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Study on Dynamic Behaviour of Crack Inclined Edge Cracked Beam with Variable Crack Angles Using Free Vibration

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Abstract - This paper contains an attempt to evaluate dynamic behaviors of beam structures with inclined edge crack subjected to free vibration. An inclined crack in vibrating component can initiate catastrophic failures. The presences of cracks change the physical characteristics of a structure which in turn alter its dynamic response characteristics. Therefore there is need to understand dynamics of cracked structures. Crack inclination, depth and location are the main parameters for the vibration analysis. So it becomes very important to monitor the changes in the response parameters of the structure to access structural integrity, performance and safety. This paper focuses on the vibration analysis of a beam with fixed free (Cantilever) boundary condition and investigates the mode shape and its frequency. The existence of inclined crack in a structural element leads a local stiffness that changes its vibration response. Finite Element Analysis (ANSYS) has been accomplished to derive the vibration signatures of the inclined cracked cantilever beam.

Keywords - ***ANSYS; Crack Depth; Inclined crack; Mode shape; Modal Natural Frequency***

I. INTRODUCTION

Most of the members of engineering structures operate under loading conditions, which may cause damages or cracks in overstressed zones. Damages like inclined crack in vibrating component can initiate catastrophic failures. The presences of cracks change the physical characteristics of a structure which in turn alter its dynamic response characteristics. Therefore there is need to understand dynamics of cracked structures. Crack inclination, depth and location are the main parameters for the vibration analysis. So it becomes very important to monitor the changes in the response parameters of the structure to access structural integrity, performance and safety. Cracks in a structural element in the form of initial defects within the material or caused by fatigue or stress concentration can reduce the natural frequencies and change the vibration mode shapes due to the local flexibility introduced by the crack. Understanding the dynamic characteristics of cracked structures is of prime importance in structural health monitoring and non-destructive damage evaluation because the predicted vibration data can be used to detect, locate, and quantify the extent of the cracks or damages in a structure.

II. CLASSIFICATION OF CRACK

Based on geometries, cracks can be broadly classified as follows:

A. Transverse crack

These are cracks perpendicular to beam axis. These are the most common and most serious as they reduces the cross section as by weaken the beam .They introduce a local flexibility in the stiffness of the beam due to strain energy concentration in the vicinity or crack tip.

B. Longitudinal cracks

These are cracks parallel to beam axis. They are not that common but they pose danger when the tensile load is applied at right angles to the crack direction i.e. perpendicular to beam axis.

C. Open cracks

These cracks always remain open .They are more correctly called "notches". Open cracks are easy to do in laboratory environment and hence most experimental work is focused on this type of crack.

D. Breathing crack

These are cracks those open when the affected part of material is subjected to tensile stress and close when the stress is reversed. Many researchers to develop various techniques for early detection of crack location, depth, size and pattern of damage in a structure. Some nondestructive methodologies for crack detection have been use in global. However the vibration based method is fast and inexpensive for crack/damage identification. Hence it is possible to use natural frequency measurements to detect cracks.

Himanshu Kumar, S C Jain, and Bhanu K Mishra have presented the analytical technique for detection of damage and its severity. Using free Vibrational analysis and applying FEM, first three Vibrational frequencies and mode shapes of the un-cracked and cracked beam has been evaluated. Effect of crack location and crack depth over the first three natural frequencies has been analyzed. It is reported that, for a cantilever beam case, damage can be identified by analyzing the changes in first three values of natural frequencies, except when the crack is located near the node of the chosen vibration mode.[1] Abdul Salam *et. al,* has presented simplified formula for the stress correction factor in terms of the crack depth to the beam height ratio, f(a/h). The natural frequencies of the cracked beam are determined numerically by solving the characteristic equation of the beam.[2] Dayal. R. Parhi, Prases. K. Mohanty, Sasmita Sahu and Amiya Kumar Dash have presented analytical as well as experimental methods to locate and quantify the size of damage in beam type structure from vibration mode.[3] Abhijit Naik and Pawan Sonawane studied on vibration based Crack/damage diagnosis techniques presented by various researchers for cracked structures. These methods use "finite element analysis techniques, together with experimental results, to detect damage in a fiber reinforced composites, laminated composites and non composite structures for its vibration analysis.[4] Ranjan K. Behera, Anish Pandey, Dayal R. Parhi in their research work has developed the theoretical expressions to find out the natural frequencies and mode shapes for the cantilever beam with two transverse cracks.[5] In the present investigation a number of literatures published so far have been surveyed, reviewed and analyzed. Most of researchers studied the effect of single crack on the dynamics of structures. However in actual practice structural members such as beams are highly susceptible to transverse cross-sectional cracks due to fatigue. Therefore to attempt has been made to investigate the dynamic behavior of basic structures with crack systematically.

