Effect of Stiffener Sizes on Natural Frequencies of Plate

Avinash J. Bhat [1], Deepak V. Bhope [2]

1 Student, IV Semester M.Tech (CAD/CAM) Mechanical Engineering Department, Rajiv Gandhi College of Engineering Research & Technology, Chandrapur- 442 403 (Maharashtra) (India)
Email: avinashjbhat@rediffmail.com
2 Professor, Mechanical Engineering Department, Rajiv Gandhi College of Engineering. Research & Technology, Chandrapur- 442 403 (Maharashtra) (India)
Email: dvbhope@rediffmail.com
Mechanical Engineering Department R.C.E.R.T, Chandrapur, Maharashtra, India

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Abstract - *The free flexural vibration of a stiffened rectangular plate is investigated by using the finite element method (FEM). In the present model, the plates have fixed boundary conditions. Numerical studies are conducted to analyze the natural frequencies of stiffened plates with fixed boundary conditions and the results show good agreement with earlier published results. The present model is also applied to parametric studies examining the effects of the stiffener on the natural frequencies of a square plate. In this work, the natural frequency is evaluated by keeping the volume of plate constant by varying the width to height ratio of stiffener and also by varying the thickness of plate to height ratio of stiffeners. The results show that the natural frequencies of the plate are notably influenced by the stiffener.*

Key Words: Free vibration, Finite element method, Stiffened plate, Stiffeners, Boundary conditions.

1. INTRODUCTION

Man has always been inspired from the nature be it art or engineering. Perhaps one of the derivatives of such inspiration is stiffened engineering structures. Sea shells, leaves, trees, vegetables all of these are in fact stiffened structures. An observation of structures created by nature indicates that in most cases strength and rigidity depend not only on the material but also upon its form. This fact was probably noticed long ago by some shrewd observers and resulted in the creation of artificial structural elements having high bearing capacity mainly due to their form such as girders, arches and shells.

Stiffeners in a stiffened plate make it possible to sustain highly directional loads, and introduce multiple load paths which may provide protection against damage and crack growth under the compressive and tensile loads. The biggest advantage of the stiffeners is the increased bending stiffness of the structure with a minimum of additional material, which makes these structures highly desirable for loads and destabilizing compressive loads. In addition to the advantages already found in using them, there should be no doubt that stiffened plates designed with different techniques bring many benefits like reduction in material usage, cost, better performance, etc.

Plates reinforced by stiffeners represent a class of structural components that are widely used in many engineering applications such as ship decks, bridges, Automobile super structure, Aircraft, industrial structures and buildings, railway wagons highway bridges, elevated roadways etc.

Devesh Pratap Singh Yadav, Avadesh Kumar Sharma and Vaibhav Shivhare[1] studied the free vibration analyses of plates with different stiffeners location by finite element method. Dipam S. Patel, S. S. Pathan and I. H. Bhoraniya[2] studied the vibration analysis of the bare plate and stiffened plates keeping all the edges of the plate as simply supported. Dayi Ou, Cheuk and Ming Mak[3] did numerical studies to analyse the natural frequencies of concentrically/eccentrically stiffened plates with different boundary condition. Gábor M. Vörös[4] performed detailed numerical evaluation to prove the efficiency of the proposed stiffener plate/shell coupling method. J.V. Mohanachari, D. Mohana Krishnudu, P. Hussain, Dr. S. Sudhakar Babu[5] studied limited component examination of Stiffened plate of different Materials. Tom Irvine[6] used the Rayleigh method to determine the fundamental bending frequency of rectangular plate. Shahed Jafarpour Hamedani, Mohammad Reza Khedmati, and Saeed Azkat[7] presented the vibration analysis of stiffened plates, using both conventional and super finite element approach. Abhijeet Mukhergee, and Madhujit Mukhopadhyay[8] studied the effect of neglecting the eccentricity in a stiffened plate. T. P. Holopainen[9] proposed new FE model for free vibration analysis of eccentrically stiffened plates. T. Nguyen-Thoi, T. Bui-Xuan, P. Phung-Van, H. Nguyen-Xuan, P. Ngo-Thanh[10] presented the static, free vibration and buckling analyses of eccentrically stiffened plates by the cell-based smoothed discrete shear gap method (CS-FEM-DSG3) using triangular elements.

