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A updating method using strain frequency response function with emphasis on local structure

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ABSTRACT

A dynamic finite element model updating method for the concerned local structure is presented using strain frequency response function test data. Firstly, a dynamic condensation technique is developed to establish the dynamic finite element model of the concerned local structure for improving the analytical efficiency of the dynamic strains and their transfer relations in model updating. Then, the sensitivity of strain frequency response function of the local structure is conducted to construct the canonical equation for model updating. Furthermore, a model updating strategy of 'grouping-iteration' is proposed to stabilize the ill-posed problem in the model updating process. Finally, numerical simulation and experimental investigation for updating the dynamic finite element model of the cantilever plate structure with elastic support are performed to validate the feasibility and efficiency of the present method. The obtained results show that the present method can be successfully used to update the dynamic finite element model of the local structure in terms of achieving a good agreement between the strain frequency response functions of the updated finite element model and the actual structure.

1. Introduction

Practically, many structures satisfy the static strength design requirement, but suffer a partial vibration failure in services due to the lack of their structural dynamic strength estimate. The accurate evaluation of structural dynamic strength is very important during the structure design. However, it is generally not necessary and sometimes it is difficult to obtain the dynamic strength characteristics of the global structure in practical projects. Thus, a structural dynamic finite element (FE) model, which can be utilized to precisely calculate the dynamic strains and their transfer relations at the critical local region of the structure, is only required in the simulative evaluation of structural dynamic strength. But due to some inevitable discrepancies originate from the uncertainties in simplifying assumptions of dynamic modeling of the structure, the analytical results obtained the established FE model do not coincide well with the corresponding test results. In order to improve the analytical precision of the dynamic strains of the structural dynamic FE model, especially at the concerned local region of the model, the dynamic model updating could be a feasible way for solving the aforementioned problem.

Historically, the dynamic FE model updating methods based on traditional displacement/acceleration test data, i.e. modal parameters [1,2], frequency response function (FRF) [3,4] and dynamic response [5,6], have been studied extensively. However, a few publications that deal with model updating methods focus on the structural dynamic stress/strain characteristics. Ha et al. [7] developed an updating method, which combined strain modal shapes with a closed-loop scheme, to decrease the

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condition number of the sensitivity matrix for enhancing the performance of the model updating procedure, and it is verified that the strain mode has advantages over displacement mode for model updating applications because it is sensitive to local changes of the structure. Esfandiari et al. [8] proposed a model updating method based on incomplete strain frequency response function (SFRF) data, and used the least square method to solve the quasi-linear sensitivity equation in model updating. Guo et al. [9] developed an updating method by means of the correlation analysis between the experimental and the calculated SFRFs at the specific critical locations of a structure, and the proposed method was validated using experimental SFRF data from a steel cantilever stepped beam.

Although the above updating methods using the structural dynamic stress/strain characteristics are studied, all the aforementioned methods are proposed for updating the global structures. However, the structural vibration failure without checking the dynamic strength often occurs within a local region of the structure. Thus, it is more important to ensure the accuracy of the analysis of the dynamic response of the concerned local region of a structure (i.e. local structure) while ensuring the accurateness of the dynamic characteristics of the global structure. Therefore, a series of updating methods were investigated to modify the incorrect design parameters of the local structure to minimize the computation scale of the dynamic response used in model updating applications. Hou and Ou [10,11] proposed a substructure isolation method to accurately update the interested local substructure utilizing the impulse responses of the local substructure [10] and the measured local modes [11], respectively. In their work, only the FE model of the local substructure is needed without any global FE modeling information, which can increase the computational efficiency. However, the influence of the mass and inertia of the surrounding substructure on the local substructure is ignored when they used the static method to construct the constrained boundary of the local substructure. Weissenburger [12] proposed a local modification method and investigated the effect of local modifications on the vibration characteristics of a linear system. Based on the above updating method, Pomzal and Snyder [13] developed a local updating method on damped linear system. In their methods, the known characteristics of the original system are used to generate the modified characteristic equation directly without solving the modified eigenvalue problem explicitly. But the proposed updating methods belong to the matrix-type updating method, and the updated results have no clearly physical meaning. By means of sensitivity analysis, Link [14] proposed a two-part updating method to update the uncertain parameters, which can be separated into two groups: local physical parameters related to the concerned local structure and global generalized parameters related to the surrounding structures, for improving the robustness of the updating process. Following with the basic idea of the Harmonic Balance method, Meyer and Link [15] presented a method to modify the local non-linear stiffness and damping parameters of the updating structure using measured frequency response datum. However, although the above updating methods are developed for local structure, the traditional dynamic characteristics are merely used as the updating target in their proposed updating methods.

The current work describes two methods aimed at improving the analytical precision and efficiency of the dynamic strains and their transfer relations at the critical local region of the structure (here after is referred to as the local structure). The first part of the paper describes a dynamic FE modeling method for the local structure, which can be separated from the global structure, to minimize the computation scale of the dynamic strains during updating the FE model of the structure.

The second part of the paper develops an updating method using the measured SFRF datum obtained from the local structure. In the author's previous work [9], the SFRF as a dynamic stress/strain parameter has been validated to be successfully used for updating a global structure. By means of sensitivity analysis of the correlation coefficients between the measured SFRFs and the calculated SFRFs of the local structure, the canonical equation for model updating is constructed. Furthermore, the constructed canonical equation is solved by a developed updating strategy of 'grouping-iteration' to stabilize the ill-posed problem in the updating process.

This paper also demonstrates the feasibility of the present updating method using the experiments of model updating for a cantilever plate with elastic support.

2. Dynamic FE modeling for the local structure considering the dynamic effects of surrounding structures

In case that the exciting force only acts on the local structure, there is no direct vibration energy transfers from the surrounding structure to the local structure, so the surrounding structure mainly functions as the support base of the local structure. According to the idea of dynamic condensation, the local structure to be updated can be separated from the global structure, meanwhile, the dynamic effects of the surrounding structure on the local structure will be considered by using an equivalent stiffness matrix and an equivalent mass matrix incorporated into the FE model of the local structure [16]. Then, the global structure can be considered as consisting of two parts: the local structure (i.e. the concerned region of the structure) and the surrounding structure, as shown in Fig. 1. The degrees of freedom (DOFs) of the FE model of the global structure $\mathbf{u}_G$ can be divided into three parts: the internal DOFs of the FE model of the local structure $\mathbf{u}_L^i$, the internal DOFs of the FE model of the surrounding structure $\mathbf{u}_S^i$ and the interface DOFs $\mathbf{u}^I$ between the FE models of the local structure and the surrounding structure.

$$\mathbf{u}_G = \begin{Bmatrix} \mathbf{u}_L^i \\ \mathbf{u}^I \\ \mathbf{u}_S^i \end{Bmatrix} \tag{1}$$