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Original Research Article

Vibration Analysis of Cracked Cantilever Beam with Varying Crack Length

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Abstract

Engineering structures such as plates, beams, and shells are subjected to different types of loads when used in applications such as bridges, buildings, and other structures. Due to the nature of loading cracks are produced in these elements over a period of time. These cracks will cause the failure of beams due to vibration. Vibration analysis is important to find the natural frequency of the structures. Modal analysis is performed to find the mode shapes and natural frequency of the cantilever beam. In the present investigation, a cantilever beam with crack is modeled and natural frequency for the first three modes is determined by using Ansys Workbench 19.2. The goal of the study is to change the length of the crack along the width of the beam and its effect on the natural frequency of the cantilever beam. During the study, the crack width is kept constant while the depth of crack is varied along with a change in the length of the crack. The crack with depth 45 mm and crack of length 50 mm gives a lower value of natural frequency.

Keywords: Beam; crack; depth; frequency; mode.

INTRODUCTION

Modal analysis is the process of finding out the dynamic characteristics of a system in terms of natural frequencies, damping factors, and mode shapes, etc. For a cracked structure like beam modal analysis is important to find out the effect of cracks on natural frequencies. The cantilever beam is one of the widely used structural elements. This beam is subjected to cracks or internal voids due to material irregularity causing failure of the beam. Different types of cracks are discussed by M. Kiran Kumar *et al.*, [1] this study highlights the area of structural discontinuity and its effect on the structural member. Md. Shumon Miaa *et al.*, [2] investigated mode shapes of the uncracked and cracked cantilever beam to find out mode shape. Abaqus has been used as a finite element package with different mesh sizes. Effect of crack depth and crack opening size on natural frequency has been studied and concluded that the natural frequency reduces with the crack. Priyanka P. Gangurde *et al.*, [3] had studied vibration characteristics of a cantilever beam, simply supported beam with different materials. They have a modelled beam with a triangular crack at a distance of 100 to 250 mm resulting that natural frequency reduces with the increment in crack depth. Vaibhav Ghodge *et al.*, [4] modelled vibration analysis of cantilever beam with mass at free and simply supported beam with mass at the center. A comparative study is made of four different materials. The study with the unloaded condition and loaded condition revels that the natural frequency increases for structural steel rather than the other three materials. Dr. K. B. Waghulde *et al.*, [5] performed an experimental investigation of cracked aluminum cantilever beam resulting that when crack depth has increased the frequencies of vibration of cracked beams decrease for any part of the beam due to reduction in the stiffness of the beam. The study is performed for multiple cracks showing that the natural frequency of beam reduces as umber of crack is increased. C. Ramachandran *et al.*, [6] used ANSYS APDL for modelling the cracked cantilever beam. The aim of the study is to simulate the effect of cracks at various locations such as 0.1m, 0.15m, 0.2m, 0.25m, 0.3m, 0.35m, 0.4m and 0.45m from the fixed end of the beam. The result shows that the natural frequency is affected by the position of crack i.e. as the crack location is moved further the natural frequency of bema is reduced. Rupali Patil *et al.*, [7] performed an investigation of a cracked and uncracked cantilever beam with different techniques such as analytical formulation, Finite element analysis using ANSYS and experimental technique. The natural frequencies of these studies with all aforesaid methods are closely in agreement with each other. The study has also extended with a new approach of Fuzzy logic for finding the correct value of crack size and crack location. Since crack location and crack depth are affecting the natural frequency of the beam. Malay Quila *et al*., [8] performed a modal analysis of cracked and uncracked cantilever beam with a change in crack position and crack depth. The result shows that the position of crack and crack depth affects the amplitude of frequency. M. Kiran Kumar *et al*., [1] have performed a similar study as that of [8] and results indicate that when crack depth is changed from 5mm to 15mm the natural frequency reduces.

