Static, Buckling and Free Vibration Analysis of Carbon Fiber Reinforced Polymer Stiffened Composite Plates

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Abstract— Stiffened composite plates have been widely employed in many disciplines of structural engineering, including bridges, decks, and ship hulls due to their ease of construction, outstanding strength to weight ratio, high energy absorption, and low manufacturing cost. Stiffeners are typically utilized to boost the plate's strength. The Carbon Fiber Reinforced Polymer (CFRP) stiffened plates are modelled in this paper with the stiffener parts randomly arranged in intricate planforms. The impact of the geometric layout of stiffeners on buckling capacity, static behavior, and vibration characteristics were investigated by analytical studies. The analysis of CFRP composite plates, both with and without stiffeners, is done using the finite element program ANSYS 16.0 APDL. The composite CFRP plates' dimensions and simply supported boundary condition are the same for all combinations .The study uses a T-shaped stiffener with [0/90/45/-45] fiber orientation on the plate. The conclusion drawn from the data is that the CFRP plate's having two transverse stiffener spaced 300mm from center has a larger buckling load coefficient than its longitudinal stiffener. Comparative analysis is done between CFRP plates that have stiffener components placed arbitrarily in complex planforms and unstiffened CFRP plates.

Keywords: CFRP, Composite, Stiffened, Buckling, Free vibration, ANSYS

I. Introduction

When two materials with various physical and chemical properties are combined, the result is a composite material. Additionally, they can increase stiffness and strength. Plates are commonly used to strengthen the structural strength of constructions. Basically, a composite plate is a plate built of composite materials. Composite materials include CFRP. The composite is made up of a matrix and a reinforcement. Carbon fiber is used as reinforcement in CFRP, which gives it its strength. Typically, a polymer resin called epoxy is used as the matrix to bond the reinforcements together. Plates are stiffened with stiffeners to provide the requisite design bending and buckling resistance while weighing less Secondary plates or sections used to stiffen the member are known as stiffeners. Stiffened plates are employed in critical and sensitive structures where safety and perfection of design are crucial. The advantage of stiffening structures is that they may be designed to be lightweight and strong. Stiffened plates are required to avoid the usage of thick plates, which would results in the constructions being too heavy. Fig 1. Depicts plate with mid-stretch stiffener.

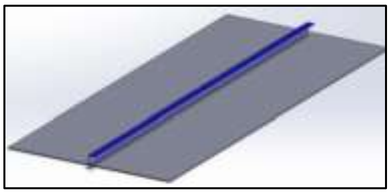


Fig. 1: plate with mid-stretch stiffener

The elastic buckling analysis of laminated glass fiber-reinforced polymer strengthened plates with varied boundary conditions exposed to axial compression was carried out using a finite strip approach. The results reveal that a composite plate stiffened using longitudinal stiffeners has a larger buckling load coefficient than a plate stiffened with diagonal or transverse stiffeners [11]. When a rectangular plate is simply supported and subjected to uniaxial load, the maximum buckling load is obtained. The Eigen value is shown to decrease as the length of the stiffener is reduced. In each case, the maximum stress is shown to decrease as the aspect ratio increases. With the inclusion of stiffeners, the frequency is growing. As the number of stiffeners is increased, the frequency values increase. The stiffener's design and size have a far greater impact on the plate's inherent frequencies. The natural frequency is higher when the stiffener is at a 90-degree angle. The inherent frequency of the plate does not change greatly as the angle value of the stiffener increases. The stiffeners are indicated to minimize the mass of plates for various natural frequencies, according to the findings. In rectangular plates, increasing the aspect ratio reduces displacement in the bare case but increases it in the stiffened case. So in this research simply supported rectangular CFRP stiffened plate is considered for analysis.

