ARCHIVES OF CIVIL AND MECHANICAL ENGINEERING 17 (2017) 609–622

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/acme

Original Research Article

Detection of fatigue cracking in steel bridge girders: A support vector machine approach

Hassene Hasni, Amir H. Alavi[*], Pengcheng Jiao, Nizar Lajnef

Department of Civil and Environmental Engineering, Michigan State University, East Lansing, MI 48823, USA

ARTICLE INFO

Article history:
Received 15 June 2016
Accepted 19 November 2016
Available online 31 January 2017

Keywords:
Support vector machine
Fatigue cracking
Steel bridges
Self-powered wireless sensors
Damage detection

ABSTRACT

This study presents an artificial intelligence approach for the detection of distortion-induced fatigue cracking of steel bridge girders based on the data provided by self-powered wireless sensors. The sensors have a series of memory gates that can cumulatively record the duration of the applied strain. The gates are activated as soon as the electrical charge generated by piezoelectric strain transducer exceeds pre-defined thresholds. In the present study, the distribution of the sensor output has been characterized by a Gaussian cumulative density function. For the analysis, extensive finite element simulations were carried out to obtain the structural response of an existing highway steel bridge girder (I-96/M-52) in Webberville, Michigan. Different damage states were defined by extending the lengths of the crack at the web gaps from 10 mm to 100 mm. Damage indicator features were extracted for different data acquisition nodes based on the sensor output distribution. Subsequently, support vector machine (SVM) classifiers were developed to fuse the clustered features and identify multiple damage states. The results indicate that the models have acceptable detection performance, specifically for cracks larger than 10 mm. The best classification performance was obtained using the information from a group of sensors located near the damage zone.

Published by Elsevier Sp. z o.o. on behalf of Politechnika Wrocławska.

1. Introduction

Multi-girder steel bridges are widely used throughout the highways in the United States. One of the main factors affecting the performance of these structures is the application of the repetitive loading over the steel-girder components. These load-carrying components deform under the live (traffic load) and the dead load of the structure. A typical steel girder bridge is composed of three main parts: girders, diaphragms, and stiffeners. The diaphragms are structural elements that provide resistance to the transverse traffic and wind loading. The stiffeners connect the girder to the diaphragm. Over many years, inspections conducted on steel-girder bridges revealed that these structures are suffering from fatigue cracking under cyclic loading [1]. More specifically, low resistance to fatigue has been observed in structural members subjected to out-of-plane distortion. The phenomenon of out-of-plane distortion is impacted by a variety of factors such as thermal forces, traffic flow, differential deflection of the adjacent beams, etc. [2,3]. Fig. 1 displays the schematic formation of fatigue cracks in a steel girder caused by out-of-plane distortion. Fig. 1(a) displays an illustration of a steel bridge before deformation in a perspective view, and Fig. 1(b) shows the side view of the

---

[*] *Corresponding author.*
E-mail addresses: ah_alavi@hotmail.com, alavi@msu.edu (A.H. Alavi).

http://dx.doi.org/10.1016/j.acme.2016.11.005
1644-9665/Published by Elsevier Sp. z o.o. on behalf of Politechnika Wrocławska.

