Vibration and Buckling Analysis of 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 column 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 column are modeled by column 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 column element to obtain the total flexibility matrix, and therefore the stiffness matrix in line with previous studies. The vibration of cracked composite column 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 column are studied. It is found that, presence of crack in a column 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 column 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 column 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 column decreased with increase in angle of the fibres and is maximum at 0 degree orientation.*

***Keywords**— Land use change, Buffer Analysis, Uncertainty analysis and Urban Sprawl.*

1. INTRODUCTION

1.1 Introduction

Composites as structural material are being used in aerospace, military and civilian applications because of their tailor made properties. The ability of these materials to be designed to suit the specific needs for different structures makes them highly desirable. Improvement in design, materials and manufacturing technology enhance the application of composite structures. The suitability of a particular composite material depends on the nature of applications and needs. The technology has been explored extensively for aerospace and civil engineering applications, which require high strength and stiffness to weight ratio materials. 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. Cracks or other defects in a structural element influence its dynamical behaviour and change its stiffness and damping properties. Consequently, the natural frequencies and mode shapes of the structure contain information about the location and dimensions of the damage. Vibration analysis can be used to detect structural defects such as cracks, of any structure offer an effective, inexpensive and fast means of nondestructive testing. What types of changes occur in the vibration characteristics, how these changes can be detected and how the condition of the structure is interpreted has been the topic of several research studies in the past. The use of composite materials in various construction elements has increased substantially over the past few years. Cracks found in structural elements have various causes. They may be fatigue cracks that take place under service conditions as a result of the limited fatigue strength. They may also be due to mechanical defects, as in the case of turbine blades of jet turbine engines. In these engines the cracks are caused by sand and small stones sucked from the surface of the runway. Another group involves cracks which are inside the material: they are created as a result of manufacturing processes.

1.2 Scope of the Present Investigation

The main aim of this thesis is to work out a composite column finite element with a non- propagating one-edge open crack. It has been assumed that the crack changes only the stiffness of the element whereas the mass of the element is unchanged. For theoretical modeling of cracked composite column dimensions, crack locations, crack depth and material properties is specified. In this work an “overall additional flexibility matrix”, instead of the “local additional flexibility matrix” is added to the flexibility matrix of the corresponding non-cracked composite column element to obtain the total flexibility matrix, and therefore the stiffness matrix in the line with the other researchers. By using the present model the following effects due to the crack of the cantilever composite column have been analyzed.

- The influence of the volume fraction of fibers, magnitude, location of the crack, angle of fibers upon the bending natural frequencies of the cantilever cracked composite column.
- The effects of above parameters on buckling analysis of cracked composite column. The present results are compared with previous studies and the new results are obtained in the MATLAB environment.

2. LITERATURE REVIEWS

2.1 Introduction

The widespread use of composite structures in aerospace applications has stimulated many researchers to study various aspects of their structural behaviour. These materials are particularly widely used in situations where a large strength-to-weight ratio is required. Similarly to isotropic materials, composite materials are subjected to various types of damage, mostly cracks and delamination. These result in local changes of the stiffness of elements for such materials and consequently their dynamic characteristics are altered. This problem is well understood in case of constructing elements made of isotropic materials, while data concerning the influence of fatigue cracks on the dynamics of composite elements are scarce in the available literature. Cracks occurring in structural elements are responsible for local stiffness variations, which in consequence affect their dynamic characteristics. This problem has been a subject of many papers, but only a few papers have been devoted to the changes in the dynamic characteristics of composite constructional elements. In the present investigation an attempt has been made to the reviews on composite cracked column in the context of the present work and discussions are limited to the following area of analysis.

