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Vibration Analysis of CFRP Cantilever Beams due to Different Types of Notches Closed to Fixed End

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***Abstract* - The aim of experiment is to analyze the vibration of undamaged and damaged Carbon Fiber Reinforced Polymer (CFRP) beams. Experimental free vibration of CFRP cantilever beam will be investigated by dynamic tests. Total three different types of notches are made artificially on the beams closed to fixed end. A comparison will be made of the experimentally extracted frequencies at each damage level and in relation to the single positions of the accelerometer. A comparison between natural frequencies due to different types notches have been investigated. The present experiment illustrates the envelope of Frequency Response Functions (FRFs) obtained by the experimental dynamic tests and the changes of natural frequency values correlated to the damage degree of CFRP beam. Numerical data is found out and discussed in comparison to the experimental results.**

Keywords - natural frequencies; frequency responses; damage analysis; CFRP cantilever beam;

I. INTRODUCTION

In recent decades fibre-reinforced composites have been extensively used for many applications because of their high strength-to-weight and stiffness-to-weight ratios [1]. Composite materials are similar to isotropic materials which are subjected to various damages that are cracks in fibres, matrix, and the interfaces of fibres and matrix is very common in the failure mode of composites [2]. In the present work, vibration analysis of the damaged CFRP cantilever beams can be done by experimental vibration tests by introducing changes of natural frequencies. The damaged condition may be correlated with the changes in frequency values, this decreased with the increasing of damaged condition [3-4]. The analysis demonstrated that the length of damage appears to have less influence as compared to width [5-6]. Experimental results are compared with theoretical results to confirm the availability of the vibration analysis method which is adopted for the analysis of undamaged and damaged CFRP beams. In order to compare the damage frequency values of beams with that of undamaged frequency values of the beams, the variation in natural frequencies of beams are required. A comparison of the values obtained during vibration values of rectangular notched beams with that of the vibration values of Curve notches and double rectangular notches to find out which notches of the beam have high strength capacity for same CFRP beams. Damages in FRP lamina may be represented by local reductions of section or/and loss of continuity of matrix or matrix and fibres [7-8]; these damages may occur for impact or high local stresses [9]. Damages reduce stiffness and lead to the development of diffused FRP cracking with a correlation on the frequency values [10].

II. EXPERIMENTAL INVESTIGATIONS

A. Tensile tests performed on CFRP specimen

Experimental tensile tests on specimens were carried out in the laboratory in order to evaluate the strength of CFRP laminas and Young's modulus before vibration tests aimed at determining the frequency values of undamaged and damaged CFRP cantilever beam elements. Tensile test beam element dimensions are 250mm*20mm*2mm (thick) and 55mm aluminum pads for gripping purpose while testing at the end of the beams. Table 1 shows the tensile test results of CFRP Cantilever beam. Fig. 1 shows the test setup of CFRP cantilever beam. Fig. 2 shows the tensile test result of CFRP cantilever beam.

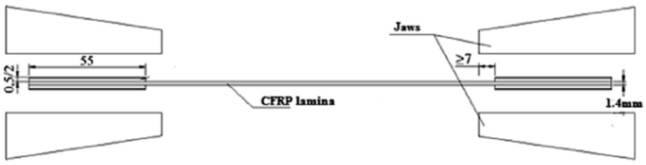


Fig. 1 Experimental setup for tensile test of a CFRP cantilever beam

Fig. 2 Experimental setup for tensile test of a CFRP cantilever beam

Table no 1: Tensile test properties of CFRP cantilever beam

Length (mm)	Width (mm)	Thickness (mm)	Young's Modulus (N/mm^2)	Poisson's Ratio	Density (Kg/m^3)	Ultimate Tensile Strength (N/mm^2)
250	19	2	70	0.43	1600	90
250	21	2	70	0.43	1600	97

B. FFT analyzer and sensors

The Instrument used for determining the frequency values are crystal instruments Coco 80x, Impact Hammer and its Property is 0.9944mv/lbf, Sensor name is P20, weight is 3 grams, and its property is 10 mv/lbf. Fig. 3 shows the FFT analyzer. Fig. 4 shows the impact hammer and the sensor.

