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Investigation of Free Vibrational responses in Laminated Composite Plates with Stiffeners at Different Positions

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Abstract: Laminated composite plates with stiffeners are frequently used in various engineering applications due to their excellent mechanical properties. The free vibrational response of such plates is an important characteristic that affects their performance and reliability. In this study, the impact of varying stiffener placements and layer orientations on the free vibrational response of laminated composite plates was investigated using the finite element (FE) approach in ANSYS software. The Shell 281 element was used for the analysis, and various boundary conditions were considered. The study found that the natural frequencies of the plates were significantly influenced by the placement of the stiffeners and the layer orientation. The findings of this study may be particularly useful in the aerospace, automotive, and construction industries, where laminated composite plates with stiffeners are commonly used. Overall, this study contributes to a better understanding of the free vibrational response of laminated composite plates and provides valuable insights into the design and optimization of such structures for various engineering applications.

Keywords:- Free Vibration, Plate, FEM, ANSYS, Stiffener, Composite Plate

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1. Introduction: Laminated composite plates have emerged as a promising material in various industrial applications due to their exceptional mechanical properties and high strength-to-weight ratio. They are not only lightweight but also cost-effective, making them an attractive option for engineers and designers. These plates consist of multiple layers of different materials that are bonded together. The unique combination of materials in the layers allows for the tailoring of the plate's properties to meet specific design requirements. Laminated composite plates are versatile materials that find a wide range of applications across various engineering fields. The unique blend of superior mechanical properties & high strength-to-weight ratio makes them an increasingly favoured choice in aircraft, maritime transportation, automobiles, and civil engineering. In the aerospace industry, these plates are used for manufacturing various components of aircraft, including fuselage, wings, and tail sections. In the automotive industry, laminated composite plates are used to make car body parts, such as hoods, doors, and fenders, contributing to the overall reduction of vehicle weight and improved fuel efficiency. In the marine industry, these plates are used in the construction of boats, ships, and submarines, which require lightweight yet durable materials that can withstand harsh marine environments. In the civil engineering industry, these plates are used in the construction of bridges, buildings, and infrastructure, where high structural integrity and weight reduction are critical factors. Their use can result in improved fuel efficiency,

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increased load capacity, and enhanced durability, making them an attractive option for modern engineering design. Understanding the vibrational behaviour of these structures is critical for their design and optimization, as it can be influenced by multiple factors, including material properties, geometry, and the presence of stiffeners (Singh Rajawat et al., 2018). The determination of natural frequencies is a crucial aspect of the design process for laminated composite structures because they significantly affect the fundamental frequency of the structure. ANSYS software is frequently used to do FEM analysis, and the finite element method (FEM) has grown in popularity as a useful technique for analysing the modal properties of laminated composite plates in recent years (Alhijazi et al., 2020). This article examines the effects of layer orientation on the vibrational responses in laminated composite plates with stiffeners at various places. The vibrational responses are analysed in terms of their natural frequencies and mode shapes. The results of this study will greatly progress laminated composite plate design and optimization for a number of technical applications.

In high-performance applications, weight reduction is an essential consideration, and introducing stiffeners to the plates is a common approach to minimize deflection without adding significant weight(de Queiroz et al., 2019). Research have revealed that plate properties, such the stiffener's location and the angle at which the fibres are oriented, significantly affect the fundamental frequencies and structural response of the plate. (Amabili & Farhadi, 2009; Bhar et al., 2010; Sahraei et al., 2022; Singh Rajawat et al., 2018a)

