Vibration Mode Localization of Aluminum Rectangular Plate

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ABSTRACT

Modal analyses are carried out to calculate the natural frequencies and natural modes of the system. Ship structures are stealth shaped structures and these stealth structures are simulated by taking an assumption that structures are plane and homogenous throughout. Rectangular aluminum plate model is simulated in this paper using ABAQUS® 13.1 and Pulse 18.1. Vibration Mode localization analysis using point mass variation has been carried out. Mode shapes and frequencies obtained in this paper shows that vibration along major portion of the plate is found to be curbed. Often modal analyses are performed using a somewhat coarser mesh, since the mode shapes and Eigen frequencies can be accurately estimated as long as the basic mass and stiffness distributions are correct. In one way or the other this analysis can also be said as acoustic analysis as sound transmitted by hammer impact on the aluminum plate is transformed into voltage signals by the use of accelerometer containing piezoelectric material. The voltage signal is transformed into displacement signal and frequency signal by means of amplifier used in the setup of the experimental modal analysis software Pulse 18.1.

Keywords: ABAQUS CAE , Modal Analysis, Vibration Mode Localization,

1. INTRODUCTION

Dynamics of rectangular plates is majorly concerned about control of noise and vibration of structures like stealth ships and modern aircraft which are made up of aluminum panels and plates. These plates have very low stiffness in transverse direction and at high frequency can lead to acoustic radiation, fatigue failure etc. In order to control the vibration of plates an economical phenomenon of mode localization is prescribed by Filoche and Moyborada [1]. Sharma et al[6] used numerical methods to predict normal vibration modes which can localize in small regions of plate by slight modification in the interior of plate. In the present work, experimental modal analysis to study the mode localization of thin rectangular aluminum plate has been conducted using Pulse 18.1(MTC-Modal Test Consultant). Mode localization phenomenon has been conducted using two techniques.

i) Adding the point mass to appropriate location on the plate.

ii) Clamping boundary condition.

Finally the results obtained are validated with CAE analysis results obtained using ABAQUS® 6.13 [7].

1.1. LITERATURE REVIEW

Extensive research has been carried by Leissa et al [3] on vibration of isotropic plates using classical plate theory with different boundary conditions. Lekhnitskii [4] and Timoshenko [8] developed a variational formulation to implement finite element method solution for orthotropic plates under different boundary condition. In 1981 Hodges [2] studied the phenomenon of mode localization in chain of pendula and spring supported strings and he observed that mode localization occurs at large distance due to departure from regularity. Dowell et al [9] developed a perturbation method to obtain mode localized vibration for disordered structures consisting of weakly coupled systems. Pierre [5] later further extended the perturbation method developed before to study mode localization in simply supported two span beams with torsional springs at intermediate point supports and he found that mode localization depends upon irregular spacing between sup- ports and stiffness of torsional springs. Filoche et al [1] observed that strong mode localization by mode localization can occur due to constraining of point in the interior of clamped rectangular plates. This clamped point would lead to divide the plate into two independent vibrating regions. They also found that localization increases with increase in aspect ratio of the plate. Sharma et al [6] studied the mode localization phenomenon using shear deformation plate theory in monolithic and composite plates. He found that mode localization effect increases with increase in the point mass on the plates and constraining the internal point. In the current paper modal parameters of rectangular plates made of aluminum are clamped on all its edges. Further point masses are added at the constrained point to capture the effects of mode localization.

1.2. MOTIVATION

Vibration Mode Localization in rectangular plates by Sharma et al [6] and Filoche and Mayborada et al [1] has not been validated yet. Hence we have performed experimental modal analysis along with CAE analysis on aluminum rectangular plates to study the viability of mode localization on the aluminum plate.

