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Free vibration Analysisof soft-core Composite-Faced Sandwich Plates Using Three-Dimensional Finite Element Method

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Abstract

In this paper, natural frequencies of the sandwich plates with soft flexible core and composite face sheets are obtained. Three-Dimensional (3D) finite element method (FEM) is used for constructing and analyzing of the sandwich plates to obtain their natural frequencies. Continuity conditions for transverse shear stresses at the interfaces as well as transverse flexibility and transverse normal strain and stress of the core are considered.The effects of plate dimensions such as aspect ratio and thickness ratio are studied. Also, different boundary conditions such as all edges clamped (CCCC), all edges simply supported (SSSS) and combined boundary conditions including (CFCF)are applied to the sandwich plates. Comparison of the present results in special case with those of the accurate plate theories confirms the accuracy of the proposedmodel.

Keyword:Finite Element Method, Free Vibration Analysis, Sandwich Plate, Composite Face Sheets, Flexible Core.

1. Introduction

High strength-to-weight ratio, good ability in sound and energy absorbing, easy installation and low production cost of composite sandwich plates have been caused to they are widely used in various engineering applications such as building structures, naval and aerospace. In the field of civil engineering, the composite sandwich plates are used for constructing light-weight structures with high strength or stiffness to weight ratios. Composite sandwich plates are generally consisted of two thin high strength face sheets and a soft thick low strength core which are adhesively bonded together. In most cases, the core consisted of a foam polymer or honeycomb material, while composite laminates are commonly used as the face sheets.

To use these structures efficiently, an excellent understanding of their dynamical behavior is needed. To date, some papers have been published by researchers about vibration analysis and dynamic behavior of sandwich plates. There are three approaches that are presented to analyze the mechanical behavior of the sandwich plates and to predict their static and dynamic responses, which are: Three-dimensional elasticity approaches, equivalent single layer (ESL) theories and layerwise (LW) theories [1]. There are a few exact 3D elasticity solutions for vibration analysis of the composite sandwich plates [2, 3]. The first-order shear deformation theory was developed by Wang [4] for vibration analysis of sandwich plates, but the accuracy of solutions of this theory is strongly dependent on the shear correction factors. Kant and Swaminathan [5] and Matsunaga [6] presented the analytical solution for vibration analysis of sandwich plates using high-order ESL theories. Also based on Reddy's higher-order theory [7], a finite element model was proposed by Nayak et al. [8] to free vibration analysis of sandwich plates. In all ESL theories, the plate is analyzed as two-dimensional equivalent single layer. This in turn, results in continuous transverse strains, hence inter-laminar transverse stresses are obtained as discontinuous functions at the interfaces between the layers with different stiffness properties [1]. For thin laminated plates, this error can be neglected, but in thick laminated or sandwich plates, the ESL theories can give erroneous results. Also, two-dimensional (2D) treatment is not suitable for predicting the local behavior of sandwich plates such as delamination, matrix cracking or wrinkling.

To model the thick laminated plates in a better manner and to evaluate their local behaviors, Robbins and Reddy [9], proposed a layerwise plate theories. To enforce the continuity conditions of the transverse shear stresses, Carrera [10] developed the mixed layerwise theories. Later, to account for the continuity of the transverse stresses at the layer interfaces, Rao and Desai [11] developed a higher order mixed layerwise theory for vibration analysis of the sandwich plates. Carrera and

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Demasi [12] extended the mixed layerwise theory for sandwich plates. In these models, the number of unknowns depends on the number of the layers in composite and it becomes large as the number of the layers increases. In order to overcome the high computational times in the layer-wise theories, zigzag theories with linear or high-order local functions were proposed. Di Sciuva [13] proposed a refined zigzag plate theory in which the unknowns for the in-plane displacements at each layer were assumed in terms of those at the reference plane and the transverse displacement was assumed constant along the plate thickness. Ganapathi et al. [14] analyzed the nonlinear dynamic behavior of the sandwich plates using a third-order zigzag theory. Two theories for sandwich plates with mixed variational formulation for free vibration were developed by Kim [15].

