Crack Detection of Cantilever Beam by using FEA

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Abstract - The most common structural defect is the existence of a crack. Cracks are present in structures due to various reasons. The presence of a crack could not only cause a local variation in the stiffness but it could affect the mechanical behavior of the entire structure to a considerable extent. Cracks may be caused by fatigue under service conditions as a result of the limited fatigue strength. They may also occur due to mechanical defects. Another group of cracks are initiated during the manufacturing processes. Generally they are small in sizes. Such small cracks are known to propagate due to fluctuating stress conditions. If these propagating cracks remain undetected and reach their critical size, then a sudden structural failure may occur. Hence it is possible to use natural frequency measurements to detect cracks.

***Keywords* -** Composite beam, Crack depth, crack width, Crack inclination, vibration Analyzer, FEA

I. INTRODUCTION

Now-a-days the plants as well as industries are running round the clock to achieve the industrial goal. During operation, all structures are subjected to degenerative effects that may cause initiation of structural defects such as cracks which, as time progresses, lead to the catastrophic failure or breakdown of the structure. The inspection for quality assurance of manufactured products is thus very much important. To avoid the unexpected or sudden failure, earlier crack detection is essential. Taking this ideology into consideration crack detection is one of the most important domains for many researchers. The most common structural defect is the existence of a crack in machine member. The presence of a crack could not only cause a local variation in the stiffness but it could affect the mechanical behavior of the entire structure to a considerable extent.

II. CRACK THEORY

2.1 Physical parameters affecting Dynamic characteristics of cracked structures:

Usually the physical dimensions, boundary conditions, the material properties of the structure play important role for the determination of its dynamic response. Their vibrations cause changes in dynamic characteristics of structures. In addition to this presence of a crack in structures modifies its dynamic behavior. The following aspects of the crack greatly influence the dynamic response of the structure.

- The position of crack
- The depth of crack
- The orientation of crack

2.2 Classification of cracks

On the basis of geometry, cracks can be broadly classified into:

2.2.1 Transverse cracks

These cracks are perpendicular to the beam axis. Due to transverse cracks the cross-section of the structure got reduced and thus weakens the beam. Due to the reduction in the cross-section it introduces a local flexibility in the stiffness of the beam due to strain energy concentration in the vicinity of the crack tip.

2.2.2 Longitudinal cracks

These cracks are parallel to the beam axis. It is dangerous when tensile load is applied at right angles to the crack direction i.e. perpendicular to beam axis or perpendicular to crack.

2.2.3 Slant cracks

These cracks are at an angle to the beam axis. It influences the torsional behavior of the beam. Their effect on lateral vibrations is less than that of transverse cracks of comparable severity.

2.2.4 Breathing cracks

These are the cracks that open when the affected part of the material is subjected to tensile stresses and close when the stress is reversed. When under tension the stiffness of the component is most influenced. A crack breathes when crack sizes are small, running speeds are low and radial forces are large.

2.2.5 Gaping cracks

These cracks always remain open. They are more accurately known as notches.

2.2.6 Surface cracks

These are the cracks that open on the surface. These can be easily detected by dye-penetrations or visual inspection. Surface cracks have a greater effect than subsurface cracks on the vibration behavior of shafts.

2.2.7 Subsurface cracks

These are the cracks that are not on the surface. Special techniques such as ultrasonic, magnetic particle, radiography or shaft voltage drop are needed to detect hem.

3.3 Modes of Fracture - The three basic types of loading that a crack experiences are

3.3.1 Mode I

Corresponds to the opening mode in which the crack faces separates in a direction normal to the plane of the crack and the corresponding displacements of crack walls are symmetric with respect to the crack front. Loading is normal to the crack plane, and tends to open the crack. Mode I is generally considered the most dangerous loading situation. This mode is called as opening mode.

3.3.2 Mode II

Corresponds to in-plane shear loading and tends to slide one crack face with respect to the other (shearing mode). The stress is parallel to the crack growth direction and perpendicular to crack front. This mode is called as sliding mode.

3.3.3 Mode III

Corresponds to out-of-plane shear or tearing in which the crack faces are sheared parallel to the crack front. Shear stress acting parallel to plane of crack and parallel to crack front. This mode is called as tearing mode.

