

Effect of Geometrical Imperfection on Buckling Failure of ITER VVPSS Tank

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Abstract. The ‘Vacuum Vessel Pressure Suppression System’ (VVPSS) is part of ITER machine, which is designed to protect the ITER Vacuum Vessel and its connected systems, from an over-pressure situation. It is comprised of a partially evacuated tank of stainless steel approximately 46 m long and 6 m in diameter and thickness 30 mm. It is to hold approximately 675 tonnes of water at room temperature to condense the steam resulting from the adverse water leakage into the Vacuum Vessel chamber. For any vacuum vessel, geometrical imperfection has significant effect on buckling failure and structural integrity. Major geometrical imperfection in VVPSS tank depends on form tolerances. To study the effect of geometrical imperfection on buckling failure of VVPSS tank, finite element analysis (FEA) has been performed in line with ASME section VIII division 2 part 5 [1], ‘design by analysis method’. Linear buckling analysis has been performed to get the buckled shape and displacement. Geometrical imperfection due to form tolerance is incorporated in FEA model of VVPSS tank by scaling the resulted buckled shape by a factor ‘60’. This buckled shape model is used as input geometry for plastic collapse and buckling failure assessment. Plastic collapse and buckling failure of VVPSS tank has been assessed by using the elastic-plastic analysis method. This analysis has been performed for different values of form tolerance. The results of analysis show that displacement and load proportionality factor (LPF) vary inversely with form tolerance. For higher values of form tolerance LPF reduces significantly with high values of displacement.

1. Introduction

The ‘Vacuum Vessel Pressure Suppression System’ is part of ITER machine. VVPSS is designed to protect the ITER Vacuum Vessel and its connected systems, from an over-pressure situation. It is comprised of a partially evacuated tank of stainless steel, with dimension approximately 46 m long and 6 m in diameter and thickness of 30 mm. Material of tank is SS304/304L dual mark. VVPSS Suppression Tank is connected to vacuum vessel by relief line which includes rupture disc and bleed valves. The VVPSS shall limit the Vacuum Vessel internal pressure, in the case of loss of coolant from the in-vessel components, to 0.15 MPa absolute by opening the rupture discs to let the steam from the vacuum vessel flow to the VVPSS Suppression Tank, where it can condense. In the case of small in-vessel water ingress or other loss of vacuum accidents, bleed valves open to connect the Vacuum Vessel to the VVPSS Suppression Tank.



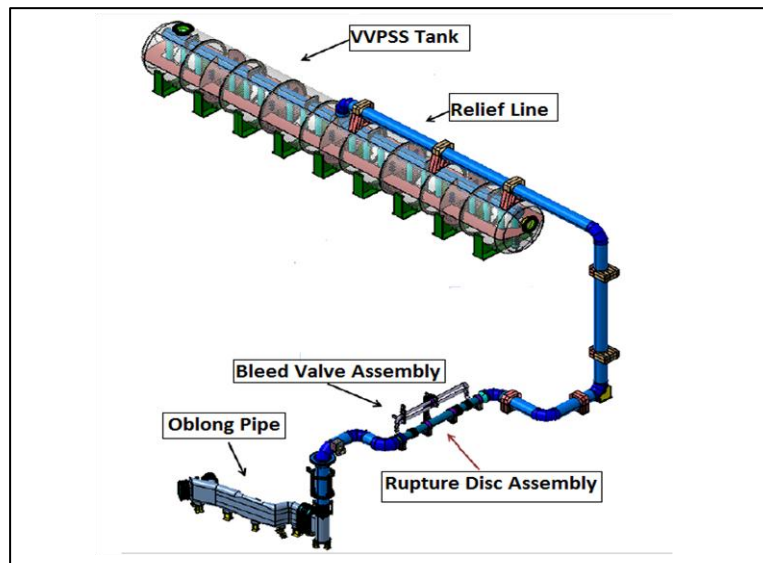


Figure 1. ITER VVPSS System

Geometrical imperfection has significant effect on buckling failure of any vacuum vessel. Major Geometrical imperfection comes from the form tolerance (Permissible out of roundness). Effect of geometrical imperfection on buckling failure of VVPSS suppression tank has been studied by FE analysis in line with ASME BPVC Section VIII Division 2. This Study has been performed for different values of form tolerance (60 mm, 40 mm, 30 mm and 15 mm) and results are shown in this paper.

