International Journal of Advances in Engineering & Scientific Research, Vol. 5, Issue 3, Mar -2018, pp 14-33 ISSN: 2349 –3607 (Online) , ISSN: 2349 –4824 (Print)

FINITE ELEMENT ANALYSIS OF LAMINATED SANDWICH STRUCTURE

Mr. Arsalan Hussain Khan
(M.Tech Scholar),
Dept of Civil Engineering
Al- Falah University
Dhauj Faridabad Haryana

Mr. Misbah Danish
Assistant Professor,
Dept of Civil Engineering
Al- Falah University
Dhauj Faridabad Haryana

ABSTRACT

In modern civil engineering structures, laminated composites are widely used in various applications including roof of buildings, bridge decks, structural panels and beams. Using the laminated composite material in construction introduces many advantages such as high strength/stiffness to weight ratio, survivability in extreme weather conditions, durability, fatigue resistance, and design flexibility, easy to install in structure replacement. The behavior of laminated composites under free vibration, bending and buckling mode is very complex phenomenon because many modes of failure like delamination, large oscillations etc. are observed. Laminated composite structures are weak in shear due to their low shear modulus compared to extensional rigidity.

The effect of shear deformation is quite significant and it becomes more complex in the case of sandwich construction, as the material property variation is very large between the core and face layers. Various available theories shows discontinuity in the shear stress distribution at the layer interfaces with continuous variation of transverse shear strain across the thickness. But the actual behavior of composite laminate is opposite, i.e., the transverse shear stress must be continuous at the layer interface and the corresponding strain may be discontinuous.

In this study, Finite Element 3-D ABAQUS (v. 6.14) model is used to analyze the behavior of laminated sandwich beams under free vibration, bending and buckling mode. The influence of material properties, loadings (uniformly distributed load, sinusoidal loading), aspect ratio (length to thickness ratio), number of material layers, boundary conditions (simply supported, fixed, free, hinged ends) are studied in detail.

Key words: *ABAQUS, 3D, FE model, Laminated sandwich*

INTRODUCTION

The word composite in composite material signifies formation of useful third material from two or more materials combined on a macroscopic scale. If composite structures are well designed, exhibit the best qualities of their constituents and often some qualities that neither constituent possesses. Some of the properties that can be improved by forming a composite material are:

strength, stiffness, corrosion resistance, wear resistance, attractiveness, weight, fatigue life, temperature-dependent behavior, thermal insulation, thermal conductivity, acoustical insulation.

Naturally, not all these properties are improved at the same time. The material can be created to perform the design task. Composite materials have a long history of usage. There are recorded references in history to form some composite materials. Straw was used by Israelites to strengthen mud bricks. Ply wood was used by ancient Egyptians when they realized that wood could be rearranged to achieve superior strength and resistance to thermal expansion as well as to swelling caused by the absorption of moisture. Medieval swords and armor were constructed with layers of different metals. More recently, fiber-reinforced, resin-matrix composite materials that have high strength to weight and stiffness to weight ratios have become important in weight sensitive applications.

Laminated Composite Sandwich Structures

Lamina is the basic building block of a laminate in a lamina which is flat (sometimes curved as in shells) arrangement of unidirectional fibers or woven fibers in a matrix. A laminate is a bonded stack of lamina with various orientations of principal material directions in the lamina. These layers are bonded together by the same matrix material that is used in the individual lamina. Sandwich composite is a special class of composite materials that is fabricated by attaching two thin but stiff skins to a lightweight but thick core. The core material is normally low strength material, but its higher thickness provides the sandwich composite with high bending stiffness with overall low density.

Applications of Laminated Sandwich Materials

Following listed are the various fields where laminated sandwich materials can be employed:

Aeronautical engineering: As the laminated structures are light in weight and are resistant towards environmental impact hence are perfect materials for making airplanes, Boeings etc.

Structural engineering: Due to light weight and enhanced properties, laminated materials are used as construction materials in field of civil engineering.

Naval engineering: On the basis of same principles as explained above, laminated materials are employed for making ships.

Automobile engineering: Properties such as insulation, resistant towards environment, light weight, wear resistant etc. makes them best suited for making automobiles.

Space applications: Weight savings, minimum value for thermal expansion coefficient etc. allows these materials for making rockets, missiles, satellites etc.

Commercial applications: various commercial applications such as making surfboards, rackets, golf clubs etc. are also made up of composites.

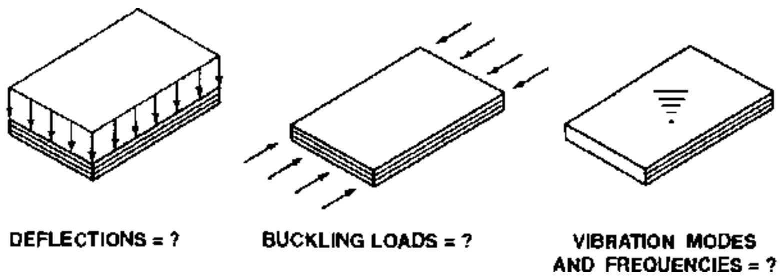


Figure 1: Problems for analysis of laminated sandwich structures [Robert M. Jones]

Material Properties The laminated composite material with different conditions including soft core, different orientations of core materials, different boundary conditions, different materials were analyzed under buckling, free vibration and bending mode. Following material properties were used for the analysis of laminated composites:

Soft Cores : The cores used in load carrying sandwich constructions can be divided into four main groups; corrugated, honeycomb, ply wood and foams. First of all the core should possess low density in order to add as little as possible to the total weight of the sandwich construction. The core is mainly subjected to shear and the core shear strains produce global deformations and core shear stresses. Thus, a core must be chosen that won't fail under the applied transverse load and which a shear modulus high enough to give the required shear stiffness. The critical wrinkling load depends both on the Young's modulus and shear modulus of the core. Other functions of the sandwich such as thermal and acoustical insulation depends mainly in the core material and its thickness. The properties of primary interest for the core are density, shear modulus, shear strength, stiffness perpendicular to the faces, thermal and acoustical insulation.

RESEARCH OBJECTIVE

The objectives of current work can be summed up in following points:

- To develop 3-D finite element model for the analysis of laminated composite Structure using ABAQUS.
- To study the influence of boundary conditions, material properties, number of layers, plate and beam thickness etc. subjected to the free vibration, buckling and bending mode.

