2019

Field Deployment of Sensing Skin on a Steel Bridge for Fatigue Crack Localization and Assessment

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Abstract

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Disciplines

Civil Engineering | Structural Engineering

Comments

This is a manuscript of a proceeding is published as Laflamme, Simon, and Jian Li. "Field Deployment of Sensing Skin on a Steel Bridge for Fatigue Crack Localization and Assessment." (2019). Posted with permission.

Field Deployment of Sensing Skin on a Steel Bridge for Fatigue Crack Localization and Assessment

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ABSTRACT: A sensor network constituted from novel soft elastomeric capacitors acting as large-area strain gauges has been deployed on a steel bridge near Kansas City, KS. The objective of the field deployment is to validate the capability of the sensing skin to localize and assess fatigue cracks.

Test Structure and Measured Data

The test steel bridge (Fig. 1(a)) is a part of the I-70 highway near Kansas City, Kansas, USA [1]. It consists of bridge concrete decks, longitudinal steel girders, and bridge piers. An exterior girder was selected for installing the soft elastomeric capacitors (SECs) [2], shown in Figure 1a. One of the target regions for sensor deployment is the web-gap region on the exterior side of the girder (Fig. 1b). The region counts two fatigue cracks according to the inspection records marked on the steel girder during inspections in 2013 and 2017. Crack 1 is located between the top flange and web, while Crack 2 initiated at the web-gap region. Both cracks propagated during the inspection interval (Figure 1c). The instrumentation is installed on the interior side of the girder. Measured data includes strain from the SEC network, strain from a single off-the-shelf strain gauge, and acceleration from a single accelerometer, discussed in what follows.

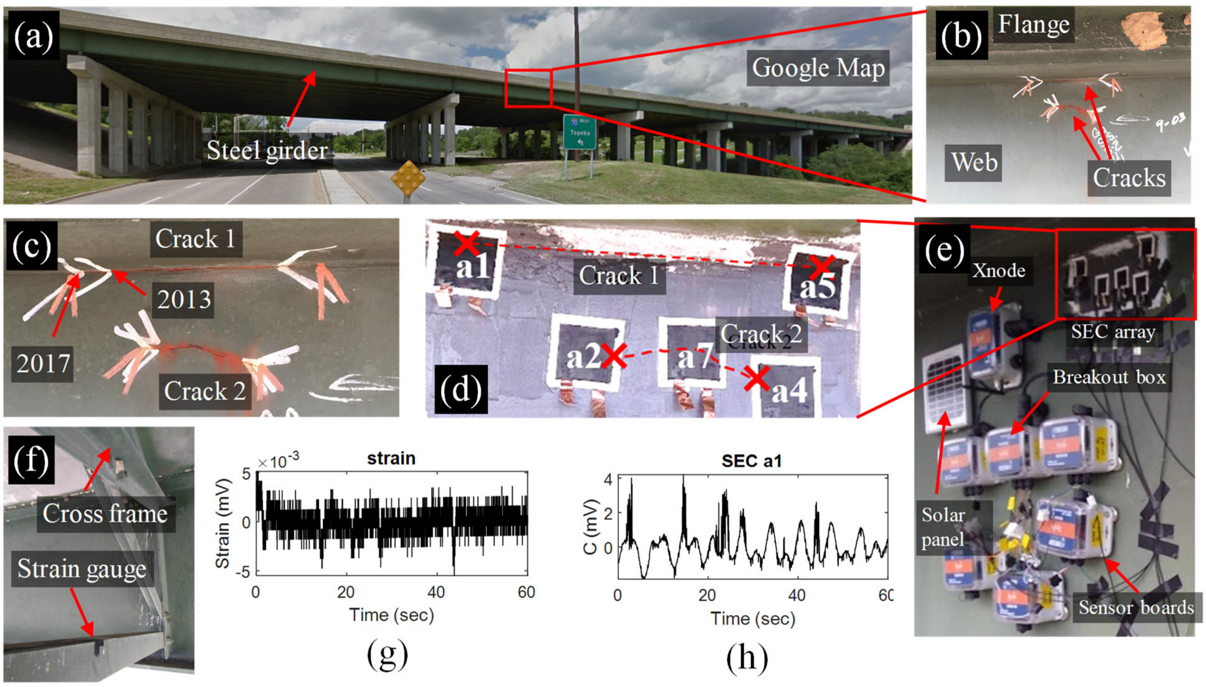

Figure 1. (a) The steel bridge for field deployment; (b) existing fatigue cracks; (c) details of existing cracks; (d) installation of the SEC array; (e) wireless sensor network; (f) strain gauge installation; (g) typical strain measurement under traffic; and (h) typical SEC measurement under traffic.

