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Vibration Analysis of Cantilever Beam

Mohamed Salman Mohamed Zakkaria[1], Nurhafizzah Hassan[1]*

[1] *Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, 86400 Johor, MALAYSIA*

*Corresponding Author: hafizzah@uthm.edu.my
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Abstract

Vibration analysis is an integral aspect of engineering, especially for structures like the cantilever beam, which have applications in mechanical, civil and aerospace engineering. Knowledge of their characteristics, like natural frequencies and mode shapes is quite important in ensuring the integrity of a structure and preventing failure by resonance. This project carries out a theoretical study on the vibration analysis of a cantilever beam with the help of LISA software-based finite element analysis. The objective is to determine the vibration frequencies and modes of the cantilever beam and evaluate the capability of FEA to provide proper and accurate results. This project starts off with an overview of the basic concepts involving mechanical vibration, assigning special emphasis on cantilever beams. Experiments are conducted to get the natural frequencies and mode shapes of the beam. The cantilever beam is then modelled in LISA software with the boundary conditions and material properties to simulate a real-life condition. Modal analysis is performed with the software to reproduce the vibration characteristics, including the first few natural frequencies and their respective mode shapes. The results of the experimental and FEA analysis are compared to validate the accuracy of the LISA software. The study shows that LISA predicts natural frequencies and mode shapes accurately, which match very well with the theoretical predictions. Besides, FEA visualization of mode shapes gives a much better insight into how the beam deforms when vibrating, something that is difficult to achieve with experimental methods alone. This study is important because it highlights the importance of vibration analysis in engineering and how a tool like LISA now can help to automate complex calculations while improving accuracy of the output.

1. Introduction

This project investigates the free vibration characteristics of cantilever beams, which are fundamental structural elements in applications ranging from bridges to aerospace systems [1]. Understanding the dynamic behaviour of these beams is a central subject in structural dynamics, as uncontrolled vibrations can significantly impact performance and safety [2]. The study recognizes that a beam's natural frequencies and mode shapes are governed by its material properties, geometric dimensions, and boundary conditions, with materials like aluminium and steel exhibiting distinct vibrational responses due to differences in stiffness and density. This research will employ a comprehensive dual methodology, combining physical experimental analysis with computational simulation using LISA software to provide a robust understanding of these dynamic behaviours [1].

The core problem this study addresses is the difficulty in accurately predicting the dynamic response of cantilever beams, a critical task for ensuring their stability and reliability in engineering applications [3]. While experimental methods provide valuable empirical data, they are often resource-intensive and limited in scope, while simulation tools like LISA, though efficient, are subject to inaccuracies if their input parameters and models are not properly validated against real-world performance [4]. To overcome these limitations, the project has three main objectives: first, to conduct an experimental analysis of the free vibration of cantilever beams made from aluminium and steel; second, to simulate their vibration characteristics using LISA software; and third, to compare the experimental and simulation results for validation. The scope is specifically focused on these two materials, with expected natural frequencies of 158- 194 Hz and 1306-3879 Hz respectively, and will utilize 2D plane and truss analysis in the simulation.

The significance of this research lies in its integrated approach, which bridges the critical gap between theoretical predictions and actual structural performance by using experimental data to validate computational models [5]. This provides a more accurate and reliable methodology for analysing structural dynamics, enabling engineers to optimize material selection and design to mitigate vibration-induced issues. The findings are of considerable importance to vibration-sensitive industries such as aerospace, automotive, and civil engineering, where structural integrity is paramount [6]. Ultimately, by enhancing the understanding of material behaviour under dynamic conditions, this project contributes to the development of more resilient and efficient structural designs for real-world applications [7][8].

1.1 Past Research Work

According to the previous studies done, the free vibration characteristics of cantilever beams are evaluated to show how different material, geometry, and structural integrity affect the beams behaviour. Materials like steel and aluminium display different natural frequencies and experimental results are greater than theoretical results showing some errors. Natural frequency is affected by the changes in the beam's geometry such length or thickness. Thicker and shorter beams show higher frequencies. Simulation method is validated by using tools such as ANSYS, which show closer consistency with theoretical data. Furthermore, composite beams with polymer adhesive have different responses compared to plain beams. Defects like crack lower the natural frequency as their depth increases. The result shows how important accurate modelling and material selection are to efficiency of the cantilever beam in engineering uses.