2.2 Review on vibration of cracked composite column

A local flexibility will reduce the stiffness of a structural member, thus reducing its natural frequency. For small crack depths the change (decrease) in natural frequency is proportional to the square of the crack depth ratio. Nikpour & Dimarogonas (1988) presented the local compliance matrix for unidirectional composite materials. They have shown that the interlocking deflection modes are enhanced as a function of the degree of anisotropy in composites. Nikpour (1990) studied the effect of cracks upon buckling of an edge notched column for isotropic and anisotropic composites. He indicated that the instability increases with the column slenderness and the crack length. In addition he has shown that the material anisotropy conspicuously reduces the load carrying capacity of an externally cracked member. Ostachowicz & Krawczuk (1991) presented a method of analysis of the effect of two open cracks upon the frequencies of the natural flexural vibrations in a cantilever column. Two types of cracks were considered: double-sided, occurring in the case of cyclic loadings, and single-sided, which in principle occur as a result of fluctuating loadings. It was also assumed that the cracks occur in the first mode of fracture: i.e., the opening mode. An algorithm and a numerical example were included. Manivasagam & Chandrasekaran (1992) presented results of experimental investigations on the reduction of the fundamental frequency of layered composite materials with damage in the form of cracks. Krawczuk (1994) formulated a new column finite element with a single non-propagating one-edge open crack located in its mid-length for the static and dynamic analysis of cracked composite column-like structures. The element includes two degrees of freedom at each of the three nodes: a transverse deflection and an independent rotation respectively. He presented the exemplary numerical calculations illustrating variations in the static deformations and a fundamental bending natural frequency of a composite cantilever column caused by a single crack. Krawczuk & Ostachowicz (1995) investigated eigen frequencies of a cantilever column made from graphite-fiber reinforced polyimide, with a transverse on-edge non-propagating open crack. Two models of the column were presented. In the first model the crack was modeled by a massless substitute spring Castigliano‟s theorem. The second model was based on the finite element method. The undamaged parts of the column were modeled by column finite elements with three nodes and three degrees of freedom at the node. The damaged part of the column was replaced by the cracked column finite element with degrees of freedom identical to those of the non-cracked done. The effects of various parameters the crack location, the crack depth, the volume fraction of fibers and the fibers orientation upon the changes of the natural frequencies of the column were studied. Computation results indicated that the decrease of the natural frequencies not only depends on the position of the crack and its depth as in the case of isotropic material but also that these changes strongly depend on the volume fraction of the fiibers and the angle of the fibers of the composite material. Ghoneam (1995) presented the dynamic characteristics laminated composite columns (LCB) with various fiber orientations and different boundary fixations and discussed in the absence and presence of cracks. A mathematical model was developed, and experimental analysis was utilized to study the effects of different crack depths and locations, boundary conditions, and various code numbers of laminates on the dynamic characteristics of CLCB. The analysis showed good agreement between experimental and theoretical results. Dimarogonas (1996) reported a comprehensive review of the vibration of cracked structures. This author covered a wide variety of areas that included cracked columns, coupled systems, flexible rotors, shafts, turbine rotors and blades, pipes and shells, empirical diagnoses of machinery cracks, and bars and plates with a significant collection of references. Krawczuk, Ostachowicz & Zak (1997) presented a model and an algorithm for creation of the characteristic matrices of a composite column with a single transverse fatigue crack. The element developed had been applied in analyzing the influence of the crack parameters (position and relative depth) and the material parameters (relative volume and fibre angle) on changes in the first four transverse natural frequencies of the composite column made from unidirectional composite material. Hamada (1998) studied the variations in the eigen-nature of cracked composite columns due to different crack depths and locations. A numerical and experimental investigation has been made. The numerical finite element technique was utilized to compute the eigen pairs of laminated composite columns through several state of cracks. The model was based on elastic-plastic fracture mechanics techniques in order to consider the crack tip plasticity in the analysis. The model has been applied to investigate the effects of state of crack, lamina code number, boundary condition on the dynamic behavior of composite columns. Zak, Krawczuk & Ostachowicz (2000) developed the work models of a finite delaminated column element and delaminated plate element. They carried out an extensive experimental investigation to establish changes in the first three bending natural frequencies due to delaminations. The subsequent results of the numerical calculations were consistent the results of the experimental investigations. Banerjee (2001) derived exact expressions for the frequency equation and mode shapes of composite Timoshenko columns with cantilever end conditions in explicit analytical form by using symbolic computation. The effect of material coupling between the bending and torsional modes of deformation together with the effects of shear deformation and rotatory inertia is taken into account when formulating the theory. The expressions for the mode shapes were also derived in explicit form using symbolic computation.

