# Crack detection in composite cantilever beam by Vibration analysis and Numerical method

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**Abstract-** The structural members are important part of buildings or mechanical system. It is required that the structure must work safely during its service life; most of the failures encountered are due to the material fatigue. This results in structural defects such as cracks, which as time progresses leads to the failure or breakdown of structure. Therefore researchers are paying attention to identify the crack and its severity prior to failure without aborting the system. The presence of crack in structure causes changes in the stiffness of that structure which results in change in frequencies and amplitudes of free vibration of structure. The objective of this work is to evaluate the changes in natural frequencies of cantilever composite beam made of Glass Epoxy. The effect of location and depth of crack on the natural frequency of beam with transverse open crack is explored. The numerical results were found in good agreement with the experimental results. The result of the study concludes that, presence of crack drops the natural frequencies and changes the mode shape of vibration.

***Keywords:*** crack, composite beam, natural frequency, experimental, numerical.

### *Nomenclature:*

w -Width of beam
h -Thickness of beam
a -Depth of crack
L -Length of beam
$L_1$-Distance of crack from left and support
E-Young's modulus
I -Moment of inertia of beam cross section
$\rho$-Mass density of beam
A-Cross-sectional area of beam
$f_n$-Natural frequency (Hz)

## 1. INTRODUCTION

Beams are the basic structural components; they can be used for different application such as in high speed machinery, aircraft and light weight structures. Composite materials are being used more frequently in many different engineering fields because of high strength, low weight, resistance to corrosion, impact resistance, and high fatigue strength. Cracks in a structure may be hazardous due to static or dynamic loadings; hence crack detection plays an important role for structural health monitoring applications.

There are several Non-destructive techniques (NDT's) available for detection of damage in the structure or mechanical component such as X-ray imaging, ultrasonic scans, infrared thermograph, and eddy current can identify damages. But their adoption becomes difficult because somehow they are difficult to implement and some of them are impractical in many cases such as in service aircraft testing, long pipelines in power plants and railway tracks etc.

It is essential to detect the damage as quick as possible to monitor, evaluate and repair the structure if necessary. To achieve this it is possible to rely on method based on vibration test.

## 2. LITERATURE REVIEW

Nahvi and Jabbari [1] have developed an analytical, as well as experimental approach to the crack detection in cantilever beams by vibration analysis. Rizos, et al. [2] has measured the flexural vibrations of a cantilever beam having rectangular cross-section with a transverse surface crack. Agrawal and Parhi [3] calculated the effect of transverse open crack on the modal parameters of the Aluminum cantilever beam subjected to free vibration. Ertuğrul et al. [5] obtain information about the location and depths of cracks in cracked beams by vibrations as a result of impact shocks. A metal ball was dropped onto the beam from a constant height in order to excite vibrations. Lakhdar et al. [11] investigated damage in composite structure by vibration analysis. The studied material is glass / polyester composite, with properties for glass E=73000 MPa and μ=0 and for polyester E=3800 MPa and μ=0.37. Yan and Yang [14] presented analytical study on the forced flexural vibration of functionally graded beams with open edge cracks under combined action of axial compressive load and concentrated load moving along longitudinal direction. Meng-Kao Yeh et al. [15] studied vibration characteristic of Multi-walled Carbon Nanotubes (MWNT's)/epoxy specimens. The specimens were prepared with different MWNT's wt% to explore vibration characteristic of composite beam. Chondros et al. [9] has analyzed the lateral vibration of cracked Euler-Bernoulli beams with single or double edge cracks. Maiti and Sinha [11] used higher order shear deformation theory for the analysis of composite beams. Nine node isoparametric elements are used in the analysis. Barad et al. [6] presented the detection of crack presence on beam type structural element using natural frequency.

