A Review and Approach to Vibration Analysis of Stiffened Plate

Dipak Vilas Patil
Department of Mechanical Engineering
Finolex Academy of Management & Technology, Ratnagiri.
Mumbai University
dvpatil46@gmail.com

Dr. Kaushal Prasad
Department of Mechanical Engineering
Finolex Academy of Management & Technology, Ratnagiri.
Mumbai University
prasadkaushal@gmail.com

***Abstract* – There are variety of engineering applications where structures subjected to vibrations and uneven noise. There are numerous techniques to study the vibration behavior of structures such as FEA and experimental modal analysis, same in harmonic analysis, mathematical modeling is another way. It predicts various modes of vibration. Plate because of high strength to weight ratio are in use for many structural applications. Such structures are subjected to dynamic load many times over its life span. Strength of these structures is increased by adding stiffeners to its plate. This paper deals with the vibration analysis of stiffened plates which forms the basis of structures. In order to continue this analysis various research papers were studied to understand the previous tasks done for stiffened plate. By considering various profiles of stiffeners and there arrangement studied by all the researchers is tabulated in one window. Various FEA software's like ANSYS WORKBENCH, NASTRAN, HYPERMESH, and Ls-Dyna are used by researchers to do the Finite element analysis.**

***Index Terms* – plates, stiffeners, natural frequency, FEA.**

I. Introduction

The analytical and mathematical methods gives a solution which is very difficult to find out and time consuming for a real life problem involving an arbitrary plate geometry and complicated loading and boundary conditions and cannot be easily realize. A numerical analysis technique or various FEA simulation packages, especially finite element analysis method, is suited most to solve such problems. Thin plates because of their high strength to weight ratio are in use in many structural design application. They act as principle load members and find variety of application ranging from stationary and moving components. These plates are successively subjected to dynamic load condition. These dynamic loads can be so severe that it can raise adverse conditions to such structures. Imposed loads basically results in Vibration of plates. These vibrations under certain condition cause resonance which can result in structural failure. It also results in high level of discomfort of user. In order to reduce it structural stiffness need to be increased. In order to improve the strength of structure and reduce the weights stiffeners are added to the plate structure. These stiffeners are very helpful in the buckling prevention [5]. Not only has this helped in maintaining better condition for vibration but also helps in reducing the overall weight with efficient working condition. One of the wide uses of plate comes in material handling equipment where it forms box structure. These box structures are subjected to high dynamic loads which result into vibration which finally get converted to resonant condition many times. Many Research has been done till now to improve the design of steel structures.

II. NEED OF REVIEW

Recently stiffened plate structures are used in almost every field, starting from automobile industry to aerospace. To design such structures Weight reduction is one of the main criteria. To avoid resonance since these structures are regularly subjected to high resonant conditions, high stiffness value becomes one of the important criteria. In order to maintain this, thickness of the plate is increased which lacks the weight optimization. A lot of work has been done so far to avoid it by addition of stiffeners to the plates. Stiffener with geometry of equal and unequal angles, flat bars and various profiles of stiffeners are readily available in market. It is very important to know how geometry of stiffeners influencing the role in vibration controls to avoid resonance along with increasing strength. This review compares the various profiles of stiffeners for vibration analysis.

III. LITERATURE REVIEW

So many researchers have been published regarding vibration analysis of stiffened laminated plates [1-2-3]. The residual stresses produced in each nugget have significant effect on the natural frequency of the plate, where natural frequency increases when residual stresses are included. This effect varies depending on the boundary conditions of the plate and on the distribution of the weld spots [1].