II EXPERIMENTAL AND CAE MODAL ANALYSIS OF ALUMINUM PLATE

1.3. PROBLEM STATEMENT

Conduct the CAE and experimental modal analysis of Aluminum plate outer frame dimension of 680*280*4mm dimension by keeping in prestine state aluminum plate and then attaching two different masses of 200gm (18.8 percentage of the weight of the aluminum plate) and 150gm (14.5 percentage of the weight of aluminum plate) at 1/5th of the length from edge of the plate using Pulse 18.1(MTC) and ABAQUS® 13.1(CAE) to determine the modal frequency and mode shapes of the plate.

1.4. EXPERIMENTAL SETUP

Experimental analysis has been carried out using software called Pulse 18.1(Modal Test Consultant) with 6 channels LAN-Xi. Here are the few of the instruments used to conduct the experimental analysis.

1.4.1. LAN XI

LAN-XI- 6 channel LAN- XI type 3050 has been used. It is a Data Acquisition hardware which is a versatile system of modular hardware that can be used as a stand-alone, single module front-end, as part of a distributed module setup, or collected in 1-module frames. The hardware is fully compatible with IDA-e hardware for PULSE and works with PULSE and test for Ideas software platform. It provides an external flexible system with frequency range from 0 to 51.2 KHz. LAN Xi has an LCD screen and LED rings around each input channel, which clearly display overloads, overload history and cable breaks. The LCD screen shows module configuration information, so you can be sure of the status of the whole working system.

Fig1: Accelerometer mounted on the aluminum plate with clamped B.C

1.4.2. LAN Cable

LAN cable- A single standard LAN cable that is used for both power and data transfer. This minimizes the number of cables required and results in lower cost, less downtime, easier maintenance and greater installation flexibility.

1.4.3. ACCELEROMETER

Accelerometer type 4384 has been used with sensitivity of 1.012pC/ms-2 or 1.012pC/g. It has a frequency range of 12.6 KHz and suitably used in general shock and vibrational measurements. It is a device used to transforms values of physical variables into equivalent electrical signals. It measures the acceleration of vibrating body.

1.4.4. CONDITIONING AMPLIFIER

Nexus Amplifier 2693 has been used. These are 4 channel conditioning amplifiers with large dynamic range. An amplifier is an electronic device that increases the power of a signal. It does this by taking energy from a power supply and controlling the output to match the input signal shape but with larger amplitude. An amplifier modulates the output of the power supply. Signal conditioning can include amplification, filtering, converting, range matching, isolation and any other processes required to make sensor output suitable for processing after conditioning. Signal amplification per- forms two important functions: increases the resolution of the input signal, and increases its signal-to-noise ratio.

Fig2: Connection of response of accelerometer into the input channel1 and the connection of BNC Cable, going into the LAN-XI, from the output channel 1

1.4.5. BNC Cable

This is the cable used to link the amplifier with ch-2 of LAN-XI.

1.4.6. Hammer

Impact hammers 8206-001, having sensitivity of 11.4mV/N has been used for hammering purpose at different grid points on the aluminum plate. Rubber tip has been used to do the hammering of the aluminum plates grid points. Maximum force that can be impressed upon hitting with impact hammer is 4448 N and it has frequency range of 5 KHz. This looks like an ordinary hammer but its head is fitted with a load cell and contains electronic circuitry and an output cable that can be connected to vibration analyzer. On hitting the impact hammer on any structure, an impulsive force is applied to the structure. An equal and opposite force is sensed by the load cell fitted in the head of the hammer. This generates an electric signal that is given to vibration analyzer which analyzes the signal, compares with the signal received from accelerometer fixed to the structure, and this information is used to develop FRF (Frequency Response Function) and finally the natural frequencies of the structure are found. The hammer excites resonance frequencies in the structure over a broad range. The physical properties of the hammer (size and mass) and the strike velocity determine the amplitude and frequency content in the force impulse. The hammer tip material determines the energy content of the impulse. The selection of the hammer tip can have a significant effect on the measurement acquired. The input excitation frequency range is controlled mainly by the hardness of the tip selected. The harder the tip, the wider the frequency range that is excited by the excitation force. The tip needs to be selected such that all the modes of interest are excited by the impact force over the frequency range to be considered. If too soft a tip is selected, then all the modes will not be excited adequately in order to obtain a good measurements.

