INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

OPEN ACCESS

Received: 27-07-2023

Accepted: 05-09-2023

Published: 12-11-2023

Citation: Verenkar S, Sridhar I, Gouda PSS (2023) Numerical Investigations on Free Vibration Analysis of Delaminated Composite Plate. Indian Journal of Science and Technology 16(42): 3714-3720. https://doi.org/10.17485/IJST/v16i42.1866

* **Corresponding author**.

saishv@gmail.com

Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Numerical Investigations on Free Vibration Analysis of Delaminated Composite Plate

Saeesh Verenkar[1,2]*, I Sridhar[1], P S Shivakumar Gouda[1]

1 Reseacrh Center, Dept. of Mechanical Engineering, SDM College of Engineering and Technology,Visvesvaraya Technological University, Belagavi, India
2 Mechanical Engineering Department, Padre Conceicao College of Engineering, Verna, Goa, India

Abstract

Background: This research investigates the numerical evaluation of delamination effects on a composite laminate by analysing the size and location of delamination under various boundary conditions. **Methods:** The study employs modal analysis on an eight-ply composite laminate with the sequence $(0/90/45/90)_s$ using the Ansys Composite PrepPost (ACP) module. Initially, the natural frequencies and mode shapes of the undamaged composite laminate are validated against existing literature. Subsequently, deliberate damage is induced in the laminate to examine the influence of the size and location of the damage for different boundary conditions. **Findings:** The results reveal that the natural frequency of the plate is highest at the midplane and diminishes progressively towards higher interfaces. Furthermore, delamination significantly affects higher modes of vibration more than the fundamental mode. The research also explores the impact of varying degrees of restraint on the composite laminate, indicating that a higher degree of constraint leads to an increased natural frequency. Finally, a substantial difference of over 20% in natural frequency is observed between an intact plate and a damaged plate when the level of constraint on the plate is intensified. **Novelty and applications:** The novelty of this work lies in the innovative approach of utilizing Finite Element simulations through the ACP module. This unique method adds a fresh dimension to the study, enabling a more comprehensive exploration of the behaviour of composite laminates under delamination. The integration of ACP contributes to a deeper understanding of the intricacies involved, thereby enhancing the significance of the findings.

Keywords: Composite; Delamination; Modal Analysis; ANSYS; Frequency; Mode Shape

1 Introduction

Composite materials excel in engineering due to their strength-to-weight ratio. Delamination, a major failure factor, arises from loading discrepancies, fabrication errors, and edge effects. This impacts stiffness and vibration, prompting precise prediction of its influence. Studying free vibration in delaminated composite plates is intricate due to material and geometric disparities. Previous research explored this, but complexity demands continued innovative approaches.

In light of the significance of understanding delamination's impact on composite structures, a body of research has emerged investigating the free vibration response of laminated composite plates under various conditions. Kumar et al.[(1)] employed sophisticated numerical models developed in MATLAB to investigate the free vibration behaviour of laminated composite plates, both with and without delamination. Biswas et al.[(2)] delved further into the influence of pivotal parameters on the fundamental frequency of rectangular laminated composite plates, taking into consideration an array of cut-out shapes.

Delving deeper into the realm of delamination's consequences, Imran et al[(3)] delved into the realm of vibrations induced by delamination. Employing a comprehensive approach involving FE simulations and experimental investigation, they unveiled the nuanced interplay between delamination size and natural frequencies. Sahu et al[(4)] ventured into the territory of hybridization's impact on advanced fibre-reinforced polymer composites, and their model's validation against empirical data underscored the significance of their findings.

The study by Srinivasa et al.[(5)] cast its focus on isotropic and laminated composite plates endowed with central cut-outs, their pursuit of understanding marked by comparisons between experimental and finite element-derived natural frequencies. The noteworthy interplay between aspect ratio and non-dimensional frequency coefficient lent depth to their exploration. Atilla et al.[(6)] investigated the influence of circular cutouts on composite plate dynamics and buckling loads. Through the skilled utilization of ANSYS software and the innovative use of artificial neural network predictions, their work paved the way for insightful predictions.

