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VIBRATION BASED HEALTH MONITORING AND DAMAGE DIAGNOSIS OF COMPOSITE BEAM STRUCTURE

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ABSTRACT

Cracks or other defects in a structural element influence its dynamic 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 non destructive testing. Present work deals with the vibration and buckling analysis of a cantilever beam made from graphite fibre reinforced polyamide with a transverse one-edge non-propagating open crack using the finite element method. The effects of various parameters like crack location, crack depth, multiple cracks upon the changes of the natural frequencies of the beam are studied. Critical fracture parameters governing the severity of stress and deformation field ahead of the cracks were evaluated. 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. So, the primary objective of Structural Health Monitoring is to detect a variety of damages at the earliest possible stage to prevent catastrophic failure.

Keywords: Composite Materials, Crack detection, Damage Diagnosis, Vibration Analysis

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 intralaminar and interlaminar failures. Interalaminar failure is manifested to 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 de-bonding 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.

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, 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.

METHODOLOGY

The basic configuration of the problem investigated here is a composite beam with a transverse one-edge non-propagating open crack. A typical cantilever composite beam structure has tremendous applications in aerospace structures and high-speed turbine machinery.

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

i. The position of a crack in a cracked composite beam
ii. The depth of crack in a cracked composite beam
iii. The number of cracks on the composite beam
iv. The effect of cracks on buckling loads

The assumptions made in the analysis are:

i. The analysis is linear. This implies constitutive relations in generalized Hook's law for the materials are linear.
ii. The Euler–Bernoulli beam model is assumed.
iii. The damping has not been considered in this study.
iv. The crack is assumed to be an open crack and have a uniform width.

GOVERNING EQUATION

The governing equations for the vibration analysis of the composite beam with an open one-edge transverse crack are developed. Here an additional flexibility matrix related to the crack is added to the normal flexibility matrix to obtain the total flexibility matrix of the corresponding composite beam element.

The differential equation of the bending of a beam with a mid-plane symmetry (B_{ij} = 0) so that there is no bending-stretching coupling and no transverse shear deformation (ε_{xz}=0) is given by;

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

It can easily be shown that under these conditions if the beam involves only a one layer, isotropic material, then,

$$IS_{11} = EI = \frac{Ebh^3}{12}$$

and for a beam of rectangular cross-section Poisson's ratio effects are ignored in beam theory, which is in the line with (Gaith, 2011).

In Equation 1, it is seen that the imposed static load is written as a force per unit length. For dynamic loading, if Alembert's Principle is used then one can add a term to Equation.1 equal to the product of mass and acceleration per unit length. In that case Equation.1 becomes

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

where ω and q both become functions of time as well as space, and derivatives therefore become partial derivatives, ρ is the mass density of the beam material, and here A is the beam cross-sectional area. In the above, q(x, t) is now the spatially varying time-dependent forcing function causing the dynamic response, and could be anything from a harmonic oscillation to an intense one-time impact.

For a composite beam in which different lamina have differing mass densities, then in the above equations use, for a beam of rectangular cross-section,

$$\rho A = \rho bh = {}_{k=1}^{N}\rho b\, h_k - h_{k-1} \tag{3}$$

However, natural frequencies for the beam occur as functions of the material properties and the geometry and hence are not affected by the forcing functions; therefore, for this study let q(x, t) be zero.

Thus, the natural vibration equation of a mid-plane symmetrical composite beam is given by;

$$IS_{11}\frac{d^4\omega(x,t)}{dx^4} + \rho A\frac{d^2\omega(x,t)}{dx^2} = 0 \tag{4}$$

It is handy to know the natural frequencies of beams for various practical boundary conditions in order to insure that no recurring forcing functions are close to any of the natural frequencies, because that would result almost certainly in a structural failure. In each case below, the natural frequency in radians/unit time are given as

$$\omega_n = \alpha^2 \frac{IS_{11}}{\rho AL^4}^{12} \tag{5}$$

Where α^2 is the co-efficient, which value is catalogued by (Banerjee, 1996) and once ω_n is known then the natural frequency in cycles per second (Hertz) is given by $f_n = \omega_n/2\pi$, which is in line with (Gaith, 2011).

MATHEMATICAL MODEL

The model chosen here for our analysis is a composite cantilever beam as shown in the figure-1. It is of uniform cross-section A, having an open-edge transverse crack of depth 'a' at position 'l_1'. The width, length and height of the beam are B, L and H respectively. The angle between the fibers and the axis of the beam is 'α'.