Additionally, the effect of using bar models for composite material stiffeners is compared with the shell models described by Lee (Lee & Lee, 1995). Nguyen (Nguyen-Thoi et al., 2013) presented evidence that cell-based triangular elements can provide more accurate results for the structural analysis of arbitrarily reinforced plates compared to isoparametric quadrilateral elements with eight nodes. The study found good agreement between deflections and rotations of the stiffeners and plate at their contact sites. Numerous studies have examined the structural behaviour analysis of composite plates with varying edge conditions. For instance, Khdeir (2010) examined symmetric cross-ply elastic plates for their free vibrational behaviour, while Sharma et al. (2013, 2017) and Singh Rajawat et al. (2018b) conducted studies on laminated composite plates for their free vibrational response, specifically focusing on those with elastic edge constraints. Liew et al. (year not specified) conducted the initial examination of free response for rectangular plates composed of symmetric cross-ply laminates with uniformly elastic-constrained edges, which has been further studied by multiple researchers. The natural frequency response of composite plates has been extensively explored by various researchers, such as Ramu (Ramu & Mohanty, 2014), Sharma (Sharma & Mittal, 2013; Yadav et al., 2015a, 2015b), Asiri (Asiri & Sayed Hedia, 2013), and Rath(Rath & Sahu, 2012). The goal of this research is to improve our understanding of the vibration response of laminated composite plates by investigating how stiffeners and layer orientation affect natural frequencies. The results of this inquiry can provide important new understandings of the vibrational response of laminated composite plates and can help with the design and optimization of these plates for a variety of engineering uses.

2. Methodology: This study's main goal was to use free vibration analysis to examine how stiffeners and layer orientation affected the fundamental frequencies of laminated composite plates. To achieve this objective, the finite element method (FEM) was applied to model the behaviour of the composite plates with stiffeners positioned at various locations. Given the intricacy of their form and material properties, the use of FEM enabled highly accurate modelling of the composite plates. The ANSYS software provided a reliable tool for simulating the natural frequencies of the plates and validating the experimental results. The results were not influenced by external factors because several boundary conditions were taken into account.

This methodology allowed for a thorough investigation of the free vibrational behaviour of plates with stiffeners positioned at different locations. The insights gained from this study

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are expected to aid in the design and optimization of such structures for various engineering applications.

Figure 1 shows how the SHELL281 element was used in the current work to analyse composites that were modelled as thin to moderately thick shell structures. This element was chosen because it can simulate the vibrational behaviour of such structures realistically. There are eight nodes in this element, each having six degrees of freedom. The analysis was conducted using a finite element software package, which allowed for the application of appropriate boundary conditions and the simulation of various scenarios to obtain accurate results. The first-order shear-deformation theory served as the foundation for the precision of the composite shell modelling. This study looked at the vibrational behaviour of a stiffened laminated plate under a variety of boundary circumstances, including fully clamped, simply supported, and fixed. The analysis used the finite element method (FEM), and the composite plate's experimental findings were confirmed using ANSYS software, specifically Mechanical APDL. The analysis process encompassed defining model geometry, distributing material properties and thickness, creating a smart-sized quadrilateral mesh, defining boundary conditions, and executing and resolving the model. The model's inherent frequencies and mode shapes were determined by a free vibration analysis. Subsequently, modifications were made to the model by varying the number and position of stiffeners, as well as introducing layers with different angles, and the effects of these modifications were analysed. The purpose of the investigation was to find out how these adjustments would impact the laminated composite plate's inherent frequencies and mode shapes.

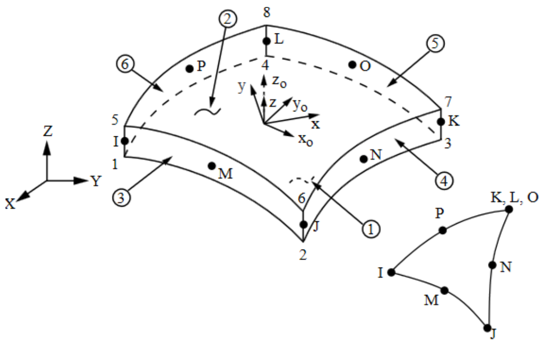

Fig 2.1 Shell 281 geometry

3 Modelling: (Sahoo et al., 2017)utilized a glass epoxy laminate composite to validate both its material and geometric properties under simply supported, cantilever, and both ends fixed conditions. The geometric properties of the composite include a height of 150mm, width of 110mm, thickness of 2.1mm, and a total of 7 layers. The material properties include Ex=46.2Gpa, Ey=14.7Gpa, Ez=14.7Gpa, Gxy=5.35Gpa, Gzx=5.22Gpa, Gyz=5.35Gpa, vzx=0.41,vxy=0.31, and vyz=0.31.

