Amirkabir Journal of Civil Engineering

Amirkabir J. Civil. Eng., 51(3) (2019) 157-160

DOI: 10.22060/ceej.2018.13723.5465

Detection of Damage in Simply-Supported Plates by Discrete Wavelet Transform of Reconstructed Modal Data

M. Payasteh[1], M. Aghajan-nashtaei[2], M. Taherinasab *[3] S.B.beheshti aval[4]

[1]Department name, Jundi-Shapur University of Technology, Dezful, Iran
[2]Department name, Civil Engineering, Shahid Beheshti University of Tehran, Iran
[3]Faculty of Civil Engineering, Jundi Shapur University of Technology, Dezful, Iran
[4]Department name, Khajeh Nasir University of Technology, Tehran, Iran

ABSTRACT: Localized singularities caused by changes in the stiffness or mass of the damaged region cannot be simply visible through modal analysis results. However, the wavelet transform of input signal can identify the location of defects by sudden changes in the spatial variation of transformed response. The aim of this research is to present a new method for damage detection in a damaged plate. Therefore, a squarely steel plate with fixed support conditions is modeled, symmetrically. The proposed method in this study is capable to detect existing defects in plates with damage ratio of 3%. In this approach, based on symmetry or asymmetry of mode shapes, the value of each point of mode shape data is respectively subtracted from or added with its symmetric point. The results demonstrat that the small defects are detected with high resolution by employing reconstructed modal data in contrast to the original mode shape data. In addition, it has been shown that less-detailed measurement can still be used provided an interpolation is used to improve the accuracy of the crack detection and decrease financial cost of structural health monitoring projects

Review History:

Received: 16 November 2017
Revised: 18 February 2018
Accepted: 02 March 2018
Available Online: 24 April 2018

Keywords:

Damage detection
Discrete wavelet transforms
Modal data
Plates
Health monitoring

1-Introduction

Health monitoring and damage detection in the shortest possible time is a necessity that needs to be felt more and more every day in all engineering sciences, especially civil engineering, mechanics and aerospace. Most of the techniques used, usually based on eye visitation or visiting a specific point (such as voice, ultrasonic, and wave reflection), lead to a change in the specification of the material. In addition, in some of these techniques, access to the site of damage is necessary, so structural monitoring and vibration monitoring methods are specifically developed to eliminate these constraints. Structural health monitoring systems generate a large amount of data, so processing data and interpreting results has become a challenging issue [1]. Various studies have used Modal analysis response for damage detection. Pandey et al. (2014) showed that the change in the modal analysis curve determines the damage location. A sudden change in the wavelet coefficients specifies the damage location and, using the intensity of these coefficients, can be detected the depth of damage [2, 3]. Sampaio et al. (1999) extracted the modal curve values from a healthy structure [4]. Gentile and Messina (2003) focused their attention on the discovery of open cracks in the beams under cross-vibration [5]. They used a discrete wavelet transform to detect open cracks in the beams with reducing the measured data and the basic information of the structure. Zhu and Law (2006) presented a new method to detect the cracks in the bridge beam under moving loads using wavelet analysis. This method was verified by laboratory and numerical simulation. The location of multiple cracks was precisely determined. The results were not sensitive to the noise of the system, velocity, and magnitude of the moving load [6]. Zhong and Oyadiji (2011) introduced a new method for detecting small cracks in beam structures without using structural modal parameters [7]. This method is based on the difference between two categories of modal analysis data, which is related to the left and right half of a simple double beam. This method was able to detect damage with a 5% damage ratio.