Also, free vibration analysis of sandwich panels with a flexible core based on the high-order sandwich panel theory (HSAPT) were presented by Frostig and Thomsen [16].

Li and Liu [17] developed the third-order global-local plate theory (GLPT) based on the double superposition hypothesis, in which the transverse shear stresses can be determined directly from the governing equations without post-processing technique. Also, based on third-order GLPT, Zhen and Wanji [18] studied free vibration analysis of sandwich plates. Shariyat [19] introduced a high-order global–local theory that guarantees the continuity conditions of all displacements and transverse stress components and considered the transverse flexibility of sandwich plates. Recently, Kheirikhah et al. [20] presented natural vibration analysis of corrugated composite sandwich plates using 3D FEM.

In this paper, natural vibration behavior of the composite sandwich plates with soft core is studied. 3D FEM is used to model and analyze the natural vibration behavior of the rectangular sandwich plates. The 20-node isoparametric brick elements are used for face sheets and core modeling. Continuity conditions for transverse shear stresses at the interfaces as well as transverse flexibility and transverse normal strain and stress of the core are considered. The effects of boundary conditions and geometrical parameters on the natural frequencies of the plate are inspected.

2. Finite element modeling

A rectangular sandwich plate with the plane dimensions of $a \times b$ and total thickness of h is considered as shown in Fig. 1. The sandwich plates are composed of three layers: the upper and lower face sheets and the core layer. Each face sheet has the thickness of h_f while the thickness of the core is h_c. Two different materials are used in the modeling of the sandwich plate: soft orthotropic foam material as the core and the stiff orthotropic composite material as the face sheets. The properties of the used materials in this paper are shown in Table 1.

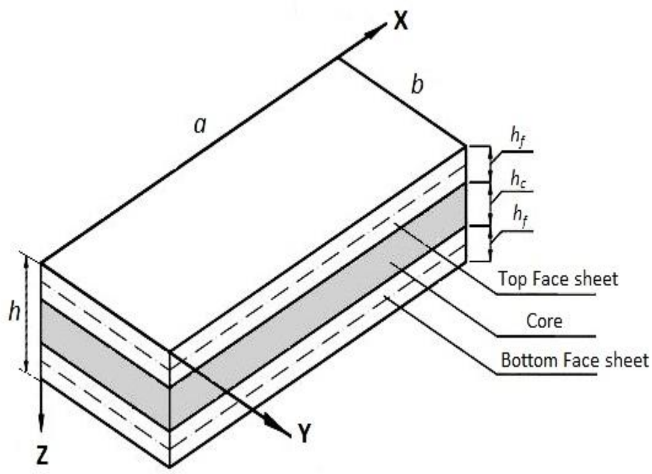

Fig. 1. Typical scheme of the sandwich plate

Table 1. Material properties of the core and the face sheets

Core	$E_x = E_z = 40$ MPa, $E_y = 500$ MPa, $\nu_{xy} = \nu_{xz} = \nu_{yz} = 0.25$ $G_x = G_{yz} = 60$ MPa , $G_{xz} = 16$ MPa , $\rho = 1300 kg/m^3$
Face sheet	$E_x = E_z = 10$ GPa, $E_z = 250$ GPa, $\nu_{xy} = \nu_{xz} = \nu_{yz} = 0.1$ $G_{xz} = G_{yz} = 0.5$ GPa , $G_{xy} = 0.2$ GPa , $\rho = 1800 kg/m^3$

FE model of the sandwich plate is constructed in the ANSYS 15.0 standard code area. For FE modeling, first, a temporary area of the sandwich plate cross section is constructed and meshed with 2D elements. Then, three zones of the temporary area are extruded with 20-node isoparametric brick elements Solid185 along the longitudinal direction using two different materials.

In this analysis, it is considered that the face sheets and the core bounded together perfectly. Therefore, after this step, the constructed three volumes are merged together. Hence, the continuity conditions for transverse shear stresses at the interfaces as well as the conditions of zero transverse shear stresses on the upper and lower surfaces of the plate are satisfied. Also, because of 3D modeling of the plate, the transverse flexibility and the transverse normal strain and stress of the core are considered. The complete FE model of a rectangular sandwich plate is shown in Fig. 2.

