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Free Vibration Analysis of Laminated Crack Composite Beam

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ABSTRACT

Composite beams are now being employed in automotive, aerospace, and other fields. One of the most serious damages to isotropic and composite materials is cracking. Since it significantly affects the member's stiffness and strength, these damages are a significant factor in increasing vibration amplitude, which results in catastrophic failures. The dynamic loads placed on the damaged composite beams cause them to vibrate, which has a technical impact on the system's structural integrity. This work deals with the free vibration analysis of laminated composite plates through finite element analysis using ANSYS. The primary objective of this paper is to present the free vibration response of an isotropic and laminated composite beam with many transverse fractures. The effect of different crack sizes and location on the beam is studied in this paper. The study's methodology offers an easy, quick, and accurate way to ascertain the natural frequencies of laminated and isotropic composite beams.

Keywords: Composite material, Beam, Finite element analysis, crack

Introduction

Damage is generally defined as changes to the material or geometric properties of structural or mechanical systems which negatively affect current or future performance of those systems. In structural components, cracks are one of the frequent flaws that, if left unchecked, can eventually cause structures to fail. Due to crack in the structure, there is a variation in the structure's stiffness. The structural stiffness variation depends on the location and depth of the cracks which affects the dynamic behaviour of the whole structure. Vibration response of composite beam with cracks is an important research in the field of structural engineering. Crack in composite beams can cause significant changes in the behaviour of the beam, leading to increased vibration and potential failure. With increasing use of composite materials in mechanics, aerospace, marine, civil and many other industries, The scientific and technical community have evolved to pay greater attention to structural health monitoring (SHM) for isotropic and composite materials.

Yet, in the presence of damages that may be a mixture of failure modes such matrix cracking, fiber pullout, fiber fracture, fiber-matrix deboning, and delaminating between plies, the mechanical properties of composites may significantly deteriorate.

Many researchers examined the extensive research on damage detection in conventional and laminated composite beams. Damage processes in composite materials are more complicated than those in traditional materials; as a result, mechanical behaviour is an essential component of an effective and reliable damage detection system.

LITERATURE REVIEW:

Das et.al had experimented that the effect of crack depth and position of the crack on the natural frequencies with Clamped-Free (CF) and Clamped-Clamped (CC) beam . It is noted that the effect of crack location on the natural frequency is more affected near the fixed support in the case of CFbeam which is more than the CC [1].

Sahu et.al had investigated with the E-glass woven fiber and epoxy resin as matrix were used for fabricating plate .The Free vibration analysis of cantilever composite beam with a single crack observed for different crack locations, the natural frequencies reduce than of intact beam[2].

Kisa et al. had worked in this paper, the vibrational characteristics of a cracked Timoshenko beam are analysed. The natural frequencies of the cracked beam are lower than the natural frequencies of the corresponding intact beam [3].

Canales et al.had experimented Free vibration of thick isotropic and laminated beams with arbitrary boundary conditions via unified formulation and Ritz method. Vibrational frequencies for laminated beams results are more inaccurate than those obtained for isotropic beams. However, higher accuracy can be obtained just by increasing the expansion order of the unified formulation [4].

Kahya et al. Free vibration analysis of laminated composite beams including open transverse cracks is presented by using a shear-deformable thirteen degrees-of-freedom finite element model. It is well-known discontinuities occur in the slope of mode shape curves at the damaged sections in which the cracks are enlarged in the thickness direction[5].

M. Aydogdu studied is concerned with the vibration analysis of cross-ply laminated beam. Itis that the frequencies of the beams with FF boundary conditions always have the highest frequencies and beams with CF conditions have the lowest frequencies for same length-to-thickness ratios. [6].

S.Yildirimhas experimented the effect of grading direction on the natural frequencies of heterogeneous isotropic beams using an axial grading generally increases the natural frequency and the influence of power-law exponent on the first fundamental natural frequency is higher for the transverse grading compared with the axial grading[7].

ÖmerCivalek Discrete singular convolution (DSC) method has been proposed to obtain the frequencies and buckling loads of composite plates. In order to transform the physical domain into computational domain, a second-order transformation is used. These equations for vibration and buckling analysis given in physical domain are then transformed to computational domain via chain rule[8].