Among them Pravin Jadhav [2], discussed about the effect of spot weld patterns and profiles of stiffeners on the vibration characteristics of plates with spot welded stiffeners. They found that stiffeners profile and its arrangement have great effect on the natural frequencies and mode shapes of the plates [2-4]. Experimental analysis of composed structures, including setup is studied [1-2] to find the natural frequencies using FFT analyzer. Some researchers have studied FEA analysis of different spot welded stiffened structures for modal analysis to find natural frequency and mode shapes [4-5]. The effect of laser spot welding technique and the design adjustments are studied [6-7]. Xin Zhang et al. investigated the effect of the size of the welds diameter and pitch of the weld on the strength analysis of spot weld joints. The effect of growth in nugget size with spot welding has a great impact in natural frequencies of the model [8]. Also in the some literature, there are few studies about optimization of spot welded structures [6-9]. Guidelines for spot welds CWELD and ACM2 are analyzed and proposed. The behavior of a spot welded structure under dynamic loads is strongly influenced by the number and locations of the resistance spot welds [9]. The effect of the size of the welds diameter and pitch of the weld on the account of absorbed energy is studied [10]. Ahmet H Er`tas et al. optimized the spot welded plates for maximum fatigue life. They suggest that number of spot welds significantly affects the fatigue strength. Sheet thickness and material are studied to the strength requirements of the structures [11].

A. *Outcome of Review*

Many experiments were performed by various researchers to know the vibration behavior of plates with and without stiffeners. An optimal position of stiffeners was analyzed to understand its effect by them. Analytical, Numerical and Experimental methods were used whose results were in good agreements to each other. In this paper different approaches of stiffened plates for vibration analysis are compared in one screen and suitable suggestions are displayed.

IV. CASE STUDY-I [1]

A rectangular stainless steel plate with dimensions of (120mm, 100mm, 0.6 mm) stiffened by another stainless steel plate of (120mm, 40mm, 0.6mm) in the longitudinal direction, is considered in this study. The measurement of natural frequencies has been done. Experimental tests were designed in order to measure the natural frequency and mode shape of the plates with spot welded stiffeners. The frequency response for each stiffened plate was investigated by slowly increasing the driving frequency of the vibrator by means of the sine generator. The natural frequency was distinguished by observing the sharp increase in amplified of the pickup output, which was amplified and displayed on the oscilloscope.. Material employed in this investigation for all tests was an austenitic stainless steel AISI 304 sheet with nominal thickness of 0.6mm. The FEM analysis was also carried out by using ANSYS

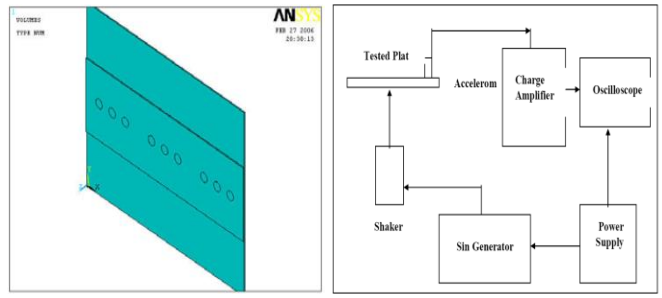


Fig. 1 stiffened plate model & Block Diagram of the Measuring Instruments [1]

TABLE I
FUNDAMENTAL NATURAL FREQUENCIES (HZ) FOR DIFFERENT BOUNDARY CONDITIONS [1]

No.	Boundary Conditions	Experimental Results	FEA Results
1	C-C-C-C	775.153	770.797
2	C-S-C-C	582.432	528.61
3	C-S-C-S	443.813	437.91
4	S-S-S-S	362.257	358.46
5	S-C-S-S	522.304	520.63
6	C-S-S-C	544.54	542.79
7	C-F-C-C	372.397	366.06
8	C-F-S-C	310.972	307.06
9	S-F-S-C	267.60	264.35

A. *Results and Discussions*

According to the results obtained, it can be seen that both experimental and FEA results showed good agreement. It was found that boundary conditions have significant effect on the natural frequency of the plate. This effect varies depending on the boundary conditions of the plate .For C-C-C-C boundary condition it gives highest value of natural frequency. If we increase the lateral stiffness of the plates, it increases the natural frequency.