1.2 Past Research Table

Table 2 *Past Research Table*

Author & Year	Title	Method	Results		Conclusion
			Mode	ω	
J.P. Chopade, R.B. Barjibhe, (2013) [26]	Free Vibration Analysis of Fixed Free Beam with Theoretical and Numerical Approach Method	ANSYS	1	16.450	The numerical study using the ANSYS program allows investigates the free vibration of fixed free beam to find out mode shape and their frequencies with high accuracy. Therefore, it can be concluded that theoretical data is in good agreement with numerical results with negligible error.
			2	103.08	
			3	288.64	
			4	565.87	
			5	936.55	

kPragnesh K. Chaudhari, Dipal Patel, Vipul Patel, (2014) [27]	Theoretical and Software Based Comparison of Cantilever Beam: MODAL ANALYSIS	MODAL ANALYSIS	Mode	Aluminium	Mild Steel	The modal testing has effective and non-destructive test method for estimating of characteristic of beam. The natural frequency of both the beam is increase with increase in the modulus of elasticity and by decreasing the density of the material. It is observed that natural frequency is higher for aluminium than mild steel material beam of same geometry
			1	2.9002	2.898	
			2	18.175	18.161	
			3	50.886	50.846	

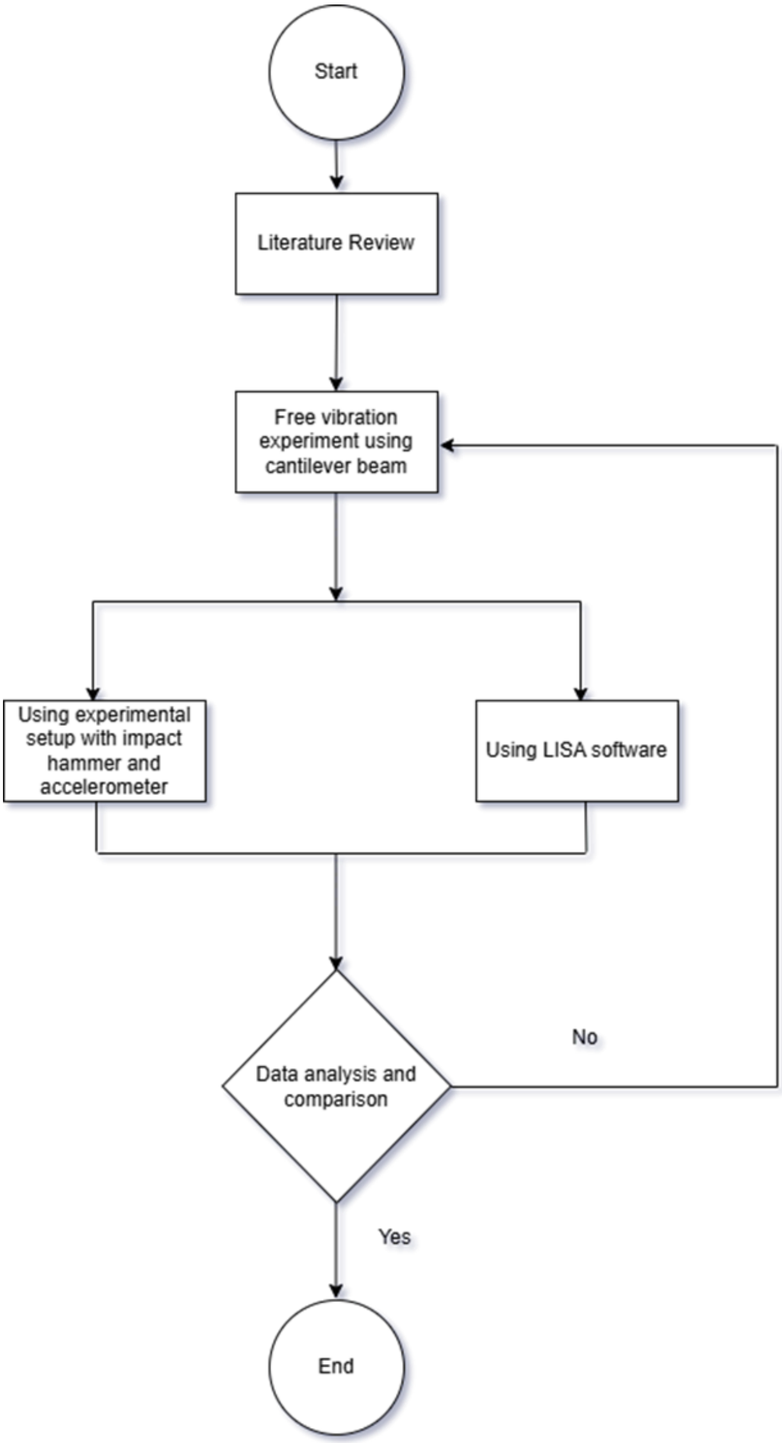
2. Methodology

This project's methodology combines simulation and experimentation to examine the free vibration behaviour of fixed-free cantilever beams composed of various materials. Cantilever beams are first made with uniform dimensions to guarantee consistency, and materials like steel, aluminium, and alloys are chosen for their unique mechanical qualities. An impact hammer or vibration exciter is used to create free vibrations in a vibration testing setup during the experimental phase. With the use of sensors like laser vibrometers or accelerometers, vibrational data including natural frequencies and mode shapes is collected.

Finite element models of the beams are made in LISA software for the simulation stage. The software is programmed with material parameters including density, Poisson's ratio, and Young's modulus in addition to the geometry of the beam. The simulation model is validated by comparing the natural frequencies and mode shapes, which are determined by free vibration analysis, with experimental findings. To increase the accuracy of the model, differences between the simulation and experimental data are examined. Insights into material selection for vibration-sensitive applications are finally provided by the evaluation of the impact of various material qualities on the vibration characteristics. The results are recorded to demonstrate how well vibration analysis may be achieved by combining simulation and experimental techniques.

