Section: Research Paper
ISSN 2063-5346

Free vibration analysis of stiffened plates.

Prashant Kumar Choudhary[a]*

[a]Department of Mechanical Engineering, GMR Institute of Technology, Rajam, Andhra Pradesh, India. 532127

Email addresses: prashantkumarchoudhary01@gmail.com

DOI: 10.48047/ecb/2023.12.si4.1656

Abstract:

This paper presents the free vibration response of orthotropic stiffened plates structure. The free vibration analyses are performed for the orthotropic plates by using the commercial finite element software ANSYS Parametric Design Language (APDL). Numerical results obtained by the finite element method are compared with published results. For stiffened orthotropic plates, the effects of number, orientation, and types of stiffeners; aspect ratios of plates, and different fiber orientations on the fundamental natural frequency are presented for different boundary conditions. The present research shows that stiffened plates are superior to unstiffened plates and the frequency of the stiffened plate increases as the number of stiffeners increases Thus, the present paper highlights some important characteristics of an orthotropic plate with a stiffener that can be useful in the design of structures made of composite.

Keywords: Finite element method, orthotropic plates, Free vibration

1. Introduction

Many engineering applications employ structural elements like beam, plates and shell. To increase the overall structural performance, further stiffeners are commonly added to plate or shell structure [1]. Stiffened plate offer higher stiffness and specific strength compared to plate without stiffener *i.e* unstiffened plate. The stiffeners enable the plates to attain greater strength with relatively less material, which reduces the cost of the structure. Stiffened thin-walled plate structures are extensively used in aircraft’s fuselages, wings, pressure vessels, launch vehicles, re-entry vehicles, spacecrafts, bridge decks for avoiding large deflection etc., For example the main structural components of an aircraft's wings and fuselage are plates that are strengthened by longitudinal stringers and circumferential frames. [2].

Additionally, composite materials are increasingly being employed for load-bearing applications due to their similar advantages to stiffener, namely high strength-to-weight and stiffness-to-weight ratios. [3,4]. The features of both stiffened structures and composite materials can be obtained by combining the design approaches for using stiffened composite plates. It makes structures suitable in a variety of applications where low weight is a critical design, such as aircraft structures, wind turbine blades, maritime vessels, automotive structures, long-span roofs or floors in buildings, and contemporary bridge decks.

These structure is regularly subjected to various static or dynamic loads during operation. As a result, researchers have developed a great interest in the examination of stiffened plates under various loading conditions.. The stiffened shells typically support extremely dynamic loads in a variety of applications, which may cause excessive vibration. Therefore, it is crucial to examine their vibrational behaviour in order to prevent resonance damage, especially during the design phase**.** Hence, a proper study of free vibration is required for stiffened laminated plates. Therefore, the research on the vibration analysis of stiffened plates has very important practical significance**.** In this paper, the free vibration analysis of stiffened laminated plates is presented for isotropic and orthotropic materials..

2. Literature Review:

Vibration analysis of isotropic stiffened plates has been researched extensively by employing various method like numerical, analytical & semi-analytical. Various researchers [5, 6, 7, 8, 9, 10] used various models of the finite element method to examine the vibration analysis of isotropic stiffened plates (FEM). For the free vibration behaviour of stiffened plates, Aksu [11] combined the finite difference approach and the variational method. Mukhopadhyay [12] employed a semi-analytical finite difference method to analyse the vibration and stability behaviour of rectangular stiffened plates. Exact solutions were used by Xiang and Reddy [13] to study the vibration and buckling analyses of rectangular plates. A comparison of experimental and numerical studies of the fundamental frequency of rib-stiffened plates was provided by Olson and Hazell [14].

