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ScienceDirect

Procedia Engineering 1 (2009) 147–150

Procedia Engineering

www.elsevier.com/locate/procedia

Mesomechanics 2009

Simulation study on damage localization of a beam using evidence theory

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Received 26 February 2009; revised 19 April 2009; accepted 21 April 2009.

Abstract

Structural damage localization plays an important role in structural damage identification. An cumulative structural damage localization method based on evidence theory is studied in this paper. An algorithm for cumulative fusion of primary localization information is presented. In the numerical study, a fixed-end beam is inspected. Two damage cases are studied, one with single damage and the other with multiple damages. White noises are added to the beam mode shapes of the first five orders to simulate the measurement noises. First, Modal Strain Energy Change Ratio (MSECR) method is used to localize the damage elements using the noise-contaminated mode shapes. Then, the locations determined by MSECR are taken as primary information and fused cumulatively. In both the single-damage-case and the multiple-damage-case, the fused results show that damaged elements are accurately identified. Furthermore, the damage elements are distinguished much more clearly than those identified from MSECR.

Keywords: Damage localization; Data fusion; Evidence theory, Numerical simulation

1. Introduction

With the development of structural engineering, modern structures are becoming more and more complex, e.g., aircrafts, long span bridges and off-shore platforms. Since the working environments of these structures are usually critical, structural damages will inevitably occur during the service life. The damages will lead to terrible consequences if they are not identified in time. Therefore, structural damage identification becomes necessary for these structures. In the past decades, varieties of damage identification methods [1] have been proposed to identify the occurrence, the location and the qualification of damage. Also, many damage localization indicators have been suggested. Based on the eigen-equation, Ojalvo et al. [2] proposed to locate the model error using modal force residue. The damaged elements are identified by their relevant degrees of freedom. Messina et al. [3] proposed to use a multiple damage location assurance criterion to locate the damaged elements. Their method is formulated on the same basis as the modal assurance criterion. Shi et al. [4, 5] proposed to locate the damaged elements by comparing the modal strain energy of each element before and after the damage. The modal strain energy change

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doi:10.1016/j.proeng.2009.06.034

ratio (MSECR) of each element is defined to be a damage indicator. In their study, the indicator is proved to be effective in locating the structural damage.

Though there are several available damage localization methods and indicators, engineers find it still difficult to determine the damage location in practice. They do not know which method to trust since the results from different methods may not be in good agreement, and are sometime discordant. Hence, it becomes necessary to research on methods to fuse structural damage identification results from multiple sources. Guo [6] proposed a method using information fusion technique. The method is able to fuse local decisions from multiple damage location assurance criterion (MDLAC) method and the frequency change damage diction method (FCDDM), where frequency data and mode shape data are used as information sources respectively.

This paper studies structural damage localization using data fusion. Different from the method of Guo, which use frequency data and mode shape data as two information sources, this study takes mode shapes of different orders as information sources. In section two, the algorithm for cumulative fusion is studied. In section three, a fixed-end beam is studied as a numerical example. Two damage cases are studied: one is single-damage-case and the other is multiple-damage-case. In both cases, MSECR is used to locate the damage element using mode shapes of different orders.

2. Theory

Dempster-Shafer (DS) evidence theory [7], which is currently the most important data fusion theory, is developed by Dempster and Shafer. The method is able to fuse data from different information sources. This provides structural engineers with the possibility of integrating multiple identification results. Based on the DS evidence theory, a cumulative damage localization methodology for fusion of primary localization results is proposed as follows.

Suppose there are $\boldsymbol{n}$ elements in the structure. These elements are treated as subsets in the DS evidence theory. Damaged elements are preliminarily localized from $\boldsymbol{s}$ types of sources. Damage indicator for $\boldsymbol{i}^{\mathbf{th}}$ element from $\boldsymbol{j}^{\mathbf{th}}$ types of source is,

$$Ind_i^j, i = 1, 2, ..., n;\ j = 1, 2, ..., s \tag{1}$$

The indicators should be pre-processed to assign the basic probability for each element before fusing. In this study, the basic probability are calculated as follows,

$$m_j(e_i) = \frac{Ind_i^j}{\sum_{i=1}^{n} Ind_i^j} \tag{2}$$

where $\boldsymbol{m_j(e_i)}$ represents the processed indicator, as well as the basic probability for $\boldsymbol{i}^{\mathbf{th}}$ element from $\boldsymbol{j}^{\mathbf{th}}$ type of source. Then, Fused Damage Indicator (FDI) could be computed,

$$m(e_k) = \frac{\sum_{e_1 \cap e_2 \cdots e_d = e_k} \left(\prod_{1 \le j \le s} m_j(e_j) \right)}{1 - K} \tag{3}$$

$$K = \sum_{e_1 \cap e_2 \cdots e_d = \phi} \left(\prod_{1 \le j \le s} m_j(e_j) \right) \tag{4}$$

Then, FDI are normalized with respect to the maximum value. And, the normalized results are defined as Normalized Fused Damage Indicator (NFDI). The primary results from different sources are fused cumulatively. The cumulative fusion procedure could be illustrated in the following flowchart.

In Fig. 1, $\boldsymbol{NFDI}^{\mathbf{k}}$ represents the normalized fused damage indicator in $\boldsymbol{k}^{\mathbf{th}}$ step. In each step, equation (3) and (4) are used to fuse the $\boldsymbol{NFDI}^{\mathbf{k}}$ and the $\boldsymbol{k}^{\mathbf{th}}$ group of processed primary indicator.