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Investigation on Buckling of Laminated Composite Plate

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Abstract: *Composite laminated plates are widely used in aerospace industries, ship industries and civil applications because of their high strength to weight ratio, high strength to stiffness ratio. It is essential to find the buckling strength of these plates as these are subjected to axial forces in practice. In the present study nonlinear analysis is carried out to find the buckling strength of laminated composite plates under axial compressive load using ANSYS. Standard tests were performed as per ASTM/BIS/BSI/ISO to find the buckling strength of the composite plate using nonlinear analysis. A stiffened composite plate was considered and nonlinear analysis to be performed on it and the weight and the load carrying capacity of the stiffened composite plate has to be compared with the results of the stiffened steel plate.*
Keywords: *Composites, buckling, nonlinear analysis, Ansys etc.*

I. Introduction

The advent of technology has lead manufacture to fabricate aircraft components using composite materials. There many advantages provided by composite materials. In this paper, due to the advantage of composite materials, is selected for the use to fabrication of aircraft components like wing, fuselage, empennage and their respective internal components.

II. Description of The Problem

Buckling is characterized by a sudden sideways failure of a structural member subjected to high compressive stress, where the compressive stress at the point of failure is less than the ultimate compressive stress that the material is capable of withstanding.

In the present analysis, buckling strength of composite laminated plate is carried out by using nonlinear analysis by considering a stiffened steel plate and a composite plate (carbon fiber).

III. Bending And Buckling of A Composite Plate

INTRODUCTION:

The section begins by introducing the idea of orthotropic properties.

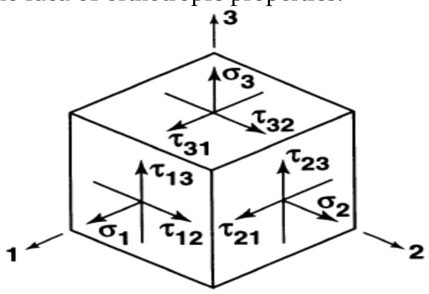

Figure 1: Stresses on an element

The strains are therefore defined by:

$$\varepsilon_1 = \frac{\sigma_1}{E_{11}}$$
$$\varepsilon_2 = \frac{\sigma_2}{E_{22}}$$
$$\gamma_{12} = \frac{\tau_{12}}{G_{12}}$$
$$\epsilon_2 = -\vartheta_{12}.\epsilon_1$$
$$\epsilon_1 = -\vartheta 21.\epsilon_2$$

$$\varepsilon 3 = \frac{\sigma_3}{E_{33}}$$

σ_1 loading:

$$\varepsilon_1 = \frac{\sigma_1}{E_{11}}$$

σ_2 loading:

$$\epsilon_1 = -\vartheta 21.\epsilon_2$$

$$= -\frac{\vartheta 21.\sigma_2}{E_{22}}$$

σ_3 loading:

$$\epsilon_1 = -\vartheta_{31}.\epsilon_3 = -\frac{\vartheta 31.\sigma_3}{E_{33}}$$

Combining these loadings and adding the strains in direction 1 by superposition gives

$$\epsilon_1 = \frac{\sigma_1}{E_{11}} - \vartheta_{21}.\frac{\sigma_2}{E_{22}} - \vartheta_{31}.\frac{\sigma_3}{E_{33}}$$

And similarly

$$\epsilon_2 = \frac{\sigma_2}{E_{22}} - \vartheta_{12}.\frac{\sigma_1}{E_{11}} - \vartheta_{32}.\frac{\sigma_3}{E_{33}}$$

e11	e22	e33	υ12	υ23	υ13	G12	G23	G13
15800	15333	15333	0.139	0.15	0.15	2806	6666	2806

Table 1: Carbon Fiber Composite Material Properties from the literature

IV. Analytical Approach

PURPOSE OF ANALYSIS:
In the present we find the displacement and stresses on the composite plate using nonlinear static analysis the finite element method is used to solve the given structure for displacement and stresses on plate.

LOAD INCREMENTATION:
Define a (force-type) load to be applied as $\lambda \mathbf{f}^{ext}$
• prescribe a displacement *u* for a selected node i
• determine the load level λ and the displacements Δ**u**from $\mathbf{K}\ \Delta\mathbf{u} = \lambda\mathbf{f}^{ext} - \mathbf{f}^{\ int}$
compose the displacement increment $\Delta\mathbf{u} = \lambda\Delta\mathbf{u}^{ext} + {}^{\Delta\mathbf{u}int}$

$$\Delta\lambda_n = \Delta\lambda_{n-1}\sqrt{\frac{N_d}{N_{n-1}}}$$

N_d is the desired number of iterations selected by the analyst,
N_{n-1} is the number of iterations required for convergence at increment n-1
Δλ is the load increment