Ngo-Cong et.al had investigated new effective radial basis function (RBF) collocation technique for the free vibration analysis. The effects on the natural frequencies are also numerically investigated, which indicates that higher constraints at the edges yield higher natural frequencies[9].

Vidala et al. had worked deals with the free vibration analysis of laminated composite plates through a variable separation approach. The natural frequencies obtained with different models are given in for the three types of boundary conditions. It is possible to reduce the error rate by building two simultaneous couples, the maximum error rate becomes only 0.3% [10].

Kim et al. has established an analysis model to study the vibration behaviour of a cracked laminated composite beam. The natural frequencies calculated by the current method and the results of FEM are compared. From this it can be seen that the results taken by the present method excellently agree with those of the FEM[11].

Yasmeen dynamic analysis of composite beams of two different materials of Fibre -reinforced Plastics (FRP) are considered for the purpose of analysis and comparison. When the fibres are lying along the length of the beam they support maximum share of the load on the beam. Hence the strength of the beam increases, which in turn increases the stiffness of the beam [12].

Reason due to the bending moment along the beam, which is concentrated at the end, a crack near the free end will have a smaller effect on the fundamental frequency than a crack closer to the end and it can be said that the frequencies are almost unchanged when the crack is located away from the end[1,2,3,6]

Finite element model:

Vibration analysis of composite beam with crack can be done by using a commercial finite element analysis package, i.e., ANSYS.

FEA is a numerical technique used to solve complex engineering problems. It involves discretizing the structures into small elements and then solving the equations of motion for each element. The equations of motion are then used to calculate the natural frequencies and mode shapes of the structure. In the case of a composite beam with a crack, the crack can be modelled as a discontinuity in the stiffness of the beam. The discontinuity can be accounted for in the FEA model by introducing a crack element with a reduced stiffness. The natural frequencies and mode shape of the beam then be calculated using the FEA model. The result of the FEA can then be used to determine the effect of the crack on the vibration characteristics of the beam. To obtain the most accurate natural frequencies and mode shapes, a mesh study was carried out on beam models using ANSYS FEA.

RESULTS AND DISCUSSION: -

Validation study

The dimensions of the beam are:

Length = 0.5m , Breadth = 0.05m, Hight = 0.02m

E = 200GPa

ν = 0.3

ρ = 7850kg/m^3

Bernouli- Euler fundamental equation

$$f_n = C\sqrt{\frac{gEI}{wl^4}}$$

f_n = natural frequency

C = constant

g = acceleration due to gravity

E = young's modulus

I = moment of inertia

w = weight per unit length

l = length of beam

The value of C for cantilever beam is 0.56, 3.51, 9.82, 19.24 for starting 1,2,3,4 mode shapes respectively.

Mode no.	Natural frequency (Hz)		
	Bernouli-Euler	ANSYS FEA	%Error
1	65.23	65.65	0.6
2	408.79	408.58	0.05
3	1144.63	1132.0	1.1
4	2242.76	2185.7	2.5

Table 1 Natural Frequency Of Cantilever Beam

In the present work, isotropic beam and laminated beam was fabricated to conduct free vibration analysis having cracks at different locations with material properties and other parameters are discussed below.

