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ENHANCEMENTS TO THE MECHANISTIC-EMPIRICAL PAVEMENT DESIGN GUIDE:

A MANUAL OF PRACTICE, 2020 THIRD EDITION

ADDENDUM NUMBER:	**FY2020.02**
ADDENDUM TITLE:	**TOP-DOWN CRACKING ENHANCEMENT TO THE MEPDG, 3RD EDITION MANUAL OF PRACTICE**
Addendum Date:	October 1, 2019
Addendum Revised:	February 26, 2020
Version 4 Revision:	June 30, 2020
Version 5 Revision:	January 6, 2021

BACKGROUND

Top-down cracking is a load-related distress in asphalt pavements and overlays, where the crack initiates at the pavement surface and propagates downward through the asphalt layer. Top-down cracks were predicted using a transfer function similar to bottom-up (alligator) cracking in the earlier versions of the Pavement ME Design software (version 2.5.5 and earlier). Top-down cracks were calculated using a transfer function where the crack length is a function of damage. The overall damage accumulated in the asphalt layer is the sum of incremental damage due to traffic loads during a specific duration of time, which was calculated using Miner's law, similar to bottom-up alligator cracks. Top-down cracks were reported as longitudinal crack length in feet per mile in version 2.5.5 and earlier versions.

The study conducted as part of NCHRP project 1-42A evaluated two models for prediction of top-down cracking – (a) a viscoelastic continuum damage (VECD) based model to predict crack initiation at damage zones and effect on pavement response, and (b) a fracture mechanics-based model to predict crack propagation in the presence of macro-cracks. The NCHRP 1-42A study concluded that both VECD and fracture mechanics based models can form the basis for a top-down cracking model suitable for use in the Pavement ME Design software.

The fracture mechanics-based cracking model was developed under NCHRP project 1-52 and added to the Pavement ME design software. The top-down cracking model from NCHRP 1-52 replaces the older bending beam-based model in the Pavement ME software and output. In addition, longitudinal cracks in the wheel paths and/or alligator cracks have been confirmed through the use of cores to initiate at the surface and propagate down through the asphalt layers. The top-down cracking transfer function was modified to include both longitudinal cracks in the wheel paths and alligator cracks in terms of percent total lane area cracked. This addendum provides the additions and revisions to the 3rd Edition of the MEPDG Manual of Practice regarding the methodology and inputs to the fracture-based top-down cracking model.

CHAPTER 3 – SIGNIFICANCE AND USE OF THE MEPDG

3.1 MEPDG Performance Indicators

- AC-Surfaced Pavements and AC Overlays
  - …
  - Load related alligator cracks and longitudinal cracks in the wheel paths ~~Bottom-Up Initiated Cracks,~~ of flexible and semi-rigid pavements. Both the longitudinal and alligator cracks can initiate at the surface of the pavement and at the bottom of the asphalt layers.
  - Load Related Fatigue Cracking of the Cementitious Stabilized Layer of semi-rigid pavements
  - ~~Load Related Longitudinal Cracking, Surface Initiated Cracks, of flexible and semi-rigid pavements (not recommended for use as a design criteria)~~
  - …

CHAPTER 4 – TERMINOLOGY AND DEFINITION OF TERMS

4.5 Distresses or Performance Indicator Terms—AC-Surfaced Pavement

- **Alligator Cracking** ~~(Bottom Up Cracking)~~ – A form of fatigue or wheel load related cracking and is defined as a series of interconnected cracks (characteristically with a "/alligator" pattern) that initiate at the bottom of the AC layers. Alligator cracks initially show up as multiple short, longitudinal or transverse cracks in the wheel path that become interconnected laterally with continued truck loadings. Alligator cracking is calculated as a percent of total lane area in the AASHTOWare PMED. (See note below.)

- **Longitudinal Cracking** ~~(Top Down Cracking)~~ – A form of fatigue or wheel load related cracking that occurs within the wheel path and is defined as cracks predominantly parallel to the pavement centerline. ~~Longitudinal cracks initiate at or near the surface of the AC pavement and initially show up as short longitudinal cracks that become connected longitudinally with continued truck loadings.~~ Raveling or crack deterioration occur along the edges of these cracks ~~but they do not form an alligator cracking pattern~~. The unit of longitudinal cracking calculated by the AASHTOWare PMED is percent of total lane area ~~feet per mile, including both wheel paths~~. (See note below.)

