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Frequency Analysis of Moderate Thickness in Orthotropic Laminated Composite Plate Using FE Method

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Abstract - A study of frequency analysis of moderate thickness in the orthotropic laminated composite plate by applying classical boundary conditions with respect to a range of thickness to width ratio by modal analysis is presented here. This analysis is performed on the ANSYS APDL 2019 R1 worked on Finite Element Method (FEM). The model responses are confirmed through the presented literature. Doing comparative study solutions are obtained and the solutions have good harmony with presented literature. This study presented that boundary conditions and thickness to width ratio have an important role in frequency analysis of orthotropic laminated composite plate.

Keywords: Orthotropic Plate, Finite Element Method, Free Vibration, Boundary Conditions

I. INTRODUCTION

Day to day the use of composite materials is increased hastily. Due to the properties like high performance, high stiffness to weight ratio, corrosion resistance and high strength, these materials have a vast range of application in areas like aerospace, aircraft, turbine blade, cryogenic fuel tanks, automobile body parts and so on. Mostly these are connected with dynamic loads (uniform or non-uniform load) and due to this connection vibration is created. For these types of structure, the laminated plate is used and vibration analysis has an important problem in the design of its application. When the system frequency matches with the natural frequency or very close, resonance takes place. Due to resonance catastrophic failure and large deformations occurs in wrong constructed composite plate and vibration creates unwanted noise and energy waste. So the careful design avoids all these problems.

A comprehensive study is done for literature review to know the present state of work. The value of normal frequencies and the mode shapes on a lamina composite plate by experimentally and compared with finite element analysis results is studied [1]. The different boundary conditions and different ply orientations of laminated composite plates to find out the free vibration frequencies by presenting an effective method based on Rayleigh-Ritz method is studied [2]. During the time, many new theories and methods were coming to study or analyze it. First-order shear deformation theory (FSDT), Higher order shear deformation theory (HSDT) and finite element method (FEM) are one of the thies. The finite element analysis method by using two theories, first one is FSDT and the second one is HSTD, is presented here. In higher order theory HSDT 6, HSDT 9, HSDT 11, HSDT 12 are applied. This study is done for the bending, free vibration and impact response of thick laminated composite plates [3]. The behavior of the cross-ply laminated plate with the first-order shear flexibility and finding the first known results of displacement, bending moments and rotations by changing boundary conditions are studied [4]. The free vibration analysis of cross-ply laminated square plates by using the Ritz method and various classical boundary is used in this analysis, like free ,clamped and simply supported edges presented here [5]. An analytical approach to apply FSDT in Radial Basis Functions (RBF) method for moderate thick symmetric laminated composite plates discussed here [6]. The various thicknesses to length ratio (t/b), a range of aspect ratios (a/b) and many boundary conditions for isotropic laminated plate and many other plates to find the behavior of plate presented here. That experiment was based on a new numerical format, which was a combination of RBF and pseudo-spectral methods to achieve correct results [7]. The classical boundary conditions have been used by the majority of the study, i.e.,[8], [9], [10], [11], [4], [12], [13], [14] and [15]. Due to this study, we can say that the thickness ratio and boundary conditions have an important impact on the analysis of the composite plate. There are mainly two types of traditional boundary conditions, related to every degree of freedom (dof). First one is the corresponding force (natural boundary conditions) and another one is the displacement (essential boundary condition). The differential principal equations, the influence of the grid pattern, modulus ratio, side to thickness ratio, and natural frequencies of symmetric

