) Variation in degree of saturation expressed in decimal.
Soil Moisture Adjustment

\[
\log \frac{M_R}{M_{R_{opt}}} = a + \frac{b - a}{1 + \exp \left( \ln \frac{-b}{a} + k_m \cdot (\$ - S_{opt}) \right)}
\]

Values of \(a\), \(b\), and \(k_m\) for coarse-grained and fine-grained materials.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Coarse-Grained Materials</th>
<th>Fine-Grained Materials</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>-0.3123</td>
<td>-0.5934</td>
<td>Regression parameter.</td>
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<tr>
<td>(b)</td>
<td>0.3</td>
<td>0.4</td>
<td>Conservatively assumed, corresponding to modulus ratios of 2 and 2.5, respectively.</td>
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<tr>
<td>(k_m)</td>
<td>6.8157</td>
<td>6.1324</td>
<td>Regression parameter.</td>
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</table>
Resilient modulus - moisture model for fine-grained materials

Fine-grained Materials

![Graph showing the relationship between (S - S_{opt})% and log \( \frac{M}{M_{opt}} \). Literature Data points are shown with diamonds, and Predicted points are shown with squares.]
Resilient modulus - moisture model for coarse-grained materials

![Graph showing the relationship between resilient modulus and moisture content for coarse-grained materials.](image)
Resilient Moduli for Thawed Unbound Materials

\[ RF = \text{modulus reduction factor} = \frac{MR_{\text{min}}}{\min(MR_{\text{unfrz}}, MR_{\text{opt}})} \]

Recommended values of \( RF \) for fine-grained materials (\( P_{200} > 50\% \)).

<table>
<thead>
<tr>
<th>( P_{200} ) (%)</th>
<th>( PI &lt; 12% )</th>
<th>( PI = 12% - 35% )</th>
<th>( PI &gt; 35% )</th>
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<tbody>
<tr>
<td>50 – 85</td>
<td>0.45</td>
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<td>&gt; 85</td>
<td>0.40</td>
<td>0.50</td>
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Resilient Moduli for Thawed Unbound Materials

\[ RF = \text{modulus reduction factor} = \frac{MR_{\text{min}}}{\min(MR_{\text{unfrz}}, MR_{\text{opt}})} \]

Recommended values of RF for coarse-grained materials \((P_{200} < 50\%)\).

<table>
<thead>
<tr>
<th>Distribution of Coarse Fraction*</th>
<th>(P_{200}) (%)</th>
<th>(PI &lt; 12%)</th>
<th>(PI = 12% - 35%)</th>
<th>(PI &gt; 35%)</th>
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<tbody>
<tr>
<td>Mostly Gravel (P_4 &lt; 50%)</td>
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<tr>
<td>&lt; 6</td>
<td>0.85</td>
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<tr>
<td>6 – 12</td>
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<tr>
<td>&gt; 12</td>
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<tr>
<td>Mostly Sand (P_4 &gt; 50%)</td>
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<tr>
<td>&lt; 6</td>
<td>0.75</td>
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<td>6 – 12</td>
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<td>&gt; 12</td>
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Resilient Moduli for Recovering Unbound Materials

- $T_R = 90$ days for sands/gravels with $P_{200}PI < 0.1$.
- $T_R = 120$ days for silts/clays with $0.1 < P_{200}PI < 10$.
- $T_R = 150$ days for clays with $P_{200}PI > 10$. 
Time-depth diagram and matrix of adjustment coefficients

**LEGEND:**
- FROZEN
- RECOVERING
- UNFROZEN

**Time (days)**

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Matrix of adjustment coefficients

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- FROZEN
- RECOVERING
- UNFROZEN

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Temperature Analysis for AC cracking and rutting
Quintile temperature distribution

If the mean monthly temperature ($\mu$) reported is $50^\circ F$ and has a standard deviation ($\sigma$) of $15^\circ F$

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Hourly Temperature Profile for AC Layers for Thermo-cracking

- Depth = 0 in.
- Depth = 3 in.
- Depth = 6 in.
Critical Response Values

⇒ Cracking: $\varepsilon_t$ at surface + bottom of all bound layers
⇒ Rutting: $\varepsilon_c$ at midthickness of all layers + top of subgrade
Critical Response Locations

⇒ Fatigue Depth Locations:
  ➡ Surface of the pavement (z=0),
  ➡ 0.5 inches from the surface (z=0.5),
  ➡ Bottom of each bound or stabilized layer.

⇒ Rutting Depth Locations:
  ➡ Mid-depth of each layer/sub-layer,
  ➡ Top of the subgrade,
  ➡ Six inches below the top of the subgrade.
Critical Response Locations
Fatigue Analysis Wander Approach

- Normal Distribution: $z = -1.2815 \times S_d$
- $z = -0.5244 \times S_d$
- $z = 0$
- $z = 0.5244 \times S_d$

Damage Locations:
- X, z
- 20% of Traffic: X, z
Flexible Pavement Performance

- Fatigue Cracking
- Longitudinal Cracking
- Thermal Cracking
- IRI
- Rut Depth
HMA Fatigue Modeling

- **Bottom – Up Crack Propagation:**

- **Top – Down Crack Propagation**

(Classical Fatigue Mechanism)
Fatigue Damage Accumulates Over Time

\[ \Delta DI = \sum_{k=1}^{m} \sum_{i=1}^{j} \left[ \frac{n_i}{N} \right] \]

Load Season

FATIGUE CRACKING

Design Period

TIME

Criteria
Allowable Number of Load Applications

\[ N_f = k_{f1} C \beta_{f1} \varepsilon_t k_{f2} \beta_{f2} E_{HMA} k_{f3} \beta_{f3} \]

\( N_f = \) Allowable number of axle load applications
\( \varepsilon_t = \) Tensile strain at critical locations
\( E_{HMA} = \) Dynamic modulus of the HMA, psi
\( k_{f1}, k_{f2}, k_{f3} = \) Global field calibration parameters
\( \beta_{f1}, \beta_{f2}, \beta_{f3} = \) Local calibration constants;
\( = 1.0 \) by default
Allowable Number of Load Applications (cont.)

\[ N_f = k_{f_1} C \beta_{f_1} \epsilon_t k_{f_2} \beta_{f_2} E_{HMA} k_{f_3} \beta_{f_3} \]

\[ C = 10^M \quad M = 4.84 \left( \frac{V_{be}}{V_a + V_{be}} - 0.69 \right) \]

- \( V_{be} = \) Effective asphalt content by volume, percent
- \( V_a = \) Percent air voids in the HMA mixture
Bottom-Up Cracking

\[
FC_{\text{bottom}} = \left( \frac{6000}{1 + e^{(C_1' C_1' + C_2' C_2' \log_{10}(D*100))}} \right) \times \left( \frac{1}{60} \right)
\]

where:
- \( FC_{\text{bottom}} \) = bottom-up fatigue cracking, percent lane area
- \( D \) = bottom-up fatigue damage
- \( C_1 \) = 1.0

\[
C_1' = -2C_2' \quad C_2 = 1
\]

\[
C_2' = -2.40874 - 39.748(1 + hac)^{-2.856}
\]
Top-Down Cracking

\[ FC_{Top} = 10.56 \left( \frac{C_4}{1 + e^{C_1 - C_2 \log(DI_{Top})}} \right) \]

where:
- \( FC_{top} \) = top-down fatigue cracking, ft/mile
- \( D \) = top-down fatigue damage
Factors Affecting Fatigue Cracking in Flexible Pavements

- HMA layer thickness.
- HMA layer dynamic modulus.
- Binder grade in the HMA mixture.
- Air voids in the asphalt layers.
- Effective binder content in the asphalt layers.
Factors Affecting Fatigue Cracking in Flexible Pavements

- Base thickness.
- Subgrade modulus.
- Traffic load configuration.
- Traffic load, contact area and tire pressure.
- Traffic load repetitions.
- Temperature and environmental conditions.
Bottom-Up Fatigue (Alligator)
Alligator Cracking National Calibration - June 2006

Se = 5.01%
Se/Sy = 0.815
N = 405
R² = 0.275
Top-Down Fatigue (Longitudinal)

Cracking Calibration

$R^2 = 0.544$
$Se = 582.8$ ft/mile
$Se/Sy = 0.688$
$N = 312$

Measured Cracking (ft/mile)
Predicted Cracking (ft/mile)
Effect of AC Thickness

Bottom Up Cracking - Alligator

Alligator Cracking (%) vs. Pavement Age (month) for different AC thicknesses:
- 50 mm
- 75 mm
- 100 mm
- 150 mm
- 150 mm
Permanent Deformation Accumulates Over Time

\[ \Delta RD = \sum_{k=1}^{m} \sum_{i=1}^{j} \sum_{d=1}^{l} P_{d,i} \]

Load Month Depth

Criteria

TIME

Design Period

RUT Depth
Accumulation of Rutting

\[ PD = \sum_{i=1}^{N_{\text{sub-layers}}} \varepsilon_p^i \times h^i \]

Similar for unbound layers

See Fig. A.
Permanent Deformation in AC Layer

\[
\frac{\Delta \varepsilon_p(HMA)}{\varepsilon_p(HMA)} = h_{HMA} = \beta_{r1} k_z \varepsilon_r(HMA) 10^{-3.35412} N^{0.4791} \beta_{z2} T^{1.5606} \beta_{z3}
\]

where:
- \(\varepsilon_p\) = Accumulated plastic strain at \(N\) repetitions of load (in/in)
- \(\varepsilon_r\) = Resilient strain of the asphalt material as a function of mix properties, temperature and time rate of loading (in/in)
- \(N\) = Number of load repetitions
- \(T\) = Temperature (deg F)
- \(a_i\) = Non-linear regression coefficients
- \(\beta_i\) = field calibration factors
Permanent Deformation in Unbound Layer (Tseng and Lytton Model)

\[ \Delta_{p(soil)} = \beta_{s1} k_{s1} \varepsilon_v h_{soil} \left( \frac{\varepsilon_o}{\varepsilon_r} \right) e^{-\left( \frac{\rho}{N} \right)^\beta} \]

\( \Delta_{p(Soil)} \) = Permanent or plastic deformation for the layer/sublayer
\( N \) = Number of axle load applications
\( \varepsilon_o, \beta, \) and \( \rho \) = material properties obtained for the resilient strain \( \varepsilon_r \)
\( \varepsilon_v \) = Average vertical resilient or elastic strain in the layer/sublayer
\( h_{soil} \) = Thickness of the unbound layer/sublayer, inches
\( k_{s1} \) = Global calibration coefficients;
  = 1.673 for granular materials
  = 1.35 for fine-grained materials
\( \beta_{s1} \) = Local calibration constant
Rut Calibration - June 2006-2- AC (0.633, 0.9, 1.2), GB (2.03), SG (1.35) - Optimizing On AC and GB

