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Investigations on Deformation and Stress Pattern of Plates with Various Types of Stiffeners

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Abstract: This research work aims to investigate the deformation and stress pattern of plates with various types of stiffeners. The analysis has been carried out using Finite Element Analysis. ANSYS software has been used. Structures consisting of thin plates stiffened by a system of ribs have found wide application for aircraft, ships, bridges, and buildings as well as in many other branches of contemporary structural engineering. The analytical investigations of stiffened plates are rarely found in literature; hence it is found apt to carry out such investigations to provide design recommendations. The finite element analysis has been carried out for an isotropic rectangular plate by considering the master element as a shell 3D 4node 181 element and beam 2node 188 as a stiffener. Comparison has been done between the results obtained from ANSYS simulation and theoretical procedure to verify the approach. During the analysis the optimal thickness, loading and boundary conditions of the plate are kept constant and the cross section of the stiffener was varied. Effectiveness of various cross section of stiffeners were studied.
Keywords: Finite Element Analysis (FEA), Isotropic rectangular plate, Stiffener and ANSYS.

I. INTRODUCTION

Man has always been inspired from the nature be it art or engineering. Perhaps one of the derivatives of such inspiration is stiffened engineering structures. Sea shells, leaves, trees, vegetables all of these are in fact stiffened structures. Observations of structures created by nature indicate that in most cases strength and rigidity depend not only on the material but also upon its form. This fact was probably noticed long ago by some shrewd observers and resulted in the creation of artificial structural elements having high bearing capacity mainly due to their form such as girders, arches and shells. Stiffened plates are extensively used as structural components in naval and offshore industry. These stiffened elements, representing a relatively small part of total weight of the structures, substantially influence their strength, stiffness and stability. The plates used in ship structure are of very thin dimension subjected to very high compressive loading include the passenger crew, machines and other combinations of dead load and live load. To increase the stability of the plates and to withstand the stress and deformations developed it is not possible to increase the thickness of the plates. Instead of increasing the thickness of plates and thereby increasing the cost of materials, stiffeners are provided. These stiffener elements presenting relatively small part of the weight of the structure substantially influence the strength of the structure under different loading conditions. It is assumed that stiffener will have the same displacement as that of plating. The stiffeners can be positioned anywhere within the plate element and need not necessarily be placed on nodal lines as the stiffness matrix of a stiffened plate element is comprised of the contributions of the plate element and that of a stiffener element. The stability of stiffened plate is determined from the arrangement and the loading conditions on the plates.

The biggest advantage of the stiffeners is the increased bending stiffness of the structure with a minimum of additional material, which makes these structures highly desirable for loads and destabilizing compressive loads. Stiffeners in a stiffened plate make it possible to sustain highly directional loads, and introduce multiple load paths which may provide protection against damage and crack growth under the compressive and tensile loads. In addition to the advantages already in using them, there should be no doubt that stiffened plates designed with different techniques bring many benefits like reduction in material usage, cost, better performance, etc.

II. REVIEW OF LITERATURE

Vanam et al[1] worked on the Static analysis of an isotropic rectangular plate using finte element analysis. The analysis has been prtformed by considering a four noded rectangular element as a basic geometric shape. During the analysis, plate thick varies from 0.01 to 0.18m, under different load conditions and different boundary conditions. Later for the same structure and load/boundary conditions, analysis has been performed using analysis software ANSYS. The results obtained from FEA and ANSYS have been compared with exact solutions, which are calculated from Kirchhoff plate theory. From the numerical results, it is observed that structure obtains better results at the thickness of 0.065m. Analysis results showed that the results obtained from FEA and ANSYS are closely converging to the results obtained from exact solutions.

Dr Alice Mathai et al[2] have worked on Finite element buckling analysis of stiffened plate and they compared the buckling load factor values between the discrete stiffener modeling and rigorous modeling. The results obtained from rigorous analysis fall on the safer side and this modeling considered as more accurate, but the memory space required for discrete analysis are minimum and these are effectively used for the analysis of complex structures.

Anupama B.M et al[3] have done Analysis of Stiffened plate using FE Approach to study the strengthening effect of the stiffeners on the buckling of unperforated and perforated plate when they are reinforced in longitudinal and traverse direction. They concluded that the influence of central transverse stiffener on unperforated plate is less when compared to central longitudinal stiffener and the plate with stiffener possessing four times higher strength than unstiffened plate.

C A Featherston and C Ruiz[4] have studied the buckling of flat plates under bending and shear. They have compared collapse loads predicted by theoretical, experimental and finite element analysis predicted collapse loads for the case of a flat rectangular plate under combined shear and bending. The plate is subjected to in plane uniform uniaxial end compression load having simply supported plate boundary condition. The parameters considered are plate aspect ratio and types of stiffeners. The analysis has been carried out using ANSYS finite element software. The buckling of a plate under shear and bending is sensitive to imperfections such as misalignment and curvature of the plate and the load carrying capacity of a plate under shear and bending is not severely affected by buckling. It should not therefore cause catastrophic failure.

