STATIC, MODAL AND TRANSIENT DYNAMIC ANALYSIS OF LAMINATED COMPOSITE PLATES WITH HOLES

By

K. MAITHRY *　　B. D. V. CHANDRA MOHAN RAO **

* PG Student, Department of Civil Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, Telangana, India.
** Professor, Department of Civil Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, Telangan, India.

ABSTRACT

The use of laminated composites has been increasing day-by-day in various fields of engineering. Laminated composite plates are quite often subjected to dynamic loads and hence it is vital to study the dynamic behavior of such structures. Structural performance of these composite plates need to be evaluated properly, when they are subjected to dynamic loads. The behaviour of laminated composite plates are affected by excessive vibrations, higher displacements and accelerations which may severely deteriorate the structural performance, when they are subjected to dynamic loads such as impulsive loads. So, there is a need to find out a fiber orientation, that produces least dynamic response parameters. Hence, the purpose of this research work is to investigate the dynamic response of the laminated composite plates subjected to excitations, varying arbitrarily with time and to suggest a robust fiber orientation. Laminates may be provided with holes to cater for different purposes in various streams of engineering. Static, Modal and Transient dynamic analysis of laminated composite plates, simply supported at all the edges has been carried out in this study. Laminated composite plates with holes at different positions are investigated for different fiber orientations by considering two types of loadings i.e., Triangular impulsive loading and Rectangular impulsive loading. This part of the research has been carried out using finite element software ANSYS 13.0.

Keywords: Laminated Composite Plates, Dynamic Loads, Modal Analysis, Fiber Orientation.

INTRODUCTION

Laminated composites are used widely in various disciplines such as civil, aerospace, automobile, naval, industrial buildings etc., in the form of prefabricated plywood laminates. They became popular due to their lightweight and high strength. Laminated composites are a series of lamina or plies stacked together with different materials, ply thicknesses, and mechanical properties. Each lamina is stacked with various fibre orientations to obtain required directional stiffness and strength properties. Ply stacking sequence is very important to obtain an efficient lamina. Weight reduction, limitations of natural frequencies, displacements, and accelerations aim at structural improvement of cost, performance and reliability in the design of plates and shells.

Laminated composite plates are quite often subjected to dynamic loads. These dynamic loads are neither harmonic nor periodic. In this research work, laminated composite plates simply supported on all sides and subjected to static, free vibration and transient loads are analysed for thirteen fiber orientations (0/0/0/0/0, 0/30/45/30/0, 0/30/0/30/0, 0/45/0/45/0, 45/0/45/0/45, 45/0/0/0/45, 45/-45/0/-45/45, 30/60/90/60/30, 30/-45/0/-45/30, 90/45/0/45/90, 90/-60/45/-60/90, 90/0/90/0/90, 0/90/0/90/0). Finite element modelling and analysis of laminated plates is carried out using ANSYS 13.0 software.

1. Objective of the Study

- To analyse the laminated composite plates by changing the following parameters.
  - Fibre orientations (13 Nos.)
  - Position and number of holes. (central, 2 holes interior, 4 holes at corners)
- To carry out static, free vibration and transient dynamic analysis of laminated composite plates.
- To suggest best fiber orientation with respect to various response parameters.

2. Literature Review

J. Chen, D.J. Dawe, and S. Wang (2000) developed the semi-analytical finite strip method for the analysis of the geometrically nonlinear response to dynamic loading of the rectangular composite laminated plates. The comparison has confirmed the validity of the new procedure which offers advantages of economy and efficiency in comparison with competing procedures.

Y.M. Desai, G.S. Ramtekkar, and A.H. Shah (2003) carried out the free vibration analysis of multi-layered thick composite plates using three-dimensional, higher order, mixed Finite Element (FE). Comparison of natural frequencies with elastic and various analytical/FE solutions revealed that the formulation is capable of dealing with the dynamic analysis of laminated composite plates.

Pathak, K.K., Vipin Arora and Jain J.K., (2007) studied the transient dynamic analysis of three dimensional composite laminated plates. Simply supported plates made up of five layers, two orthotropic materials stacked in alternate layers are investigated. Number of plates are analyzed by varying the fiber orientation, thickness and type of loading.

A. Houmat, (2012) investigated the geometrically nonlinear free vibration of a composite rectangular plate with variable fiber spacing and found that the hardening behavior of the plate with variable fiber spacing decreases with increasing fiber volume fraction. The simply supported plate presents a more accentuated hardening behavior than the clamped one.

