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Numerical modal analysis of cracked cantilever beam to study the effect of location and size of cracks

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ABSTRACT

This study proposes a numerical model for vibrations in a cantilever beam having rectangular cross section. Aluminum beam contains single crack in the form of continuous line at various locations along the surface of beam. The presences of cracks change the physical characteristics of a structure which in turn alter its dynamic response characteristics. Therefore crack detection and localization is the main topic of discussion for various researchers across the world. Crack locations and depth of cracks varied. Natural frequency and mode shapes will be found for the uncracked beam first and then for the beam having single crack developed on the same three beams at three different locations. Further study involves changing the depth of the cracks at all the three locations. The natural frequencies and mode shapes of the cracked beam calculated for various crack sizes in case of a single crack and for various crack positions from the fixed end of cantilever. The effect of the locations of the crack through the part on natural frequencies studied considering appropriate crack. Using these results, a class of three dimensional surfaces is constructed for the first three modes of vibration, which indicate natural frequencies in terms of the crack depth and crack position. The vibration characteristics of various depths of cracks and their layout within the material compared in terms of the natural behavior that is modal analysis. The FEM formulation carried out in ANSYS workbench R14.5.

Keywords— **Cracked Cantilever beam, Natural Frequency, Mode Shapes, FEM, Modal Analysis.**

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I. INTRODUCTION

Modal analysis is a process whereby we describe a structure in terms of its natural characteristics which are the frequency, damping and mode shapes – its dynamic properties. The proposed method tested for beams with cracks of varying sizes at different locations. The beam is in a rectangular cross section. Mechanical vibrations, long-term service or applied cyclic loads may result in the initiation of structural defects such as cracks in the structures. Accordingly, the determination of the effects of these deficiencies on the vibration safety and stability of the structures is an important task of engineers. Cracks in a structural element modify its stiffness and damping properties. In view of that, the modal data of the structure hold information relating to the place and dimension of the defect. There have been different attempts to quantify local effects introduced by the crack in the structural elements. Fine mesh finite element techniques have been used to compute local flexibility by different investigators. With respect to crack detection and location, most of the methods proposed are based on the study of the eigenvector and eigen frequency, since it is evident that the presence of the crack produces changes in those dynamic properties. A method of crack location in cantilever beams based on the change that this failure produces in natural frequencies and mode shapes of the system.

In view of this many researchers did their work as P. N. Savedra and L. A. Cuitino [5] studied the theoretical and experimental dynamic behavior of different multi-beams systems containing a transverse crack. However the principle inconvenience of this method is that it is very difficult to determine the mode shapes of engineering structures by analytical methods. Young-Shin Lee and Myung-Jee Chung [6] presented a simple and easy nondestructive evaluation procedure for identifying a crack, the location and size of the crack, in a one-dimensional beam-type structure. H. Nahvi and M. Jabbari [8] established an analytical, as well as experimental approach to the crack detection in cantilever beams by vibration analysis. Shuncong Zhong and S. Olutunde Oyadiji [9] proposes a new approach for damage detection in beam-like structures with small cracks, whose crack ratio [$r = H_c/H$] is less than 5%, without baseline modal parameters. The approach is based on the difference of the continuous wavelet transforms (CWTs) of two sets of mode shape data which correspond to the left half and the right half of the modal data of a cracked simply supported beam. Murat Kisa and M. Arif Gurel [12] proposes a numerical model that combines the finite element and component mode synthesis methods for the modal analysis of beams with circular cross section and containing multiple non-propagating open cracks. Sachin S. Naik and Surjya K. Maiti [13] paper presents the full formulation for a crack model for analyzing the triply coupled free vibration of both Timoshenko (short) and Euler–Bernoulli (long) shaft beams based on compliance approach in the presence of a planar open edge crack in an arbitrary angular orientation with a reference direction. Sadettin Orhan [7] presented free and forced vibration analysis of a cracked beam in order to identify the crack in a cantilever beam. Single- and two-edge cracks were evaluated. The study results suggest that free vibration analysis provides suitable information for the detection of single and two cracks, whereas forced vibration can detect only the single crack condition.

