International Journal of Mechanical Engineering (IJME)
ISSN(P): 2319-2240; ISSN(E): 2319-2259
Vol. 2, Issue 5, Nov 2013, 1-18
© IASET

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

EXPERIMENTAL AND NUMERICAL VIBRATION STUDY OF WOVEN REINFORCEMENT COMPOSITE LAMINATED PLATE WITH DELAMINATION EFFECT

MUHANNAD AL-WAILY

Department of Mechanical Engineering, Faculty of Engineering, University of Kufa, Baghdad, Iraq

ABSTRACT

In this work, a natural frequency of composite laminated plate presented, with different size and location of delamination effect, through long and width of composite plate in addition to effect of delamination through the thickness of plate. The composite plate studied made of woven reinforcement glass fiber and polyester resin with eight layer with different delamination through the plate. The natural frequency of woven composite plate calculated by using experimental work for different aspect ratio and boundary conditions of plate and compare the experimental results with numerical study by using of finite element method with using of ANSYS program. The natural frequency of woven laminated plate are evaluated by analysis the acceleration signal evaluated by experimental work with fast Fourier transformation by using of sig-view program, to evaluated natural frequency of plate by FFT method. The resulted of natural frequency with delaminated effect show that the delamination decreasing of natural frequency of plate and decreasing the stiffness of plate. The compare of experimental with numerical results given good agreement with maximum error about 5.8% and minimum error about 2.3%.

KEYWORDS: Delamination Effect, Vibration Composite Plate with Delamination, Internal Crack Effect, Defect Effect, Plate with Defect Effect, Vibration with Delamination Effect

INTRODUCTION

Key components of primary aircraft structures, such as wingskins, are currently being designed using laminated composites. Although the structural designer is interested in the global behavior of these structures, very often phenomena such as impact loading, varying geometrical features, such as tapering, etc. have localized structural effects, **[3]**.

As the increase in the application of composite materials to the primary loading structures, the refined strength evaluations and stress predictions are required. For the enhanced analysis of laminated composite plates, three types of higher-order theory have been developed. Vibration problems of delaminated beam/plate were analyzed by numerous researchers. Classical beam model, first-order shear deformation model, and higher-order shear model with piezo-layers are employed for the natural frequency analysis, **[2]**.

For the analysis of laminated plates with arbitrary shaped multiple delaminations, finite element method is a suitable choice to treat the general loading, boundary conditions, layups, and geometry. Even though finite element based on layer-wise plate theory can provide an adequate framework for the delamination analysis, this theory is not computationally efficient since the number of degrees-of-freedom of this theory depend upon the number of layers, **[2]**.

E. J. Barbero and J. N. Reddy [1], the layer-wise laminate theory of Ruddy is extended to account for multiple delaminations between layers and the associated computational model is developed delaminations between layers of composite plates are modeled by jump discontinuity conditions at the interfaces.

M. Cho and J.-S. Kim [2], presented A higher-order zig-zag theory has been developed for laminated composite plates with multiple delaminations. By imposing top and bottom surface transverse shear stress-free conditions and interface continuity conditions of transverse shear stresses including delaminated interfaces, the displacement field with minimal degree-of-freedoms are obtained. This displacement field can systematically handle the number, shape, size, and locations of delaminations. Through the dynamic version of variational approach, the dynamic equilibrium equations and variationally consistent boundary conditions are obtained. The delaminated beam finite element is implemented to evaluate the performance of the newly developed theory.

S.L. Angioni, A. Visrolia, and M. Meo [3], in this work, the displacement field is represented as the superposition of a number of plate fields, and a unifying strain field is derived. By appropriately defining boundaries to the ‘enhancing’ displacement fields, it is demonstrated that the superposition of displacement fields can be used to locally enrich the solution where more information is required. In this manner, an efficient global model can be used to determine gross displacements, and an enriching model can be used to determine stresses at lamina interfaces for the accurate prediction of localized phenomena. The proposed theoretical framework would allow an analyst to study both thin and thick walled laminated structures by introducing simple switch-over criteria between single and multiple layer theories.

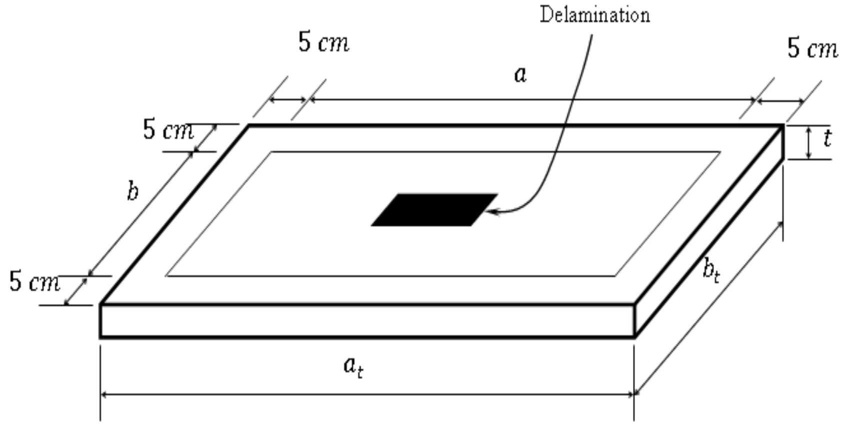
Yang Jinhua, Fu Yiming [4], By introducing the Heaviside step function into the assumed displacement components and using the Rayleigh–Ritz method for minimizing the total potential energy, a set of dynamic governing equations for the delaminated cylindrical shells is derived. Then, the dynamic governing equations are written as the Mathieu-type equations to describe the parametric vibrating behavior of the shells, and these equations are solved by employing the Bolotin method.

In this research evaluated of the natural frequency of composite woven laminated plate with different aspect ratio and boundary condition of plate with effect of delamination with different size of delamination. The natural frequency evaluated by experimental study and compare the results with numerical results evaluated by using of finite element method with using Ansys Ver. 14.

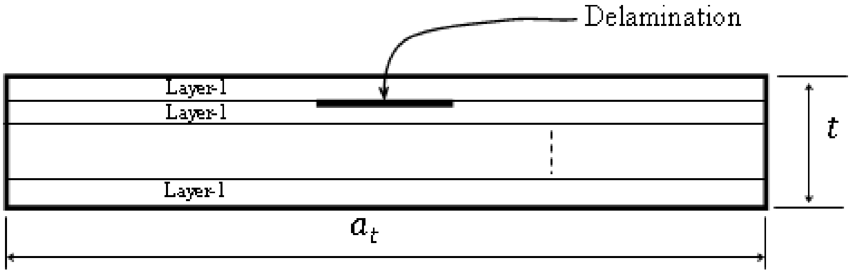
EXPERIMENTAL WORK

The experimental work include vibration test to calculate the fundamental natural frequency of woven composite laminated plate with and without delamination effect for different aspect ratios, and boundary conditions of composite plate and with different delamination size and location effect.

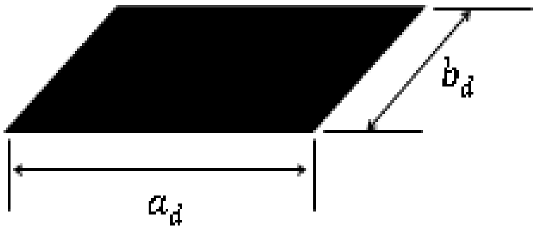
The woven composite plate sample using in experimental study with delamination effect shown in the Figure 1,



a) Dimensions and Shape of Laminated Plate with Delamination



b) Side View of Laminated Plate with Delamination



c) Dimensions of Delamination

Figure 1: Shape and Dimensions of Plates Samples and Delamination

The dimensions of laminated plate used are, as shown in Figure 2,

$$\mathrm{a_t = a + 10\ cm\ (Supported) - Length\ of\ Plate}$$

$$\mathrm{b_t = b + 10\ cm\ (Supported) - Width\ of\ Plate} \tag{1}$$

where,

$$\mathrm{b = 24\ cm,\ b_t = 24\ cm + 10\ cm\ (Supported) = 34\ cm\ ,\ t = 6.5\ mm}$$

And for difference aspect ratio (a/b), as,

$$\mathrm{a_t = a + 10\ cm\ (Supported) = (a/b).b + 10\ cm\ (Supported)}$$

$$\mathrm{a_t = 58\ cm - for\ (a = 48\ cm)\ aspect\ ratio = 2}$$

$$\mathrm{a_t = 46\ cm - for\ (a = 36\ cm)\ aspect\ ratio = 1.5}$$

$$\mathrm{a_t = 34\ cm - for\ (a = 24\ cm)\ aspect\ ratio = 1} \tag{2}$$

And the dimensions of delamination for different aspect ratio of plate are,

$$\mathrm{a_d - Length\ of\ Delamination = 10\%\ from\ lenght\ of\ plate} = \begin{cases} \mathrm{2.4\ cm - for\ aspect\ ratio = 1} \\ \mathrm{3.6\ cm - for\ aspect\ ratio = 1.5} \\ \mathrm{4.8\ cm - for\ aspect\ ratio = 2} \end{cases}$$

$$\mathrm{a_d - Length\ of\ Delamination = 20\%\ from\ lenght\ of\ plate} = \begin{cases} \mathrm{4.8\ cm - for\ aspect\ ratio = 1} \\ \mathrm{7.2\ cm - for\ aspect\ ratio = 1.5} \\ \mathrm{9.6\ cm - for\ aspect\ ratio = 2} \end{cases}$$

$$\mathrm{a_d - Length\ of\ Delamination = 30\%\ from\ lenght\ of\ plate} = \begin{cases} \mathrm{7.2\ cm - for\ aspect\ ratio = 1} \\ \mathrm{10.8\ cm - for\ aspect\ ratio = 1.5} \\ \mathrm{14.4\ cm - for\ aspect\ ratio = 2} \end{cases}$$

$$\mathrm{b_d - Width\ of\ Delamination = 10\%\ form\ width\ of\ plate = 2.4\ cm} \tag{3}$$

And, the location of different delamination size shown in equation (3), through length; width; and thickness of woven composite laminated plate, are show in the Table 1.