Wang & Inmana (2002) investigated the free vibration of a cantilever column, made of unidirectional fiber-reinforced composite, of high aspect ratio and with an open edge crack is. The column model is based on the classical lamination theory; the crack modeled with the local flexibility method such that the cantilever column could be replaced with two intact columns with the crack as the additional boundary condition. It was demonstrated that changes of eigen-frequencies and corresponding mode shapes depend on not only the crack location and ratio, but also the material properties (fiber orientation, fiber volume fraction).

Kisa (2003), investigated the effects of cracks on the dynamical characteristics of a cantilever composite column, made of graphite fibre-reinforced polyamide. The finite element and the component-mode synthesis methods were used to model the problem. The cantilever composite column divided into several components from the crack sections. The effects of the location and depth of the cracks, and the volume fraction and orientation of the fibers on the natural frequencies and mode shapes of the column with transverse non-propagating open cracks, were explored. The results of the study leaded to conclusions that, presented method was adequate for the vibration analysis of cracked cantilever composite columns, and by using the drop in the natural frequencies and the change in the mode shapes, the presence and nature of cracks in a structure can be detected.

3. METHODOLOGY

3.1 Proposed Shear Failure Model

A common feature of lightly confined reinforced concrete (RC) columns is to exhibit shear strength degradation under large lateral loading with considerable shear deformation. As the magnitude of shear deformation increases, columns suffer progressive loss of lateral resistance under reversed cyclic loading. The degree of strength decay depends on various factors, including the concrete strength, shear stress, and the level of axial load. Early and rapid strength degradation may have a very significant effect on the post-peak behavior and collapse of columns. Thus, an accurate representation of shear response or a shear strength-shear displacement envelope up to shear failure point is always required. In general, shear failure can be detected when the shear force reaches the resistance of inclined shear failure surface of column specimens. An important aspect of modeling shear-critical RC columns is to predict the point of shear failure accurately and conveniently. In this study, the onset of shear failure is defined as the specific point on the shear envelope where the column response reaches the peak shear strength and followed by a quickly increasing lateral displacement accompanied with constant strength degradation. The proposed model defines the shear displacement, $\Delta_{u,sh}$ of the column at the onset of shear failure. In other words, the ultimate shear displacement is defined as the maximum shear deformation just before any significant shear strength decay occurs. As the shear degradation is detected on the shear force-shear displacement curve, all the parameters which influence the lateral deformation at shear failure (i.e., transverse reinforcement ratio, concrete compressive strength, and axial load ratio) may affect the ultimate shear displacement. Recovery shear displacement refers to the part of shear deformation that varies with lateral force linearly and disappears when the force is removed. In contrast, permanent shear displacement represents some residual shear deformation that cannot restore. These two shear displacements are related to the elastic and plastic behavior of reinforced concrete. The backbone of shear force-shear displacement response can be represented with an envelope depicted by several critical points. The proposed shear envelope is illustrated in Figure 4.5