Average Measured Rutting vs Predicted Rutting

R^2 = 0.577
N = 334
S_e = 0.107
Se/Sy = 0.818
Effect of AC Thickness

Permanent Deformation: Rutting

- Hac=50 mm
- Hac=75 mm
- Hac=100 mm
- Hac=150 mm
Thermal Cracking
HMA-Thermal Fracture

- **Uses SHRP Thermal Fracture Model**
  - Recalibrated Using Approximately 30 Sections in NCHRP Project 9-19

- **Thermal Fatigue (cyclic)**
  - Propagation of Cracks Through the Asphalt Layer

- **Thermal Stresses**
  - Very Low Temperature
  - Mixture Properties
  - Friction

- **Mixture Fracture Properties**
Materials Characterization (IDT)

CREEP TEST: VISCOELASTIC PROPERTIES

STRENGTH TEST: FRACTURE PROPERTIES

PAVEMENT RESPONSE MODEL

THERMAL STRESS

PAVEMENT DISTRESS MODEL
Schematic of Crack Depth Fracture Model

\[ C_0 \]

\[ C \]

\[ \Delta C \]
Amount of Crack Propagation in a Cooling Cycle

\[ \Delta C = A \Delta K^n \]

- \( \Delta C \) = Change in the crack depth due to a cooling cycle.
- \( \Delta K \) = Change in the stress intensity factor
- \( A, n \) = Fracture parameters for the asphalt mixture
Stress Intensity Factor Approximation

\[ K = \sigma (0.45 + 1.99 C_o^{0.56}) \]

- \( K \) = stress intensity factor
- \( \sigma \) = far-field stress from pavement response model at depth of crack tip
- \( C_o \) = current crack length
Schapery-Molenaar-Lytton Model

\[ n = 0.8 \left( 1 + \frac{1}{m} \right) \]

\[ A = 10^{b \times (4.389 - 2.52 \times \log(E \times \sigma_m \times n))} \]

where:
- \( E \) = Mixture stiffness.
- \( \sigma_m \) = Undamaged mixture tensile strength.
- \( b \) = Calibration parameter.
Effect of AC Thickness on Thermal Cracking

Thermal Cracking: Total Length Vs Time

- Hac=50 mm
- Hac=75 mm
- Hac=100 mm
- Hac=150 mm
Pavement Smoothness – IRI
Generalized Smoothness Model

\[
\text{IRI} = \text{IRI}_i + \Delta \text{IRI}_D + \Delta \text{IRI}_{SF}
\]

\[\text{IRI}_i\] = Initial IRI at construction

\[\Delta \text{IRI}_D\] = Change in IRI due to distress

\[\Delta \text{IRI}_{SF}\] = Change in IRI due to site factors

(age, subgrade properties, non-load distress)
Site Factor

$$SF = Age^{0.02} (PI + 1) + 0.008 (Precip + 1) + 0.00064 (FI + 1)$$

*Age* = Pavement age, years  
*PI* = Percent plasticity index of the soil  
*FI* = Average annual freezing index, degree F days  
*Precip* = Average annual precipitation or rainfall, inches
Generalized Smoothness Model

\[
IRI = IRI_o + 0.0150SF + 0.400FC_{Total} + 0.0080TC + 40.0RD
\]

\(IRI_o\) = Initial IRI after construction, in./mi.
SF = Site factor
\(FC_{Total}\) = Area of fatigue cracking \(ft^2/mi\)
TC = Length of transverse cracking \(ft./mi\).
RD = Average rut depth, inches
M-E PDG for flexible pavements

Summary

- Incremental Damage Approach
- Sub-layering for structural analysis
- Aging model (surface, air void adjustment, depth model)
- Enhanced Integrated Climate Model (EICM)
  - Temperature
  - Moisture
M-E PDG for flexible pavements

Summary

- The M-E PDG incorporated the following performance prediction models:
  - Load Related Cracking
  - Rutting Models
  - Thermal Cracking
  - Roughness

- The models are calibrated based on the performance data from the LTPP sections located throughout the US and Canada.

- Local calibration of the models is recommended.
More Information

www.trb.org/M-E PDG

⇒ Guide Documentation
⇒ Software
⇒ Climatic database
Program Layout Screen

Click on each item to create inputs

General Inputs

Outputs

Inputs

Run Analysis
**General Information Screen**

**Project Name:** 350102.dgp

- **Design Life (years):** 4
- **Base/Subgrade Construction Month:** September, **Year:** 1995
- **Pavement Construction Month:** November, **Year:** 1995
- **Traffic open month:** November, **Year:** 1995

**Description:**
- **State Code:** 35
- **SHRP ID:** 0102
- **State:** New Mexico
- **Project Type:** SPS
- **Pavement Type:** Conventional

**Type of Design**
- **New Pavement:** Flexible Pavement

**Overlay**
- **Asphalt Concrete Overlay**
- **PCC Overlay**

**Buttons:**
- **OK**
- **Cancel**
Help Options – CSH and HTML Help

**General Information**

This screen allows the user to make broad choices about the design. The name assigned to the project appears on this screen. The user then inputs information regarding the design life, the construction month and the month that the pavement will be open to traffic. The design life is the expected service life of the pavement. Pavement performance is predicted over the design life beginning from the month the pavement is open to traffic.

On this screen, the user also indicates the nature of the project. All pavement design projects can be classified under three main categories. It can be either a new design, or a restoration, or rehabilitation. In each category, the user then chooses the pavement type, flexible or rigid pavement. All pavements with an asphalt concrete surface are treated as flexible pavements (new or rehabilitated) while those with a concrete surface are treated as rigid pavements. Rigid pavement design offers two alternatives, Jointed Plain Concrete Pavement (JPCP) and Continuously Reinforced Concrete Pavement (CRCP). The choice of the type of pavement is critical in choosing the distress types to be considered.
Software inserts the Thermal Cracking Screens and an AC Layer.
Site/Project Identification

Information provided on this screen is only for the purpose of identification. These inputs will not affect the design in any way.
Analysis Parameters

Project Name: 350102-2.dgp
Initial IRI (in/ mi) 63

Analysis Type
- Deterministic

Performance Criteria
- Rigid Pavement
- Flexible Pavement

- Terminal IRI (in/mile)
- AC Surface Down Cracking
- Long. Cracking (ft/500 ft)
- AC Bottom Up Cracking
- Alligator Cracking (ft/2/500 ft)
- AC Thermal Fracture (ft/500 ft)
- Chemically Stabilized Layer (Fatigue Fracture)
- Permanent Deformation - AC Only (in)
- Permanent Deformation - Total Pavement (in)

<table>
<thead>
<tr>
<th>Limit</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>252</td>
<td>50</td>
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<td>100</td>
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<tr>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>0.25</td>
<td>50</td>
</tr>
<tr>
<td>0.75</td>
<td>50</td>
</tr>
</tbody>
</table>

[OK] [Cancel]
Program Indicates Status of Inputs

- Completed Inputs have “Green” Icons
- Default Inputs have “Yellow” Icons
- Incomplete Inputs have “Red” Icons
Program automatically creates a file called “350102” in C:\DG2002\Projects\ to store all project files

Save in the directory: C:\DG2002\Projects
Filename: 350102.dgp
Traffic Main Screen

3 main categories of traffic input

Input
Traffic Volume Adjustment Factors Monthly Adjustment Factors (MAF)

Level 3: Default MAF

Load Monthly Adjustment Factors (MAF)
- Level 1: Site Specific - MAF
- Level 2: Regional - MAF
- Level 3: Default MAF

Monthly Adjustment Factors:

<table>
<thead>
<tr>
<th>Month</th>
<th>Class 4</th>
<th>Class 5</th>
<th>Class 6</th>
<th>Class 7</th>
<th>Class 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
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<td>February</td>
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<td>March</td>
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<td>1.00</td>
<td>1.00</td>
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</tr>
<tr>
<td>May</td>
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<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>June</td>
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<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
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<tr>
<td>July</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>August</td>
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<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
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<td>September</td>
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<td>1.00</td>
<td>1.00</td>
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<tr>
<td>October</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>November</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Load MAF From File
Export MAF to File

OK
Cancel
Vehicle Class Distribution

Level 3: Default Distribution

Note: AADDT distribution must total 100%.
Current Traffic Data Requirements —FHWA
Vehicle Classification

1. Bicycle
2. Single Axle Truck
3. Single Axle Truck with Cargo Area
4. Coach Bus
5. Single Axle Tractor-Semitrailer
6. Tractor-Semitrailer
7. Tractor-Semitrailer
8. Tractor-Semitrailer
9. Tractor-Semitrailer
10. Tractor-Semitrailer
11. Tractor-Semitrailer
12. Tractor-Semitrailer
13. Tractor-Semitrailer
Hourly Distribution

<table>
<thead>
<tr>
<th>Time</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midnight</td>
<td>2.3</td>
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<tr>
<td>1:00 am</td>
<td>2.3</td>
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<td>2:00 am</td>
<td>2.3</td>
</tr>
<tr>
<td>3:00 am</td>
<td>2.3</td>
</tr>
<tr>
<td>4:00 am</td>
<td>2.3</td>
</tr>
<tr>
<td>5:00 am</td>
<td>2.3</td>
</tr>
<tr>
<td>6:00 am</td>
<td>5.0</td>
</tr>
<tr>
<td>7:00 am</td>
<td>5.0</td>
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<tr>
<td>8:00 am</td>
<td>5.0</td>
</tr>
<tr>
<td>9:00 am</td>
<td>5.0</td>
</tr>
<tr>
<td>10:00 am</td>
<td>5.9</td>
</tr>
<tr>
<td>11:00 am</td>
<td>5.9</td>
</tr>
<tr>
<td>Noon</td>
<td>5.9</td>
</tr>
<tr>
<td>1:00 pm</td>
<td>5.9</td>
</tr>
<tr>
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<td>5.9</td>
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<tr>
<td>3:00 pm</td>
<td>5.9</td>
</tr>
<tr>
<td>4:00 pm</td>
<td>4.6</td>
</tr>
<tr>
<td>5:00 pm</td>
<td>4.6</td>
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<tr>
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<td>3.1</td>
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<tr>
<td>10:00 pm</td>
<td>3.1</td>
</tr>
<tr>
<td>11:00 pm</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Note: The hourly distribution must total 100%

Total: 100
Traffic Growth Factors

Note: Vehicle-class distribution factors are needed to view the effects of traffic growth.

