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ANSYS based Modal Analysis of a Fixed Beam of Uniform Cross Section with a Concentrated Mass at Mid Span

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ABSTRACT– The report outlines ANSYS based modal and structural analysis of a fixed beam of dimension 20mm*20mm*1000mm that was constructed in SOLIDWORKS. Structural steel was selected as the material for analysis. The analysis was done in 3 phases, the first analysis was done without any crack and the other two analysis involved cracked beams with cracks created at different lengths. Suitable boundary and loading conditions were used to find the modes of frequencies. The resulting variation in static deflection, position of mode shapes representing transverse deflection and variation in position of equivalent stress corresponding to varying beam conditions with and without cracks are studied.

KEYWORDS: Modal analysis, Meshing of cracks, Stationary nodes, Variation of mode shapes

1. Introduction

Beams are known as continuous systems and the beams by themselves will normally have an infinite number of kinematically independent particles, but when the beam is connected to a spring or any other material which separates the displacement of beam from the load then it is known as discrete continuous system, which then have finite number of degrees of freedom.

Understanding both natural frequency and mode shape, helps to design structural system for noise and vibration application (P. S., Walunj, 2015). The early studying of natural frequencies and associated mode shapes for different geometric parameters and different boundary conditions is considered an integral approach that has received great attention in industrial applications to prevent catastrophic failure in machines (E. H., Flaieh, et al., 2021).

When there are disturbances created in the system through different mediums (i.e., forces, load) etc., the systems vibrate at different frequencies. A mode shape describes the deformation that the component would show when vibrating at the natural frequency (Dlubal Software, 2022). The study of the dynamic property system in these frequency domains is called modal analysis (He J., 2001). The Numerical modal analysis method using the Finite element modeling software ANSYS enables engineers to get a better understanding of dynamic properties of structures (L. Zhang et al., 2005).

Three different modes shapes conforming to the transverse deflection of beam were studied in this project. Our problem statement is explained in the figure 1 below:

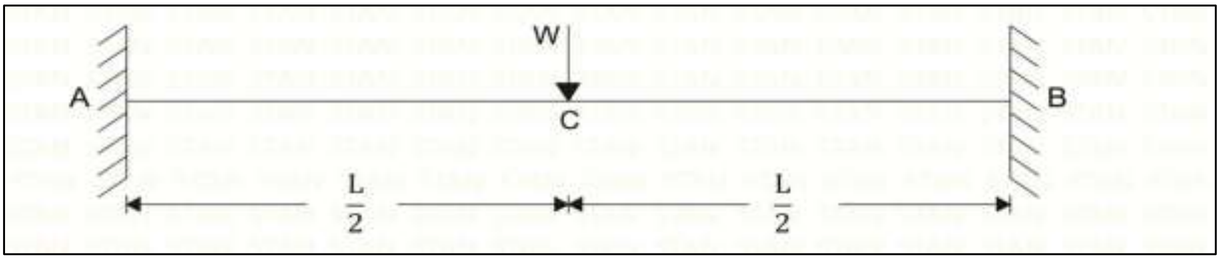

Figure 1. Illustration of fixed beam considered for the problem

The system under study is an undamped system with free response and it has single degree of freedom. The details of loading and crack conditions for different conditions of beam are are:

Case 1:

W = 200 N

No cracks present.

Case 2:

W=200 N

Crack 1 = 0.15 L from fixed end B

Case 3:

W = 200 N

Crack 2 = 0.35 L from fixed end B

2. Process and Methodology

Structural analysis was done in ANSYS. Then, setup for structural analysis was done. Material properties was set to that of structural steel (1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1).

ANSYS is a widely accepted software for engineering simulations and design. Therefore, ANSYS was used as the simulation software. Similarly, as structural steel was selected because it is one of the most common construction materials and the code for the structural steel was readily available in ANSYS.

2.1 Modelling of the beam geometry

The beams were modelled in SOLIDWORKS. The geometric specification of all the beam 1000mm*20mm*20mm (l*b*h) is shown in figure 2. They were exported in step format for use in ANSYS software. Rectangular notch cut throughout the width

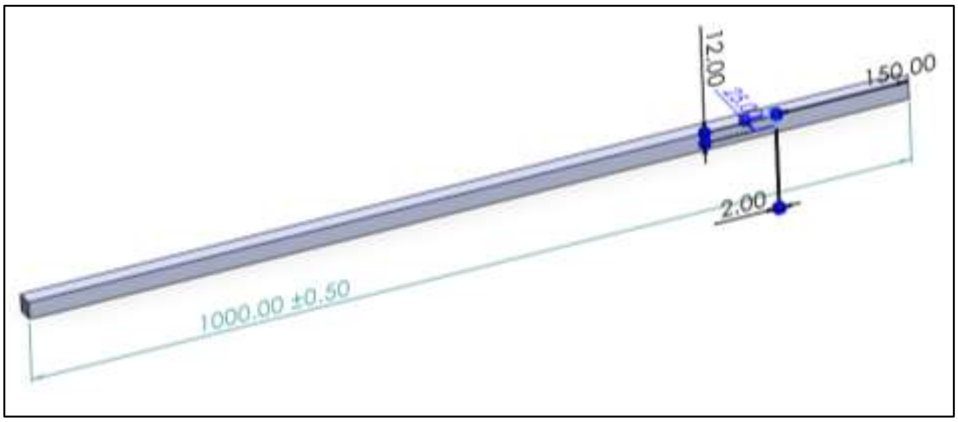

Figure 2. Geometry of the beam with crack at 150mm from fixed end

was used to represent the cracks as shown in figure 3.

