Design and Analysis of Corrugated Intertank Structure

Christie Mariam Yohannan
PG Student
Department of Civil Engineering
Mar Athanasius College of Engineering, Kothamangalam
Kerala, India

Deepa Varkey
Professor
Department of Civil Engineering
Mar Athanasius College of Engineering, Kothamangalam
Kerala, India

***Abstract*— The study is based on a novel concept of using corrugated shell as the intertank structure. The intertank acts as a structural link connecting the propellant tanks at their ends. The propellant tanks considered here hold cryogenic fuels. Intertank structures in the cryogenic environment are chosen such that its ability to accommodate thermal stresses is also considered. The intertank structure undergoes a large contraction in diameter when the propellant tanks are loaded with fuels at cryogenic temperature. Corrugated structures are efficient in in-plane compression, and thereby ideal in being used as an intertank structure. The corrugated shell structure with sufficient bulkheads are designed and the this is further analyzed using software ANSYS Workbench such that it can withstand the mechanical stresses that its being subjected to without undergoing any buckling.**

***Keywords*— Corrugated shell; intertank; ANSYS Workbench, launch vehicle**

I. INTRODUCTION

Interstages are structures connecting two stages in a launch vehicle. When these are present between fuel tanks, they are called intertank structures. Intertank structures are designed such that they are efficient in accommodating thermal contraction due to the thermal loads from the fuel tanks, and at the same time withstand the mechanical loads that they are subjected to.

Corrugated shell structures are ideal for accommodating in-plane compression due to its geometry. This property of the corrugated structure is used in designing a corrugated shell intertank structure that can withstand the loads coming on it. Analysis of the corrugated shell intertank structure is subsequently done to ensure that the stresses that are developed are within tolerable limits. The intertank structure in a launch vehicle is shown in figure 1.

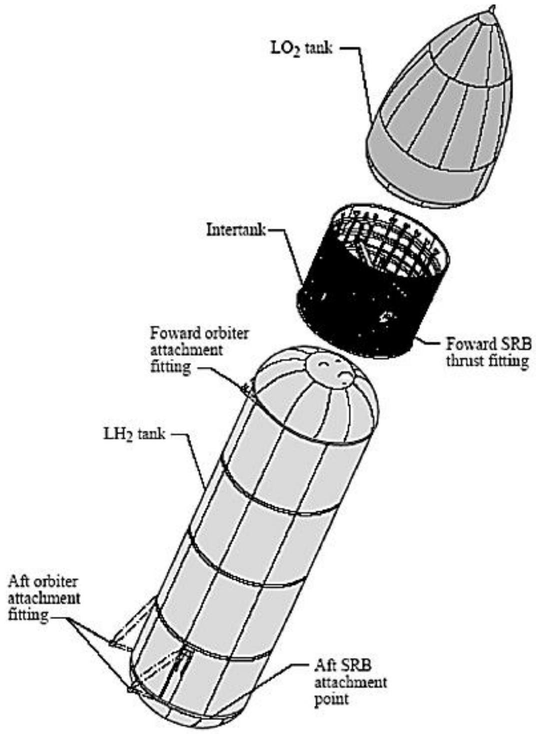

Fig.1 Intertank structure in a launch vehicle

II. PROBLEM DEFINITION

The corrugated shell structure is used to model the intertank structures in the cryogenic stage are used to connect two structures with at least one structure at cryogenic temperature. Cryogenic engines use liquid hydrogen (LH2) as fuel and liquid oxygen (LOX) as the oxidizer. LOX temperature inside the tank is 90K and LH2 temperature is even lower at 20K. The intertank structure at ambient temperature acts as the structural link between the LH2 and the LO2 tanks of the launch vehicle. The intertank structure that's placed is designed such that they can withstand the loads that they are designed for.

