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Probabilistic fatigue life prognostic using SNPL method and crack measurement data

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ABSTRACT

Fatigue life prognostic is a major concern in many structural infrastructures including bridges, which is exposed to various sources of uncertainty. The Paris law is widely used to predict the remaining life of a structure after detecting a crack during inspection. However, the Paris law alone is not sufficient to address the entire fatigue process, because there are several stages for fatigue process. The S-N Paris law (SNPL) method was recently proposed to quantify the uncertainties lying in the Paris law parameters, by finding the best estimates of their statistical parameters from the S-N curve data. Through a series of steps, the SNPL method helps determine the statistical parameters (e.g., mean and standard deviation) of the Paris law parameters that will maximize the likelihood of observing the given S-N data. In this research, the SNPL method is introduced to probabilistically predict the remaining fatigue life based on crack measurement data. Although it is assumed that only deterministic S-N curve data is available, the proposed method enables the probabilistic fatigue life prognostic of a steel bridge based on various measured crack lengths.

1. INTRODUCTION

Steel bridges which are critical nodes in a road transportation network are exposed to the risk of fatigue failure. It is thus necessary to predict the fatigue life so that appropriate decisions on optimal bridge maintenance can be made for a target period. However, such fatigue life prognostic is a challenging task because various sources of uncertainty involve with it.

Over the years, numerous studies have been conducted to investigate the fatigue process in materials as well as to predict fatigue life, and they can categorized into two groups. The methods in the first group are based on the S-N curve (Suresh 1998) which is based on the stress-life method, whereas those in the second one often count on the Paris law (Paris and Erdogan 1963) which accounts for the crack propagation rate based on fracture mechanics. Although these two approaches have been

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developed separately and applied to various structural problems for fatigue life prognostic, there has been few attempts to use them together to complement each other and maximize the benefits.

Recently, a new method, termed the S-N Paris law (SNPL) method, was developed. Through a series of steps, the SNPL method helps determine the statistical parameters (e.g., mean and standard deviation) of the Paris law parameters that will maximize the likelihood of observing the given S-N data. In this research, the SNPL method is introduced to probabilistically predict the remaining fatigue life based on crack measurement data. Although only deterministic S-N curve data is available, the proposed method enables the probabilistic fatigue life prognostic of a steel bridge based on various measured crack lengths.

2. PROPOSED METHOD FOR PROBABILISTIC FATIGUE LIFE PROGNOSTIC

To present the proposed method, the SNPL method is explained briefly. The SNPL method is based on the Paris law which presents a relationship between the crack propagation rate (*da*/*dN*) and the range of stress intensity factor (Δ*K*), as shown in the following equation:

$$\frac{da}{dN} = C\Delta K^m \tag{1}$$

Where *a* is the crack length, *N* is the number of loading applications, and *C* and *m* are the material parameters. Using the Newman’s approximation, the stress intensity factor range can be estimated as

$$\Delta K = \Delta S \cdot Y\left(a\right)\sqrt{\pi a} \tag{2}$$

where Δ*S* is the range of the far-field stress and *Y*(*a*) is the geometry function. In fact, the stress intensity factor range is known to vary with the geometry of the structure around the crack of interest, and various geometry functions are available from a literature by Tada *et al*. (1985).

Based on Eqs. (1) and (2), a formulation which gives us the required number of loading applications (N_f) until fatigue crack growth from an initial crack length (a_0) to another crack length (a_c) can be derived analytically as follows (Lee and Song 2014, Lee *et al*. 2017):

$$N_f = \int_{a_0}^{a_c} \frac{1}{C\left(\Delta K\right)^m} da = \int_{a_0}^{a_c} \frac{1}{C\left(\Delta S \cdot Y\left(a\right)\sqrt{\pi a}\right)^m} da \tag{3}$$

Using Eq. (3), the limit-state functions representing non-failure and failure cases, which are respectively called *inequality* and *equality* cases in the SNPL method (Ramachandra Prabhu and Lee 2017), can be obtained. Then, the probability observing the given S-N curve can be expressed by the multiplication of individual probabilities of the given *inequality* and *equality* cases, and the SNPL method determines the Paris law parameters through an optimization process, which maximizes the probability that the given S-N test results are observed. The more detailed information can be found in Ramachandra Prabhu and Lee (2017).

Once the statistical parameters of the Paris law parameters, such as *C* and *m* in Eq. (1), are determined, the remaining fatigue life (*T*) based on crack measurement data is calculated as

$$T = \frac{1}{C\nu_0 \left(\Delta S\right)^m} \int_{a_0+\varepsilon_m}^{a_c} \frac{1}{\left[Y(a)\sqrt{\pi a}\right]^m} da = 0 \quad (4)$$

where ν_0 is the loading frequency, a_c is the critical crack length, and ε_m is the measuring error (Lee and Song 2014, Lee *et al*. 2017). As a result, the proposed method enables the probabilistic fatigue life prognostic of a steel bridge based on various measured crack lengths.

3. CONCLUSIONS

A new probabilistic method was proposed to predict the remaining fatigue life of a steel bridge based on S-N curve and crack measurement data. The proposed method employs the SNPL method in order to determine the statistical parameters of the Paris law parameters, by finding the best likelihood estimates from given S-N curve. Once the statistical parameters are determined, the remaining fatigue life can be estimated with various measured crack lengths, which enables the probabilistic fatigue life prognostic of a steel bridge.

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