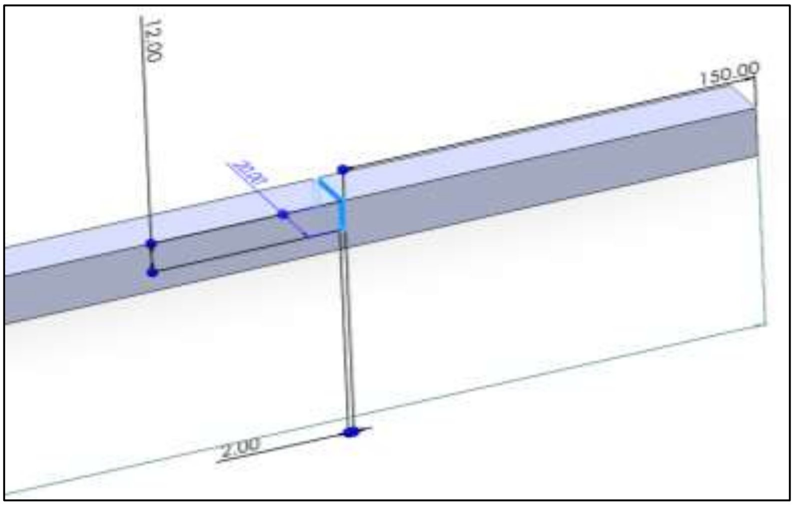

Figure 3. Zoomed image of the beam with crack at 150mm from fixed end

Further modifications on the geometry were done using ANSYS Spaceclaim. The top face of the beam was split into two and load was applied to the edge that emerged at the middle of the faces.

2.2 Material properties

Properties of the structural steel (1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1) was selected for analysis. The relevant details of material properties have been presented in figure 4.

2.3 Mesh Generation

Multiple variation of notches to represent cracks were tested. Regardless, rectangular notch cut throughout the width provided better control during meshing process and provided more precise conclusive results during analysis. The use of rectangular notch provided creation of structured quadrilateral mesh and better captured the effect of crack presence while other shape of notches could only be captured using unstructured triangular meshes. So rectangular notch was selected to increase the extent of accuracy in results.

Different meshing condition were employed differing among the cases with and without cracks. The non-cracked beam was meshed using quadrilateral structured mesh of size 10mm. Beams with crack had mesh size of 3mm. Also, to better capture the crack geometry additional meshing feature like adaptive sizing with resolution of 6 was selected for the cracked beams. Figure 5 and 6 show the resulting mesh for cracked beam after aforementioned mesh settings were applied.

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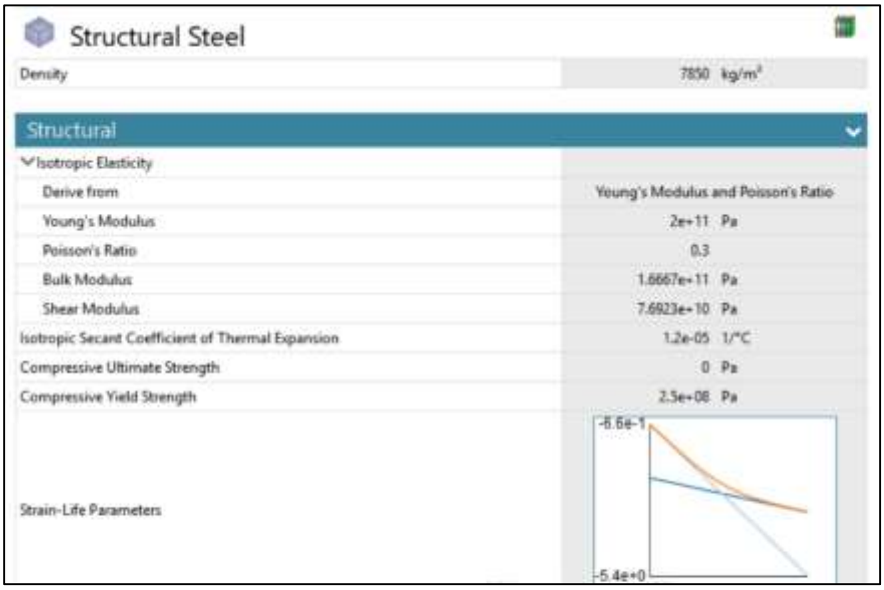

