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Investigation of Frequency Characteristics of GFRP/Phenolic Sandwich Beams

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Abstract— **At the University of Southern Queensland, a research project is being carried out to study the dynamic characteristics of a new innovative fibre composite polymer (FRP) sandwich panel. As a part of the project, the natural frequency behaviour of such fibre composite sandwich beam has been investigated by experimental tests and numerical simulation. The innovative FRP sandwich panel was developed by LOC Composite Pty Ltd for civil engineering applications. The FRP sandwich beam was cut from this panel for the experimental investigation. The FRP sandwich beam is made from two FRP skins and modified phenolic core material. The experimental analysis was conducted to find the FRP sandwich beam natural frequency behaviour under different support conditions. The experimental results were then compared with the FE numerical analysis and a first order shear deformation theory was used in the modelling. In addition, the experimental results were compared with the existing analytical equations. It is found that the FE analysis showed a good agreement with the existing experimental results.**

Keywords-fibre composite; sandwich; finite elemnt; frequency; beam.

I. INTRODUCTION

FRP sandwich panels are now been considered by the structural engineers as a most attractive application. The FRP sandwich floor panel might be used in the sport stadiums, clubs, shopping centres, offices and houses. Highway bridge deck represents one of the well-known sandwich panel applications because it involves several problems related to the decking system [1, 2]. In addition, there are many applications for sandwich panels in the constructions of partitions, doors and furniture [3]. An Australian manufacturer has fabricated a new structural FRP sandwich panel for civil engineering applications such as floors, pedestrian bridges and railways sleepers [4]. The sandwich panel is made from E-CR glass fibre for the skin material and modified phenolic solid core as shown in Fig. 1. The difference between the innovative fibre composite sandwich panel and that traditional sandwich panels is; this panel has a higher core density than the others to improve its structural behaviour. The innovative FRP sandwich panel offers many benefits such as; ability to carry high flexural load, high strength to weight ratio, fire resistance, moisture resistance and termite resistance [5]. The properties of the innovative FRP sandwich panel are shown in Table 1. Manallo et al. [6] studied the FRP sandwich glued beam made from this FRP sandwich panel. One of the conclusions of their work was that the glued FRP sandwich beam has better structural properties than the single sandwich beam.

Most current design studies are concerned in avoiding structural failure and excessive vibration problems [7]. Many design formulas do not consider the frequency of the load as a design parameter. However, many researchers believe that the natural frequency is important to control the human-induced vibration. Murphy [8] presented a numerical formula to find the natural frequency of a simply supported beam . This formula showed a good agreement with the analytical solution. Murphy equation is shown below:

$$f^2 = 2.467 * \frac{E.I.L}{\rho.S^4} \tag{1}$$

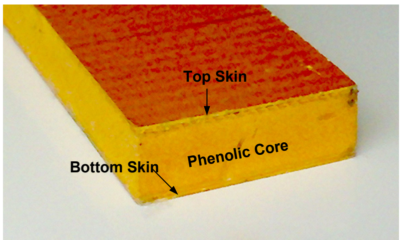
where f is the frequency, E is the elastic modulus, I is the moment of inertial, L is the total length, S is the span and ρ is the density.

The analysis of a free vibration of sandwich beam is more complicated than the normal homogenous beam section. The sandwich beam is usually made from three main layers top skin, bottom skin and core materials. The behaviour of the core material is more complicated due to the shear deformation of the core. The core part is designed to carry the shear forces, while the skins are more appropriate to carry the flexural forces. Nilsson and Nilsson [9] used the six order differential equation to simulate the free vibration of the sandwich beam depending on the Hamilton's principle. The conclusion was that shear effect is dominant in the light weight composite sandwich beam. Żak et al [10] studied the free vibration of multi-layered beam with delamination effects. Their work showed that the natural frequency decreased with the delamination length. Frostig and Thomsen [11] presented a higher order theory for free vibration of FRP sandwich panel. This theory was applied on the FRP sandwich panel with soft and light core (density=100-250 kg/m^3). Kärger et al. [12] formulated a three-layer sandwich element with improved transfers shear stiffness to analyse the sandwich panel. The formulation depends on the first order shear deformation theory (FSDT) and C_o- continuity was obtained in the solution. The solution was applied on the fibre composite sandwich panel with a soft core.

