Damage Identification of Space Trusses Based on the Modal Strain Energy and Wavelet Transformation

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Abstract. To demonstrate the applicability of damage identification methods, wavelet analysis is used in damage detection of space trusses. For a single identification method may not be sensitive to structural damages in multiple locations. A damage identification approach based on the modal strain energy and wavelet transformation was proposed in this paper. A structural damage index has been built on the coefficients of the wavelet transformation based of the modal strain energy variations. Through the numerical simulation of a space truss, it has been demonstrated that the structural damage index, based on the wavelet transformation coefficients of the modal strain energy is effective. The proposed method can effectively determine different damage locations in a structure. The results have laid solid foundation for the practical engineering applications for the proposed method.

Introduction

Space trusses are widely used structures. During its service, a truss will be inevitably damaged. Therefore, it is very important to determine as well as repair the damage of a space truss in time and ensure its safety during its service. Structural damage can reduce the stiffness of the structure, increase the damping and change the vibration frequency and modal vibration mode of the structure. These changes can be reflected through the dynamic response of the structure (Doebling, Farrar et al. 1996). Sohn (2001) has reviewed damage identification methods based on structural vibration. The identification methods based on the damage index includes: methods that based on the frequency, vibration mode and the curvature mode, energy change, and flexibility matrix, methods for determining the damage size has been derived based on the modal strain energy change (Stubbs and Osegueda 1990, Pandey, Biswas et al. 1991,Doebling, Hemez et al. 2015). The experimental modal analysis, which involves vibration theory, vibration measurement technology, signal acquisition and analysis, has gained general recognition in damage identification of space trusses (Shi, Law et al. 1998). Although there are numerous investigations in the aspect of identifying the damage, few researches have been done on damage identification method at different level at the same time (Stubbs and Kim 1996). Normally, the damage identification method based on the modal strain energy may not be able to identify the damage in some bars if the modal strain energy change has very small values. Wavelet analysis can be focused to any details of a signal for frequency domain, which can make a better analysis of the singularity of the signal. As demonstrated by Li (2013) in a net shell structure, the maximum point of the wavelet coefficients of the modal strain energy corresponds to the damage location. This paper, however, did not provide the information of the modal strain energy, hence it is impossible to tell whether or not the modal strain energy identify the damage locations and to what extent the wavelet transformation enhance the identification.

This article improves the method reported by Li (2013). The variation of the modal strain energy along with the truss damage has been investigated and the singularity of the modal strain energy at the damage location has been analyzed by the wavelet transformation.

The Modal Strain Energy (MSE)

Structural damage can be represented by the reduction of the local structural stiffness. In this paper, the element modal strain energy is taken as the basic index for structural damage diagnosis. The modal strain energy of the i-th element about the j-th order mode before and after the structural damage, $MSE_{i,j}$ and $MSE_{i,j}^{d}$, defined as:

$$MSE_{i,j} = \frac{1}{2}(EI)_j \int_{a_j}^{a_j+1} (\frac{\partial^2 \varphi_i}{\partial^2 x})^2 \, dx \quad (1)$$

$$MSE_{i,j}^{d} = \frac{1}{2}(EI)_j \int_{a_j}^{a_j+1} (\frac{\partial^2 \varphi_i^d}{\partial^2 x})^2 \, dx \quad (2)$$

In the formula, andare x-coordinates of the node j and j+1, where $(EI)_j$ is the flexural rigidity of the j-th element, and the superscript 'd' represents damage and $\{\varphi_i\}$ is the i-th modal shape.

The sum of the modal strain energy (SMSE) about the first m modes before and after structural damage is:

$$SMSE_{i,j} = \frac{1}{2}\sum_{i=1}^{m}\left[(EI)_j \int_{a_j}^{a_j+1} (\frac{\partial^2 \varphi_i}{\partial^2 x})^2 \, dx\right] \quad (3)$$

$$SMSE_{i,j}^{d} = \frac{1}{2}\sum_{i=1}^{m}\left[(EI)_j \int_{a_j}^{a_j+1} (\frac{\partial^2 \varphi_i^d}{\partial^2 x})^2 \, dx\right] \quad (4)$$

The change of the element modal strain energy is a damage index, which is sensitive to the structural damage and is used to diagnose damage location. The modal strain energy change is:

$$SMSEC_{i,j} = \left|SMSE_{i,j} - SMSE_{i,j}^{d}\right| \quad (5)$$

According to (5), if a local damage exists in the structure, the bar with the maximum modal strain energy change is most likely the damage position.

Wavelet Transform Theory

The wavelet transform of a signal can be used to characterize the time-frequency variations of the spectral components. Details regarding wavelet analysis and its applications can be found in Mallat (2009). The wavelet transformation of a function ψ(t) is as follows:

$$CWT(a,\tau) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(t)\psi_{a,t}(\frac{t-\tau}{a})dt \quad (6)$$

The index comprises of the wavelet parameters a andwhich represents the scale (dilation) and translation (position), respectively; f(t) is the vibration response signal. is the conjugate of the basis function (or mother wavelets function).

In the decomposition and reconstruction of the signal, the selection of an appropriate wavelet function may have a significant impact to the analysis results. After the analysis and comparison, the wavelet bior6.8 of the bi-orthogonal wavelet family, which has a rapid transformation, regularity and a better vanishing moment, will be selected. The mutational signal of the modal strain energy change can lead to the obvious change of the coefficient of the wavelet (Loutridis, Douka et al. 2005).