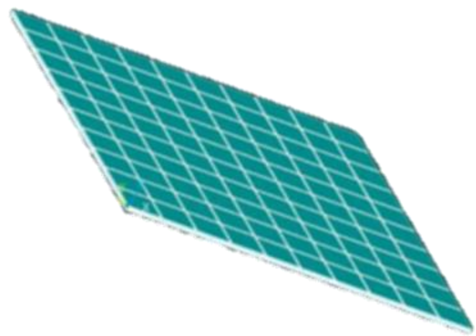

Figure 3. 1 Laminated Composite Plate

Free vibration analysis was used to identify the natural frequencies and mode shapes. Additionally, the model was modified by altering the position of the stiffeners and the orientation of the layers. The effects of these modifications were examined, and the results were compared to experimental results from other authors. The results obtained, as shown in Table 1, exhibit favourable concurrence with the experimental findings of previous researchers.

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Table 1: The fundamental frequency of a composite laminated plate without a stiffener, organised in the intervals 0/90/0/90/0/90/0

Table Number-1			
Boundary Conditions	**Mode No.**	**Experimental Frequency** (Dhanduvari Dinesh Kumar et al., 2015)	**ANSYS Frequency** **(**Present result)
Cantilever	1	80	65.92
	2	134	130.89
	3	383	373.48
Both Ends Fixed	1	482	468.65
	2	539	534.38
	3	708	704.85
Simply Supported	1	189	178.68
	2	349	331.17
	3	418	407.89

Here is a description of the fundamental frequency parameter's range for composite laminated plates under different boundary and loading conditions. In this, the natural frequency response of composite laminated plates with various orientations are compared. The frequencies representing various orientations demonstrate analogous behavior, as observed, with alterations occurring in the frequencies as the stiffener position and orientation angle varies.

Table 2 Fundamental Frequency Comparison of Angle-Ply Laminated Composite Plate with 45/-45/45/-45/45/-45/45 Fiber Orientation, Without Stiffener

Mode Number	**Cantilever**	**Simply Supported**	**Both Ends Fixed**
1	59.923	176.71	456.86
2	123.57	367.01	531.49
3	269.57	457.85	695.58

The table shows the angle-ply laminated composite plate's natural frequency values without any stiffeners. The plate has a fiber orientation of 45/-45/45/-45/45/-45/45. The frequency values are provided in hertz (Hz) and represent the different modes of vibration of the plate. The table makes it simple to compare the natural frequency values for the various vibrational modes.

Table 3 Fundamental frequency of cross-ply composite laminated plate with central Stiffener(0/90/0/90/0/90/0)

Mode Number	**Cantilever**	**Both Ends Fixed**	**Simply Supported**
1	98.56	497.05	232.224
2	171.04	557.48	347.12
3	405.08	805.13	625.64

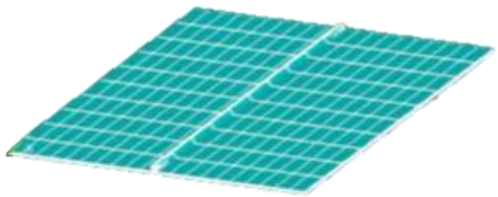

Figure 3. 2 laminated composite plate with central stiffener

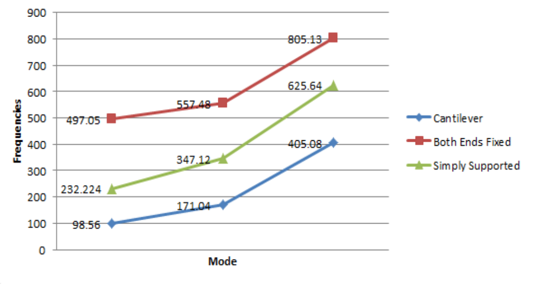

Figure 3. 3 Chart depicting fundamental frequency for a cross-ply laminated composite plate with a centrally positioned

The frequency response of cross-ply laminated composite plates with a central stiffener are compared in this graph.. The chart provides a visual representation of the changes in natural frequencies as the orientation of the stiffener is varied. The information provided in this data can be valuable in comprehending the characteristics of laminated composite plates with stiffeners, and can aid in enhancing their design for particular applications..

