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Prediction of Nonlinear Behavior Of Thin Skew Plates With Cut-Out Using Finite Element Analysis

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Abstract

The present research work deals with the prediction of geometric nonlinear behavior of a thin five-layered symmetric cross-ply Fiber Reinforced Plastic (FRP) skew laminated composite plate with circular cutout at the geometric centre of the plate subjected to uniform transverse pressure loading using Classical Laminate Theory (CLT) based finite element method. The problem is simulated in finite element software ANSYS for the prediction of transverse deflection and in-plane stresses after proper validation. The importance of geometric nonlinear analysis of skew plate based on the FE results is discussed. The present analysis is useful for the safe and efficient design of skew laminates with circular cutouts that find applications in the slender structures in aerospace, civil and mechanical engineering.

1. Introduction

Skew plates are often used in civil, marine, aeronautical and mechanical engineering applications. Swept wings of aero planes can be idealized by introducing substitute structures in the form of skew plates. Complex alignment problems in bridge design are often solved by the use of skew plates due to functional, aesthetic or structural requirements. Various other applications of skew plates can be found in ship hulls, as well as parallelogram slabs in buildings. Study of skew plate is interesting and challenging due to mathematical complexity involved in the analysis. In addition, several factors such as geometry, loading, constraints, material arrangement causes for the nonlinear behavior of FRP laminate. The stiffness matrix calculated for the structure from finite element method related to the load and response is assumed to be constant for linear static analysis. In nonlinear analysis, the stiffness matrix consisting of geometric and material parameters will be updated after execution of problem at each load step by the deformed structure configuration and solved for the next load step. Neglecting nonlinear effects may lead to serious design errors. Good number of papers are published on the nonlinear design of the structures which are highly related to present work. Hsuan-Teh Hu, Chia-Hao Yang, Fu-Ming Lin [1] determined nonlinear material constitutive model, including a nonlinear in-plane shear formulation and the Tsai–Wu failure criterion, for fiber–composite laminate materials is employed to carry out finite element buckling analyses for composite laminate skew plates under uniaxial compressive loads. The influences of laminate layup, plate skew angle and plate aspect ratio on the buckling resistance of composite laminate skew plates are predicted. A.H. Sheikh, M. Mukhopadhyay [2] predicted the behavior of geometric nonlinear analysis of stiffened plates by the spline finite strip method. Von's nonlinear plate theory is adopted and the formulation is made in total Lagrangian coordinate system. Plates and stiffened plates are analyzed and the results are presented along with those of other investigators for necessary comparison and discussion's. Sarath Babu , T. Kant [3],evaluated two shear deformable finite element models, one based on first-order shear deformation theory and the other based on a higher order shear deformation theory, are developed for buckling analysis of skew laminated composite and sandwich panels. R. L. Wankhade [4] performed the work on geometric nonlinear analysis of skew plates which has become essential due to its wide use in modern structural applications. Sridhara Raju.

V.V , BalaKrishna Murthy. V [5], at all predicted the effect of thickness ratio of the laminated composite plate influence on stiffness and stresses of the plate. Y.X. Zhang a, C.H. Yang [6] reviewed of the recent development of the finite element analysis for laminated composite plates from 1990 is presented in there paper.

The aim of the current work is to perform the static linear and static geometric nonlinear analysis of the Hybrid FRP thin skew laminates with cutout to evaluate the stresses and transverse deflection in the clamped skew laminates which is subjected to uniform transverse pressure load with five layered symmetric cross-ply laminates ($0^0/90^0/0^0/90^0/0^0$).

2. Problem Formulation

The geometry of the problem is shown in Fig. 1. The side of the plate ‘l’ is taken as 20mm and five layers are considered with total thickness (h) of 0.5mm, so that the length to thickness ratio becomes ‘s’=40. The skew angle α is taken as a value varying from 0^0 to 60^0. A circular hole is placed at the geometric center of the plate. The size of the cutout is taken as per the ratio d/l equal to 0.2.

