BUCKLING ANALYSIS OF TAPERED CURVED LAMINATES USING ANSYS

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Introduction: Due to the variety of tapered curved composite plates and the complexity of the analysis, no buckling behavior analysis is available at present (except the present authors' works) regarding their response to compressive loading. The linear and non-linear buckling analyses of tapered curved composite plates are analyzed using SHELL99 element of ANSYS®. The results using ANSYS® are compared with that of the Finite Element Method (FEM), Classical Shell Theory (CST), and First order Shell Theory (FST) and Ritz analysis. The strength characteristics and load carrying ability of the tapered curved plates are investigated considering first-ply failure and delamination failure. Based on these analyses, the critical sizes and parameters of the tapered curved plates that will not fail before global buckling are determined. A parametric study is also carried out.

Modeling: The tapered curved plate configuration considered has five internal resin pockets as shown in the Fig. 1. The work-plane of ANSYS® was set perpendicular to x-axis and several arcs were drawn by using the center and radius options. Nine areas were created to relate the nine real constants for the tapered cross-section. Fifteen areas were created for the hybrid (tapered and uniform) cross-section. Finally, the areas were glued.

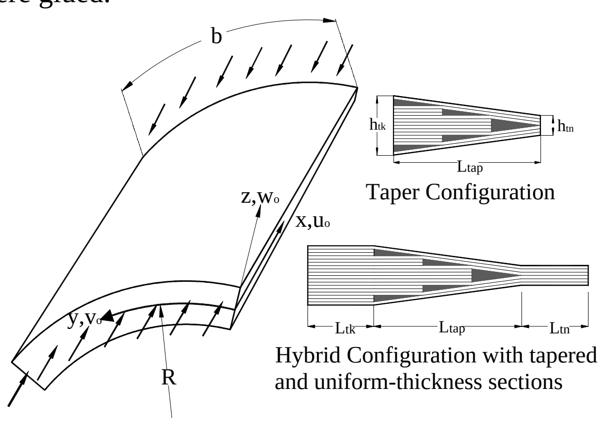


Figure 1: Different sections of curved laminated plate.

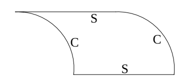
Meshing: Different real constants were assigned corresponding to the longitudinal cross-sections of the laminates. The material properties of composite ply and epoxy resin are given in the Table 1. Based on the convergence test, the mesh selected and used for the taper configuration and hybrid configuration are 9×9 and 15×15 respectively.

Validation: The buckling analysis result obtained using ANSYS® is compared with that of the experimental and analytical solution. The Example 1 of Ref. 3 (clamped-simply supported uniform-thickness cylindrical plate with $[90/0]_{2s}$ lay-up) is considered and the results are shown in the Table 2. It is observed from this table that the critical buckling load calculated using ANSYS® is higher than that of experimental and analytical results.

Table-1: Material properties of NCT/301 graphite-epoxy composite ply and epoxy materials

Composite ply		Epoxy	
Material Property	Value	Material Property	Value
$E_{x''}$	113.9 GPa	$E_{x''} = E_{y''} = E_{z''}$	3.93 GPa
$E_{y''} = E_{z''}$	7.985 GPa	$G_{x''y''} = G_{x''z''} = G_{y''z''}$	1.034 GPa
$G_{x''y''} = G_{x''z''}$	3.137 GPa	$\nu_{x''y''} = \nu_{x''z''} = \nu_{y''z''}$	0.37
$G_{y''z''}$	2.852 GPa		
$\nu_{x''y''} = \nu_{x''z''}$	0.288		
$\nu_{y''z''}$	0.400		

Table-2: Comparison of critical buckling load (N_{cr}) for uniform cylindrical plate using different methods

Lay-up Configu-ration	Becker [1] $(N_{cr}L_{tap}^2)/(E_{x''}h_{tk}^3)$		Present $(N_{cr}L_{tap}^2)/(E_{x''}h_{tk}^3)$ 		
	Theo.	Exp.	Donnell's shell theory		ANSYS®
			CST [Ref.2]	FST [Ref.3]	
$[90/0]_{2s}$	33.30	24.50	34.95	34.84	37.34

Parametric Study

Failure Analyses: To study the compressive response of tapered curved plates several types of analyses are carried out using ANSYS®: linear buckling, non-linear buckling, first-ply failure, and delamination failure analyses. A finite element analysis using a Lagrange element has also been carried out independent of ANSYS® solution and referred to as LFE results.

