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Modal Analysis of Beam Type Structures

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***Abstract* : The purpose of this project is to study Modal behaviour of Beam type structures. Beams under study include Cantilever, Simply Supported and Fixed beam. Mode shapes and natural frequencies of these three types of beams are obtained using Theoretical analysis, Simulation in ANSYS and Experiment using FFT analyser. Finally natural frequencies obtained from Simulation and Experiment are compared with Theoretical values of natural frequency. The mode shapes obtained from simulation and experiment are matching closely with analytical ones. Natural frequencies obtained by simulation are within 6% deviation when compared to theoretical results whereas for experimental natural frequencies the maximum deviation from theoretical values is 19.31%.**

Keywords—Modal Analysis, Beam type structure, FFT Analyzer, Natural Frequency, Mode Shapes

I. INTRODUCTION

Modal analysis is the study of the dynamic properties of structures under vibration excitation. The goal of modal analysis in structural mechanics is to determine the natural mode shapes and frequencies of an object or structure during free vibration.

The various research papers studied are based on evaluation of specific properties or characteristics of vibration of beams by various techniques. L.Rubio's [4] work focuses on crack identification by means of modal parameters. P.Šuránek et.al[6] work is on decaying rate of vibration in cantilever beam for which they used an aluminum frame as an accessory to increase decay rate. Farooq and B. Feeny's[5] work is on new approach in theoretical modal analysis where they have used and evaluated the results experimentally for validity. H. Auweraer[2] has adopted a black box approach and evaluated them on industrial application. S. Mahalingam[1] has found changes occurring in modal parameters when support changes its position at an instance. A. Cusano et.al[3] used Bragg grating sensors instead of conventional accelerometer in experimental modal analysis and results were evaluated by experiment and simulation.

The literature survey shows that lot of efforts have been taken for determining the modal properties of beam type structures using numerous methods. Industry is focusing on reducing noise and vibration level for betterment of performance of various products. Beam type of structures are used in various application, hence it becomes an important structure to be studied for noise and vibration reduction. Mode shapes of beam type structures may provide more information to control vibration. The present study will attempt to conduct experimental modal analysis of beam type structures namely Cantilever, Simply Supported and Fixed Beam. Thus, the scope involves:

- Determination of Mode Shapes of Beam type structures analytically.
- Simulation of Beam type structure in ANSYS.
- Experimental Modal Analysis.

II. THEORETICAL ANALYSIS

Beams are slender members used for supporting transverse loading. It is a basic structural element that is capable of withstanding load primarily by resisting bending. Simply supported, cantilever and fixed beam are considered for analysis and description of them are given below.

Cantilever beam:

A beam which is supported on the fixed support and having the other end free is termed as a cantilever beam: Fixed support is obtained by building a beam into a brick wall, casting it into concrete or welding the end of the beam. Such a support provides both the translational and rotational constrain to the beam, therefore the reaction as well as the moments appears, as shown in the figure below.

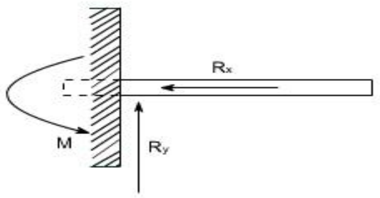

Fig 1 Cantilever Beam

Simply supported beam:

The beams are said to be simply supported if their supports creates only the translational constraints. When both the supports of beams are roller supports or one support is roller and the other hinged, the beam is known as a simply supported beam.

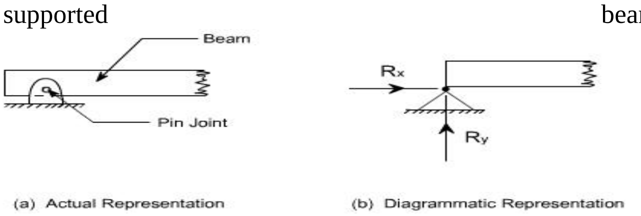

Fig 2 Simply Supported Beam

Fixed beam:

A beam which is supported on the fixed support on both the ends is termed as a fixed beam. It provides both the translational and rotational constrain to the beam at both the ends.

