MODAL ANALYSIS OF DELAMINATED WOVEN FIBER COMPOSITE PLATES

Shishir Kr. Sahu*, Jayaram Mohanty*, Bankim C. Ray*, Indira P. Bhanja* and Pravat Kr Parhi**
*Department of Civil Engineering, NIT, Rourkela-769008, Orissa, India
** CET, Bhubaneswar-751003, Orissa, India

Introduction:

Fiber reinforced composite laminates are increasingly being used in the construction of the aerospace, mechanical, civil, marine, automotive and other high performance structures due to their high specific stiffness and strength, excellent fatigue resistance, longer durability as compared to metallic structures and their ability to be tailored for specific application. Delamination which is a debonding or separation between individual plies of the laminate frequently occurs in the composite laminate manufacturing or during service. The presence of delamination may significantly reduce the stiffness and strength of the structures and may affect some design parameter such as vibration characteristics of the structures. It is therefore important to understand the performance of delaminated composites in a dynamic environment. The previous studies on vibration of delaminated composite laminates are recently reviewed by Della and Shu(1). A considerable amount of analytical models and numerical analysis have been reported for the vibration analysis of unidirectional composite laminates with delaminations. However, the experimental investigations on modal analysis of delaminated fiber composite plates are scarce in literature. *Zak et al.* (2) studied numerical and experimental investigation of free vibration of multilayer delaminated composite beams and plates. *Ju et al.*(3) worked on finite element analysis of free vibration of delaminated composite plates. *Parhi et al.*(4) developed FE model dynamic analysis of laminated composite plates with multiple delamination**.** *Chattopadhyay et al.* (5) worked on dynamic stability analysis of delaminated composite plates using a higher order theory. The present work deals with experimental and numerical study on vibration of industry-driven 'woven' fiber Glass/Epoxy (G/E) composite plates with different size of delamination and boundary conditions (B.C.).

Experimental Programme:

Materials:

The following constituent materials were used for fabricating the delaminated composite plates: Glass woven roving (WR) fiber as reinforcement, Epoxy as resin, hardener (catalyst), Polyvinyl alcohol as a releasing agent, Teflon foil (for artificial introduction of delamination).

Equipment and Test Procedure

The composite plate specimens used in this research were made from 0/90 woven glass fiber with epoxy matrix. Specimens were fabricated by hand lay-up technique and cured under room temperature. The percentage of fiber and matrix is 50:50 in weight. The plates were left for a minimum of 48 hours before being transported and then cut to exact shape for testing. Four 8 layered specimens (200X200X3) mm are prepared with different size of mid plane delamination i.e. (0, 50X50, 100X100, 150X150) mm. The material constants (i.e. of: E_1, E_2, E_{45}) of woven fiber Glass/Epoxy composite plate were determined experimentally by performing unidirectional tensile tests on specimens cut in longitudinal and transverse directions, and at 45° to the longitudinal direction using INSTRON machine as per relevant ASTM standard. The Poisson's ratio was assumed as 0.17 in line with Chakraborty *et al.* [6]. The shear modulus was determined using the formula from Jones [7]. Then natural frequencies were determined for all specimens with different boundary conditions ,i.e (fixed, simply supported, cantilever).The excitation was provided by impact hammer (B&K type 2302-5) and the response was picked up by accelerometer (B&K, Type 4507) fixed below the plate. The natural frequencies are obtained by analyzing the spectrum obtained from the FFT analyzer using Pulse software.

Finite elment formulation

A simple FE model for the modal analysis of multilayered composite plates having delamination is analyzed using eight-node two dimensional quadratic isoparametric element with 5 degrees of freedom per node. A computer program is developed to perform all the necessary computations. Reduced integration technique is adopted to avoid possible shear locking. The overall stiffness and mass matrices are obtained by assembling the corresponding element matrices, using skyline technique. Subspace iteration method is adopted throughout to solve eigenvalue problems.

RESULTS AND DISCUSSION

The numerical and experimental investigation for single delaminated woven roving glass/epoxy composite plates with various boundary conditions are carried out. The material constants which are determined from the tensile test are given in Table 1. To validate the program, the natural frequencies of undelaminated composite plates are compared with the results obtained *by Ju et al.[3*]. The results show good agreement and omitted here for sake of brevity. The modal analysis results on the free vibration of simply supported (SSSS) delaminated woven fiber composite plates are presented by both the approach. As

shown in Fig.1, the fundamental frequencies of vibration decreased by 36%, 25.17% and 24% for 6.25%, 25.0% and 56.25% of delamination respectively. Similarly the study is extended to fully clamped (Fig. 2) and cantilever plates (Fig.3). As expected, the laminated plates with 25% delamination shows highest frequency for clamped case and the cantilever plates shows the least due to restraint at the edges.

Table 1: Material properties of the laminate as used in the experimental program

Plate	Lay-up	No of layer	E1	E2	G12	v12	P Kg/m^3
1	WR	8	7.57	7.57	2.81	0.17	1661

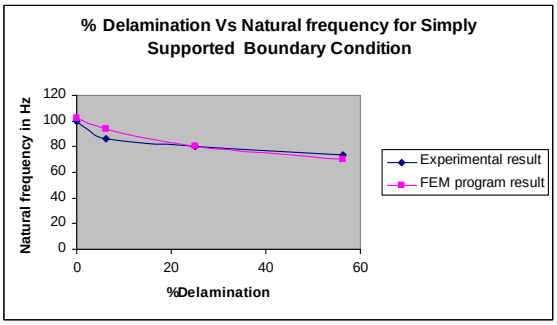

Fig 1: Variation of fundamental frequency with **%** of delamination for SSSS composite plates

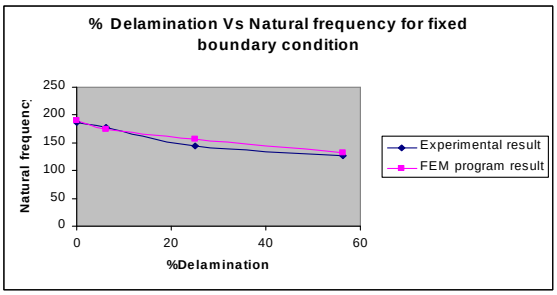

Fig 2 Variation of fundamental frequency with **%** of delamination for CCCC composite plates

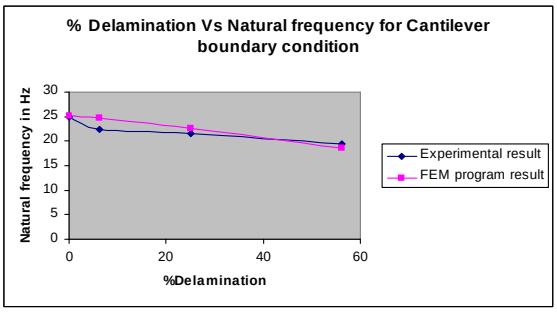

Fig 3 Variation of fundamental frequency with **%** of delamination for Cantilever composite plates

From the graphs (Fig.1-Fig.3), it is observed that the % of error between the experimental & numerical result lies below 15%. It seems that there is fair agreement between experimental and numerical study.

Conclusion:

In the present work, both experimental and numerical study is conducted for woven roving G/E composite plates. Quantitative results are presented to show the effect of delamination in composite plates. It shows that there is a fair agreement in between those two.The natural frequency is very less for cantilever than fully clamped and simply supported boundary conditions. The frequencies of vibration decrease with introduction and further increase of size of delamination in woven fiber composite plates.

References:

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