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NUMERICAL STUDY ON COMPOSITEPANEL SUBJECTED TO TRANSVERSE LOADING

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Abstract
Bending analysis of laminated composite stiffened panels is conducted by finite element (FE) models. The trapezoidal stiffened panel is fabricated with 13 layers of CFC/epoxy laminated composite material of equal thickness, arranged in angle ply and cross-ply. The stiffened panel is subjected to a uniformly distributed load on the panel with simply supported boundary conditions.FE models have been analyzed using ABAQUS and a parameter is prepared with variation of inclination of trapezoidalstiffeners, changing the layup sequence and thickness of plies of laminated composite stiffened panel. Based on the studies, a few important parameters influencing the bending behavior of the stiffened panel are identified and guidelines for better trapezoidalstiffened panels are developed. Also, the central displacement of the simply supported panel has been studiedwith a variation of the aspect ratio of the panel.
Key Words: Bending Behavior,Finite Element,Fiber Reinforced Polymer (FRP),TrapezoidalStiffeners

1. Introduction
Composite panels are used in multi-story buildings to reduce the dead load of the structure likepartition walls,roofs, and out walls of the building. The stability of the plate increases with the increase in the thickness of the platebut a more economical solution is obtained by keeping the thickness of the panel as small as possible and inducing the stiffeners.The design of the stiffened panel is governed both by the stability and strength criterion of the panel. Stiffened panels are used in structural applications because of their high stiffness and specific strength per unit weight of the panel.
Tripathy et al. (1994) presented the FE model and analytical model for the deflection and stress analysis of multi-cellular symmetrical composite laminate box beam.**Rikards et al.** (2001) developed a triangular finite element for FE analysis of laminated composites stiffened plates and shells. **Kant and Swaminathan (2002)** presented a theoretical model for the effects of transverse shear deformation, transverse normal strain stress, and a nonlinear variation of in-plane displacements.**Kalyanaraman and Upadhyay** (2003) discussed the behavior of FRP box girder and prepared a simplified computationally efficient method for the analysis of single-cell FRP box, girder bridges made of blade angle and T-stiffened panels.**Brochel and Prusty** (2004) carried out experimental studies on unstiffened and stiffened composite panels under uniform transverse loading..**Chang et al. (2005)** presented geometric parameters of corrugated-core sandwich plates and the lower ratios of h_c/t_c, t_c/t_f, and p/h_cmake the plate stronger. Optimum Sandwich plates should have the following properties tc is identical to t_f, the corrugation angle is between 45° and 70°, the ratio h_c/t_c is around 20 and the ratio p/h_c is between 1 and 1.2. **Girish and Ramachandra (2006)** presented numerical results for symmetric $0^0/90^0/0^0$ and antisymmetric $0^0/90^0$cross-ply laminated shell panels and illustrated the influence of mechanical edge loads, laterally distributed load, initial imperfection, and temperature field on the limit loads.**Santiuste** et al. (2010) analyzed the failure of composite laminated beams subjected to low-velocity impacts by an FE model implemented in ABAQUS/Explicit.**Patel and Gupta (2014)**obtained the non-local variables from corresponding local variables using layer-wise finite elements with quadratic through the thickness variation in each

layer.**Li et al. (2016)** presented an analytical model and balanced design approach for modeling lightweight wood-based structural panels in bending.
This paper presents the bending behavior of with a variation of inclination of trapezoidalstiffeners (ϴ), changing the layup sequence and thickness of plies of laminated composite stiffened panels.FEanalysis has been performed with two types of boundary condition of two sides simply supported as well asall four sides simply supported of the stiffened panel.