A.K.L.Srivastava et al[5] have carried out the dynamical Analysis of stiffened plates under patch loading. The vibration characteristics are discussed and the results have been compared with those available in the literature. Buckling and vibration behavior of the stiffened plates with/without cutout is greatly influenced by the stiffener parameters, the type and position of loads. So the designer has to be cautious while dealing with structures subjected to non- uniform loading. This can be used to the advantage of tailoring during design of stiffened plate structures.

III. PROBLEM FORMULATION

In literature, for flat plate with stiffener there are no formulae available. By using Euler- Bernoulli's beam theory and Kirchoff's plate theory we can find the plate and beam deflection values individually. So, that these theoretical results will be compared with the numerical results from ANSYS software. If the theoretical and numerical results were same then we can extend our work to plates with stiffeners numerically.

Table 3.1. Materil properties of beam and plate

Section/Parameter	Young's Modulus(N/m^2)	Poisson's ratio
Plate	$2*10^{11}$	0.3
Beam	$2*10^{11}$	0.3

Table 3.2.Geometrical properties of plate

Section/Parameter	Length(m)	Width(m)	Thickness (m)
Plate	1	1	0.006

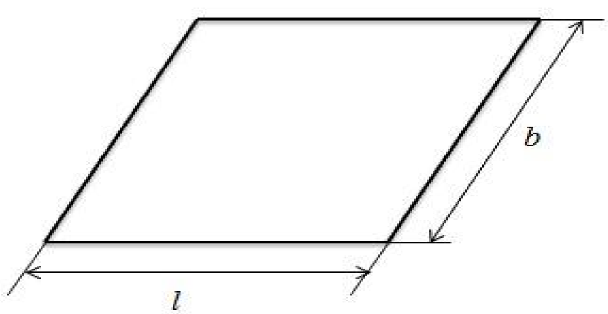

Figure 3.1. Rectangular plate with uniform pressure (4 edges simply supported)

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Table 3.5. Geometrical properties of beam(solid rectangle):

Section/Parameter	Length(l)(m)	Width(b)(m)	Depth(h)(m)
Beam	1	0.00596	0.075

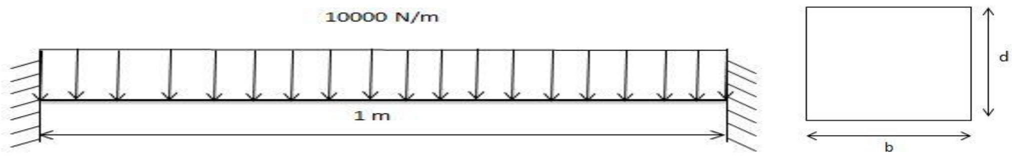

Figure 3.2. Solid rectangular section beam carrying UDL (fixed at both edges)

IV. THEORETICAL APPROACH

BEAM: Beam is a structural element which is capable of sustaining load by bending. The bending phenomenon is included into the material of beam as a result of external loads. Beams are usually used for buildings or civil engineering structures but smaller frames like truck or automobile. Machine and mechanical systems also contain beam structures. A thin walled beam is a very important type of beam. The cross section of thin walled beams is made up from thin panels connected among together to form closed or open cross sections of a beam. Typical closed sections include round, square, and rectangular tubes. Open sections include I-beams, T-beams, L-beams, etc. thin walled beams preferably exist because their bending stiffness per unit cross sectional area is higher than that for solid cross sections such a rod or bar. In this way, stiffness in beams can be achieved with minimum weight.

A. *Euler- Bernoulli's Beam Theory*

Moment of inertia equation in bending moment, $M = EI\frac{d^2w(x)}{dx^2}$

The maximum deflection occurs at the center of the beam and its value is given by, $\boldsymbol{y_{max}} = \frac{\boldsymbol{w.l^4}}{\boldsymbol{384EI}}$

Where, w = load per unit length; l = length of the beam; EI = flexural rigidity; E = modulus of elasticity; I = area moment of inertia of the cross-section about the neutral axis

1) *Plate:* When a body is bounded by surfaces, flat is geometry, whose lateral dimensions are large compared to the separation between the surfaces is called a plate or simply it is a structural member whose middle surface lies in a plane. Plates are subjected to transverse loads where loads normal to its mid-surface. Transverse loads supported by combined bending and shear action. Plates may be subjected to in-plane loading. Plate bending where plate's mid-surface doesn't experience appreciable stretching or contraction but, whereas the in-plane loads cause stretching and/or contraction of mid-surface. In plates the thickness is normal to mid-surface plane and is relatively small to length and width. Thickness may be constant or variable.

B. *Kirchoff's Classical Plate Theory*

Deflection of a rectangular plate(for uniformly distributed load), $w_{max} = C(1-\vartheta^2)\left(\frac{pb^4}{Eh^3}\right)$

Where, $C = \frac{0.16}{1+2.4\propto^3}$; $\propto = {}^{b}/_{a}$; b = length of the short edge; a = length of long edge; E = Young's modulus; p = applied pressure per unit area; h = thickness of the rectangular plate; ϑ = poisson's ratio