V. CASE STUDY-II [2]

This study focuses effect of spot weld pattern and profiles of stiffeners under the vibration analysis of structures. Both FEA and experimental study are carried out for vibration analysis of plates with spot welded stiffeners. In FEA study, modal analysis method is used to find the natural frequencies of all test structural models. Ls-Dyna and HYPERMESH software are used for FEA study. To back up the results obtained by FEA study, experimental analysis is done to find frequencies of the same models using FFT analyzer.

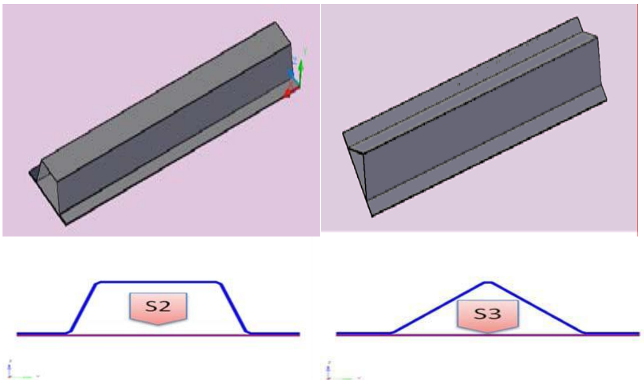
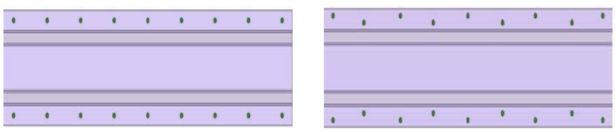


Fig. 2 Profiles of different structural models [2]



(a) (b)

Fig. 3 (a) Weld pattern P1 (b) Weld pattern P2 [2]

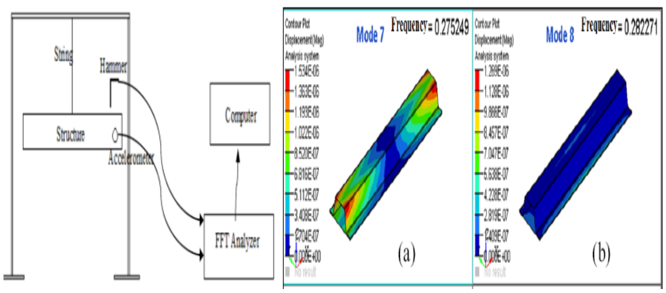


Fig. 4 Experimental Setup & FEA Analysis [2]

TABLE II
COMPARISON OF RESULTS BY FEA& EXPERIMENTAL MODAL ANALYSIS [2]

Model	FEA Results (Frequencies in Hz)				Experimental Results (Frequencies in Hz)
	Mode 7	Mode 8	Mode 9	Mode 10	
S2P1	275.24	282.27	284.36	287.07	262.00
S2P2	247.62	253.28	255.18	266.27	236.00
S3P1	273.43	287.06	288.69	303.24	286.00
S3P2	241.29	252.39	259.95	269.21	260.00

A. Results and Discussions

For this study, modal testing conducted to free-free boundary condition for each structure. The structures are tested for one hammer point. The location for the impact is carefully chosen to get accurate results. The vibration response measured using FFT Analyzer system. All the structures are made up of mild steel with thickness of 0.7mm.The welding is carried out using spot welding machine has power of 10 KVA. The electrodes have a truncated conical shape with a flat circular contacting area of 5 mm diameter. For the FEA analysis same boundary condition & material properties are used.

The natural frequency of structure S2P1 is highest but the difference between frequencies of base structure S2P1 and S3P1 is less but if the spot-weld pattern changes then the variation of frequency is large.