Space Truss Structure Damage Identification

To demonstrate the capability of the proposed technique approach, a space truss (Figure 1) is considered in this study. The truss is made of steel Q235, and its Young's modulus is 212 GPa, and mass density 7850 kg/m3, and Poisson's ratio 0.288. The damage is introduced by reducing the diameter of the corresponding bar element.

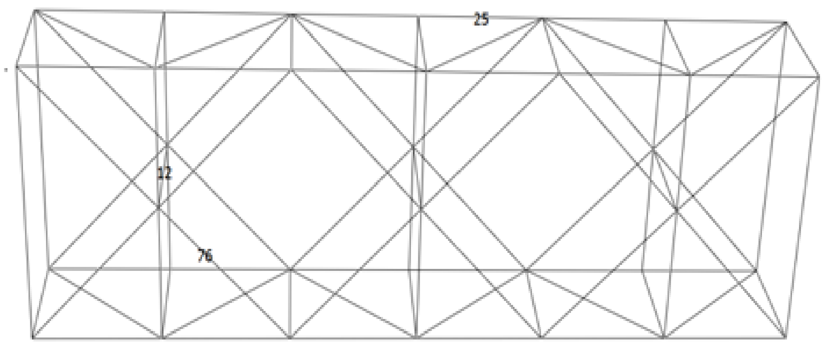

Fig.1. A modal for space truss

The finite element model is analyzed using abaqus. The modal strain energy change is shown in Figure 2 for the case that the damage appears in the bar 12, 25, 76 simultaneously.

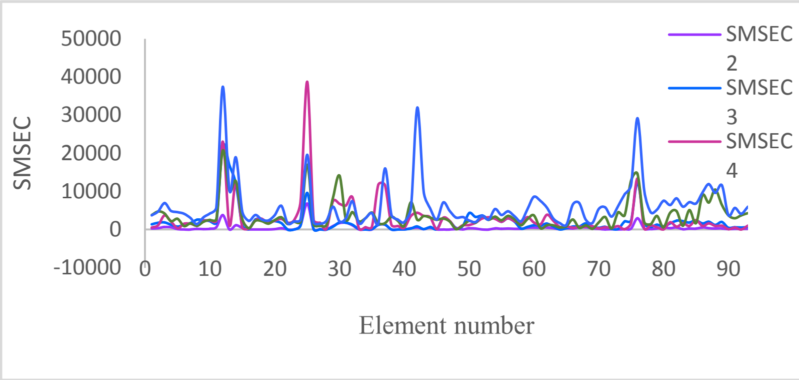

Fig.2 The SMSEC result of identifaction

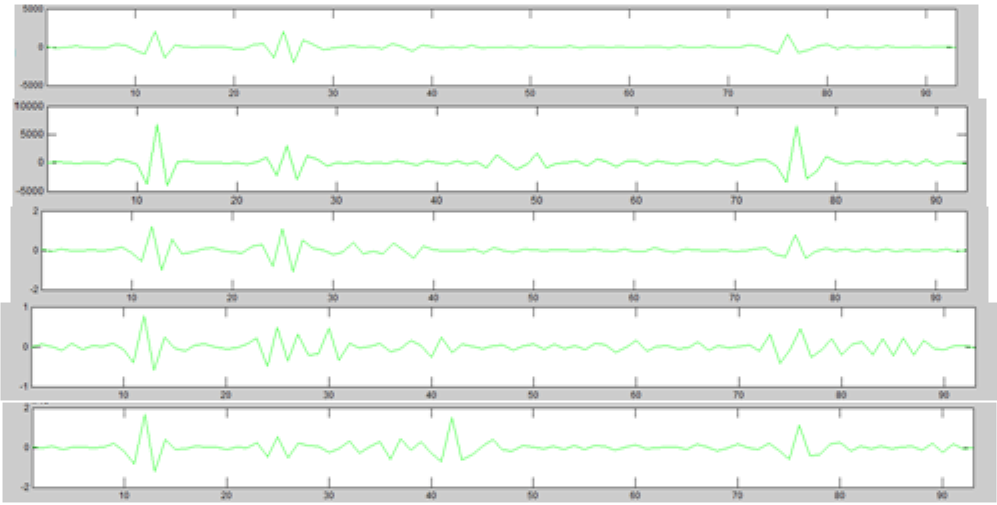

Fig.3 (a-e) SMSECi,jContinous wavelet transform

When the damage appears in the bar 12, 25, 76 simultaneously, the sum of first two modal strain energy changes in the damaged elements are higher than the undamaged elements , while it does not vary much for undamaged elements. Furthermore, the extremums also appear in some bars (e.g., 43) which do not have damage. These extremums are misleading for damage identification. The continuous wavelet transform of the modal strain energy change has obvious mutations in the damaged bars; while the misleading extremums of the modal strain energy change disappear in most coefficients of its continuous wavelet transform. The damaged location can be determined by the singularity which exists in all the coefficients of the continuous wavelet transform of the modal strain energy change.

Conclusions

A damage identification method for space trusses has been proposed using the wavelet transform of the modal strain energy change. The numerical simulations show that the modal strain energy change alone is not able to identify the damage location in space truss accurately. The extremums may appear in some bars which do not have damage. The misleading extremums may also appear in some wavelet transform coefficients but not in all; combinations of multiple wavelet transform coefficients are able to remove the misleading extremums. The wavelet transform of the modal strain energy change is able to identify the damage location of a space truss accurately.

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