S.No.	Type of support	Value of C at maximum deflection for $w_{max} = C(1-\vartheta^2)\left(\frac{pb^4}{Eh^3}\right)$
1	Rectangular slab, Four edges simply supported	$C = \frac{0.16}{1+2.4\propto^3}$
2	Rectangular slab, span b fixed, span a simply supported	$C = \frac{0.032}{1+0.4\propto^3}$
3	Rectangular slab, span a fixed, span b simply supported	$C = \frac{0.16}{1+\propto^2+5\propto^4}$
4	Rectangular slab, all edges fixed	$C = \frac{0.032}{1+\propto^4}$

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C. Frequency and Stress Analysis

For flat plate with fixed edges, Natural frequency, $f = \frac{\lambda}{a^2}\sqrt{\frac{Et^2}{12\rho(1-\vartheta^2)}}$

Where, $\lambda = 1.57\sqrt{(5.14 + 3.13\mu^2 + 5.14\mu^4)}$; μ = a/b; a, b = length and width of the plate; ϑ = poisson's ratio; E = young's modulus; t = thickness of the plate; ρ = density

For flat plate with simply supported along each edge, Stress at the center of the plate, $\sigma = \frac{0.75*a^2*p}{t^2*(1+1.61*\frac{a^3}{b^3})}$

Where, a, b = width and length of the plate; t = thickness of the plate; p = applied pressure

1) *Buckling Load Factor:* The buckling load factor (BLF) is an indicator of the factor of safety against buckling or the ratio of the buckling loads to the currently applied loads. When the structure is subjected to compressive stress, buckling may occur. Buckling is characterized by a sudden sideways deflection of a structural member. This may occur even though the stresses that develop in structure are well below those needed to cause failure of the material of which the structure is composed. As an applied load is increased on the member, such a column, it will ultimately become large enough to cause the member to become unstable and it is said to have buckled. Further loading will cause significant and somewhat unpredictable deformations, possibly leading to complete loss of the member's load carrying capacity. If the deformations that occur after buckling do not cause the complete collapse of that member, the member will continue to support the load that caused it to buckle. If the buckled member is part of a larger assemblage of components such as building, any load applied to the buckled part of the structure beyond that which caused the member to buckle will be redistributed within the structure.

$$\text{Buckling load factor} = \frac{\text{buckling pressure}}{\text{applied pressure}}$$

Close form formulae are not available in literature for buckling of plates. So, the numerical formulation for buckling of plates has been considered.

V. NUMERICAL APPROACH (FEM)

A. Finite Element Analysis Using Ansys

Finite element analysis (FEA) is a powerful computational technique used for solving engineering problems having complex geometries that are subjected to general boundary conditions. While the analysis is being carried out, the field variables are varied from point to point, thus possessing an infinite number of solutions in the domain. So, the problem is quite complex. To overcome this difficulty FEA is used; the system is discretized into a finite number of parts known as elements by expressing the unknown field variable in terms of the assumed approximating functions within each element. These functions are, included in terms of field variables at specific points referred to as nodes. Nodes are usually located along the element boundaries, and they connect adjacent elements. Because of its flexibility in ability to discretize the irregular domains with finite elements this method has been used as a practical analysis tool for solving problems in various engineering disciplines.

B. Ansys Analysis

Finite element analysis software ANSYS is a capable way to analyze a wide range of different problems. ANSYS can also solve various problems such as elasticity, fluid flow, heat transfer and electro magnetism. Beside those, it can also do non-linear and transient analysis. ANSYS analysis has the following steps for problem solving:

D. Stiffener (Beam188)

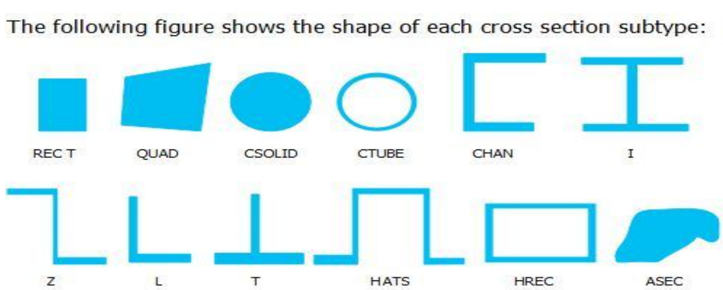

Figure 5.1. Types of cross-sections in beam188

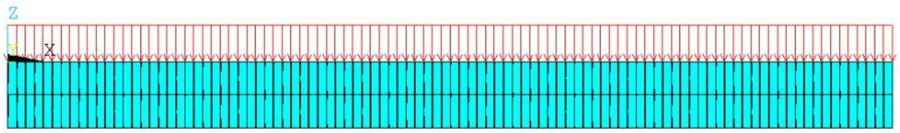

Figure 5.2. Solid rectangular beam carrying 10,000 N/m UDL

Table 5.1. Deformation and stress variation of beam carrying 10,000 N/m UDL for different cross sections

S.No.	Section Type	Deformation (mm)	Minimum Stress (N/mm^2)	Maximum Stress (N/mm^2)
1	Rev T-section	0.555	0.541504	150
2	L –Section	1.21	0.379214	198
3	I-Section	0.409	$0.239*10^{-9}$	77.1
4	Hollow Circle	0.509	$0.291*10^{-15}$	102
5	Hollow Rectangle	0.452	$0.158*10^{-10}$	91.5
6	Z-Section	1.366	0.129708	189
7	Solid Rectangle	0.664	$0.758*10^{-16}$	145
8	C-Section	9.059	0.0248	292
9	T-Section	0.555	0.541504	150
10	Hat Section	0.457	0.995260	103
11	Solid Circle	8.237	-	607