Chaudhari J. R. [9] performed an investigation of cracked cantilever beam and static structural analysis. The beam has been modelled with Solid 185 with element type as tetrahedral. The study is performed for varying beam lengths as of 100mm and 200 mm while crack depth is considered as 1mm and 2mm. Cracked beam with more depth the amplitude reduces but natural frequency increases, while the increase in crack location for given depth amplitude reduces but natural frequency increases. P. Yamuna et al. [10] modelled simply supported beam with crack and performed modal analysis and the first five frequencies are recorded. The meshed model obtained using the SOLID 186 tetrahedral 20 node brick element. The boundary conditions considered as crack depth changed from 10mm to 15 mm with a step of 0.5mm while the crack location is changed from 100 mm to 450 mm and changed with a step of 50 mm. The lower value of frequency is obtained at the middle of beam.

Rane H. S. *et al.*, [11] performed free vibration analysis of cantilever beam with conditions such as crack depth 1mm, 2mm, 3mm and location of 150mm, 300mm, 450mm from the fixed end. With constant location of crack depth increases but the natural frequency of the beam decreases. Based on various researchers' contribution, it has been seen that the modal analysis is performed with cantilever beam and simply supported beam. The cracked and uncracked beams are studied and natural frequencies are obtained. The study is focused with change in crack depth, change in position of crack and size of crack opening with constant crack length along the width of beam but not much attention is paid towards change in length of crack and its effect on natural frequency of beam.

Numerical Modelling Approach

The objective modal analysis is to find out the frequency at which the beam vibrates. When a cracked beam or other structure starts vibrating i.e. the natural frequency of beam is equal to the frequency of the applied load. The boundary conditions applied will decide the behavior of beam when it starts vibrating at a number of mode shapes. In the present study, a structural steel cantilever beam with length 1000 mm, width 150 mm and depth 80mm is taken. An open triangular crack along the width is modelled with varying crack length as 30mm, 60 mm, 90mm 120, and 15mm. The crack depth is 15 mm and 30 mm, and 45 mm while the crack opening size is considered as 2mm while the position of crack from the fixed end of the beam is taken as 150 mm, 300mm, 450mm, 600mm, and 750mm. The beam parameters are shown in Table-1.

Table-1: Beam Parameters

Parameter	Value
Length	1000 mm
Width	150 mm
Depth	80 mm
Material:	Structural Steel
Elastic Modulus	$7.1x10^{10}$ N/mm^2
Density	7560 Kg/m^3
Poissons Ratio	0.3

Crack Modelling

The finite element analysis formulation is used for the modal analysis of a cantilever beam. The analysis is performed with Ansys Workbench 2019 R3 Student version. The crack opening size is 2mm for all three crack depths. A total of 15 CAD Models are prepared in Catia for analysis. Meshing is performed by varying mesh size from 7 to 10 mm with an increment of 0.5mm for grid independence and results are similar. But due to the limitation of a maximum number of nodes finer mesh size has not been chosen. Finally, the discretization is performed with a global mesh size of 7 mm.

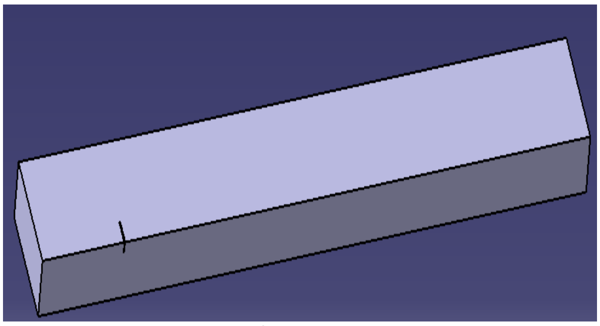

Fig-1: Solid model of Cantilever Beam with crack

RESULTS AND DISCUSSION

In this analysis, we are considering three cases such as 1. Crack depth 15 mm 2. Crack depth 30 mm and 3. Crack depth 45 mm

Case-1

Crack depth 15 mm, here the crack location is changed from 150 mm to 750mm with the step of 150mm as shown from Figure-2 to Figure-6. It shows that the lowest value of frequency is 389.11 Hz for mode 3 when the crack is located at 450mm from fixed end of beam. With the increment in the crack length, the frequency gets lower. The mode 1 value varies from 65 Hz and up to 64Hz while mode 2 values are close to 120Hz.