Corresponding Author: Alinaseri@stu.nit.ac.ir

2-Methodology

•Discrete wavelet transform

In this section, a summary of the discrete wavelet transforms used in this study is presented. A discrete wavelet transform is an implementation of the wavelet transform using a discrete set of the wavelet scales and translations obeying some defined rules. In discrete wavelet transform the signals can be represented by approximation and details. The detail at level j is defined as [8]:

$$D_j(t) = \sum_{k \in Z} cD_{j,k} \psi_{j,k}(t) \quad (1)$$

Where is wavelet $cD_{j,k}$ function and is wavelet $\psi_{j,k}$

coefficient at level j. the approximation at level j is defined as:

$$A_j(t)=\sum_{k=-\infty}^{+\infty} cA_j(k)\phi_{j,k}(t) \quad (2)$$

Where $\phi_{j,k}$ is scaling functions and $cA_{j,k}$ is scaling coefficient at level j. the signal $f(t)$ can be represented by:

$$f(t)=A_J+\sum_{j<J} D_j \quad (3)$$

•Reconstructed modal analysis data

The modal analysis signal of plate is divided into two symmetric and antisymmetric groups. The first and fourth mode data of the plate are symmetric with respect to the center of symmetry of the plate (point O), but the second and third mode data are antisymmetric. For symmetric states in the first and fourth modes, the values of any point such as *(i, j)* are deducted from its corresponding point (*n-i + 1, n-j + 1)* with a central symmetry relative to it and this new value is replaced at (i, j). On the other hand, for the antimetric mode, in the second and third modes, the values of each point *(i, j)* are accumulated with the points of the atomic symmetry coordinates relative to the center of the plate *(n-i + 1, n-j + 1*) and this new value is replaced at *(i, j)*. The results of this process are presented for each of the four damaged plate modes, as a symmetric matrix of the center of the plate, which is used as the wavelet analysis input signal.

•Numerical modeling

The selected structure is presented for numerical modeling is an elastic square-shaped plate with dimension $L \times W \times h$ and four-edge fixed support with a low thickness element as a damage in Figure 1. The damaged area is characterized by a lower degree of stiffness (less thickness) at a point with x_d and Z_d coordinates. The damage ratio $r_d = h_d / h$ is fixed at 3% for all models. In the damage ratio relation, h_d is the thickness of the damage and h is the thickness of the plate.

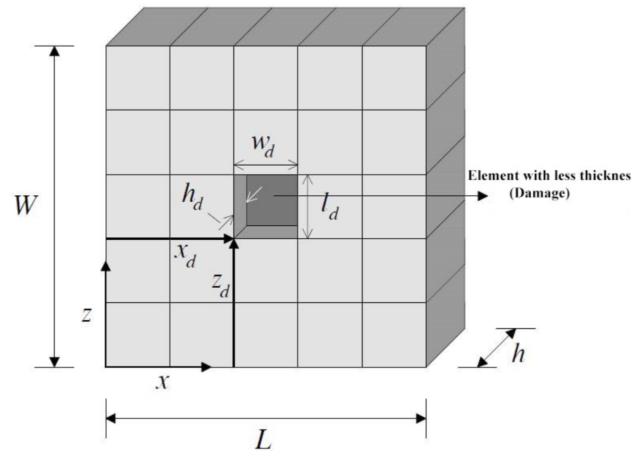


Figure 1. Finite element view of damaged plate

In this research, the finite element model has been used in the Ansys software to obtain the frequencies and mode shapes of fixed support plate. The damage site is modeled in part with a less thickness. Modal analysis results of Ansys software in the form of a two-dimensional matrix consisting of a plate deflection were used as input in MATLAB software.