Continuing this pursuit, Arun et al.[(7)] conducted dynamic characterization of delaminated composite plate structures through finite element methodologies. The interplay between free vibration responses and delamination brought forth valuable insights. Zhang et al.[(8)] introduced an ingenious vibration-based approach to delve into the intricacies of delamination in curved composite plates. Their work involved harnessing the prowess of artificial neural networks and surrogate-assisted genetic algorithms, enabling them to successfully predict delamination parameters.

Sinha et al.[(9)] investigated free vibration characteristics of laminated composite plates with and without cut-outs. They explored parameters' effects and examined cut-out attributes. The study's strong agreement between experimental and numerical findings supports precise composite plate design. Mrityunjay et al.[(10)] analysed modal behaviour in sandwich composite plates with honeycomb cores using finite element analysis and ANSYS APDL software. They focused on natural frequencies, mode shapes, and the significance of face sheet thickness and core material.

While these studies have contributed to our understanding of delamination's impact on composite plate vibration, there still exists a research gap that calls for deeper investigation and improved analysis techniques. Recognizing this, the current study employs FE simulations using ACP module to gain more profound insights into the behaviour of delaminated composite laminates, addressing this crucial issue comprehensively.

2 Methodology

2.1 Parametric Design of Composite Plate

In this study, the primary analysis stage involves initiating the investigation by parametrically configuring the composite plate. During this phase, the geometry's design is formulated using ANSYS SpaceClaim. Following this, the model undergoes the process of mesh generation. The subsequent step involves a crucial element: layering the composite laminates, a fundamental component of the modelling advancement. Once this modelling is complete, the model is introduced into modal analysis to extract the natural frequencies and create visual representations of the mode shapes. The entirety of this procedural flow is effectively illustrated in Figure 1.

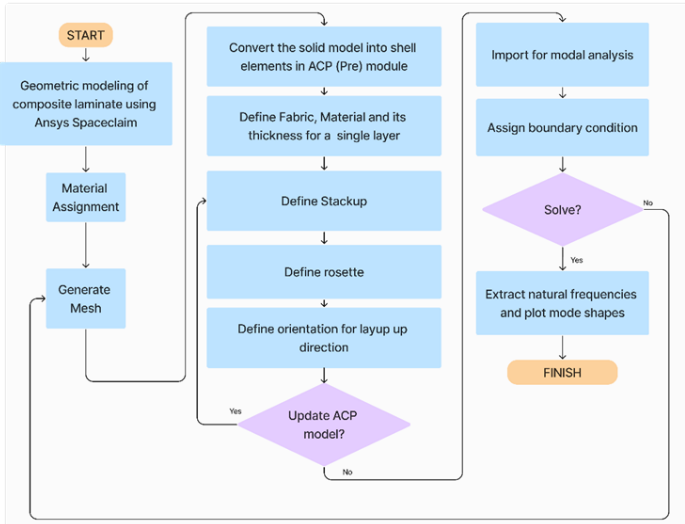

Fig 1. Flow chart depicting the sequential process and analysis workflow for modal analysis of laminated composite plate

2.2 Comparison with Previous study

Based on the finite element formulation and modelling of the delaminated composite, a numerical program was developed using ANSYS software. To validate the results, the observations obtained for the free vibration analysis of a healthy composite laminate by Ju et al [11] and Parhi et al [12] were used for comparison with the present results. Excellent agreement was found between the two results, as shown in Table 1, thus validating the finite element model.

