Journal of Material Science and Mechanical Engineering (JMSME)
Print ISSN: 2393-9095; Online ISSN: 2393-9109; Volume 2, Number 5; April-June, 2015 pp. 381-385

http://www.krishisanskriti.org/jmsme.html

Buckling and Post-buckling of Stiffened Composite Shell: Prediction and Optimization

Sagar A Kulkarni[1] and Shaikh Firoz Ahmed[2]

[1,2]Vishwakarma Institute of Information Technology, Pune
E-mail: [1]sagar.gen@gmail.com, [2]firoz_ahmed49@yahoo.co.in

Abstract—*Composite structures are well known for their high strength to weight ratio. Increased use of composites in weight sensitive applications like submarine hulls, helicopter tails, aircraft fuselages, aerospace carriers etc can cause significant weight reduction without compromising strength and durability. Thin composite structures are susceptible to elastic instability (buckling) under axial force. Thus for safe design, it becomes very essential to accurately predict their critical load and post-buckling behavior. A large number of experimentations were performed by various researchers to study the same.*

This paper presents Finite Element Analysis of stiffened shell made up of Carbon Fibre Reinforced Polymer (CFRP) for prediction of their critical load and to observe their post-buckling behavior. The FEA results are validated with already documented experimental results.

This paper also suggests a structural modification to this shell to optimize its pre-buckling and post-buckling load carrying capacity. It was observed that the pre-buckling load carrying capacity is increased by 2.26times that of the previous.

1. INTRODUCTION

Composites are known for their higher mechanical, chemical, thermal performance as compared to other metals. Composites provide wide range of design freedom than conventional metals due to high stiffness to weight ratio and capacity to handle different loading conditions. There is a wide scope of applications of composites especially in weight sensitive areas like aircraft fuselages, submarine hulls, space launch vehicles and helicopter tails etc. Increased application of composites seems to be the only option to bring down structural weight without actually compromising on strength and durability. In addition to it, for weight reduction is possible if the structure is allowed to undergo buckling during the operation because even in its post-buckled stage it can sustain certain load.

Carbon-epoxy composites can provide same strength as that of the aluminum materials and reduce weight to half! But though there is demand for light weight materials in these fields, we can see that aeronautical structures are still made by metals such as aluminum alloys. This is because comparatively less knowledge of buckling and post-buckling behavior of composite structures.

Structural components used in aeronautical, aerospace, re-entry modules and marine applications are likely to be subjected to static and dynamic loads during their operation and they are susceptible to buckle thus it becomes very essential aspect of design to accurately predict their critical load, mode shapes and post buckling capacity before it collapses. Buckling of engineering structures may occur in a variety of forms, such as global or local deflections, and they might lead to the collapse of structures. Hence, avoiding buckling failure is an essential criterion in design of structural components. A lot of researchers have proved that structures still have the load carrying capacities in their post-buckling phase but it could not be accurately predicted.

What makes the analysis and prediction of composite buckling a challenge? As mentioned by Jifeng Xu, Qun Zhao and Pizhong Qiao [4], initial geometric imperfections including local ply-gaps, non uniform applied end loads, delamination, impact of foreign objects, improper manufacture etc are some of the aspects which hampers load carrying capacity of composite structures. Thus the prediction of delamination-driven buckling becomes an important branch of composite structural analysis.

A series of experiments are conducted by Chiara Bisagni, Potito Cordisco and supported by European commission under title POSICOSS, on composite cylindrical shells under various loading conditions [1,2,3]. Experimental results of one of them is used to validate the analysis presented in this paper [1].

2. FINITE ELEMENT MODEL AND ANALYSIS

Pre-buckling phase of composite is an almost linear process but after the object crosses its critical load level, the buckling comes to the post-buckling phase. As the buckling occurs, the deformed configuration of the structure changes consistently as well as the stiffness of the structure reduces. This means that the behavior of the structure is nonlinear or equivalently that the stiffness of the structure

depends on the deformed configuration. Hence a non linear analysis is needed to be performed to detect its behavior in post buckling phase. Thus this analysis is performed in two phases viz., Linear buckling (Eigen value buckling) and non-linear static analysis [5]. The steps common to both the analyses are modeling and meshing. They are discussed as follows.