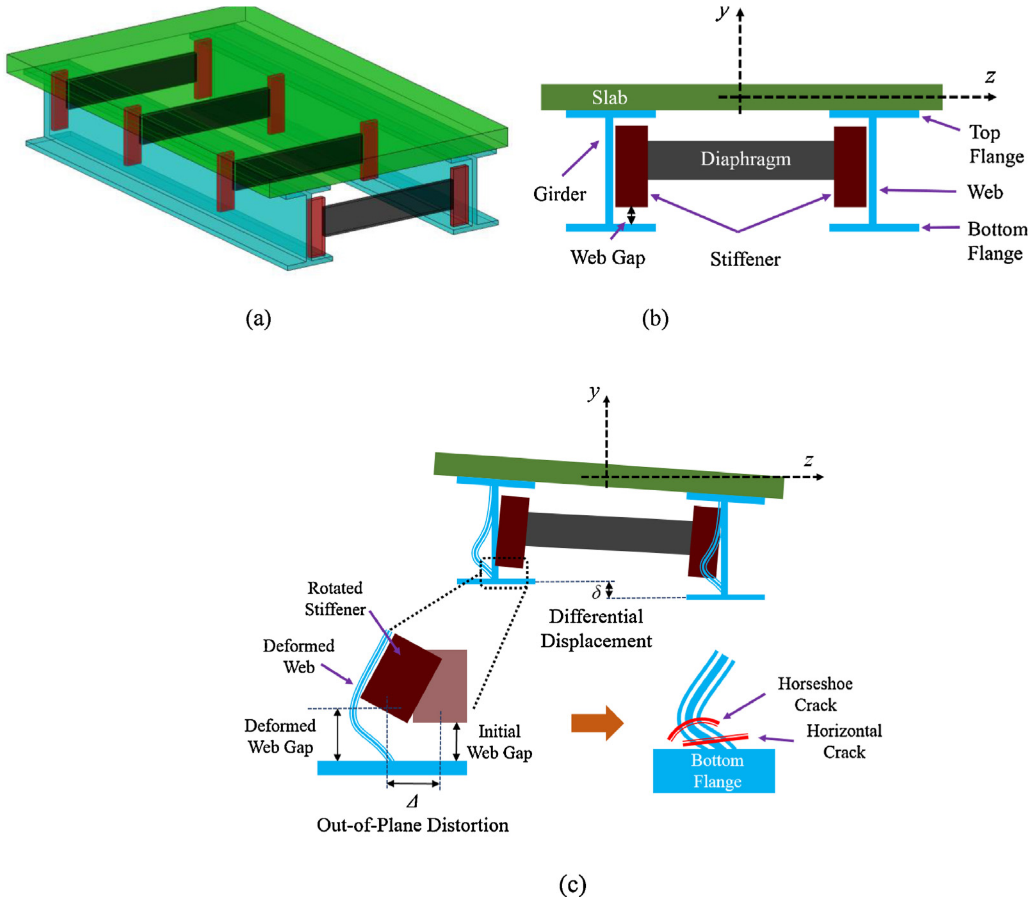

Fig. 1 – Schematic illustration of distortion-induced fatigue cracking: (a) bridge before deformation in a perspective view, (b) side view of the bridge in the initial stage, and (c) different types of fatigue cracks caused by out-of-plane distortion (Δ).

bridge in the initial stage. Fig. 1(c) schematically shows the cracks caused by out-of-plane distortions. It can be seen that the deformations of the girder web are caused by the differential displacement (δ) between the two girders, which leads to the out-of-plane distortion (Δ). Such distortion eventually causes fatigue cracks on the girders in the form of horseshoe and horizontal cracks.

Therefore, fatigue cracks usually occur at the girder web gap due to out-of-plane distortion. The distortion-induced fatigue cracks may occur as horizontal or horseshoe cracks at the top or bottom of the girder to stiffener connections (Fig. 1 (c)). More details on the forming mechanism of these cracks can be found in [4,5]. Different models have been developed to investigate the behavior of bridges [6], with particular focus on the retrofitting approaches to deal with this common type of structural damage [5,7]. However, the selection of an appropriate repair strategy is complicated and depends on many factors. On the other hand, significant cost of maintenance and retrofitting of stiffener-girder connections implies the necessity of detecting the damage progression at early stages to prevent severe damage to the bridge structures.

The main goal of this study is to develop a new artificial intelligence (AI)-based approach for the detection of distortion-induced fatigue cracking of steel bridges based on the data provided by a newly developed self-powered wireless sensor. The sensor is empowered using piezoelectric transducers through harvesting energy from the mechanical loading experienced by the structure. Different studies have been conducted to investigate the energy harvested from ambient excitation [8]. In order to calibrate the AI detection models, different finite element (FE) models of steel girders with complex geometry components were developed and the structural response of the girder was subsequently obtained. The fatigue life of the girder was determined based on the J-integral concept and Paris Law [9,10]. Several damage states were defined by extending the crack lengths. Different numbers of sensing locations were defined to monitor the strain changes due to damage progression. The sensing nodes were placed around the connection between the webs and the stiffeners to determine the optimal sensors configurations that maximize the detection performance of fatigue cracking. Thereafter, features representing the sensor output were extracted from the strain data at the sensing nodes. The obtained features were then fed into a support vector machine (SVM) classifier to identify multiple damage states.

2. The self-powered wireless sensor

Wireless sensors are widely used as alternatives to the traditional wired sensors for structural health monitoring (SHM) [11,12]. A major limitation in the deployment of the