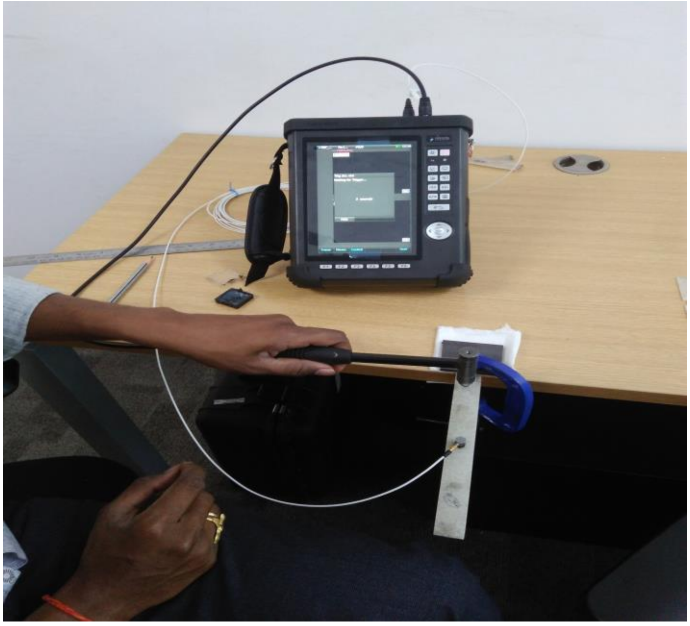


Fig. 3 FFT analyzer (Crystal Coco 80x)

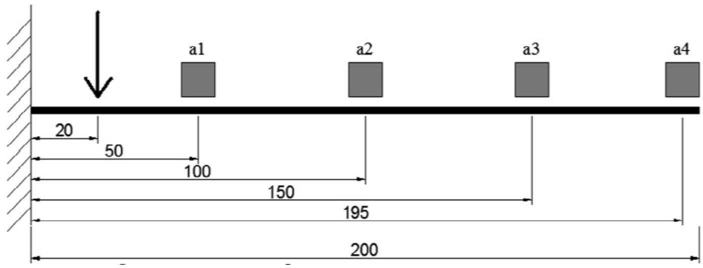
Fig. 4 Impact Hammer and P20 sensor

C. Free vibration tests using FFT analyzer

Table no.2 the theoretical natural frequencies of an undamaged CFRP beam assumed as uniform slender beam. The hypothesis of rotary inertia, shear deformation and damping negligible are considered in the damage analysis of cantilever beam. A set of 10 hits was made for each position of the accelerometer a_1 and the average value was acquired. The CFRP cantilever beam was initially tested in undamaged condition (D_0). Frequency values were extracted by transformed signals in frequency domain using the Fast Fourier Transform (FFT) technique. The same procedure is repeated for all damaged conditions are Single rectangle notch damage (D_1), single rectangle with curve notch damage (D_2) and double rectangle notch damage (D_3). Tables 3 – 6 shows the frequencies for each damage condition. Table 7 shows the average frequency values for each damage level. Fig. 5 shows the accelerometer positions on the testing CFRP cantilever beam. Fig. 6 – 9 shows the CFRP Cantilever beams with different damage conditions as stated.

Table no 2: Experimental CFRP cantilever beam parameters

Length (mm)	Width (mm)	Thickness (mm)	Young's Modulus (N/mm^2)	Poisson's Ratio	Density (Kg/m^3)	Ultimate Tensile Strength (N/mm^2)
250	21	2	70	0.43	1600	97



vibration test

Fig. 6 CFRP cantilever beam in undamaged condition

Fig. 7 CFRP cantilever beam in a single rectangle notch damage condition

Fig. 8 CFRP cantilever beam in a single rectangle with notch damage condition

Fig. 9 CFRP cantilever beam in double rectangle notch damage condition

D. Free vibration frequency test values *using FFT analyzer*

Table no 3: CFRP cantilever beam in undamaged condition frequency values

Undamaged	f_1	f_2	f_3	f_4
a_1	33.7500	127.5000	357.5000	737.5000
a_2	32.7500	125.0000	386.2500	741.7500
a_3	32.5000	121.2500	381.2500	715.0000
a_4	33.7500	116.2500	351.2500	697.5000
Average	33.1875	122.5000	369.0625	722.3119

Table no 4: CFRP cantilever beam in single rectangle notch damage condition frequency values

Damaged	f_1	f_2	f_3	f_4
a_1	31.7500	101.2500	353.7500	727.0000
a_2	31.2500	112.2500	359.0000	729.2500
a_3	29.5000	105.7500	346.5000	706.5000
a_4	27.5000	103.5000	342.2500	691.2500
Average	30.0000	105.6875	350.375	713.5000

