Experimental Investigations on GFRP 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 Glass Fiber Reinforced Polymer (GFRP) beams. Experimental free vibration of GFRP 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 GFRP beam. Numerical data is found out and discussed in comparison to the experimental results.***

Index Terms – natural frequencies,frequency responses,damage analysis, GFRP 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 GFRP 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 GFRP 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 GFRP 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 GFRP specimen

Experimental tensile tests on specimens were carried out in the laboratory in order to evaluate the strength of GFRP laminas and Young's modulus before vibration tests aimed at determining the frequency values of undamaged and damaged GFRP 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 GFRP Cantilever beam. Figure 1 shows the test setup of GFRP cantilever beam. Figure 2 shows the tensile test result of GFRP cantilever beam.

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

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

Table 1 Tensile test properties of GFRP 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	72	0.32	1376	400
250	21	2	72	0.32	1376	425

B. 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

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 GFRP 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). Table 2 shows the theoretical natural frequencies of an undamaged GFRP beam assumed as uniform slender beam. Tables 3 – 6 shows the frequencies for each damage condition. Table 7 shows the average frequency values for each damage level. Figure 5 shows the accelerometer positions on the testing GFRP cantilever beam. Figires 6 – 9 shows the GFRP Cantilever beams with different damage conditions as stated.

Table 2 Experimental GFRP 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	0.32	1376	425

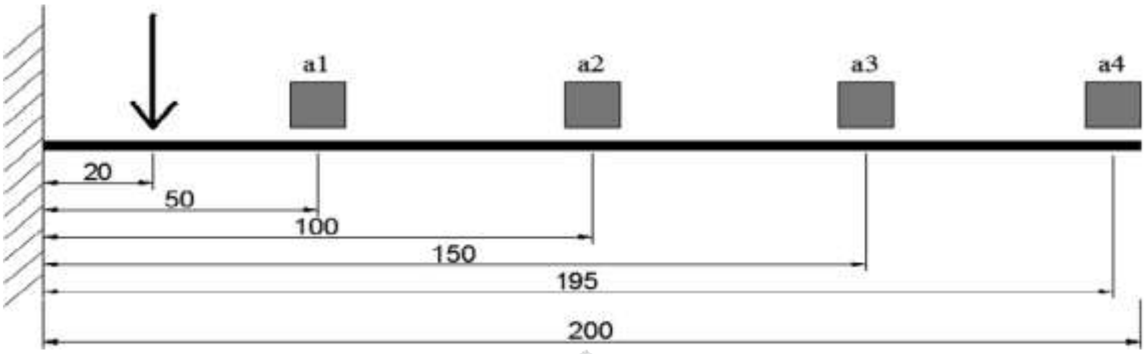

Fig. 6. GFRP cantilever beam in undamaged condition

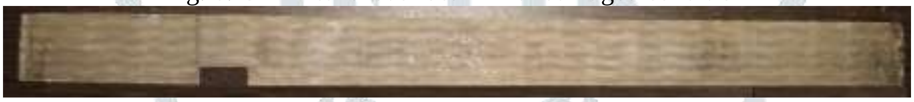

Fig. 7. GFRP cantilever beam in a single rectangle notch damage condition

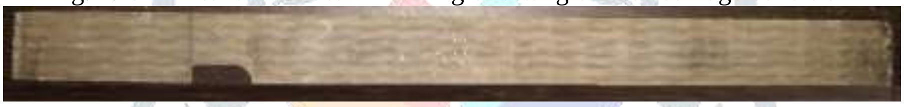

Fig. 8. GFRP cantilever beam in a single rectangle with notch damage condition

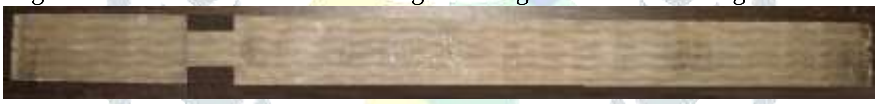

Fig. 9. GFRP cantilever beam in double rectangle notch damage condition

D. Free vibration frequency test values using FFT analyzer

Table 3 GFRP cantilever beam in undamaged condition frequency values

Undamaged	f_1	f_2	f_3	f_4
a_1	32.5000	91.2500	250.0000	542.5000
a_2	33.7500	88.7500	291.2500	527.0000
a_3	34.0000	95.0000	240.0000	538.7500
a_4	33.7500	88.7500	257.5000	524.5000
Average	33.5000	90.9375	259.6875	533.1875

