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Nonlocal damping model in finite element structural vibration analysis

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Abstract: The paper is devoted to development of an uncomplicated, flexible and controllable damping model for structurally complex materials such as composites and nanomaterials. The model is applicable for the computer dynamic analysis of composite structures. The Newmark method modification, which is used for the finite element dynamic structural analysis, is considered. This modification allows one to consider both external and internal damping when studying the dynamic response of a structure. For internal damping simulation in an implicit Newmark scheme the matrix FE nonlocal in time model is used. This model is further called "damping with memory". The model is controlled by its key parameters. Damping with memory model is calibrated on the data of composite beam dynamic analysis. The characteristics of beam material were determined experimentally. In this paper the numerical simulation results obtained in Simulia Abaqus software are used as the base for nonlocal model calibration. In the numerical simulation the reasonably detailed 3D FE beam model is used. The composite material of the beam is considered as orthotropic. The results of 1D modelling of beam vibrations considering damping with memory coincide with those via the 3D FE modelling with sufficient accuracy.

Keywords: structural dynamics, nonlocal damping, computer simulation, composite materials

1. Introduction

The problem of damping process simulation for structural elements made of composite materials is significantly complicated. Generally, detailed 3D finite element models are used to simulate numerically the dynamic behaviour of composite structures. In cases when such approach is inefficient, the models that are flexible and controllable are needed, such as fractional hereditary models [1,2] or nonlocal damping models [3-6]. The present paper is devoted to the damping model nonlocal in time.

2. Results and Discussion

Within the nonlocal in time model, damping of a structure at current time t is assumed to be dependent not only on instant value of motion velocity at this point $\dot{v}(t)$, but also on the values of motion velocity in the previous time history. The more the gap between the two time points, the lower influence that one of them has on the other. Such damping model is further called "damping with memory".

Since the finite element method is the dominant method of engineering calculations, the damping with memory is integrated to its algorithm.

In the algorithm of the finite element analysis, the equilibrium equation of a structure deformed in motion is represented in the matrix form [7, 8]:

$$M \cdot \ddot{\bar{V}}(t) + D_{int} \cdot \dot{\bar{V}}(t) + D_{ext} \cdot \dot{\bar{V}}(t) + K \cdot \bar{V}(t) = \bar{F}(t). \quad (1)$$

Here $\bar{V}(t)$ is the displacement vector, K is the stiffness matrix of the finite element model, D_{int} and D_{ext} are the matrices of internal and external damping, respectively, M is the mass matrix, and $\bar{F}(t)$ is the load vector. As well as matrices M and K, matrices D_{int} and D_{ext} are derived according to the stationary requirement of the full energy of moving deformable structure change.

The Newmark implicit scheme is used for the numerical integration of the equation, and it is more stable than the method of central differences. To modify the Newmark scheme for the damping with memory model, the part which is responsible for the internal damping is supplemented with the discrete analogue of the integral of normalized kernel function, that describes the diminishing of the influence of the time points on one another.

After modified Newmark method application, equation (1) transforms to

$$M \cdot \left[\frac{2}{\Delta t^2}\left(\bar{V}_{i+1} - \bar{V}_i - \dot{\bar{V}}_i \Delta t\right) - \ddot{\bar{V}}_i\right] + D_{int} \cdot \sum_{j=0}^{i} \bar{G}(i,j)\,\dot{\bar{V}}_j + D_{ext}\frac{1}{\Delta t}(\bar{V}_{i+1} - \bar{V}_i) + K \cdot \bar{V}_{i+1} = \bar{F}_{i+1}(t). \tag{2}$$

The key parameters of the model were determined on the base of 3D composite [9,10] beam vibration numerical simulation data. The root mean square error for calibrated nonlocal model is four times less than that for the classical Kelvin-Voight damping model.

3. Concluding Remarks

In comparison to classic local models, the model presented in this paper allows one to manage the main characteristics of the simulated vibration process in more reliable and flexible way. Increased flexibility makes it possible to use one-dimensional models of beam elements in the dynamic analysis of structures which are made of modern composite materials with orthotropic properties.

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