View plots
Axle Load Distribution Factors
Example – Tandem Axle Distribution for the First Month of Traffic
General Traffic Inputs – Traffic Wander and Number of Axles/Truck

Lateral Traffic Wander:
- Mean wheel location (inches from the lane marking): 20
- Traffic wander standard deviation (in): 10
- Design lane width (ft): (Note: This is not slab width)

Number Axles/Truck:

<table>
<thead>
<tr>
<th>Class</th>
<th>Single</th>
<th>Tandem</th>
<th>Tridem</th>
<th>Quad</th>
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</thead>
<tbody>
<tr>
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<td>Class 6</td>
<td>1.02</td>
<td>0.99</td>
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<td>0.26</td>
<td>0.83</td>
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<td>Class 8</td>
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<td>1.09</td>
<td>0.89</td>
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<td>Class 11</td>
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<td>0.26</td>
<td>0.06</td>
<td>0</td>
</tr>
<tr>
<td>Class 12</td>
<td>3.52</td>
<td>1.14</td>
<td>0.06</td>
<td>0</td>
</tr>
<tr>
<td>Class 13</td>
<td>2.15</td>
<td>2.13</td>
<td>0.35</td>
<td>0</td>
</tr>
</tbody>
</table>

Default values
Axle Configuration

General Traffic Inputs

[Information on lateral traffic wander, mean wheel location, traffic wander standard deviation, and design lane width]

Number Axles/Truck

Axle Configuration

Wheelbase

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

OK Cancel
Wheelbase

Wheelbase distribution information for JPCP top-down cracking. The wheelbase refers to the spacing between the steering and the first device axle of the truck-tractors or heavy single units.

- **Short**: Average Axle Spacing (ft) = 12, Percent of trucks (%) = 2.0
- **Medium**: Average Axle Spacing (ft) = 15, Percent of trucks (%) = 20.0
- **Long**: Average Axle Spacing (ft) = 18, Percent of trucks (%) = 78.0
Check Status of Inputs on Layout Screen

Traffic Input Completed

Start Climate
Generate Climatic File
Create "Virtual" Weather Station

Step 1: Select the option for interpolating climatic data for a given location.

Step 2: Enter the latitude, longitude, and elevation for the location.

Step 3: Choose appropriate weather stations from the list.

Step 4: Generate the interpolated climatic data after selecting desired weather stations and inputting elevation and depth of water table.
Check Status of Inputs on Layout Screen

- Climate Input Completed
- Start Structure Input
Structure Inputs

- User needs to choose layers and the trial design
- Example 1: Conventional AC design:
  - 4.8-inch Asphalt Concrete layer
  - 12.2-inch Granular Base layer (A-1-a)
  - 12-inch Compacted Subgrade (A-7-6)
  - Natural subgrade (A-7-6)
Insert Layers

Structure

Layers

<table>
<thead>
<tr>
<th>Layer</th>
<th>Type</th>
<th>Material</th>
<th>Thickness (in)</th>
<th>Friction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Asphalt</td>
<td>Asphalt concrete</td>
<td>10.0</td>
<td>1</td>
</tr>
</tbody>
</table>

Opening Date: September, 2002
Design Life (years): 20

[Insert, Delete, Edit, OK, Cancel]
Add Layers and Edit Layer Properties

Edit material properties either from this screen or from the main screen.
Asphalt Mix Properties

- Level: 3
- Asphalt material type: Asphalt concrete
- Layer thickness (in): 4.8

Aggregate Gradation:
- Cumulative % Retained 3/4 inch sieve: 4
- Cumulative % Retained 3/8 inch sieve: 25.3
- Cumulative % Retained #4 sieve: 44.3
- % Passing #200 sieve: 5.4
Asphalt Binder Properties
Asphalt General Properties

Input volumetric properties

- Level: 3
- Asphalt material type: Asphalt concrete
- Layer thickness (in): 4.8
- Reference temperature (F°): 70
- Effective binder content (%): 9.22
- Air voids (%): 7.86
- Total unit weight (pcf): 142.4
- Poisson's ratio: 0.35
- Thermal conductivity asphalt (BTU/hr-ft-F°): 0.67
- Heat capacity asphalt (BTU/lb-F°): 0.22
Granular Base Layer – Strength Properties

Calculated Modulus based on CBR value
Granular Base Layer - ICM Input

Level 2 analysis: Input measured properties
Compacted Subgrade Layer – Strength Properties

Calculated Modulus based on CBR value
Compacted Subgrade Layer - ICM Input

Level 2 analysis: Input measured properties
ICM Warning Capability

Unbound Material - ICM - Warning

Optimum gravimetric water content (%):
Material: A-7-6
Outside typical range.
[28] is greater than the typical range.
Minimum = 2   Maximum = 25

Ignore  Edit  Ignore All
Natural Subgrade Layer – Strength Properties

Calculated Modulus based on CBR value
Natural Subgrade Layer - ICM Input

Level 2 analysis: Input measured properties
Thermal Cracking Input

Option available to import or export a thermal cracking file.
Drainage and Surface Properties

Based on shoulder type
- Tied Shoulder--Minor (10%)
- Asphalt Shoulder--Moderate (50%)
- Gravel Shoulder--Extreme (100%)

Drainage and Surface Properties

Surface shortwave absorptivity: 0.85

Drainage Parameters
- Infiltration: Moderate (50%)
- Drainage path length (ft): 12
- Pavement cross slope (%): 2

[OK] [Cancel]
Save Project File and Run Program
2002 Design Procedure – Performance Models for Asphalt Concrete Pavements

**INPUTS**

2002 Design Guide Software

**OUTPUTS:**

- Performance prediction
- IRI
- Surface-Down Cracking
- Bottom-Up Cracking
- Thermal Fracture
- Permanent Deformation

Traffic, Materials and Climatic Models

- Thermal cracking model
- Structural response model: Linear Elastic Analysis
- Damage prediction
- Reliability
- Distress prediction models
Program Runs Traffic Module
Software Creates Axle Load Distribution for Each Axle Type for Each Month – Single Axle Example

Class 4
January
Software Creates Axle Load Distribution for Each Axle Type for Each Month – Tandem Axle Example

Class 9 January
Run Program, cont.
– Climate Module
EICM Module predicts:

- Environmental effects adjustment factors for unbound Resilient modulus

  **Finite Element/Linear Elastic Analysis Modules**

- Hourly temperature profile through AC layers

  **Thermal Cracking Module**

- Temperature Frequency Distribution at mid-depth of bound sublayers

  **Fatigue/Permanent Deformation Modules**

- Average moisture content for unbound materials

  **Unbound Permanent Deformation Module**
Environmental Effects Adjustment Factors

EICM computes climatic adjustment factors for the Resilient modulus for:

- Frozen material
- Recovering material
- Unfrozen or fully recovered material
- Environmental effect composite adjustment factor
Hourly Temperature Profile for AC Layers
Run Program, cont.
- Thermal Cracking Module
Thermal Cracking
Thermal Cracking Model

- Uses SHRP Thermal Fracture Model
- Use 100 sec creep data
  - Previously required 1000 sec creep data
- Tensile Strength Data
Thermal Cracking Model

- Material Properties
- Pavement Structure
- Environment

Thermal Cracking Model (TCMODEL)

Amount of Thermal Cracking vs. Time

Enhanced version of SHRP Thermal Cracking Model
Run Program, cont.
– Asphalt Concrete Analysis Module
Different Strategies
Sub-Layering for Structural Analysis

Maximum Sub-Layering Depth = 8 feet

- Asphalt Surface
- Asphalt Base
- Unbound Base
- Unbound Sub-base
- Compacted Subgrade
- Natural Subgrade
- Bedrock

\[
\begin{align*}
0.5'' & \\
\quad h'_{ac} &= h_{ac} - 0.5'' \\
\end{align*}
\]

No Sub-Layering

\[
\begin{align*}
2'' & \text{ if } h_B \geq 6'' \\
\quad n_B &= \text{int} \left( \frac{h_B - 2}{4} \right) \text{ for } h_B > 6'' \\
\quad n_{SB} &= \text{int} \left( \frac{h_{SB}}{4} \right) \text{ for } h_{SB} \geq 8'' \\
\quad n_{CSG} &= \text{int} \left( \frac{h_{CSG}}{12} \right) \text{ for } h_{CSG} > 12'' \\
\quad n_{SG} &= \text{int} \left( \frac{h_{SG}}{12} \right) \text{ for } h_{SG} > 12'' \\
\end{align*}
\]
Computation Methodology

1. Define sub-layers
2. Adjust layer properties from EICM output.
   Temp./Aging of HMA
   Frost/Moisture in unbound materials
3. Simulate traffic loads.
4. Compute pavement critical response
   FEA
   MELT - JULEA
Critical Response Values

- $\epsilon_t$ at surface + bottom of all bound layers (cracking)
- $\epsilon_c$ at midthickness of all layers + top of subgrade (rutting)
Critical Response Locations

\[
\begin{array}{cccccccccc}
B1 & B2 & B3 & B4 & B5 & B6 & B7 & B8 & B9 & B10 \\
\end{array}
\]
5. Calculate incremental damage for each traffic load & time period

6. Cumulate damage over time

7. Calculate distress over time
Damage Methodology

\[ \Delta DI = \sum_{k=1}^{m} \sum_{i=1}^{j} \left[ \frac{n_i}{N \left( \epsilon_t^i \right)} \right]_k \]

Distortion:
\[ \Delta RD = \sum_{k=1}^{m} \sum_{i=1}^{j} \sum_{d=1}^{l} \left( P \left( \delta_{k,d} \right) \right)_{k,i} \]

- \( k = \) load level
- \( i = \) time/season
- \( d = \) sublayer
Accumulation of Rutting

Load, $P$

Sub-layer

AC Layer

See Fig. A.