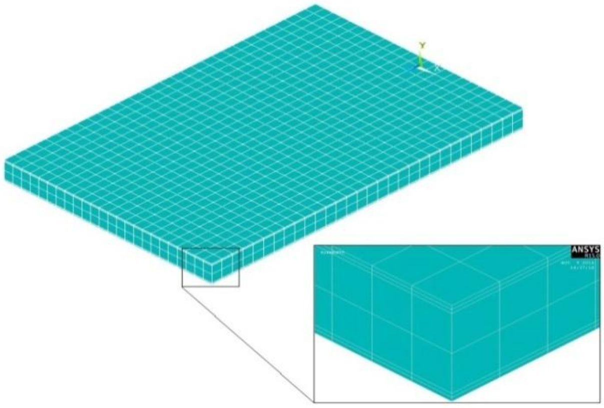

Fig. 2. The complete finite element model of a rectangular sandwich plate

An important factor which affects on the vibrational behavior of the sandwich plate is the boundary conditions which applied to the edges of the sandwich plate. In the present finite element modeling, various boundary conditions such as all edges clamped (CCCC), all edges simply supported (SSSS) and combined boundary condition (SCSC) are investigated.

Boundary conditions which are applied to the edges can be defined as follows:

Clamped Boundary Conditions:

$u = v = w = \theta_x = \theta_y = \theta_z = 0$ (1)

Simply supported Boundary Conditions:

For edges parallel to Y-axis ($x = 0, x = a$): $v = w = \theta_y = 0$ (2)

For edges parallel to X-axis ($y = 0, y = b$): $u = w = \theta_x = 0$ (3)

where *u*, *v* and *w* are displacements along *X*, *Y* and *Z* directions, respectively. Also, θ_x , θ_y and θ_z are rotations about *X*, *Y* and *Z* directions, respectively.

To obtain the natural frequencies of the sandwich plate, the *Modal* analysis in the ANSYS 15 standard code is performed for sandwich plates with different geometrical parameters and boundary conditions.

In this section, the natural frequencies of the composite sandwich plates for different geometrical parameters and boundary conditions are studied. Three geometrical parameters are investigated in this paper which are the aspect ratio (*b/a*), the thickness ratio (*h/a*) and the face sheet thickness ratio (h_f /*h*). The following non-dimensional frquency used in the present analysis are defined as:

$$\bar{\omega} = \frac{\omega_n a^2}{h}\left(\sqrt{\rho/E_2}\right)_f \qquad (4)$$

To verify the accuracy of the present FE modeling and analysis, the obtained results are compared with those of published results. A five-layer square sandwich plate (*a/b = 1*) with stack up $[0^\circ/90^\circ/Core/90^\circ/0^\circ]$ is analyzed. It has the total thickness of h in which the thickness of each face sheet is *0.1h* and the thickness of the core is *0.8h*. The simply support conditions are applied to the all edges of the plate (SSSS). The analysis is performed for two thickness ratios *(a/h = 100 and 10)*. The six non-dimensional natural frequencies are obtained from the present FE model and compared with those presented by Shariyat using high-order GLPT [19], Rao using mixed layerwise theory [11], Kant using high-order ESL theory [5] and Reddy using third-order theory [7] in Table 2. Also, the corresponding mode shapes of each case *(m,n)* are presented in the Table 2 in which *m* and *n* are the number of half sinusoidal wave along X and Y direction, respectively. It can be seen that the present results are in excellent agreement with high-order GLPT [19] and mixed layerwise theory [11]. Also, it can be seen that the ESL theories cannot able to calculate the natural frequencies of the thick sandwich plates with soft core because in these theories neglect the transverse shear and normal stress continuity condition at the layers interfaces and ignore the transverse flexibility. Fig. 3 shows the vibrational mode shapes of the square (*b/a = 1*) sandwich plates.

