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Nonlinear Vibrations of Two-Span Composite Laminated Plates with Equal and Unequal Subspan Lengths

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Abstract. The nonlinear transverse vibrations of ordered and disordered two-dimensional (2D) two-span composite laminated plates are studied. Based on the von Karman's large deformation theory, the equations of motion of each-span composite laminated plate are formulated using Hamilton's principle, and the partial differential equations are discretized into nonlinear ordinary ones through the Galerkin's method. The primary resonance and 1/3 sub-harmonic resonance are investigated by using the method of multiple scales. The amplitude-frequency relations of the steady-state responses and their stability analyses in each kind of resonance are carried out. The effects of the disorder ratio and ply angle on the two different resonances are analyzed. From the numerical results, it can be concluded that disorder in the length of the two-span 2D composite laminated plate will cause the nonlinear vibration localization phenomenon, and with the increase of the disorder ratio, the vibration localization phenomenon will become more obvious. Moreover, the amplitude-frequency curves for both primary resonance and 1/3 sub-harmonic resonance obtained by the present analytical method are compared with those by the numerical integration, and satisfactory precision can be obtained for engineering applications and the results certify the correctness of the present approximately analytical solutions.

AMS subject classifications: 70-08, 35Q72, 65M60

Key words: Ordered and disordered two-span composite laminated plates, nonlinear vibration localization, method of multiple scales, primary and 1/3 sub-harmonic resonances.

1 Introduction

Multi-span structures are important structural elements that are widely used in various

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engineering applications such as aeroplane panels, slabs in house construction, glass window panels and bridge decks. Vibration of multi-span beams and plates with internal line supports have been an intensive research focus from many researchers for several decades. However, most of them focused on the analysis of natural frequencies of free linear vibration, and the numerical approximate solutions or Levy solutions of free or forced linear vibration.

Veletsos and Newmark [1] calculated the natural frequencies of plates with internal line supports in one direction by employing the Holzer's method. Abramovich et al. [2] carried out the analysis on the vibration frequencies of multi-span non-symmetric composite beams using the exact element method considering the effects of rotary inertia and shear deformations and gave the mode shapes for the clamped-clamped boundary conditions. Wang and Lin [3] proposed the component method to study the free vibration of a multi-span Mindlin plate to a moving load and analyzed the orthogonality of any two distinct sets of the mode shape functions. They discussed the effects of span number, rotary inertia and transverse shear deformation on the critical velocity of the plates. Wang [4] investigated the effects of span member, rotary inertia and shear deformation on the maximum moment, maximum deflection and critical velocity of multi-span Timoshenko beams using the method of modal analysis.

Xiang and Wei [5] presented the exact solution for the vibration of multi-span rectangular Mindlin plates and obtained the exact vibration frequencies varying with the span ratios, number of spans and boundary conditions. Zhao et al. [6] introduced discrete singular convolution to solve the vibration of plates under complex and irregular internal support conditions. Xiang et al. [7] presented a Levy solution to investigate the vibration behavior of multi-span rectangular plates and studied the impact of the internal line supports on the vibration behavior by varying both the number of internal line supports and support positions. Xiang and Reddy [8] employed the levy type solution, state-space technique and first order shear deformation plate theory to study the natural vibration of rectangular plate with an internal line hinge. Lv et al. [9] investigated the influence of location of internal line supports on the natural frequencies of multi-span plates with large aspect ratios based on the classical Kirchhoff plate theory.

Mikata [10] mathematically proved the orthogonality condition of the eigenfunctions for multi-span beams of variable cross-section and obtained an exact closed-form solution as an application of the general orthogonality condition. Song and Li [11] investigated the influences of the disorder degree on the vibration localization and aeroelastic properties of the two-span panels in supersonic airflow. Li and Song [12] studied the vibration properties of nearly periodic two-span beams and used the velocity feedback control algorithm to design the active controller.

The nonlinear vibration characteristics in various engineering structures have also attracted numerous researchers' attention. Özkaya et al. [13, 14] investigated the nonlinear transverse vibrations and 3:1 internal resonance of a beam or a tensional beam on multiple supports applying the method of multiple scales. Davtabal et al. [15] constructed an electromechanical device to investigate the frequency-dependent vibrations of a