by assuming the symmetrical performance in both loading directions. Due to very limited test data, the complicated shear degrading behavior may be approximately replaced by a linear degrading relation when the appropriate shear failure and axial failure points are determined clearly. As previously proposed by researchers at the Ohio State University (Patwardhan, 2005), the proposed shear envelope model consists of two straight lines for pre-peak behavior, a flat plain, and a degradation portion with a negative stiffness. At shear failure, an inclined backbone is defined to a degradation slope by both proposed shear failure point and axial failure point. Once the permanent and recovery shear displacements are determined, the shear failure point is detected with the deformation limits, $\Delta_{u,sh}$ and $\Delta_{a,sh}$,. Therefore, the proposed shear stiffness can define the shear envelope model. When the shear capacity of column is lower than flexural capacity, shear failure can be estimated through a limiting shear strength. Similarly, limiting deformation measures can be used to determine shear failure initiation. The limit state model triggers shear failure when one of the limit states is reached first. Several studies on deformation capacity of RC columns at shear failure used column lateral drift as the limit state for shear failure (Elwood and Moehle, 2005a; Mostafaei and Kabeyasawa, 2007). A shear failure model is proposed using the data and relationships presented in this chapter. The proposed shear displacement at shear failure can be determined as a function of axial load ratio, concrete strength, aspect ratio, and effective shear stress. The proposed model contains two deformation components, permanent and recovery shear displacements, respectively. The two components of shear displacement are delivered finally into a general β equation. The shear strength correlation coefficient, is adopted in the correction of permanent shear displacement. The total shear displacement at 80% of peak shear strength, $\Delta'_{u\,sh}$ is thus calculated.

3.2 Proposed Axial Failure Model

Previous experimental tests of full-scale shear-critical reinforced concrete (RC) columns have demonstrated that the axial load capacity is not necessarily lost immediately after the loss of lateral load capacity (Lynn, 2001; Sezen, 2002). The experimental results also suggest that the drift at which axial failure occurs depends more on the axial stress and the amount of transverse reinforcement. Generally, for RC columns having a lower axial ratio, the axial load failure has a tendency to occur at relatively large drifts, regardless of whether shear failure had just occurred or whether shear failure occurred at much smaller drift ratios. For RC columns with higher axial ratio, axial load failure tends to occur at smaller drift ratios, and might occur almost immediately after loss of lateral load capacity. Unfortunately, during laboratory tests, a common practice has been to terminate the test after observing approximately 50% drop in lateral load resistance without measuring the axial load failure of the column specimens. Very limited test data is available for shear critical RC columns being tested all the way through axial failure. However, many post earthquake reconnaissance studies report building damage or collapse that might be attributed to an early or sudden column collapse due to axial failure typically following shear failure. Different approaches were used to define the point of axial failure during previous tests. Since most tests were performed under constant axial load, a common sign of axial failure is a significant drop in axial load resistance even without full disintegration of the specimens. This approach could be sometimes misleading since the axial load may decrease for several reasons including axial stiffness degradation because of diagonal cracking, concrete crushing or hydraulic pressure drop for a mechanical reason. The main objective of this chapter is to develop a mechanics based model that predicts the maximum lateral deformation of shear-critical RC columns at axial load failure. The proposed macro model is an extension of the current modeling approaches used to calculate the total lateral displacement of RC columns due to flexure, longitudinal steel slip, and shear independently. The main focus in this chapter is to improve the estimation of overall shear response using a mechanics-based model. An analytical model based on shear friction mechanism is proposed in this chapter according to Elwood and Moehle (2005a) axial capacity model. The proposed model is based on experimental observation of column specimen response including axial load failure at the end. The model assumes that the primary failure mechanism is along a shear friction surface, with column longitudinal reinforcement resisting in axial load while providing a secondary resistance mechanism triggered after shear-friction failure on the shear failure plane. Three components of axial capacity through a critical crack plane at large drift can be derived using shear-friction mechanism. The axial capacity model is proposed using the coefficient of friction and drift ratio at axial failure.

