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EXPERIMENTAL ANALYSIS OF VIBRATION AND BUCKLING CRACKED COMPOSITE BEAM

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Abstract: Cracks in structural members lead to local changes in their stiffness and consequently their static and dynamic behaviour is altered. The influence of cracks on dynamic characteristics like natural frequencies, modes of vibration of structures has been the subject of many investigations. However studies related to behavior of composite cracked structures subject to in-plane loads are scarce in literature. Present work deals with the vibration and buckling analysis of a cantilever beam made from graphite fiber reinforced polyimide with a transverse one-edge non-propagating open crack using the finite element method. The undamaged parts of the beam are modeled by beam finite elements with three nodes and three degrees of freedom at the node. An „overall additional flexibility matrix" is added to the flexibility matrix of the corresponding non-cracked composite beam element to obtain the total flexibility matrix, and therefore the stiffness matrix in line with previous studies. The vibration of cracked composite beam is computed using the present formulation and is compared with the previous results. The effects of various parameters like crack location, crack depth, volume fraction of fibers and fibers orientations upon the changes of the natural frequencies of the beam are studied. It is found that, presence of crack in a beam decreases the natural frequency which is more pronounced when the crack is near the fixed support and the crack depth is more. The natural frequency of the cracked beam is found to be maximum at about 45% of volume fraction of fibres and the frequency for any depth of crack increases with the increase of angle of fibres. The static buckling load of a cracked composite beam is found to be decreasing with the presence of a crack and the decrease is more severe with increase in crack depth for any location of the crack. Furthermore, the buckling load of the beam decreased with increase in angle of the fibres and is maximum at 0 degree orientation.

I. INTRODUCTION

Preventing failure of composite material systems has been an important issue in engineering design. Composites are prone to damages like transverse cracking, fiber breakage, delamination, matrix cracking and fiber-matrix debonding when subjected to service conditions. The two types of physical failures that occur in composite structures and interact in complex manner are interalaminar and interlaminar failures. Interalaminar failure is manifest in micro-mechanical components of the lamina such as fiber breakage, matrix cracking, and debonding of the fiber-matrix interface. Generally, aircraft structures made of fiber reinforces composite materials are designed such that the fibers carry the bulk of the applied load. Interlaminar failure such as delamination refers to debonding of adjacent lamina. The possibility that interalaminar and interlaminar failure occur in structural components is considered a design limit, and establishes restrictions on the usage of full potential of composites. Similar to isotropic materials, composite materials are subjected to various types of damage, mostly cracks and delamination. The crack in a composite structure may reduce the structural stiffness and strength, redistribute the load in a way that the structural failure is delayed, or may lead to structural collapse. Therefore, crack is not necessarily the ultimate structural failure, but rather it is the part of the failure process which may ultimately lead to loss of structural integrity. As one of the failure modes for the fiber-reinforced composites, crack initiation and propagation have long been an important topic in composite and fracture mechanics communities. 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. Thus, the importance of inspection in the quality assurance of manufactured products is well understood. Several methods, such as non-destructive tests, can be used to monitor the condition of a structure. It is clear that new reliable and inexpensive methods to monitor structural defects such as cracks should be explored. These variations, in turn, affect the static and dynamic behavior of the whole structure considerably. In some cases this can lead to failure, unless cracks are detected early enough. To ensure the safe, reliable and operational life of structures, it is of high importance to know if their members are free of cracks and, should they be present, to assess their extent. The procedures that are often used for detection are called direct procedures such as ultrasonic, X-rays, etc. However, these methods have proven to be inoperative and unsuitable in some particular cases, since they require expensive and minutely detailed inspections. To avoid these disadvantages, researchers have focused on more efficient procedures in crack detection based on the changes of modal parameters likes natural frequencies, mode shapes and modal damping values that the crack introduces.

Structures are weakened by cracks. When the crack size increases in course of time, the structure becomes weaker than its previous condition. Finally, the structure may breakdown due to a minute crack. The basic configuration of the problem investigated here is a composite beam of any boundary condition with a transverse one-edge non-propagating open crack. However, a typical cracked cantilever composite beam, which has tremendous applications in aerospace structures and high-speed turbine machinery, is considered.

The following aspects of the crack greatly influence the dynamic response of the structure.