VI. CASE STUDY-III [3]

Plate No.	Base dimensions X × Y × Z (mm)	Angle of stiffener A(degree)	Thickness of stiffener ts (mm)
1		Bare plate	
2		70	1.5
3		70	2
4		70	3
5	480 × 300 ×3.5	90	1.5
6		90	2
7		90	3
8		120	1.5
9		120	2
10		120	3

A thin rectangular plate is considered as shown in fig. 5(a) for the free vibration analysis of rectangular plate. The plate is assumed to follow the Classical Thin Plate Theory also known as the Kirchhoff’s Plate Theory which is fundamental theory to model thin plates. The plate has length along x direction, width along y direction and thickness along z direction, hence the plate is assumed to lie in the x-y plane. The plate has three independent displacements i.e. displacement along x, y and z directions. The rectangular plate with three angle shaped stiffeners is as shown in fig. 5(b). The stiffeners are lying on the plate such that length of the stiffeners is parallel to the width of the plate. The stiffeners and the plates are assumed to have rigid coupling at their connecting interface. The stiffener has an angle A and thickness ts, both Angle of stiffener (A) and thickness of stiffener (ts) are considered as variables. The plates which are considered for modal analysis are tabulated as shown in table 3. It is assumed that the plate and the stiffeners are made of the same material. The bare plate and the stiffened plates have following material characteristics;

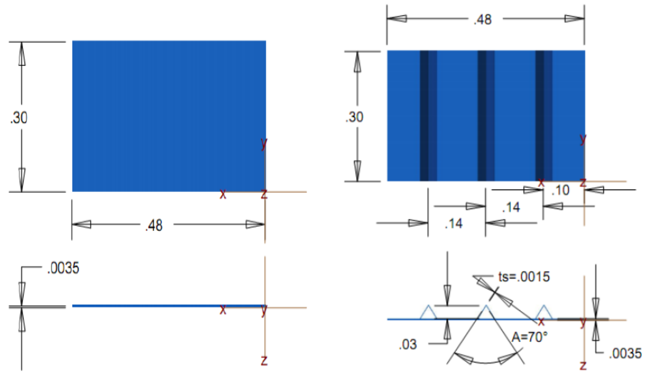
Material: Steel.

Modulus of Elasticity: 2×1011 N/m2.

Poisson’s ratio: 0.3.

Density: 7800 kg/ m3.

TABLE III
DETAILS OF ALL PLATES [3]



(a) (b)

Note: All dimensions are in m.

Fig. 5 (a) Bare rectangular plate; (b) Rectangular plate with angle shaped stiffener [3]

The finite element models of all the plates are generated in ANSYS software using the Solid45 element. This element is used for meshing the solid geometry; the element has eight nodes and three degree of freedom per each node. The meshed models are then used for FEA in ANSYS software. The modal analysis is performed by keeping all edges of the plate as simply supported; this set of boundary conditions is SSSS.

A. Results and Discussions

TABLE IV
COMPARISON OF NATURAL FREQUENCIES OF ALL PLATES BY FEA (SSSS) [3]

Model	Natural frequency(Hz)									
	Plate 1	**Plate 2**	**Plate 3**	**Plate 4**	**Plate 5**	**Plate 6**	**Plate 7**	**Plate 8**	**Plate 9**	**Plate 10**
	Base plate	**A=70 Ts=1.5**	**A=70 Ts=02**	**A=70 Ts=03**	**A=90 Ts=1.5**	**A=90 Ts=02**	**A=90 Ts=03**	**A=120 Ts=1.5**	**A=120 Ts=02**	**A=120 Ts=03**
1	131.05	598.36	641.22	689.74	630.09	674.86	725.56	601.23	645.66	705.91
2	244	682.33	722.59	766.69	722.07	763.17	808.08	637.92	689.14	774.47
3	417.72	829.94	865.05	900.08	889.47	924.58	958.78	696.72	762.7	898.16
4	436.86	1271.5	1330.4	1403.5	1469.5	1551	1652.8	1318.7	1424.8	1636.1
5	535.84	1608.7	1658.5	1806.9	1806.9	1875	1951.2	1350.3	1453.1	1651.7
6	716.93	1689.7	1783.5	1890.1	1890.1	2021.7	2177.8	1389.7	1491.3	1683.4
7	737.2	1763.5	1844.1	1982.8	1982.8	2108.2	2256.1	1502.5	1598	1733.8
8	906.65	2009.1	2084.7	2166.9	2166.9	2283.3	2414.3	1587.6	1669.3	1816.1
9	1029.2	2037.9	2102.4	2315.2	2315.2	2384.9	2460.5	1784.2	1844.7	2000.5
10	1033.8	2099.5	2147.2	2382.8	2382.8	2472.6	2581.8	1984.4	2102.2	2350.3