Sharayu, U. Ratnaparkhi, and S.S. Sarnobat (2013) conducted experiments to investigate the free vibration response of the woven fiber Glass/Epoxy composite plates in free-free boundary conditions. It is found that the natural frequency decreases as the ply orientation increases up to [45/-45] and again increases up to [30/-60].

Sang Jin Lee, and Ha Ryong Kim (2013) investigated structural behavior of laminated composite plates by developing a four-node laminated plate element using a Higher Order Shear Deformation Theory (HSDT). It is found that the proposed FE is very effective to remove the locking phenomenon and produces reliable numerical solutions for most laminated composite plate structures.

Bahi-Eddine Lahouel and Mohamed Guenfoud, (2013) carried out vibration analysis on symmetric angle-ply laminated composite plates with and without square holes when subjected to compressive loads. Buckling analysis is also performed to determine the buckling load of laminated plates. The results showed that the presence of a constant compressive load tends to reduce uniformly the natural frequencies for materials which have a low degree of orthotropy.

Junaid Kameran Ahmed, V.C. Agarwal, P. Pal, and Vikas Srivastav, (2013) carried out Static and Dynamic analysis of Graphite / Epoxy composite plates under transverse loading. The minimum deflection was found at an angle of 150 for clamped plates and in case of simply supported plates, the minimum deflection was found at an angle of 450.

Syed Altaf Hussain, V. Pandurangadu, and K. Palani Kumar (2014) carried out free vibration analysis of a four layered angle-ply symmetric laminated plates with various lamination angles ($\pm 0°$ to $\pm 90°$) of laminas with different hole locations. It is found that the fundamental frequency of laminated composite plates decreases with increase in L/h ratio.

Suleyman Basturk, Haydar Uyanık, and Zafer Kazancı (2014) investigated the nonlinear dynamic response of a hybrid laminated composite plate composed of basalt, Kevlar/epoxy and E-glass/epoxy under the blast load with damping effects and found that the deflection amplitude and the vibration frequencies increase while increasing the peak pressure value.

3. Modelling and Analysis

A rectangular laminated composite plate 3m x 2m simply supported on all sides is analysed in this paper. The laminate consists of five layers and thickness of each layer is 4mm. Diameter of the hole is 0.5m. Finite element analysis of the plate is carried out using a layered shell element and is shown in Figures 1 to 4. The plate is discretized into 1204 elements and 1276 nodes. For static

