Analysis and Comparison of Simulation and Experimental Modal Analysis of Square Plate with All Edge Fixed Boundary Condition for Uncertain Parameters

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Abstract: - This work is based on the study of dynamic responses of various vibrating structure at multiple frequencies with uncertain parameters. In major engineering applications plates are used as structural elements. All the machines, vehicles, aircraft and home appliances structures are made up of plates so it becomes necessary to study plate vibration. These structures which mostly made up of plates are complex in geometry and may possess variability in their material or geometric properties, as well as variation arising from the assembly and manufacturing processes. In this work typical all edge fixed boundary condition of plate is considered. The dynamic response for all edge fixed boundary conditions of plate is found by considering the plate without uncertainty and with uncertainty. The uncertain parameters considered are mass, stiffness and combination of mass and stiffness. FEM (Finite Element Method) and Experimental work is done to predict the dynamic response by finding fundamental frequencies and mode shapes for all edge fixed boundary condition of standard plate as well as plate with all uncertain parameters.

Keywords: - FEM, Uncertainty, Modal Analysis, ANSYS and Free Vibration.

1. INTRODUCTION

Vibration analysis of plates is important research subject. As plate are used for making many mechanical structures. Though analytical solutions have been found for plates with specified mass and stiffness but for the plates with arbitrary mass and stiffness have been important to study [1].

All the machines, vehicles, aircraft and home appliances structures are made up of plates so it becomes necessary to study plate vibration. These structures which mostly made up of plates are complex in geometry and may possess variability in their material or geometric properties, as well as variation arising from the assembly and manufacturing processes [2,3]. The concept of uncertainty plays an important role in the design of practical mechanical system. So, it becomes important to study its effects on mechanical system for different frequency domain [4]. Here in this paper structural element square plate with all edge fixed boundary condition is selected on which mass, stiffness and combination of it, uncertainty is taking in account [5]. By using Finite Element Method technique finding out, how plate is dynamically behaves in vibration [6]. During modal analysis natural frequency and mode shapes are find and compared the response of standard plate and the plate with mass, stiffness, mass-stiffness combination uncertainty [7,8]. Experimental set up is developed to perform the testing of all edge fixed boundary condition and find the response of plate for a standard as well as for uncertain parameters [9]. The analysis of dynamic response is carried out to predict the characteristic and the behavior of plate with uncertain parameters [10,11].

2. MODAL ANALYSIS OF PLATE USING SIMULATION SOFTWARE

A square plate of dimension 0.3048m×0.3048m×0.002m of steel material with properties of $\rho=7.86\times10^3$ Kg/m^3, $\nu=0.3$,$E=2\times10^5$ MPa was created using ANSYS software. The element selected for the plate is quadratic shell element 181. Total mass of plate is 1.5Kg. Mass uncertainty is taken 2% of total mass [11]. Number of masses taken is 13 of 2.78×10^{-3} Kg each. All these masses are placed on a plate. Similarly, for stiffness uncertainty springs of stiffness 2452.5 N/m are fixed on plate. Numbers of springs used are five with the same stiffness. For combination of mass and stiffness uncertainty assembly of 13 masses and springs are used. Weight of each mass is 11.12×10^{-3} Kg and stiffness of each spring is 327 N/m. The FEM geometrical model of square plate is for standard plate, mass uncertainty, stiffness uncertainty and mass and stiffness uncertainty shown in Figure 1.