Base Layer

Subgrade

Fig. A

$$PD = \sum_{i=1}^{N_{sub-layers}} \varepsilon_p^i \times h^i$$

Similar treatment for permanent deformation of unbound layers
Time Hardening Approach

\[ \varepsilon_p, \varepsilon_{p,i}, \varepsilon_{p,i-1}, N_{tequiv_i}, N_t_i, N_{t_{i-1}}, T_1, \varepsilon_{r,i}, T_2, \varepsilon_{r,i}, T_3, \varepsilon_{r,i}, T_4, \varepsilon_{r,i} \]
Design Criteria

RUT DEPTH

FATIGUE CRACKING

Criterion

TIME

Criterion

TIME

Design Period
Predicted Distresses

- Fatigue Cracking
- Thermal Cracking
- Longitudinal Cracking
- Rutting
Permanent Deformations
Basic Rutting Equation

Captures stress level effect

\[ \log \left( \frac{\varepsilon_p}{\varepsilon_r} \right) = a_o + a_1 \log(N) + a_2 \log(T) \]

- \( R^2 = 0.73 \)
- \( S_e = 0.309 \)
- \( S_e/S_y = 0.522 \)
- \( N_{\text{tests}} = 3476 \)
  (>300 mixes)

Function of material characteristics, but these less important than \( N \) and \( T \)

Similar treatment for HMA and unbound material permanent deformation
Rutting in HMA

\[
\log \left( \frac{\varepsilon_p}{\varepsilon_r} \right) = -3.15552 + \log \beta_{r_1} + 1.734 \beta_{r_2} \log T \\
+ 0.39937 \beta_{r_3} \log N
\]

\( \varepsilon_p = \) plastic strain
\( \varepsilon_r = \) resilient strain
\( T = \) layer temperature (deg F)
\( N = \) no of load repetition
\( \beta_{r_1}, \beta_{r_2}, \beta_{r_3} = \) calibration factors
Fatigue Cracking
Simplified Fatigue Model

**Bottom – Up Crack Propagation**

Classical Fatigue Mechanism.

**Top – Down Crack Propagation**

- Temp. Gradient; Cooler @ Surface
- High Shear Stress
- Aging @ Surface
- E* Gradient High @ Surface
- Contact Pressure
- High E @ Surface
Fatigue Cracking Model

\[ N_f = \beta_{f_1} k_1 \left( \frac{1}{\varepsilon_t} \right)^{k_2} \beta_{f_2} \left( \frac{1}{E} \right)^{k_3} \beta_{f_3} \]

\[ \beta_{f_1} ; \beta_{f_2} ; \beta_{f_3} \]

Calibration Factors
Pavement Smoothness
Smoothness Model

\[ IRI = IRI_O + \Delta IRI_D + \Delta IRI_{SF} \]

\[ IRI_O = \text{Initial IRI} \]

\[ \Delta IRI_D = \text{Change in IRI due to distress} \]

\[ \Delta IRI_{SF} = \text{Change in IRI due to site factors} \]
Smoothness Components

**Surface Distresses** $D_j$:
- $D_1 =$ Rut Depth Coefficient of Variation
- $D_2 =$ Fatigue Cracking
- $D_3 =$ Patching*
- $D_4 =$ Pot Holes, etc...$D_n$*

**Non-Distress Variables** $S_f$:
- Rainfall
- Material Gradation
- Plasticity Index
- Freezing Index

* Determined from separate empirical models
# IRI vs. Distress Summary

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unbound Base</th>
<th>ATB</th>
<th>CTB</th>
<th>HMA OVERLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>HMA</td>
</tr>
<tr>
<td>Site Factor</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Alligator Ckg</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Rut Depth</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Transverse Ckg.</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Block Ckg.</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Longitudinal Ckg.</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Pot Holes</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Patching</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Outline

⇒ Overview of Rehabilitation Design Process
  ⇒ Major Rehabilitation Strategies
  ⇒ Recycling of Existing Pavement
  ⇒ Identification of Feasible Strategies

⇒ AC Rehabilitation

⇒ PCC rehabilitation
Overview of Rehabilitation Design Process

Zofka, Fall 2010
Pavement Rehabilitation and Maintenance Activities

- Preventive Maintenance
  - REDUCE AGING
  - RESTORE SERVICEABILITY

- Minor Rehabilitation
  - INCREASE CAPACITY
  - INCREASE STRENGTH
  - REDUCE AGING
  - RESTORE SERVICEABILITY

- Major Rehabilitation

- Reconstruction
  - INCREASE CAPACITY
  - INCREASE STRENGTH
  - REDUCE AGING
  - RESTORE SERVICEABILITY
Major Rehabilitation Strategies

⇒ Objective:
  ⇒ To repair existing deterioration and minimize future deterioration

⇒ Parameters: *type*, *quantity*, and *timing*

⇒ Conditions addressed:
  ⇒ *Structural* (distresses)
  ⇒ *Functional* (smoothness)
  ⇒ *Material durability*
  ⇒ *Shoulder condition*
## Major Rehabilitation Strategies

### Reconstruction with/without Lane Additions

<table>
<thead>
<tr>
<th>Pavement Type</th>
<th>Deficiency Addressed</th>
<th>Scope of Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible</td>
<td>H-severity fatigue cracking H-severity rutting Stripping Major subgrade movements Frost heave</td>
<td>Remove &amp; Replace paved lane(s) Remove complete structure Add extra lane Widen existing lane</td>
</tr>
<tr>
<td>Rigid</td>
<td>High %% of cracked slabs High %% of deteriorated joints D-cracking Inadequate subgrade support Frost heave</td>
<td></td>
</tr>
</tbody>
</table>
## Major Rehabilitation Strategies

### Structural Overlay

<table>
<thead>
<tr>
<th>Overlay Type</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thick HMA over Flexible (h &gt; 1.5 in)</td>
<td>Increase structural capacity for anticipated future traffic</td>
</tr>
<tr>
<td></td>
<td>Correct functional deficiencies</td>
</tr>
<tr>
<td>Thin HMA over Flexible (h &lt;= 1.5 in)</td>
<td>Improve ride quality</td>
</tr>
<tr>
<td></td>
<td>Increase surface friction</td>
</tr>
<tr>
<td></td>
<td>Repair M-severity rutting, bleeding, weathering, raveling, bumps,</td>
</tr>
<tr>
<td></td>
<td>settlement, or heaves</td>
</tr>
<tr>
<td></td>
<td>(Does not address fatigue cracking and H-severity rutting)</td>
</tr>
</tbody>
</table>
## Major Rehabilitation Strategies

### Structural Overlay (Cont.)

<table>
<thead>
<tr>
<th>Overlay Type</th>
<th>Purpose</th>
</tr>
</thead>
</table>
| Thin HMA over Intact Rigid or Composite (1in <= h <= 3 in)                     | Improve ride quality
|                                                                              | Increase surface friction                                 |
| Thick HMA over Intact Rigid or Composite (h > 3 in)                          | Increase structural capacity for anticipated future traffic|
|                                                                              | Correct functional deficiencies                           |
| HMA over Intact Rigid:                                                       |                                                           |
| • Must withstand reflective cracking                                         |                                                           |
| • Does not address excessive joint/crack deterioration                        |                                                           |
| HMA over Fractured PCC (Rubblized in 12-in pieces or Crack-and-Seated in 1-3ft pieces) | Prevent reflective cracking
|                                                                              | Increase structural capacity for anticipated future traffic |

- *HMA* stands for Hot-Mix Asphalt.
- *PCC* stands for Portland Cement Concrete.
Major Rehabilitation Strategies

PCC over PCC

Bonded

Unbonded

Concrete Overlay

Existing Concrete Pavement

$h_{ol}$

$h_e$

HMA $h < 2''$
## Major Rehabilitation Strategies

### Structural Overlay (Cont.)

<table>
<thead>
<tr>
<th>Overlay Type</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonded PCC over PCC (h &lt;= 4in)</td>
<td>Increase structural capacity Correct L,M-severity distresses (Not recommended if H-severity deterioration or D-cracking exists)</td>
</tr>
<tr>
<td>Unbonded PCC over PCC (h &gt; 5in)</td>
<td>Address H-severity distresses (separation level) Increase structural capacity</td>
</tr>
</tbody>
</table>
Major Rehabilitation Strategies

Structural Overlay (Cont.)

PCC over HMA (Whitetopping)

Conventional (>=8in)

Thin (4-8in)

Ultrathin (2-4in)
## Major Rehabilitation Strategies

### Structural Overlay (Cont.)

<table>
<thead>
<tr>
<th>Overlay Type</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Whitetopping</td>
<td>Behaves as a new PCC over asphalt treated base (ATB)</td>
</tr>
<tr>
<td>Thin Whitetopping</td>
<td>Increases structural capacity</td>
</tr>
<tr>
<td></td>
<td>Repairs H-severity distresses</td>
</tr>
<tr>
<td>Ultrathin Whitetopping</td>
<td>Requires bonding between UTW overlay and existing HMA</td>
</tr>
<tr>
<td></td>
<td>Requires shorter joint spacing (2-6 ft)</td>
</tr>
<tr>
<td></td>
<td>Substantial HMA thickness is desired (e.g., full-depth HMA)</td>
</tr>
<tr>
<td></td>
<td>Medium or low traffic volume is recommended</td>
</tr>
<tr>
<td></td>
<td>Best addresses rutting and washboarding on parking lots and intersections</td>
</tr>
</tbody>
</table>
# Other Repair and Preventive Treatments

<table>
<thead>
<tr>
<th>Pavement Type</th>
<th>Distress</th>
<th>Repair/Treatments</th>
<th>Preventative Treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible and composite</td>
<td>Alligator (fatigue) cracking</td>
<td>Full-depth repair</td>
<td>Crack sealing</td>
</tr>
<tr>
<td></td>
<td>Bleeding</td>
<td>Apply hot sand</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Block cracking</td>
<td>Seal cracks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Depression</td>
<td>Level up overlay</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Polished aggregate</td>
<td>Skid resistant surface treatment</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slurry seal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Potholes</td>
<td>Full-depth repair</td>
<td>Crack sealing and seal coats</td>
</tr>
<tr>
<td></td>
<td>Raveling</td>
<td>Seal coats</td>
<td>Rejuvenating seal</td>
</tr>
<tr>
<td></td>
<td>Rutting</td>
<td>Level up overlay and/or cold milling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reflective cracking</td>
<td>Full or partial depth repair</td>
<td>Saw and seal</td>
</tr>
<tr>
<td>Rigid</td>
<td>Jointed concrete pavement pumping (and low joint load transfer efficiency)</td>
<td>Subseal (effectiveness depends on materials and procedures)</td>
<td>Reseal joints Restore joint load transfer Subdrainage Edge support (tied PCC shoulder edge beam)</td>
</tr>
<tr>
<td></td>
<td>Jointed concrete pavement joint faulting</td>
<td>Grind Structural overlay</td>
<td>Reseal joints Restore load transfer Subdrainage Edge support (tied PCC shoulder edge beam)</td>
</tr>
<tr>
<td></td>
<td>Jointed concrete pavement slab cracking</td>
<td>Full-depth repair Replace/recycle lane</td>
<td>Subseal (loss of support) Restore load transfer Structural overlay</td>
</tr>
<tr>
<td></td>
<td>Jointed concrete pavement joint or crack spalling</td>
<td>Full-depth repair Partial-depth repair</td>
<td>Reseal joints</td>
</tr>
<tr>
<td></td>
<td>Punchout (CRCP)</td>
<td>Full-depth repair</td>
<td>Polymer or epoxy grouting Subseal (loss of support)</td>
</tr>
<tr>
<td></td>
<td>PCC disintegration</td>
<td>Full-depth repair</td>
<td>None, thick overlay</td>
</tr>
</tbody>
</table>
# Recycling of Existing Pavements

Table 3.5.2. Highway and pavement applications and material uses (11).