## 3. THEORY OF FREE VIBRATION OF BEAM

The natural frequency for free-free vibrations of beam in general is given as [24]

$$f_n = \frac{1}{2\pi}\alpha^2\sqrt{\frac{EI}{\rho A L^4}}$$

If a structure is defective, there is a change in the stiffness and damping of the structure in the region of the defect. A reduction in stiffness (EI) implies a reduction in the natural frequencies of vibration.
Major characteristics of structures, which undergo change due to presence of crack, are

- The natural frequency
- The amplitude response due to vibration
- The mode shapes

Hence it is possible to use natural frequency measurements to detect cracks.

## 4. EXPERIMENTAL ANALYSIS

A composite beam of E Glass Epoxy with dimensions 550mm×50mm×10mm is used for analysis. The transverse cracks were created at different locations with varying depths by using Hack saw [32 teeth per inch]. The beam is excited for free vibrations to obtain the natural frequencies. The beam is clamped on a table with the help of clamping device arrangement (baby vice). The impact is applied by striking the hammer at different positions. During free vibrations, the dynamic responses of the beam are measured through the accelerometer as shown in figure. For this test, the position of accelerometer is also varied in order to extract the signals of vibration. The layout of the sensors on the test specimen is depicted in Figure A data acquisition system i.e. vibration analyzer is used to record and transfer measured data to the user interference (laptop) for post processing. Frequency response functions (FRFs) were obtained and analyzed.

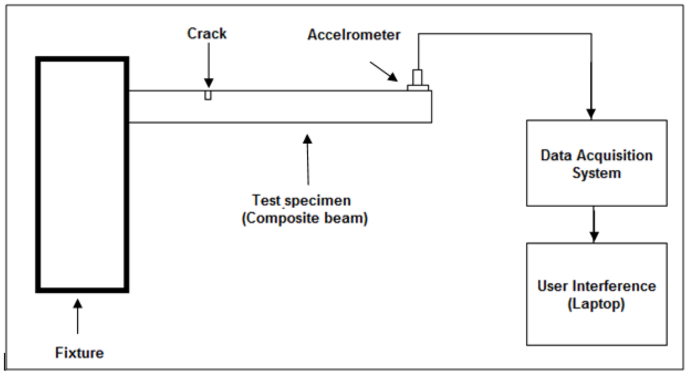


**Fig-1** Block diagram of experimental setup

### *A. Steps in experimental analysis*

1. A composite beam of E Glass Epoxy was used as a cantilever beam.
2. For cantilever beam the fixed end was made by fixing the beam with the help of baby vise fixed on the table.
3. The connections of the accelerometer, impact hammer, vibration analyzer and user interference (laptop) were properly made.
4. The cantilever beam was struck with an impact hammer and is excited by means of it.
5. Accelerometer was placed at the different positions on the cantilever beam, to measure the vibration response.
6. All the data was recorded and obtained from the vibrating beam with the help of accelerometer attached to it.
7. The experiments were repeated to check the repeatability of the experimentation.
8. The whole set of data was recorded and then the data was imported into the user interference (Laptop). Further processing and analysis was done using Virtual unit VA4 Pro software. The signal obtained from the data acquisition system is used to extract the mode frequencies
9. Repeat impact testing procedures and calculate the natural frequency of the structure by varying following parameters such as,
    a) Location of crack.
    b) Depth of crack.

**Fig-2** Experimental setup for crack detection in cantilever beam

## 5. NUMERICAL ANALYSIS

Finite Element Analysis (FEA) approach is widely used these days for numerical analysis. ANSYS is commercial finite element software package which has capability to analyze a wide range of different problems. Modal Analysis is a tool used to determine vibration characteristics or natural frequencies of a mechanical structure. It can also be used for dynamic analysis, harmonic response, and transient dynamic analysis. Modal analysis in ANSYS® is linear analysis. The proposed work is concentrated on determination of natural frequency of vibration. A Composite beam of dimensions 550mm×50mm×10mm with 20 layers of epoxy glass fibers having thickness 0.5mm is modeled using ANSYS 16.2. The material properties for woven glass fabric are considered as $E_{11}$=25GPa, $E_{22}$=25GPa, $E_{33}=0.6E_{11}$, μ=0.2 and modulus of rigidity G=4GPa.The natural frequency and mode shapes for cantilever conditions with and without crack were analyzed for varying crack depth and crack locations. Following procedures for a cracked composite beam were followed for the analysis-