  - Note: Top-down and bottom-up cracks are difficult to segregate from visual observations. Both longitudinal and alligator cracks can initiate at the surface of the flexible pavement. Cores are usually required to confirm whether the fatigue-based longitudinal and/or alligator cracks initiate at the surface or bottom of the asphalt layers. For the calibration of the top-down cracking transfer function, longitudinal cracks were converted to an area basis by multiplying the measured length of longitudinal cracks in the wheel paths by 1-foot.
- …

CHAPTER 5 – PERFORMANCE INDICATOR PREDICTION METHODOLOGIES

5.3 Distress Prediction Model for Flexible Pavements and HMA Overlays

5.3.3 Load-Related Cracking

Asphalt ~~Concrete~~ Layers
Two types of load-related cracks are predicted by the MEPDG: top-down and bottom-up cracking. The MEPDG assumes that longitudinal and alligator cracks can initiate at the bottom of the asphalt layers and propagate to the surface with continued truck traffic, and can initiate at the surface and propagate downward…

The section titled “*For top-down or longitudinal cracks”* is removed and replaced with the following paragraphs.

Top-Down Cracking
The fracture mechanics model incorporated into Pavement ME uses the Paris’ law of crack propagation to characterize crack growth due to repeated application of traffic loads.

$$\frac{dc}{dN} = A(\Delta K)^n \qquad \text{Equation 1}$$

$$\frac{dc}{dT} = A(\Delta K)^n \qquad \text{Equation 2}$$

Where:
C = Crack length and dc is the change or growth in crack length.
N = Number of loading cycles and dN is the increase in loading cycles during a time increment.
T = Temperature and dT is the increase in thermal cycles during a time increment.
ΔK = Stress intensity amplitude that depends on the stress level, the geometry of the pavement structure, the fracture model, crack length, and load transfer efficiency across the crack or joint
A, n = Fracture properties of asphalt concrete mixture

The NCHRP 1-52 study found that transverse thermal stress does not contribute significantly to the growth of top-down cracking. Therefore, stress intensity at the crack tip due to traffic loading is used to calculate crack length increments. The formation of micro cracks and subsequent failure of asphalt concrete is modeled using the modified Paris’ law shown below in Equation 3.

$$\frac{dc}{dN} = A'(J_R)^{n'} \qquad \text{Equation 3}$$

Where:
C = Crack length and dc is the change or growth in crack length.
N = Number of loading cycles and dN is the increase in loading cycles during a time increment.
A', n' = Fracture properties of asphalt concrete mixture
J_R = Pseudo J-integral

The pseudo J-integral used in the modified Paris' law is defined as the increment in dissipated pseudo work per unit crack surface area. The J-integral is related to the stress intensity factors (K, as defined in Equation 1) as shown in Equation 4.

$$J_R = \frac{1-\upsilon^2}{E_R}(K_I^2 + K_{II}^2) + \frac{1+\upsilon}{E_R}K_{III}^2 \qquad \text{Equation 4}$$

Where:

v = Poisson's ratio of asphalt concrete
E_R = Representative elastic modulus
K_I = Stress intensity factor in Mode I (opening)
K_{II} = Stress intensity factor in Mode II (in-plane shear)
K_{III} = Stress intensity factor in Mode III (out-of-plane share)

The J-integral is computed from stress intensity factors in all three modes of fracture, which are shown below in Figure 5.1.

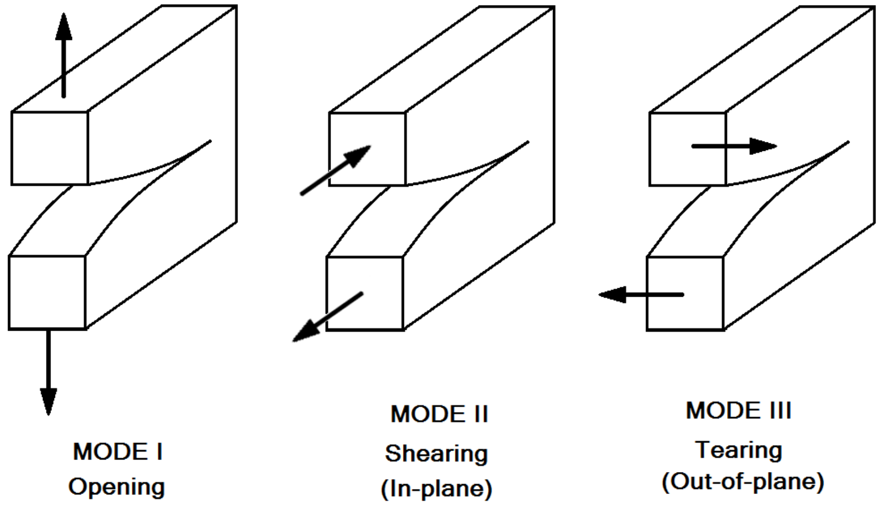

Figure 5.1. Mechanisms of Thermally Induced Reflective Cracks of Asphalt Overlays

