Design and Validation of Spherical Pressure Vessel under Seismic Loads using FEA as per ASME

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Abstract— The present work involves design, modeling and analysis of spherical pressure vessel. In the design of pressure vessel safety is the essential thought, because of the potential effect of conceivable accident. High pressure rise is created in the pressure vessel and pressure vessel needs to withstand extreme forces. The generally applied loads are dead loads, live loads, snow loads, wind loads, seismic loads, thermal stresses, shock, e.g., by crane, fatigue loads, soil and water pressure and others, e.g., load from mechanical device. This work is focusing on designing a spherical pressure vessel as per ASME codes, geometric modeling using CATIA V5 R20 and FEA validation using ANSYS 14.5. Endeavors are made in this work to design the pressure vessel utilizing ASME codes & standards to authorize the design. The obtained FEM results are contrasted with analytical ones and a decent agreement between them is noticed. The seismic resistant design for these bigger storage tanks has turnout to be more critical in terms of safety and the environmental impact on society overall. This work is also focussing on seismic resistance design of a pressure vessel.

Key words: FEA, ASME

I. INTRODUCTION

A closed container intended to hold gases or fluids at a pressure significantly different from the ambient is known as pressure vessel. The pressure difference is perilous and deadly accidents have happened in the historical backdrop of pressure vessel advancement and operation. Common examples are tanks, pipelines and Vessels that convey, store, or receive liquids. Pressure vessels can hypothetically be any shape yet shapes made of segments of spheres, cylinders and cones are normally utilized. Hypothetically, a spherical pressure vessel has pretty nearly double the strength of a cylindrical pressure vessel with the same wall thickness.

Also, these vessels must be outlined deliberately to adapt to the working temperature and pressure. It ought to be remembered that the crack of a pressure vessel can possibly bring about broad physical harm and property harm. Plant wellbeing and trustworthiness are of principal concern in pressure vessel design and these obviously rely on upon the sufficiency of design codes.

A. Seismic Loading

Seismic loading is the essential idea of earthquake engineering which implies utilization of an earthquake generated agitation to a structure. It happens at surfaces of a structure which are in contact with the ground or with adjacent structures.

Seismic loading fundamentally relies on upon,

- Geotechnical parameters of the site.
- seismic hazard, which is the Anticipated earthquake's parameters at the site
- Structures parameters.
- Characteristics of the expected gravity waves.

II. LITERATURE REVIEW

A. *Apurva R. Pendbhaje, Mahesh Gaikwad, Nitin Deshmukh, Rajkumar Patil*

The work presents design and examination of pressure vessel. This work is concentrating on investigating the safety parameter for allowable working pressure. Endeavors are made in this paper to design the pressure vessel utilizing ASME codes & norms to legalize the design.

Code selection is important in the design of pressure vessel to accomplish the safety of pressure vessel. The standards utilized as a part of this work are according to ASME VIII div 2.

It is noticed that all the pressure vessel parts are chosen on basis of available ASME standards and the manufactures likewise take the ASME norms in manufacturing the components. So that leaves the designer free from designing the components. This aspect of Design greatly decreases the Development Time for a new pressure vessel.

B. *Jeevan T. P, Divya H. V:*

In this work impact of cylindrical pressure vessel having torispherical enclosure is taken into consideration. The stress, buckling and vibration characteristics of the pressure vessel subjected to an internal pressure are examined by Finite Element Method (FEM). The two dimensional static stress examinations are performed for various vessel thicknesses to analyze the stresses and deformation in the wall of pressure vessel subjected to internal pressure. Finite Element Analysis was carried out using ANSYS.

They observed taking in to account the outcomes obtained from static stress analysis that the thickness of the pressure vessel takes a vital part in withstanding the applied internal pressure. High stresses occurred at the region of geometric irregularity, i.e. at the head of the cylinder and cylinder intersection. It is observed that the deformity of pressure vessel is un-uniform when the pressure applied is uniform. It is also noticed that the toroidal region of the vessel distorts in inverse course to the spherical and cylindrical region thus it offers large resistance. The stress analysis results acquired by using Finite Element Method are in good agreement with results got by establishing classical approach.

C. *Hossein Kazem and Mahmood Minavand*

The work presents the evaluation and seismic improving of pressure vessels which are among the most important equipments in the field of refining oil. Oil and its products are still the most important source of the energy in the world especially in the industrially developed countries. Therefore safety of oil equipments against the earthquake became very important.