II. Objectives of the present work

1) Create a model of a composite plate made of carbon fibre reinforced polymer (CFRP) with randomly positioned stiffeners in ANSYS software
2) Using ANSYS, analyse the static, buckling and free vibration behaviour of CFRP plates with various stiffener arrangements.
3) Compare CFRP composite stiffened and unstiffened plates in terms of buckling, frequency, deformation, stress and strain

III. Methodology

There are typically five steps involved in modelling any finite element problem:

1) Specifying the models material characteristics.
2) Producing the models geometry.
3) Reducing the models number of finite component.
4) Application of boundary and loading condition.
5) Solving the issue to achieve the desired outcomes.

IV. MODEL DESCRIPTION

CFRP unstiffened plate and CFRP plate with longitudinal, Transverse, Angle grid and ortho grid are modelled. The SHELL181 element is a part of the ANSYS Workbench16 and is used to model the composite plate and stiffener. For studying thin to moderately thick shell structures, SHELL181 is appropriate. It functions well in linear, heavy rotational, or heavy strain nonlinear applications. It takes into account the impact of scattered stresses on load stiffness.

V. BOUNDARY CONDITIONS AND MESHING

All sides of a simply supported rectangular CFRP stiffened plate with two eccentric stiffeners positioned 300 mm from the center of the plate and an aspect ratio of 1.20 were taken into consideration to examine the analysis of the model, and load was applied as displacement. For stiffening, a mesh of 12x12 is used in the longitudinal, transverse, angle grid, and ortho grid patterns.

Table I provides the material parameters for CFRP stiffened and un-stiffened plate used for analysis and Table II presents the geometric measurements of the CFRP plate that were taken for the current work

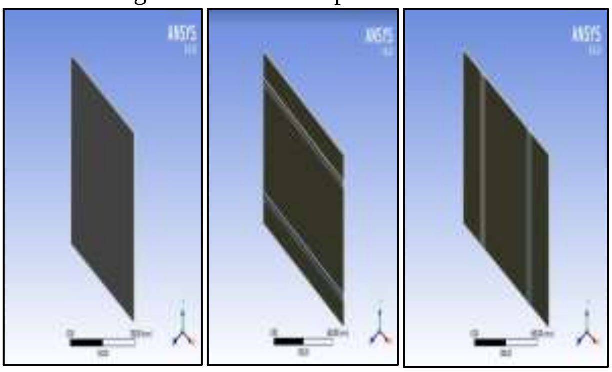
Modulus of elasticity(E) in MPa	Poisson's ratio(γ)	Shear modulus(G)in MPa
E_{11}= 64750500	γ_{12}= 0.23	G_{12} = 6152.3
E_{22}= 14020.6	γ_{23} = 0.3	G_{23}= 5392.53
E_{33}= 14020.6	γ_{13}= 0.23	G_{21}=5392.53
Density	1800 Kg/m^3	

Table I: Material Properties of CFRP

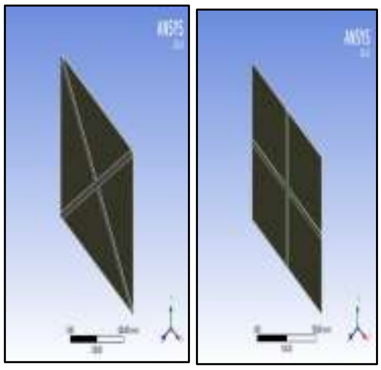
Parameter	Dimensions
Length(mm)	1160
Width(mm)	960
Thickness(mm)	10
Number of layers	16
Thickness of stiffener(mm)	5
Boundary Conditions	Simply supported

Table II: Geometric Properties of Plate

Fig 2 shows modelled CFRP plates with arbitrarily oriented stiffeners along with unstiffened plate.



Unstiffened Longitudinal Transverse



Angle Grid Ortho Grid

Fig. 2: CFRP plates with arbitrarily oriented stiffener

VI. STATIC ANALYSIS

The CFRP stiffened plate with and without stiffeners and with all edges simply supported having subjected to displacement of 0.285mm. Load is given as per displacement convergence method. The plate is having an aspect ratio (length-to-breadth ratio) is of 1.20. In a static structural analysis, the displacements, stresses, strains, and forces in a structure or component are calculated as a function of the load. The internal forces in a body between its particles are measured by stress. Strain is used to determine the material's level of stress. The results of static analyses of an element subjected to a range of loading conditions are resultant stress, strain and deformation.