2. INTRODUCTION TO THE PROBLEM

A normal plate, and stiffened plate with stiffeners attached parallel to z-axis along with the notations for significant dimensions and coordinate system used for the present analysis is shown in Fig. 1(a), 1(b), 1(c), and 1(d). It is assumed that the stiffeners are always parallel to the edges of the plate and they are rigidly connected to the plate. The mathematical formulation is further based on the following assumption.

1. Plate and stiffener materials are isotropic, homogeneous, and linearly elastic.
2. Thicknesses of the plate and stiffener are uniform.
3. The thickness of the plate is sufficiently small compared to the lateral dimensions, so that the effect of shear deformation and rotary inertia may be neglected.

The material properties considered are as follows,
Modulus of elasticity (E) = $200*10^9$ N/m^2, Poisson's Ratio (μ) =0.3, Density (ρ) = 7860 kg/m^3, width of plate = 0.250 m, volume of the plates is constant for single, for double, three and cross stiffeners.

Where,
b_1 = width of plate
h_1 = thickness of plate
b_2 = width of stiffeners
h_2 = thickness of stiffeners
Length of stiffeners is same as the length of plate.

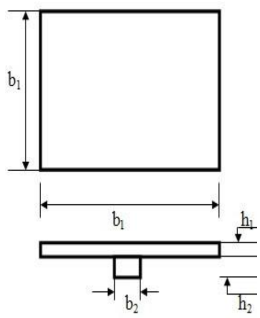


Fig. 1(a): Square Plate with stiffener

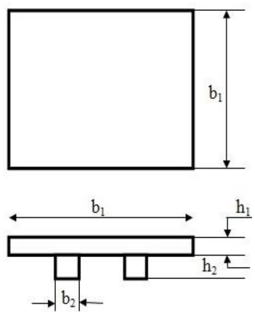


Fig.1 (b): Square plate with two stiffeners

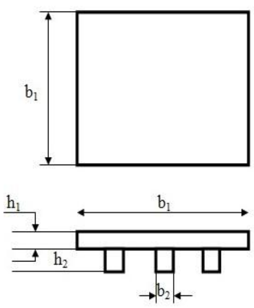


Fig. 1 (c): Square Plate with three stiffeners

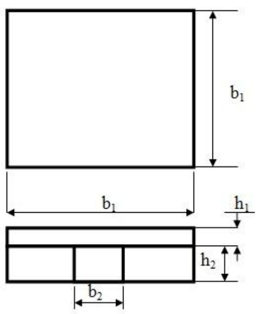


Fig. 1 (d): Square Plate with cross Stiffeners

3. EFFECT OF VARIATION OF STIFFENER SIZE AND PLATE THICKNESS ON NATURAL FREQUENCY

In the present work, the finite element approach is used to evaluate the natural frequencies of plate by changing the width to thickness (height) ratios of stiffener and keeping the thickness ratio of plate and stiffener constant for single, double, three and cross stiffeners. For FE analysis, the ANSYS workbench software is used. In this study, the following cases are considered to evaluate the effect of stiffener size and plate thickness on natural frequency. The fig. 1(a), fig. 1(b), fig. 1(c), and fig. 1(d) shows the geometry of the plates with single, double, three and cross stiffeners.

In the following cases, the volume of square plate with stiffeners is considered as 312500 mm^3 and the following cases are analyzed.

Case1: Natural frequencies for width to thickness ratios (b_2/h_2) of stiffener from 0.1 to 1 and thickness ratio (h_1/h_2) from 0.1 to 1 for single stiffener.

Case 2: Natural frequencies for width to thickness ratios (b_2/h_2) of stiffener from 0.2 to 1 and thickness ratio (h_1/h_2) from 0.2 to 1 for double stiffeners.

Case 3: Natural frequencies for width to thickness ratios (b_2/h_2) of stiffener from 0.2 to 1 and thickness ratio (h_1/h_2) from 0.2 to 1 for three stiffeners.

