A Review and modal analysis of stiffened plate

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Abstract- ***One of the method to study the dynamic nature of plate is to go for dynamic analysis. 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 it's life span. Strength of these structures are increased by adding stiffeners to its plate. This paper deals with the analysis of rectangular 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. Hyper mesh and Nastran is used to do the Finite element analysis. Modal analysis of a rectangular stiffened plate is done with aspect ratio of 2. Equal flange angle is used as.***

Key Words:*Stiffened Plate; Dynamic load; Vibration; Aspect ratio; Modal Analysis*

1. INTRODUCTION

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 often subjected to dynamic loads. These dynamic loads can be so severe that it can raise adverse conditions to such structures. Imposed loads basically results in Vibration of plates. This vibration under certain condition cause resonance which can result in structural failure. It also result 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. 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 use 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.

2. NEED OF RESEARCH

Plate structures are now in use in almost every field. Starting from automobile to aerospace. Weight reduction is one of the main criteria while designing such structures. In the optimization process since these structures are often subjected to high resonant conditions high stiffness value becomes one of the important criteria. In order to maintain this the thickness of the plate is increased which obstruct the weight optimization. A lot of work has been done so far to avoid it by addition of stiffeners. Stiffener with geometry of equal and unequal angles, flat bars are readily available in market. It is very important to know how geometry of stiffeners are playing role in restriction of vibration Paragraph comes content here. Paragraph comes content here.

3. LITERATURE REVIEW

3.1. A Review of papers

Dayi Ou, Cheuk Ming Mak [1], presented paper on free flexural vibration analysis of stiffened plates with general elastic boundary supports. In this paper finite element method is used to analyze the vibration of stiffened rectangular plate with clamped boundary condition. Free vibration is analyzed with single stiffener in two different positions. The stiffener considered was of rectangular shape. The same analysis then imposed to glass window with a diagonal stiffener. It was found that the vibration gets effected due to change in the stiffeners position. The natural frequencies were getting notably influenced by the positioning and location of stiffener. Although only one stiffener was used for the parametric studies but the results were fairly matching with the past analysis done. There is further scope in this task as the same analysis can be performed with number of different stiffeners under different boundary conditions.

J.M. Hale, A.H. Daraji [2], presented paper on analysis of vibration reduction of stiffened plate by using sensors and actuators. A rectangular plate was used with cross stiffened stiffener. In order to analyses the vibration 10 piezoelectric actuators were used. The optimal placement of these actuators were analyzed by following defined algorithm. These 10 actuators were placed in two separate positions on the two plate with same dimensions and stiffeners position. Frequency response analysis was also done.

Dae Seung Cho, Nikola Vladimir,Tai Muk Choi [3],presented a paper on vibration analysis of stiffened plate with opening by Numerical method. Different shapes of openings are considered with arbitrary edge constraint. A permutation and combination of various spacing of stiffeners, numbers and various shapes of cutout is considered. Energy method is used to get the solution. For the stiffeners in addition a very simple method is used to add or subtract their strain and kinetic energies to get the solution. This procedure was validated by using Finite element method. The results were showing good agreement with the achieved mode shapes and natural frequencies. Being very simple method it is not having any limitation of applying with different edge conditions, stiffeners and cutout dimensions. This analysis was done for isotropic plate and further analysis of orthotropic plates can also be done as future project.

Davesh Prasad Sing Yadav, Avadesh Kumar Sharma, Vaibhav Shivhare [4], presented a paper on vibration analysis of plates with different stiffener's position. This paper presented the effect of stiffener on the free vibration analysis of the stiffened plate. Different cases of stiffener location, different boundary conditons aspect ratios and skew angle were taken into considerations. Finite element method was used to come to conclusion. They used Solid186 element in Ansys software. Three different boundary conditions were considered and the results were compared to the earlier research work done.