2.1 Modeling

Table 2.1

Geometry details	
Shell Diameter (mm)	700
Shell length (mm)	540
Stiffeners:	
Number	8
Length (mm)	540
Width (mm)	25 x 32
Lay-up:	
Skin	[450/-450]
Reinforcements	[450/-450/00/450/-450]
Stiffeners	[00/900]3s

Model of the shell is created and meshed. Element size of is maintained to be approx 11mm to strike a balance between accuracy and solution time. At the rivet peripheral nodes of hole of stringer and skin are connected to respective centrally created node with rigid connection. Later these centrally created nodes are connected together. Element type of SHELL 181 was assigned to the shell elements and BEAM 188 element type was assigned to the rivet connections

Assigned material properties and ply orientations (lay-up) are defined as per the table no 2.1 and 2.2

Table: 2.2

Material Properties	
Young's modulus (longitudinal) [GPa]	57.765
Young's modulus (transverse) [GPa]	53.686
Shear modulus [GPa]	3.065
Poison's ratio	0.048
Density [kg/m3]	1510
Ply thickness [mm]	0.33

The shell is fixed to its bottom edge and and axial compressive load is applied in small load steps.

2.2 Eigen-value buckling analysis

Eigen-value buckling is linear buckling analysis. In this, the model is considered to be an 'ideal' one without any imperfections. But in actual practice the model has many imperfections as mentioned above.

In the analysis that is performed using ANSYS, a unit load was applied at the set of upper nodes. Some of the mode shapes that are obtained are as follows:

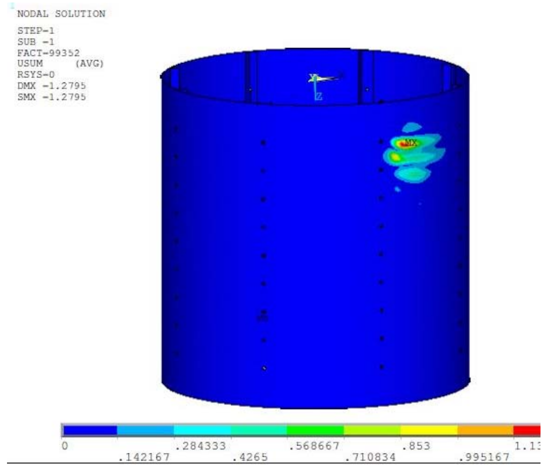


Fig. 2.1: First mode shape showing local buckling at 99.35kN

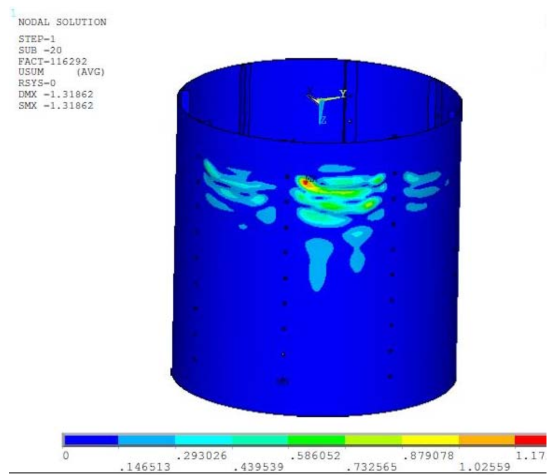
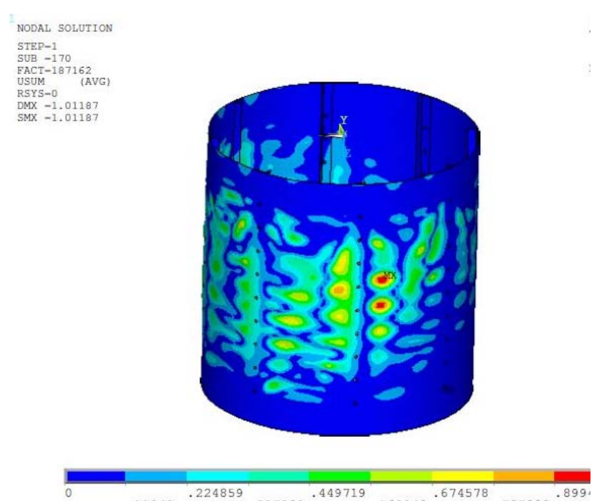


Fig. 2.2: Further mode-shapes showing buckling contours at 116.1kN and 187.16kN respectively