Table 1: Location of Delamination Studied through Thickness, Length, and Width of Laminated Plate

Location of Delamination through Thickness of Plate	Location of Delamination through Length of Plate	Location of Delamination through Width of Plate
Layer 1-2, Layer 2-3, Layer 3-4, or Layer 4-5	0.25*a	0.25*b
		0.5*b
		0.75b
	0.5*a	0.25*b
		0.5*b
		0.75b
	0.75a	0.25*b
		0.5*b
		0.75b

And, the weight required of composite plate samples can be calculated by,

$$\text{Weight of Fiber} = \rho_f * \forall_t * \forall_f$$

$$\text{Weight of Resin} = \rho_m * \forall_t * \forall_m$$

$$\forall_t = a_t * b_t * t \tag{4}$$

Where, ρ_f, ρ_m are mass density of woven fiber and polyester resin, respectively, defied as, [11],

$$\text{Density of Woven Glass Fiber} = 2400\ \text{kg/m}^3$$

$$\text{Density of Polyester Resin} = 1000\ \text{kg/m}^3 \tag{5}$$

$\forall_f, \forall_m$ are volume fraction of reinforcement fiber and resin, respectively. And $\forall_t$ is total plate volume.

Then, the weight required of woven reinforcement glass fiber and polyester resin for composite plate samples defined in Table 2 for different aspect ratio of plate, volume fraction of woven fiber $30\%$and 6.5 mm plate thickness and with plate compound from eight layer.

Table 2: Required Weight (g) for Woven Reinforcement Fiber and Polyester Resin for Composite Laminated Plate Sample with Fiber Volume Fraction of 30% and Plate Thickness $H = 6.5$ mm

Aspect Ratio	Woven Reinforcement Glass Fiber (g)	Polyester Resin (g)
2	923	897
1.5	732	712
1	541	526

The vibration of woven composite plate with delamination effect samples studied are supported with different boundary conditions, as shows in the Figure 3, of different aspect ratios, $\left(\frac{b}{a} = 1, 1.5, 2\right)$,

- Cantilever plate supported (CFFF).
- Clamped supported along $x = 0$ and 1 edges and free support along $y = 0$ and 1 edges (CCFF).

The composed parts of the vibration structure rig, shown in the Figure 4, are:

- Structure to support the plate sample,
- Support of fixed plate sample.
- Impact hammer tool, model (086C03) (PCB Piezotronics vibration division), with the information about measurement range (2224 N), resonant frequency (≥ 22 kHz), excitation voltage (20 to 30 VDC), constant

current excitation (2 to 20 mA), output bias voltage (8 to 14 VDC), discharge time constant (≥ 2000 sec), hammer mass (0.16 kg), head diameter (1.57 cm), tip diameter (0.63 cm), and hammer length (21.6 cm).

Impulse force test hammer is adapted for adapts FFT analysis of structure behavior testing. Impulse testing of the dynamic behavior of mechanical structure involves striking the test object with the force-instrumented hammer, and measuring the resultant motion with an accelerometer.

- Accelerometer, model (4371), with the information; lower frequency (determined by the amplifier used), upper frequency limit (+10%) (12.6 kHz), mounted resonance frequency (42 kHz), and weight (11 g).
- Amplifier, type 7749, the amplifier measures the response signal from accelerometer and gives output signal to the digital storage oscilloscope.
- Digital storage oscilloscope, modal GDS-810, with the information; maximum frequency (100 MHz), maximum read of sample per second (25 GS/s), FFT spectrum analysis, and two input channels, this digital storage oscilloscope system can be driven with a computer (by using the RS-232 serial connection).

Then analysis of response signal is read from digital storage oscilloscope to FFT function by using sig-view program to get the fundamental natural frequency of the plate with different parameters studied, as shown in the Figure 7.

The flow chart in Figure 5 shows the sketch of the vibration structure rig shown in Figure 4, its test the plate sample used to evaluate the fundamental natural frequency with different delamination size and location effect for different aspect ratio and boundary condition of plate.

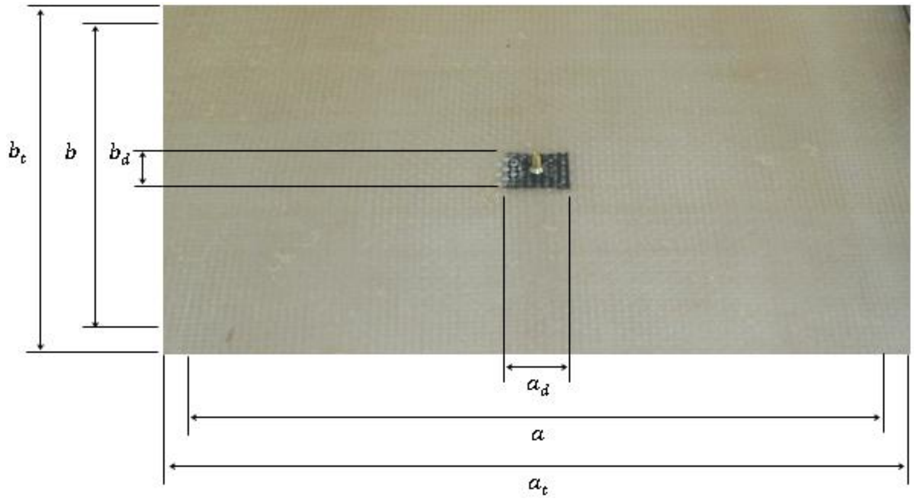
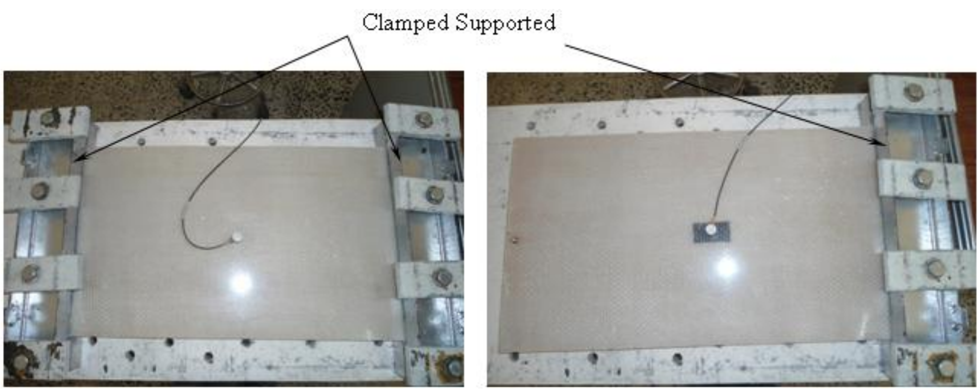


