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An Experimental Study of Modal Parameter of Cantilever Beam with Various Cracked Condition

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Abstract--Use of beams in construction industries as well as in different engineering application is obvious. When this beam undergoes in different types of loading, crack may generate in beam. Crack is main cause for failure of beam like structure. Crack changes the physical and dynamic properties like stiffness and natural frequencies of beam which are function of crack depth and crack location. In this study vibration analysis of cantilever beam has been done under damaged and undamaged condition to investigate the effect of crack on natural frequency. Numerical analysis of beam is done through finite element analysis of beam using ANSYS software. Vibration analysis of beam has been also done through experimentation and results are compared with analytical analysis and it hold well. Different crack location with single as well as with multi cracks are considered in this paper and results are compared with without crack beam results.
KeyWords:-Natural frequency, Beam, Crack, vibration, finite element method.

I. INTRODUCTION

Crack in structure may develop due to cyclic loads, vibration in structure, manufacturing defects, collision or due to impact. Presence of crack affects the stability of beam structure. Crack affects the physical as well as dynamic characteristics of a structure. This paper discusses the effect on natural frequency of beam due to crack depth at various crack locations. The early detection of crack in structure is very important for safety and economic point of view. For detection of crack two methods are preferred destructive and non-destructive. Destructive test performed through stress test, crash test, hardness test, metallographic test etc which are time consumable and costly too. Non destructive testing methods done through ultrasonic testing, X-ray, acoustic emission, acoustic-ultrasonic, lamb wave etc. These non destructive methods are not economical and also nor reliable for complex structures. Using natural frequency for detection of fault is very much attractive in non destructive testing. The fact that natural frequency can be measured from a single location on the beam for any length provides time saving, less costly and also free from robust condition. In this paper study of crack on beam is done through finite element analysis performed in ANSYS 11.0. The dynamic response of beam is mainly function of position of crack, depth of crack, orientation of crack and number of crack.

Kumar and Mahto [1] analysed the crack in aluminium cantilever beam using such vibration monitoring technique. The concept of experiment was based on changes in natural frequencies of structure due to the presence of crack. Such phenomenon was very useful for fault diagnostic and detection of crack in structure. In this aluminium cantilever beam with crack was exited by a power exciter and accelerometer attached to the beam provide the response. The specimens with edge cracks of different lengths were analyzed experimentally. The experimental result of frequency was obtained by Digital Storage Oscilloscope (DSO).The first three natural frequencies were considered as basic criteria of crack detection. For crack location 3D graph of normalized frequency in terms of crack depth and location were plotted. The intersection of these three contours gave the desire location of crack and crack depth.

Revi et al. [2] analysed the crack in propped cantilever beam using dynamic analysis. The dynamic response properties of structures are used for damage detection with Finite Element Discretisation method applied for evaluating stiffness and modal property of the structure. Reinforced concrete propped cantilever beam was used in experiment and crack was induced in beam by applying incremental load at different stages. Curvature Damage Factor (CDF) with curvature mode shape was used to find cracked position in beam.

Yamuna and Sambasivarao [3] analysed the varying crack location of beam with vibration analysis. In this natural frequency of a simply supported beam with triangular crack on it was analysed numerically by FEM using Finite Element Analysis software ANSYS. The different position of crack effects results were compared with without crack result of the beam. The comparison showed that the fundamental frequency of beam without crack is greater than that of with crack.

Satpute et al. [4] proposed the detection of multiple cracks in a rotating shaft. The vibration analysis of shaft was done through Experimental Modal Analysis and Finite Element Analysis. The first three natural frequencies of transverse vibration were evaluated and the mode shapes were extracted and plotted using ANSYS 14.5. The comparison of results between Experimental Modal Analysis and Finite Element Analysis holds good. The result shows that natural frequency of vibration of all three transverse modes of vibration decreases with increase in depth of crack.

Kamble and Chavan [5] identified the crack in cantilever beam by using experiment and wavelet analysis. In this study crack was modeled by rotational spring and equation was developed for non-dimensional spring stiffness. Now by taking first three natural frequencies by vibration measurement, curves of crack equivalent stiffness were plotted and the intersection of the three curves indicated the crack location and size. The experiment on cantilever was done with single crack at different position and different depth size by FFT Analyzer and the natural frequency obtained was compared with ANSYS package. The time-amplitude data obtained was further used in the wavelet analysis to obtain time-frequency data. The above data played vital role to find the small crack parameters which affect the dynamic properties of the system.

Ghadami et al. [6] developed a new algorithm to detect multiple cracks in beam like structures. In this study natural frequency was used for detection, localization and quantization of multiple cracks in beams. Crack was modeled as rotational spring, and author demonstrates a relationship between natural frequencies, crack depth and crack location. An algorithm was developed know the exact number of cracks available.