The following Figure 1 shows the three cracking modes of body.

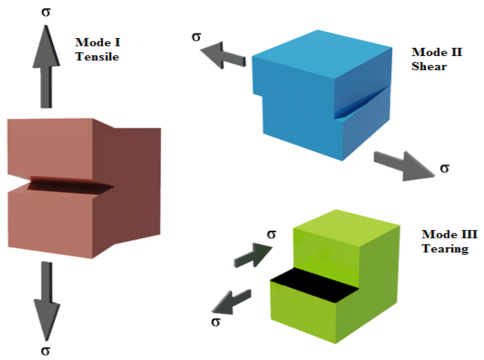


Figure 1 Three Cracking Modes of Body

III. Design Consideration

The cantilever beam with a transverse edge crack is clamped at left end, free at right end and has same cross section and same length like model in Figure 2.1. The Euler- Bernoulli beam model is assumed for the theoretical formulation. The crack in this particular case is assumed to be an open surface crack and the damping is not being considered in this theory. The beam under consideration extends from $x = 0$ to $x = L$ and has a bending rigidity EI, which may be a function of x. The free bending vibration of a beam of a constant rectangular cross section having length l, width b, and depth h is given by the Euler's beam theory. If the cross sectional dimensions of beam are small compared to its length, the system is known as Euler-Bernoulli beam. Only thin beams are treated in it. The differential equation for transverse vibration of thin uniform beam is obtained with the help of strength of materials. The beam has cross section area A, flexural rigidity EI and density of material ρ. The following figure 2.1 shows that cantilever beam.

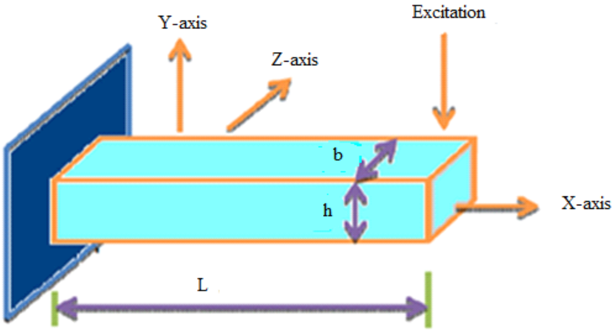


Figure 2.1 Cantilever Beam

The following figure 2.2 shows that cantilever beam with crack.

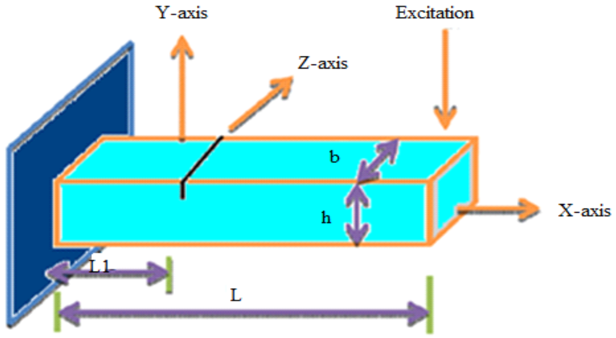
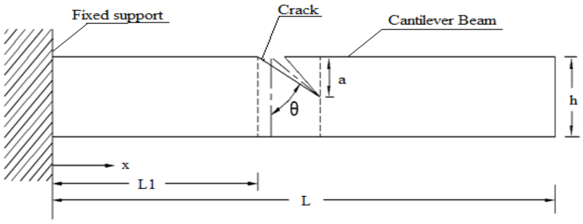


Figure 2.2 Cantilever Beam with crack

The following Figure 2.3 shows that, representation of open edged inclined crack in cantilever beam.



2.3 Representation of open edged inclined crack in cantilever beam.

The continuous model of the beam has been discretized for simplification. According to Ranjan K. Behera, Anish Pandey, Dayal R. Parhi[11] for inclined edge crack cantilever beams,

the difference in the two extreme locations is less than 4%

of the beam length. The relative crack position range 0.1 ≤ c ≤ 0.75 from fixed end and relative edged crack depth range 0.1 ≤ e ≤ 0.5 are tested.

