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Static Analysis of Hat Stiffened Plate: A Parametric Study

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***Abstract*—In the present investigation, the finite element analysis is done for determining the internal responses of stiffened plates with various boundary conditions for uniformly distributed load. The different geometries of hat stiffeners are used to stiffen the plate. The study has been carried out by varying the geometry of the stiffener keeping the volume constant throughout. The maximum deflection and maximum von Mises stress of the stiffened plate is determined using a finite element tool, ANSYS Workbench 14.0. To compare the stiffened plate, a parametric study is carried out.**

***Index Terms*—Isotropic plate, finite element method, Hat Stiffened Plate (HSP), Structural Response, ANSYS Workbench 14.0.**

I. Introduction

Plate is a flat structural element in which its transverse dimension, i.e. thickness (t) is very small compared to length and width. A mathematical expression of this idea is $t/L<<1$, where t represents the plates thickness and L represents a representative length or width. Plate might be classified as very thin if, $L/t>100$, moderately thin if $20<L/t<100$, thick if $3<L/t<20$, and very thick if $L/t<3$. The classical theory of plate is applicable to very thin and moderately thin plate, while higher order theories for thick plate are useful.

These two theories (2) are applicable to carried out analysis:

1) The Kirchhoff–Love theory of plates (classical plate theory)
2) The Mindlin–Reissner theory of plates (first-order shear plate theory)

HSP has a number of closed profile stiffeners provided along the dominant direction as shown in Fig.1. In the case of steel structures, hat stiffeners are usually formed sections. The stiffeners are either welded or riveted to the plate and if riveted, flanges are provided for the stiffener. For composite structures, hat stiffeners are usually made by hand lay-up. The hat stiffeners are bonded to the plate through the flanges of the stiffeners.

Analysis of stiffened plate has always been a matter of concern for the structural engineers since it has been rather difficult to quantify the interaction between stiffeners and plating or rather the actual load sharing between these two. The interaction of beams and plating is an interaction between two modes of loading and response. Strain energy method has always remained as a solution strategy but of limited scope for actual stiffened plate problems. Application of matrix method and subsequent developments in the form of Finite Element Method (FEM) or Finite Element Analysis (FEA) has solved the complexities of analysis of stiffened plated structure. The single biggest development in ship structural design and analysis over the last few decades has been the introduction and acceptance of FEM as the structural analysis strategy. This tool offers both faster and more accurate solution to ship structural systems with complexities in geometry and boundary condition.

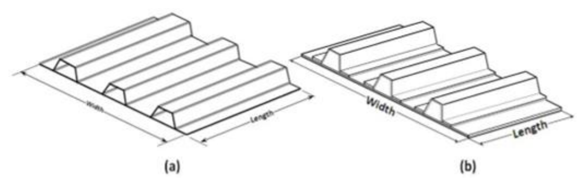

Fig. 1. Schematics of a typical: (a) Metallic hat stiffened plate (b) Composite hat stiffened plate

The present study starts with the validation with the results published in the literature. The effectiveness of plate with three stiffeners has been investigated in the present study. Also, the three stiffener plate is studied based on the results of maximum stress and deflection considering both simultaneously.

While many shapes like flat, L-shaped (angle), trapezoidal (hat shape) or other shapes can be used to stiffen the plate however a flat plate stiffener is used in the present study.

II. Finite Element Modelling

Finite element modelling consists of following steps:

1) Creating the geometry or model.
2) Discretise the model into elements.
3) Applying boundary condition and loading.
4) Solve the model.

ANSYS Workbench 14.0 is used in the present study. A stiffened plate shown in Fig. 1, of size 1000×1000×10 mm (plate) is used in the present study with stiffener of different dimensions described in Table I by keeping the volume of material constant (320000 mm3) throughout.

But before proceeding for the finite element analysis

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convergence study is performed on the bare plate to determine the optimum mesh size for the modelling and analysis. The analysis is carried out on bare plate with uniformly distributed load of 1.0 kN/m2 for all edges fixed and simply supported boundary condition. Stress is plotted against mesh size as shown in fig. 2 and it is clearly found that results are converging for mesh size of 20×20. So that, mesh size of 20×20 is adopted for the rest of the analysis as well.