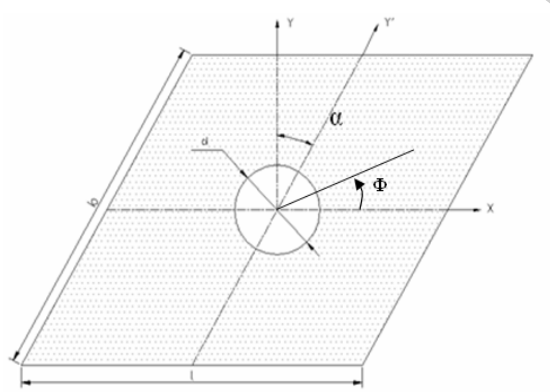

Fig1.A skew composite plate with circular cut-out

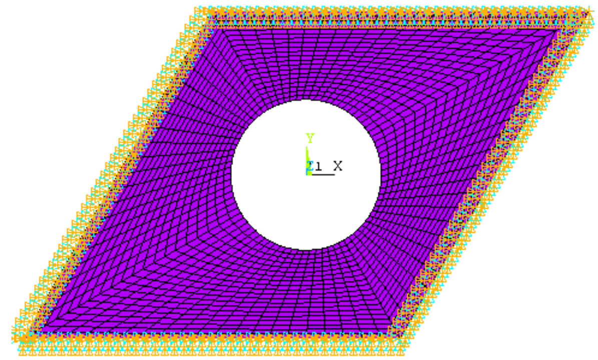

Fig.2. Finite element mesh on skew plate

2.1 Element Type

A laminated composite general shell element (nonlinear layer 91 of ANSYS software) is used for meshing the geometry of the problem. This element is suited for modeling moderately thin FRP laminates. This element has nonlinear and large strain capabilities. This element consists of number of layers of perfectly bonded orthotropic materials. The element is quadratic and has six degrees of freedom per node namely, translations in x, y and z directions respectively, and rotations about x, y and z axes respectively. .

2.2 Loading, Boundary conditions

All the sides of the skew plate are clamped. The skew laminate is subjected to the transverse pressure load of 5MPa.

2.4 Material Properties

The materials selected to carry out the present work are Boron-epoxy and Graphite-epoxy. The material properties are given in Table 1. [ ]

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Table.1. Material Properties

	Boron-epoxy	Graphite-epoxy
E_1 (GPa)	241.87	141.68
E_2 (GPa)	25.51	12.38
E_3 (GPa)	25.51	12.38
ν_{12}	0.254	0.258
ν_{23}	0.265	0.421
ν_{13}	0.254	0.258
G_{12} (GPa)	6.72	3.88
G_{23} (GPa)	10.08	4.36
G_{13} (GPa)	6.72	3.88

3. FE Model Convergence

To validate the finite element results, a five layered skew FRP laminate having a circular cutout at centre with clamped edges and applied pressure (5 MPa) on top surface is considered. The out-of-plane normal stresses at the top and bottom surfaces of the plate are calculated. The stresses at the top face of the plate are approximately equal to the applied load and the stresses at the bottom side the plate are almost equals to zero. Hence the present FE model is validated.

3.1 Analysis of results: The nonlinear static analysis is performed by the applying the load in steps of regular intervals on skew plate the with Graphite-epoxy (0)/Boron-epoxy (90)/Graphite-epoxy (0)/Boron-epoxy (90)/Graphite-epoxy (0) stacking sequence and compared with linear response. A clear variation in the displacements is observed from the load 2MPa.

