

# Vibration Analysis of Stepped Laminated Composite Beam in ANSYS

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## Abstract

Composite beams and beam like elements are major constituents of various structures and are being used widely now a day. A numerical study using finite element was performed to analyze the free transverse vibration response of composite stepped cantilever beam due to transverse crack. Crack is a damage that often occurs in members of structures and may cause sudden catastrophic failure of the structures. The finite element software ANSYS was used to stimulate the free transverse vibrations. The parameters studied were the effects of ply angle of the fibers, the location of cracks relative to the restricted end, depth of cracks, fiber volume fraction and support conditions. By this research work it was analyzed that an increase in the depth of the cracks leads to a decrease in the values of natural frequencies, also crack location and support have great effect over natural frequencies in case of free transverse vibration. The value of natural frequency was found to be higher in case of clamped-clamped configuration compared to clamped free configuration.

**Keywords:** Composite beam, transverse vibration, composite stepped beam, cantilever beam, catastrophic failure, ply angle, ANSYS, clamped-clamped, clamped-free configuration.

## 1. Introduction

Materials are too much essential for each and every industry. Accessibility of desirable properties such as, improved specific strength, high fatigue strength, flexibility in design, high impact strength, light weight, dimensional stability, non-corrosiveness and a wide scope of properties make composites beneficial and crucial in application. Just because of attracting properties of the composite materials,

these are going to be utilized adequately in infrastructure, marine boats, aerospace industry and avionics industry.

Basically, composite materials are characterized as the materials comprised of at least two materials which must not be dissoluble themselves i. e. having considerably different chemical and physical properties. When united, they should provide a resultant material with different characteristics from the individual ones. These days almost all alloys and metal products are being replaced with composite materials because of their high strength to weight proportion and also good forming capabilities. Use of composite materials in 3D printing as crude materials makes them more desirable and depicts great extent of composite materials for future. After the mechanical insurgency, new materials were created depending upon applications like enterprises initially began to use metals and then alloys and these days industries are concentrating on composite materials because of the different inadequacy of alloys. However, alloys give excellent properties but because of confinements like Hume-Rothery rule and other properties composites are considered superior to them.

Generally, composite materials have reinforcement phase and matrix phase. Matrix phase is continuous and used for bonding while, reinforcement phase provides strength to composites. Plywood, reinforced concrete, fiberglass are some of the perfect examples of composite materials.

Vibration analysis is required for practical application of every structure for its better performance. Also, every system has its own permissible limit of natural frequency. When the permissible limit is reached or crosses by frequency caused due to external force then sudden failure (catastrophic failure) occurs. To avoid these conditions it is

very essential to know about the natural frequency of any structure which has mass and elasticity properties.

To prevent failure of any structure which occurs due to undesired vibrations, it is important to determine;

1. Natural frequencies, for avoiding the resonance condition.
2. Damping factors.
3. Mode shapes for establishing the most versatile indicators or to choose the right position so that weight can be decreased or to increase damping.

## 2. Reviews on vibrations of cracked composite beams

**Nikpur *et al.*** obtained the local compliance matrix for the composite materials which were unidirectional. It was concluded that the interlocking deflection modes were improved as a purpose of degrees of anisotropy of composites

**Ostachowicz *et al.*** offered a technique to examine the impact of two surface cracks which were open upon the frequencies for the flexural vibrations on a cantilever beam. Here two category of cracks (double sided and single sided) were analyzed. Double-sided cracks occur when there is cyclic loading and occurrence of single-sided cracks is an outcome of fluctuating loading. The assumption of occurrence of cracks in the primary modes of fracture which is also called opening mode was also taken.

**Krawczuk *et al.*** originated a new beam finite element along with a solitary non- propagating one-edge open crack positioned at its mid-length for the static and dynamic observations of the structures like cracked composite beams. This component had 2 degrees of freedom at each of the three nodes: deflection in transverse direction and an autonomous rotation individually. The ideal numerical examinations explaining variations in the static alterations and a basic natural frequency of composite cantilever bars caused by a single crack were presented.

**Zak *et al.*** formulated the work models of a finite element delaminated beam and delaminated plate component. A broad practical investigation was conceded out to record variations in the 1<sup>st</sup> three bending natural frequencies because of delamination. The outcomes of the mathematical calculations were almost same as the outcomes of the experimental observations.