SHELL181 element is used for the three-dimensional modelling of square plate. The element is defined by four nodes having six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes. BEAM3 element is a uniaxial element with tension, compression, and bending capabilities which is used as stiffener (hat stiffener). The element has three degrees of freedom at each node: translations in the nodal x and y directions and rotation about the nodal z-axis.

TABLE I
DIMENSION OF STIFFENERS KEEPING THE CONSTANT VOLUME OF MATERIAL ($320000\ mm^3$)

Case No.	Thickness (T)	Bottom width (A)	Top width (B)	Height (H)	Length (L)
1	2	35	60	65	955.90
2	3	35	60	65	637.26
3	4	35	60	65	477.95
4	5	35	60	65	382.36
5	6	35	60	65	318.63
6	2	40	60	65	932.78
7	3	40	60	65	621.86
8	4	40	60	65	466.39
9	5	40	60	65	373.11
10	6	40	60	65	310.93
11	2	40	65	70	878.09
12	3	40	65	70	585.39
13	4	40	65	70	439.04
14	5	40	65	70	351.23
15	6	40	65	70	292.70
16	2	40	60	70	881.92
17	3	40	60	70	587.95
18	4	40	60	70	440.96
19	5	40	60	70	352.77
20	6	40	60	70	293.97
21	2	35	65	65	950.02
22	3	35	65	65	633.35
23	4	35	65	65	475.01
24	5	35	65	65	380.01
25	6	35	65	65	316.67

*All dimensions are in mm

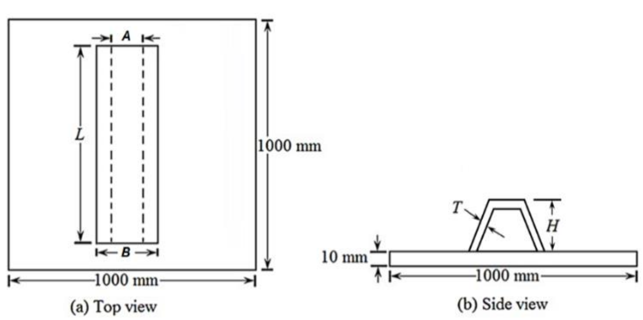

Fig. 2. Geometry of stiffened plate

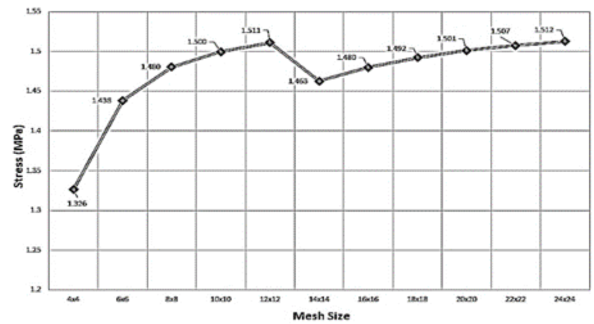

Fig. 3. Convergence study

III. RESULTS AND DISCUSSION

Several numerical experiments are carried out by varying the geometry of central and side stiffeners and are discussed in following sections.

A. *Validation of Results*

In this section, a square plate is analysed for uniformly distributed load of 1 kN/m^2 with both the boundary condition fixed and simply supported on all edges. The results obtained were found to be very close to the results reported by Timoshenko & Krieger for bare plate and Deepak et al. for stiffened plate and presented in Table II.

TABLE II (a)
VALIDATION OF RESULTS FOR UNSTIFFENED PLATE

S. No.	Boundary and loading conditions	Maximum deflection (mm) obtained by ANSYS	Maximum deflection (mm) calculated by formula given by Timoshenko	Percent age error (%)
1.	All edges fixed with uniformly distributed load ($1kN/m^2$)	0.06909	0.06880	0.4288
2.	All edges simply supported with uniformly distributed load ($1kN/m^2$)	0.22215	0.22790	2.5230

TABLE II (b)
VALIDATION OF RESULTS FOR STIFFENED PLATE

S. No.	Boundary and loading conditions	Maximum deflection (mm) obtained by ANSYS	Maximum deflection (mm) calculated by formula given by Timoshenko	Percent age error (%)
1.	All edges fixed with uniformly distributed load ($5\ kN/m^2$)	0.245507	0.245606	0.0403
2.	All edges simply supported with uniformly distributed load ($5\ kN/m^2$)	0.491030	0.491230	0.0407

B. Comparison based on Deflection

In this section, stiffened plate with fixed edges boundary is analysed for uniformly distributed load of 1kN/m2 with variation in the stiffener geometry. Contour and results of maximum deflection in the stiffened plate has been shown in Fig. 4 and Fig. 5 respectively.