The fracture parameter *n'* is calculated from asphalt mixture volumetrics and the asphalt's relaxation modulus Power law function parameters (E_1 and m) as shown below in Equation 5. The parameter A' was found to be strongly correlated to *n'* and is calculated directly using a regression equation as shown in Equation 6.

$$n' = -9.00498 + 1.0627\psi + \frac{2.8713}{m} - 40.8788\left(\frac{1}{E_1}\right)^m + 18.868\frac{P_b}{V_a + P_b} \qquad \text{Equation 5}$$

$$A' = 10^{-1\times(1.2752n+1.713)} \qquad \text{Equation 6}$$

Where:

V_a = Air voids in the asphalt layer, %
P_b = Percent asphalt binder by weight of mix, %
ψ = Shape parameter of the aggregate power law function
E_1, m = Relaxation modulus Power law function parameters, aged asphalt

The pseudo J-integrals were calculated using finite element analysis in ABAQUS using different pavement structures, layer thicknesses, material properties (layer moduli) and crack depths. The analyses were performed by inserting a longitudinal crack of length 1 m (39.4 in.) in the middle of the pavement lane in the longitudinal direction (along the direction of traffic). Artificial neural networks were developed to compute J-integrals at runtime for each set of inputs, i.e. aged asphalt modulus and crack depth at each monthly interval.

Crack growth is modeled using the modified Paris' law over the pavement's design life as described above. The time to crack initiation, defined as the time to reach a crack length of 7.5 mm (0.3 inches), is calculated using a regression equation as shown in Equation 7. The longitudinal and alligator cracking data from LTPP database was used for calibrating the t_0 and crack area transfer functions.

$$t_0 = \frac{\mathrm{K}_{L1}}{1 + e^{\mathrm{K}_{L2} \times 100 \times (\mathrm{a}_0/2\mathrm{A}_0) + \mathrm{K}_{L3} \times \mathrm{HT} + \mathrm{K}_{L4} \times \mathrm{LT} + \mathrm{K}_{L5} \times \log_{10} \mathrm{AADTT}}} \qquad \text{Equation 7}$$

Where:

t_0 = Time to crack initiation, days
HT = Annual number of days above 32°C
LT = Annual number of days below 0°C
$AADTT$ = Annual average daily truck traffic (initial year)
$a_0/2A_0$ = Energy parameter, calculated using Equation 8
$K_{L1\text{-}L5}$ = Calibration coefficients for time to crack initiation

$$a_0 / 2A_0 = 0.1796 + 1.5 \times 10^{-5} E_1 - 0.69m - 7.169 \times 10^{-4} H_a \qquad \text{Equation 8}$$

Where H_a is the total asphalt thickness, K_{L1}, K_{L2}, K_{L3}, K_{L4} and K_{L5} are calibration coefficients. $K_{L1} = 64271618$, $K_{L2} = 0.2855$, $K_{L3} = 0.011$, $K_{L4} = 0.01488$, $K_{L5} = 3.266$

The total percent lane area of top-down cracks is calculated as a function of the number of months to failure and the maximum allowable area of cracking, L_{MAX}. A value of 58 percent is assumed for L_{MAX} and represents the total area of two wheel paths. According to the NCHRP 1-52 study, the definitions of terms related to crack length prediction are:

- Crack initiation: Crack length (depth of the crack from surface) is equal to 7.5 mm (0.3 in.).
- Failure: Crack length is equal to 40 mm (1.575 in.).
- Months to failure, Month: Number of months required for crack (after initiation) to reach the failure criterion of 40 mm.