3. Results and discussions

Table 2. Non-dimensional natural frequencies of five-layer square sandwich plate [0/90/core/90/0]

a/h	Mode No	Present	Shariyat [19]	Rao [11]	Kant [5]	Reddy [7]
10	(1,1)	1.865641	1.90755	1.848	4.8594	7.0473
	(1,2)	3.330059	3.28515	3.2196	8.0187	11.9087
	(2,2)	4.372619	4.37354	4.2894	10.2966	15.2897
	(1,3)	5.492193	5.31929	5.2234	11.7381	17.3211
	(2,3)	6.351563	6.20419	6.0942	13.4706	19.8121
	(3,3)	7.92774	7.80781	7.6762	16.132	23.5067
100	(1,1)	12.44143	12.0645	11.9401	15.5093	15.9521
	(1,2)	24.75823	23.7158	23.4017	39.0293	42.2271
	(2,2)	31.74535	31.3844	30.9432	54.7618	60.1272
	(1,3)	38.23798	36.7314	36.1434	72.7572	83.9982
	(2,3)	43.13799	42.1218	41.4475	83.4412	96.3132
	(3,3)	50.83942	50.6149	49.7622	105.3781	124.2047

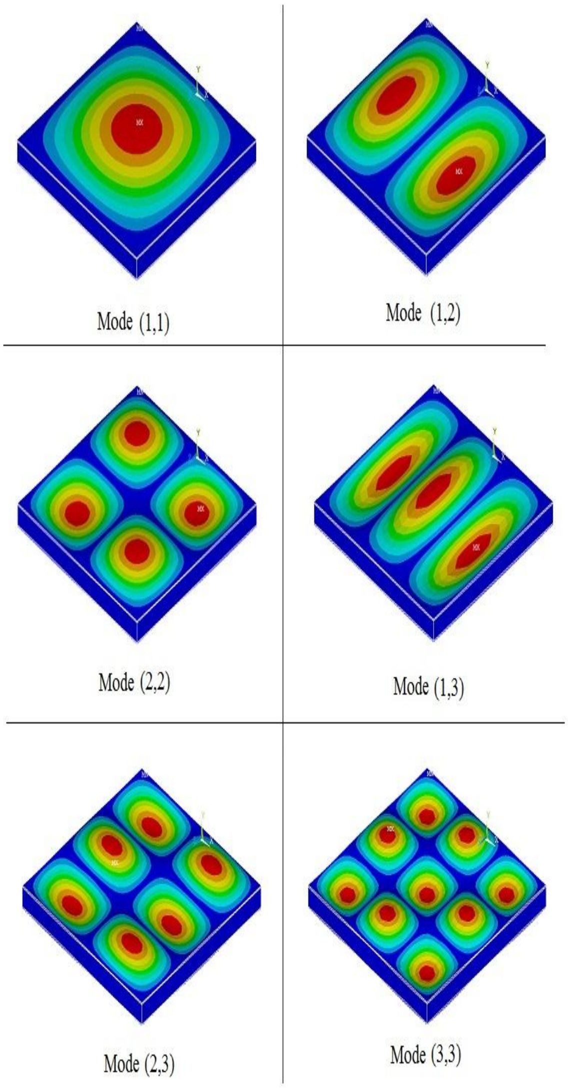

Fig. 3. Some vibrational mode shapes of the square sandwich plate

Fig. 4 shows the variation of the natural frequencies of the first five mode shape of the sandwich plate versus its thickness ratio. The analysis is performed for different thickness ratios (*a/h = 5, 10, 20, 50 and 100*). The sandwich plate is assumed to be square (*b/a = 1*) and its face sheet thickness ratio is considered *ht /h = 0.1*. Also, all edges of the plate is considered to be simply supported (SSSS). It can be seen that the natural frequencies increase with increase in thickness ratio (*h /a*), because the flexural rigidity of the plate increase with increase in thickness ratio.

