European Journal of Mechanics A/Solids 46 (2014) 60–71

Contents lists available at ScienceDirect

European Journal of Mechanics A/Solids

journal homepage: www.elsevier.com/locate/ejmsol

Nonlinear response of imperfect eccentrically stiffened FGM cylindrical panels on elastic foundation subjected to mechanical loads

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ARTICLE INFO

Article history:
Received 23 November 2013
Accepted 9 February 2014
Available online 18 February 2014

Keywords:
Nonlinear response
Eccentrically stiffened cylindrical panels
Elastic foundations

ABSTRACT

In the present paper, the nonlinear response of eccentrically stiffened FGM cylindrical panels on elastic foundation subjected to mechanical loads is presented. Material properties are graded in the thickness direction of the FGM panel according to a simple power law distribution. By applying Bubnov-Galerkin method, the Lekhnitsky smeared stiffeners technique with Pasternak type elastic foundation and stress function, explicit relations of load-deflection curves for simply supported eccentrically stiffened FGM panels are determined. Numerical results are given for evaluate effects of material and geometrical properties, elastic foundation and eccentrically outside stiffeners on the buckling and postbuckling of the FGM panels. The obtained results are validated by comparing with those in the literature.

1. Introduction

Flat and curved panels are important components of space structures and nuclear reactors. The static behavior of panels attracts special attention of a lot of authors in the world. Kabir and Chaudhur (1993) presented a direct Fourier approach for the analysis of thin finite-dimensional cylindrical shells. Alijani and Aghdam (2009), by applying the extended Kantorovich method, given a semi-analytical solution for stress analysis of moderately thick laminated cylindrical panels with various boundary conditions. Dennis et al. (1994), Yamada and Croll (1989) investigated instability, buckling behaviors of pressure loaded cylindrical panels. Shahraki et al. (2013) obtained nonlinear buckling analysis of laminated composite curved panels constrained by Winkler tensionless foundation. The study involving postbuckling of laminated cylindrical panels loaded by improved arc-length method can be found in the paper of Kweon and Hong (1994).

Functionally Graded Materials (FGMs) are microscopically inhomogeneous made from a mixture of metal and ceramic, and its mechanical properties vary smoothly and continuously from one surface to the other. Functionally graded structures such as cylindrical panels and cylindrical shells in recent years, play the important part in the modern industries. Therefore, researchers on stability problems of FGMs structures have received considerable attention. Regarding to the static stability of FGM shells, Yang et al. (2006) presented investigations on thermo-mechanical postbuckling of FGM cylindrical panels with temperature-dependent properties. Sofiyev (2005) studied the stability of compositionally graded ceramic-metal cylindrical shells under periodic axial impulsive loading. Closed-form solutions of free-vibration problems of simply supported multilayered shells made of functionally graded material have been examined by Cinefra et al. (2010a). Cinefra et al. (2010b) also considered the thermo-mechanical analysis of a simply supported functionally graded shell. Using the first-order shear deformation shell theory and von Karman strains, Liew et al. (2012) investigated post-buckling responses of functionally graded cylindrical shells under axial compression and thermal loads. Li and Batra (2006) determined critical compressive loads for hybrid cylindrical shells with FGM between layer. Elasticity solution is presented in Javanbakht et al. (2011) for finitely long, simply-supported, functionally graded shallow and non-shallow shell panel with two piezoelectric layers under pressure and electrostatic excitation. Some investigations on postbuckling of FGM cylindrical panels and cylindrical shells subjected to axial loading or pressure loading in thermal environments are presented by Shen (2002), Shen and Noda (2005). Recently, Shen and Wang (2014) focused on the large amplitude vibration behavior of a shear deformable FGM cylindrical panel resting on elastic foundations in thermal environments. Alibeigloo (2014) studied free vibration behavior of functionally graded carbon nanotube-reinforced composite cylindrical panel embedded in piezoelectric layers with simply supported boundary conditions is investigated by using three-dimensional theory of elasticity. He et al. (2010), Alibeigloo and Chen, 2010 published the results on the three-

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http://dx.doi.org/10.1016/j.euromechsol.2014.02.005
0997-7538/

dimensional elasticity solution for static analysis of a functionally graded material cylindrical panel with simply supported edges. Duc and Tung (2010a, 2010b) investigated the nonlinear response of thin and moderately thick FGM cylindrical panels subjected to mechanical and thermo-mechanical loads. In recent years, the investigation of nonlinear stability of FGM structures on elastic foundations takes much attention. In spite of practical importance and increasing use of FGM structures, investigations on the effects of elastic media on the response of FGM plates and shells are comparatively scarce. Tung (2013) has studied the postbuckling behavior of FGM cylindrical panels with tangential edge constraints and resting on elastic foundations (without stiffeners). Duc and Quan (2013) researched the nonlinear postbuckling of imperfect eccentrically stiffened P-FGM double curved thin shallow shells on elastic foundation in thermal environments.