Fig 3 depicts the deformation of CFRP unstiffened and stiffened plates.

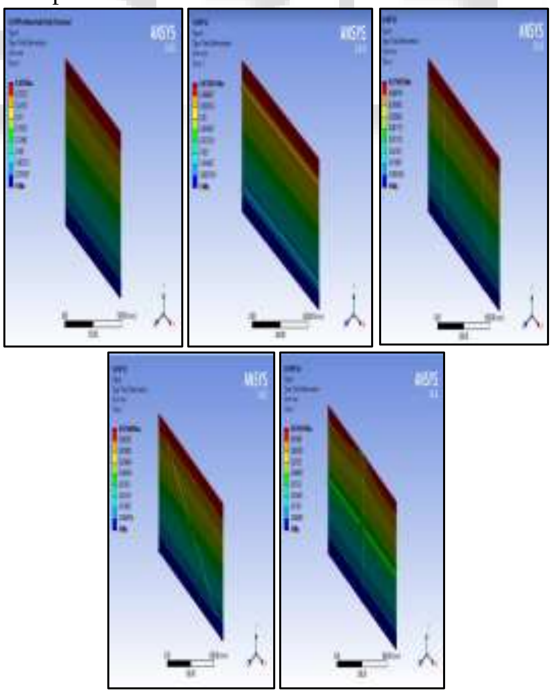


Fig. 3: Deformation of CFRP unstiffened and stiffened plate

VII. BUCKLING ANALYSIS

The stability of a structure under compressive loading circumstances is assessed via buckling analysis. Under certain conditions shear loads and compression loads results in a plate buckling. Fig 4 shows the buckling modes of CFRP unstiffened plate and CFRP stiffened plate with arbitrarily oriented stiffeners.

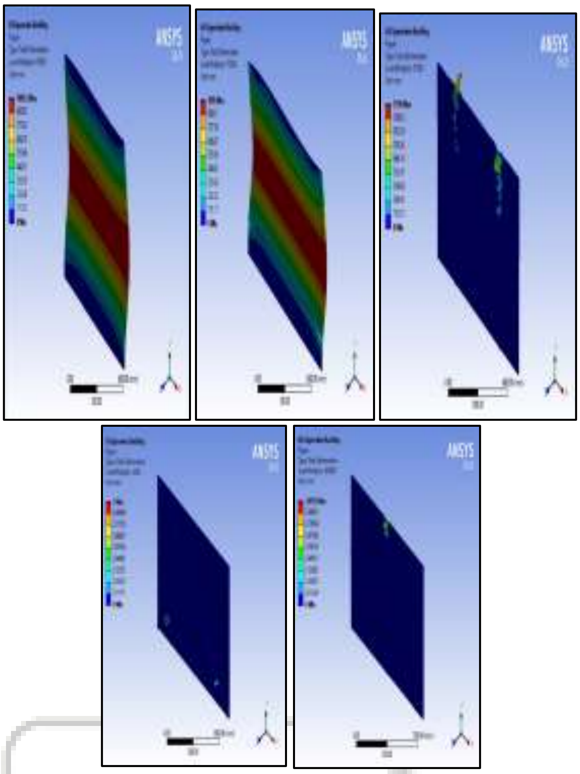
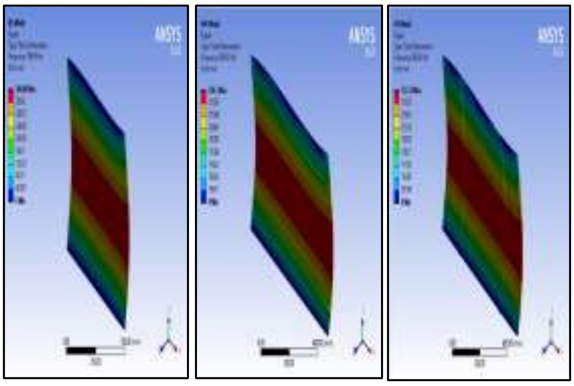


Fig. 4: Buckling modes of CFRP unstiffened and stiffened plate

VIII. FREE VIBRATION ANALYSIS

Free vibration analysis determine the vibration properties of a mechanical structure or component. Imposed loads are basically resulting in the vibration of plates. This vibration under certain condition causes resonance which will results in the structural failure. To reduce it, structural stiffness are need to be increased. Fig 5 shows the mode shape of CFRP unstiffened plate and CFRP plate with arbitrarily oriented stiffeners.