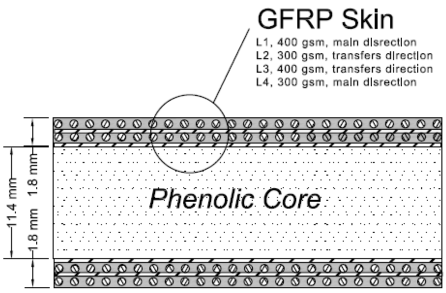
It can be seen that there is a lack in understanding of free vibration behaviour of the innovative FRP sandwich panel with high core density 850 kg/m^3 and the overall density of the panel is 1050 kg/m^3. The present work is part of the comprehensive experimental and numerical studies at CEEFC –USQ to understand the static and dynamic behaviour of the innovative FRP sandwich panel.

TABLE 1 MECHANICAL PROPERTIES [13]

Materials	Density Kg/m^3	Elastic Modulus MPa	Poisson Ratio	Ultimate Tensile strain%	Tensile strength MPa	Shear strength MPa
FRP Skin- 0^o	1,800	15,380	0.3	1.6	246	22.8
FRP Skin- 90^o	1,800	12,631	0.3	1.57	208	21.8
Core	850	1,154	0.20	0.61	5.95	4.25



a- Real FRP-panel



b- Section details

Figure 1. FRP Sandwich Panel

II. Experimental Test

The fibre composite sandwich beam was prepared by cutting a sample of 50 mm in width and 1100 mm in length. The beam was cut in the strong direction where the major fibre skin is parallel to the span. The experimental test was done by using the LMS Test-lab instrument. The experimental model is shown in Figure 2. Two-channel data reading was used; one for the sensor and the second for the impact hammer. The beam was supported by using steel supports as shown in Table 2. The experimental test was conducted with three different boundary conditions; simply supported, cantilever and both fixed supports. The details of the three tests are shown in Table 2. The results of the three different boundary conditions are shown in Figures 2,3,and 4. It can be seen that the natural frequency values depends on the type of the supports conditions.

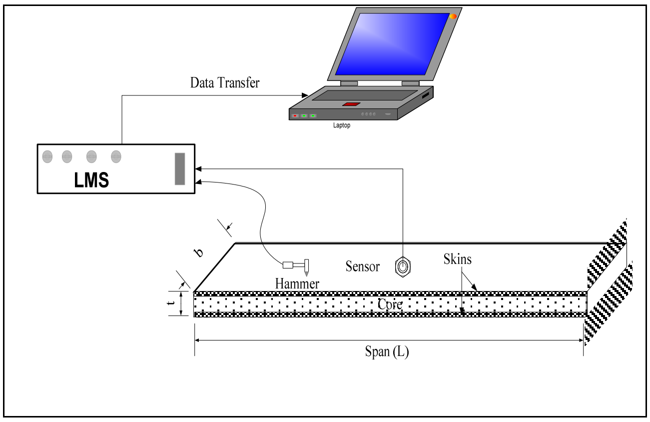
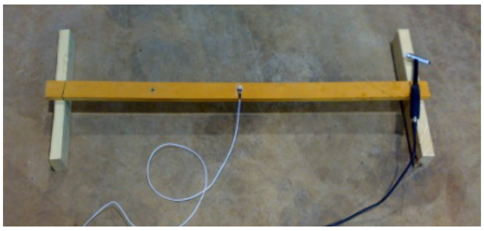
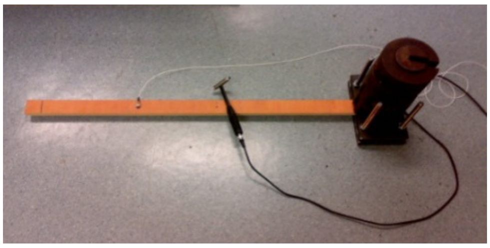
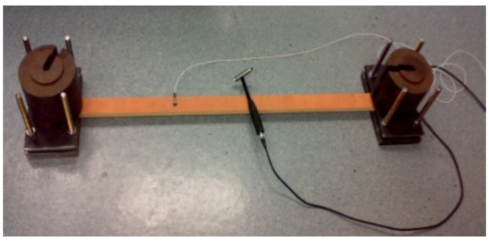