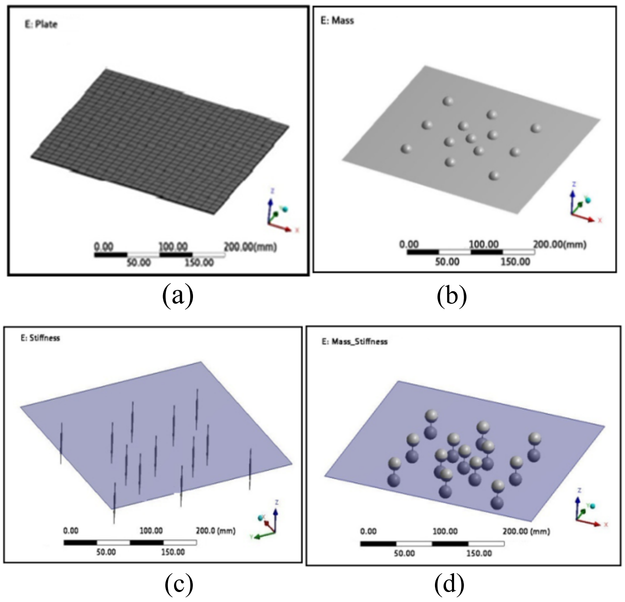


Figure 1: FEM geometrical model of square plate (a) standard plate, (b) plate model with mass uncertainty, (c) plate model with stiffness uncertainty, (d) plate model with mass and stiffness uncertainty

3. MODAL ANALYSIS OF PLATE

Modal analysis for all edge fixed boundary condition of plate with and without uncertainty is solved by ANSYS 14.5 FEA software using Block Lanczos solver [14]. The frequency range is taken from 0 Hz to 4000Hz and 30 modes for plate are captured. Thus 30 modes of vibration of standard plate and plates with different uncertainty are obtained as shown in figure 2 and figure 3. The comparison of standard plate with different uncertainty plates is done.

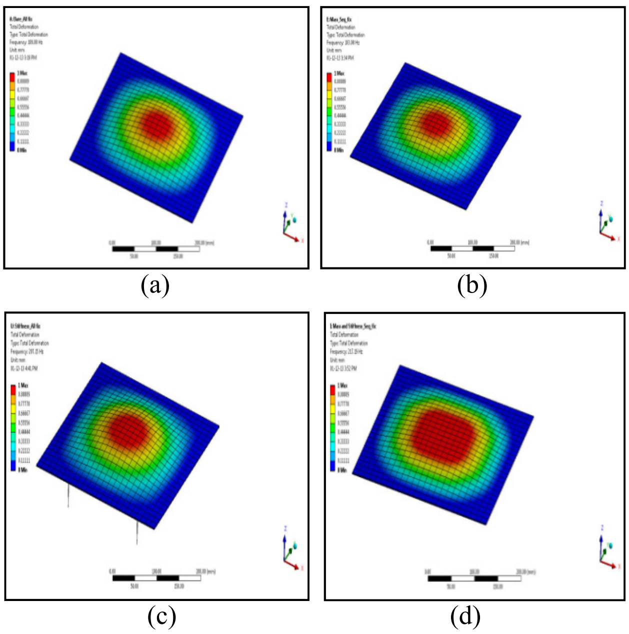


Figure 2: First mode shape of plate (a) standard plate, (b) mass uncertainty (c) stiffness uncertainty and (d) mass and stiffness uncertainty

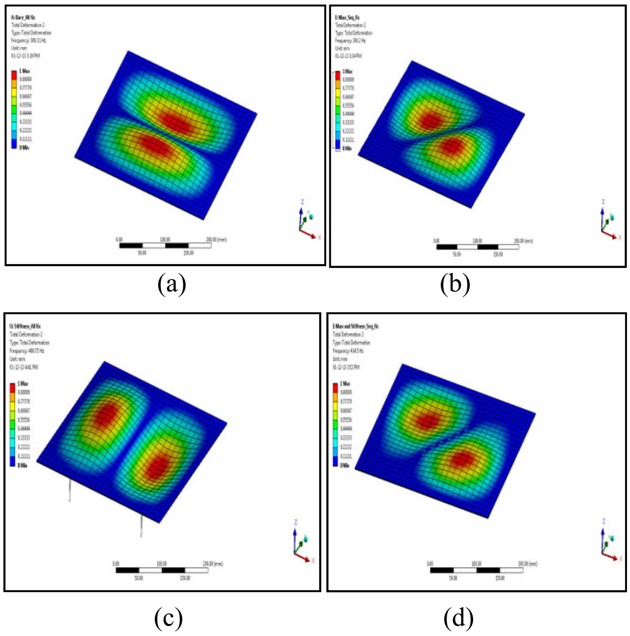


Figure 3: Second mode shape of plate (a) standard plate, (b) mass uncertainty (c) stiffness uncertainty and (d) mass and stiffness uncertainty

In the figure1 first mode of plate is shown with and without uncertainty. In the first mode change in mode shape is obtained. As the red colour dimple size is changing in figure 2(a,b,c,d). However in second mode of standard plate and plate with uncertain parameters phase change and shifting of mode is obtained as shown in figure 3(a,b,c,d). These are the effects of uncertainty on the mode shapes, which were observed during analysis.