The following assumptions hold well as long as behaves in linear elastic manner.

- Perfect bonding exists between fibres and matrix.
- Both fibres and matrix are isotropic and obey Hooke's law.
- The matrix is free of voids or micro cracks and initially in a stress-free state.
- The applied loads are either parallel or perpendicular to the laminate.
- The laminate thickness is very small compared to its other dimensions.
- Fibres are randomly distributed throughout.

A reference [4] or an equation (3) designation

IV.FINITE ELEMENT ANALYSIS

FEA helps us to obtain new designs to meet the changing conditions in order to avoid material failure. FEA uses a lot of algorithms for its functioning. 2-D and 3-D model analysis are done by FEA in industry.

4.1 Types of analysis done by FEA

I. Structural Analysis

Both linear and non-linear model comes under it. In case of linear models simple parameters are used and it is assumed that the material cannot plastically deformed. In case of non-linear models the material is stressed beyond its elastic properties for which the stress in the material vary with the amount of deformation.

II. Vibrational Analysis

In this the material is tested for shock, impact and continuous and sudden vibrations. These situations affect the natural frequency of the structures and which may cause resonance and subsequent failure.

III. Fatigue Analysis

It helps to predict the life cycle of a material by having cyclic loading on the material. It helps to know the areas more prone to propagation of cracks.

IV. Heat Transfer Analysis

It helps to predict the thermal conductivity or fluid dynamics of the material.

4.2 Role of FEA

FEA helps the designer know all the theoretical stresses within the structure by showing all the problem areas in detail and thus helping the designer to predict the failure of the structure. It is an economic method of determining the causes of failure and the way the failures can be avoided.

4.3 Modal Analysis:

The modal analysis is used to determine the vibration characteristics (natural frequencies and mode shapes) of the structures or machine component while it is being designed. It also can be starting point for another, more detailed, dynamic analysis, a harmonic response analysis, or a spectrum analysis.

The modal analysis used to determine the natural frequencies and mode shapes of structures. The natural frequencies and mode shapes are important parameters in the design of structures for dynamic loading conditions. They are also required if you want to do spectrum analysis or a mode superposition harmonic or transient analysis. We can do the modal analysis on pre-stressed structures such as spinning turbine blade. Another useful feature is modal cyclic symmetry, which allows reviewing the mode shapes of cyclically symmetric structure by modeling just a sector of it. Modal analysis in the ANSYS family of products is a linear analysis. Any non linearity, such as plasticity and contact (gap) elements, are ignored even if they are defined.

Following steps show the guidelines for carrying out Modal analysis.

a) Startup: This path is followed and modal analysis workbench is started, as shown in Figure 3.

ANSYS > workbench > modal

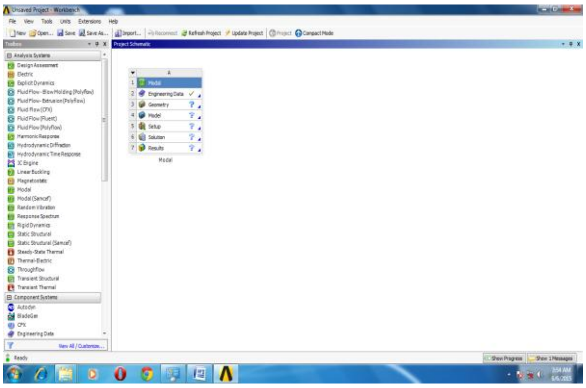


Figure 3 Startup Path

b) Engineering data: The engineering data refers to the physical properties of the material. The new material named E-Glass Epoxy is entered and selected as 'the default material for object'.

c) The isotropic density is entered as 2000 kg/m^3. Poisson's ratio = 0.30, young's modulus of elasticity = 39 GPa.