Fig3: Impact hammer with a rubber tip

1.4.7. Aluminum Plate

An Aluminum plate of dimension 680mm by 280mm with 4mm thickness has been used for modal analysis purpose.

1.4.8. MASSES

Masses-150 gm and 200 gm- In order to capture the mode localization in aluminum plate two masses of 150gm and 200gm have been used to conduct the modal analysis.

1.4.9. MESHING ON THE PLATE

Grid or mesh creation in aluminum plate- Manually Fine grid meshing has been carried out to conduct modal analysis.

1.4.10. PC WITH DONGLE

PC with Dongle Dell PC with installed Pulse 18.1 having Labshop, MTC and Reflex has been used.

EXPERIMENTAL SETUP DESCRIPTION

In order to extract the modal parameters of a 600*200 mm Aluminum plate, the plate is clamped to a Mild Steel C-channel which is subsequently mounted on a firm Mild steel base weighing approx. 400kg. The C-channel is bolted to the plate with M10 bolts at a distance of 40mm between each other. All edges clamped is chosen to be the boundary condition for the experimental modal analysis of the plate. The fine grid points were also made by taking 23 lateral and 7 longitudinal lines to ensure the positions of the excitation force provided by the impact hammer and the output response by the accelerometer. Using a fixed accelerometer and a roving hammer as excitation gave a MISO(Multiple input, Single output) analysis, which is mathematically identical to SIMO (Single input, Multiple output), due to principle of reciprocity. Modal parameters of Al plate is extracted using Bruel and Kjaer Pulse Labshop and Pulse Reflex software. The extracted mode shapes are validated using Abaqus software. In first step, a suitable (admissible) set of test data, consisting of forcing excitations and motion responses, for various pairs of degrees of freedom of the test object are obtained. Next, compute the frequency transfer functions (frequency response functions) and the coherence functions of the pairs of test data using Fourier analysis. Digital Fourier analysis using fast Fourier transform (FFT) is the standard way of accomplishing this. Curve fitting of analytical transfer functions to the computed transfer functions is done. Hence, natural frequencies and the mode shapes for various modes in each transfer function are obtained.

Fig4: Experimental setup demonstrating masses being attached to the AluminumPlate

1.5. METHODOLOGIES

As per the analysis using impact hammer the natural frequencies and mode shapes are obtained by this equation: Impact hammer excitation = One row of Frequency response function matrix is measured.Various experiments to conduct modal analysis have been carried out using Pulse 18.1. The two different masses shown above were alternatively used by fixing them using feviquick at distance of 150mm from left edge. The sensitivity values of transducer are properly set in Amplifier as well as in Pulse 18.1 MTC, such that results obtained are perfect. Accelerometer is mounted on aluminum plate on node number 103 and readings are taken by hitting at various grid points as mentioned above. The bandwidth of 1.6 KHz and averaging of 5 and 10 were respectively taken to conduct the experiments. Data were taken by hitting on 165 grid points on the plate. Trigger level were properly set in between 8 to 12Hz frequencies and so do the hammer weighing and response weighing were set. Post processing was carried out in Pulse18.1/Reflex and finally natural frequencies and modes shapes generated were perfectly produced.

