

Vibration Assessment of Cracked Composite Beams

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ABSTRACT

Composite beams and beam-like parts are widely employed in many buildings; they are also commonly found in aeroplanes, lightweight constructions, and machinery that operates at high speeds. Cracks are a type of damage that commonly affects structural elements and can cause significant structural failure. The impact of cracks on dynamic properties such as natural frequencies and modes of vibration of buildings has been the subject of numerous research. However, there are few written parametric analyses of the effects of arithmetic, break area, and backing conditions on the regular frequencies of composite pillars. This paper presents a numerical and finite element analysis of the free vibration response of composite beams. To simulate the free vibrations, ANSYS's limited component programming is used. To observe the effects of various modifications to the cover borders on the regular frequencies, several parametric analyses are carried out. The boundaries that are being studied include the effects of the direction of the fibre, the area where breaks are compared to the constricted end, the depth of breaks, the volume portion of the filaments, the length of the pillar, and the backing circumstances. The study's conclusions indicate that the biggest variation in frequencies is caused by the fibre orientation value at zero degrees. The composite bar's regular frequencies decrease as the pillar length increases, and this also demonstrates how a decrease in the normal frequencies' upsides is caused by an increase in the depth of the breaks.

1. INTRODUCTION

Fibre reinforced composite materials have become more common in many different engineering sectors in the last few decades. Composites are used in the automotive, aerospace, naval, and civil industries. Because of their great strength, low weight, impact resistance, corrosion resistance, and high fatigue strength, composite materials are becoming more and more common. Additional benefits include flexible design, ease of manufacture, and changing material qualities to suit nearly any application. The use of composite materials has expanded beyond these instances in the automotive and aircraft industries, encompassing sectors like athletic products, the maritime industry, and civil and aerospace construction. However, for structural reasons including reducing noise and vibrations in machine sheet metal frames and improving wear resistance at contact surfaces, the application of laminated composite materials as a covering for isotropic materials may prove beneficial. A common component of many mechanical structures, beams and beam-like elements are utilised in high-speed machinery, aircraft, and lightweight constructions. The majority of structural members are fiber-reinforced laminated beams, which are frequently utilised as moveable components in items like robot arms, rotating machine parts, and turbine and helicopter blades. Beams experience dynamic excitations just like any other structural element. One of the fundamental needs of engineers is to minimise the vibration of such structures. Shifting a structure's inherent frequencies away from the excitation force's frequency is one strategy to lessen vibration in the structure. The inherent frequencies of beam structures can be changed using a variety of techniques. Any continuous structure, in general, has an endless number of natural frequencies and the accompanying modal shapes because of its infinite

degrees of freedom. When a structure vibrates at the same frequency as the natural frequency, the amplitude of the vibration increases quickly over time and requires relatively little energy to start. Consequently, the structure either experiences overstressing failure or suffers high-cycle fatigue damage as a result of the nonlinear effects limiting the amplitude to a large value. Therefore, it is necessary to identify the inherent frequencies of any structure in order to prevent resonances by making sure that the loading frequencies imposed and the natural frequencies differ significantly.

To avoid structural damages caused by undesirable vibrations, it is important to determine:

- Natural frequencies of the structure to avoid resonance.
- Mode shapes to reinforce the most flexible points or to determine the right positions to reduce weight or to increase damping;
- Damping factors.

2. MODELING & MODEL ANALYSIS

A commercial finite element programme that can analyse a large number of different problems is called ANSYS. ANSYS solves governing differential equations by segmenting the issue into smaller parts, just like any finite element programme. Time-tested, industry-leading applications for structural, thermal, mechanical, computational fluid dynamics, and electromagnetic analysis are included in the FEA programme ANSYS. By precisely modelling the mixed behaviours resulting from "metaphysics interaction," ANSYS software solves for the combined effects of various forces. Many aspects of the FORTRAN programming language are also included in the ANSYS batch language. Do loops and if statements are all compatible with ANSYS batch files. For additional manipulation of ANSYS results or geometry parameters, ANSYS also includes a number of built-in functions. The graphical user interface and batch files and ANSYS commands are the two main ways to use ANSYS interactively. In this project, the GUI has been utilised. Interactive learning of ANSYS is the most straightforward approach, particularly when contrasted with the challenging endeavour of mastering all pertinent ANSYS commands.

