Design of Integrally Stiffened Shell Structures

Archa S Lal[1], Jiss K Abraham[2]

[1]M.Tech student, Dept. of Civil Engineering, Saintgits College of Engineering, Kottayam, Kerala, India
[2]Assist.Professor, Dept. of Civil Engineering, Saintgits College of Engineering, Kottayam, Kerala, India

---***---

Abstract - *In launch vehicle structures, for withstanding buckling failures due to the compressive loads and external pressure, integrally stiffened shell structures (waffle and isogrid shell structures) are employed. This paper discusses about the design of cylindrical and conical shaped isogrid structures subjected to axial compression and the external pressure and the effect of variation of design parameters like height of the triangle, skin thickness, rib width, rib depth etc. on the buckling load capacity. First, theoretical computation of the buckling load factor has been carried out using design equations for isogrid structure. A near optimum configuration is arrived at, which results in minimum equivalent weight thickness and positive margins of safety. By using inhouse software FEAST, a parametric modeling tool has been developed for modeling isogrid and waffle shell structures. Static analysis, buckling analysis and free vibration analysis have been carried out for both structures using FEAST software. By comparing the results, isogrid structures have less static displacement and more buckling load factor when compared with waffle structure.*

Key Words: Integrally Stiffened Shell Structure, Waffle and Isogrid Shell Structures, Finite Element Analysis, Static and Buckling Analysis, FEAST[SMT] Software.

1. INTRODUCTION

Structures form the backbone of any launch vehicle. In order to make launch vehicle low weight and effective, thin shell structures are used for the manufacturing of launch vehicle structures. For withstanding buckling failures like general instability, skin buckling and rib crippling due to the axial compressive load and external pressure, integrally stiffened shell structures are employed. Recently, isogrid structures due to its high structural efficiency because of triangular rib pattern and low weight are used. The designing of isogrid shell structure is the tedious and most important problem aroused in the field of aeronautics. In waffle structures, since lattices are made separate from the skin and assembled to the skin, it will result in tension, compression, bending, shear etc. Hence, isogrid structures developed by neglecting these problems since skin and lattice are made out of one part. Parametric study for the determination of optimum design for isogrid structures are hence important for modeling, analysis and fabrication. This result compared with the result of an already existing waffle structure having optimum design parameters.

1.1 Waffle Shell Structures

Waffle structure is also called orthogonally stiffened shell structure, where the shell is stiffened by the use of longitudinal stiffeners and circumferential rings. The stiffeners can be oriented either in 45degree or 90 degree. This wall stiffening helps in increasing the buckling strength without increasing the weight, when compared to monocoque structures. These are ideal for structures subjected to external pressure.

1.2 Isogrid Shell Structures

Isogrid is a type of partially hollowed- out structure formed usually from a single metal plate with triangular integral stiffening ribs. It is extremely light and stiff.

Isogrids are manufactured from single sheets of material and with large-scale triangular openings and an open pattern to the flanges. The triangular pattern is very efficient because it retains rigidity and also it is saving material content of the structure. Hence we can reduce the structural weight. The term isogrid is used because the structure acts like an isotropic material, with equal properties measured in any direction, and grid, referring to the sheet and stiffeners structure.

Isogrid design aspects

An isogrid structure is characterized by face- sheet thickness(t), rib thickness(b), rib depth(d), and height of triangle(h).These parameters ensure simultaneous failure of isogrid structure by local skin buckling, rib crippling and general instability. It will provide minimum weight to structures.

2. Scope and Methodology

Main scope of the thesis is to obtain an efficient design of aerospace structures by adopting isogrid pattern in cylindrical and conical shells.
According to NASA-CR-124075, "ISOGRID DESIGN HANDBOOK", to get an optimum design parameter, minimum equivalent weight thickness, t' and positive margin of safety corresponding to buckling failure are considered

for theoretical calculation .The optimum design parameters adopted for the design of model are skin thickness t= 2mm, rib width, b =3mm, rib depth, d= 18mm, height of the triangle, h = 100mm. Modelling is carried out in an inhouse software FEAST. Design loads considered are;
Axial compressive load =2000KN
External pressure = 100KPa.

