DAMAGE IDENTIFICATION IN BRIDGES BASED ON WPECD TRANSFORM

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Abstract. Bridges suffer damage throughout their lives due to variations in the performance of the materials, loads, and other uncontrollable factors. During the service period of the structure, the key parts will continue to accumulate damage and defects trapped, affecting the safety of its use. Therefore, structural health monitoring is important for engineering structures. In this work, the numerical and experimental verifications are used to verify the effectiveness of the wavelet packet energy curvature difference (WPECD) method in identifying structural damage, the beam body replaced by the bridge model is used to simulate the two damage levels. In this work the damage level increases from 5% to 20%. The acceleration response of each point in intact and damaged states was tested, and the WPECD method was used to identify the damage, and the effect of the number of decomposition layers and the wavelet function on the Knot identification effect were studied. The results of the presented method show that the WPECD technique is more effective for damage, and sensitive in small lesions (5%), it can also be effectively identified. It shows that the method is effective and can be applied to practical engineering.

Keywords: wavelet, WPECD, damage simulation, damage identification, experiment.

Introduction

In recent years, with the completion and opening of bridges, the maintenance and management of bridges have become the key to ensure safe operation of bridges. However, in the development of bridges has long existed the problem of "heavy construction and neglect maintenance". In terms of bridge maintenance and management, the non-destructive testing technology is different to a certain extent, and cannot meet the huge bridge traffic network. Therefore, how to promote the transformation and upgrading of bridge maintenance management technology through technological innovation, realize transition from a big bridge to a bridge power stage is important. The research of bridge non-destructive testing technology is imminent. In the past two decades, scholars at home and abroad have carried out extensive and in-depth research on non-destructive testing of cracks, and have achieved some research results. However, bridge crack images are different from pavement crack images and rock crack images studied by mainstream algorithms [1-10].

During the service period of the structure, the key parts will continue to accumulate damage and defects trapped, affecting the safety of its use. Therefore, structural health monitoring is important for engineering structures. The evaluation of usage performance is of great significance. Structural health monitoring can be divided for both local and global detection. Local damage detection using infrared detection damage information can be obtained by using technologies such as damage and ultrasonic waves; the overall detection is carried out through structural vibration changes in dynamic characteristics to evaluate structural health [11-15].

We can obtain the damage identification method mainly by the transient signal Fourier transform for parameters of structural modeling such as mode shape and frequency [16-19]. While it is not enough to use Fourier transform because the loss of the time domain information during the transformation process. To solve the drawback of other techniques of signal processing, the wavelet transform technique is used to signal analysis. The components of wavelet are the essential functions set that characterize in the frequency domain the local properties and signal time.

The big advantage is that the signal can be analyzed locally, at any time or in space. Wavelet analysis can discover other signal analysis methods. Unrecognized information that expresses structural characteristics hidden in the data. These characteristics are particularly important for damage identification. Therefore, in the structural damage identification the wavelet transform is the most used method [20-22]. However, in the high frequency zone, the accuracy of the wavelet transform to analysis is low, so the damage identification based on WPECD theory has become a critical point of research. Ding Youliang et al. [23] used WPECD spectrum theoretically and numerically for structural damage prediction with testing verification. Sun et al. [24] investigated combined WPECD and neural network

for structure damage identification. Han Jiangang et al. [25] investigated experimentally using WPECD for indexing of structural damage. In the existing researches on structural damage identification based on wavelet packets, most of them are in the theoretical research stage, with only a small amount of experimental verification. However, the structures like bridge are more complex in damage analysis in the real situation than laboratory conditions.

In order to achieve this end, this work proposes an index damage-based on WPECD, using numerical value and on-site real bridge tests are carried out to verify the effectiveness of the method in identifying structural damage, and re-search on the effect of wavelet packet decomposition layers and different wave-let functions on influencing damage identification.

Damage identification method based on wavelet packet analysis

Introduction to wavelet packet theory

The several resolution characteristics for the wavelet transform, and the time-frequency index are the most features of the wavelet transform to ability to extract the features from signal. Each wavelet decomposition layer is of different accuracy, but the steady of layers are fixed the sub-bands, and decomposed from only the low-frequency part. So, the drawback of wavelet transform is poor accuracy in the high frequency band, the solution of this drawback is to apply it only to certain signal characteristics. WPECD analysis divides each layer sub bands into two parts, and transfers to the next layer for high and low frequencies decomposition, but the accuracy of each layer is different, as shown in Figure 1 [25].