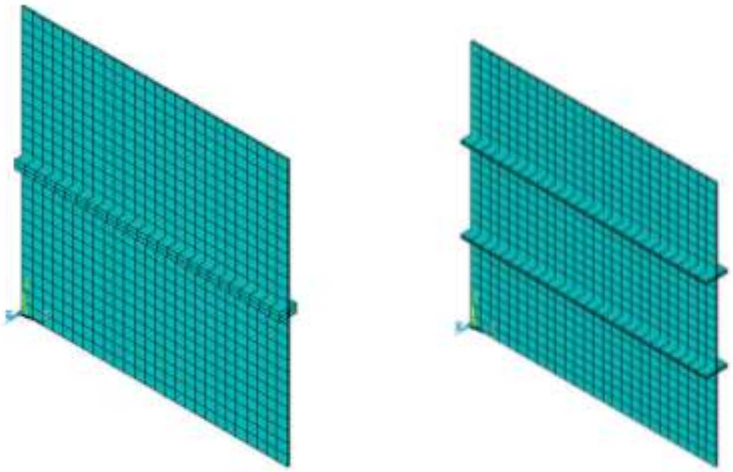
The focus of researchers has moved from isotropic stiffened plates to laminated composite ones in modern engineering applications.. For the free vibration analysis of stiffened composite plates and shells utilising first order shear deformation theory, FEM was employed by Chattopadhyay et al. [15], Rikards et al. [16], and Prusty and Ray [17]. For the free vibration analysis of laminated stiffened thin and thick plates, Chandrashekhar and Koli [18] developed a finite element model. Taking into account first order and higher order shear deformation theory, Bhar et al. [19] compared static and vibration analyses of stiffened plates. By combining a nine-node isoparametric plate/shell element with a three-node isoparametric curved beam element, Nayak and Bandyopadhyay [20] examined free vibration analysis of laminated stiffened shallow shells using FEM. Damnjanovic et al. [21] investigated the free vibration analysis of composite stiffened and cracked plates using the dynamic stiffness method. Qing et al. [22] developed a semi-analytical a mathematical model for analysing composite plates with stiffened under free vibration.

3. Finite element analysis:

In engineering and mathematical modelling, the finite element method (FEM) is a popular numerical technique for solving differential equations. The FEM procedure allows the structure to be discretized into a finite number of elements. The finite element analysis is perfomed using the the commercial FE code ANSYS software to determine the first natural frequency of the orthotropic plates. The four-noded SHELL 181 element, which has six degrees of freedom (translation along X, Y, and Z axes and rotation about X, Y, and Z axes) at each node, was used to generate the finite element model of the plate.. Beam 188 was used to model stiffeners.. The finite element model shown in Fig. 1. In order to improve accuracy, solution time, and stability, a convergence analysis with regard to mesh size was carried out. The element can analyse multilayer plates and shells that are thin and moderately thick. First Order Shear Deformation Theory is used as the basis for the finite element analysis of plates. The free vibration of equation of the system is:

3.1 Validation study:

In this subsection, we validated our finite element (FE) result in ANSYS with some published result. A square plate with two stiffener is considered. The plate and stiffener are made of same materials. The Young's modulus of elasticity is 68.9 GPa , Poisson's ratio is 0.3, and density is 2670 kg/m3. The geometric model of the stiffened plate is shown in Fig 2. The geometry and the material properties are as follows: *a*=0.2032 m, thickness of plate (*t*) = 0.00127 m, height (*h*) and width (*w*) of stiffener is 0.01778 m and 0.002286 m respectively. Distance of both stiffener is *l*= 0.06773 m. Table 1 compares the results by the present method and those presented by Olson and Hazell [14]. The FEM result using ANSYS is in an good agreement with the published results. It should also be noted that the natural frequencies obtained using the present method are lower than those obtained by Olson and Hazell [14].



(a) **(b)**

Fig. 1**.** The Finite element meshed model of stiffened plate. (a) Single stiffened (b) Double stiffened