S.M. Nacy , N.K. Alsahib, F.F. Mustafa [5], presented a paper on the vibration analysis of plated with spot welded stiffeners. They considered the effect of spot welding done to attach the stiffener to the plate. Spot welding produces the residual stress whose effect on the vibration of plate was required to be known. Both analytical as well as FEA methods were used to cross verify the results. Different boundary conditions were considered to get the results. The results of analytical and FEA method, both were tabulated with two columns heading with and without residual stresses. Both theoretical and experimental results showed good agreement. Plate vibration was found to be increasing with the induced residual stresses.

Ali Reza Pouladkhan, Jalil Emadi, Majid Safemehr [6], presented a paper on vibration analysis of thin plate using modal analysis. They considered rectangular plate with simply supported conditions. Abaqus software as used to do the analysis. Various mode shapes were taken out and the results were matching with the exact results. The plates used were not having any stiffener and same exercise could have been done with stiffener so there is future scope in it.

X.D.Xu, H.P.Lee, Y.Y.Wang, C.Lu [7], presented a paper on energy flow analysis in stiffened plate which was very useful in determining the vibration in the plate. The vibrational energy flow in the plate was determined by structural intensity method. They considered three cases – stiffened plate under point force excitation, same case under area pressure excitation, cross stiffened plate under in plane pressure excitation. By following same theory Force displacement stiffness matrix were formed which was later subjected to FEA process using Ansys. The results showed that despite the existence of stiffeners within the plate the structural intensity fields still indicate the source, the sink and the direction of energy flow from the source to sink. Meanwhile the existence of stiffener will change the energy flow in the plate. This method was found to be very useful in determining the vibration in any structure.

A.K.L.Shrivastava, P.K.Datta,A.H.Seikh [8], presented a paper on transverse vibration of stiffened plate with cutouts subjected to in plane uniform edge loading. This paper analyzed plate with and without cutout with all edges simply supported and plotted the result. The process used was of finite element method. The output of report clearly shows that the vibration pattern differs due to the cutout availability. This effect was found more in higher mode than in fundamental mode.

3.2. Outcome of Review

Many experiments were performed to know the vibration behavior of plates with and without stiffeners. Optimal placement of stiffeners were analyzed to understand its effect. Analytical, Numerical and Experimental methods were used whose results were in good agreements to each other.

In none of the papers modal analysis of angular stiffened plate were done. There is a clear scope for further analysis.

4. VIBRATION ANALYSIS OF PLATE

4.1. Basic Theory

Various Assumptions are considered for the plate analysis:

a) The material of the plate is elastic, homogenous and Isotropic in nature.
b) The plate is initially flat.
c) The deflection of the mid plane of the plate is small as compared to its thickness.
d) The straight line initially perpendicular to the mid plane of the plate will remain perpendicular even after bending of the plate.
e) Normal component of the stress will be assumed small as compared to other component.
f) With reference to the assumption b,c,&d it will be assumed that middle plane of the plate will remain unstiffened.
g) The welding effect of the stiffeners to the plate shall be ignored.

Partial Differential equation is used to model the dynamics of plate.

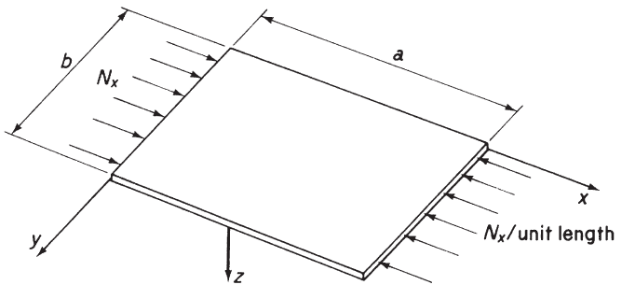

Figure-1 Plate with compressive force along X-axis [11]

For the above shown figure the stadard differential equation comes to be :

$$D\left(\frac{d^4(w)}{dx^4}\right)+2*D\left(\frac{d^4(w)}{(d^2(x)*d^2(y))}\right)+D\left(\frac{d^4(w)}{dy^4}\right)+\rho h\left(\frac{d^2(w)}{dt^2}\right)=Nx\left(\frac{d^2(w)}{dx^2}\right)$$