E. Plate(shell181

Table 5.2. numerical values of plate without stiffener

	Deformation	Stress at center of the plate	Frequency
Flat plate with Simply supported edges	51.498 mm	400 N/mm^2	-
Flat plate with fixed edges	-	-	55.646 Hz

F. Plate (stiffened plate

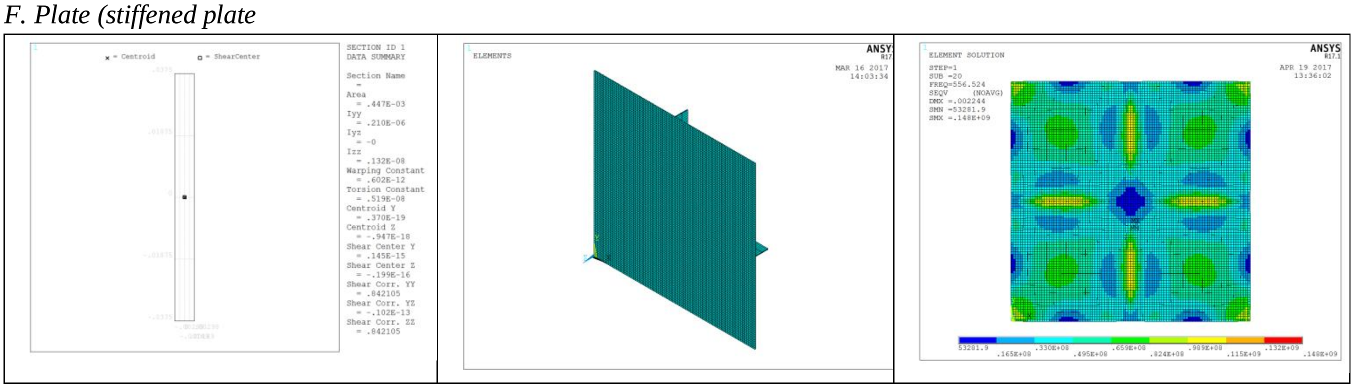

Figure 5.3. Plate with solid rectangular stiffener

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Poisson's ratio = 0.3; Young's modulus = $2*10^{11}$N/m^2 ; Pressure on area = 50,000 N/m^2; Density = 7800 kg/m^3; Thickness of the plate = 0.006m; Length of the plate = 1m; Width of the plate = 1m; depth of stiffener = 75mm; flange length is 40-50mm; thickness is 3-4mm; area of the stiffener is 447 mm^2.

VI. RESULTS AND DISCUSSIONS

Table 6.1. Comparison of numerical and theoretical results of plate

S.No.	Parameter	ANSYS	Theoretical
1	DEFORMATION (simply supported edges)	51.498 mm	49.56427mm
2	STRESS at center (simply supported edges)	400 N/mm^2	399.106 N/mm^2
3	Natural frequency (fixed edges)	52.646 Hz	52.933182 Hz

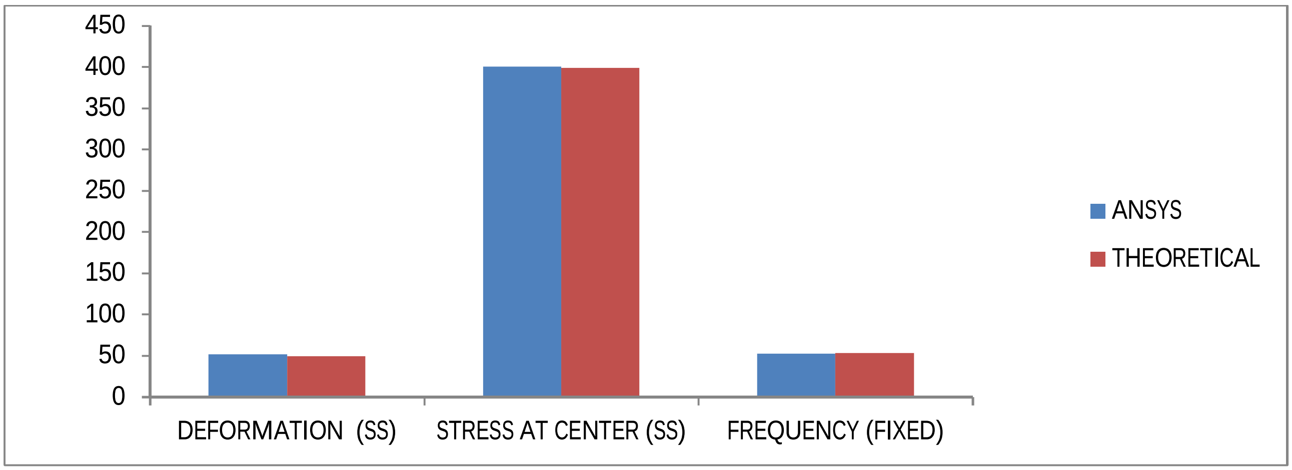

Figure 6.1. comparison between numerical and theoretical results of plate

From the Figure 6.1. it is observed that, for the flat plate with simply supported edges, the analytical and theoretical results of deformation, stress at center and natural frequency were nearly equal. For the flat plate with fixed edges, the natural frequency values of theoretical and analytical results were also compared.