Figure 4. Material properties

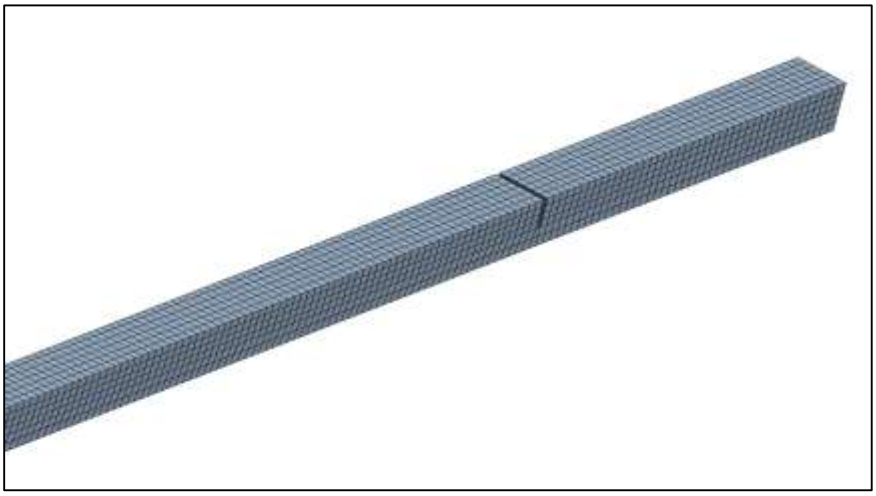

Figure 5. Meshing details of the beam with crack at 150mm

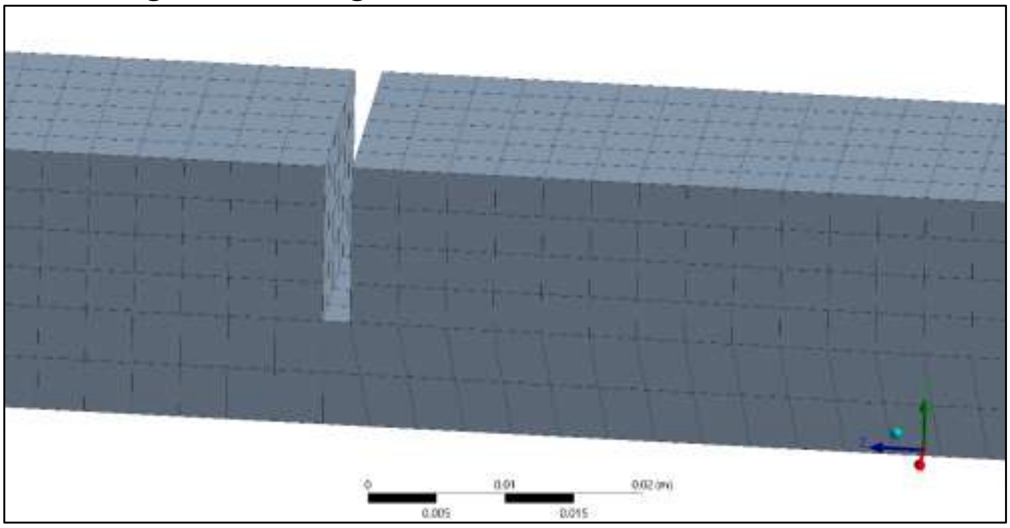

Figure 6. Zoomed view of meshing details for the beam with crack at 150mm

2.4 Boundary Conditions and Loading Conditions

Fixed support was applied to the fixed ends of the beam. Load of 200N was applied at the edge created at the middle of the top faces i.e., at the midpoint of beam in negative y direction as shown in figure 7. (At x=0 and x=l: $w_x = 0$ // $w_y = 0$ // w_z // dw/dx=0 // dw/dy =0 // dw/dz=0).

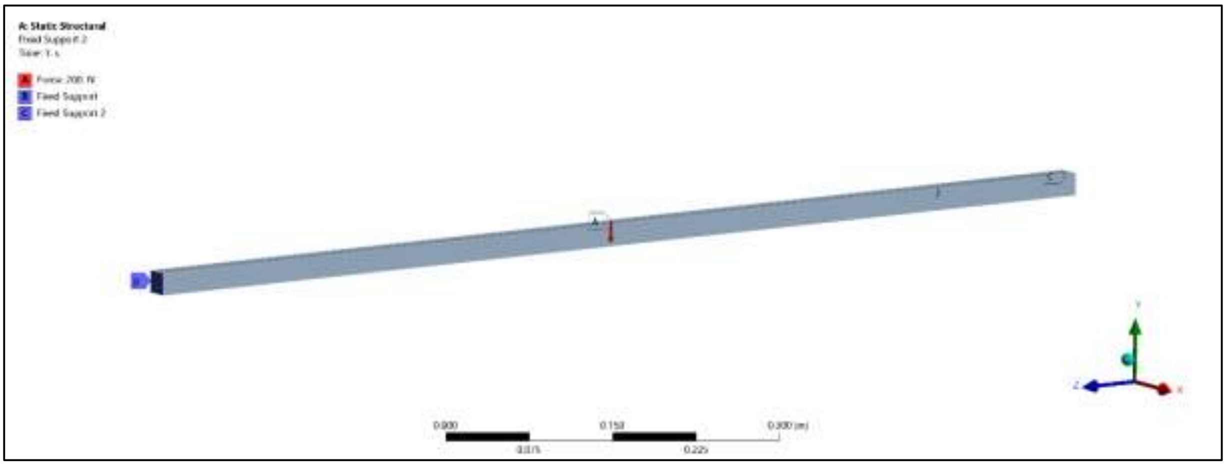

Figure 7. Loading condition for the beam with crack at 150mm

2.5 Structural and Modal analysis

Firstly, simulation was run to obtain solution for the structural analysis. The solution obtained for non-cracked and cracked beams in the structural analysis were used to analyze six number of modes in modal analysis in ANSYS software. Damping condition was set to undamped as shown in figure 8.