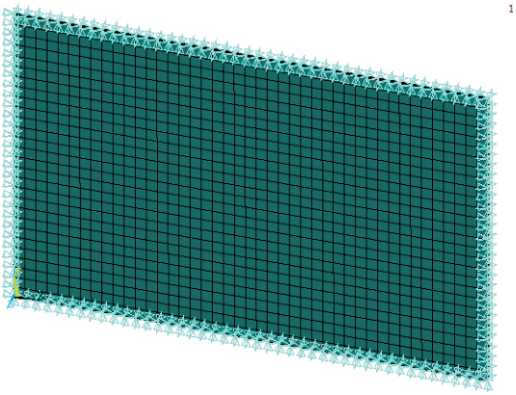

Figure 1. Finite Element Model of Simply Supported Plate without Hole

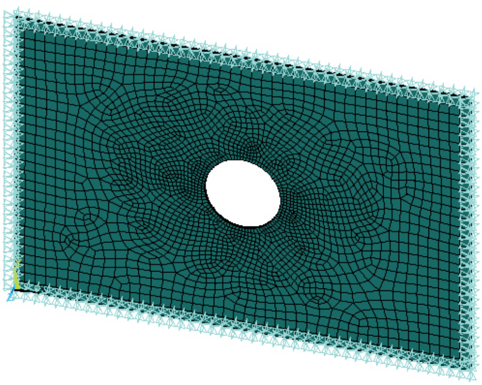

Figure 2. Finite Element Model of Simply Supported Plate with Central Hole

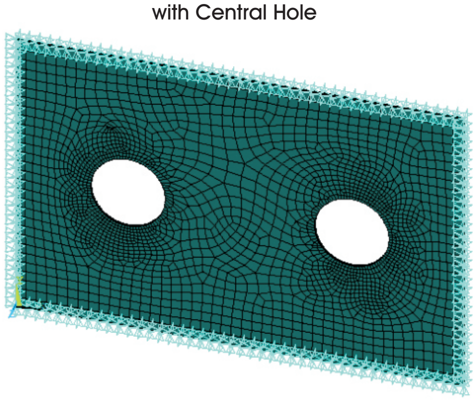

Figure 3. Finite Element Model of Simply Supported Plate with two Interior Holes

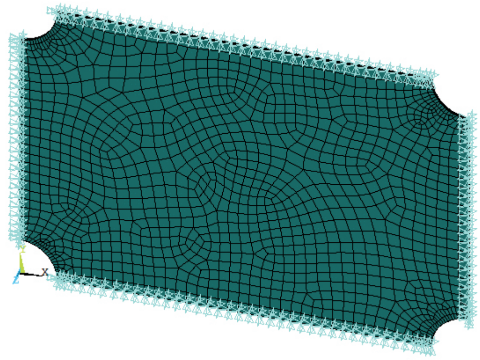

Figure 4. Finite Element Model of Simply Supported Plate with Four Corner Holes

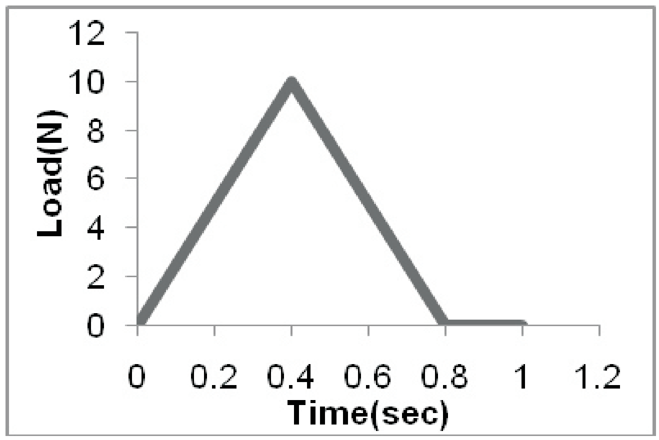

Figure 5. Triangular Impulsive Load – Load Case 1

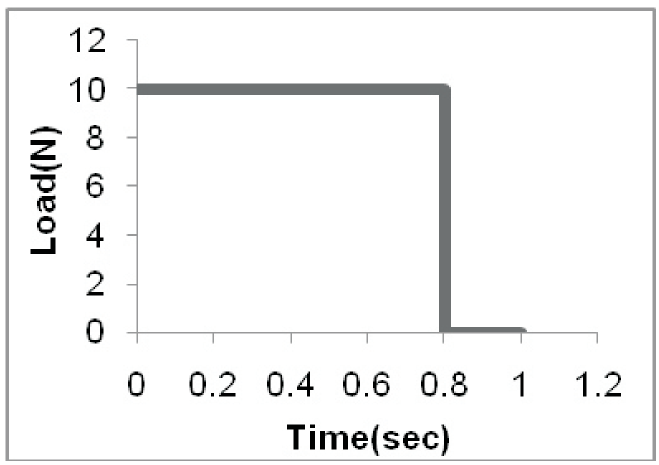

Figure 6. Rectangular Impulsive Load - Load Case 2

analysis, uniform pressure of 1000 N/m^2 is applied on the plate. For transient dynamic analysis, two types of dynamic loads i.e., triangular impulsive load as shown in Figure 5 and rectangular impulsive load as shown in Figure 6 are applied on the plate. The peak load at each node is 10 N and load duration is one second in both the cases. Laminated composite plates subjected to static, modal, and transient dynamic loads are analysed for thirteen different fiber orientations as shown in Figures 7(a) and (b).