Table 6.1 Material Properties

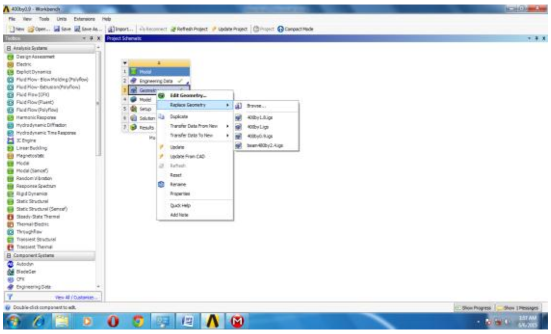
Sr. No.	Property	Value	Unit
1	Mass Density (ρ)	2000	Kg/m^3
2	Young's Modulus (E)	39×10^{3}	N/mm^2
3	Poisson's Ratio ()	0.30	-

d) Save: Save the file in the preferred location.

Save > File name

e) Geometry: The required cantilever beam is designed in catia and saved with the extension of '.igs' and then imported to ANSYS, as shown in Figure 3.2.

Geometry > Import geometry> .igs file > Open



f) Modal:

- **Mesh** The mesh is used to divide the element into number of parts. Fine mesh is generated in this problem which increases the accuracy.

  Mesh >Mesh setting > Fine mesh

  Mesh >Right click > Generate mesh

- **Support** The fixed support is provided at the end of beam to transform the beam to cantilever.

  Select the surface to be Fixed > Insert > Support >Fixed support.

- **Number of modes** in this case four number of modes are selected.

  Analysis setting > Number of modes > 3.

g) Solution: After entering above settings the solution is being solved for modal results. Figure 3.3 shows that solution of model.

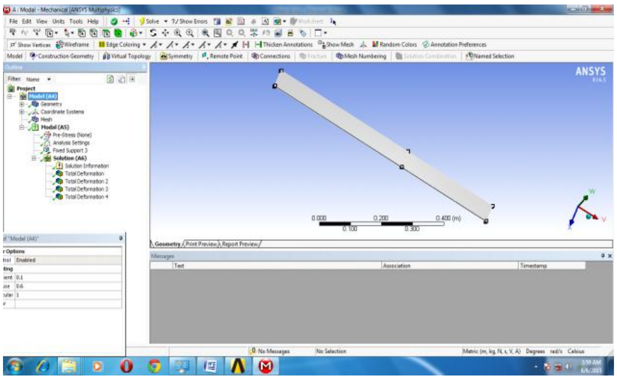


Figure 3.3 Solution of Model

- Generating the model in designing software:

The designing software used here is CATIA VR19. The model of the beam having crack is generated in Catia software with different crack location, crack depth and various crack inclination. Figure 6.4 shows that cantilever beam in CATIA V5R19.

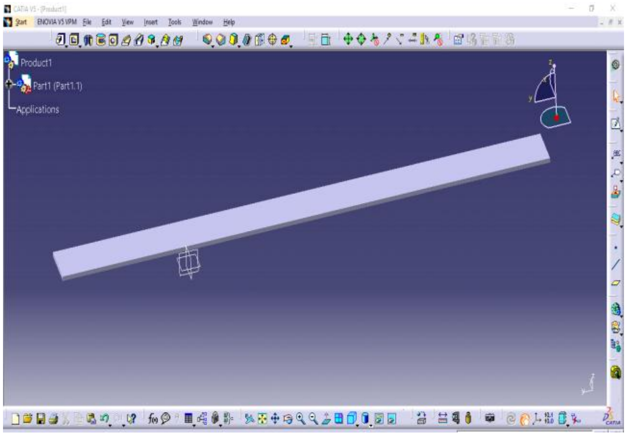


Figure 3.4 Cantilever beam in CATIA V5R19

Figure 3.5 shows that model having crack in CATIA V5R19.

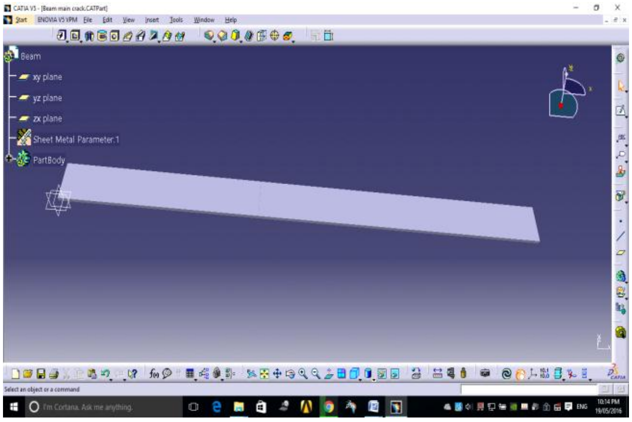


Figure 3.5 Model having crack in CATIA V5R19

Figure 3.6 shows that side view of crack.