Table 6.2. Comparison of numerical and theoretical results of beam

S.No.	Section Type	Deformation(mm) [ANSYS]	Deformation(mm) [Theoretical]
1	Rev T-section	0.555	0.49
2	I-Section	0.409	0.3304
3	Hollow Circle	0.509	0.4347
4	Hollow Rectangle	0.452	0.39206
5	Solid Rectangle	0.664	0.6198
6	T-Section	0.555	0.49
7	Hat Section	0.457	0.3959
8	Solid Circle	8.237	8.1595
9	L –Section	1.21	0.49
10	Z-Section	1.366	0.3304
11	C-Section	9.059	0.33045

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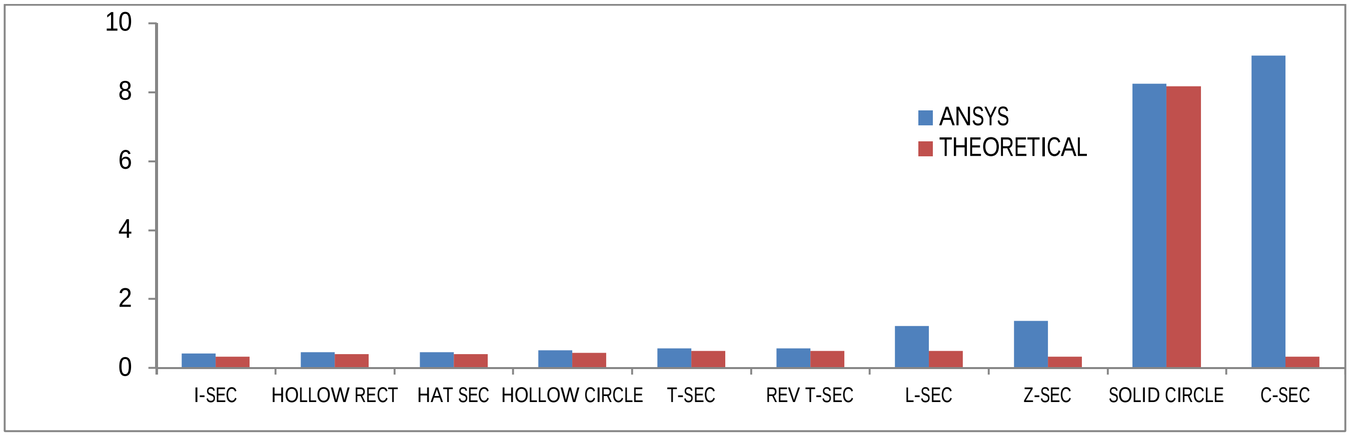

Figure 6.2. comparison between analytical theoretical results of beam with fixed ends

From the Figure 6.2. it is observed that the theoretical and numerical results of the beam for the values of moment of inertia with both ends fixed were observed to be same. For the values of deformation it is observed that the results were matched for some sections. But for L, Z, and C sections there observed a lot of variation, which will be investigated further.

Table 6.3. Deformation and stress variation of plate with various types of stiffeners

S.No.	Section Type	Deformation (mm)	Minimum Stress (N/mm^2)	Maximum Stress (N/mm^2)
1	Rev T-section	2.08	0.0946461	116
2	L -Section	2.151	0.533518	225
3	I-Section	2.181	0.0717288	123
4	Hollow Circle	2.218	0.0161665	135
5	Hollow Rectangle	2.222	0.0505563	179
6	Z-Section	2.236	0.105693	196
7	Solid Rectangle	2.244	0.0532813	148
8	C-Section	2.362	0.0740555	234
9	T-Section	2.493	0.281365	217
10	Hat Section	2.647	1.99	337
11	Solid Circle	7.843	2.33	362