II. OBJECTIVE OF THE WORK

The main aim of this study is to analyze the vibration behavior of cantilever beam in damaged and un-damaged condition. The analysis of beam is done experimentally in lab and numerically through finite element analysis software ANSYS 11.0. Analysis of beam was performed with open transverse rectangular cracks. In this study effect of single crack and multi crack on dynamic behavior of beam are considered.

III. MODELING OF CANTILEVER BEAM

A. Experimental Modeling Of Cantilever Beam

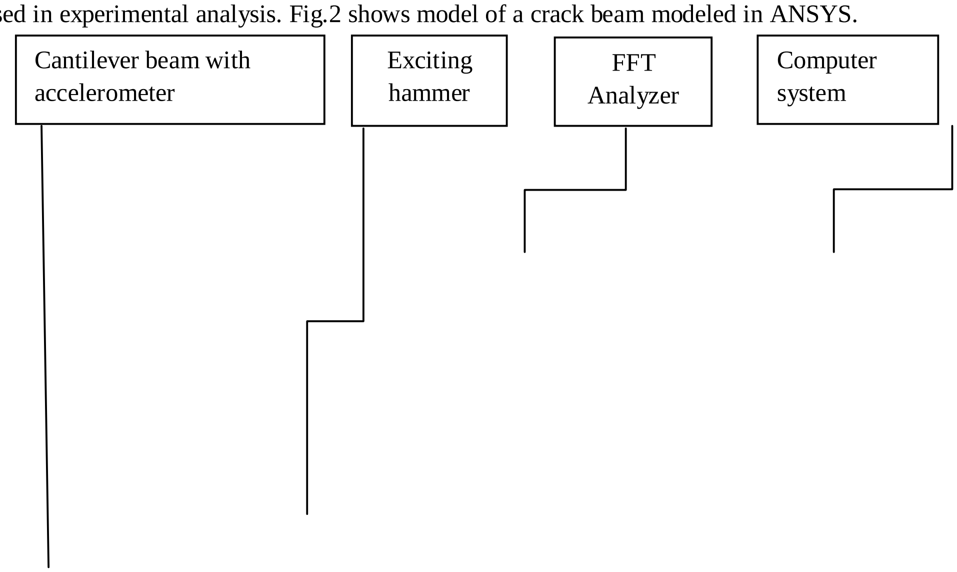
An elastic iron beam is taken for analysis in experiment whose dimension is measured through scale and found 400mm in length and of 12.4mmX12.4mm cross section. Material properties of beam are tested in UTM (Universal testing machine) and are as follows:

Young's modulus, E=43.17GPa, density, ρ=7542Kg/m^3, Poisson ratio, μ=0.3.

For experimental analysis of beam one end of cantilever is fixed in between two rectangular plates and other end is free as shown in fig 1. An accelerometer is placed on the beam to analyze its vibration through FFT Analyzer. FFT Analyzer further connects with computer system to display the graphical analysis of beam. Beam is analyzed in damaged and un-damaged condition. Crack in beam was generated through hexa blade whose thickness is 1mm (approximately). For vibration analysis of a cracked beam, single open transverse rectangular crack with minimum 2mm depth and width 1mm is considered. The initial position of crack is taken at a location of 100mm from fixed end. Later, for comparative analysis the position of crack is varied from 100mm to 300mm and depth of crack also varied from 2mm to 10mm. Cantilever beam is also analyzed with multiple cracks. The output of experimental analysis is compared with finite element analysis of beam in ANSYS software and it holds good.

B. Numerical Modeling Of Cantilever Beam

Numerical analysis of beam is done through finite element analysis software package ANSYS 11.0. The volumetric model in ANSYS is modeled using SOLID 186 tetrahedral 20 node brick element. The material and dimensional properties of beam are same as used in experimental analysis. Fig.2 shows model of a crack beam modeled in ANSYS.



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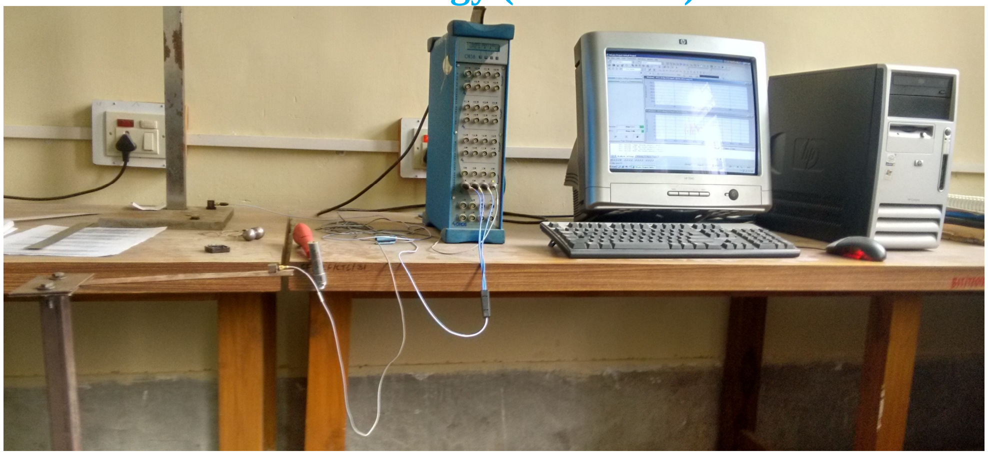

