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Free Vibration Analysis of Eccentric and Concentric Isotropic Stiffened Plate with Orthogonal Stiffeners using ANSYS

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Abstract

This paper shows the study of free vibration analysis of stiffened isotropic plates with orthogonal stiffeners placed eccentrically and concentrically to the plates. In this paper finite element model is developed in ANSYS parametric design language code and discretized using 20 node structural element (SOLID 186) and convergence study of isotropic stiffened plates has been performed and compare the results with related published literature. Effects of various parameters such as boundary conditions, aspect ratios, position of stiffeners eccentrically and concentrically to the stiffened plates has been studied. The vibration analysis of stiffened plate have been studied using Block - Lanczos algorithm. The results of non dimensional frequency of eccentric and concentric isotropic stiffened plate have been compare at different mode shapes, aspect ratio's, boundary conditions using ANSYS.

Keywords*: Free vibration, FEM, Stiffened plate, Natural frequency, Aspect ratio, Boundary conditions, orthogonal Stiffeners*

1. Introduction

Research into stiffened plates has been a subject of interest for many years. Substantial efforts by many researchers were devoted to investigate the response of the stiffened plates. The research done on stiffened plates can be classified into two categories, analysis and design. In this work the initiation has been taken to carry on analysis of free vibration of isotropic stiffened plates by Ansys software package and the results has been validated with the literatures available. The extensive review on plate vibration can be found in the literature provided by J. M. Klitchief and Y. Belgrade [1] analyzed the stability of infinitely long, simply supported, transverse stiffened plates under uniform compression and lateral load. An extreme motivation of the work was to assess for design rules used in naval architecture. Even though their objective was to analyze eccentric stiffeners. Their approach appears to be valid only for the concentric case. In the eccentric case, difficulties appear over the concentric configuration in the coupling between the in-plane and out-of-plane displacements, by which results in an increase of the order of the differential equations for the structure which has been ignored in the analysis of their solution. W. H. Hoppmann and M. Baltimore [2] and H. W. Hoppman, N. J. Hungton and L. S. Magness [3] used an orthotropic plate approach for analyzing simply supported orthogonally stiffened plates under static and dynamic loading. The plate rigidities and stiffness were determined experimentally. Simply supported orthogonally stiffened plates under static and dynamic loading. W. Soper [4] investigated a large deflection analysis for laterally loaded orthotropic plates using Levy's approach. An approximated the stress functions by a trigonometric series and solved the resulting set of non-linear equations numerically. B.R. Long [5-6] used the stiffness method of structural analysis for the computational

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evaluation of the natural frequency of simply supported plates stiffened in the longitudinal direction. They illustrated the method for the analysis of a plate with one longitudinal stiffener and a plate with one longitudinal and one transverse stiffeners. R. Avent and D. Bounin [7] presented an discrete element approach to compute the elastic buckling of stiffened plates subjected to uniform longitudinal compression. These formulations were connected to simply supported plates with the equally spaced and equally sized stiffeners. In that analysis, using the equilibrium and compatibility conditions between the plate panel and the stiffener, a set of differential equations were obtained. Using the double Fourier series approximation, the buckling load was calculated by solving the resulting eigen value problem. The main advantage of this approach is the size of the eigen value problem is not depending of the number of ribs compared with other numerical methods. This is because of the confinement of the derivation to equally spaced and geometrically identical stiffeners. M.D. Olson and C.R. Hazell [8] examine results from a theoretical and experimental comparison study of the vibrations of four integrally machined rib-stiffened plates. In the study, effective use of most advanced analysis tools available today namely, the finite element method with high precision elements for the theory and real-time laser holography for the experiment. Integral rib-stiffened plates are becoming common in aerospace applications where it is desired to have natural frequencies as high as possible for a given plate weight. Such configurations may be analysed satisfactorily with orthotropic plate theory when the density of stiffeners is high. G. Qing, J. Qiu and Y. Liu [9] developed a fictitious mathematical model for free vibration analysis of stiffened laminated plates by separate consideration of plate and stiffeners. By using the semi-analytical solution of the state-vector equation theory, the method accounts for the compatibility of displacements and stresses on the interface between the plate and stiffeners, the transverse shear deformation, and naturally the rotary inertia of the plate and stiffeners. Meanwhile, there is no restriction on the thickness of plate and the height of stiffeners. H. Zeng and C. W. Bert [10] have studied a differential quadrature analysis of free vibration of plates with eccentric stiffeners is presented. The plate and the stiffeners are presented separately. Simultaneous governing differential equations are derived from the plate dynamic equilibrium, the stiffener dynamic equilibrium, and equilibrium and compatibility conditions along the interface of a plate segment and a stiffener. C.J. Chen, W. Liu, and S.M. Chern [11] a spline compound strip method has been presented for the free vibration analysis of stiffened plates. The plate was discretized and modeled as strip elements the theory has been illustrated with several examples including one directional stiffened plates and cross direction stiffened plates. S. J. Hamedani, M. R. Khedmati and S. Azkat [12] studied the vibration analysis of stiffened plates, using both conventional and super finite element methods. An effective use of Mindlin plate and Timoshenko beam theories has been investigated to formulate the plate and stiffeners, respectively and have been used for free vibration studies of different geometries and materials. S. I. Ebirim, J. C. Ezeh and M. O. Ibearugbulem [13] free vibration of simply supported plate with one free edge was tested in detail and formulation of model is based on Ibearugbulem’s shape function and Ritz method. In the study, Ibearugbulem’s shape function was added into the potential energy functional, was reduced to obtain the fundamental natural frequency. A. T. Samaei, M. R. M. Aliha and M. M. Mirsayar [14]. Frequency analysis of a graphene sheet embedded in an elastic medium with consideration of small scale. Eccentricity of the stiffeners is considered and they are not limited to be placed on nodal lines. Therefore, any configuration of plate and stiffeners can be modeled. Numerical examples are proposed to study the accuracy and convergence characteristics of the super elements.

