Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 52(8) (2020) 545-548
DOI: 10.22060/mej.2019.15404.6115

Free Vibration Analysis of Doubly Curved Composite Sandwich Panels with Variable Thickness

M. Livani*, K. Malekzadehfard

Department of Aerospace Engineering, Aeronautical University of Shahid Sattari, Tehran, Iran2 Space Research Institute, Malek Ashtar University of Technology, Tehran, Iran

ABSTRACT: In this research, the free vibration analysis of doubly curved composite sandwich panels with variable thickness is studied using higher order sandwich panel theory. For the first time, considering different radii of curvatures of the face sheets in this paper, the thickness of the core is a function of plane coordinates (x,y). In addition, in the current model, the continuity conditions of the transverse shear stress, transverse normal stress and transverse normal stress gradient at the layer interfaces, as well as the conditions of zero transverse shear stresses on the upper and lower surfaces of the sandwich panel are satisfied, which is unique. The vertical displacement component of the face sheets is assumed as a quadratic one, while a cubic pattern is used for the in-plane displacement components of the face sheets and all displacement components of the core. The equations of motion and boundary conditions are derived using the Hamilton principle. The effects of some important parameters including composite layup sequences, length to width ratio, varying properties of the face sheets materials, Face sheet thicknesses ratio and varying materials of the face sheets were investigated. The results are validated by the latest results published in the literature.

Review History:

Received: 2018/12/08
Revised: 2019/04/22
Accepted: 2019/05/05
Available Online: 2019/05/10

Keywords:

Double curved sandwich panels
Higher order theory
Variable thickness
Free vibration
Hamilton principle

1- Introduction

Sandwich plates are widely used in many engineering applications such as aerospace, automobile, and shipbuilding because of their high strength and stiffness, low weight and durability. These plates are generally consisting of two stiff face sheets and a soft core, which are bonded together. Zhen and Wanji [1] applied a C0 type higher order equivalent single layer theory to investigate the bending analysis of composite sandwich plates subjected to the thermal and mechanical loadings. The continuity conditions of transverse shear stresses at interfaces and the conditions of zero transverse shear stresses on the upper and lower surfaces were considered. Biglari and Jafari [2] studied a three layer theory for the free vibration and bending analyses of open single curved sandwich structures. In their model, Donell's theory was applied for the face sheets. Ghavanloo and Fazelzadeh [3] using Novozhilov's linear shallow shell theory presented the free vibration analysis of simply supported doubly curved shallow shells. Livani et al. [4] studied the supersonic panel flutter of doubly curved composite sandwich panels with variable thicknesses under aerothermoelastic loading. In their model, the continuity conditions of the transverse shear stress, transverse normal stress, and transverse normal stress gradient at the layer interfaces, as well as the conditions of zero transverse shear stress on the upper and lower surfaces of the sandwich panel are satisfied.

In this paper, the free vibration analysis of doubly curved composite sandwich panels with variable thickness is studied using higher order sandwich panel theory.

2- Methodology

Consider a doubly curved composite sandwich panel which is composed of two composite laminated face sheets. The sandwich is composed of three layers: the top and bottom face sheets and the core layer. The panel is assumed to have the length of a and width of b, as shown in Fig. 1.

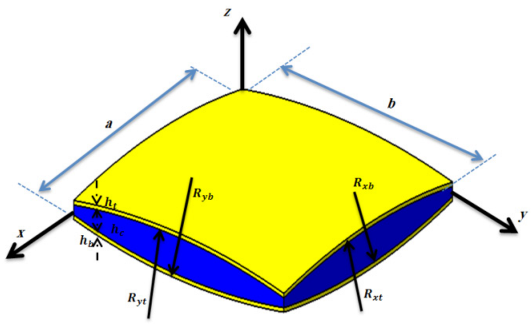

Fig. 1. The geometry of the studied doubly curved sandwich panel

The relation of the core thickness can be defined as follows:

$$h_c(x,y)=\frac{h_c^0}{2}+\frac{1}{2}\left(x-\frac{a}{2}\right)^2\left(\frac{1}{R_{xb}}-\frac{1}{R_{xt}}\right)+\frac{1}{2}\left(y-\frac{b}{2}\right)^2\left(\frac{1}{R_{yb}}-\frac{1}{R_{yt}}\right). \tag{1}$$