Table 4 GFRP cantilever beam in single rectangle notch damage condition frequency values

Damaged	f_1	f_2	f_3	f_4
a_1	30.5000	88.7500	242.5000	531.2500
a_2	31.7500	85.0000	255.0000	539.7500
a_3	30.2500	83.2500	260.0000	514.2500
a_4	29.5000	81.7500	246.2500	498.0000
Average	30.5000	84.6875	250.9375	523.3125

Table 5 GFRP cantilever beam in a single rectangle with notch damage condition frequency values

Damaged	f_1	f_2	f_3	f_4
a_1	30.7500	84.7500	251.2500	556.2500
a_2	29.2500	81.5000	253.7500	523.7500
a_3	28.7500	83.7500	258.7500	509.5000
a_4	27.5000	83.5000	231.7500	502.7500
Average	29.0625	82.375	248.8750	518.0625

Table 6 GFRP cantilever beam in double rectangle notch damage condition frequency values

Damaged	f_1	f_2	f_3	f_4
a_1	29.5000	81.2500	236.2500	526.7500
a_2	28.7500	82.0000	245.7500	506.2500
a_3	26.7500	79.7500	211.7500	488.7500
a_4	26.2500	76.7500	207.2500	485.5000
Average	27.8125	79.9375	225.2500	501.8125