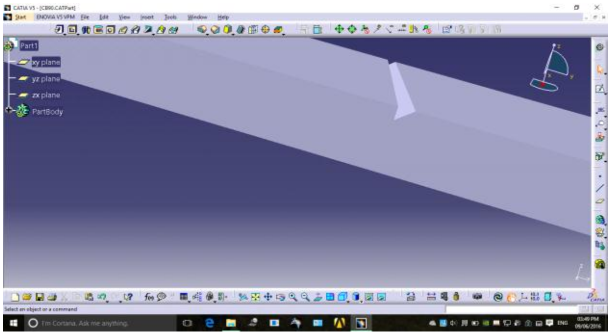


Figure 3.6 Side view of crack

Figure 3.7 shows that magnified view of crack.

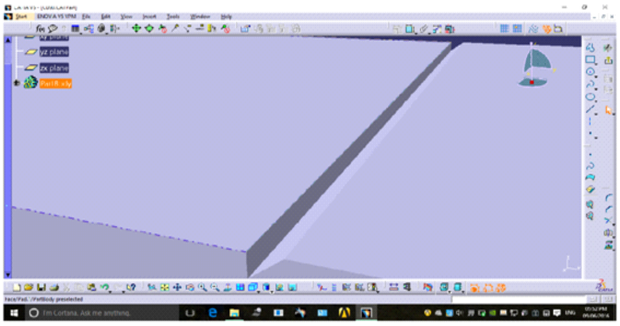
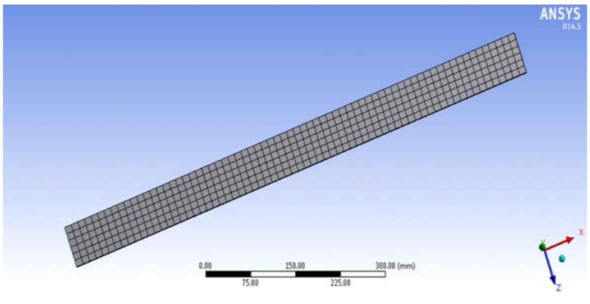


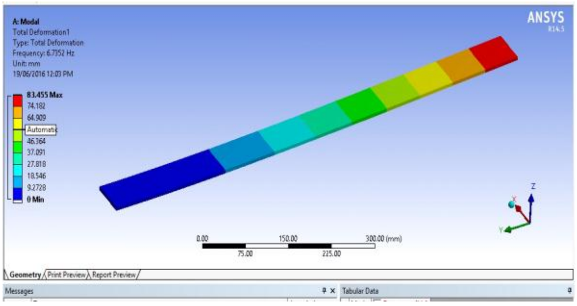
Figure 3.7 Magnified View of crack

Figure 3.8 shows that mesh modal of beam.



The modal becomes as follows

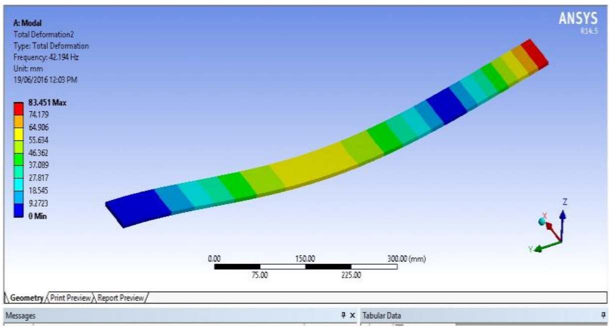
The first three natural frequencies and corresponding mode shapes are calculated by FEA using ANSYS workbench 14.5. Figure 3.9 shows that first Mode shape of uncracked beam.