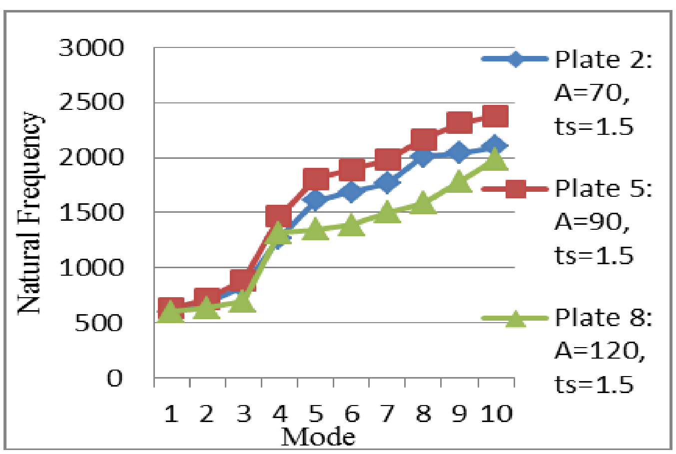


Fig.6 Comparison of natural frequency of plates with same thickness & different angles of stiffener plates [3]

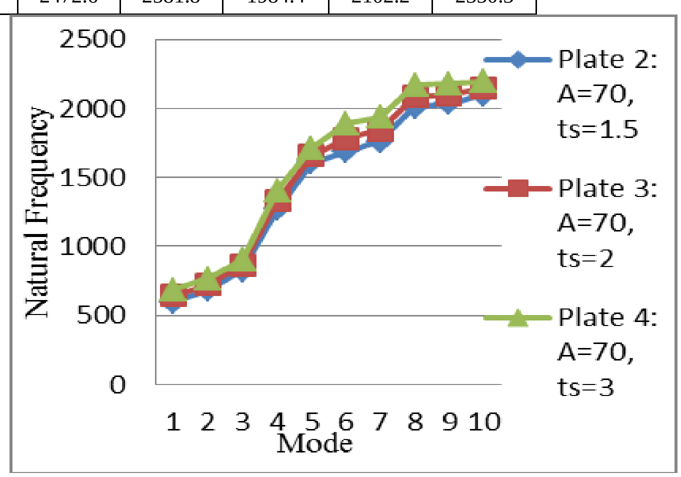


Fig. 7 Comparison of natural frequency of plates with same angles as 70° & different thickness of stiffener plates [3]

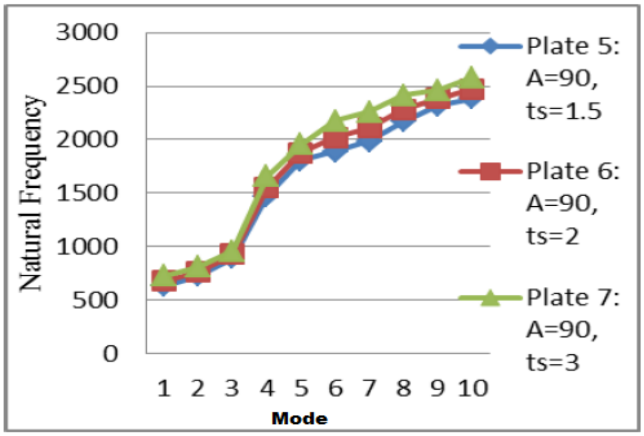


Fig.8 Comparison of natural frequency of plates with same angles as 90° & different thickness of stiffener plates [3]

