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Non-linear buckling behavior of FGM truncated conical shells subjected to axial load

A.H. Sofiyev *

Department of Civil Engineering of Suleyman Demirel University, Isparta, Turkey

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ABSTRACT

In this study, the non-linear buckling behavior of truncated conical shells made of functionally graded materials (FGMs), subject to a uniform axial compressive load, has been investigated using the large deformation theory with von the Karman–Donnell-type of kinematic non-linearity. The material properties of functionally graded shells are assumed to vary continuously through the thickness of the shell. The variation of properties followed an arbitrary distribution in terms of the volume fractions of the constituents. The fundamental relations, the modified Donnell type non-linear stability and compatibility equations of functionally graded truncated conical shells are obtained and are solved by superposition and Galerkin methods and the upper and lower critical axial loads have been found analytically. Finally, the influences of the compositional profile variations and the variation of the shell geometry on the upper and lower critical axial loads are investigated. Comparing the results of this study with those in the literature validates the present analysis.

1. Introduction

The conical shells are often used as transition elements between cylinders of different diameters and/or end closures and sometimes as stand-alone components in various engineering applications such as tanks and pressure vessels, missiles and spacecraft, submarines, nuclear reactors, jet nozzles and such other civil, chemical, mechanical, marine and aerospace engineering structures. Studies of the linear buckling of homogenous conical shells under axial load have received its due importance in the literature [1–7]. All these solutions are based on the small deflection theory. In the study of the stability of a thin-walled cone the prebuckling deformation may be of the order of the thickness. Thus, a non-linear theory is probably necessary for such investigations. A review of the literature shows that few studies have been carried out to investigate the non-linear buckling of homogeneous conical shells. This may be attributed to the inherent complexity of basic equations of the conical shell in curvilinear coordinates that are a system of non-linear partial differential equations [8–13].

Functionally graded materials (FGMs) are a new type of materials with continuously varied microstructure, which lead to the continuous variation of physical and mechanical properties through the thickness. This gradual variation of the properties compensates for the adverse effects of discontinuities in layered composites especially in high temperature environments. So that, these materials are appropriate for applications involving high thermal gradients such as aerospace structures [14]. The concept of FGM, initially developed for super heat resistant materials to be used in space planes or nuclear fusion reactors, is now of interest to designers of functional materials for energy conversion [15], for joining dissimilar materials [16], sensors and thermogenerators [17].

The investigations on the static/dynamic characteristics of FGM shell structures due to their evident importance in practical applications have recently attracted the attention of many researchers. Most of the researches have been limited to the linear stability and vibration analyses of FGM cylindrical [18–23] and FGM conical shells [24–27].

Previous studies show that geometric non-linearity plays a significant role in the buckling behavior of homogenous shells. As the geometrical non-linearity is taken into account in the governing equations of FGM shells, unpredictable behaviors may occur. Therefore, it is of vital importance to study the non-linear response of inhomogeneous materials such as functionally graded shells. Shen [28] presented a post-buckling analysis for a functionally graded cylindrical thin shell of finite length subjected to external pressure and in thermal environments. Woo et al. [29,30] provided an analytic solution for the coupled large deflection and postbuckling behavior of plates and shallow cylindrical shells made of FGMs under transverse and edge compressive loads, respectively, and a temperature field. Yang et al. [31] studied

* Tel.: +90 246 211 1195; fax: +90 246 2370859.
E-mail address: asofiyev@mmf.sdu.edu.tr

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