A: Modal
Total Deformation1
Type: Total Deformation
Frequency: 6.7352 Hz
Unit: mm
19/06/2016 12:03 PM

Figure 3.9 First Mode shape of uncracked beam

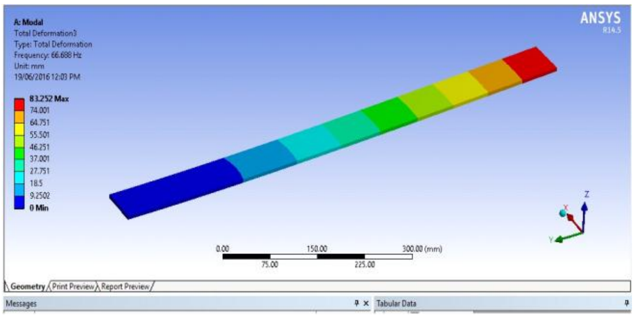
Figure 3.10 shows that second mode shape of uncracked beam.



A: Modal
Total Deformation2
Type: Total Deformation
Frequency: 42.194 Hz
Unit: mm
19/06/2016 12:03 PM

Figure 3.10 Second Mode shape of uncracked beam

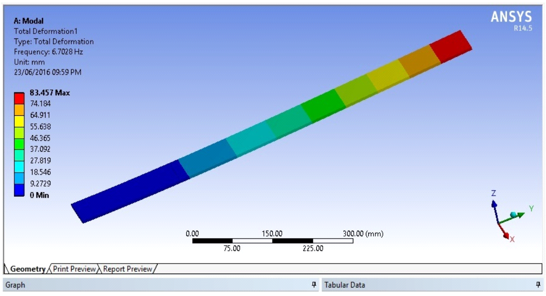
Figure 3.11 shows that third mode shape of uncracked beam.



A: Modal
Total Deformation3
Type: Total Deformation
Frequency: 66.688 Hz
Unit: mm
19/06/2016 12:03 PM

Figure 3.11 Third Mode shape of uncracked beam

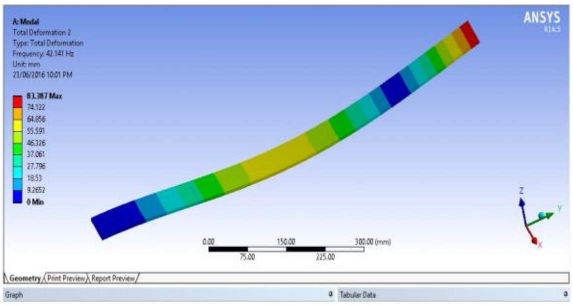
Figure 3.12 shows that first Mode shape of cracked beam with c=0.25, e=0.30, θ=15^0



A: Modal
Total Deformation1
Type: Total Deformation
Frequency: 6.7028 Hz
Unit: mm
23/06/2016 09:59 PM

Figure 3.12 First Mode shape of cracked beam with c=0.25, e=0.30, θ=15^0

Figure 3.13 shows that second Mode shape of cracked beam with c=0.25, e=0.30, θ=15^0



A: Modal
Total Deformation 2
Type: Total Deformation
Frequency: 42.141 Hz
Unit: mm
23/06/2016 10:01 PM

Figure 3.13 Second Mode shape of cracked beam with c=0.25, e=0.30, θ=15^0

Figure 3.14 shows that third mode shape of cracked beam with c=0.25, e=0.30, $\theta=15^0$.

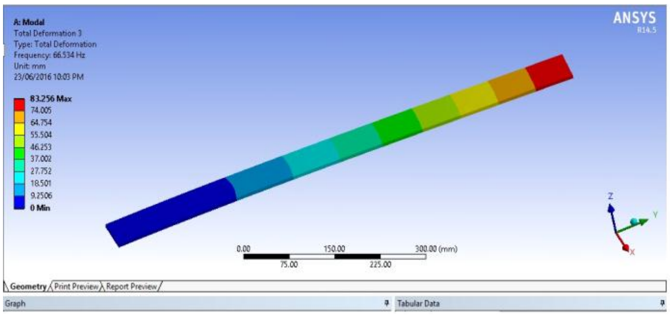


Figure 3.14 Third Mode shape of cracked beam with c=0.25, e=0.30, $\theta=15^0$

Figure 3.15 shows that first mode shape of cracked beam with c=0.35, e=0.30, $\theta=30^0$.