*Corresponding author's email: m.livani@ssau.ac.ir

where h_c^0 is the thickness of the core in the center of the panel. The displacement fields of the face sheets are based on model II of Frostig for the thick core, take a cubic pattern for the in-plane displacements and a quadratic one for the vertical ones and are read as [5]:

$$\begin{aligned} u_i(x,y,z_i,t) &= u_{0i}(x,y,t)+u_{1i}(x,y,t)z_i + \\ & u_{2i}(x,y,t)z_i^2+u_{3i}(x,y,t)z_i^3, \\ v_i(x,y,z_i,t) &= v_{0i}(x,y,t)+v_{1i}(x,y,t)z_i + \\ & v_{2i}(x,y,t)z_i^2+v_{3i}(x,y,t)z_i^3, \\ w_i(x,y,z_i,t) &= w_{0i}(x,y,t)+w_{1i}(x,y,t)z_i + \\ & w_{2i}(x,y,t)z_i^2 \quad ; \quad (i=t,b). \end{aligned} \tag{2}$$

where z_i is the vertical coordinate of each face-sheet (i = t, b) and is measured upward from the mid-plane of each face-sheet. Also, all displacement fields of the core are cubic polynomial functions as:

$$\begin{aligned} u_c(x,y,z_c,t) &= u_{0c}(x,y,t)+u_{1c}(x,y,t)z_c + \\ & u_{2c}(x,y,t)z_c^2+u_{3c}(x,y,t)z_c^3, \\ v_c(x,y,z_c,t) &= v_{0c}(x,y,t)+v_{1c}(x,y,t)z_c + \\ & v_{2c}(x,y,t)z_c^2+v_{3c}(x,y,t)z_c^3, \\ w_c(x,y,z_c,t) &= w_{0c}(x,y,t)+w_{1c}(x,y,t)z_c + \\ & w_{2c}(x,y,t)z_c^2+w_{3c}(x,y,t)z_c^3.. \end{aligned} \tag{3}$$

The compatibility conditions in this paper were perfect bonding between the face sheets and core, continuity conditions of the transverse shear stresses, transverse normal stress and transverse normal stress gradient at the layer interfaces and the conditions of zero transverse shear stresses on the upper and lower surfaces of the sandwich panel.
The equilibrium equations for the face sheets and core are derived using the Hamilton principle:

$$\int_0^t \delta L dt \equiv \int_0^t [\delta K - \delta U] dt = 0. \tag{3}$$

where δK and δU denote variation of kinetic energy and variation of strain energy, respectively.
The displacement fields based on double Fourier series for a composite sandwich panel satisfying the simply supported boundary conditions are assumed to be in the following forms($(i=0,1,2,3)$, $(l=0,1,2)$,$(j=t,b)$.):

$$\begin{bmatrix} u_{ij}(x,y,t) \\ v_{ij}(x,y,t) \\ w_{lj}(x,y,t) \\ u_{ic}(x,y,t) \\ v_{ic}(x,y,t) \\ w_{ic}(x,y,t) \end{bmatrix} = \sum_{n=1}^{N}\sum_{m=1}^{M} \begin{bmatrix} \bar{U}_{ij}^{mn}(t)\cos(\alpha_m x)\sin(\beta_n y) \\ \bar{V}_{ij}^{mn}(t)\sin(\alpha_m x)\cos(\beta_n y) \\ \bar{W}_{lj}^{mn}(t)\sin(\alpha_m x)\sin(\beta_n y) \\ \bar{U}_{ic}^{mn}(t)\cos(\alpha_m x)\sin(\beta_n y) \\ \bar{V}_{ic}^{mn}(t)\sin(\alpha_m x)\cos(\beta_n y) \\ \bar{W}_{ic}^{mn}(t)\sin(\alpha_m x)\sin(\beta_n y) \end{bmatrix} \tag{4}$$

3- Results and Discussion

In this section, the results of the free vibration analysis of doubly curved composite sandwich panels with variable thickness are presented.