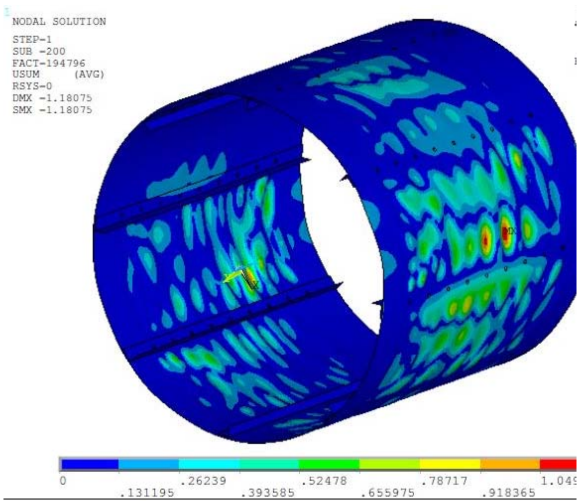


Fig. 2.3: Globally buckled shell at 194.8kN

In this manner through Eigen value buckling, it was predictable that critical load of this shell is approximately at 99kN.

2.3 Non liner static analysis

Non linear analysis was performed by applying displacement of 2mm subdivided in 300 substeps. The results obtained in the form of load vs. axial displacement plot are presented as follows, in comparison with the experimental values [1].

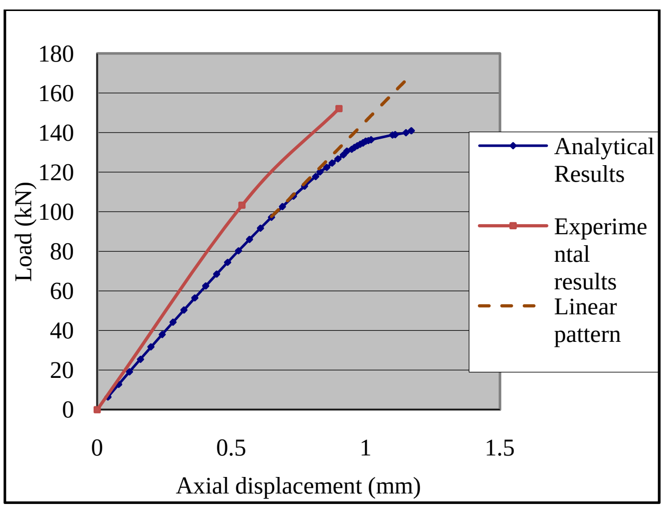


Fig. 2.4: Load vs. displacement plot

It is seen that, in case of analytical results, till 97.25kN the graph follows a linear pattern. But slope of the graph bends after 97.25kN. Thus the critical load of the shell is identified as 97.25kN, at an axial displacement of 0.65mm. In comparison to the experimented results, critical load is estimated as 103.3kN. Both the results match with a very minimal error of 5.8%. This error is on account of Geometric, material non-linearities, thickness variations etc. A comparison in experimental, eigen-value buckling analysis and non-linear analysis is shown in table no. 2.3

Table 2.3: Comparison of results

Experimental critical load (kN) [1]	Critical load estimation by Eigen-value buckling (kN)	Critical load estimation by non-linear buckling (kN)	Error
103.3	99.35	97.25	5.8%

