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Influence of Stiffeners on the Natural Frequencies of Rectangular Plate with Simply Supported Edges

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Abstract

The work presented here is the study of vibrational behavior of rectangular plate with angle shaped stiffeners. The rectangular thin plate is considered and its natural frequencies are simulated by modal analysis using FEA software. The analysis is performed by simply supporting all the edges of the plate. The rigid coupling condition is assumed between the plate and stiffeners. The modal analysis is performed for different thickness and angles of stiffeners. In all the previous work the plate with rib stiffeners and beams having rectangular cross section was considered, here the analysis is performed for the rectangular plates with angle shaped stiffeners.

Keywords: Rectangular plate; Stiffeners; Simply supported; Dynamic analysis; Vibration analysis; Modal analysis; FEA.

1. Introduction

The structures finds a variety of engineering application in which they are subjected to dynamic loads which are periodic in nature, as a response to such loads the structures vibrate. In the dynamic service conditions if the operating frequency of loading meets the natural frequency of the system the resonance occurs and structure fails irrespective of its strength. This means the static design is not sufficient and design for vibration becomes necessary to ensure safety of the structure under service. Vibration also creates detrimental effect on relevant structures, human being and creates annoying noise. It is not possible to completely avoid such vibration however its harmful effects can be mitigated, so design for vibration involves keeping operating frequency of loading away from natural frequencies of the structure and minimizing displacement, velocity and acceleration of vibrating structure within permissible limits. One of the ways to achieve the desired dynamic characteristics is the structural modification by tuning the stiffness, mass and damping of the structure.

Plates reinforced by stiffeners represent a class of structural components that are widely used in many engineering applications such as ship decks, bridges, Automobile super structure, Aircraft, industrial structures and buildings etc. Addition of stiffener significantly affects the dynamic characteristics of the plate hence it is of direct interest in structural designs.

Nomenclature

SSSS All edges of the plate are simply supported

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The fundamental research work related to free vibration analysis of the rectangular plate and plates with other geometry is well documented by Leissa W [1]. In his work the effect of plate's various boundary conditions on the modal parameters is studied and equations of natural frequency and mode shapes are given. The effect of Poisson's ratio and aspect ratio of the plate on natural frequencies was studied by Rossi *et al*. [2]. Manzanares B.*et al*.[3] carried out theoretical and experimental studies on the transverse vibration of rectangular plate with all edges free. They developed experimental technique using electromagnetic-acoustic transducer which is highly reliable for the lower normal modes.

Vibrations of stiffened plates have been extensively studied by many researchers using various analytical and numerical techniques, as comprehensively reviewed in Refs. [4-5]. Recently, Patel D.S. *et al*.[6] studied on the vibration of rectangular plate with angle shaped stiffeners. The effect of stiffeners on the natural frequency of plate for different boundary conditions and thickness of stiffeners are analysed. Luan Yu *et al*.[7] developed an improved smearing technique for modelling the vibration of cross stiffened thin rectangular plate. The smearing technique given by Szilard has inadequate accuracy of predicted natural frequencies whereas the improved smearing technique gives considerable accuracy comparatively. Hongan Xu *et al*. [8] presented an analytical method for the vibration analysis of plates reinforced by beams of arbitrary lengths and placement angles. The effects of various support conditions, general coupling conditions, and reinforcing arrangements with respect to the number, orientations, and lengths of attached beams on modal properties of combined system was studied. Dozio L.*et al*. [9] proposed analytical–numerical method for quick prediction of the modal characteristics of rectangular ribbed plates. The approach is suitable for low-frequency free vibration analysis of thin rectangular plates reinforced by a small number of light stiffeners. Zeng H.*et al*. [10] studied the vibration of rectangular stiffened plate by Differential Quadrature Method. The plate and the stiffeners are treated separately and their compatibility is modelled by their governing differential equations. Chen Z.*et al*.[11] studied the vibration localization in plates rib-stiffened in two orthogonal directions to see the effect of small misplacements of stiffeners, with various combinations of flexural and torsional rigidities, on both the free vibration and forced vibration responses of the plate. Holopainen T.P.*et al*. [12] proposed a new finite element model for free vibration analysis of eccentrically stiffened plates; using this model the mesh distortion does not have any significant effect on the accuracy of the results.

During the past decades, vibrations of stiffened plates have been extensively studied. Most of the previous research was directed toward the vibration analysis of the rectangular plates with rib stiffeners and beams having rectangular cross section but recently, Patel D.S. *et al*.[6] studied on the vibration of rectangular plate with angle shaped stiffeners. The analysis was performed for free and clamped boundary conditions. In the present work the analysis is performed on the rectangular plates with simply supported edges reinforced by angle shaped stiffeners.

