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Analysis of Laminated Composite Structures under Free Vibration Conditions using ABAQUS/CAE

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Abstract

Laminated sandwich structures with soft core are finding a number of applications now a days due to their excellent properties such as light weight, high stiffness etc. When using these materials as structural components, it is essential to analyze them under static, free vibration and buckling conditions. In this paper, an attempt is carried out to highlight the importance of application of softwares during the analysis of laminated sandwich structures. The analysis is carried out in ABAQUS/CAE. The model is validated with the results obtained by previous researchers. The effect of geometrical parameters, material properties and boundary conditions is also carried out. It is found the sound application of ABAQUS/CAE in the analysis of such structures.

Keywords: Laminated composites; sandwich structures; free vibration; sandwich plates

1. Introduction

Laminated sandwich plates as design components are of great use in various sensitive structures having applications in field of marine, civil, aerospace and mechanical engineering. Laminated sandwich plates can absorb energy in an efficient way under both dynamic and static conditions. Sandwich constructions are gaining popularity day by day as they are composed of a low strength core with high strength face sheets as they are light in weight and possess good stiffness having good load bearing capacity. As in case of laminated sandwich plates, they are weak in shear because of change in properties of plate along its thickness. Hence it is difficult to carry out their analysis.

Finite element method (FEM) is one of the best methods for carrying out the vibration analysis of plates. Classical plate theory (CPT) proposed by Kirchoff cannot be applied to laminated sandwich plates as CPT neglects transverse shear deformation and hence gives an overestimation of natural frequencies. Using first order shear deformation theory (FSDT), structural behavior of sandwich laminates predicted by Chakraborty et al. [1], Goyal and Kapania [2] etc. Shi et al. [3] recommended the use of shear correction factor for implication of FSDT to sandwich laminates. To avoid the use of shear correction factor, higher order shear deformation theory (HSDT) has been developed. Aagaah et al. [4], Ghosh et al. [5], Manna [6] etc., analyzed composites using HSDT with implication of FEM. Chandrashekhara and Bangera [7,8], Marur and Kant [9], Aydogdu [10] extended this theory for vibration analysis. Using third order shear deformation theory, Aagaah et al. [4] analyzed free vibration of laminated plates under different boundary conditions and ply orientation. For improving interlaminar stresses, Chalak et al [11, 12] proposed FEM based zigzag theory. Recently, a new high-order sandwich panel theory (HSAPT) with introduction of kinematic assumptions based on any plate theory for face sheets and equations of elasticity for core layer and is employed by Elmalich et al. [13], Frostig et al. [14]. Zhang et al. [15] explained in detail the theoretical portions for different theories used for vibration analysis of laminated plates in both linear and nonlinear mode of vibrations. Carrera et al. [16] used Reissner's mixed variational theorem for analysis of multi layered plate and shell structures.

Finite element method (FEM) is the most widely used tool by the researchers for analyzing the laminated plates as it can be employed to various numbers of plates with ease. Large number of FE models has been developed. With keeping in mind all this, a number of plate problems made up of different materials, having different end conditions are analyzed using ABAQUS are presented in this paper, results of which are compared from literatures of researchers available. At the end, the applicability of each model is discussed based upon the results drawn.

2. Modeling

A comparative study of analysis of laminated plates for vibration is studied using ABAQUS. Non-dimensional natural frequencies are compared in order to draw out the conclusions and for comparing the results available from different models. Using pre-processor ABAQUS/CAE, all the FE models were created. Lanczos method was applied for calculating eigenvalue for natural frequencies and mode shapes. Intel® Core™ i5-5200U CPU @ 2.2 GHz is used for carrying out computational efforts.

Models are based on 3d solid elements. In case of laminated sandwich structures, transverse shear effects are predominant and normal transverse stresses cannot be ignored, and also magnitudes of stresses at the layer interface is necessary and hence must be employed while analyzing the sandwich plates. 3D solid elements allow the application of a fully three-dimensional material law for plate/shell-like structures. The standard 20 node quadratic brick element with reduced integration is used as element to create finite element model. This kind of element is used because of its superiority among elements available in the ABAQUS library to create finite elements.