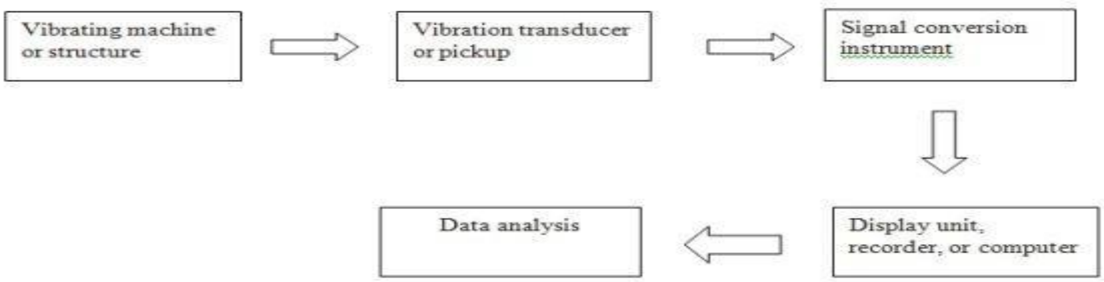


Fig6: Basic Mechanism of Modal Analysis

II NUMERICAL ANALYSIS

Any sort of experimental results cannot be blindly believed so some sort of validation is required to be carried out. Thus CAE analysis of aluminum plate has been carried out using ABAQUS® 6.13.

2.1 MODULES

1. PART MODULE: 3D Deformable shell element has been modeled in the part module of the ABAQUS® Standard. Section properties with 4mm thickness and section assignment with aluminum material property are properly and carefully assigned to the structure. The default properties has not been assigned blindly but the aluminum sample has been tested in laboratory to get the actually Young's modulus of the aluminum plate. Figure below shows the aluminum sample tested for calculating the Young's modulus and Poisson's ratio.

Aluminum specimen tested

Tested Material	Young's Modulus	Poisson's ratio
Aluminum	65.14GPa	0.37

Fig7: Aluminum Sample tested to get actual material properties

2. Mesh Module: S4R linear reduced integration shell elements have been used for analysis purpose. By having the grid points in the structure it was quite easy to locate the same position as in experimental analysis, so node sets were prepared and respective Inertia/point mass was attached to the plate.

3. Assembly Module: As we all know ABAQUS requires each and every model or parts may be individual or assembled need to be analyzed in assembly. Thus single plate instance was created in the assembly module.

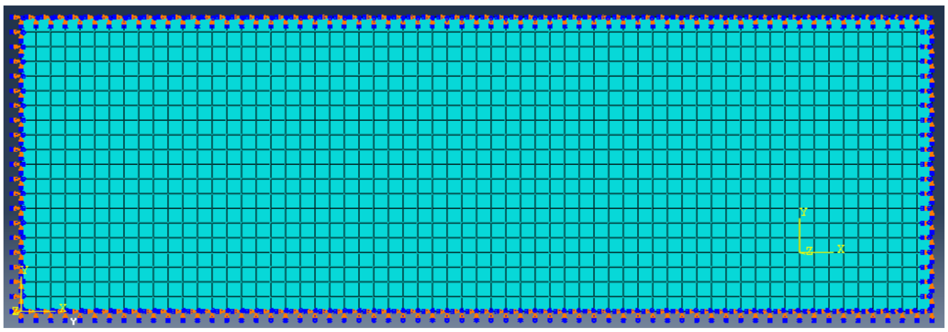


Fig8: Numerical Analysis setup for Clamped Aluminum Plate using ABAQUS

4. Step Definition: Step definition in ABAQUS® tells us about what kind of analysis we are going to perform. As we are to perform frequency analysis, linear perturbation step was created with frequency substep. It's important to note that step module captures all the boundary conditions, loadings, field output request, History output request. As we are interested in only mode shapes at present field output request of displacement and stress Mises were only requested.

5. Boundary Condition: As we can see easily that our experimental model represents the clamped boundary condition in the experimental modal analysis so in order to validate the experimental results similar clamped boundary condition are to be considered in FE simulation. This is required because FE simulation carried out on similar replica of experimental model will give proper and uniform results.

6. Job Preparation and Submission: Finally after conducting all the steps above a job with some name is prepared and submitted for analysis.

7. Post processing: Post processing of results are carried out using ODB averaging options available in result section taking on the final frame definition. Results have been discussed in Result and Discussion section.