The laminate considered is made up of two orthotropic materials, stacked alternatively to make a full plate. First, third and fifth layers are made of material-1 and second

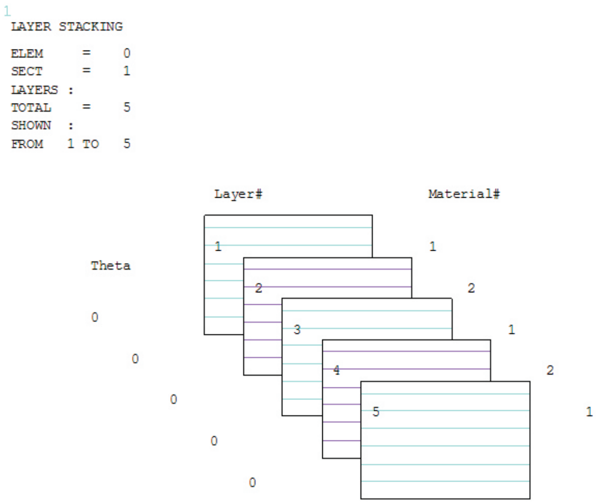

Figure 7(a). Fiber Orientation-1 is SS Laminated Composite Plate

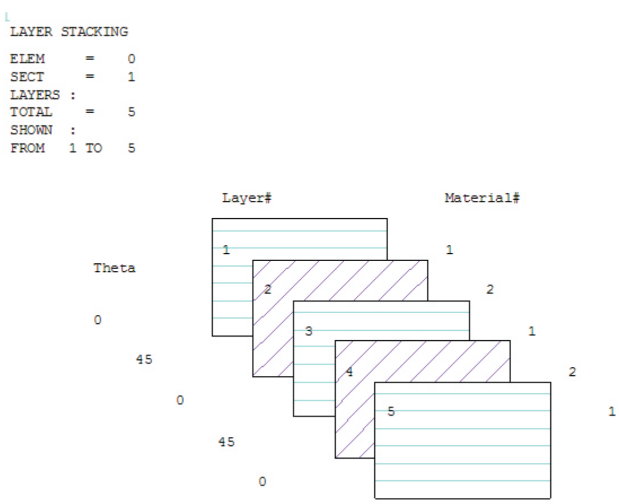

Figure 7 (b). Fiber Orientations in SS Laminated Composite Plate

S. No.	Property	Material-1	Material-13
1	E_{11}	155 x 10^9 N/m^2	50 x 10^9 N/m^2
2	E_{22}	12.1 x 10^9 N/m^2	15.2 x 10^9 N/m^2
3	E_{33}	12.1 x 10^9 N/m^2	15.2 x 10^9 N/m^2
4	μ_{12}	0.458	0.428
5	μ_{23}	0.248	0.254
6	μ_{31}	0.248	0.254
7	G_{12}	3.2 x 10^9 N/m^2	3.28 x 10^9 N/m^2
8	G_{23}	4.4 x 10^9 N/m^2	4.7 x 10^9 N/m^2
9	G_{31}	4.4 x 10^9 N/m^2	4.7 x 10^9 N/m^2
10	Density	2200 kg/m^3	2500 kg/m^3

Table 1. Mechanical properties of Materials

and fourth layers are of material-2. The mechanical properties of materials are taken from K.Maithry and B.D.V Chandra Mohan Rao (2015) are given in Table1.

S.No	Fiber Orientation	Deflection (in mm)			
		No Hole	Central Hole	Two Holes	Four Holes
1	F – 1	7.71	12.40	9.74	4.88
2	F – 2	7.07	10.67	8.37	4.65
3	F – 3	7.17	10.60	8.58	4.68
4	F – 4	3.94	5.23	4.82	4.86
5	F – 5	3.95	5.17	4.76	4.80
6	F – 6	3.45	4.84	4.39	4.44
7	F – 7	4.62	6.81	5.99	4.98
8	F – 8	4.22	6.58	5.65	4.44
9	F – 9	2.46	4.67	5.23	5.24
10	F – 10	2.42	4.96	5.42	5.46
11	F – 11	2.57	4.84	5.26	5.15
12	F – 12	6.89	9.54	7.83	4.44
13	F – 13	6.90	10.07	7.93	4.54

Table 2. Static Response of Simply Supported Laminated Composite Plate (Deflection in mm)

4. Results and Discussion

4.1 Static Analysis of Simply Supported Laminated Composite Plate

A rectangular laminated composite plate simply supported along all the four edges is subjected to a uniform pressure of 1000 N/m^2. The maximum and minimum deflections for various fiber orientations are given in Table 2.

For a simply supported plate without hole, it is observed that the peak deflection is minimum in the case of 90/-60/45/-60/90 and maximum in case of 0/0/0/0/0.

For the plate with central hole, it is observed that the peak deflection is minimum in the case of 90/45/0/45/90 and maximum in case of 0/0/0/0/0.