Suitable boundary conditions are provided at the top and bottom. Material used for isogrid and waffle structure is Aluminium, having Young's modulus as 70000N/mm^2 and poissons ratios 0.3. Software used for the finite element analysis is inhouse software FEAST^{SMT} developed in VSSC.

Free vibration analysis

Free vibration analysis is conducted on isogrid and waffle structures both for conical and cylinder. Free vibration analysis is done to determine the frequencies for different modes and to check the stiffness criteria of the shell structure. During the free vibration analysis the top and bottom of the structure are constrained.

Table -1: Comparison Of Frequencies Obtained From Free Vibration

Modes	Frequencies(Hz)			
	Conical		Cylindrical	
	Isogrid	Waffle	Isogrid	Waffle
1	156.002	144.727	83.6083	76.0726
2	160.239	144.728	84.1269	78.7704
3	160.627	148.659	86.5771	80.2113
4	160.978	148.66	86.9284	81.6156
5	165.209	149.729	87.8894	83.6772

While comparing the results of frequencies obtained for conical and cylindrical shaped isogrid and waffle shell structures, the frequency is high for isogrid structures when compared with waffle shell structure. Hence we can say that the isogrid structure having its triangular rib pattern is stiffer than waffle shell structure of rectangular rib pattern.

Static Analysis

Static analysis is done for the conical and cylindrical shaped isogrid and waffle shell structures, which are subjected to axial compressive load and external pressure. Maximum deflection and stresses corresponding to the axial compressive load and external pressure are determined and it is shown below.
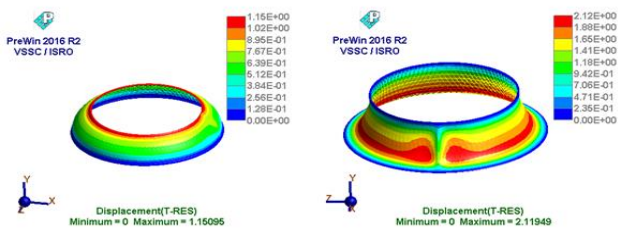

Fig -1: Deflection contour for conical isogrid under axial loading and external pressure
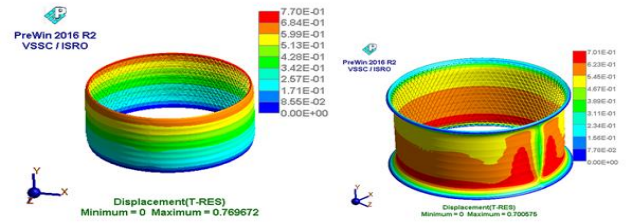

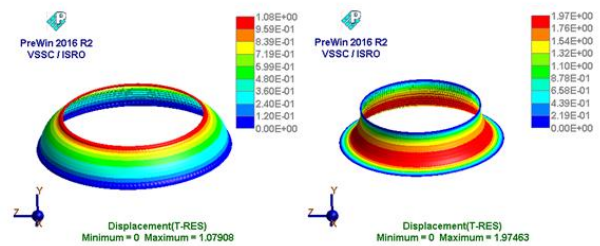**Fig -2** Deflection contour for cylindrical isogrid under axial loading and external pressure

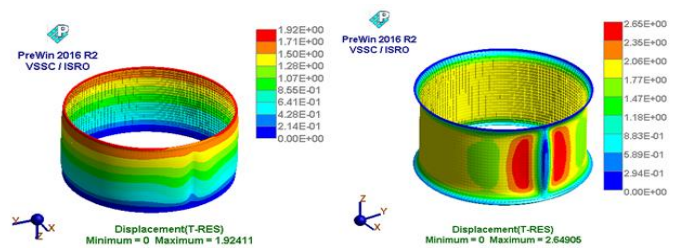**Fig -3:** Deflection contour for conical waffle under axial loading and external pressure