2. Explanation of Ansys and Material Properties of plates

ANSYS is a general-purpose finite-element modeling package for numerically solving a wide variety of mechanical problems. These problems include static/dynamic, structural analysis (both linear and nonlinear), ansys provides a complete set of element behavior material model and equation solvers for a wide range of mechanical design problems. It permits an evaluation of a design without having to build and destroy multiple prototypes in testing. The ANSYS package has a variety of design analysis applications, ranging from such everyday items as dishwashers, cookware, automobiles, running shoes and beverage cans to such highly sophisticated systems as aircraft, nuclear reactor containment buildings, bridges, farm machinery, X-ray equipment and orbiting satellites.

In general, a finite-element solution may be broken into the following three stages.

1. Preprocessing- The major steps in preprocessing are

(i) define keypoints/lines/areas/volumes,

(ii) define element type and material/geometric properties,

(iii) mesh lines/areas/ volumes as required. The amount of detail required will depend on the dimensionality of the analysis, *i.e.*, 1D, 2D, axisymmetric, and 3D.

2. Processing- Solution: assigning loads, constraints, and solving here, it is necessary to specify the loads (point or pressure), constraints (translational and rotational), and finally solve the resulting set of equations.

3. Post processing- further processing and viewing of the results In this stage one may wish to see (i) lists of nodal displacements, (ii) element forces and moments, (iii) deflection plots, and (iv) stress contour diagrams or temperature maps.

Solution Procedure for Free Vibration Analysis

The free vibration analysis involves determination of
natural frequencies from the condition

$$[K] - \omega^2 [M] = 0$$

This is a generalized eigenvalue problem
Where [K] and [M] are the stiffness and mass matrix respectively

Plates Element

The SOLID186 is a higher order 3-D 20-node solid element that exhibits quadratic displacement behavior. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element supports plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyperelastic materials. The geometry, node locations, and the element coordinate system for this element are shown in Figure 2.

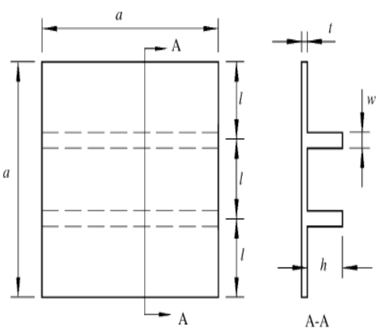

Figure 1. Geometry of Eccentrically Stiffened Isotropic

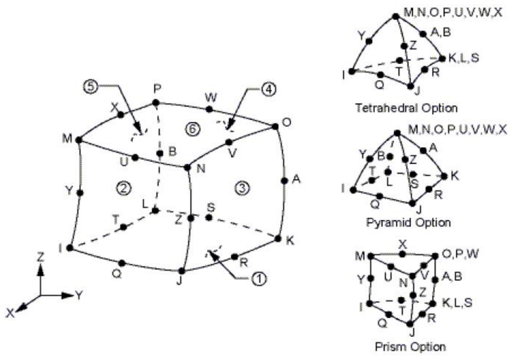

Figure 2. SOLID 186 Element Plate with Double Stiffener

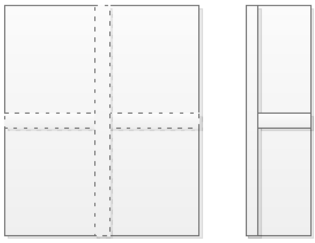

Figure 3. Geometry of Eccentrically Stiffened Isotropic Plate Stiffened with Two Orthogonal Stiffeners

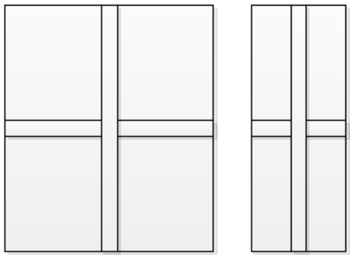

Figure 4. Geometry of Concentrically Isotropic Plate with Two Orthoganal Stiffener