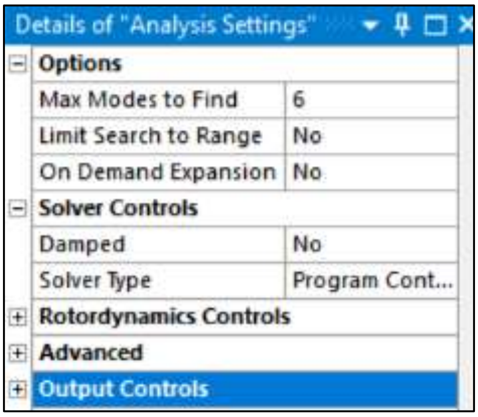

Figure 8. Details of Modal analysis for the beam with crack at 150mm

3. Results and Discussion

3.1 Fixed beam with concentrated central load with no crack:

3.1.1 Structural analysis

The static deflection resulting from the loading and boundary condition was observed to be 0.39105 mm for the beam with no cracks as seen in figure 9.

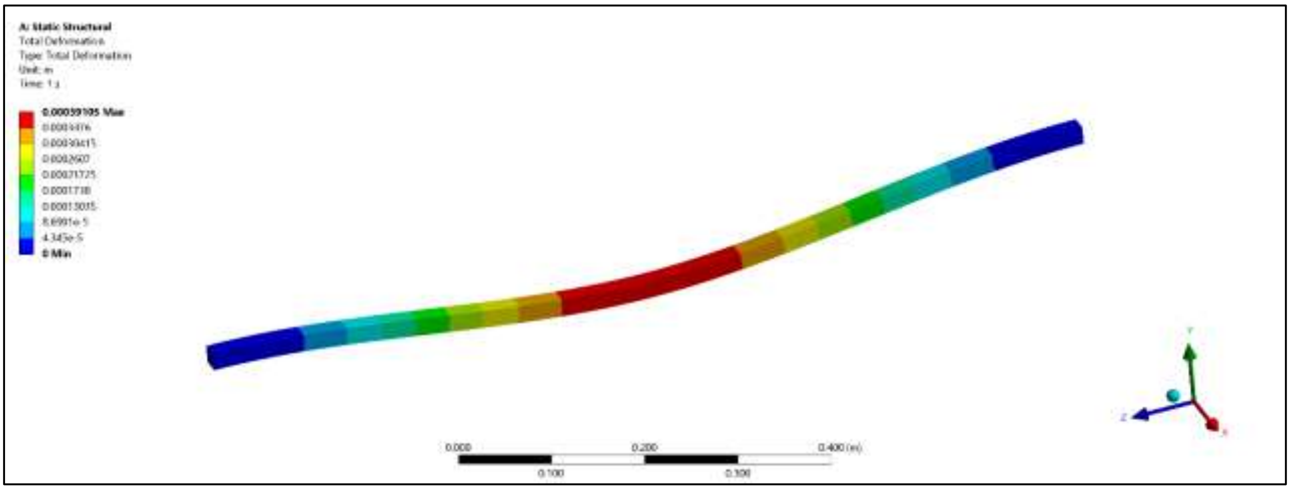

Figure 9. Total static deflection for beam with no crack (Static Structural)

3.1.2 Modal analysis

The result of the structural analysis was used in modal analysis system and following mode shapes representing the transverse deflections were obtained.

The first mode shape resulting from the modal analysis is shown in figure 10. It represents transverse deflection and is located at 103.78 Hz frequency. There are two stationary nodes present in this mode shape located at ends of the beam. The regions displayed in blue color indicate the location of stationary nodes.

The fourth mode shape resulting from the

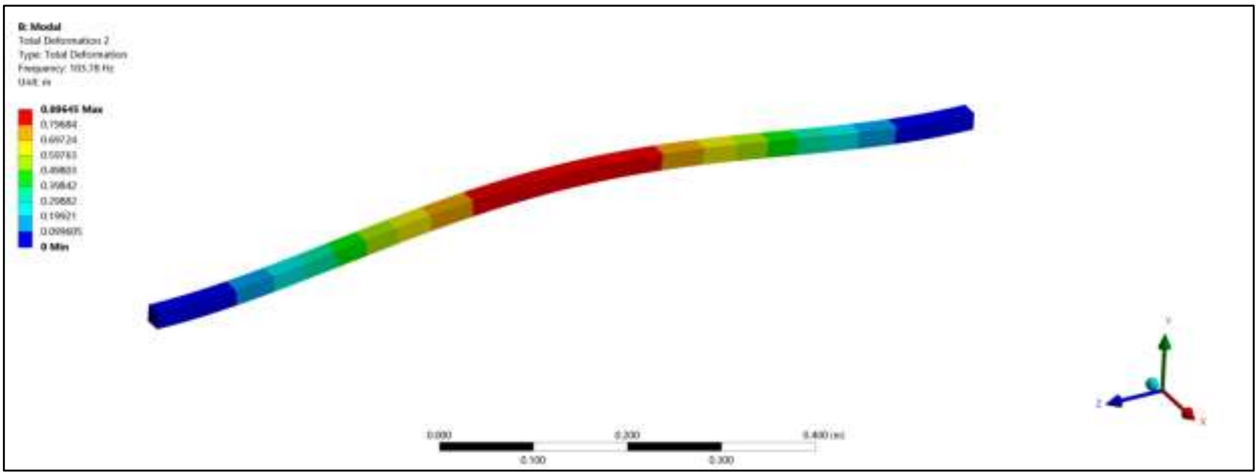

Figure 10. First mode shape for beam with no crack (transverse)