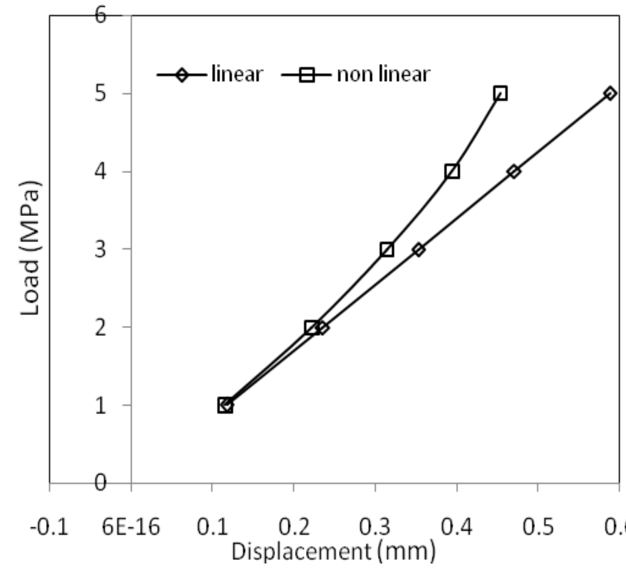

Fig.3. Variation of linear and nonlinear de flection with respect to the load

As it is observed that the response of the structure is not linear at 5MPa load, the normal stresses are calculated by varying the skew angle of the laminated plate.The variation of normal stresses by varying the skew angle (θ) of the composite plate by considering 4 cases which are listed in Table

Table. 2. Reinforced materials with stacking sequence

	Case1	Graphite epoxy(0)/Boron epoxy(90)/Graphite epoxy(0)/Boron (90)/Graphite epoxy (0)
	Case2	Graphit eepoxy(90)/Boron epoxy (0)/Graphite epoxy(90)/Boronepoxy (0)/Graphite epoxy (90)
	Case3	Boron epoxy(0)/Graphite epoxy(90)/Boron epoxy (0)/Graphite epoxy (90)Boron epoxy (0)
	Case4	Boron epoxy (90)/Graphite epoxy (0)/Boron epoxy (90)/Graphite epoxy (0)Boron epoxy (90)

The variation of normal stress σ_x for case 1 by varying the skew angel is shown in (Fig. 4.). It is observed that values in the graph decrease as the skew angle increases from 10^0 to 60^0 and as the skew angle increases the difference between the normal stresses obtained from the linear and nonlinear analysis is decreased. This is due to the increase in resultant stiffness of the structure with increase in skew angle.

And at the skew angle of 50^0 and 60^0 no variation in these analyses is observed. Fig. 5. Shows the variation of normal stress in case 2 for all considered skew angles. In this case no variation is observed between linear and non linear analysis from the skew angle of the plate at 30^0 to 60^0. Similar type of graph is plotted for case 3 and 4 (Fig.6 and 7). Deviation between linear and nonlinear is ended at 40^0 in case 3 and 30^0 in case 4.

The variation of σ_y for case 1 is shown in Fig. 8. From this it is observed that at 50 and 60^0 skew angles the both static analysis are revealed the same response. Fig. 9-11, shows the variation of σ_y in other three cases similar type of response is obtained as in case 1. The variation of shear stresses in considered four cases are shown in Fig. 12-15. It is observed that magnitudes of shear stress are lower than normal stresses and clear deviation in both analyses is obtained in all cases.

Fig. 16 shows the variation of displacements in linear and nonlinear static analysis it is observed that considered difference between both analysis in all cases except at 50^0 and 60^0 skew angles. As the skew angle of the plate increases the displacement of the skew plate is decreased. The maximum difference between the displacement obtained from linear and nonlinear analysis is observed at 0^0 and 10^0 and as the skew angle of the plate is increased the magnitude of the difference is decreased and at the last there is no difference is observed in both the analysis at 50^0 and 60^0.The same graph is plotted for other three cases; same type of response is obtained as in the case 1.

Difference between linear and nonlinear analysis is observed from the skew angle of the plate from 0^0 to 30^0 later no considerable change in both analysis is obtained Fig. 17-19.

3.2RESULTS

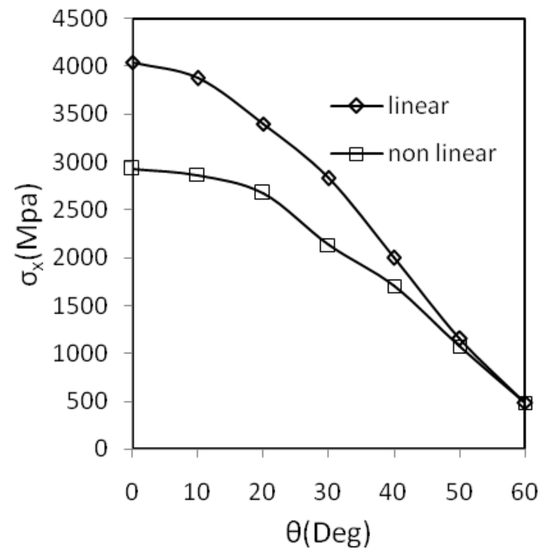

Fig.4. Variation of σ_x with θ (case 1)