**Banerjee (2001)** obtained exact terms for the frequency equations and mode shape of Timoshenko composite beam having cantilever end conditions in open analytical form using figurative calculations. Influence of material coupling in between torsional and bending modes of buckling, accompanied by the impact of shear deformation and rotating inertia was taken into consideration while formulation of the theory. The expressions analyzed for the mode shapes were also resulting in explicit form using figurative computation.

**Wang *et al.*** examined the vibrations of a circular shaped plate surface reinforced by two piezoelectric layers, considering the Kirchhoff plate model. The nature of the electric potential field in the piezoelectric layer was expected

to be like that of the Maxwell electricity produced via friction condition. The theoretical model was approved by contrasting the frequencies of resonance of the piezoelectric coupled round plate acquired by the hypothetical model and those acquired by limited component examination. The mode shapes of the electrical potential acquired from free vibration examination was appeared to be non-uniform for most of the part. The piezoelectric layer was appeared to affect the frequencies of the structure. The proposed display for the examination of a coupled piezoelectric plate gave a way to acquire the conveyance of electric potential in the piezoelectric layer. The model gave a plan reference for applying piezoelectric material, for example, an ultrasonic engine.

**Gaith *et al.*** executed vibration theory of a continuously cracked beam for lateral vibration of cracked Euler – Bernoulli beam having one-edge open cracks. Crack detection for simply supported graphite/epoxy fiber-reinforced composite beam was taken into account. The impact of crack depth, crack position, faction of fiber volume and its direction on the elasticity and therefore on natural frequency and mode shapes for cracked fiber- reinforced composite beam was examined.

**Lu and Law *et al.*** analyzed the impact of multiple cracks in the finite beam element by the help of dynamic analysis and local crack detection. The beam element was originated by the composite element technique with a one-member – one-element relationship with cracks where the interactive effect among cracks in the same component was included itself. The accuracy and convergence speed of the planned model in addition were validated with the use of existing models and experimental outcomes. The need of adjustment was find out by the crack parameters when this planned model was used.

## 3. Material and Methods

### 3.1. Governing Equation

Under the situation of mid-plane symmetry bending a beam (  $j = 0$  ) means there is no displacement under transverse shear and no combine effect of stretching-bending (  $\epsilon_{xx} = 0$  ), the differential governing equation is given by,

$$IS_{11} \frac{d^4 \omega}{dx^4} = q(X) \quad (1)$$

In general composite material is assumed as orthotropic in nature the above expression is for orthotropic material. For an isotropic beam having rectangular cross-section:  $IS_{11} = EI$ .

In the present analysis under the above governing equation conditions the effect of Poisson's ratio is ignored in beam theory as taken by Vinson & Sierakowski (1991). Static force is assumed in force per unit length in the equation (1). By applying D'Alembert's Principle, product of mass and acceleration per unit length term is added in the above expression then the expression becomes,

$$IS_{11} \frac{d^4 \omega}{dx^4} = q(x,t) - \rho A \frac{d^2 \omega(x,t)}{dt^2} \quad (2)$$

Both  $\omega$  and  $q$  in the above expression are depends on time

and space means both are function of time and space, thus used derivatives are partial derivatives,  $\rho$  is density of beam A is cross-sectional area of the beam. The term  $q(x, t)$  used in the above expression is varying time space dependent forcing function which is as a result of dynamic response. The response is possibly the result of intense-one time impact or harmonic oscillation.

The formula for moment of inertia in case of stepped beam is given as follows, which is used to calculate moment of inertia in classical method.

$$I_{eq} = \frac{(L_{Total})^3}{\frac{(L_1')^3}{I_1} + \frac{(L_2')^3 - (L_1')^3}{I_2}} \quad (3)$$