<table>
<thead>
<tr>
<th>Major Layer Category</th>
<th>Primary Application of Recycled Paving or Byproduct Material</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Asphalt concrete or AC-treated layers</strong></td>
<td>Blast fume slag, coal bottom ash, coal boiler slag, foundry sand mineral processing wastes, nonferrous slag, recycled asphalt pavement, scrap tires, steel slag</td>
</tr>
<tr>
<td>Aggregate in AC</td>
<td>Coal bottom ash, Recycled asphalt pavement</td>
</tr>
<tr>
<td>Aggregate in cold mix AC</td>
<td>Blast fume slag, Coal boiler slag</td>
</tr>
<tr>
<td>Aggregate in seal coat or surface treatment</td>
<td>Cement kiln dust, lime kiln dust, coal fly ash</td>
</tr>
<tr>
<td>Mineral filler</td>
<td></td>
</tr>
<tr>
<td><strong>PCC or cement-treated layers</strong></td>
<td>Recycled concrete, Coal fly ash, Blast fume slag</td>
</tr>
<tr>
<td>Aggregate</td>
<td></td>
</tr>
<tr>
<td>Supplementary cementitious materials</td>
<td>Coal bottom ash, Coal boiler slag</td>
</tr>
<tr>
<td><strong>Pozzolan stabilized base/subbase</strong></td>
<td>Coal fly ash, Cement kiln dust, Lime kiln dust</td>
</tr>
<tr>
<td>Aggregate</td>
<td>Coal bottom ash, Coal boiler slag</td>
</tr>
<tr>
<td>Cementitious material</td>
<td></td>
</tr>
<tr>
<td>• Pozzolan</td>
<td></td>
</tr>
<tr>
<td>• Pozzolan activator</td>
<td></td>
</tr>
<tr>
<td>• Self-cementing material</td>
<td></td>
</tr>
<tr>
<td><strong>Granular unbound base and subbase</strong></td>
<td>Blast fume slag, coal boiler slag, mineral processing wastes, nonferrous slag, cycled asphalt pavement, Recycled concrete</td>
</tr>
<tr>
<td>Granular base</td>
<td></td>
</tr>
<tr>
<td>Embankment or fill</td>
<td>Coal fly ash, mineral processing wastes, nonferrous slag, Recycled asphalt pavement, Recycled concrete</td>
</tr>
<tr>
<td><strong>Flowable fill</strong></td>
<td></td>
</tr>
<tr>
<td>Aggregate</td>
<td>Coal fly ash, Cement kiln dust, Lime kiln dust</td>
</tr>
<tr>
<td>Cementitious material</td>
<td>Coal fly ash, Cement kiln dust, Lime kiln dust</td>
</tr>
<tr>
<td>• Pozzolan</td>
<td></td>
</tr>
<tr>
<td>• Pozzolan activator</td>
<td></td>
</tr>
<tr>
<td>• Self-cementing material</td>
<td></td>
</tr>
</tbody>
</table>
Identification of Feasible MR Strategies

Phase I: Evaluate Existing Pavement

Step 1: Determine Existing Condition
Step 2: Determine Causes and Mechanism of Distress
Step 3: Define Existing Problems and Inadequacies
Step 4: Identify Possible Constraints

Phase II: Select and Design MR Alternatives

Step 5: Select feasible Candidate Strategies
Step 6: Develop Preliminary Design for Each Candidate Strategy

Step 7: Perform Life-Cycle Cost Analysis
Step 8: Determine Relevant Non-Monetary Factors

Phase III: Evaluate MR Alternatives

Phase IV: Select Most Feasible MR Alternative

Step 9: Determine Most Feasible or Preferred MR Strategy
Identification of Feasible MR Strategies

Phase I Considerations and Assessments

<table>
<thead>
<tr>
<th>Area of Assessment</th>
<th>Data Source</th>
<th>Condition Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Distress Survey</td>
<td>Adequate</td>
</tr>
<tr>
<td>Structural Adequacy</td>
<td>Smoothness Testing</td>
<td>Marginal</td>
</tr>
<tr>
<td></td>
<td>Friction Testing</td>
<td>Inadequate</td>
</tr>
<tr>
<td></td>
<td>Drainage Survey</td>
<td>Adequate</td>
</tr>
<tr>
<td></td>
<td>Nondestructive Testing</td>
<td>Marginal</td>
</tr>
<tr>
<td></td>
<td>Destructive Testing</td>
<td>Inadequate</td>
</tr>
<tr>
<td>Functional Adequacy</td>
<td></td>
<td>Adequate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Marginal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inadequate</td>
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<tr>
<td>Drainage Adequacy</td>
<td></td>
<td>Adequate</td>
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<tr>
<td></td>
<td></td>
<td>Marginal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inadequate</td>
</tr>
<tr>
<td>Materials Durability</td>
<td></td>
<td>Adequate</td>
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<td></td>
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<td>Marginal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inadequate</td>
</tr>
<tr>
<td>Maintenance Applications</td>
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<td>Adequate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Marginal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inadequate</td>
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<tr>
<td>Shoulders Adequacy</td>
<td></td>
<td>Adequate</td>
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<tr>
<td></td>
<td></td>
<td>Marginal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inadequate</td>
</tr>
<tr>
<td>Variability Along Project</td>
<td></td>
<td>Adequate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Marginal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inadequate</td>
</tr>
<tr>
<td>Misc.</td>
<td></td>
<td>Adequate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Marginal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inadequate</td>
</tr>
</tbody>
</table>
## Identification of Feasible MR Strategies

- **Phase II Step 5 – Candidate MR Treatment Selection for existing HMA and HMA on PCC pavements**

### Candidate Treatments for Developing Rehabilitation Strategy

<table>
<thead>
<tr>
<th>Pavement Condition</th>
<th>Distress Types</th>
<th>Full-Depth Asphalt Repair</th>
<th>Partial-Depth Asphalt Repair</th>
<th>Cold Milling</th>
<th>Hot or Cold In-Place Recycling</th>
<th>Crack Sealing</th>
<th>Chip Seal</th>
<th>AC Overlay</th>
<th>AC Overlay of Fractured Slab</th>
<th>Bonded PCC Overlay</th>
<th>Unbonded PCC Overlay</th>
<th>Subsurface Improvement</th>
<th>Reconversion (AC or PCC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural</td>
<td>Fatigue cracking</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Longitudinal cracking in wheel path (low severity)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td></td>
<td>Thermal cracking</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<td>Same treatments as recommended for traveled lanes</td>
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</table>
# Identification of Feasible MR Strategies

## Phase II Step 5 (Cont.) – Candidate MR Treatment Selection for existing PCC pavements

<table>
<thead>
<tr>
<th>Pavement Condition</th>
<th>Distress Types</th>
<th>Candidate Treatments for Developing Rehabilitation Strategy</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Full-Depth Repair</td>
</tr>
<tr>
<td>Structural</td>
<td>JPC and JRC deteriorated cracked slabs</td>
<td>✓</td>
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<tr>
<td></td>
<td>CRC longitudinal cracking</td>
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</tr>
<tr>
<td></td>
<td>JPC and JRC transverse joint/crack faulting</td>
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</tr>
<tr>
<td></td>
<td>CRC punchouts</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>JPC, JRC, and CRC patch/patch deterioration</td>
<td>✓</td>
</tr>
<tr>
<td>Functional</td>
<td>Excessive patching</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Smoothness</td>
<td>✓</td>
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<tr>
<td>Drainage</td>
<td>JPC and JRC pumping</td>
<td>✓</td>
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<tr>
<td></td>
<td>JPC and JRC transverse joint/crack faulting</td>
<td>✓</td>
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<tr>
<td></td>
<td>PCC durability (D-cracking and reactive aggregates)</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>JPC and JRC corner breaks</td>
<td>✓</td>
</tr>
<tr>
<td>Durability</td>
<td>PCC Durability (D-cracking and ASR)</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>JPC, JRC, and CRC Patch/Patch Deterioration</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>PCC Longitudinal Joint Spalling</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>JPC and JRC Transverse Joint Spalling</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Treated base/subbase durability</td>
<td>✓</td>
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<tr>
<td>Shoulders</td>
<td>Same as traveled lanes</td>
<td>✓</td>
</tr>
<tr>
<td>Joint condition</td>
<td>JPC and JRC load transfer deterioration</td>
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</tr>
<tr>
<td></td>
<td>JPC and JRC transverse joint seal damage</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>JPC and JRC pumping</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>JPC and JRC transverse joint/crack faulting</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Joint surround cracking</td>
<td>✓</td>
</tr>
</tbody>
</table>
Identification of Feasible MR Strategies

Phase II Step 6 – Preliminary Design of Alternatives

Information needed:

- Project location and right of way
- Description of MR strategy
- Project Layout
- Layout of all repair work required prior to MR
- Design data (layer geometry and features (shoulders, slopes, medians, curbs etc.))
- Estimates of materials required for MR
Identification of Feasible MR Strategies

⇒ Phase III Step 7 – Life-Cycle Cost Analysis

⇒ Objective:
  ⇒ compare cost versus benefit (service life) of the candidate MR strategies

⇒ Highway Agency Costs:
  ⇒ Initial rehabilitation construction
  ⇒ Future Maintenance and rehabilitation
  ⇒ Future salvage value

⇒ Highway User Costs:
  ⇒ Traffic delay
  ⇒ Vehicle operation
  ⇒ Accident and discomfort
Identification of Feasible MR Strategies

Phase III Step 7 – Life-Cycle Cost Analysis

Benefit/Cost Ratio Concept

\[ EUAC_i = \sum PW_i \left[ \frac{d(1+d)^{p_i}}{(1+d)^{p_i} - 1} \right] \]

\[ \%BENEFIT = \frac{AREA_{BENEFIT}}{AREA_{DO-NOTHING}} \times 100\% \]

\[ B/C = \frac{\%BENEFIT}{EUAC} \]
Identification of Feasible MR Strategies

Phase III Step 8 – Determine Non-monetary factors that influence rehabilitation

- Overall policies for pavement management of a network
- Future rehabilitation options and needs
- Traffic volume
- Future maintenance requirements
- Traffic control during MR construction (safety and congestion)
- Duration of MR construction
- Potential foundation and climate problems
- Performance of similar pavements in the area
- Material availability and contractor capabilities
- Incorporation of experimental features
- Stimulation of competition
- Municipal/local preference and industry recognition
Identification of Feasible MR Strategies