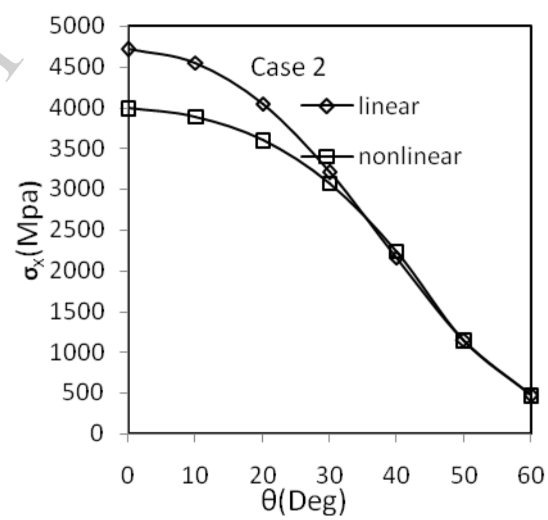

Fig.5. Variation of σ_x with θ (case 2)

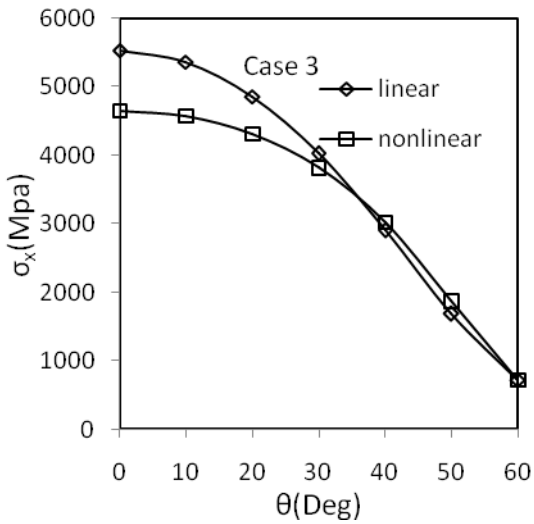

Fig.6. Variation of σ_x with θ (case 3)

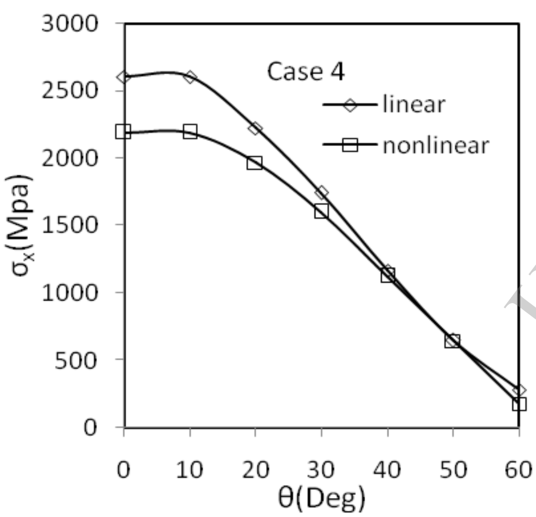

Fig.7. Variation of σ_x with θ (case 4)

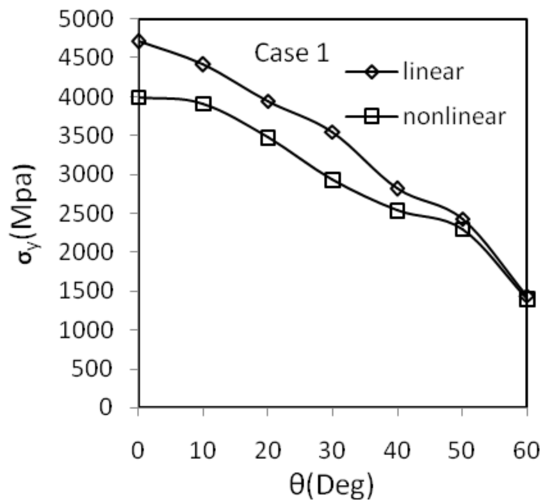

Fig.8. Variation of σ_y with θ (case 1)

