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MODAL ANALYSIS OF A COMPOSITE LAMINATE PLATE WITH CUTOUTS USING FINITE ELEMENT ANALYSIS

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Abstract

This work deals with vibration (Modal) analysis of a laminated composite plate structure with completely different Angle orientation of ply. In this work various cutout sections has been considered which produces singularity in the plate. These cut-out out sections are square and circular. After many considering and analyzing various case scenarios of location of singularity present the center position of the square laminate plate has been found to be optimum which gives minimum natural frequency in case of self weight consideration. The finite part methodology has been used for calculation via ANSYS 15.0 MODAL analysis module. Main reason for adopting ANSYS 15.0 is that there's no such analytical model has been develop for Laminate composite plate structure in presence of singularities . Furthermore constant analysis has additionally been distributed for careful convergence study of plate vibration. Following analysis are distributed for completely different precondition i.e. CFFF and SSSS to achieve optimum natural frequency so as to create laminate composite structure statically and dynamically balanced.

Keywords: ANSYS 15.0, Modal analysis, Singularity in Laminate Plate, SSSS and CFFF.

1. Introduction

Materials science, composite laminates are assemblies of layers of fibrous composite materials which can be joined to provide required engineering properties, including in-plane stiffness, bending stiffness, strength and coefficient of thermal expansion.

The individual layers consist of high-modulus, high-strength fibers in a polymeric, metallic, or ceramic matrix material. Typical fibers used include graphite, glass, boron, and silicon carbide, and some matrix materials are epoxies, polyimides, aluminium, titanium, and alumina.

Layers of different materials may be used, resulting in a hybrid laminate. The individual layers generally are orthotropic (that is, with principal properties in orthogonal directions) or transversely isotropic (with isotropic properties in the transverse plane) with the laminate then exhibiting anisotropic (with variable direction of principal properties), orthotropic, or quasi-isotropic properties. Quasi-isotropic laminates exhibit isotropic (that is, independent of direction) in-plane response but are not restricted to isotropic out-of-plane (bending) response. Depending upon the stacking sequence of the individual layers, the laminate may exhibit coupling between in-plane and out-of-plane response. An example of bending-stretching coupling is the presence of curvature developing as a result of in-plane loading.

2. Methodology

The block diagram below shows the methodology employed for carrying out the Modal analysis. The set by step procedure has been followed to achieve results related singularity and non singularity. Later the results has been compared to determine which case is giving minimum value of natural frequency which is our desired objective,

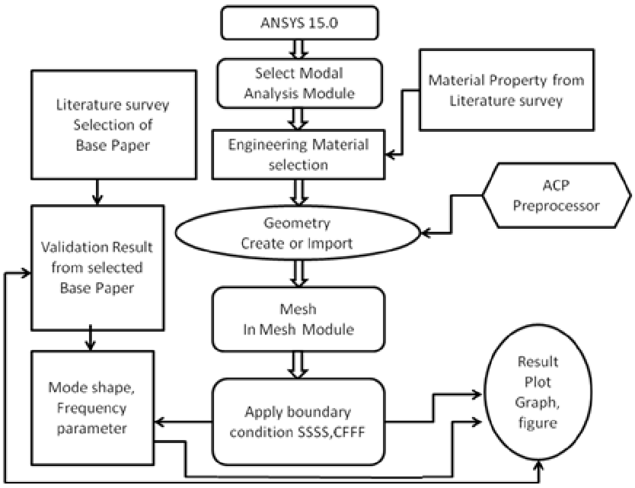

Fig. 1 Flow Chart of Methodology

The starting of procedure begins with preparing model for analysis. In this paper we are dealing with the singularity thus as discussed earlier the square laminate plate with 4 ply layer with different ply orientation has been modeled in design modeler of ANSYS 15.0. The model has been created laminate plate using ACP Preprocessor tool. The obtained model is then meshed uniformly such that finer mesh around singularity. The mesh type used is Mapped Faced Meshing. The obtained meshed geometry with singularity are as follows.