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laminated composites plate using trigonometric theory and inverse multiquadric radial basis function are discussed here [16]. An empirical formula for the orthotropic laminated rectangular plate to calculate the resonance frequencies fastly are presented here. In it the classical boundary conditions. All edges of the plate are supported according to boundary conditions and the formula is based on the Rayleigh-Ritz method [17]. A new effectual RBF collocation method by using the FSDT for laminated composite plates free vibration analysis are suggested with the help of may example i.e thickness to span ratio, boundary conditions and material properties and one–dimensional integrated RBF networks(1D-IRBFN) also used [18]. The Orthotropic shear deformable cracked plates investigated here. The model and harmonic analysis are done to study it. A direct time-domain Boundary Element Method formulation based on the electrostatic fundamental solution of the problem is used on it [19]. A free vibration analysis of moderate thick laminated composite plates by using the model and harmonic analysis and many classical boundary conditions with different thickness ratio are used in this study. ANSYS Finite element software package is used to perform this study [20]. The boundary conditions of composite plate and find the free vibration frequencies are presented here [21]. The study of skew cut-out on composite plate using the FE method and perform the vibration analysis of the plate [22]. Free vibration analysis of laminated composite plate using ANSYS software worked on FEM. The glass fibre reinforced polymer is used and results are compared with results already available in the literature [23]. The behavior of the smart cantilever composite beam using ANSYS doing model analysis. Modal frequencies and mode shapes were analyzed [24]. The effect of delamination, stacking sequences and classical boundary conditions of CFRPC are investigated here by using FEM software ANSYS and MATLAB also used [25].

II. METHODOLOGY

The analysis is perform on ANSYS mechanical APDL2019 R1 to determine the orthotropic moderately thick laminated composite plate free vibration frequency. It has two types of operations-basically, one is pre-processer and another one is post-processor. Given element description, making the geometry of the plate and meshing are performed on pre-processer. Applying load, giving the analysis type, generate the solution and related command for the solution and time heat command are performed on post-processor. The analysis has been done on orthotropic plates with respect to the various thickness ratio and various combinations of different boundary conditions. The boundary conditions are clamped, free and simply supported (CCCC, SSSS, SFSF, CFCF and CFFF). The static structural analysis is chosen to perform operation. To find the mode frequencies and mode shapes of composites plate model analysis is used and it is applicable on dynamic load and provide an overview of system response. Modal analysis is used for determining the fundamental frequencies of the plate. The shear correction factors and non-dimnesional natural frequencies are same for every ply. The thickness, density is the same for all layers and same linearly elastic composite material is used for all layers.

2.1 Modelling

The material parameters are given below : $E_1/E_2=40$; $G_{12}=G_{13}=0.5E_2$; $G_{23}=0.5E_2$; $\nu_{12}=0.25$, $\rho=1$ ^{3} here the grapheme 1 represents the directions parallel and grapheme 2 represent at a 90 degree angle to the fibre direction in a layer and E denote the young modulus , G denote the shear modulus and ν denote the posion ratio. The orientation of plies is determined from the x-axis to the fibre direction for all layers. Clockwise measurement of an angle is positive and anticlockwise is negative. The Shear correction factor is $K_S=\pi^2/12$. Non-dimensionalised natural frequency; $\bar{\omega}=\omega(b^2/\pi^2)\sqrt{\rho t/D_0}$ with $D_0=E_2t^3/12(1-\nu_{12}\nu_{21})$. The Block-Lanczos algorithm is used on ANYS APDL. The square orthotropic moderate thick plate of, which aspect ratio is 1, is used to perform the analysis. The study is done till 8 nodes of element and it is sufficient to analyze the parameters. The quard free mesh is used in this mesh generation .