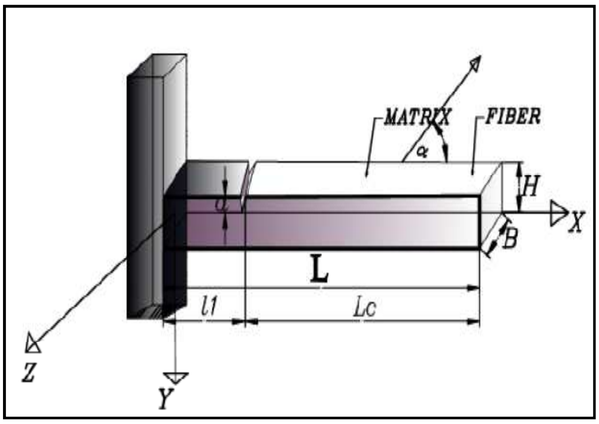

Fig 1: Schematic diagram of a composite cantilever beam with a crack

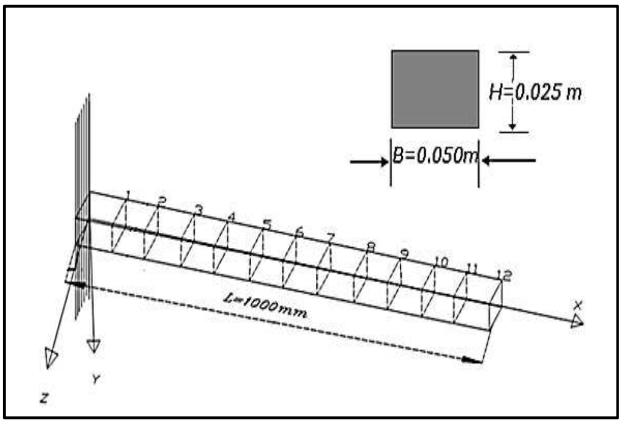

Fig 2: Geometry of the non-cracked composite cantilever beam with 12 elements

RESULTS AND CONCLUSIONS

The finite element solver namely ANSYS 10.0 is used to perform all the necessary computations. In the initialization phase, geometry and material parameters are specified. For example for a Euler–Bernoulli composite beam model with localized crack, material parameters like modulus of elasticity, the modulus of rigidity, the Poisson ratio and the mass density of the composite beam material along with geometric parameters like dimensions of the composite beam, also the specifications of the damage like size of the crack, location of the crack and extent of crack are supplied as input data into the preprocessor of the ANSYS 10.0 software. The beam is descritized into n number of elements. The model is then solved to obtain the non-dimensional natural frequencies and buckling load for non-cracked and cracked composite beam element.

Table 1. Material Properties of Composite Beam

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	V_m	0.33
	V_f	0.2
Mass density	ρ_m	1600 kg/m^3
	ρ_f	1900 kg/m^3

The results of vibration and buckling analysis of composite beam structure with or without crack were found out using the above given formulation. Each of the cracked composite beam problems are presented separately for the following studies:

I. Convergence testing

II.Vibration and Buckling analysis of beam with single crack

III. Vibration and Buckling analysis of beam with multiple cracks

CONVERGENCE TESTING

A fundamental premise of using the finite element procedure is that the body is sub-divided up into small discrete regions known as finite elements.It is necessary to conduct convergence tests on finite element model to confirm that a fine enough element discretization has been used. In this problem, this would be done by creating several models with different mesh sizes and comparing the resulting natural frequencies and mode shapes.

Table 2. The results of natural frequencies for different mesh divisions

Mesh Division	First Natural frequency (Hz)	Second Natural frequency(Hz)	Third Natural frequency(Hz)
2	0	24.225	25.005
3	15.689	24.654	29.433
4	13.684	24.531	25.387
5	13.67	24.53	25.32
6	13.55	24.44	25.311
7	13.52	24.39	24.72
8	13.519	22.378	24.413
9	13.517	22.37	24.41
10	13.512	22.368	24.4
11	13.51	22.33	24.394
12	13.495	22.277	24.392
13	13.494	22.265	24.392
14	13.493	22.265	24.392

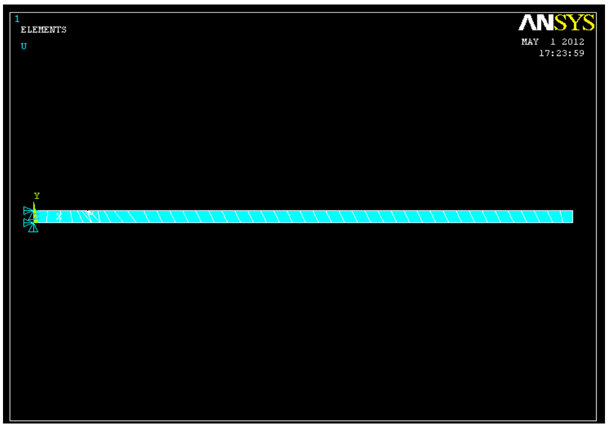

Fig 3: Geometric modeling of the cracked beam done in ANSYS

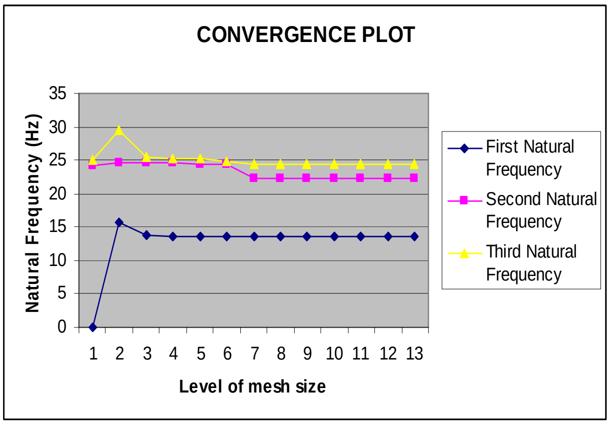

Fig 4: Convergence plot indicating the Level of Mesh size versus Natural Frequency in Hertz

VIBRATION ANALYSIS

After carrying out the convergence study of the non-cracked beam various crack scenarios are simulated using the ANSYS 10.0 CAE software package. The results of the non-dimensional natural frequencies as a function of various crack locations are presented here. Initially the cracks are simulated for a uniform crack depth of 0.1 at various crack locations. The locations are indicated in terms of relative crack locations from the fixed end. The beam is made up of unidirectional graphite fiber reinforced polyamide composite material

The geometrical characteristics of the beam are taken as length = 1m, breadth = 0.050m and height = 0.025m respectively. The finite elements were taken as brick 8 Node 45. These were selected because, due to the presence of cracks, the beam will assume an irregular cross section. The material properties were as listed in Table-1.

The crack locations and crack depths were varied to obtain the vibration characteristics of the beam. So, the variables are Relative crack location (RCL) and relative crack depths (RCD)

$$\text{RCL}=\frac{Lengthofthebeamatcrack}{OriginalLength}$$

$$\text{RCD}=\frac{Depthofthecrack\ (a)}{Heightofthebeam\ (h)}$$

Six RCL values were taken by keeping each RCD constant. The various relative locations were taken at 0.1, 0.2, 0.4, 0.6, 0.8, and 0.9 respectively.

Variation of Natural Frequencies on Account of Crack Locations

In the first six runs the beam having a constant relative crack depth (RCD) = 0.1 is simulated at various locations (RCL), at 0.1, 0.2, 0.4, 0.6, 0.8, and 0.9 and were analyzed and the first, second and third Natural Frequencies were found out. This procedure is repeated for all the values RCD and correspondingly graphs were plotted.