### *A. Steps in numerical analysis*

1. Geometry modeling of composite beam.
2. Selection of element type (here SOLSH190 element of 3D modeling is used).
3. Applying material properties to composite beam (Material modeling > Orthotropic properties)
4. Section Lay-up of composite beam. Specify the thickness of layer (0.5mm), orientation (0/90 orientation), number of integration points.
5. Meshing of model.
6. Apply boundary conditions (one end fixed for cantilever structure) and define number of modes to be extracted.
7. Solution.
8. Perform post processing to read and plot result.

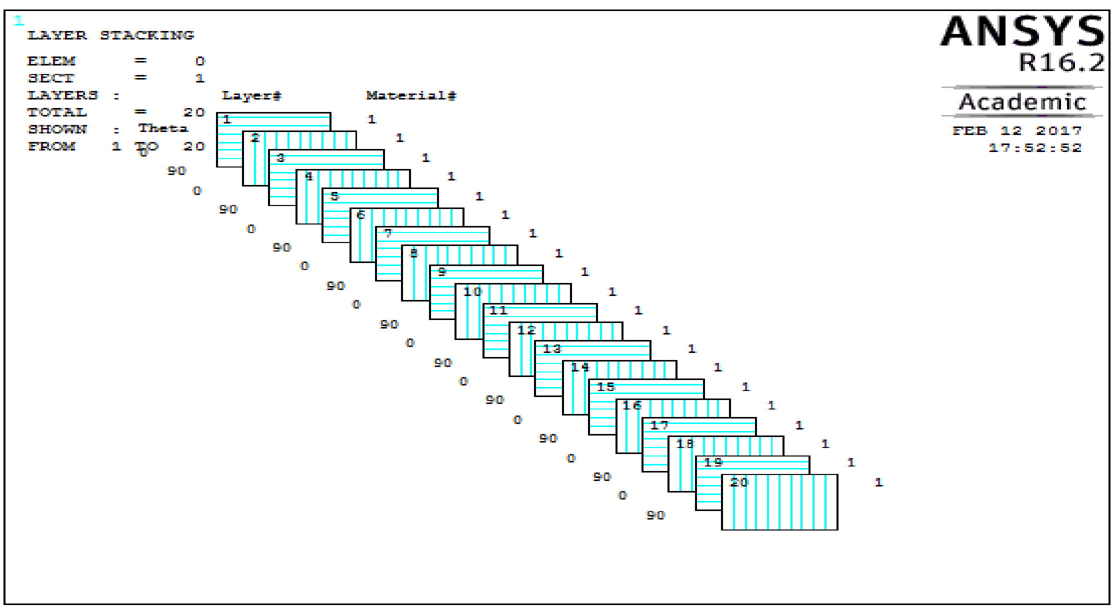


**Fig-3** Layers stacking in ANSYS.

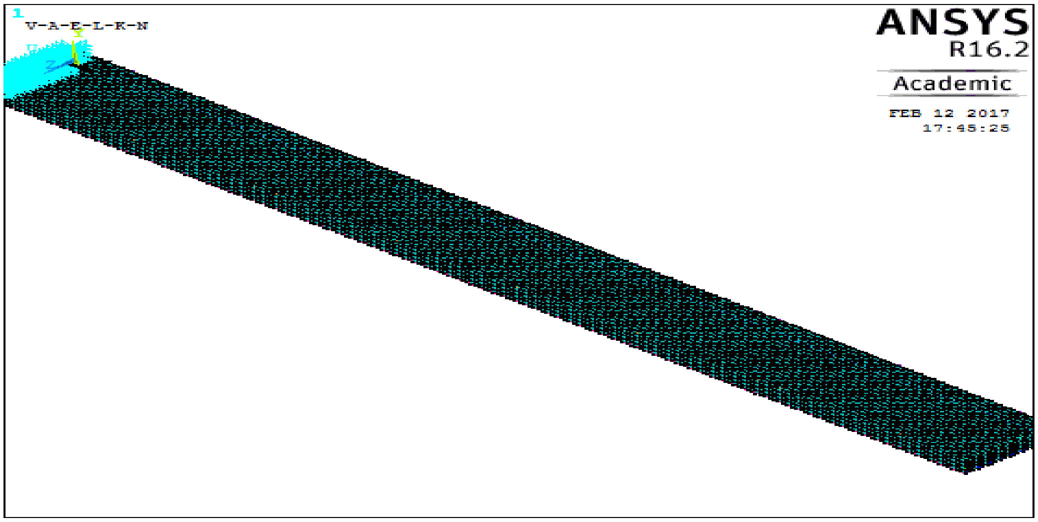


**Fig-4** Meshed composite cantilever beam model.

## 6. RESULTS AND DISCUSSION

The results obtained from the experimental and numerical analysis on cracked composite plate for crack depth 2 mm, 4 mm and 6 mm. The length of the crack is also varied as 110mm, 220mm and 330mm from left hand support.