- The position of a crack in a cracked composite beam
- The depth of crack in a cracked composite beam
- The angle of fibers in a cracked composite beam
- The volume fraction of fibers in a cracked composite beam

Mathematical Model: The model chosen is a cantilever composite beam of uniform cross-section A, having an open-edge transverse crack of depth „a‟ at position „l1’. The width, length and height of the beam areB, L and H, respectively in Figure.3.1. The angle between the fibers and the axis of the beam is „α‟.

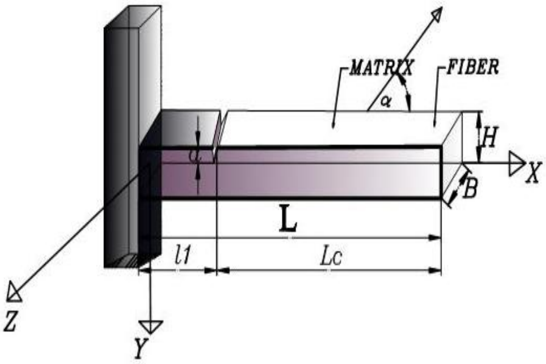

Figure.3.1 Schematic diagram cantilever composite beam with a crack

Derivation of Element Matrices: In the present analysis three nodes composite beam element with three degree of freedom (the axial displacement, transverse displacement and the independent rotation) per node is considered. The characteristic matrices of the composite beam element are computed on the basis of the model proposed by Oral (1991). The stiffness and mass matrices are developed from the procedure given by Krawczuk & Ostachowicz (1995).

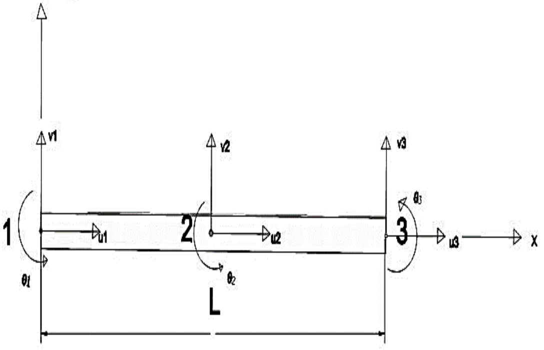

Figure.3.2 Nodal displacements in the element coordinate system

In order to check the accuracy of the present analysis, the case considered in Krawczuk & Ostachowicz (1995) is adopted here. The beam assumed to be made of unidirectional graphite fiber-reinforced polyamide. The geometrical characteristics and material properties of the beam are chosen as the same of those used in Krawczuk & Ostachowicz (1995). The material properties of the graphite fiber-reinforced polyamide composite, in terms of fibers and matrix, is identified by the indices f and m, respectively, are in Table-4.1

Table-4.1 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		0.33
		0.2
Mass density	ρ_m	1600 kg/m^3
	ρ_f	1900 kg/m^3

The geometrical characteristics, the length (L), height (H) and width (B) of the composite beam, are taken as 1.0 m, 0.025 m and 0.05m respectively.

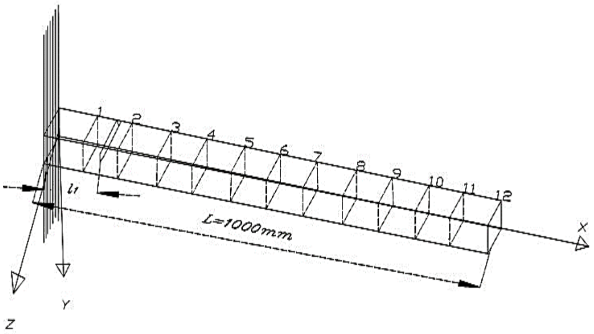

Figure.4.1 Geometry of cantilever cracked composite beam with 12 elements

In this chapter, the results of vibration and buckling analysis of composite beam structure with or without crack are presented using the formulation given in Chapter-3. Each of the cracked composite beam problems is presented separately for the following studies:

- Convergence Studies
- Comparison with Previous Studies
- Numerical Result

A. Vibration and Buckling Analysis of results of composite beam with single crack

B. Vibration Analysis of results of composite beam with multiple cracks

Numerical Results: After obtaining the comparison with previous study and validating the formulation with the existing literatures, the results for non-dimensional natural frequencies of the non-cracked composite beam as a function of the angle of fibers (α) are presented. The changes of the two first natural frequencies of the beam due to the crack as functions of the angle of fibers (α) and volume fraction of fiber are analyzed and buckling analysis is carried out for free vibration of a composite beam with single crack for various crack positions and crack depths. Similarly, the three first natural frequencies of the composite beam due to the crack as functions of the angle of fibers (α) and volume fraction of fiber are analyzed for free vibration of a composite beam with multiple cracks for various crack positions. The beam assumed to be made of unidirectional graphite fiber-reinforced polyamide. The geometrical characteristics and the material properties of the graphite fiber-reinforced polyamide composite beam are chosen as the same of those used in Ozturk & Sabuncu (2005). The material properties of the graphite fiber-reinforced polyamide composite are

G13 = 4.3053GPa,
G23 = 2.5414GPa,

The geometrical characteristics, the length (L), height (H) and width (B) of the composite beam were chosen as 1.0m, .009525m and 0.0127m, respectively.
The crack is located at x/L =0.1, 0.2, 0.4, 0.6 and 0.8.
Relative crack depth (a/H) = 0.2, 0.4 and 0.6
Vibration analysis of results of composite beam with single crack
Firstly, the present method has been applied for the free vibration analysis of a non-cracked composite cantilever beam by using twelve elements FE model of the same length. The three lowest non-dimensional natural frequencies for various values of the angle of fibers (α) and the volume fraction of fibers (V) are determined and tabulated in Table 4.6, 4.7, 4.8 and 4.9. The results are also plotted in Figures 4.7 to 4.10. As the angle of the fiber increases from 0º to 90º, the non-dimensional natural frequency decreases. It is also found that the rate of decrease in non dimensional natural frequency with increase in volume fraction of fibers is more as the volume approaches approximately 45%.

Table-4.6 Numerical Result of First three non-dimensional natural frequencies of the non-cracked composite beam as a function of the angle of fibers α, where Value of V=0.02

Angle of fibers(degree)	Present analysis		
	1st Non-dimensional Frequency	2nd Non-dimensional Frequency	3rd Non-dimensional Frequency
0	2.6780	6.2190	10.3191
15	2.6605	6.3681	10.2488
30	2.6286	6.1887	10.0580
45	2.5081	5.8617	9.7541
60	2.2001	5.0901	9.0700
75	1.8163	4.4184	8.1543
90	1.6045	4.0736	7.4392

II. CONCLUSION

The following conclusions can be made from the present investigations of the composite beam finite element having transverse non-propagating one-edge open crack. This element is versatile and can be used for static and dynamic analysis of a composite or isotropic beam.

1) From the present investigations it can be concluded that the natural frequencies of vibration of a cracked composite beam is not only the functions of the crack locations and crack depths but also the functions of the angle of fibers and the volume fraction of the fibers. The presence of a transverse crack reduces the natural frequencies of the composite beam.

2) The rate of decrease in the natural frequency of the cracked composite beam increases as the crack position approaches the fixed end.

3) The intensity of the reduction in the frequency increases with the increase in the crack depth ratio. This reduction in natural frequency along with the mode shapes of vibrations can be used to detect the crack location and its depth.

4) When, the angle of fibers (α) increase the values of the natural frequencies also increase. The most difference in frequency occurs when the angle of fiber (α) is 0 degree. This is due to the fact that the flexibility of the composite beam due to crack is a function of the angle between the crack and the reinforcing fibers.

5) The effect of cracks is more pronounced near the fixed end than at far free end. It is concluded 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.

6) The decrease of the non-dimensional natural frequencies depends on the volume fraction of the fibers. The non-dimensional natural frequency is maximum when the volume fraction of fiber is approximately 45%. This is due to the fact that the flexibility of a composite beam due to crack is a function of the volume fraction of the fibers.

7) Buckling load of a cracked composite beam decrease with increase of crack depth for crack at any particular location due to reduction of stiffness.

8) When, angle of fibers increase the values of the buckling loads decrease. This is due to the fact that for 0 degree orientation of fibers, the buckling plane normal to the

fibers is of maximum stiffness and for other orientations stiffness is less hence buckling load is less.

Scope of future work:

1. The vibration and stability results obtained using this formulation can be verified by conducting experiments.
2. The dynamic stability of the composite beam with cracks
3. Static and dynamic stability of reinforced concrete beam with cracks.
4. The dynamic stability of beam by introducing slant cracks (inclined cracks) in place of transverse crack.

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