It is required to know about the natural frequencies of beam in different boundary conditions to make sure that there must not be any cyclic forcing function nearer to the natural frequencies value. The cyclic forcing function possibly because of sudden failure (catastrophic failure) of the structure. For finding the natural frequency the expression in radian/unit time is given by,

$$\omega_n = \alpha^2 \sqrt{IS_{11}/\rho AL^4} \quad (4)$$

In the above expression  $\alpha^2$  is co-efficient which is specified by Warburton et al. For finding the natural frequency expression in cycles per unit time (Hertz) is given by

$$f_n = \frac{\omega_n}{2\pi} \quad (5)$$

For free vibration condition Governing equation which governs of the beam is given by

$$[K] - \omega^2[M]\{q\} = 0$$

In above expression,

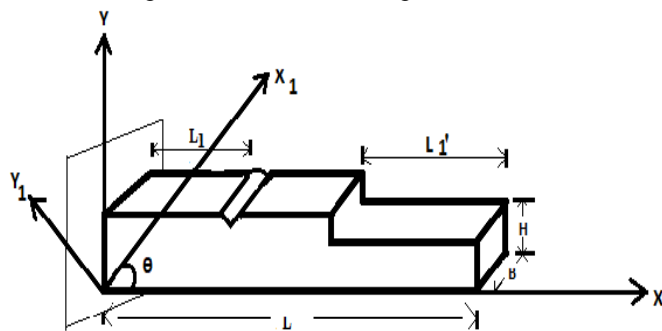
K= Stiffness Matrix

q = Degree of Freedom

M= Mass Matrix

### 3.2. Model of Beam

In the present, analysis a prismatic cantilever composite stepped beam of rectangular cross-section is used which have a transverse crack at a distance  $L_1$  from the fixed end, and a depth of crack 'a'. In the present model of beam



crack is transverse crack having V-shape. Length (L) and height (H) and width (B) towards the right side of the beam is shown in fig. 3.1. All the fibers are assumed to be oriented at an angle  $\theta$ .

**Fig. 3.1** Labelled layout of composite stepped beam with transverse crack in clamped-free configuration.

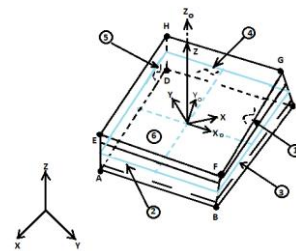
### Steps of Simulation in ANSYS APDL

In General procedure of simulation in ANSYS is independent to the analysis. It follows same steps in all type of analysis which are given below:

1. Pre-processing
2. Solution stage
3. Post-processing

### 3.3. Description of used elements

Solid shell type of element is used in the present analysis which shows two merge properties of shell element and solid element. **Solid shell 190 (SOLSH 190)** element is used in the present analysis



**Fig. 3.2.** Geometry of SOLSH 190 element

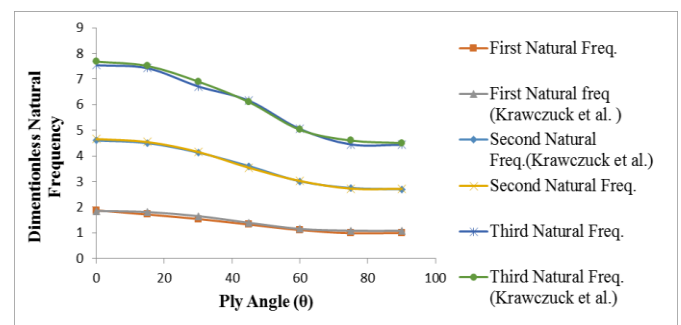
**Table 3.1.** Properties of Boron Epoxy

Young's Modulus (GPa)	Em	3.25
	Ef	393
Modulus of Rigidity (GPa)	Gm	1.25
	Gf	163.75
Poisson's Ratio	vm	0.3
	vf	0.2
Mass Density (kg/m <sup>3</sup> )	ρm	1250
	ρf	2700

Where m & f represents the properties of matrix and fiber respectively.

### 4. Results and Discussions

First of all validation is done for Graphite polyamide and results are compared with Krawczuck & Ostachowicz for perfect cantilever unidirectional composite beam.



**Fig.4.1.** Ply Orientation Angle ( $\theta$ ) as a factor for first three dimensionless natural frequencies of perfect cantilever composite beam for Fiber Volume Ratio ( $V$ ) = 0.1

### Effect of various factors on natural frequencies

Effects of various factors like beam length (L), support boundary conditions, Fiber Volume Ratio (V) and influence of Ply Orientation Angle on first three lowest Nat. Freq. are investigated.