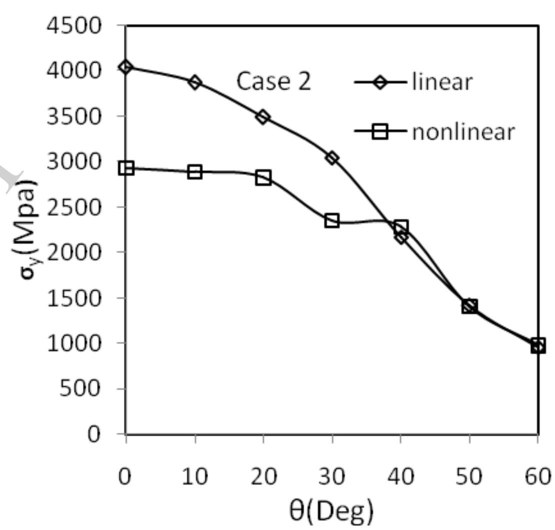

Fig.9. Variation of σ_y with θ (case 2)

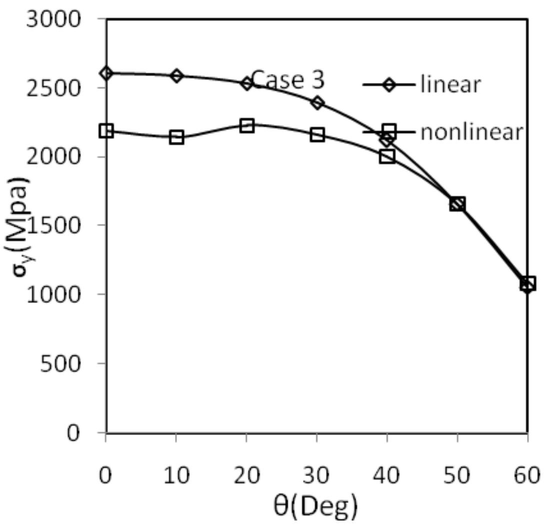

Fig.10. Variation of σ_y with θ (case 3)

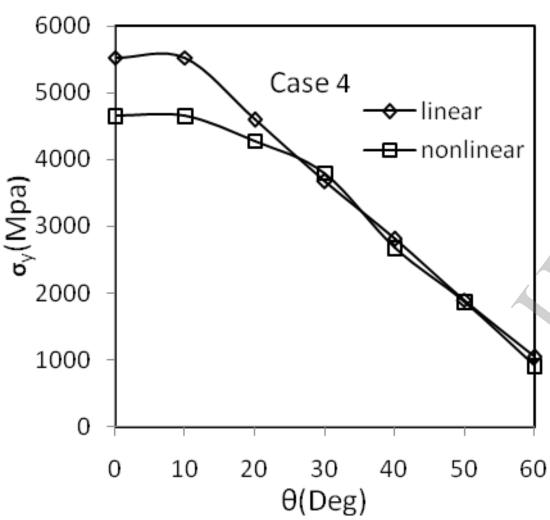

Fig.11. Variation of σ_y with θ (case 4)

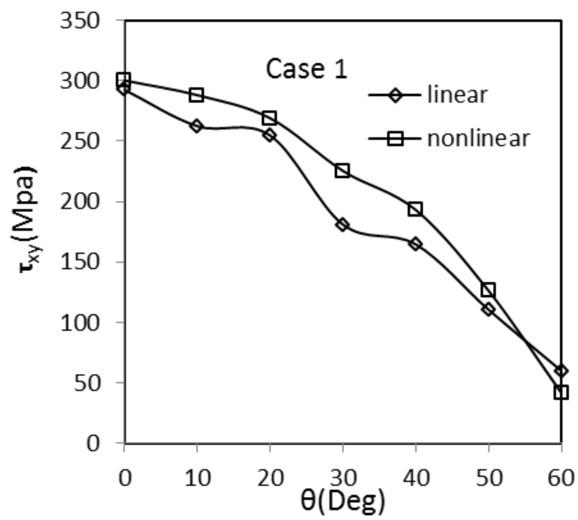

Fig.12. Variation of $\tau_{xy\,y}$ with θ (case 1)