Figure1: Experimental set up

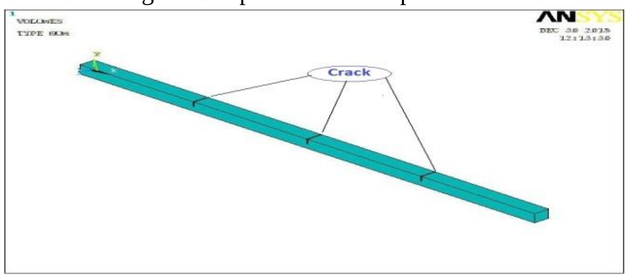

Figure2: model of a crack beam modeled in ANSYS

IV. RESULT AND DISCUSSION

Table 1 shows the comparison of experimental and analytical results for first three modes of natural frequency. The same analysis has also been done for damaged beam.

Table 1: First three natural frequency of un-damaged iron beam

Mode	*fn* Experimental (Hz)	*fn* ANSYS (Hz)
1	28.8	30.059
2	186.5	188.12
3	522.8	525.57

Now cracks in beam were made by hexa blade at different positions like 100 mm, 200mm and 300mm in different samples of beam. Beam also analyzed in multi crack situation. Table 2 shows the analysis of beam in different crack positions with different crack depths.

Table 2: Natural frequencies of first three mode of cantilever beam for various crack positions and crack depth.

Crack position (mm)	Crack Depth (mm)	Natural Frequency(Hz)		
		1st mode	2nd mode	3rd mode
100	2	29.798	187.23	518.83
	4	29.183	187.11	511.17
	6	27.859	186.79	495.33
	8	25.197	186.04	467.12
	10	20.768	185.28	429.56
200	2	29.949	186.02	521.17
	4	29.772	181.50	521.08
	6	29.424	173.58	520.94
	8	28.473	156.61	520.67
	10	26.352	132.94	520.29

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300	2	30.001	186.77	517.27
	4	29.997	185.17	504.80
	6	29.981	182.12	483.83
	8	29.900	172.48	432.17
	10	29.686	152.59	372.41
100 and 200	2	29.741	185.92	518.66
	4	28.977	181.56	510.95
	6	27.046	172.54	495.09
	8	24.368	156.76	463.26
	10	19.444	131.04	411.93
100,200 and 300	2	29.757	185.50	514.91
	4	29.020	179.94	496.40
	6	27.403	168.22	458.94
	8	24.304	148.94	399.68
	10	19.373	120.00	320.02

From Table 2 it is very much clear that natural frequency of beam decrease for every modes of frequency as the crack depth increases at any position of crack. The same is also valid for the multiple cracks in beam.

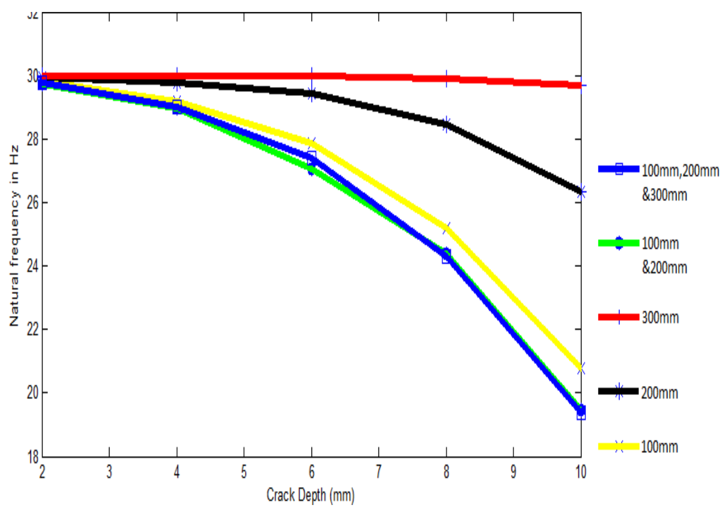

Figure.3 Fundamental natural frequency in terms of crack depth for different crack positions