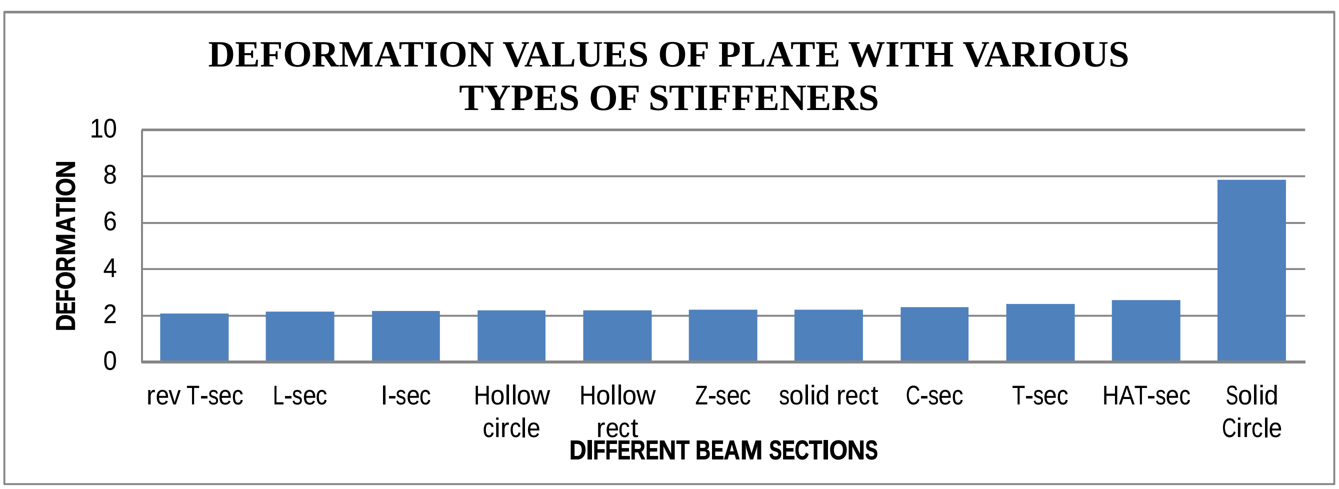

Figure 6.3. Deformation plot for plate with various types if stiffeners

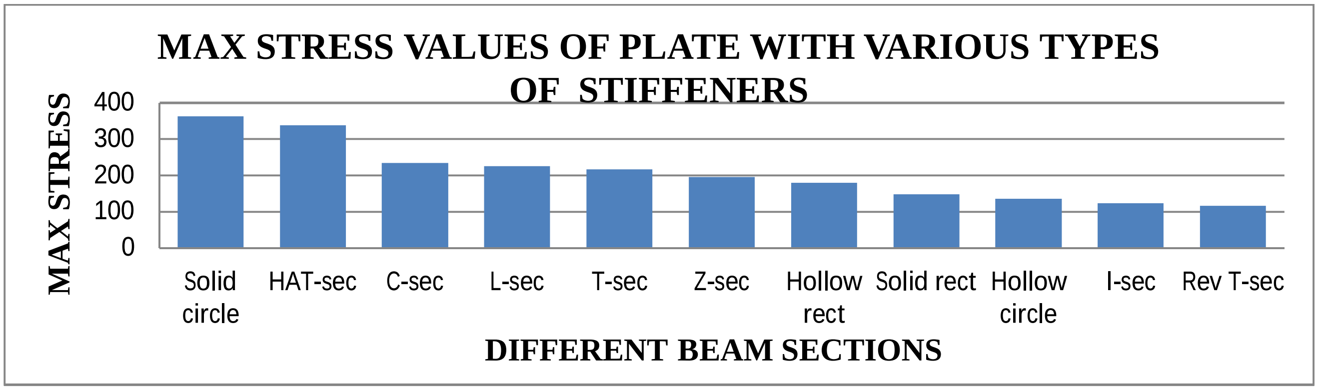

Figure 6.4. Maximum stress plot for plate with various types if stiffeners

Form the above Figures 6.3. and 6.4 it is observed that the lesser deformation value occurred for plate with reverse T-section stiffener and the higher deformation value observed for the plate with solid circular stiffener. For maximum stress the higher value obtained for plate with solid circular stiffener. And the lesser value observed for plate with reverse T-section stiffener.

Table 6.4. Section modulus values of plate with various types of stiffeners

S.No.	Section Type	Y(mm)	Moment of Inertia(I) (mm^4)	Section Modulus(z) (mm^3)
1	I-Section	37.5	393000	10480
2	C-Section	37.5	393000	10480
3	Z-Section	37.5	393000	10480
4	Hollow Rectangle	37.5	331000	8826.7
5	Hat Section	37.5	328000	8746.7
6	Hollow circle	37.5	298000	7946.7
7	L-Section	37.5	265000	7067
8	Rev T-Section	37.5	265000	7067
9	T-Section	37.5	265000	7067
10	Solid Rectangle	37.5	210000	5600
11	Solid Circle	11.93133	15900	1332.62

