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# Flexural Analysis of Laminated Composite Flat Panel

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**Abstract—***In this paper, the geometrical linear and nonlinear flexural behaviour of laminated composite plates under uniform distributed load has been investigated. The modeling of the plate is done using ANSYS 15.0 based on the First order Shear Deformation Theory (FSDT) and von-Karman nonlinear strain. An eight nodes element with six degrees of freedom at each node has been considered for discretization purpose. The convergence and comparison test of the present model has been done by considering results available in published literature. These analyses demonstrate the efficacy and applicability of the present model for the given problem. A number of finite element analyses have been carried out to study the effect of thickness ratio, aspect ratio, lamina scheme and support condition on the flexural response of laminated composite flat panel.*

## 1. INTRODUCTION

In weight sensitive and high performance engineering industries the laminated composites are favorably used not only due to their unique flexibility in design, but also owing to cost effective, easy to machining, high durability, corrosion resistance, repairability characteristics. In addition, they possess high specific strength, high specific modulus, good directional properties, greater energy absorption and good electrical/chemical/environmental resistance. The interesting property of composite material is the ability to control fiber alignment. By organizing the fiber directions and layers with required strength and stiffness properties, specific required properties can be achieved. The mechanical and elastic properties of the composite materials are not set unless the final structure is manufactured. These properties can be obtained using standardized tests or using numerical methods. Due to the inconvenience and expenses associated with the experimental investigations, it is always desirable to have numerical estimation of their responses. To analyze the flexural behaviour of laminated structures, shear deformation theories must be adopted because laminate composites undergo small strain and large deformation under various loads. In addition, the nonlinearity in the geometry must be considered during their numerical analysis.

Many attempts have already been made in past to investigate the linear/nonlinear flexural behavior of laminated composite flat panels by using various existing and refined shear deformation theories. With a view to predict the flexural responses more accurately, many theories have been evolved since past few decades such as Classical Laminated Plate Theory(CLPT), First order Shear Deformation Theory(FSDT), Higher order Shear Deformation Theory(HSDT). CLPT is a straightforward development of the classical Kirchhoff plate theory(CPT), thus neglecting the transverse shear effect. The FSDT and the HSDT incorporate the effect of shear deformation and provide more accurate prediction of structural behavior than CLPT. In FSDT, linear displacement and constant transverse shear strain/stress are assumed through the plate thickness and shear correction factors are required for actual stress states through the layer thickness. However, the FSDT is capable of giving very accurate prediction of gross structural responses for most of the laminated composite structures. By using the HSDT, more accurate approximations of the transverse shear effect can be obtained in which higher-order polynomials are used to represent displacement components through the thickness of the laminates and shear correction factors are not required. However, complexities in formulation and large computational effort make them computationally unattractive. Putcha and Reddy (1986) developed a mixed shear flexible finite element model (FEM) to observe linear and geometrically nonlinear responses of layered anisotropic plates blending the HSDT and von-Karman nonlinear kinematics. Argyris and Tenek (1994) investigated the linear and geometrically nonlinear bending behaviour of isotropic and multi-layered composite plates. Zhang and Kim(2005) proposed a simple displacement based three nodes 18 degree of freedom flat triangular plate/shell element for linear and geometrically nonlinear bending behaviour of thin and thick laminated composite plates. Zhang and Kim (2006) developed two displacement-based four noded quadrilateral elements (20 and 24 degrees of freedom) in the frame work of the FSDT and von-Karman nonlinearity, to analyze the linear and geometrically nonlinear responses of thin to moderately thick laminated composite plates. Zhang and Yang (2006) developed four-noded flat quadrilateral element having 24 degrees of freedom to analyse the linear and nonlinear bending behaviour of laminated composite flat plates and shells. They have developed the model based on the FSDT and Timoshenko's laminated composite beam functions. Dash and Singh(2009) studied the flexural behavior of laminated composite plates using Green Lagrange nonlinerity. Mahapatraet al. (2016) investigated nonlinear flexural responses of laminated curved panel by employing the newly developed nonlinear mathematical model, based on the HSDT and Green Lagrange nonlinearity. Reddy et al. (2012) investigated the bending behaviour of simply supported laminated composite plate under uniformly distributed load using FEM. A trigonometric layer-wise FE formulation was established by Mantari et al. (2012) for the flexural analysis of thick laminated composite plates following HSDT. Ahmed et al. (2013) presented static and dynamic analysis of Graphite /Epoxy composite plates under transverse loading by using an 8-node iso-parametric quadratic element based on the FSDT. Chen et al. 2012 proposed a model for composite laminated plate based on the HSDT and new modified couple stress theory.

