Analyzing the Buckling Strength of Stiffened Steel Plates with Longitudinal Stiffeners Subjected To Uniaxial Compression

A.Aruljothi[1]*,

[1]*Assistant Professor, Department of Automobile Engineering, Karpaga Vinayaga College of Engineering and Technology, Chennai,* arulnanda@gmail.com

Abstract

In many engineering industries, especially in aircraft and ship construction, it is important to achieve higher stiffness with high strength to weight ratio. One of the commonly used structural components is stiffened steel plates. Stiffened plates can be stiffened longitudinally and /or transversely using stiffeners of different size and shape. The stiffeners not only carry a portion of load but also subdivide the plate into smaller panels, thus increases considerably the critical stress at which the plate buckles. The stiffeners are generally used to increase the strength of stiffened plate. Stiffened plates are usually failed by buckling. From the literature survey carried out, it is found that factors such as size of the subpanel, shape and size of stiffener and number of equi-spaced stiffeners will affect the critical buckling strength of stiffened plates with longitudinal stiffeners. Hence in this work, buckling of stiffened plates under uniform edge compression is taken for study. In phase-II of the project work, for the above said purpose, two types of stiffened plates which are used in ship construction industry [1] are taken for study. FENON-linear buckling analysis is used to determine the buckling strength of the stiffened plate. For FE analysis the loaded sides of the plate are simply supported are considered. The plate FE models are generated, analysed and validated. The results of the parametric analysis are reported in this paper.

Key words: Stiffened Plates; Buckling analysis; Shell element; Beam element;

1. INTRODUCTION

Composite materials are known to have high specific modulus, high specific Stiffeners provide improvement to load carrying capacity of structures. The benefit of stiffening of a structure lies in achieving lightweight and robust design of the structure. For this purpose they have wide use in structural engineering domain. Specially, stiffened plates are used in critical and sensitive structures such as in aircrafts, ship hulls and box girders in which safety and a perfect design is crucial. Buckling is the one of the most complex phenomenon that is inevitable for heavily axially loaded stiffened plate structures. For this purpose, it is necessary to carry a deep interest and investigation about their responses under expected loads to design such structures safely. In structural engineering, it is one of the first priorities to save weight, without loss of any Strength in the used of structural elements against subjected loads. The approach of the uses of stiffeners to improve structural response is simple, but the practical stiffened plate design is a complex task. Due to involving many design variables, a complete understanding of response of such structures is not fully figured out. Therefore, a stiffened plate is developed using Ansys program for evaluating their buckling critical load factor by varying the plate thickness and stiffener thickness to obtain maximum efficiency from stiffened plates.

According to Troitsk, the development of stiffened plates was probably based on the observation of existing forms of nature. From an engineering point of view, manipulating the distribution of material in a structural member is the most efficient way to resist stress and deformation economically. The use of stiffened plates began in the nineteenth and early twentieth century, mainly in the construction of steel bridges, hulls of ships and aircraft applications.

In the last three decades, extensive experimental, numerical and statistical studies have been conducted on the behavior and ultimate load carrying capacity of stiffened steel plate panels with longitudinal stiffeners. Despite a large number of researchers involved, the behavior of stiffened steel plates has been only investigated to certain extent. The earlier research work concentrated on the buckling behavior of stiffened steel plates under uniaxial compression [2].

Sheikh et al was investigated stability of stiffened steel plates under uniaxial compression and bending using finite element method. The parameters investigated where; the transverse slenderness of the plate, the slenderness of the web and flange of the stiffener, the ratio of torsional slenderness of the stiffener to the transverse slenderness of the plate, and the stiffener to plate area ratio [15]

Kumar and Mukhopadhay [10] were presented a stiffened plate element for stability analysis of laminated stiffened plates that the basic plate element was a combination of Allman's plane stress triangular element and a discrete thick plate and includes transverse shear effects.

Brubak was studied an approximate semi-analytical computational model for plates with arbitrarily oriented stiffeners and subjected to uniaxial loading. Their estimation of the buckling strength is made using the von Mises' yield criterion [6]. Peng investigated a mesh-free Galerkin method for the free vibration and stability analyses of stiffened plates via the first order shear deformable theory.

