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Combined effects of elastic foundations and shear stresses on the stability behavior of functionally graded truncated conical shells subjected to uniform external pressures

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ABSTRACT

According to the framework of the Donnell's shell theory the stability behavior of functionally graded (FG) truncated conical shell interacting with two-parameter elastic foundations within the shear deformation theory (SDT) is investigated. The major goal of this research was to obtain a closed form of the solution for critical external pressures associated with the problem outlined above. The basic equations of FG truncated conical shell shells subjected to the external pressures are derived within the SDT. By using the Galerkin method to resulting basic equations are obtained the expressions for critical hydrostatic and lateral pressures of FG truncated conical shell interacting with two-parameter elastic foundations within the SDT. In particular, similar expressions within the classical shell theory (CST) are obtained, also. Comparison the current results and those available in the literature demonstrates the availability and accuracy of solutions. Finally, the calculation and presentation of the effects of many parameters included in the analysis conclude the goals to be reached in the study.

1. Introduction

A functionally graded material (FGM) is a composite material consisting of two or more phases in which the volume fractions of the constituents change so that the composition, microstructure and properties vary gradually along one direction [1]. Designing FGMs allows manipulation of many material properties or new functions. Various production methods are available for manufacturing graded structures such as casing, deposition, laser cladding, combustion synthesis and powder metallurgy that found in the studies of Kieback et al. [2] and Hong et al. [3].

The study on design, manufacture, applications and techniques of FGMs can be found in the study of Miyamoto et al. [4]. Modeling, analysis and detailed review on the stability performance of FGM shells are given in the book of Shen [5].

In recent years, functionally graded (FG) truncated conical shells are being used as structural components in modern industries of different engineering fields such as aerospace, mechanical, civil and nuclear engineering. In order to use them effectively and successfully, a good understanding of stability and vibration of FG conical shells is necessary. A number of analytical and numerical studies have been conducted on the stability analysis of unconstrained FG conical shells within the CST [6–12].

The increasing use of shell structures has motivated great interest in developing various shell theories and computational approaches for analyzing their stability and vibration behaviors [13,14].

Shear deformation theories (SDTs) eliminate the deficiency of the CST considering shear stresses of FG conical shells. The influences of shear stresses are quite significant in the stability behavior of FG conical shells. In recent decades, attempts have been made to the stability and vibration analysis of FG conical shells within the SDTs [15–23].

In some practical applications, conical shells made of different materials are in contact with soils or other solids. One-and two-parameter models for the soil underneath the shell are introduced to model the foundation. The Pasternak-type model or two-parameter elastic foundations model is widely adopted to describe the mechanical behavior of elastic foundations, and the well known Winkler model or one-parameter elastic foundation model is one of its special cases [24].

Investigations on the stability characteristics of FGM shells resting on elastic foundations are identified as an interesting field of study in recent years. As a result, many studies are carried out on the analysis of shell's behavior embedded in soil simulated with two elastic parameters through the Winkler–Pasternak (WP)

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model. Among them, the thermal vibration, buckling and dynamic stability of FG cylindrical shells embedded in an elastic medium within the FSDT were studied by Sheng and Wang [25]. The postbuckling behaviors of shear deformable FGM cylindrical shells surrounded by an elastic medium were studied by Shen [26]. The buckling of FG cylindrical shells under combined external pressure and axial compression was investigated by Khazaeinejad et al. [27]. The solution of buckling problem of FGM truncated conical shells subjected to axial compressive load and resting on Winkler–Pasternak foundations within the CST was presented by Sofiyev [28]. The mechanical buckling of functionally graded material cylindrical shells surrounded by Pasternak elastic foundation was investigated Bagherizadeh et al. [29]. Analysis of FGM and laminated doubly-curved and degenerate shells with a posteriori stress and strain recovery and resting on nonlinear elastic foundations using a GDQ were examined by Tornabene and Reddy [30]. Free vibration analysis of FGM cylindrical shell partially resting on the Pasternak elastic foundation with an oblique edge was investigated by Kim [31]. The postbuckling of FGM cylindrical panels subjected to combined loadings and resting on elastic foundations in thermal environments were investigated by Shen and Wang [32]. Free vibration analysis of 2D-FGM truncated conical shell resting on Winkler–Pasternak foundations based on FSDT using differential quadrature method was studied by Asanjarani et al. [33]. The buckling analysis of FGM toroidal shell segments filled inside by an elastic medium under external pressure loads including temperature effects is studied by Bich et al. [34].

To the best of authors' knowledge and considering the review of literature, it is revealed that the closed form solution of the stability of FG truncated conical shells interacting with two-parameter elastic foundations and subjected to external pressures within the SDT has not received due attention. The major goal of this study was to obtain a closed form solution for the critical external pressures associated with the problem outlined above. The comparison current results and those available in the literature demonstrate the availability and accuracy of solutions. Finally, the effects of many parameters such as elastic foundations, shear stresses, FG profiles and truncated conical shell characteristics on the critical lateral and hydrostatic pressures within CST and SDT are investigated in detail.

