

RamSeries - Validation 1

Benchmarks for membrane and bending analysis of laminated shells

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1. Validation Case 1 - Laminate Shell Strength Analysis

1.1. Model Description

This document presents the results regarding a set of academic benchmark problems for the analysis of the strength of laminated shells subjected to mechanical membrane and bending loads [1]. In all cases, a single 4-noded quadrilateral element is used for shell discretization. An schematic representation of the shell geometry under analysis is presented in Fig.1.

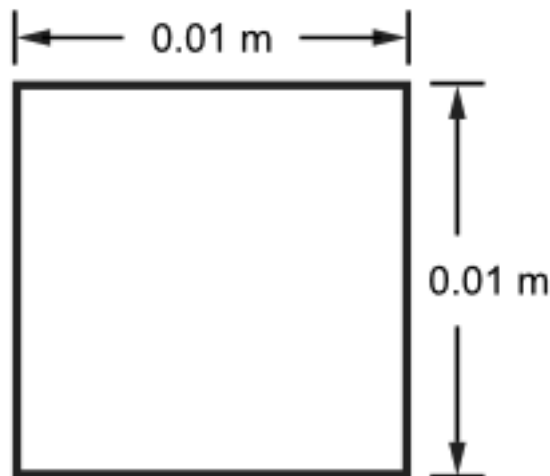


Fig.1. Dimensions of the laminated shell under analysis. The shell is discretized using a single quadrilateral element.

The laminate's stacking sequence, ply thickness and ply orientation, unidirectional stiffness properties and unidirectional strength properties are the same in the three cases under analysis (see Tables 1-2). Only the actual load and boundary conditions are varied from one case to the other. The corresponding constrained degrees of freedom and nodal loads to achieve a unit tension per unit length in the laminate reference axis are summarized in Tables 3-5 for the three considered cases.

Ply orientation (deg)	Ply thickness (m)
90	5.00E-05
-45	5.00E-05
45	5.00E-05
0	5.00E-05

Table 1. Lay-up of the laminated shell under analysis. Orientation and thickness of the four plies of the laminate are reported.

Unidirectional module	(Pa)	Unidirectional strength	(Pa)
E1	2.07E+11	slt	5.00E+08
Et	7.60E+09	slc	3.50E+08
Glt	5.00E+09	stt	5.00E+06

nlt	0.3	stc	7.50E+07
		tlt	3.50E+07

Table 2. Material properties of all four individual plies of the laminated shell. In the three cases under analysis the elastic properties and admissible stresses of the constituent material of all four layers of the laminate are identical.

The three test cases under consideration differ only by their load and boundary conditions. Constrained degrees of freedom and nodal loads are summarized for each test case in the following tables.

LSSAM - Case 1						
Laminated load	N ₁	N ₂	N ₁₂	M ₁	M ₂	M ₁₂
	1.50E+03	0	0	0	0	0
Constrained degrees of freedom (1 = Fixed , 0 = Free)						
Node #	X	Y	Z	θ _x	θ _y	θ _z
1	1	1	1	1	1	1
2	0	0	0	0	0	1
3	0	0	0	0	0	1
4	1	0	0	0	0	1
Nodal loads						
Node #	F _x	F _y	F _z	M _x	M _y	M _z
1	0	0	0	0	0	0
2	7.5	0	0	0	0	0
3	7.5	0	0	0	0	0
4	0	0	0	0	0	0

Table 3. Constrained degrees of freedom and nodal loads applied in case 1.

LSSAM - Case 2						
Laminated load	N ₁	N ₂	N ₁₂	M ₁	M ₂	M ₁₂
	23.125	-25.0	5.0	-0.750	0.4	-0.175
Constrained degrees of freedom (1 = Fixed , 0 = Free)						
Node #	X	Y	Z	θ _x	θ _y	θ _z
1	1	1	1	0	0	1
2	0	1	1	0	0	1
3	0	0	0	0	0	1
4	0	0	1	0	0	1
Nodal loads						
Node #	F _x	F _y	F _z	M _x	M _y	M _z
1	0	0	0	0	0	0
2	0.1375	0	0	0	7.50E-03	0
3	0.09375	-0.125	0	4.00E-03	7.50E-03	0
4	-0.04375	-0.125	0	4.00E-03	0	0

Table 4. Constrained degrees of freedom and nodal loads applied in case 2.