III. DESIGN PARAMETERS

The design input data are:

Radius of the cylinder	: 4000 mm
Length of the cylinder	: 2120 mm
Axial Compressive Load	: 3200 kN
Margin of safety is taken as	: 1.3
Young's Modulus of the material	: 70000 N/mm^2
Poisson's ratio	: 0.3

IV. DESIGN OF THE STRUCTURE

The intertank structure made of corrugated cylinder is of 4000mm diameter and 2120mm length. The structure interfaces with the LH2 tank at its fore end and the LOX tank at its aft end. The intertank structure is connected to the cryogenic fuel tanks through end rings. The intertank structure is a corrugated shell that's stiffened internally using C-shaped bulkheads. First, a simplified geometry is considered to represent the corrugated shell intertank structure. The simplicity of the geometry enables us to represent the model with pre-defined mathematical equations to conduct initial studies.

A. Design of corrugated shell

The intertank designed of aluminum was approximated to a corrugated cylinder of diameter, D, length, L, thickness of corrugation, t, width of the corrugation, b and depth of corrugation, f. t, b and f are the variables in the optimization problem. The objective is to minimize the volume of the corrugated shell cylinder by changing the variables to optimize for minimum weight of the structure.

The interstage structure designed as corrugated shell structure for the loads given. The following geometrical design parameters are involved in the corrugated intertank structure. The angle of corrugation (φ) of the corrugated shell was taken as 60^{O} as it was found to be the optimum for the corrugated structure [1]. The cross-section of the corrugated structure is given in figure 2.

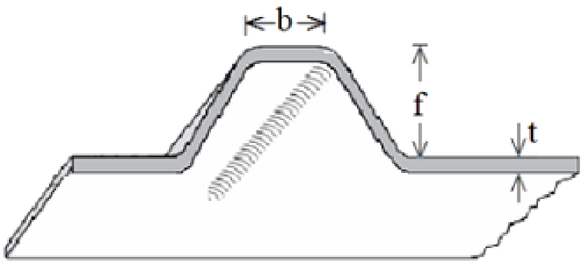

Fig.2 Corrugated shell geometry

The corrugated shell was designed using Johnson-Euler equation used to find the critical load that's required to buckle a column in conditions of low slenderness ratio. Using Johnson-Euler equation;

Using Johnson-Euler equation;

$$F_c = F_{cs} - \frac{F_{cs}^2}{4\pi^2 E}\left(L'/\rho\right) \quad [1]$$

Computing critical stress using Gerard's equation,

$$\frac{F_{cs}}{F_{cy}} = 0.56\left[\left(\frac{gt^2}{A}\right)\left(\frac{E}{F_{cy}}\right)^{1/2}\right]^{0.85} \quad [2]$$

Stress at local buckling,

$$\sigma_{loc} = \frac{k_w \pi^2 E}{12(1-\mu^2)}\left(\frac{t}{b}\right)^2 \quad [3]$$

B. Design of C-shaped bulkheads

In general instability, failure is not confined to the region between two adjacent frames or rings but may extend over a distance of several frame spacing's for a stiffened cylindrical shell in bending. Cross-section of a bulkhead is given in figure 3.

For simplified analysis of general instability of shells, Shanley's equation is ,

$$(EI)_f = C_f \frac{M D^2}{L} \quad [4]$$

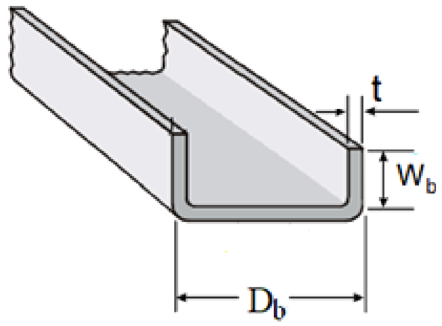

Fig.3 Cross-section of a bulkhead

The value of moment of inertia(I) of the frame section is computed from the Shanley equation and about 4 times its value is taken as the moment of inertia(I) of the bulkhead to be designed such that a node is formed at the corresponding position of the bulkhead, thereby reducing the effective length of the frame section and correspondingly increasing its critical load capacity.

The bulkhead is designed as C-shaped section. The width (W_b) of the bulkhead was designed such that it could accommodate the rivets along the width without any inter rivet buckling.