modal analysis is shown in figure 11. It represents transverse deflection and is located at 285 Hz frequency. There are three stationary nodes present in this mode shape; one node in located at the middle and other two are located at each end of the beam. The sixth mode shape resulting from the modal analysis is shown in figure 12. It represents transverse deflection and is located at 556.11 Hz frequency. There are four stationary nodes present in this mode shape indicated by regions with blue color.

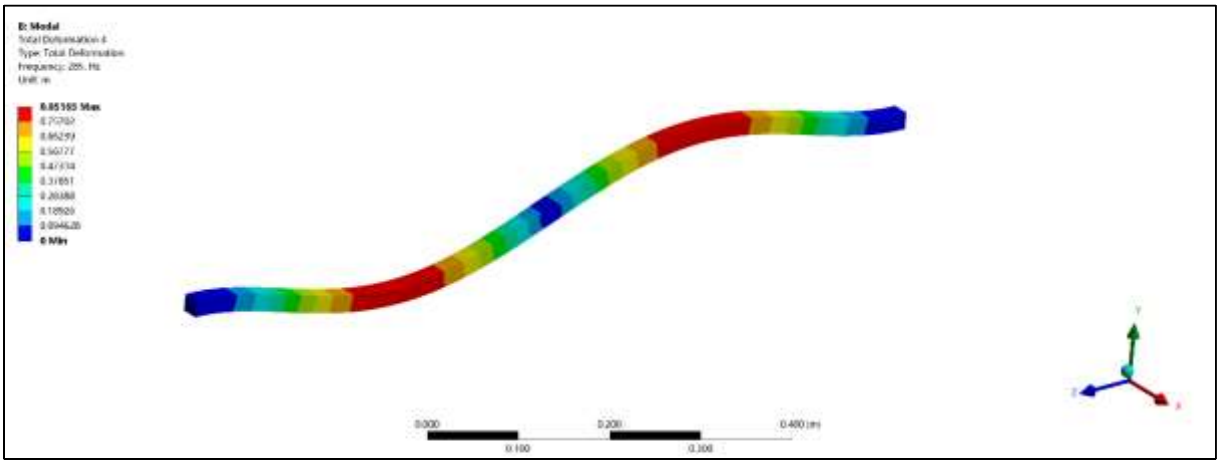

Figure 11. **Fourth mode shape for beam with no crack (transverse)**

3.2 Fixed beam with concentrated central load and crack at 0.15L i.e., 150mm:

3.2.1 Structural analysis

The static deflection resulting from the loading and boundary condition was observed to be 0.40924 mm for the beam with no cracks as seen in figure 13.

3.2.2 Modal analysis

The result of the structural analysis was used in modal analysis system and following mode shapes representing the transverse deflections were obtained.

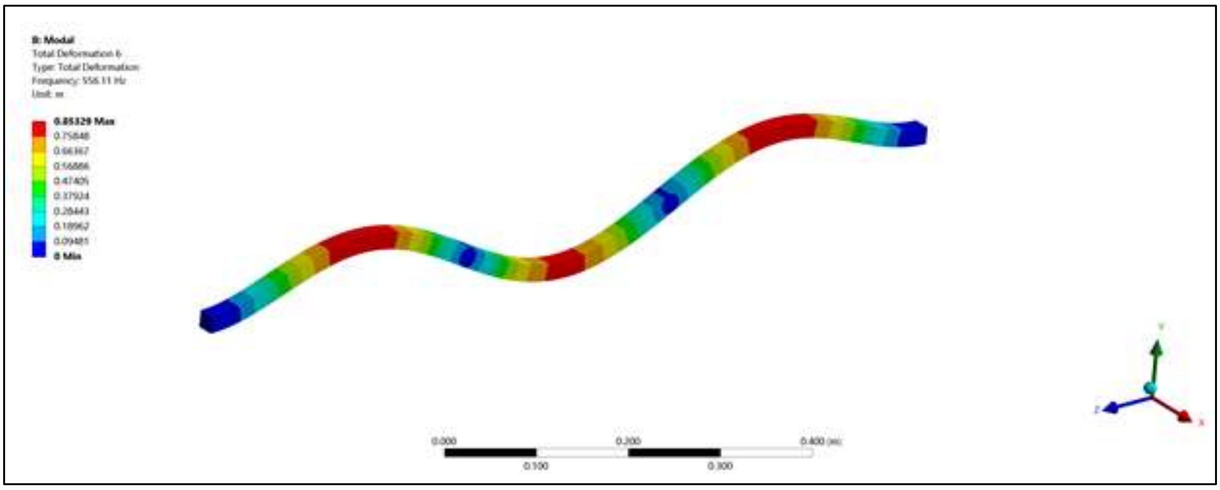

Figure 12. Sixth mode shape for beam with no crack (transverse)

The first mode shape resulting from the modal analysis is shown in figure 14. It represents transverse deflection and is located at 101.74 Hz frequency. There are two stationary nodes present in this mode shape located at ends of the beam. The regions displayed in blue color indicate the location of stationary nodes.