⇒ Phase IV Step 9 – Determine Preferred MR Strategy

⇒ Considerations:

⇒ Cost-effectiveness
⇒ Addressing the specific problems of the existing pavement
⇒ Prevention of future problems
⇒ Meeting all existing constraints of the project

Example
HMA Overlay
Rehabilitation Design Process

Zofka, Fall 2010
Overview of HMA Overlay Design
Inputs for HMA Rehabilitation Design

- General information
- Site/project identification
- Analysis parameters
- Traffic
- Climate
- Drainage and surface properties
- Pavement structure
  - Overlay structure
  - Existing pavement
  - Drainage and surface properties
### Inputs for HMA Rehabilitation Design

#### General Information

<table>
<thead>
<tr>
<th>Input Variable</th>
<th>Description/Source of Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project name and description</td>
<td>• User input</td>
</tr>
<tr>
<td>Design life</td>
<td>• Expected rehabilitation design life</td>
</tr>
<tr>
<td>Existing pavement construction date</td>
<td>• Month in which existing pavement was constructed</td>
</tr>
<tr>
<td></td>
<td>• Year in which existing pavement was constructed</td>
</tr>
<tr>
<td>Pavement overlay construction date</td>
<td>• Month in which HMA overlay construction is expected</td>
</tr>
<tr>
<td></td>
<td>• Year in which HMA overlay construction is expected</td>
</tr>
<tr>
<td>Traffic opening date</td>
<td>• Expected month in which rehabilitated pavement will be opened to traffic</td>
</tr>
<tr>
<td></td>
<td>• Expected year in which rehabilitated pavement will be opened to traffic</td>
</tr>
<tr>
<td>Asphalt Concrete Overlay</td>
<td>• HMA overlay of existing HMA surfaced pavement</td>
</tr>
<tr>
<td></td>
<td>• Includes conventional, deep-strength, full-depth, and semi-rigid pavements.</td>
</tr>
<tr>
<td></td>
<td>• HMA overlay of fractured PCC slabs</td>
</tr>
<tr>
<td></td>
<td>• Includes HMA overlays of fractured JPCP and CRCP.</td>
</tr>
<tr>
<td></td>
<td>• HMA overlay of existing intact PCC pavement</td>
</tr>
<tr>
<td></td>
<td>• Includes HMA overlays of intact JPCP and CRCP.</td>
</tr>
</tbody>
</table>
Inputs for HMA Rehabilitation Design

Analysis Parameters

<table>
<thead>
<tr>
<th>Distress</th>
<th>HMA over HMA</th>
<th>HMA over Fractured PCC</th>
<th>HMA over Intact PCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal Smoothness/IRI</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Longitudinal Cracking</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bottom-up Fatigue (Alligator) Cracking¹</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes, Unless Bonded to JPCP or CRCP</td>
</tr>
<tr>
<td>Thermal Cracking</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Rutting in HMA Layers</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Rutting in Unbound Layers</td>
<td>Yes</td>
<td>Yes</td>
<td>When Used in Overlay Layers</td>
</tr>
<tr>
<td>CSM¹ Modulus Reduction</td>
<td>Yes</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>CSM Fatigue Cracking²</td>
<td>Yes</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>PCC: CRCP Punchouts</td>
<td>NA</td>
<td>NA</td>
<td>CRCP only</td>
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<tr>
<td>PCC: JPCP Transverse Cracking</td>
<td>NA</td>
<td>NA</td>
<td>JPCP only</td>
</tr>
<tr>
<td>Reflection Cracking</td>
<td>Yes</td>
<td>NA</td>
<td>Yes</td>
</tr>
</tbody>
</table>

¹ Alligator cracking is not expected to be a major distress type in these pavement systems unless in some special cases where the HMA overlay debonds with the PCC or when relatively thicker overlays are placed.

² CSM = Chemically stabilized material (e.g., cement-treated, lime flyash, soil cement bases or subbases). Note that the fatigue cracking prediction procedures for CSM layers are uncalibrated.
Inputs for HMA Rehabilitation Design

Analysis Parameters

- **Project Name:** HMA_overlay_HMA
- **Initial IRI (in/mile):** 63

**Performance Criteria**

- **Terminal IRI (in/mile):** 1.72 (90)
- **AC Surface Down Cracking:** 1000 (90)
- **AC Bottom Up Cracking:** 100 (90)
- **AC Thermal Fatigue (in/mile):** 100 (90)
- **Chemically Stabilized Layer Fatigue Factor:** 25 (90)
- **Permanent Deformation - Total Pavement (in):** 0.75 (90)
- **Permanent Deformation - AC Only (in):** 0.25 (90)

- **Project Name:** HMA_overlay_JPCP
- **Initial IRI (in/mile):** 73

**Performance Criteria**

- **Terminal IRI (in/mile):** 15 (90)
- **Transverse Cracking (Pavement cracking):** 0.15 (90)
- **Mean Joint Faulting (in):**
- **CRCP Existing Punchouts:**
- **Maximum CRCP Crack Width (in):**
- **Minimum CRCP Crack Load Transfer Efficiency (LTET):**
- **Minimum Crack Spacing:**
- **Maximum Crack Spacing:**
Rehabilitation Prediction Models

CSM Modulus Reduction

The CSM modulus is reduced due to traffic induced damage during the overlay period (for existing HMA only).

$$E = E_{\text{min}} + \frac{(E_{\text{max}} - E_{\text{min}})}{1 + e^{a+b(d)}}$$

Where:
- $E$ = Modulus of chemically stabilized material, psi.
- $E_{\text{min}}$ = Minimum modulus, psi.
- $E_{\text{max}}$ = Maximum modulus, psi.
- $a$ and $b$ = Fitting parameters.
- $d$ = Fatigue damage in chemically stabilized material.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cement Treated Material</th>
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<tr>
<td>$E_{\text{max}}$, psi</td>
<td>PART 2, Chapter 2</td>
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<tr>
<td>$E_{\text{min}}$, psi</td>
<td>50,000</td>
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<tr>
<td>$A$</td>
<td>-4</td>
</tr>
<tr>
<td>$B$</td>
<td>14</td>
</tr>
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</table>

1 These values pertain to cement treated base or subbase materials.
Rehabilitation Prediction Models

Reflection Cracking

- RC is a major distress in HMA on HMA and HMA on PCC pavements
- RC propagates from bottom up due to:
  - Load-related movements ($f(\text{overlay } h, \exists \text{ exist. } h, E, \text{ and LTE})$)
  - Temperature-induced movements ($f(dT, CTE \text{ and crack spacing})$)
Rehabilitation Prediction Models

M-EPDG Reflection Cracking Model

\[ RC = \frac{100}{1 + e^{c+a+d\cdot t}} \]

- \( RC \) = Percent of cracks reflected, \%  
- \( t \) = Time, years  
- \( h_{AC} \) = Overlay thickness (in)  
- \( a \) = 3.5 + 0.75(Heff)  
- \( b \) = -0.688584 - 3.37302(Heff)\(^{0.915459}\)  
- \( c \) = 1  
- \( d \) = Calibration parameter (user input)

<table>
<thead>
<tr>
<th>Heff</th>
<th>( h_{AC} )</th>
<th>( h_{AC} - 1 )</th>
<th>( h_{AC} - 3 )</th>
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<tbody>
<tr>
<td>AC over AC</td>
<td>AC over Rigid, Good Load Transfer</td>
<td>AC over Rigid, Poor Load Transfer</td>
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</table>

- Recommended Calibration Parameter - d

<table>
<thead>
<tr>
<th>Heff</th>
<th>Delay Cracking by 2 years</th>
<th>Accelerate Cracking by 2 years</th>
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</thead>
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<tr>
<td>&lt; 4”</td>
<td>0.6</td>
<td>3</td>
</tr>
<tr>
<td>4 – 6”</td>
<td>0.7</td>
<td>1.7</td>
</tr>
<tr>
<td>&gt; 6”</td>
<td>0.8</td>
<td>1.4</td>
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</table>

Reflective cracking c: 1.000  
Reflective Cracking d: 1.000
Rehabilitation Prediction Models

Analysis of Fatigue in Existing HMA Layers after Overlay

⇒ Existing layer undergo additional fatigue damage even after overlay

\[ D_m = \sum_{i=1}^{m} \Delta D_i \]

Where:
- \( D_m \) = Damage for month \( m \).
- \( \Delta D_i \) = Increment of damage in month \( i \).

\[ CA_m = \frac{100}{1 + e^{6-6D_m}} \]

\[ TRA_m = \sum_{i=1}^{m} RC_{m-i} \times \Delta CA_i \]

Where:
- \( TRA \) = Total reflected area for month \( m \).
- \( RC_{m-i} \) = Percent cracking reflected for Age = \( m - i \); (Age in years).
- \( \Delta CA_i \) = Increment of fatigue cracking for month \( i \).
Rehabilitation Prediction Models

Analysis of Fatigue in Existing JPCP

⇒ Use the same cracking model as new JPCP

Effect of $h_{\text{HMA}}$, pavement type and LTE on RC

Effect of $h_{\text{HMA}}$ on RC
Rehabilitation Prediction Models

Equivalency Principle in HMA on JPCP Analysis
Rehabilitation Prediction Models

Equivalency Principle in HMA on JPCP Analysis

⇒ Assumptions
  ⇒ Equality of temperature gradient moments between actual and equivalent structure
  ⇒ Equality of deflection basin at the same axle configuration and temperature loading

⇒ Modified properties
  ⇒ Layer thickness
  ⇒ Layer modulus
  ⇒ Temperature gradients
Rehabilitation Prediction Models

Smoothness Prediction

HMA over HMA

\[
IRI = IRI_0 + 0.011505(t) + 0.0035986(FC) + 3.4300573 \left( \frac{1}{(TC_S)_{MH}} \right) \\
+ 0.000723(LC_S)_{MH} + 0.0112407(P)_{MH} + 9.04244(PH)
\]

Where:
- \(IRI_0\) = Initial IRI at the time of HMA overlay placement, m/km.
- \(t\) = Time after overlay placement, years.
- \(FC\) = Total area fatigue cracking, % of wheel path area.
- \((TC_S)_{MH}\) = Average spacing of medium and high severity transverse cracks, m.
- \(LC_S\) = Medium and high severity sealed longitudinal cracks in the wheel path, m/km.
- \((P)_{MH}\) = Area of medium and high severity patches, % of total lane area.
- \((PH)\) = Pot holes, % of total lane area.
Rehabilitation Prediction Models

Smoothness Prediction

HMA over PCC

\[
IRI = IRI_0 + 0.0082627(t) + 0.0221832(RD) + 1.33041 \left( \frac{1}{(TC_3)_{MH}} \right) \tag{3.6.7}
\]

Where:

\(RD\) = Average rut depth, mm.