E. Free vibration frequency spectrums of GFRP cantilever beam

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

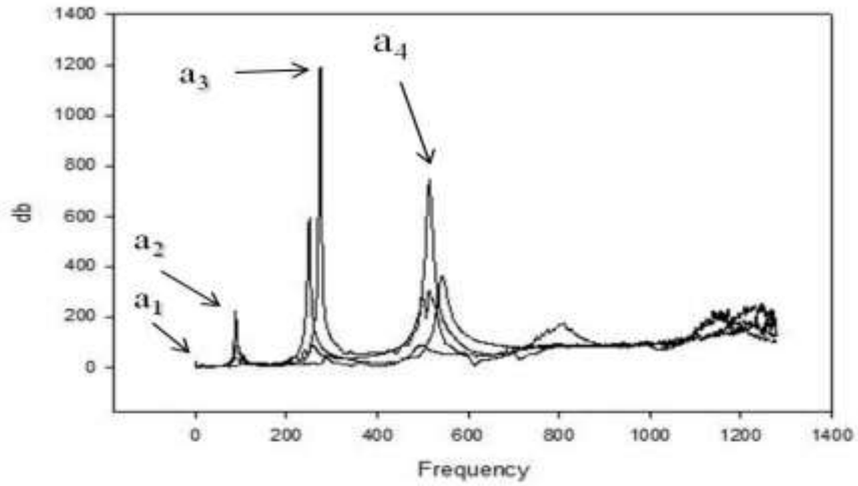

Fig. 10. Frequency spectrums of GFRP undamaged condition

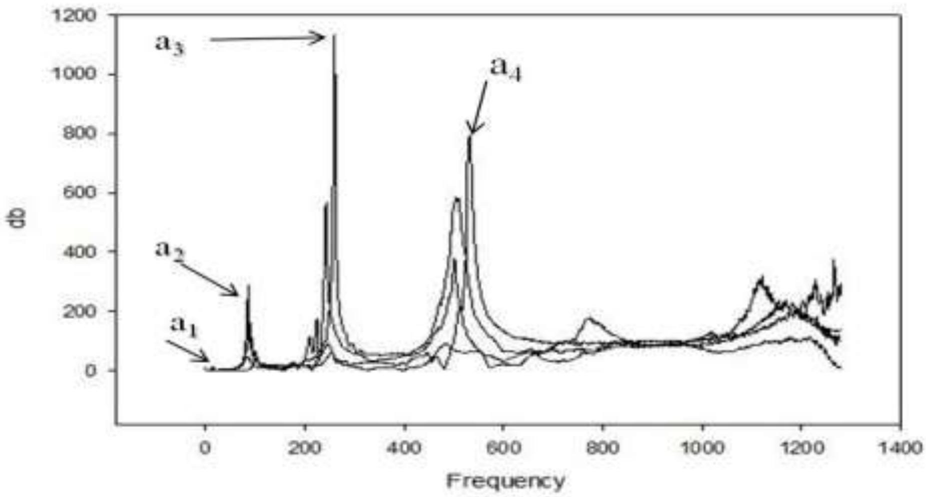

Fig. 11. Frequency spectrums of GFRP single rectangle notch damaged condition

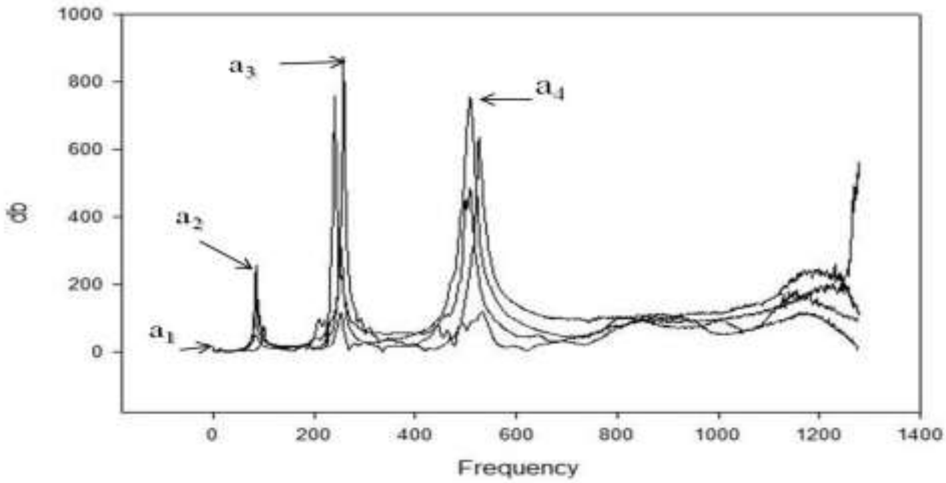

Fig. 12. Frequency spectrums of GFRP single rectangle with curve notch damaged condition