Maximum and minimum deflection observed are 0.05045 (Case no. 15) and 0.02132267 mm (Case no. 11) respectively for fixed edges condition, shown in fig. 5 (a).

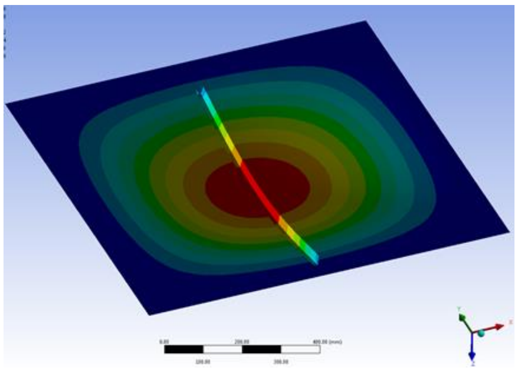

Fig. 4 (a). Contour of maximum deflection: Fixed edges with uniformly distributed load of 1 kN/m^2

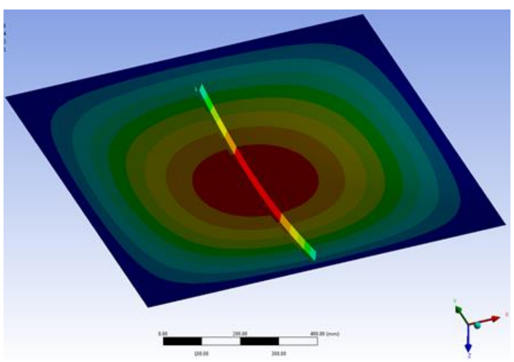

Fig. 4 (b). Contour of maximum deflection: Simply supported edges with uniformly distributed load of 1 kN/m^2

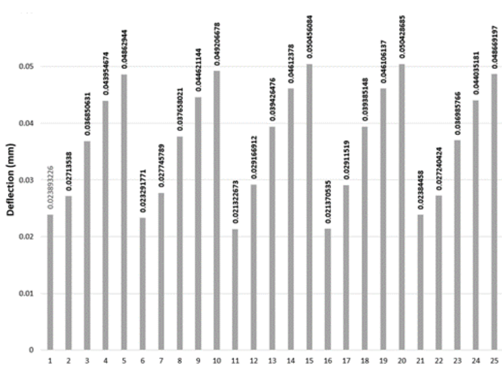

Fig. 5 (a). Maximum deflection in the stiffened plate for uniformly distributed load of 1 kN/m^2 and fixed edges condition

When simply supported edges condition is considered for the stiffened plate, the maximum and minimum deflection observed is 0.170 mm (Case no. 15) and 0.0502 mm (Case no. 16) respectively, shown in fig. 5 (b).

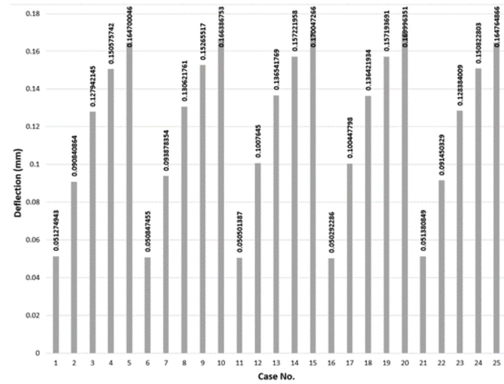

Fig. 5 (b). Maximum deflection in the stiffened plate for uniformly distributed load of 1 kN/m^2 and simply supported edges condition

C. Comparison based on Stress

Maximum von Mises stress is calculated for the stiffened plate for uniformly distributed load of 1kN/m^2 for both the edges conditions. The distribution of stress in the form of contour has been shown in the Fig. 6.

For fixed edges condition, maximum and minimum stress observed is 5.168 MPa (Case no. 13) and 2.890 MPa (Case no. 11) respectively.

When simply supported edges condition is considered, a maximum and minimum stress of 11.561 MPa (Case no. 07) and 6.381 MPa (Case no. 20) is observed respectively. These stresses are observed for the same combination of stiffeners geometry.