Condition based monitoring is one of the preventive maintenance method used in the plant maintenance. The present work is aimed at finding the natural frequency of a cantilever beam having inclined crack with variation in crack angle and depth. The objective of the work is to study effect of crack inclination and location on natural frequency for inclined edge cracked beam.

III. FINITE ELEMENT ANALYSIS

Premature identification of damages in dynamic structures during their service period is the key challenge to the researchers because of its importance. At early stage of damages, it is very difficult to find out damages using visual inspection. It may be identified by Non-Destructive Techniques (NDT) such as ultrasonic, magnetic particle, radiography or shaft voltage drop etc. Though dynamic based damage diagnosis has been advanced for last three decades and there are many literatures, still there are so many problems avoid doing it from application. There are many techniques to solve the problem of a cracked beam such as numerical, wavelet, artificial intelligence, analytical, semi-analytical, experimental etc. FEA (Finite Element Analysis) is a common technique to obtain the stiffness matrix of the cracked beam element.

IV. MODELING OF BEAM USING ANSYS

The Beam is modeled in ANSYS Software. Element SOLID185 is used for the 3-D modeling of solid structures. Material properties are provided which is briefly listed in Table 1. After that 16 models are prepared with various inclination angles for crack with the location of crack as L/2 and L/4 of beam. After that the beam is meshed (Fig. 2). Modal analysis is carried out using the Block Lanczos method for finding the natural frequencies. Fixed free boundary condition was applied by constraining the nodal displacement in both x and y direction. The results are tabulated in Table I, Table II and Table III. The four mode shapes of beam with and without crakes for various locations are shown in Fig.3, Fig.4 and Fig 5.

TABLE I: MATERIAL PROPERTY AND DIMENSIONS OF BEAM

Dimensions and Properties	**Aluminum**
Length	0.35 m
Width	0.05 m
Thickness	0.006 m
Density	2700 kg/m^3
Young modulus	70 Gpa
Poisson’s ratio	0.33

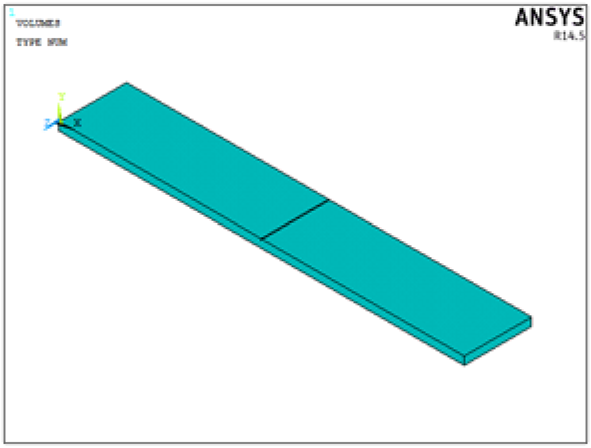


FIG. 1: CRACKED BEAM MODELED IN ANSYS (CRACK LOCATION L=L/2)