3.3 Proposed Axial Load Capacity Model

When the axial load applied on a shear-critical reinforced concrete (RC) column exceeds its axial capacity, axial load failure may happen and thus result in a sudden loss of axial resistance leading to total column collapse. The process of axial load failure accompanied by considerable degradation of axial capacity after shear failure under lateral loading is still not very well understood. Axial loads after shear failure are mainly supported by shear-friction mechanism in a column based on the proposed mechanical model. The column continues to possess some axial capacity when axial loads start to decay. Most axial load capacity models were developed and calculated based on the axial resistance contributed by concrete and reinforcement strength through force-based methods. Only a few analytical models to assess axial load capacity after shear failure are available (Elwood and Moehle 2005a and 2005b). Therefore, an axial capacity model of columns is required to evaluate the degradation of lateral strength and subsequent loss of axial load capacity in a shear-critical column. This chapter investigates the axial load degradation associated with both vertical and lateral deformations. Two main steps are carried out with parametric studies and regression analysis. An axial load capacity model with average degradation stiffness is developed. Furthermore, empirical formulas for predicting ultimate lateral deformations at column collapse or axial failure are also presented. The proposed models are applicable to shear-critical columns only. The combination rules of lateral deformation components follow the same pattern as the displacement based method discussed (Sezen, 2002, Setzler, 2005, and Lodhi, 2010). The total lateral response is derived by combining flexure, shear responses, and bar slip, as springs in series as shown. Each spring is subjected to the same total lateral force, and the total lateral displacement depends on the different rules for combination of each spring response as described in Setzler (2005). Under initial loading with small lateral loads, the behavior of RC columns is approximately elastic. The column returns to its original position if the load is removed. Therefore, the initial assumption in the combined model is that the flexure, slip, and shear deformation components can simply be summed up for a given lateral load. As the load increases, inelastic deformation starts to appear. During reversed cycling loading, the inelastic deformation is gradually accumulated and accompanied by internal damage. The combination rule is applied until the maximum lateral strength is reached.

4. RESULTS AND DISCUSSIONS

Effect of an open edge transverse crack on various parameters of a composite column like vibration and buckling are studied and compared with previously studied results. The formulation is then validated and extended for other problems.

Introduction

In order to check the accuracy of the present analysis, the case considered in Krawczuk & Ostachowicz (1995) is adopted here. The column assumed to be made of unidirectional graphite fiber-reinforced polyamide. The geometrical characteristics and material properties of the column 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	υ_m	0.33
	υ_f	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 column, are taken as 1.0 m, 0.025 m and 0.05m respectively.

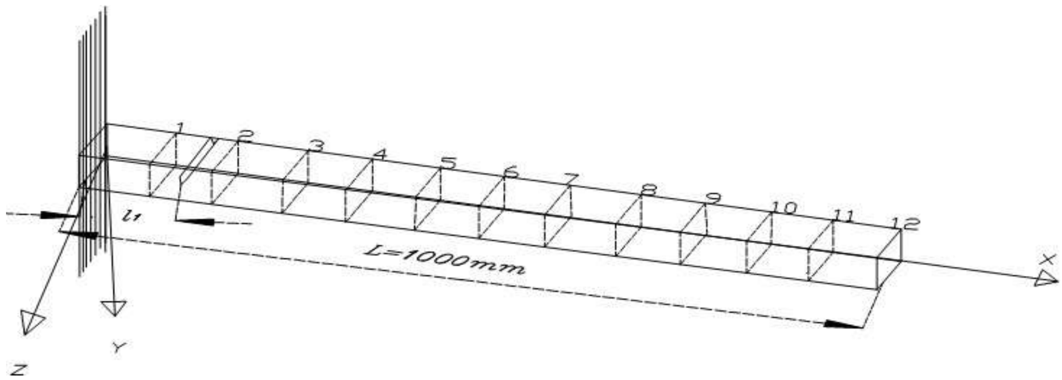

Figure.4.1 Geometry of Cantilever Cracked Composite Column with 12 Elements

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

i. Convergence Studies

ii. Comparison with Previous Studies

iii. Numerical Result

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

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

Convergence Study

The convergence study is carried out for the free vibration of cracked composite column and omitted here for sake of brevity. Based on this study, a mesh of 12 elements shows good convergence of numerical solutions for free vibration of cracked composite column, which is shown in Fig.4.2.