Case 4: Natural frequencies for width to thickness ratios (b_2/h_2) of stiffener from 0.2 to 1 and thickness ratio (h_1/h_2) from 0.2 to 1 for cross stiffeners.

3.1. Natural Frequencies for Width to Thickness Ratios (b_2/h_2) of Stiffener from 0.1 to 1 and Thickness Ratio (h_1/h_2) from 0.1 to 1 for Single Stiffener

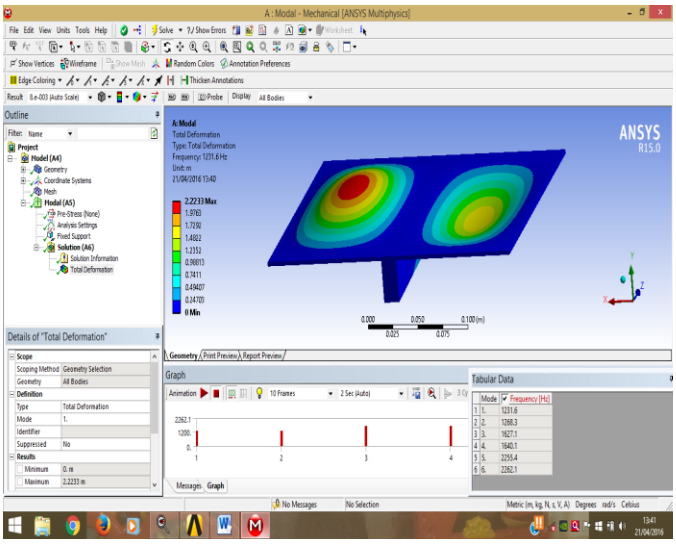


Fig. 3.1: Deformation & natural frequency of plate with single stiffener

Table 3.1 shows the values of natural frequencies for varying width to thickness ratios of stiffeners for constant volume of the plates.

Table 3.1: Natural frequencies for varying b_2/h_2 and h_1/h_2 =0.1

SR. NO.	Volume (V)	Width of plate (b_1) mm	Thickness of stiffener (h_2) mm	Thickness of plate (h_1) mm	Width of stiffener (b_2) mm	Frequency (η_f) Hz	h_1/h_2	b_2/h_2
1	312500	250	42.70	4.27	4.27	1121.9	0.1	0.1
2	312500	250	38.28	3.83	7.66	1177.2	0.1	0.2
3	312500	250	35.16	3.52	10.55	1237.3	0.1	0.3
4	312500	250	32.80	3.28	13.12	1246.0	0.1	0.4
5	312500	250	30.90	3.09	15.45	1231.6	0.1	0.5
6	312500	250	29.34	2.93	17.60	1210.5	0.1	0.6
7	312500	250	28.01	2.80	19.61	1203.8	0.1	0.7
8	312500	250	26.88	2.69	21.50	1174.5	0.1	0.8
9	312500	250	25.88	2.59	23.29	1145.8	0.1	0.9
10	312500	250	25.00	2.50	25.00	1123.6	0.1	1.0

In fig 3.2 , the frequency varies linearly till $b_2/h_2 = 0.4$ and then decreases continuously upto $b_2/h_2 = 1.0$.

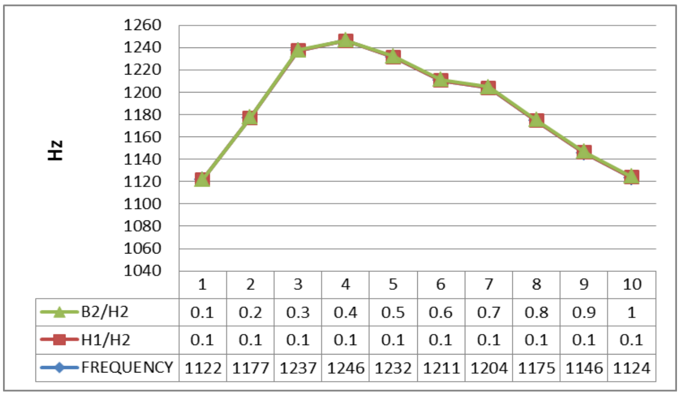


Fig. 3.2: Natural frequency with variation in b_2/h_2 for h_1/h_2 = 0.1

3.2 Natural Frequencies for Width to Thickness Ratios (b_2/h_2) of Stiffener from 0.2 to 1 and Thickness Ratio (h_1/h_2) from 0.2 to 1 for Double Stiffener