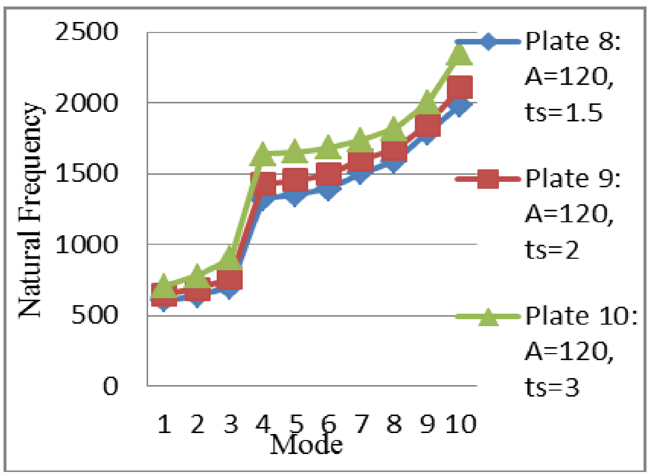


Fig. 9 Comparison of natural frequency of plates with same angles as 120°& different thickness of stiffener plates [3]

The vibration analysis of the bare plate and stiffened plates is performed keeping all the edges of the plate as simply supported. The results of the analysis give the following information on vibration of stiffened plates.

1. It is observed that with addition of stiffener of any size the natural frequencies of the plate increases from that of the plate without stiffener.
2. Out of three angle shaped stiffener 70°, 90°, 120°.The 90° angle shaped stiffener gives the highest value in natural frequency for simply supported boundary condition.
3. The increasing angle of stiffener does not necessarily increase the value of the natural frequency,
4. The increasing thickness of the stiffener increases the natural frequencies of the plate for all the boundary conditions.

VII. CASE STUDY-4 [4]

The Finite element analysis by using ANSYS WORKBENCH was carried out to study the combine effect of Spot weld pattern and Stiffener parameters on the vibration characteristics of spot welded stiffened plates at free-free boundary conditions. The different structural models investigated for this study, its brief information given below. Models are made of mild steel (CR) material. It consist total three structures having two plates, one flat and one hat section joined together by twenty spot welds. The Plate's thickness is 1.5 mm, Plate length 565 mm, Spot weld diameter 6 mm, Spot weld spacing 60 mm. This is most representative technique to prepare the model of structural object. FE models are generated to obtained detailed response of structures and to determine structural characteristics. F.E Models are more practical because they predict realistic structural response. This Section describes the geometrical and finite element modeling process in detail. Also brief information regarding analysis of structural models is included.

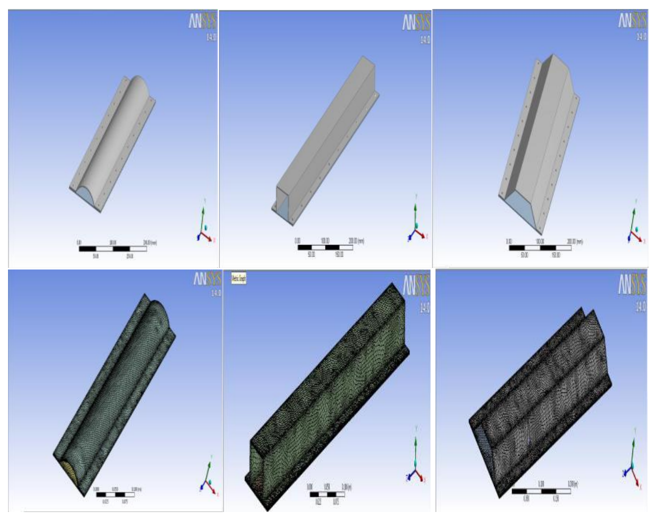


Fig. 10 Spot weld model &meshing of structure S1, S2, S3 [4]

Modes are inherent properties of structure and are determined by material properties (mass, damping and stiffness), and boundary conditions of the structure. Each mode is defined by natural frequency, mode shape (modal parameters).If either the material properties or the boundary conditions of a structure change its modes will change. Also natural frequencies are different due to different mass and stiffness. This study includes the different structures. So, material size, shape and mass are different at same boundary condition. Thus analysis of structures is carried out by observing natural frequencies of the same structures.