3-Results and Discussion

Figure 2 shows the modal analysis of reconstructed wavelet coefficients for four modes. According to the location of the damage, all of the mode in Figure 2 (except for the third modes) display a large peak in the damage region and the wavelet coefficients of these have high clarity compared to the wavelet transformation of basic modes. The shock caused by the support effects on the wavelet coefficients in the basic modal analysis, completely eliminated in the reconstructed modal analysis. The resulting noise caused by the location of damage and numerical solution caused the damage effect in Figure 2, the third mode not easily visible. Damage is a localized phenomenon. As shown in Figure 2, the use of the reconstructed modal analysis method makes it possible to clearly detect the damage location at low frequencies (modes one and two). The results indicated that the reconstructed modal analysis method is superior to the base modal analysis method for detecting damage in the plate. In other words, the removal of the support effects, reducing the noise caused by numerical solution and displaying the damage location in low-frequency modes are the achievements of the proposed method, which provides small damage detection with a 3% damage ratio on the plates. The results showed that damage near any of the modal analysis peaks leads to the exact damage detection. In other words, if the damage is located near the point that its displacement is close to zero, there will be intense noise in the wavelet analysis results. This effect is well visible as shown in Figure 2. The results showed that with increasing sampling points distance, the accuracy of determination of the location of the damage is decreased. The use of interpolation of modal analysis data has had an extraordinary effect on the accuracy of the discovery of the damage detection on the plate. Comparison of the results showed that the use of interpolation with the distance of the sampling points makes it economical not only by using less sensors, but also by reducing the noise.

4-Conclusions

This research is a simple but precise method based on wavelet transformation on the reconstructed modal analysis results for detecting small damage in structures such as symmetric square plates with a 3% damage ratio. The modal response of the plate with a fixed support is measured based on finite element method in Ansys software. Different location of damage and different sampling point were investigated. The results demonstrated the efficiency of the proposed method for detecting damage and, in fact, provide a powerful tool for detecting damage in terms of the wavelet transformation method on the basic modal analysis results. Despite the higher sensitivity and high frequency performance (Mode 4), the proposed method showed high potential in detecting damage at low frequencies. In fact, the location of the damage and its closeness to the peak of modal analysis displacement is the main factor behind the successful operation of the proposed method. In addition, in order to improve the accuracy of damage detection, interpolation was used on measured data of modal analysis of all four mode. The results showed an amazing interpolation effect on the modal analysis results, in order to improve damage detection on the plate. On the other hand, the use of interpolation in some way reduces the number of sensors in the monitoring system, which also reduces the exhausting cost of monitoring systems.

References

[1] A. Behnia, H. Chai, M. Yorikawa, S. Momoki, M. Terazawa, T. Shiotani, Integrated non-destructive assessment of concrete structures under flexure by acoustic emission and travel time tomography, Construction and Building Materials, 67 (2014) 202-215.

[2] H. Pahlavan, A. Naseri, A. Einollahi, Probabilistic Seismic Vulnerability assessment of RC Frame Structures Retrofitted with Steel Jacketing, Amirkabir Journal of Civil Engineering, (2018). (in Persian)

[3] A. Pandey, M. Biswas, M. Samman, Damage detection from changes in curvature mode shapes, Journal of sound and vibration, 145(2) (1991) 321-332.

[4] S. Ravanfar, H. Razak, Z. Ismail, H. Monajemi, An improved method of parameter identification and damage detection in beam structures under flexural vibration using wavelet multi-resolution analysis, Sensors, 15(9) (2015) 22750-22775.

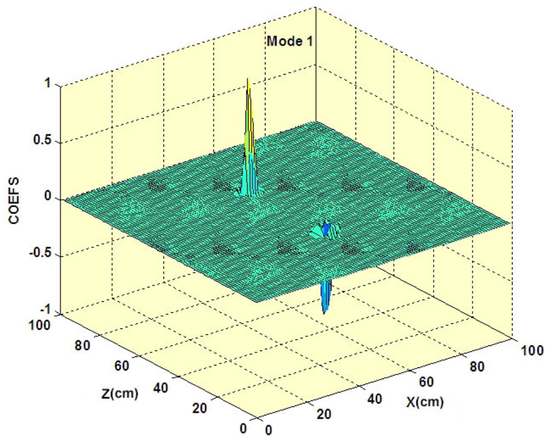
[5] R. Sampaio, N. Maia, J. Silva, Damage detection using the frequency-response-function curvature method, Journal of sound and vibration, 226(5) (1999) 1029-1042.

[6] A. Gentile, A. Messina, On the continuous wavelet transforms applied to discrete vibrational data for detecting open cracks in damaged beams, International Journal of Solids and Structures, 40(2) (2003) 295-315.