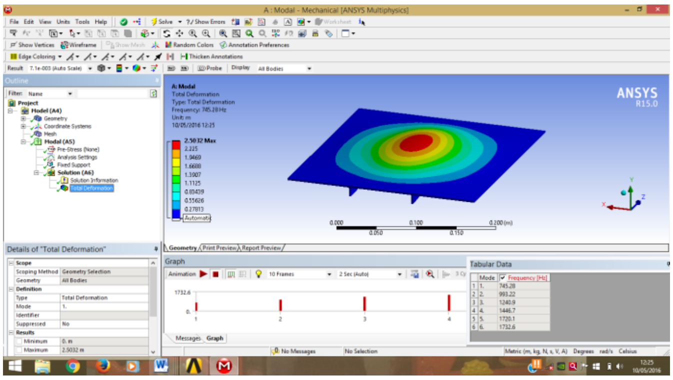


Fig. 3.3: Deformation & natural frequency of plate with double stiffeners

Fig. 3.3 shows the frequncy of plate with double stiffeners at b_2/h_2=0.2 for the same volume when h_1/h_2 = 0.2

Table 3.2: Natural frequencies for varying b_2/h_2 and h_1/h_2 =0.2

SR. NO.	Volume (V)	Width of plate (b_1) mm	Thickness of stiffener (h_2) mm	Thickness of plate (h_1) mm	Width of stiffener (b_2) mm	Frequency (η_f) Hz	h_1/h_2	b_2/h_2
1	312500	250	11.931	2.386	2.386	745.28	0.2	0.2
2	312500	250	11.451	2.290	4.58	853.21	0.2	0.4
3	312500	250	11.038	2.208	6.623	911.37	0.2	0.6
4	312500	250	10.676	2.135	8.541	938.30	0.2	0.8
5	312500	250	10.355	2.071	10.355	947.61	0.2	1.0

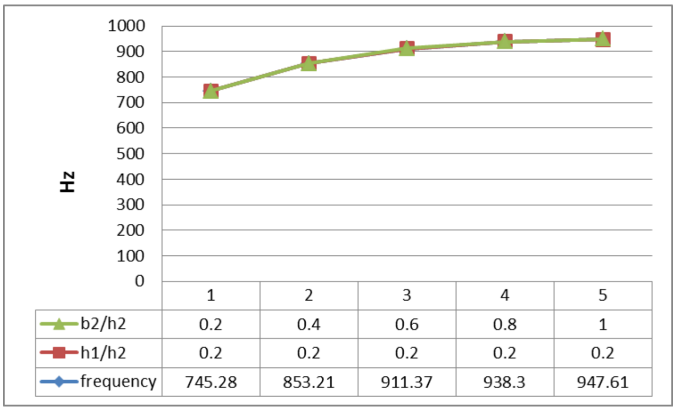


Fig. 3.4: Natural frequency with variation in b_2/h_2 for h_1/h_2 = 0.2

In fig 3.4 for h_1/h_2 = 0.2, it is observed that from b_2/h_2= 0.6 to 1.0, the frequency of the plate remains almost constant.