The predicted top-down cracking versus time is an S-shaped curve and is calculated using the model shown in Equation 9.

$$L(t) = L_{MAX} e^{-\left(\frac{C_1 \rho}{t - C_3 t_0}\right)^{C_2 \beta}} \qquad \text{Equation 9}$$

Where:

$L(t)$ = Top-down cracking total lane area (%)
L_{MAX} = Maximum area of top-down cracking (%)
ρ = Scale parameter of the top-down cracking curve
β = Shape parameter of the top-down cracking curve

t_0 = Time to crack initiation, days
t = Analysis month in days

The scale and shape parameters ρ and β are calculated as a function of number of months to failure, Month using Equations 10 and 11, respectively.

$$\rho = \alpha_1 + \alpha_2 \times Month \qquad \text{Equation 10}$$

$$\beta = 0.7319 \times \left(\log_{10} Month\right)^{-1.2801} \qquad \text{Equation 11}$$

α_1 and α_2 are calibration parameters whose values depend on whether the pavement is located in a wet (WF or WNF) or dry (DF or DNF) climatic zone.

The calibration of top-down cracking model applies to both the cracking prediction model shown in Equation 9 as well as the number of days to crack initiation, t_0 shown in Equation 7. Figure 5.2 includes a comparison of the measured and predicted number of days, t_o, from the LTPP sites included in the study. Figure 5.3 includes a comparison between the measured and predicted area of top-down cracking.

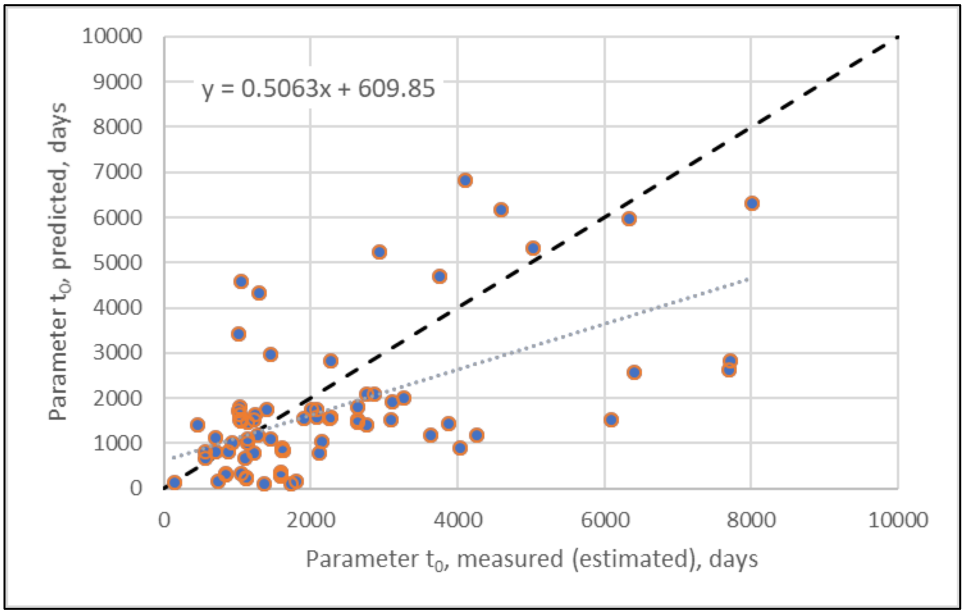

Figure 5.2. Measured versus Predicted Number of Days to Crack Initiation.