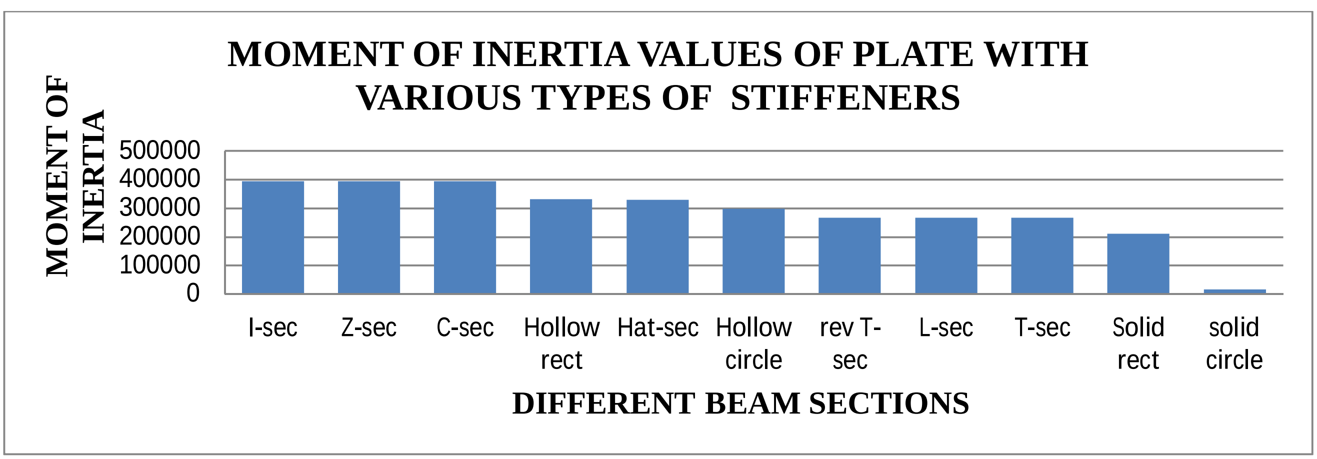

Figure 6.5. Moment of inertia plot for plate with various types if stiffeners

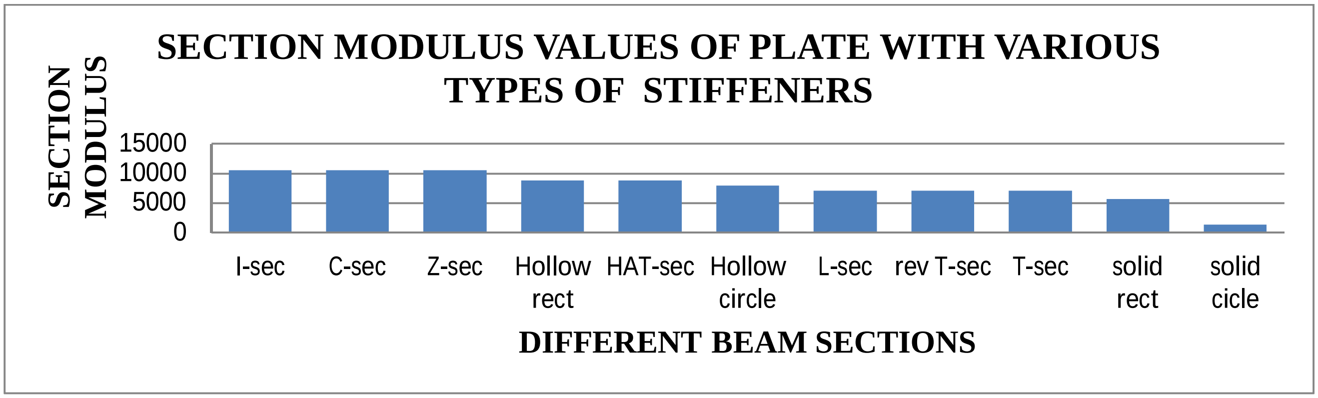

Figure 6.6. Section modulus plot for plate with various types if stiffeners

Form the above the Figures 6.5. and 6.6 the higher moment of inertia values were observed for plate with I, Z, and C sections and the lesser moment of inertia value observed for plate with solid circular stiffener. The higher section modulus values were observed for plate with I, Z, and C sections and the lesser section modulus value observed for plate with solid circular stiffener.

Table 6.5. Buckling load factor and frequency values of plate with various types of stiffeners

S.No	Beam section	Buckling Load Factor	Frequency(Hz)
1	Solid circle	3.96039	63.506
2	T-section	5.68839	117.31
3	Solid rectangle	14.0837	120.59
4	HAT-section	28.8187	122.53
5	I-section	30.8845	126.44
6	C-section	42.5846	131.35
7	Z-section	43.5031	132.63
8	Rev T-section	44.6003	133.86
9	L-section	53.078	137.92
10	Hollow circle	80.4836	134.72
11	Hollow rectangle	83.2312	134.65