Table 3 List of natural frequencies at various crack locationsat RCD of 0.1

RCL	First Natural frequency(Hz)	Second Natural frequency(Hz)	Third Natural frequency(Hz)
0.1	401.6	795.06	2495.9
0.2	409.55	796.61	2521.5
0.4	399.94	794.85	2532.2
0.6	408.32	797.58	2584.5
0.8	397.67	795.32	2488.6
0.9	404.85	796.83	2520.4

Table 4 List of natural frequencies at various crack locations at RCD of 0.2

RCL	First Natural frequency(Hz)	Second Natural frequency(Hz)	Third Natural frequency(Hz)
0.1	400.15	793.45	2503.8
0.2	398.52	793.93	2509.4
0.4	397.8	793.91	2509.9
0.6	401.07	796.13	2526.3
0.8	398.88	796.52	2515.2
0.9	397.88	795.13	2490.4

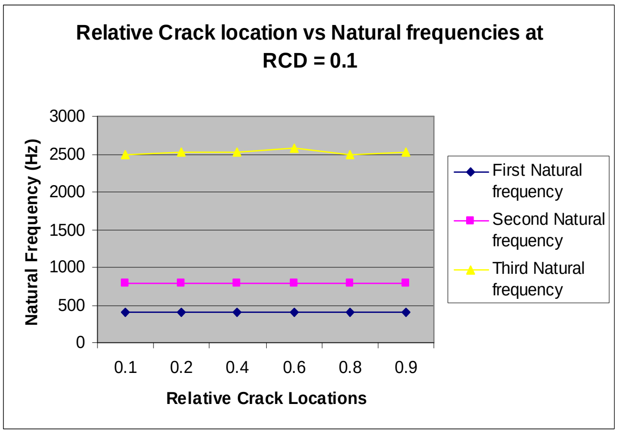

Fig 5. Relative Crack location versus Natural frequencies at RCD = 0.1

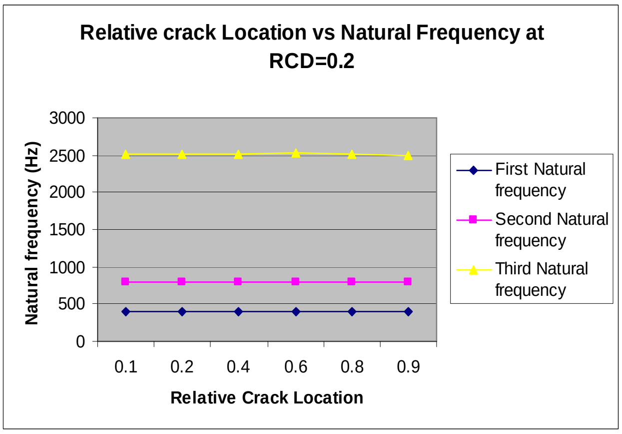

Fig 6. Relative Crack location versus Natural frequencies at RCD = 0.2

Table 5 List of natural frequencies at various crack locations at RCD of 0.4

RCL	First Natural frequency(Hz)	Second Natural frequency(Hz)	Third Natural frequency(Hz)
0.1	395.12	786.49	2549.4
0.2	397.13	789.95	2615.6
0.4	404.39	796.61	2686.4
0.6	400.68	799.95	2578.7
0.8	445.57	826.46	3144.3
0.9	766.35	1327.1	4669.7

Table 6 List of Natural frequencies at various crack locationsat RCD of 0.6

RCL	First Natural frequency(Hz)	Second Natural frequency(Hz)	Third Natural frequency (Hz)
0.1	335.33	773.14	2453.7
0.2	540.84	1077.2	3407.7
0.4	706.89	1173.2	4468.7
0.6	715.4	1211.3	4243.8
0.8	684.96	1301.1	4317
0.9	632.31	1138.6	3979.2

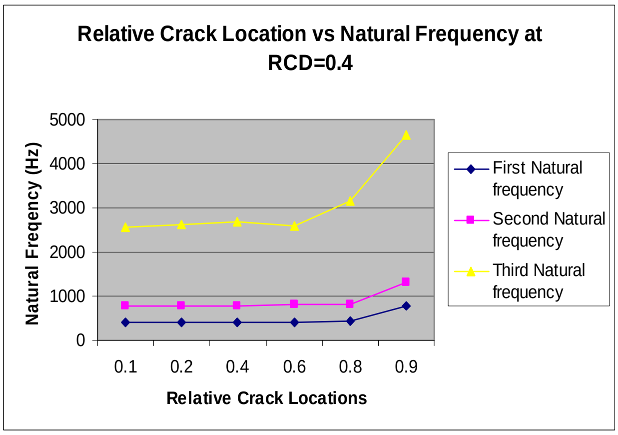

Fig7. Relative Crack location versus natural frequencies at RCD = 0.4

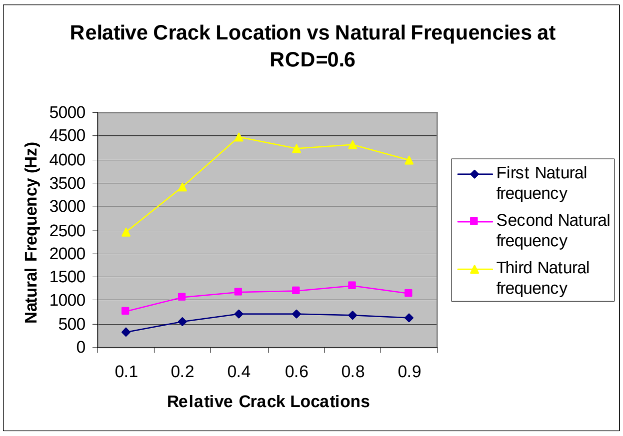

Fig8. Relative Crack location versus natural frequencies at RCD = 0.6

Table 7 List of Natural frequencies at various crack locations at RCD of 0.8

RCL	First Natural frequency (Hz)	Second Natural frequency (Hz)	Third Natural frequency (Hz)
0.1	467.39	1120.9	4637.6
0.2	506.32	976.87	4606
0.4	645.8	1121.4	3861.9
0.6	741.93	1247.3	3485.1
0.8	801.49	1308.1	4202.4
0.9	828.89	1348.3	4947