Table no 5: CFRP cantilever beam in a single rectangle with notch damage condition frequency values

Damaged	f_1	f_2	f_3	f_4
a_1	30.2500	100.2500	338.7500	714.7500
a_2	30.7500	99.7500	341.2500	721.2500
a_3	29.5000	97.2500	321.7500	701.7500
a_4	29.2500	96.7500	301.2500	698.2500
Average	29.9375	98.5000	325.7500	709.000

Table no 6: CFRP cantilever beam in double rectangle notch damage condition frequency values

Damaged	f_1	f_2	f_3	f_4
a_1	28.5000	86.2500	246.2500	710.7500
a_2	27.7500	85.0000	253.7500	695.7500
a_3	26.5000	84.2500	247.5000	702.2500
a_4	24.2500	83.7500	245.7500	689.7500
Average	26.7500	84.8125	248.3125	699.6250

E. Free vibration frequency spectrums of CFRP cantilever beam

Frequency spectrum with respect to accelerometer positions All graphs are frequency vs DB. Fig. 10 shows the frequency spectrums of CFRP undamaged condition. Fig. 11 shows the frequency spectrums of CFRP single rectangle notch damaged condition. Fig. 12 shows the frequency spectrums of CFRP single rectangle with curve notch damaged condition. Fig. 13 shows the frequency spectrums of CFRP single rectangle notch damaged condition.

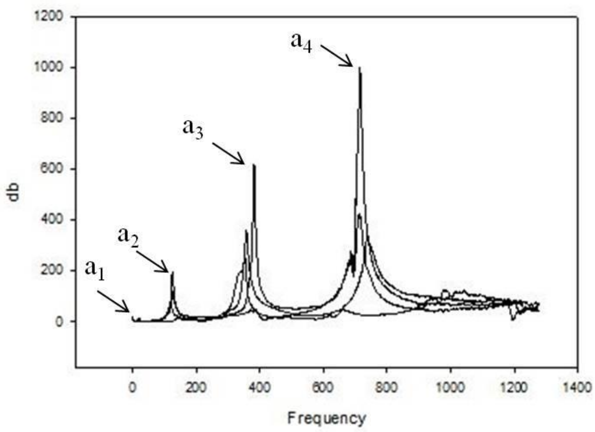


Fig. 10 Frequency spectrums of CFRP undamaged condition

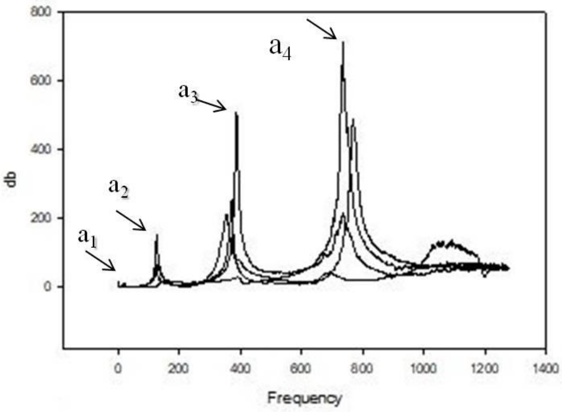


Fig. 11 Frequency spectrums of CFRP single rectangle notch damaged condition.

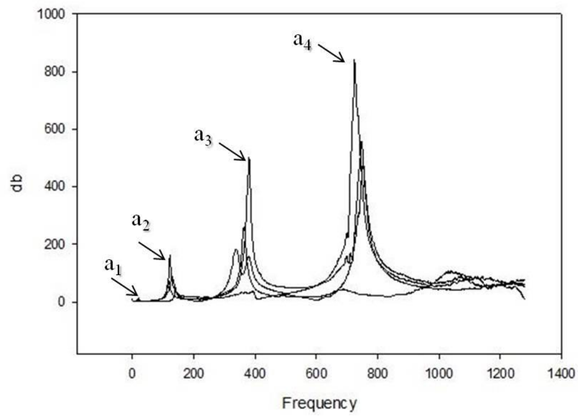
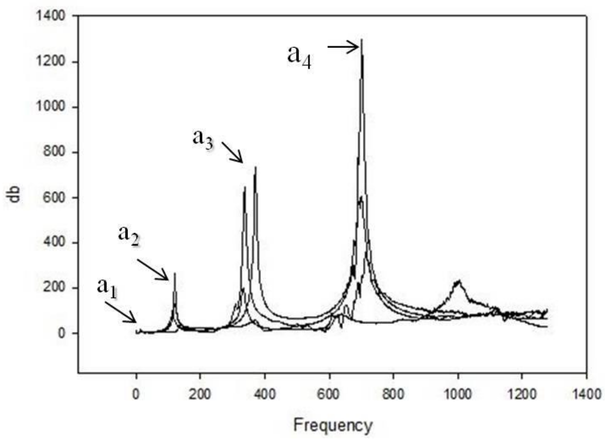


