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Deterministic and probabilistic fatigue prognosis of cracked specimens using acoustic emissions

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ABSTRACT

This paper presents and compares two methodologies for predicting fatigue life of structural elements using Acoustic Emission data. These methodologies have the potential to be used by bridge owners to assess the state of key structural elements in an almost real time fashion and forecast the state of the element at any time in the future. This information can be used to schedule maintenance or replacement. The proposed methodologies have the potential to be applied to any structural element with active cracks and do not require knowledge of the load history. One approach uses fracture mechanics models and relationships between acoustic emission features, while the other approach is based on relationships between acoustic emission features and stress intensity range to estimate the stress intensity range of a particular crack a number of cycles in the future. Compact tension specimens are used to explore the capabilities of both techniques.

1. Introduction

Most bridges in the United States were built in the 50s and 60s with a life expectancy of 50 years. Today the American Society of Civil Engineers (ASCE) estimates that about 15% of the bridges in the United States are obsolete while the average bridge is approaching its designed service life at 43 years [1]. In addition, an ASCE study found that 80 to 90% of steel structure collapses were caused by a combination of fracture and fatigue [2]. Maintaining a safe use of this aging infrastructure is a monumental task that highlights the importance of the proper conditioning assessment techniques.

Different methodologies for prognosis of fatigue life of structural elements have been proposed [3–5]. For instance, field strain measurements from key components or hot spots in the structure have been widely used. These strain based methodologies use different means to obtain the average stress range according to the Guide Specifications for Fatigue Evaluation of Existing Steel Bridges [6] and the Guide Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges [7]. The technique employs the strain measurements to build a histogram of the fatigue stress range where the number of cycles is counted using the peak-to-peak or the rainflow algorithms [8]. Then the average stress range is calculated and used to determine the remaining life using the proper Stress Range versus Number of Cycles (S–N) curve for the element. The methodology has been successfully used to assess the remaining fatigue life of actual bridges components in Refs. [9,10].

These methodologies present an important step forward in the reduction of uncertainty for fatigue prognosis by including field strain measurements. However, they depend heavily on the S–N curves of the elements, which for some elements and specific loading conditions might be uncertain or unavailable. Additionally, these methodologies do not present a quantitative assessment of the current or future condition of the element, beyond determining the total fatigue life of the element. For most structures the prior loading history of the element is not known and therefore, it is very difficult to assess the remaining fatigue life of the element.

This paper proposes the use of Acoustic Emission (AE) in conjunction with strain gauges as field data measurement. AE is proposed in here for bridge long term monitoring because: i) it allows in-service structural monitoring, ii) is adaptable to any structural element, iii) is easy to install, and iv) can be installed fast and at low cost by using nodes with wireless communication and remote data collection capabilities that are commercially available [11]. The advantage of AE compared to other monitoring techniques like the use of only strain gauge measurements resides in the fact that AE allows the detection and monitoring of cracks without the need of prior knowledge of the load history, empirical information like the S–N curves, or even a finite element model. Furthermore, the proposed techniques that use AE in conjunction with strain gauge measurements have the potential for assertive prognosis of fatigue life, because AE can be related to the actual crack length and the number of cycles (calculated from strain gauge measurements) as shown by different researchers [12–18]. AE has been used for the monitoring of bridges since the 1970s. The technique has been applied to assess and monitor a wide range of structural components in bridges such as: steel elements, concrete elements, prestressed elements, cables, anchorages, among

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