2. FE Analysis

Linear static analysis, linear buckling analysis and nonlinear buckling analysis of ITER VVPSS Tank has been performed in ANSYS WORKBENCH 15.0. Analysis has been performed for Normal Operation Load case.

2.1. FE Model

VVPSS Tank and part of relief line has been considered for analysis. Geometric model has been prepared by creating a shell model by extracting mid surface from solid CATIA model of VVPSS Tank and relief line. Fillet joints have been modeled by MPC 184 rigid connection. To consider the inertia effect of tank internal, point masses has been applied at Centre of gravity of internal stiffeners.

Model has been meshed with SHELL281 elements and bonded contacts are defined.

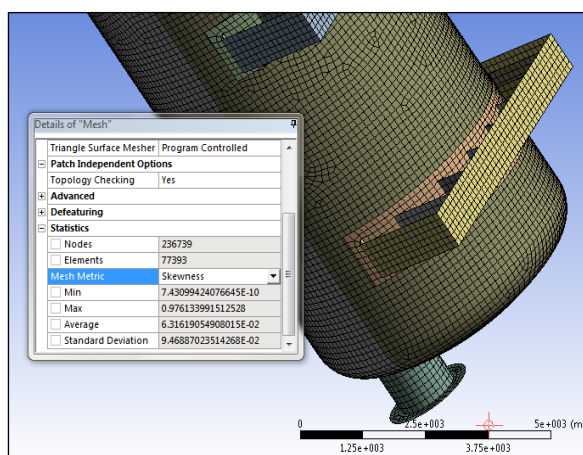


Figure 2.a. Mesh Details (Skewness)

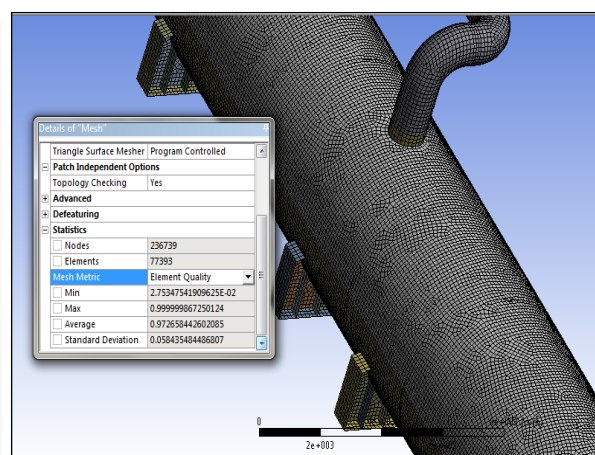


Figure 2.b. Mesh Details (Element Quality)

2.2. Loads

Analysis has been done for Normal operation load case. This load case includes dead weight of tank and relief line, external pressure of 0.1MPa. Tank has been considered half-filled and corresponding to that variable hydrostatic pressure of fluid has been applied to tank. The dead weight of the water has been modelled by modifying the density of the lower half of the tank.

2.3. Linear Analysis

Linear Static structural analysis and Linear Buckling analysis has been performed

First Linear static analysis has been performed for above said load case and plastic collapse and local failure of tank has been assessed as per [1]. Tank has been found safe against plastic collapse and local failure mode.

Linear Elastic buckling analysis has been performed to find the modes of buckling. First Buckling Mode has been amplified up to the form tolerance value to create deformed geometry for nonlinear analysis.

2.4. Non Linear Buckling Analysis

Nonlinear buckling analysis has been performed in line [1] by Elastic plastic method.

2.4.1. Geometrical Imperfection. Geometrical imperfection due to form tolerance of 60mm is incorporated in FE model. Deformation of first mode of linear buckling has been scaled up to 60 mm i.e. up to the form tolerance value. This deformed geometry has been used as input geometry for nonlinear buckling analysis.

2.4.2. Material Nonlinearity. Material Nonlinearity has been included by incorporating the true stress strain graph of material in analysis.