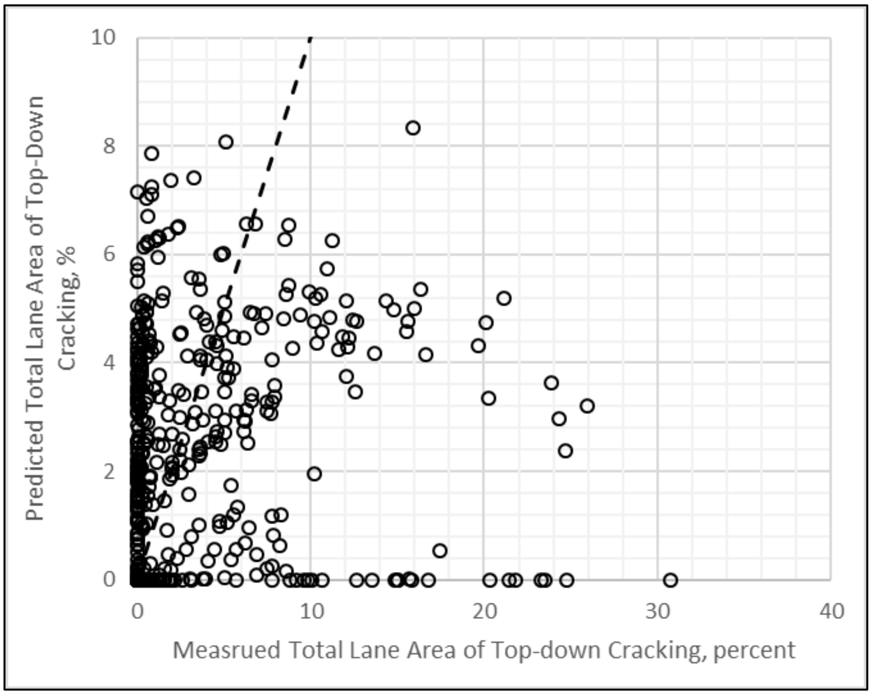

Figure 5.3. Measured versus Predicted Area of Top-Down Cracking

Table 5.1 shows the values of α_1 and α_2 for the four climatic zones. The calibration parameters for the t0 values are shown in Table 5.2. Equation 12 is the standard deviation of residual errors, σ_{RE}, for determining the reliability of a specific design strategy.

$$\sigma_{RE} = 0.3657(TDC_{Mean}) + 3.6563 \qquad \text{Equation 12}$$

Where TDC_{Mean} is the predicted top-down cracking (percent total lane area) based on average inputs.

Table 5.1 Calibration Parameters α_1 and α_2 – Global Coefficients

Climatic Zone	α_1	α_2
Wet freeze (WF)	631.04	2269.8
Wet non-freeze (WNF)	631.04	2269.8
Dry freeze (DF)	1617.6	-1705.3
Dry non-freeze (DNF)	1617.6	-1705.3

Table 5.2 Calibration Parameters for Crack Initiation Time, t_0 – Global Coefficients

Calibration Parameter	**New Flexible**
K_{L1}	64271618
K_{L2}	0.2855
K_{L3}	0.011
K_{L4}	0.01488
K_{L5}	3.266

CHAPTER 7 – SELECTING DESIGN CRITERIA AND RELIABILITY LEVEL

7.1 Recommended Design-Performance Criteria

… Table 7-1 provides the performance values for considerations by highway agencies, realizing that these values may vary among agencies, based on their specific conditions.

Table 7-1. Design Criteria or Threshold Values Recommended for Use in Judging the Acceptability of a Trial Design

Pavement Type	Performance Criteria	Threshold Value at End of Design Life
AC pavement & overlays	AC bottom up cracking; longitudinal/alligator cracks	Interstate: 10% lane area Primary: 20% lane area Secondary: 35% lane area
	AC top-down cracking; longitudinal/alligator cracks in the wheel paths	Interstate: 10% lane area Primary: 20% lane area Secondary: 35% lane area
	Total Rut depth (permanent deformation in wheel paths)	Interstate: 0.40 in. Primary: 0.50 in. Others (<45 mph): 0.65 in.
	Transverse cracking length (thermal cracks)	Interstate: 500 ft./mi Primary: 700 ft./mi Secondary: 700 ft./mi
	IRI (smoothness)	Interstate: 160 in./mi Primary: 200 in./mi Secondary: 200 in./mi
JPCP new, CPR, and overlays	Mean joint faulting	Interstate: 0.15 in. Primary: 0.20 in. Secondary: 0.25 in.
	Percent transverse slab cracking	Interstate: 10% Primary: 15% Secondary: 20%
	IRI (smoothness)	Interstate: 160 in./mi Primary: 200 in./mi Secondary: 200 in./mi

SJPCP overlays of flexible pavements	Percent longitudinal slab cracking	Interstate: 10 percent slabs* Primary: 15 percent slabs* Secondary: 20 percent slabs*
CRCP new and overlays	Punchouts	Interstate: 10 Primary: 15 Secondary: 20
	IRI	Interstate: 160 in./mi. Primary: 200 in./mi. Secondary: 200 in./mi.
* Performance criteria levels need review by agency for adequacy.		

The following paragraph is added to the Manual of Practice after Table 7.1.

Two parameters are predicted by the top-down cracking model as discussed in Chapter 5: percent total lane area with top-down cracking and the average crack depth (see Equation 9) and crack depth (see Equation 3). Both percent total lane area and crack depth are included as graphs in the output report. The percent lane area with top-down cracks is a design criterion, but crack depth is not considered a design criterion. The reliability is only calculated for the percent total lane area with top-down cracks, because the standard deviation of the residual errors between the measured and predicted top-down cracks is only applicable to the percent total lane area and not crack depth (see Equation 12). The average crack depth with age graph, however, can be used by the designer to determine when a rehabilitation or repair strategy should be considered to prevent the top-down cracks from reaching a lower asphalt layer.

