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DAMAGE IDENTIFICATION METHOD BASED ON VIBRATION FOR LATTICE TRUSS CORE SANDWICH PANELS

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ABSTRACT

Lattice truss core sandwich panels are widely applied in transportation, automobile, aircraft and aerospace industries for their outstanding characteristics and excellent designable properties. However, only a little work concentrates on their non-destructive testing (NDT) methods. In this paper, based on vibration and continuous wavelet transform (CWT), a baseline-free NDT method is proposed for damage identification in lattice truss core sandwich panels. Firstly, the special mode shapes are chosen and the 2D CWT is applied to process the mode curvatures. Then, considering the periodicity, which is the instinct characteristic of lattice truss core sandwich panel, a damage index is defined by a combination of the structural periodicity and the coefficients of CWT. Finally, numerical simulations and experimental tests are conducted for damage identification in sandwich panels. Results show that the proposed method is efficient and reliable, and has a good identification resolution for one or more truss core bars missing detection without a baseline. It indicates the proposed method has an applicable potential in damage detection of sandwich panels.

Keywords: lattice truss core sandwich panel, non-destructive testing, mode shape, continuous wavelet transform

NOMENCLATURE

Ψ	wavelet function
a	scale parameter
$\vec{\mathbf{b}}$	translation vectors
θ	rotation parameter
$\hat{f}$	Fourier transform of f
$\bar{f}$	conjugation of f

1. INTRODUCTION

The complexity of sandwich panel can induce many kinds of defects in manufacturing, assembly and service, and make current non-destructive testing (NDT) methods face a bigger challenge than the damage identification for simple plates, which limits the application of sandwich panels. Some special defects are very common in lattice truss core sandwich panels, such as the debonding between face sheet and lattice truss, the buckling or broken bars in truss core. These defects are invisible and difficult to be detected on the face sheet, but they can make the structure cause catastrophic collapse. Therefore, it is a quite vital concern about NDT method for monitoring sandwich panels.

Li et al. [1] proposed a NDT method by combining 2D gapped smoothing method (GSM) and Teager energy operator (TEO) to process mode parameters from uniform load surface curvature. Furthermore, Lu et al. [2, 3] did lots of experimental work for damage detection. However, they had to use TEO to process the damage index obtained by 2D GSM for suppressing the discontinuities caused by lattice truss core, and identified the debonding in composite lattice truss core sandwich panel. How to utilize the instinct periodic characteristics of lattice truss core to provide a simpler baseline-free NDT method without complex signal processing is still difficult, but it is significant in damage detection of sandwich panels.

In this paper, a damage identification method based on mode curvatures for lattice truss core sandwich panels is proposed.

2. DAMAGE IDENTIFICATION METHOD

For damage detection methods based on vibration, we first should choose the vibration data for signal process, and then the signal processing method and the definition of damage index .

2.1 The choice of mode shapes

A composite sandwich panel with lattice truss core is considered for numerical simulation. The intact cell is a pyramidal truss core and the damaged cell is just lost one bar as shown in Figure 1. The numerical model has 10 times 10 cells. We choose 1D-bending like mode shapes as vibration data as shown in Figure 2 to process, for their excellent periodicity.

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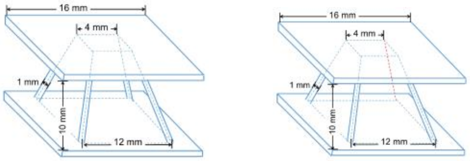

(a) Intact cell (b) Damaged cell

FIGURE 1: PYRAMIDAL TRUSS CORE

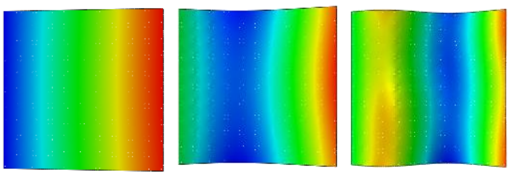

FIGURE 2: TYPICAL 1D BENDING-LIKE MODE SHAPES

2.2 Two dimensional continuous wavelet transform

Using continuous wavelet transform to process the chosen mode curvatures which obtain by the central different method, the wavelet transform coefficients can be calculated by

$$C_f\left(a,\vec{\mathbf{b}},\theta\right) == \int_{R^2} \hat{f}(\vec{\boldsymbol{\omega}})\bar{\hat{\psi}}_{a,\vec{\mathbf{b}},\theta}(\vec{\boldsymbol{\omega}})e^{i\vec{\mathbf{b}}\cdot\vec{\boldsymbol{\omega}}}d^2\vec{\boldsymbol{\omega}} \qquad (1)$$