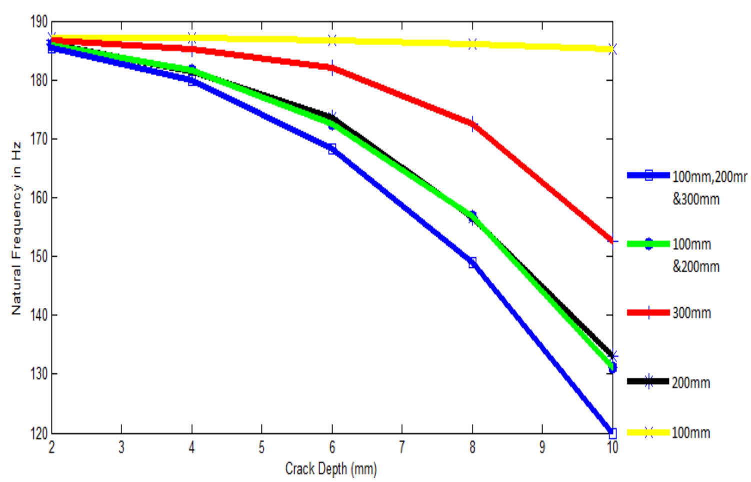

Figure.4 Second natural frequency in terms of crack depth for different crack positions

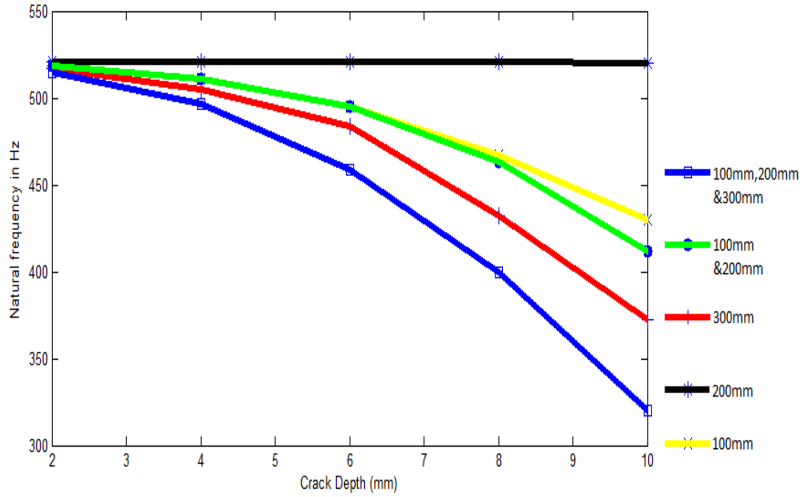

Figure.5 Third natural frequency in terms of crack depth for different crack positions

Natural frequencies of beam also vary according to position of crack. Fig.3, fig.4 and fig.5 show the effect of position of crack on different modes of natural frequencies. Fig.3 shows the variation in fundamental mode of natural frequency in terms of crack depth for different crack locations. Graph between natural frequency and crack depth shows that first mode of natural frequency was mostly affected by crack position near to fixed end i.e.; at 100mm of beam. This implies that natural frequency was mostly affected for the greatest value of bending moment of beam. Graph also concludes that as the number of cracks increases the natural frequency decreases subsequently. Fig.4 shows the variation in second mode of natural frequency in terms of crack depth for different crack locations. Graph between natural frequency and crack depth shows that second mode of natural frequency was mostly affected at 200mm crack position. Due to large value of bending moment second mode of natural frequency was mostly affected at centre of beam. From graph it is also very much clear that as the number of cracks increases second mode of natural frequency decreases subsequently.

Fig.5 represents the variation in third mode of natural frequency in terms of crack depth for different crack locations. Plot between natural frequency and crack depth shows that third mode of natural frequency was mostly affected at 300mm crack position. One interesting conclusion comes from graph is that affect of multiple crack position of 100mm and 200mm on third mode of natural frequency is lesser than the single crack position of 300mm. This happens due to the fact that nodal point of third mode was located at the centre of the cantilever beam. Third mode of natural frequency was most affected for multiple crack positions of 100mm, 200mm and 300mm.

V. CONCLUSION

The effect of the crack on the different natural frequencies has been studied in this paper. Experimental as well as finite element analysis of the beam has been done here. It is found that there is a very close agreement between the results obtained from the experimental analysis and the finite element analysis. It is found in this study that the first mode of natural frequency was mostly affected by crack position near to fixed end. Second mode of natural frequency was mostly affected at centre of the beam i.e. at 200mm from fixed end of beam. Third mode of natural frequency was mostly affected at 300mm crack position. Multiple cracks also affect significantly all modes of natural frequency. From this analysis the effect of the crack on the modal parameters can be explained in good fashion.

VI. ACKNOWLEDGMENTS

All the experiments of this study were conducted in the Central Instrumentation Facility (CIF) Lab of BIT, Mesra, Ranchi and the results obtained from those experimental set up were compared with the finite element analysis. The photograph of the experimental setup is taken in CIF Lab.

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