#### 4.1. Analysis for vibration behavior of unidirectional composite stepped perfect beam

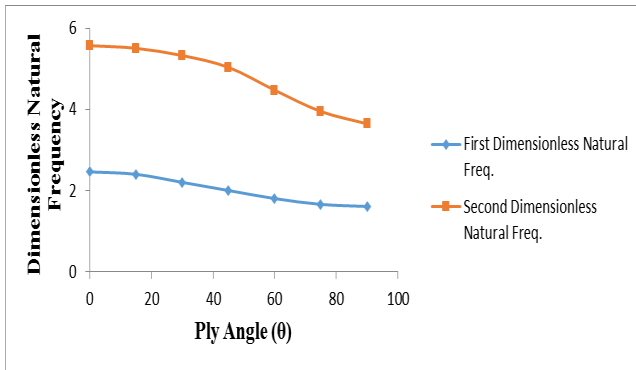


Fig. 4.2 Analysis for vibration behavior of unidirectional composite stepped cantilever beam with single transverse crack

#### 4.2. Analysis for vibration behaviour of unidirectional composite stepped cantilever beam with single transverse crack

##### 4.2.1. Influence of Fiber Volume Ratio on natural frequencies for different relative crack depth 0.3, 0.6 and 0.9 (Crack Position $L_1/L=0.2$ )

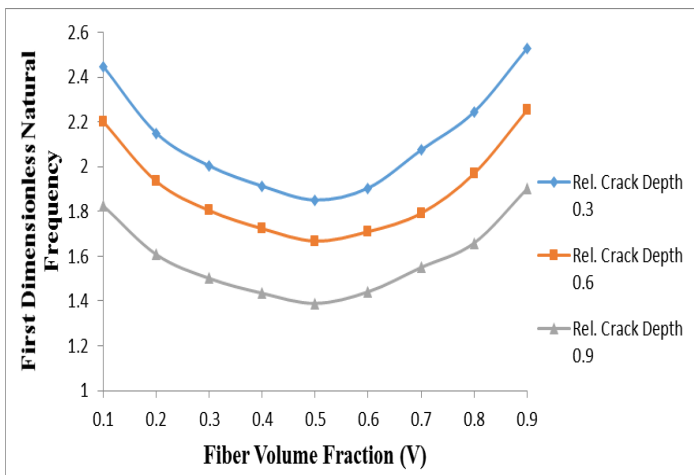


Fig. 4.3. Fiber Volume Ratio (V) as a factor for first dimensionless natural frequency of a single cracked unidirectional composite stepped cantilever beam of boron epoxy

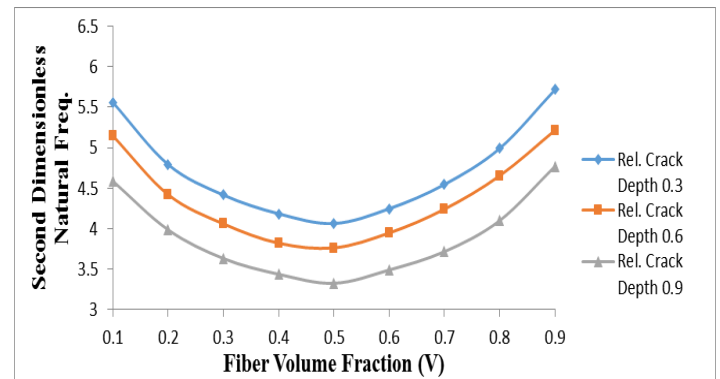


Fig. 4.4. Fiber Volume Ratio (V) as a factor for second dimensionless Nat. Freq. of a single cracked unidirectional composite stepped cantilever beam of boron epoxy

#### 4.3. Influence of Ply Orientation Angle on natural frequencies for Crack Position=0.3

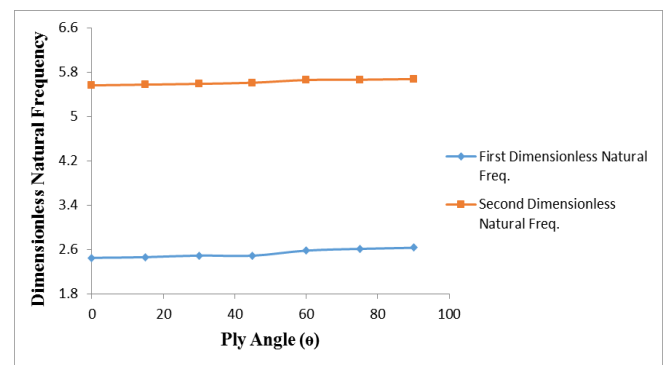


Fig. 4.5. Ply Orientation Angle as a function of Nat. Freq. for boron epoxy beam for Fiber Volume Ratio ( $V=0.1$ )

