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16. Abstract

The objective of TxDOT project 0-5798 is to develop the framework for the development and implementation of the next level of MEPDG (Mechanistic-Empirical Pavement Design guide) for TxDOT (Tex-ME). One critical feature of the new system will be transfer functions which are used to estimate pavement life from the load and environmentally induced pavement stresses and strains. This product documents the research team's recommended pavement distress transfer functions.

These transfer functions should be considered as draft at this time, they will continue to be refined for the duration of this study and the final versions will be included in the project final report.

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# TRANSFER FUNCTIONS FOR VARIOUS DISTRESS TYPES

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The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. The engineer in charge was Tom Scullion, P.E. (Texas, #62683).

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# RECOMMENDED PAVEMENT TRANSFER FUNCTIONS

This product documents the drafted pavement distress transfer functions. Four major pavement distresses considered in this study are fatigue cracking (bottom-up), rutting, reflective cracking, and low-temperature cracking. The corresponding transfer function for each distress is presented as follows:

## 1. Fatigue Cracking Transfer Function

The proposed fatigue cracking transfer function is composed of three components: 1) fatigue life function, 2) fatigue damage function, and 3) fatigue amount function. Note that the fatigue life function described below originated from this study, and the fatigue damage function and fatigue amount function are similar to those used in the MEDPG. Detailed functions are given below:

### 1) Fatigue life function

Fatigue cracking is the combination of crack initiation and crack propagation process. The number of traffic load repetitions ($N_f$ or fatigue life) to cause a crack to initiate and propagate through the asphalt surface layer is the sum of the number of load repetitions needed for micro-cracks to coalesce to initiate a macro-crack (crack initiation, $N_i$) and the number of load repetitions required for the macro-crack to propagate to the surface (crack propagation, $N_p$).

$$N_f = N_i + N_p \tag{1}$$

$$N_i = k_1\left(\frac{1}{\varepsilon}\right)^{k_2} \tag{2}$$

$$N_p = \int_{c_0}^{h} \frac{1}{A(K)^n}\,dc \tag{3}$$

$$k_2 = n \tag{4}$$

$$k_1 = 10^{6.97001 - 3.20145 k_2 - 0.83661 \log E} \tag{5}$$

where,

$\varepsilon$ = the maximum tensile strain at the bottom of asphalt layer,

$c_0$ = the initial crack length ($c_0$=7.5 mm),

$h$ = asphalt layer thickness,

$A$, $n$ = fracture properties determined from Tex-248-F: Overlay test,

$E$ = modulus of asphalt mixture concrete, and

$K$ = stress intensity factors from traffic loading in bending ($K_I$) and shearing ($K_{II}$). Regression equations for $K_I$ and $K_{II}$ have been developed based on massive finite element computations under this study.

### 2) Fatigue damage function

$$Damage = \sum \frac{ESALs}{N_f} * 100\% \tag{6}$$

### 3) Fatigue amount function

$$Fatigue\ crack\ area(\%) = \frac{100}{1 + \exp(-7.65 \log Damage)} \tag{7}$$

The main features of the proposed fatigue transfer function are 1) consideration of both crack initiation and crack propagation, 2) consideration of each asphalt layer crack resistance property, and 3) simple, rapid lab test for determining transfer function inputs.

## 2. Rutting Transfer Function

After reviewing all existing rutting transfer functions, the VESYS layer rutting transfer function was selected for this study. The layer rutting transfer function estimates the permanent deformation in each finite layer as the product of the elastic compression in that layer and the layer material permanent deformation law associated with that layer. Note that the VESYS rutting model was originally developed by the Federal Highway Administration in late 1970s. Similar conceptual rutting model has been used in the MEPDG.
Detailed layer rutting transfer function is presented below:

$$R_D = \int_{N_1}^{N_2} U_s^{+} \frac{e_t}{e_s} \mu_{sub} N^{-\alpha_{sub}} + \sum_{i=1}^{n-1} \int_{N_1}^{N_2} (U_i^{+} - U_i^{-}) \mu_i N^{-\alpha_i} \tag{8}$$

where,

$U_s^{+}$ = deflection at top the subgrade due to single axle load,

$U_i^{+}$, $U_i^{-}$ = deflection at top and bottom of finite layer i due to axle group,

$e_t$ = strain at top of subgrade due to the axle group,

$e_s$ = strain at top of subgrade due to a single axle,

$\mu_{sub}$, $\alpha_{sub}$ = rutting parameters of the subgrade determined from repeated load test, and

$\mu_i$, $\alpha_i$ = rutting parameters of layer *i* determined from repeated load test.