Table 8 List of Natural frequencies at various crack locations at RCD of 0.9

RCL	First Natural frequency (Hz)	Second Natural frequency (Hz)	Third Natural frequency (Hz)
0.1	325.72	969.49	4096.1
0.2	356	933.57	4439.1
0.4	656.88	1096.4	3899
0.6	721.8	1229.1	3572.3
0.8	808.43	1235.5	4421.8
0.9	808.49	1285.5	4892.9

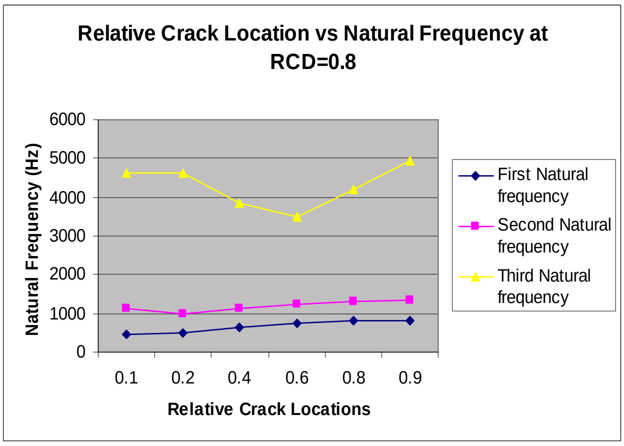

Fig 9. Relative Crack location versusNatural frequencies at RCD = 0.8

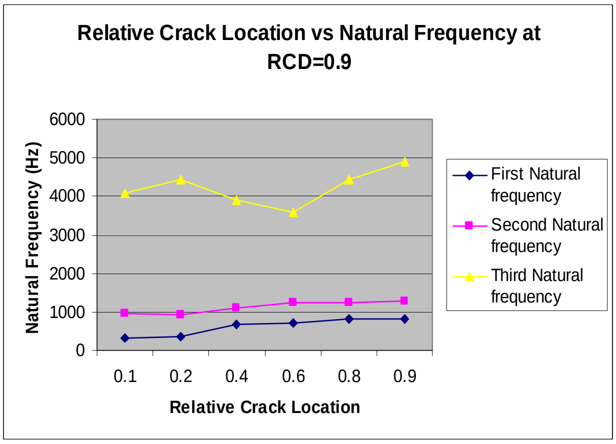

Fig 10. Relative crack location versus natural frequencies at RCD = 0.9

Variation of Natural Frequencies on Account of Crack depths

By rearranging the above results we can find the vibration characteristics of the beam (Variation of natural frequencies) at a specific location For example, In the first six runs the beam is having a crack at location 0.1 (constant RCL=0.1) However the depth of the crack varies from 0.1 to 0.9. This crack growth is analyzed and the following results were noted.

Table 9 List of natural frequencies at various crack depths at RCL of 0.1

RCD	First Natural frequency (Hz)	Second Natural frequency(Hz)	Third Natural frequency(Hz)
0.1	401.6	795.06	2495.9
0.2	400.15	793.45	2503.8
0.4	395.12	786.49	2549.4
0.6	335.33	773.14	2453.7
0.8	467.39	1120.9	4637.6
0.9	325.72	969.49	4096.1

Table 10 List of natural frequencies at various crack depthsat RCL of 0.2

RCD	First Natural frequency (Hz)	Second Natural frequency (Hz)	Third Natural frequency (Hz)
0.1	409.55	796.61	2521.5
0.2	398.52	793.93	2509.4
0.4	397.13	789.95	2615.6
0.6	540.84	1077.2	3407.7
0.8	506.32	976.87	4606
0.9	356	933.57	4439.1

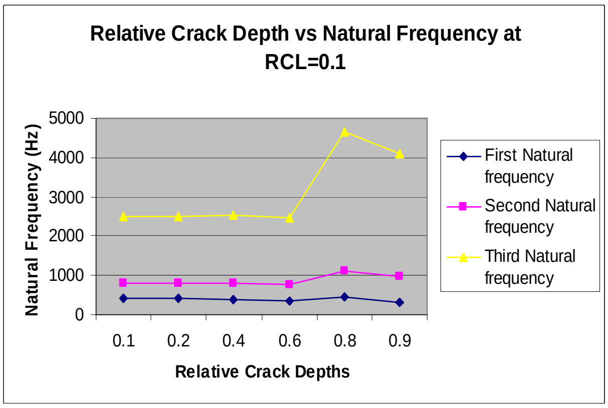

Fig 11. Relative crack depthsversus Natural frequencies at RCL = 0.1

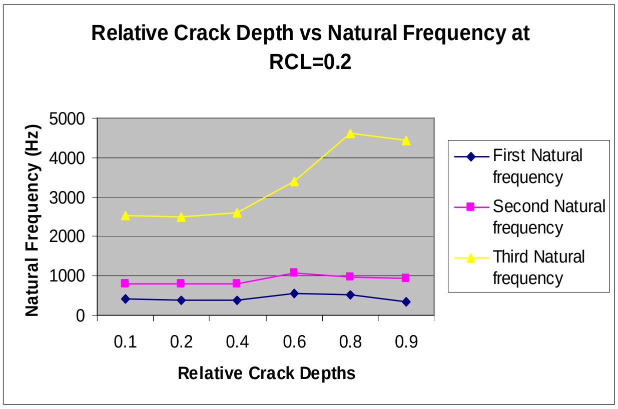

Fig 12. Relative crack depths versus Natural frequencies at RCL = 0.2

Table 11 List of natural frequencies at various crack depthsat RCL of 0.4

RCD	First Natural frequency (Hz)	Second Natural frequency(Hz)	Third Natural frequency(Hz)
0.1	399.94	794.85	2532.2
0.2	397.8	793.91	2509.9
0.4	404.39	796.61	2686.4
0.6	706.89	1173.2	4468.7
0.8	645.8	1121.4	3861.9
0.9	656.88	1096.4	3899

