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Finite element model validation of bridge based on structural health monitoring—Part II: Uncertainty propagation and model validation

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ABSTRACT

Because of uncertainties involved in modeling, construction, and measurement systems, the assessment of the FE model validation must be conducted based on stochastic measurements to provide designers with confidence for further applications. In this study, based on the updated model using response surface methodology, a practical model validation methodology via uncertainty propagation is presented. Several criteria of testing/analysis correlation are introduced, and the sources of model and testing uncertainties are also discussed. After that, Monte Carlo stochastic finite element (FE) method is employed to perform the uncertainty quantification and propagation. The proposed methodology is illustrated with the examination of the validity of a large-span prestressed concrete continuous rigid frame bridge monitored under operational conditions. It can be concluded that the calculated frequencies and vibration modes of the updated FE model of Xiabaishi Bridge are consistent with the measured ones. The relative errors of each frequency are all less than 3.7%. Meanwhile, the overlap ratio indexes of each frequency are all more than 75%; The MAC values of each calculated vibration frequency are all more than 90%. The model of Xiabaishi Bridge is valid in the whole operation space including experimental design space, and its confidence level is upper than 95%. The validated FE model of Xiabaishi Bridge can reflect the current condition of Xiabaishi Bridge, and also can be used as basis of bridge health monitoring, damage identification and safety assessment.

1. Introduction

Model validation for structural dynamics has been comprehensively studied for the last 20 years and is still under active development in research and in the field of industrial applications (Babuska and Oden, 2004; Oberkampf and Roy, 2010; Roache, 1998). The objective of model validation is to refine the mathematical model of a critical structure by using reference data obtained from experimental tests or numerical simulations in order that the refined mathematical model can be capable of representing the physical behavior of the actual

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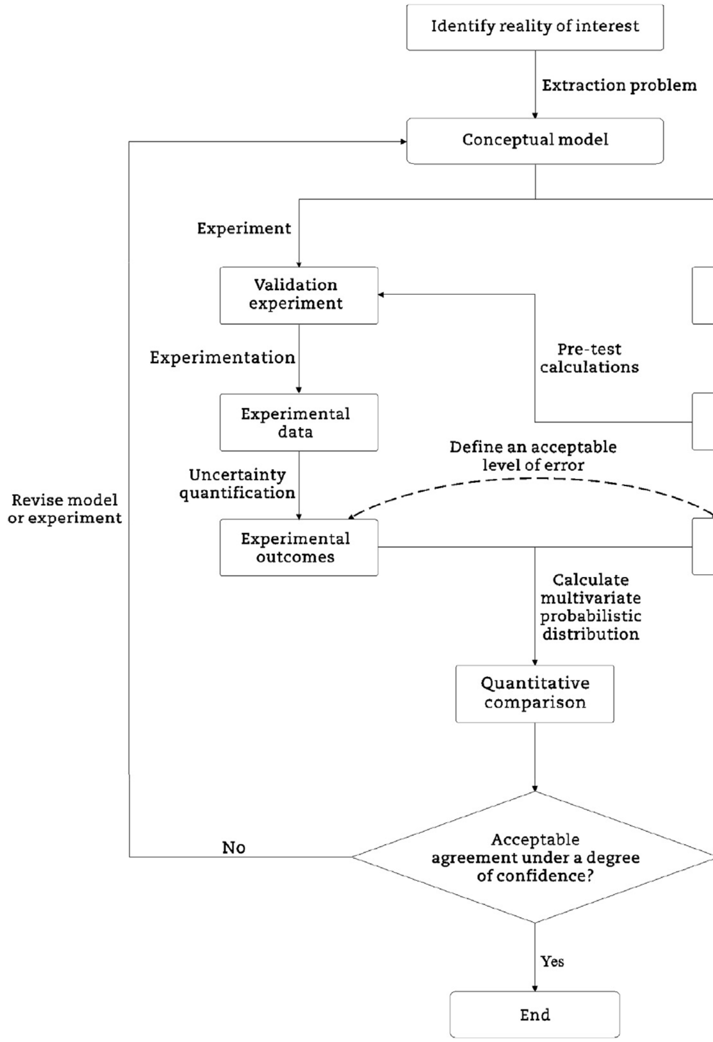

Fig. 1 – Flowchart of model validation process.

structure within a required accuracy, and can thus be used for design optimization (Thacker et al., 2004). The flowchart for validating the analytical model is shown in Fig. 1.

Three types of uncertainties are included in both uncertainty quantification and model validation: (1) natural variability in loading and material properties; (2) data uncertainty due to measurement errors, sparse data, and different inspection results (crack not detected, crack detected but size not measured, and crack detected with size measurement); (3) modeling uncertainty and errors during numerical approximations, and finite element discretization. Global sensitivity analysis is used to quantify the contribution of each source of uncertainty to the overall prediction uncertaint, and to identify important parameters that need to be calibrated. A computational model may generate multiple response quantities at a single location or the same response quantity at multiple locations, and a validation experiment might yield corresponding measured responses in a single test. In each case, the multiple responses, being derived from the same input, are correlated. In both cases, model validation involves comparison of multiple quantities of model prediction and test data (multivariate analysis). In recent years, a number of stochastic finite element methods, probabilistic models, and non-probabilistic models have been investigated and applied to structural modelling and validation, taking into account uncertainties and modelling errors (Ladevèze et al., 2006; Roy and Oberkampf, 2011; Soize et al., 2008; Zang et al., 2008). These stochastic methods are more complex and require more computing resources than deterministic methods.

The concept of using experiments to inform numerical models, such as test–analysis correlation, uncertainty quantification and propagation, and model validation, has only recently been extended to civil engineering structures. Atamturktur et al. (2012) focused on the verification and validation (V&V) of numerical models for establishing confidence in model predictions, and demonstrated the complete process through a case study application completed on the Washington National Cathedral masonry vaults. Successful repair and retrofit schemes ultimately depend on the development of a verified and validated simulation capability that can be used to better understand the behavior of historic monuments. Sankararaman et al. (2011) presented a methodology for uncertainty quantification and model validation in fatigue crack growth analysis. Several models