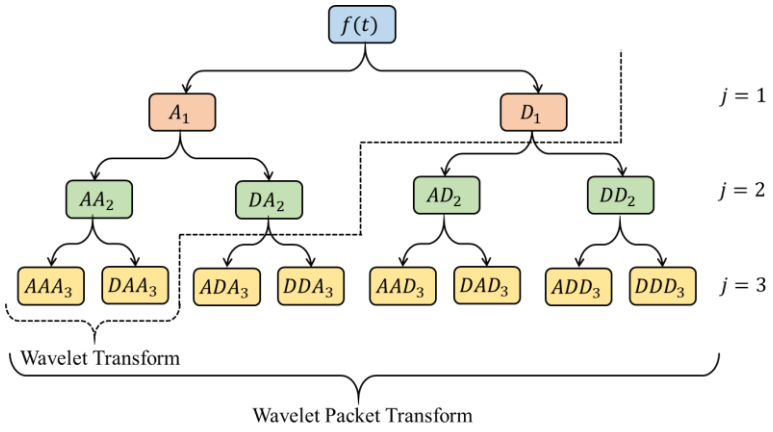


Fig. 1. **Wavelet transform and wavelet packet transform [25]**

WPECD can be used to signal analysis more accurately. WPECD is usually formulated by $\psi_{j,k}^{i}$, $k\ i,j,k$ representing the wavelet respectively. The package function parameters of modulation, scale, and translation are expressed as [25]:

$$\psi_{j,k}^{i}(t) = 2^{j/2}\psi^{i}\left(2^{j}t-k\right),(i = 1,2,\cdots), \quad (1)$$

The wavelet function recurrence relation $\psi^{i}$is:

$$\psi^{2i}(t) = \sqrt{2}\sum_{-\infty}^{\infty}h(k)\,\psi^{i}(2t-k), \quad (2)$$

$$\psi^{2i+1}(t) = \sqrt{2}\sum_{-\infty}^{\infty}g(k)\,\psi^{i}(2t-k). \quad (3)$$

In the formula: ψ is the wavelet mother function, $h(k)$, $g(k)$ are the scale function. After some algebraic processes and use of the orthogonal conditional expression, we get:

$$E_{f} = \sum_{i=1}^{2i}E_{f_j^i}, \quad (4)$$

where wavelet packet component energy $E_{f_j^i}$ can be regarded as stored in the component signal $f_j^i(t)$ energy of:

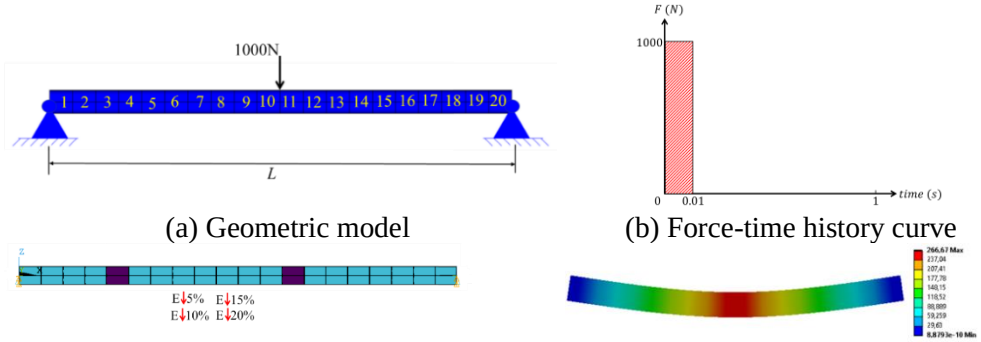
$$E_{f_j^i} = \int_{-\infty}^{\infty}f_j^i(t)^2\,dt, \quad (5)$$

where E_f – energy of the signal $f(t)$.

Numerical study

Consider a beam subjected to an impact force, as shown in Figure 2(a) as an example, the beam length is $20m$, $E = 210$ GPa, $\rho = 7850$ kg·m^{-3}, $A = 1$ m^2, $I = 0.083$ m^4. A total of 20 orders element, 21 nodes, and an impact exciting force of 1000 N is applied at the midpoint of the beam. Fig. 2(b) introduced the force-time relation. Use of ANSYS performs a transient analysis, simulating damage with stiffness drop, assuming element. The stiffness of 5 and 13 (corresponding to node numbers 5-6, 13-14) decreased by 5%, 10%, 15%, 20% respectively as shown in Figure 2(c). The deflection of a simply supported beam is shown in Figure 2(d). The displacement of the 21 nodes before and after the damage under the action of the exciting force. The response is subjected to wavelet packet transform, the function of the wavelet used is daubechies, and the sequence No. $N = 15$, called Db15 wavelet, and the decomposition layer number is 7. First 8 components WPECD are shown in Figure 3(a).