Vörös focussed on the application of the new stiffener element with seven degrees of freedom per node and subsequent application in determining frequencies, mode shapes and buckling loads of different stiffened plates. The development of the stiffener is based on a general beam theory and includes the constraint torsional warping effect and the second order terms of finite rotations. Riks investigated implementation of the finite strip (FS) method that extends the scope of the determination of the post-buckling stiffness of stiffened panels for wing structures [16].

Todoroki and Sekishiro was proposed a fractal branch and bound method for optimizing the stacking sequences to maximize the buckling load of blade-stiffened panels with strength constraints. Bedair was explained the influence of stiffener location on the stability of stiffened plates under combined compression and bending. He idealized the structure as assembled plate and beam elements rigidly connected at their junctions. Various researches have been carried out to optimize the response of plates[5].

This paper is to investigate the shape and size optimization of stiffened plates for improving the critical buckling load using various analysis and optimization method. In these studies, effects of one or two parameters on buckling load were investigated. The objective of this study is to carry out to determine the critical buckling load.

2. BUCKLING

For a layman, the word 'Buckling' evokes an image of failure of a structure, which has compressed in some way leading to a sudden catastrophic failure involving large deformations. But from the scientific and engineering point of view, the buckling is a phenomena that generally occurs before deformations are very large i.e. to the unaided eye, the structure appears to be un-deformed or only slightly deformed

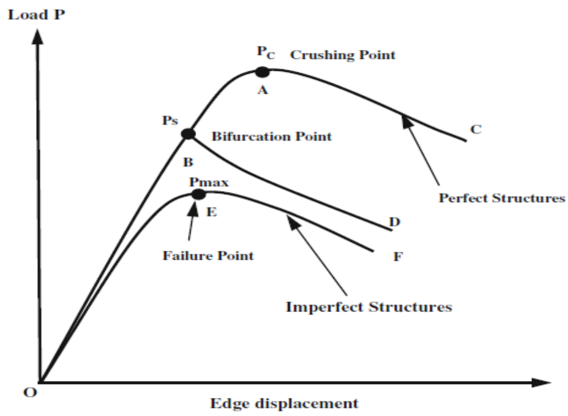

Fig. 1. Bifurcation buckling.

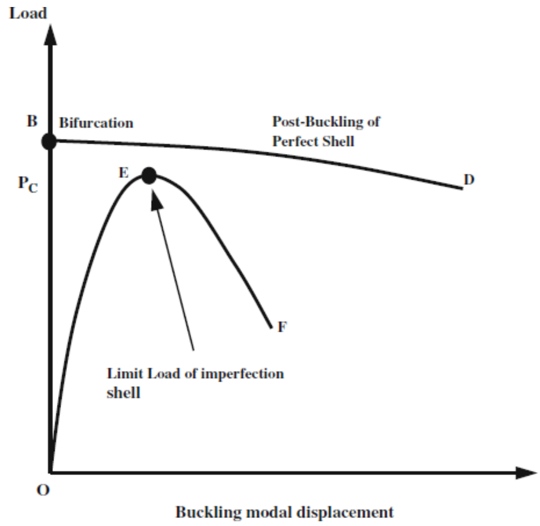

Fig. 2. FE analysis of eigen and non-linear buckling.

When a thin cylindrical shell is axially compressed, it deforms approximately in an axisymmetrical form along the equilibrium path OA as shown in Fig.1 until maximum or limit load Pc is reached at point A. The perfect thin cylindrical shell will fail, following either the path OBAC along which it continues to deform axisymmetrically or in some other path OBD along which it first deforms axisymmetrically up to critical load Pc at bifurcation point B and then asymmetrically from B to D.

Limit point or Snap through buckling occurs at point A and bifurcation buckling occurs at point B. The equilibrium path OBAC corresponding to axisymmetric mode of deformation is called the fundamental or primary or pre-buckling path; the post buckling path BD, corresponds to non-axisymmetric mode of deformation and is called the secondary or post-buckling path.