Table: 4 Angle-ply laminated composite plate with central stiffener: fundamental frequency comparison (45/-45/-45/-45/-45/45)

Mode Number	Cantilever	Both Ends Fixed	Simply Supported
1	92.05	495.64	255.39
2	156.96	568.61	352.183
3	399.13	862.98	643.73

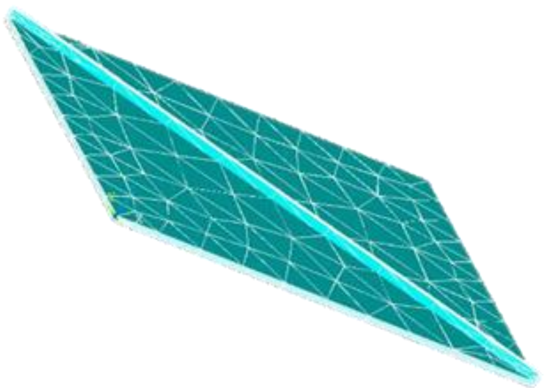

Figure 3. 4 laminated composite plate having diagonal stiffener

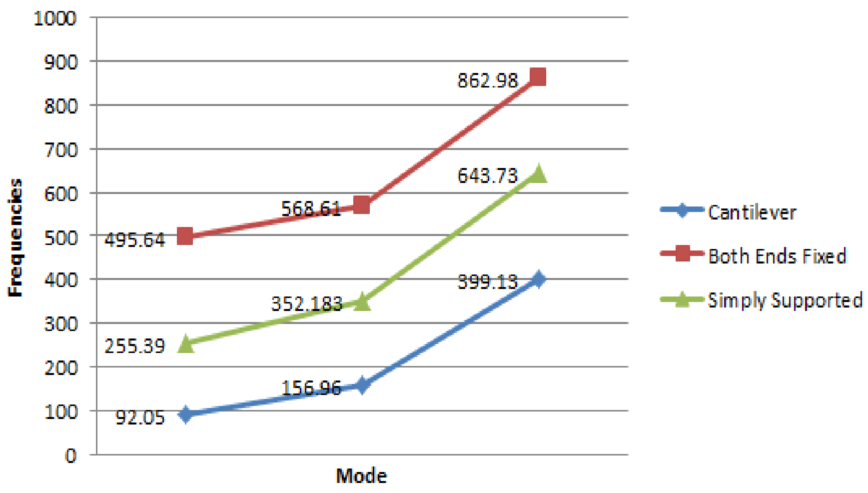

Figure 3. 5 Chart depicting fundamental frequency for a angle-ply composite laminated plate with a centrally positioned stiffener

Table 4 Comparison of the fundamental frequency for a composite plate with diagonal stiffeners made of cross-ply laminated materials (0/90/0/90/0/90/0).

Mode Number	Cantilever	Both Ends Fixed	Simply Supported
1	111.61	513.75	259.82
2	190.17	593.69	367.54
3	426.24	895.29	670.85

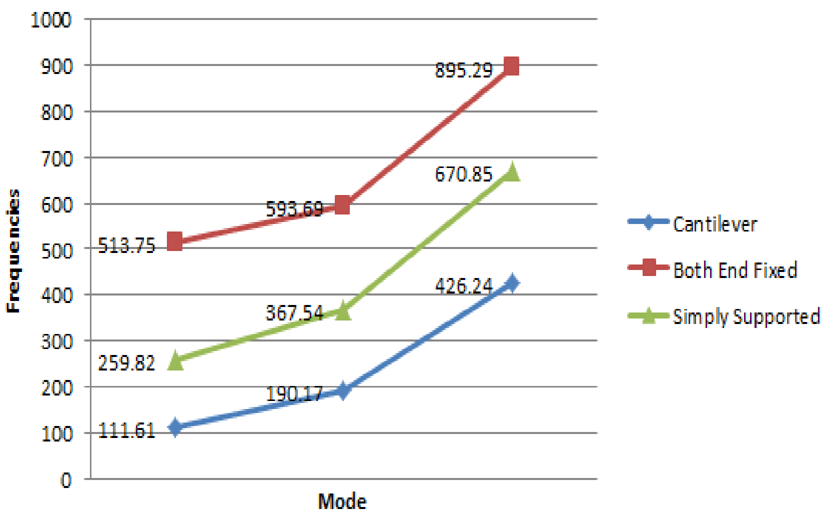

Figure 3. 6 The fundamental frequency of a cross-ply laminated composite plate with a diagonally positioned stiffener is shown in the graph.