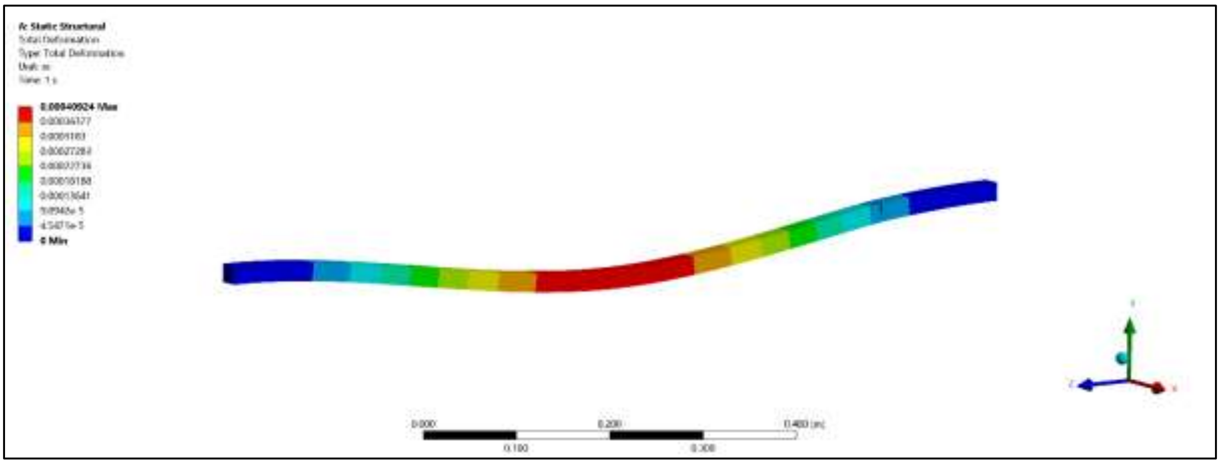

Figure 13. Static deflection for the beam with crack at 150mm (static structural)

The third mode shape resulting from the modal analysis is shown in figure 15. It represents transverse deflection and is located at 284.11 Hz frequency. There are three stationary nodes present in this mode shape. One node in located at the middle and other two are located at each end of the beam. The fifth mode shape resulting from the modal analysis is shown in figure 16. It represents transverse deflection and is located at 535.04 Hz frequency. There are four stationary nodes present in this mode shape indicated by regions with blue color.

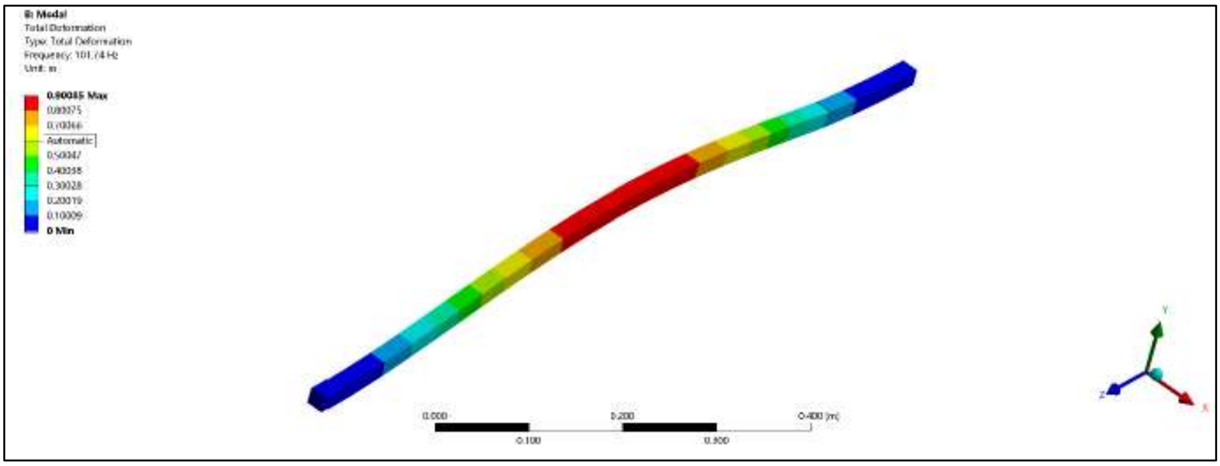

Figure 14. First mode shape for beam with no crack (transverse)