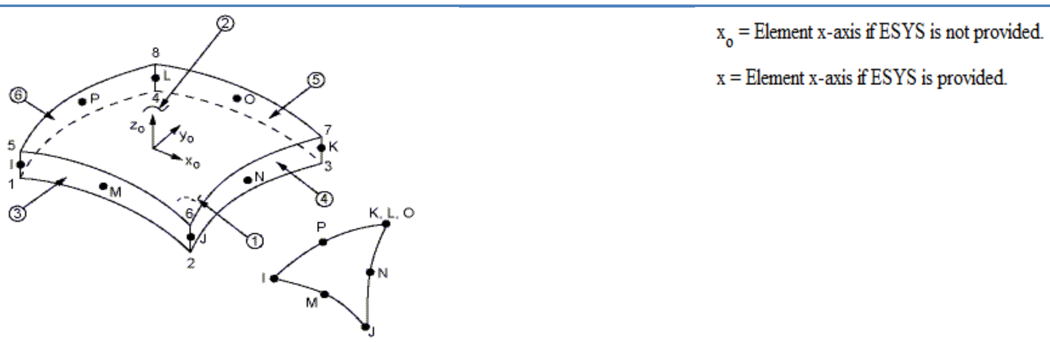

Figure 1 SHELL 281 Geometry

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The element type 8-nodes SHELL 281 is used because of its the suitability of analyzing moderately-thick shell structure. It consists of six degrees of freedom at each node: there are translations in the x, y, and z-axes, and three are rotations about the x, y, and Z-axes. The quard free mesh is used in mesh generation. The frequency varies from 0 to 3000 Hz. The orthotropic moderately thick plate has an aspect ratio (a/b) is 1 means square plate is used.

III. RESULT & DISCUSSION

In the modal analysis, firstly, the comparative study has been done with available literature, then the non-dimensional natural frequency of laminated composite plates studied to determine the response of plates followed by convergence study.

3.1 CONVERGENCE STUDY

The convergence study has been done for orthotropic square laminated composite plate (a/b=1) with different boundary conditions and the convergence takes place at the mesh size of 13 × 13.The thickness to width ratio (t/b) is **0.05**. Table 1 shows the convergence study. The ply orientation is $[0^\circ/90^\circ/0^\circ]$ used and it is fully clamped.

Table 1

Clamped three-ply $[0^\circ/90^\circ/0^\circ]$ square laminated plate : Non –dimensional fundamental frequencies $\varpi = \omega(b^2/\pi^2)\sqrt{\rho t/D_0}$ . .And a/b= 1.

	Mode Sequence Number							
Mesh size	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
7×7	10.898	13.817	19.808	23.101	24.784	28.394	28.753	35.404
9×9	10.896	13.802	19.704	23.075	24.749	27.967	28.649	35.018
11×11	10.896	13.799	19.670	23.068	24.740	27.828	28.617	34.896
13×13	10.895	13.796	19.655	23.063	24.734	27.770	28.605	34.847
15×15	10.895	13.796	19.650	23.063	24.734	27.745	28.600	34.825
17×17	10.895	13.796	19.648	23.062	24.734	27.731	28.597	34.814
19×19	10.895	13.796	19.645	23.062	24.732	27.723	28.596	34.807

3.1.2 COMPARISON STUDY

Table 2 shows the comparison study of non-dimensional fundamental frequencies for Simply Supported four-ply (SSSS) [0°/90°/90°/0°] square laminated composite plate for different thickness to width ratio. The comparison of results is done with [18], [4] and [7]. Table 2 clearly shows that the results are very close to the available literature.

Table 2

Simply Supported four-ply (SSSS) [0°/90°/90°/0°] square laminated plate: Non –dimensional fundamental frequencies $\varpi = \omega(b^2/\pi^2)\sqrt{\rho t/D_0}$ . .And a/b= 1. Mesh is used 13×13 grid.

t/b	**0.01**	**0.02**	**0.04**	**0.05**	**0.08**	**0.1**	**0.2**	**0.25**
Present	6.603	6.540	6.314	6.162	5.624	5.245	3.691	3.165
IRBFN	6.607	6.547	6.338	6.189	5.668	5.300	3.792	3.281
% Error	0.060	0.107	0.378	0.436	0.776	1.037	2.663	3.535
Liew(p-ritz)	6.606	6.549	6.338	6.193	5.677	5.311	3.807	3.295
% Error	0.045	0.137	0.378	0.501	0.933	1.242	3.047	3.945
Ferreira and Fasshauer	6.602	6.544	6.330	6.185	5.665	5.296	3.791	3.280
% Error	0.015	0.061	0.252	0.372	0.723	0.962	2.637	3.506

Figure 2 present the comparsion of all the results with respect b/w non dimentional fundamental frequencies and thickness ratio. It shows the very high close proximity on the lowest thickness ratio to width ratio (t/b) and at high t/b the result has a greater difference from the low t/b.