2.4.3. Load combination. Nonlinear buckling analysis has been done for Normal operation load case. The load combination has been followed from ASME section VII division 2. Buckling analysis has been performed up to 3 load proportionality factor (LPF).

Same analysis has been repeated for form tolerance value of 40 mm, 30 mm and 15 mm.

3. Results and Discussions

3.1. Results of Linear analysis

In linear static analysis membrane stress value is 39.9 MPa and sum of membrane and bending stresses are 67 Mpa. Allowable value for membrane stress is 138 MPa and that is for sum of membrane and bending stress is 207 MPa. Plastic Collapse and local failure has been assessed on the basis of [1] by linear elastic analysis.

In linear buckling analysis for the first mode of buckling, the buckling load factor is 15.02. Deformation of this mode has been scaled up to the form tolerance value to incorporate the geometrical imperfection in nonlinear buckling analysis as this is the most likely mode of buckling.

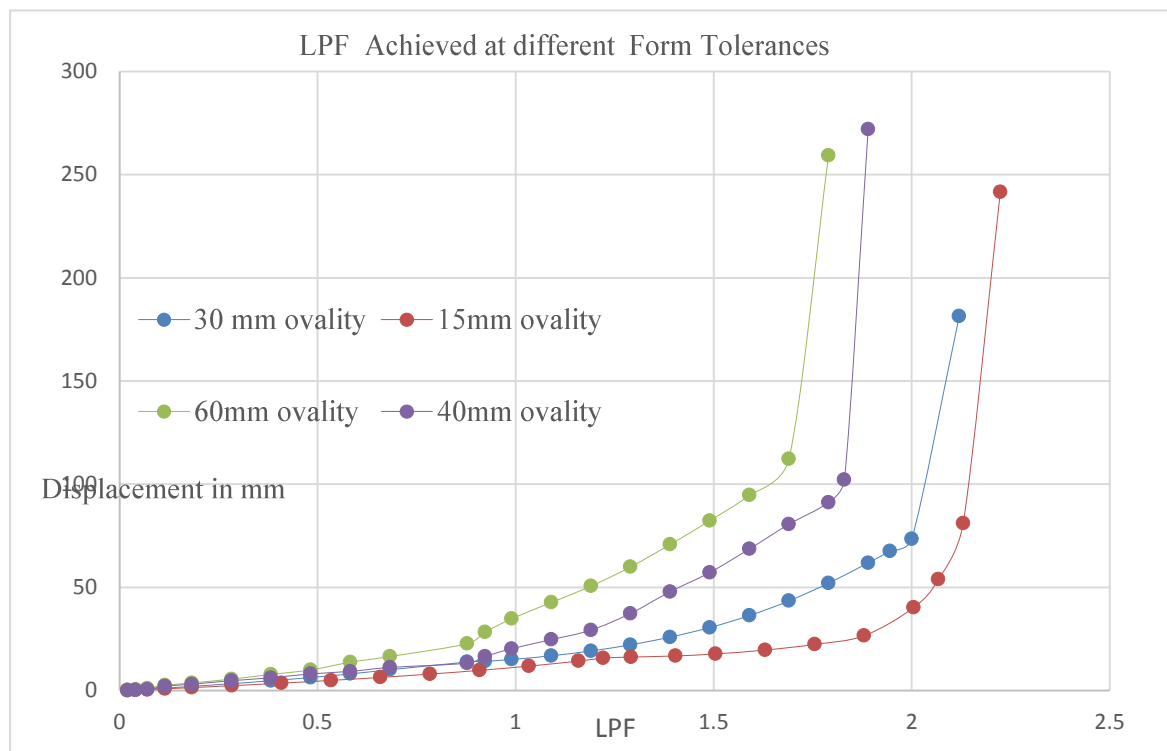
3.2. Results of nonlinear analysis

Nonlinear buckling analysis for different form tolerance values has been performed. The load proportionality factors, displacement and equivalent plastic strain has been noted for different values of form tolerance and presented in Table 1.

Table 1. Results for buckling analysis.