C. Design of end-rings

The configuration of the end ring at the aft end of the intertank was designed, such that it could connect the ends of the intertank structure to the fuel tanks such that a load path is established between them. The ring configuration is decided so that it accommodates the corrugated shell structure attached to it without inducing any local failures at its point of contact. The joint should be flexible enough such that it would allow sufficient movement at the ends of the corrugated intertank structure.

The figure showing the configuration of the aft ring of the intertank structure is in figure 4.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 04, April-2019

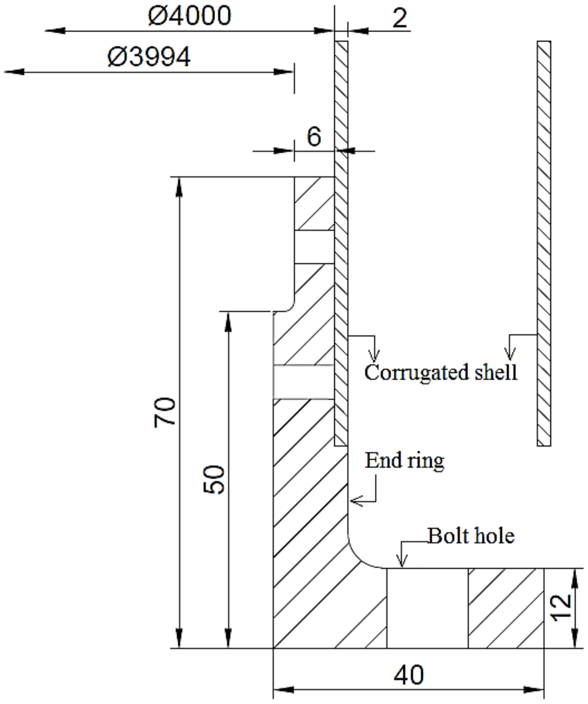

Fig.4 Cross-section of an end ring

D. Results

The optimum values of design variables obtained of corrugated shell and bulkhead from the software MATLAB corresponding to the design requirements are given in table 1.

Table 1. Optimized design variables from MATLAB

Corrugated shell structure			Bulkhead			Buckling load, P_{cr} (kN)
Thickness t (mm)	Width b (mm)	Depth f (mm)	Number of bulkheads	Thickness t_r (mm)	Width b_r (mm)	
2	35	30.23	5	4	50	4545

V. ANSYS WORKBENCH SOFTWARE

ANSYS software is used to simulate interactions of all disciplines of physics, structural, vibration, heat transfer and electromagnetic for engineers. The ANSYS workbench environment provides a complete environment for geometry modelling, mesh manipulation, structural/thermal analysis, and optimization, which is tightly integrated with CAD packages like DesignModeler. So ANSYS enables to test in virtual environment before manufacturing prototypes of products.

VI. FINITE ELEMENT ANALYSIS

ANSYS Mechanical is used for analysis of the geometry. The loads and boundary conditions are defined to the geometry and the local coordinates were set to cylindrical coordinate system. Once the geometry of the structural model has been established using the CAD Software DesignModeler, meshing is used to define the finite elements.

The corrugated intertank structure with bulkheads were modelled and meshed, an axial compressive load of 3200kN was applied and the boundary conditions defined. The analytical results obtained for deformation and stress developed are given in figure 5 and 6 respectively.