2. Modeling and configuration of composite panel

FEanalysis has been performed on stiffened composite panels with a variation of inclination of trapezoidalstiffeners (ϴ), changing the layup sequence and thickness of plies of laminated composite stiffened panels by using ABAQUS. Shell element S4R has been taken for analysis of the panel which has both bending and membrane capabilities. The element has six degrees of freedom at each nodal point. The structural geometry of the panel is shown in Fig. 1.The panel has a width of 1550 mm and a length of 3000 mm. 8 trapezoidal type stiffeners have 200 mm center-to-center spacing,50 mm depth of stiffeners, and top width of stiffener 50mm. Numerical studies have been carried out on laminated stiffened panels made with carbon fiber composite (CFC). Panelsare fabricated with 13 plies of30^0/-30^0angle ply, 45^0/-45^0angle ply, 60^0/-60^0angle ply, and 0^0/90^0cross-plywith a variation of thickness of laminated sheet of panel of 1.95 mm to 2.6 mm. The material property of CFC composite material is given in Table 1.

Table 1: CFC composite materials are used by (Kant and Swaminathan, 2002)

E_x (GPa)	E_y (GPa)	μ_{xy}	G_{xy} (GPa)	G_{xz} (GPa)	G_{yz} (GPa)	ρ(Kg/m^3)
131	10.34	0.22	6.895	6.895	6.205	1600

