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Nonlinear structural joint model updating based on instantaneous characteristics of dynamic responses

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A R T I C L E I N F O

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This paper proposes a new nonlinear joint model updating method for shear type structures based on the instantaneous characteristics of the decomposed structural dynamic responses. To obtain an accurate representation of a nonlinear system's dynamics, the nonlinear joint model is described as the nonlinear spring element with bilinear stiffness. The instantaneous frequencies and amplitudes of the decomposed mono-component are first extracted by the analytical mode decomposition (AMD) method. Then, an objective function based on the residuals of the instantaneous frequencies and amplitudes between the experimental structure and the nonlinear model is created for the nonlinear joint model updating. The optimal values of the nonlinear joint model parameters are obtained by minimizing the objective function using the simulated annealing global optimization method. To validate the effectiveness of the proposed method, a single-story shear type structure subjected to earthquake and harmonic excitations is simulated as a numerical example. Then, a beam structure with multiple local nonlinear elements subjected to earthquake excitation is also simulated. The nonlinear beam structure is updated based on the global and local model using the proposed method. The results show that the proposed local nonlinear model updating method is more effective for structures with multiple local nonlinear elements. Finally, the proposed method is verified by the shake table test of a real high voltage switch structure. The accuracy of the proposed method is quantified both in numerical and experimental applications using the defined error indices. Both the numerical and experimental results have shown that the proposed method can effectively update the nonlinear joint model.

1. Introduction

Structural models such as finite element model have been extensively used for analyzing and researching purposes in civil, aerospace and mechanical engineering fields. An accurate alternative structural model can greatly reduce cost in engineering application. However, these structural models are normally constructed based on idealized engineering designs, and they may not accurately represent all the aspects of actual structures. As a result, the structural model predictions usually differ from the results of the real structures. Especially, many complex structures are composed of substructures and components connected by mechanical joints [1,2]. How to model the joint may significant affect the simulation results.

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To obtain a better predicted result, the residuals between the structural model and the corresponding real structure can be optimized by updating or calibrating parameters of the model. In the last decades, the finite element model updating procedure has been developed for modifying the model parameters based on the experimental data [3]. For instance, the non-iterative method [4,5] is directly used to update the elements of mass and the stiffness matrices. However, this method does not generally maintain structural connectivity and the updated matrices are not always physically meaningful. The other finite element model updating method is the iterative parameters updating method [6–13]. For this kind of method, an objective function based on the residuals between experimental data and model predictions is designed, and the model parameters are then updated by minimizing the objective function.

However, complex nonlinear behavior of structures has been observed not only when they are subjected to extreme loads (such as, earthquake, typhoon, etc.), but also during the operational conditions. Characterization of the nonlinearity can provide critical diagnostic and prognostic information. At present, the structures can be analyzed by use of tools with assumptions of linear and stationary structural behavior. Determination of the dynamic characteristics for a structure exhibiting nonlinear behavior by assuming linearity may lead to misleading results. Thus, it is critical to know if a structure is behaving nonlinearly and to detect and estimate the impact of the nonlinearity both qualitatively and quantitatively.

In order to calibrate the nonlinear model, some researchers suggested to identify the parameters of nonlinear structures, whose nonlinearity is simulated by defining hysteresis models. Therefore, the nonlinear system is considered as the identification of constant parameters of a nonlinear hysteretic model. In the previous studies, the parameters of hysteretic models have been identified based on dynamic response data by using different time-domain methods, mainly including least-square estimation [14–16] and Kalman filter methods [17–23].

The other methods to calibrate nonlinear system are to update the nonlinear model based on the nonlinear properties of the responses. For instance, Hemez and Doebling et al. [24] presented the correlation of non-linear models with test data based on the test responses. Their purpose is to provide experimental data for validating the strategies implemented for test–analysis correlation and inverse problem solving of nonlinear structures. Song et al. [25] further introduced a nonlinear FE model updating method for RC structure under low amplitude ambient vibration. Silva et al. [26] compared the nonlinear finite element model updating methods in frequency domain, such as, harmonic balance method, restoring force surface method, and proper orthogonal decomposition method. Wang et al. [27] further proposed a new nonlinear model updating method based on the instantaneous frequencies and amplitudes of the decomposed dynamic responses. In their study, the structural nonlinear properties are simulated by using a global hysteresis Bouc–Wen model.

More recently, the local nonlinear model updating method was developed [28,29]. The nonlinear characteristics of the structures can be simulated by using a local joint element. For instance, Luan et al. [28] used a simplified rigid mass with two bilinear springs to simulate nonlinear mechanical properties of bolted flange joints in the pipe structures. Alamdari et al. [29] introduced a nonlinear joint model updating method based on structural nonlinear frequency response function. The updating procedure is successfully used to update a nonlinear joint model in assembled structures under a single level excitation.

In this paper, a new nonlinear joint model updating method based on the instantaneous characteristics of the decomposed structural dynamic responses is proposed. Since the nonlinear characteristics of a nonlinear structure are implied in both amplitude and frequency of the responses during the oscillation, thus, the structural instantaneous characteristics including the instantaneous frequencies and the instantaneous amplitudes are used as the objective functions for the nonlinear joint model updating. The instantaneous frequencies and amplitudes are first extracted by using analytical mode decomposition (AMD) and Hilbert transform method [30–34]. The extracted instantaneous amplitude and frequency of the decomposed mono-component can keep the complete information of the nonlinear features and can be used to update the nonlinear model. Thus, an objective function is defined using the residuals of the instantaneous frequency and amplitude of the decomposed mono-component between the experimental structure and the nonlinear model. The optimal values of the nonlinear parameters are obtained by minimizing the objective function using the annealing global optimization method [35,36]. To validate effectiveness of the proposed method, a single-story nonlinear shear type structure with a nonlinear

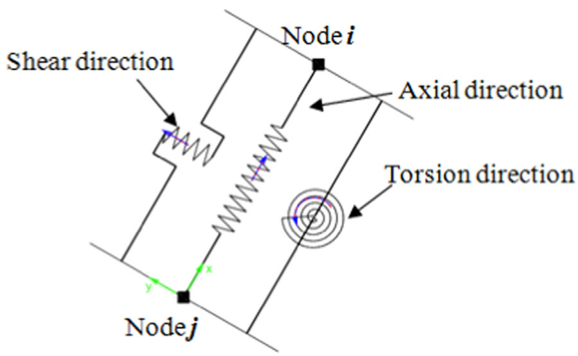

Fig. 1. The detail of a two-dimensional zero length joint element.