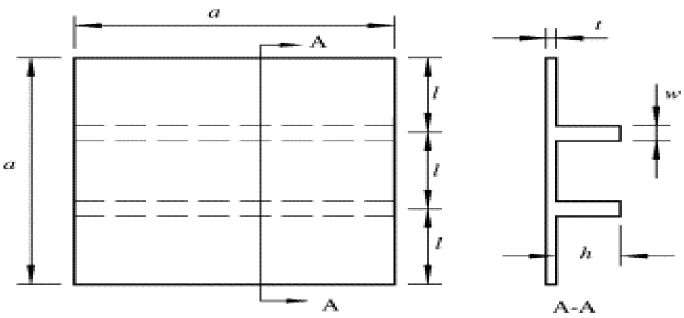
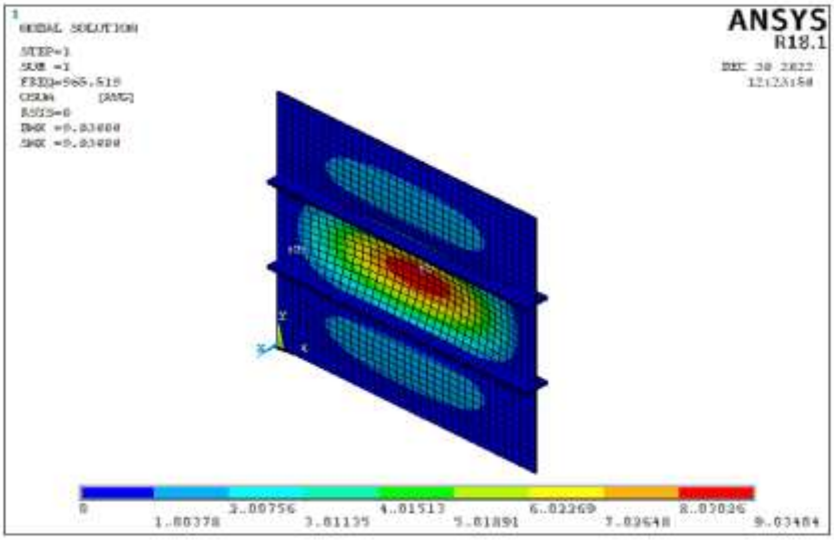


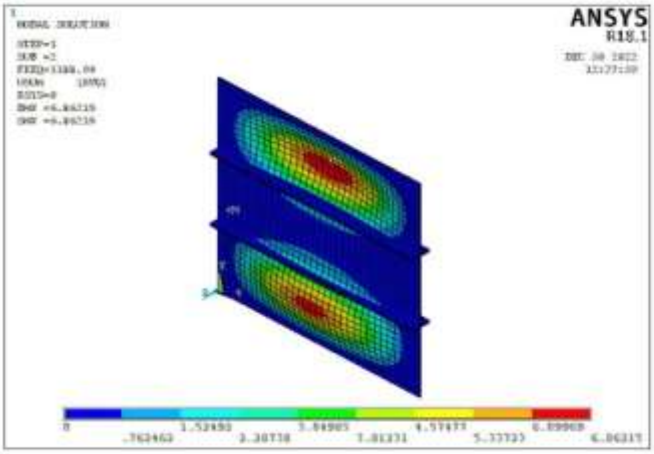
Fig. 2. An plate with double stiffeners

Table 1. Natural frequencies (Hz) of the double stiffened plate with all edges clamped.

Mode	Ref [14]	Present study (ANSYS)
1	965.3	965.5
2	1272.3	1188.9
3	1364.3	1192.4
4	1418.1	1392



(a)



(b)

Fig 3: Mode shape of stiffened plate: (a) First mode (b) Second mode

The second validation is a square isotropic plate with single stiffener located at the centre. The stiffened plate is clamped on all edges. The geometry and the material properties are as same as above. The comparison of the results of the present study and the published results is given in Table 2. The first four natural frequencies from the present study are compared with the result of Olson and Hazell [14]. It is clear from the comparison in Table 2 that the present investigation produced an excellent agreement with the available literature, with a maximum discrepancy of less than 2-3%.

Table 2. Natural frequencies (Hz) of the single stiffened plate with all edges clamped

Mode	Ref [14] (FEM)	Ref [14] (Experimental)	Present study (Ansys)
1	718.1	689	712.08
2	751.4	725	719.6
3	997.4	961	994.53
4	1007.1	986	1001.4

4. Results and discussions:

4.1 Comparison of free vibration analysis of stiffened and unstiffened plate:

In this subsection, we considered a rectangular plate with a central stiffener and without a stiffener. The geometric model of the stiffened plate is shown in Fig 2. Table 3 shows the comparison of first natural frequencies of the stiffened and unstiffened plate. The results show that the frequencies of the stiffened plate are clearly higher than those of the unstiffened plate, implying that the stiffener has a restriction effect.. The natural frequency for all edges clamped boundary condition give maximum frequency.