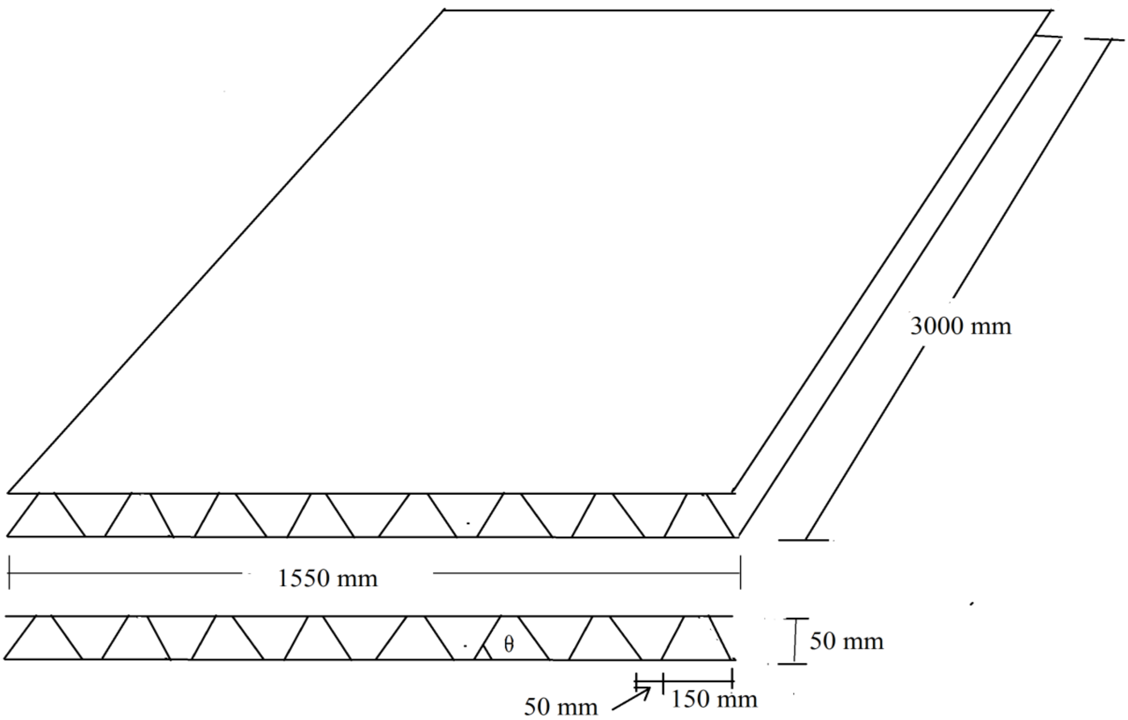

Fig. 1. Structural geometry of stiffened panel with ϴ° orientation of stiffeners

2.1 Validation Study

The bending behavior of composite sandwich plate is validated with the problem example of Kollar and Springer (2003), who studied composite plate of size 900 mm x 200 mm, core thickness 20 m, face thickness 2 mm, and ply configuration [(+45/-45)$_2$/0$_{12}$/(+45/-45)$_2$] of each ply thickness 0.1. The sandwich plate was subjected to uniform 500 kN/m^2 transverse loading with simply supported boundary conditions.The result of the central deflection of the sandwich plate is shown in Table 2. In the present study, the central deflection of the sandwich plate is .30 % more in compare to the analytical results of Kollar and Springer (2003).

Table 2.Validation of the FE model

Maximum Central deflection (mm)		%Difference
ABAQUS Result	Result by Kollar and Springer (2003)	
0.335	0.334	0.30

3. Results and Discussion

3.1 Panel with two sides simply supported and two sides freeboundary condition:

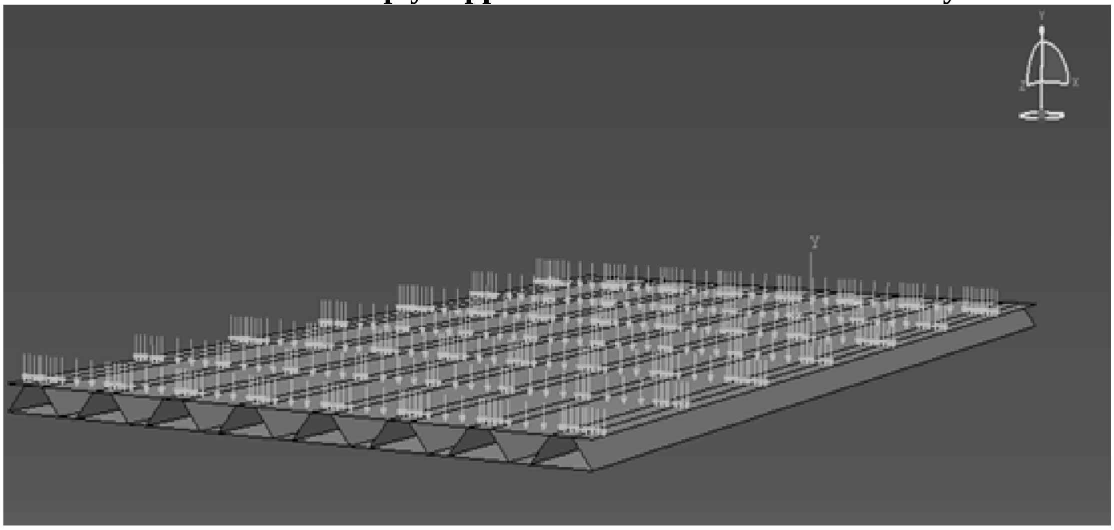

Fig. 2. Transverse loading with two sides simply supported and two sides free boundary conditions of panel

FE models areanalyzedwith boundary conditions of two sides simply supported and two sides free of panel.The bendingbehavior of composite stiffened panels is analyzed with the application of 1000 N/m^2 uniformly distributed load (UDL)on the panel as shown in Fig. 2. Laminatedstiffened panel is studiedwith four types of ply configuration for fivetypes of oriented angle of trapezoidal stiffeners of 33.7^0,45°, 60°,75°and 90°.The deformed shape of 60^{0}inclinedtrapezoidal stiffeners of panels with +60^0 / -60^0 angle plyis shown in Fig. 3. Central deflection of stiffened panels is almost constant with an increase in the inclination of trapezoidal stiffeners fordifferent ply configurations but in the case of 30^0/-30^0 configuration central displacement is decreased with increasing the inclination angle of trapezoidal stiffeners after 75^0 inclination of stiffeneras shown in Fig. 4. Minimum central displacement of panel is found in case of 0°/90° angle plies.

