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Probabilistic prognosis of fatigue crack growth for asphalt concretes

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ABSTRACT

A probabilistic approach is presented for the prognosis of fatigue crack growth for asphalt concretes using the particle filtering method based on Bayesian theory. The random response of fatigue behavior is successively updated with the accumulation of the measured data by the particle filtering method. During the updating, particles with high probability are reproduced more, while others are eliminated via resampling procedures. The *J* integral is adopted for the fatigue crack growth to take into account the viscoelastic characteristics of asphalt concretes. The prognosis of fatigue crack growth and remaining service life under different conditions is presented using this method.

1. Introduction

Asphalt pavement is subjected to repeated vehicle loads that cause fatigue damage to the pavement [1]. As a consequence of the damage, cracks develop as shown in Fig. 1. Cracks in the thickness direction of a pavement can be classified into two groups depending on the direction of their growth: (1) top-down crack and (2) bottom-up crack [2–4]. If the crack grows from the top surface of the pavement, the crack is called a top-down (TD) crack. In cases where the crack grows from the bottom to the top surface, the crack is called a bottom-up (BU) crack. A few nondestructive methods to detect cracks and their growth are available for TD cracks [5–7].

Once cracks are found, the prediction of the crack growth and the remaining service life are very important for building proper maintenance plans. The growth of a fatigue crack can be modeled by the well-known Paris' law, in which the rate of the crack growth is proportional to the power of the stress intensity factor [8]. The application of Paris' law to asphalt concrete, which is distinctly viscoelastic in nature, requires an extension of the classical law. The viscoelastic *J* integral can be used for fatigue prediction in asphalt pavement instead of the stress intensity factor [9–11].

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Nomenclature

A_0	load amplitude
B	specimen width
C	material parameter of Paris law based on J integral
C^*	material parameter of Paris law based on stress intensity factor
$D(t)$	creep compliance
D_0	glassy compliance
D_m	Prony coefficients of the creep compliance
E	elastic modulus
E_R	reference modulus
E_{NRMS}	normalized root mean square error
$F_k(\cdot)$	time-dependent nonlinear state function for augmented particle filtering method
$G(a)$	geometry function
$H_k(\cdot)$	time-dependent nonlinear measurement function for augmented particle filtering method
J	J integral
J_e	J integral in the reference elastic domain
K	stress intensity factor
K_I	stress intensity factor according to mode I
M	number of Maxwell units
N	number of loading cycles
N_{exp}	number of cycles from experiment
N_{pre}	predicted number of cycles
$P''(\boldsymbol{\theta}\|\boldsymbol{y})$	posterior probability distribution
$P'(\boldsymbol{\theta})$	prior probability distribution
$P(\boldsymbol{y}\|\boldsymbol{\theta})$	likelihood function
$P(t)$	load function defined by a sinusoidally fluctuating load
T	temperature
W	specimen geometry
ΔJ	amplitude of the J integral
ΔK	variation of the stress intensity factor
α	coefficient of the regression line for two material parameters C and m
$\bar{J}_0$	J integral of infinite relaxation time
β	coefficient of the regression line for two material parameters C and m
$\boldsymbol{C_k}$	random state vectors of the unknown material parameters of the fatigue law
$\boldsymbol{N}_0$	initial number of cycles which is equal to zero
$\boldsymbol{N}_k$	random variable of the predicted number of cycles
$\boldsymbol{\eta}_k$	state process noises
$\boldsymbol{\theta}$	vector of model parameters
$\boldsymbol{\theta}_k$	vector of unknown parameters
$\boldsymbol{m_k}$	random state vectors of the unknown material parameters of the fatigue law
$\boldsymbol{v}_k$	measurement noise
$\boldsymbol{w}_{1k}$	zero-mean Gaussian white noise sequences
$\boldsymbol{w}_{2k}$	zero-mean Gaussian white noise sequences
$\boldsymbol{w}_k$	state process noise
$\boldsymbol{x}_k$	state vector
$\boldsymbol{y}$	measured data
$\boldsymbol{y}_k^*$	measured number of cycles at a specific crack length from the experiments
$\boldsymbol{y}_k$	measurement function
$\boldsymbol{z}_k$	augmented state vector
σ_v^2	variance for zero-mean Gaussian measurement function $\boldsymbol{y}_k^*$
$\sum_{m=1}^{M}\bar{J}_m$	J integral of Maxwell units with finite relaxation times
τ_m	relaxation time
a	crack length
a_{cr}	critical crack length
c_1	normalizing constant for Bayesian theory
f	load frequency
$f_k(\cdot)$	time-dependent nonlinear state function
$h_k(\cdot)$	time-dependent nonlinear measurement function
k	time index
m	material parameter of Paris law based on J integral