Table-4.2 Convergence of non-dimensional free vibration frequencies of cracked composite column for different angle of fibers

V = 0.1, a/H = 0.2, Em = 2.756; Ef = 275.6; =.2; G_m=1.036; G_f=114.8; ν_f =1600; ρ_m =1900; ρ_f

$$\omega_n \ \alpha \ = l \quad \omega \ \alpha = 0$$

Mesh Division	Non dimensional frequencies for different angle of fibers "α"(degrees)		
	α = 0	**α = 15**	**α = 30**
2 Elements	1.5982	1.6703	1.7125
4 Elements	1.6815	1.7255	1.7732
8 Elements	1.6995	1.7257	1.7748
12 Elements	1.7055	1.7245	1.7743
Krawczuk & Ostachowicz (1995)	1.7055	1.7245	1.7743

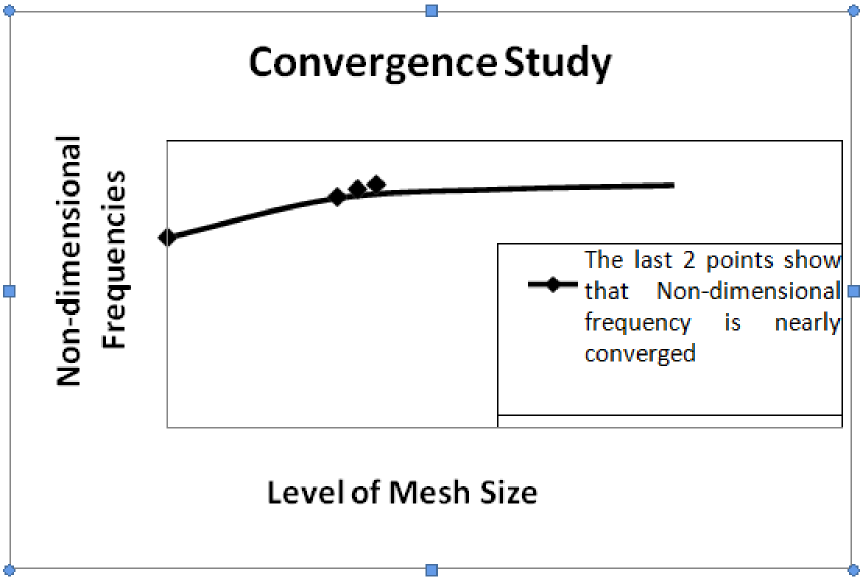

Figure.4.2 The Convergence Of Non-Dimensional Free Vibration Frequencies Of Cracked Composite Column For Angle Of Fibers "A = 0" (Degrees)

Comparison with Previous Studies

Quantitative results on the effects of various parameters on the vibration and buckling analysis of cracked composite are presented.

Vibration analysis studies

The presented method has been applied for the free vibration analysis of a non-cracked and cracked composite cantilever column. Free vibration analysis of a cantilever cracked composite column has been examined by Krawczuk & Ostachowicz (1995) using finite element method (FEM). In this study the results obtained with present element are compared with the results of Krawczuk & Ostachowicz. Throughout this investigation, 12 elements are used in modeling the cracked composite column. In addition, the three lowest eigen-frequencies for various values of the angle of the fiber (α) and the volume fraction of fibers (V) are determined and given in Table-4.3 and Fig. 4.3, 4.4. In Figure.4.5 and 4.6 the changes of the two first natural frequencies of the column due to the crack as functions of the angle of fibers (α) are compared with the results of Krawczuk & Ostachowicz(1995). As seen from the tables agreements are good.

5. CONCLUSION

The following conclusions can be made from the present investigations of the composite column 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 column.

1. From the present investigations it can be concluded that the natural frequencies of vibration of a cracked composite column 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 column.
2. The rate of decrease in the natural frequency of the cracked composite column 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.
5. 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 column due to crack is a function of the angle between the crack and the reinforcing fibers.
6. 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 rear of the fixed end, the middle of the column and the free end, respectively.
7. 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 column due to crack is a function of the volume fraction of the fibers.
8. Buckling load of a cracked composite column decrease with increase of crack depth for crack at any particular location due to reduction of stiffness.

9. 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

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

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