1.1 Governing Equation

The differential equation for the bending of a beam with a mid-plane symmetry ($B_{ij} = 0$) that results in no transverse shear deformation ($\epsilon_{xz} = 0$) and no bending-stretching coupling is as follows:

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

In accordance with Vinson & Sierakowski (1991), it is simply demonstrated that under these circumstances, if the beam consists of only one layer of isotropic material, then $IS_{11} = EI = Ebh^3/12$ and Poisson's ratio effects are ignored in beam theory. The applied static load is expressed as a force per unit length in Equation 1. If Alembert's Principle is applied for dynamic loading, a term can be added to the equation. 1 is the mass and acceleration of the product per unit length.

In that case Equation.1 becomes

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

where F is the beam cross-sectional area, ρ is the mass density of the beam material, and both ω and q become functions of time as well as space, making derivatives become partial derivatives. Here, the dynamic reaction is being caused by the spatially variable time-dependent forcing function, $q(x, t)$, which could be anything from a strong one-time impact to a harmonic oscillation.

If a composite beam has lamina with varying mass densities, then use the following formulae for a rectangular

cross-section beam:

$$\rho F = \rho b h = \sum_{k=1}^N \rho b (h_k - h_{k-1}) \quad (3)$$

1.2 Beam Model

The cantilever composite beam with uniform cross-section A that has an open transverse fracture at point L1 with depth "a" is the model that was selected. In Fig. 3.1, the beam's width, length, and height are, respectively, B, L, and H. α is the angle formed by the fibres and the beam's axis.

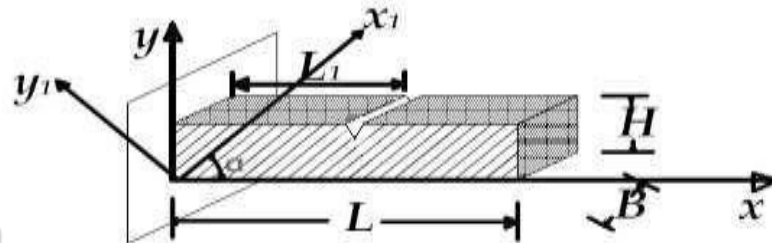


Figure. 2.1 Schematic diagram cantilever composite beam with a crack

1.3 Modelling Procedure in ANSYS 13

Regardless of the type of problem involved, an ANSYS analysis consists of the same steps as follows:

- Preprocessing
- Solution stage
- Post processing.

Choosing an element type is the next step in the preprocessing after deciding on the analysis type in the preferences. A list of broad categories, like Structural Mass, Structural Link, Structural Solid, Beam, Solid Sell, etc., is included in the element type. There will be several distinct specialised elements for every broad group. The degrees of freedom (DOFs) for which ANSYS will discover a solution are unique to each element. Next, inputs for section, real constants, and material attributes are required.