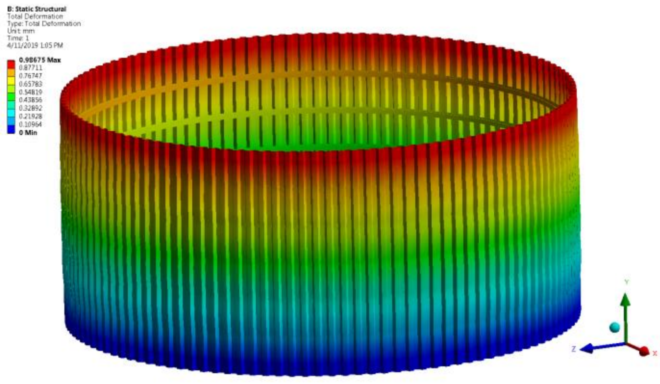
Fig.5 Total deformation in intertank

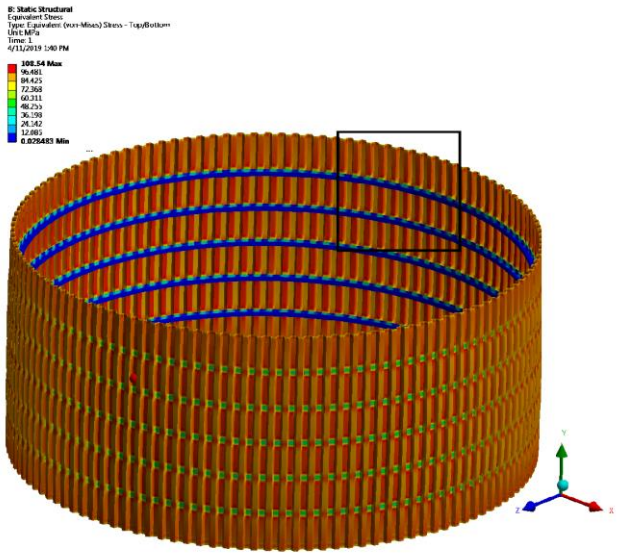
Fig.6 von Mises stress developed in intertank

A. Validation

The theoretical displacement,

$$\delta = \frac{PL}{AE}$$

= 0.961 mm

≈0.968 mm

(obtained from analysis)

The theoretical stress developed,

$$\sigma = \frac{P}{A}$$

= 95.23 MPa

≈ 108.54 MPa

(obtained from analysis)

To define the load line, an existing model of fuel tank was connected to the intertank structure at both its ends using the end rings designed in the previous section. The pressure in the fuel tanks i.e. 0.17 MPa was applied along with the other existing loads and the results obtained. The corresponding deformation and stresses developed in the structure is given in figure 7 and 8 respectively.

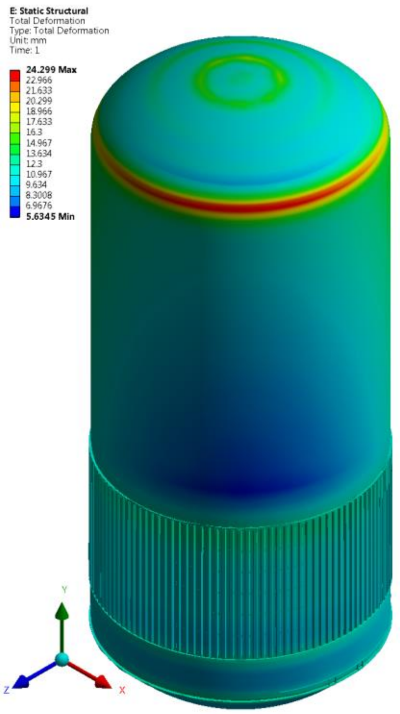

Fig.7 Deformation developed in structure

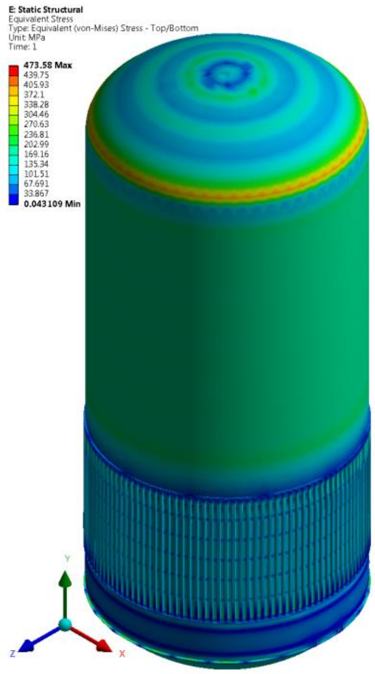

Fig.8 von Mises stress developed in structure

B. Validation

Stress developed due to the axial load of 3200 kN,

$$\sigma = \frac{P}{A} = 121.84 \text{ MPa}$$

Due to the pressure load of 0.17 MPa applied,

Longitudinal stress, $\sigma_{longitudinal} = \frac{P\,r}{2\,t} = 81.4$ MPa

Hoop stress, $\sigma_{hoop} = \frac{P\,r}{t} = 170$ MPa

Therefore, the total stresses developed due to the nodally applied axial load of 3200kN and the pressure load of 0.17 MPa are 203MPa, 291MPa, -40MPa and -48MPa and these tally along with the results obtained analytically

VII. EIGEN VALUE BUCKLING

Eigenvalue buckling analysis in ANSYS Workbench is generally used to estimate the critical buckling load of structures. The analysis is usually a linear perturbation procedure.