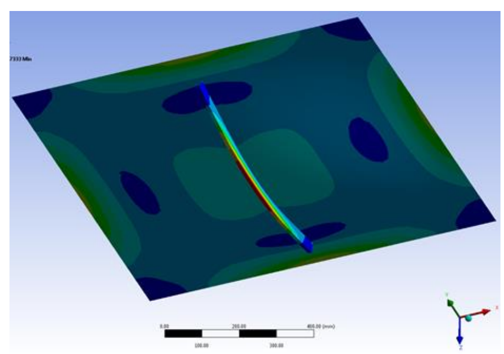

Fig. 6 (a). Contour of maximum stress: Fixed edges with uniformly distributed load of 1 kN/m^2

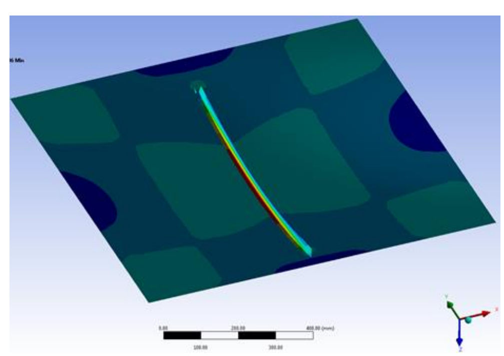

Fig. 6 (b). Contour of maximum stress: Simply supported edges with uniformly distributed load of 1 kN/m^2

D. Comparison based on Consideration of Deflection and Stress Together

Maximum von Mises stress and deflection are compared together in this section. Figure 7 shows the variation of deflection (scaled) and corresponding stress of stiffened plates for uniformly distributed load of 1 kN/m^2 for both the edges. It is observed that the maximum deflection is not occurred where the stiffened plate is having high stress.

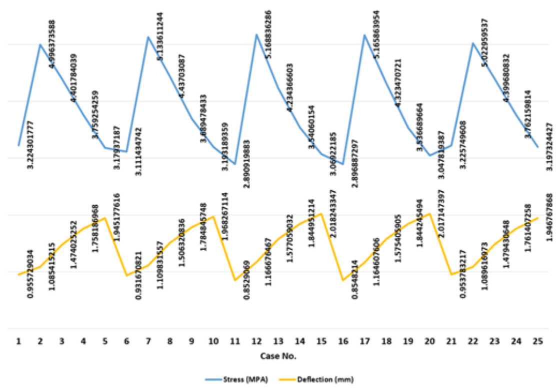

Fig. 7 (a). Maximum deflection (scaled) and stress in the stiffened plate: Maximum deflection (scaled =*40) and stress generated for uniformly distributed load (1 kN/m^2) and fixed edges condition

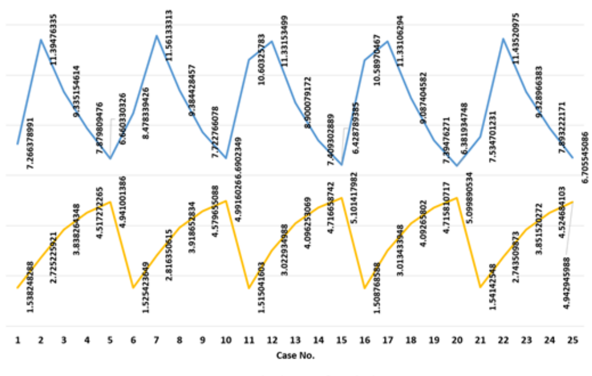

Fig. 7 (b). Maximum deflection (scaled) and stress in the stiffened plate: Maximum deflection (scaled =*30) stress generated for uniformly distributed load (1 kN/m^2) and simply supported edges condition

IV. Conclusion

Based on the study carried out, the following conclusions are drawn:

- It is observed that the value of deflection for stiffened plate having flat stiffener is more than stiffened plate having Hat stiffener for both the boundary conditions. The variation is less for fixed edge condition and significantly more for simply supported edges condition.
- The value of deflection for stiffened plate with Hat stiffener is quite less compared to unstiffened plate
- The stiffened plate having Hat stiffener occupies less space than stiffened plate having flat stiffener and may be better where space is the constraint.
- The hollow space between the Hat stiffener(s) may be utilized as a duct for cables and wires.

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