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Damage detection in continuous deck bridges using statistical cross-correlation function method

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ABSTRACT: The damage detection (DD) of the bridge has always been a major concern for engineers. This paper attempts to detect damage in the continuous deck bridges by providing a new method based on acceleration responses and their instantaneous amplitudes. The DD in this paper has two steps: firstly, determining the vicinity of damage in global DD. Secondly, determining the location of damage in local DD. Then by acceleration signals, the instantaneous amplitude values of healthy and damaged structural responses are extracted via HHT. Further, for the accurate evaluation of the proposed method, damage locations are determined by the cross-correlation damage index (DICC). To assess the feasibility and reliability of proposed methods, several analytical models of concrete bridges of one to three spans, as well as as experimental model of a simply supported steel beam, have been used. In order to consider noise pollution during data acquisition, a certain amount of noise is added to the response. The results in the analytical and experimental models showed that the proposed methods can determine the damage locations with appropriate accuracy for different damage scenarios and it could provide more exact results with a rapid estimation.

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1. INTRODUCTION

Growing concerns about the increasing age of highway bridges, which are vital structures making the connection between cities for transportation, have made it crucial to properly evaluate the existing status of these structures [1]. These infrastructures are exposed to various environmental phenomena, temperature variations, and various loads such as wind load, tornadoes, gusts, storms, severe earthquakes, and other human-induced loads including vehicle collisions. Accordingly, bridge structures are likely to be damaged and consequently, it is very important to make appropriate decisions about their service level or remaining life cycle [2]. Therefore, one of the major challenges of current engineering knowledge is to continuously evaluate the structural behavior of bridges and identify possible damages in order to avoid high costs due to unpredictable damages [3]. In this paper, it is attempted to propose a new method for determining the damage location in continuous bridge decks based on the measured acceleration responses. In this paper, the results of analytical and experimental studies are used. The damage index based on the cross-correlation function is also employed for the damage detection process. The damage detection method is evaluated at two global and local levels. To verify the sensitivity and robustness of the proposed method, analytical models of single-, two-, and three-span concrete bridges are used.

2. DAMAGE DETECTION METHODOLOGY

In the first part of the damage detection procedure, the cross-correlation is used in two damaged and healthy conditions. First, each acceleration response recorded from the structure is decomposed into a set of IMFs. Then, for each of the IMFs, the instantaneous amplitude and the associated analytical signal are calculated. This procedure is repeated for all available responses in damaged and undamaged conditions. In order to detect the location of damage, an innovative method that is more compatible with the actual behavior of bridges is proposed. In this method, damage detection is performed using a cross-correlation index. The cross-correlation values of the instantaneous amplitudes of structural response are calculated for two damaged and healthy states, and finally, by defining a new damage index the location of the damage is determined with much higher accuracy. The new index is defined based on the comparison between different levels of the cross-correlation functions of instantaneous amplitudes.

$$R_{hd}(\tau)=\lim_{T\to\infty}\frac{1}{T}\int_{0}^{T}A_{Ah}(t)A_{Ad}(t+\tau)dt \qquad (1)$$

Where equation 1, is the cross-correlation function of two structural response signals in either damaged or undamaged

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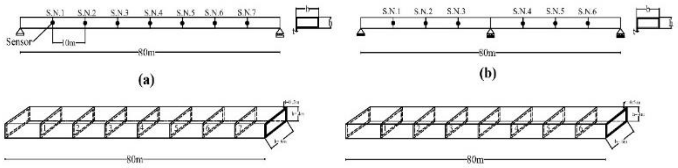

Fig. 1. Three-dimensional and front view of the (a) single-span, (b) two-span

Table 1. The properties of damage scenarios

Damage scenarios	Bridge structure	Damage location with a damage value of 40%
1	Single-span	Between sensors 2 and 3 with a width of 2.5 m
2	Two-span	Between sensors 2 and 3 with a width of 2.5 m