3.3. Natural Frequencies for Width to Thickness Ratios (b_2/h_2) of Stiffener from 0.2 to 1 and Thickness Ratio (h_1/h_2) from 0.2 to 1 for Three Stiffeners

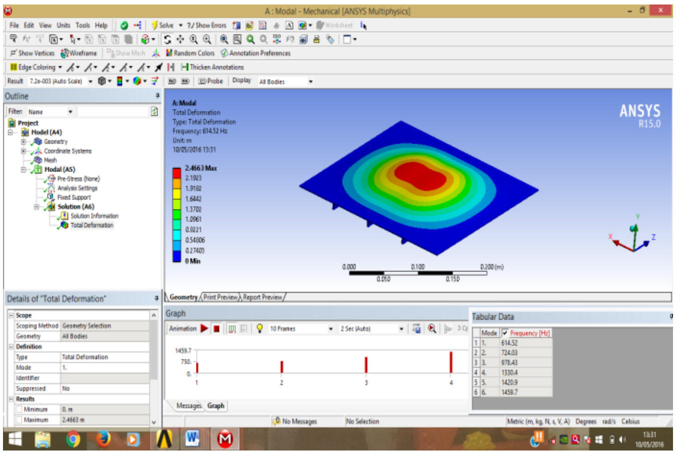


Fig. 3.5: Deformation & natural frequency of plate with three stiffeners

Table 3.3: Natural frequencies for varying b_2/h_2 and h_1/h_2 =0.2

SR. NO.	Volume (V)	Width of plate (b_1) mm	Thickness of stiffener (h_2) mm	Thickness of plate (h_1) mm	Width of stiffener (b_2) mm	Frequency (η_f) Hz	h_1/h_2	b_2/h_2
1	312500	250	8.073	1.615	1.615	519.4	0.2	0.2
2	312500	250	7.841	1.568	3.136	614.52	0.2	0.4
3	312500	250	7.634	1.527	4.580	664.38	0.2	0.6
4	312500	250	7.446	1.489	5.957	690.63	0.2	0.8
5	312500	250	7.275	1.455	7.275	703.5	0.2	1.0

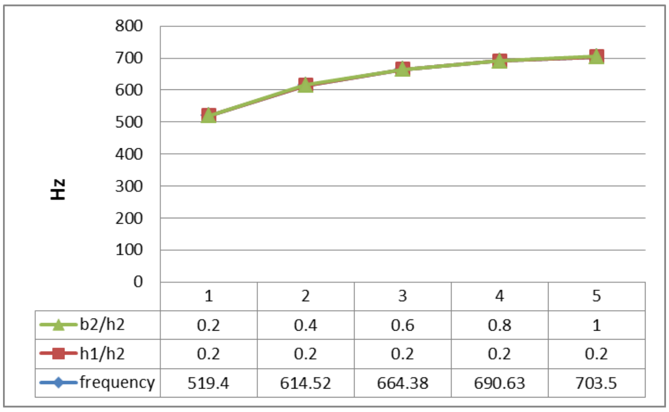


Fig. 3.6: Natural frequency with variation in b_2/h_2 for h_1/h_2 = 0.2

In fig. 3.6 for h_1/h_2 = 0.2, it is observed that for b_2/h_2= 0.2 to 0.8, the frequency of the plate varies continuously and then it remains constant.

3.4 Natural Frequencies for Width to Thickness Ratios (b_2/h_2) of Stiffener from 0.2 to 1 and Thickness Ratio (h_1/h_2) from 0.2 to 1 for Cross Stiffener

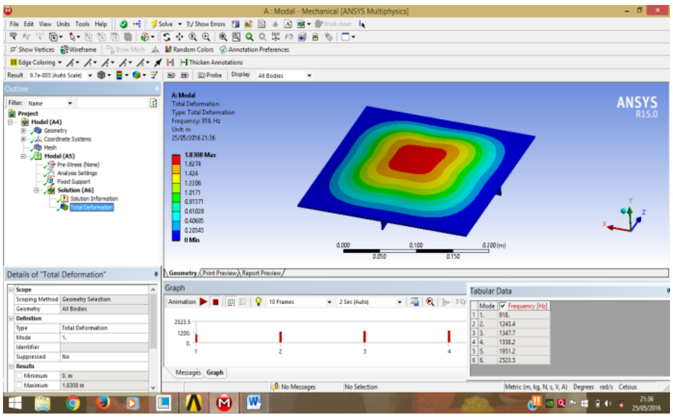


Fig. 3.7: Deformation & natural frequency of plate with cross stiffeners

Fig. 3.7 shows the Deformation & natural frequency of plate with cross stiffeners at b_2/h_2 =0.2.