1) Isotropic beam with crack

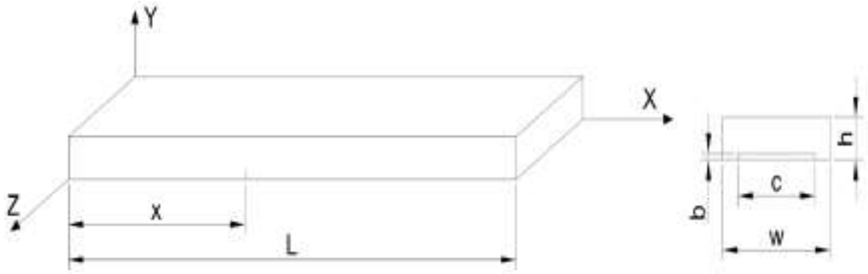
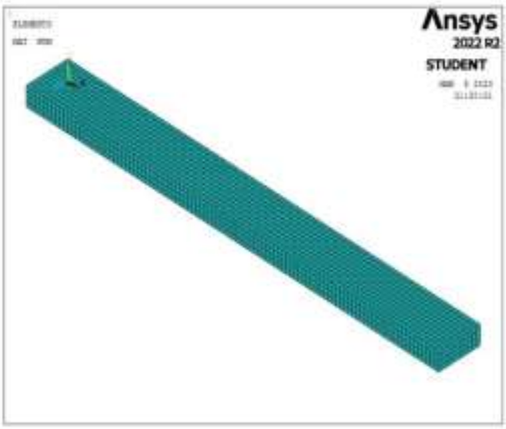


Figure 1 Isotropic Beam geometry

Anisotropic beam was fabricated to conduct free vibration analysis. The material properties were taken as Young's modulus (E)=200GPa, Poison ratio (ν)=0.3 and Mass density (ρ) =7850kg/m^3. The geometric properties of the beam are length (L) = 0.5m, width (b) = 0.05m and hight (h)=0.02m. In this study, the effects of position of the crack on the natural frequencies of the beam were discussed with cantilever and simply support boundary condition. Several relative crack locations x = 0.1,0.2,0.3and 0.4 are considered. Crack dimension are b=0.001m and c=0.03m.



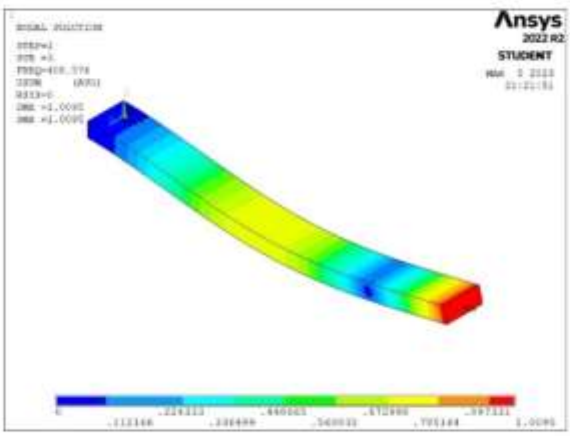


Figure 2 Meshed isotropic beam in ANSYS APDL **Figure 3 Mode shape of isotropic beam in ANSYS APDL**

Effect of crack location on the natural frequency: -

In Fig2,3 the variation in natural fundamental frequency is presented for a constant crack dimension with varying locations of the crack. CC and SS boundary conditions are considered for the analysis. From the figure, the change in fundamental frequency is observed for different crack locations. It is noted that the fundamental frequency is more affected near the fixed support and gradually increases as x/L ratio increase.

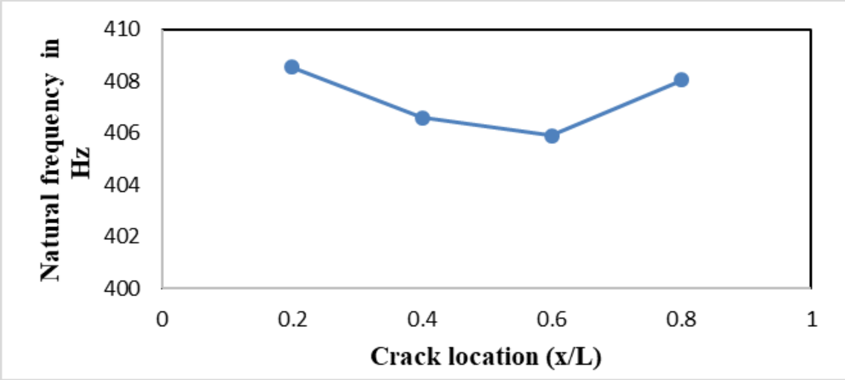


Figure 4 Variation of Fundamental Frequency with respect to crack locations for cantilever beam