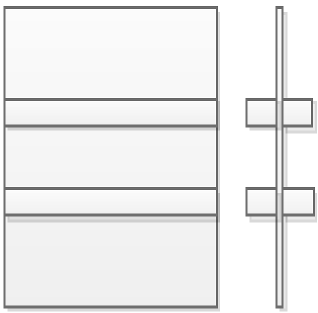

Figure 5. Geometry of Concentrically Stiffened Isotropic Plate with Double Stiffener

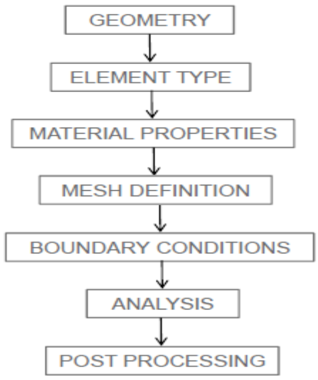

Figure 6. Modeling Procedure in the Ansys

The material properties and geometric parameters for eccentrically stiffened isotropic plate with two orthogonal stiffeners shown in Figure 3 and Figure 4 are

E=68.9Gpa, μ=0.3, ρ=2670 kg/m^3, t=0.00127m, w=0.002286m, h=0.01778m while values of l, a, b, are changed according to the aspect ratio's (1,1.5,2,2.5)

The material properties and geometric parameters for eccentrically stiffened isotropic plate with four orthogonal stiffeners shown in Figure 5 and Figure 6 are

E=68.9Gpa, μ=0.3, ρ=2670 kg/m^3, t=0.00127m, w=0.002286m, h=0.01778m while values of **l**, **a**, b, are changed according to the aspect ratio's (1,1.5,2,2.5)

3. Numerical Results and Discussion

Various boundary conditions of eccentrically and concentrically stiffened isotropic plate with different aspect ratio and affect of number of orthogonal stiffeners are investigated. Boundary conditions along the edges are described by the alphabets so that C-C-C-C indicates a stiffened plate with edge x=0 clamped edge y=o clamped, edge x=a clamped and edge y=a clamped in which x,y,z are co-ordinates axes.

Convergence study

To demonstrate the efficiency of Ansys software package an eccentrically stiffened isotropic plate with double stiffener is considered. The material properties and geometric parameters shown in Figure 1. are E=68.9Gpa,μ=0.3, ρ=2670kg/m^3, a=0.2032m, l=0.6773m, t=0.00127m, w=0.002286m, h=0.01778m.l=0.6773m, t=0.00127m,w=0.002286m, h=0.01778m An eccentrically stiffened isotropic plate with double stiffener (Figure 1.) which is a previously reported experimental and theoretical example (Olson & Hazell, 1977; Zeng & Bert, 2001; Qing & Liu, 2006;), are selected as the first example to validate present method. The results, as listed in Table 1, show that reasonable convergence has been achieved with relatively small decrements in the first five frequencies, never as much as 1%, between corresponding value for mesh size 82×82,1 and mesh size 92×92,1. It is obvious (see Table 2 and Figure 7.) that the first four modes are in acceptable range. The same trend was seen in reference (Olson & Hazell, 1977). & (Zeng & Bert, 2001). It can be also seen that natural frequencies are obtained by using Ansys (APDL) are lower for first two modes and higher for remaining two modes than those of FEM (Olson & Hazell, 1977).

Table 1. Natural Frequencies (Hz) for Eccentrically Stiffened Isotropic Plate with Double Stiffeners and Clamped at Edges

Mesh size		Mode number				
Plate	Stiffeners	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
11×11,1	1×11,8	1806.5	1967.9	1999.0	3121.6	3539.6
22×22,1	2×22,8	1054.9	1397.4	1527.6	1637.5	1799.9
33×33,1	2×33,8	974.93	1287.7	1405.0	1475.2	1647.8
42×42,1	2×42,8	963.55	1268.0	1382.9	1440.9	1613.6
52×52,1	2×52,8	959.80	1261.7	1375.2	1430.6	1604.2
62×62,1	2×62,8	958.18	1258.4	1371.8	1425.4	1599.5
72×72,1	2×72,8	957.25	1256.8	1370.2	1422.3	1596.9
82×82,1	**2×82,8**	**956.64**	**1255.5**	**1369.0**	**1420.1**	**1595.0**
92×92,1	2×92,8	956.36	1255.0	1368.6	1419.6	1594.0