It is evident from the above review that, numerous attempts have already been made in past regarding the theoretical developments, analytical/numerical solutions of linear/ nonlinear bending analysis of laminated composite plates/shells. The objective of the present investigation is to study the linear and nonlinear responses of laminated composite flat panel under uniform distributed loading condition using ANSYS and to study the responses of this laminated composite flat panel under different parameters such as thickness ratio, aspect ratio, support condition and laminate scheme.

## 2. FORMULATION

In ANSYS Mechanical APDL, there are many elements types available to model layered composite materials. For present analysis SHELL281 (8-Node Structural Shell) element has been taken. To analyze thin to moderately thick shell structures SHELL281 is suitable. This element contains eight nodes having six degrees of freedom at each node: translations along the x, y and z axes, and rotations about x, y and z-axes. SHELL281 is satisfactory results for linear, large rotation, and/or large strain nonlinear solutions. This element accounts for load stiffness effects of distributed pressure. For modeling composite shells or sandwich structure SHELL281 is very well suited. First-order shear-deformation theory governs the accuracy in modeling composite shells. Formulation of this element is based on logarithmic strain and true stress measures. The element kinematics allow for finite membrane strains (stretching). However, the curvature changes within a time increment are assumed to be small. The following Fig. shows the geometry, node locations, and the element coordinate system for this element. The element is defined by shell section information and by eight nodes (I, J, K, L, M, N, O and P). Midside nodes may not be removed from this element. A triangular-shaped element may be formed by defining the same node number for nodes K, L and O.

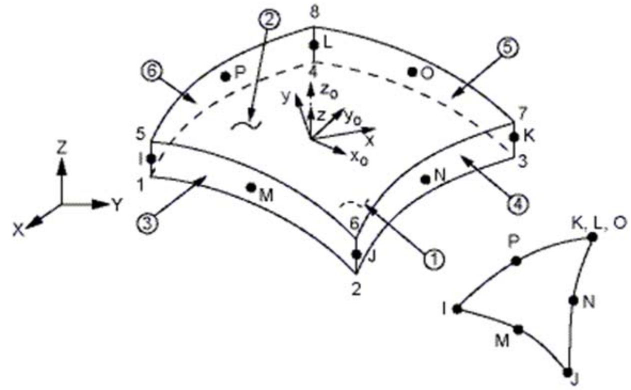


**Fig. 1: SHELL281 Geometry (ANSYS 15.0)**

A typical example of laminated flat plate composite panel is presented in Fig. 2. The panel consists of N number of uniformly thick orthotropic layers of length a, width b and thickness h has been considered for present analysis. Based on the FSDT, the displacement components u, v and w along x,y and z directions can be expressed by the corresponding mid-plane displacement components $u^0, v^0, w^0$ and rotaion of the mid-plane normal arround the x and y axes $\theta_x$, $\theta_y$ as

$u(x,y,z)=u^0(x,y)+z\,\theta_x(x,y)$,

$v(x,y,z)= v^0(x,y)+z\,\theta_y(x,y)$,

$w(x,y,z)=w^0(x,y)$

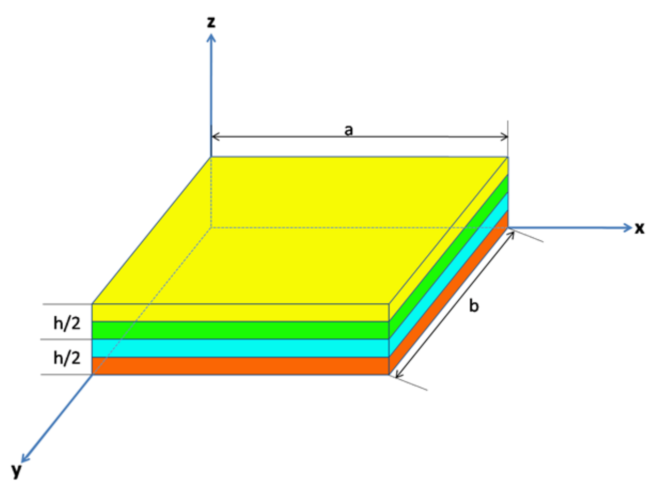


**Fig. 2: Laminated composite flat panel**

The strain vector $\varepsilon=\{\varepsilon_x \varepsilon_y \varepsilon_{xy}\}^T$