Table 3.4: Natural frequencies for varying b_2/h_2 and h_1/h_2 =0.2

SR. NO.	Volume (V)	Width of plate (b_1) mm	Thickness of stiffener (h_2) mm	Thickness of plate (h_1) mm	Width of stiffener (b_2) mm	Frequency (η_f) Hz	h_1/h_2	b_2/h_2
1	312500	250	11.931	2.386	2.386	918.0	0.2	0.2
2	312500	250	11.451	2.290	4.580	1042.0	0.2	0.4
3	312500	250	11.038	2.208	6.623	1131.4	0.2	0.6
4	312500	250	10.676	2.135	8.541	1154.1	0.2	0.8
5	312500	250	10.355	2.071	10.355	1153.0	0.2	1.0

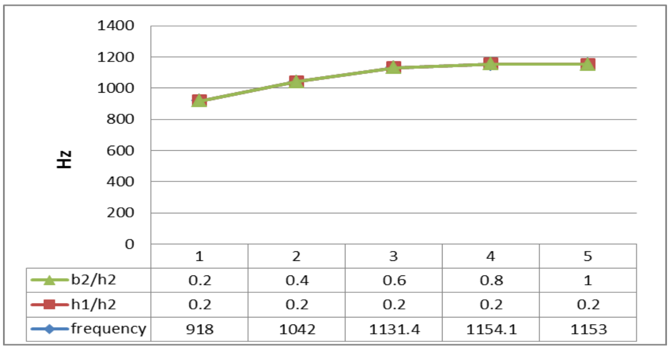


Fig. 3.8: Natural frequency with variation in b_2/h_2 for h_1/h_2 = 0.2

In fig. 3.8 for h_1/h_2 = 0.2, it is observed that the frequency of the plate with cross stiffeners varies continuously up to b_2/h_2 = 0.8 then it remains constant with rise in b_2/h_2.

3.5 Natural Frequencies for varying b_2/h_2 Ratios for Double, Three and Cross Stiffeners for Same h_1/h_2 Ratio

The behaviour of natural frequency of double stiffeners, three stiffeners and cross stiffeners for the same thickness ratios are evaluated in this case. In this case, the influence of all these stiffeners on natural frequencies is studied by varying the width to thickness ratio of stiffeners (b_2/h_2). The following tables and figures shows the behaviour of double, three and cross stiffners on natural frequencies.

Table 3.5: Natural frequency of double, three and cross stiffener for h_1/h_2 = 0.2

Sr. No.	η_f (double)	η_f (three)	η_f (cross)	b_2/h_2	h_1/h_2
1	745.28	519.4	918	0.2	0.2
2	853.21	614.52	1042	0.4	0.2
3	911.37	664.38	1131.4	0.6	0.2
4	938.3	690.63	1154.1	0.8	0.2
5	947.61	703.5	1153	1	0.2

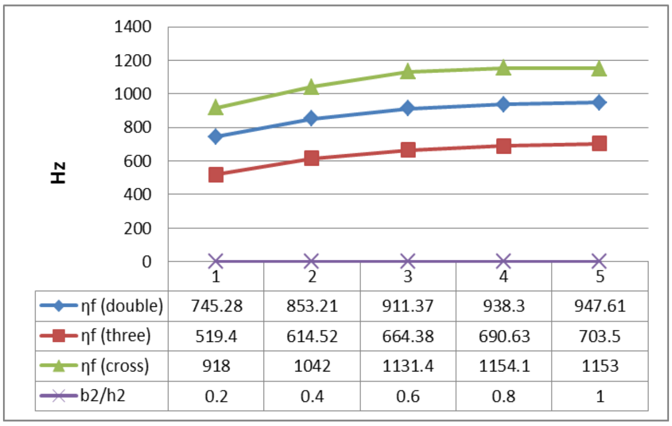


Fig. 3.9: Natural frequency of double, three and cross stiffener for $h_1/h_2 = 0.2$

Table 3.6: Natural frequency of double, three and cross stiffener for $h_1/h_2 = 0.4$