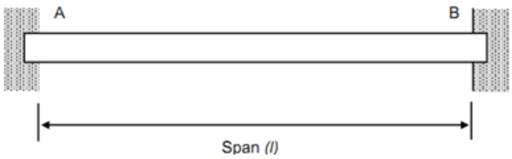

Fig 3 Fixed Beam

Calculation of Natural Frequency

Natural frequencies for first five mode shapes of cantilever, simply supported beam and fixed beam are calculated in this section.

Using modified expression,

$$f_n = C\sqrt{\frac{gEI}{wl^4}}$$

f_n = natural frequency
C = constant
g = acceleration due to gravity
E = young's modulus
I = moment of inertia
w = weight per unit length
l = length of beam

The value of constant (C) is different for different beam types which have been enlisted in Table 1.

Table 1: Values of c for different type of beams

Beam	1st	2nd	3rd	4th	5th
Cantilever	0.56	3.51	9.82	19.24	31.81
Simply Supported	1.57	6.28	14.14	25.13	39.27
Fixed	3.56	9.82	19.24	31.81	47.52

The dimensions of beam considered for all types of beam structures are shown in figure 4.
Length= 0.5 m
Width= 0.04 m
Depth= 0.005 m

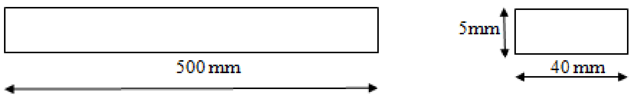

Fig. 4 Dimensions of Beam

Natural Frequencies of three types of beam are calculated and listed in following table 2.

Table 2 Theoretical natural frequencies

Beam Type →	Cantilever	Simply Supported	Fixed
1	16.68	46.78	104.10
2	104.30	187.12	286.75
3	292.52	420.92	562.36
4	573.66	748.02	929.52
5	948.21	1168.2	1384.99

III. SIMULATION

Simulation of modal analysis is done on FEA software 'ANSYS' for three different types of beam structures which are cantilever, simply supported and fixed beam.

Cantilever Beam

The following parameters have been used in simulation.
Young's Modulus = 2.1 × 1011 N/mm2
Poisson's ratio = 0.3
Density = 7886 kg/m3

The Grid size has been gradually increased from 20 to 85 to reach a point where Natural frequencies obtained in simulation matches very closely with that of Analytical results. As the results best match at a mesh size of 85 all beam elements are further given a mesh size of 85 for analysis.

The natural frequencies of cantilever beam are found with the help ANSYS software and shown in the following table 3

Table 3 Natural Frequency of Cantilever beam

Set	Natural Frequency(Hz)
1	16.75
2	105.02
3	294.05
4	575.09
5	952.08

Mesh model of cantilever beam is shown in fig 5 and first five mode shapes obtained using Ansys are shown in figure 6, 7, 8, 9 and 10.