The square taper configuration of radius 0.5 m shown in the Fig. 1 is considered with 36 and 12 plies at the thick end and the thin end respectively. Thickness at the thick end is 4.5 mm and the lay-up configuration LC_1 of Table 3 is considered. The mechanical properties are the same as given in the Table 1.

Table-3: List of lay-up configurations

Lay-up Configu-ration	Ply staking sequence		Lengths of the plate (m)		
	Thick section	Thin section	Thick section	Tapered section	Thin section
LC_1	$[0/90]_{9s}$	$[0/90]_{3s}$	0.0382	0.1146	0.0382
LC_2	$[\pm 45]_{9s}$	$[\pm 45]_{3s}$	0.0382	0.1146	0.0382
LC_3	$[0_2/\pm 45_8]_s$	$[0_2/\pm 45_2]_s$	0.0382	0.1146	0.0382

The 3-D version of Tsai-Wu failure criterion is used for the analysis of first-ply failure to find out the critical sizes of the plates that will not fail before global buckling. The same computational procedure is applied for both composite ply and resin pocket. The results of first ply failure and delamination analyses are tabulated in the Tables 4 and 5 respectively.

Table 4: Critical buckling and first-ply failure loads (×10⁴ N/m) of tapered curved plate with clamped boundary condition

Taper Angle (ϕ^o)	Buckling Load Using ANSYS®	First-ply Failure Load	Failure Location (FE, FL)*
0.10	14.08	48.05	1, 2
0.50	42.00	48.75	1, 3
0.75	62.17	45.05	1, 3
1.00	92.08	51.67	9, 34

Table 5: Average interlaminar shear stress of taper curved plate with clamped boundary condition

Taper angle (ϕ^o)	Buckling load using ANSYS® (× 10⁴ N/m)	Maximum interlaminar shear stress, (MPa)	Location (FE, LL)*	Remark
0.50	42.00	0.95	63, 15	No
0.75	62.17	1.00	63, 15	Delamination
1.00	92.08	1.445	63, 5	Failure

* FE, FL and LL denote, respectively, the Failed Element and Failed Layer numbers at first-ply failure, and Lower Layer number (adjacent to the interface) that has maximum interlaminer shear stress

Critical size of the tapered plate: The critical buckling load and first-ply failure load of Table 4 are plotted in the Fig. 2. The critical sizes of the tapered plates corresponding to 0.51 and 0.79 degrees are obtained from the linear and non-linear analyses respectively. The critical sizes corresponding to varius radii are also shown in the Fig. 3.

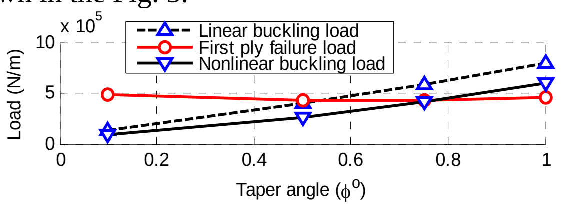


Figure 2: Variation of buckling and first-ply failure load with the change of taper angle (R=0.5 m).

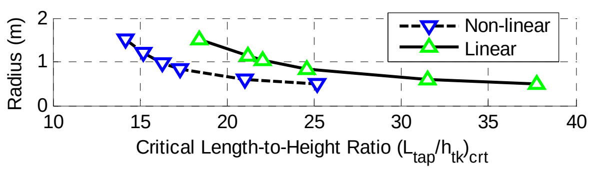


Figure 3: Variation of critical length-to-height ratio with the change of radius.