Table 3. Frequencies (Hz) of the plate with stiffener and without stiffener for all edge clamped.

Boundary condition	Stiffened plate	Unstiffened plate	% increase
C-C-C-C	965.5	271.1	256
S-S-S-S	552.9	148.5	272

4.2 Laminated composite stiffened plate stiffener

A square laminated plate with stiffener is considered. All edges of the plate are simply supported. [90/0/90] laminates were used. It is expected that the plate and stiffener are made of the same material (graphite/epoxy). The lamina properties for composite material (glass-epoxy) taken from reference [8] are as follows: E_1 = 132.38 GPa, E_2 = 10.76 GPa, G_{12} = G_{13} = 5.65 GPa, G_{23} = 3.38 GPa, ν_{12}= ν_{23}= ν_{31}= 0.24. This study takes into account two boundary conditions: (i) simply-supported at all edges (SSSS) and (ii) clamped at all edges (CCCC). For the plate, the layers/plies are assumed to be of same thickness. Table 4 and Table 5 are the natural frequency of orthotopic plate with double stiffener for Simply-supported at all endges (SSSS), and (ii) Clamped at all edges (CCCC) boundary conditions.

Table 4. Natural frequencies (Hz) of the double stiffened orthotropic plate with all edges clamped.

Mode	Present study (Ansys)
1	927.8
2	1078.2
3	1223.5
4	1297.2

Table 5. Natural frequencies (Hz) of the double stiffened orthotropic plate with simply supported boundary condition.

Mode	Present study (Ansys)
1	671.52
2	693.08
3	764.38
4	847.47

5. Conclusions:

The current investigations lead to the following conclusion:

1. As the number of stiffeners increases, the natural frequencies of the stiffened laminated plates increase.
2. The natural frequency of stiffened plate depends on the boundary condition. The enhancement in frequency is greatest for all edge clamped boundary conditions.
3. The natural frequency of stiffened plate increases on comparing with unstiffened plate.

The free vibration behaviour of laminated orthotropic stiffened plates is revealed in this parametric analysis., which will be useful in the primary selection of the stiffener number and boundary conditions of the plate.

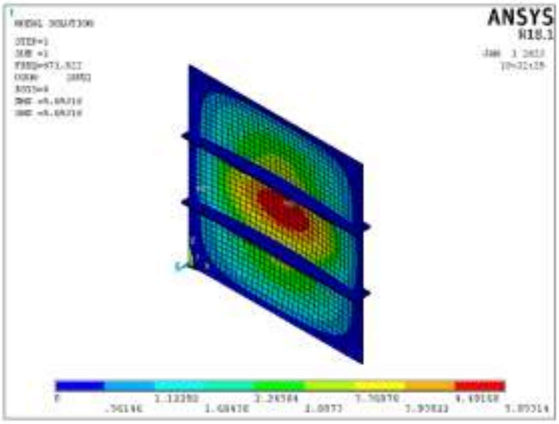


Fig 4: Mode shape of orthotropic laminated stiffened shell for all edge simply-supported

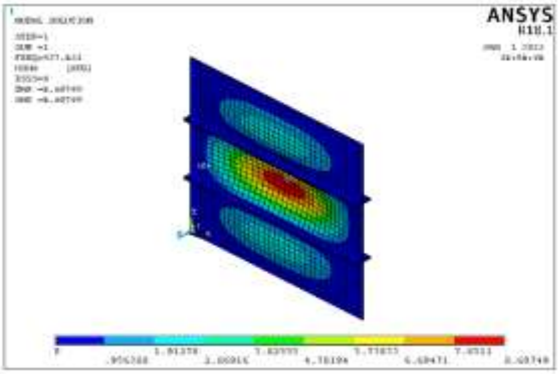


Fig 5: Mode shape of orthotropic laminated stiffened shell for all edge clamped

References.