All other variables as described previously.
## Pre-Overlay Treatments
### HMA-on-HMA Overlay

<table>
<thead>
<tr>
<th>Distress</th>
<th>Severity</th>
<th>Pre-Overlay Treatment</th>
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</thead>
<tbody>
<tr>
<td>Alligator Cracking</td>
<td>Medium to High</td>
<td>Full-Depth Repair</td>
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<tr>
<td></td>
<td></td>
<td>Cold Milling</td>
</tr>
<tr>
<td>Longitudinal Cracking</td>
<td>Medium to High</td>
<td>Cold Milling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Partial-Depth Repair (for joints)</td>
</tr>
<tr>
<td>Transverse Cracking</td>
<td>Low to Medium</td>
<td>Cold Milling</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Full-Depth Repair or Fabric</td>
</tr>
<tr>
<td>Rutting</td>
<td>Low to Medium</td>
<td>Cold Milling</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Overlay is not recommended</td>
</tr>
</tbody>
</table>
Effect of Design Factors on HMA-on-HMA Performance

Site Factors:
Climate: Midwest
Traffic: 18 million trucks

Design Features:
Existing pavement: 7.5 in HMAC, 12 in granular base, A-1-b subgrade
HMA Overlay: 2, 4, and 6 inches

Design Life:
20 years

Effect of HMA overlay thickness on alligator cracking
Effect of Design Factors on HMA-on-HMA Performance

Effect of HMA overlay thickness on total rutting
Effect of Design Factors on HMA-on-HMA Performance

Effect of HMA overlay thickness on transverse cracking
Effect of Design Factors on HMA-on-HMA Performance

Site Factors:
Climate: Midwest
Traffic: 18 million trucks

Design Features:
Existing pavement: 7.5 in HMAC, 12 in granular base, A-1-b subgrade
HMA Overlay: 2, 4, and 6 inches

Design Life:
20 years

Effect of HMA overlay thickness on IRI
Effect of Design Factors on HMA-on-HMA Performance

Site Factors:
- Climate: Midwest
- Traffic: 18 million trucks

Design Features:
- Existing pavement: 5.0 in HMAC, 4 in cement treated base, A-6 subgrade

Design Life:
- 20 years

Effect of existing pavement condition on alligator cracking
Effect of Design Factors on HMA-on-HMA Performance

Site Factors:
- Climate: Midwest
- Traffic: 18 million trucks

Design Features:
- Existing pavement: 5.0 in HMAC, 4 in cement treated base, A-6 subgrade

Effect of existing pavement condition on total rutting
Effect of Design Factors on HMA-on-HMA Performance

Effect of existing pavement condition on IRI

Site Factors:
- Climate: Midwest
- Traffic: 18 million trucks

Design Features:
- Existing pavement: 5.0 in HMAC, 4 in cement treated base, A-6 subgrade

Design Life: 20 years
# Pre-Overlay Treatments

## HMA-on-PCC Overlay

<table>
<thead>
<tr>
<th>Distress</th>
<th>Severity</th>
<th>Pre-Overlay Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cracking, heaves, spalling, punchouts</td>
<td>Medium to High</td>
<td>Full-Depth PCC Repair (dowelled or tied)</td>
</tr>
<tr>
<td>Faulting and Pumping</td>
<td>Medium to High</td>
<td>Installation of edge drains, Maintenance of existing drains, Other drainage improvements Clean-up of incompressibles HMA leveling course</td>
</tr>
</tbody>
</table>
Pre-Overlay Treatments
HMA-on-PCC Overlay

⇒ Reflection Crack Control:
  ⇒ Sawing and sealing joints in HMA Overlay
  ⇒ Increasing HMA Overlay thickness
  ⇒ Granular Interlayers
  ⇒ Fabric treatments and Stress Absorbing Membrane Interlayers (SAMIs)
Effect of Design Factors on HMA-on-JPCP Performance

Effect of existing pavement condition on alligator cracking
Effect of Design Factors on HMA-on-JPCP Performance

Effect of existing pavement condition on total rutting
Effect of Design Factors on HMA-on-JPCP Performance

Effect of existing pavement condition on IRI
PCC Overlay
Rehabilitation Design Process

Zofka, Fall 2010
Overview of PCC Overlay Design

**JPCP/CRCP Overlay Design/Analysis**
- **Existing Pavement**
  - HMAC or HMAC/PCC
  - JPCP or CRCP

**Preoverlay Treatments**
- Milling/levelling
- Patching
- Shoulder repair/replacement
- Subdrainage improvement
- Load transfer restoration (LTR)
- Full-depth repair
- Partial-depth repair
- Slab replacement
- Shoulder repair/replacement
- Retrofit tied PCC shoulder
- Subdrainage improvement

**Analysis**
- PCC Overlay
  - Cracking
  - Faulting
  - Punchouts
  - Smoothness

**JPCP Restoration Design/Analysis**
- JPCP

- Diamond grinding and a combination of:
  - Full-depth repair
  - Transverse joint LTE restoration (LTR)
  - Slab replacement
  - Retrofitted tied PCC shoulder, shoulder repair/replacement
  - Subdrainage improvement

- Existing PCC
  - Cracking
  - Faulting
  - Smoothness
## JPCP Restoration Strategies

<table>
<thead>
<tr>
<th>Distress</th>
<th>Repair Treatments</th>
<th>Preventive Treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jointed concrete pavement pumping (and low joint load transfer efficiency)</td>
<td></td>
<td>• Reseal joints</td>
</tr>
<tr>
<td>Jointed concrete pavement joint faulting</td>
<td>Diamond grinding</td>
<td>• Restore joint load transfer</td>
</tr>
<tr>
<td>Jointed concrete pavement slab cracking</td>
<td>Structural overlay</td>
<td>• Subdrainage</td>
</tr>
<tr>
<td>Jointed concrete pavement joint or crack spalling</td>
<td>Full-depth PCC repair</td>
<td>• Edge support (tied PCC shoulder)</td>
</tr>
<tr>
<td>PCC disintegration (e.g., D-cracking and alkali-silica reaction [ASR])</td>
<td>Partial-depth repair</td>
<td>• Reseal joints</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Restore load transfer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Subdrainage</td>
</tr>
<tr>
<td></td>
<td>Full-depth repair</td>
<td>• Retrofit tied PCC shoulder</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Restore load transfer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Bonded and unbonded PCC overlays</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Thick HMA overlays</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Clean and reseal joints</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Thick hot mix AC overlay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Unbonded PCC overlay</td>
</tr>
</tbody>
</table>
Inputs for PCC Rehabilitation Design

- General information
- Site/project identification
- Analysis parameters
- Traffic
- Climate
- Pavement structure
- Design features
  - Drainage and surface properties
  - Layer definition and material properties
- Existing Pavement Condition
# Inputs for HMA Rehabilitation Design

## General Information

<table>
<thead>
<tr>
<th>Input Variable</th>
<th>Description/Source of Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project name and description</td>
<td>• User input</td>
</tr>
<tr>
<td>Design life</td>
<td>• Expected rehabilitation design life</td>
</tr>
<tr>
<td>Existing pavement construction date</td>
<td>• Month in which existing pavement was constructed</td>
</tr>
<tr>
<td></td>
<td>• Year in which existing pavement was constructed</td>
</tr>
<tr>
<td>Pavement overlay construction date(^1)</td>
<td>• Month in which PCC overlay construction is expected</td>
</tr>
<tr>
<td></td>
<td>• Year in which PCC overlay construction is expected</td>
</tr>
<tr>
<td>Pavement restoration date(^2)</td>
<td>• Month in which existing PCC restoration is expected</td>
</tr>
<tr>
<td></td>
<td>• Year in which existing PCC is restoration is expected</td>
</tr>
<tr>
<td>Traffic opening date</td>
<td>• Expected month in which rehabilitated pavement will be opened to traffic</td>
</tr>
<tr>
<td></td>
<td>• Expected year in which rehabilitated pavement will be opened to traffic</td>
</tr>
<tr>
<td>Type of rehabilitation strategy</td>
<td>• JPCP rehabilitation without overlays</td>
</tr>
<tr>
<td></td>
<td>1. Existing JPCP subjected to CPR(^3)</td>
</tr>
<tr>
<td></td>
<td>2. Rehabilitation with JPCP or CRCP overlays</td>
</tr>
<tr>
<td></td>
<td>1. Existing JPCP, JRCP, CRCP, or composite overlaid with unbonded JPCP overlay</td>
</tr>
<tr>
<td></td>
<td>2. Existing JPCP, JRCP, CRCP, or composite overlaid with unbonded CRCP overlay</td>
</tr>
<tr>
<td></td>
<td>3. Existing JPCP and CRCP overlaid with bonded PCC overlay</td>
</tr>
<tr>
<td></td>
<td>4. Existing flexible pavement overlaid with JPCP overlay</td>
</tr>
<tr>
<td></td>
<td>5. Existing flexible pavement overlaid with CRCP overlay</td>
</tr>
</tbody>
</table>

1. Applicable to PCC overlays only.
2. Applicable to existing JPCP subjected to CPR only.
3. CPR is defined as diamond grinding with a combination of CPR treatments such as full-depth patching, load transfer restoration, shoulder replacement, and lane widening.
Inputs for HMA Rehabilitation Design

Analysis Parameters – JPCP Overlay
Inputs for HMA Rehabilitation Design

Analysis Parameters – CRCP Overlay

Project Name: Unbonded_CRCP_over_JPCP
Initial IRI (in/mi): 35

Performance Criteria

<table>
<thead>
<tr>
<th>Performance Criterion</th>
<th>Limit</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal IRI (in/mi)</td>
<td>172</td>
<td>90</td>
</tr>
<tr>
<td>Transverse Cracking (% slabs cracked)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Joint Faulting (in)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRCP Existing Punchouts</td>
<td>10</td>
<td>90</td>
</tr>
<tr>
<td>Maximum CRCP Crack Width (in)</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Minimum Crack Load Transfer Efficiency (LTE%)</td>
<td>75.0</td>
<td></td>
</tr>
<tr>
<td>Minimum Crack Spacing (ft)</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>Maximum Crack Spacing (ft)</td>
<td>6.0</td>
<td></td>
</tr>
</tbody>
</table>