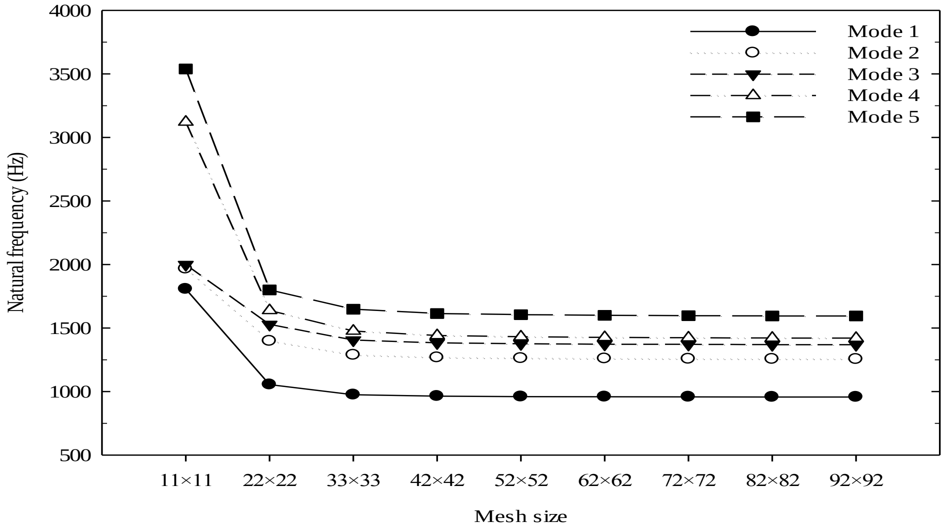

Figure 6. Convergence Study of the Element used for Eccentrically Stiffened Isotropic Plate with Double Stiffener

Table 2. Comparison of Natural Frequencies (Hz) for Eccentrically Stiffened Isotropic Plate with Double Stiffener and Clamped at Edges

Papers	Mode number (Error % = 100 · (Present-Ref.)/Ref.)			
	Mode 1	Mode 2	Mode 3	Mode 4
Experimental, Olson and Hazell (1977)	909 (5.240)	1204 (4.277)	1319 (3.790)	1506 (-5.703)
FEM, Olson and Hazell (1977)	965.3(-0.897)	1272.3(-1.320)	1364.3(0.344)	1418.1 (0.141)
Zeng and Bert (2001)	915.9(4.448)	1242.2(1.070)	1344.4(1.829)	1414.1 (0.424)
Qing, G., Qiu, Y., Liu, Y. (2006)	931.5 (2.698)	1220.9 (2.833)	1331.8 (2.793)	1403.3 (1.197)
Present	**956.64**	**1255.5**	**1369.0**	**1420.1**

Table 3. Variation of Non Dimensional Frequency Parameter ($\Omega = \omega a^2 \sqrt{\frac{\rho h}{D}}$) for Eccentrically Stiffened Isotropic Square Plate with Two Orthogonal Stiffeners at Different Boundary Conditions

MODE	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
CCCC	20.24858	21.63537	21.63537	22.76495	40.80852
SSSS	16.62907	17.8312	17.83332	18.62317	29.46201
SCSC	18.33549	19.39991	19.95201	20.75562	37.05808
CCSS	17.42083	19.68167	19.69944	21.71787	35.87774
CFFF	1.689475	3.502739	4.925495	7.599456	12.00797

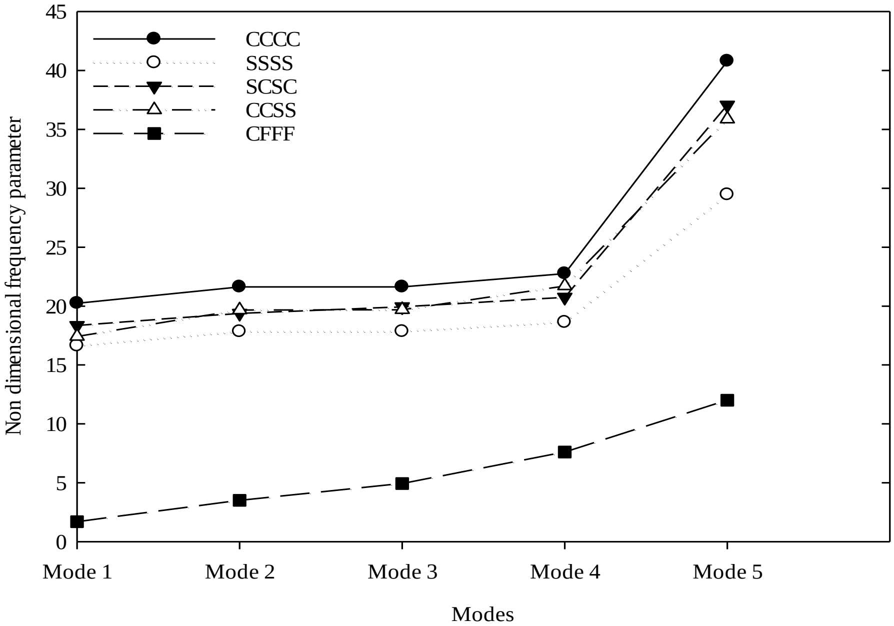

Figure 7. Variation of Non Dimensional Frequency Parameter ($\Omega = \omega a^2 \sqrt{\frac{\rho h}{D}}$) for Eccentrically Stiffened Isotropic Square Plate with Two Orthogonal Stiffeners at Different Boundary Conditions

Table 4. Variation of Non Dimensional Frequency Parameter ($\Omega = \omega a^2 \sqrt{\frac{\rho h}{D}}$) Concentrically Stiffened Isotropic Square Plate with Two Orthogonal Stiffeners at Different Boundary Conditions