Figure 2: Dimensions and Shape of Woven Composite Laminated Plate with Delamination Effect



a) Clamped-Clamped, Free-Free Plate Supported **b) Cantilever Plate Supported**

Figure 3: Supported of Woven Composite Plate Studied with Delamination Effect

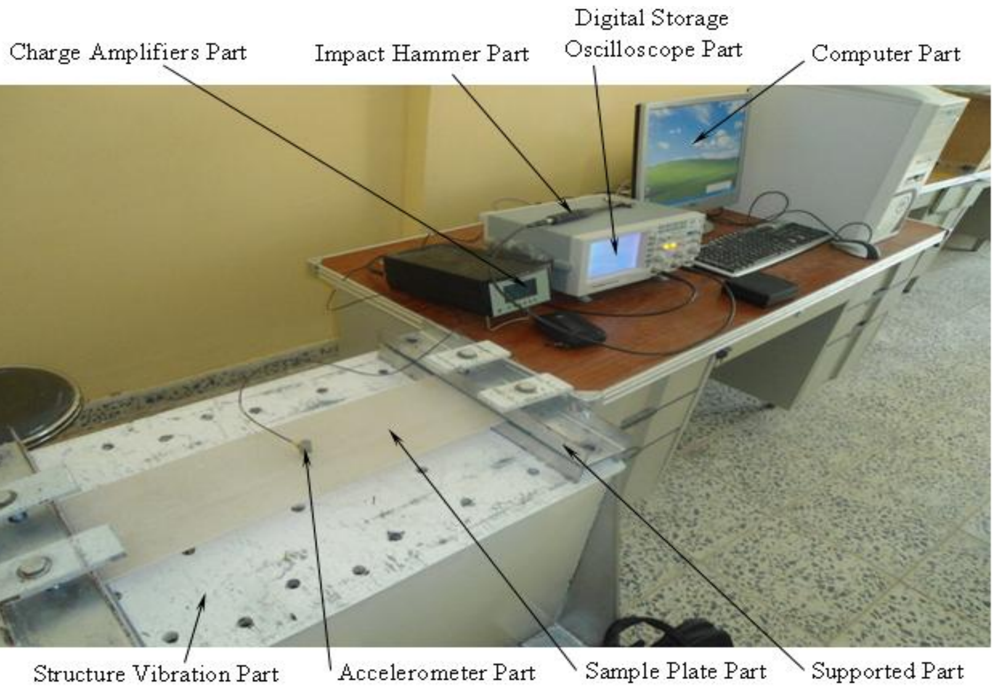


Figure 4: Rig Vibration Test of Plate

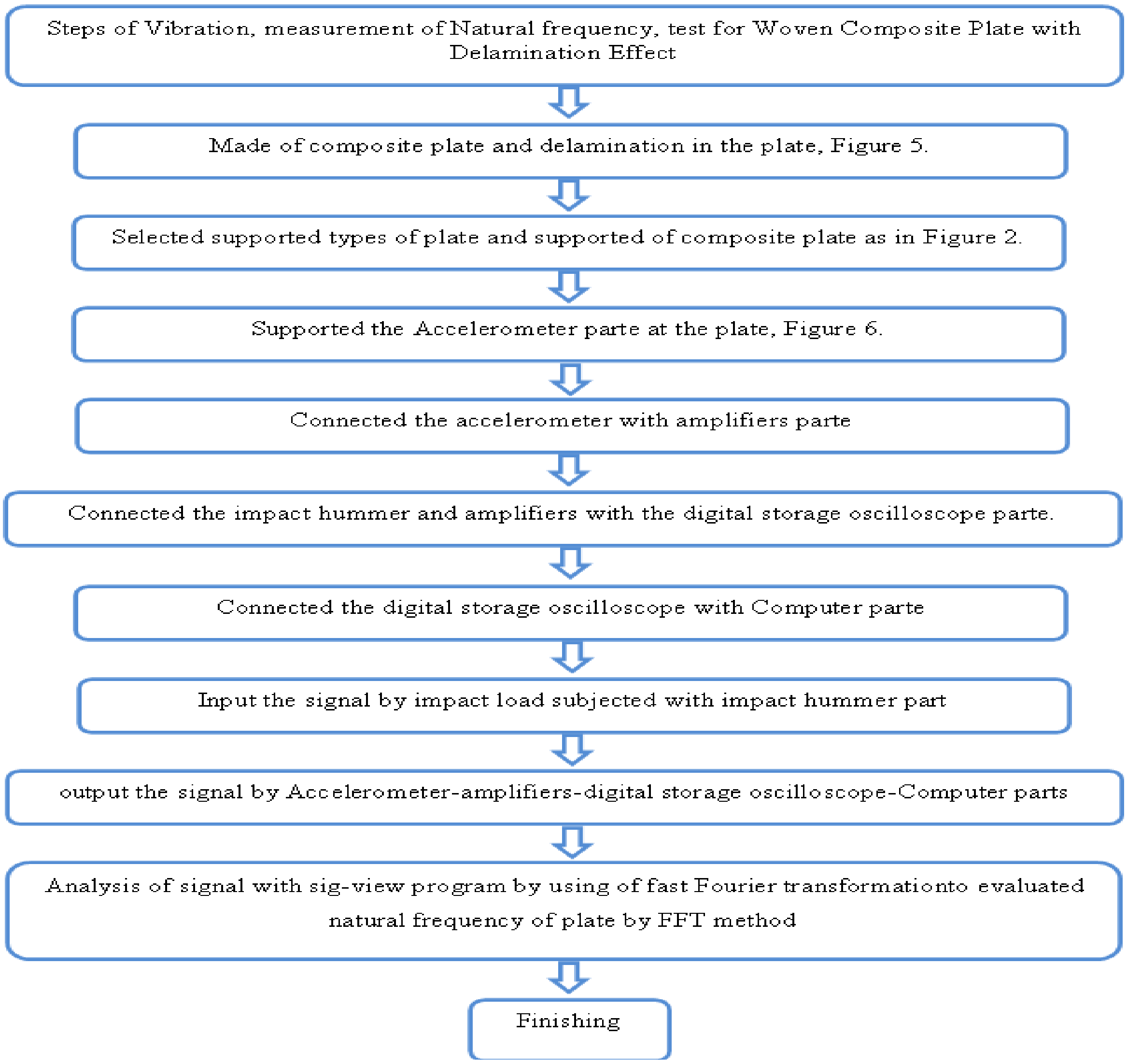
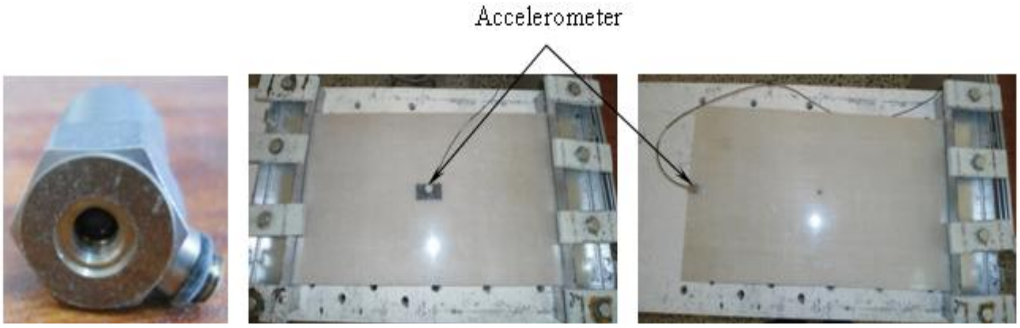


Figure 5: Flow Chart of Testing Steps for Evaluated the Natural Frequency of Woven Composite Plate with Delamination Effect by Experimental Work



a) Accelerometer b) Accelerometer Location Support

Figure 6: Different Accelerometer Location of Composite Plate

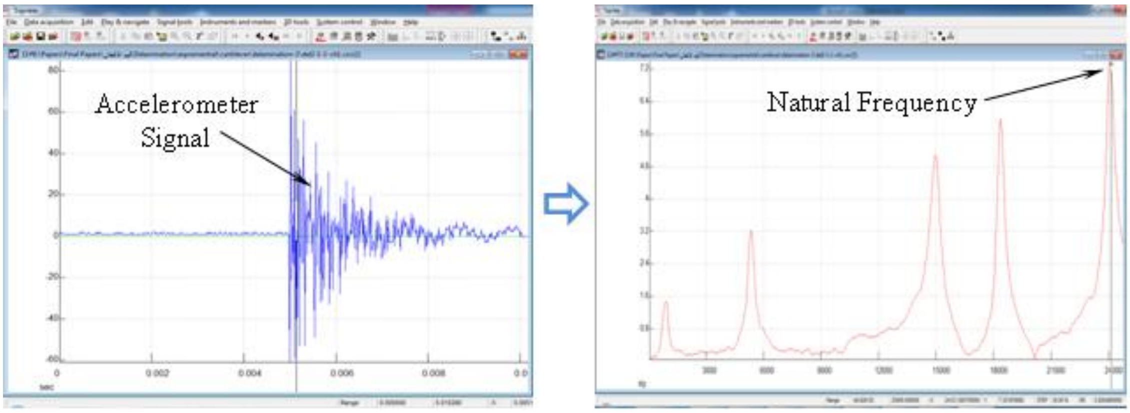


Figure 7: Analysis of Digital Storage Oscilloscope Signal by FFT Function with Sig-View Program