3. Numerical Results

The results are demonstrated by solving numerical on free vibration analysis of laminated sandwich plates. Results obtained are compared with results published in different literatures. Following boundary conditions were used

a. Simply supported boundary condition: the d.o.f. u_0, v_o, w_0, θ_x, u_u,w_u,$u_l$and $w_l$are restrained whileθ_y, v_u, *and* v_l, are unrestrained in one boundary. In other boundary, the field variables w_l, w_o, $w_u$are restrained while v_0, θ_y, v_u, *and* $v_l$are unrestrained (parallel to y axis). The field variables u_0, v_o, w_0, θ_y, v_u, w_u, v_l, w_l, are restrained whileθ_x, u_u and u_l, are restrained in one boundary. In the other boundary, the field variables w_0, $w_u$and $w_l$are restrained while θ_x, u_0, u_u, and u_l, are unrestrained.
b. Clamped boundary condition: all the nodal d.o.f. at boundary are fully restrained.
c. Free boundary condition: all the nodal d.o.f. at the boundary are unrestrained.

Following laminates are used in the problems:

(a) Three layered (0°/90°/0°) symmetric cross ply composite laminate of material 1 with layers of equal thickness.
(b) Five layered (0°/90°/C/90°/0°) symmetric sandwich plate with each ply in the face sheet being of thickness 0.05h and material 2 and core of thickness 0.8h and material 3.

(c) Five layered (0°/90°/C/0°/90°) unsymmetric sandwich plate with each ply in the face sheet being of material 4 and core of material 5.

Table 1 Material property for different sandwich plate.

Property	Material				
	1	2	3	4	5
E_1 (GPa)	25	276	0.5776	131	0.00689
E_2 (GPa)	1	6.0	0.5776	10.34	0.00689
E_3 (GPa)	1	6.0	0.5776	10.34	0.00689
G_{12} (GPa)	0.5	6.9	0.1079	6.895	0.00345
G_{23} (GPa)	0.2	6.9	0.22215	6.895	0.00345
G_{13} (GPa)	0.5	6.9	0.1079	6.205	0.00345
υ_{12}	0.25	0.25	0.0025	0.22	0
υ_{13}	0.25	0.25	0.0025	0.22	0
υ_{23}	0.25	0.3	0.0025	0.49	0
ρ (kg/m^3)	100	681.8	1000	1627	97

Non dimensional natural frequencies for vibrations to show results are:

(1) Plates (a): $\lambda_{nond}=\lambda a^2/h\sqrt{\frac{\rho}{E}}$

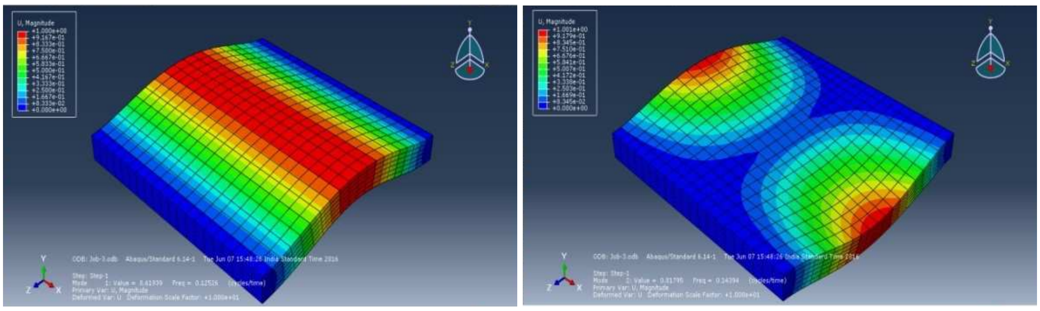
(2) Plate (b): $\lambda_{nond}=100\lambda a/h\sqrt{\frac{\rho_c}{E}}$

(3) Plate (c): $\lambda_{nond}=\lambda b^2/h\sqrt{\frac{\rho_f}{E}}$

Where a, b and E are the plane dimensions along x and y direction and transverse modulus of elasticity of face layer respectively. ρ_c and ρ_f are density of face sheet and core resp.