Table 1. Results comparison with previous literature

Boundary Condition	Mode No	Natural Frequency (Hz)		
		Results of Ju et al	Results of Parhi et al	Present Results
SSSS	1	164.37	163.651	163.43
	2	404.38	400.918	400.83
	3	492.29	494.141	494.63
	4	658.40	650.089	649.84
CCCC	1	346.59	342.543	342.94
	2	651.51	635.641	636.21
	3	781.06	766.580	768.92
	4	1017.2	963.542	964.71
CFFF	1	41.347	41.1620	41.167
	2	60.663	60.520	60.568
	3	221.52	220.461	220.57
	4	258.72	257.709	258.04

SSSS- Simply supported, CCCC- Fully clamped, CFFF-Cantilever

2.3 Numerical Example

In this investigation, authors have focused on a series of delaminated composite plates. The dimensions, stacking sequence, and locations of the induced delamination regions are represented in Figure 2. Material properties relevant to the analysis are provided in Table 2. To simulate delamination, a single square delamination was strategically introduced at the plate's centre, with its dimensions defined as a/2 and 3a/4, where 'a' corresponds to the length of one side of the square. Additionally, delamination was implemented at various interfaces denoted as IF00, IF01, IF02, and IF03 (as shown inFigure 2). The investigation further explored the influence of different boundary conditions on the natural frequency of the delaminated composite. The delamination was introduced by debonding the nodes within the designated delaminated regions, thereby allowing a detailed analysis of the structural response.

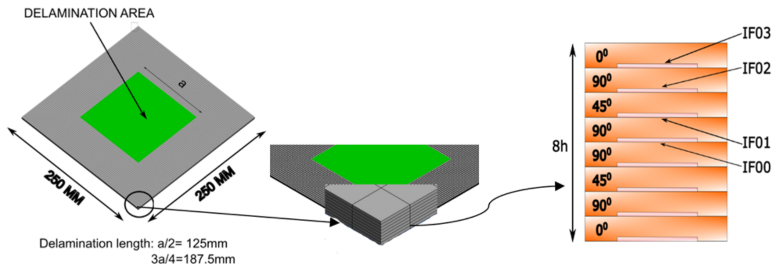

Fig 2. Finite element mesh with delamination, individual plies and their stacking sequence

Table 2. Material Properties

Material Properties	Values
E_{11}	132 GPa
E_{12}	5.35Gpa
$G12$	2.79 GPa
$v_{12=13}$	0.291
v_{23}	0.3
ρ	1446.20 kg/m^3

3 Results and Discussion

3.1 Effect of delamination size and location

The present study delves into an investigation centered around two square-shaped delamination. This delamination possesses distinct sizes, namely a/2 and 3a/4, and are placed within the context of exploring their impact on a cantilever support. The focus is on the effects induced by delamination at different interfaces, and their consequences on the cantilever's behavior were thoroughly examined.

Upon reviewing the data presented in Table 3, it can be inferred that as the length of the delamination increases, the natural frequency of the system experiences a reduction. This decline is especially prominent in instances where the delamination size is 3a/4, compared to the case where the delamination size is a/2. It is noteworthy that the decrease in the fundamental frequency when the delamination is a/2 is comparatively minor.

Intriguing insights can be collected from the observation of the delamination's position and its relation to the natural frequency. The data suggests that the natural frequency is the highest when the delamination is positioned at the midplane, denoted as IF00. Subsequently, as the delamination shifts to subsequent locations—IF01, IF02, and IF03—the natural frequency exhibits a visible decline. For a delamination situated at IF00, the first mode experiences a 4% reduction in natural frequency, whereas this reduction intensifies to 9.3% for the sixth mode.

Examining the graphical representation in Figure 3, a notable pattern emerges. Higher modes (such as modes 4, 5, and 6) appear to be more susceptible to the influence of delamination compared to the lower modes. This observation underscores the intricate relationship between delamination and the various modes of the system.

For instances where the delamination is located at IF03, the drop in the natural frequency becomes even more pronounced. In particular, the sixth mode experiences a substantial 17% decrease in natural frequency. This variation indicates that the natural frequency is particularly sensitive to damage occurring in close proximity to the upper surface of the structure.