For the plate with two interior holes, it is observed that the peak deflection is minimum in the case of 45/-45/0/-45/45 and maximum in case of 0/0/0/0/0.

For the plate with four corner holes, it is observed that the peak deflection is minimum in the case of 0/90/0/90/0 and maximum in case of 90/-60/45/-60/90.

4.2 Modal Analysis of Simply Supported Laminated Composite Plate

Free vibration analysis is carried out on a rectangular laminated composite plate simply supported along all the four edges. The maximum frequency obtained for various fiber orientations are given in Table 3.

S.No	Fiber Orientation	Frequency (in Hz) No Hole	Central Hole	Two Holes	Four Holes
1	F – 1	10.62	9.10	9.84	13.66
2	F – 2	11.08	9.80	10.50	13.97
3	F – 3	11.00	9.67	10.39	13.92
4	F – 4	14.74	13.76	13.43	13.36
5	F – 5	14.73	13.83	13.51	13.45
6	F – 6	15.73	14.38	14.10	13.93
7	F – 7	13.63	12.25	12.08	13.26
8	F – 8	14.25	12.54	12.67	14.02
9	F – 9	18.13	13.70	12.65	12.58
10	F – 10	18.23	13.35	12.36	12.30
11	F – 11	17.81	13.55	12.51	12.74
12	F – 12	11.24	10.28	10.88	14.25
13	F – 13	11.22	10.07	10.75	14.11

Table 3. Modal Response of Simply Supported Laminated Composite Plate (Frequency in Hz)

For a simply supported plate without hole, it is observed that the frequency is minimum in the case of 0/0/0/0/0 and maximum in case of 90/-60/45/-60/90.

For the plate with central hole, it is observed that the frequency is minimum in the case of 0/0/0/0/0 and maximum in case of 45/-45/0/-45/45.

For the plate with two interior holes, it is observed that the frequency is minimum in the case of 0/0/0/0/0 and maximum in case of 45/-45/0/-45/45.

For the plate with four corner holes, it is observed that the frequency is minimum in the case of 90/-60/45/-60/90 and maximum in case of 0/90/0/90/0.

4.3 Transient Analysis of Simply Supported Laminated Composite Plate – Load Case 1

S.No	Fiber Orientation	No Hole-Load Case 1 Deflection	Velocity (mm/sec)
1	F – 1	15.27	73.67
2	F – 2	14.39	67.03
3	F – 3	14.50	67.91
4	F – 4	8.21	60.97
5	F – 5	5.23	61.25
6	F – 6	7.05	31.23
7	F – 7	9.21	43.18
8	F – 8	8.69	81.80
9	F – 9	5.10	32.08
10	F – 10	5.01	29.23
11	F – 11	5.31	39.48
12	F – 12	14.20	84.11
13	F – 13	14.20	80.72

Table 4. Maximum responses of SS Laminated Plate – No Hole, Load Case 1

S.No	Fiber Orientation	Central Hole-Load Case 1 Deflection (mm)	Velocity (mm/sec)
1	F – 1	87.55	710
2	F – 2	73.58	334
3	F – 3	76.13	342
4	F – 4	35.45	161
5	F – 5	35.20	159
6	F – 6	33.83	314
7	F – 7	47.33	364
8	F – 8	45.47	202
9	F – 9	30.69	139
10	F – 10	32.56	149
11	F – 11	31.41	144
12	F – 12	63.27	298
13	F – 13	68.10	316

Table 5. Maximum responses of SS Laminated Plate - Central Hole, Load Case 1

S.No	Fiber Orientation	2 Interior Holes-Load Case 1 Deflection (mm)	Velocity (mm/sec)
1	F – 1	41.34	184
2	F – 2	34.51	162
3	F – 3	35.49	165
4	F – 4	21.85	99
5	F – 5	21.53	98
6	F – 6	20.34	128
7	F – 7	28.32	195
8	F – 8	25.02	110
9	F – 9	20.68	92
10	F – 10	21.72	138
11	F – 11	21.48	94
12	F – 12	32.03	149
13	F – 13	33.04	154

Table 6. Maximum responses of SS Laminated Plate – 2 Interior Holes, Load Case 1

S.No	Fiber Orientation	4 Interior Holes-Load Case 1 Deflection (mm)	Velocity (mm/sec)
1	F – 1	8.50	39.15
2	F – 2	8.29	76.67
3	F – 3	8.32	72.57
4	F – 4	9.22	43.29
5	F – 5	9.06	42.71
6	F – 6	8.48	39.34
7	F – 7	9.17	43.07
8	F – 8	8.26	42.83
9	F – 9	10.10	46.37
10	F – 10	10.72	58.17
11	F – 11	9.83	45.46
12	F – 12	8.05	74.25
13	F – 13	8.20	83.24

