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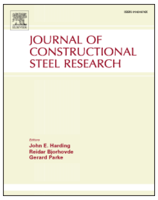

A continuum model for damage evolution simulation of the high strength bridge wires due to corrosion fatigue

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ABSTRACT

Continuum damage model and simulation algorithm are developed to simulate the corrosion fatigue process of high strength bridge cable steel wires. The developed model can be used to predict the damage curves during the corrosion fatigue process based on the concept of continuum damage mechanics (CDM). The algorithm can be used to simulate the corrosion fatigue damage evolution process of bridge wires from local damage to failure. As case study, the developed model and algorithm have been applied to simulate corrosion fatigue damage evolution of bridge wires under cyclic tensile in 3.5 wt% NaCl solution at 6 Hz, and the numerical prediction results are compared with experimental results. It shows that the developed model and algorithm are reasonable and can be used to study and describe corrosion fatigue damage evolution of bridge wires.

1. Introduction

Many long-span cable-stayed bridges have been built in the world, which are in the order of kilometers. Since stay cables are the main bearing component of long-span cable-stayed bridges [1], their service lives play an important role in the safety of the whole bridge. However, bridge cables are subjected with aggressive corrosion environments and cyclic loading during their service time, and prone to corrosion fatigue failure. Many old cable-stayed bridges all over the world have deteriorated cables, in which some of the steel wires for the main bridge cables are heavily corroded and fractured [2,3]. Rehabilitation work of deteriorated wires due to corrosion fatigue was carried out on the Brooklyn Bridge and the other bridges [4,5].

Since many researches pointed that fatigue life in corrosive environment is significantly lower than it in dry air [6,7], it shows that aggressive corrosive environment has an important effect on the fatigue performance of metallic structures, which is because corrosion pits initiate and grow on the material surface in corrosive environments and then continue to cause crack initiation and growth even at very low stress levels [8,9]. Therefore, in order to better evaluate fatigue damage and life of bridge cable steel wires in service corrosive environment, it is necessary to consider the combined action of stress and corrosion. Although many researches have been done, the corrosion fatigue phenomenon of bridge cable steel wires are still necessary to be studied [10].

The objective of this paper is to develop a model within continuum damage mechanics (CDM) framework which can be used to simulate the damage evolution of bridge cable steel wires due to the combined action of stress and corrosion. The concept of CDM is first presented by Kachanov [11] and widely used in engineering application due to its simplicity, in which a damage variable is used to describe the degradation of material mechanical properties. Although CDM has been widely used to develop cumulative fatigue damage models due to cyclic stress, e.g. Manson [12], Chaboche [13], Fatemi [14], Franke [15], very few continuum models are developed to describe the damage of the high strength bridge cable steel wires due to combined action of cyclic stress and corrosion.

In this study, a continuum corrosion fatigue damage model of bridge wires is developed based on an evolution law for damage accumulation due to cyclic stress [13], pit and crack growth rates [16], and pit-to-crack transition criteria [17]. Using the developed model, corrosion fatigue damage simulation algorithm is also developed. Finally, as a case study, corrosion fatigue damage evolution of a pre-split high strength bridge cable steel wire is simulated under cyclic loading within 3.5 wt % NaCl solution at 6 Hz.

2. Corrosion fatigue damage model of bridge wires based on CDM

In CDM, macroscopic state variable D is used to describe the distribution, characterization and growth of micro-structural defects. As shown in Fig. 1, D is defined as the gradual loss of effective cross-sectional area A_e due to material degradation processes [18]:

$$D = 1 - A_e / A_0 \quad (1)$$

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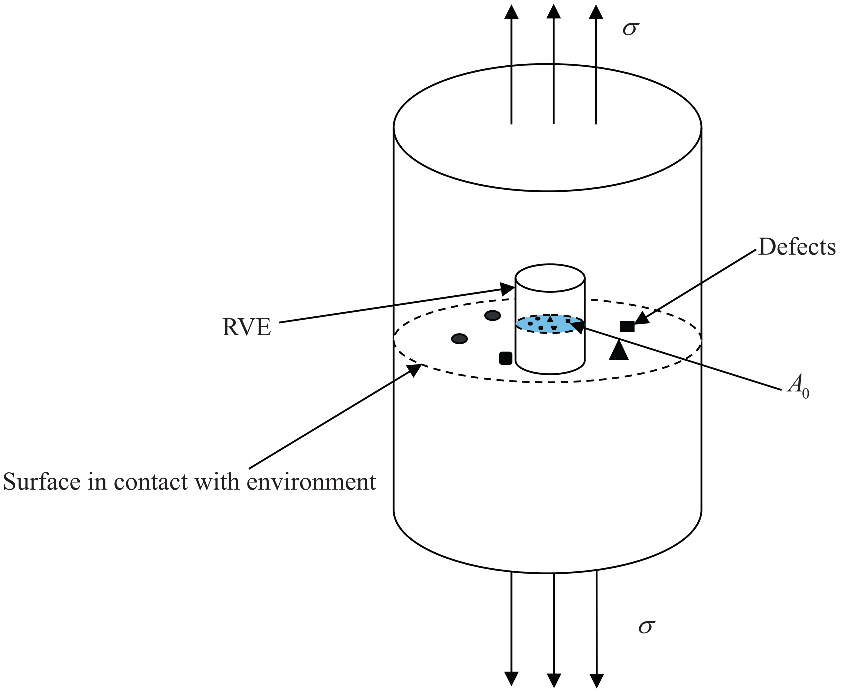