1 Ye Y, Zhu W, Jiang J, Xu Q, Ke Y. Design and optimization of composite sub-stiffened panels. Composite Structures. 2020 May 15;240:112084.

2 Ye Y, Zhu W, Jiang J, Xu Q, Ke Y. Design and optimization of composite sub-stiffened panels. Composite Structures. 2020 May 15;240:112084.

3 Jones RM. Mechanics of composite materials. CRC press; 2018 Oct 8

4 Choudhary PK, Jana P. Position optimization of circular/elliptical cutout within an orthotropic rectangular plate for maximum buckling load. Steel and Composite Structures. 2018 Jan 1;29(1):39-51.

5 Mukherjee A, Mukhopadhyay M. Finite element free vibration of eccentrically stiffened plates. Computers & structures. 1988 Jan 1;30(6):1303-17..

6 Koko TS, Olson MD. Vibration analysis of stiffened plates by super elements. Journal of Sound and Vibration. 1992 Oct 8;158(1):149-67.

7 Harik IE, Guo M. Finite element analysis of eccentrically stiffened plates in free vibration. Computers & structures. 1993 Dec 17;49(6):1007-15.

8 Chen CJ, Liu W, Chern SM. Vibration analysis of stiffened plates. Computers & structures. 1994 Feb 17;50(4):471-80.

9 Hamedani SJ, Khedmati MR, Azkat S. Vibration analysis of stiffened plates using finite element method. Latin American Journal of Solids and Structures. 2012;9:1-20.

10 Yadav D, Sharma A, Shivhare V. Free vibration analysis of isotropic plate with stiffeners using finite element method. Engineering Solid Mechanics. 2015;3(3):167-76..

11 Aksu G, Ali R. Free vibration analysis of stiffened plates using finite difference method. Journal of sound and vibration. 1976 Sep 8;48(1):15-25.

12 Mukhopadhyay M. Vibration and stability analysis of stiffened plates by semi-analytic finite difference method, part I: consideration of bending displacements only. Journal of sound and vibration. 1989 Apr 8;130(1):27-39.

13 Xiang Y, Reddy JN. Buckling and vibration of stepped, symmetric cross-ply laminated rectangular plates. International journal of structural stability and dynamics. 2001 Sep;1(03):385-408.

14 Olson MD, Hazell CR. Vibration studies on some integral rib-stiffened plates. Journal of Sound and Vibration. 1977 Jan 8;50(1):43-61.

15 Chattopadhyay B, Sinha PK, Mukhopadhyay M. Finite element free vibration analysis of eccentrically stiffened composite plates. Journal of reinforced plastics and composites. 1992 Sep;11(9):1003-34.

16 Rikards R, Chate A, Ozolinsh O. Analysis for buckling and vibrations of composite stiffened shells and plates. Composite structures. 2001 Apr 1;51(4):361-70.

17 Prusty BG, Ray C. Free vibration analysis of composite hat-stiffened panels by method of finite elements. Journal of reinforced plastics and composites. 2004 Mar;23(5):533-47.

18 Chandrashekhara K, Kolli M. Free vibration of eccentrically stiffened laminated plates. Journal of reinforced plastics and composites. 1997 Jul;16(10):884-902.

19 Bhar A, Phoenix SS, Satsangi SK. Finite element analysis of laminated composite stiffened plates using FSDT and HSDT: A comparative perspective. Composite Structures. 2010 Jan 1;92(2):312-21..

20 Nayak AN, Bandyopadhyay JN. Free vibration analysis of laminated stiffened shells. Journal of engineering mechanics. 2005 Jan;131(1):100-5.

21 Damnjanović E, Marjanović M, Nefovska-Danilović M. Free vibration analysis of stiffened and cracked laminated composite plate assemblies using shear-deformable dynamic stiffness elements. Composite Structures. 2017 Nov 15;180:723-40..

22 Qing G, Qiu J, Liu Y. Free vibration analysis of stiffened laminated plates. International Journal of Solids and Structures. 2006 Mar 1;43(6):1357-71.