MODE	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
CCCC	21.24827	22.2340	22.2340	23.14359	41.74561
SSSS	17.4441	18.46939	18.46981	19.35126	33.11726
SCSC	19.21821	19.97084	20.58808	21.30961	37.45576
CCSS	18.18255	20.27523	20.44572	22.34188	35.77409
CFFF	1.804633	3.92855	4.873035	9.186572	12.55097

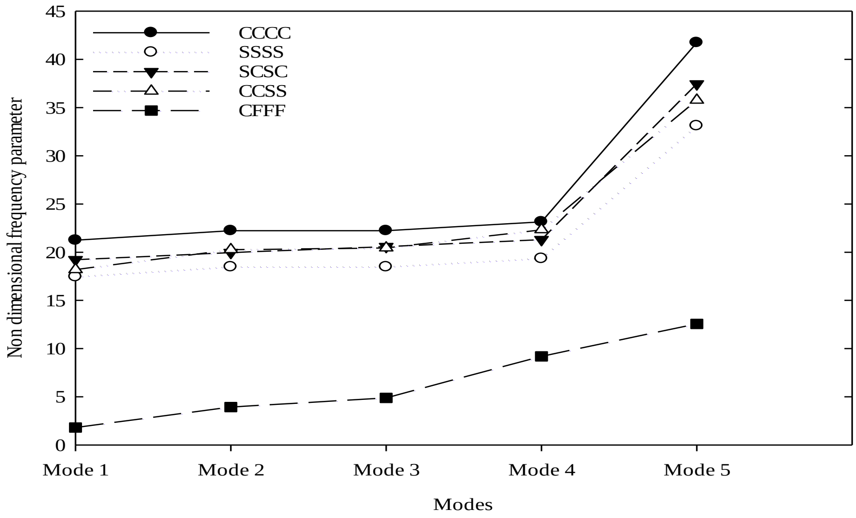

Figure 8. Variation of Non Dimensional Frequency Parameter ($\Omega = \omega a^2\sqrt{\frac{\rho h}{D}}$) for Concentrically Stiffened Isotropic Square Plate with Two Orthogonal Stiffeners at Different Boundary Conditions

Table 5. Variation of Non Dimensional Frequency Parameter ($\Omega = \omega a^2\sqrt{\frac{\rho h}{D}}$) for Eccentrically Stiffened Isotropic Plate with Two Orthogonal Stiffeners at and Clamped at Edges with Different Aspect Ratio's

Aspect ratio(a/b)	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
1	20.24858	21.63537	21.63537	22.76495	40.80852
1.5	31.06584	32.26141	37.12747	37.47586	53.15346
2	49.11492	49.65136	60.18475	60.2059	72.91552
2.5	70.47149	71.09551	80.08557	83.1792	93.49133

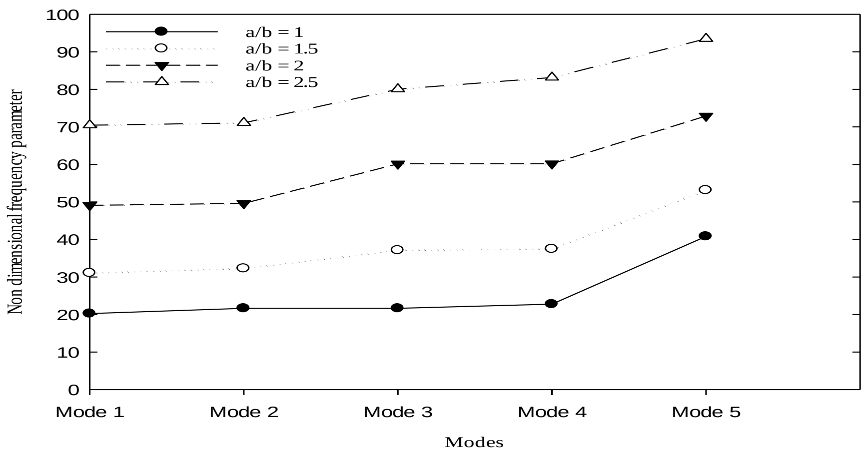

Figure 09. Variation of First Five Non Dimensional Frequency Parameter ($\Omega = \omega a^2\sqrt{\frac{\rho h}{D}}$) for Eccentrically Stiffened Isotropic Plate with Two Orthogonal Stiffeners and Clamped at Edges with Different Aspect Ratio's

Table 6. Variation of Non Dimensional Frequency Parameter ($\Omega = \omega a^2 \sqrt{\frac{\rho h}{D}}$) for Concentrically Stiffened Isotropic Plate with Two Orthogonal Stiffeners and Clamped at Edges with Different Aspect Ratio's

Aspect ratio(a/b)	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
1	21.24827	22.2340	22.2340	23.14359	41.74561
1.5	32.44608	33.1323	37.91753	38.5703	54.96776
2	51.21246	51.5949	62.32459	62.57505	75.81518
2.5	71.79885	72.2483	88.02835	90.3501	96.31527