A further dimension to the analysis is provided by Figure 4, which contrasts the mode shapes of the intact plate with those of the plate featuring delamination. This comparison visually accentuates the alterations in mode shapes caused by the presence of delamination.

Table 3. Effect of Delamination Length and Location on the natural frequency (Hz)

Delaminated Interface	Delamination Length	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
Intact	-	41.167	60.568	220.57	258.04	286.21	406.1
Delamination At IF00	a/2	39.436	58.887	211.86	238.49	275.83	368.03
	3a/4	35.516	57.846	167.53	198.74	236	244.61
Delamination At IF01	a/2	40.106	59.845	214.21	241.84	280.4	342.18
	3a/4	36.141	58.721	148.85	191.96	213.3	237.9
Delamination At IF02	a/2	40.758	61.348	199.69	227.56	271.03	290.3
	3a/4	36.921	59.939	96.088	189.84	193.76	218.76
Delamination At IF03	a/2	40.854	61.362	170.93	200.93	225.52	255.11
	3a/4	37.255	59.859	77.967	90.013	118.02	164.33

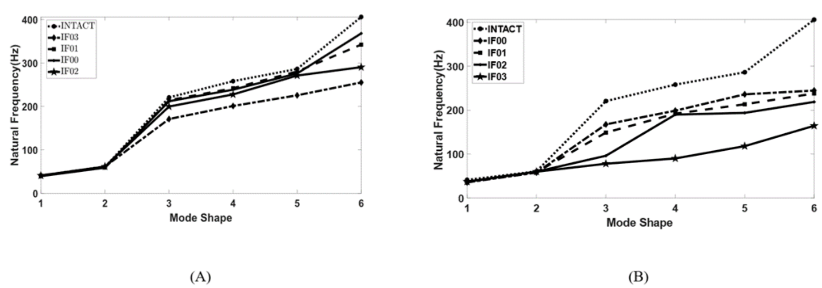

Fig 3. Mode shape at various interface locations for (a) a/2 (b)3a/4

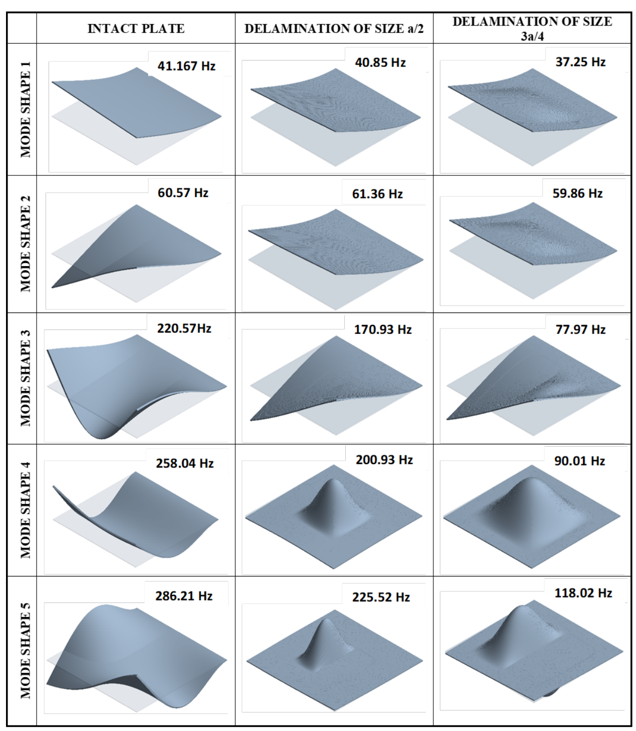

Fig 4. Mode shape comparison for healthy and damaged plate

3.2 Effect of boundary condition and delamination size

In this particular scenario, a comprehensive exploration involved the consideration of three distinct boundary conditions: cantilever (CFFF), simply supported (SSSS), and fully clamped (CCCC). The focal point of this investigation was the meticulous examination of how these boundary conditions interplay with composites containing delamination of sizes a/2 and 3a/4 positioned at the middle interface (IF00).