When sinusoidal time response is assumed then we have:

$$w(x,y,t)=w(x,y)\sin(\omega t+\emptyset) \quad (2)$$

By applying time response to the standard equation we get:

$$\nabla^4(w)-k^4w=\frac{Nx}{D}\left(\frac{d^2(w)}{dx^2}\right) \quad (3)$$

$$K^4=\frac{\rho h\omega^2}{D} \quad (4)$$

For considering simply supported edges Let us assume an elementary solution for the same as:

$$w(x,y)=\sum_{m,n=0}^{\infty}A_{mn}\sin\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right) \quad (5)$$

Substituting equation 5 into equation 4 we get the frequency equation as below:

$$\rho h\omega_{mn}{}^2=D\left[\left(\frac{m\pi}{a}\right)^2+\left(\frac{n\pi}{b}\right)^2\right]^2+\left[N_x\left(\frac{m\pi}{a}\right)^2\right] (6)$$

If we consider the force effect and plated buckling effect due to the force value then the formula frequency calculation will be as below [10]

$$\omega_{mn}=\left[\left(\frac{m\pi}{a}\right)^2+\left(\frac{n\pi}{b}\right)^2\right](N_x+N_{xcr})^{\frac{1}{2}} \quad (7)$$

Where

$$N_{xcr}=-\frac{D\pi^2}{a^2}\left[m+n\frac{n}{m}\left(\frac{a}{b}\right)^2\right]^2$$

Nxcr is clearly negative quantity. Thus the fundamental frequency for this loading will always occur at n=1, but not necessarily at m=1.

The force acting on it is not dynamic in nature and hence while calculating the modal shape we can avoid it and hence natural frequency will be the output. Hence finally we get the formula as below:

$$\omega_{mn}=\left(\frac{D}{\rho*h}\right)^{0.5}\left[\left(\frac{m\pi}{a}\right)^2+\left(\frac{n\pi}{b}\right)^2\right] (8)$$

Where,

$$D=\frac{Eh^3}{12(1-\nu^2)}$$

(1)

a,b-Plate Dimensions, (a-long edge, b-small edge), Nx-Force in x direction, W-Deflection of plate in the transverse direction, ω- Frequency of the plate, m ,n-Waves along x & y axis of plate.Nxcr – Critical Buckling Load

4.2. Analytical Analysis

In order to understand the governing equation more clearly let us take a case of stiffened plate with stiffener and the same plate without stiffener.

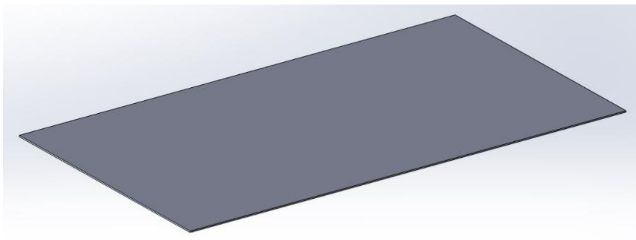

Figure-2 Plate without stiffener

Corresponding Dimensions are:-

Length (a)-2.4m

Width (b)-1.2m

Thickness (h)-6mm

Using equation-8 and considering the above value and figure-2 plate condition we get the fundamental frequencies as12.85 Hz. Similar type of Analysis were done for plate with one stiffener at center and two stiffener which divides the complete panel into equal part by following process discussed by orthotropic plate concept [9]& equivalent stiffness concept[7]. The process of analytical calculation is very complex and hence FEA method is followed for the same. Equation -9 depicts the same in the next section.

4.3. FEA Analysis of three different Case

Hypermesh and Nastran software were used to do the analysis. 4 node shell elements were used to discretize the complete plate structure. After applying the boundary condition Nastran was used to do the post processing and the results of first 6 modes were divided into three sections.