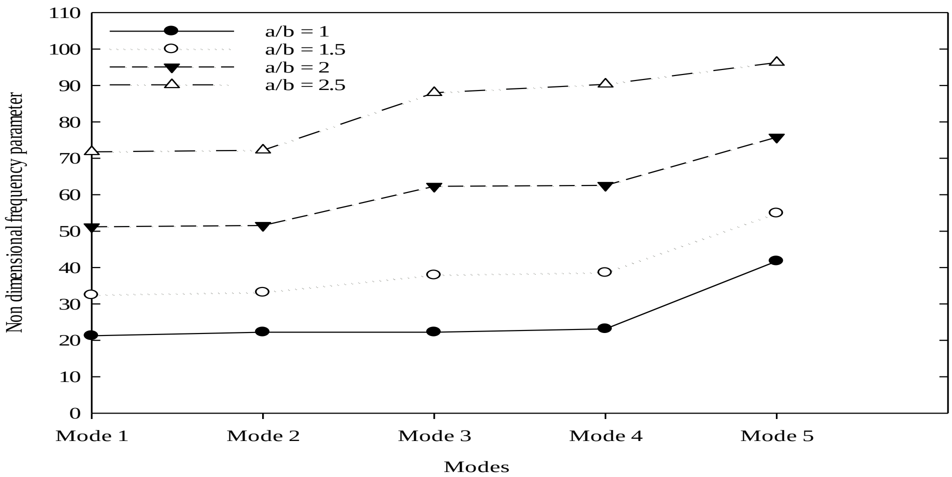

Figure 10. Variation of First Five Non Dimensional Frequency Parameter ($\Omega = \omega a^2 \sqrt{\frac{\rho h}{D}}$) for Concentrically Stiffened Isotropic Plate with Two Orthogonal Stiffeners and Clamped at Edges with Different Aspect Ratio's

Table 3 and Figure 7, Table 4 and Figure 8 shows the variation of first five on dimensional frequencies for different boundary conditions of eccentrically and concentrically stiffened isotropic square plate with orthogonal stiffeners respectively. In both the Tables and figures frequencies for all mode shapes increases at different boundary conditions and the highest values of non dimensional frequencies are obtained for CCCC boundary condition and lowest values of non dimensional frequencies are obtained for CFFF boundary condition, also there is small difference between the values of frequencies for SCSC vs CCSS boundary conditions as compared to the rest of the boundary conditions. Table 5. and Figure 9., Table 6. and Figure 10. Shows the variation of first five mode shapes of non dimensional frequencies for different aspect ratio's , CCCC boundary condition of eccentrically and concentrically stiffened isotropic plate with orthogonal stiffeners respectively. In both the tables and figures the variation of first five non dimensional frequencies for CCCC boundary condition have been increases as aspect ratio increases and maximum set of values are obtained for aspect ratio 2.5 and minimum set of values are obtained for aspect ratio 1.

4. Comparison of Eccentric and Concentric Stiffened Isotropic Plate on Natural Frequency Parameter

Table 7. Variation of Non Dimensional Frequency Parameter ($\Omega = \omega a^2 \sqrt{\frac{\rho h}{D}}$) of a Clamped Square Isotropic Plate for Concentric and Eccentric Stiffeners at Different Modes

Non dimensional frequency				
Stiffener	Double Stiffeners	Double Stiffeners	Orthogonal stiffeners	Orthogonal stiffeners
Mode number	Eccentric	Concentric	Eccentric	Concentric
Mode 1	20.2361	20.74335	20.24858	21.24827
Mode 2	26.55769	26.64019	21.63537	22.2340
Mode 3	28.95857	30.89196	21.63537	22.2340
Mode 4	30.04161	32.8740	22.76495	23.14359
Mode 5	33.73916	34.75663	40.80852	41.74561

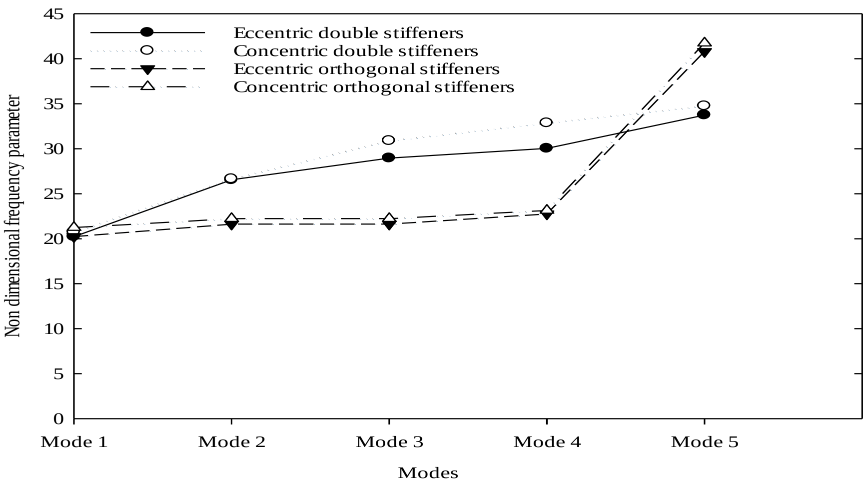

Figure 11. Variation of Non Dimensional Frequency Parameter of a Clamped Square Isotropic Plate for Concentric and Eccentric Stiffeners at Different Modes