The 1st, 2nd and 3rd mode natural frequencies in case of both cracked and uncracked composite beams for cantilever condition are shown in Table

| Crack Location (mm) | Crack Depth (mm) | Experimental | | | Numerical | | |
|---|---|---|---|---|---|---|---|
| | | $\omega_1$ (Hz) | $\omega_2$ (Hz) | $\omega_3$ (Hz) | $\omega_1$ (Hz) | $\omega_2$ (Hz) | $\omega_3$ (Hz) |
| Uncracked | - | 17.5 | 91.0 | 118 | 19.390 | 95.627 | 121.14 |
| 110 | 2 | 17.5 | 89.5 | 111 | 19.206 | 95.260 | 121.10 |
| | 4 | 17.0 | 86 | 108 | 18.573 | 93.768 | 121.07 |
| | 6 | 15.0 | 85.0 | 103 | 16.866 | 90.211 | 120.98 |
| 220 | 2 | 17 | 87.5 | 104 | 19.312 | 95.478 | 120.42 |
| | 4 | 16 | 85.5 | 102 | 19.045 | 94.864 | 117.89 |
| | 6 | 16 | 84.5 | 97.5 | 18.241 | 93.324 | 111.23 |
| 330 | 2 | 17.5 | 86.5 | 105 | 19.369 | 95.600 | 120.15 |
| | 4 | 17 | 85 | 100 | 19.303 | 95.456 | 116.68 |
| | 6 | 16 | 83.5 | 98.5 | 19.086 | 95.066 | 107.21 |