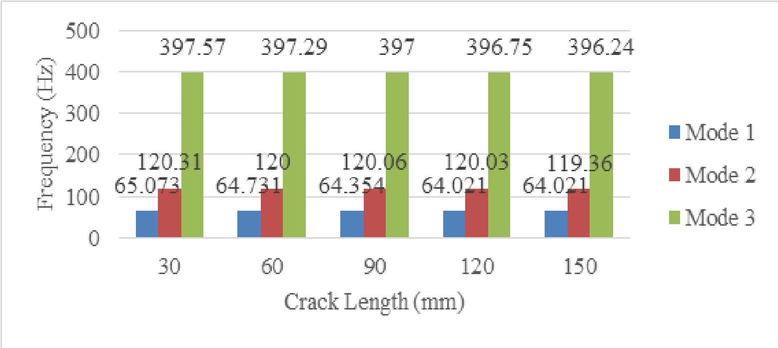

Fig-2: Frequency with crack depth 15mm and crack located at 150 mm

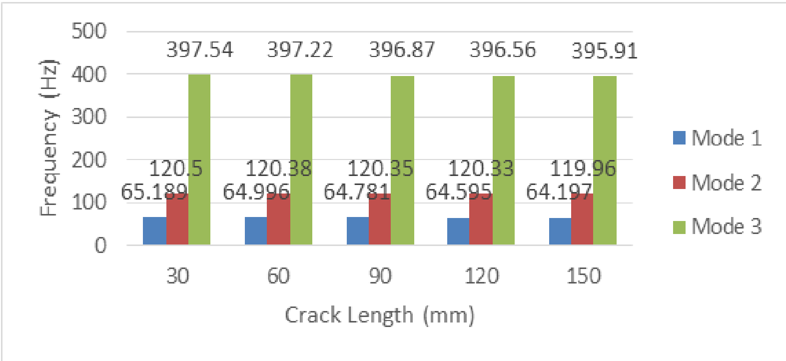

Fig-3: Frequency with crack depth 15mm and crack located at 300 mm

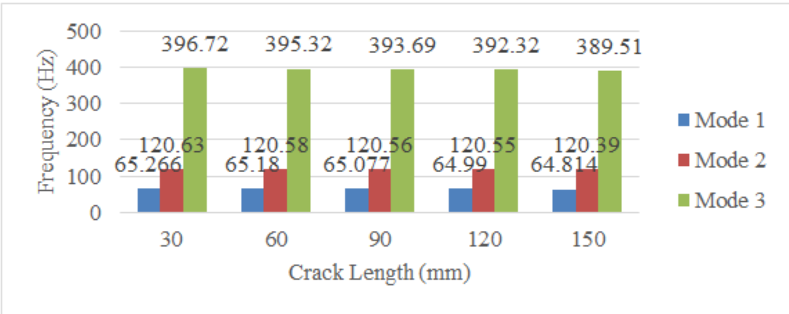

Fig-4: Frequency with crack depth 15mm and crack located at 450 mm

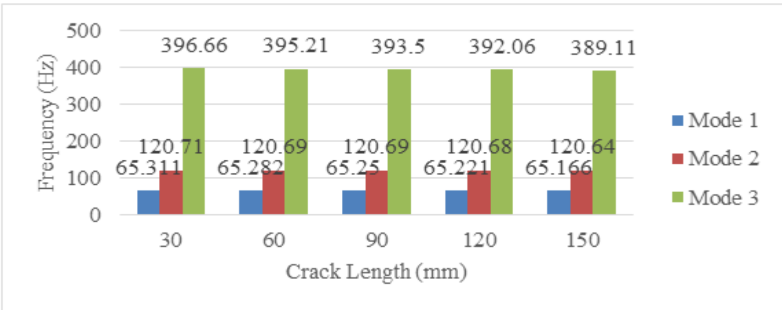

Fig-5: Frequency with crack depth 15mm and crack located at 600 mm

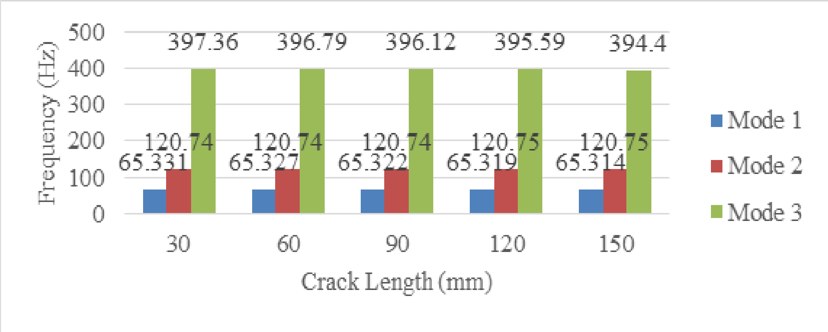

Fig-6: Frequency with crack depth 15mm and crack located at 750 mm

Case-2

Crack depth 30 mm Figure 7 to Figure 11 gives various positions of the crack along the width of the beam. It shows that the lowest value of frequency is 57.72 Hz for mode 1 when the crack is located at 150mm from fixed end of beam. The change in the crack depth has reduced the frequency of more than 15mm depth. The mode 1 value varies from 64Hz and up to 57Hz while mode 2 values are lying from 120 Hz to 115Hz.