2.3 Total damage index (TDI)

Based on the mode shapes, we use the mode curvatures for damage identification, because mode curvatures have good sensitivities than mode shapes. After getting wavelet transform coefficients of 1D bending-like mode curvatures, we can find that it has significant periodic features in columns. A baseline for each column cell can be obtained by averaging the cells in the same column

$$\bar{\mathbf{C}}_j^k = \frac{1}{n}\sum_{i=1}^{n} \mathbf{c}_{ij}^k \qquad (2)$$

where i, j respectively means the number of row and column, and k is the number of mode shape. $\bar{\mathbf{C}}_j^k$ is the baseline for column j and mode k, and $\mathbf{c}_{ij}^k$ is the wavelet coefficients of mode k for cell position (i, j).

The total damage index for cell (i, j) can be defined as

$$\mathbf{TDI}_{ij} = \sum_{k=1}^{p}(\mathbf{c}_{ij}^k - \bar{\mathbf{C}}_j^k) \qquad (3)$$

where p is the number of used mode shapes.

3. RESULTS AND DISCUSSION

Numerical simulations and experimental tests are conducted by the proposed NDT method.

In numerical simulation, the software ABAQUS is employed to calculate the 1D bending-like mode shapes of lattice truss core composite sandwich panel. The damaged models are designed with one, two and three damaged cells in which only one truss bar is lost. By using the isotropic Morlet wavelet function, the TDIs can be obtained and shown in Figure 3. We can find all damaged cells can be identified and even the lost bar can be detected. Moreover, two damage in the same column in model with three damaged cells can be also detected, that is to say that the proposed method is robust and applicable.

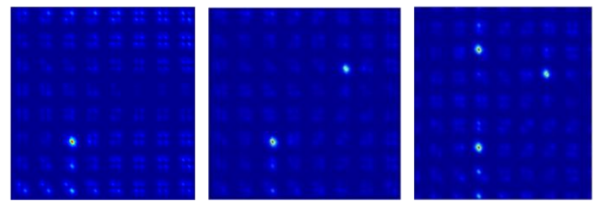

FIGURE 3: THE TDIS OF THREE DAMAGED MODELS

In experimental test, a lattice truss core composite sandwich panel with a broken truss bar (Figure 4) was employed to verify the proposed method. The mode shapes were captured by a scanning Laser Doppler vibrometer. By the same data processing procedure, the damage can be also identified in Figure 5.

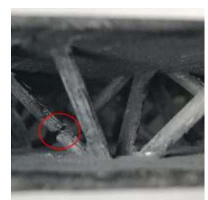

FIGURE 4: EXPERIMENTAL SAMPLE

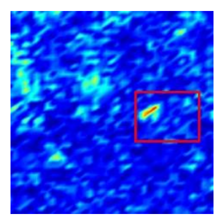

FIGURE 5: THE TDIS OF EXPERIMENTAL TEST

4. CONCLUSION

For damage detection method of lattice truss core composite sandwich panel, the big challenge is how to overcome the disturbance of connecting joints between face sheets and truss core. By numerical and experimental studies, we can get the following main conclusions:

(1) Combining 2D CWT and structural periodicity, the proposed baseline-free NDT method for damage identification of lattice truss core sandwich panel is perfectly valid. Without complicated multi-stage signal processing method, only the 2D CWT of mode curvatures can provide good detecting results.

(2) The baseline construction depends on the damaged mode shape in 1D bending-like shape. The cell number needs large enough along the direction for baseline construction, then the accuracy of damage identification can be increased effectively.

(3) The proposed method can be used for a single damaged cell or multi-damaged cells identifications, and the more mode

shapes can be chosen, the better result can be achieved without location dependence.

The proposed NDT method not only has the applicability in damage detection of composite lattice truss core sandwich panels, but also has the potentiality and capability to be developed in damage identification for complicated periodic composite structures.

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REFERENCES

[1] Li B, Li Z, Zhou J, Ye L, Li E. Damage localization in composite lattice truss core sandwich structures based on vibration characteristics. Composite Structures. 2015; 126:34-51.

[2] Lu L, Song H, Huang C. Experimental investigation of unbound nodes identification for metallic sandwich panels with truss core. Composite Structures. 2017; 163:248-56.

[3] Lu L, Song H, Yuan W, Huang C. Baseline-free damage identification of metallic sandwich panels with truss core based on vibration characteristics. Structural Health Monitoring. 2017; 16:24-38.