As can be seen from the Fig. 3, the critical length-to-height ratio increases with the decrease of radius as the plates become stiffer with the decrease of radius.

Behavior of Hybrid Curved Plates: The hybrid configuration (with tapered and uniform-thickness sections) is taken into account in the present section. The tapered section of hybrid plate is modeled using the taper configuration considered in the above and three types of lay-up configurations, namely LC_1, LC_2 and LC_3 given in the Table 3 are considered. For the buckling analysis, a width of b = 114.6 mm and the material properties given in Table 1 are considered. Figs. 4-6 show the variation of linear critical buckling load with the increase of radius calculated using different solution methods.

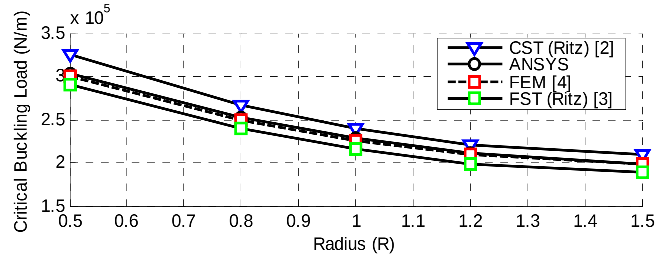


Figure 4: Variation of critical buckling load with the radius for the clamped hybrid laminate with LC_1 lay-up configuration.

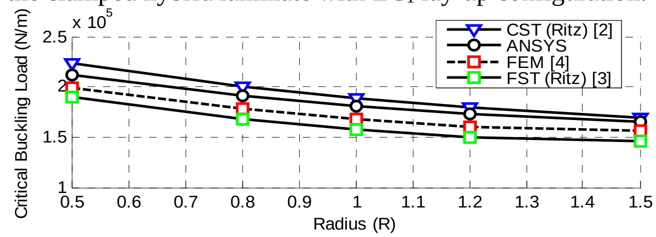


Figure 5: Variation of critical buckling load with the radius for the clamped hybrid laminate with LC_2 lay-up configuration.

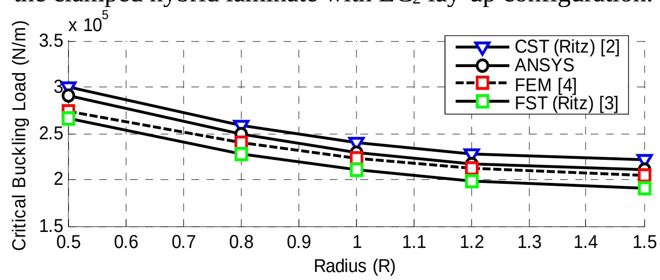


Figure 6: Variations of critical buckling load with the change of radius for the clamped hybrid laminate with LC_3 lay-up configuration.

It is observed from Figs. 4-6 that the normalized critical buckling loads of all lay-up configurations decrease with the increase of radius-to-thickness ratio of the plates.

Conclusions: The critical buckling loads calculated using ANSYS® are higher than that obtained using FEM and FST. The critical size and the critical buckling load of tapered/hybrid curved plates decease with the increase of radii. At higher value of radius, lay-up configurations LC_3, LC_1 and LC_2 become the strongest, moderate and weakest laminate respectively.

References

1. M. L. Becker, "Analytical/Experimental Investigation of the Instability of Composite Cylindrical Panels", MSc Thesis, Wright-Patterson AFB, OH, *Air Force Institute of Tech*, 1979.

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3. S. Akhlaque-E-Rasul and R. Ganesan, "The Compressive Response of Tapered Curved Composite Plates", *The* Annual Technical C*onference of American Society for Composites* (ASC), University of Delaware, Delaware, USA, 2009.

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