Table 12 List of natural frequencies at various crack depthsat RCL of 0.6

RCD	First Natural frequency (Hz)	Second Natural frequency(Hz)	Third Natural frequency(Hz)
0.1	408.32	797.58	2584.5
0.2	401.07	796.13	2526.3
0.4	400.68	799.95	2578.7
0.6	715.4	1211.3	4243.8
0.8	741.93	1247.3	3485.1
0.9	721.8	1229.1	3572.3

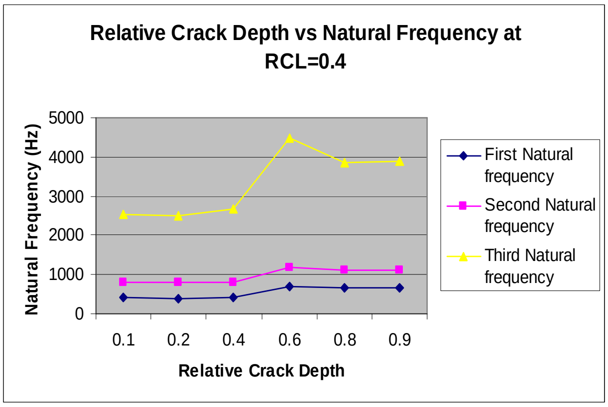

Fig 13. Relative crack depths versusnatural frequencies at RCL = 0.4

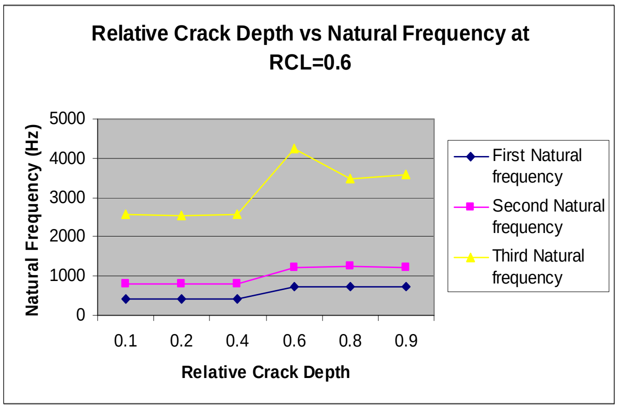

Fig 14. Relative Crack depths versus natural frequencies at RCL = 0.6

Table 13 List of natural frequencies at various crack depthsat RCL of 0.6

RCD	First Natural frequency (Hz)	Second Natural frequency(Hz)	Third Natural frequency(Hz)
0.1	408.32	797.58	2584.5
0.2	401.07	796.13	2526.3
0.4	400.68	799.95	2578.7
0.6	715.4	1211.3	4243.8
0.8	741.93	1247.3	3485.1
0.9	721.8	1229.1	3572.3

Table 14 List of natural frequencies at various crack depthsat RCL of 0.9

RCD	First Natural frequency(Hz)	Second Natural frequency(Hz)	Third Natural frequency(Hz)
0.1	404.85	796.83	2520.4
0.2	397.88	795.13	2490.4
0.4	766.35	1327.1	4669.7
0.6	632.31	1138.6	3979.2
0.8	828.89	1348.3	4947
0.9	808.49	1285.5	4892.9

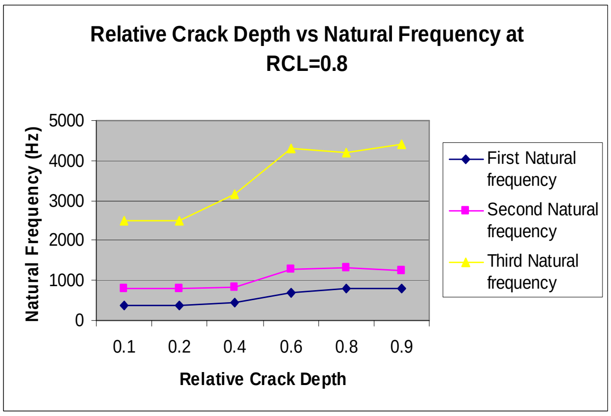

Fig 15. Relative Crack depth versus natural frequencies at RCL = 0.8

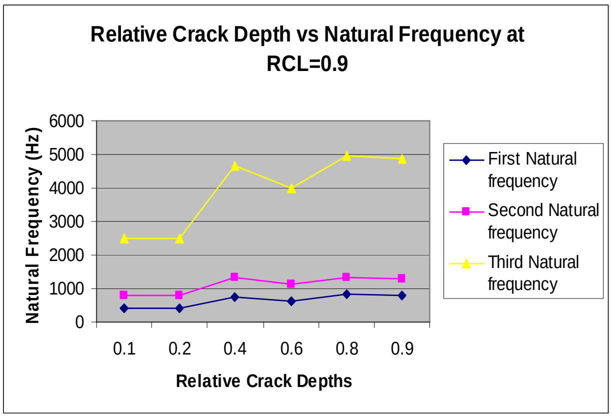

Fig 16. Relative crack depth versus natural frequencies at RCL = 0.9

BUCKLING ANALYSIS

Buckling loads are critical loads where certain types of structures become unstable. Each load has an associated buckled mode shape; this is the shape that the structure assumes in a buckled condition. There are two primary means to perform a buckling analysis.

Eigen value buckling analysis predicts the theoretical buckling strength of an ideal elastic structure. It computes the structural Eigen values for the given system loading and constraints. This is known as classical Euler buckling analysis. Buckling loads for several configurations are readily available from tabulated solutions. However, in real-life, structural imperfections and nonlinearities prevent most real world structures from reaching their Eigen value predicted buckling strength; i.e. it over-predicts the expected buckling loads.