Table 7. Maximum responses of SS Laminated Plate - 4 Corner Holes - Load Case 1

A rectangular laminated plate simply supported along all the four edges is subjected to a triangular impulsive load i.e. load case-1. The maximum response parameters i.e. Deflection, and Velocity are obtained for various fiber orientations given in Tables 4 to 7.

For a simply supported plate without hole, it is observed that the peak deflection, velocity is minimum in the case of 90/-60/-45/60/90 and maximum in case of 0/0/0/0/0 and 0/90/0/90/0 respectively. Hence, 90/-60/-45/60/90 is the most robust orientation with respect to various response parameters.

For a simply supported plate with a central hole, it is observed that the peak deflection, velocity is minimum in the case of 90/45/0/45/90 and maximum in case of 0/0/0/0/0. Hence, 90/45/0/45/90 is the most robust orientation with respect to various response parameters.

For a simply supported plate with two interior holes, it is observed that the peak deflection, velocity is minimum in the case of 45/-45/0/-45/45 and 90/45/0/45/90 respectively and maximum in case of 0/0/0/0/0 and 30/60/90/60/30 respectively. Hence, 45/-45/0/-45/45 is the most robust orientation with respect to various response parameters.

For a simply supported plate with four corner holes, it is observed that the peak deflection, velocity is minimum in the case of 0/90/0/90/0 and 0/0/0/0/0 respectively and maximum in case of 90/-60/45/-60/90 and 0/45/0/45/0 respectively. Hence, 0/90/0/90/0 is the most robust orientation with respect to various response parameters.

4.4 Transient Analysis of Simply Supported Laminated Composite Plate – Load Case 2

A rectangular laminated plate simply supported along all the four edges is subjected to a rectangular impulsive load i.e. load case-2. The maximum response parameters i.e. Deflection, and Velocity are obtained for various fiber orientations given in Tables 8 to 11.

For a simply supported plate without hole, it is observed that the peak deflection, velocity is minimum in the case

S.No	Fiber Orientation	No Hole-Load Case 2 Deflection (mm)	No Hole-Load Case 2 Velocity (mm/sec)
1	F – 1	30.93	931
2	F – 2	28.30	1646
3	F – 3	28.66	1625
4	F – 4	15.84	645
5	F – 5	15.86	645
6	F – 6	14.00	918
7	F – 7	18.69	823
8	F – 8	16.89	1571
9	F – 9	10.48	463
10	F – 10	10.27	447
11	F – 11	10.78	501
12	F – 12	27.80	1562
13	F – 13	27.71	1600

Table 8. Maximum responses of SS Laminated Plate – No Hole, Load Case 2

S.No	Fiber Orientation	Central Hole-Load Case 2 Deflection (mm)	Central Hole-Load Case 2 Velocity (mm/sec)
1	F – 1	162.82	4304
2	F – 2	139.65	7189
3	F – 3	143.05	7296
4	F – 4	68.18	3748
5	F – 5	67.36	3879
6	F – 6	64.36	4059
7	F – 7	88.51	4238
8	F – 8	86.87	5284
9	F – 9	60.73	3069
10	F – 10	65.08	2273
11	F – 11	63.01	2197
12	F – 12	126.90	3549
13	F – 13	132.14	4961

Table 9. Maximum responses of SS Laminated Plate – Central Hole, Load Case 2

S.No	Fiber Orientation	2 Interior Holes-Load Case 2 Deflection (mm)	2 Interior Holes-Load Case 2 Velocity (mm/sec)
1	F – 1	102.95	5384
2	F – 2	89.24	2662
3	F – 3	91.82	2656
4	F – 4	49.12	1727
5	F – 5	48.34	1714
6	F – 6	44.37	3917
7	F – 7	62.13	2044
8	F – 8	57.88	3358
9	F – 9	50.21	2944
10	F – 10	52.66	2920
11	F – 11	52.62	3243
12	F – 12	81.47	3961
13	F – 13	84.10	3314