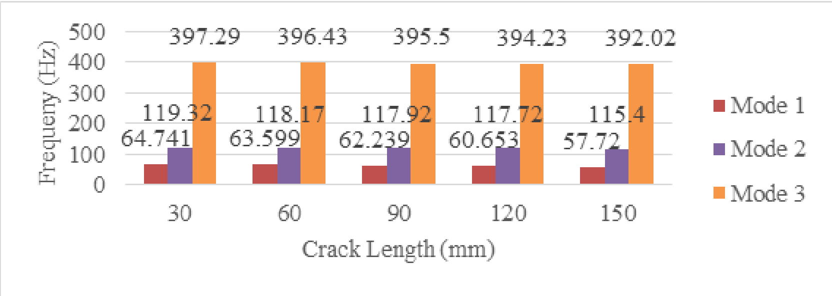

Fig-7: Frequency with crack depth 30 mm and crack located at 150 mm

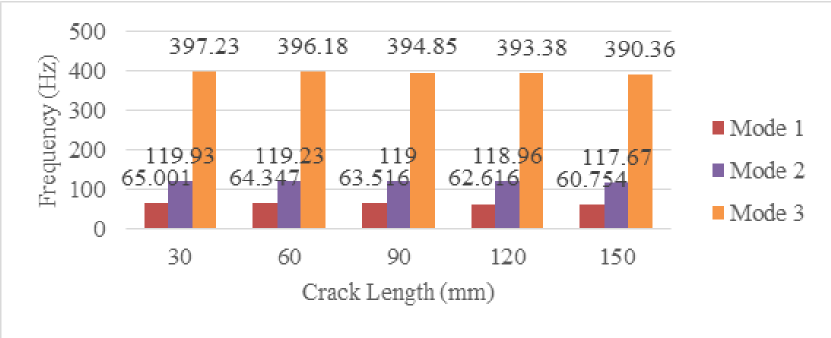

Fig-8: Frequency with crack depth 30 mm and crack located at 300 mm

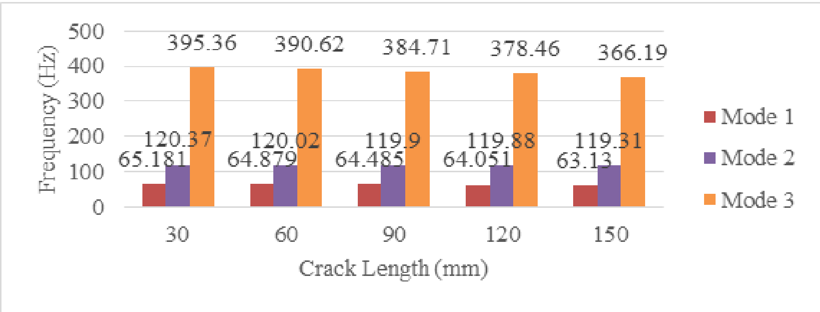

Fig-9: Frequency with crack depth 30 mm and crack located at 450 mm

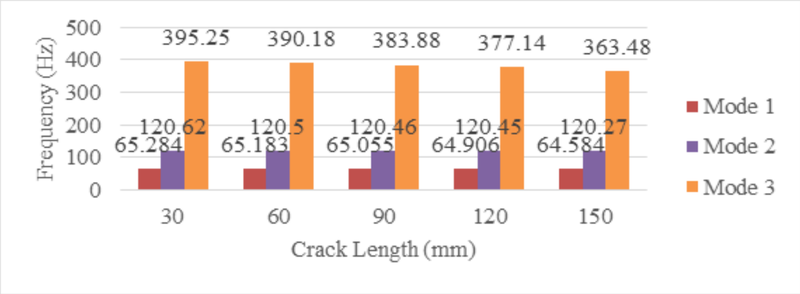

Fig-10: Frequency with crack depth 30 mm and crack located at 600 mm

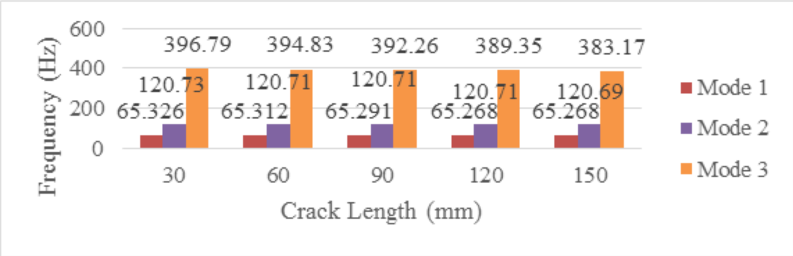

Fig-11: Frequency with crack depth 30 mm and crack located at 750 mm

Case-3

Crack depth 45 mm Figure 12 to 16 represents the different locations of crack on beam width. It shows that the lowest value of frequency is 47.6 Hz for mode 1 when the crack is located at 150mm from the fixed end of the beam. The change in the crack depth has reduced the frequency more than case 1 and case 2 of analysis. The crack length as of 150mm and for all the locations of crack shows a much lower value of natural frequency in comparison with all other analysis results.