Nonlinear buckling analysis is more accurate than Eigen value analysis because it employs non-linear, large-deflection; static analysis to predict buckling loads. Its mode of operation is very simple: it gradually increases the applied load until a load level is found whereby the structure becomes unstable (i.e. suddenly a very small increase in the load will cause very large deflections). The true non-linear nature of this analysis thus permits the modeling of geometric imperfections, load perturbations, material nonlinearities and gaps. For this type of analysis, small off-axis loads are necessary to initiate the desired buckling mode.

Variation of Buckling loads on account of crack locations

The result of the buckling analysis is as follows. The variation of buckling loads on account of crack locations as well as on account of crack depths is obtained.

Table 15 List of non-dimensional buckling loads for various crack locations at relative crack depths of 0.1, 0.2 and 0.4

RCL	RCD= 0.1	RCD=0.2	RCD=0.4
0.1	6872.8	10454	10418
0.2	6954.8	10418	10440
0.4	6851.1	8256.7	10598
0.6	6892	8444.5	10605
0.8	6837.7	10464	12149
0.9	6920.8	10442	15160

Table 16 List of non-dimensional buckling loads for various crack locations at relative crack depths of 0.6, 0.8 and 0.9

RCL	RCD=0.6	RCD=0.8	RCD=0.9
0.1	10399	33495	12950
0.2	14735	31323	14903
0.4	10573	35002	41137
0.6	50817	55745	44749
0.8	60894	66656	61164
0.9	76142	81688	61180

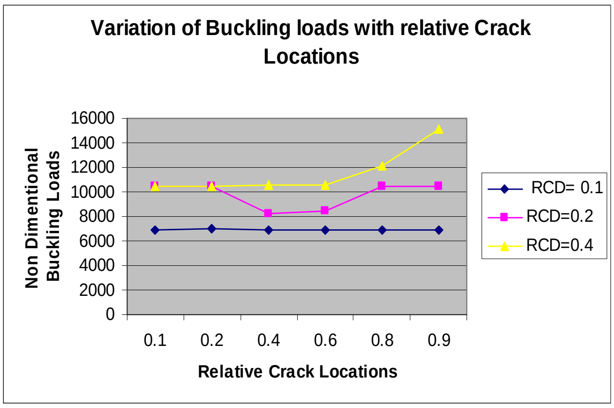

Fig 17. Relative crack locations versus non dimensional buckling loads at relative crack depths of 0.1, 0.2 and 0.4

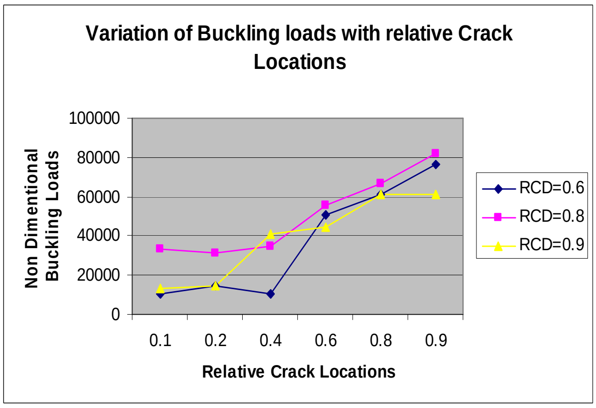

Fig 18. Relative crack locations versus non dimensional Buckling loads at relative crack depths of 0.6, 0.8 and 0.9

The results are tabulated in separate tables and plotted separately as it would rather be difficult to express in a single graph. So buckling load values for RCD 0.1, 0.2 and 0.4 are plotted in the first graph and the remaining RCD values i.e. 0.6, 0.8and 0.9 are plotted in the second graph.
The graphs basically indicate the relationship between the crack parameters and the buckling loads. The figures 19 and 20 show the variation of the buckling loads with respect to the crack locations. This has been simulated for uniform crack depths of 0.1, 0.2 and 0.4. Similarly in the second graph buckling loads are plotted with respect to the crack locations at uniform crack depths of 0.6, 0.8 and 0.9.
It is seen that the buckling loads (the load at which deformation occurs) increases as the crack moves to the free end. This means that if the crack is near to the fixed end it becomes critical. i.e., the structure fails at low buckling loads.

Thus the location of the crack is critical in the variation of buckling loads. In other words the value of buckling loads is instrumental in determining the location or position of cracks in the structure

Variation of Buckling loads on account of crack growth

Similar to the previous section, the results are tabulated in separate tables and plotted separately as it would rather be difficult to express in a single graph. So buckling load values for RCL 0.1, 0.2 and 0.4 are plotted in the first graph and the remaining RCL values i.e. 0.6, 0.8and 0.9 are plotted in the second graph.

Table 17 List of non-dimensional buckling loads for various crack depths at relative crack locations 0.1, 0.2 and 0.4

RCD	RCL=0.1	RCL=0.2	RCL=0.4
0.1	6872.8	6954.8	6851.1
0.2	10454	10418	8256.7
0.4	10418	10440	10598
0.6	10399	14735	10573
0.8	33495	31323	35002
0.9	12950	14903	41137

Table 18 List of non-dimensional buckling loads for various crack depths at relative crack locations 0.6, 0.8and 0.9

RCD	RCL=0.6	RCL=0.8	RCL=0.9
0.1	6892	6837.7	6920.8
0.2	8444.5	10464	10442
0.4	10605	12149	15160
0.6	50817	60894	76142
0.8	55745	66656	81688
0.9	44749	61164	61180

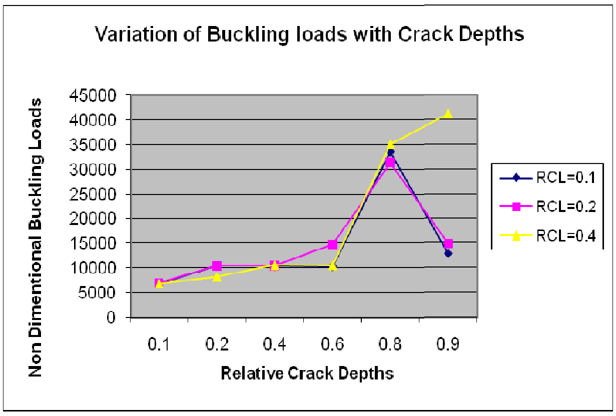

Fig 19. Relative Crack depths versus non dimensional buckling loads at relative crack locations of 0.1, 0.2 and 0.4