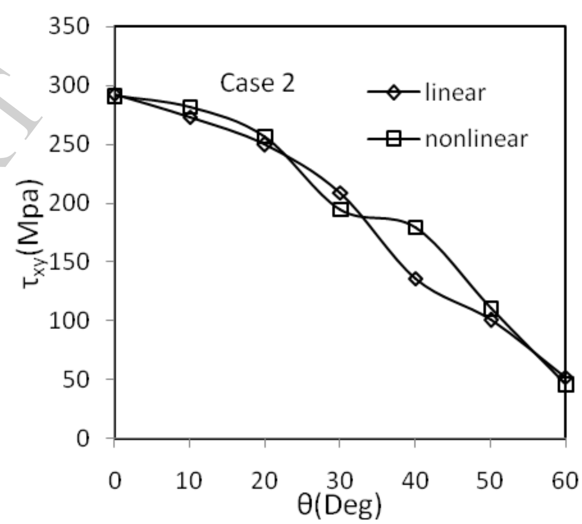

Fig.13. Variation of τ_{xy} with θ (case 2)

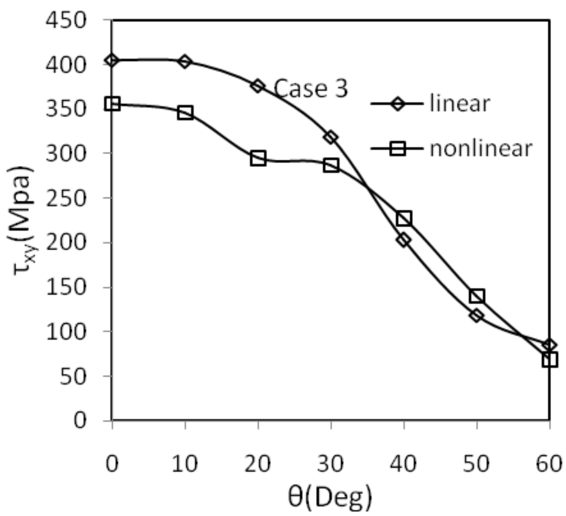

Fig.14. Variation of τ_{xy} with θ (case 3)

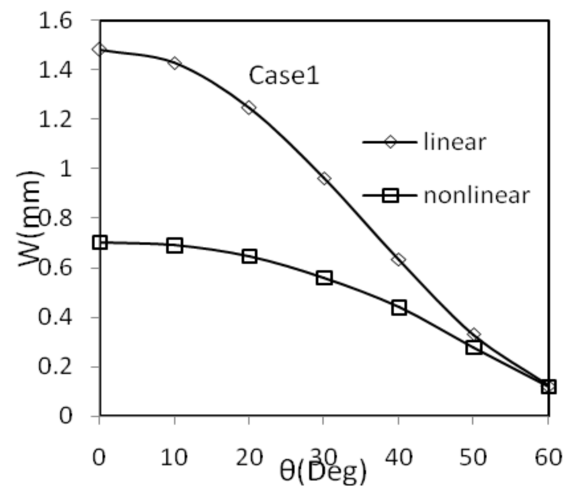

Fig.16. Variation of "W" with θ (case 1)