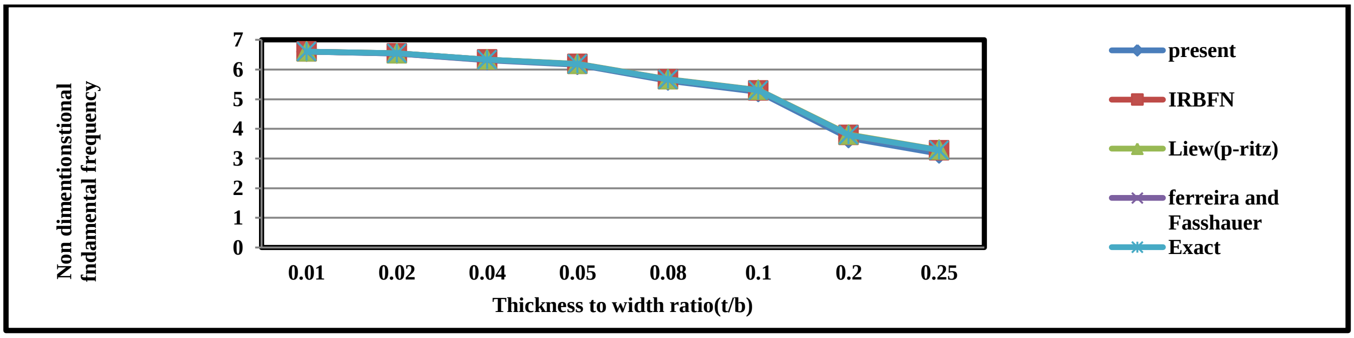

Figure 2(Comparison of all literature results with present result with respect to various thickness ratio and non-dimensional fundamental frequencies**)**

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Table 3 present the analysis of fully clamped four ply square plate and various thickness ratio is used. It shows the non-dimensional natural frequencies for a square laminated plate for fully clamped boundary condition .from the table it is clear that the difference b/w to frequencies from t/b 0.08 to 0.25 at mode 4, 5, 6, 7 & 8 is low form other mode and from other t/b.

Table 3

Clamped four-ply (CCCC) [0°/90°/90°/0°] square laminated plate: Non-dimensional fundamental frequencies $\varpi = \omega(b^2/\pi^2)\sqrt{\rho t/D_0}$ .Mesh is used 13×13 grid.

Mode	t/b	0.01	0.02	0.04	0.05	0.08	0.1	0.2	0.25
1		14.467	13.893	12.167	11.248	8.882	7.69	4.437	3.631
2		20.403	19.667	17.396	16.15	12.82	11.093	6.379	5.228
3		32.635	31.127	26.011	22.938	16.558	13.888	7.61	6.186
4		36.443	33.339	26.713	24.434	18.78	16.055	8.907	7.257
5		39.564	36.431	29	25.829	19.038	16.082	9.042	7.376
6		47.548	44.057	35.549	31.794	23.525	19.872	10.978	8.931
7		50.44	47.177	38.627	34.662	25.712	21.296	11.263	9.086
8		61.669	56.894	43.095	37.09	25.759	21.701	11.884	9.637