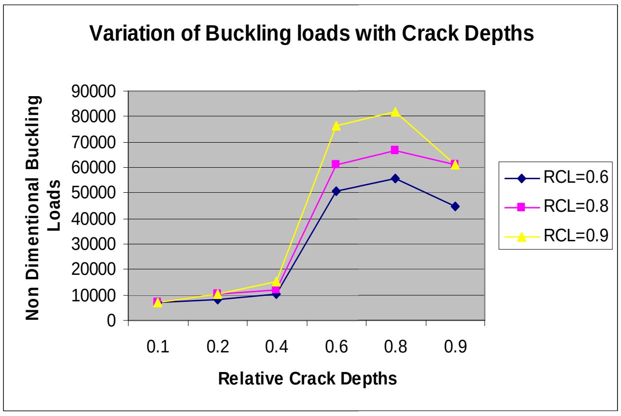

Fig 20. Relative crack depths versus non dimensional buckling loads at relative crack locations of 0.6, 0.8 and 0.9

Now the variation of buckling loads with respect to the crack growth is described here. Crack growth essentially means the variation or increase in the relative crack depths of the beam. In this case the RCL is kept constant for a set and depths are varied to find out the buckling loads. It is found that as the crack depths increase the value of buckling loads also increases and reaches a maximum and falls sharply. This indicates that minor cracks and major cracks equally aid the buckling phenomenon and they both are equally dangerous. If the specimen initially crosses the failure zone then it would withstand further depth. But as the crack growth continues abrupt failure was noticed

EFFECT OF MULTIPLE CRACKS ON THE BEAM

In this section the effect of multiple cracks on the cantilever beam is being studied. Here only three cracks are taken at a time for analysis. In the first part the effect of crack formation nearer to the fixed end is studied and in the next part crack formation at the free end is studied. It is found that there is a notable change in the frequency. The extent and nature of change will help us to identify the number of cracks and the possible concentration area of the cracks on the beam. In the first part the cracks are simulated at relative locations 0.1, 0.2 and 0.4 near to the fixed end and in the second part the cracks are simulated at locations 0.6, 0.8 and 0.9 near to the free end.

Vibration Analysis of the Beam with Multiple cracks

The procedure for vibration analysis is same as that of the analysis done on a beam with single crack. Here the mode shapes associated with each natural frequency were also found out. The beams with multiple cracks near to the fixed end and the beam with multiple cracks near to the free ends were analyzed separately. The mode shape diagrams along with the variation of natural frequency provide a strong signature of the crack found on the beam.
The figure 23 shows the geometry of the beam with the cracks at locations 0.1, 0.2 and 0.3. When it undergoes vibration analysis their mode shapes gets extracted. The mode shape shows the displacement of the beam from the mean position with respect to time when it undergoes free vibration. The cracks simulated are of uniform depth of 0.6 RCD at locations close to each other. By this analysis we will be able to identify how the presence of multiple cracks will alter the dynamic characteristics of the beam.

Table 19 First, Second & Third natural frequencies of the beam with multiple cracks obtained from vibration analysis

Location of the Cracks	First Natural frequency(Hz)	Second Natural frequency(Hz)	Third Natural frequency(Hz)
Fixed end	412.27	783.85	2694.6
Free End	416.85	812.4	2727.5

Table 20 Non dimensional buckling loads of the beam with multiple cracks obtained from Eigen Buckling Analysis

Location of the Cracks	Non Dimensional Buckling Loads
Cracks at Fixed end	8530
Cracks at Free End	8798.9

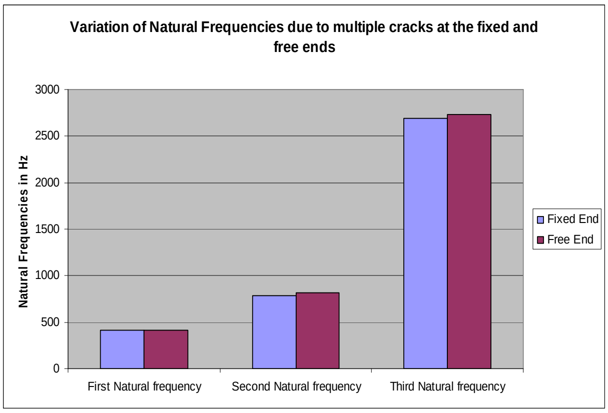

Fig 21. Bar chart showing the rise of natural frequency when the concentration of the crack is near to the free end

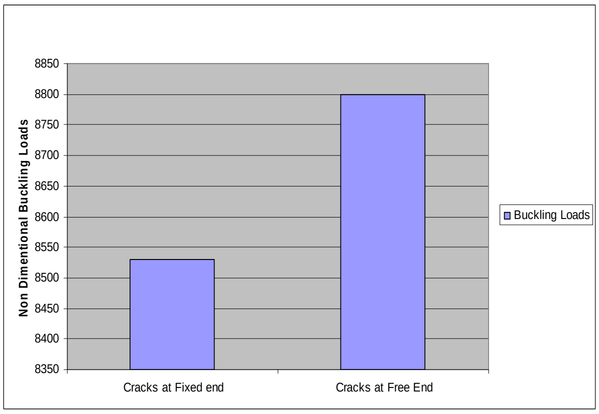

Fig 22. Bar chart showing the changes in buckling Loadswhen the concentration of the crack is near to the free end.

The results can be fed into a microprocessor and can be stored s a reference for comparison. Once the real time data, from the sensor, matches with the reference data, the crack or flaw will be detected.

From the graphs it is found that as the beams tend to exhibit a higher natural frequency if their concentration is nearer to the free end. It is applicable to the cases of First, Second and Third frequencies. But the rate of increase is higher for the third frequency compared to the first frequency. Moreover to gets an overall idea of the fracture modes it is important to simulate all crack scenarios. Future work is very much required as the scope of this work is limited to multiple cracks with uniform depth only. In addition to this simulation may be performed with cracks with varying densities on the beam.