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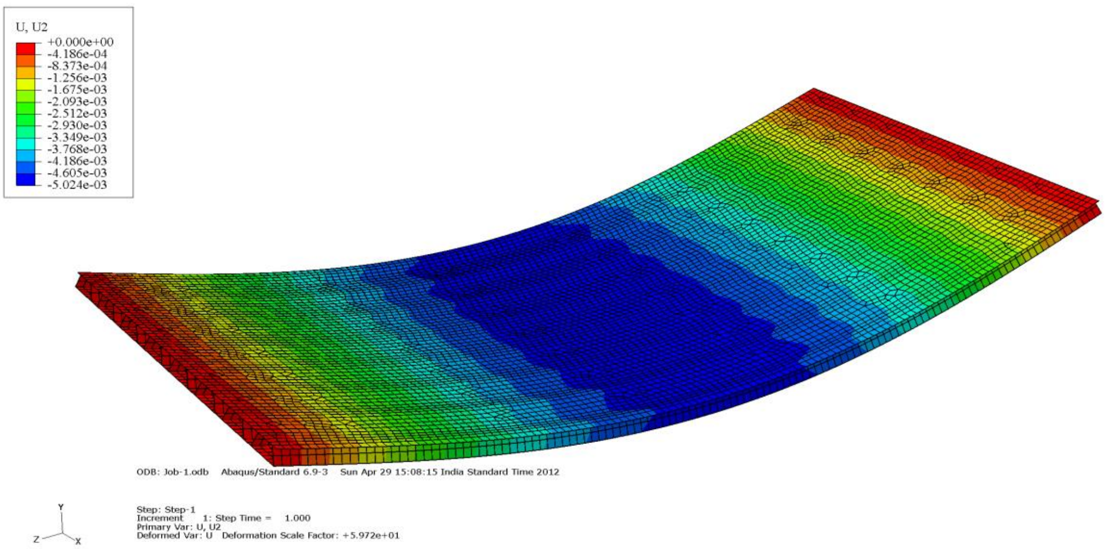

Fig.3. Deformed shape of 60^0 inclined trapezoidal stiffeners of panel with $+60^0$ / -60^0 angle ply