To investigate the effect of eccentricity for the free vibrational behaviour of isotropic stiffened plates, a fully clamped isotropic stiffened square plates with double, orthogonal stiffeners respectively have been analyzed for both concentric and eccentric types for different mode shapes. The results obtained from such case are presented in Table 07 & Figure 11. For the eccentric and concentric isotropic stiffened plate with double stiffeners. The effect of eccentricity on non dimensional frequencies have been observed. It is interesting to note that the addition of eccentricity does not make difference to the values of non dimensional frequencies of stiffened isotropic plate but the values of non dimensional frequency parameter increases gradually. Comparison of eccentric and concentric isotropic stiffened plate with orthogonal stiffeners shows the value of non dimensional frequency of mode 5 is higher in magnitude as compared to the previous mode shapes. But Comparison of eccentric and concentric isotropic stiffened plate with double stiffeners shows that effect of eccentricity does not make a difference to values of non dimensional frequencies.

Table 8. Variation of Non Dimensional Frequency Parameter ($\Omega = \omega a^2 \sqrt{\frac{\rho h}{D}}$) of a Clamped Isotropic Plate with Eccentric and Concentric Stiffeners for Different Aspect Ratio's at Mode 1

Non dimensional frequency				
Stiffener	Double Stiffeners	Double Stiffeners	Orthogonal stiffeners	Orthogonal stiffeners
Aspect ratio a/b	Eccentric	Concentric	Eccentric	Concentric
1	20.20361	20.74335	20.24858	21.24827
1.5	35.86336	41.95735	31.06584	32.44608
2	47.52759	59.62969	49.11492	51.21246
2.5	46.4913	59.07527	70.47149	71.79885

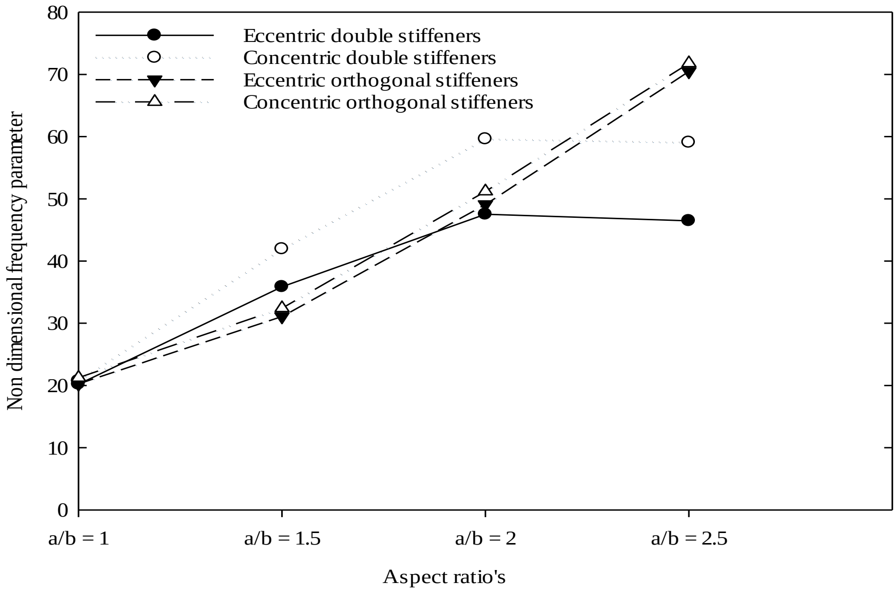

Figure 12. Variation of Non Dimensional Frequency Parameter of a Clamped Isotropic Plate with Concentric and Eccentric Stiffeners for Different Aspect Ratio's at Mode 1

To investigate the effect of eccentricity on the free vibration behaviour of isotropic stiffened plates, a fully clamped square plate with double stiffeners and orthogonal stiffeners respectively have been analyzed for both eccentric and concentric types for different aspect ratio's at mode 1. The results obtained from such case are presented in Table 08 & Figure 12. The effect of eccentricity on non dimensional frequencies have been observed. It is interesting to note that the addition of eccentricity does not make a difference to the values of non dimensional frequencies of the clamped isotropic stiffened plate in the comparison of eccentric and concentric isotropic stiffened plates with orthogonal stiffeners of increasing aspect ratio's. Comparison of eccentric and concentric isotropic stiffened plate with double stiffeners shows as aspect ratio's increases effect of eccentricity affect the values of non dimensional frequency parameter but the magnitude of difference is moderate.

