The 2014 World Congress on
Advances in Civil, Environmental, and Materials Research (ACEM14)
Busan, Korea, August 24-28, 2014

Crack detection in composite bridges with relative displacement sensors

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ABSTRACT

One of the typical bridge construction types on Australia highways is composite structure consisting of steel or precast reinforced concrete (RC) girders with cast-in-situ RC slab. The girders and slab are connected together by distributed steel shear links. The composite bridges are under constant cyclic loading during bridge operations therefore may experience fatigue damage besides possible corrosion damage and overstressing owing to increased traffic volume and weight. A slab-on-girder composite bridge model was constructed in laboratory as an example to investigate if the newly developed relative displacement sensors can be used to detect the cracks occurred in the bridge model. Static loading test were conducted to introduce the cracks into the composite bridge and the damage in shear links. Both the vertical deflection and relative displacement were used for the crack and shear link condition identification. Experimental studies demonstrated that the developed sensor is more sensitive than traditional deformation measurements to identify the cracks in composite bridges.

1. INTRODUCTION

One of the typical bridge construction types on Australia highways is composite structure consisting of steel or precast reinforced concrete (RC) girders with cast-in-situ RC slab. The girders and slab are connected together by distributed steel shear links. The shear connection between slab and girders subjects to fatigue and possible corrosion damage, as well as possible overstressing owing to increased traffic weights and volume. Deterioration or break of the shear connection in some regions of the bridge structure causes a loss in the composite action so that the bridge slab and girder respond to traffic loadings independently, resulting in a significant decrease of the overall rigidity and ultimate resistance of the bridge (Dilena and Morassi 2004).

Xia et al. (2007) proposed a local detection method by directly comparing the frequency response functions of simultaneously measured vibrations on the slab and girder. Recently, the wavelet based Kullback-Leibler distance (Zhu et al. 2012) and wavelet packet energy (Ren et al. 2008) have also been proposed for damage

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identification of shear connectors. Wang and Hao (2013) used laser displacement sensors to obtain the relative displacements between slab and girder and found out that this is a promising index for the damage detection of shear connections. A relative displacement sensor has been developed and its sensitivity radius for structural health monitoring has been investigated (Li et al. 2013). This paper mainly investigates if the newly developed relative displacement sensors can be used for crack detection of composite bridges.

2. DEVELOPMENT OF A RELATIVE DISPLACEMENT SENSOR

A relative displacement sensor has been developed based on the principle of Wheatstone bridge circuit to measure the relative displacement (Li et al. 2013), which can be used to monitor the relative slip of the shear connection between slab and girder in composite bridges. The output relative displacement is calibrated with measured strain, and then the developed sensor can output the displacement information from measured strains. The design of the relative displacement sensor ensures that there are no voltage outputs for the tension, compression, bending and torsion effects, but only measures the relative displacement between the two connecting pads of the sensor. More details on the features of the relative displacement sensor, calibration and validation test can be referred in (Li et al. 2013). The developed relative displacement sensor will be used for crack detection of composite bridges and experimental studies will be presented in the next section.

3. EXPERIMENTAL STUDIES

3.1 Experimental Setup

Experimental studies on a composite bridge model are conducted to investigate if the developed relative displacement sensor can be used for crack detection of composite bridges by tracking the shear connection conditions. A composite bridge model was constructed with a reinforced concrete slab supported on two steel girders. Sixteen shear connectors were mounted with equal spacing in each girder to link the slab and steel girders. The dimensions of the model are shown in Fig. 1. The length is 3.16m and the width is 0.55m. The height of steel beam and the thickness of slab are 0.15m and 0.065m, respectively. The slab constructed with Grade 40 concrete was connected to two 150UB14 universal steel girders by shear connectors. The bridge was located on two steel frames which are fixed to the laboratory strong floor. The shear connectors connecting the slab and girder are denoted as SC1 to SC32.