It can be seen from Figure 3 that the magnitude of the first energy component (10-5) is relative. The rest (10-9, 10-10) are much larger, adding the energy of the first 8 components, as shown in Figure 3 (b).

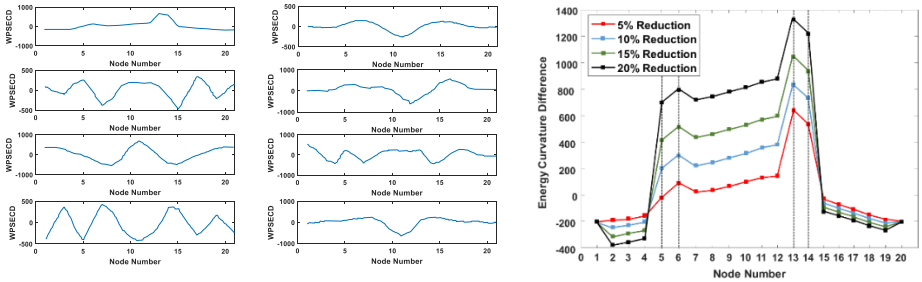


(a) Geometric model (b) Force-time history curve

(c) Damage location (d) Deflection

Fig. 2. **Schematic diagram of simply supported beam under impact force applied at the midpoint**

Four cases are used to achieve the presented WPECD index application for damage identification as presented in Table 1. In this work the damage level increases from 5% to 20%. Figure 3(b) presents the corresponding WPECD curves for each case of four cases. As shown in Figure 3(b), the sudden change occurred in WEED with the structural damaged. So we can conclude that the WPECD index has high sensitivity to low damage levels even 5% of stiffness reduction. For selected 11 measurement points from nodes 1, 3, 5, …, 21the effect of these points on the identification results was investigated. The damage identification results are shown in Figure 3(b) and Table 1. 5% of the damage information in element 5 is submerged, while in element 13, 10% of the damage was still identified, and then it increases from 5 to 20% at each element.



(a) WPECD signal (b) WPECD energy

Fig. 3. **Damaged simply supported beam WPECD (first 8 components)**

Experimental verification

Test introduction

A simple supported beam body replaced by the bridge model was used as the test object. The beam is 20 m long (between two supports), 1 m wide. 21 measuring points are arranged on the longitudinal

centerline of the beam, near the mid-span measuring points arranged relatively densely. The beam is excited by an impact force (Figure 4) and the damage levels are shown in Figure 5.

Table 1

Test cases for damage severity identification

Cases	Damage element	Damage location	Damage level	Young's modulus
C1	Element 5	Between node 5 and node 6	5%	210 GPa × 95%
	Element 13	Between node 13 and node 14	5%	210 GPa × 95%
C2	Element 5	Between node 5 and node 6	10%	210 GPa × 90%
	Element 13	Between node 13 and node 14	10%	210 GPa × 90%
C3	Element 5	Between node 5 and node 6	15%	210 GPa × 85%
	Element 13	Between node 13 and node 14	15%	210 GPa × 85%
C4	Element 5	Between node 5 and node 6	20%	210 GPa × 80%
	Element 13	Between node 13 and node 14	20%	210 GPa × 80%