Fig -4: Deflection contour for cylindrical waffle under axial loading and external pressure

Table -2: Comparison Of Deflection Obtained From Static Analysis

Load	Deflection (mm)			
	Conical		Cylindrical	
	Isogrid	Waffle	Isogrid	Waffle
Axial load	1.15	1.07	0.76	1.92
External pressure	2.1194	1.9746	0.7005	2.649

By comparing the results obtained during static analysis, the deflection is maximum for waffle structure than isogrid structure. Minimum deflection of the structure under axial loading and external pressure will result in high structural stability and it will result in additional buckling of the structure. Hence it enhances the efficiency of the launch vehicle.

Table -3: Comparison Of Stress Obtained From Static Analysis

Maximum Stress (N\mm²)				
load	Conical		Cylindrical	
	Isogrid	Waffle	Isogrid	Waffle
Axial load(KN}	88.4	103.91	45.54	83.24
External pressure (KPa)	85.8	102.913	52.74	124.90

When axial compressive load and external pressure is applied, maximum stress will develop either in top, middle or bottom of the structure and comparing the stress obtained for conical and cylindrical shaped isogrid and waffle shell structures, stress developed in waffle structures are comparatively higher than isogrid structures. Since waffle structure is made by assembling the skin and rib, while isogrid is an isotropic integrally stiffened shell structure.

Buckling Analysis

Buckling analysis is carried out to find the buckling load factor of the conical and cylindrical shaped isogrid and waffle shell structures, which is subjected to axial compressive load and external pressure, using the FEAST^{SMT} software and buckling load factor corresponding to mode 1 is taken for comparison.
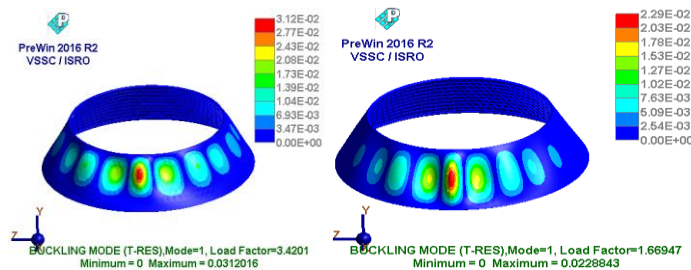

Fig -5: Buckling contour for mode shape 1 for conical isogrid shell structure under axial load and external pressure.
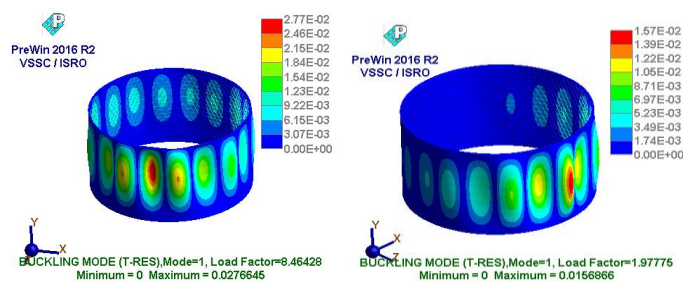

Fig -6: Buckling contour for mode shape 1 for cylindrical isogrid shell structure under axial load and external pressure.
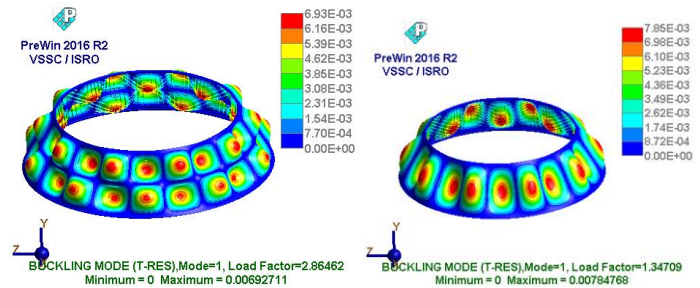