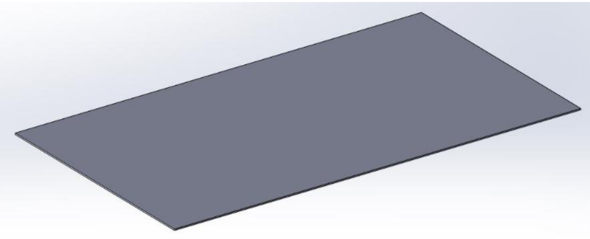

Figure-3 Plate without stiffener

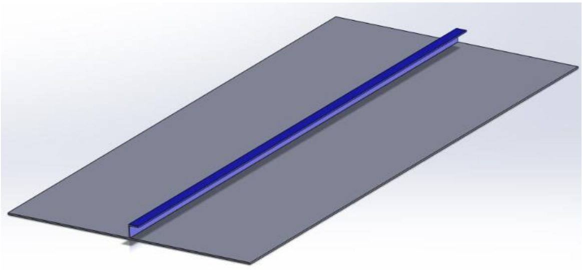

Figure-4 Plate with stiffener at mid

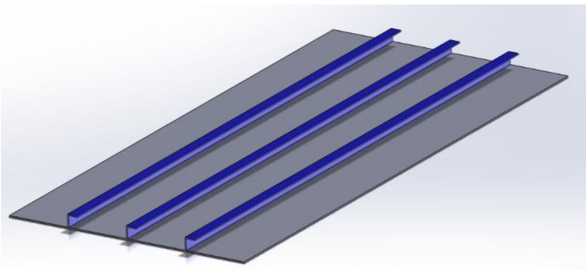

Figure-5 Plate with three stiffener which divided the plate into equal parts.

Modal Analysis involves below mentioned two steps:-

(a) Frequency Extraction Procedure

(b) Eigen value extraction method

Frequency Extraction method involves the Eigen value extraction and corresponding mode shapes finding. This analysis is linear so no need of considering the initial stress and preloading.

Eigen value extraction procedure involves below mentioned equation:

$$(-\omega^2 M + K)\phi = 0 \quad (9)$$

Where,

M-Mass matrix (symmetric and positive matrix)

K- Global stiffness matrix.

ϕ – Eigen vector (mode of vibration)

Element type used is CQUAD4. It is a 4 node isoparametric flat plate element. It used PShell property entry in which we can define the thickness