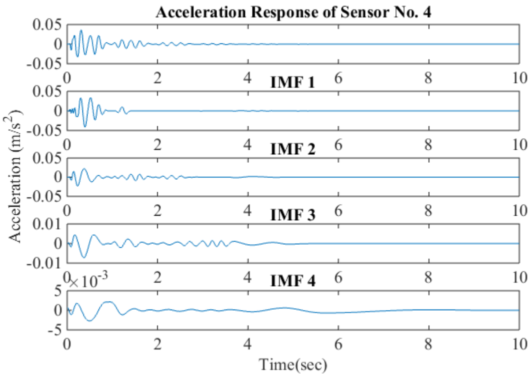

Fig. 2. The IMFs of sensor 1 obtained by the EEMD method

states, equation 2, cross-correlation damage index, and equation 3 is the Hilbert transform of the time series *x*(*t*).

$$\text{DICC} = \frac{S_{R_{hd}(\tau)}(L) - S_{R_{hd}(\tau)}(R)}{S_{R_{hd}(\tau)}(T\,.)} \tag{2}$$

$$HT\,[x\,(t\,)] = y\,(t\,) = \frac{1}{\pi} PV \int_{-\infty}^{+\infty} \frac{x\,(\tau)}{t-\tau} d\,\tau \tag{3}$$

3. FINITE ELEMENT AND EXPERIMENTAL MODEL

To evaluate the proposed damage detection methods, the structural model of single-span, two-span, and three-span concrete bridges with specific dimensions and a simply supported steel beam are used. The length of the single-span and two-span bridges is 80 meters, and the three-span bridge length is 120 meters. The length of each span is also 40 meters as shown in Fig. 1.

Moreover, for receiving the responses of the damaged structures, different damage scenarios, as described in Table 1, are considered for the concrete bridges. The major moment of inertia in structural members is reduced by 40% in different scenarios. The damage in a structural member can include different kinds of defects which may ultimately reduce the stiffness of that member

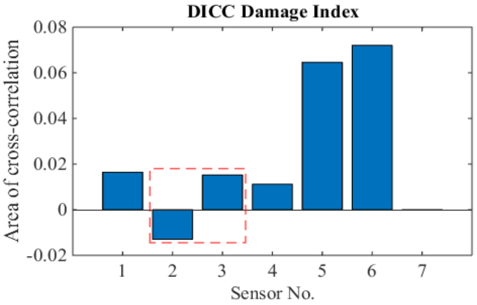

Fig. 3. The DICC damage index for damage scenario 1

4. RESULTS AND DISCUSSION

The instantaneous amplitudes of all sensors are calculated for healthy and damaged conditions. For instance, Fig. 3 shows the IFMs of sensor 1 based on the EEMD process for the three-span bridge.

Fig. 3 shows the DICC damage index values for the first damage scenario with a 40% damage value. According to the first damage scenario, the damage zone is located between sensors 2 and 3. According to Fig. 3, the damage location is recognized between sensors 2 and 3, which is due to the change in the cross-correlation function and the CCDI index from negative values in sensors 2 to positive values in sensor 3. This pattern correctly shows the location of the damage.

According to Fig. 4, the damage is located between sensors 2 and 3, and the location is correctly determined due to the changes in cross-correlation values from the negative to the positive region for the two-span bridge.

5. CONCLUSIONS

New methods for global and local damage detection in concrete bridges and steel beams were presented. To determine the damage location in both global and local views, DICC damage indices were employed. Numerical models of single-, two-, and three-span concrete bridges, as

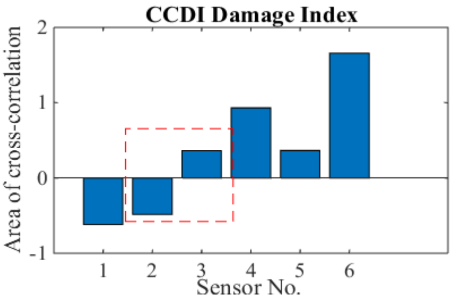

Fig. 4. The DICC damage index for damage scenario 1

well as experimental models of a simply supported beam, were utilized. Afterward, damage detection procedures were followed for different damage scenarios separately via DICC indices. The convenience and high reliability of the proposed methods using the instantaneous amplitudes of acceleration responses along with the HHT transform, as well as the combination with the instantaneous amplitudes energy, were evaluated for both indices The results showed that the CCDI index has high reliability, acceptable accuracy, and fast performance for detecting the global and local damages in analytical and experimental models.

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