LSSAM - Case 3						
Laminated load	N ₁	N ₂	N ₁₂	M ₁	M ₂	M ₁₂
	26.573	-28.728	5.7455	-0.8618	0.45964	-0.2011
Constrained degrees of freedom (1 = Fixed , 0 = Free)						
Node #	X	Y	Z	θ _x	θ _y	θ _z
1	1	1	1	0	0	1
2	0	1	1	0	0	1
3	0	0	0	0	0	1
4	0	0	1	0	0	1
Nodal loads						
Node #	F _x	F _y	F _z	M _x	M _y	M _z
1	0	0	0	0	0	0
2	0.158	0	0	0	8.618E-03	0
3	0.107728	-0.14363	0	4.596E-03	8.618E-03	0
4	-0.05027	-0.14363	0	4.596E-03	0	0

Table 5. Constrained degrees of freedom and nodal loads applied in case 3.

1.2. Results

For the sake of validation, ply stresses obtained with Ramseries are compared to the results reported in [1]. The failure index and the reserve factor corresponding to the Tsai-Wu criteria are also compared. As it can be observed, the results obtained with RamSeries are in good agreement with those reported in the NAFEMS document [1].

	Ply 1		Ply 2		Ply 3		Ply 4	
	Theory	RamSeries	Theory	RamSeries	Theory	RamSeries	Theory	RamSeries
σ _l (Pa)	-5.1280E+06	-5.1285E+06	1.2590E+07	1.2593E+07	8.5200E+06	8.5204E+06	9.3579E+06	9.3579E+06
σ _t (Pa)	4.4070E+06	4.4073E+06	1.9830E+06	1.9833E+06	1.2560E+06	1.2564E+06	-1.8600E+06	-1.8596E+06
τ _{lt} (Pa)	-1.6630E+06	-1.6635E+06	2.5720E+06	2.5719E+06	-2.0510E+06	-2.0514E+06	-5.5570E+06	-5.5577E+06
Tsai-Wu RF	1.1223	1.1223	2.5367	2.5367	14.3040	14.3010	31.8790	31.8840
Tsai-Wu FI	0.8840	0.8841	0.3731	0.3731	0.0199	0.0199	-0.3431	-0.3430

Table 6. Ply stresses and Tsai-Wu reserve factor and failure index for case 1 (LSSAM1)

	Ply 1		Ply 2		Ply 3		Ply 4	
	Theory	RamSeries	Theory	RamSeries	Theory	RamSeries	Theory	RamSeries
σ _l (Pa)	9.2070E+07	9.2239E+07	-8.5470E+07	-8.5507E+07	-7.0820E+07	-7.8076E+07	1.3640E+08	1.3635E+08
σ _t (Pa)	-3.0440E+07	-3.0405E+07	-1.8840E+07	-1.8847E+07	-1.2247E+07	-1.2247E+07	-1.0650E+07	-1.0650E+07
τ _{lt} (Pa)	2.5620E+07	2.5619E+07	-1.1630E+07	-1.1636E+07	1.3370E+05	1.3230E+05	2.1690E+07	2.1693E+07
Tsai-Wu RF	1.8527	1.8539	4.0967	4.1024	7.3440	7.3467	2.5661	2.5670
Tsai-Wu FI	-2.3598	-2.3594	-2.5439	-2.5415	-1.9038	-1.9031	-1.3300	-1.1314

Table 7. Ply stresses and Tsai-Wu reserve factor and failure index for case 2 (LSSAM2)

	Ply 1		Ply 2		Ply 3		Ply 4	
	Theory	RamSeries	Theory	RamSeries	Theory	RamSeries	Theory	RamSeries
σ _l (Pa)	1.0581E+08	1.0577E+08	-9.8210E+07	-9.8165E+07	-8.1376E+07	-8.1430E+07	1.5670E+08	1.5667E+08
σ _t (Pa)	-3.4970E+07	-3.4969E+07	-2.1650E+07	-2.1650E+07	-1.4070E+07	-1.4073E+07	-1.2240E+07	-1.2241E+07
τ _{lt} (Pa)	2.9440E+07	2.9445E+07	-1.3370E+07	-1.3367E+07	1.5370E+05	1.5576E+05	2.4930E+07	2.4927E+07
Tsai-Wu RF	1.6123	1.6129	3.5651	3.5688	6.3911	6.3920	2.2331	2.2333
Tsai-Wu FI	-2.1290	-2.1276	-2.7689	-2.7670	-2.1325	-2.1321	-1.1354	-1.1330

Table 8. Ply stresses and Tsai-Wu reserve factor and failure index for case 3 (LSSAM3)

1.3. Validation Summary

RamSeries Solver version	14.0.2
CompassFEM version	14.0.2
Validation date	2018/10/23
Benchmark status	Successful

1.4. References

[1] Peter Hopkins. *Benchmarks for Membrane and bending analysis of Laminated Shells. Part 2. Strength Analysis*. ISBN 1 874 376 08 5, 2005 NAFEMS.