Mode shape-1

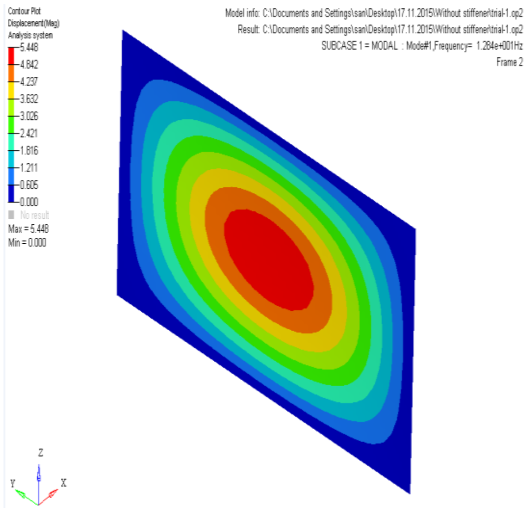

Figure-5Plate without stiffener

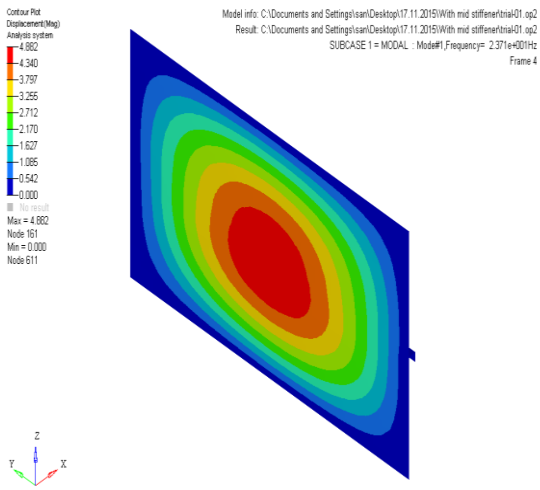

Figure-6 Plate with stiffener at mid

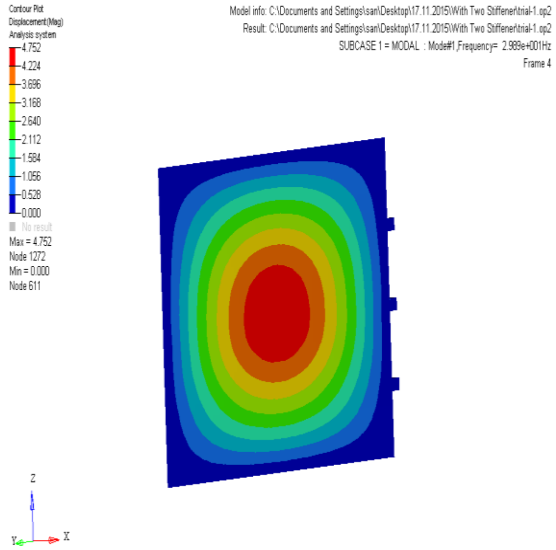

Figure-7 Plate with three stiffener which divided the plate into equal parts.

Mode shape-2

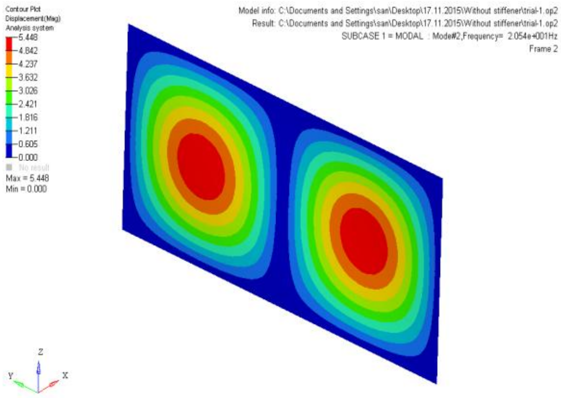

Figure-8 Plate without stiffener

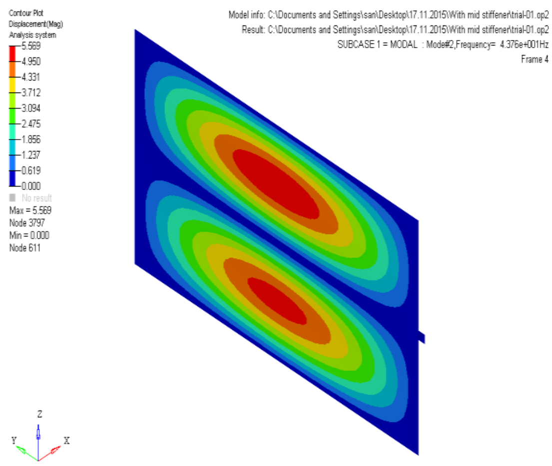

Figure-9 Plate with stiffener at mid

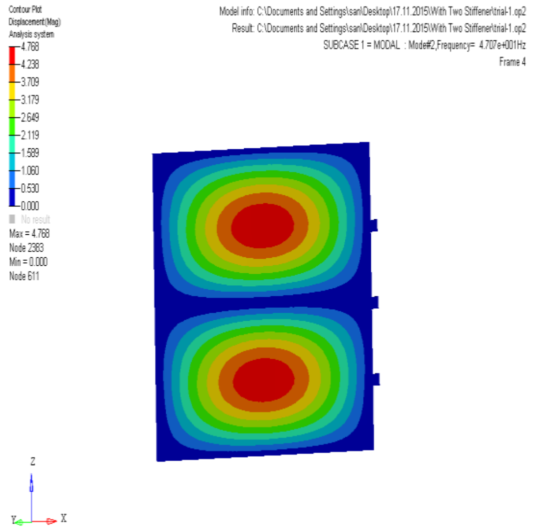

Figure-10 Plate with three stiffener which divided the plate into equal parts.