Fig 5 Meshed Model of Cantilever Beam

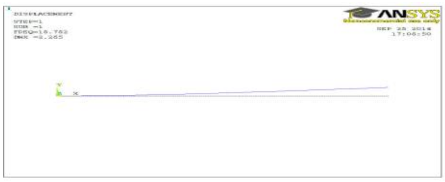

Fig 6 First mode shape

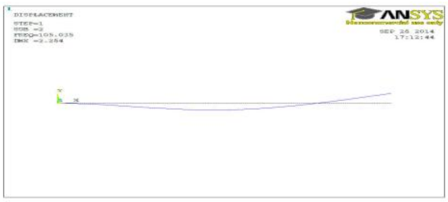

Fig 7 Second mode shape

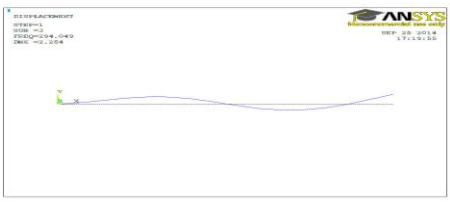

Fig 8 Third mode shape

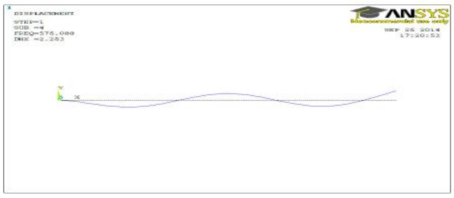

Fig 9 Fourth mode shape

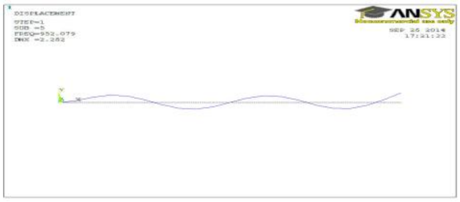

Fig 10 Fifth mode shape

Similarly mode shapes and natural frequencies are found out for Simply Supported and Fixed beam. Natural frequencies obtained by simulation for different beam structures are given in Table 4.

Table 4 Natural Frequencies of Beam Type Structure

Beam Type	Natural Frequencies				
	1	2	3	4	5
Cantilever	16.75	105.02	294.05	575.09	952.08
Simply Supported	47.05	188.18	423.22	752.43	1175
Fixed	105.56	293.97	575.20	952.20	1422

IV. EXPERIMENTAL SETUP

In this chapter, the various types of beams studied in the project are realized. Natural frequencies and mode shapes of different beams are obtained using FFT analyzer.

A. Cantilever Beam

A Cantilever beam can be made by restricting all degrees of freedom of beam's one end only. This arrangement can be realized using the same setup of fixed beam by eliminating its second support as shown in figure 11.

Fig 11 Cantilever Beam Setup

B. Simply Supported Beam

Simply supported beam can be made if the supports create only translational constraint at one end and only vertical reaction at other end. The set up prepared is shown in figure12.

Fig 12 Combined Setup for Simply Supported & Fixed Beam

C. Fixed Beam

Fixed beam can be made by restricting all degrees of freedom of beam at ends as shown in figure 5.1. Fixed beam arrangement consists of two identical I-sections, two plates and mild steel strip of dimensions 70×4×0.5 cm. Two I-sections are welded to base, which is in the form of C-section, at 50 cm. Ends of strip are sandwiched between upper flange of I-section and plate and then bolted tightly. The setup is shown in figure 13.

Fig 13 Fixed Beam Setup

V. EXPERIMENTAL ANALYSIS

Experimental analysis is performed on three types of beam using FFT analyzer. Modes shapes and Natural Frequencies of Cantilever Beam are shown in this section. Figure 14 shows five peaks corresponding to five natural frequencies. Figure 15 to 19 represents first five mode shapes obtained experimentally.