4. EFFECT OF UNCERTAIN PARAMETERS ON THE VALUES OF NATURAL FREQUENCIES USING SIMULATION MODEL

In the simulation model plate is examined for a standard plate, mass uncertainty, stiffness uncertainty, and mass and stiffness uncertainty. Thirty natural frequencies and mode shapes was determined but for study purpose only first 10 modes are shown. In table 1 it has been seen that as mass uncertainty is added in the plate, the natural frequency value decreases and when the stiffness is added it drastically increases. Also combination of mass and stiffness uncertainty increases the natural frequencies prominently.

The graph is plotted between frequency and mode number shown in figure 4. It is observed from the graph that the effect of uncertainty is more at the higher mode number and it is has very less effect at the lower mode number.

Table 1: Natural frequency values without and with uncertain parameters of plate by simulating software

Mode No.	Standard Plate (Hz)	Mass Uncertainty (Hz)	Stiffness Uncertainty (Hz)	Mass & Stiffness Uncertainty (Hz)
1	189.08	183.08	207.15	217.19
2	388.31	380.2	400.75	414.5
3	388.31	380.2	409.61	414.5
4	572.59	562.57	624.15	866.18
5	705.04	687.24	746.37	937.53
6	708.39	691.14	758.15	948.77
7	880.45	861.27	910.01	1047
8	880.45	861.27	916.02	1047
9	1147.7	1131.8	1174.7	1168.3
10	1147.7	1131.8	1184.9	1168.3

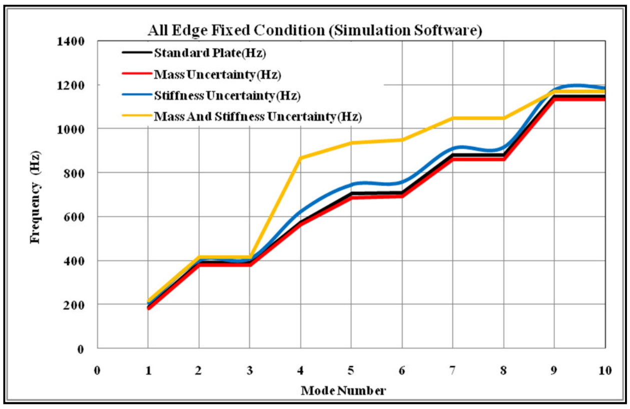
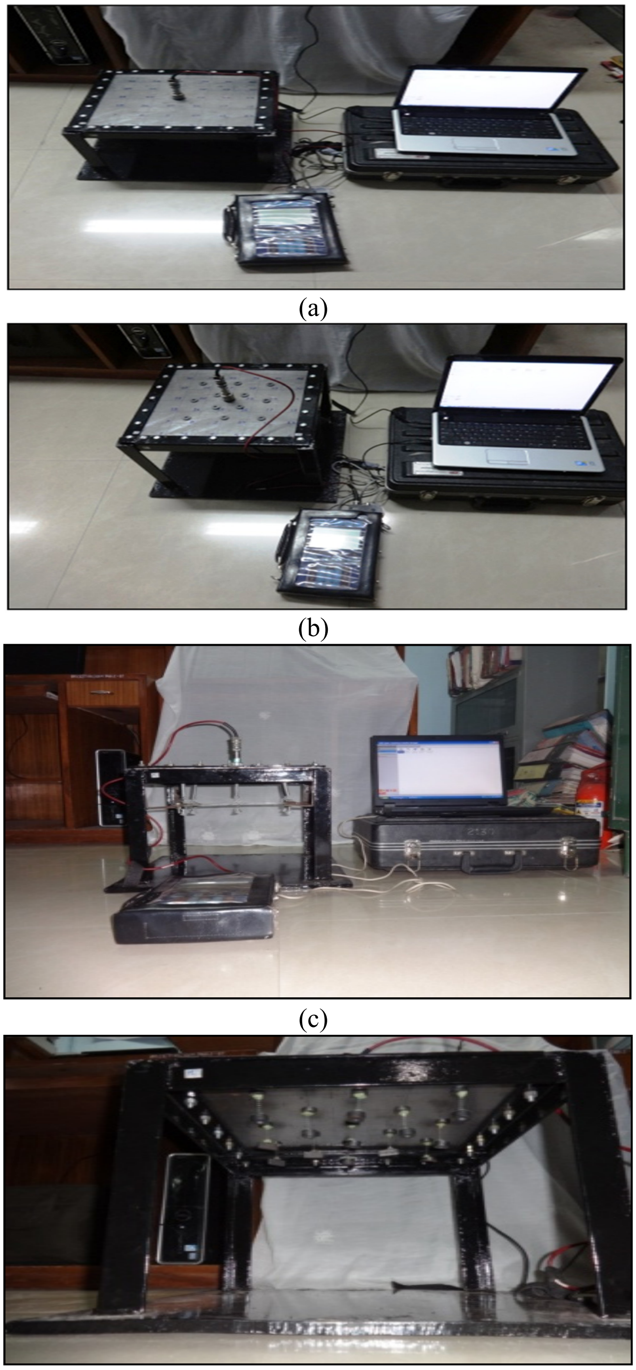