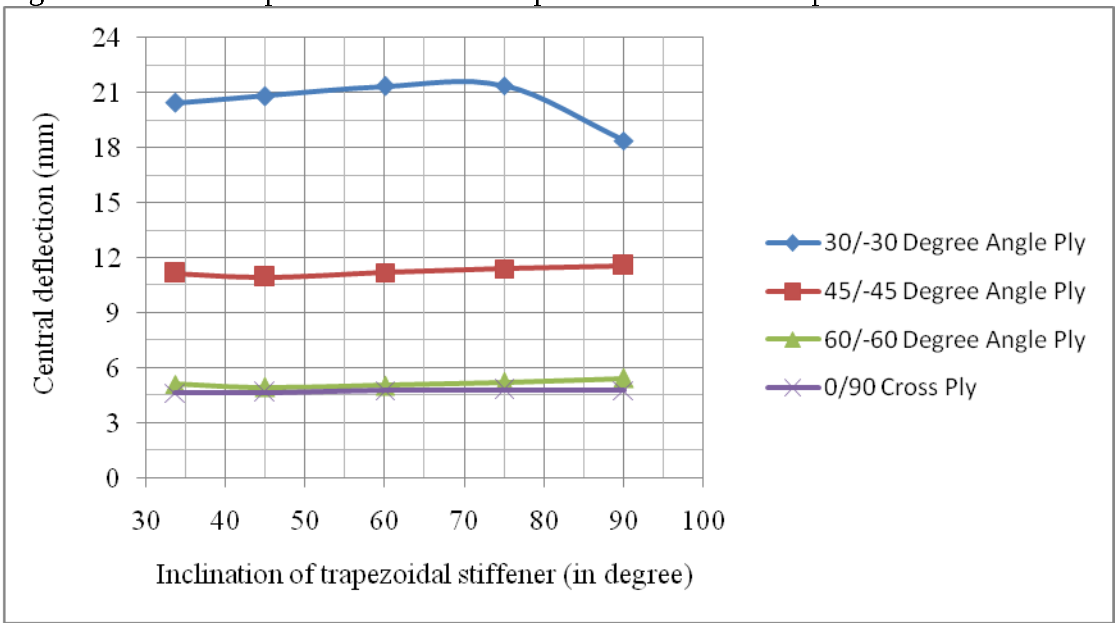

Fig.4.Variation of central deflection of panel.

3.2Panel with boundary condition of all four sides simply supported:

The bendingresponse of composite stiffened panels has been analyzed with an application of 10000 N/m^2 UDL transverse loading on the panel of all four sides simply supported. FRP stiffened panels have been studied with variations of configuration fordifferent trapezoidal stiffened panels.After analysis, the deformed shape of the panel is found.The central displacement of the panel is increased with the increase in the inclination of the trapezoidal stiffener for all plies configurations of the panel as shown in Fig. 5. For $0^0/90^0$cross-ply configuration, the minimum central displacement of the panel is observed up to 75^0 inclined of trapezoidal stiffeners after that the minimum of central displacement of the panel is found with $60^0/-60^0$plies configuration. Hence panel of33.7^0inclinedtrapezoidal stiffenershas been considered a more effective shape of trapezoidal stiffeners of panel with $0^0/90^0$ cross plyof all sides simply supported boundary condition.

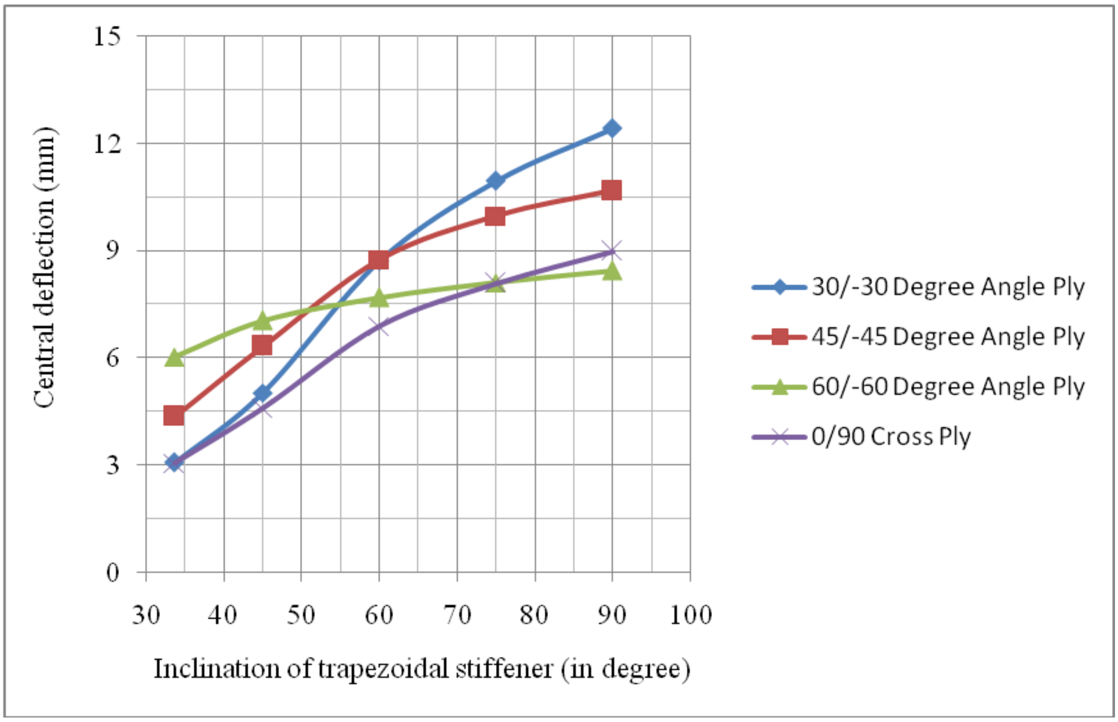

Fig.5 Variation of central deflection of panel with angle ply of face sheet for different orientation of stiffeners with all sides simply supported.