2.1 Methodology Flow Chart

In order to properly understand the field of research on the free vibration analysis of cantilever beams, the method begins with a thorough literature survey. A free vibration experiment is then carried out using both a simulation and an experimental setup. An impact hammer and an accelerometer are used in the experimental setup to measure the vibration characteristics, while LISA software is used in the simulation to computationally analyse the beam's vibrational characteristics. The correctness and inconsistencies are then checked by comparing and analysing the results from the two approaches. The investigation is then finished when conclusions are drawn from the data.


Start
Literature Review
Free vibration experiment using cantilever beam
Using experimental setup with impact hammer and accelerometer
Using LISA software
Data analysis and comparison
No
Yes
End

2.2 Apparatus/Instrument

Table 2 *List of apparatus*

NO	Apparatus/Instrument	Function
1	Impact Hammer	To deliver a controlled impact force to the beam during free vibration testing.
2	Data Acquisition System	To collect, measure, and store data from accelerometer that can be analysed by the computer.
3	Laptop with the Dewesoft Software	To record, analyse, and visualise data.
4	Accelerometer	To measure the vibration of the beam.
5	Cantilever Beam Testing Rig	A support system that allows us to rig the cantilever beam to be tested on.

2.3 Experimental Procedure

An experiment for free vibration will be conducted to determine the natural frequency and mode shape of the cantilever beam. The list of procedures has been listed below.

I. The 60 cm beam is divided into 4 nodes, which means each element is 20 cm long.
II. Then the accelerometer is fixed at node 1 which is the free end of the beam.
III. The accelerometer is plugged in to the data acquisition system.
IV. The impact hammer is plugged in to the data acquisition system.
V. The data acquisition system is connected to the laptop with the dewesoft software.
VI. The dewesoft software is opened to perform the free vibration test.
VII. Knock consistently on all the nodes using the impact hammer.
VIII. After the data is stored in the modal testing tab, go to the modal analysis tab to analyse the natural frequency and mode shape of the beam.
IX. Finally save the data in file format.