The major feature of the proposed rutting transfer function is to characterize layer properties rather than global parameters used in the MEPDG. For each pavement layer, the rutting transfer function requires permanent deformation parameters ($\mu$ and $\alpha_i$) which can be determined from repeated load test.

Additionally, to consider the effects of stresses of different magnitudes on the development of rutting, which result from variations in *traffic loads* and *environmental conditions*, an accumulative damage hypothesis is required, just as for fatigue cracking. A **"***time-hardening***"** procedure appears to provide a reasonable approach.

## 3. Fatigue Cracking Transfer Function for Chemically Stabilized Materials

At this moment, three fatigue cracking transfer functions for chemically stabilized materials are reviewed: MEPDG model, PCA model, and CalME crushing model. All three models are presented as follows:

### 1) MEPDG Fatigue Cracking Models for Chemically Stabilized Materials

The fatigue relationship used in the MEPDG is a function of the stress ratio:

$$\log N_f = \frac{(0.972\beta_{c1} - (\frac{\sigma_t}{M_r})}{0.0825 * \beta_{c2}} \tag{9}$$

where,

$N_f$ = number of repetitions to fatigue cracking of the stabilized layer;

$\sigma_t$ = maximum traffic induced tensile stress at the bottom of the stabilized layer (psi);

$M_r$ = 28-day modulus of rupture (Flexural Strength) (psi); and

$\beta_{c1}$, $\beta_{c2}$ = field calibration factors, for cement treated base: $\beta_{c1}=1.0645$ and $\beta_{c2}=0.9003$; for fine-grained soil cement: $\beta_{c1}=1.8985$ and $\beta_{c2}=2.5580$

### 2) PCA-CTB Fatigue Cracking Models for Chemically Stabilized Materials

The PCA already have a fatigue relationship which they have used for many years to design pavements containing cement treated bases. This relationship is also a function of the stress ratio but in an exponential form and is shown below:

$$N_f = \left(\frac{\beta_{c4}}{\sigma_t / M_r}\right)^{\beta_{c3} \cdot 20} \tag{10}$$

where,

$\beta_{c3}$, $\beta_{c4}$ = field calibration factor, for cement treated base: $\beta_{c3}=1.0259$ and $\beta_{c4}=1.1368$; for fine-grained soil cement: $\beta_{c3}=0.6052$ and $\beta_{c4}=2.1154$.

### 3) CalME Crushing Model

A damage function for cement stabilized materials was proposed. It may be based on either the maximum tensile strain or stress at the bottom of the layer. The damage caused by the traffic load is defined:

$$\omega = A \times MN^{\alpha} \times \left( \frac{resp}{resp_{ref}} \right)^{\beta} \times \left( \frac{E}{E_{ref}} \right)^{\gamma} \tag{11}$$

where,

$MN$ = the number of load repetitions in millions,
$resp$ = the response (horizontal tensile stress or strain at the bottom of the layer),
$resp$ref = a reference response (can be related to strength),
$E$ = the modulus of the material (adjusted for climate and damage),
$E$ref = a reference modulus, and
$A$, a, b and g = calibration factors.

## 4. Reflective Cracking Transfer Function

The proposed reflective cracking transfer function includes three components: reflective crack propagation transfer function, reflective damage transfer function, and reflective cracking amount transfer function. These three transfer functions are exactly the same as those developed under the TxDOT Research Project 0-5123.