#### 4.3. Influence of support condition on natural frequencies for different Ply Orientation Angle of fibers (Fiber Volume Ratio $V=0.5$ )

##### (a) Influence on perfect stepped beam

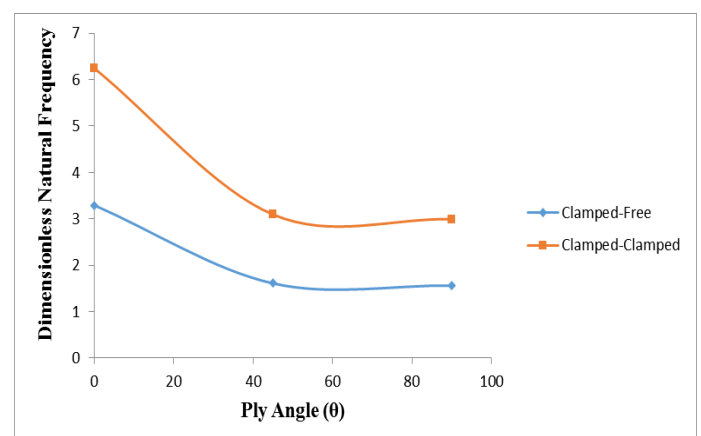


Fig. 4.6. Different boundary conditions as a factor for first dimensionless natural frequencies of perfect stepped beam of boron epoxy

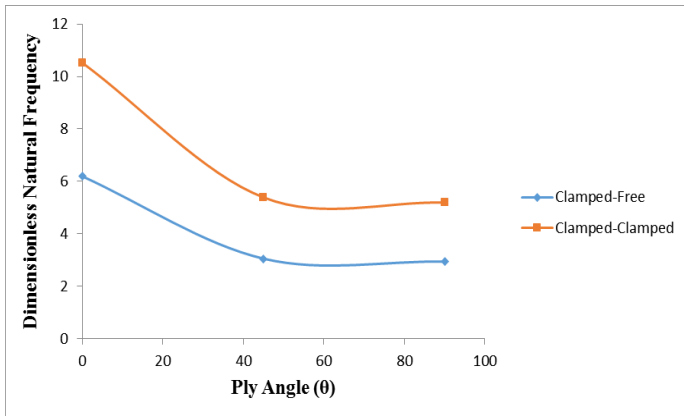


Fig. 4.7. Different boundary conditions as a factor for second dimensionless natural frequencies of perfect stepped beam of boron epoxy

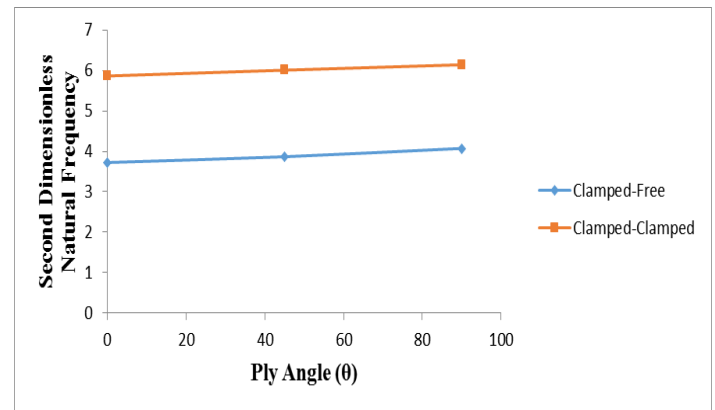


Fig. 4.10. Different boundary conditions as a factor for second dimensionless natural frequencies of composite stepped beam with crack of boron epoxy