Figure 4: Graph showing the effect of uncertain parameter on the plate by Simulation model

5. EXPERIMENTAL SETUP FOR STANDARD PLATE AND PLATE WITH UNCERTAIN PARAMETERS

In all edge fixed boundary condition, the bare plate is fixed on the fixture tightly with the help of nut and bolts so that there should not be any movement takes place in the plate and the fixture as shown in figure 5 (a). At the centre of the plate magnetic type of accelerometer is placed through the FFT analyzer. Than excitation is done by using hammer impact to the plate and the natural frequency is recorded in FFT analyzer. After that the FFT analyzer is attached to the computer to get this recorded natural frequency value through the AMS suite software into the computer for the further analysis. Similarly for the plate with the mass uncertainty, stiffness uncertainty and mass and stiffness uncertainty in combination as shown in figure 5 (b), 5(c), and 5(d) respectively.



(a)

(b)

(c)

(d)

Figure 5: Experimental Setup of Plate (a) standard plate, (b) mass uncertainty, (c) stiffness uncertainty and (d) mass and stiffness uncertainty in combination

6. EFFECT OF UNCERTAIN PARAMETERS ON THE VALUES OF NATURAL FREQUENCIES USING EXPERIMENTAL MODEL

Experimental work is performed for the 30 natural frequencies but only 10 modes are shown and is compared with simulation. It is observed that in experimental work same trend of effect of uncertain parameters on plate is obtained, as obtained in case of simulation. But in experimental work there are some changes in values due to experimental discrepancy. The values of natural frequencies are shown in table 2. The graph plotted between frequency and mode numbers are shown in figure 6.

Table 2: Natural frequencies values without and with uncertain parameters of plate by experimental work

Mode No.	Standard Plate (Hz)	Mass Uncertainty (Hz)	Stiffness Uncertainty (Hz)	Mass &Stiffness Uncertainty (Hz)
1	190.82	184.07	208.16	218.38
2	388.25	383.40	405.57	414.77
3	389.28	385.83	413.02	414.86
4	569.66	563.89	573.53	883.59
5	726.19	650.33	747.52	901.33
6	729.71	712.80	804.81	967.73
7	918.66	789.21	939.49	1081.71
8	934.25	889.14	954.07	1082.04
9	1169.52	1087.12	1200.00	1211.00
10	1169.62	1165.99	1238.76	1211.11