In Fig.2, the load is plotted as a function of bifurcation buckling mode deflection. In case of perfect structures, since the bifurcation buckling mode is orthogonal to pre-buckling displacement pattern of perfect shell, its amplitude remains zero until the bifurcation point 'B' is reached. The curve BD implies that the post buckling state is unstable, since, load carrying capacity decrease with increasing amplitude of bifurcation buckling mode deformation.

In case of real structures, which contain unavoidable imperfections, there is no true bifurcation buckling. All real structures are imperfect and their equilibrium path is similar to the load-lateral deflection curve EF as shown in Fig.2. The amplitude of lateral deflection increases with increase in load until instability via non-linear snap-through or collapse at the reduced load Pmax. The difference between the critical bifurcation load Pc of the perfect structure and the collapse load Pmax of the imperfect structure depends on the amplitude of the initial imperfections.

3. FE ANALYSIS

Validation of FE Model

To initiate the FE analysis, the initial geometry of the structure must be generated.Table.1&2 shows P1R and P2R model of the investigated of two types of stiffened plates. Width and length of plates will be constant during FE analysis procedure. . Based on the type the stiffened plates are analyzed for the following cases:

(i) Thicknesses of the plate and stiffener
(ii) Height of the stiffener.
(iii) Location of the stiffeners.

Using different shell element the stiffened plates will be analyzed. Among those we will select which gives the better results for the P1R and P2R model.

Types of shell element namely,

(i) Shell43
(ii) Shell93
(iii) Shell181
(iv) Shell281

Finite element method can analyze structures which are simply supported on diaphragms at two opposite edges with the remaining edges arbitrarily restrained, and the cross section does not change between the simply supported ends.

The loaded sides of plates are simply supported. The plates are loaded under uniformly distributed compression force in stiffeners direction. Force applied as a uniformly distributed compressive load over the plate and stiffeners.

Material Properties

The following material properties are used

Material : STEEL

Poisson's ratio : 0.3

Table1. Lower and upper bounds of thickness of plate and Stiffener

Description	**Minimum (m)**	**Maximum (m)**
Thickness of plate	0.004	0.0048
Thickness of stiffener	0.005	0.007
Height of the stiffener	0.028	0.031

Table2. Parameters for P1R and P2R model

Parameter	**P1R**	**P2R**
Young's modulus (N/m^2)	1.81E11	1.95E11
Plate Length (m)	0.650	0.650
Plate Breadth	0.650	0.651
Plate Yield stress (N/m^2)	218E6	224E6
Stiffener Yield Stress (N/m^2)	390E6	390E6
Plate Thickness (m)	0.0044	0.0044
Stiffener Height (m)	0.030	0.030
Stiffener thickness (m)	0.007	0.007

Boundary Condition

Fig 3 &4 Boundary condition for P1R model.

The stiffened plates were loaded in axial compression along the stiffeners. Also in their tests the simply supported boundary conditions were assumed in the models.