Mode shape-3

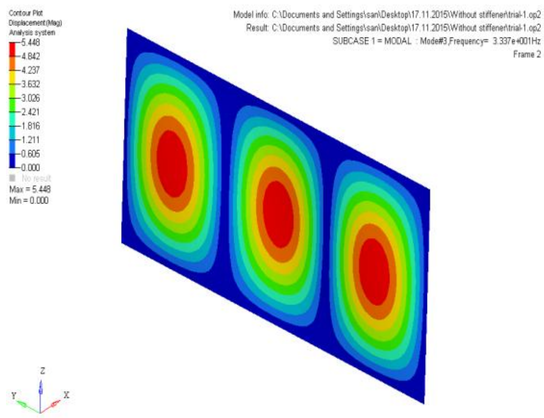

Figure-11 Plate without stiffener

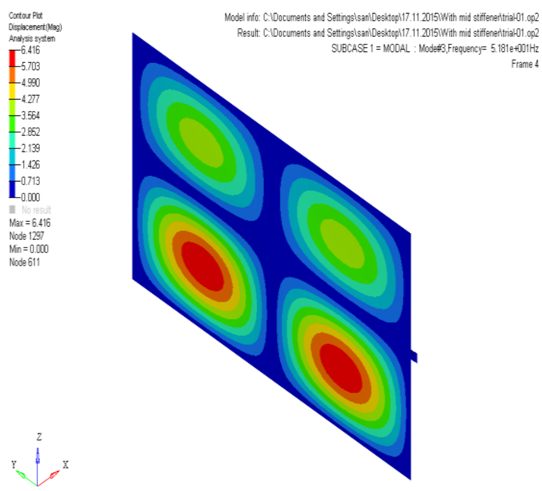

Figure-12 Plate with stiffener at mid

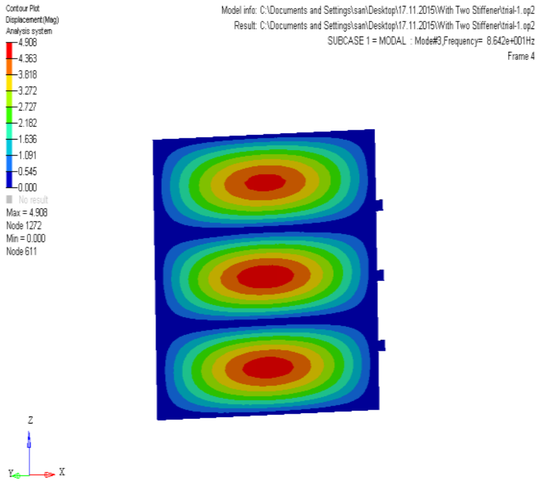

Figure-13 Plate with three stiffener which divided the plate into equal parts.

