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Acoustic emission detection of fatigue damage in cruciform welded joints

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ABSTRACT

Weld seams are critical points for the initiation of fatigue cracks in steel structures subjected to cyclic loads. Semi-elliptical surface cracking at the toes of a fillet weld is not easily found when it is partially through the thickness and subcritical. In this study the acoustic emission (AE) method is used to detect crack propagation in cruciform fillet welded joints that are representative of typical fatigue sensitive details in steel bridge superstructures. The effect of geometry and fatigue load on the AE data is investigated by varying the width of the base plate and the stress ratio. AE data filtering based on load pattern, source location, and waveform feature analysis was implemented to minimize noise-induced AE signals and false indications due to wave reflections. AE time domain features such as amplitude (b-value), counts, signal strength, and absolute energy are employed to study the influence of geometry and fatigue load on the AE data.

1. Introduction

Fatigue sensitive details in steel structures often include weldments [1], where relatively high residual ("locked-in") stresses, weld geometries and discontinuities concur to the formation and growth of fatigue cracks under cyclic loads [2]. The initiation of fatigue cracks is significantly accelerated if initial defects exist in the weldments. A typical example of fatigue sensitive detail in a steel bridge is shown in Fig. 1, where a fatigue crack developed along a fillet weld at the gap between the I-girder web and a welded stiffening plate. In fact, in a welded I-girder superstructure the mechanical stress cycles produced by traffic loads may cause the initiation and propagation of fatigue cracks in the weld seam between the web or flange and stiffeners or diaphragm connection plates. In the case of fatigue cracks at the weldment between webs and diaphragm connection plates, the likelihood of damage increases due to the combination of longitudinal bending stresses (i.e., parallel to the longitudinal axis of the girder) and the distortion effect from out-of-plane forces that are imparted by the diaphragm [2].

Representative cruciform specimens under uniaxial load that is applied either on the main base plate or on symmetrically welded plates are typically used to study these details, where fatigue cracks may initiate at weld toes or at weld roots [3–5]. Fig. 2(a) shows a cruciform specimen loaded along the main base plate, which simulates either a portion of flange-to-stiffener connection or a web-to-stiffener connection where secondary distortional effects are neglected [4,5]. Under these conditions, weld root cracks propagate through weld throats whereas weld toe cracks propagate into the base plate forming semi-elliptical surface fatigue cracks [6]. Both weld root cracks and weld toe cracks are likely to be non-visible as they are partially through the thickness and subcritical, making traditional visual inspections ineffective [7]. The detection of fatigue cracks in weldments is a significant challenge in the assessment of structural integrity.

Acoustic emission (AE) monitoring has been utilized in welding operations for the detection of weld defects during both the welding and cooling phases [8,9], including special applications such as nuclear reactor structures where high-quality weldments are required [10]. The cracks produced during welding and cooling make the weldments susceptible to fatigue damage. Ultrasonic and radiographic (especially X-ray) techniques are only available for post-weld inspection, whereas the AE method can perform timely monitoring of the welding process and offers the possibility to provide immediate feedback for the correction of anomalies [11]. Cold cracks may form after welding due to the residual stresses produced by cooling of welded joints and the heat-affected zone. It has been reported that cold cracking can generate high-amplitude AE signals [8].

The sensitivity and non-invasive nature of AE method makes it well suited for the health monitoring and assessment of civil steel structures, such as bridges [12,13]. Studies on AE monitoring of crack propagation in full size steel I-girders indicate that AE method is able to detect small fatigue cracks at early stage of fatigue life of the I-girders [7]. The effective use of AE method to detect active

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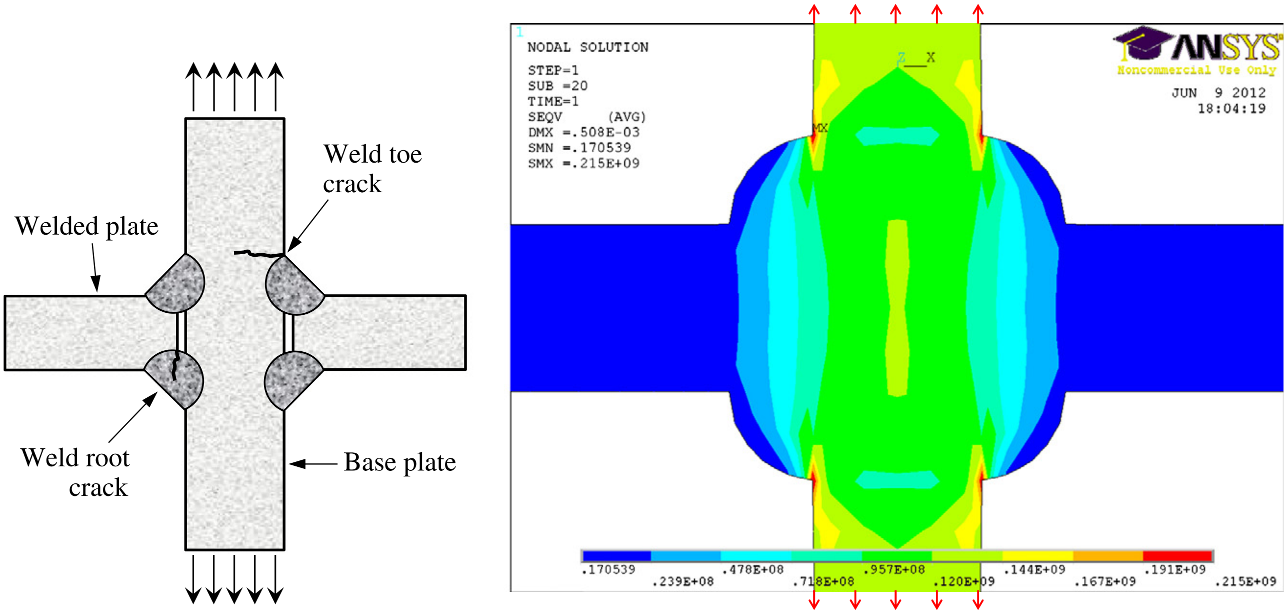
Fig. 1. Crack along fillet weld at gap between I-girder web and welded stiffening plate.

cracks in steel railroad bridges have been reported [14] and models to predict fatigue life based on AE features have been presented for base materials of steel bridges [13,15,16]. Signal identification has been carried out to ease challenges associated with noise in practical applications of AE monitoring [16,17]. Efforts are progressing for an improved understanding of AE mechanisms for the development of bridge health monitoring systems [14,18].

AE behavior corresponds to the crack growth behavior for monitoring of fatigue damage. AE signals can indicate different crack growth behaviors in stable and unstable stages [13]. Crack growth behavior is usually described using the relationship between the stress intensity range and crack growth rate. The stress intensity range depends on the loading conditions and geometry of the structural details subjected to fatigue, including weld geometry [4]. For a given material and load



a) Fatigue cracks

b) Stress distribution, applied maximum load 98.7 kN

Fig. 2. Representative fatigue cracks and Von Mises stress distribution in cruciform welded joints.