### 1) Reflective Crack Propagation Transfer Function

The reflective crack propagation transfer function (Equation 12) is based on Paris's law with the combination of bending, shearing, and thermal loading.

$$\Delta C = k_1 A\left(K_{bending}\right)^n \Delta N_i + k_2 A\left(K_{shearing}\right)^n \Delta N_i + k_3 A\left(K_{thermal}\right)^n \tag{12}$$

where,

$\Delta C$ = daily crack length increment,
$\Delta N$ = daily load repetitions,
$A$, $n$ = HMA fracture properties,
$K_{bending}$ = stress intensity factor caused by traffic load in bending,
$K_{shearing}$ = stress intensity factor caused by traffic load in shearing,
$K_{thermal}$ = stress intensity factor caused by thermal load, and
$k_1$, $k_2$, $k_3$ = calibration factors.

Regression equations for $K_{bending}$, $K_{shearing}$, and $K_{thermal}$ have been developed based on massive finite element computations under the Research Project 0-5123.

### 2) Reflective Cracking Damage Transfer Function

$$D = \sum \Delta C / h \tag{13}$$

where,

$h$ = the overlay thickness, and

$\sum\Delta C$ = the total crack length.

### 3) Reflection Cracking Amount Transfer Function

A sigmoidal function (Equation 14) is used to describe the development of reflection cracking amount

$$RCR = \frac{100}{1 + e^{C_1 \log D}} \tag{14}$$

where,

$RCR$ = reflective cracking rate (%),

$C_1$ = calibration factor, and

$D$ = the reflective cracking damage from Equation 13.

## 5. Low Temperature Cracking Transfer Function

Although low temperature cracking is not often observed in Texas, it does exist in north Texas, such as Amarillo district. Generally, contraction strains induced by cooling lead to thermal tensile stress development in the restrained surface layer. Depending upon the magnitude of these stresses and the asphalt mixture's resistance to fracture (crack propagation), transverse cracks may develop at different points along the length of the pavement. Low temperature cracking transfer function proposed is the same one used in the MEPDG. The transfer function is composed of two major components: crack propagation transfer function and cracking amount transfer function.

### 1) Crack Propagation Transfer Function

$$\Delta C = A(\Delta K)^n \tag{15}$$

where,

$\Delta C$ = change in the crack depth due to a cooling cycle

$\Delta K$ = change in the stress intensity factor due to a cooling cycle defined as

$$K = \sigma\left(0.45 + 1.99{C_0}^{0.56}\right) \tag{16}$$

$A, n$ = fracture parameters defined in the following equations:

$$\log A = 4.389 - 2.52 * \log(10000 * \sigma_m * n) \tag{17}$$

$$n = 0.8 * \left(1 + \frac{1}{m}\right) \tag{18}$$

where,

$C_o$ = current crack length.

$\sigma_m$ = undamaged mixture strength measured from indirect tension test.

$m$ = slope of the linear portion of the log compliance-log time relationship determined from creep tests.

$\sigma(\zeta)$ = thermal stress defined as

$$\sigma(\zeta) = \int_0^{\zeta} E(\zeta - \zeta') \frac{d\varepsilon}{d\zeta'} d\zeta' \tag{19}$$

where,

$\sigma(\zeta)$ = Stress at reduced time $\zeta$,

$E(\zeta - \zeta')$ = Relaxation modulus at reduced time $\zeta - \zeta'$,

$\varepsilon$ = Strain at reduced time $\zeta$ (= $\alpha(T(\zeta') - T_0)$),

$\alpha$ = Linear coefficient of thermal expansion/contraction,

$T(\zeta')$ = Pavement temperature at reduced time $\zeta'$,

$T_0$ = Pavement temperature when $\sigma = 0$, and

$\zeta'$ = Variable of integration.

**2) Cracking Amount Transfer Function**

$$AC = \beta_1 * N\left(\frac{\log C/D}{\sigma}\right) \tag{20}$$

where,

$AC$ = observed amount of thermal cracking,

$\beta_1$ = regression coefficient determined through field calibration =353.5,

$N(\ )$ = standard normal distribution evaluated at ( ),

$\sigma$ = standard deviation of the log of the depth of cracks in the pavement =0.769,

$C$ = crack depth, and

$D$ = thickness of surface layer.

Note that the calibration factors $\beta_1$and $\sigma$ were originally developed by Rey Roque et al. under the SHRP program in 1993 and later refined by the MEPDG research team using 22 GPS sections (SHRP general pavement sections), 14 Canadian SHRP sections, and 5 Mn/Road sections.