Fig -7: Buckling contour for mode shape 1 for conical waffle shell structure under axial load and external pressure.
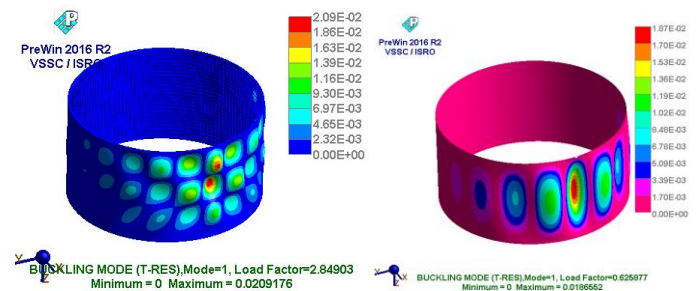

Fig -8: Buckling contour for mode shape 1 for cylindrical waffle shell structure under axial load and external pressure.

Buckling Load Factor(mode1)			
Shape	Load	Isogrid	Waffle
Conical Shell Structure	Axial Load	3.4201	2.86462
	External Pressure	1.66947	1.34709
Cylinder Shell Structure	Axial Load	8.46428	2.84903
	External Pressure	1.97775	0.625877

From the above result for buckling it is observed that isogrid structures have higher buckling load factor when compared to waffle shell structures under both axial load application and external pressure. Hence isogrid structure with optimum design parameters can resist the buckling than waffle shell structure due to the triangular rib pattern given to the stiffeners.

3. CONCLUSIONS

In launch vehicles, buckling failure will occur since it is made out of thin shell structures if load acting on it is very high. So design of shell structure mainly depends on the maximum load acting on it. By taking two load cases, axial compressive load and external pressure, a parametric study is done theoretically and using the optimum design parameter for minimum equivalent weight thickness and positive margin of safety for buckling load capacity, an isogrid model is analyzed for free vibration, static analysis, and buckling analysis using an inhouse software FEAST^{SMT}. And the results are compared with a waffle structure. From the results we can conclude that;

- Frequencies obtained from free vibration analysis for isogrid is more than waffle, hence isogrid is more stiffer than waffle
- Deflection corresponding to axial compressive load and external pressure is low for isogrid than waffle, hence isogrid structural efficiency is high
- From buckling analysis, buckling load factor for isogrid is more when compared to waffle shell structures.

So, the design parameter adopted for modeling isogrid satisfies the requirement like high structural efficiency, low-weight, and stiffness higher than waffle structure. Here the size of waffle adopted as 80mm x 80mm, that can be easily compared with isogrid structure.

REFERENCES

[1] McDonnell Douglas Astronautics Co., "Isogrid Design Handbook".MDC G4295A(Contract NASA 8-28619)), Feb, 1973.

[2] Danial J Knighton, Delta Launch vehicle Isogrid Structure Nastran analysis,MC Donnell Douglas Astronautics Co,1970

[3] B.Wang et al., "Numerically and experimentally predicted knockdown factors for stiffened shells unde axial compression.,"Science Direct ,2016 , pp.13-24

[4] M.I Baig and T.Y.Yang.,"Buckling Analysis of Orthogonolly stiffened waffle cylinders", J.Spacecraft, 1974, pp. 832-837.

[5] G. Totaro., "Local buckling modelling of isogrid and anisogrid lattice cylindrical shells with triangular cells ", Science Direct,2012,pp. 446-452.

[6] W.Akl et al., "optimization of the static and dynamic characteristics of plates with isogrid stiffeners",Scicence Direct,2008,pp. 513-523.

[7] Kazuo Kunoo and T.Y Yang.,"Minimum Weight design of an orthogolnolly stiffened Waffle cylindrical shell with BucklingConstraints",J.spacecraft,1976,Vol.13,No.3,Pp.1 37-143.

[8] Romy Mathew et al."Design studies of conical shells in launch vehicles."IJIRAE,ISSN:2349-2163, 2015,Issue 4, Vol. 2

[9] Vijay Thammisetty,Narasimha Reddy.,"Optimization of Isogrid Rib- Pattern on Mechanical Housing", IJIRSET,2015,Vol.4, Issue 11,pp. 10929-19036