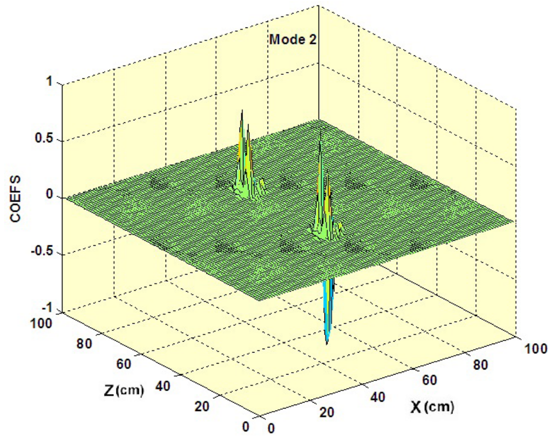
[7] X. Zhu, S. Law, Wavelet-based crack identification of bridge beam from operational deflection time history, International Journal of Solids and Structures, 43(7-8) (2006) 2299-2317.

[8] S. Zhong, S.O. Oyadiji, Detection of cracks in simply-supported beams by continuous wavelet transform of reconstructed modal data, Computers & structures, 89(1-2) (2011) 127-148.

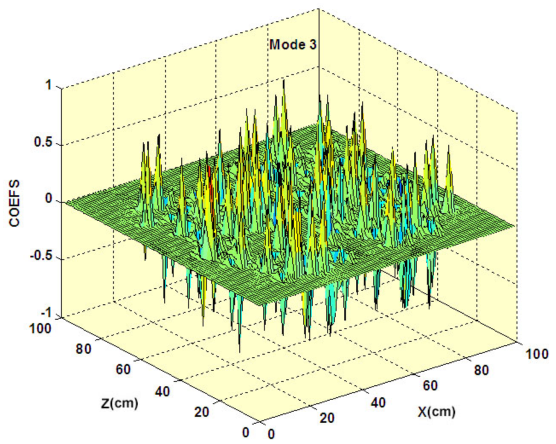
[9] A. Bagheri, G. Ghodrati Amiri, M. Khorasani, H. Bakhshi, Structural damage identification of plates based on modal data using 2D discrete wavelet transform, Structural Engineering and Mechanics, 40(1) (2011) 13-28.



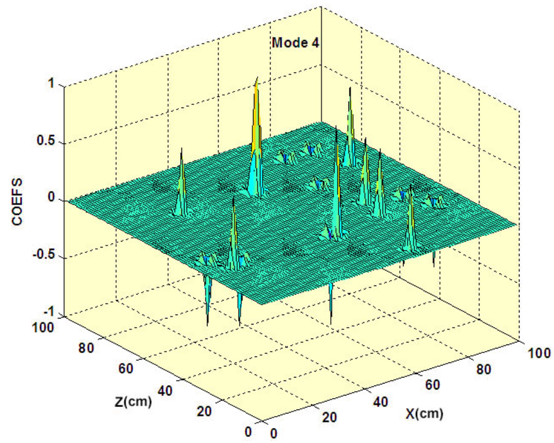
a: wavelet coefficients of reconstructed modal analysis



b: wavelet coefficients of reconstructed modal analysis



c : wavelet coefficients of reconstructed modal analysis



d: wavelet coefficients of reconstructed modal analysis

Figure 2. wavelet coefficients of reconstructed modal analysis of damaged plate

, $r_d = 3\%$, $l_S = 10mm$, $(n \times n) = (101 \times 101)$ $(x_d, z_d) = (500, 300)$

Please cite this article using:

M. Payasteh, M. Aghajan-nashtaei, M. Taherinasab S.B.beheshti aval, Detection of Damage in Simply-Supported Plates by Discrete Wavelet Transform of Reconstructed Modal Data, *Amirkabir J. Civil Eng., 51(3)(2019)503-522*.

DOI: 10.22060/ceej.2018.13723.5465