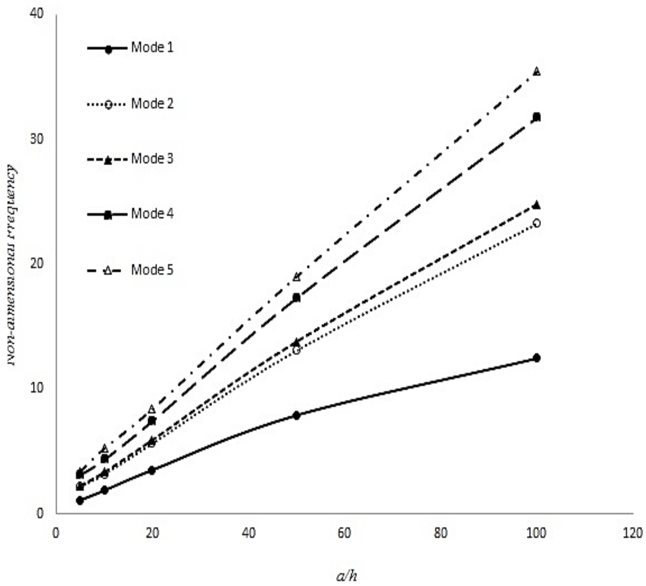

Fig. 4. First five natural frequency of sandwich plate versus thickness ratio

Fig. 5 shows the variation of the natural frequencies of the first five mode shape of the sandwich plate versus plate's aspect ratio. The analysis is performed for different aspect ratios (*b/a = 0.5, 1, 2, 3, 4 and 5*). The thickness ratio and face sheet thickness ratio are considered to be constant (*h/a = 0.05, ht /h = 0.1*). All edges of the plate is considered to be simply supported (SSSS). Obtained results show that the natural frequencies decrease with increase in aspect ratio.

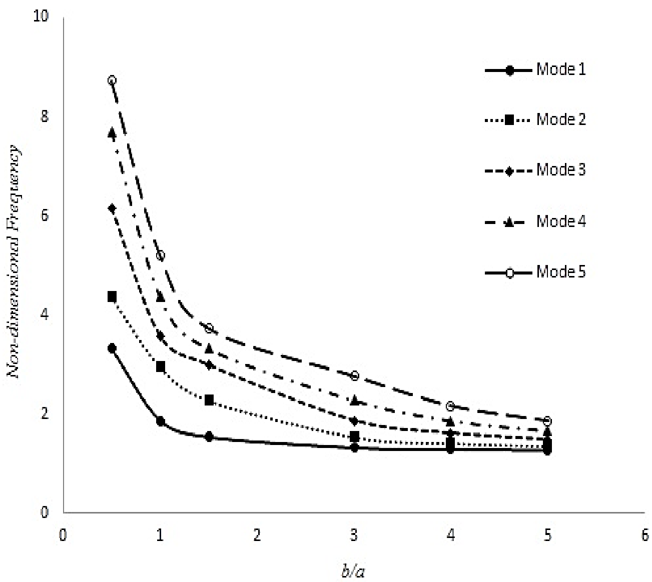

Fig. 5 Natural frequency of sandwich plate versus aspect ratio

Another important factor which affects the natural vibration behavior of the sandwich plate is the boundary conditions applied to the edges of the sandwich plate. In the present finite element modeling, three types of boundary conditions, all edges clamped (CCCC), all edges simply supported (SSSS) and two edges clamed (CFCF) are investigated. The variation of the first natural frequencies of the sandwich plate with above boundary conditions is shown in Table 3. The sandwich plate is assumed to be square (*b/a = 1*) and its face sheet thickness ratio is considered *ht /h = 0.1*. It can be seen that the sandwich plates with CCCC and SSSS boundary conditions have the largest and smallest natural frequencies for all thickness ratios, respectively.

Table 3. Non-dimensional natural frequencies of five-layer square sandwich plate with different boundary conditions

MODE NO.	BUNDARY CONDITION		
	SSSS	CFCF	CCCC
1	1.865641	2.100186	2.326306
2	3.201204	3.285695	3.947919
3	3.330059	4.020148	4.143819
4	4.372619	4.933976	5.383775
5	5.206068	5.121826	6.323648

4. Conclusion

In this paper, a three-Dimensional finite element method was employed for natural vibration analyzing of the sandwich plates with flexible core and composite face sheets. Comparison between obtained results and those of published results, verified the accuracy of the present FE modeling and analysis.