LITERATURE REVIEW

Manet (1998) studied behavior of sandwich structures using ANSYS. The influence of mesh refinement and of the ratio of Young's moduli of the layers was studied. All models lead to a correct value of displacements, but Plane 82 (ANSYS library) is the most accurate; plane stress in z-direction can be correctly given by Shell 91 and Plane 82, the latest being the most accurate; plane stress in xz is only very accurately computed with Shell 91, but for Es/Ec=200; plane stress in the core can be calculated using any model, Plane 82 being the most accurate; plane stress in the skin is very accurately computed with Plane 82 and with Shell 91 (but only for Es/Ec=20), and acceptable with Solid 46 (and only for Es/Ec=20).

Rust and Schweizerhof (2003) analyzed buckling of thin structures using ANSYS and LS-DYNA. It was found that standard ANSYS has a lot of advanced nonlinear features, solution methods and convergence tools, a quasi-static LS-DYNA analysis can be an advantageous alternative in the case of systems containing multiple highly nonlinear effects.

Kapuria and Kulkarni (2007) analyzed composite and sandwich plates and beams using improved discrete Kirchhoff element based upon third order zigzag theory and compared the analytical results obtained using ABAQUS under bending conditions. The results calculated by ABAQUS using 3D models. 20 noded quadratic brick element was used to create mesh. It was reported that for thin plates, results were comparable but for thick plates, results were highly enormous with % error in deflection ranging from .8% to 10%. Results start to converge at mesh size of 12x12. Finer results yields better results as compared to coarse mesh. Hence, in present study finer mesh was used.

Ramesh et al. (2009) analyzed laminated composite plates for inter laminar stresses using ABAQUS. It was reported that transverse shear stresses do not vanish at free surfaces of the structure and are usually discontinuous at the ply surfaces.

Vidal and Polit (2010) studied free vibration of three layered sandwich beams using ANSYS. The analytical results were near to those calculated using ANSYS. For thick beams the classical results depart from actual results which were calculated analytically.

Chakrabarti et al. (2011), (2012) analyzed variation of in-plane displacement, in-plane normal stress, transverse deflection and transverse shear stress using ABAQUS for multi-layered sandwich beam (l/h=10). It was reported that transverse deflection was constant with thickness of beam. Transverse shear stresses are continuous at the layer interface and the corresponding strain is discontinuous. Hence, results using ABAQUS depict the actual behavior of structure.

Chalak et al. (2011) analyzed thick beams with different boundary conditions under free vibration and buckling mode using ABAQUS. The results for fundamental mode were comparable with HOZT but for higher mode there exist variation of non-dimensional natural frequency for higher modes deviates using theory when obtained using ABAQUS.

Burlayenko et al. (2015) carried out detailed study of composite plates under free vibration mode. It was reported that the use of 3D finite elements may be preferred when transverse shear effects are predominant and normal transverse stresses cannot be ignored, as well as accurate magnitudes stresses at layer interfaces being necessary. Hence, solid elements allow the application of fully three-dimensional material law for plate structure. Thus the transverse shear stiffness as well as transverse shear stresses will be calculated directly from the equilibrium equations of stress tensor components. This provides a real distribution through the thickness of transverse stresses and, in turn, real behavior of plates. With increase in model size, degree of accuracy of result depends upon quality of mesh. Fine mesh results in accurate calculation of quantities.

RESULTS AND DISCUSSIONS

Various examples covering wide range of features on laminated soft core sandwich structures (beam) solved. The results obtained are presented in the form of tables and figures. For the purpose of validation of the proposed models developed using commercial FE software package ABAQUS (v. 6.14) results are compared with

It may be concluded from the literature that it is difficult to accurately predict the deformation of the sandwich structures. Also very few literature is available on software analysis of sandwich structures and the results reported are mostly for thin composite laminates.

The results are presented according to the following categories in sections based on types of structures considered for the analysis:

Again there are three separate divisions for static, vibration and buckling analyses of laminated beams and plates. The results are presented in tabular as well as graphical forms. The results are in the form of deflections and stresses in the case of static analysis, natural frequencies of vibration for first few modes in free vibration analysis and buckling load parameter in buckling analysis.

Sandwich Beams

Static analysis

The applicability of the FE beam model is presented by analyzing soft core sandwich beams of different configurations.

Convergence study

Simply supported 3-layered laminated composite beam (0/90/0): A three layered laminated sandwich plate made up of material 1 is used for study the convergence. All layers are of equal thickness. The results from convergence study are reported below in graphical form. Along thickness 3 mesh division are taken.

Numerical Examples

Simply supported 3-layered laminated composite beam (0/90/0) made up of material 3 is chosen for convergence study. All layers are of equal thickness. Form the non-dimensional parameters as reported in table 1.the l/h ratio is taken as 100. From the results reported in table 1, a higher mesh size of 100 is needed. But for the present study, mesh division is kept limited to 100.

Laminated sandwich beam (0/90/0): A simply supported three layered laminated sandwich beam with different boundary conditions is subjected to sinusoidal loading. The face layer is made up of material 3 and core of material 6. The results obtained for non-dimensional displacements and stresses are reported in table 2.. The effect of l/h ratio with different boundary conditions was studied and the results are shown in figure 2. From graph it can be concluded that the results for transverse deflections in case of C-F beam is higher than among all the conditions which was expected. The variations of transverse shear stress (at boundary) and in-plane displacement (at mid span) across the depth obtained by usingt FE model and are shown in figure 3(a) and 3 (b).

Angle ply laminated beam under uniformly distributed load: An angle ply laminated beam (0/45/45/0) under uniformly distributed load is studied. The face layer is made up of material 3 and core layer of material 6. All layers are of equal thickness. The effects of l/h ratio with different boundary conditions were studied.

Multi layered sandwich beam subjected to uniformly distributed load is analyzed. The beam is 11 layered having layup as of material 6/11/3/6/3/12/3/6/3/11/6. The thickness of layup is as $(0.01h/0.025h/0.015h/0.02h/0.03h/0.4h)_s$ where h is the overall thickness of beam. The variation of transverse deflectionand in-plane displacement with depth at boundary are shown graphically (figure 4).