NUMERICAL STUDY

To assess the validity of the proposed theory, a finite element isdeveloped for one-dimensional problems. The primary displacementunknowns are expressed in terms of nodal values and shape functions as follows, **[2]**,

$$\left(u_\alpha^0, \emptyset_\alpha, \overline{u_\alpha^i}\right) = \sum_{m=1}^{n} \left\{N_m \left[(u_\alpha^0)_m, (\emptyset_\alpha)_m, \left(\overline{u_\alpha^i}\right)_m\right]\right\}$$

$$w = \sum_{m=1}^{n} P_m (w)_m + H_{xm} \left(w_{,x}\right)_m + H_{ym} \left(w_{,y}\right)_m$$

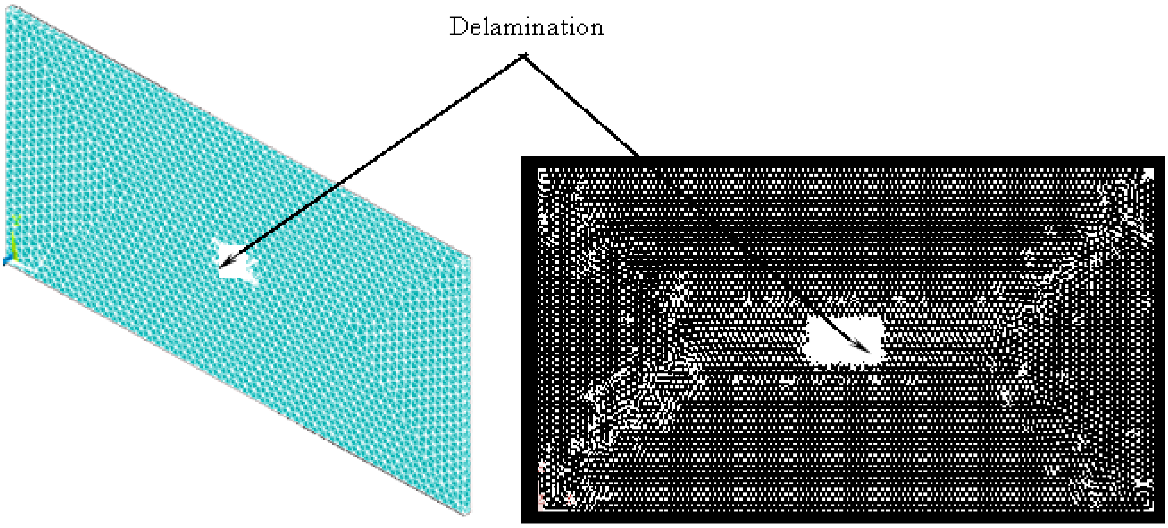
$$\overline{w^j} = \textstyle\sum_{m=1}^{n} \left\{P_m \left(\overline{w^j}\right)_m + H_{xm} \left(\overline{w_{,x}^j}\right)_m + H_{ym} \left(\overline{w_{,y}^j}\right)_m\right\} \tag{6}$$

Where n is the number of nodes in a typical finite element. N_m isa Lagrangian interpolation function and P_m , H_{xm} , H_{ym} are Hermiteinterpolation functions. In this study, we used a two-nodes beam element with one-dimensional linear Lagrangian interpolation functions for u_α^0, $\emptyset_\alpha$, $u_\alpha^i$and Hermite interpolation functionsfor$w$, w^j .

The finite element model of the natural vibration problem can be expressed as follows, **[2]**,

$$([K] - \omega^2[M])\{u\} = \{0\} \tag{7}$$

Where [K] and [M] are the stiffness matrix and the mass matrix. The parameters ω and {u} denote the natural frequency, and the eigenvector of nodal displacements corresponding to an eigenvalue, respectively. To solve Eq. 7 needed analysis of stress strain relation of laminated plate with delamination effect and evaluated of forces and moment results on the plate, then evaluated the general equation of motion of plate and solve equation to evaluated the natural frequency of plate. Then, this solution can be evaluated by using of the numerical study with finite element method to fine the natural frequency by using ANSYS ver. 14. Where Figure 8 shown the elements and nodes analysis about delamination in plate.



a) Elements Analysis of Plate with Delamination Effect **b) Nodes Analysis of Plate with Delamination Effect**

Figure 8: Mash of Plate with Delamination Effect

RESULTS AND DISCUSSIONS

The vibration results of composite plates includes the evaluation of the natural frequency of composite plate, made of polyester resin and woven glass fiber with fiber volume fraction $\forall_f$=30%, with delamination effect of plate, included the effect of delamination size, delamination location, and other parameters of composite plate as aspect ratio and boundary condition of plate. Where the mechanical properties of each layer of woven composite plate lamina, with 30% woven Reinforcement Glass fiber and 70% polyester resin volume fraction, are, **[11]**,

$$E_1 = E_2 = 18.25\ Gpa, , G_{12} = 1.96\ Gpa,$$

$$\rho = 1420\ kg/m^3,\ \nu_{12} = 0.355 \tag{8}$$

The method studied to evaluated the natural frequency of composite plate with delamination effect are, experimental study and numerical study, by using ANSYS Program Version 14.

The experimental work includes the study of the delamination effect of woven composite plate with different delamination size (length of delamination in x-direction with width of delamination in y-direction equal to 10%b=2.4 cm), different delamination position (in x and y-directions and location through thickness of laminated plate), different plate dimensions (aspect ratio, plate length) and different boundary conditions of plate (cantilever plate CFFF, clamped supported through x = 0 and 1 edges and free supported along y = 0 and 1 edges CCFF, and Clamped supported through all edges CCCC).

The experimental results are compared with those obtained numerically by using the ANSYS Program (Version 14) for each parameters effect studied as shown in Figures 9 to 12. Where, the figures shown the maximum error between experimental and numerical results about (5.8 %). The effect of delamination size as length and depth of delamination for woven reinforcement composite plate with different aspect ratios and boundary conditions, with different location of delamination through x and y-direction are shown in figures 13 and 14. And the study of delamination position in x and y-directions effect of woven composite plate with different boundary conditions and aspect ratio of composite plate are shown in figures 15 and 16 fordelamination size$a_d = 30\%$a and $b_d = 10\%b$.

From Figures 9 to 16 shows the following effect of the delamination on the natural frequency of plate with delamination effect,

- **Effect of Delamination Position (x and y-Direction)**

The natural frequency of composite plate decreasing with move delamination position near the middle location plate, since the stiffness of plate is decreasing with the moving the delamination to the middle plate location, then deceasing of the natural frequency of plate, as shown in Figures 15 to 16, with different aspect ratio of composite plate, and boundary condition effect.

- **Delamination Size Effect (Length and Depth of Delamination)**

The natural frequency of composite plate is decreasing with the increasing of the delamination size as length of delamination or location near the centre through the thickness of plate depth since the delamination cause decreasing of the stiffness of plate, then cause decreasing of the natural frequency of plate, as shown in Figures 13 and 14 with different aspect ratio of composite plate, boundary condition effect, and location through x and y-direction of delamination.

- **Effect of Aspect Ratio of Plate,**

The natural frequency of composite plate is decreasing with the increasing of aspect ratio due to the increasing of the mass for composite plate, then decreasing of the natural frequency of plate as shown in Figures 9 to 16 with different parameters of delamination effect.