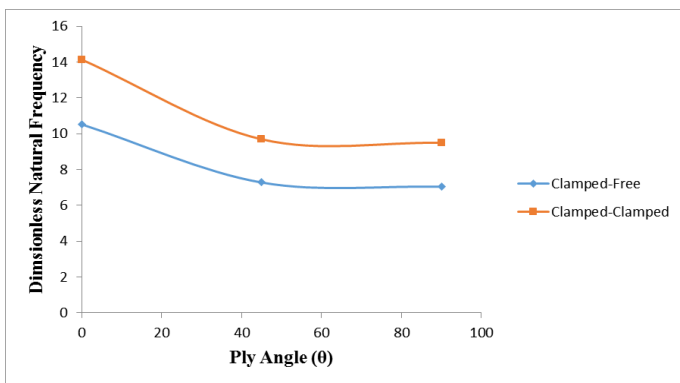


Fig. 4.8. Different boundary conditions as a factor for third dimensionless natural frequencies of perfect stepped beam of boron epoxy

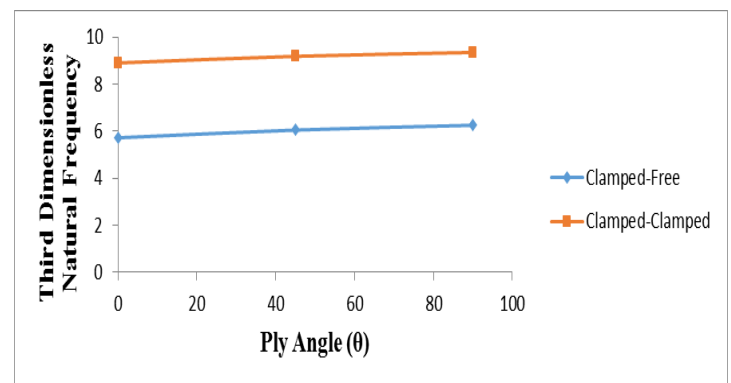


Fig. 4.11. Different boundary conditions as a factor for third dimensionless natural frequencies of composite stepped beam with crack of boron epoxy

#### (b) Influence on beam with relative crack depth .2

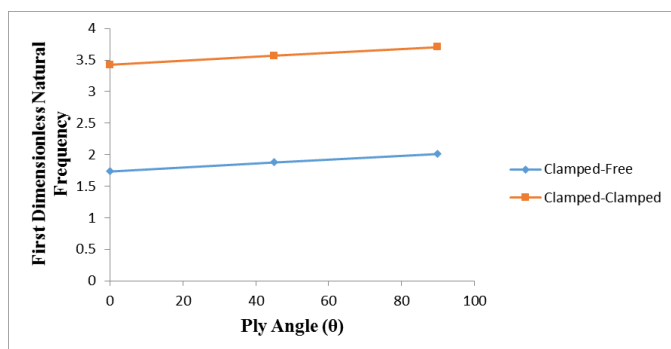


Fig. 4.9. Different boundary conditions as a parameter for first dimensionless natural frequencies of composite stepped beam with crack of boron epoxy

#### 4.4. Influence of Crack Position on Nat. Freq.

##### (a) For clamped-free configuration in stepped beam

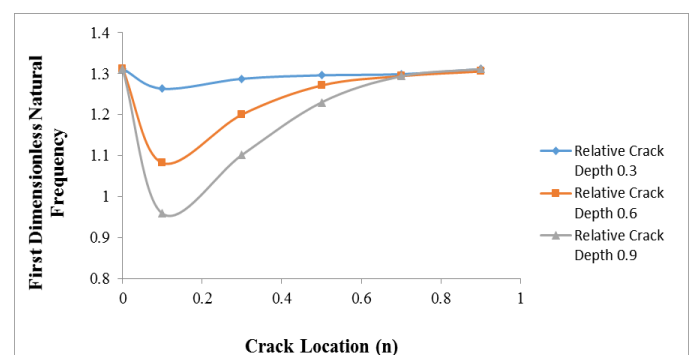


Fig. 4.12. Crack Positions a factor for first dimensionless Nat. Freq. of stepped beam for different relative crack depth ratios for boron epoxy

