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Nonlinear Free Vibration of Reinforced Skew Plates with SWCNs Due to Finite Strain

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Abstract. This paper is an attempt to investigate the nonlinear free vibration of skew plates reinforced by carbon nanotubes (CNTs) due to finite strain tensor. The material properties of the nano-composite are estimated using the molecular dynamic results and the rule of mixture. Also, the differential equations governing the motions are derived on the basis of Classical Plate Theory (CPT) regarding the nonlinear Green-Lagrange strain tensor. In order to solve the nonlinear equations, Galerkin's method, Frechet derivative and differential quadrature method are used. The effects of volume fraction of functionally graded materials (FGM), skew angle, distribution of CNTs and geometrical features of the plate on the nonlinear vibration of system have been studied. The results of this study have been compared with other researches and a good agreement has been achieved.

AMS subject classifications: 34A34

Key words: Finite strains, nonlinear vibration, skew plate, carbon nanotubes, functionally graded materials.

1 Introduction

Skew plates are important structural components in many kinds of high performance surface and aircraft industry for example, they are used in the construction of wings, tails, and fins of swept-wing aircrafts, missiles and skew bridges. There is a large number of papers which focus on the free vibration of thin and thick skew plates. In the following section, some of the relevant studies will be discussed.

Singha and Daripa [1] studied the nonlinear vibration of laminated composite skew plates by finite element method. They used von-Karman's kinematic relations in order to formulate the problem. By applying the Galerkin's method and Newmark's technique,

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the nonlinear frequency ratio has been investigated with respect to the fiber orientation, skew angle and boundary condition. They found that nonlinear frequency ratio increases by increasing the skew angle and thickness of plate.

Malekzadeh [2] investigated the nonlinear free vibration of thin composite skew plates. In order to derive the governing differential equations, he has used von-Karman's kinematics relations. Obtained equations were solved by generalized differential quadrature (GDQ) method. Finally, nonlinear frequency ratios of plate by considering the skew angle, ratio of thickness-to-width, and amplitude ratios, in different tables have been investigated. Upadhyay and Shukla [3] studied the static and dynamic analysis of functionally graded skew plates under dynamic and static loading. as many published papers, they used nonlinear von-Karman's kinematic relations and Hamilton's principal for obtaining the equations of motions. After solving the governing equations, the effect of skew angle and different boundary conditions on the plate deflection and bending moment have been discussed. Malekzadeh [4] investigated the nonlinear free vibration of thin to moderately laminated skew plates based on the FSDT and DQ method. He used direct iteration technique and harmonic balance method for solving the nonlinear governing equations of motions. At the end, nonlinear frequency ratio in terms of geometrical variables and orientation of fibers have been shown in different figures. Obtained results indicate that DQ method is a powerful technique in solving nonlinear problems. Recently Liew et al. [5] analysed the nonlinear behavior of reinforced laminated composite plates by CNTs. For reinforcing the mentioned plates they applied several distributions of CNTs such as UD, FG-V, FG-O and FG-X type. It is obvious from the results presented in this paper that the non-dimensional central deflections of laminated functionally graded carbon nanotube reinforced (FG- CNTR) plates have been decreased by increasing the volume fraction of carbon nanotubes, since the stiffness of CNTRC plate increases when the volume fraction of carbon nanotubes increases.

Asadi et al. [6] investigated the application of piezoelectric materials and CNTs in nonlinear vibration behaviors of FG-CNTs reinforced composite plates. After solving the governing differential equations by GDQ method the effects of many parameters such as volume fractions of CNTs, thickness of piezoelectric layers and electrical boundary conditions on the nonlinear natural frequencies of system have been discussed. Malekzadeh [7] studied the free vibration of quadrilateral laminated plates with carbon nanotube reinforced composite layers. Distributions of CNTs which are selected include UD, FG-X, FG-V, FG-O and GDQ method used for solving the governing differential equations. Finally, the first three natural frequencies of system in SSSS and CCCC boundary conditions have been determined in a numerical example. Liew et al. [8] derived vibration frequencies and mode shapes of carbon nanotube-reinforced composite skew plates. They used IMLS approximation and Ritz method for solving the problem. At the end of mentioned paper they obtained mode shapes and natural frequencies of plate in terms of thickness-to width ratio and skew angle in different kinds of CNTs distributions. Malekzadeh [9] worked on the low velocity impact of FG-CNT composite skew plates. In this research, deflection of plate under the impact force formulated based on the FSDT and finite ele-