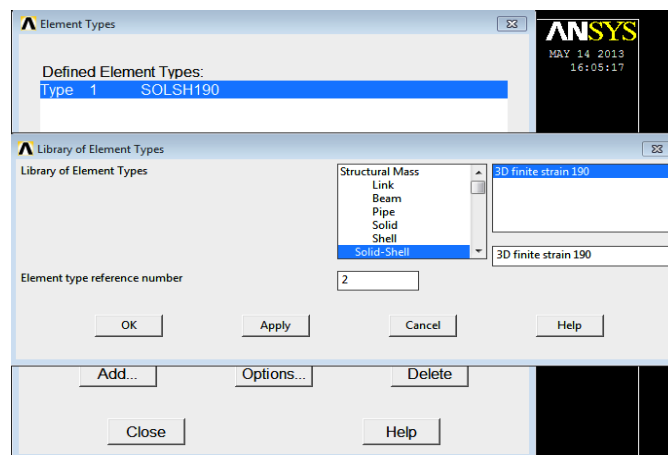


Fig.2.2 Defined element type

3. RESULT & DISSCUSION

The impact of a fracture and other additional factors on the dynamic properties of a composite beam are examined and juxtaposed with earlier research findings. This analysis uses the case studied in Krawczuk & Ostachowicz (1995) to verify the accuracy of the current analysis. The beam is thought to be composed of polyamide reinforced with unidirectional graphite fibres. The beam's geometrical features and material composition are selected to be identical to those employed by Krawczuk & Ostachowicz (1995). The graphite fiber-reinforced polyamide composite's material properties, as indicated by the indices f and m, respectively, are listed in Table 3.1.

Table.3.1 Properties of the graphite fibre-reinforced polyamide composite

Modulus of Elasticity	E_m	2.756 GPa
	E_f	275.6 GPa
Modulus of Rigidity	G_m	1.036 GPa
	G_f	114.8GPa
Poisson's Ratio	ν_m	0.33
	ν_f	0.2
Mass density	ρ_m	1600 kg/m ³
	ρ_f	1900 kg/m ³

The dimensions of the composite beam are determined to be 1.0 m for length (L), 0.025 m for height (H), and 0.05 m for width (B). The findings of the vibration analysis of the compositebeam structure, with or without cracks, are shown in this chapter. For the following research, each of the cracked composite beam issues is given separately:

- I. Comparison with Previous Studies
- II. Numerical Results
 - A. Vibration Analysis of composite beam with single crack
 - B. Vibration Analysis of composite beam with multiple cracks

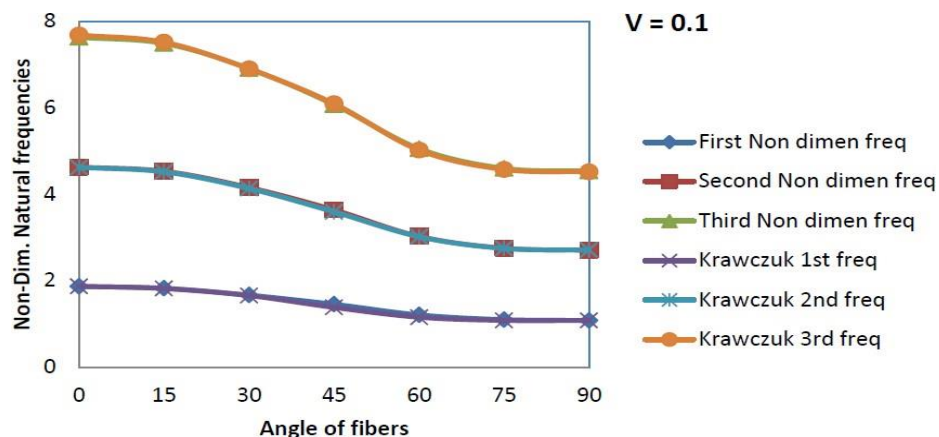


Fig.3.1. The non-cracked composite beam's first three non-dimensional frequencies as a function of the fibre angle α and for $V: 0.1$

The results of several parametric investigations, such as the impact of geometry, crack location, and support conditions on natural frequencies of composite beams, are given after a comparison with earlier research and the body of literature. We examine how the crack affects the beam's two initial natural frequencies as a function of fibre volume fraction. Similarly, for free vibration of a composite beam with multiple cracks for different crack positions, the three first natural frequencies of the composite beam due to the crack are analysed as functions of fibre orientations (α) and fibre volume percentages. The beam is thought to be composed of polyamide reinforced with unidirectional graphite fibres. The graphite fiber-reinforced polyamide composite beam's geometrical properties are selected to match those employed by Krawczuk & Ostachowicz (1995). The following are the material characteristics of the polyamide composite reinforced with graphite fibre:

$E_{11} = 139.18 \text{ GPa}$, $E_{22} = 8.0539 \text{ GPa}$, $G_{12} = 3.0352 \text{ GPa}$, $G_{23} = 2.9944 \text{ GPa}$, $\nu_{12} = 0.2650$, $\nu_{23} = 0.3448$,

The geometrical characteristics, the length (L), height (H) and width (B) of the composite beam were chosen as 1.0m, 0.025 and 0.050 m, respectively.