2. Formulation of the problem

2.1. Modeling of elastic foundations and external pressures

The FG truncated conical shell resting on the two-parameter elastic foundation is shown in Fig. 1, wherein a coordinate system $OS\theta\zeta$ is established on the reference surface of the truncated conical shell. The length of truncated conical shell denoted by L, the shell thickness by h, the radii at the two ends by R_1 and R_2 ($R_2 > R_1$), respectively, and the distances from vertex to the small and large edges by S_1 and S_2, respectively.

The reaction of the two-parameter elastic foundation is assumed to be

$$N_0 = K_w w - K_p\left(\frac{\partial^2 w}{\partial S^2} + \frac{1}{S}\frac{\partial w}{\partial S} + \frac{1}{S^2}\frac{\partial^2 w}{\partial \theta_1^2}\right) \tag{1}$$

where N_0 is the force per unit area, K_w (N/m^3) is the spring parameter of the one-parameter elastic foundation (or Winkler foundation parameter) and K_p (N/m) is the shear parameter of the two-parameter elastic foundations (or Pasternak type elastic foundation), $\theta_1 = \theta \sin\gamma$, w is the displacement of the middle surface in the normal direction, positive towards the axis of the cone and assumed to be much smaller than the thickness. Note that by setting $K_p = 0$, the Pasternak model becomes that of the Winkler foundation model (Sun and Huang [24]).

The FG truncated conical shell is subjected to the uniform external pressures:

$$N_S^0 = -0.5SP_1 \tan\gamma,\ N_\theta^0 = -SP_2 \tan\gamma,\ N_{S\theta}^0 = 0 \tag{2}$$

where N_S^0, N_θ^0 and $N_{S\theta}^0$ are the membrane forces for the condition with zero initial moments. The external pressures turn into the lateral pressure, as $P_1 = 0$, $P_2 = P_L$ and the external pressures turn into the hydrostatic pressure, as $P_1 = P_2 = P_H$.

2.2. Modeling of FGM conical shell

The truncated conical shell made of functionally graded material, which consists of a mixture of metal and ceramics. The mechanical properties of FGMs are determined from the volume fraction of the material constituents. The effective material properties of the FGM (like Young's modulus and Poisson's ratio) are usually assumed to be given by the rule of mixture of materials

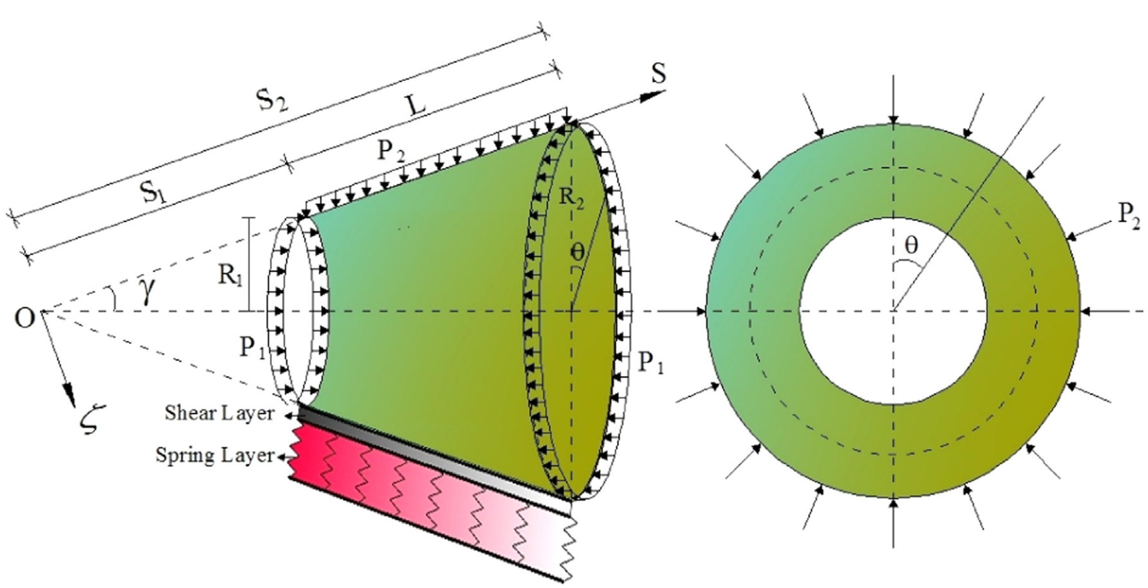

Fig. 1. Geometry of FG truncated conical shell interacting with two-parameter elastic foundations subjected to external pressures.