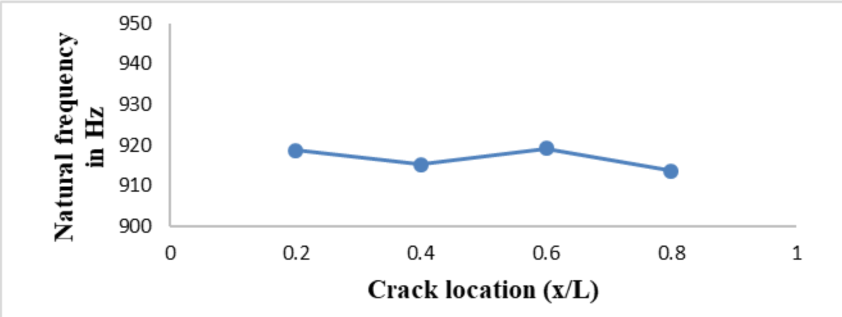


Figure 5 Variation of Fundamental Frequency with respect to crack locations for simply supported beam

2) Composite beam with crack

A four-layered composite beam was fabricated to conduct free vibration analysis. The material properties taken as recorded in Table. The geometric properties of the beam are length (L) = 0.25 m, width (b) = 0.025 m and hight (h) = 0.0032m. In this study, the effect of position of the crack on the natural frequencies of the laminated beam were discussed. Beam is laminated by cross-ply and angle-ply (45°)with Cantilever (CC) boundary condition. Several relative crack locations x=0.05,0.1,0.15and 0.2 m are considered with a crack depth of 0.001 m.

Table 2 Material properties of composite beam

Material property		
Young's modulus	E_{11}	15.71 GPa
	E_{12}	15.71 GPa
	E_{13}	2.94 GPa
Poison ratio	ν_{12}	0.28
	ν_{13}	0.28
	ν_{23}	0.28
Shear modulus of rigidity	G_{12}	2.963667 GPa
	G_{13}	2.963667 GPa
	G_{23}	2.963667 GPa
Mass density	ρ_m	1644.65 kg/m^3