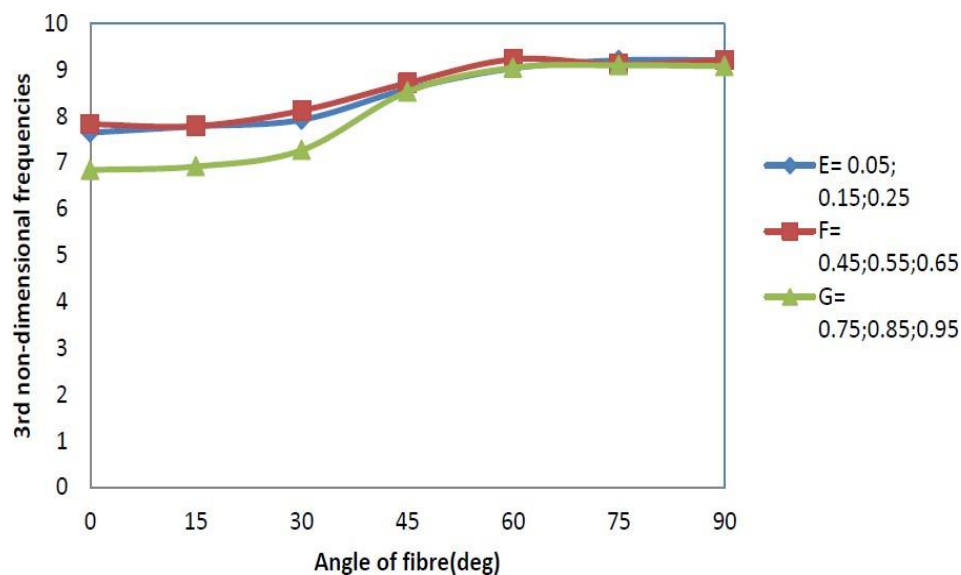


Fig 3.2 The third non-dimensional natural frequencies for the three cases with fractures positioned differently, as shown by $a/H=0.4$ and $V=0.5$, as a function of fibre angle

When the cracks are placed near the fixed end the decrease in the first natural frequencies are highest, whereas, when the cracks are located near the free end, the first natural frequencies are almost unaffected. This observation goes to the conclusion that, the first, second and third natural frequencies are most affected when the cracks located at the near of the fixed end, the middle of the beam and the free end, respectively.

4. Conclusion

The current studies of the composite beam finite element with transverse open fracture, or v-notch, lead to the following findings. Because of its versatility, this element can be applied to both static and dynamic analysis of composite beams.

- i. Generally speaking, the in-plane bending frequencies fall as the fibre angle increases; they reach their maximum at $\alpha = 0^\circ$ and then progressively decrease as the fibre angle increases, reaching a minimum value at $\alpha = 90^\circ$.
- ii. When a composite beam has a crack, the value of the natural frequencies increases together with the fibre angle (α). When the angle of the fibres is 0 degrees, the frequency difference is greatest.
- iii. The volume proportion of the fibres also affects the non-dimensional natural frequencies. When the volume fraction of the fibre is between 0.2 and 0.8, the flexibility due to crack is considerable, and it reaches its maximum when the fibre fraction is almost 0.45.
- iv. As the crack's depth increases, the natural frequencies decrease more sharply.
- v. The inherent frequencies of the composite beam drop as the beam length increases.
- vi. The natural frequencies are remarkably influenced by boundary circumstances. When compared to the clamped-free support condition, the natural frequencies of the clamped-clamped support are higher.
- vii. The first natural frequency has a minimum at $L_1/L = 0.5$ and a maximum at crack sites $L_1/L = 0.1$ and 0.9 . At fracture positions $L_1/L = 0.3$ and $L_1/L = 0.7$, however, the second natural frequency is at its lowest.

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