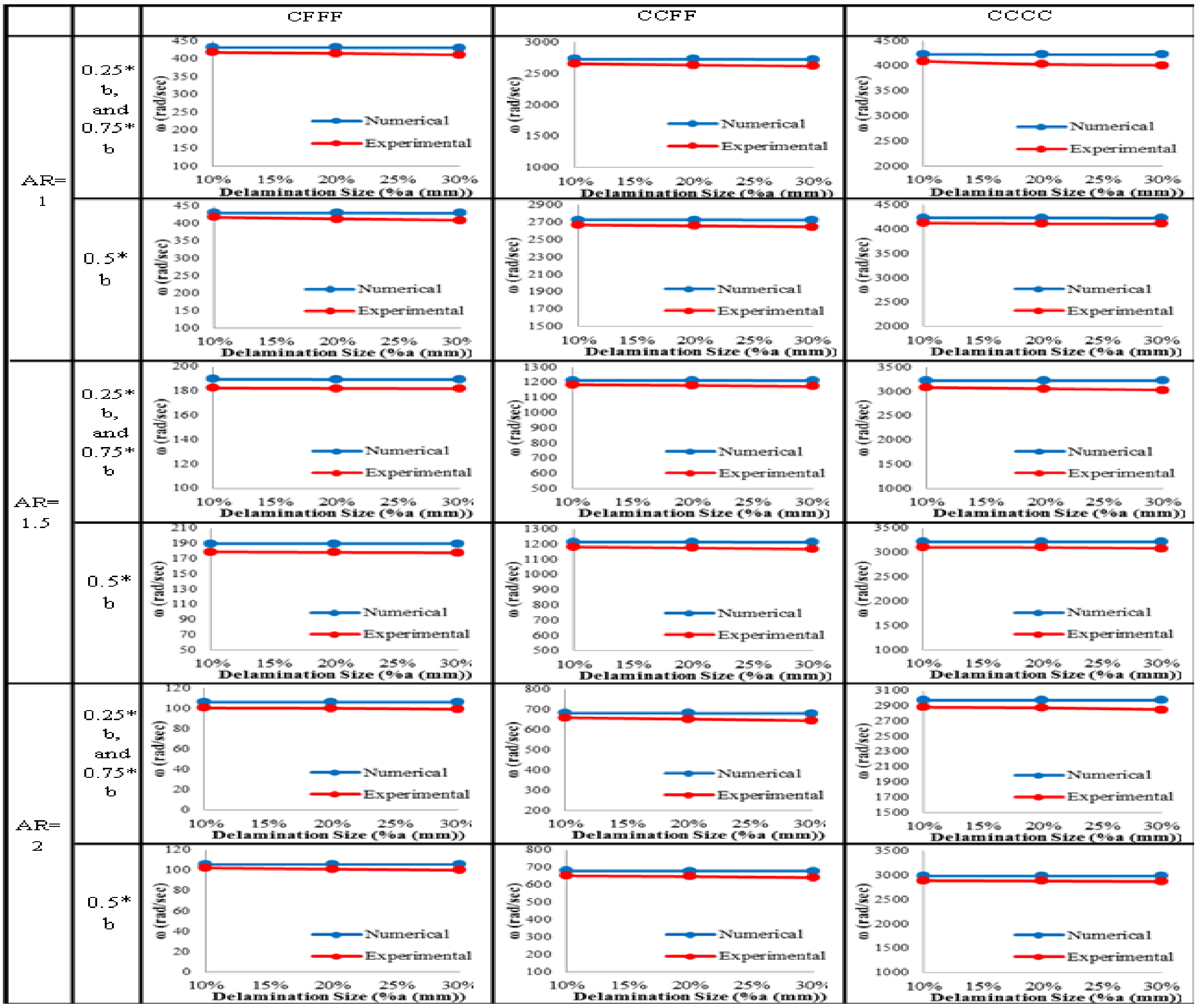


Figure 9: Compare between Experimental and Numerical Study for Composite Plate, for Different Aspect Ratio, Boundary Conditions, and Delamination Size Effect, with Delamination Location between Layers 1-2 through Thickness and 0.25*a Delamination Location through x-Direction Effect

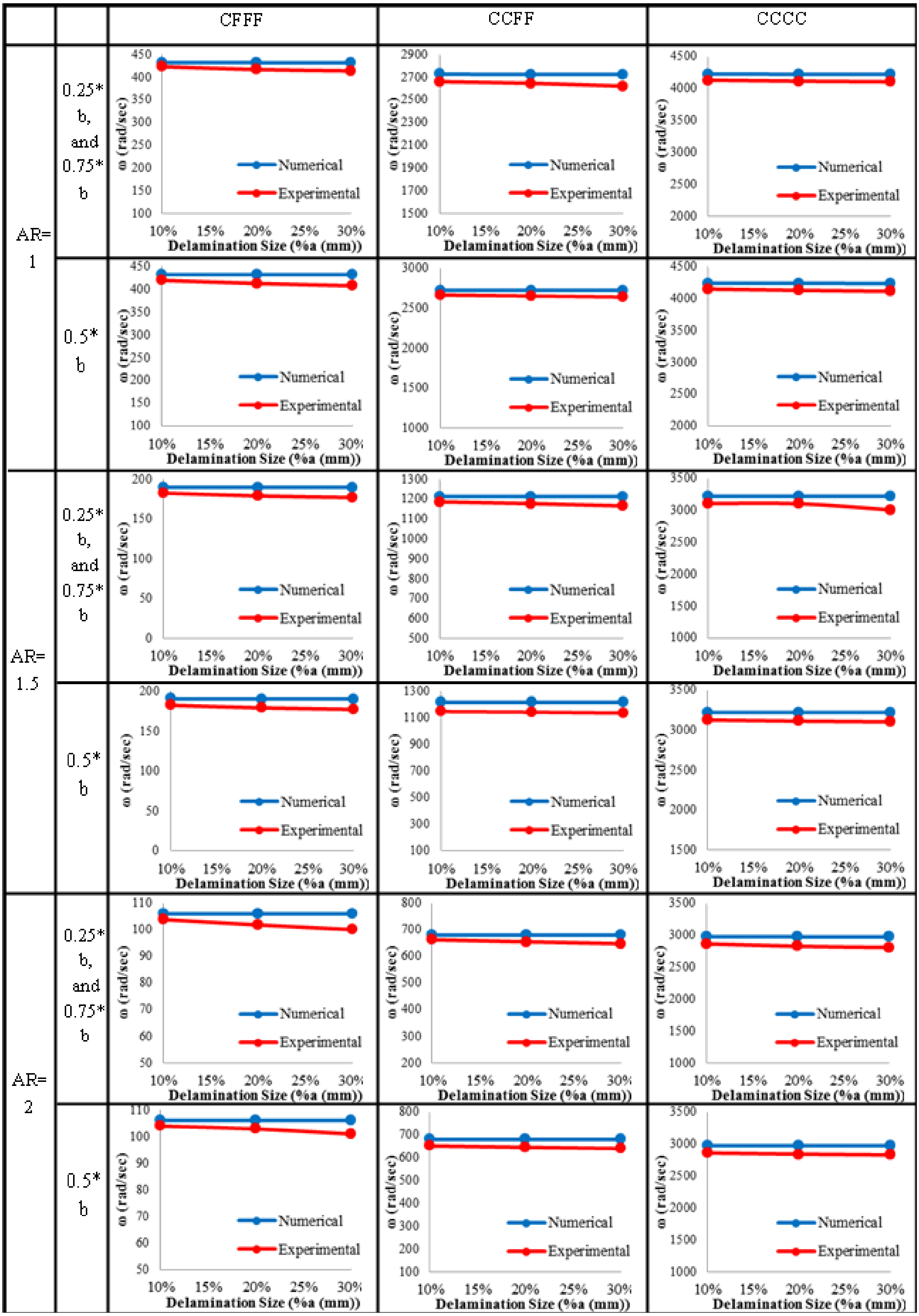


Figure 10: Compare between Experimental and Numerical Study for Composite Plate, for Different Aspect Ratio, Boundary Conditions, and Delamination Size Effect, with Delamination Location Between Layers 1-2 through Thickness and Middle Delamination Location through x-Direction, 0. 5*a, Effect