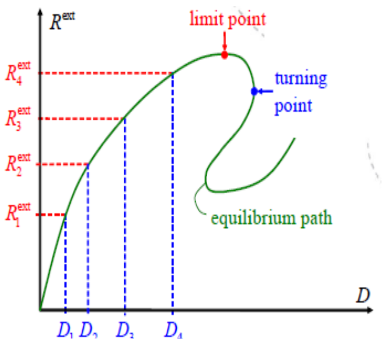

Figure 2: load increment in sub steps

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ARC LENGTH METHOD:

The most reliable indication for an ultimate load is reaching the post buckling region. The arc-length method should do, however, what looks like a maximum in the load-deflection curve emerges as a change in the load direction, i.e. unloading, which is not detected by the algorithm, because loading and unloading path differ due to plastic material.

In order to trace the equilibrium path beyond critical points, a more general incremental control strategy is needed, in which displacement and load increments are controlled simultaneously. Such methods are known as “arc-length methods” in which the ‘arc length’ ℓ of the combined displacement-load increment is controlled during equilibrium iterations.

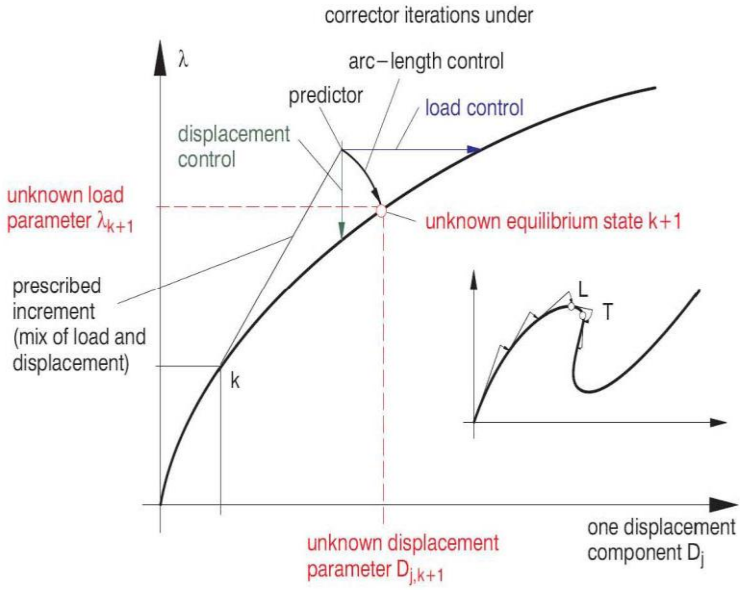


Figure 3: Arc length technique

V. Results

ANALYTICAL RESULTS IN NONLINEAR ANALYSIS:

The created model was analyzed to find the ultimate load carrying capacity of the stiffened composite plate using finite element software ANSYS. Newton-Rapson iteration method is often not suitable to track the slope portion of the load-displacement curve. Hence arc-length method of solving non-linear structural problems is adopted in ANSYS.

Arc-Length technique is a process of solving non-linear structural problems in which the iteration process is forced along an arc of a sphere with its centre at the starting point. Using arc-length method, it is possible to track the slope portion of the load-displacement curve. Geometrical non-linearity was taken into consideration during the analysis.

Analysis was carried out on an ideal structure without imperfections. If the imperfection profile of the structure is not known, Eigen-value buckling analysis can be performed and the structure can be updated to create the initial imperfections from the displacements of first mode shape obtained from the eigen-value buckling analysis. In arc-length method of solving nonlinear problems load is increased in a series of load steps to perform a non-linear post buckling analysis.

STIFFENED COMPOSITE PLATE MODEL
SCHEMATIC DIAGRAM:

Size of the stiffened plate was taken from the literature 956 mm * 956 mm with 5.77 mm * 25 mm stiffeners. In the literature the plate was modeled with steel, we are replacing it with composites and calculating the load carrying capacity.

The results from the nonlinear analysis are the maximum stress, buckled mode shapes and the corresponding load- displacement curve which are depicted below.

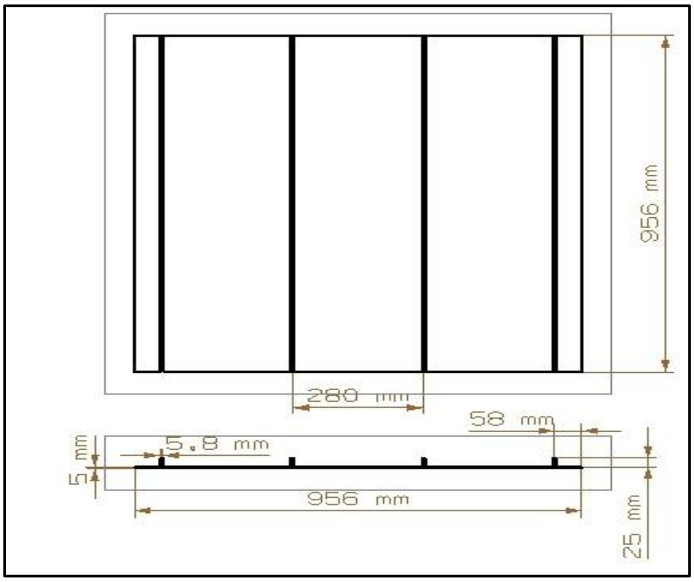


Figure 4: schematic of stiffened plate

STIFFENED COMPOSITE PLATE MODEL WITH SHELL 99 ELEMNT:

SHELL99 element was used in the analysis which is used for layered applications of a structural shell model; the element has 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.

It can be used for linear or nonlinear analysis with its art of element ease, the element supports laminated structural analysis

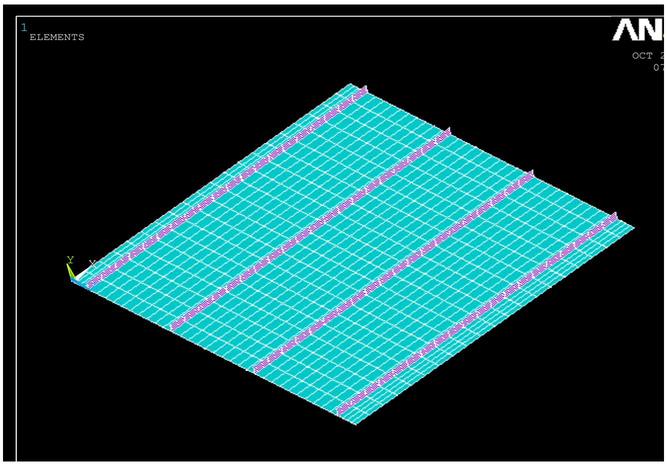


Figure 5: shell 99 element

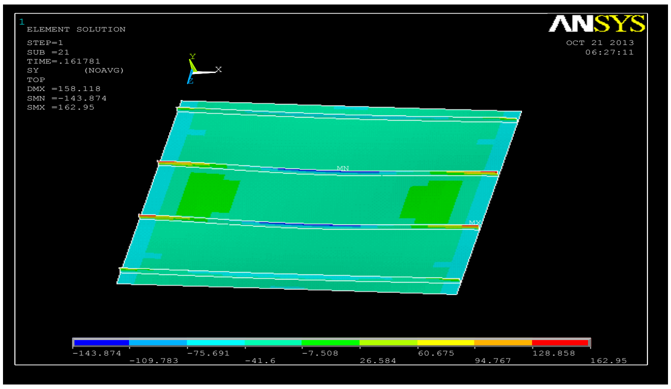


Figure 6: Element solution- maximum stress:

A curve is drawn between the displacement on x-axis and load on – axis by using load increments and the corresponding displacements as shown in figure below

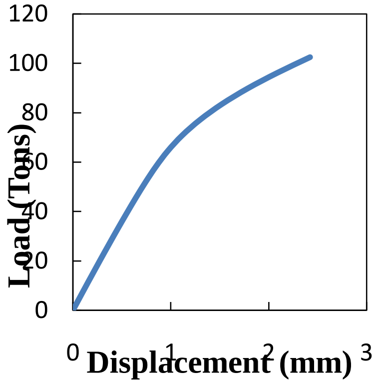
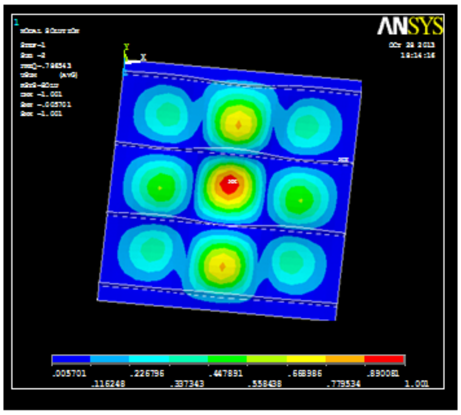


Figure 7: Load displacement curve

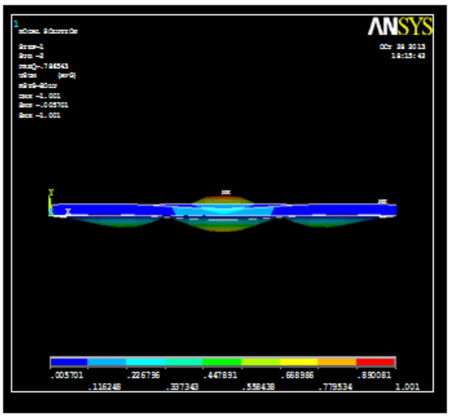
The load increments (tons) and the corresponding displacements in nonlinear analysis using arc length technique are tabulated in the below table