Table 9. Variation of Non Dimensional Frequency Parameter ($\Omega = \omega a^2 \sqrt{\frac{\rho h}{D}}$) of a Isotropic Square Plate with Concentric and Eccentric Stiffeners for Different Boundary Conditions at Mode 1

Non dimensional frequency				
Stiffener	Double Stiffeners	Double Stiffeners	Orthogonal stiffeners	Orthogonal stiffeners
Boundary condition	Eccentric	Concentric	Eccentric	Concentric
CCCC	20.2361	20.74335	20.24858	21.24827
SSSS	17.32501	17.19471	16.62907	17.44410
SCSC	18.42708	18.63333	18.33549	19.21821
CCSS	18.25638	18.43872	17.42083	18.18255
CFFF	3.55266	3.831035	1.689475	1.804633

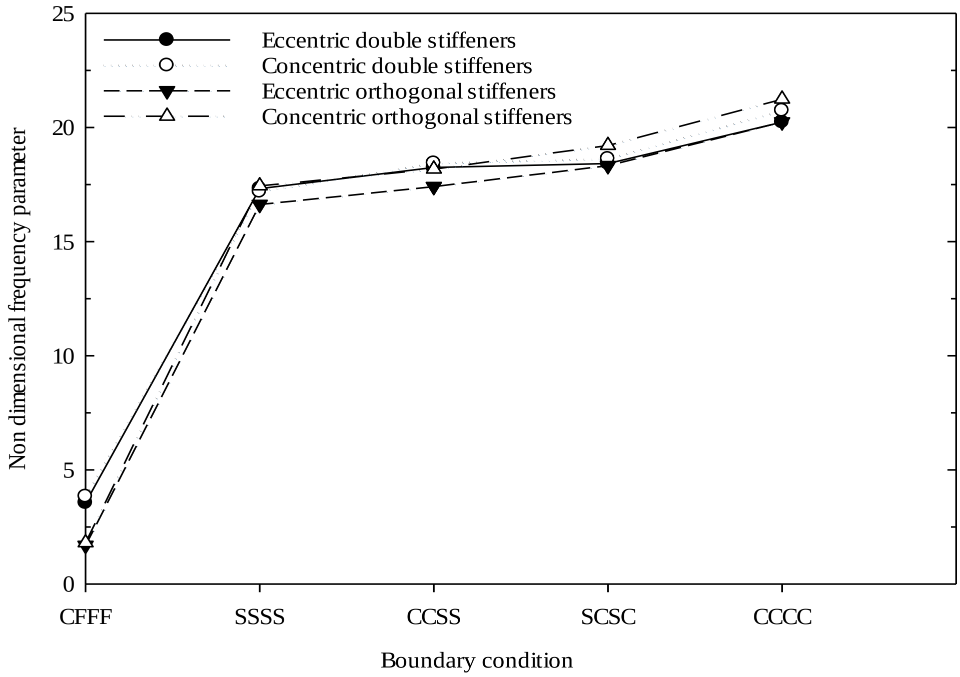

Figure 13. Variation of Non Dimensional Frequency Parameter of a Square Isotropic Plate with Concentric and Eccentric Stiffeners for Different Boundary Conditions at Mode Shape 1

To investigate the effect of eccentricity on the free vibrational behaviour of isotropic stiffened plates, a fully clamped square plate with double stiffeners and orthogonal stiffeners respectively have been analyzed for both concentric and eccentric types for different boundary condition at mode 1. The results obtained from such cases are presented in Table 09 & Figure. 13. The effect of eccentricity on non dimensional frequencies have observed. It is interesting to note that the addition of eccentricity does not make a difference to the values of non dimensional frequencies of the clamped plate with double stiffeners and orthogonal stiffeners also the difference the between the values of non dimensional frequencies of eccentric and concentric isotropic stiffened plates with double stiffeners and eccentric and concentric isotropic plates with orthogonal stiffeners is very small in magnitude for the different boundary conditions.

5. Conclusions

In this paper free vibration analysis of eccentric and concentric stiffened isotropic plates with orthogonal stiffeners have been studied using Ansys (APDL). Convergence study of eccentrically stiffened plate has also been obtained which shows the moderate and satisfactory range with the results of available published literature .It is observed that non dimensional frequencies increases as aspect ratio increases. Non dimensional frequencies are higher for fully clamped boundary as compared to the other boundary conditions and lower for CFFF boundary condition of eccentrically and concentrically stiffened plate with double stiffeners and orthogonal stiffeners. It is also seen that non dimensional frequencies are increases in a moderate value of eccentric and concentric isotopic plate with double stiffeners as compared to the orthogonal stiffeners. It is also interesting to note as aspect ratio's increases. Effect of eccentricity doesnot make a difference to the values of non dimensional frequencies of eccentric and concentric isotopic plate with orthogonal stiffeners. The values of non dimensional frequencies increases gradually as compared to the eccentric and concentric isotropic stiffened plates with double stiffeners for different mode shapes. Comparison of eccentric and concentric orthogonal stiffeners values of non dimensional frequencies increases in a very small in magnitude upto mode shapes 4 but for mode shape 5 value of non dimensional frequency increases in a moderate magnitude.

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