Buckling Analysis of the Beam with Multiple cracks

Eigen value buckling analysis was performed in the beam with multiple cracks. The procedure being the same as adopted in the beam with a single crack. But this was done in two parts. In the first part the beam with multiple cracks near to the fixed end was analyzed and in the second part the beam with multiple cracks near to the free end was done. The results are as follows

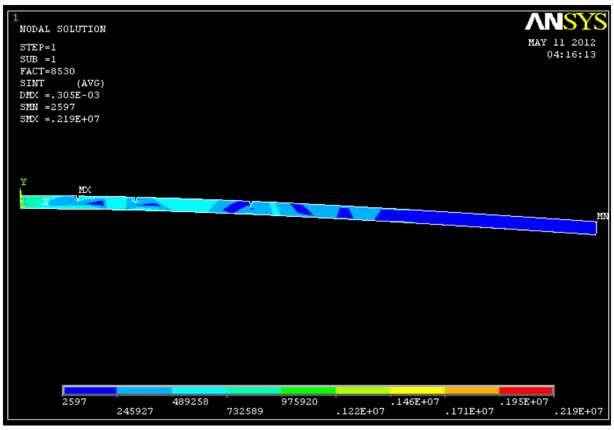

Figure 23. Deformed shape of the beam with multiple acks after Eigen value buckling analysis when the cracks near to the fixed end

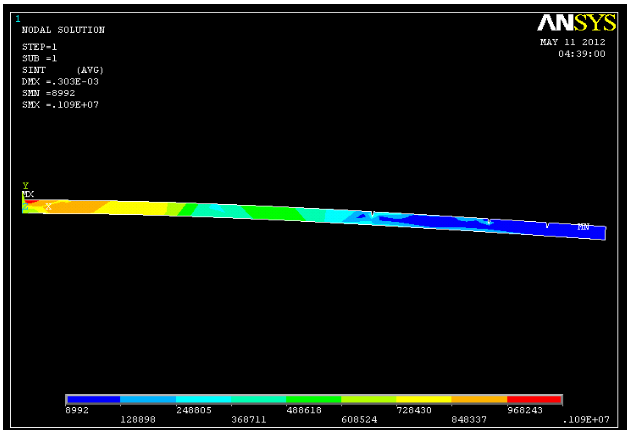

Figure 24. Deformed shape of the beam with multiple racks after Eigen value buckling analysis when the cracks near to the free end

From the results it is found that the presence of multiple cracks near to the fixed end of the beam is more critical than the presence of multiple cracks near to the free end. Also the mode shape diagram is another signature which can be used for comparing the characteristics of the beam to the standard non cracked one. The buckling mode shapes are as given in the figure 23 and 24. Thus the variation of buckling load and the mode shape diagram gives us a clear picture of the location and size of the crack that too without any disadvantages faced in the conventional non-destructive evaluation methods.

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.

1. From convergence study it was noticed that, a mesh of 14 elements shows good convergence of natural frequencies of the cantilever beam in free vibration.
2. Further this element is versatile and can be used for static and dynamic analysis of a composite or isotropic beam.
3. From the vibration analysis it can be concluded that the natural frequencies of vibration of a cracked composite beam are the functions of the crack locations and crack depths.
4. The presence of a transverse crack increases the natural frequencies of the composite beam. On account of position, as the crack moves from the fixed end to the free end it is found that initially the frequencies rise and reaches maximum at an RCL of 0.6 and further the frequency decreases.
5. In the case of beam with uniform crack depth of 0.4, the natural frequencies tend to rise towards the free end of the beam and attain a maximum value at an RCL of 0.9.
6. But in the case of beam with crack with crack of uniform crack depth of 0.6 the natural frequency becomes maximum at RCL 0.4 and then it is found to decrease towards the free end of the beam.
7. In the case of uniform crack depths of 0.8 and 0.9, the natural frequency tends to decrease in the middle of the beam. The frequencies are highest in the fixed as well as the free end of the beam.
8. It is seen that the buckling loads (the load at which deformation occurs) increases as the crack moves to the free end. This means that if the crack is near to the fixed end it becomes critical.
9. It is found that as the crack depths increase the value of buckling loads also increases and reaches a maximum and falls sharply. This indicates that minor cracks and major cracks equally aids the buckling phenomenon.
10. From the results it is found that the presence of multiple cracks near to the fixed end of the beam is more critical than the presence of multiple cracks near to the free end.

NOMENCLATURE

The principal symbols used in this research paper are presented for easy reference. A symbol is used for different meaning depending on the context and defined in the text as they occur.

NOTATION	DESCRIPTION
$\mathbf{A}$	Cross-sectional area of the element
$\mathbf{a}$	Crack depth
α	Angle of the fibre
$\mathbf{B}$	Width of the composite beam
δ	Linear displacement
$\mathbf{E_f}$	Modulus of Elasticity of the Fibre Material
$\mathbf{E_m}$	Modulus of Elasticity of the Matrix Material
ε	Linear Strain
$\mathbf{G_f}$	Modulus of Rigidity of the Fibre Material
$\mathbf{G_m}$	Modulus of Rigidity of the Matrix Material
$\mathbf{H}$	Height of the composite beam
$\mathbf{I}$	Moment of inertia
$\mathbf{L}$	Length of the composite beam
l_1	Crack location
$\mathbf{P(t)}$	Periodic axial force
$\mathbf{P_{cr}}$	Critical Buckling load
$\mathbf{q}$	Vector
ρ	Mass Density of the beam
ρ_f	Mass density of the Fibre Material
ρ_m	Mass density of the Matrix material
$\mathbf{S_{11}}$	Material property of the composite material
$\mathbf{V_f}$	Poisson's Ratio of the Fibre material
$\mathbf{V_m}$	Poisson's Ratio of the Matrix material
ω	Natural frequency
ω_n	Non-dimensional natural frequency
Ω	Disturbing frequency

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