3. RESULT AND FINDING

3.1 Introduction

This chapter shows the findings and results of the study conducted on free vibration characteristics of cantilever beams fixed-free of two materials which are mild steel and aluminium. It is in this chapter that the natural frequencies and the mode shapes are described having been tested experimentally, as well as simulated using LISA software. Experimental conditions consisted of free vibration excitation by an impact hammer and the corresponding data of the response was measured by accelerometer. This was done to present the effect of material attributes such as density, young modulus and Poisson ratio.

The joint comparison of the experimental and simulation methods is important to a more refined knowledge in the behaviour of cantilever beams under free vibration in assisting in better design decisions in applications that are sensitive to vibration.

3.2 Experimental Results

3.2.1 Mild Steel Beam

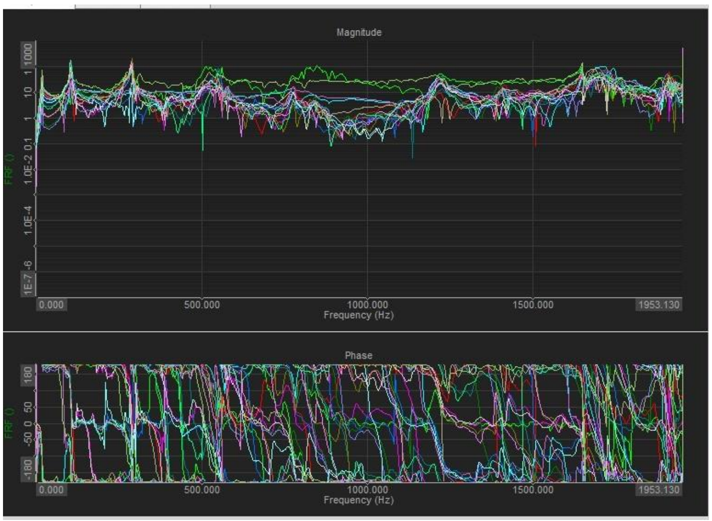


Fig. 1 *Frequency Response Function (FRF) Graph for mild steel beam.*

Table 3 *Free vibration test result for mild steel beam.*

Mode	Frequency, Hz
1	104.98
2	290.53
3	512.70
4	1220.70
5	1650.39

From the Frequency Response Function (FRF) graph in Fig 1, 5 modes were selected by picking the peaks. The fundamental frequency in the first mode is 104.98 Hz, where the vibration amplitude reaches its highest magnitude; this mode is usually the most serious in design as it is most likely to be excited. The second mode is at a higher frequency of 290.53Hz with one more nodal point, while the third, fourth, and fifth modes are at frequencies of 512.70Hz, 1220.70Hz, and 1650.39Hz respectively. As expected, the natural frequency increases in a non-linear manner with the mode number, and these higher order modes reveal more nodal lines. The material, mild steel, with its high stiffness and density, results in these specific frequency values. Such test data are important for characterizing simulation models and providing a baseline, helping engineers design systems that can operate safely away from these influential frequencies to avoid fatigue, noise, and failure of the structure.