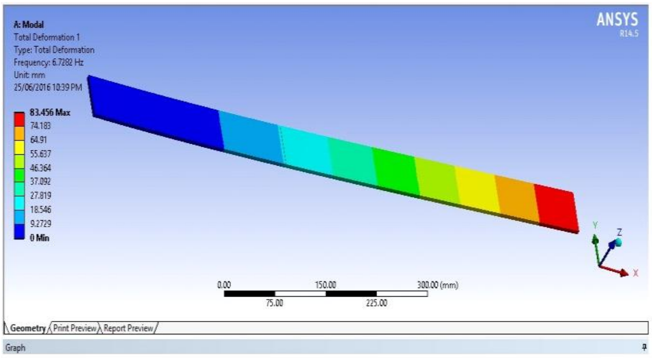


Figure 3.15 First Mode shape of cracked beam with c=0.35, e=0.30, $\theta=30^0$

Figure 3.16 shows that second Mode shape of cracked beam with c=0.35, e=0.30, $\theta=30^0$.

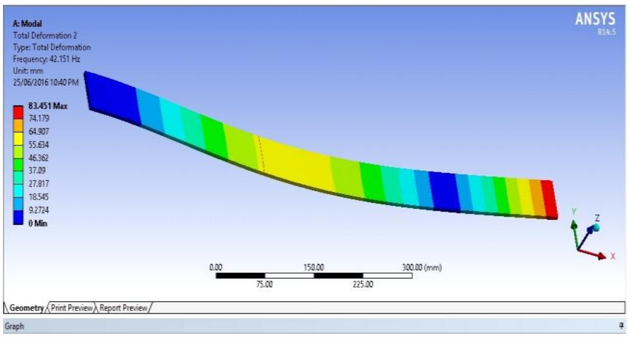


Figure 3.16 Second Mode shape of cracked beam with c=0.35, e=0.30, $\theta=30^0$

Figure 3.17 shows that third mode shape of cracked beam with c=0.35, e=0.30, $\theta=30^0$.

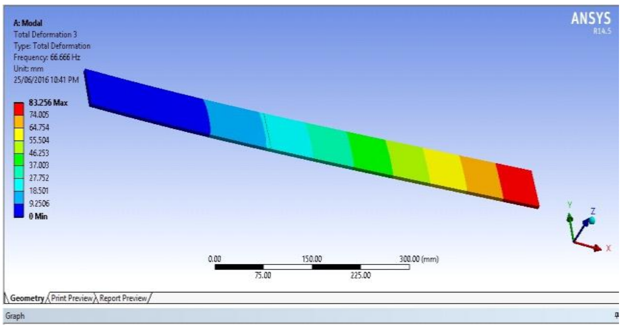


Figure 3.17 Third Mode shape of cracked beam with c=0.35, e=0.30, $\theta=30^0$

Figure 3.18 shows that first mode shape of cracked beam with c=0.20, e=0.10, $\theta=45^0$.

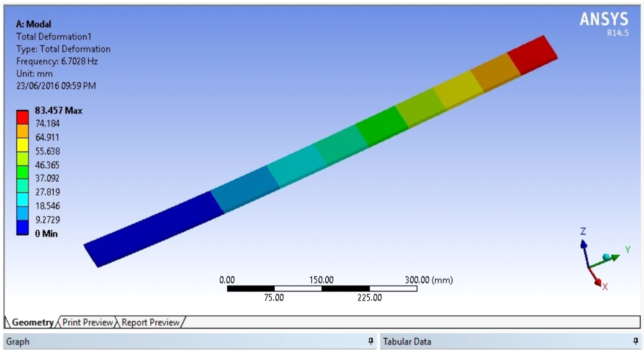


Figure 3.18 First Mode shape of cracked beam with c=0.20, e=0.10, $\theta=45^0$

V. Conclusions

- It is found that if crack location and crack inclination is constant then crack depth is increases natural frequency is decreases.
- If crack depth and crack inclination is constant then crack location is increases natural frequency is increases.
- Crack is near to fixed end it imparts more reduction in natural frequency.
- The present study provides an efficient non destructive technique for the detection and prediction of the current size and position of the crack for any composite structure system.

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BIOGRAPHIES

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