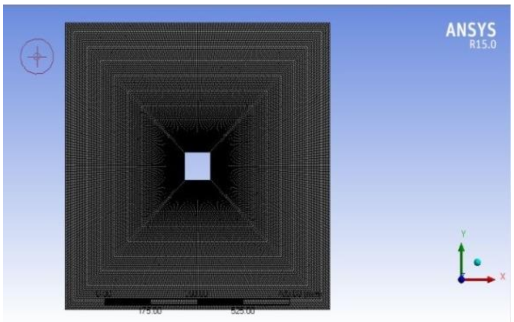

Fig. 2 Square Laminate Plate with square singularity at center

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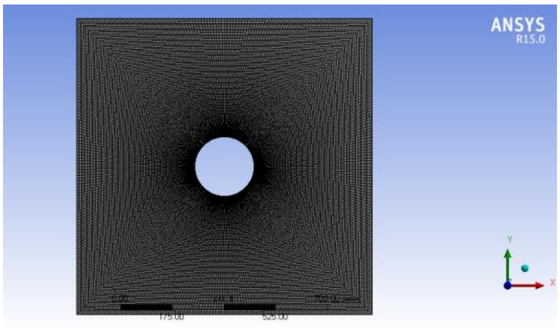

Fig. 3 Square Laminate Plate with circular singularity at center

Further play thickness and orientation has been set various times as per fixed set of boundary condition in both SSSS and CFFF boundary condition where S denotes the simply supported boundary condition at edge of plate and C denotes the clamped or fixed boundary condition at any edge of plate. F shows the free boundary condition at any edge of the plate. The values of ply orientation are in degree and set of boundary conditions are shown below.

Table 1 Boundary Conditions with 0.2 m play Thickness

	End Support Conditions	Ply Rotation			
a=b=1m, a/h=5, $E_1/E_2=40$, $G_{23}=G_{13}=0.6E2$, $G_{22}=0.5E_2$, $v_{12}=v_{13}=v_{23}=0.25$, $\rho=2200$ kg/m3	SSSS	0	90	90	0
		0	45	45	0
		0	45	45	0
		0	90	90	0
		0	30	60	0
		0	60	60	0
		0	90	60	0
	CFFF	0	90	90	0
		0	45	45	0
		0	45	45	0
		0	90	90	0
		0	30	60	0
		0	60	60	0
		0	90	60	0

Similarly same ply orientation settings with 0.1 meter play thickness have been used for the sake of comparison. Later comparative study will give result about the best ply orientation for minimum value of natural frequency.

I. Results

The following tables shows the results of modal analysis performed for laminate plate with square singularity at the centre of the plate.

Table 2 Natural Frequency of laminated plate in SSSS a=b=1m,a/h=5, E_1/E_2=40, G_{23}=G_{13}=0.6E_2, G_{22}=0.5E_2, v_{12}=v_{13}=v_{23}=0.25, ρ=2200 kg/m³

Mode	0/90/90/0	0/45/45/0	0/45/-45/0	0/-45/-45/0	0/-90/-90/0	0/30/60/0	0/60/60/0	0/90/60/0
1	1123.7	729.7	922	729.66	1123.7	1109.8	1063.6	1042.6
2	1730.3	1005.2	1242.4	1002.1	1730.3	1228.3	1148.2	1617.8
3	1824.1	1553	1387	1552.8	1824.1	1584.1	1682.5	1701.4
4	2046.9	1846.7	1634.6	1842.7	2046.9	2001.8	1946.9	1799.1
5	2628.4	2050.2	1775	2049.1	2628.4	2145.7	2294.4	2326
6	2906.9	2376.4	1906.8	2381.4	2906.9	2432.4	2613.5	2468.9

Table 3 Natural Frequency of laminated plate in CFFF a=b=1m, a/h=5, E_1/E_2=40, G_{23}=G_{13}=0.6E_2, G_{22}=0.5E_2, v_{12}=v_{13}=v_{23}=0.25, ρ=2200 kg/m³

Mode	0/90/90/0	0/45/45/0	0/45/-45/0	0/-45/-45/0	0/-90/-90/0	0/30/60/0	0/60/60/0	0/90/60/0
1	243.71	207.68	279.73	207	243.71	279.62	240.86	252.14
2	500.19	365.02	503.55	364.69	500.19	500.45	440.71	494.26
3	821.91	617.72	873.74	617.1	821.91	857.03	843.11	875.37
4	983.43	769.85	1002.6	768.25	983.43	1052.4	890.35	991.9
5	1036	953.77	1123.4	953.41	1036	1109	1042.6	1035.6
6	1449.4	1090	1212.4	1090	1449.4	1338.9	1232.3	1311

Table 4 Natural Frequency of laminated plate in SSSS a=b=1m, a/h=10, E_1/E_2=40, G_{23}=G_{13}=0.6E_2, G_{22}=0.5E_2, v_{12}=v_{13}=v_{23}=0.25, ρ=2200 kg/m³