It can be concluded from the obtained results that the natural frequencies increase with increase in thickness ratio but decrease with increase in aspect ratio. Also, obtained results indicated that boundary conditions affect on natural frequencies of sandwich plates, significantly and plates with CCCC boundary conditions have the largest natural frequencies.

5. References

[1] Reddy, J. N. (2004). Mechanics of Laminated Composite Plates and Shells, Theory and Analysis. 2nd Edition, CRC Press, New York.

[2] Noor, A.K. (1973). Free vibration of multilayered composite plates. AIAA J, 11, 1038–1039.

[3] Noor, A.K., Burton, W.S. (1989). Stress and free vibration analysis of multilayered composite plates. ComputStruct, 11, 183–204.

[4] Wang, C.M. (1996). Vibration frequencies of simply-supported polygonal sandwich plates via Kirchhoff solution. Journal of Sound Vibration, 190, 255–260.

[5] Kant, T., Swaminathan, K. (2001). Analytical solutions for free vibration of laminated composite and sandwich plates based on a higher order refined theory. J. Composite Structures, 53(4), 73-85.

[6] Matsunaga, H. (2002). Assessment of a global higher-order deformation theory for laminated composite and sandwich plates. J. Composite Structures, 56(3), 279-291.

[7] Reddy, J. N. (1987). A refined nonlinear theory of plates with transverse shear deformation. J. Solids and Structures, 20(9), 881-896.

[8] Nayak, A.K., Moy, S.S.J., Shenoi, R.A. (2002). Free vibration analysis of composite sandwich plates based on Reddy's higher-order theory. Composites: Part B, 33, 505–519.

[9] Robbins, D. H. and Reddy, J. N. (1993). Modeling of thick composites using a layerwise laminate theory. J. Numerical Methods in Engineering, 36(4), 665-677.

[10] Carrera, E. (1998). Mixed layer-wise models for multilayered plates analysis. J. Composite Structures, 43(1), 57-70.

[11] Rao, M. K., Desai, Y. M. (2004). Analytical solutions for vibrations of laminated and sandwich plates using mixed theory. J. Composite Structures, 63(3-4), 361–373.

[12] Carrera, E., Demasi, L. (2003). Two benchmarks to assess two-dimensional theories of sandwich composite plates. J. AIAA, 41(7), 1356–1362.

[13] Di Sciuva, M. (1986). Bending, vibration and bucking of simply-supported thick multilayered orthotropic plates: an evaluation of a new displacement model. J. Sound and Vibration, 105, 425–442.

[14] Ganapathi, M., Patel, B.P., Makhecha, D.P. (2004). Nonlinear dynamic analysis of thick composite/sandwich laminates using an accurate higher-order theory. Composites: Part B engineering, 35(4), 345–355.

[15] Kim, J.S. (2007). Free vibration of laminated and sandwich plates using enhanced plate theories", J Sound Vib, 308, 268–86.

[16] Frostig, Y., Thomsen, O.T. (2004). High-order free vibration of sandwich panels with a flexible core. Int J Solids Struct, 41, 1697–724.

[17] Li, X., Liu, D. (1997). Generalized laminate theories based on double superposition hypothesis. J. Numerical Methods in Biomedical Engineering, 40 (7), 1197–1212.

[18] Zhen, W., Wanji, C. (2006). Free vibration of laminated composite and sandwich plates using global–local higher-order theory. Journal of Sound and Vibration, 298, 333–349.

[19] Shariyat, M. (2010). A generalized global–local high-order theory for bending and vibration analyses of sandwich plates subjected to thermo-mechanical loads. J. Mechanical Sciences, 52(3), 495-514.

[20] Kheirikhah, M. M., Babaghasabha, V., NaeimiAbkenari, A., Edalat, M. E. (2012). Natural Vibration Analysis of Soft Core Corrugated Sandwich Plates Using Three-Dimensional Finite Element Method. Mechanics and Properties of Composed Materials and Structures, Advanced Structured Materials, Springer-Verlag Berlin Heidelberg, 31, 163-174.