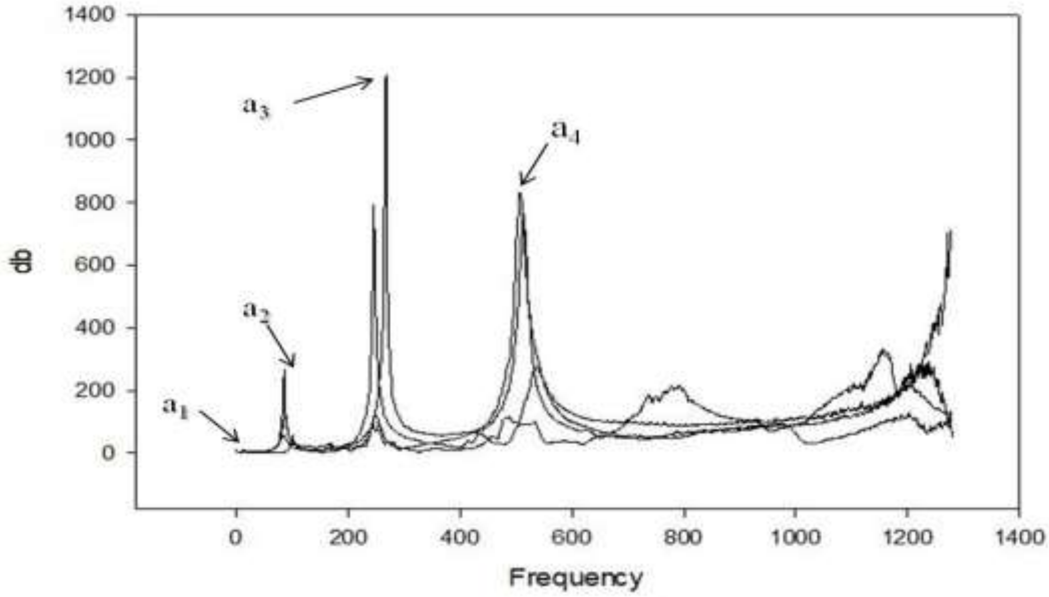

Fig. 13. Frequency spectrums of GFRP double rectangle notch damaged condition

IV. THEORETICAL CALCULATIONS

Theoretical natural frequencies in the case of the damaged condition of the GFRP 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 (ʎ) are 1.875, 4.694, 7.855

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

V. RESULTS AND DISCUSSION

A series of experiments are conducted to determine the natural frequencies of a GFRP cantilever beam. The frequency near to the notch at accelerometer position (a_1) for undamaged condition is 33.5000, for single rectangular notch damage condition is 30.5000, for single rectangle with curve notch condition is 29.0625, and for double rectangle notch condition is 27.8125. 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 37.21, for single rectangular notch damage condition is 34.86, for single rectangle with curve notch condition is 32.14, and for double rectangle notch condition is 28.84.

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

Table 7 Average frequency values in all damaged conditions by experimental investigations

Damage Condition	f_1	f_2	f_3	f_4
Undamaged	33.5000	90.9375	259.6875	533.1875
Single Rectangular Notch	30.5000	84.6875	250.9375	523.3125
Combination of Single Rectangle & Arc Notch	29.0625	82.375	248.8750	518.0625
Double Rectangular Notch	27.8125	79.9375	225.2500	501.8125

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

Damage Condition	f_1	f_2	f_3
Undamaged	37.21	100.16	284.26
Single Rectangular Notch	34.86	90.28	260.84
Combination of Single Rectangle & Arc Notch	32.14	87.9	255.7
Double Rectangular Notch	28.84	80.68	240.16

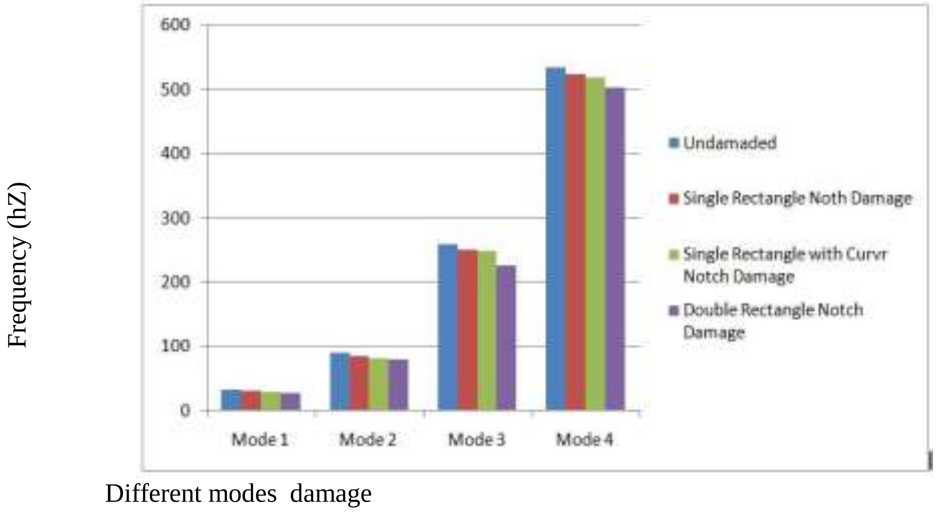

Fig. 14. Variation of natural frequencies for experimental investigations

VI. CONCLUSIONS

An experimental dynamic research on the damage behaviour of GFRP 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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