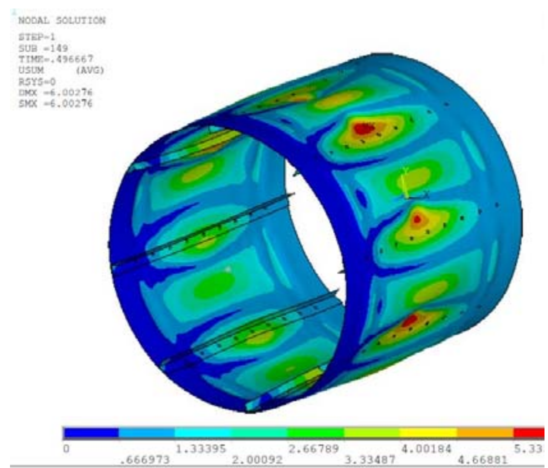


Fig. 2.5: Show the deformed shapes of shell and stiffener

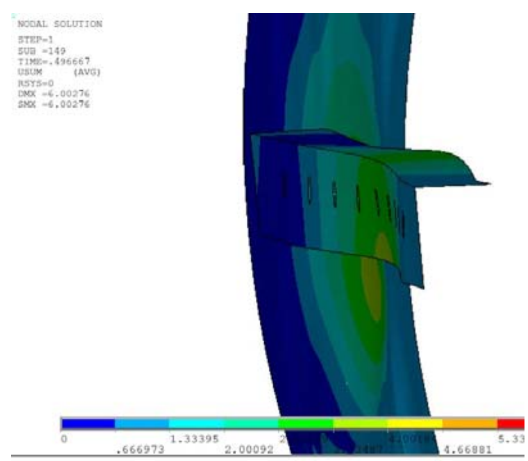


Fig. 2.5 Deformed shape of the shell and stiffener

It can be seen that even after the first local buckling of the shell, though there is reduced stiffness, there is no sudden collapse and the shell can continue to carry more load. Due to large deformations and out of plane movement of the elements, they get distorted and thus FEM software faces difficulty in converging the solution. Thus the analysis could not converge till the collapse load but it gives very clear indications of its load carrying capacity even in post buckling field.

3. OPTIMIZATION OF LOAD CARRYING CAPACITY

It can be seen from Fig. 2.5 that out of plane displacement of the skin takes place maximum at the center of the shell. This is a circumferential reinforcing ring placed around the shell can significantly contribute to the pre-buckling and also post buckling load carrying capacity of the skin.

To study the effect of such a modification in the skin, the same cylinder is re-analyzed using the above mentioned stages. A circumferential ring of width 40mm and ply orientations $[0^0/90^0]_{2s}$ is riveted centrally to its height as shown in Fig. 3.1.

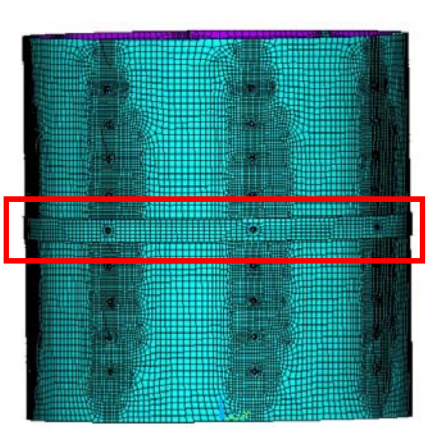


Fig. 3.1: Shell with centrally placed circumferential ring

It is evident from the load vs. displacement plot that, at 220.29kN, the curve shows sudden step and at further increment of load, larger deformation is obtained and the curve bends. Thus critical load of the shell is estimated to be 220.29kN. The deformed shape of the shell is shown in Fig. 3.3.

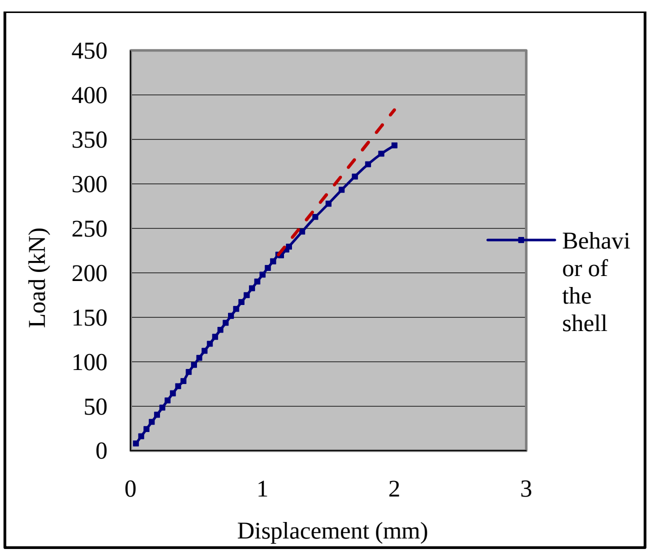


Fig. 3.2: Load vs. displacement plot

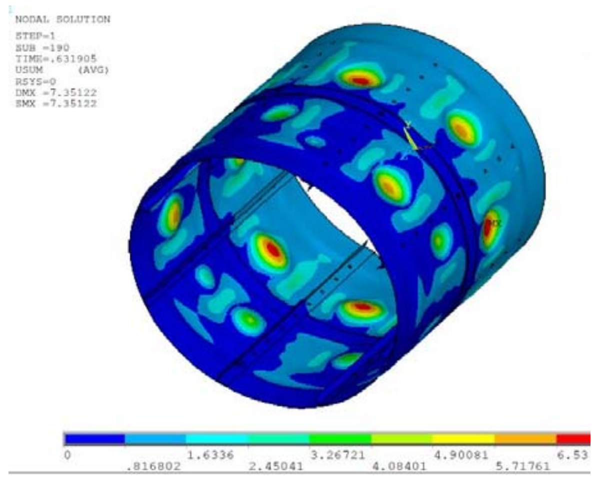


Fig. 3.3: Deformed shape of the shell with circumferential ring

3.1 Comparison of shell with and without the reinforcing ring

Comparative load vs. displacement plot of the shell with and without the central ring is shown in plot no 3.4.