Table 1 Convergence of non-dimensional displacements and stresses at different locations of a laminated sandwich beam (l/h = 100)

No. of Mesh	w (l/2,0)	u(0,h/2)	τ_{xz} (0,0)	σ_{xx} (l/2,h/2)
2x2	0.418	8048	146.46	6323.19
5x5	0.5064	8046	132.60	6323.50
10x10	0.5132	8029	77.62	6324.61
16x16	0.5139	8023	58.17	6322.52
20x20	0.5139	8022	53.23	6319.09
30x30	0.514	8020	48.40	6316.50
50x50	0.514	8020	46.11	6315.14
100x100	0.514	8020	45.23	6315.00

Table 2 Non-dimensional displacements and stresses at different locations of a laminated sandwich beam for various thickness ratio (l/h)

s.no	I/h	w (l/2, 0)	u (0. h/2)	τ_{xz}	σ_{xx} (l/2, ±h/2)
1.	100	0.5131	8022	45.31	6314.81
2.	50	0.5261	1006	22.42	1587.21
3.	20	0.6171	66.86	8.91	263.10

Table 3 Non-dimensional displacements and stresses of an angle ply laminated sandwich beam for various thickness ratio

l/h	B.C.	w (l/2,0)	σ_{xx} (l/2, -h/2)
50	H-H	0.1528	676.83
	C-C	0.7189	2113.36
100	H-H	0.1451	2813.62
	C-C	0.7069	8460.04

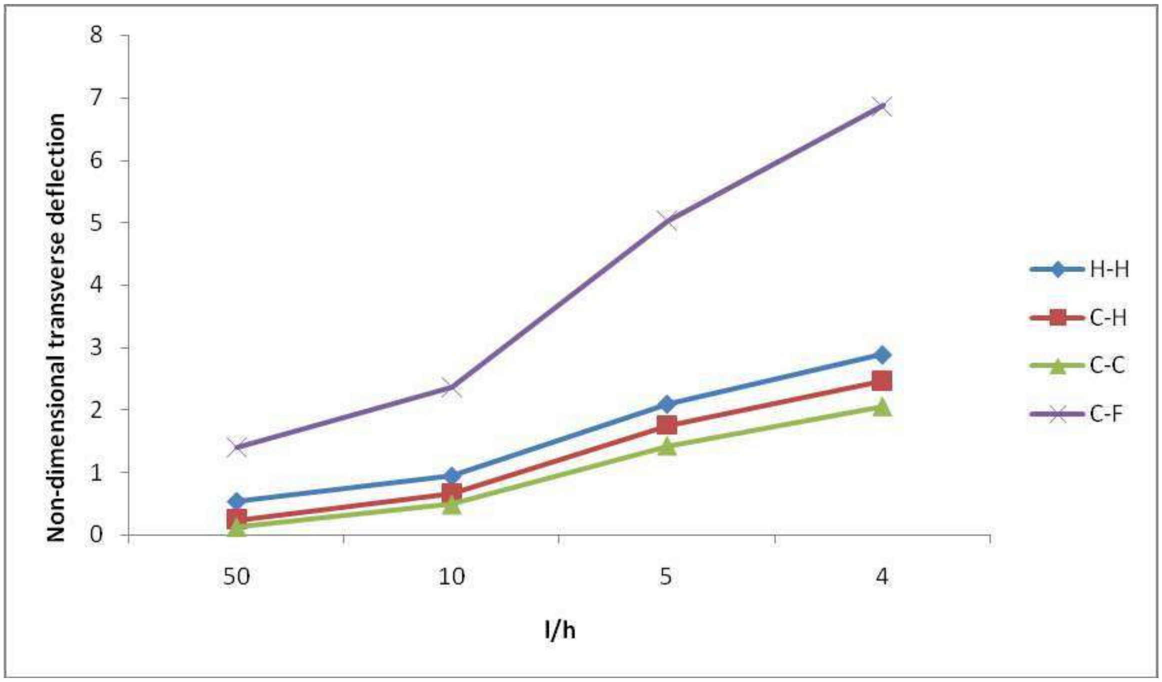


Figure 2 Variation of non-dimensional transverse deflection with length to thickness ratio at mid span for sandwich beam with different end conditions

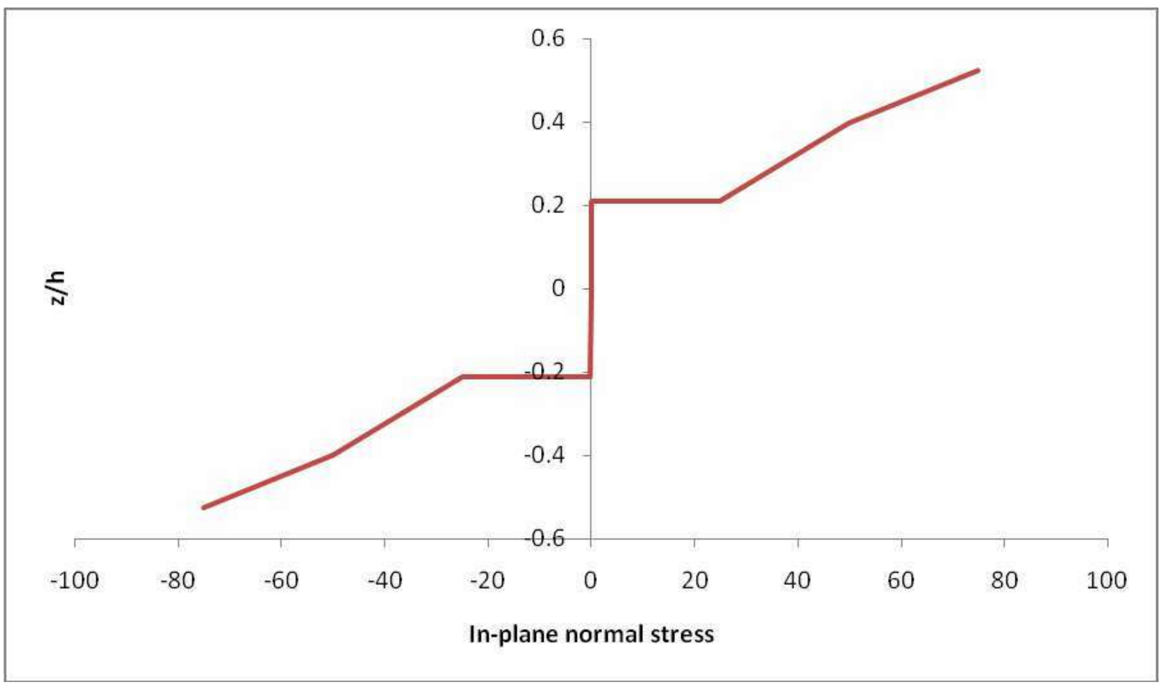


Figure 3 (a) Variation of transverse shear stress across the depth of a sandwich beam (0/90/0)(l/h=10)