A. Results and Discussions

TABLE V
RESULTS OF MODAL ANALYSIS USING ANSYS WORKBENCH [4]

Structure	Frequencies in Hz			
	Mode 7	**Mode 8**	**Mode 9**	**Mode 10**
S1P1	329.4	836.49	845.38	1415.1
S2P1	812.02	871.46	895.7	1050.4
S3P1	492.98	557.66	572.01	606.49

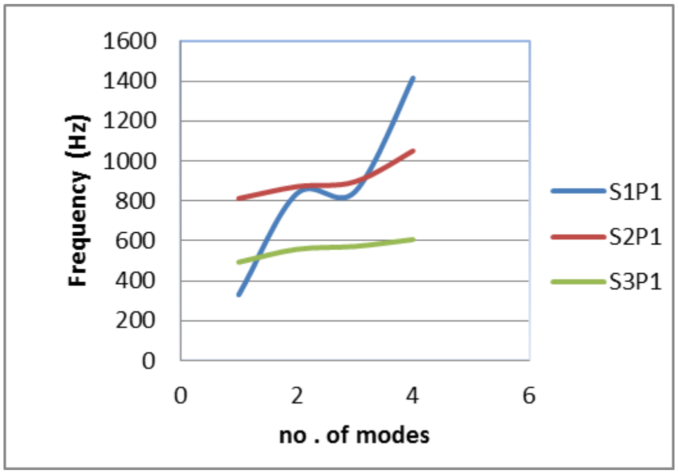
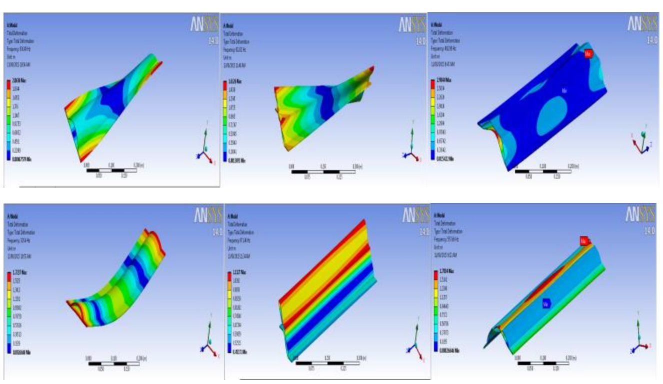


Fig.11 Variation of natural frequencies of three structures [4]

The result includes frequencies of all structural models in Hz. First six modes are the rigid modes. Therefore remaining modes are considered for analysis.

From the above FEA results, it is revealed that, the shape and size of stiffener has great influence on natural frequencies as compared to mass.

The natural frequency of Structure S1P1 is high and Structure S3P1 has a lowest frequency. From the mode shapes it is seen that Structure S3P1 is more stable and gives more strength.



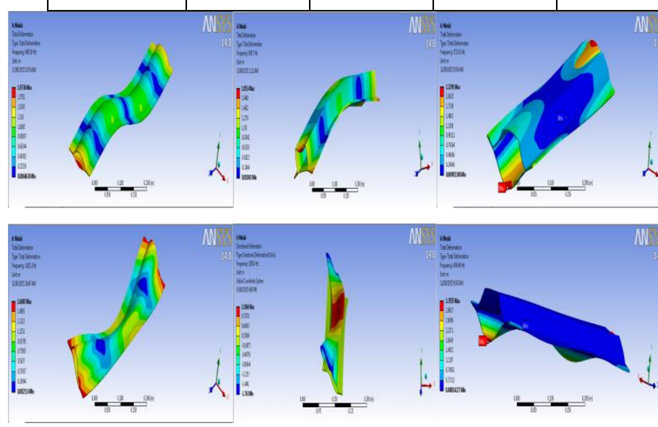


Fig. 12 Mode shapes of structure S1, S2, S3 [4]

VIII. CONCLUSIONS

According to the all case studies boundary conditions have significant effect on the natural frequency of the plate. As compare to free-free boundary condition the both end fixed boundary condition gives rise in value of natural frequency.