**Table-1** Natural frequency for both Uncracked and cracked composite cantilever beam.

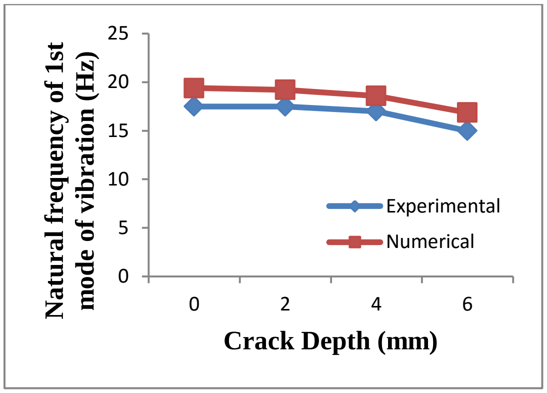


**Fig-5** First mode natural frequencies Vs Crack depth for Crack location 110 mm (Cantilever)

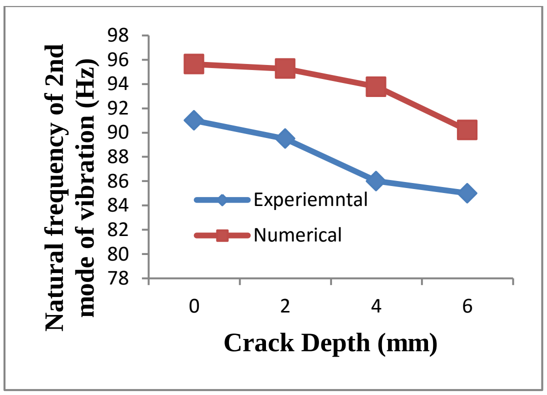


**Fig-6** Second mode natural frequencies Vs Crack depth for Crack location 110 mm (Cantilever)

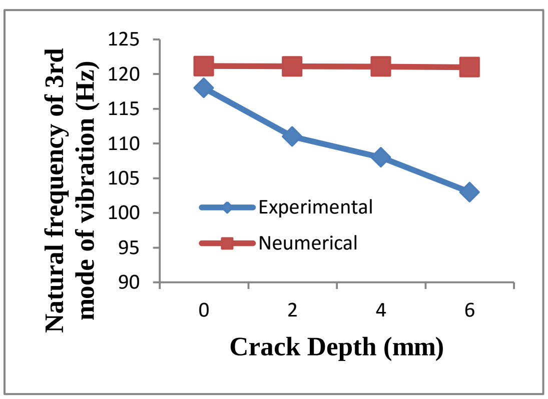


**Fig-7** Third mode natural frequencies Vs Crack depth for Crack location 110 mm (Cantilever)

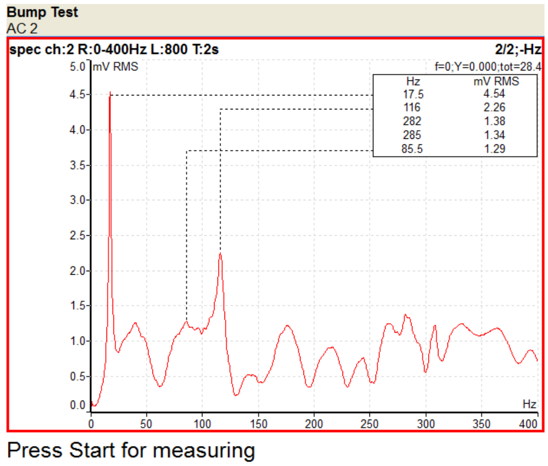


**Fig-8** FRF of Uncracked cantilever beam

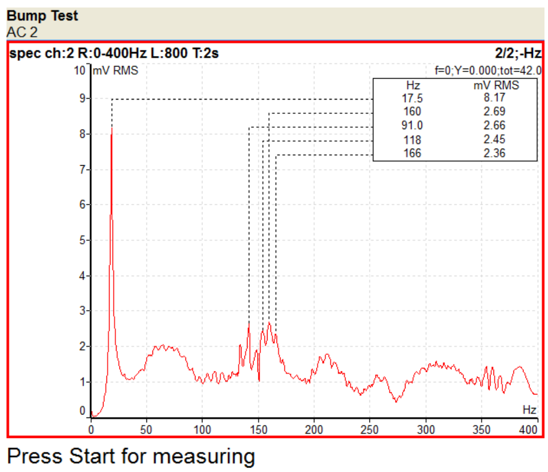


**Fig-10** FRF of cracked cantilever beam at 110mm and depth 2mm.

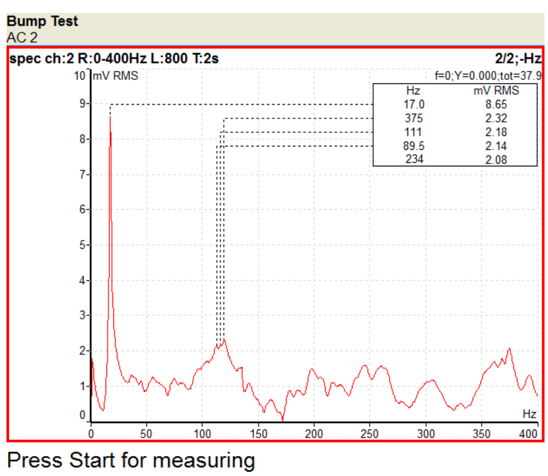

**Fig-9** FRF of cracked cantilever beam at 110mm & depth 4mm.

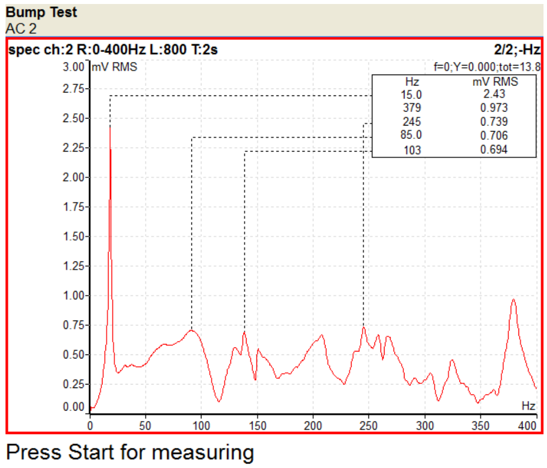


**Fig-11** FRF of cracked cantilever beam at 110mm & depth 6mm.

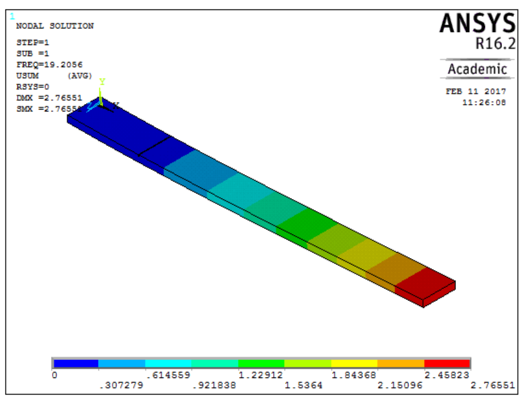