Four relative displacement sensors were fabricated and mounted on the bridge model. Fig. 2 shows a developed sensor prototype installed on the bridge, respectively. One end of the sensor is fixed on the steel girder, and the other end on concrete slab. Such installation manner is much easier than vision-based approaches, which need to setup a number of cameras or other optical devices, and easier than linear variable differential transformer (LVDT) measurement approach which needs a fixed reference point. Moreover, the inaccessibility of the interface between slab and girders makes the setup of cameras and LVDT difficult. This also demonstrates the advantages of the developed relative displacement sensor to directly install it on the bridge and track the behavior of shear slip. A National Instruments (NI) data acquisition system was used for data recording and quick in-situ analysis. Fig. 3 shows the locations of placed relative displacement sensors. The relative displacement sensors are defined as S1, S2, S3 and S4. These sensors are placed in the center of two shear connectors, for example, S1 is placed in the center of SC1 and SC2. It may be noted that S1 and S4 are located close to supports.

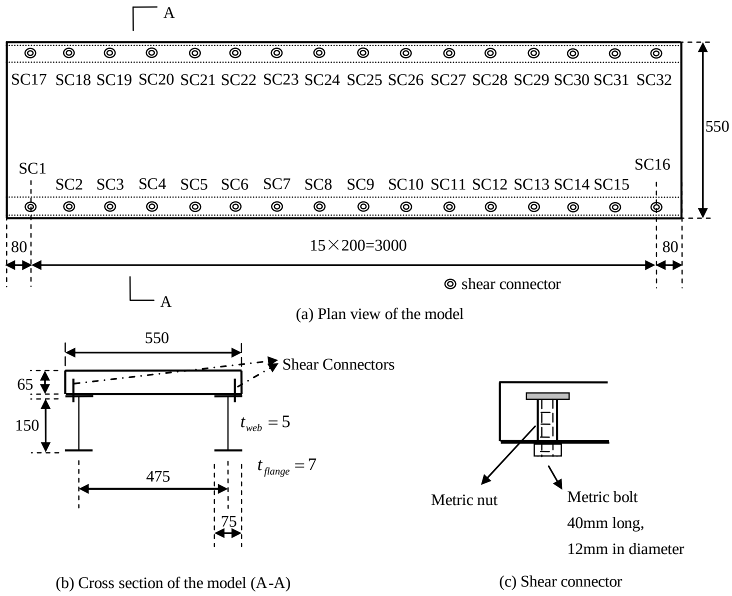

Fig. 1 Dimensions of the composite bridge model in laboratory

Fig. 2 A prototype of the developed relative displacement sensor

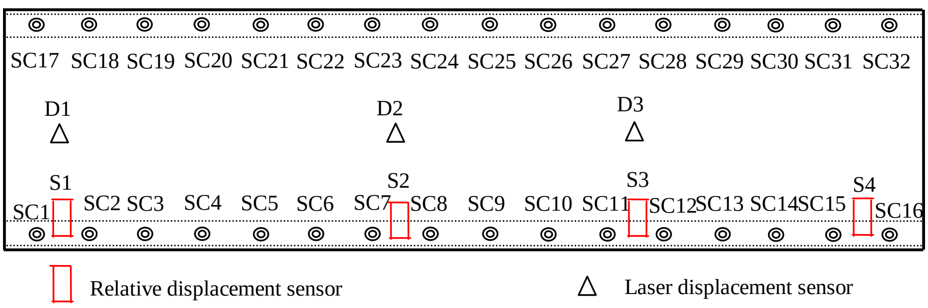

Fig. 3 Sensor placement configuration in the experimental testing

3.2 Experimental Testing and Results

The composite bridge model was statically loaded until intensive cracks appear on the concrete slab. The loading force was applied with the two-point static load in the center of the bridge. Fig. 4 shows the experimental setup for these two loading scenarios. A 20ton load cell was used to measure the applied load. Three laser displacement sensors were placed to measure the vertical deflection of the bridge, and they are denoted as D1, D2 and D3. It should be noticed that D1, D2 and D3 were placed in the same cross sections as the relative displacement sensors S1, S2 and S3, as shown in Fig. 3. The vertical deflections of the bridge model and relative displacements between girder and slab were measured to check if these measurements can be used for detecting the crack occurrence.