Form Tolerance	LPF	Displacement at LPF =1 (in mm)	Equivalent Plastic Strain at LPF =1	Displacement at Buckling Point (in mm)
15mm	2.13	11.3	0.00116	181.2
30mm	2.02	15.2	0.00126	242.3
40mm	1.83	22.71	0.00164	259.1
60mm	1.69	39.1	0.00244	272

Divergence of analysis has been observed for different form tolerance values. It has been observed that solution diverges with sudden rise in displacement value. This sudden rise in displacement signifies the buckling failure shown in Figure 3. The LPF has been noted at point of buckling. It has been observed that LPF varies inversely with form tolerance. It has been observed that LPF reduces significantly with increase in form tolerance shown in Figure 4.

**Figure 3.** LPF achieved and buckling point at different form tolerances

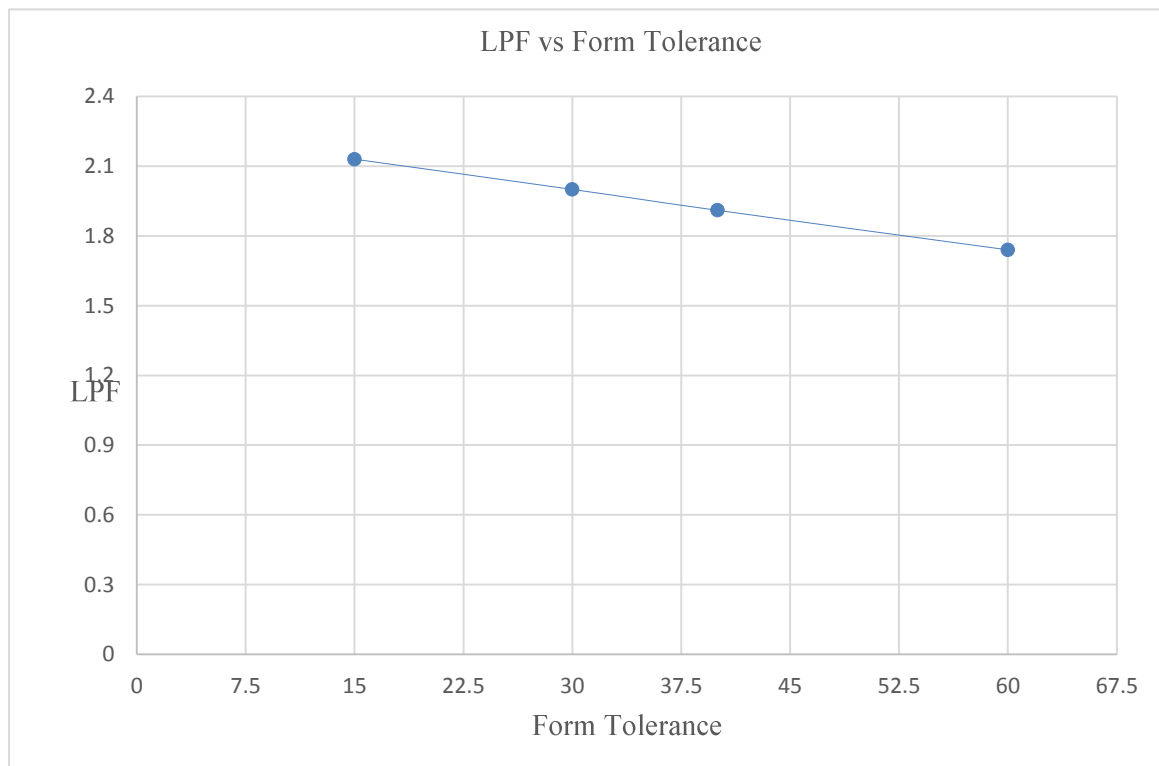


Figure 4. Variation of LPF with different form tolerances

4. Conclusion

The results of Study shows that load proportionality factor (LPF) vary inversely with form tolerance. Displacement and equivalent plastic strain Varies proportionally with form factor .For higher values of form tolerance LPF reduces significantly with high values of displacement.

Acknowledgement

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References

- [1] ASME, "Rules for the Construction of Pressure Vessels," *ASME Boiler and Pressure Vessel Code, Section VIII, Division 2, Alternative Rules*, (2010).