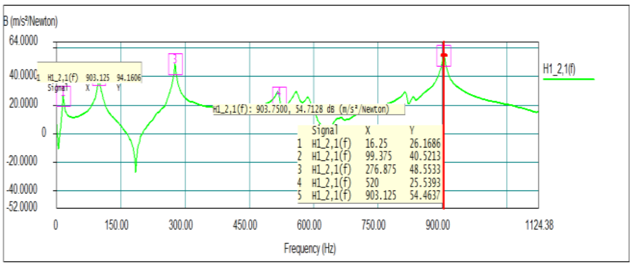

Fig 14 Peaks obtained for Cantilever Beam

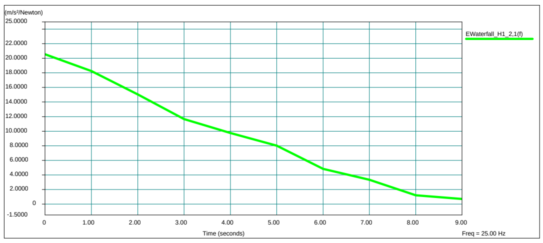

Fig 15 First mode shape for Cantilever Beam

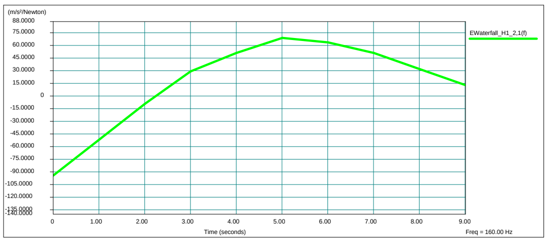

Fig 16 Second mode shape for Cantilever Beam

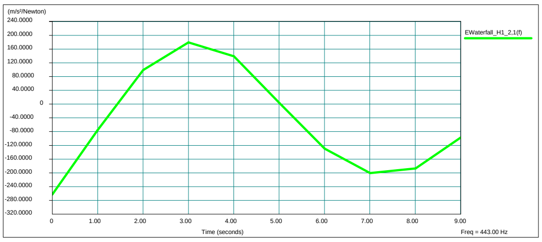

Fig 17 Third mode shape for Cantilever Beam

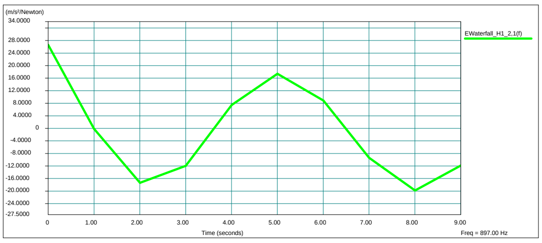

Fig 18 Fourth mode shape for Cantilever Beam

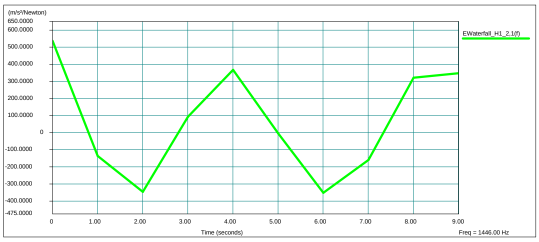

Fig 19 Fifth mode shape for Cantilever Beam

Similarly mode shapes and natural frequencies are found out for Simply Supported and Fixed beam. Natural frequencies obtained experimentally for different beam structures are given in Table 5.

Table 5 Natural Frequencies of beams by Experiment

Beam Type	Natural Frequencies				
	1	2	3	4	5
Cantilever	16	99.3	276	520	903
Simply Supported	57	217	366	758	1195
Fixed	84	238	546	911	1367

VI. RESULTS AND DISCUSSION

This chapter compares results obtained by simulation and experimental analysis with theoretical values. Percentage deviation of experimental and simulation values from theoretical value is calculated and listed in following two tables. Table 6 gives percentage deviation of simulation values from theoretical and table 7 gives percentage deviation of experimental values from theoretical values.

Table 6 % Deviation of Simulation and Theoretical values

Beam Type	Natural Frequencies				
	1	2	3	4	5
Cantilever	0.42	0.69	0.52	0.25	0.41
Simply Supported	5.59	5.64	5.71	5.68	5.78
Fixed	1.39	2.51	2.28	2.43	2.67

Table 7 % Deviation of Experimental and Theoretical values

Beam Type	Natural Frequencies				
	1	2	3	4	5
Cantilever	2.62	4.72	5.34	9.35	4.75
Simply Supported	15.37	9.05	18.40	4.89	4.18
Fixed	19.31	17.00	2.90	1.99	1.29

It is observed that maximum percentage deviation is 5.78 for theoretical analysis and simulation and that for theoretical and experimental results it is from 19.31. For experimental analysis larger deviation are observed.

VII. CONCLUSION

Based on theoretical, analytical & experimental results it is hereby concluded that:

- Results obtained by simulation are matching closely with theoretical values. The maximum percentage deviation is 5.78%.
- Results obtained by experimental analysis deviate more from theoretical analysis compared to simulation. The maximum percentage deviation is 19.13%.
- In experimental analysis of Simply Supported Beam and Fixed Beam some extra peaks are observed along with peaks corresponding to natural frequencies.
- Modes shapes obtained from simulation and experiment are in agreement with the theoretical ones.

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