Fig. 4 Experimental setup for static loading

Fig. 5(a) presents the load-vertical deflection curve of D2 for the loading and unloading processes. The load is gradually increased to 122 kN. The load-vertical deflection curve within 80 kN is mainly linear-elastic. A notable change is observed around 85 kN with a significant increase in the measured vertical deflection from D2, which corresponds to the occurrence of cracks. The same behavior is observed in the load-relative displacement curve of S2, as shown in Fig. 5(b). These notable changes are highlighted with red circles in figures. It can be observed that there are several small oscillations in the relative displacement as shown in Fig. 5(b) when the static load is equal to 105 kN. These show the growth of the existing cracks due to further increasing loading applied on the bridge model. Fig. 6 shows that a longitudinal crack is observed in the middle of the cross-section of the slab because the stiffness of steel girders is very strong in this bridge model. The concrete slab is supported on two strong steel girders, which is the reason why the longitudinal crack is observed. A significant increase in the vertical deflection of the bridge is evidenced due to the crack. It can be noticed that the final displacement after unloading is about 8mm and the relative displacement 0.13mm as the bridge has been damaged with permanent deformations. Both the vertical deflection and relative displacement are capable of identifying the occurrence of such cracks. However, the relative displacement is more sensitive for identifying the growth of exiting cracks than vertical deflection.

(a) Load-Displacement Curve (b) Load-Relative Displacement Curve

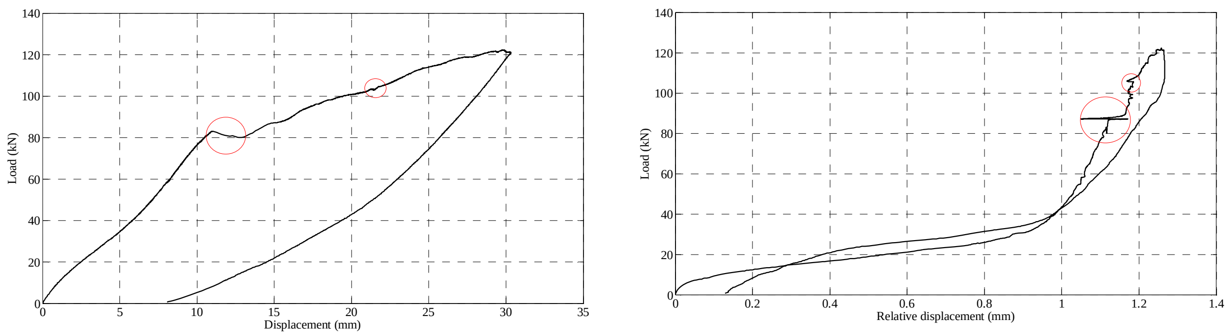

Fig. 5 Load-Deformation curves

Fig.6 Observed crack in the testing

4. CONCLUSIONS

A slab-on-girder composite bridge model was constructed in laboratory as an example to investigate if the newly developed relative displacement sensors can be used to detect the cracks occurred in the bridge model. Static loading test were conducted to introduce the cracks into the composite bridge and the damage in shear links. Both the vertical deflection and relative displacement were used for the crack and shear link condition identification. However, the relative displacement is more sensitive for identifying the growth of exiting cracks than vertical deflection. Experimental studies demonstrated that the developed sensor is more sensitive than traditional deformation measurements to identify the cracks in composite bridges.

ACKNOWLEDGMENTS

The work described in this paper was supported by Australia Cooperative Research Centre for Infrastructure and Engineering Asset Management (CIEAM-II) "Supporting Infrastructure Management by Combining Sensors and Asset Information Models - Project No. 3104", and Australian Research Council Discovery Early Career Researcher Award DE140101741 “Development of a Self-powered Wireless Sensor Network from Renewable Energy for Integrated Structural Health Monitoring and Diagnosis”.

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