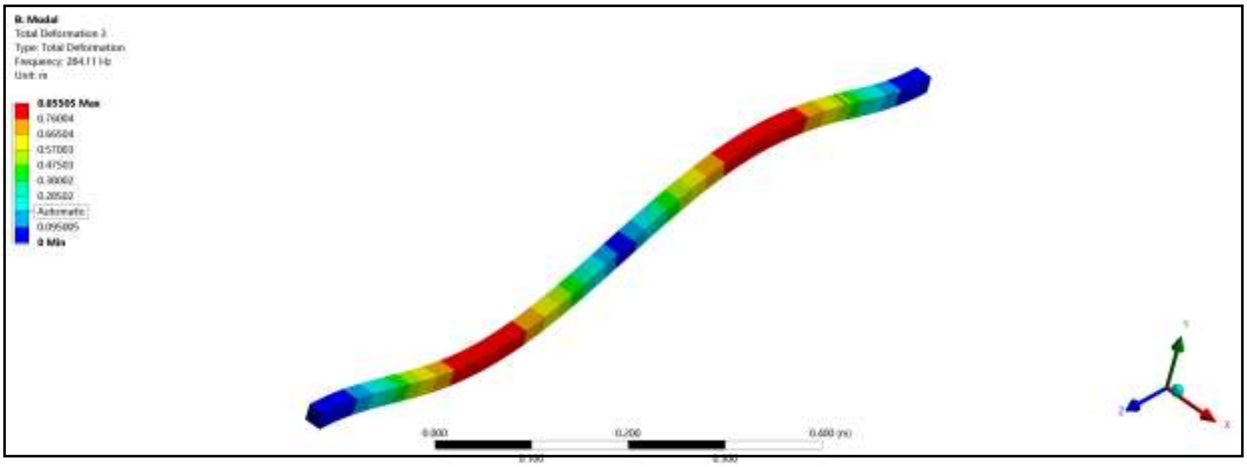

Figure 15. Third mode shape for beam with no crack (transverse)

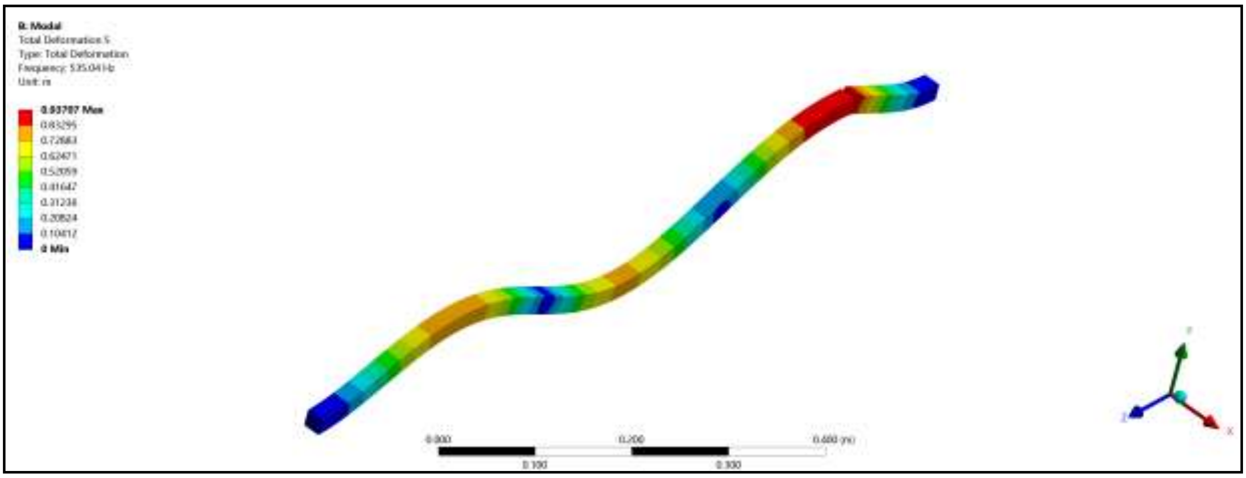

Figure 16. Fifth mode shape for beam with no crack (transverse)

It was observed that the increase in order of mode shapes corresponded to increase in number of stationary nodes as seen in the resulting contours representing mode shapes for various cases of beam conditions. Similar steps were repeated for the third case i.e., Fixed beam with concentrated central load and crack at 0.35L i.e., 350mm and the resulting values of frequencies of mode shapes representing transverse deflection have been tabulated in table 1. Unlike the beam with no crack, first case of transverse deflection was observed in first mode for cracked beam. Similarly, the consecutive order of some other higher mode shapes representing transverse deflection also varied among different beam conditions.

Table 1.Values of natural frequencies of mode shapes representing transverse deflection for various beam conditions.

Crack condition	1st Mode of frequency	2nd Mode of frequency	3rd Mode of frequency	4th Mode of frequency	5th Mode of frequency	6th Mode of frequency

No crack		103.78		285		556.11
Crack at 0.15L	101.74		284.11		535.04	
Crack at 0.35L	100.37		265.5			555.49

Static deflection deduced from the structural analysis for varying beam conditions have been tabulated in table 2 below. The value is observed to increase gradually as we move from beam with no crack to beam with cracks at different position. This is because the stiffness of the beam decreased when the when the position of the crack was moved towards the center of the beam and change in the stiffness in vibratory system will have an effect on the natural frequency

Table 2. Value of static deflection for various beam condition.

Crack condition	**Static deflection(mm)**
No crack	0.39105
Crack at 0.15L	0.40924
Crack at 0.35L	0.41236

The values of frequencies representing modes shape are seen to decrease to lower values by the introduction of cracks in the beam. The first transverse deflection is value reduced for beam with crack at 0.15L compared to beam with no crack, but the value of frequency increases for beam with crack at 0.35L in comparison to crack at 0.15L. For other cases of mode shapes representing transverse deflection there is gradual decrease in value of frequency as we vary the beam conditions depicted by the horizontal axis of figure 17.