Table 2 Nondimensional natural frequencies of a composite plate (a) (0°/90°/90°/0°) for different modular ratio (E_1/E_2)

Reference	E_1/E_2			
	10	20	30	40
Present (8x8)	8.3055	9.5395	10.2580	10.7692
Present (12x12)	8.3106	9.5420	10.2794	10.7825
Present (16x16)	8.3349	9.5699	10.2866	10.7965
Present (20x20)	8.3349	9.5699	10.2866	10.7965
Chalak et al. [12]	8.3456	9.5703	10.2976	10.7984
Rodrigues [17]	8.4142	9.6629	10.4013	10.9054
Liew et al. [18]	8.2924	9.5613	10.320	10.849



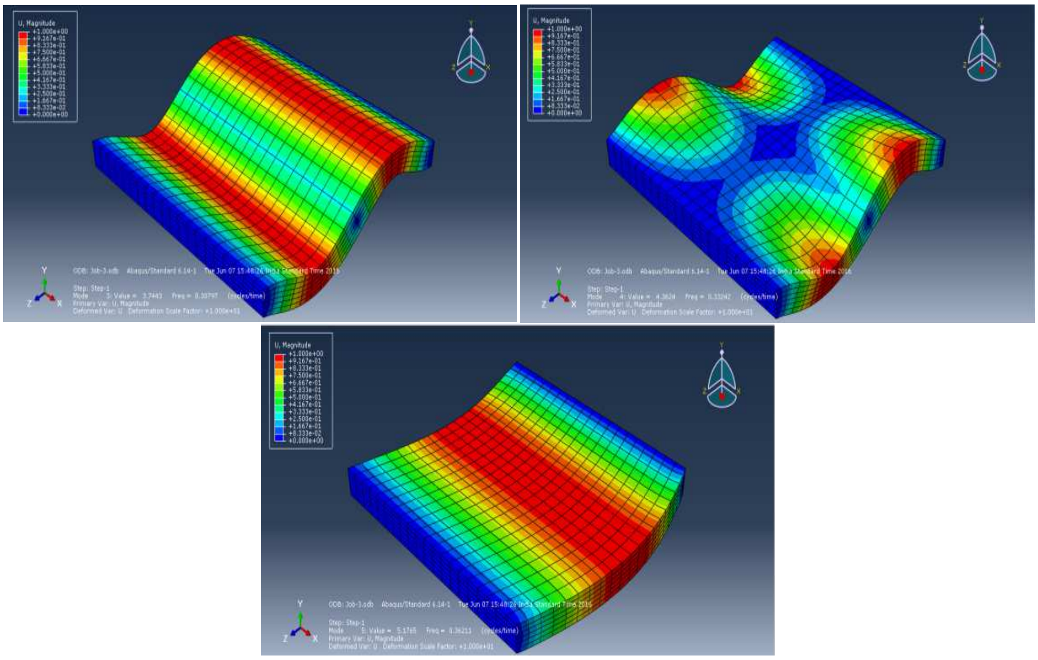


Figure 1 First 10 mode shapes for CFCF laminated sandwich plate under free vibration condition (type: a)

- **Four Layered (0°/90°/90°/0°) Laminate Plate**

A four layer simply supported square plate (type: a) is analyzed by taking mesh sixes (8x8), (12x12), (16x16) and (20x20) for convergence studies of fundamental natural frequency. Thickness of all layers is same and thickness ratio is considered to be 5. Results are obtained for different E_1/E_2 values and the results are shown in table 2. It is indicated from table 2 that the results converge at mesh size of (16x16). The present results hold well with that of Chalak et al. [12] using HOZT and Rodrigues et al. [17] using ZZT.