…

CHAPTER 8 - DETERMINING SITE CONDITIONS AND FACTORS

8.1 Truck Traffic

8.1.2 Inputs Extracted from WIM Data

…

- **Axle-Load Distributions** (single, tandem, tridem, quads) – The axle-load distribution represents a massive amount of data and the data processing should be completed external to the AASHTOWare PMED software. There are multiple software tools or packages available for processing the axle load distribution data (*8*). These software tools have varying capabilities and functionality, and users may want to evaluate the options so as to select the tool most suitable to their agency needs. Five normalized axle load spectra (NALS) are included as input level 3 default distributions to the MEPDG. Table 1 lists and provides a description of the default NALS. Table 8.3 also includes some recommendations for selecting the default NALS to be used for a specific roadway

  The top-down cracking model requires two traffic inputs – the average annual daily truck traffic at the start of pavement design life ($AADTT_0$), which was defined above, and the cumulative axle load distribution (CALD) parameters. CALD parameters are calculated from the normalized axle load spectrum (NALS), truck class distribution, average number of axles per truck, tire width and tire pressure. Equation 13 shows the CALD function.

$$P(L) = \alpha e^{-e^{\beta-\gamma L}} \qquad \text{Equation 13}$$

Where P(L) is the normalized CALD as a function of tire length L, and α, β, and γ are CALD parameters. The distribution is obtained from non-linear optimization, separately for both single and dual tires. The CALD parameters – α, β, and γ are used as inputs to the ANN model for calculating the J-integral. Load-related distress models in Pavement ME such as rutting and bottom-up fatigue (alligator) cracking assume dual tires for all axles.

…

8.1.3 Truck Traffic Inputs Not Included in the WIM Data

…

- **Number of Tires; Single or Duals:** The top-down cracking model calculates incremental crack length for single and dual tires separately and adds the two values to calculate a cumulative increment in crack length. The number of tires (single or dual) on an axle is not a measured parameter from the WIM data or included in the volume measurements. Thus, single versus dual tires are assumed from other traffic inputs. Truck axles are divided into eight categories based on the axle type and number of tires on each axle. The TDC software code, however, includes only categories 3 and 4, i.e. tandem axles with single and dual tires. Typical characteristics for different axle types are shown in Table 8.1.

  The traffic loads for different axle types (single, tandem, tridem and quad) and FHWA truck classes are divided into single tire and dual tire groups as shown in Table 8.2. The equivalent repetitions of tandem axles with single tires is calculated as sum of groups 1, 3, 5 and 7 as shown by shaded cells in Table 8.2, and dual tires is equal to sum of groups 2, 4, 6 and 8.

Table 8.1 Typical Characteristics for Axle Types

Group	Axle Type	Tires	Tire Width (in.)	Tire Pressure (psi)	Axle Load Interval (lb.)
1	Single	Single	7.874	40 (< 6,000 lb.) 120 (> 6,000 lb.)	3,000 – 41,000 at 1,000 lb. intervals
2		Dual	8.740		
3	Tandem	Single	7.874	120	6,000 – 82,000 at 2,000 lb. intervals
4		Dual	8.740	120	
5	Tridem	Single	7.874	120	12,000 – 102,000 at 3,000 lb. intervals
6		Dual	8.740	120	
7	Quad	Single	7.874	120	12,000 – 102,000 at 3,000 lb. intervals
8		Dual	8.740	120	

Table 8.2. Axle Load Groups for Single and Dual Tires

FHWA Vehicle Class	**Single Axle**	**Tandem Axle**	**Tridem Axle**	**Quad Axle**
4	Group 1	Group 3	Group 5	Group 7

5				
6		Group 4	Group 6	Group 8
7				
8	Group 2			
9				
10				
11				
12				
13				

- …
- **Tire Pressure** – The Pavement ME Design software assumes a constant tire pressure for all loading conditions that represents operating conditions (hot inflation tire pressure) for calculating all pavement distresses, except for top-down fatigue cracks in asphalt wearing surfaces. A median value of 120 psi was used in all calibration efforts. It is recommended that this value be used, unless hot inflation pressures are known from previous studies or a special loading condition is simulated.