$\varepsilon=\varepsilon_m+z\varepsilon_b$

where, $\varepsilon_b=\left(\dfrac{\delta\theta_x}{\delta x} \quad \dfrac{\delta\theta_y}{\delta y} \quad \dfrac{\delta\theta_x}{\delta y}+\dfrac{\delta\theta_y}{\delta x}\right)^T$

for linear analysis,

$$\varepsilon_m = \left( \frac{\partial u_0}{\partial x} \quad \frac{\partial v_0}{\partial y} \quad \frac{\partial u_0}{\partial y} + \frac{\partial v_0}{\partial x} \right)^T$$

For nonlinear analysis,

$$\varepsilon_m = \left( \frac{\partial u_0}{\partial x} + \frac{1}{2}\left(\frac{\partial w}{\partial x}\right)^2 \quad \frac{\partial v_0}{\partial y} + \frac{1}{2}\left(\frac{\partial w}{\partial y}\right)^2 \quad \frac{\partial u_0}{\partial y} + \frac{\partial v_0}{\partial x} + \frac{\partial w}{\partial x}\frac{\partial w}{\partial y} \right)^T$$

## 3. RESULTS AND DISCUSSIONS

The linear and nonlinear flexural responses of laminated composite flat panels have been obtained by developing a model using APDL code, in ANSYS 15.0 environment. First of all, the convergence and validation behaviour of the developed model has been established by solving different examples available in open literature. Finally, numerous parametric studies have been presented for laminated composite plates and their significance has been discussed in details.

### 3.1 Convergence Study

A clamped 4-layer symmetric cross-ply [$0^o/90^o/90^o/0^o$] laminated composite square plate with geometry, material properties and support conditions similar to Zhang & Kim (2006) is considered. Flexural responses are computed under five different load values ($q_o$= 0.4, 0.8, 1.2, 1.6 and 2.0) and plotted with various mesh refinements in Fig. 3. It is clearly observed that the results are converging well and 12×12 mesh is found to be suitable to obtain responses further.

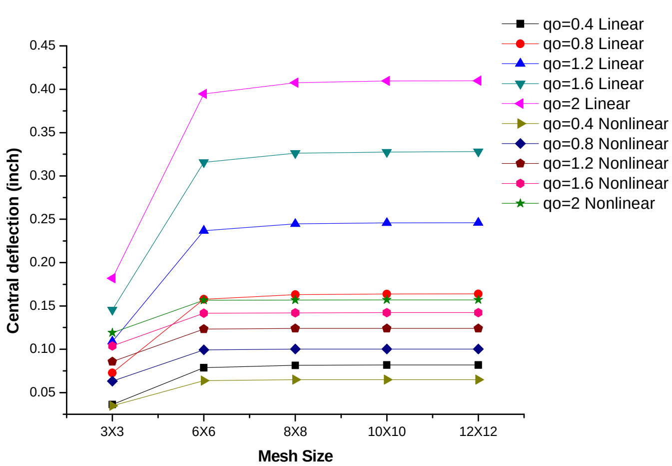


**Fig. 3: Convergence behaviour of linear and nonlinear central deflection of laminated composite flat panel**

### 3.2 Comparison Study

The example considered for the convergence study is further extended for the validation study. The linear and nonlinear transverse central deflections are computed using the present model and shown in Fig. 4 along with the results of Putcha and Reddy (1986) and Zhang and Kim (2006).It is clearly seen that the present results are showing excellent agreement with the available data.

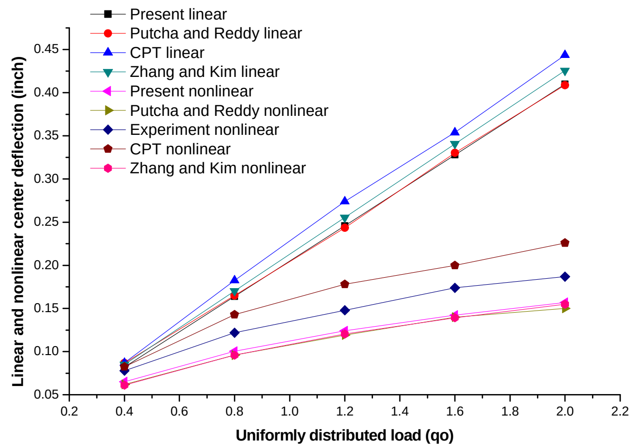


**Fig. 4: Comparison study of linear and nonlinear bending responses of clamped 4-layer symmetric cross-ply square plate subjected to uniform distributed load.**