Mode shape-4

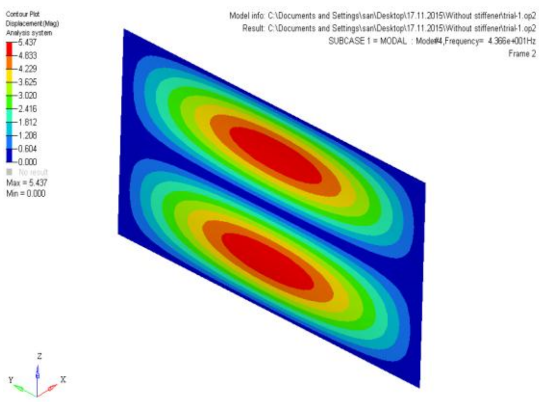

Figure-14 Plate without stiffener

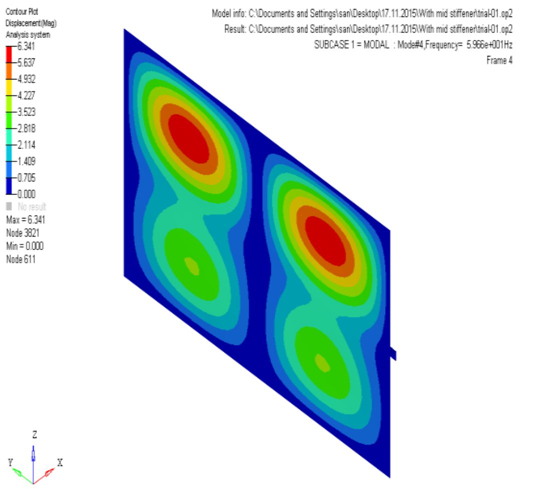

Figure-15 Plate with stiffener at mid

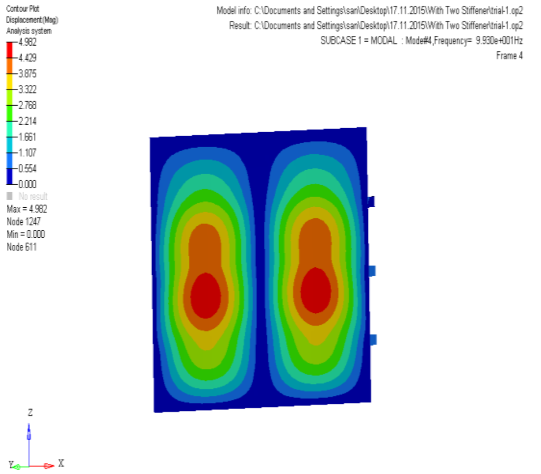

Figure-16 Plate with three stiffener which divided the plate into equal parts.

Mode shape-5

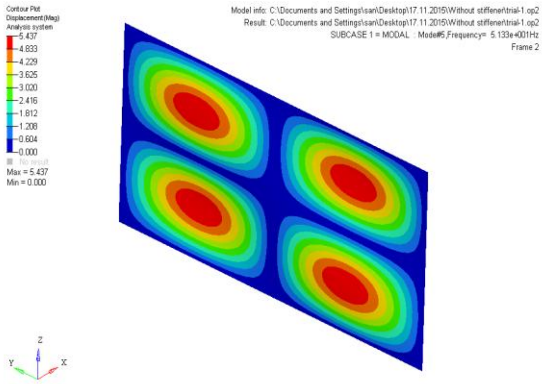

Figure-17 Plate without stiffener

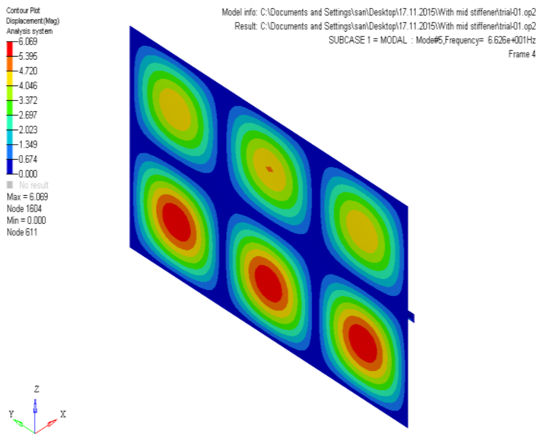

Figure-18 Plate with stiffener at mid

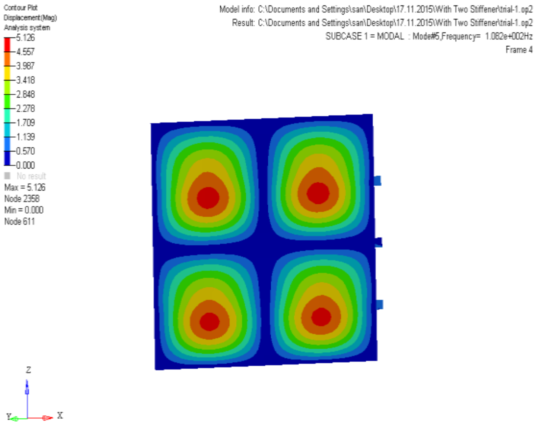

Figure-19 Plate with three stiffener which divided the plate into equal parts.