Mode	0/90/90/0	0/45/45/0	0/45/-45/0	0/-45/-45/0	0/-90/-90/0	0/30/60/0	0/60/60/0	0/90/60/0
1	754.62	622.01	704.61	622.01	754.91	746.73	691.57	733.07
2	1316.16	1000.96	1045.46	988.1	1316.45	1144.45	1166.75	1242.3
3	1439.86	1290.36	1451.16	1240.1	1440.15	1551.55	1362.55	1403.7
4	2127.66	1392.86	1512.86	1394.4	2127.95	1642.85	1686.25	1916.7
5	2194.06	1414.86	1777.46	1398.1	2194.35	2031.25	2025.85	2080.3
6	2254.86	1762.76	1956.16	1733.9	2255.15	2061.15	2064.45	2250.3

Table 5 Natural Frequency of laminated plate in CFFF a=b=1m, a/h=10, E_1/E_2=40, $G_{23}=G_{13}=0.6E_2$, $G_{22}=0.5E_2$, $v_{12}=v_{13}=v_{23}=0.25$, ρ=2200 kg/m^3

Mode	0/90/90/0	0/45/45/0	0/45/-45/0	0/-45/-45/0	0/-90/-90/0	0/30/60/0	0/60/60/0	0/90/60/0
1	153.2	143.26	166.22	143.05	153.2	164.68	153.62	156.42
2	353.86	263.46	353.3	263.33	353.86	367.63	330.54	364.36
3	657.65	485.58	648.99	485.41	657.65	627.55	608.69	668.56
4	675.89	572.69	775.85	571.07	675.89	798.46	675.81	695.62
5	982.94	777.3	997.87	776.56	982.94	1021.46	938.38	1052.8
6	1068.8	830.44	1052.8	829.55	1068.8	1051.46	1064.44	1059.6

After carefully observing above obtained results one can conclude that the ply orientation 0/-45/-45/0 is giving minimum value of natural frequency. Thus comparing results of 0/-45/-45/0 ply orientation

Table 6 Comparison of all 4 conditions in case of Square Cut-out

0/-45/-45/0			
SSSS (a/h=5)	CFFF (a/h=5)	SSSS (a/h=10)	CFFF (a/h=10)
729.66	207	622.01	143.05
1002.1	364.69	988.1	263.33
1552.8	617.1	1240.1	485.41
1842.7	768.25	1394.4	571.07

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2049.1	953.41	1398.1	776.56
2381.4	1090	1733.9	829.55

Now in case of circular cutout results obtained are as follows

Table 7 Natural Frequency of laminated plate in SSSS a=b=1m, a/h=5, E_1/E_2=40, $G_{23}=G_{13}=0.6E_2$, $G_{22}=0.5E_2$, $v_{12}=v_{13}=v_{23}$=0.25, ρ=2200 kg/m^3

Mode	0/90/90/0	0/45/45/0	0/45/-45/0	0/-45/-45/0	0/-90/-90/0	0/30/60/0	0/60/60/0	0/90/60/0
1	1124.15	730.15	922.45	729.79	1124.06	1110.16	1063.96	1043
2	1730.75	1005.65	1242.85	1015.7	1730.66	1228.66	1148.56	1618.2
3	1824.55	1553.45	1387.45	1548.3	1824.46	1584.46	1682.86	1701.8
4	2047.35	1847.15	1635.05	1621.3	2047.26	2002.16	1947.26	1799.5
5	2628.85	2050.65	1775.45	2071.8	2628.76	2146.06	2294.76	2326.4
6	2907.35	2376.85	1907.25	2264	2907.26	2432.76	2613.86	2469.3

Table 8 Natural Frequency of laminated plate in CFFF a=b=1m, a/h=5, E_1/E_2=40, $G_{23}=G_{13}=0.6E_2$, $G_{22}=0.5E_2$, $v_{12}=v_{13}=v_{23}$=0.25, ρ=2200 kg/m^3

Mode	0/90/90/0	0/45/45/0	0/45/-45/0	0/-45/-45/0	0/-90/-90/0	0/30/60/0	0/60/60/0	0/90/60/0
1	238.69	202.66	274.71	201.93	238.7	274.61	235.85	247.13
2	495.17	360	498.53	350.22	495.18	495.44	435.7	489.25
3	816.89	612.7	868.72	608.29	816.9	852.02	838.1	870.36
4	978.41	764.83	997.58	739.11	978.42	1047.39	885.34	986.89
5	1030.98	948.75	1118.38	951.12	1030.99	1103.99	1037.59	1030.6
6	1444.38	1084.98	1207.38	1049.4	1444.39	1333.89	1227.29	1306