Table 3 Non-dimensional natural frequencies of five layered (0°/90°/C/90°/0°) symmetric laminated sandwich plate (b) for different boundary conditions and thickness ratio (a/h)

a/h	B.C.		Present	Chalak et al. [12]	ZIGT FE [19]	TSDT [19]
5	CCCC	1	12.0403	12.0996	12.3654	15.5290
		2	18.2698	18.3920	18.9369	24.2409
		3	20.5701	20.6783	21.2618	25.5266
		4	24.8828	25.0272	26.2432	32.1377
		5	26.4152	26.6774	27.7205	34.9302
	CFFF	1	3.4102	3.4180	3.4344	4.5877
		2	4.6589	4.6458	4.0958	5.7835
		3	10.5498	10.5933	10.6732	14.2124
		4	12.6683	12.6853	12.8165	16.4524
		5	18.7435	17.6734	17.7161	21.4570
10	CCCC	1	11.2203	11.2607	11.4158	14.5032
		2	16.6771	16.7446	17.0329	22.4345
		3	18.9503	19.0385	19.3780	23.7631
		4	22.1986	22.8018	23.4305	29.6142
		5	27.1422	23.6414	24.0862	32.1539
	CFFF	1	2.9572	2.9721	2.9791	3.7121
		2	3.6013	3.6053	3.6348	4.4746

3	9.3738	9.3976	9.4418	12.3658
4	10.7198	10.7219	10.8109	13.7840
5	15.8291	15.8489	15.8500	18.6261

- **Symmetric Laminated Sandwich Plate**

Simply supported sandwich plate of type: b having different boundary conditions is analyzed. The results are indicated in table 3 and are compared with available results. The present results hold well with Chalak et al. [12] and other models. The results are for first five non-dimensional natural frequencies and they also hold well.

- **Unsymmetric Laminated Sandwich Plate**

A typical unsymmetric simply supported square plate with soft core type: c is considered for analysis. The thickness ratio is varied in order to study both thin as well as thick plate. The results shown in table 4 are compared with Chalak et al. [12] and Rao et al [22], and the results are in good agreement with both. Hence both the models i.e., HSDT and HOZT can be applied for the free vibration analysis of laminated sandwich plates.

Table 4 Non-dimensional natural frequencies of five layered (0°/90°/C/0°/90°) unsymmetric laminated sandwich plate (c) for different thickness ratio (a/h)

a/h	Present	3D Elast. [22]	Chalak et al. [12]	HSDT [22]	HSDT [21]	FSDT [21]
10	1.8401	1.8480	1.8420	1.9712	4.8519	13.8694
20	3.4305	3.4791	3.4568	3.6836	8.5838	15.5295
30	5.0032	5.0371	5.0032	5.3034	11.0788	15.9155
40	6.4302	6.4634	6.4212	6.7727	12.6555	16.0577
50	7.5824	7.7355	7.6882	8.0698	13.6577	16.1264
60	8.7911	8.8492	8.7995	9.1929	14.3133	16.1612
70	9.6303	9.8118	9.7618	10.1530	14.7583	16.1845
80	10.4305	10.6368	10.5880	10.9672	15.0702	16.1991
90	11.2617	11.3408	11.2940	11.6561	15.2946	16.2077
100	11.7938	11.9400	11.8960	12.2374	15.4647	16.2175

4. Conclusions

In this paper, FEM is employed to solve the number of problems because it is considered as the most efficient method to handle the complex problems. FEM is used to calculate the natural frequencies and mode shapes for plates made up of different types of materials, having different boundary conditions using ABAQUS. Comparisons of results lead to the following general conclusions:

- The FEM formulations holds good results when they are compared with the results from Chalak et al. [12] who employed higher order zigzag theory for evaluation of laminated sandwich plates for vibrations.
- It can also be stated that the FEM models can be applied for the free vibration analysis of laminated sandwich beams.
- Results also hold good in table 2 and table 4 as when compared with results of Chalak et al. [9].

- From table 3 and table 4 it can be indicated that TSDT [21] and FSDT [21] overestimates the non-dimensional fundamental frequencies. Hence these models should not be preferred for the same to analyze.

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