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# A probabilistic damage detection approach using vibration-based nondestructive testing

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## Abstract

With the aim of improving the accuracy of the assessment of existing structures, damage detection using vibration-based nondestructive testing (NDT) has been extensively studied. It has been recognized that a considerable amount of uncertainties exist in the damage detection process. This paper proposes a novel probabilistic damage detection approach that accounts for the underlying uncertainties. The proposed approach combines two techniques: A Bayesian model updating and a vibration-based damage identification technique (VBDIT). The model updating uses modal frequencies from a damaged structure to build a baseline finite element model (FEM). VBDIT uses mode shapes from the baseline model and the damaged structure to detect damage at local level. The proposed framework makes use of the advantages of the Bayesian model updating and the VBDIT, and compensates for their drawbacks. The sources and types of errors that may occur in the damage detection process are discussed and considered in the proposed formulation. In particular, the proposed approach considers the measurement errors in the vibration tests, the modeling errors in the damage detection process, and the statistical uncertainties in the unknown model parameters. As an application, a finite element model simulating a two-span aluminum beam is used to illustrate the proposed framework. The effects of the measurement and modeling errors on the performance of the proposed damage detection are studied. Modal data can be easily extracted from out-put only responses on an existing structure, making the proposed methodology of practical value.

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## Highlights

► A Bayesian model updating and a vibration-based damage detection method are combined. ► Uncertainties that occur in damage detection process are properly treated. ► The framework can be used in SHM as only output data is needed. ► An strategy is proposed to obtain accurate mode shapes using limited sensors.

## Keywords

Nondestructive testing; Damage detection; Vibration test; Modal analysis; Measurement error; Modeling error; Bayesian model updating

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Figures and tables from this article:

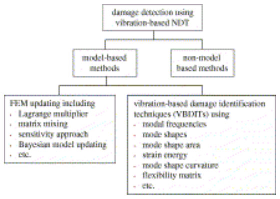

Fig. 1. Damage detection using vibration-based NDT.

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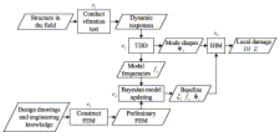

Fig. 2. Flowchart of the proposed damage detection approach.

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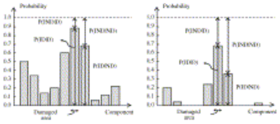

Fig. 3. Conceptual illustration of correct and false detection probabilities when a low threshold (left) and a high threshold (right) are used.

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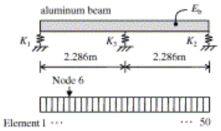

Fig. 4. Schematic of the example beam and the FEM.

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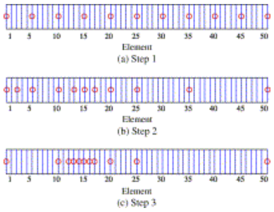

Fig. 5. Sensor locations denoted by circles for Damage Case 1 under 1% noise level with stiffness reduction 10%.

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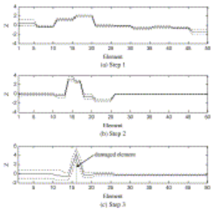

Fig. 6. *Z* values (solid line: mean, dotted line: mean ± 1 standard deviation) for the beam elements of Damage Case 1 under 1% noise level with stiffness reduction 10%.

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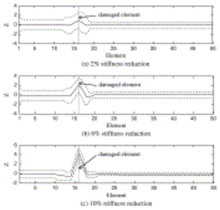

Fig. 7. *Z* values (solid line: mean, dotted line: mean ± 1 standard deviation) for the beam elements with Damage Case 1 under 1% noise level.

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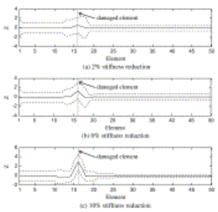

Fig. 8. $Z$ values (solid line: mean, dotted line: mean ± 1 standard deviation) for the beam elements with Damage Case 1 under 2% noise level.

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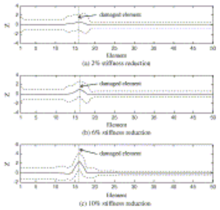

Fig. 9. $Z$ values (solid line: mean, dotted line: mean ± 1 standard deviation) for the beam elements with Damage Case 1 under 3% noise level.

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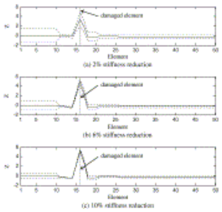

Fig. 10. $Z$ values (solid line: mean, dotted line: mean ± 1 standard deviation) for the beam elements with Damage Case 1 considering error $e_2$.

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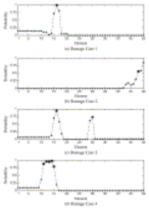

Fig. 11. Probability of damage detection for Damage Cases 1 – 4 with 10% flexural stiffness reduction under 1% noise level using $\lambda = 1.0$.

Figure options

Table 1. Errors and uncertainties in the proposed damage detection approach.

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Table 2. Comparison of modal frequencies (Hz).

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Table 3. Estimates of $e_{3a}$ for the example beam.

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Table 4. Comparison of modal frequencies of no damage case and damage cases[a] (Hz).

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