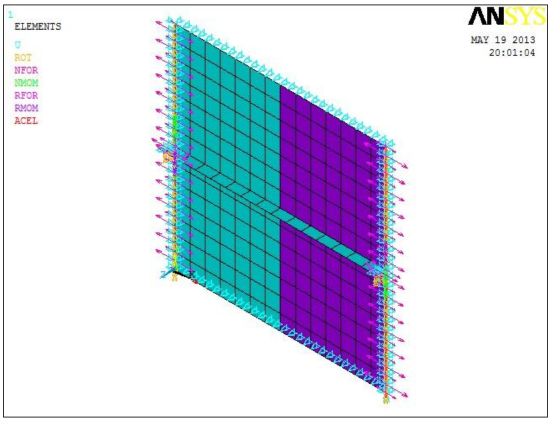

Fig 3. Boundary Condition for P1R Model

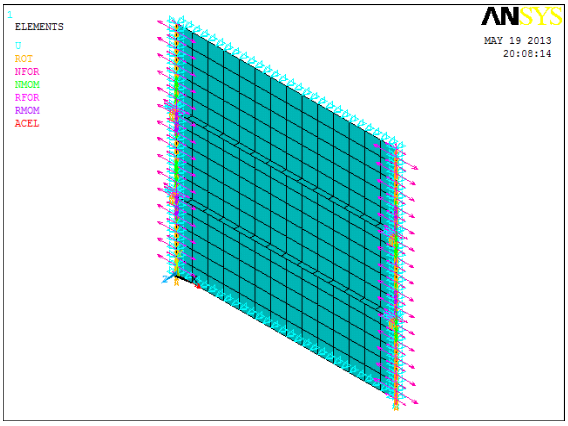

Fig 4. Boundary Condition for P2R Model

Top side – simply supported boundary condition
Bottom side- simply supported boundary condition
Left side- simply supported boundary condition and 'Rot Y' will be constrained.
Right side – translation of X and Y will be constrained

Geometrical Imperfections

Uniform axial pressure was applied first on the stiffened plate model and a linear elastic finite element analysis was carried out. This analysis was repeated in a trial and error sequence of calculations so that the magnitude of maximum deflection of plate reached. At this time linear buckling load will be added with the initial deflection of the plate and after that the nonlinear analysis will be carried out. For P1R model W/tp=69 % of the plate and P2R model W/tp= 25% of the plate is taken from the Ghavami experiment.

Table 3. Buckling strength for P1R and P2R model

SHELL	**Reference Value N/mm^2**	
	P1R Model=169.73	**P2R Model**=155.232
SHELL43	166.49	164.87
SHELL93	161.57	156.90
SHELL181	167.15	144.32
SHELL281	160.15	156.99

Table 4. Buckling strength ratio for different shell element P1R)

Shell type	**Reference value**	**Obtained value**	**Ratio**
Shell43	169.73	166.497	0.980953
Shell93	169.73	161.5718	**0.951934**
Shell181	169.73	167.1515	0.984808
Shell281	169.73	160.156	0.943593

Table 5. Buckling strength ratio for different shell element (P2R)

Shell type	**Reference value**	**Obtained value**	**Ratio**
Shell43	155.232	164.32	1.058545
Shell93	155.232	156.9028	**1.010763**
Shell181	155.232	144.32	0.929705
Shell281	155.232	156.9996	1.011387

The FE models are analysed using different types of shell element and the results are tabulated for the two models namely P1R and P2R. From the tabulated results we conclude that the buckling strength ratio for Shell 93 elements gives better results. So shell 93 element is used for the work to carry out the parametric study.

4 .RESULTS AND DISCUSSION

In order to validate the results obtained from the analysis, first FE stiffened plate models are generated as per the geometric parameter given in ref [1] and the same is presented in Table3. These models are analyzed using ANSYS Non-linear buckling analysis module assuming simply supported boundary condition taking Young's modulus (E)=2.1x10^5 N/m^2 and Poisson's ratio =0.3 and the results are compared with results given in the reference[1] that was obtained by Ghavami . The compared results are shown in Table 3. From this table it can be concluded that the deviation from that of the reference values [1] are less. Thereby the FE analysis and models are validated. A sample of mode shape obtained for P1R model is shown in Fig.4