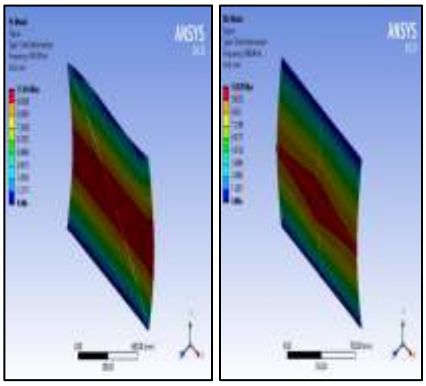


Fig. 5: Mode shape of CFRP unstiffened &stiffened plate

IX. RESULT AND DISCUSSION

Load Deformation curve: The term "deformation" describes how an object changes in size or shape. A structure's deformation under load is influenced by a number of factors, including: the load's characteristics. Fig6. Shows the load – deformation curve of CFRP unstiffened and stiffened plate with arbitrarily oriented stiffeners are shown.

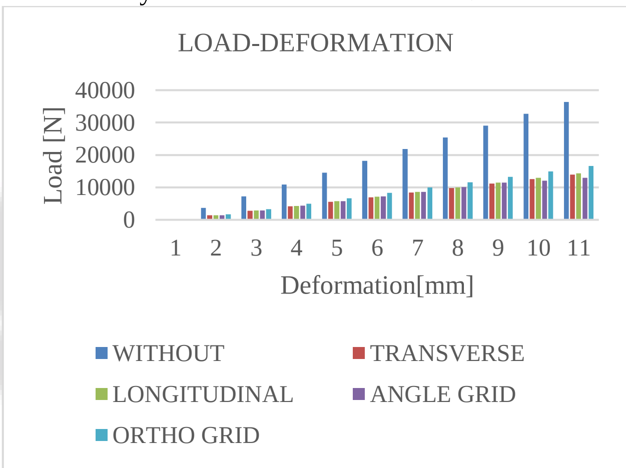


Fig. 6: Load –Deformation curve of CFRP unstiffened and stiffened plate with arbitrarily oriented stiffener

The force per unit area applied to a body that causes it to change shape is known as stress. Strain is the result of a material's deformation due to stress.Fig.7 shows the stress-strain graph of CFRP plate with arbitrarily oriented stiffeners and unstiffened CFRP plate.