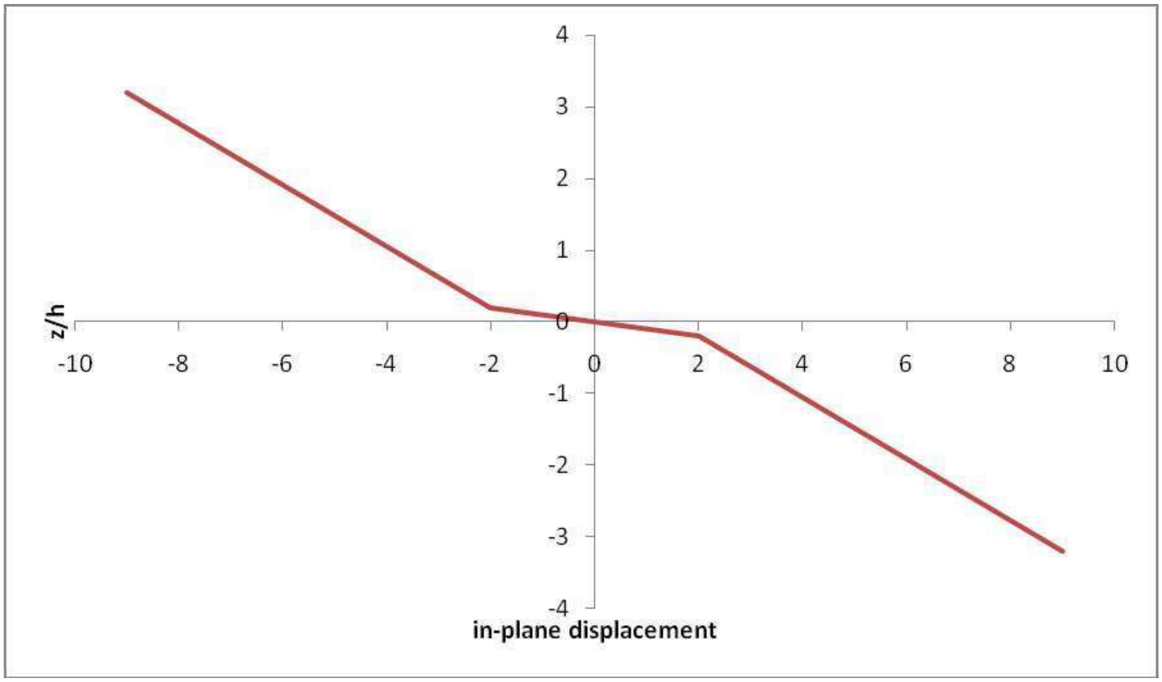


Figure 3 (b) Variation of in-plane displacement across the depth of a sandwich beam (0/90/0) (l/h=10)

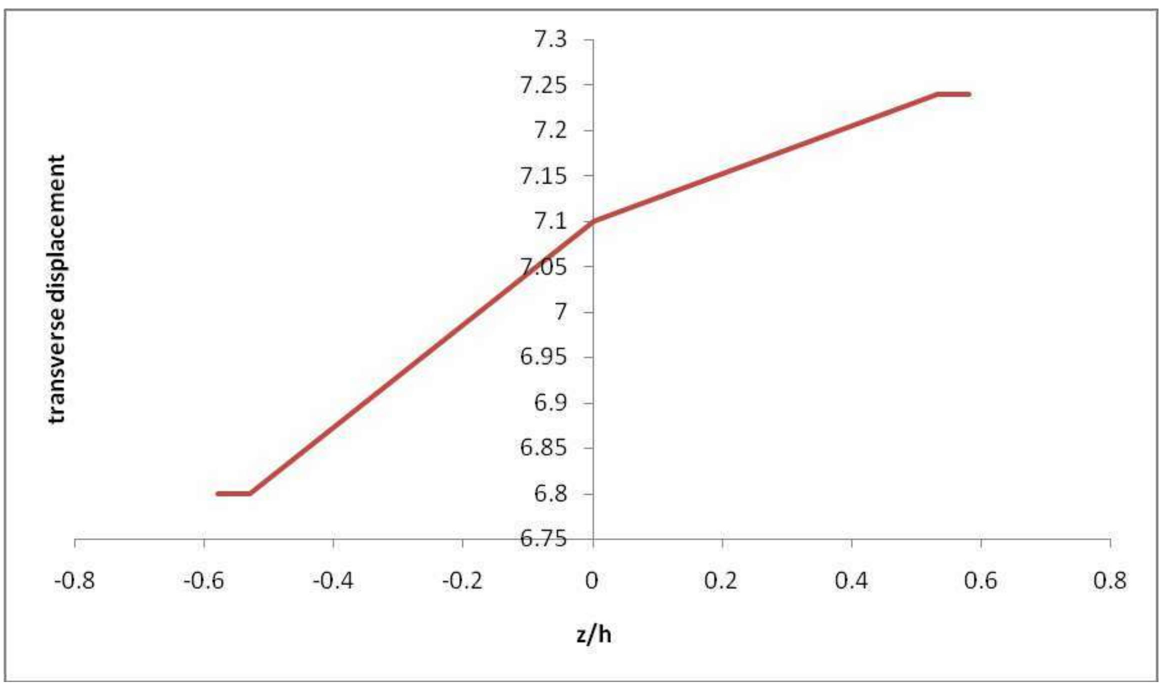


Figure 4 (a) variation of transverse deflection of a multi layered sandwich beam (l/h=10)

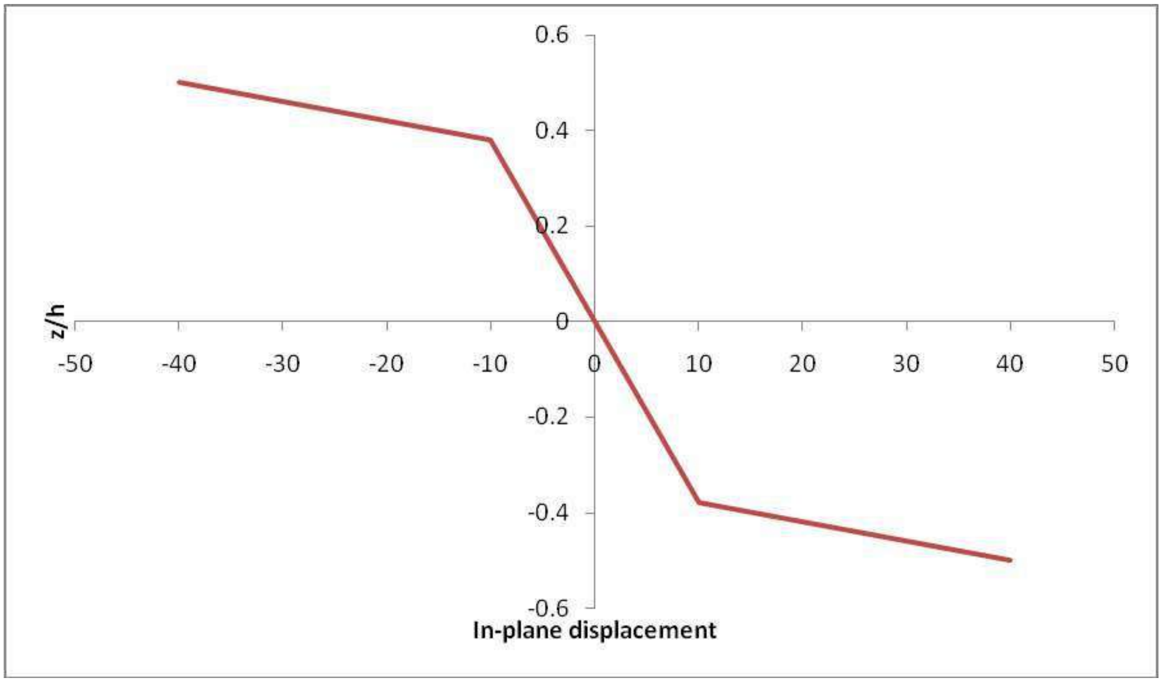


Figure 4 (b) Variation of in-plane displacement of a multi-layered sandwich beam (l/h=10)