III RESULT AND DISCUSSION

3.1 Mode Shapes of Pristine Aluminum Plate

The freely vibrating aluminum plate clamped on all the edges without any internal boundary constraints is found to behave with high modal frequencies. In the pristine state vibration level was high and curbing vibration in general phenomenon without adding any stiffeners or point masses was not possible. Comparison of Experimental and CAE modal analysis shows that the results are well within the acceptable limit.

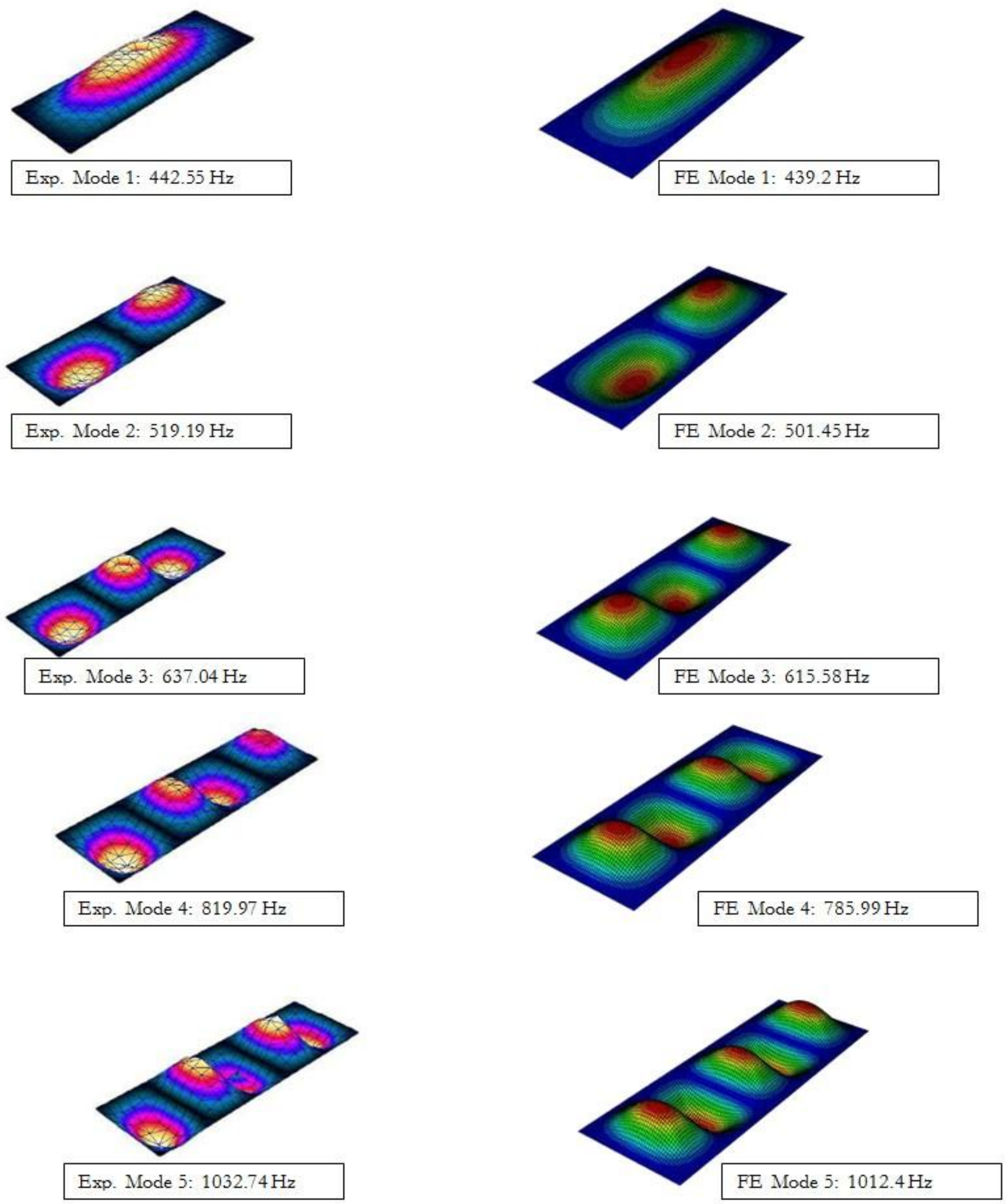


Fig9: Mode shapes for pristine Aluminum Plate: Comparison between experimental (left) and FE (right) results