Table 9 Natural Frequency of laminated plate in SSSS a=b=1m, a/h=10, E_1/E_2=40, $G_{23}=G_{13}=0.6E_2$, $G_{22}=0.5E_2$, $v_{12}=v_{13}=v_{23}$=0.25, ρ=2200 kg/m^3

Mode	0/90/90/0	0/45/45/0	0/45/-45/0	0/-45/-45/0	0/-90/-90/0	0/30/60/0	0/60/60/0	0/90/60/0
1	771.38	638.77	721.37	638.87	770.58	762.4	707.24	748.74
2	1332.92	1017.72	1062.22	972.9	1332.12	1160.12	1182.42	1257.9

3	1456.62	1307.12	1467.92	1136.7	1455.82	1567.22	1378.22	1419.3
4	2144.42	1409.62	1529.62	1385.1	2143.62	1658.52	1701.92	1932.3
5	2210.82	1431.62	1794.22	1407.5	2210.02	2046.92	2041.52	2095.9
6	2271.62	1779.52	1972.92	1743.3	2270.82	2076.82	2080.12	2265.9

Table 10 Natural Frequency of laminated plate in CFFF a=b=1m, a/h=10, E_1/E_2=40, $G_{23}=G_{13}=0.6E_2$, $G_{22}=0.5E_2$, $v_{12}=v_{13}=v_{23}$=0.25, ρ=2200 kg/m^3

Mode	**0/90/90/0**	**0/45/45/0**	**0/45/-45/0**	**0/-45/-45/0**	**0/-90/-90/0**	**0/30/60/0**	**0/60/60/0**	**0/90/60/0**
1	151.4	141.46	164.42	141.05	151.6	163.08	152.02	154.82
2	352.06	261.66	351.5	250.57	352.26	366.03	328.94	362.76
3	655.85	483.78	647.19	475.48	656.05	625.95	607.09	666.96
4	674.09	570.89	774.05	557.05	674.29	796.86	674.21	694.02
5	981.14	775.5	996.07	757.83	981.34	1019.86	936.78	1051.2
6	1067	828.64	1051	847.15	1067.2	1049.86	1062.84	1058

After carefully observing above obtained results one can conclude that the ply orientation 0/-45/-45/0 is giving minimum value of natural frequency. Thus comparing results of 0/-45/-45/0 ply orientation

Table 11 Comparison of all 4 conditions in case of Circular Cut-out

0/-45/-45/0			
SSSS (a/h=5)	CFFF (a/h=5)	SSSS (a/h=10)	CFFF (a/h=10)
729.79	**201.93**	**638.87**	**141.05**
1015.7	**350.22**	**972.9**	**250.57**
1548.3	**608.29**	**1136.7**	**475.48**
1621.3	**739.11**	**1385.1**	**557.05**
2071.8	**951.12**	**1407.5**	**757.83**
2264	**1049.4**	**1743.3**	**847.15**

Table 12 Comparison of all minimum frequency condition in all three types of plate i.e simple, with square and circular cut out.

Simple plate	**Square Cutout**	**Circular Cutout**
CFFF (a/h=5) 0/-45/-45/0	CFFF (a/h=10) 0/-45/-45/0	CFFF (a/h=10) 0/-45/-45/0
68.48	143.05	141.05
162.93	263.33	250.57
292.78	485.41	475.48

356.82	571.07	557.05
491.04	776.56	757.83
506.92	829.55	847.15

II. Results

Thus the results shown above clearly indicates that The 4 layered laminated ply with different ply orientation as 0/-45/-45/0 gives best result in case of minimization of the natural frequency in all the cases of ply orientation we have considered in above iteration. We have also taken singularity at center of the laminated ply as square singularity and circular singularity. On comparing the results for all three the simply plate without singularity is giving the minimum result for the natural frequency. The 6 modes of natural frequencies are as follows.