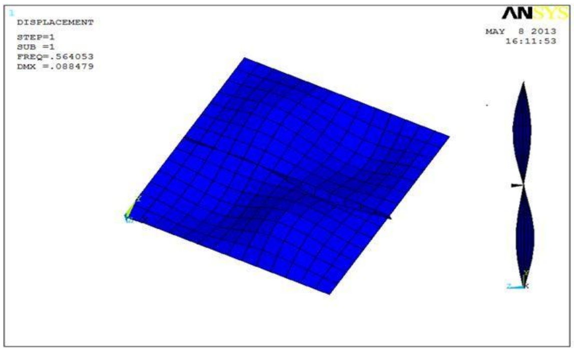

Fig 4. Buckling mode shape for P1R model

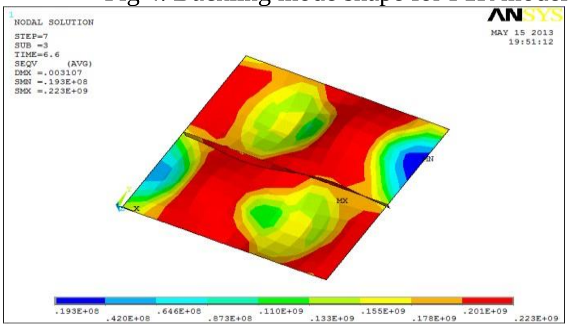

Fig 5. Stress contour diagram for P1R model

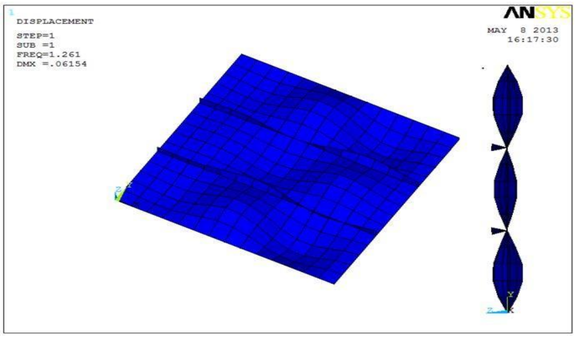

Fig 6. Buckling mode shape for P2R model

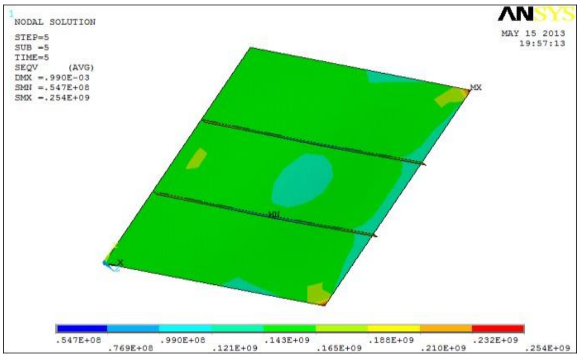

Fig 7. Stress contour diagram for P2R model

Plate Thickness Variation

Table 6. Plate thickness variation

Plate Thickness (m)	BUCKLING STRENGTH (Mpa)	
	PIR	P2R
0.004	150.36	151.4
0.0042	155.65	157.6
0.0044	161.57	163.5
0.0046	168.46	169.9
0.0048	178.55	182.4

From the Table no 6, the value it is evident that as the thickness of plate increases the critical buckling strength also increases. The increase in shell thickness from 0.004m to 0.0048m as the increase in plate strength is 15.18% for P1R and 17.006% for P2R with respect to strength value.

Table 7. Stiffener Thickness Variation

STIFFENER Thickne ss (m)	BUCKLING STRENGTH (Mpa)	
	PIR	P2R
0.005	157.7	162.5
0.0055	158.5	169.2
0.006	159.4	175.9
0.0065	160.5	182.7
0.007	161.6	183.3

From the Table.7 it is evident that as the thickness of stiffener increases the critical buckling strength also increases. The increase in stiffener thickness from 0.005m to 0.007m as the increase in plate strength is 2.407% for P1R and 12.295% for P2R with respect to strength value.

Table 8. Stiffener Height variation

STIFFENER HEIGHT (m)	BUCKLING STRENGTH (Mpa)	
	PIR	P2R
0.028	161.1	172.1
0.0285	161.2	178.2
0.029	161.3	191.3
0.0295	161.5	197.3
0.030	161.6	203.8
0.0305	161.7	210.6
0.031	161.8	211.4

From the Table8.

it is evident that as the thickness of stiffener increases the critical buckling strength also increases. The increase in stiffener height from 0.028m to 0.031m as the increase in stiffened plate strength is 0.4194% for P1R and 18.57% improvement for P2R with respect to strength value.

5. CONCLUSIONS

From the present analysis carried out on the stiffened plate taken for study, the following conclusions are derived.

(i) When the plate thickness increases the buckling strength will also increases. Compare to P1R model the % of improvement for P2R model is high.

(ii) When the stiffener thickness increases the buckling strength will also increases. But the % of buckling strength for P1R model is low compared with P2R model.

(iii) When the stiffener height increases the buckling strength will increases. The stiffener height variation is not much effective on P1R model compared with P2R model.

(iv)When the location of the stiffener increases the buckling strength will decreases for P2 R model.

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