Table 10. Maximum responses of SS Laminated Plate – 2 Interior Holes, Load Case 2

S.No	Fiber Orientation	4 Interior Holes-Load Case 2 Deflection (mm)	4 Interior Holes-Load Case 2 Velocity (mm/sec)
1	F – 1	17.14	1263
2	F – 2	16.39	1490
3	F – 3	16.49	1525
4	F – 4	18.69	700
5	F – 5	18.46	694
6	F – 6	16.99	999
7	F – 7	18.55	694
8	F – 8	16.42	1433
9	F – 9	19.92	1175
10	F – 10	20.85	1298
11	F – 11	19.55	1011
12	F – 12	15.62	713
13	F – 13	16.22	1233

Table 11. Maximum responses of SS Laminated Plate – 4 corner holes, Load Case 2

of 90/-60/-45/60/90 and maximum in case of 0/0/0/0/0 and 0/30/45/30/0 respectively. Hence, 90/-60/-45/60/90 is the most robust orientation with respect to various response parameters.

For a simply supported plate with a central hole, it is observed that the peak deflection, velocity is minimum in the case of 90/45/0/45/90 and 0/90/0//90/0 respectively and maximum in case of 0/0/0/0/0 and 0/30/0/30/0 respectively. Hence, 90/45/0/45/90 is the most robust orientation with respect to various response parameters.

For a simply supported plate with two interior holes, it is observed that the peak deflection, and velocity is minimum in the case of 45/-45/0/-45/45 and 45/0/0/0/45 respectively and maximum in case of 0/0/0/0/0. Hence, 45/-45/0/-45/45 is the most robust orientation with respect to various response parameters.

For a simply supported plate with four corner holes, it is observed that the peak deflection, and velocity is minimum in the case of 0/90/0/90/0 and 45/0/0/0/45 respectively and maximum in case of 90/-60/45/-60/90 and 0/30/0/30/0 respectively. Hence, 0/90/0/90/0 is the most robust orientation with respect to various response parameters.

Conclusions

- Laminated composite plates simply supported along all the four edges subjected to triangular and rectangular impulsive loads are investigated for various types of fiber orientations. It is observed that fiber orientation plays a vital role while studying the dynamic behaviour of plates.
- By properly orienting the fibers in a laminated composite plate, the maximum deflections can be reduced to an extent of about 70 %. This implies that, considerable saving in material can be achieved by properly orienting the fibers.
- It is observed that the peak deflection, is minimum for orientations 90/-60/45/-60/90, 90/45/0/45/90, 45/-45/0/-45/45, 0/90/0/90/0 for plate without hole, central hole, two holes at interior and four holes at corners respectively and maximum in 0/0/0/0/0 orientation (most of the cases). Hence proper orientation of fibers in plates evolves most robust design.

Recommendations for the Study

The present work can be further extended as below.

- By changing the shape and position of holes (rectangle, square, oval etc).
- By changing the boundary conditions (clamped on all sides, opposite sides simply supported or clamped etc).
- By changing the fiber orientations.
- With different aspect ratios.

Notations

E_{11} - Longitudinal Elasticity Modulus

E_{22} - Transverse Elasticity Modulus

E_{33} - Longitudinal Elasticity Modulus

μ_{12} - In-plane Poisson's ratio

μ_{23} - Transverse Poisson's ratio

μ_{31} - In-plane Poisson's ratio

G_{12} - In-plane Shear Modulus

G_{23} - Transverse Shear Modulus

G_{31} - In-plane Shear Modulus

F – 1- 0/0/0/0/0

F – 2- 0/30/45/30/0

F – 3- 0/30/0/30/0

F – 4- 45/0/45/0/45

F – 5- 45/0/0/0/45

F – 6- 45/-45/0/-45/45

F – 7- 30/60/90/60/30

F – 8- 30/-45/0/-45/30

F – 9- 90/45/0/45/90

F – 10- 90/-60/45/-60/90

F – 11- 90/0/90/0/90

F – 12- 0/90/0/90/0

F – 13- 0/45/0/45/0

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ABOUT THE AUTHORS

K. Maithry is pursuing her M.Tech, in Structural Engineering at VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, India.

Dr. B. D. V. Chandra Mohan Rao is working as a Professor in the Department of Civil Engineering at VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, India. He has 18 years of teaching experience and his research areas include Earthquake Engineering, Finite Element Analysis and Structural Optimization.