Buckling of Non-spherical LNG Tank

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Problem

The demand of LNG carriers with larger capacity has increased in the recent years according to Moss Maritime. A modified design of the spherical LNG tank is needed in order to transport an increasing amount of LNG per ship. The idea is to design the LNG tank with spherical end caps and a cylindrical middle section. Existing rules today provide formulas for capacity checks of spherical LNG tanks, but not for a non-spherical tank. The buckling capacity of the non-spherical tank therefore needs to be investigated.

Method

LS-Dyna was used together with LS-PrePost for the finite element analyses in this thesis. Patran was used to create the geometric models, this model was imported to LS-PrePost. The specifications for the analysis was added in LS-PrePost, and the finite element model was solved using LS-Dyna finite element solver. Results were compared with existing rules and formulas if possible.

Models

Several shell models were analysed. These were a half-sphere, the spherical LNG tank, and a non-spherical model. The spherical tank can be

Results

The spherical, and the non-spherical tank were exposed to two different loading conditions. The first loading condition was only external pressure, while the second loading condition included the weight of isolation in the tank, external pressure, acceleration on the material due to ship movements and a sloshing load. The second loading condition is taken from DNVGL (2016). The sloshing load was modelled as a static sloped liquid surface causing a hydrostatic pressure according to DNVGL (2016). The results for the first loading condition are presented first, followed by the second loading condition.

The model of the sphere had a diameter and uniform thickness of 43 m and 55 mm respectively. The non-sphere had a thickness of 55 mm on the spherical sections, and 110 mm thickness on the cylindrical middle section. The increase in thickness is because the circumferential stresses in the cylinder is twice as large as the stresses in the sphere. Both linear and non-linear buckling analysis was performed with the largest initial geometrical imperfection of 40 mm. The ten lowest buckling modes from the linear analyses were used as imperfections in the non-linear analyses. Elastic and elasto-plastic aluminium was used as material in the linear and non-linear analysis respectively.

Table 1: Buckling pressure of spherical and non-spherical tank exposed to external pressure

Model	Lin. buckling pres.	Non-lin. buckling pres.	Analytic lin. pres.
Sphere	0.56 MPa	0.16 MPa	0.54 MPa
Non-sphere	0.29 MPa	0.14 MPa	0.28 MPa

It can be seen from table 1 that the results from LS-Dyna has an error less than 4% compared to analytic results. The non-linear buckling pressure can be seen to be approximately 30% and 50% of the linear value. The spherical tank buckles at the top, while the cylinder buckles in the non-spherical tank.

For the second loading condition, the governing load for failure will be the hydrostatic pressure from the sloshing load. The value of this is examined based on the acceleration in $P = \rho a h$, where ρ is the density of the liquid and h is the height of the liquid. The loads are applied linearly up to a specific value, and the acceleration is increased until buckling occurs. Table 2 summarizes the critical value for the accelerations.

Table 2: Critical acceleration of spherical and non-spherical tank

seen in figure 1, while the non-spherical tank can be seen in figure 2. Both tanks are modelled with the supporting skirt along the equator.
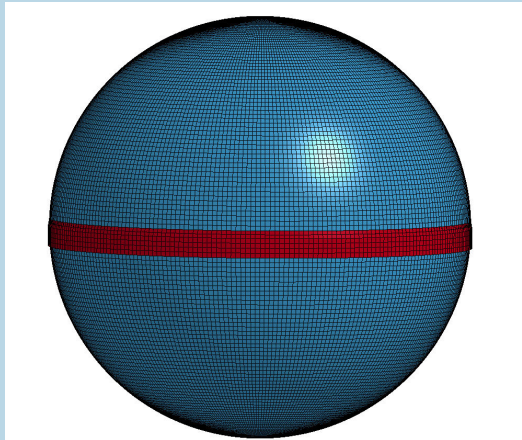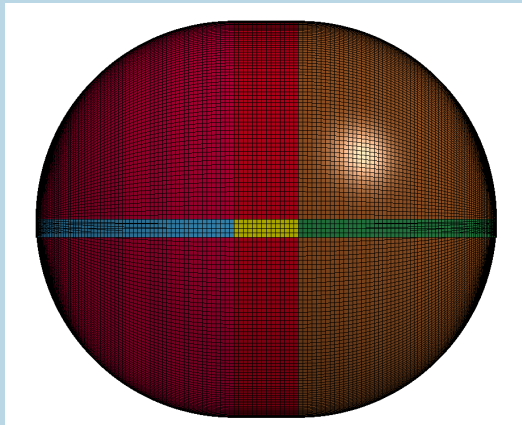

Figure 1: Model of spherical LNG tank

Figure 2: Model of non-spherical LNG tank

References

DNVGL (1997). *Buckling Criteria of LNG Spherical Cargo Tank Containment System - Skirt and Sphere, Classification Notes No. 30.3*. DNVGL.