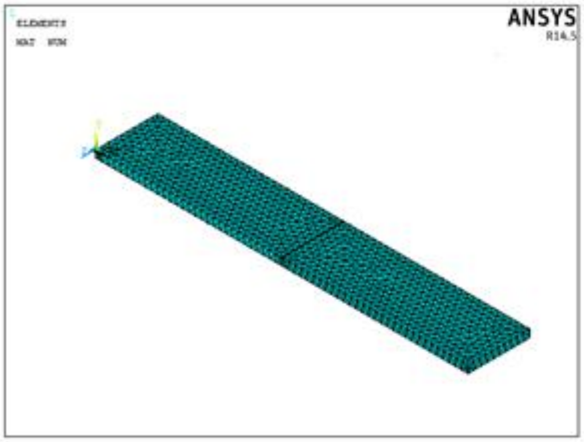
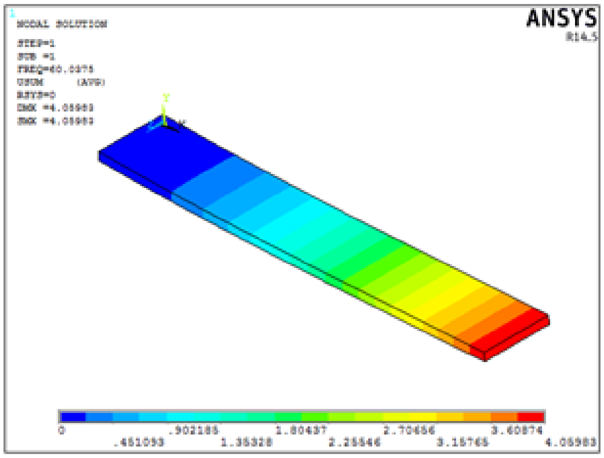
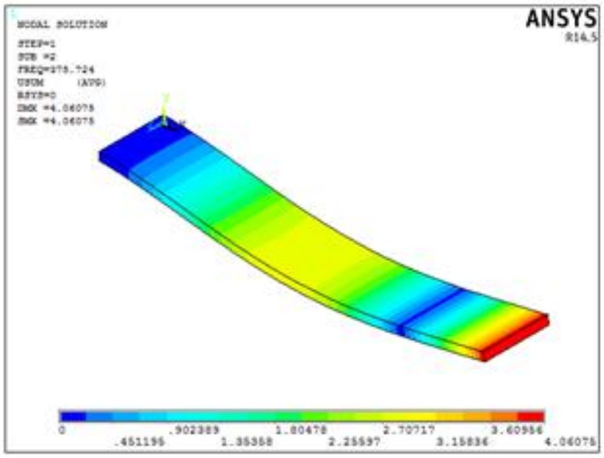


FIG. 2: MESHED BEAM



First Mode



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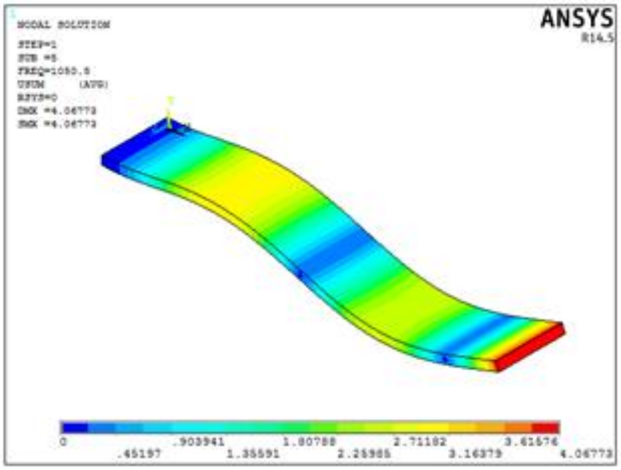
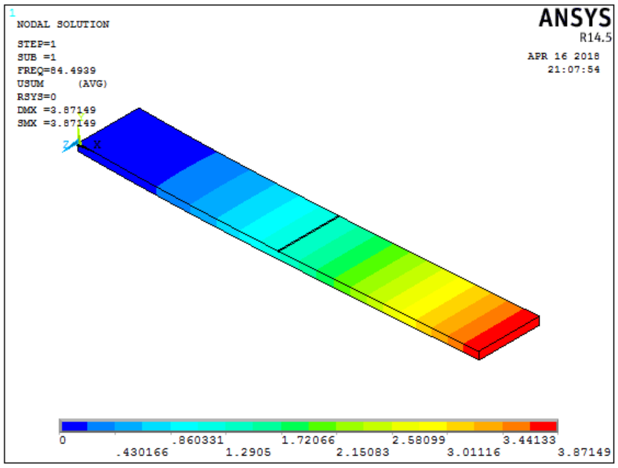
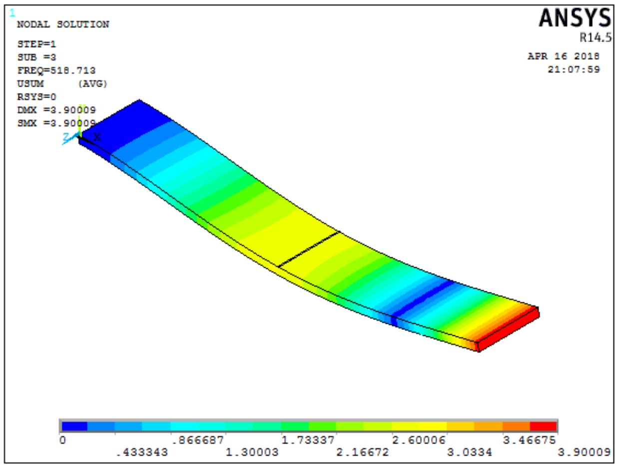