Fig. 12 Frequency spectrums of CFRP single rectangle with curve notch damaged condition



Frequencies (Hz)

Fig. 13 Frequency spectrums of CFRP double rectangle notch damaged condition

III. THEORETICAL CALCULATIONS

Theoretical natural frequencies in the case of the damaged condition of the CFRP cantilever beam has been analyzed solving Eq. 1 and Eq.2) for non-dimensional stiffness values, k, of the spring capable of describing the damages in a limited zone of the beam.

The equations are taken from [1] for theoretical calculations Eigen values (λ) are 1.875, 4.694, 7.855

The Theoretical frequency values obtained from solving above equation was are shown in Table 8.

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IV. RESULTS AND DISCUSSION

A series of experiments are conducted to determine the natural frequencies of a CFRP cantilever beam. The frequency near to the notch at accelerometer position (a_1) for undamaged condition is 33.1875, for single rectangular notch damage condition is 30.0000, for single rectangle with curve notch condition is 29.9375, and for double rectangle notch condition is 26.7500. As a result of conducting two types of analysis, it can be found that the frequency decreases with the increase in damage condition.

The frequency values obtained by theoretical calculations for undamaged condition is 36.4, for single rectangular notch damage condition is 33.7, for single rectangle with curve notch condition is 31.81, and for double rectangle notch condition is 27.29.

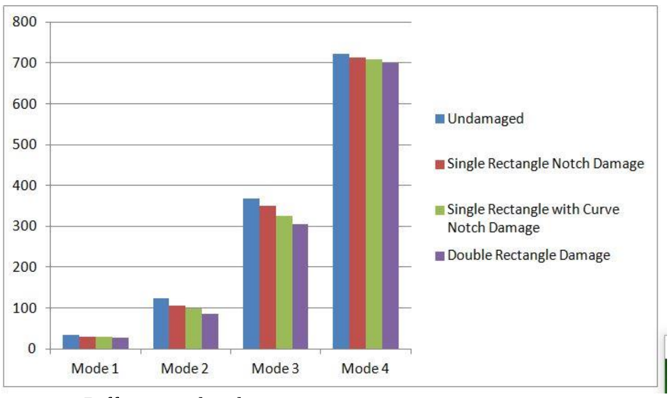
Tables 7 and 8 shows the experimental and theoretical natural frequencies. Fig.14 shows the varaiation of natural frequencies by experimental investigations.

Table no 7: Average frequency values in all damaged conditions by experimental investigations

Damage Condition	f_1	f_2	f_3	f_4
Undamaged	33.1875	122.5000	369.0625	722.3119
Single Rectangular Notch	30.0000	105.6875	350.375	713.5000
Combination of Single Rectangle & Arc Notch	29.9375	98.5000	325.7500	709.000
Double Rectangular Notch	26.7500	84.8125	305.3125	699.625

Table 8 Average frequency values in all damaged conditions by theoretical calculations

Damage Condition	f_1	f_2	f_3
Undamaged	36.4	130.14	390.42
Single Rectangular Notch	33.7	115.26	375.26
Combination of Single Rectangle & Arc Notch	31.81	108.8	360.27
Double Rectangular Notch	27.29	90.12	331.35



Different modes damage

Fig. 14 Variation of natural frequencies for experimental investigations

V. CONCLUSIONS

An experimental dynamic research on the damage behaviour of CFRP cantilever beams was developed both in the undamaged condition and in three types of damage due to notches close to the fixed end. The damaged condition may be correlated with the changes in frequency values; these decrease with the increasing of damage condition. Both experimental and theoretical methods results are demonstrated. The error is found between experimental and analytical frequency calculation methods and it is observed that it varies from 5% - 10%. In this experimentation, there is not much frequency difference between single rectangle notch and single rectangle with a curved cross-section. By using curved notches in place of rectangle notches to avoid sharp corners so that better performance of beams can be achieved.

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