— (2016). *Liquefied gas carriers with spherical tanks of type B, DNVGL-CG-0134*. DNVGL.

Acknowledgements

Table 2: Critical acceleration of spherical and non-spherical tank

Model	Non-linear critical acceleration on fluid
Sphere	26 m/s^2
Non-Sphere	20 m/s^2

The non-spherical tank can be seen to have a smaller capacity for the sloshing load than the spherical tank. Figure 3 and 4 show how the models buckle because of the sloped liquid surface indicated by the orange line. The structure can be seen to buckle in the area around the liquid surface.
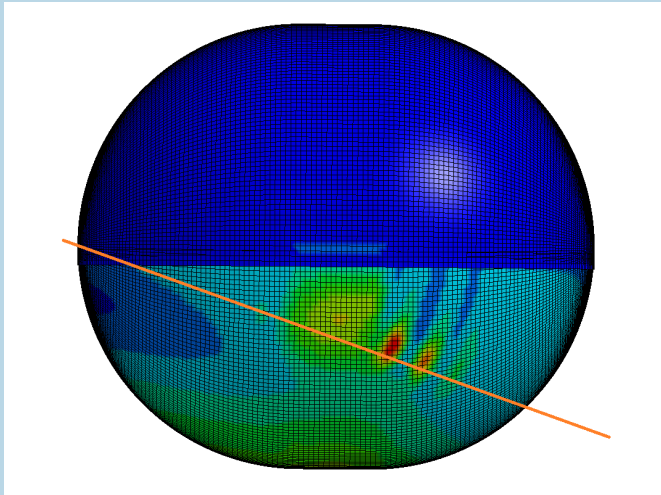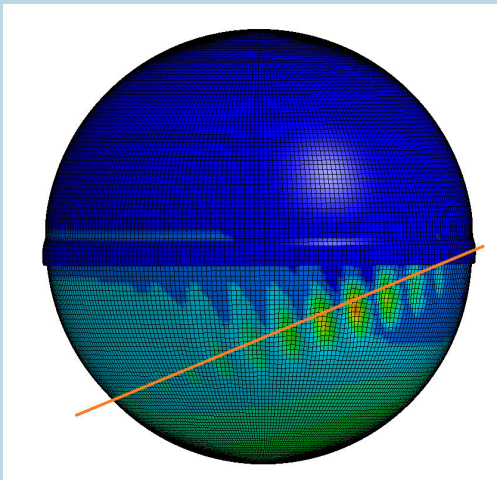

Figure 3: Spherical tank at buckling **Figure 4:** Non-Spherical tank at buckling

Conclusion

The linear buckling pressure for the sphere corresponds to analytic value for a sphere. While the linear buckling pressure for the non-sphere corresponds to analytic value for a cylinder, because the cylinder buckles in the case for the non-sphere. The buckling pressure is seen to decrease severely in the non-linear analysis.

The size of the sloshing load in terms of the acceleration was compared with the rules in DNVGL (1997). The capacity of the sphere is utilized by 50% at critical level from DNV compared to Dyna. And the capacity of the non-sphere is utilized by 75%. A decrease in safety factor is therefore suggested for the non-sphere in order obtain the same level of safety. A safety level of 50% for the non-spherical tank is obtained by multiplying the critical level from DNV with a factor of 0.667 for the sloshing load. Further analyses should include different sections with different thicknesses in the two tanks. These are illustrated in figure 5 and 6.
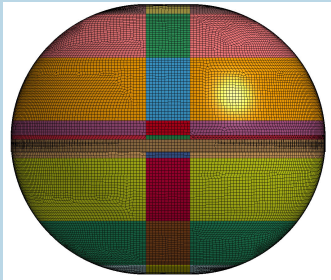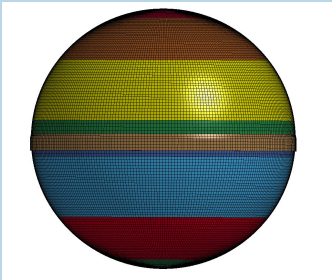

Figure 5: Spherical tank with sections **Figure 6:** Non-spherical tank with sections