Figure 2. Experimental model

TABLE 2 TESTS PROFILE

Boundary conditions	Width mm	Thickness mm	Span mm
Simply supports	50	18	1,000
 Profile			
Cantilever	50	18	1,050
 Profile			
Fixed supports	50	18	1,000
 Profile			

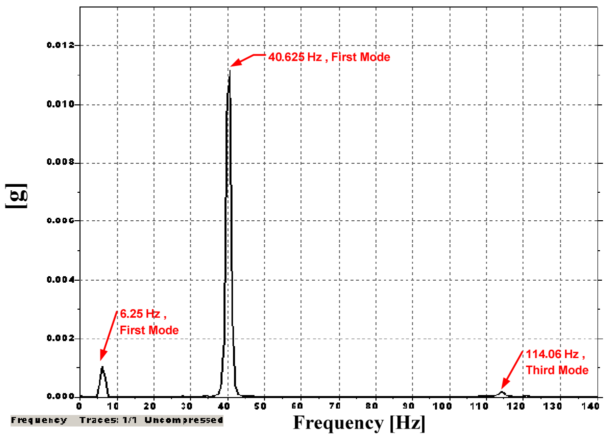


Figure 2. Free Vibration of Cantilever Beam

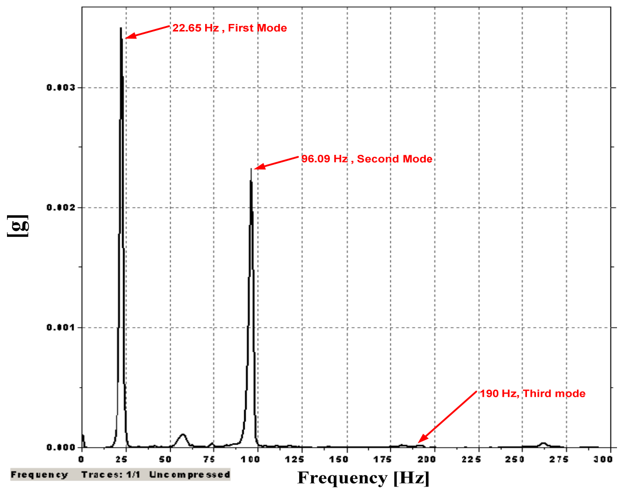


Figure 3. Free Vibration of Simply Supported

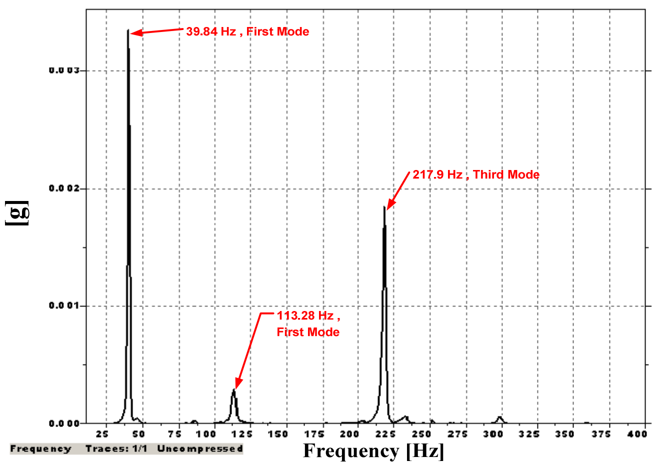


Figure 3. Free Vibration of Fixed Supported

III. Analytical Solution

There are few existing formulas suggested for the calculation of the natural frequency of homogenous beams section. Most of these equations depend on the section rigidity, mass and the span of the beam. For a sandwich beam, section rigidity is divided into two parts; skin rigidity and core rigidity. The flexural rigidity of sandwich beam is [14]:

$$D = \left(\frac{Ebt^3}{6} + \frac{Ebtd^2}{2}\right)_{face} + \left(\frac{Ebc^3}{12}\right)_{core} \quad (2)$$

where, E is the elastic modulus, b is the width, c is the core thickness and d is the distance between two faces centre to centre. The deflection of the mode at any location within the beam is calculated equal to:

$$X(x) = C_1 \cos\lambda x + C_2 \sin\lambda x + C_3 \cosh\mu x + C_4 \sinh\mu x \quad (3)$$

where, x is the distance from the support. C_1- C_4 are constants. X is the deflection. λ and μ are values that depend on the cross section and material properties as described in Reference [15].

The Euler-Bernoulli beam model represents one of the analytical solutions for the free vibration analysis of beams. The Euler-Bernoulli beam model can be applied for different type of boundary conditions. The general equation of Euler-Bernoulli beam is described below [16].

$$w = \left(\frac{a_n}{L}\right)^2 * \sqrt{\frac{EI}{\rho A}} \quad (4)$$

where, A is the cross section area and a_n is the boundary conditions parameters. The analytical values of the present FRP sandwich beam are calculated by using equations 2 and 4, and listed in Table 3.

It can be seen that the results of the Euler-Bernoulli equation gives a higher estimation than the experimental results, especially for the first mode. Flexural analysis on the same fibre composite sandwich beam with span equal to 300 mm was conducted by Awad et al. [17]. Equivalent rigidity equation number 4 was used to calculate the equivalent rigidity of the beam section. It was concluded that a shear deformation effect of around 5% and the equivalent rigidity equation can be used with this type of fibre composite sandwich beam.

IV. FE Simulation

The FE simulation is formulated for the analysis fibre composite sandwich beam and conducted using ABAQUS commercial software. FE methods are regarded as efficient methods to predict the natural frequency of sandwich structures [15]. The top and bottom skin are formulated using a shell element type S8R (8- node doubly curved shell element). While, the core is meshed by using 3D solid element type C3D20R. The FE model of a simply supported beam is shown in Figure 4, and the other two models are same, but with different boundary conditions. First order shear deformation theory (FSDT) is used for the formulation of the 3D solid element used in the simulation of the core. The formulation of FSDT needs only C_o continuity and it is the most common in FE analysis. The FE analysis results are shown in Table 3, with the predicted mode shape.

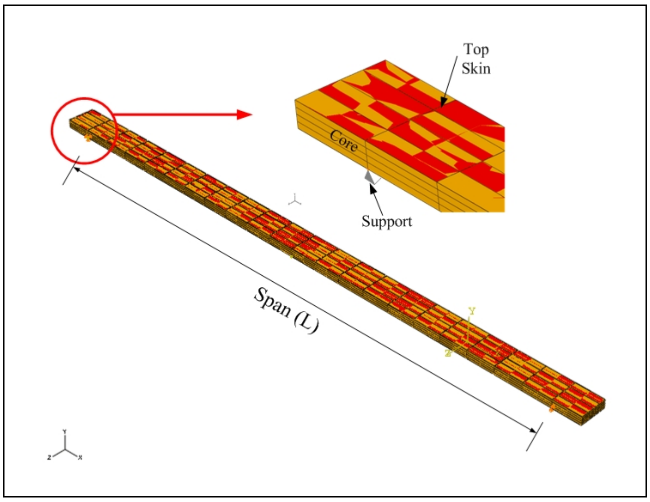
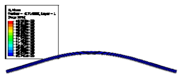
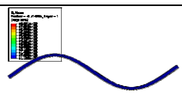
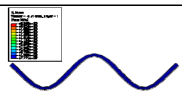


