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Review

Dealing with uncertainty in model updating for damage assessment: A review

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ABSTRACT

In structural engineering, model updating is often used for non-destructive damage assessment: by calibrating stiffness parameters of finite element models based on experimentally obtained (modal) data, structural damage can be identified, quantified and located. However, the model updating problem is an inverse problem prone to ill-posedness and ill-conditioning. This means the problem is extremely sensitive to small errors, which may potentially detract from the method's robustness and reliability. As many errors or uncertainties are present in model updating, both regarding the measurements as well as the employed numerical model, it is important to take these uncertainties suitably into account. This paper aims to provide an overview of the available approaches to this end, where two methods are treated in detail: a non-probabilistic fuzzy approach and a probabilistic Bayesian approach. These methods are both elaborated for the specific case of vibration-based finite element model updating for damage assessment purposes.

Contents

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1. Introduction

1.1. Why model updating?

In practically all areas of science and engineering, numerical or mathematical models are used to simulate the behavior of real systems. The purposes of these numerical models vary widely, but can generally be classified into three main categories: analysis, prediction, and design. In civil and structural engineering, finite element (FE) models are most often used to analyze e.g. the internal forces and displacements of structures in several limit states, or to predict vibration responses due to dynamic loading such as earthquakes, wind and traffic. These FE analyses can also be used to design structural components or complete structures. It goes without saying that for all the above purposes, the validity of the adopted numerical models is imperative. There are, however, always numerous unknown or uncertain system properties (e.g. regarding material properties, geometric properties, boundary conditions, load conditions) for which inevitably conjectures have to be made. Moreover, due to a lack of knowledge or other restrictions, often simplifying modeling assumptions regarding the model structure are required or implicitly made. These issues may detract from the quality and accuracy of the numerical model and its purposes.

This has led to the development of *model updating* techniques, also referred to as model calibration or, in more generic terms, parameter identification or estimation. Generally speaking, model updating aims to reconstruct or calibrate unknown system properties which appear as parameters in numerical models, based on actually observed behavior of the system of interest. In a structural mechanics context, often (processed) data acquired in vibration experiments (i.e. acceleration time histories, frequency response functions, natural frequencies and mode shape displacements, modal strains or curvatures, modal flexibilities, etc.) are deemed most suited for FE model updating purposes, as they provide detailed information regarding the global and local behavior of the structure of interest, and can be measured in an operational state of the structure. Standard reference works on deterministic vibration-based FE model updating include those of Mottershead and Friswell [1,2], Fritzen et al. [3] and Imregun and Visser [4]; for a comprehensive overview of FE model updating in civil engineering applications, the reader is referred to the work of Teughels [5].

Structural FE model updating serves a wide array of purposes; it can for instance be applied for design verification and validation, to obtain improved predictions of structural response quantities, or simply to identify unknown system characteristics. One of the most prominent application areas of vibration-based FE model updating is found in structural health monitoring (SHM). The basic principle behind this consists in assuming that localized structural damage results in a local reduction of stiffness. As such, updating stiffness parameters of the FE model in several damage states provides a (non-destructive) means to thoroughly and accurately investigate the condition of the structure. Up-to-date reference works on SHM can be retrieved in [6–9]; for vibration-based SHM, the reader is referred to the extensive literature reviews by

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