**Fig-12** Deformed shape for 1st mode of vibration of composite cantilever beam for crack at 110mm and depth 2mm.

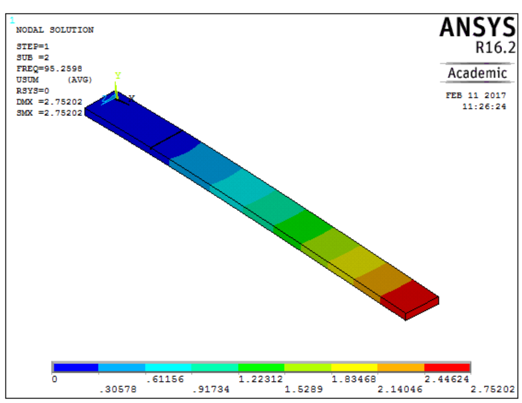

**Fig-13** Deformed shape for 2nd mode of vibration of composite cantilever beam for crack at 110mm and depth 4mm.

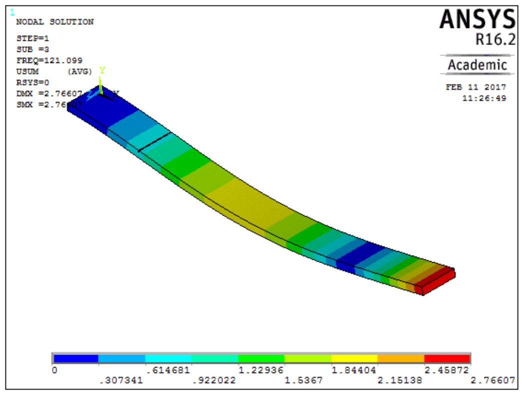


**Fig-14** Deformed shape for 3rd mode of vibration of composite cantilever beam for crack at 110mm and depth 6mm.

## 7. CONCLUSION

It can be seen that the natural frequencies for cantilever conditions decrease with the introduction of a crack. It can be concluded that the natural frequency of vibration of the composite plate decreases with increase in depth of the crack. The natural frequency of the beam decreases with increase in length of the crack from left hand fixed end till the mid span of beam and again starts increasing towards free end.

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