The intricate relationship between these boundary conditions and the composites' behavior with delamination yields intriguing insights, as highlighted by the data presented in Table 4. Evidently, the presence of delamination exerted a substantial impact on the composite plate, and this impact was notably influenced by the specific boundary condition in play.

As the level of restraint on the composite plate heightened, a corresponding gradual increase in the natural frequency was observed. This trend is effectively visualized in Figure 5. This finding indicates that the choice of boundary condition plays a pivotal role in shaping the dynamic response of the composite structure.

Delving deeper into the specifics, when the cantilever boundary condition was considered, the data revealed an average reduction in the natural frequency of approximately 5% for delamination of size a/2, compared to an intact plate. However, this average reduction intensified significantly to 20% for delamination of size 3a/4. This result underscores the higher sensitivity of larger delamination to the cantilever boundary condition, resulting in a more pronounced effect on the natural frequency.

In stark contrast, the fully clamped boundary condition yielded a markedly different outcome. In this case, an average drop in the natural frequency of more than 20% was observed. This substantial reduction in the natural frequency signifies that as the level of resistance and restraint imposed on the composite plate increases (as in the fully clamped condition), the magnitude of the decrease in the natural frequency becomes more prominent. This trend reinforces the notion that stronger boundary conditions, in terms of clamping, lead to a more significant impact on the dynamic behavior of the composite structure.

In essence, this comprehensive analysis underscores the intricates between boundary conditions, delamination sizes, and their combined influence on the natural frequencies of composite plates. The findings unravel the interdependent dynamics thus shedding light on the delicate balance between structural integrity and the various forces that shape it.

Table 4. Effect of boundary condition on natural frequency (Hz)

Boundary condition	Delamination length	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
Cantilever	intact	41.167	60.568	220.57	258.04	286.21	406.10
	a/2	39.436	58.887	211.86	238.49	275.83	368.03
	3a/4	35.516	57.846	167.53	198.74	236.00	244.61
Simply Supported	intact	163.43	400.83	494.63	649.84	838.76	956.46
	a/2	153.63	316.98	328.81	520.24	571.93	574.13
	3a/4	130.53	232.61	236.04	254.57	404.58	422.63
Fully Clamped	intact	342.94	636.21	768.92	964.71	1145.7	1380.2
	a/2	293.45	494.95	506.30	524.94	758.82	799.25
	3a/4	199.21	237.66	358.34	403.38	424.27	554.91

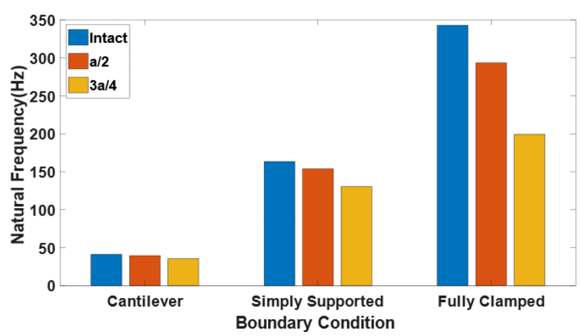

Fig 5. Natural Frequency for various boundary conditions

4 Conclusion

A finite element model of a composite plate, with and without delamination, was developed using ACP module. The results obtained for a healthy composite plate without damage were compared with those in the existing literature and were found to be in good agreement. Upon insertion of delamination in composite plate and conducting a parametric study several conclusions can be drawn from the analysis of the results. First, it was observed that the natural frequency of the plate was the highest at the midplane, that is, IF00, and gradually decreased as we approached IF03. Additionally, the higher modes of vibration (such as modes 4, 5, and 6) were found to be more significantly affected by delamination than the fundamental mode. The natural frequency of the plate increased as the composite became more strongly restrained. Finally, a substantial difference of over 20% in natural frequency was observed between an intact plate and a damaged plate as the level of constraint on the plate increased.