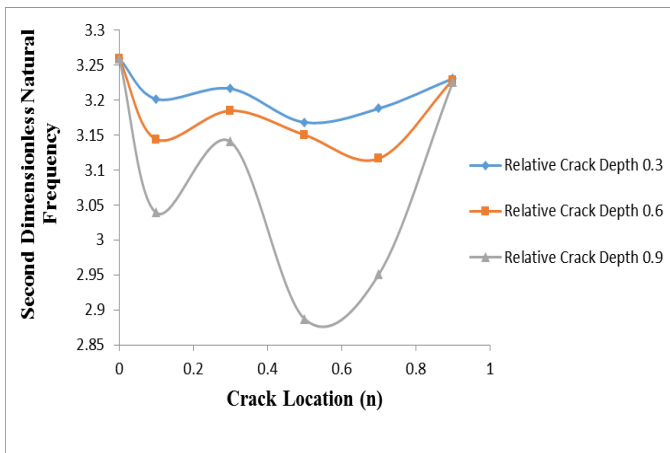


Fig. 4.13. Crack Positions a factor for second dimensionless Nat. Freq. of stepped beam for different relative crack depth ratios for boron epoxy

**(b) For clamped-clamped configuration in stepped beam**

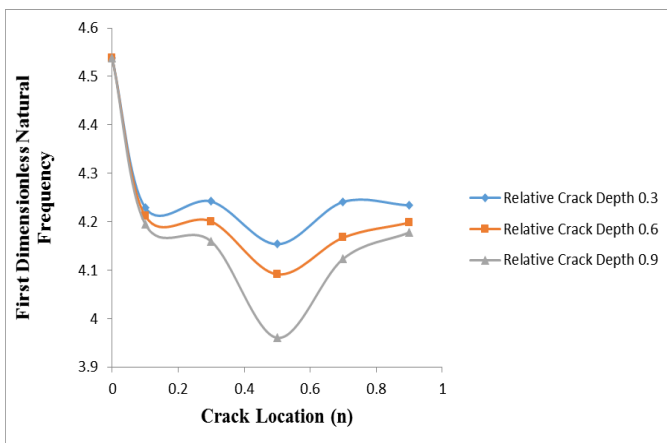


Fig. 4.14. Crack Positions a factor for first dimensionless Nat. Freq. of stepped beam for different relative crack depth ratios for boron epoxy

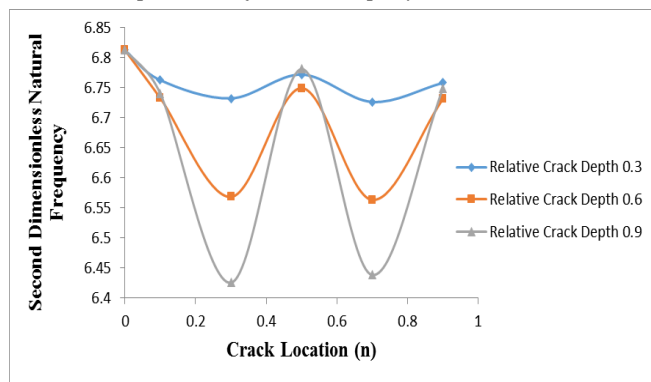


Fig. 4.15. Crack Positions a factor for second dimensionless Nat. Freq. of stepped beam for different relative crack depth ratios for boron epoxy

**5. SUMMARY AND CONCLUSION**

1. Generally, with increase in the ply orientation angle of fibers under the bending condition the values of natural frequency decreases at  $0^\circ$  orientation angle of fibers t the natural frequency has maximum value and then with the increase of ply angle of fibers it starts decreasing progressively, then at  $90^\circ$  natural frequency has minimum value.
2. For composite stepped beam with crack of unidirectional fibers, the value of natural frequency increases with the increase in the value of the angle of orientation at  $90^\circ$  natural frequency has maximum value and minimum value of natural frequency is at  $0^\circ$ .
3. The beam with crack becomes more flexible for the value of fiber volume fraction was in between 0.2 to 0.8 and maximum values of flexibility has seen at the value of fiber volume fraction  $V=0.5$ .
4. The value of natural frequencies is highest for the crack locations  $L_1/L = 0.1$  and  $L_1/L = 0.9$ , the value of first natural frequency is lowest at  $L_1/L = 0.15$  and second natural value is lowest at  $L_1/L=0.55$ .
5. It is clear by the present investigation for clamped-clamped configuration first natural frequency has lowest value for crack location of 0.5 and highest at the end points of beam. For second natural frequency lowest value is obtained at 0.3 and 0.7 which are approximately same.

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