Third Mode

FIG. 3 MODE SHAPE OF UN-CRACKED CANTILEVER BEAM



First Mode



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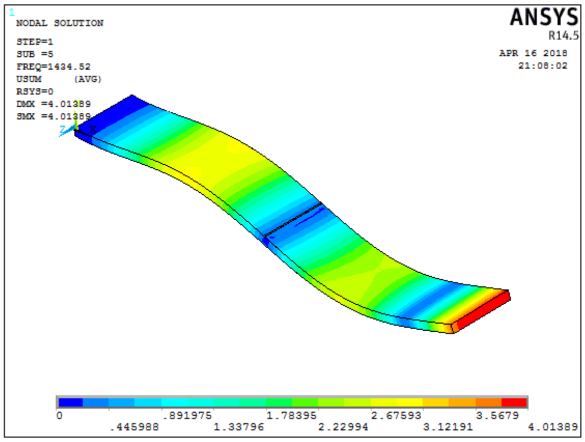
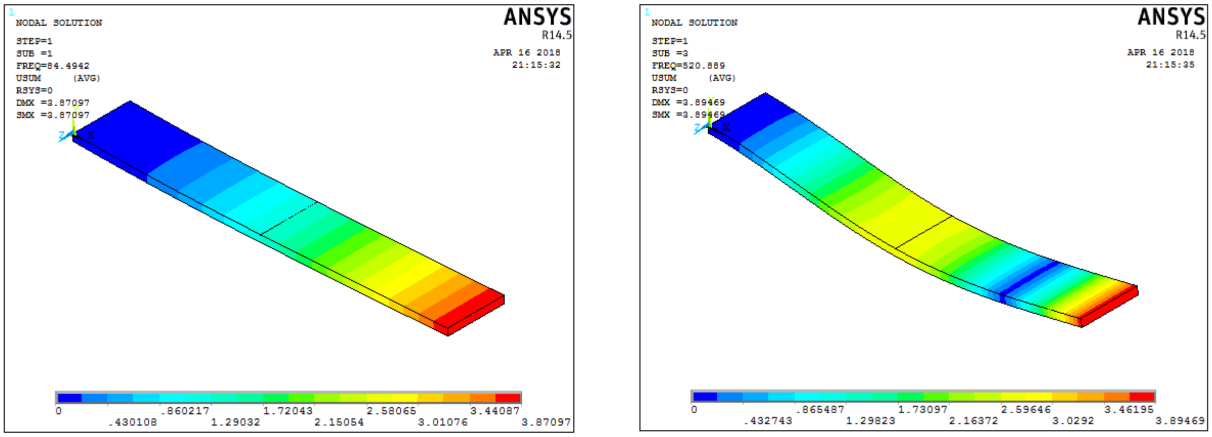


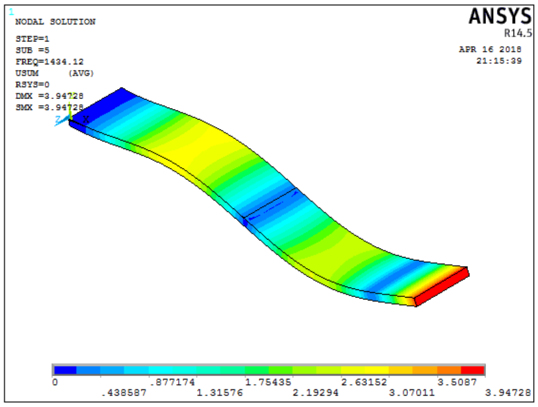
Third Mode

FIG. 4: MODE SHAPE OF CRACKED CANTILEVER BEAM (Θ=00, A = 0.1 AND L= L/2)