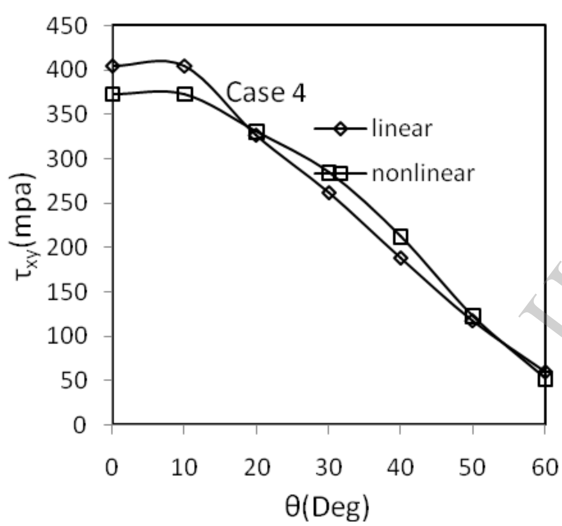

Fig.15. Variation of τ_{xy} with θ (case 4)

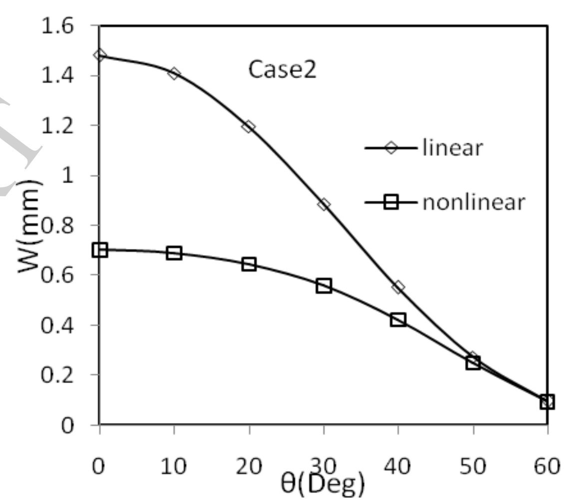

Fig.17. Variation of "W "with θ(case 2)

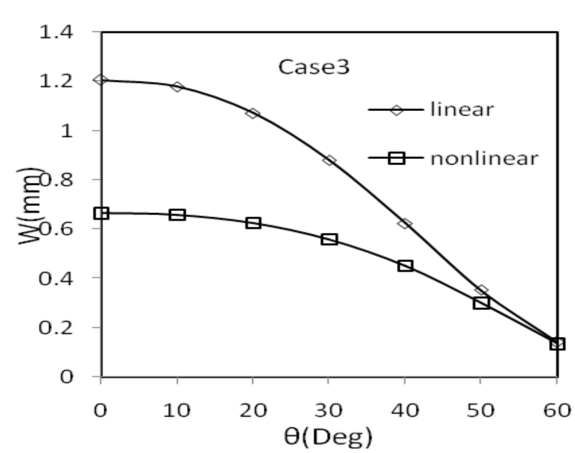

Fig.18. Variation of “W” with θ (case 3)

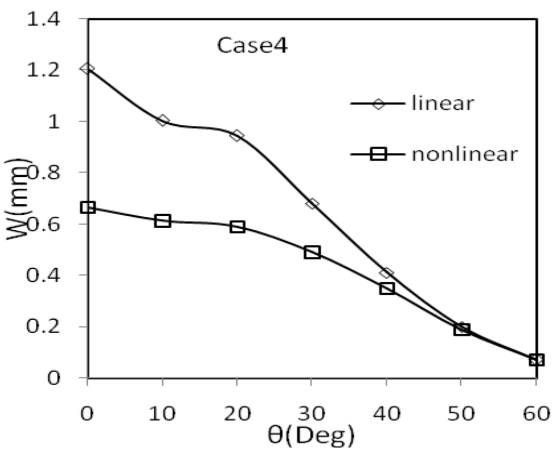

Fig.19. Variation of “W “with θ(case 4)

4. Conclusions: The importance static nonlinear analysis is predicted by varying the skew angle of the composite laminate with different materials.

- The stresses and deflections are evaluated and it is observed that as the skew angle increases the stresses and the deflections decrease both in linear and nonlinear analysis.
- As Boron material properties are better than the Graphite, so the skew laminates with three Boron materials and two Graphite materials have the least values of the deflection. (Case 3 and case 4).
- Nonlinear analysis is required for the skew laminated composites for the angle of skew (θ) from 0^0 to 30^0 for better design

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