Sr. No.	η_f (double)	η_f (three)	η_f (cross)	b_2/h_2	h_1/h_2
1	421.04	278.5	480.56	0.2	0.4
2	466.4	309.78	544.36	0.4	0.4
3	500.3	334.45	591.79	0.6	0.4
4	526.39	354.53	621	0.8	0.4
5	547.2	371.09	673.92	1	0.4

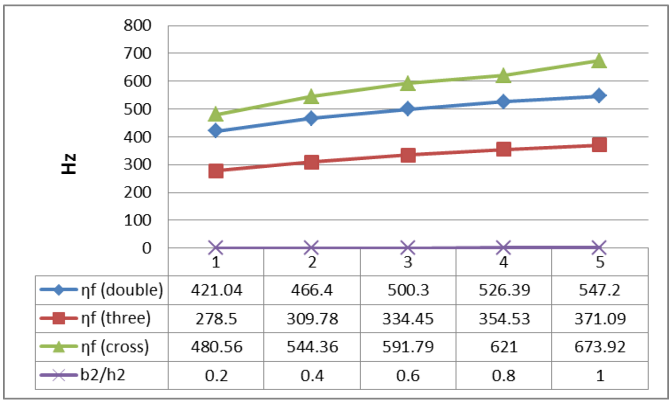


Fig. 3.10: Natural frequency of double, three and cross stiffener for $h_1/h_2 = 0.4$

Table 3.7: Natural frequency of double, three and cross stiffener for $h_1/h_2 = 0.6$

Sr. No.	η_f (double)	η_f (three)	η_f (cross)	b_2/h_2	h_1/h_2
1	369.5	246.77	409.16	0.2	0.6
2	384.95	256.52	429	0.4	0.6
3	398.93	265.67	450.03	0.6	0.6
4	411.12	274.04	472.28	0.8	0.6
5	422.03	281.84	481.48	1	0.6

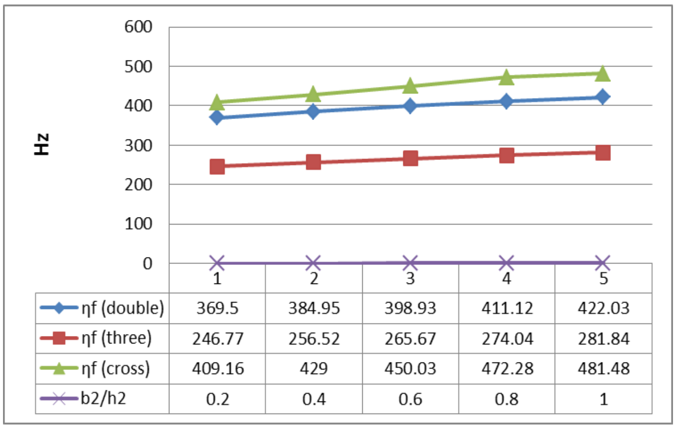


Fig. 3.11: Natural frequency of double, three and cross stiffener for $h_1/h_2 = 0.6$

Table 3.8: Natural frequency of double, three and cross stiffener for $h_1/h_2 = 0.8$

Sr. No.	η_f (double)	η_f (three)	η_f (cross)	b_2/h_2	h_1/h_2
1	359.99	238.93	388.6	0.2	0.8
2	364.52	242.86	400.32	0.4	0.8
3	370.38	246.62	407.36	0.6	0.8
4	376.14	250.5	418.41	0.8	0.8
5	381.53	254.32	424.5	1	0.8