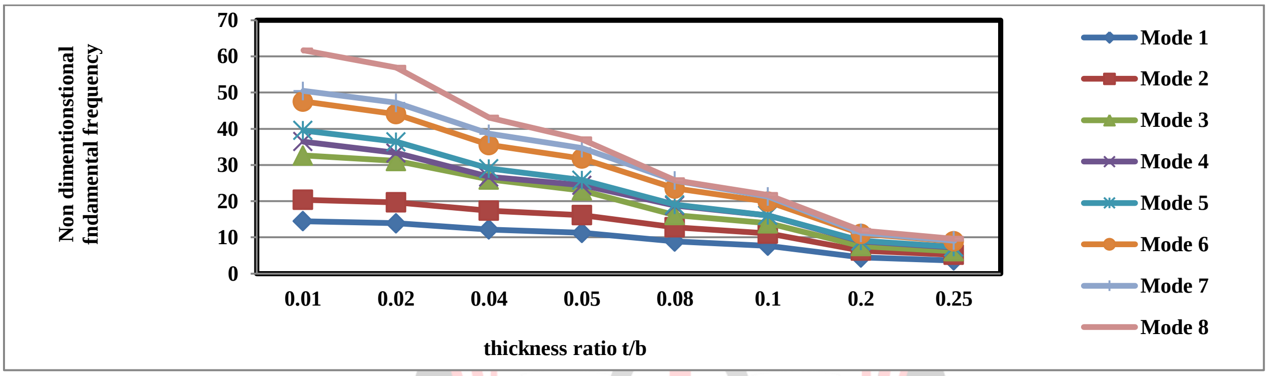

Figure 3(Clamped four ply [0°/90°/90°/0°] square plate: relation b/w non-dimensional fundamental frequencies and thickness ratio for first eight node)

Table 4 clearly shows that the value difference b/w frequencies from mode 1 to 2,4 to 5 and 7 to 8 is very low and other mode have a larger difference. The frequency difference for t/b 0.01 to 0.1is low on mode 1,2. Figure 4 shows it clearly and it is also shown that the frequencies of mode 1, 2 and mode 3,4,5 have near values of frequencies. The plate is clamped free clamped free boundary condition.

Table 4

CFCF four-ply [0°/90°/90°/0°] square laminated plate: Non-dimensional natural frequencies $\varpi = \omega(b^2/\pi^2)\sqrt{\rho t/D_0}$. Mesh is used 13×13 grid.

Mode	t/b	0.01	0.02	0.04	0.05	0.08	0.1	0.2	0.25
1		5.474	5.405	5.155	4.988	4.415	4.03	2.604	2.172
2		5.789	5.711	5.433	5.25	4.631	4.221	2.736	2.295
3		14.971	14.611	13.269	12.475	10.183	8.35	4.18	3.347
4		15.015	14.761	13.632	12.813	10.437	8.914	5.26	4.336
5		15.445	15.023	14.02	13.539	10.468	9.179	5.492	4.562
6		21.459	20.938	19.251	16.696	11.932	10.877	7.032	5.87
7		29.265	27.964	20.87	18.262	15.365	13.699	8.289	6.694
8		29.735	28.403	24.104	22.089	17.056	14.616	8.359	6.773

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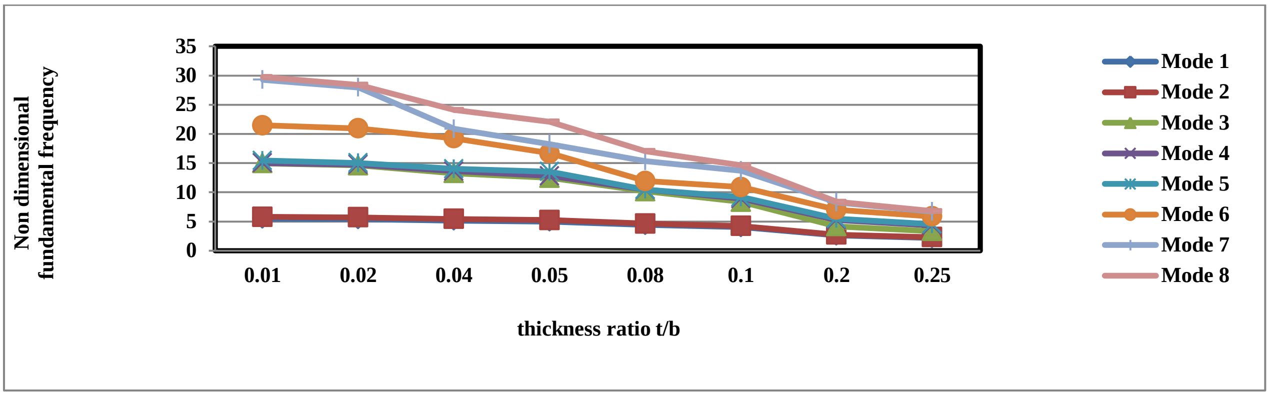