Free vibration analysis

Convergence study

Three layered laminated sandwich beam($0^0/90^0/0^0$) made up of material 1. All layers are of same thickness having length to thickness ratio equals 5. From figure 8 it may be observed that the results converge at mesh size 20x20. Hence, for the further study of free vibration of beams, mesh size of 20x20 was taken.

Numerical examples

Three layer laminated sandwich beam: Beam is made up of material 2. Core layer is 0.8h thick and each face layer is 0.1h thick. Results are indicated in table 4 for first five modes of non-dimensional natural frequencies for different thickness ratios (l/h). From table 4. For first three modes results are identical. But for higher modes of frequency,

Multilayered sandwich beam ($0^0/90^0/0^0/90^0/C/90^0/0^0/90^0/0^0$) Beam structure is made up of material 2. Ratio of core thickness to face thickness is taken as 5. Results are indicated in table 5 for modes of non-dimensional natural frequencies for different thickness ratios (l/h). Figure 6 shows variation of non-dimensional natural frequency with length to thickness ratio for different end conditions. From table 5, it can be seen that for deep beams, there is a gap between the results.

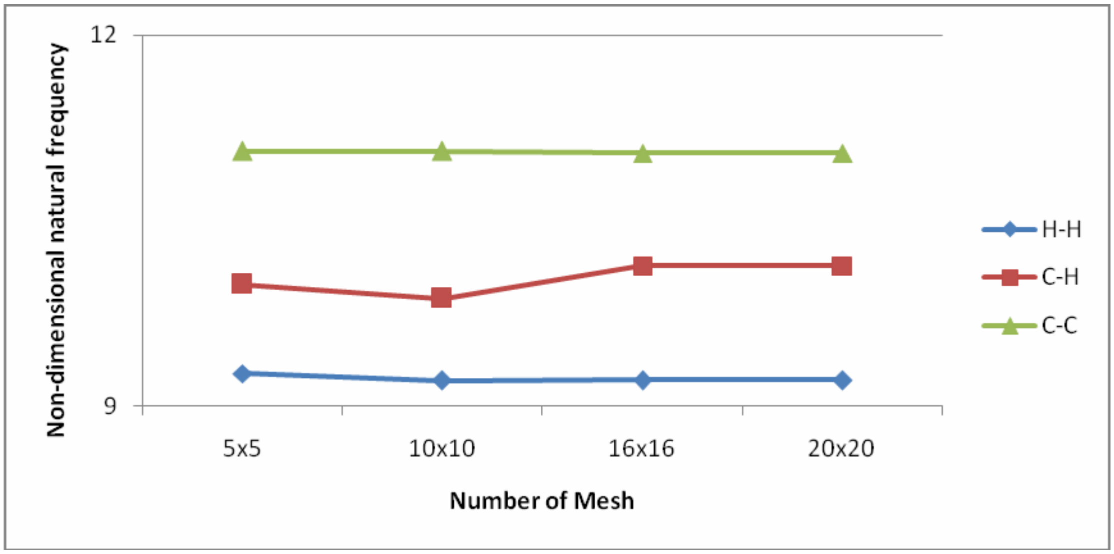


Figure 5 Convergence of mesh for laminated beam under free vibration condition

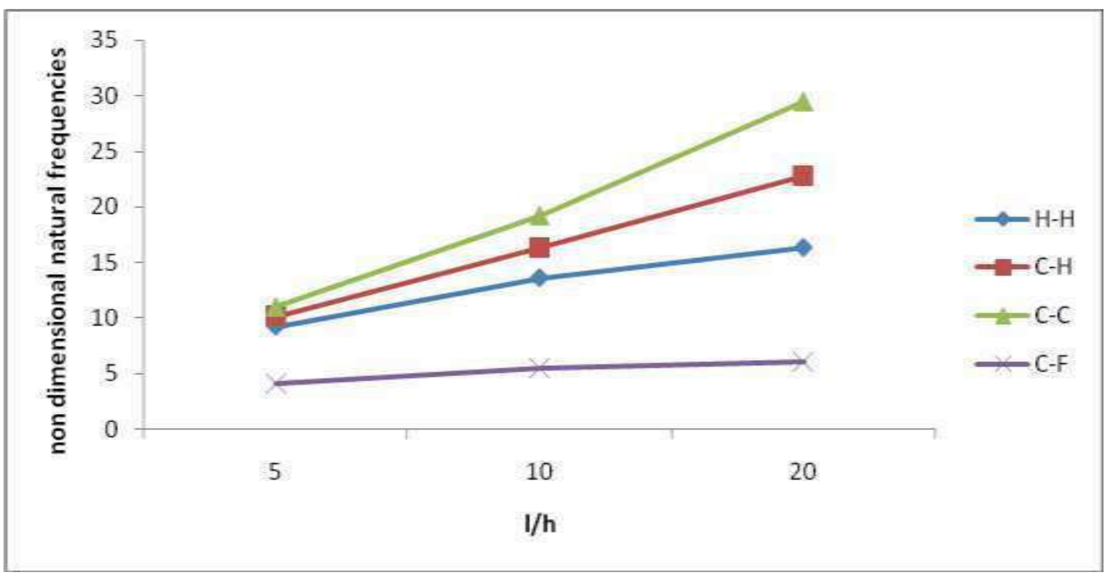
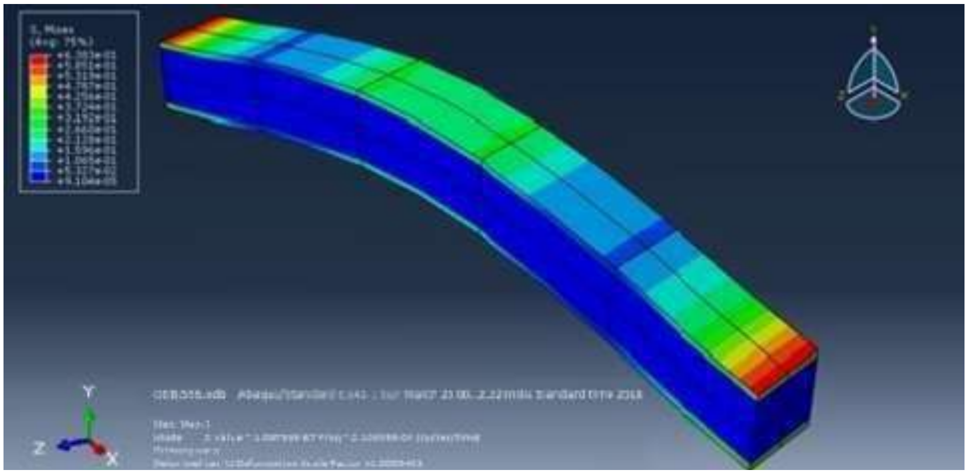
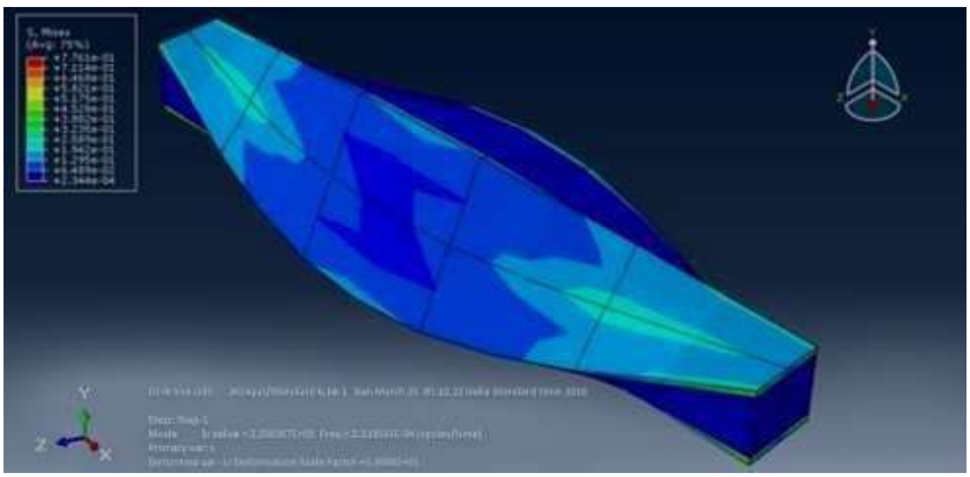
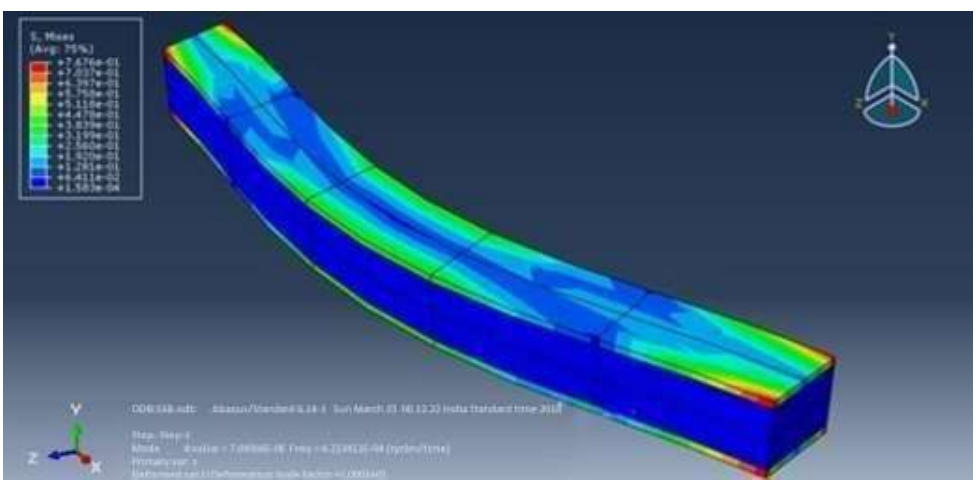


Figure 6 Variation of non-dimensional natural frequencies for different end conditions with l/h