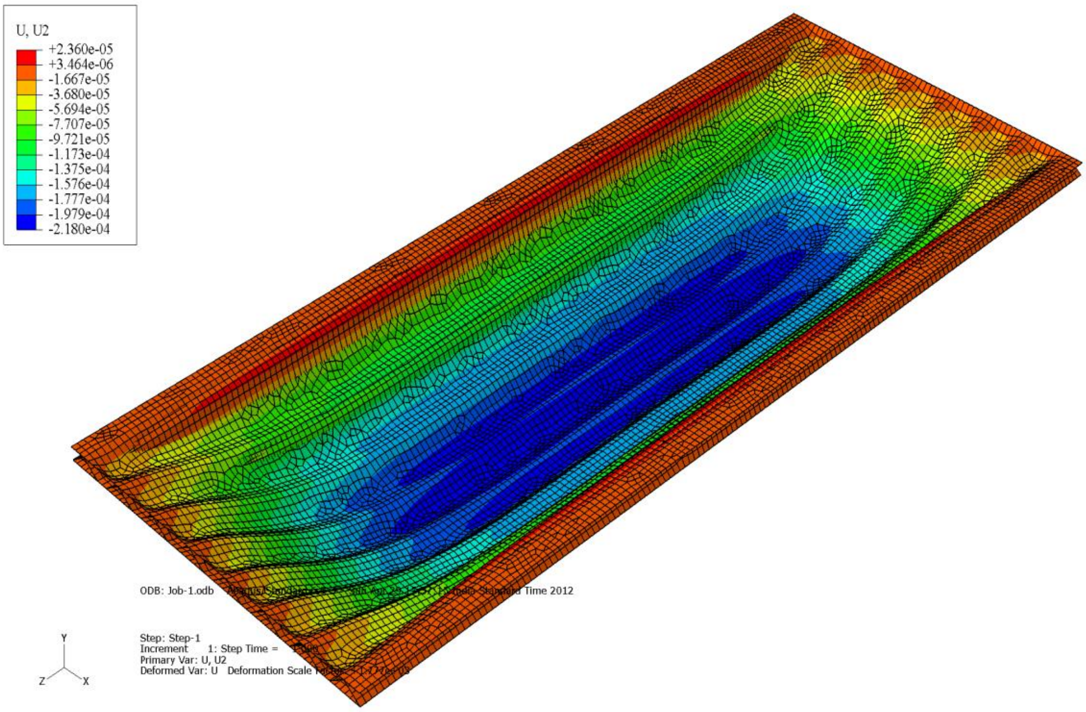

Fig. 6.Deformed shapeof 33.7^0 corrugated angle panelofaspect ratio 3 with 0^0 / 90^0 cross ply

3.3 Aspect Ratio of Panel

Central displacement of the panel of 33.7^0 inclined trapezoidal stiffeners has been analyzed with the aspect ratio of the panelfor30^0/-30^{0}angle ply, 45^0/-45^{0}angle ply, 60^0/-60^0 angle ply, and 0^0/90^{0}cross-ply configuration.Fig. 6 shows thedeformed shapeof 33.7^0 corrugated angle panel with 0^0 / 90^0 cross ply for aspect ratio 3 of the panel.Central deflection of the panel has been studied with a variation of the aspect ratio of the panel and it has been observed that central displacement increases with increasing the aspect ratio of the panel as shown in Fig. 7. Thecentral displacement of the panel has been found minimum with 0^0/90^{0}cross-ply configuration. Hence panel of 33.7^0 inclined trapezoidal stiffenerhas performed the best result with $0^0/90^0$cross-ply configuration for aspect ratio analysis of the stiffened panel.