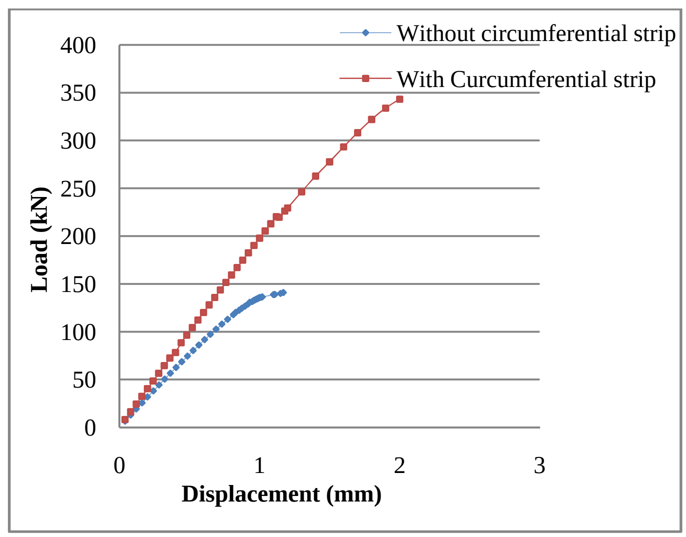


Fig. 3.4: Comparative load vs displacement curves of shell with and without stiffener

Table 3.1 shows % increase of load carrying capacity of the shell after it was reinforced with the circumferential strip.

Table 3.1

Parameter	Shell w/o strip	Shell with strip	% increase
Critical buckling load (kN)	97.25	220.29	126.5
Pre-buckling stiffness(kN/mm)	151.77	200.3	31.97
Post-buckling range	1.45	1.55	7.47

4. CONCLUSION

Critical buckling load was predicted using FEA to be 97.25kN. The value of critical load is close to the experimentally calculated load [1]. A minimal error of 5.8% was found which is on account of geometric irregularities, material anisotropy, thickness variations etc.

It was observed from the load vs displacement curve that the structure continues to carry load even after the first buckling point was reached. This increases design flexibility of composite structures especially in weight sensitive applications.

When the shell was further reinforced with a circumferential strip, there was 2.26times increment in pre-buckling load carrying capacity, 31.97% increase in pre-buckling stiffness and 7.47% increment in post-buckling load carrying capacity of the shell.

REFERENCES

[1] Chiara Bisagni, Potito Cordisco, Post-buckling and collapse experiments of stiffened composite cylindrical shells subjected to axial loading and torque, Composite Structures 73 (2006) 138–149.

[2] Chiara Bisagni, Potito Cordisco, An experimental investigation into the buckling and post-buckling of CFRP shells under combined axial and torsion loading, Composite Structures 60 (2003) 391–402.

[3] Chiara Bisagni, Potito Cordisco and Luca Lanzi, Experimental buckling tests and numerical analyses of stiffened cylindrical shells in composite materials, icas 2002 congress.

[4] Jifeng Xu, Qun Zhao, Pizhong Qiao, A Critical Review on Buckling and Post-Buckling Analysis of composite Structures, Frontiers in Aerospace Engineering Volume 2 Issue 3, August 2013.

[5] Elisa Pietropaoli & Aniello Riccio, Finite Element Analysis of the Stability (Buckling and Post-Buckling) of Composite Laminated Structures: Well Established Procedures and Challenges, Appl Compos Mater (2012) 19:79–96.

[6] Shaikh Firoz Ahmed, Vivek Bhandarkar, Buckling and Post-buckling behavior of CFRP composite cylindrical shells under axial and torsion loading- Prediction and Validation.

[7] D. Hull, T.W. Clyne, An Introduction to Composite Materials, second edition, Cambridge University Press.