3.2.2 Aluminium Beam

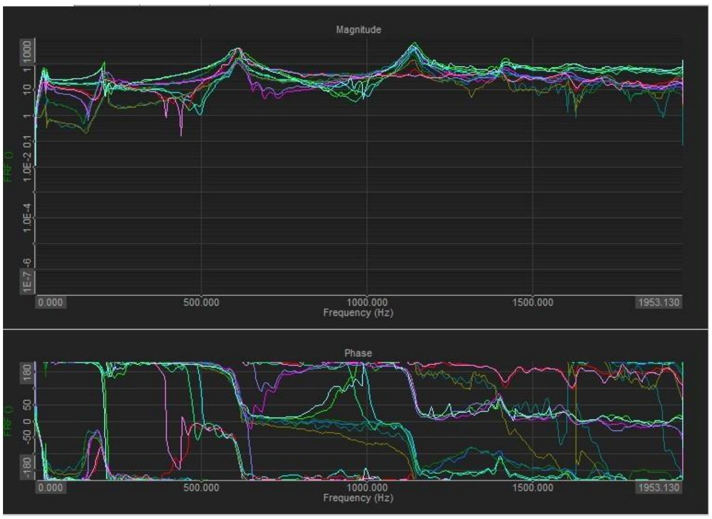


Fig 2 *Frequency Response Function (FRF) Graph for aluminium beam.*

Table 4 *Free vibration test result for aluminium beam.*

Mode	Frequency, Hz
1	24.41
2	209.96
3	610.35
4	1142.58
5	1418.48

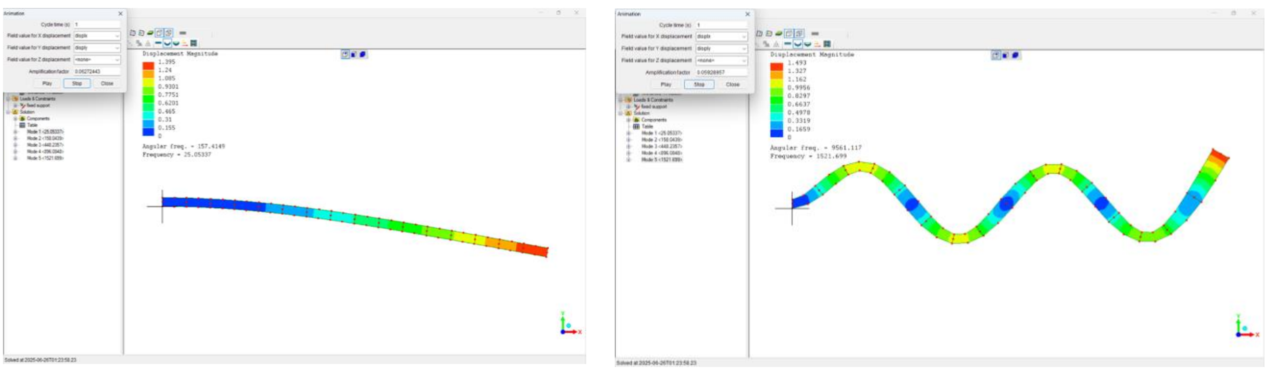
From the Frequency Response Function (FRF) graph in Fig 2, 5 modes were selected by picking the peaks, with the frequency results shown in table 4.2. The fundamental frequency of the aluminium beam is 24.41 Hz for the first mode, which represents the maximum vibration amplitude and is generally the most important for dynamic behaviour. The second mode, with a frequency of 209.96 Hz, has an extra nodal point and a more complicated deformation. The natural frequency is higher as the mode number increases, with the third, fourth, and fifth modes at 610.35 Hz, 1142.58 Hz, and 1418.48 Hz respectively. The main reason the aluminium beam has a lower fundamental frequency than materials like mild steel is that it is less stiff and lighter. This lower stiffness, despite its attractive lightweight feature, gives aluminium a low natural frequency, increasing the possibility of resonance if inadequately designed. The measured data is necessary to correct finite element results and to ensure aluminium beams operate away from these resonance regions to avoid fatigue, vibration damage, and a reduction in performance.