SHM Methodology and Results

An SEC array was deployed to monitor the region of interest. As shown in Fig. 1d, SEC a1 and a2 covered the two ends of Crack 1, while the rest three SECs were attached to cover the path of Crack 2. The deployed sensor network is shown in Figure 1e. A dedicated capacitance sensor board was developed [3] to convert low-level dynamic capacitance changes to voltage signals, which can be captured with wireless sensing platforms. In particular, this sensor board was designed to interface with the Xnode platform that includes 3.3V power supply, analog-to-digital conversion, onboard signal processing, and wireless data communication. A breakout box was used to serve as the interface between the Xnode and the sensor boards. Sensing was traffic triggered through an acceleration threshold of 100 mg, determined experimentally. A strain gauge was installed at the cross frame on the interior side of the girder to indirectly measure the load level (Figure 1f), necessary in fusing sensor signal into a crack growth index (CGI).

Figure 1g shows a typical strain measurement under the traffic loads. As can be seem in the figure, several impulse-like peaks indicate the traffic load caused by the passing vehicles. The corresponding SEC measurement under the same traffic is shown in Figure 1h. Only the time series measurement of SEC a1 is illustrated. The SEC data captured the same peaks as the strain data. Due to the space limitation, more data analysis results are available in Ref. [5].

Lessons Learned

Results from the field deployment has successfully validated the promise of the SEC at localizing and assessing fatigue cracks. However, due to the unique challenges of the field environment, the collected data contains relatively higher noise levels compared with laboratory conditions. The strain measurement in Figure 1g has large quantization error, which could be removed by adding extra signal amplification. The SEC measurements, on the other hand, contain unexpected long-period fluctuations (Figure 1f), for which the electromagnetic interference is considered as a potential contributor. Additional data processing strategies are needed to enhance the quality of both the strain and SEC measurements in the field.

Acknowledgements

This work was supported by Transportation Pooled Fund Study TPF-5(328), which includes the following participating state DOTs: Kansas, Iowa, Minnesota, North Carolina, Pennsylvania, Texas, and Oklahoma; and Iowa Department of Transportation grant #RT454-494. Their support is gratefully acknowledged.

References

[1] Kong, X., Jeong, J.-H., Asadollahi, P., Fu, Y., Jo, H., Bennett, C., Collins, W., Laflamme, S., & Li, J. (2019), “Wireless soft elastomeric capacitor sensor network for long-term fatigue crack monitoring of steel bridges”, in Proc. of the 9th Intl. Conf. on SHM of Intelligent Infrastructure, St-Louis, MO.

[2] Kharroub, S., Laflamme, S., Song, C., Qiao, D., Phares, B., & Li, J. (2015). Smart sensing skin for detection and localization of fatigue cracks. *Smart Materials and Structures*, *24*(6), 065004.

[3] Jeong, J. H., Xu, J., Jo, H., Li, J., Kong, X., Collins, W., & Laflamme, S. (2018). Development of wireless sensor node hardware for large-area capacitive strain monitoring. *Smart Materials and Structures*, *28*(1).

[4] Kong, X., Li, J., Collins, W., Bennett, C., Laflamme, S., & Jo, H. (2017). A large-area strain sensing technology for monitoring fatigue cracks in steel bridges. *Smart Materials and Structures*, *26*(8), 085024.

[5] Li, J., Bennett, C., Collins, W., Laflamme, S., & Jo, H. (2019). *Strain-based Fatigue Crack Monitoring of Steel Bridges using Wireless Elastomeric Skin Sensors*. Final Report, Kansas DOT, Topeka, KS.