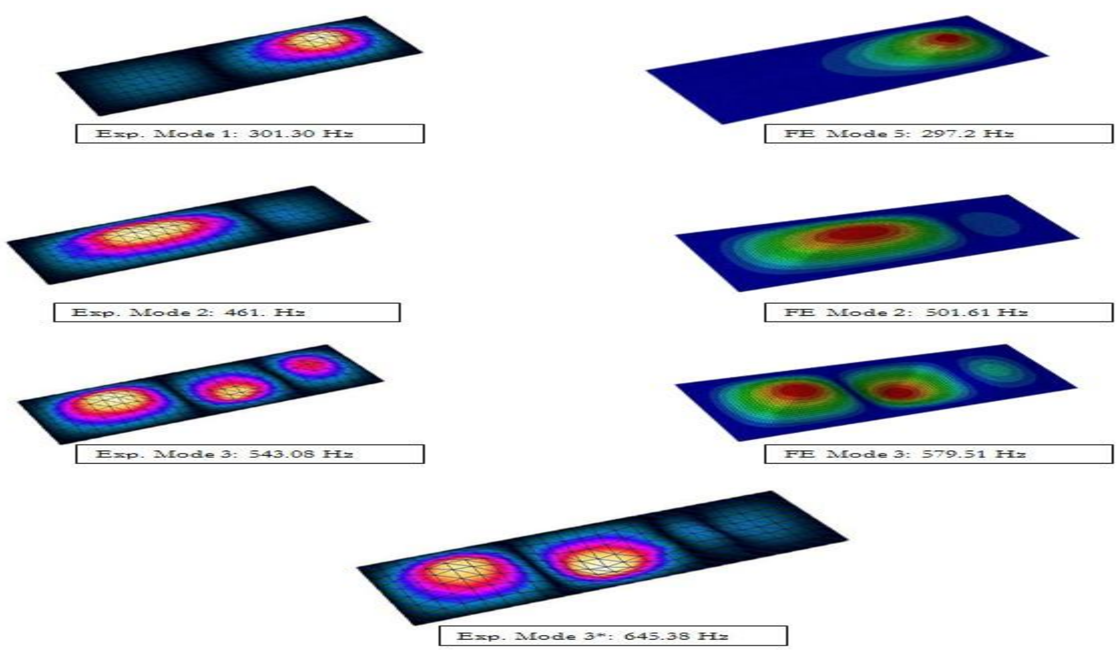
Table1: Comparison of Frequency for Pristine Aluminum Plate

Mode	Experimental(Hz)	CAE(Hz)	Percentage Diff.(%)
I	442.55	439.20	0.76
II	519.19	501.45	3.42
III	637.04	615.58	3.37
IV	813.97	785.99	3.44
V	1032.74	1012.4	1.97

3.2 Mode Shapes of 200 gm and 150 gm point mass loaded Aluminum Plate

In this section experimental and CAE modal analysis of aluminum plate is carried by adding point mass to the interior point on the plate. The point mass of 200gm (18.8 percent of aluminum plate weight) and 150gm(14.5 percent of aluminum plate weight) are used to check the effects of mode localization on the vibration of aluminum plate. Mode shapes with both mass attached are in good agreement with the CAE analysis. It is to be noted that under both the masses attached to the plate the vibration modes are localized at the point attached in the first mode.