In the graph, the fundamental frequencies of composite cross-ply plates with diagonal stiffeners are compared.. The different diagonal stiffener positions are represented by different colours in the chart. The chart clearly demonstrates the impact of shifting the location of the diagonal stiffener on the laminated composite plate's natural frequency.

Table 5 fundamental frequency of angle-ply laminated composite plate having diagonal stiffener (45/-45/45/-45/45/-45/45)

Mode Number	**Cantilever**	**Both Ends Fixed**	**Simply Supported**
1	107.65	507.68	266.86
2	182.03	579.36	377.01
3	413.94	888.02	697.32

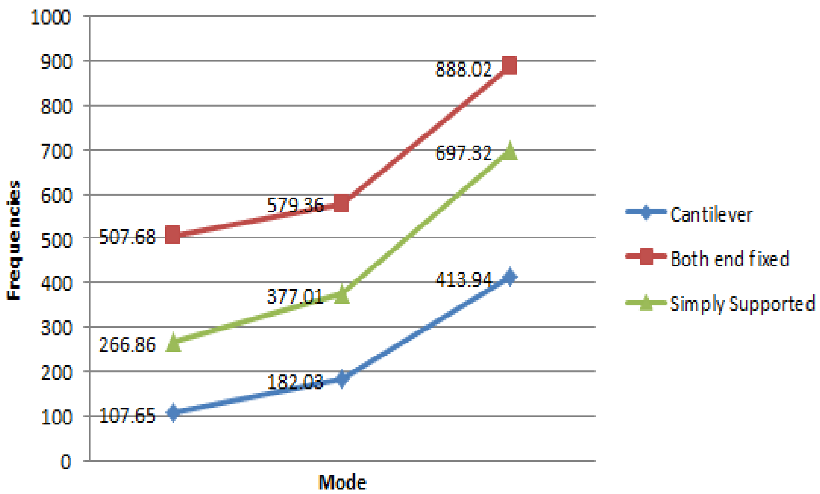

Figure 3. 7 The fundamental frequency of an angle-ply laminated composite plate with a diagonal stiffener is shown in the chart.

The fundamental frequency of composite plates made of angle-ply laminate and diagonal stiffeners is shown in a comparison chart. For plates with various stiffener orientation angles and locations, the frequencies are compared. The outcomes reveal how the stiffener affects the fundamental frequency of the composite plates with angle-ply orientation.

4 Results: In the current work, a laminated composite plate was subjected to a different boundary conditions, involving simply supported, clamped and both ends fixed, and a modal analysis was performed on the plate. The effects of these parameters were examined and discussed, yielding several results. Comparing the fundamental frequency of composite laminated plates reveals that the addition of stiffeners significantly raises the natural frequency at each mode. Furthermore, increasing the number of stiffeners resulted in higher values of natural frequencies. These results collectively imply that stiffeners can significantly improve the vibrational response of composite laminated plates.