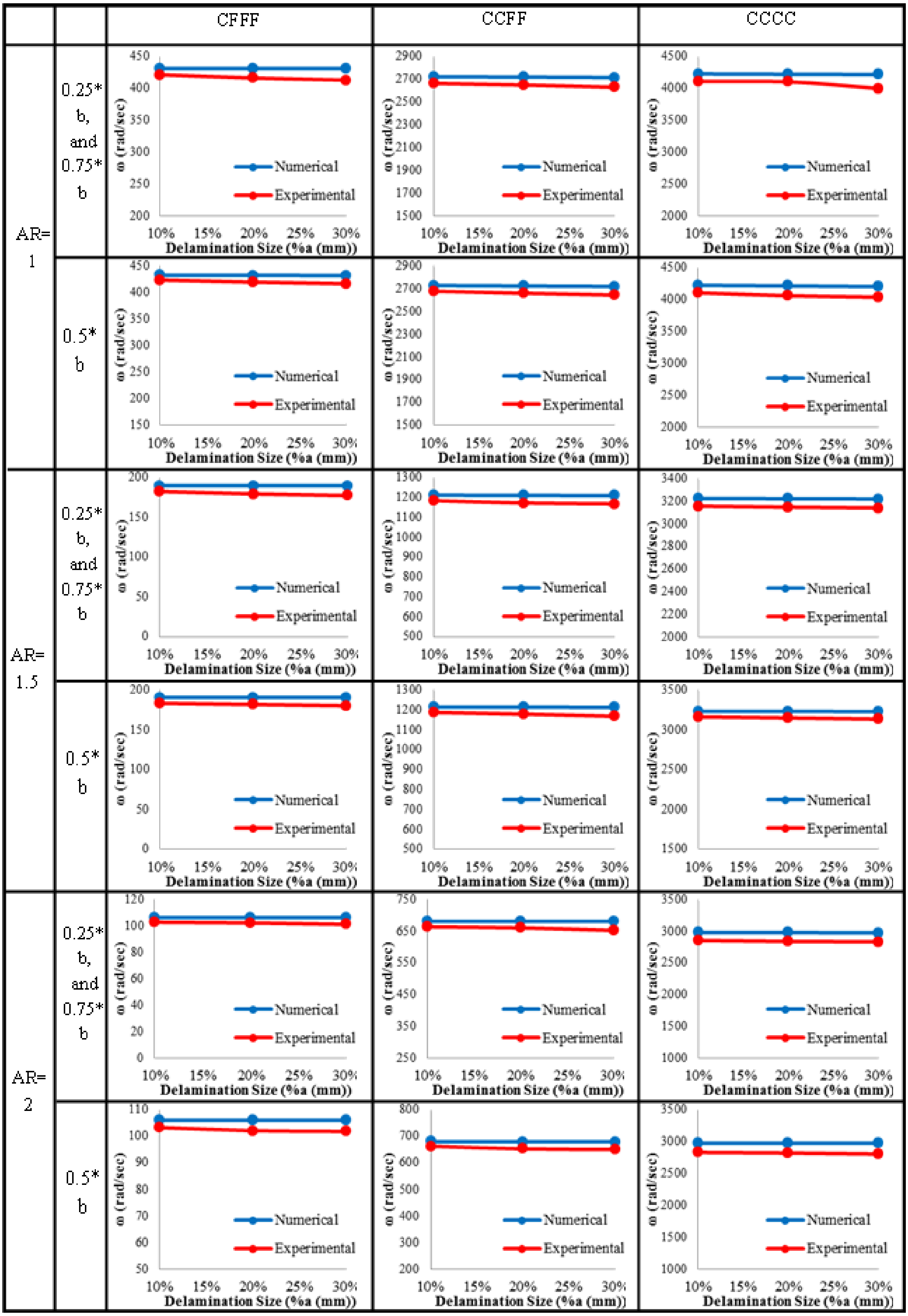


Figure 11: Compare between Experimental and Numerical Study for Composite Plate, for Different Aspect Ratio, Boundary Conditions, and Delamination Size Effect, with Middle Delamination Location through Thickness, between Layers 4-5, and 0.25*a Delamination Location through x-Direction Effect

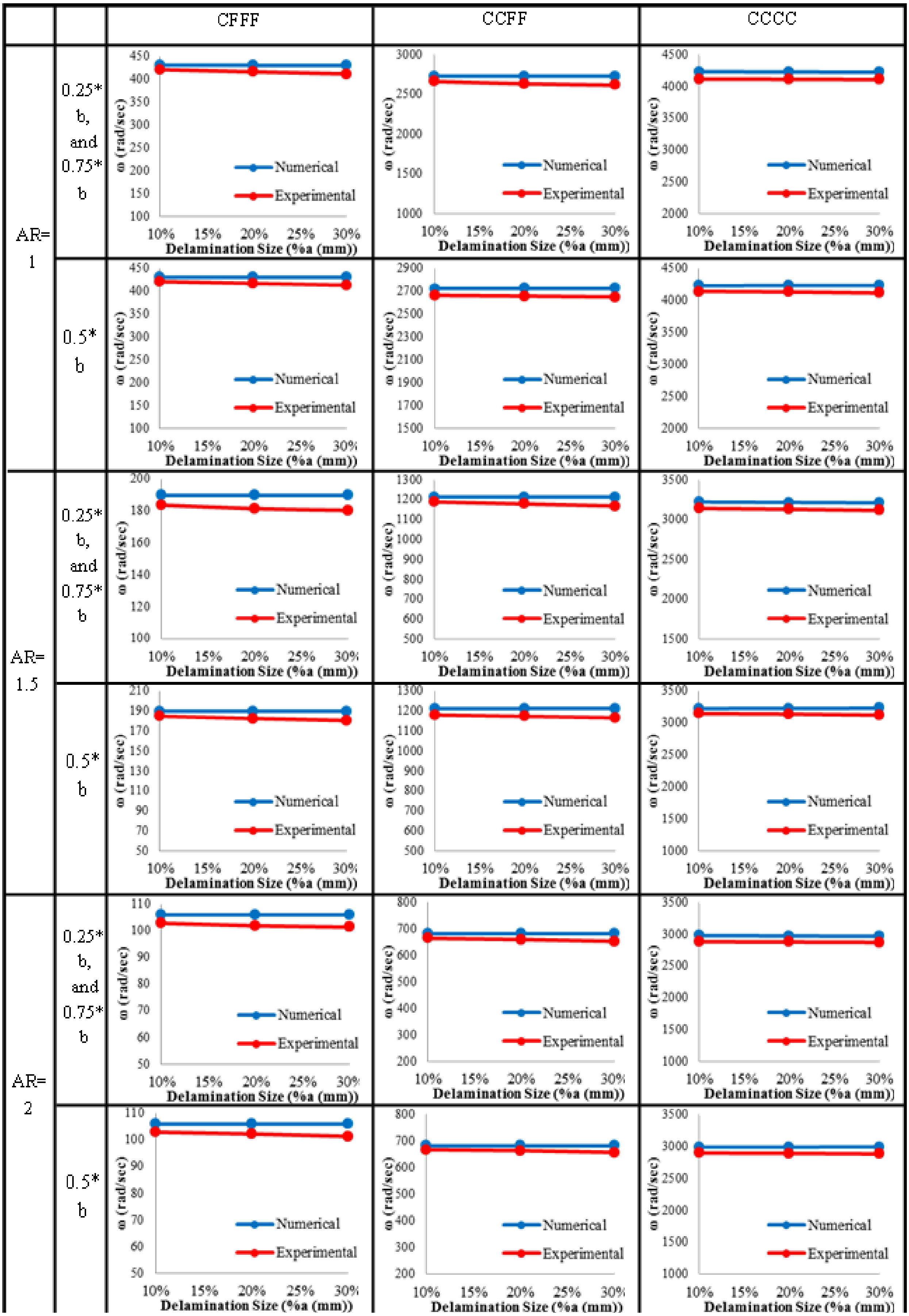


Figure 12: Compare between Experimental and Numerical Study for Composite Plate, for Different Aspect Ratio, Boundary Conditions, and Delamination Size Effect, with Middle Delamination Location through Thickness, between Layers 4-5, and Middle Delamination Location through x-Direction, 0. 5*a, Effect

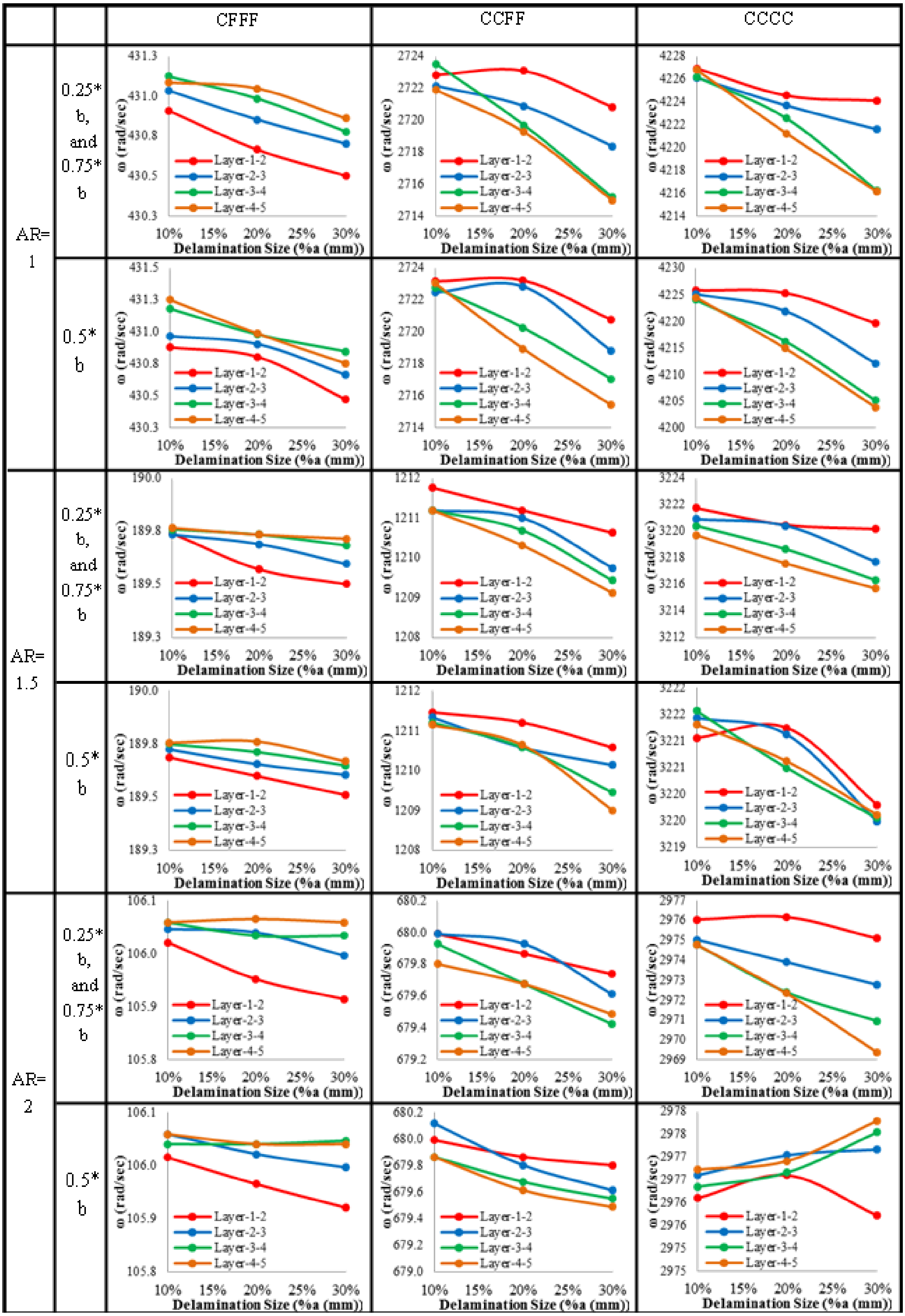


Figure 13: Natural Frequency Results for Composite Plate, for Different Aspect Ratio, Boundary Conditions, Delamination Size and Location through Thickness Effect, with (0.25*a) Delamination Location through x-Direction and Diffraction Delamination Location in y-Direction Effect