3.3 Simulation Results

3.3.1 Mild Steel Beam

Table 5 *Simulation test results for mild steel beam.*

Mode	Frequency, Hz
1	25.05
2	158.04
3	448.24
4	896.08
5	1521.70



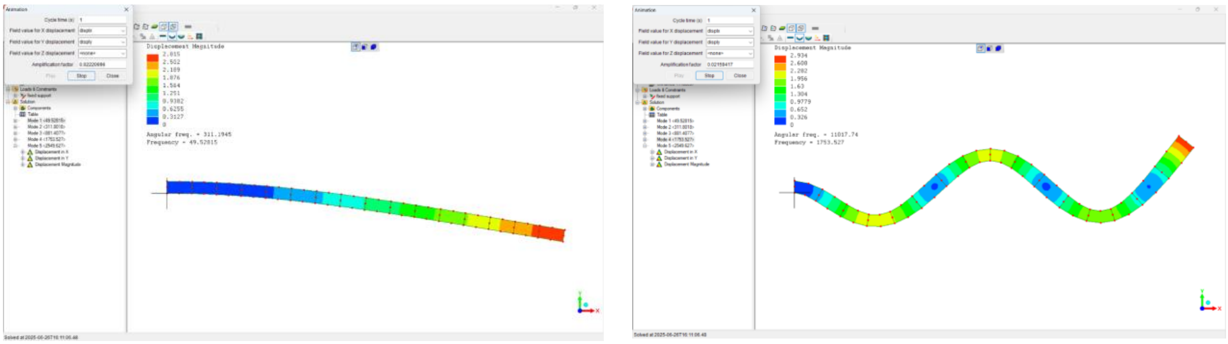
(a) (b)

Fig 3 *(a) First mode shape of mild steel beam at 25.05 Hz (b) Fifth mode shape of mild steel beam at 1521.70 Hz*

3.3.2 Aluminium Beam

Table 6 *Simulation test results for aluminium beam*

Mode	Frequency, Hz
1	49.52
2	311.80
3	881.41
4	1753.53
5	2549.63



(a) (b)

Fig 4 *(a) First mode shape of aluminium beam at 49.52 Hz (b) Fourth mode shape of aluminium at 1753.53 Hz.*

3.4 Comparison of Vibration Analysis

The results tables for the mild steel and aluminium cantilever beams compare the natural frequencies from experiments and simulation. This comparison is meant to validate the simulation model and see how well it can predict real-world behaviour. In the case of mild steel, the experimental natural frequencies were higher than the simulated ones in the first 4 modes, but they matched well at the fifth mode. For example, the first mode was 104.98 Hz (experimental) versus 25.05 Hz (simulation). In the case of the aluminium beam, the trend was opposite, with the simulation result giving a higher frequency (49.52 Hz) compared to the experimental one (24.41 Hz). As the mode order increased, the simulation results were always greater than the experiment (2nd mode: 209.96 Hz (experiment) vs. 311.80 Hz (simulation).

These differences are likely due to modelling assumptions and real-world imperfections. For mild steel, the large difference in low modes may be because of boundary condition assumptions, as the actual clamping may be stiffer than in the model. For aluminium, the simulation likely presumes ideal boundary conditions and material homogeneity, ignoring damping and minor flaws, which makes the simulated beam seem stiffer than it is. The results indicate that both methods give the same mode sequence but may not agree on the exact values. These differences show the significance of comparing simulation models to experimental data and manipulating parameters like boundary conditions, mesh refinement, and material properties to increase the accuracy of predicting realistic structural vibrations.

4. Conclusion

This project managed to study the free vibration of fixed-free cantilever beams constructed with mild steel and aluminium materials both experimentally and by simulation. The mode shapes and natural frequencies of each material were found by impact hammer testing and using accelerometers, and the experiment was accompanied by simulation run with the LISA software to complete the view on the case. Though certain differences were noted between the simulated and experimental results, especially due to idealized boundary conditions and material assumptions in the simulation, some results were found to be similar. The paper has emphasised the importance of material properties, like stiffness and density, in contributing to the vibrational behaviour, whereby aluminium presents lower fundamental frequencies as compared to mild steel because of its reduced stiffness. Conducting an experimental study enables one to understand dynamic behaviour in engineering structures, and complementing this with simulation ensures a more detailed understanding. The two methods make design and testing more accurate, confirm theoretical models, and offer more resilient structural designs.

It was also found that accurate modelling is necessary, correct boundary conditions should be represented, and the effects of things that occur in the real world such as damping and sensor effects should be considered. In conclusion, this study provides useful input for designing and optimising vibration-sensitive parts and opens future research opportunities for more complicated materials and shapes.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

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