3- 1- The effect of elastic modulus ratio

In this example, the effect of elastic modulus ratio of the face sheets of doubly curved composite sandwich panels with cross ply [0/90/0/90/0/Core/0/90/0/90/0], angle ply [45/-45/45/-45/45/Core/45/-45/45/-45/45] and [30/-30/30/-30/30/Core/30/-30/30/-30/30] stacking sequence on the dimensionless fundamental natural frequency is investigated. As can be seen from Fig. 2, by increasing the elastic modulus ratio, the dimensionless fundamental natural frequencies for three types of lay-ups are decreased.

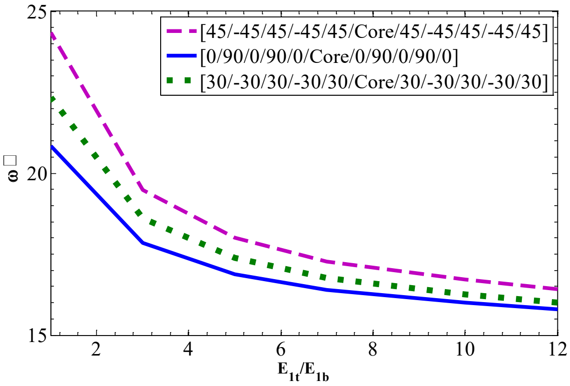

Figure 2. The effect of elastic modulus ratio of the face sheets on the dimensionless natural frequency

3- 2- The effect of panel length to width ratio

In this example, the effect of the panel length to width ratio on the dimensionless fundamental natural frequency with [0/90/0/Core/0/90/0], [45/-45/45/Core/45/-45/45] and [30/-30/30/Core/30/-30/30] stacking sequence on the dimensionless fundamental natural frequency is investigated. Fig. 3 demonstrates that by increasing the panel length to width ratio from 1 to 3, the dimensionless fundamental natural frequencies for three types of lay-ups are increased.

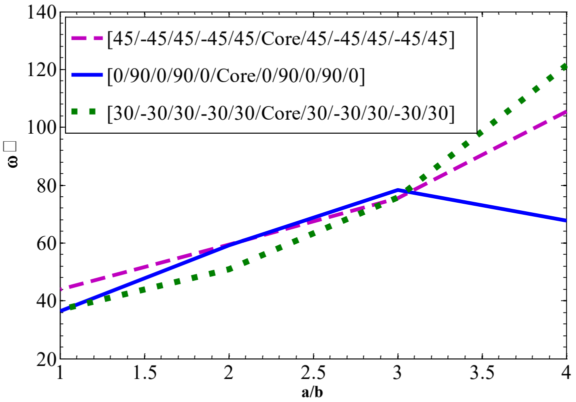

Fig. 3. The effect of panel length to width ratio on the dimensionless natural frequency

4- Conclusions

In this work, the free vibration analysis of doubly curved composite sandwich panels with variable thickness is studied based on a new improved higher order sandwich plate theory. The main conclusions are:

- The new higher-order sandwich panel theory used in this paper can accurately predict the dynamic behavior of doubly curved composite sandwich panels.
- With the increase of the effect of elastic modulus ratio, the dimensionless fundamental natural frequencies are decreased.
- By increasing the panel length to width ratio from 1 to 3, the dimensionless fundamental natural frequencies are increased.

5- References

[1] W. Zhen, C. Wanji, A C0-type higher-order theory for bending analysis of laminated composite and sandwich plates, Composite Structures, 92(3) (2010) 653-661.

[2] H. Biglari, A.A. Jafari, High-order free vibrations of doubly-curved sandwich panels with flexible core based on a refined three-layered theory, Composite Structures, 92(11) (2010) 2685-2694.

[3] E. Ghavanloo, S.A. Fazelzadeh, Free vibration analysis of orthotropic doubly-curved shallow shells based on the gradient elasticity, Composites Part B: Engineering, 45(1) (2013) 1448-1457.

[4] M. Livani, K. MalekzadehFard, S. Shokrollahi, Higher order flutter analysis of doubly curved sandwich panels with variable thicknesses under aerothermoelastic loading, Structural Engineering and Mechanics, 60(1) (2016) 1-19.

[5] Y. Frostig, O.T. Thomsen, High-order free vibrations of sandwich panels with a flexible core, International Journal of Solids Structures, 41 (2004) 1697-1724.