As highlighted in the paper, ACP proves advantageous over Ansys APDL due to its tailored focus on composites, offering specialized tools for efficient composite analysis, visualization, and post-processing, while APDL's general-purpose nature might require more manual configuration and scripting, especially for composites. Applications of ACP include designing composite structures, optimizing laminate layups, predicting failure modes, and simulating various manufacturing processes to enhance the performance and durability of composite materials in diverse industries such as aerospace, automotive, and civil engineering.

References

1) Kumar KD, Sarathchandra SB, Prasad SMM, Prasad K. Effect of delamination on natural frequencies of laminated FRP composite plate. *Materials Today: Proceedings*. 1490;72. Available from: https://doi.org/10.1016/j.matpr.2022.09.376.
2) Biswas S, Lokavarapu BR. Fundamental frequencies of composite rectangular plates with different cut-outs. *Materials Today: Proceedings*. 2023. Available from: https://doi.org/10.1016/j.matpr.2023.03.062.
3) Imran M, Khan R, Badshah S. Investigating the Effect of Delamination Size, Stacking Sequences and Boundary Conditions on The Vibration Properties of Carbon Fiber Reinforced Polymer Composite. *Materials Research*. 2019;22(2). Available from: https://doi.org/10.1590/1980-5373-MR-2018-0478.
4) Sahu P, Sharma N, Panda SK. Numerical prediction and experimental validation of free vibration responses of hybrid composite (Glass/Carbon/Kevlar) curved panel structure. *Composite Structures*. 2020;241:112073. Available from: https://doi.org/10.1016/j.compstruct.2020.112073.
5) Venkateshappa SC, Kumar P, Ekbote T. Free vibration studies on plates with central cut-out. *CEAS Aeronautical Journal*. 2019;10:623–655. Available from: https://doi.org/10.1007/s13272-018-0339-7.
6) Atilla D, Sencan C, Kiral BG, Kiral Z. Free vibration and buckling analyses of laminated composite plates with cutout. *Archive of Applied Mechanics*. 2020;90(11):2433–2448. Available from: https://doi.org/10.1007/s00419-020-01730-2.
7) Kumar A. Different interface delamination effects on laminated composite plate structure under free vibration analysis based on classical laminated plate theory. 2020. Available from: https://doi.org/10.1088/1361-665X/abaec7.
8) Zhang Z, Pan J, Luo W, Ramakrishnan KR, Singh HK. Vibration-based delamination detection in curved composite plates. *Composites Part A: Applied Science and Manufacturing*. 2019;119:261–274. Available from: https://doi.org/10.1016/j.compositesa.2019.02.002.
9) Sinha L, Das D, Nayak AN, Sahu SK. Experimental and numerical study on free vibration characteristics of laminated composite plate with/without cut-out. *Composite Structures*. 2021;256:113051. Available from: https://doi.org/10.1016/j.compstruct.2020.113051.
10) Kumar M, Kar VR, Chandravanshi ML. Free vibration analysis of sandwich composite plate with honeycomb core. *Materials Today: Proceedings*. 2022;56:931–935. Available from: https://doi.org/10.1016/j.matpr.2022.02.561.
11) Ju F, Lee HP, Lee KH. Finite element analysis of free vibration of delaminated composite plates. *Composites Engineering*. 1995;5(2):195–209. Available from: https://doi.org/10.1016/0961-9526(95)90713-L.
12) Mohanty J, Sahu SK, Parhi PK. Numerical and experimental study on free vibration of delaminated woven fiber glass/epoxy composite plates. *International Journal of Structural Stability and Dynamics*. 2012;12(02):377–394. Available from: https://doi.org/10.1142/S0219455412500083.