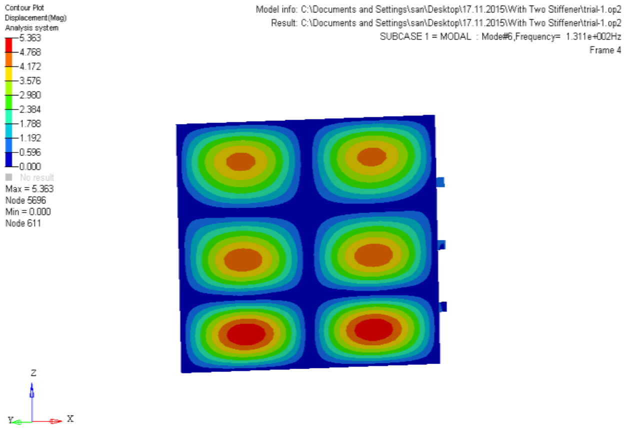

Figure-22 Plate with three stiffener which divided the plate into equal parts.

Mode shape-6

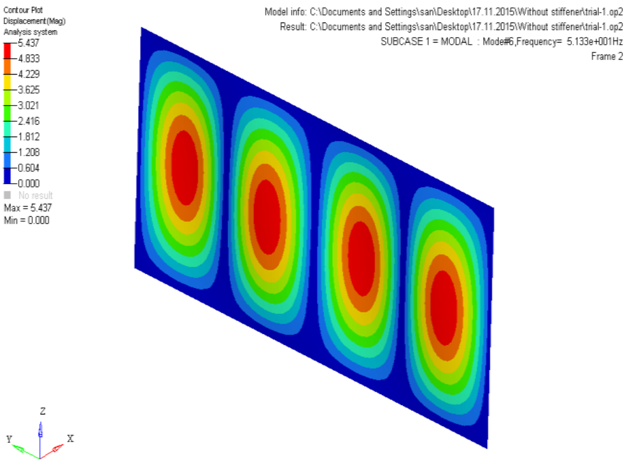

Figure-20 Plate without stiffener

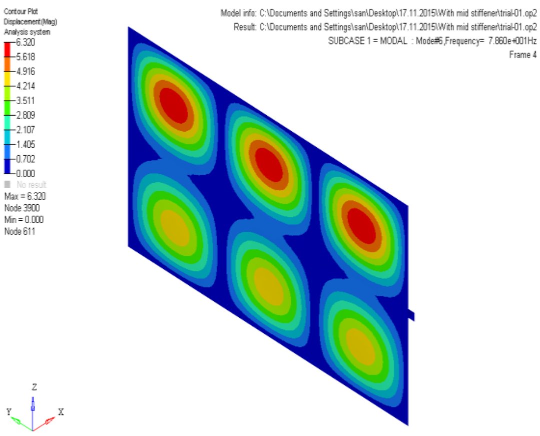

Figure-21 Plate with stiffener at mid

Table-1 Value of Modal analysis

Mode	Frequency(Hz) chart for three conditions		
	Plate with below condition		
	No stiffener	Single Stiffener	Two stiffeners
Mode-1	12.84	23.71	29.89
Mode-2	20.54	43.76	47.07
Mode-3	33.37	51.81	86.42
Mode-4	43.66	59.66	99.3
Mode-5	51.33	66.26	108.2
Mode-6	61.13	78.6	131.12

Comparison of analytical calculation with FEA output is as below.

Analytical value for the principal mode-12.85 Hz

FEA output for the same mode-12.84 Hz

$$\%\ Variation in value = \frac{(12.85 - 12.84)}{12.85}(100) = 0.078$$

This variation is well within acceptable limit

4. CONCLUSION

Analytical calculation and FEA results were in good agreement to each other. It was found that modal frequency is increasing with the addition of stiffeners. Overall stiffness of the plate can be effectively increased by addition of stiffener which can yield better result.

Modal analysis shows almost similar pattern for all the three cases with different frequency value. Modal Frequency values are increasing according to the addition of number of stiffener1 is of prime importance as the other modes are having very safe value.

There is further analysis scope to analyze the same case with different stiffeners geometry.

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