Most of the researchers [14-16] followed the analytical method of vibration analysis and beams are of the material steels and composite materials. It is noticed that researchers in the field of composite beam analyses avoided use of 3D theory of elasticity and developed and used thick beam theories. Many researchers use the finite element method for their analyses in different aspects such as smart or damaged beams. Much of the research is paying attention to evolving technologies on smart materials, and applications such as blades and shafts. Other research focused on vibration control through damping and structural health monitoring through vibration testing.

II. METHODOLOGY

There have been different attempts to quantify local effects introduced by the crack in the structural elements. Fine mesh finite element techniques have been used to compute local flexibility by different investigators. With respect to crack detection and location, most of the methods proposed are based on the study of the eigenvector and eigen frequency, since it is evident that the presence of the crack produces changes in those dynamic properties. A method of crack location in cantilever beams based on the change that this failure produces in natural frequencies and mode shapes of the system. In this work, an improved finite element model for a cracked beam is developed as shown in Fig 1.

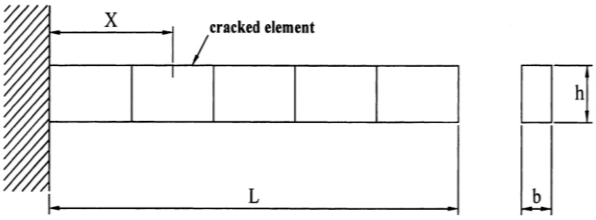

Figure 1. Finite element model of cracked beam

Modal analysis for each position and depth will then performed to find the natural frequencies of the beam. The finite element model of the cracked cantilever beam will be established by using a software package ANSYS. An Aluminium composite beam of breadth b = 75mm, depth h = 32mm and length L = 500 mm will be modelled. Crack position will be assumed to be in elements at a length of 125mm, 250mm, and 375 mm from the fixed end respectively. Next, for each position of the crack, depth of the crack will be varied as 5mm, 10mm, 15mm at all the locations of crack. Modal analysis for each position and depth will be then performed to find the first three natural frequencies and first three mode shapes of the beam. The contour lines for the first, second and third modes will be plotted from the numerical results. These plane curves show couples of crack depth ratio and crack locations that result the natural frequencies of the cracked beam.

III. SCOPE

As the whole structure is detached from the crack sections, the present model enables also one to investigate the non-linear interface effects such as contact and impact when the cracks breathe. Although the analysis of the present study is mainly for beams with constant cross sections, extension to tapered beams can be carried out easily. Other possible extensions of the study are the inclusion of damping effects, as well as the propagation of cracks, which are left for future works by few researchers. Flaws/cracks developing in a component during service may seriously influence its dynamic behaviour. These may cause changes in its mass distribution and damping properties. The crack may also modify the stress–strain field over a larger distance than covered by a solution based on the stress intensity factor. In such cases continuous cracked beam approach for obtaining the natural frequencies with better accuracy. To help in a continuous safety assessment of a machine or structure it is very necessary to constantly assess the health of its critical components. This calls for a continuous assessment of changes in their static and/or dynamic behaviour. The changes have very often their origin in local reduction of structural stiffness caused by cracks or crack-like defects. The development of a crack does not necessarily make a component instantly useless, but it is a signal that its behaviour has to be monitored more carefully. Such monitoring can play a significant role in assuring an uninterrupted operation in service by the component. This has made the vibration based monitoring of components consisting of cracks or crack-like defects in service very important and generated a lot of interest in the study of vibration of components with one or more cracks.

IV. Numerical analysis

An aluminium beam that is clamped at one end, with the dimensions, Length of the Beam = 500 mm, Width of the beam = 75 mm, Height of the Beam = 32 mm, Crack width = 2 mm. Material properties of aluminium are density=2770 kg/m^3, young's modulus=70*10^9 Pa, Poisson ratio=0.35. Numerical analysis is done by using commercially available software package ANSYS R14.5 academic. Various trials are planned as shown in the table 1.