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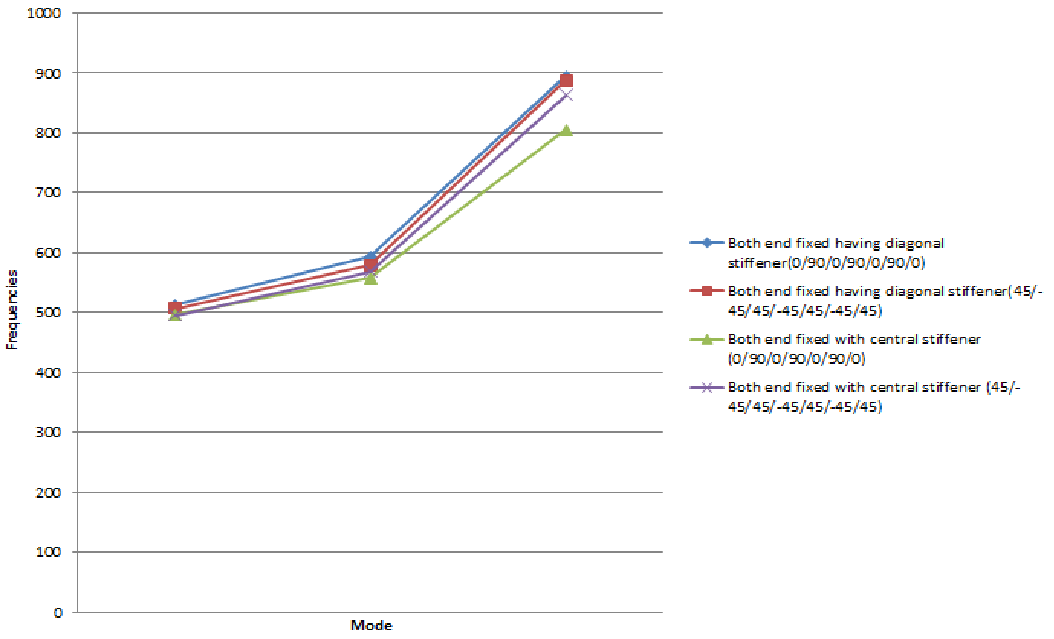

Figure 4. 1 Comparison of the fundamental frequency for cross-ply and angle-ply circumstances with different position stiffeners for laminated composite plates that are fixed at both ends.

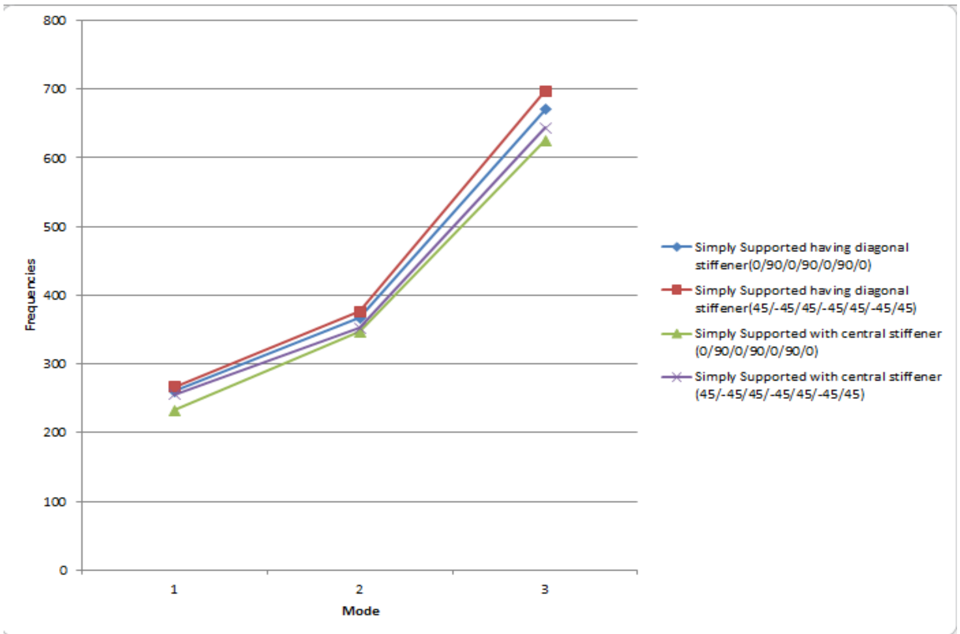

Figure 4. 2 Comparison of the fundamental frequency of cross-ply and angle-ply laminated composite plates under various stiffener position condition.

Conclusion: This paper presents a thorough analysis of the frequency response of laminated composite plates using commercially available software (ANSYS). The study examines laminated composite plates with various orientations and investigates the impacts of boundary conditions on their fundamental frequencies. The observed results demonstrate good concordance with those published in the literature for various positions and support settings. The study highlights that the introduction of stiffeners in the laminated composite plates leads to an increase in frequency and that the fundamental frequency of the composite laminated plate varies significantly at each mode with changes in the position of the stiffener. Additionally, the findings of the modal analysis show that the fundamental frequency response of cross-ply composite laminated plates are higher than those of angle-ply composite laminated plates, providing important new information about how thin to thick FGM plates behave.

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