2. Modeling of Plates

A thin rectangular plate is considered as shown in fig. 1(a) for the free vibration analysis of rectangular plate. The plate is assumed to follow the Classical Thin Plate Theory also known as the Kirchoff's Plate Theory which is fundamental theory to model thin plates. The plate has length along x direction, width along y direction and thickness along z direction, hence the plate is assumed to lie in the x-y plane. The plate has three independent displacements i.e. displacement along x, y and z directions. The rectangular plate with three angle shaped stiffeners is as shown in fig. 1(b). The stiffeners are lying on the plate such that length of the stiffeners is parallel to the width of the plate. The stiffeners and the plates are assumed

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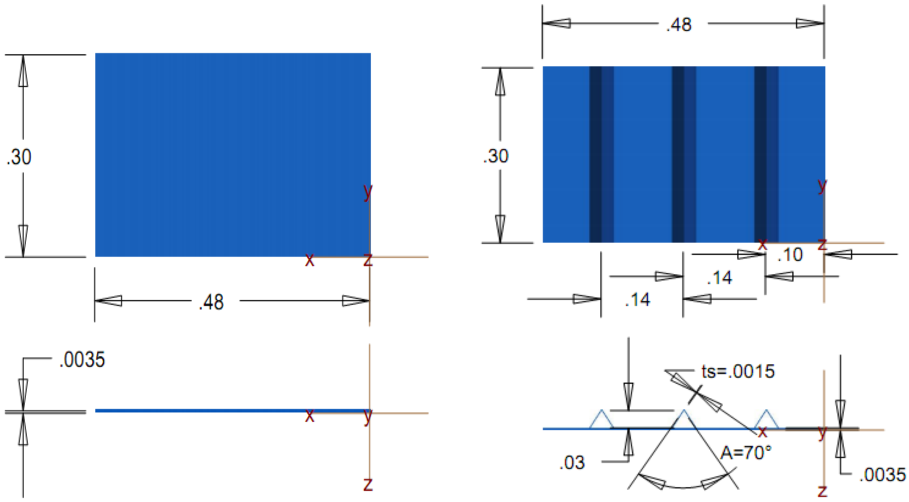
to have rigid coupling at their connecting interface. The stiffener has an angle A and thickness ts, both Angle of stiffener (A) and thickness of stiffener (ts) are considered as variables.



(a) (b)

Note: All dimensions are in m.

Fig.1. (a) Bare rectangular plate; (b) Rectangular plate with angle shaped stiffener

Table 1 Details of plates.

Plate No.	Base dimensions X × Y × Z (mm)	Angle of stiffener A (degree)	Thickness of stiffener ts (mm)	Material
1		Bare plate		
2		70	1.5	
3		70	2	
4		70	3	
5	480 × 300 × 3.5	90	1.5	Steel
6		90	2	
7		90	3	
8		120	1.5	
9		120	2	
10		120	3	

The plates which are considered for modal analysis are tabulated as shown in table 1. It is assumed that the plate and the stiffeners are made of the same material. The bare plate and the stiffened plates have following material characteristics;

- Material: Steel.
- Modulus of Elasticity: 2×10^{11} N/m^2.
- Poisson's ratio: 0.3.
- Density: 7800 kg/ m^3.

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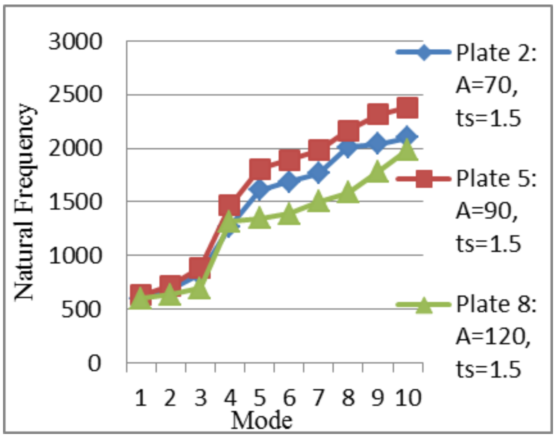
The finite element models of all the plates are generated in ANSYS software using the Solid45 element. This element is used for meshing the solid geometry; the element has eight nodes and three degree of freedom per each node. The meshed models are then used for FEA in ANSYS software. The modal analysis is performed by keeping all edges of the plate as simply supported; this set of boundary conditions is SSSS.

3. Results and discussions

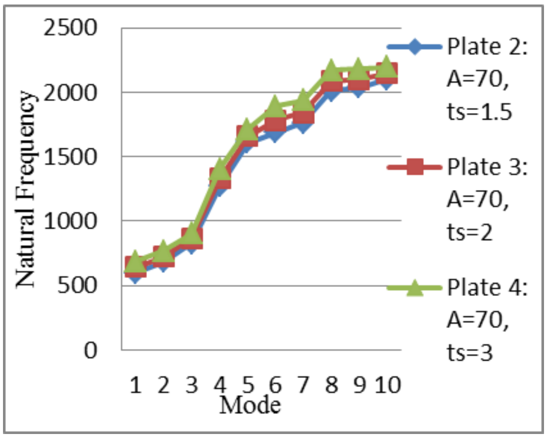
The modal analysis is performed on the bare plate and on the stiffened plates having all edges simply supported. The results of first ten modes and corresponding natural frequencies of all the ten plates having all edges simply supported (SSSS) are compared and shown in table 2.