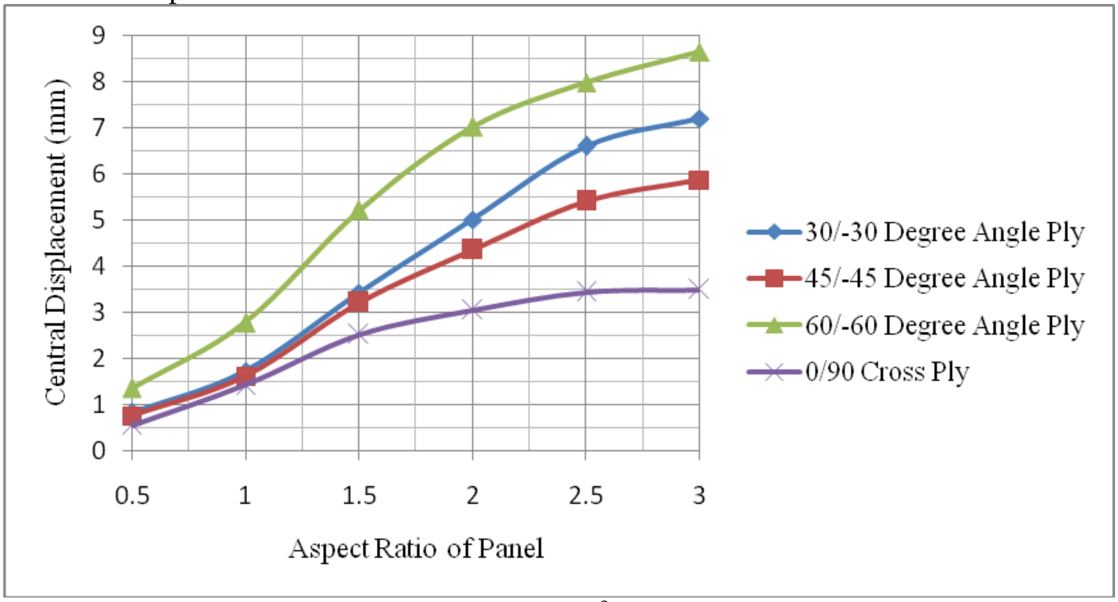

Fig. 7.Central displacement of a panel of 33.7^0 inclined trapezoidal stiffeners with an aspect ratio of the panel

4. Conclusions

Stiffened panels have been analyzed with a variation of trapezoidal stiffeners for different cases of simply supported boundary conditions.Stiffened panels have been studied due to the application of transverse loading on the panels with$30^0/-30^0$angle ply, $45^0/-45^0$angle ply, $60^0/-60^0$ angle ply, and $0^0/90^0$cross-ply configuration, and the following conclusions are drawn.

For a panel with a boundary condition of two sides simply supported and two sides free:

- Central deflections of stiffened panels areapproximately constant with an increase in the inclination of trapezoidal stiffeners for different ply configurations. But in the case of $30^0/-30^0$ configuration, central displacement is decreased with increasing the inclined angleafter 75^0 inclination of the trapezoidal stiffener.
- The minimum central displacement of the panel is found for 0°/90° cross-ply configuration.

For Panel with boundary conditions of all four sides simply supported:

- The minimum central displacement of the panel is found with $0^0/90^0$ cross-ply configuration up to 75^0 inclined of trapezoidal stiffeners after that the minimum central displacement of the panel is found with $60^0/-60^0$ plies configuration.
- A panel of 33.7^0 inclined trapezoidal stiffeners has performed the best result with a $0^0/90^0$ cross-ply configuration for the aspect ratio of the panel.

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