	Displacement (mm)	Load (Tons)
0	0	0
-8.56E-03	0.00856388	0.6336
-1.71E-02	0.017138	1.2672
-3.00E-02	0.0300078	2.2176
-4.93E-02	0.0493389	3.6432
-7.84E-02	0.07843	5.7816
-0.12221	0.122205	8.9892
-0.18826	0.18826	13.8006
-0.27606	0.27606	20.1366
-0.36496	0.364958	26.4726
-0.45523	0.455225	32.8086
-0.54729	0.547289	39.1446
-0.64195	0.641949	45.4806
-0.74078	0.740782	51.8166
-0.84725	0.847248	58.1526
-0.96865	0.968647	64.4886
-1.11649	1.11649	70.8246
-1.29999	1.29999	77.1606
-1.5222	1.5222	83.4966
-1.78604	1.78604	89.8326
-2.08937	2.08937	96.1686
-2.42368	2.42368	102.5046

Table 2: load Vs displacement



Figures 8: Buckled mode shape 1



Figures 9: Buckled mode shape 2

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The buckling strength of the composite plate is analyzed and the weight and the load carrying capacity of stiffened steel plate is compared with the stiffened composite plate. The following are the figures showing weight versus load carrying capacity of stiffened plate, stiffened composite plate and comparison between them.

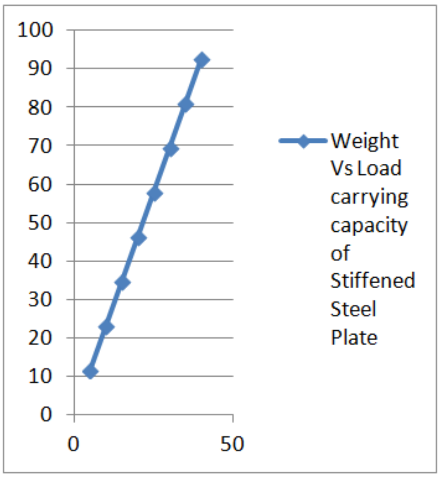

Figure 10: Weight Vs Load carrying capacity of stiffened steel plate

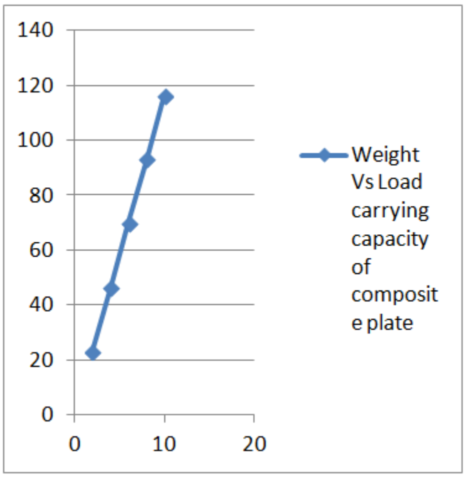

Figure 11: Weight Vs Load carrying capacity of composite plate

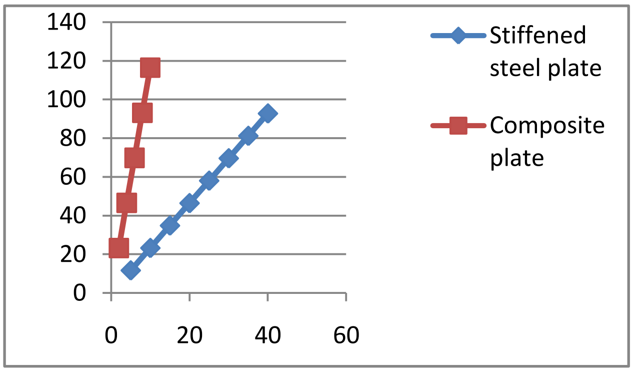

Figure12: Comparison of stiffened steel and composite plate

VI. Conclusion

The load carrying capacity of the stiffened steel plate was found to be equal to 81.19 tons, and in the present project work the steel stiffened plate was replaced by a stiffened composite plate modeled in ANYS and the load carrying capacity with the stiffened composite was found to be 102.504 tons and the analysis was stopped using maximum stress criteria, which gave the increase in load carrying capacity up to 20.83%. Weight of the stiffened steel plate was found to be 35kg from the literature survey and the weight of the stiffened composite plate was found to be 8.8 kg in the present analysis, giving the reduction in weight up to 74.85%.

VII. Future Scope

The present study can be extended in the following directions:-

1. Post buckling behavior of the composite plates can be depicted exactly by considering the solid element using nonlinear analysis in ANSYS.
2. The similar nonlinear analysis can be extended for different stiffener sections like I, T, L and hat sections etc.

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