Table 1. Various cases of the beam for ANSYS solution

Case No	Crack location from fixed end of cantilever (mm)	Crack Depth (mm)
First	No Crack	No Crack
Second	125	5
Third	125	10
Fourth	125	15
Fifth	250	5
Sixth	250	10
Seventh	250	15
Eighth	375	5
Ninth	375	10
Tenth	375	15

For above mentioned each type of the beam first three natural frequencies and mode shapes are found. Steps followed for numerical analysis are as follows.

1. Set preferences- Ansys workbench have a provision to select the type of analysis as 'Modal Analysis' from the toolbox available. In this work the modal analysis option is selected as a standalone system in the project schematic.
2. Engineering data- In this section defined constant material properties: Density, Young's modulus, Poisson's ratio for the aluminium. Aluminium with the material properties mentioned above is added as a new material in the material library.

3. Model the Geometry- From the project schematic a geometry option is available which allows us to create the three dimensional model of the project. For modelling the said beam a rectangular section with mentioned dimension is generated in a plane and same was extruded to specified width to generate a beam as shown in the figure 2.

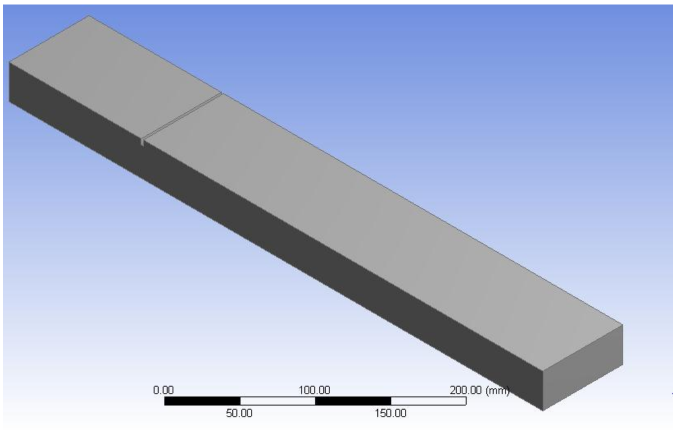

Figure 2. Cracked model of beam in ANSYS

4. Mesh the area- In model section of the project schematic a program controlled type of element was selected, the size of the element is limited to 50 mm in the sizing section. The mesh is generated which looks like as shown in figure 3.

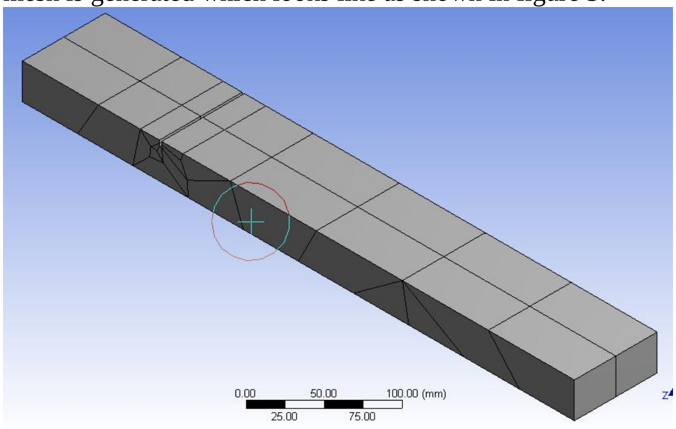

Figure 3. Meshed model in ANSYS

5. Apply constraints to the model- Aluminum material which was defined with the said properties in the engineering data section is then applied to the meshed beam model in the material assignment section. Fixed support is applied to the left end of the beam from the insert menu available in the modal option so that the beam is set to be cantilever.
6. Specify analysis types and options- In the solution section the number of modes to be extracted were selected as three modes. For those three modes total deformation i.e. mode shapes and natural frequencies are to be found.
7. Obtain Solution by solving the modal project with the said options. Ansys will list out the natural frequencies and mode shapes for the three modes. After solving the said program following results are obtained in ANSYS Workbench R 14.5, for the natural frequency for various cases of the beams mentioned above shown in table 2.