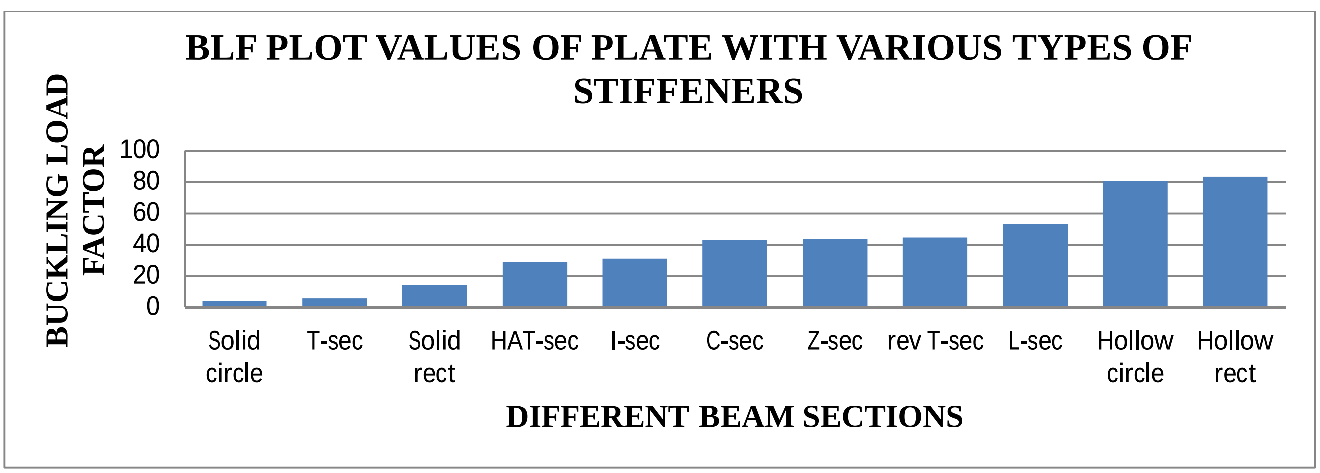

Figure 6.7. Buckling load factor plot for plate with various types if stiffeners

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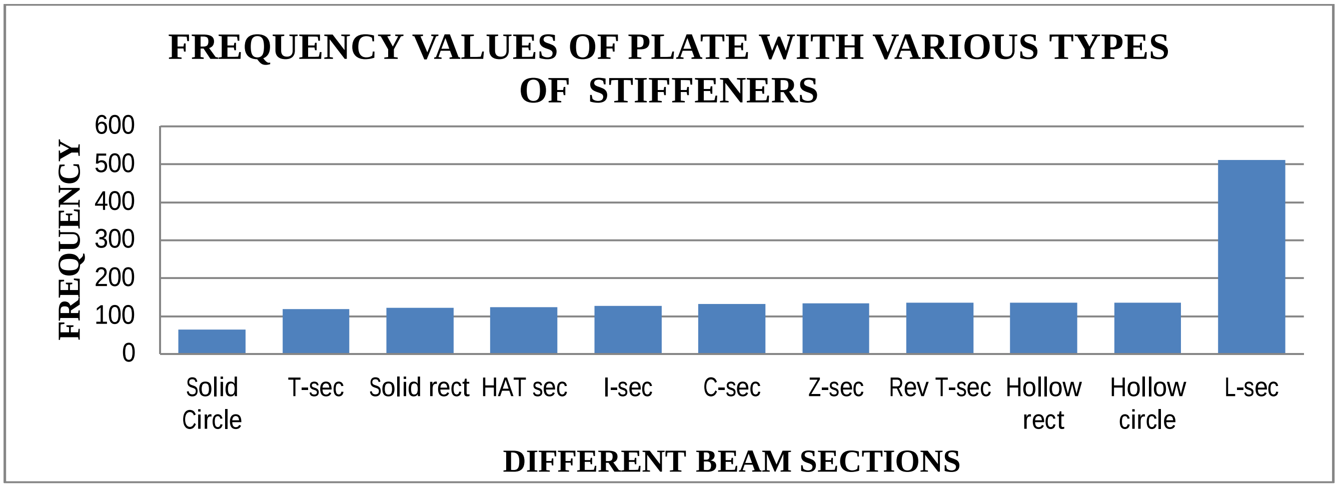

Figure 6.8. Frequency plot for plate with various types if stiffeners

From the above Figures 6.7. and **6.8.** it is observed that for the natural frequencies the higher value obtained for plate with L-section stiffener and the lesser value observed for plate with solid circular stiffener. For buckling load factor the higher value obtained for plate with hollow rectangular stiffener. And the lesser value observed for plate with solid circular stiffener.

VII. CONCLUSIONS AND FUTURE SCOPE

A. Conclusion

From results and discussions chapter it is observed that the deformation of the plate with stiffener is less when compared with the plate without stiffener. In literature, there are no formulas to calculate the deformation for flat plate with stiffener. By using Euler-Bernoulli's beam theory and Kirchoff's plate theory we have found the plate and beam deflection values individually. So, that these theoretical results were compared with the numerical results from ANSYS software. The theoretical and numerical results were nearer, then we extended our work to plates with stiffeners numerically.
From the numerical results of plate with stiffener it is observed that the lesser deformation 2.08mm, is observed for the plate with reverse T section stiffener and higher deformation observed for plate with solid circular stiffener, i.e.,7.843mm. For maximum stresses lesser stresses observed for plate with reverse T section stiffener and higher stresses observed for plate with solid circular stiffener.
For moment of inertia and section modulus, higher values observed for plate with I, C, Z section stiffeners and lesser values observed for plate with solid circular stiffener. And also it is observed that the lesser buckling load factor observed for the plate with solid circular stiffener and higher for plate with hollow rectangular stiffener. For the vibrational study the lesser natural frequency observed for the plate with solid circular stiffener and higher for the plate with L-section stiffener.

VIII. FUTURE SCOPE

In the present thesis work investigations on deformation and stress patterns of stiffened rectangular plate has been carried out in the elastic regime for homogeneous and isotropic materials. There is a scope for extending the studies carried out in the present thesis work to different type structures like cylinders, hemi- spherical domes, etc.
It is also possible to extend the present formulation in the field of dynamic studies. From the material point of view, the entire work has been undertaken for isotropic and homogeneous material behavior. In the context of present wide spread use of plates of composites and functionally graded materials (FGM) in industrial and structural application, extension of the present formulation of static and dynamic behavior of stiffened plates to include composites and functionally graded materials is an obvious choice and can be taken up in future.
In the present work only simply supported end conditions are taken into account. But the formulation can be extended to simulate elastically restrained ends or plate edges resting on elastic foundations. There is always scope for improving the simulation model by incorporating complications hitherto neglected in order to make the prediction for system output as close to the true behavior as possible.

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