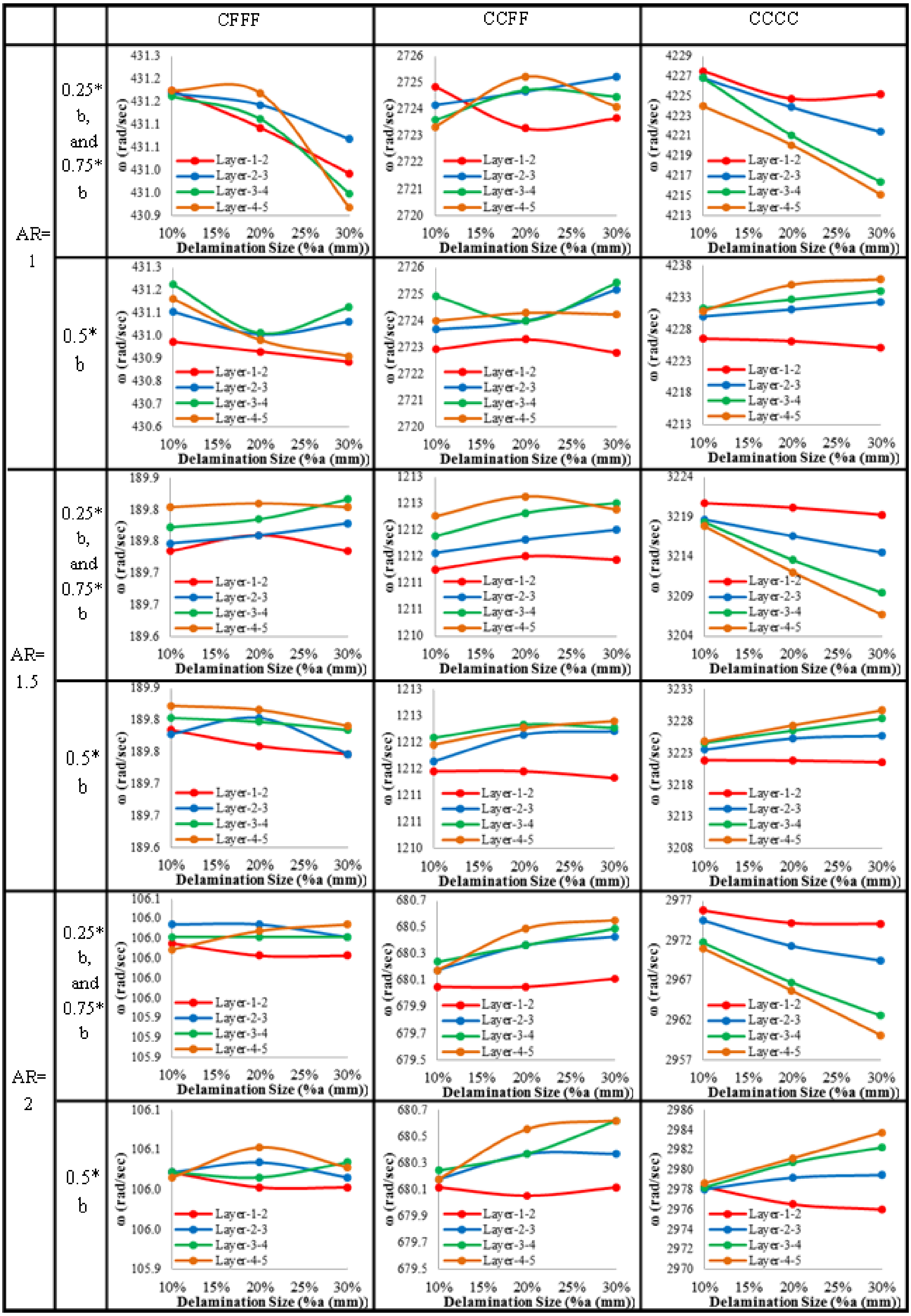


Figure 14: Natural Frequency Results for Composite Plate, for Different Aspect Ratio, Boundary Conditions, Delamination Size and Location through Thickness Effect, with middle Delamination Location through x-Direction (0. 5*a) and Diffraction Delamination Location in y-Direction Effect

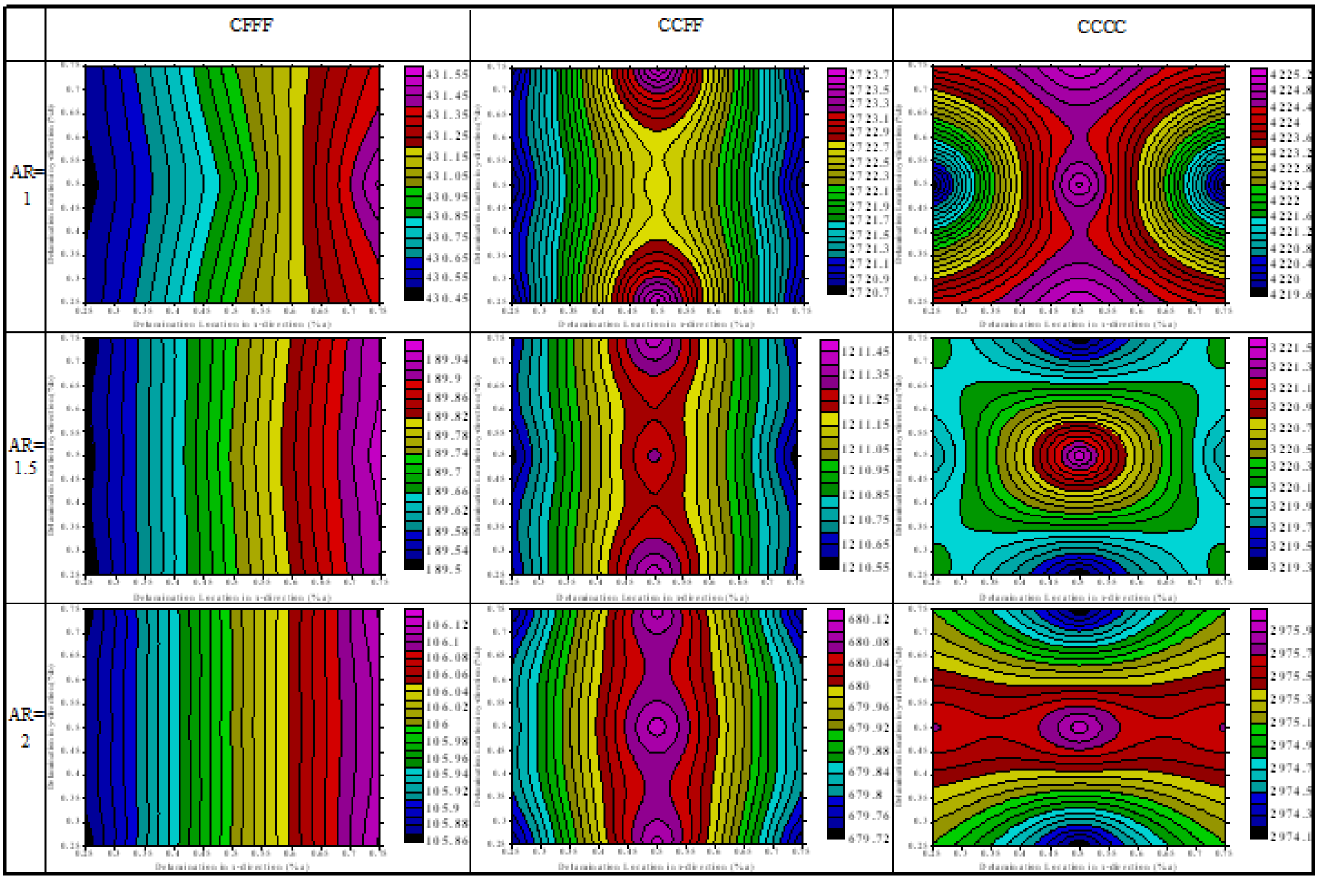


Figure 15: Contour of Experimental Natural Frequency with Different Delamination Location in x and y-Directions, for Delamination Size (0.3*a) and between Layers 1-2