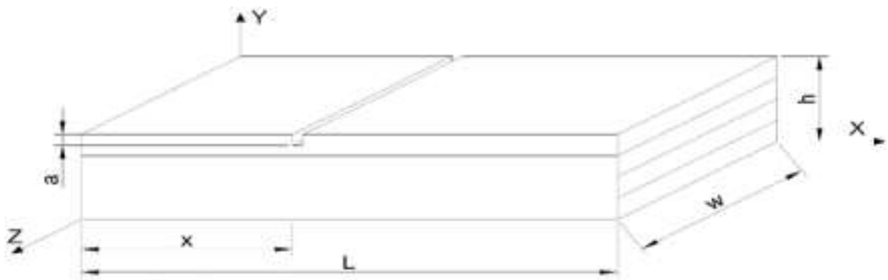


Figure 6 Composite laminated beam geometry with an open transverse crack

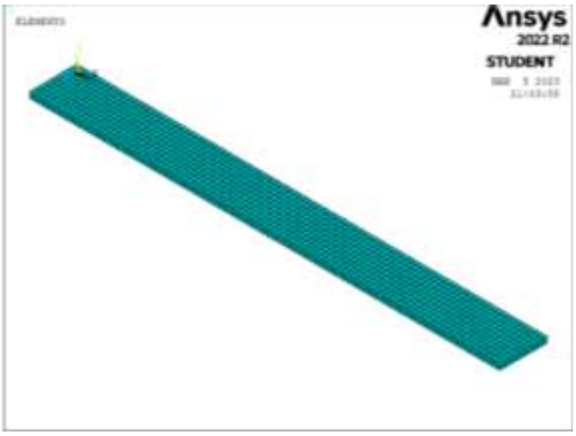


Figure 7 Meshed isotropic beam in ANSYS APDL

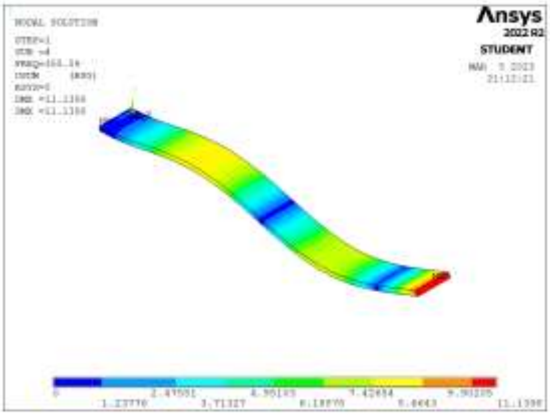


Figure 8 Mode shape of isotropic beam in ANSYS APDL

Effect of crack location on the natural frequency: -

In Fig9 the variation in natural fundamental frequency is presented for a constant crack dimension with varying locations of the crack. Cantilever boundary conditions are considered for the analysis. From the figure, the change in fundamental frequency is observed for different crack locations. It is noted that the fundamental frequency is more affected near the fixed support.