[OK] [Cancel]
## Inputs for HMA Rehabilitation Design

### Analysis Parameters – Pavement Condition

<table>
<thead>
<tr>
<th>Existing Pavement Type</th>
<th>Structural Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Good</td>
</tr>
<tr>
<td>JPCP (percent slabs cracked)</td>
<td>&lt;10</td>
</tr>
<tr>
<td>JRCP (percent area deteriorated)</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>CRCP (percent area deteriorated)</td>
<td>&lt; 3</td>
</tr>
</tbody>
</table>

1. Percent slabs cracked with all severities and types of cracks plus any repairs.
2. Percent area including repairs or patches, deteriorated joints, and deteriorated cracks (deteriorated joints and cracks converted to repair areas).
3. Percent area includes repairs, patches, and localized failures and punchouts converted to repair areas.
## Pre-Overlay Treatments

### Unbonded JPCP/CRCP on JPCP

<table>
<thead>
<tr>
<th>Distress</th>
<th>Pre-Overlay Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spalling (H-severity)</td>
<td>Remove any loose material&lt;br&gt;If HMA separator layer $\geq$ 1in, no repair is necessary</td>
</tr>
<tr>
<td>Faulting</td>
<td>If HMA separator layer $\geq$ 1in, no repair is necessary&lt;br&gt;If LTE $&lt; 50$, HMA sep. layer $\geq$ 1.5 in is needed&lt;br&gt;Fracturing of existing pavement&lt;br&gt;Increase CRCP reinforcement</td>
</tr>
<tr>
<td>D-cracking</td>
<td>HMA separator layer $\geq$ 1in&lt;br&gt;Remove loose pieces&lt;br&gt;Improve drainage&lt;br&gt;Fracture existing slabs</td>
</tr>
<tr>
<td>Loss of support</td>
<td>Slab replacement&lt;br&gt;Level settlements with HMA layer&lt;br&gt;Fracture existing slabs</td>
</tr>
</tbody>
</table>
### Pre-Overlay Treatments

#### Unbonded JPCP/CRCP on CRCP

<table>
<thead>
<tr>
<th>Distress</th>
<th>Pre-Overlay Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punchouts</td>
<td>Full-depth CRCP repair</td>
</tr>
<tr>
<td></td>
<td>Repair foundation beyond the distress boundary</td>
</tr>
<tr>
<td>Deteriorated Transverse Cracks</td>
<td>Full-depth CRCP patch</td>
</tr>
<tr>
<td>Joint Spalling</td>
<td>Full-depth patch</td>
</tr>
</tbody>
</table>
## Pre-Overlay Treatments

**Bonded PCC on PCC**

<table>
<thead>
<tr>
<th>Distress</th>
<th>Critical Severity</th>
<th>Pre-Overlay Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corner Breaks</td>
<td>Low</td>
<td>Slab stabilization&lt;br&gt;LTE restoration with full-depth repair</td>
</tr>
<tr>
<td>Punchouts (CRCP only)</td>
<td>Low</td>
<td>Full-depth reinforced repair</td>
</tr>
<tr>
<td>Joint Spalling</td>
<td>Medium</td>
<td>Partial-depth repair&lt;br&gt;Full depth repair (where deterioration extends beyond mid depth)</td>
</tr>
<tr>
<td>D-Cracking</td>
<td>Medium</td>
<td>Partial-depth repair&lt;br&gt;Full depth repair (where deterioration extends beyond mid depth)</td>
</tr>
<tr>
<td>Transverse cracking</td>
<td>Medium</td>
<td>LTE restoration with full-depth repair&lt;br&gt;Saw joint above repair oint</td>
</tr>
<tr>
<td>Longitudinal Cracking</td>
<td>Medium</td>
<td>Cross-stitch crack&lt;br&gt;Place reinforcement bars across crack</td>
</tr>
</tbody>
</table>
### Pre-Overlay Treatments
#### PCC on HMA

<table>
<thead>
<tr>
<th>Distress</th>
<th>Critical Severity</th>
<th>Pre-Overlay Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rutting</td>
<td>Medium (&lt;=1 in)</td>
<td>No milling (direct placement)</td>
</tr>
<tr>
<td>Rutting</td>
<td>High (&gt;1 in)</td>
<td>Milling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leveling course</td>
</tr>
</tbody>
</table>
Effect of Design Factors on Unbonded JPCP Overlay Performance

Effect of dowel diameter on faulting
Effect of Design Factors on Unbonded JPCP Overlay Performance

Effect of joint spacing on faulting
Effect of Design Factors on Unbonded JPCP Overlay Performance

Effect of existing PCC condition on faulting
Effect of Design Factors on Unbonded JPCP Overlay Performance

Effect of existing HMA condition on faulting
Effect of Design Factors on Unbonded JPCP Overlay Performance

Effect of slab thickness on transverse cracking
Effect of Design Factors on Unbonded JPCP Overlay Performance

Effect of joint spacing on transverse cracking

- 12-ft
- 16-ft
- 20-ft

10-in PCC slab; no dowels
AC shoulder; no initial cracking (0 percent)
20 million trucks
Effect of Design Factors on JPCP over HMA Performance

Effect of existing HMA condition on transverse cracking
M-EPDG Example - HMA on HMA
General Information Screen - Inputs

- Design Life (years): 20
- Existing pavement construction month: August, Year: 1985
- Pavement overlay construction month: September, Year: 2010
- Traffic open month: September, Year: 2010

- Type of Design
  - New Pavement
    - Flexible Pavement
    - Jointed Plain Concrete Pavement (JPCP)
    - Continuously Reinforced Concrete Pavement (CRCP)
  - Restoration
    - Jointed Plain Concrete Pavement (JPCP)
  - Overlay
    - Asphalt Concrete Overlay
    - PCC Overlay

[Options: OK, Cancel]
M-EPDG Example - HMA on HMA
Site/Project Identification

- Location: Route 195
- Project ID: 
- Section ID: 
- Date: 10/20/2010
- Station/milepost format: Miles: 0.000
- Station/milepost begin: 6.177
- Station/milepost end: 6.877
- Traffic direction: North bound

[OK]  [Cancel]
M-EPDG Example - HMA on HMA

Analysis Parameters

Project Name: Project10
Initial IRI (in/mi): 63

Performance Criteria

- Rigid Pavement
- Flexible Pavement

- Terminal IRI (in/mile)
- AC Surface Down Cracking
- Long. Cracking (ft/mi)
- AC Bottom Up Cracking
- Alligator Cracking (%)
- AC Thermal Fracture (ft/mi)
- Chemically Stabilized Layer
- Fatigue Fracture(%)
- Permanent Deformation - Total Pavement (in)
- Permanent Deformation - AC Only (in)

Limit: 172, 2000, 25, 25, 1000, 25, 0.75, 0.25
Reliability: 90, 90, 90, 90, 90, 90, 90, 90
Example – JPCP Design

Program Indicates Status of Inputs

Completed Inputs have “Green” Icons

Default Inputs have “Yellow” Icons

Incomplete Inputs have “Red” Icons
M-EPDG Example - HMA on HMA

Traffic

- Design Life (years): 20
- Opening Date: September, 2010
- Initial two-way AADTT: 140
- Number of lanes in design direction: 2
- Percent of trucks in design direction (%): 50.0
- Percent of trucks in design lane (%): 100
- Operational speed (mph): 40

Traffic Volume Adjustment: Edit
Axle load distribution factor: Edit
General Traffic Inputs: Edit
Traffic Growth: Compound, 4%

[OK, Cancel]
# M-EPDG Example - HMA on HMA

![Structure Diagram]

## Structure

**Surface short-wave absorptivity:** 0.85

**Layers:**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Type</th>
<th>Material</th>
<th>Thickness</th>
<th>Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Asphalt</td>
<td>Asphalt concrete</td>
<td>2.0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Asphalt</td>
<td>Asphalt concrete (existing)</td>
<td>5.0</td>
<td>1</td>
</tr>
</tbody>
</table>

**Flexible Rehabilitation**

- **Rehabilitation Level:** Level 3
- **Milled thickness (in):** 1
- **Pavement rating:** Fair
- **Total Rutting (in):** 0

**Opening Date:** September, 2010  
**Design Life (years):** 20

[Diagram showing Structure dialog box with input fields for surface absorptivity, layers, rehabilitation level, milled thickness, pavement rating, total rutting, and design life.]
M-EPDG Example - HMA on HMA

HMA Design Properties

HMA E* Predictive Model
- NCHRP 1-37A Visosity based model (nationally calibrated).
- NCHRP 1-40D G* based model (nationally uncalibrated).

HMA Rutting Model Coefficients
- NCHRP 1-37A coefficients (nationally calibrated).

- Check to set a Fatigue analysis endurance limit [only applicable to bottom up alligator cracking] (microstrain):
- Check to include Reflective Cracking in analysis.
M-EPDG Example - HMA on HMA
M-EPDG Example -HMA on HMA

Thermal Cracking

Average tensile strength at 14 °F (psi): 361.14

<table>
<thead>
<tr>
<th>Loading Time sec</th>
<th>Creep Compliance (1/psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low Temp (*F)</td>
</tr>
<tr>
<td>1</td>
<td>2.93692e-007</td>
</tr>
<tr>
<td>2</td>
<td>3.22726e-007</td>
</tr>
<tr>
<td>5</td>
<td>3.65559e-007</td>
</tr>
<tr>
<td>10</td>
<td>4.01698e-007</td>
</tr>
<tr>
<td>20</td>
<td>4.4141e-007</td>
</tr>
<tr>
<td>50</td>
<td>4.99994e-007</td>
</tr>
<tr>
<td>100</td>
<td>5.49423e-007</td>
</tr>
</tbody>
</table>

- Compute mix coefficient of thermal contraction.
  - Mixture VMA (%): 18.6
  - Aggregate coefficient of thermal contraction: 5e-006
  - Mix coefficient of thermal contraction (in/in°F): ...

[OK] [Cancel]
M-EPDG Example - HMA on HMA

![Image of Insert Layer After window]

- Insert after: Layer 2 - Asphalt
- Material Type: Granular Base
- Material: River-run gravel
- Layer Thickness: 8 (in)
- Last layer: No

[OK] [Cancel]
M-EPDG Example - HMA on HMA
M-EPDG Example - HMA on HMA
M-EPDG Example - HMA on HMA
M-EPDG Example - HMA on HMA