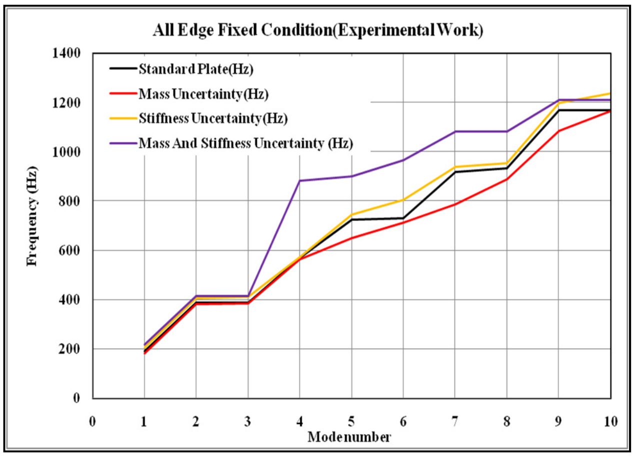


Figure 6: Graph showing the effect of uncertain parameter on the plate by Experimental model

7. SIMULATION SOFTWARE (ANSYS) AND EXPERIMENTAL WORK RESULTS

In table 3 percentage deviation of simulation and experimental work is compare and the average deviation is found in between 1.97 to 4.21 for standard as well as for all uncertain parameters. This is happened because of discrepancy occurring in the experimentation. The average deviation for all parameters is very less. Hence the values for the natural frequencies are more acceptable for the researcher.

Table 3: Percentage deviation of Simulating software and Experimental work values

Mode No.	Standard Plate (Hz)			Mass Uncertainty(Hz)		
	ANSYS	Experi mental	% Devia tion	ANSYS	Experi mental	% Devia tion
1	189.08	190.82	0.92	183.08	184.07	0.54
2	388.31	388.25	-0.02	380.20	383.40	0.84
3	388.31	389.28	0.25	380.20	385.83	1.48
4	572.59	569.66	-0.51	562.57	563.89	0.23
5	705.04	726.19	3.00	687.24	650.33	-5.37
6	708.39	729.71	3.01	691.14	712.80	3.13
7	880.45	918.66	4.34	861.27	789.21	-8.37
8	880.45	934.25	6.11	861.27	889.14	3.24
9	1147.70	1169.52	1.90	1131.80	1087.12	-3.95
10	1147.70	1169.62	1.91	1131.80	1165.99	3.02
Average			**3.75**			**1.97**

Mode No.	Stiffness Uncertainty (Hz)			Mass and Stiffness Uncertainty (Hz)		
	ANSYS	Experi mental	% Devia tion	ANSYS	Experi mental	% Devia tion
1	207.15	208.16	0.49	217.19	218.38	0.55
2	400.75	405.57	1.19	414.50	414.77	0.07
3	409.61	413.02	0.83	414.50	414.86	0.09
4	624.15	573.53	-8.83	866.18	883.59	2.01
5	746.37	747.52	0.15	937.53	901.33	-3.86
6	758.15	804.81	5.80	948.77	967.73	2.00
7	910.01	939.49	3.14	1047.0	1081.7	3.32
8	916.02	954.07	3.99	1047.0	1082.0	3.35
9	1174.70	1200.0	2.11	1168.3	1211.0	3.65
10	1184.90	1238.7	4.35	1168.3	1211.1	3.66
Average			**4.21**			**3.66**

8. CONCLUSION

By adding the uncertain mass, the different dynamic characteristic of plate is observed. Though, the amount of uncertain mass is very low, still it has influence on the structure. First frequency of the plate has been shifted from 189.08 Hz to 183.08 Hz. It clearly shows the effect of addition of uncertain mass. This trend of decreasing the plate frequencies are continued for all the modes, which proves the mathematical certainty of frequency, mass and stiffness.

The characteristic is compared for standard plate with that of plate with uncertain mass for first 30 modes. Natural frequency shift is found which may affect the working condition of entire structure. In case of uncertain mass there is a deviation of -3.17% in fundamental mode, which may not be acceptable in case of precise instrumentation or precision manufacturing systems.