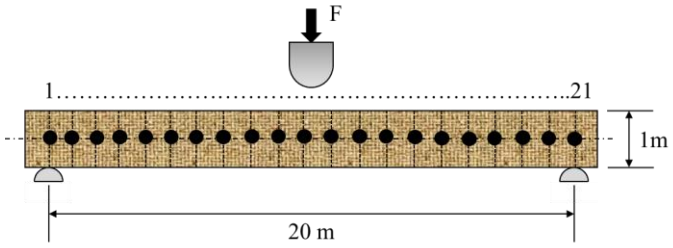


Fig. 4. **Test beam and measuring point layout**

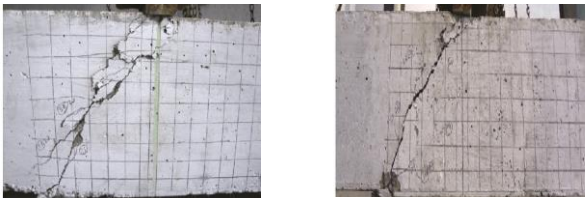
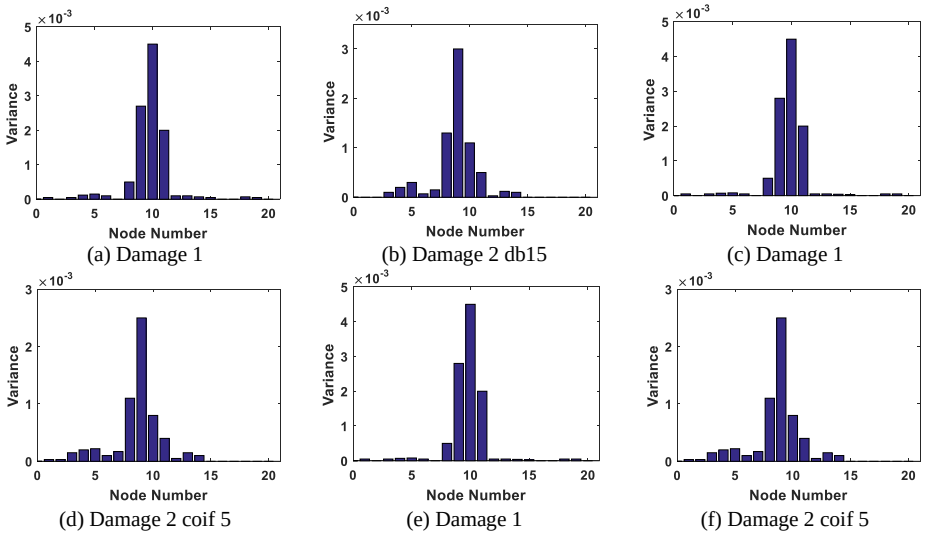


Fig. 5. **Damage level (left: level 1, right: level 2)**

Damage identification based on WPECD

The response of each number of node has three operating conditions subjected to WPECD. The decomposition layer number is 7, the function of wavelet is Db15 wavelet, and 2^7 = 128 WPECD coefficient components and energies, wavelet packets under two damage levels.



(a) Damage 1 (b) Damage 2 db15 (c) Damage 1

(d) Damage 2 coif 5 (e) Damage 1 (f) Damage 2 coif 5

Fig. 6. **WPECD Signal of first eight components**

Figure 6 (a), (b) shows the WPECD signal first components, superposition from eight components. As shown in Figure 6 (a), (b), the WPECD signal curvature energy is in the level (1) of the damage. The damage identification results are shown in Figure 6 (c), (d). By comparing between Figure 6 (a), (b) and Figure 6 (c), (d), we can see the difference between the two packet functions. Checking the effect of the number of decomposition layers on the wavelet recognition results, we can see that better recognition effect occurred when increasing the decomposition layer number of WPECD. Figure 6 (e), (f) shows the damage identification results, using Db15 wavelet and eight decomposition layers. By comparing between Figure 6 (a), (b) and Figure 6 (e), (f), we can see that the identification results of both figures are similar at nearly twice as long calculation time 101s, and the amplitude value is slightly reduced.

Conclusions

In this article, the simple support beam damage numerical simulation analysis index is presented. It can be shown that WPECD can effectively identify the location of damage. In this work the damage level increases from 5% to 20%. The performance of this technique was confirmed experimentally by studying the damage of a real bridge, we found the conclusions below:

1. The WPECD technique in numerical computation shows that it is more effective for damage. Sensitive, that is, small lesions (5%), can also be effectively identified. But at the measuring point, due to sparseness, less damage information will be drowned out.
2. The presented method was confirmed experimentally to study the damage of a real bridge, and our research will provide an online reference of SHM of engineering structures.
3. A little effect was of different wavelet functions on calculation effectiveness. But each other can be verified by different wavelet functions.
4. Finally, we can conclude that each time the number of layers increases, the wavelet packet signal component doubles, and the calculation time also increases. Therefore, it is necessary to comprehensively consider the influence of the number of layers of wavelet packet decomposition, select the appropriate number of decomposition layers, and try to do as much as possible under the premise of ensuring the identification quality, reduce the computation time. In this example, the decomposition level of 7 levels has met the requirements.

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