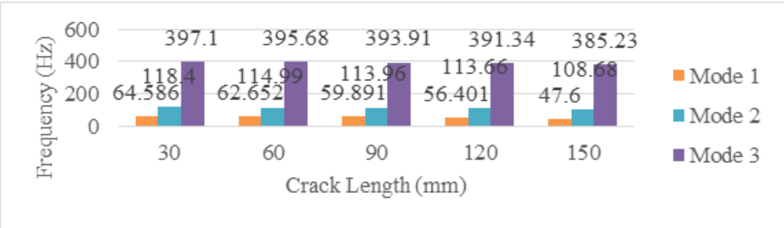

Fig-12: Frequency with crack depth 45 mm and crack located at 150 mm

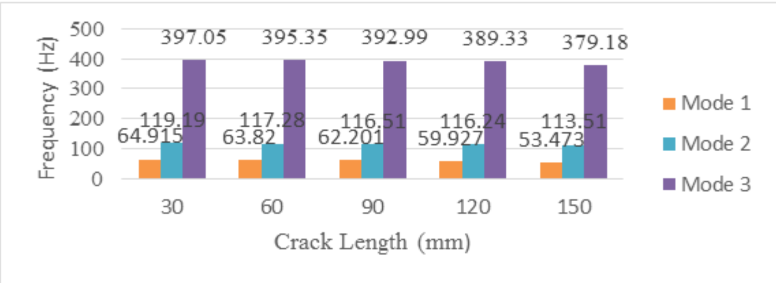

Fig-13: Frequency with crack depth 45 mm and crack located at 300 mm

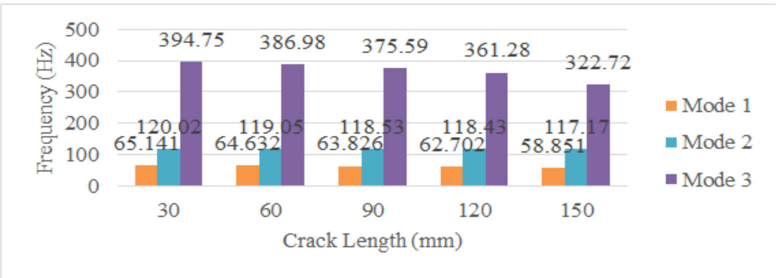

Fig-14: Frequency with crack depth 45 mm and crack located at 450 mm

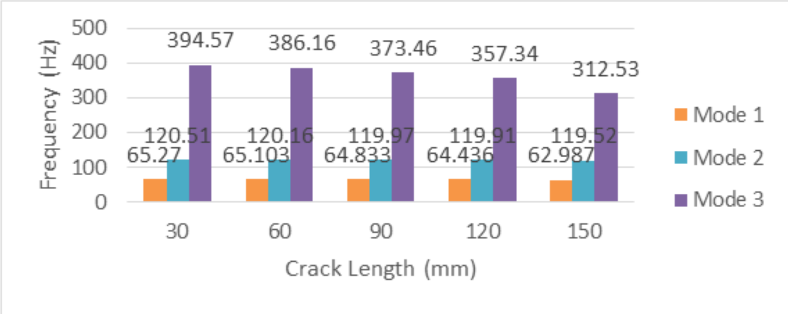

Fig-15: Frequency with crack depth 45 mm and crack located at 600 mm

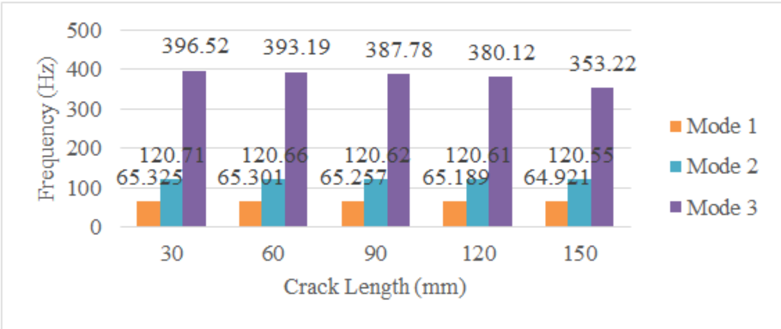

Fig-16: Frequency with crack depth 45 mm and crack located at 750 mm

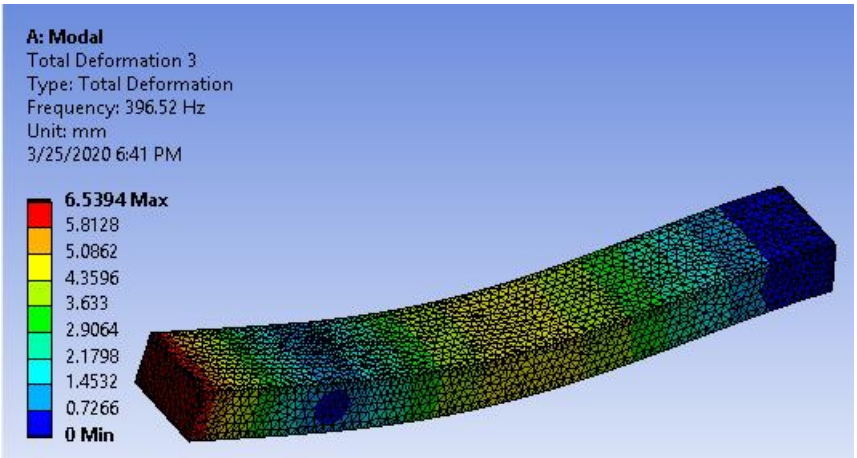

Fig-17: Mode shape at third Mode

CONCLUSION

The crack opening size will affect significantly the natural frequency of the beam. As suggested by [2] we had chosen a small crack opening size as 2mm. The change in the crack depth affects the natural frequency as the lowest frequencies are obtained for 45mm crack depth than 15mm and 35mm. The crack position also affects the frequency as crack distance from fixed increases the frequency reduces for different modes. The current investigation is much focused on the effect of different lengths of crack on natural frequency. It has been observed that for larger crack length the frequency is lower for all three crack depths under study. Mesh refinement will give more accurate results for all cases since due to computational limitation this study has not performed and can be undertaken in the future. Further research can be extended by an Experimental approach.

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