Figure 4(CFCF four ply [0°/90°/90°/0°] square laminated plate: relation b/w non-dimensional fundamental frequencies and thickness ratio for first eight node)

Table 5 shows clearly that the mode 1 frequencies are very low and there are very low variations on changing the t/b. It also shows that the frequencies variations on every mode is very less from t/b 0.01 to 0.1. The difference b/w mode 2 and mode 3 frequencies are very low .the plate is used simply supported free simply supported free four ply with orientation [0°/90°/90°/0°].

Table 5

SFSF four-ply [0°/90°/90°/0°] square laminated plate non-dimensionalised natural frequencies $\varpi = \omega(b^2/\pi^2)\sqrt{\rho t/D_0}$ for mesh 13×13.

Mode	t/b	0.01	0.02	0.04	0.05	0.08	0.1	0.2	0.25
1		0	0	0	0.001	0	0.001	0.001	0.001
2		2.423	2.416	2.391	2.373	2.299	2.236	1.863	1.682
3		2.952	2.933	2.88	2.847	2.725	2.63	2.113	1.877
4		9.666	9.565	9.195	8.946	8.065	7.451	4.028	3.223
5		10.233	10.113	9.693	9.415	8.453	7.793	4.27	3.416
6		14.042	13.859	13.212	12.789	10.067	8.053	5.019	4.23
7		17.911	17.627	16.679	16.08	10.673	8.539	5.208	4.373
8		21.666	21.175	19.511	16.106	11.352	10.394	6.831	5.735

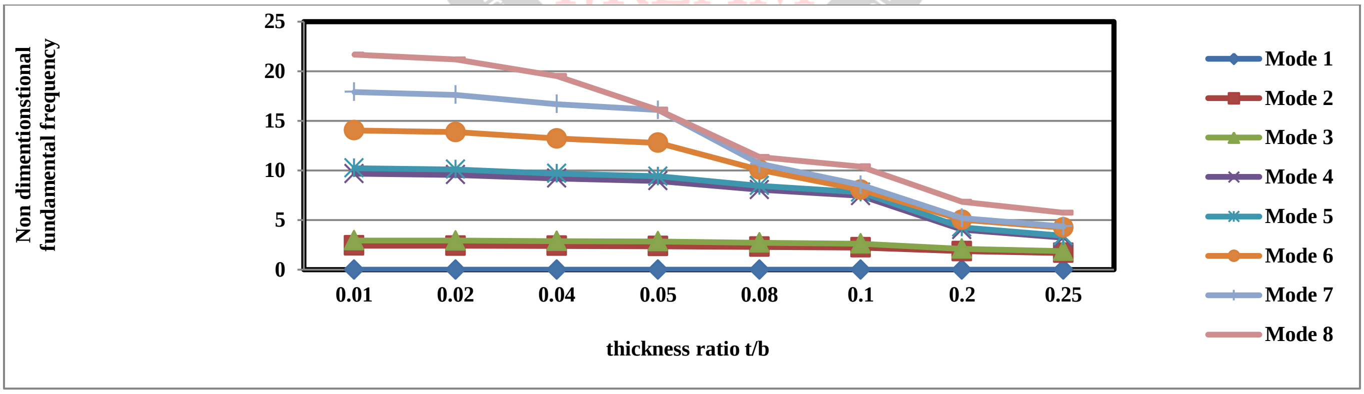

Figure 5(SFSF four ply [0°/90°/90°/0°] square laminated plate: relation b/w non-dimensional fundamental frequencies and thickness ratio for first eight node)

Table 6 shows clearly that the changing of frequencies on increasing t/b from 0.01 to 0.1 is low in all mode. The frequencies suddenly increase from from mode 2,3 and mode 4 to 5.