Fig. 1. Schematic diagram of physical damage as defined in CDM framework.

where A_0 is the elemental area of the representative volume element (RVE) shown in Fig. 1, in which all properties including micro-structural defects are represented by homogenized variables [19]. For the undamaged material with effective cross sectional area $A_e = A_0$, the damage variable D equals to zero based on Eq. (1).

Using the definition of D shown in Eq. (1), the effective stress σ_e can be defined as [19]:

$$\sigma_e = \sigma/(1-D) \tag{2}$$

where σ is the nominal stress.

According to the symmetry feature of cylindrical bridge wires, here the corrosion fatigue damage rates are assumed to be the same along the radius in their cross section. Such as shown in Fig. 2, the loss of length rate along the two arbitrary radius R1, R2 due to corrosion fatigue are same based on the above assumption. Similar to definition of damage variable due to cyclic stress shown in Eq. (1), here corrosion fatigue damage model of bridge wires D_{CF} is defined based on the effective radius R_e which is similar to the definition of the effective cross-sectional area A_e.

$$D_{CF} = 1-R_e/R = R_l/R \tag{3}$$

where R is the initial radius for the undamaged material, R_l is the loss of length along the radius within the cross section of the bridge wire.

As shown in Eq. (3), in order to obtain the corrosion fatigue damage of bridge wires, R_l should first be calculated. In this study, the loss of the length along the radius within cross section of bridge wires R_l were divided into two conditions R_l^1 and R_l^2 ($R_l = R_l^1 + R_l^2$): in the first condition, R_l^1 can be obtained based on the pit initiation and growth to cracks from outside surface in contact with environment to material inward of bridge wires due to combined action of cyclic stress and corrosion; in the second condition, R_l^2 can be obtained based on loss of effective cross-sectional area within inward of bridge wires due to the action of cyclic stress, where has not been corroded.

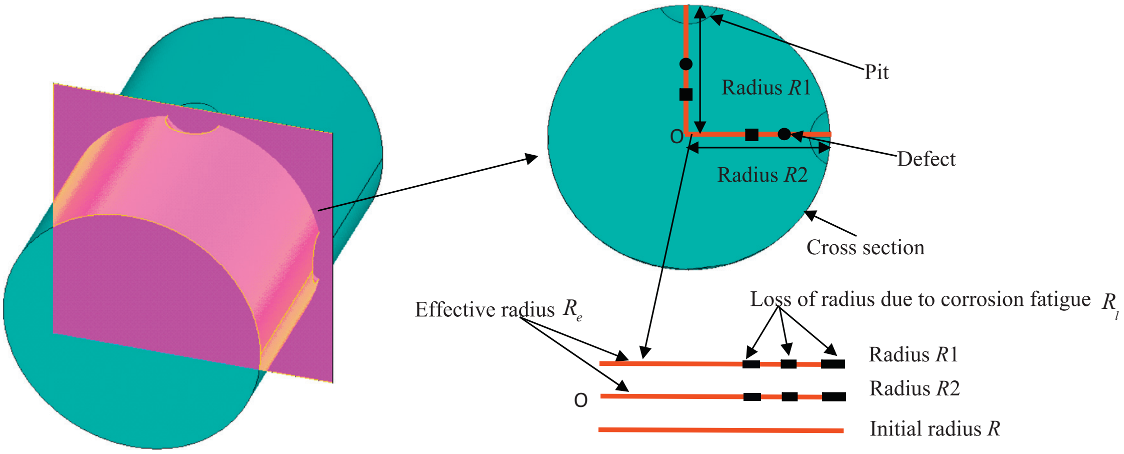

Fig. 2. Schematic diagram of definition of the corrosion fatigue damage model of bridge wires.