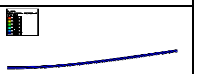
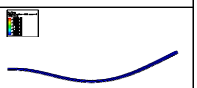
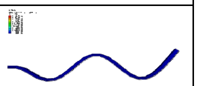
Figure 4 FE model

TABLE 3 ANALYTICA, EXPERIMENTAL AND NUMERICAL RESULTS

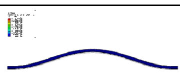
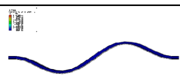
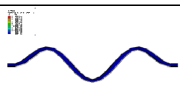
a-Simply Supported

	Frequency (Hz)			Mode Shape
	Analytical	FE	Experimen -tal	
f_1	23.57	23.1	22.65	
f_2	94.31	95.36	86.09	
f_3	212.21	183.81	190	

B-Cantilever Beam

	Frequency (Hz)			Mode Shape
	Analytical	FE	Experimen -tal	
f_1	7.62	6.7	6.25	
f_2	47.47	41.97	40.625	
f_3	132.8	116.2	114.06	

C-Fixed Supported

	Frequency (Hz)			Mode Shape
	Analytical	FE	Experimen -tal	
f_1	53.47	46.6	39.84	
f_2	147.41	126.42	113.28	
f_3	289	242.88	217.9	

V. SANDWICH BEAM DAMPING

Damping is very important in the structural design. The damping properties of the structure affect on the long fatigue life of the structure. Structure with high damping might hasve longer life than the structure with low damping ratio. Fibre glass usually has low damping ratio with less than 1% [18]. A half power method was used to calculate the damping ratio of fibre composite beam for three different boundary conditions. The damping ratio (ξ) is calculated from the equation below and the explanation of this method is shown in Figure 5.

$$\xi = \frac{w_2 - w_1}{2w_r} \tag{5}$$

Where, w_r is the resonance frequency. w_1 and w_2 are the left and write frequencies at 3dB below the resonance amplitude as shown in Figure 5.

The damping ratio for the three different supports is calculated and shown in Table 4.

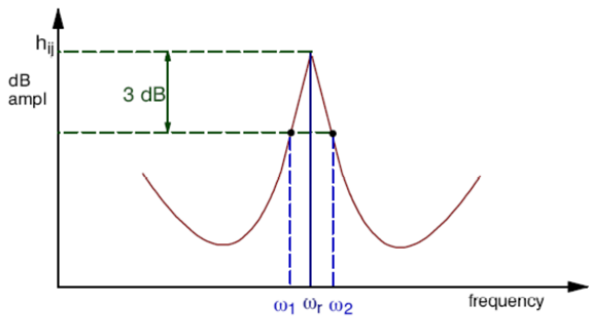


Figure 5 Half power method for damping estimation

TABLE 4 DAMPING RATIOS

Beam support type	w_r (Hz)	w_1 (Hz)	w_2 (Hz)	Damping %
Simply supported	21.87	21.45	22.27	1.8
Cantilever	6.25	6.0	7.03	8
Fixed supported	39.84	41.9	42.65	0.99

VI. RESULTS DISCUSSION

The result of the above three sections shows the boundary conditions effect on the natural frequency of the fibre composite sandwich beam. The first three natural frequencies are calculated by experimental, analytical and numerical approaches for the innovative fibre composite sandwich element. The results show that there are differences between the analytical and the experimental results. These differences due to the effect of core shear deformation and boundary conditions. The FE results are more accurate than the analytical results, because the shear deformation is considered in the simulation. However, the FE method is underestimates the results because the FSDT gives over-estimation for the transfers shear stiffness. The type of the supports has great effect on the damping of the fibre composite sandwich beam.

The cantilever beam shows more damping ratio than the others.

VII. CONCLUSIONS

An experimental investigation of the natural frequency of a new fibre composite sandwich beam was carried out. The effect of three different boundary conditions was presented. The experimental results were compared with the FE methods and it showed a good agreement. The analytical equation required a correction factor to consider the core shear deformation effect. In addition, the type of supports has an effect on the damping ratio of fibre composite beam. Increasing the supports condition cause a reduction in the damping ratio.

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