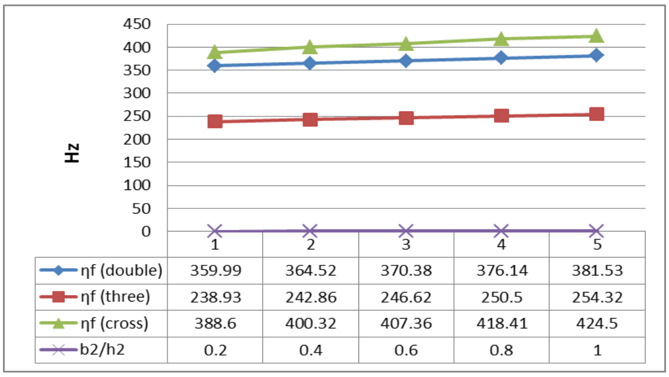
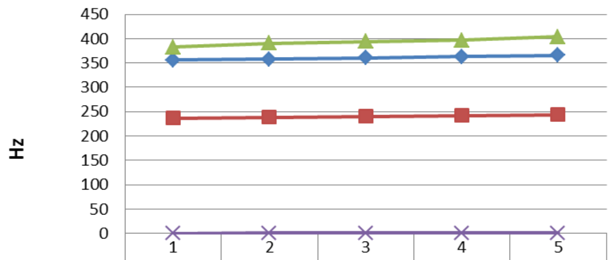


Fig. 3.12: Natural frequency of double, three and cross stiffener for $h_1/h_2 = 0.8$

Table 3.8: Natural frequency of double, three and cross stiffener for $h_1/h_2 = 0.8$

Sr. No.	η_f (double)	η_f (three)	η_f (cross)	b_2/h_2	h_1/h_2
1	356.45	236.67	382.8	0.2	1
2	357.52	238.49	390.36	0.4	1
3	360.38	240.36	394.19	0.6	1
4	363.26	242.3	397.19	0.8	1
5	366.12	244.29	403.54	1	1



	1	2	3	4	5
ηf (double)	356.45	357.52	360.38	363.26	366.12
ηf (three)	236.67	238.49	240.36	242.3	244.29
ηf (cross)	382.8	390.36	394.19	397.19	403.54
b2/h2	0.2	0.4	0.6	0.8	1

Fig. 3.13: Natural frequency of double, three and cross stiffener for h_1/h_2 = 1.0

4. CONCLUSIONS

With reference to the results obtained for the square plate with and without stiffener, following discussion is done and the various conclusions are drawn as follows.

4.1 Effect of Variation of Plate and Stiffener Sizes on Natural Frequencies

In the analysis, various combinations of thickness ratios (h_1/h_2) and considering same volume of plate, by varying the width to thickness ratios for stiffeners are considered to determine the natural frequencies and also the effect of stiffeners on plates are studied. On the basis of the results given in the previous chapter the discussion and conclusions are as follows.

As the b_2/h_2 ratio is increased from 0.1 to 1.0 for the same volume in case 1, it is observed that as the natural frequency of the plate also increases and as the ratio of h_1/h_2 increases from 0.1 to 1.0 the natural frequency decreases.

As the b_2/h_2 ratio is increased from 0.2 to 1.0 for the same volume, it is observed that the natural frequency of the plate is also increases and as the ratio of h_1/h_2 is increases from 0.2 to 1.0 the natural frequency decreases.

As the b_2/h_2 ratio is increased from 0.2 to 1.0 for the same volume, it is observed that the natural frequency of the plate is also increases and as the ratio of h_1/h_2 is increases from 0.2 to 1.0 the natural frequency decreases.

As the b_2/h_2 ratio is increased from 0.2 to 1.0 for the same volume, it is observed that the natural frequency of the plate is also increases and as the ratio of h_1/h_2 is increased from 0.2 to 1.0 the natural frequency decreases.

From the figures 3.2, 3.4, 3.6, and 3.8 it is observed that, as the width to thickness ratio (b_2/h_2) of stiffener increases the natural frequency of the plate increases, and with varying the ratios of thickness of plate and stiffeners (h_1/h_2), the natural frequency of the plate decreases.

4.2 Comparison of Double Stiffener with Cross Stiffeners

When comparing the cross stiffeners with double stiffeners for the same values of width to thickness ratios of stiffeners (b_2/h_2) and thickness ratio of plate and stiffener (h_1/h_2) with same volume, it is observed that, the frequency of cross stiffeners is more than the natural frequency of double stiffeners. So, for the same volume of plate, cross stiffener is recommended as compared to double stiffeners.

Thus, it is concluded that the stiffeners are recommended to minimize the mass of plates for various natural frequencies. It is further recommended to use cross stiffeners rather than two parallel stiffeners.

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