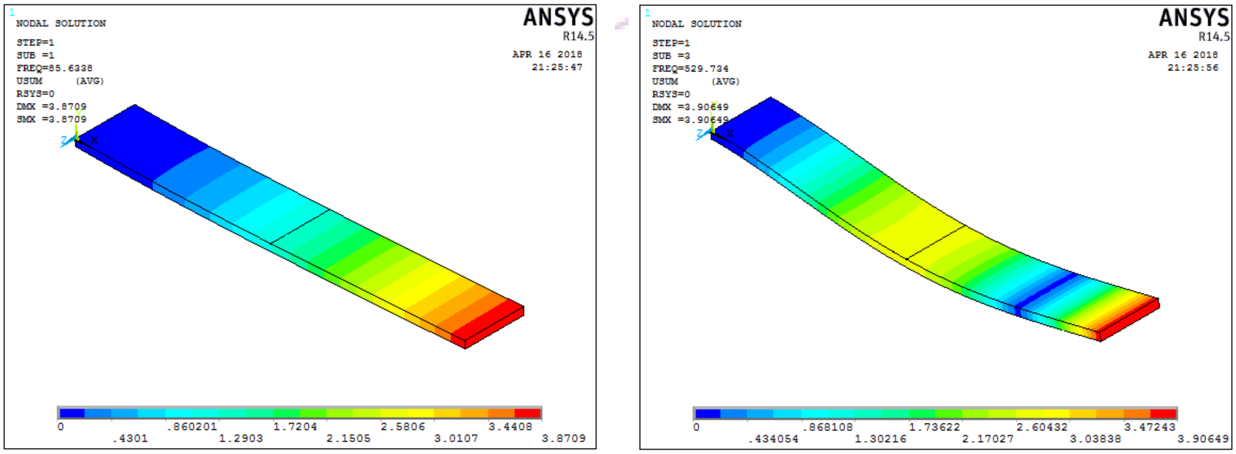
First Mode

Second Mode



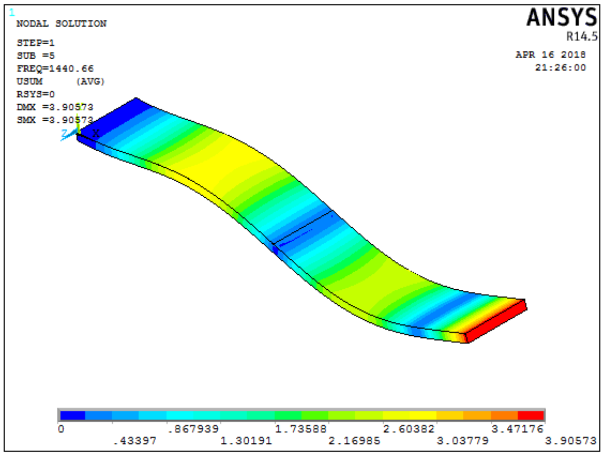
Third Mode

FIG. 5: MODE SHAPE OF CRACKED CANTILEVER BEAM (Θ =150, A = 0.1 AND L= L/2)