### 3.3 Numerical Illustrations

In order to evaluate the effect of geometrical parameters and boundary conditions on the bending responses of laminated composite flat panels, some new examples are solved. The material properties of composites are taken as: $E_x$=12604.9953 N/mm$^2$, $E_y$=12627.748 N/mm$^2$, $G_{xy}$=$G_{xz}$=$G_{yz}$=2154.6117 N/mm$^2$, $\mu_{xy}$=0.23949. The centre deflection and the load parameter are non-dimensionalised as $w_{nondimensional}$= w/h and $Q=q_o a^4/E_y h^4$.

**3.3.1 Effect of thickness ratio(a/h):** A clamped 4-layer symmetric cross-ply square plate [$0^0/90^0$]$_s$ having side length of plate a=100mm is subjected to uniformly distributed load ($q_o$). Nondimensional central deflection are computed for four thickness ratio(a/h=10, 30, 60, 100 and 125) and presented in Fig. 5. It is observed that both the linear and nonlinear deflection values are more for thicker plates in comparison to thinner ones. It is due to the fact that the transverse shear stress and the membrane stresses are dominant in case of the thick panel in comparison to the thin panel.

**3.3.2Effect of aspect ratio (a/b):** In this example the effect of aspect ratios (a/b=1, 1.5, 2 and 2.5) on the non-dimensional linear and nonlinear bending responses of thin (a/h=80) clamped anti-symmetric angle-ply [$45^0$/-$45^0$]$_2$ laminated composite flat panel under uniform distributed load parameter has been investigated. The variation of non-dimensional centre deflection with load parameter has been presented in Fig. 6. It is observed that as the aspect ratio (a/b) increases both linear and nonlinear central deflection values decrease. This is expected because the load per unit area of plate decreases with increase in the aspect ratio.

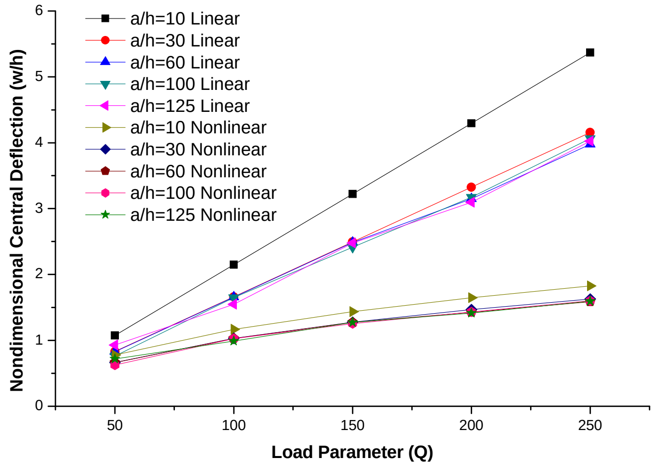


**Fig. 5: Effect of thickness ratio(a/h) on the non-dimensional linear and nonlinear centre deflection of laminated composite flat panel.**

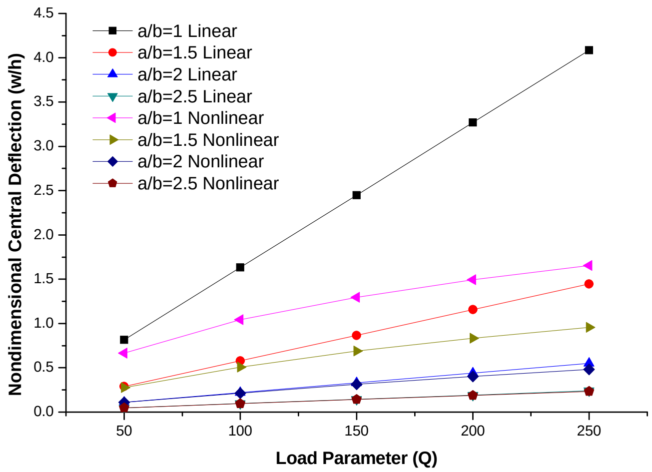


**Fig. 6: Effect of aspect ratio(a/h) on the non-dimensionallinear and nonlinear centre deflection of laminated composite flat panel.**

**3.3.3Effect of support conditions:** The effect of support conditions (SSSS, CCCC, HHHH and SCSC) on the linear and nonlinear flexural responses of laminated composite flat panel is investigated in this section. An anti-symmetric cross-ply $[0^o/90^o]_2$ laminated composite square plate (a/h=50) is considered under uniformly distributed load and the non-dimensional centre deflection are presented in Fig. 7. It is observed that the non-dimensional central deflections are lowest for clamped and highest for simply-supported case. This is due to the fact that as the number of constraints decreases, the stiffness of the structure decreases and the deflection value increases monotonically.