The profile and size of stiffener have much more impact on natural frequencies of the plate. The different kind of profiles gives different value of stiffness to the plate or structure.

The stiffener having angle 90^{o} gives the higher value of natural frequency. Increase in angle value of stiffener does not affect the natural frequency of plate much more.

Thickness of plate is most dominant parameter in the study of vibration analysis of plates. According to theory of plates as thickness increases the natural frequency of structure decreases. Unlike case study 2 shows adverse results. Therefore we can say that profile of stiffener also affects the natural frequency rather than mass as it is related to thickness.

The profile selection of stiffener must be based upon the excitation frequency of system in order to avoid resonance condition of the system. The arc shaped stiffener gives the lowest natural frequency, the stiffener having rectangular shape gives highest value of natural frequency as compare to the triangular and semi honeycomb shaped stiffener.

For getting more accurate results of natural frequency need to do modal analysis by FEA simulation method with more accurate 3D cad model having proper meshing with necessary boundary conditions and material properties. Along with experimental modal analysis by using FFT analyzer with impact hammer test. For experimental modal analysis the sensitivity of sensors (accelerometer) or transducer is important with the location of sensor, impact point location of hammer, and data acquisition system. For more accurate response either selects the zero to peak or peak to peak sort of graph in real time analysis.

REFERENCES

[1] S. M. Nacy ,N. K. Alsahib, F. F. Mustafa " Vibration Analysis of Plates With Spot Welded Stiffeners" JJMIE Volume 3, Number 4, December 2009.

[2] Jadhav P.N. , Dr.Kaushal Prasad., "Vibration Analysis Plates with Spot Welded Stiffeners" International Journal of Latest Trends in Engineering and Technology (IJLTET).

[3] Dipam S. Patel, S. S. Pathan, I. H. Bhoraniya "Influence of Stiffeners on the Natural Frequencies of Rectangular Plate with Simply Supported Edges" International Journal of Engineering Research & Technology (IJERT) Vol. 1 Issue 3, May 2012.

[4] Dipak V.Patil, Dr.Kaushal Prasad, "Modal analysis of spot welded stiffened plates" International Conference On Emerging Trends in Science Technology Engineering and Management 09th & 10th, October 2015.

[5] Ashutosh Kumar,Dr. Rachayya R. Arakerimath "A Review and modal analysis of stiffened plate" International Research Journal of Engineering and Technology (IRJET) ,Volume: 02 ,Nov-2015.

[6] E. Rusi´nskia, A. Kopczy´nskib, J. Czmochowskia "Tests of thin-walled beams joined by spot welding" Journal of Materials Processing Technology 157–158 (2004) 405–409.

[7] Ch.Goutham, D.Vijay Praveen, Dr.M.Venkateswara Rao "Analysis of Plates Welded With Stiffeners under Harmonic Loading"International Journal for Scientific Research & Development,Vol. 3, Issue 05, 2015.

[8] Xin Zhang, Bing Liu "Strength Analysis and Simulation of Multiple Spot Welded Joints" SEM Annual Conference June 1-4, 2009 Albuquerque New Mexico USA.

[9] Matteo palmonella, Michael Friswell, "Improving spot weld model in structural dynamics" ASME 2003 Design Engineering Technical Conferences and Computers and Information in Engineering Conference Chicago, Illinois, USA, September 2-6, 2003.

[10] Q.I.Bhatti, M.Ouisse "An adaptive optimization procedure for spot-welded structures" Computers and Structures 89 (2011) 1697–1711.

[11] Ahmet H.Ertas a, FazılO.Sonmez "Design optimization of spot-welded plates for maximum fatigue life" Finite Elements in Analysis and Design 47 (2011) 413–423.