Table 2. Natural Frequencies of beam

Crack (mm)		Frequencies (Hz)		
Position	**Depth**	**First**	**Second**	**Third**
125	5	104.86	241.99	655.5
	10	100.69	238.33	652.56
	15	93.228	231.56	655.67
250	5	105.29	243.28	646.29
	10	104.62	241.81	616.4
	15	101.98	239.75	568.89

375	5	105.9	243.55	647.51
	10	106.11	243.2	638.76
	15	106.06	243.24	613.96
No Crack		106.33	243.08	655.05

Also the mode shapes of the beam were fond for all the cases; one case of uncracked beam is as shown in the figure 4.

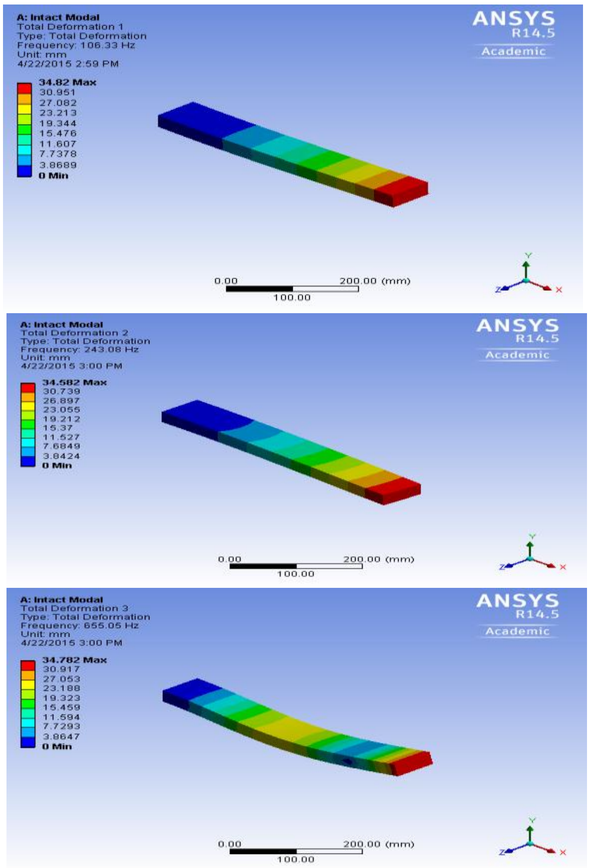

Figure 4. **Three m**ode shapes of intact beam

V. Discussion and Conclusion

From the above mentioned mode shapes it is observed that maximum deflection of the beam is for the beam having crack at the location farthest away from the fixed end i.e. 38.46 mm and increases as the depth of crack is increased. There is less effect on the deflection of beam with cracks near to the fixed end and having small size of crack. Minimum deflection of the uncracked beam is observed to be 34.82 mm. The maximum deflections of all other beams are found in between 34.82 mm to 38.46 mm.

Figure 5 shows plot of the 1st natural frequency with crack location and depth of crack. From this plot we can easily conclude that natural frequency of beam decreases as the crack developed near to the fixed end and with increase in the depth of the crack. Figure 6 shows plot of the 2nd natural frequency with crack location and depth of crack. The same conclusion can be drawn as that of the previous case for this mode of vibration also. Maximum frequency in second mode was observed to be 243 Hz in case of intact beam and 239 Hz is the minimum frequency in this mode. Figure 7 shows plot of the 3rd natural frequency with crack location and depth of crack. There is less effect of the crack on the third natural frequency for crack location at 125mm and 375 mm, but if the crack is at midway of beam then frequency decreases significantly