Table 2 Comparison of Natural frequencies of all plates by FEA (SSSS)

ModE	Natural frequency (Hz.)									
	Plate 1	Plate 2	Plate 3	Plate 4	Plate 5	Plate 6	Plate 7	Plate 8	Plate 9	Plate 10
	Bare plate	A= 70 ts=1.5	A= 70 ts=2	A=70 ts=3	A= 90 ts=1.5	A=90 ts=2	A=90 ts=3	A=120 ts=1.5	A=120 ts=2	A=120 ts=3
1	131.05	598.36	641.22	689.74	630.09	674.86	725.56	601.23	645.66	705.91
2	244	682.33	722.59	766.69	722.07	763.17	808.08	637.92	689.14	774.47
3	417.72	829.94	865.05	900.08	889.47	924.58	958.78	696.72	762.07	898.16
4	436.89	1271.5	1330.4	1403.5	1469.6	1551	1652.8	1318.7	1424.8	1636.1
5	535.84	1608.7	1658.5	1713.8	1806.9	1875	1951.2	1350.1	1453.1	1651.7
6	716.93	1689.7	1783.5	1892.6	1890.1	2021.7	2177.8	1389.7	1491.3	1683.4
7	737.2	1763.5	1844.1	1938.8	1982.8	2108.2	2256.1	1502.5	1598	1733.8
8	906.65	2009.1	2084.7	2168.4	2166.9	2283.3	2414.3	1587.6	1669.3	1816.1
9	1029.2	2037.9	2102.4	2178.4	2315.2	2384.9	2460.5	1784.2	1844.7	2000.5
10	1033.8	2099.5	2147.2	2194.8	2382.8	2472.6	2581.8	1984.4	2106.2	2350.3



(a)



(b)

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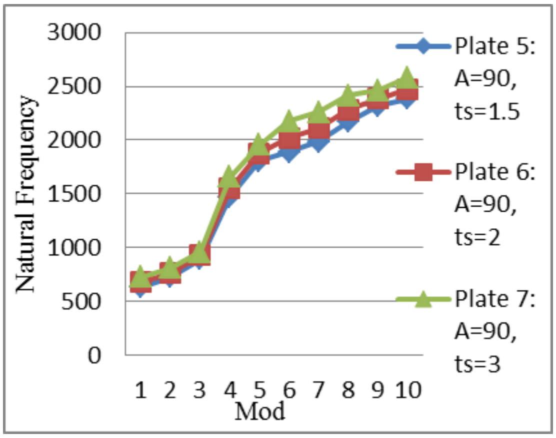
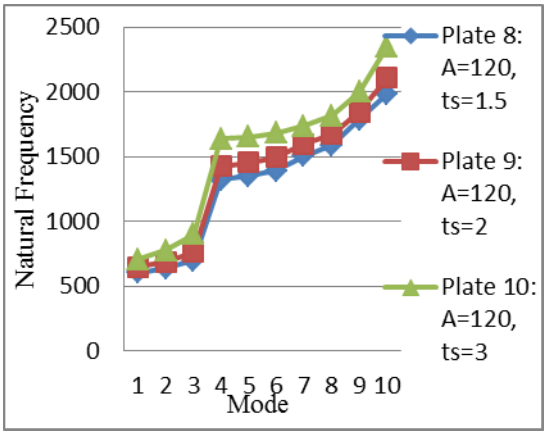


(c)



(d)

Fig.2. (a) Comparison of natural frequency of plate 2, 5 and 8 (SSSS); (b) Comparison of natural frequency of plate 2, 3 and 4 (SSSS); (c) Comparison of natural frequency of plate 5, 6 and 7 (SSSS); (d) Comparison of natural frequency of plate 8, 9 and 10 (SSSS)

It is observed that with addition of stiffener of any size the natural frequencies of the plate increases from that of the plate without stiffener.

The comparison of natural frequencies of the stiffened plates with 70°, 90° and 120° angle of stiffener and all edges simply supported (SSSS) is shown in fig. 2(a), it can be observed that plate with 90° angle of stiffener gives highest value of natural frequency for all modes.

The natural frequencies of the stiffened plates with 70° angle and 1.5, 2, 3 mm thick stiffeners having all edges simply supported (SSSS) is shown in fig. 2(b), comparing the results it can be observed that the stiffened plate with 3 mm thick stiffener gives highest value of natural frequencies.

Similar trend is observed in stiffened plate with 90° angle and 1.5, 2, 3 mm thick stiffeners as well as stiffened plate with 120° angle and 1.5, 2, 3 mm thick stiffeners having all edges simply supported (SSSS) as shown in fig. 2(c) and fig. 2(d) .

4. Conclusion

The vibration analysis of the bare plate and stiffened plates is performed keeping all the edges of the plate as simply supported. The results of the analysis give the following noteworthy information on vibration of stiffened plates.

1. Addition of the stiffener to the plate has an effect of shifting natural frequencies of the plate towards higher side.
2. The increasing angle of stiffener does not necessarily increase the value of the natural frequency, out of three angle shaped stiffener 70°, 90°, 120°; the 90° angle shaped stiffener gives the highest value in natural frequency for simply supported boundary condition.
3. The increasing thickness of the stiffener increases the natural frequencies of the plate for all the boundary conditions.

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