  For top-down cracking, a constant tire pressure of 120 psi is assumed for all dual tires and single tires with the higher axle loads. However, 40 psi is assumed and used for single tires with the lower axle loads (see Table 8.1).
- …

8.2 Climate

…The most important climatic input to the top-down cracking model is the pavement temperature at the crack tip, which is calculated from the pavement nodal temperatures from EICM outputs. Aging models for asphalt mixture wearing surface require the climatic zone (wet/dry, freeze/non-freeze) as an input, which is also calculated by the software from EICM outputs. Equation 5.10 includes the climate parameters defined from the climate that are used to calculate the total percent lane area with top-down cracking.

CHAPTER 10 – DETERMINATION OF MATERIAL PROPERTIES FOR NEW PAVING MATERIALS

10.2 HMA Mixtures; Including SMA, Asphalt-Treated or Stabilized Base Layers, Asphalt Permeable Treated Base Mixes

The following rows were added to Table 10-2.

Table 10-2. Asphalt Materials and the Test Protocols for Measuring the Material Property Inputs for New and Existing HMA Layers

Design Type	Measured Property	Source of Data		Recommended Test Protocol and/or Data Source
		Test	Estimate	

New HMA (new pavement and overlay mixtures), as built properties prior to opening to truck traffic	Percent asphalt by total weight of mix	X		AASHTO T 164: Quantitative Extraction of Asphalt Binder for Hot-Mix Asphalt (HMA). AASHTO T 308: Determining the Asphalt Binder Content of Hot-Mix Asphalt (HMA) by Ignition Method.

…

- **Aggregate gradation** - For new asphalt mixtures use values that are near the mid-range of the project specifications or use average values from previous construction records for a particular type of mix. For existing asphalt layers, use the average value recovered from as built construction records, or if construction records are unavailable, measure the gradation from the aggregates recovered from cores or blocks of the asphalt (refer to Chapter 9).

  For top-down cracking predictions, a gradation index or parameter is needed as an input. Aggregate gradation parameter is the shape parameter ψ in the Power law function shown below in Equation 14.

  $$f(x) = \theta x^{\psi} \quad \text{Equation 14}$$

  Where f(x) is the percent passing sieve with opening size x mm, θ is the scale parameter and ψ is the shape parameter of the Power law fit. The gradation parameter is calculated by default when the user enters aggregate gradation of the asphalt mix, or can be entered by the user as an input. Aggregate gradation is a required input for the top-down cracking model, irrespective of the input level for the asphalt mixture dynamic modulus and is now part of the mixture volumetric inputs for the asphalt layer.

- **Air voids, effective asphalt content by volume, asphalt content by total weight, density, voids in mineral aggregate (VMA), voids filled with asphalt (VFA)** - For new asphalt mixtures, use values that are near the mid-range of the project specification or use average values from previous construction records for a particular type of asphalt mixture. More detail is provided in the latter part of this subsection for determining the volumetric properties for new asphalt mixtures. For existing asphalt layers, measure the air voids from cores recovered from the project. The other volumetric properties are calculated from the in-place air voids and volumetric properties recovered from as built construction records (refer to Chapter 9). If construction records are unavailable, measure the effective asphalt content, VMA, and VFA from the cores or blocks taken from the project.

  Percentage of asphalt by weight of the mix, P_b is a user input for the top-down cracking model, which is used to calculate time to crack initiation, t_0. This input is required in addition to the effective asphalt binder content by volume, V_{be} which is the difference between voids in mineral aggregate (VMA) and air voids in the asphalt concrete (V_a). The relationship between P_b and V_{be} is shown in Equation 15.

$$P_b = 100 \times \left[1 - \left(\frac{100 - (V_{be} + V_a)}{100 - V_a}\right) \times \frac{G_{sb}}{G_{mm}}\right] \quad \text{Equation 15}$$

Where:

P_b = Asphalt by weight of mix, %
V_{be} = Effective asphalt binder content by volume, %
V_a = Air voids at time of construction, %
G_{sb} = Bulk specific gravity of the aggregate blend
G_{mm} = Theoretical maximum specific gravity of the asphalt mix

- …
- **Dynamic modulus** - For new asphalt mixtures, input Levels 2 or 3 could be used, unless the agency has a library of test results. Material properties needed for input Levels 2 and 3 include gradation, asphalt PG classification, and test results from the dynamic shear rheometer (DSR; AASHTO T 315). The AASHTOWare PMED software provides the user with two options for estimating the dynamic modulus; one listed as NCHRP 1-37A viscosity-based model and the other listed as NCHRP 1-40D* (dynamic shear modulus of the asphalt) based model. The global calibration factors for all AC predictive equations (refer to Subsection 5.5) were determined using the NCHRP 1-37A viscosity-based model. The option selected depends on the historical data available to the designer. For existing asphalt layers, use input Levels 2 or 3 and the backcalculated values from the FWD deflection basins for estimating the dynamic modulus.