Table 6

CFFF four-ply [[0°/90°/90°/0°] square laminated plate: convergence study of non-dimensional natural frequencies $\varpi = \omega(b^2/\pi^2)\sqrt{\rho t/D_0}$. Mesh is used 13×13 grid.

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Mode	t/b	0.01	0.02	0.04	0.05	0.08	0.1	0.2	0.25
1		0.864	0.863	0.859	0.855	0.842	0.83	0.748	0.7
2		1.401	1.393	1.371	1.358	1.309	1.271	1.062	0.963
3		5.398	5.352	5.178	5.058	4.621	3.977	1.99	1.593
4		6.185	6.12	5.897	5.75	4.971	4.306	3.001	2.571
5		13.57	13.402	9.94	7.953	5.233	4.873	3.448	2.989
6		15.059	14.76	12.791	12.386	10.996	9.942	5.982	4.788
7		15.648	15.413	13.726	13.085	11.118	10.07	6.247	5.217
8		15.761	15.433	14.325	13.646	11.583	10.373	6.571	5.506

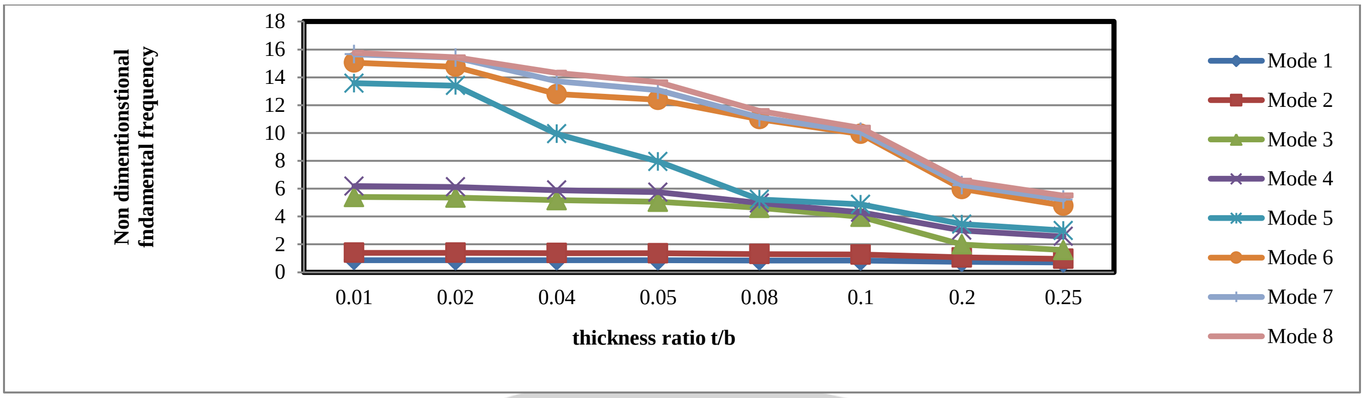

Figure 6 (CFFF four ply [0°/90°/90°/0°] square laminated plate: relation b/w non-dimensional fundamental frequencies and thickness ratio for first eight node)

IV. CONCLUSIONS

In present study, the free vibration analysis of orthotropic thick symmetric square laminated plate of four ply with [0°/90°/90°/0°] orientation is analyzed. The following conclusion has found:

a) From the convergence study, 13 ×13 mesh size is achieved and the comparison of results from the available literature has very close value.

b) The percentage error from available literature and obtained thickness result for all the obtained thickness to width ratio results is form 0.15% to 3.945%, so it illustrated a good relation with the available literature.

c) The fully clamped (CCCC) boundary condition has achieved the highest range of fundamental frequencies and CFFF boundary conditions achieved the lowest range.

d) It is observed that there is a significant variation in the resonance condition for CFFF in comparison to the other boundary conditions (i.e., SSSS, CFCF, and CCCC).

e) In every boundary conditions, the fundamental frequencies decrease with the increasing of thickness to width ratio and the effect of boundary conditions o plate is very high.

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