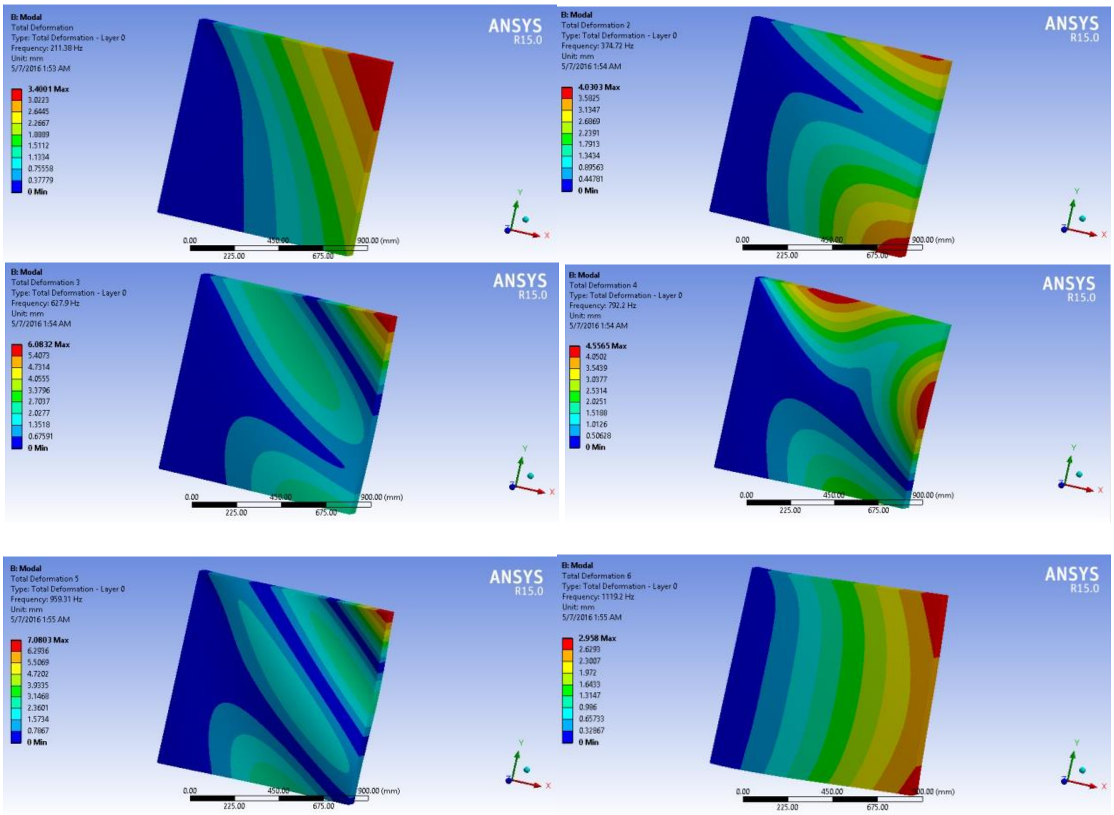

Fig. 4 All Mode Shapes of Optimal Ply Orientation

4. Conclusion

Thus we can conclude that in case of self weight a square laminate plate has been analyzed in Modal module to check the which orientation of ply set will give the minimum value of the ply orientation. The laminate ply has been made up of 4 players each of equal thickness. The ply has been tasted in various set of boundary condition in three physical conditions. Simple and with presence of square and circular singularity. On comparing all results we can conclude that the simply ply with 0/-45/-45/0 ply orientation gives the best result among all set of boundary condition and physical condition.

References

[1] Aagaah, M. Rastgaar, M. Mahinfalah, and G. Nakhaie Jazar. "Natural frequencies of laminated composite plates using third order shear deformation theory." *Composite structures* 72.3 (2006): 273-279.

[2] Zeki Kiral, M. Evren Toygar, Binnur Gören Kiral, Onur Sayman, "Effect of the root crack on the lateral buckling loads and natural frequencies of sandwich composite beams", Composites Part B: Engineering, Volume 53, October 2013, Pages 308-313.

[3] Süleyman Baştürk, Haydar Uyanık, Zafer Kazancı, "Nonlinear damped vibrations of a hybrid laminated composite plate subjected to blast load", Procedia Engineering 88 (2014) 18 – 25

[4] E.P. Bowyer, V.V. Krylov, "Experimental investigation of damping flexural vibrations in glass fibre composite plates containing one- and two-dimensional acoustic black holes", Composite Structures 107 (2014) 406–415.

[5] Sudip Dey, Tanmoy Mukhopadhyay, Sondipon Adhikari, " Stochastic free vibration analysis of angle-ply composite plates– A RS-HDMR approach", Composite Structures, 122 (2015) 526-536.

[6] K. Sepahvand, M. Scheffler, S. Marburg, "Uncertainty quantification in natural frequencies and radiated acoustic power of composite plates: Analytical and experimental investigation", Applied Acoustics, Volume 87, January 2015, Pages 23-29.

A Brief Author Biography

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