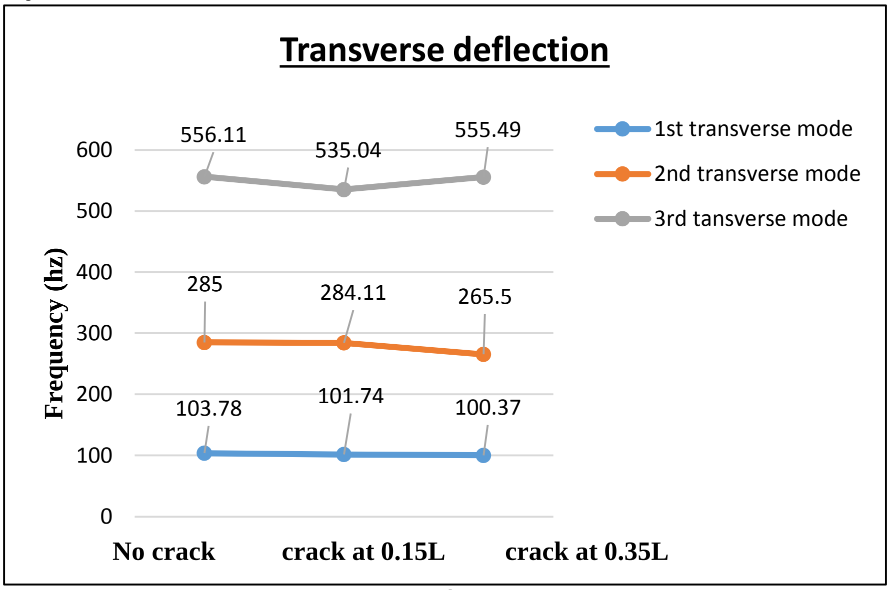

Figure 17. Graphical representation of modes shape representing transverse deflection of various beam conditions

The graphical representation of the variation of static deflection has been presented in figure 18. The value of deflection is seen to increase for beam with crack at 0.15L by 4.65 percent compared to beam with beam with no crack. Then for the change in crack position to 0.35L there is comparatively small increase of 0.762 percent in static deflection.

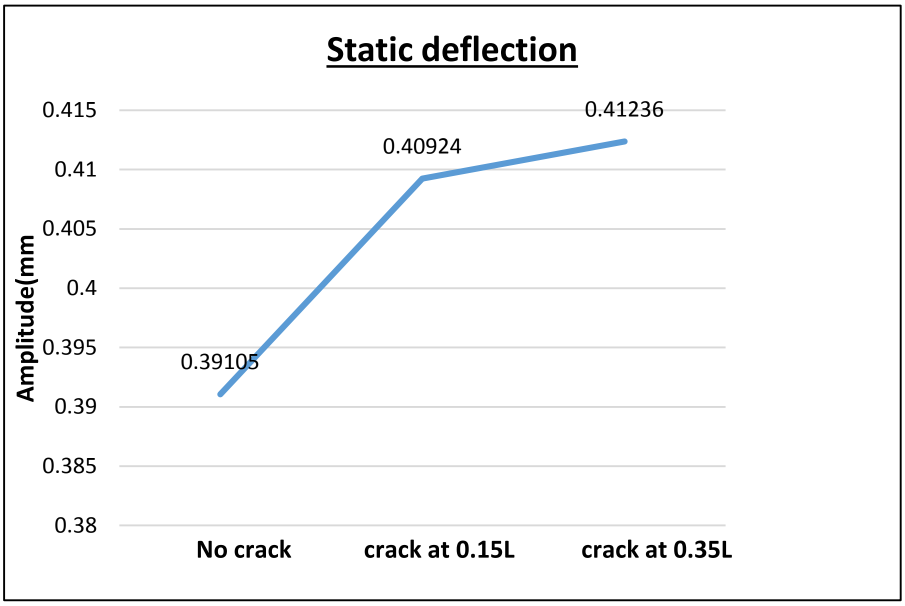

Figure 18. Graphical representation for static deflection of various beam conditions

4. Conclusion

In conclusion, the research findings reveal significant insights into the behavior of cracked beams. The natural frequencies exhibited a notable reduction as cracks were introduced, leading to a decrease in mode shape values. Moreover, the variations in natural frequencies were observed in relation to the crack's distance from the fixed end towards the beam's center. The static deflection showed a 4.65 percent increase for a beam with a crack at 0.15L compared to a crack-free beam, and within the cracked beams, the highest deflection was found at a crack location of 0.35L, surpassing that at 0.15L by 0.762 percent. Furthermore, the equivalent (Von-misses) stress experienced a 38.37 percent increase with a crack at 0.15L compared to a crack-free beam, and among the cracked beams, the stress was 14.94 percent higher at a crack location of 0.35L compared to 0.15L. The study suggests that crack detection in beams can be based on their resulting natural frequencies.

As recommendations, further exploration of analytical methods to assess the impact of temperature variation is proposed, along with the encouragement for correlation and verification of simulations through experimental validation.

6. Acknowledgement

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7. References

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