PHYSICAL AND MATHEMATICAL SCIENCES

STUDY OF NONLINEAR VIBRATIONS OF REINFORCED COMPOSITES USING HAAR WAVELET

Pysarenko Alexander Mykolayovich,
Candidate of Physical and Mathematical Sciences, Associate Professor
Odessa State Academy of Civil Engineering and Architecture
Odesa, Ukraine

Introductions. Reinforced composites are a class of new materials with properties that vary spatially according to a given non-uniform distribution of the reinforcement phase. Studies of local shears and deformations along fixed directions in an isotropic composite matrix are now widespread. In particular, extensive studies have been conducted on beams, plates and shells made of composite material with gradient inclusions to study their mechanical properties, such as static bending behavior, elastic buckling and post-buckling characteristics, and linear and nonlinear free vibration characteristics. Studies of nonlinear, as well as freely nonlinear and dynamic stability of beams have found that the natural and excitation frequencies of beams with symmetrical load distribution are higher than those of beams with uniform or asymmetrical distribution of local external action. In addition, it has been shown that geometrical defects also have a significant effect on the mechanical behavior of beams.

Aim. In this paper, the Haar wavelet method was improved for analyzing the nonlinear behavior of beams made of reinforced composite material in a thermal environment. The model uses boundary conditions that fix the composite sample on a three-parameter nonlinear elastic foundation with cubic nonlinearity and a shear layer. The elastic substrate, in turn, is subjected to a uniform increase in temperature.

Conducting numerical experiments assumed taking into account the temperature-dependent properties of the material as well as the initial thermal stress arising due to a uniform increase in temperature. Based on the theory of first-order shear deformation, nonlinear governing equations of beams are derived using Hamilton's principle.

Materials and methods. A fixed beam of reinforced composite material was reduced to a structure that was on a three-parameter nonlinear elastic foundation with

cubic nonlinearity and a shear layer. The supporting surface of the composite specimen

was parallel to the mid-plane, where the orthogonal coordinate system with the origin at one end of the beam was fixed. The abscissa and applicate axes are located along the length and thickness directions, respectively. It is assumed that the nonlinear elastic foundation consists of massless springs with shear interaction between them. The planes of the composite specimen and the foundation are mutually immobile during amplitude vibration. The load-displacement ratio of the mechanical model of the fixed foundation was determined by a system of governing equations for the propagation of vibrations in local areas of the composite volume.

The mechanical properties of the isotropic matrix, representing the local volume of the composite material in this model, were determined by the efficiency parameters. It was found that the kinematic properties of the propagating vibration waves depend on the mutual arrangement of the vibration sources. The numerical values of the mass density, the effective Poisson's ratio and the thermal expansion coefficient of the composite were obtained in accordance with the rule of displacement of matrix coefficients.

The method for solving nonlinear basic equations of vibration propagation in the volume of the composite was based on a simple and effective numerical approach based on the Haar orthonormal wavelet discretization method. The control function for the Haar wavelet is chosen to be square-integrable and finite in the interval [0, 1]. This function can be expanded into a Haar wavelet series with infinite terms. This calculation method operated with a truncated series that contained only finite terms of the Haar wavelet series.

Results and discussion. Parametric vibration studies indicate a significant influence of the concentration of vibration sources in the emerging field of shear deformations. It is shown that an increase in the flexibility coefficient for the boundary condition of the first kind, as well as an increase in the coefficients of the elastic foundation, generate significant nonlinearity of vibration processes. The speed and phase of vibration waves are also determined by the temperature gradient and the initial thermal stress.

The effects of distribution and influence of the volume fraction of thermal stress sources together with the boundary condition on the nonlinear behavior of oscillations of reinforced composite samples were investigated. As solutions of the system of control equations, the linear parameters of the fundamental frequency and nonlinear frequency ratios were investigated at different dimensionless oscillation amplitudes with different types of oscillation mode distributions. The results are generalized to three types of boundary conditions. The influence of the flexibility coefficient on the linear parameters of the fundamental frequency and the nonlinear and frequency ratios of the samples with and without an elastic foundation was studied. It was found that the linear parameter of the fundamental frequency decreases with an increase in the flexibility coefficient. For a beam without an elastic foundation, an increase in the flexibility coefficient leads to a decrease in the nonlinear frequency coefficient, but for a beam supported by a nonlinear elastic foundation, the nonlinear frequency ratio first decreases and only then increases quite sharply.

In this study, the changes in the dimensionless linear fundamental frequency as a function of temperature increase with and without taking into account the initial thermal stress were compared. It was found that with increasing temperature, the linear parameter of the fundamental frequency monotonically decreases to zero. In the case of taking into account the initial thermal stress, the decrease in the linear parameter of the fundamental frequency occurs much faster than without taking into account the initial thermal stress. In addition, it was found that with an increase in the linear and shear stiffness coefficients, both the linear fundamental frequency and the critical temperature increase.

Conclusions. The nonlinear vibration behavior of reinforced composite specimens supported on a nonlinear elastic foundation in a thermal environment was investigated in this paper using the discrete Haar wavelet transform. Using wavelet transforms, a system of governing equations was written and kinematic relations for vibration waves propagating in the local volume of the composite were modeled. Both the initial thermal stress and the temperature dependence of the material properties were considered in the theoretical modeling.

The nonlinear governing equations of the composites supported on a nonlinear elastic foundation were derived and then solved using wavelet transforms in combination with the direct iteration method to obtain linear and nonlinear natural frequencies. Parametric studies have revealed that the nonlinearity of vibrations in local volumes of composites is largely determined by the spatial distribution of vibration sources, the numerical value of the flexibility coefficient, the type of boundary conditions, the stiffness coefficients of the foundation and, finally, the temperature gradient and the initial thermal stress.