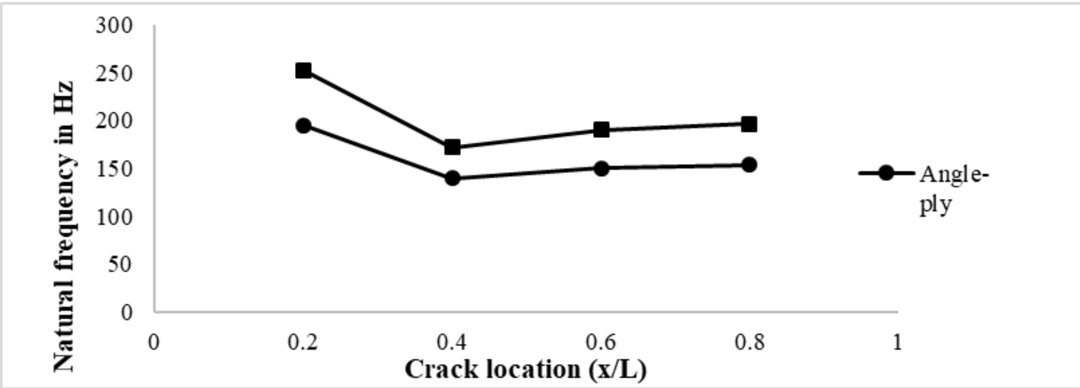


Figure 9 Variation of Fundamental Frequency with respect to crack locations

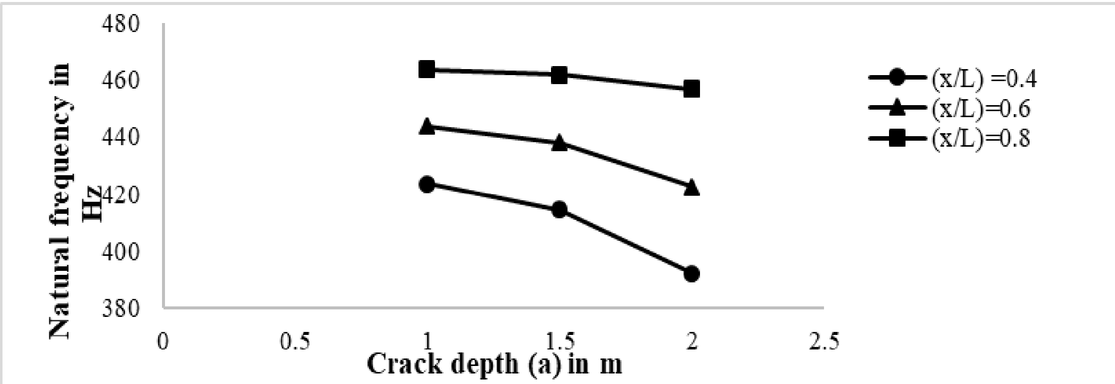


Figure 10 Variation of Fundamental Frequency of Angle-ply beam

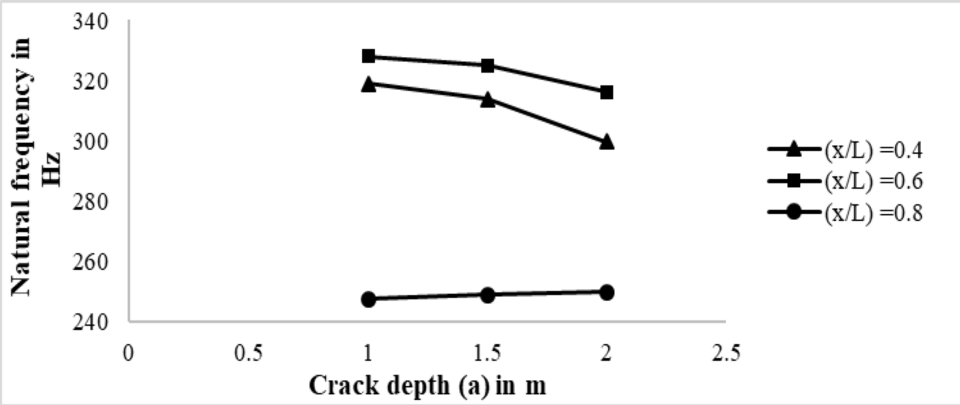


Figure 11 Variation of Fundamental Frequency of Cross-ply beam

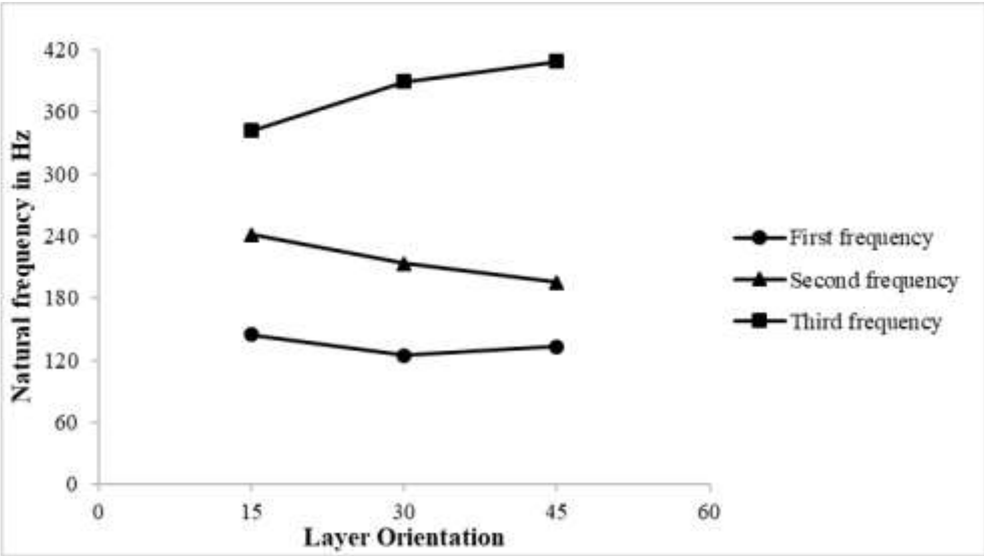


Figure 12: Change in Natural Frequency with respect to layer orientation for Cantilever boundary condition

CONCLUSION:

In the present investigation the damage of the laminated composite plates were detected analysis by using ansys and finite element analysis**.**

FOLLOWING ARE THE CONCLUSIONS DRAWN FROM THE PRESENT STUDY.

- This study presents a finite element model and its experimental validation for free vibration analysis of laminated composite beams.
- FEA can then be used to determine the effect of the crack on the vibration characteristics of the beam. To obtain the most accurate natural frequencies and mode shapes, a mesh study was carried out on beam models using ANSYS FEA.
- Isotropic and laminated beam are fabricated to conduct free vibration analysis having cracks at different locations with material properties . Crack position and depth are the most important parameters in crack investigation.
- For cantilever beam, when cracks are located closer to the fixed end of the beams, the maximum reduction in fundamental frequency occurs than cracks are located near the middle and free end has been observed.
- For second mode frequency, cracks located in the centre of the beam will experience a higher effect on frequencies. For third mode frequency, when cracks are located near the free end will have a higher effect.

From the above investigation cracks and damage detections has been observed and detected through the ansys and finite element analysis.

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