Addition of uncertain mass to the standard plate not only shifts its frequencies but also it affects the mode shapes of plate. By adding an uncertain mass to the plate structure, apart from fundamental mode, most of the modes are losing their pattern. Irrespective of the frequency shift, the changing vibrating behavior of plate itself is a critical and unavoidable issue.

Addition of the uncertain stiffness dominantly changes dynamic characteristic of plate. First frequency of the plate has been shifted from 189.08 Hz to 207.15 Hz in this boundary condition having the deviation of 9.55% in fundamental mode which may not be acceptable.

By adding the uncertain mass and stiffness, the drastically different dynamic characteristic of plate is obtained. First frequency of the plate has been shifted from 189.08 Hz to 217.19 Hz and deviation of 14.86 % in first mode and in forth mode it is 51.27% of fundamental mode, which may not be acceptable in any case.

ACKNOWLEDGMENTS

The authors acknowledge with tanks to the Department of Mechanical Engineering of Priyadarshini College of Engineering, Nagpur for their support during this research work

REFERENCES

[1] Lin R. M., Lim M. K., "Natural frequencies of plates with arbitrary concentrated mass and stiffness modifications", *Computers &Structures*, Vol. 57. No 4, 1995, pp.721-729.

[2] Lucas, G., Kessissoglou, N.J., "Mid-Frequency Modelling of the Vibroacoustic Responses of Structures with Uncertainties", *Proceedings of Acoustics Christchurch*, New Zealand, 2006, 20-22.

[3] Tufoi M., Hatiegan C., Vasile O., Gillich G.R., "Dynamic Analysis of Thin Plates with Defects by Experimental and FEM Methods*", Romanian Journal of Acoustics and Vibration*, 10 (2), 2013, 83-88.

[4] Fang Z., "Dynamic analysis of structures with uncertain parameters using the transfer matrix method", *Computers & Structures*, Vol. 55, No. 6, 1995, pp. 1037-1044.

[5] Cicirello1 A., Langley R. S., "The analysis of random systems with combined parametric and non-parametric uncertainty models", *Proceedings of ISMA* 2010 including usd 2010.

[6] Wei Gao, "Natural frequency and mode shape analysis of structures with uncertainty", *Mechanical Systems and Signal Processing* 21, 2007, 24–39.

[7] Nicole J. Kessissoglou, GeoffI. Lucas, "Gaussian orthogonal ensemble spacing statistics and the statistical overlap factor applied to dynamic systems", *Journal of Sound and Vibration* 324, 2009, 1039–1066.

[8] Zhiping Qiu, Xiaojun Wang, "Parameter perturbation method for dynamic responses of structures with uncertain-but-bounded parameters based on interval analysis", *International Journal of Solids and Structures*, 2005, 424958–4970.

[9] Cotoni V., Langley, R.S. and Kidner, M.R.F. "Numerical and experimental validation of variance prediction in the statistical energy analysis of built-up systems", *Journal of Sound and Vibration* 288, 2005, 701-728.

[10] Abhijit Sarkar, Roger Ghanem, "Mid-frequency structural dynamics with parameter uncertainty", *Comput. Methods Appl. Mech. Engg.* 191, 2002, 5499–5513.

[11] Manson G., "Calculating frequency response functions for uncertain systems using complex affine analysis" *Journal of Sound and Vibration* 288, 2005,487–521.

[12] Sondipon Adhikari, Michael I. Friswell, and Kuldeep P. Lonkar, "Uncertainty in structural dynamics: experimental case studies on beams and plates, *ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering, Rethymno, Crete, Greece*, 13-16 June 2007.

[13] Tufoi M., Gillich G.R., Hatiegan C., Gillich N., Lorenz P., "Some Aspects Regarding the Transition from Beam to Plate Behavior of Vibrating Structures", *Romanian Journal of Acoustics and Vibration,* 12 (1), 2015, 62-68

[14] ANSYS® Mechanical. 14.5, Help ANSYS, Structural analysis guide, ANSYS, Inc (2013).