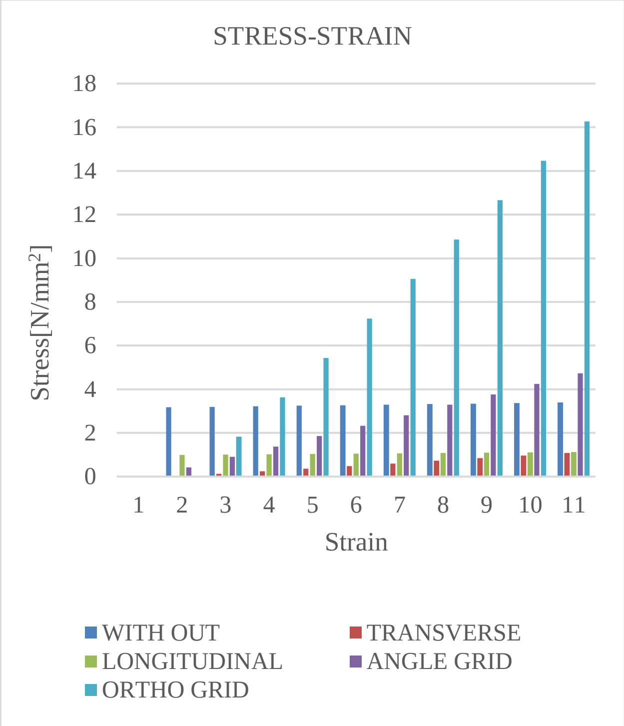


Fig. 7: Stress strain graph of CFRP unstiffened and stiffened plate

In most cases, eigenvalue buckling is employed to calculate the critical buckling loads of rigid structures. A failure mechanism known as buckling may be seen in thin structures subjected to loads that haven't reached the material strength limits. Buckling load coefficient of unstiffened CFRP and CFRP plate with arbitrarily oriented stiffener are shown in Fig.8

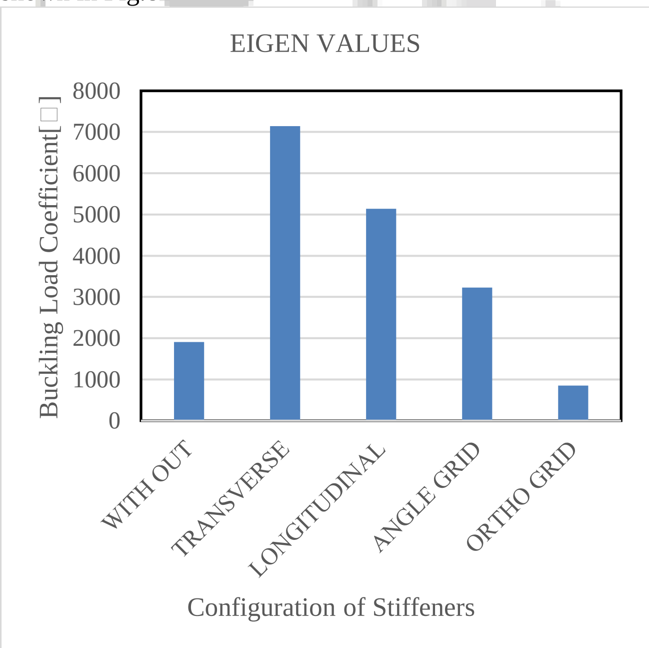


Fig. 8: Buckling load coefficient of unstiffened CFRP plate and CFRP plate with arbitrarily oriented stiffener

The number of recurring events that pass through a specific location a particular time frame is referred to as frequency. Frequency of unstiffened CFRP plate and CFRP plate with different configuration of stiffeners are shown in Fig 9.

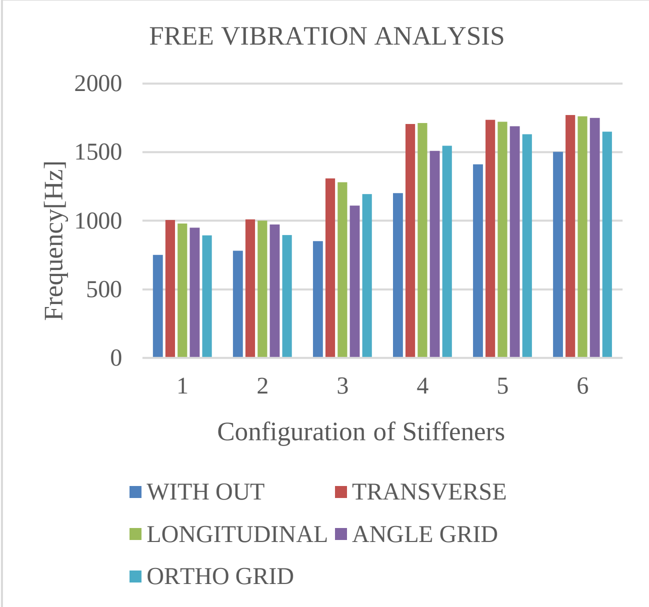


Fig. 9: Frequency of CFRP unstiffened plate and CFRP plate with different configuration of stiffeners

X. CONCLUSION

The static, free vibration, and buckling characteristics of CFRP plates with randomly placed stiffeners and CFRP plates without stiffeners were predicted using a finite element analysis.The results concluded that:

1) Deformation is highest for plate without stiffeners and least for plate with transverse stiffener. CFRP composite plate stiffened with transverse stiffeners, shows much less deformation. Deformation of plate with longitudinal stiffener is higher than transverse orientation. ortho grid pattern has high deformation compared to angle grid pattern.
2) Stress-strain is highest for plate with ortho grid stiffener and lowest for transverse stiffener. ortho grid pattern has much high stress and strain values compared to angle grid pattern. Longitudinally stiffened plate shows high stress strain compared to angle grid.
3) Eigen value is the highest for plate with transverse stiffener and lowest for plate without stiffener. Buckling load coefficient of ortho grid pattern seems to be very less comparing to angle grid pattern and longitudinally arranged stiffener shows a better result compared to angle grid.
4) Frequency is highest for plate with transverse stiffener and lowest for plate without stiffener. Frequency is higher in transverse orientation compared to longitudinally arranged stiffener. Angle grid pattern shows higher frequency compared to orthogrid pattern.
5) CFRP Plates having stiffener in Transverse direction shows a better result in buckling, free vibration and static characteristics. Consequently, it may be said that for CFRP composite plates stiffeners arranged in transverse pattern shows much better result compared to other orientations. CFRP plates with different configuration of stiffeners shows a better result than plates without stiffener

REFERENCES

[1] A.Aruljothi,"Analysing the Buckling Strength of Stiffened Steel Plates with Longitudinal Stiffeners Subjected to Uniaxial Compression'' Journal of Xi'an University of Architecture & Technology, vol.7,pp149-153, 2020.

[2] A. J. Bhat and D.V. Bhope, "Effect of Stiffener Sizes on Natural Frequencies of Plate'', International Research Journal of Engineering and Technology, vol.03, pp 1041-1047, 2016.

[3] A. K. Pal, N.N. Harry and Y.K. Kumar, "A Parametric Study on Hat stiffened plates". International Journal of Research in Engineering, Science and Management, vol.1, pp 128-131, 2018.

[4] A N. Nayak, L. Satpathy and P. K.Tripathy, "Free vibration characteristics of stiffened plates'', International Journal of Advanced Structural Engineering, vol .09, pp1-14, 2018.

[5] A. Mathai, S. Varghese and T. V. Alice, "Finite Element Buckling Analysis of Stiffened Plates'', International Journal of Engineering Research and Development,vol.10,pp79-83,2014.

[6] A. R. Pouladkhan, J. Emadi, and M. Safemehr, "The vibration of thin plates using modal analysis'', World academy of science, Engineering and Technology, vol.3, pp 28-34, 2011.

[7] A.R. Pouladkhan, J. Emadi and M. Safamehr, "Numerical Study of Buckling of Thin Plates'' World Academy of Science Engineering and Technology, vol.78, pp 152-157, 2011.

[8] B. Reddy, A. Akbar, Vinod, and B. Prasad, "Static Analysis of Thin Plates: Bare and Stiffened'', Incas Bulletin, Vol.12, pp 67 – 81, 2020.

[9] B.R. Isanaka, M.A. Akbar, B.P Mishra and Vinod Kushvaha, "Free vibration analysis of thin plates: Bare versus Stiffened'', Engineering Express, Vol. 1, pp2-11, 2020.

[10] D. S. Patel, S. S. Pathan, and I. H. Bhoraniya, "Influence of Stiffeners on the Natural Frequencies of Rectangular Plate with Simply Supported Edges'', International Journal of Engineering Research & Technology, vol.1,pp3: 1-6,2012.

[11] M. Rafiee, H. Amoushahi and M. Hejazi, "Experimental and numerical buckling analysis of thin stiffened GFRPs with arbitrarily located stiffeners", Mechanics Based Design of Structures and Machines, vol.13, pp16-26, 2021.

[12] S. Maurya, "Buckling Analysis of Stiffened Plate with Varying Stiffener and Various Load Position'', International Journal of Science and Research, Vol.10, pp 1-4, 2021.