S, Mises
(Avg: 75%)
Y
Z
X


S, Mises
(Avg: 75%)
Y
Z
X


S, Mises
(Avg: 75%)
Y
Z
X

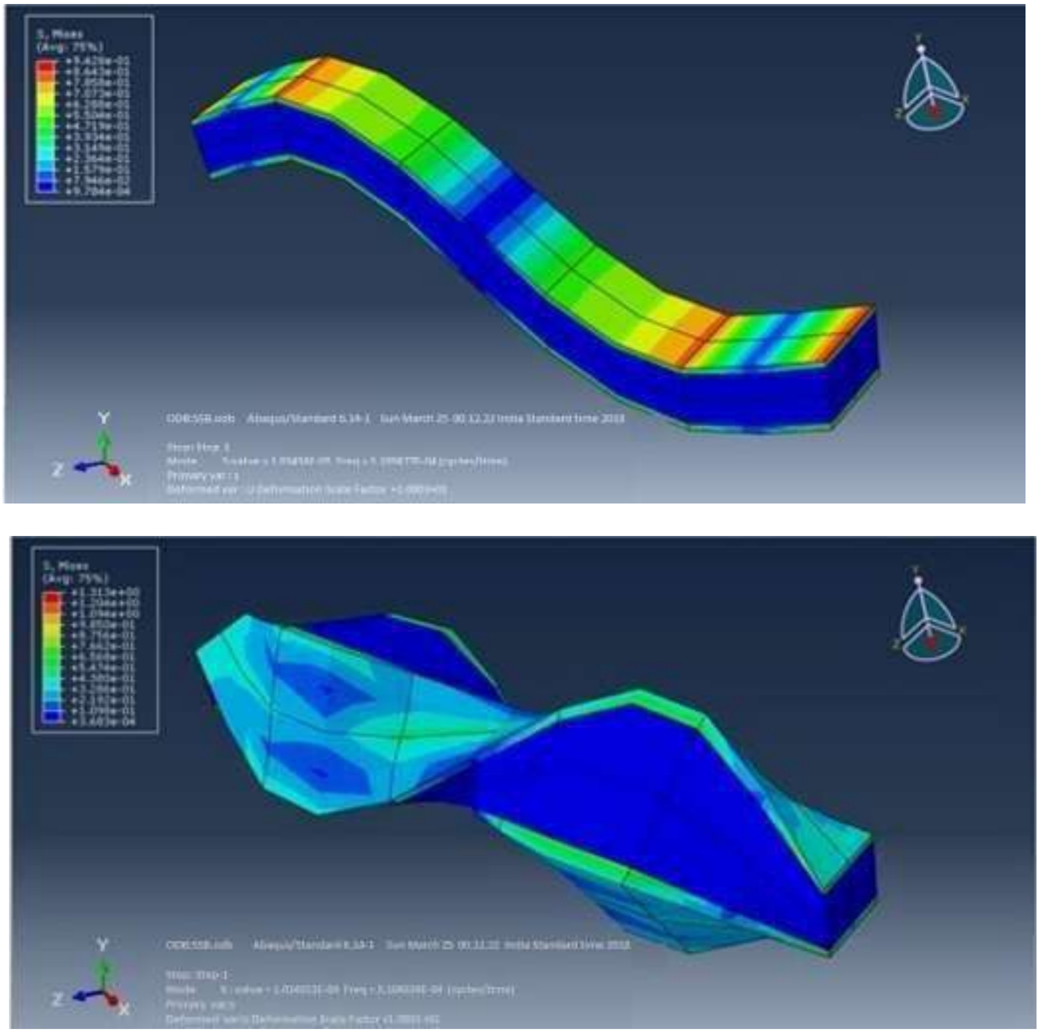


Figure 7 mode shapes for simply supported laminated sandwich beam under free vibration conditions (0/90/0) (l/h=10)

Table 4 Non dimensional frequencies for three layered sandwich beam with different thickness ratio.

s.no	l/h	1	2	3	4	5
1	2	3.53	5.34	7,59	12.03	16.58
2	5	7.83	17.28	26.92	33.40	36.97
3	10	12.24	31.32	50.30	69.21	88.31
4	20	15.39	49.01	87.06	163.52	201.61

Table 5 Non-dimensional natural frequencies of a thick laminated sandwich beam for different boundary conditions and thickness ratio.

s.no	l/h	B.C.	1	2	3	4	5	6
		H-H	1.1295	3.1933	5.9752	9.3427	9.6825	13.2625
1.	10	C-H	1.2089	3.5877	5.9874	10.6583	9.8045	13.4460
		C-C	1.6768	4.0966	6.9553	10.8447	9.9302	13.5899
2.	20	H-H	2.3029	5.3991	8.6608	12.9283	17.9403	24.0327
		C-H	2.5849	5.7194	8.9173	13.3739	18.8003	25.1944
		C-C	2.7528	6.0885	9.9582	14.4390	19.0372	26.0457
3.	100	H-H	8.1319	21.7500	35.3045	48.5490	61.5991	74.5468
		C-H	9.6244	22.2083	35.5163	48.6462	61.6514	74.7690
		C-C	11.2319	22.7514	35.7481	48.7309	61.7087	79.7590

Buckling analysis

Convergence study

Three layered laminated sandwich beam (0/90/0)is analyzed for convergence study by taking mesh divisions 2,5,10, 16, 20 and 30. All layers are of equal thickness. The plate is made up of material 8 and having l/h=5. The beam is analyzed for four different boundary conditions. The results are presented in Figure 8. It was seen that the results converge at mesh size of 20. Therefore, for further analysis of laminated composite beams under buckling conditions, mesh size of 20 is taken.

Numerical examples

A multi layered laminated sandwich beam: A multi layered laminated sandwich beam with number of layers 3, 4…., 10 having simply supported ends is analyzed. All layers are of equal thickness. All layers are made up of material 3. Beam in this example having odd number of layers is a symmetric layup and even number of layers being anti-symmetric. The results for buckling stresses are shown in Figure 9. From graph it is clear that anti-symmetric layup shows lesser amount of buckling stresses. Therefore, while using a multi layered beam subjected to buckling loads, anti-symmetric configuration must be employed in order to have minimum amount of buckling stresses.

Three layered soft core sandwich beam: A three layer simply supported sandwich beam with different core to face thickness ratio is analyzed having material properties of material 13.

Multi layered laminated sandwich beam: Table7 shows the results for multi layered laminated sandwich beam made up of material 14 having ply configuration as (0/90/0/90/C/90/0/90/0)