**3.3.4Effect of lamination scheme:** The stacking sequence is a vital factor in deciding the stiffness of the laminated structure. In order to investigate the effect of lamination scheme on the non-dimensional centre deflection, symmetric/anti-symmetric cross-ply and angle-ply laminated composite square plate (a/h=20) under alternate clamped and simply supported condition is considered. The variation of non-dimensional linear and nonlinear centre deflection under various uniformly distributed load parameters is presented in Table5 (a) and (b), respectively. It is interesting to note that the flexural responses for symmetric lamination scheme is more than the anti-symmetric for cross-ply whereas reverse trend is observed in case of angle-ply lamination scheme.

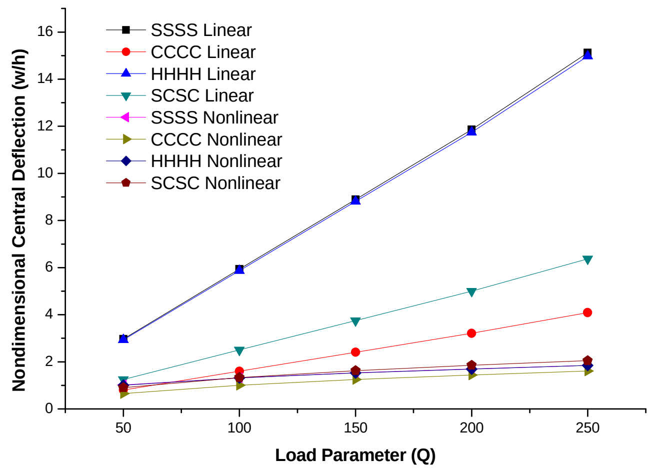


**Fig. 7: Effect of support condition on the non-dimensional linear and nonlinear centre deflection of laminated composite flat panel.**

**Table 5(a)-Effect of lamination scheme on the non-dimensional linear centre deflection of laminated composite flat panel.**

| Lam. Scheme | Linear Solution | | | | |
|---|---|---|---|---|---|
| | Load parameter=Q | | | | |
| | 50 | 150 | 250 | 350 | 450 |
| **[0/90]s** | 1.3457 | 4.0338 | 6.7219 | 9.4100 | 12.1015 |
| **[0/90]2** | 1.3453 | 4.0324 | 6.7196 | 9.4067 | 12.0973 |
| **[60/-60]s** | 1.3206 | 3.9585 | 6.5963 | 9.2342 | 11.8754 |
| **[60/-60]2** | 1.3289 | 3.9832 | 6.6376 | 9.292 | 11.9497 |

**Table 5(b)-Effect of lamination scheme on the non-dimensional nonlinear centre deflection of laminated composite flat panel.**

| Lam. Scheme | Nonlinear Solution | | | | |
|---|---|---|---|---|---|
| | Q | | | | |
| | 50 | 150 | 250 | 350 | 450 |
| **[0/90]s** | 0.9395 | 1.6776 | 2.1003 | 2.4027 | 2.6545 |
| **[0/90]2** | 0.9393 | 1.6775 | 2.1001 | 2.4018 | 2.6518 |
| **[60/-60]s** | 0.9398 | 1.7001 | 2.1356 | 2.4582 | 2.7209 |
| **[60/-60]2** | 0.9428 | 1.7035 | 2.1356 | 2.4620 | 2.7257 |

## 4. CONCLUSION

The linear and nonlinear flexural responses of laminated composite flat panel have been analysed using FEM. The panel model is based on the FSDT and von-Karman nonlinear strain and responses are computed using APDL code in

ANSYS 15.0 environment. After convergence and validation of the present model few new examples are worked out to investigate the effect of various parameters on the flexural behavior of the laminated composite flat panel. Based on the parametric studies some useful inferences are brought out and discussed in details. It is observed that both the linear and nonlinear transverse central deflection of laminated composite flat panel decrease with increase in thickness ratio, aspect ratio and number of constraints at the support. It is worthy to note that the flexural responses for symmetric lamination scheme is more than the anti-symmetric for cross-ply whereas reverse trend is observed in case of angle-ply lamination scheme.

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