Fig10: Mode shapes 1-3 for Aluminum Plate when a 200 gram lumped mass is attached at (1/4,1/2): Comparison between experimental (left) and FE (right) results



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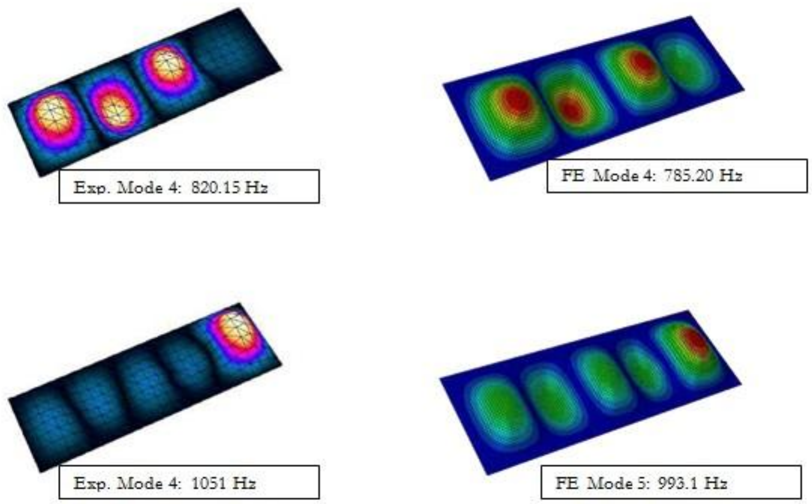

Fig11: Mode shapes 4-5 for Aluminum Plate when a 200 gram lumped mass is attached at (1/4,1/2): Comparison between experimental (left) and FE (right) results

Table2: Comparison of Frequency for 200gm mass attached

Mode	Experimental(Hz)	CAE(Hz)	Percentage Diff.(%)
I	301.30	297.75	1.07
II	461.00	501.61	-8.80
III	543.08	597.05	-9.09
IV	834.15	784.96	5.80
V	1051.00	975.32	7.20

Table3: Comparison of Frequency for 150gm mass attached

Mode	Experimental(Hz)	CAE(Hz)	Percentage Diff.(%)
I	340.19	325.56	4.30
II	455.89	502.55	-10.20
III	556.07	598.47	-7.26
IV	820.30	785.54	4.23
V	1017.23	979.82	3.67

IV CONCLUSION

From the above mode shapes and natural frequencies obtained it can be concluded that we have been able to curb the vibration along major portion of the plate. If you see the mode I, it clearly signifies the previous results obtained by Sharma et al [6] that plate structures localizes at the same position where mass is attached thereby minimizing the vibration along other side. Often modal analyses are performed using a somewhat coarser mesh, since the mode shapes and Eigen frequencies can be accurately estimated as long as the basic mass and stiffness distributions are correct. Thus vibrational mode localization phenomenon helps us to curb vibration along the major portion of the plate.

REFERENCE

[1] M. Filoche and S. Mayboroda, Strong localization induced by one clamped point in thin plate vibrations, 2009.

[2] C. H. Hodges and Woodhouse, Vibration isolation from irregularity in a nearly periodic structure: Theory and measurements, *Journal of the Acoustical Society of America*, *74,1983,894–905,*.

[3] Arthur W Leissa ,*Vibration of plates*, Ohio State University Columbus, 1969.

[4] Tsai S.W. Cheron T. Lekhnitskii, S.G. Anisotrpic plates, 1968.

[5] C. Pierre and E. H. Dowell, Mode localization in composite laminates, *Journal of Sound and Vibration*, *114(3),1987, 549–564*.

[6] Sharma D,Gupta S.S and Batra R.C, Mode localization in composite laminates,*Composite Structures*,94, 2012, 2620-2631.

[7] Dassault Systemes, ABAQUS documentation,2013

[8] S.W Timoshenko S., Krieger. Theory of Plates and Shells, McGraw-Hill Classic Textbook Reissue, 2nd edition, 1989.

[9] Dowell EH Yan M-J, Governing equations for vibrating constrained layer damping sandwich plates and beams, *Journal of Applied Mechanics*, 39, 1997,1041–1046.