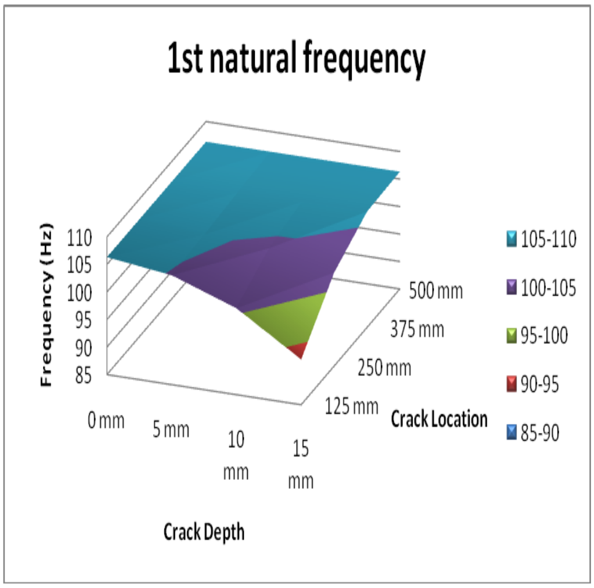

Figure 5. Plot of 1st natural frequency with location and depth of crack

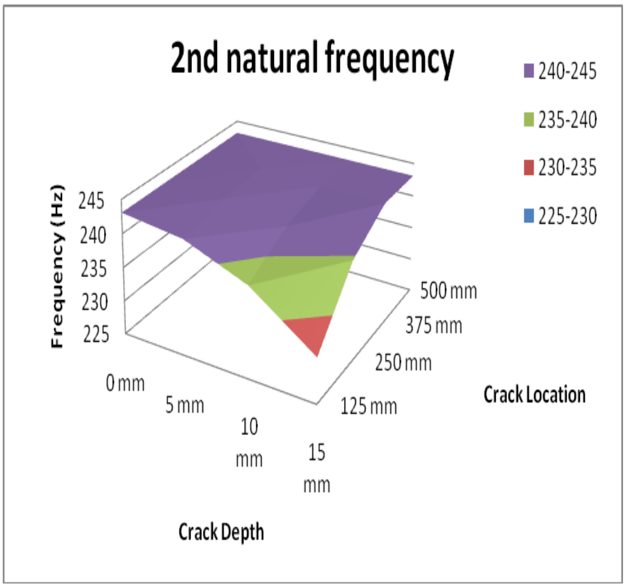

Figure 6. Plot of 2nd natural frequency with location and depth of crack

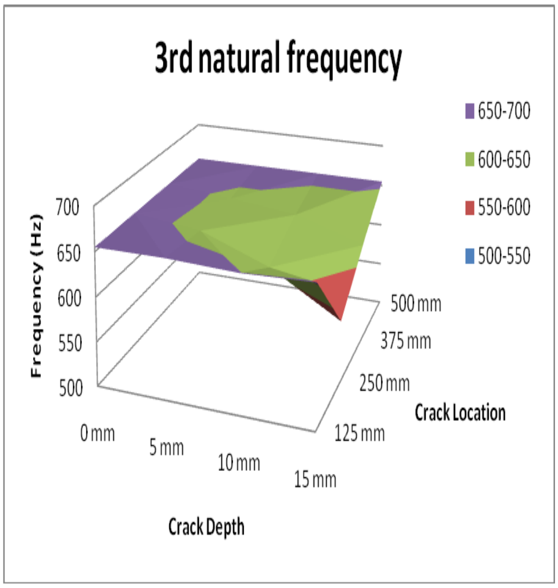

Figure 7. Plot of 3rd natural frequency with location and depth of crack

Following conclusions can be derived from the above mentioned work:

1. A numerical model is developed for the analysis of the cracks transversely located on the surface of the beam and shows the effect of location and size of the crack. Thus it is deduced that the presence of crack in the structure reduces the frequency and increases the amplitude of vibration. This decrease in the frequency is maximum as the crack size increases and as the crack location comes near to the fixed end of the cantilever.
2. In the case if crack location kept constant and depth of crack is increased, the natural frequency is going to decrease and maximum deflection increases for first two modes of vibration.
3. If depth of the crack kept constant and location is changed, it is observed that as crack comes close to the fixed end of cantilever frequency decreases and amplitude also decreases for first two modes of vibration.
4. In case of third mode of vibration the maximum drop of frequency is observed in the case having crack at the midlength of the beam which is distinctly different than the trend observed in case of first two modes of vibration.

This work further is planned to validate by experimental modal analysis with the FFT analyzer set up, also it can be extended for early detection of the cracks in the structure. Also it is possible to extend this work by changing the boundary conditions, type of loadings and the materials of the model.

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