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Stable and unstable fatigue prediction for A572 structural steel using acoustic emission

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ABSTRACT

The association of acoustic emission (AE) signals with crack growth behavior in the material of interest is the basis for monitoring the fatigue damage of in-service steel structures with the AE method. A model including the absolute energy rate of AE, stress intensity, fracture toughness and load ratio is presented to predict crack extension and remaining fatigue life for stable and unstable crack stages. The model is based on the Forman equation, and the balance between AE signal energy and the energy released due to crack growth. Results from AE-monitored fatigue tests with load ratios of 0.02, 0.1 and 0.7 are utilized to validate the presented model. To separate AE signals associated with crack growth from noise, a combined approach involving pattern recognition and analysis of waveform features was employed. Prediction procedures are demonstrated based on the presented model and experimental data. Reasonable agreement exists between the observed and predicted test results. The presented model conservatively estimates fatigue damage and remaining fatigue life.

1. Introduction

Fatigue cracks may develop in steel components if the fatigue life has been reached due to extended service. Crack growth has three stages: low-speed cracking near the threshold of the stress intensity range, stable cracking, and unstable cracking that may cause catastrophic failure. Stages II and III are of practical importance for damage evaluation and remaining fatigue life prediction. The transition point between stable and unstable cracking is referred to as the critical cracking level [1]. Two driving forces, stress intensity range and maximum stress intensity, govern the crack growth behavior in stages II and III, respectively [2,3]. The Paris equation [4] describes the relationship between crack growth rate and stress intensity range for stage II. The final or critical crack length usually needs to be determined prior to the application of the Paris equation. The Forman equation [5], involves the load ratio, fracture toughness, and maximum stress intensity with the Paris equation to depict stages II and III. Both equations are capable of predicting remaining fatigue life whereas the Forman equation addresses the critical cracking level as well.

The AE technique has high sensitivity and demonstrated reliability in the detection of active cracks [6,7], and can provide insight to the integrity of in-service steel structures and components, including steel bridges [8–11]. Another notable advantage of the AE technique is the capability of locating active cracks in the region where a crack is likely to occur. Signal identification is a necessary step in the application of AE techniques. In addition to cracking signals, AE sensors are also sensitive to grating between fracture surfaces, abrasion in the load train, and environmental noise. Spatial filtering techniques [12–14] may not always be feasible for monitoring implementations for a number of reasons. These include source location challenges caused by geometric irregularities and limitations on the numbers of sensors, computational processing power, and data transmission rates. In the study described pattern recognition of waveforms from genuine hits and noise were compared to filter AE data independent of source location [15–17]. Waveform features such as rise time, duration and amplitude were involved in filtering of the AE data [18–20]. The combination of pattern recognition and waveform feature analysis is suitable for both laboratory studies and field tests [21,22].

Previous studies have focused on relating AE parameters to crack growth for damage evaluation and fatigue life prediction. Harris and Dunegan identified the relationship between AE and stress intensity range by relating the energy released during crack extension to AE counts [23]. Lindley, et al. [24] further investigated the physical meanings of the material constants in the Harris and Dunegan model based on the observation that the AE source mechanisms might be caused not only by crack extension but also by plastic deformation and small fracture events within the plastic zone. Efforts on the application of the Harris and Dunegan model were made to determine the specific curve of AE count rate versus stress intensity range for the material of interest [13,25,26]. Considering that AE absolute energy [27] is less dependent on the gain of the electronics and trigger level of the AE sensors, the relationship between absolute energy rate and stress intensity range has been presented for the application of AE monitoring [22]. The presented models mentioned above apply to stage II crack growth behavior because the Paris equation was involved

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