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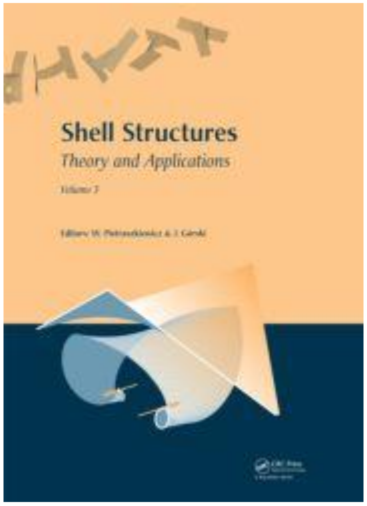

Shell Structures: Theory and Application

Published: September 18, 2013 by CRC Press
Content: 600 Pages
Editor(s): Wojciech Pietraszkiewicz, Jaroslaw Gorski

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Shell Structures: Theory and Application

Chapter 7. Laminated smart shell structures; theory and analysis

T . M . B . Albarodyand H . H . Al-Kayiem

Citation Information
Shell Structures: Theory and Application
Edited by Wojciech Pietraszkiewicz and Jarosław Górski
CRC Press 2013
Pages 49–52
Print ISBN: 978-1-138-00082-7
eBook ISBN: 978-1-4822-2908-0
DOI: 10.1201/b15684-10

Shell Structures: Theory and Applications, Vol. 3 – Pietraszkiewicz & Górski (Eds)

Laminated smart shell structures; theory and analysis

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ABSTRACT: Modeling of shells integrated with smart lamina and taking account of thermo-magneto-electro-elastic fields represents a challenge to be formulated and solved. In the present work, analytical model is proposed based on Hamilton's variational principle linked with Gibbs free energy functions. The model is casted according to the first-order shear deformation shell theory. The exact solution is derived for linearly constitutive properties, simply supported, shallow shell having rectangular plane-form under static loadings. The effects of the material properties, lay-ups of the constituent layers, and shell parameters on the free vibration behavior are investigated and analyzed. The accurate treatment of thermal, magnetic, electric, and elastic energies that are taken into account in this smart shell yields rather sophisticated equations for magnetic inductions, electric displacements and stress resultants. Therefore, the introduced model is expected to provide a foundation to investigate the interactive effects among the thermal, magnetic, electric, and elastic fields in smart shell structures.

1 INTRODUCTION

A smart shell is a thin-walled solid structure integrated with piezoelectric, magnetostrictive and like materials. Smart materials are used to provide new features to shell structures used frequently in construction of spacecrafts and aerospace vehicles. In fact, the idea of developing adaptive structures is to create new properties that can be utilized in health monitoring, aside of the structures designed for load supporting capability.

Several accurate solutions have been found in the literature for multilayered piezoelectric and magnetostrictive plates. Some of them were found for special cases of Pan's analysis. Heyliger (1996) demonstrated the free vibration analysis of the simply supported (SS) and multilayered magneto-electro-elastic (MEE) plates under cylindrical bending. Then, Heyliger (2004a,b) studied two cases of the MEE plates subjected to static fields, one under cylindrical bending only and the other completely traction-free under surface potentials.

In this paper, an analytical model of the smart shell based on the first-order shear deformation (FOSD) theory is presented. We examine mathematically the interactive effects of the thermal, magnetic, electric and elastic fields on the vibration of the smart shell structures.

2 THEORETICAL FORMULATION

2.1 *Constitutive Relations*

The thermodynamic potential Q of a linear quasi-static and reversible system subjected to mechanical, electric, magnetic, and thermal influences can be approximated by:

$$\begin{aligned}2Q=&\varsigma_{ijkl}^{E,G,T}\varepsilon_{ij}\,\varepsilon_{kl}-\epsilon_{mn}^{S,G,T}\xi_m\,\xi_n-\mu_{pq}^{S,E,T}\chi_p\,\chi_q-\theta^{S,E,G}\,\tau^2\\&-2\varrho_{mkl}^{G,T}\varepsilon_{kl}\,\xi_m-2\kappa_{pkl}^{E,T}\varepsilon_{kl}\chi_p-2\lambda_{kl}^{E,G}\varepsilon_{kl}\tau\text{-}2\eta_{pn}^{S,T}\xi_n\,\chi_p\\&-2\rho_n^{S,G}\xi_n\,\tau\text{-}2\gamma_q^{S,E}\chi_q\,\tau,\end{aligned}\tag{1}$$

where Q is known as the Gibbs free energy. The constitutive relations are expressed formally as:

$$\begin{aligned}S_{ij}&=\left(\frac{\partial Q}{\partial\varepsilon_{kl}}\right)=[\varsigma_{ijkl}^{E,G,T}\varepsilon_{ij}-\varrho_{mkl}^{G,T}\xi_m-\kappa_{pkl}^{E,T}\chi_p-\lambda_{kl}^{E,G}\tau],\\E_k&=-\left(\frac{\partial Q}{\partial\xi_n}\right)=[\varrho_{ijn}^{G,T}\varepsilon_{ij}+\epsilon_{mn}^{S,G,T}\xi_m+\eta_{pn}^{S,T}\chi_p+\rho_n^{S,G}\tau],\\G_l&=-\left(\frac{\partial Q}{\partial\chi_q}\right)=[\kappa_{ijq}^{E,T}\varepsilon_{ij}+\eta_{mq}^{S,T}\xi_m+\mu_{pq}^{S,E,T}\chi_p+\gamma_q^{S,E}\tau],\\T&=-\left(\frac{\partial Q}{\partial\tau}\right)=[\lambda_{ij}^{E,G}\,\varepsilon_{ij}+\rho_m^{S,G}\xi_m+\gamma_p^{S,E}\chi_p+\theta^{S,E,G}\,\tau].\end{aligned}\tag{2}$$

2.2 *Kinematic relations*

According to the FOSD shell theory, the following representation of the 3D displacement, electric and magnetic potentials is postulated:

$$\begin{aligned}&u(\alpha,\beta,\zeta,t)=u_o(\alpha,\beta,t)+\zeta\psi_\alpha(\alpha,\beta,t),\\&v(\alpha,\beta,\zeta,t)=v_o(\alpha,\beta,t)+\zeta\psi_\beta(\alpha,\beta,t),\\&w(\alpha,\beta,\zeta,t)=w_o(\alpha,\beta,t),\\&\vartheta(\alpha,\beta,\zeta,t)=-\left(\vartheta_o(\alpha,\beta,t)+\zeta\vartheta_1(\alpha,\beta,t)\right),\\&\varphi(\alpha,\beta,\zeta,t)=-\left(\varphi_o(\alpha,\beta,t)+\zeta\varphi_1(\alpha,\beta,t)\right),\end{aligned}\tag{3}$$