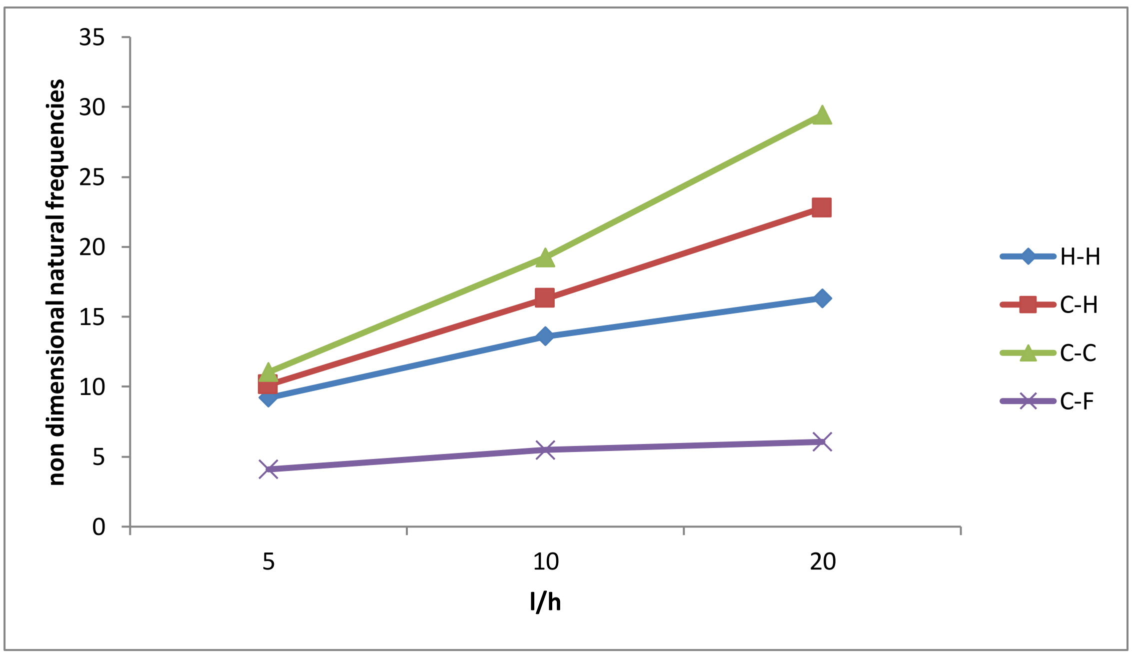


Figure 8 Convergence of mesh for laminated beam under buckling condition

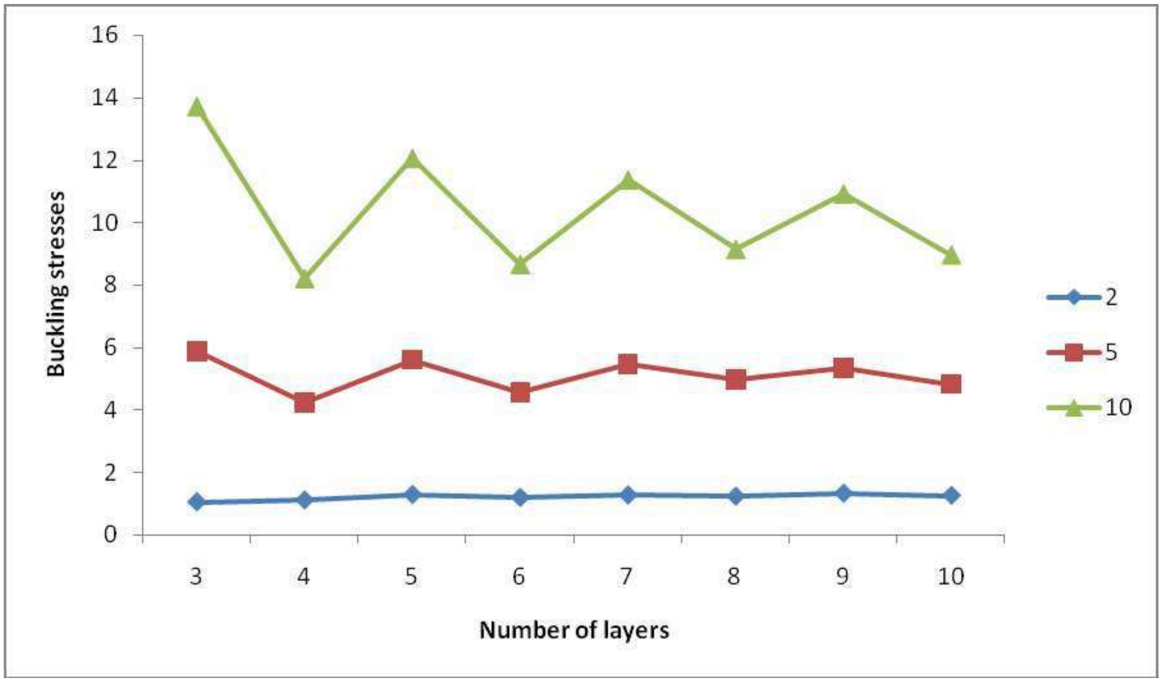


Figure 9 Variation of buckling stresses of multi layered laminated beams having different number of layers

Table 6 Critical buckling loads for three layered soft core sandwich beam

t_c/t_f	l/h	Results
5	2	0.001584
	5	0.009770
	10	0.036991
	50	0.342710
25	2	0.001511
	5	0.009010
	10	0.031111
	50	0.116809
50	2	0.001490
	5	0.008611
	10	0.026765
	50	0.060722

Table 7 Critical buckling loads for multi layered soft core sandwich beam

t_c/t_f	l/h	Results
	5	0.00843
25	10	0.03299
	50	0.49398
	100	0.80085

CONCLUSIONS

From the study, following inferences are drawn for ABAQUS model:

- The model holds good results with that from literatures for static, free vibration and buckling mode.
- Graphical variation of transverse shear stresses is continuous at the layer interface which is the true behavior of composites.
- It is found that the in-plane displacement increases with increase in length for beam while transverse shear stress, in-plane normal stress and transverse displacement decreases.
- Natural frequencies for C-F beam end conditions are lowest while for C-C end conditions are highest.
- As the thickness of laminated sandwich beams increases, natural frequency decreases.
- Laminated sandwich beams having even number of layers gives lower value of buckling load as compared to laminated sandwich beams having odd number of layers.
- Laminated sandwich beams having greater thickness of core to face thickness ratio shows buckling at higher loads.
- As ply angle in laminated sandwich beams increases, buckling load decreases

References

A. Chakrabarti, H. D. Chalak, Mohd. Ashraf Iqbal and A. H. Sheikh (2011) A new FE model based on higher order zigzag theory for the analysis of laminated sandwich beam with soft core, Journal on Composite Structure 93: 271-279.

A. Chakrabarti, H. D. Chalak, Mohd. Ashraf Iqbal and A. H. Sheikh (2012) Buckling analysis of laminated sandwich beam with soft core, Latin American Journal of Solids and Structures 9: 367-381.

A. J. M. Ferreira, C. M. C. Roque, A. M. A. Neves, R. M. N. Jorge, C. M. M. Soares and K. M. Liew (2011) Buckling and vibration analysis of isotropic and laminated plates by radial basis function, Composites: Part: B, 42: 592-606.

H. D. Chalak, A. Chakrabarti, Mohd. Ashraf Iqbal and A. H. Sheikh (2012) A new C_0 FE model for the analysis of laminated sandwich plate with soft core, Journal Finite Element Analysis and Design 56: 20-31.

H. D. Chalak, A. Chakrabarti, Mohd. Ashraf Iqbal and A. H. Sheikh (2011) Vibration of laminated sandwich beams having soft core, Journal of Vibration and Acoustics 135: 1-14.

H. D. Chalak, A. Chakrabarti, Mohd. Ashraf Iqbal and A. H. Sheikh (2013)[1]Free vibration analysis of laminated soft core sandwich plates, Journal of Vibration and Control 18 (10): 1422-1435.

H. D. Chalak, A. Chakrabarti, Mohd. Ashraf Iqbal and A. H. Sheikh (2013)[2] Stability analysis of laminated soft core sandwich plates using higher order zig-zag plate theory, Mechanics of Advanced Materials and Structures, 22: 897-907.

J. .N. Reddy and N. D. Phan (1985) Stability and vibration of isotropic, orthotropic and laminated plates according to a higher order shear deformation theory, Journal of Sound and Vibration, 98 (2): 157-170.

J. B. Dafedar, Y. M. Desai and A. A. Mufti (2003) Stability of sandwich plates by mixed, higher order analytical formulation, International Journal of Solids and Structures, 40: 4501-4517.

M. K. Rao, K. Scherbatiuk, Y. M. Desai and A. H. Shah (2004) Natural vibrations of laminated and sandwich plates. Journal of Engineering Mechanics, 130 (11): 1268-1278.

N. J. Pagano (1969) Exact solutions for composite laminates in cylindrical bending Journal Composite Material 3: 398-411.

N.J. Pagano (1970) Exact solutions for rectangular bidirectional composites and sandwich plates, Journal of Composite Materials 4: 20-35.