Even when the response of a structure is nonlinear before collapse, a general eigenvalue buckling analysis can provide useful estimates of collapse mode shapes. The buckling mode shapes (eigenvectors) are also predicted by the eigenvalue buckling analysis.

The deformation corresponding to Eigen mode 1 for the entire intertank structure along with the LOX tank and LH2 tank is shown and the scaled deformation in intertank structure is given in figure 9. The maximum deformation was seen to occur at the intertank structure. The load factor was given a lowest load factor 2 in ANSYS Workbench by default. The eigen load factor obtained corresponding to the lowest eigen mode of buckling is 2.37.

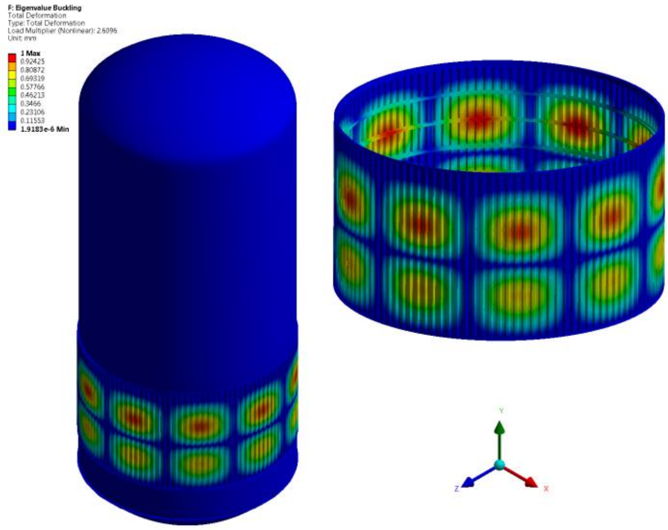

Fig.9 Deformation corresponding to Eigen Buckling analysis

VIII. CONCLUSIONS

The corrugated shell structure geometry with bulkheads were designed and its structural geometry was optimized using the software MATLAB and further analyzed for all the loads that it was subjected to using the FE Software ANSYS Workbench. The stresses and deformations developed were found to be within the limit.

REFERENCES

[1] Peterson P. James, Structural Efficiency of Ring-Stiffened Corrugated Cylinders in Axial Compression , NASA Technical Note, 1967
[2] Bruhn E.F., Analysis and Design of Flight Vehicle Structures, 1965
[3] T.A. Soilars, E.E. Spier, Stability Analysis and Test Verification of Shuttle/Centaur Composite Corrugated Adapters, American Institute of Aeronautics, AIAA Paper No. 83-1003-CP, 1983

[4] Harold J. Kasper, Darryl S, Graphite/Epoxy Composite Adapters for the Space Shuttle/Centaur Vehicle, NASA Technical Paper 3014, 1990
[5] N.P. Semenyuk, N.A. Neskhodovskaya, Design Models in Stability Problems for Corrugated Cylindrical Shells, Proceedings of the Royal Society: Mathematical, Physical & Engineering Science, 2008
[6] N.P. Semenyuk, N.A. Neskhodovskaya, Design Models in Stability Problems for Corrugated Cylindrical Shells, International Applied Mechanics, Vol 38, No 10, 2002
[7] Kumar et al., Thermo-structural analysis of composite structures, Material Science and Engineering, 2005, pp. 66-70
[8] Kumar.et al., Design and Analysis of Intertank Structure for Cryogenic Stage, MAT Journals, 2016, pp. 1-12
[9] Katragadda et al., Optimization of an External Fuel tank of a Space Shuttle, American Institute of Aeronautics and Astronautics, 2011