  For top-down cracking predictions, three additional asphalt mixture properties are needed: the representative elastic modulus, the relaxation modulus, and the m-value. The m-value and the relaxation modulus represent the power coefficients from the dynamic modulus master curve, while the representative elastic modulus is the dynamic modulus at the reference temperature for the climate and asphalt binder. As such, all modulus of the asphalt mixture is calculated using the same inputs used for the dynamic modulus calculation.
- …

CHAPTER 11 - PAVEMENT DESIGN STRATEGIES

11.1 New Flexible Pavement Design Strategies – Developing the Initial Trial Design

The following section is added to the Manual of Practice.

11.1.9 Pavement Structure for Top-Down Cracking Prediction

The pavement structure used to develop the stress intensity factors and ANN models was a three-layered asphalt pavement consisting of an asphalt surface, aggregate base course and subgrade. Flexible pavements and overlays typically consist of more than three layers. When more than 3 layers are simulated, the top-down cracking module automatically converts the structure to an equivalent three-layered pavement structure. The conversion is applied to all possible scenarios – multiple asphalt layers, stabilized base, multiple aggregate base layers, multiple subgrade layers and overlay designs, including AC over JPCP and AC over CRCP. Existing layers such as JPCP, CRCP, granular base and stabilized base are all considered to be part of the base layer. The program calculates an equivalent thickness and modulus value for each layer in the converted structure, which are used as input to the stress intensity computations.

CHAPTER 13 - INTERPRETATION AND ANALYSIS OF THE TRIAL DESIGN

13.4 Predicted Performance Values

…

- Flexible pavements.
    - ~~Longitudinal fatigue cracking - cracks in or at the edges of the wheel paths, propagating in the direction of travel. A critical value is reached when longitudinal cracking accelerates and begins to require significant repairs and lane closures.~~
    - Longitudinal and alligator fatigue cracks – area cracking in the wheel paths in terms of percent total lane area cracked. A critical value is reached when the total longitudinal and alligator cracking accelerates and begin to require significant repairs and lane closures.
        - The Pavement ME Design software calculates top-down and bottom-up cracking separately, but both are represented by the percent total lane area with longitudinal and/or alligator cracks.
        - The other parameter calculated by the top-down cracking model is the crack depth over time. Crack depth is graphically included in the output report. The crack depth versus age is included in the output report to provide the designer with information as to the age when the top-down crack will propagate through each asphalt layer simulated in the design strategy.
            - Depending on the site conditions, traffic, climate, and properties of the wearing surface, the top-down crack can be confined to the wearing surface throughout the design life or propagate very rapidly through many of the asphalt layers once the crack starts to grow.
            - The designer should be aware that there can be a combination of conditions when the top-down crack propagates rapidly through thick asphalt layers, even though the total percent lane area with top-down cracks is less than 5 percent. This condition is considered an anomaly. As such, it is recommended the crack depth only be considered in judging the acceptability of a design when more than 5 percent total lane area with top-down cracks is calculated.
    - …

13.5 Judging the Acceptability of the Trial Design

The following rows are added to Table 13.3.

Table 13-3. Guidance for Modifying AC Trial Designs to Satisfy Performance Criteria

Distress & IRI	Design Feature Revisions to Minimize or Eliminate Distress

Area Cracking (Top-Down Cracking)	• Increase thickness of the asphalt layers. • Use a finer-graded asphalt mixture for the wearing surface; lower permeability and higher asphalt content. • Revise mixture design of the asphalt wearing surface layer (use a harder or stiffer asphalt but ensure that the same percent compaction level is achieved along the roadway, use a polymer modified asphalt, etc.) • Increase density, reduce air void of the asphalt wearing surface. • Increase resilient modulus of the aggregate base (increase density, reduce amount of fines, etc.)
Crack Depth (Top-Down Cracking; see Paragraph 13.4)	[Only consider crack depth if the calculated total percent lane area for top-down cracks is less than 5 percent.] • Use a finer-graded asphalt mixture. • Use a stronger or stiffer base layer. • Increase the density, reduce the air voids of the asphalt wearing surface. • Use a stiffer or harder asphalt binder in the wearing surface. • Increase the asphalt content of the wearing surface.