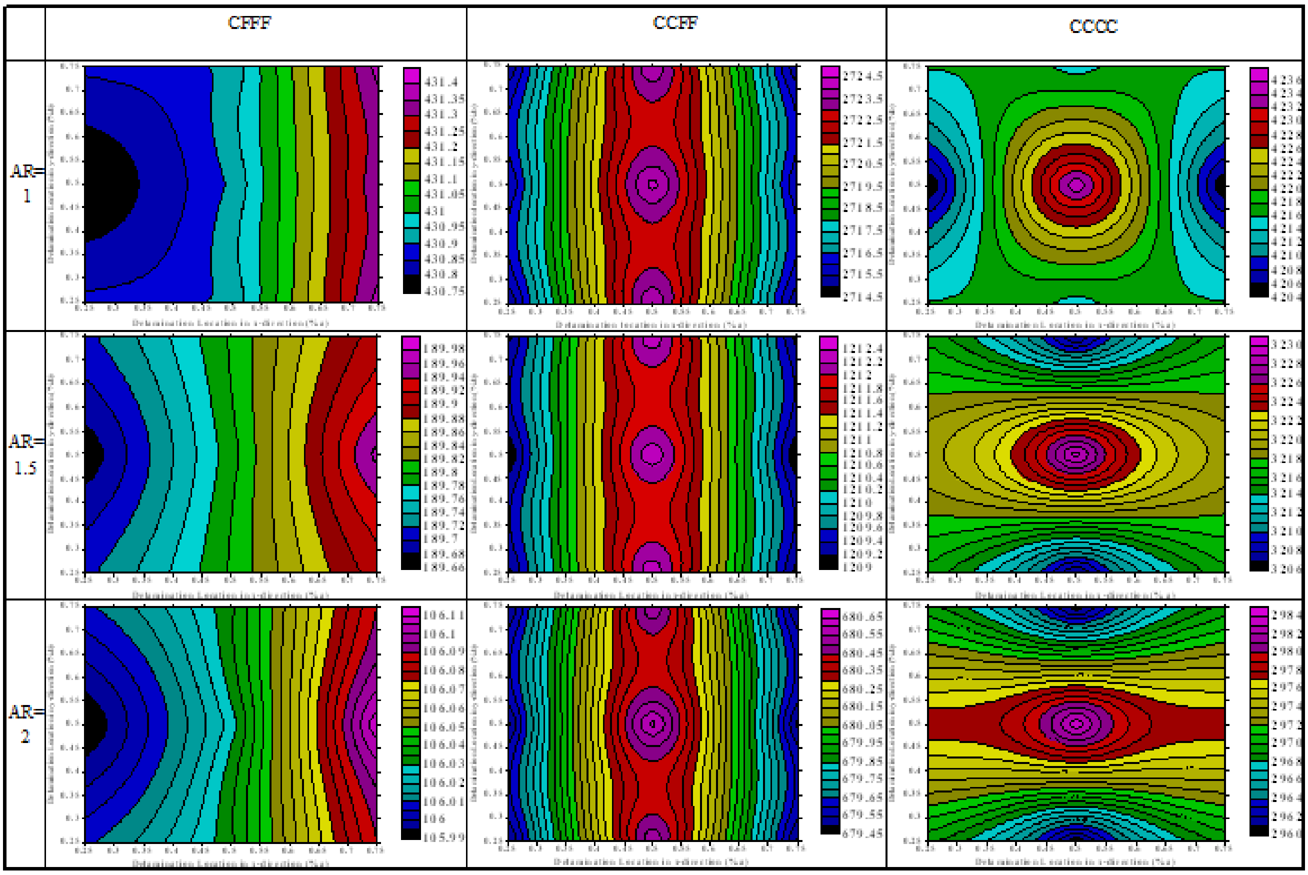


Figure 16: Contour of Experimental Natural Frequency with Different Delamination Location in x and y-Directions, for Delamination Size (0.3*a) and between Layers 4-5

CONCLUSIONS

The dynamics of the composite plate with delamination has been discussed. The procedure has been used to characterize the effect of delamination on the frequencies of woven composite laminates plate with eight layers. The effects of number, placemen, and size of delamination on the dynamic response were studied. The following important observations are made from the present study:

- The natural frequencies obtained using the developed model correlates well with both experimental results and results obtained using finite element method by ANSYS program.
- With increase of aspect ratio, the natural frequency decreases
- With increase of % delamination, the natural frequency decreases. This is due to reduction in stiffness caused by delamination.
- Local internal delamination has slight effect on the natural frequencies of a multi-layer composite plate although the extent of the natural frequency variation increases with both the delamination dimension and the order of the natural frequency.

REFERENCES

1. E. J. Barbero and J. N. Reddy ‘Modeling of Delamination in Composite Laminates Using A Layer-Wise Plate Theory’ International Journal Solids Structures, Vol. 28, No. 3, pp. 373-388, 1991.
2. M. Cho and J.-S. Kim ‘Higher-Order Zig-Zag Theory for Laminated Composites With Multiple Delaminations’ Journal of Applied Mechanics, Vol. 68, pp. 869-877, 2001.
3. S.L. Angioni, A. Visrolia, and M. Meo ‘A hierarchical multiple plate models theory for laminated composites including delamination and geometrical nonlinear effects’ Composite Structures, Vol. 93, pp. 780-791, 2011.
4. Yang Jinhua, Fu Yiming ‘Analysis of dynamic stability for composite laminated cylindrical shells with delaminations’ Composite Structures, Vol. 78, pp. 309-315, 2007.
5. Ali A. Yazdi, and JalilRezaeepazhand ‘Structural similitude for flutter of delaminated composite beam-plates’ Composite Structures, Vol. 93, pp. 1918-1922, 2011.
6. Amin Farrokhabadi, HosseinHosseini-Toudeshky, and BijanMohammadi ‘A generalized micromechanical approach for the analysis of transverse crack and induced delamination in composite laminates’ Composite Structures, Vol. 93, pp. 443-455, 2011.
7. HasanCallioglu and GokmenAtlihan ‘Vibration Analysis of Delaminated Composite Beam Using Analytical and FEM Models’ Indian Journal of Engineering and Materials Sciences, Vol. 18, pp. 7-14, 2011.
8. HosseinHosseini-Toudeshky, Samira Hosseini, BijanMohammadi ‘Delamination buckling growth in laminated composites using layerwise-interface element’ Composite Structures, Vol. 92, pp. 1846-1856, 2010.
9. M. Al_Waily "Analysis of Stiffened and Un-Stiffened laminated Plates Subjected to Time Dependant Loading" M.Sc. Thesis Submitted to the Mechanical Engineering Department, College of Engineering, Kufa University, 2005.

10. Javed Ather ‘Dynamic Stability of Delaminated Cross ply Composite Plates and Shells’ M.Sc. Thesis in Structural Engineering Submitted to theDepartmentof Civil Engineering, National Instituteof Technology, 2011.
11. M. Al_Waily " Investigation of Health Monitoring of Composite Plate Structures-Using Vibration Analysis" Ph.D. Thesis Submitted to the Mechanical Engineering Department, College of Engineering, Alnahrain University, 2012.
12. Mohsen fatahi and Amin shokuhy ‘Analysis of delamination buckling and post buckling of composite structure by generalized differential quadrature method (GDQM)’ International Journalof Advanced Engineering Sciencesand Technologies, Vol. 1, No. 1, pp. 30-37, 2010.
13. P.F. Liu, S.J. Hou, J.K. Chu, X.Y. Hu, C.L. Zhou, Y.L. Liu, J.Y. Zheng, A. Zhao, L. Yan ‘Finite element analysis of postbuckling and delamination of composite laminates using virtual crack closure technique’ Composite Structures, Vol. 93, pp. 1549–1560, 2011.
14. Praveen K. Pinnoji, and PuneetMahajan ‘Analysis of impact-induced damage and delamination in the compositeshell of a helmet’ Materials and Design, Vol. 31, pp. 3716–3723, 2010.
15. Y. Zhang and S. Wang ‘Buckling, post-buckling and delamination propagation in debonded composite laminates, Part 1: Theoretical development‘Composite Structures, Vol. 88, pp. 121–130, 2009.
16. Z. Zhang, K. Shankar, M. Tahtali and E. V. Morozov ‘ Vibration Modelling of Composite Laminates with Delamination Damage’ Proceedings of 20th International Congress on Acoustics, ICA, 2010.