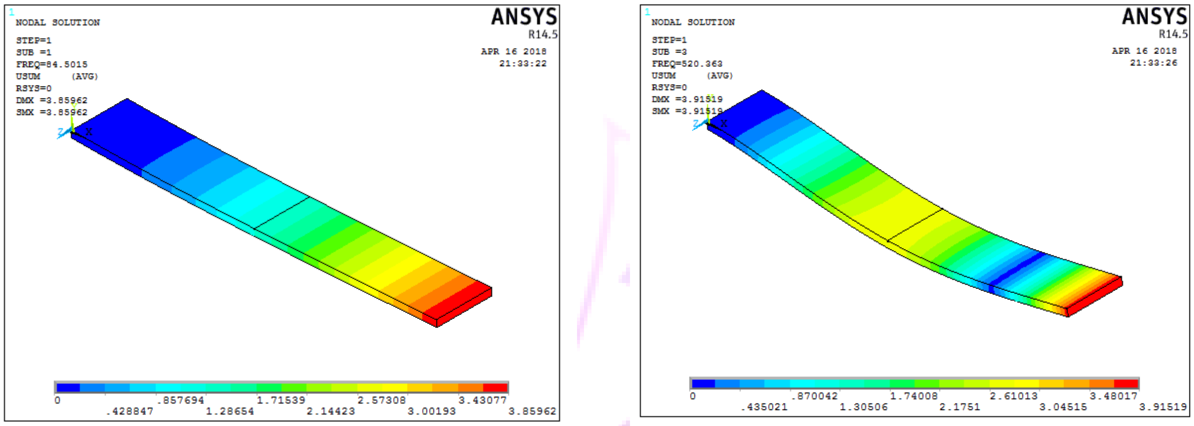
First Mode

Second Mode

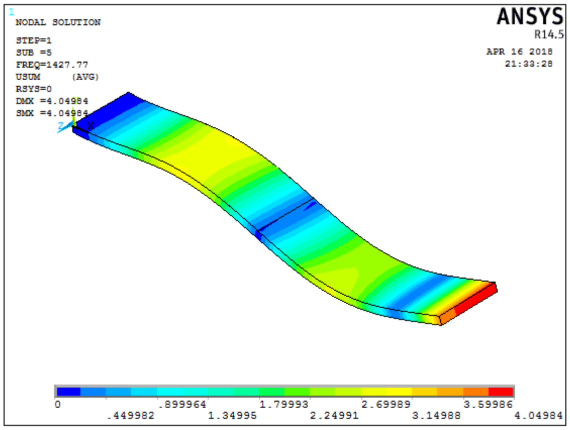


Third Mode

Fig. 6: Mode Shape of Cracked Cantilever Beam (θ=300, a= 0.1 and L= l/2)



First Mode **Second Mode**



Third Mode

Fig. 7: Mode Shape of Cracked Cantilever Beam (θ=450, a= 0.1 and L= l/2)

TABLE II: NATURAL FREQUENCIES OF CRACKED CANTILEVER BEAM (ANSYS)

Crack angle θ	a/t Ratio	Natural Frequency Hz		
		I st Mode	II nd Mode	III rd Mode
0	0.1	84.493	518.713	1434.52
0	0.2	84.267	521.635	1428.26
0	0.3	84.175	514.842	1428.12
15	0.1	84.494	520.889	1434.12
15	0.2	84.575	523.093	1433.02
15	0.3	83.824	517.527	1431.44
30	0.1	85.633	529.734	1440.66
30	0.2	84.322	521.652	1431.67
30	0.3	83.972	519.566	1431.78
45	0.1	84.811	525.818	1432.92
45	0.2	84.501	520.363	1427.77
45	0.3	84.266	519.814	1433.91

TABLE III: NATURAL FREQUENCIES OF UN- CRACKED BEAM (ANSYS)

	Natural Frequency in Hz		
Condition	I st Mode	II nd Mode	III rd Mode
Cantilever Beam	45.225	284.473	7996.9567

V. RESULTS AND DISCUSSION

Figures 3 show that natural frequency of the beam without crack. Figure 4, Figure 5, Figure 6, and Figure 7 shows that natural frequencies of the cantilever beam with inclined edge crack at location L=l/2, angle of inclination is 15^0 and depth 0.1, 0.2 and 0.3 respectively for first, second, and third modes of vibration. Finite elements analysis of uncracked and cracked beam is carried out. Normal mode analysis result of uncracked and cracked beam are tabulated in Table 2 and Table 3. Results show that there is an appreciable variation between natural frequency of cracked and un-cracked cantilever beam. It is observed that natural frequency of the cracked beam decreases both with increase in crack inclination and crack depth due to reduction in stiffness.

VI. CONCLUSION

This identification method is based on the Euler-Bernoulli theory where it is assumed that the beam deflects because of pure bending. The main advantage of this method is the simplicity with which frequency of a structure can be measured in comparison to the measurement of mode shapes which is difficult for complex structures. It has been observed that the natural frequency changes significantly due to the presence of cracks depending upon inclination and depth of cracks. The results of the crack parameters have been obtained from the comparison of the results of the un-cracked and cracked cantilever beam during the Modal analysis using ANSYS software. It has been observed that the natural frequency changes substantially due to the presence of cracks depending upon location and size of cracks. It has been observed that when the crack positions are constant i.e. at particular crack location, the natural frequencies of a cracked beam are inversely proportional to the crack depth. The natural frequency of the cracked beam decreases with increase the crack depth. the change in frequencies is not only a function of crack depth, and crack inclination, but also of the mode number.

VII. REFERENCES

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