For FGM structures, many researches focused on nonlinear stability of un-stiffened plates and shells. However, the investigation on static and dynamic of reinforced functionally graded plates and shells by outside stiffeners have received comparatively little attention, this may be because of their inherent complexity. Najafizadeh et al. (2009) used both analytical and finite element methods to obtain the critical loads of FGM stiffened cylindrical shells under axial compression. Bich et al. (2011) studied the nonlinear static postbuckling of eccentrically stiffened thin ES-FGM plates and shallow shells. The nonlinear dynamical analysis of eccentrically stiffened functionally graded cylindrical panels based on classical theory is investigated by Bich et al. (2012). Duc (2013) investigated nonlinear dynamic response of imperfect eccentrically stiffened doubly curved ESP-FGM shallow shells on elastic foundations. There is no investigation on the nonlinear static stability of FGM cylindrical panel with stiffeners on elastic foundation.

This paper considered the nonlinear postbuckling for imperfect eccentrically stiffened FGM cylindrical panels on elastic foundations using a simple power-law distribution under mechanical loads (ESP-FGM). Using Bubnov-Galerkin method and using stress function, the effects of geometrical and material properties, elastic foundation and eccentrically outside stiffeners on the nonlinear response of the imperfect eccentrically stiffened ESP-FGM cylindrical panels are analyzed and discussed.

2. Eccentrically stiffened FGM cylindrical panels on elastic foundations

Consider an eccentrically stiffened functionally graded cylindrical panel as shown in Fig. 1. The radii of curvature, thickness, axial length and length of the panel are R, h, a and b, respectively.

For ES-FGM panel, the volume fractions of constituents are assumed to vary through the thickness according to the following power law distribution (ESP-FGM)

$$V_m(z) = \left(\frac{2z+h}{2h}\right)^N, \quad V_c(z) = 1 - V_m(z), \tag{1}$$

where N is volume fraction index ($0 \le N < \infty$).

Material coefficient $E(z)$ is obtained as

$$E(z) = E_c + E_{mc}\left(\frac{2z+h}{2h}\right)^N, \tag{2}$$

where

$$E_{mc} = E_m - E_c. \tag{3}$$

The values with subscripts m and c belong to metal and ceramic, respectively. It is evident from Eqs. (2) and (3) that the upper surface of the panel ($z = -h/2$) is ceramic-rich, while the lower surface ($z = h/2$) is metal-rich, and the percentage of ceramic constituent in the panel is enhanced when N increases.

The Poisson ratio ν is assumed to be constant ($\nu = \text{const}$).

Assume that the panel is reinforced by eccentrically longitudinal and transversal homogeneous stiffeners with the elastic modulus E_0. In order to provide the continuity between the shell and stiffeners, suppose that stiffeners are made of full metal ($E_0 = E_m$) if putting them at the metal-rich side of the panel, and conversely full ceramic ones ($E_0 = E_c$) at the ceramic-rich side of the panel (Duc, 2013; Duc and Quan, 2013; Bich et al., 2011, 2012).

The panel–foundation interaction is represented by Pasternak model as

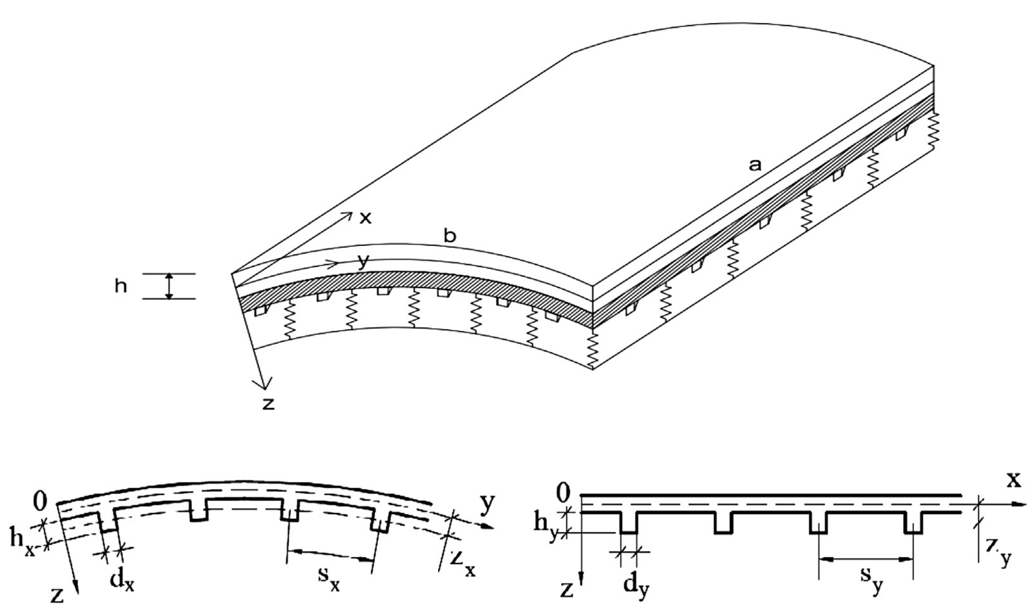

Fig. 1. Configuration of an eccentrically stiffened cylindrical panel (ES-FGM panel) on elastic foundations.