The load considered on the structure consists of the dead load, live load, thermal load, internal pressure load and earthquake load. From results that are obtained from the seismic evaluation and analysis of the vessels, it is seen that the shell of horizontal and vertical pressure vessel is not vulnerable and the static design of the vessel according to the thermal loads and internal pressure is adequate. In most cases for the horizontal pressure vessel the stresses in the connection place of the saddle shaped support of the vessel is high due to seismic load combination, therefore it should be controlled. In most cases the soil under the foundation should be checked for stresses and compared to the allowable values.

III. PRESENT STUDY

Pressure vessels are one of the most important equipments in the refining of crude oil. For this reason, these equipments must be resisting against the loads resulting from earthquake. The present study involves optimizing the model in concern with the seismic resistance. The seismic analysis is carried out by applying the following load conditions.

- Design condition, with and without cross bars.
- Operating condition, with and without cross bars.

A. *Objective of Present Work*

- Perform the modal analysis to determine the natural frequency of the vessel.
- Coupling modal analysis with the response spectrum analysis.
- Validate it as per load case combination mentioned in ASME standards.
- Determining the stress distribution and the deformation and substantiate the value in the limit.
- Also determine the directional acceleration under seismic load.
- Make an observation and conclusions.
- Redesign the support configuration with brazing or cross bars.

IV. GEOMETRICAL MODELING

The geometric modeling of the spherical pressure vessel is done as per ASME codes using CATIAV5 R20 software.

The pressure vessel shell is modeled by taking some allowance to the shell thickness. The shell thickness obtained as per ASME is 14mm and allowances such as corrosion allowance and thinning allowance are added to the obtained thickness. Usually 10% of the obtained thickness value is taken as the allowance. Therefore by applying the allowance the spherical pressure vessel is modeled for the shell thickness of 17mm.

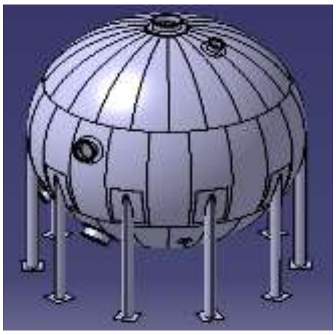


Fig. 1: spherical pressure vessel assembly

Then the pressure vessel is modified by applying cross bars to the support columns in order to strengthen the model.

Fig. 2: Spherical pressure vessel assembly with cross bars

V. ANALYSIS OF SPHERICAL PRESSURE VESSEL

The finite element examination of spherical pressure vessel is conducted based on ASME section viii division ii load combinations. The model is imported in to the ANSYS and the meshing is done by using hexahedral elements. Meshing is the process of discretizing the model in to finite number of elements. In the process of meshing different operations such as merge, slice, sweep etc. are used to obtain good quality of mesh

In order to obtain the results four different analysis are to be performed and these are coupled as shown in the project schematic below.

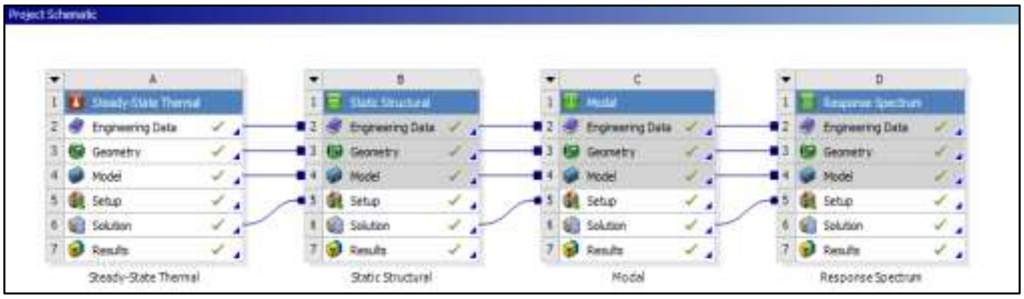


Fig. 3: project schematic

A. *Response Spectrum Analysis:*

Earthquake examinations can be performed by applying various procedures. The most prevalent procedure is the Response Spectrum analysis (RS-analysis). Response spectrum examination is one in which results of modal analysis are utilized with a known response spectrum to know displacements and stresses in the modal. Response spectra are curves plotted between maximum response of the system (may be velocity, acceleration, displacement, or force) subjected to specified earthquake ground motion and its time period (or frequency). The RS-analysis uses the modal results and response spectrum data as input for determination of the earthquake response to obtain directional acceleration.

There are two stages in performing a response spectrum analysis in ANSYS. To start with is to run a modal analysis which will gives the modes/eigenvalues of the structure. Besides to run the Response Spectrum analysis, which do the accompanying.

Here the response spectrum analysis is done where the acceleration of ground is applied in the x direction. Hence, it is important to verify that the effective mass in the x-direction is more than 90 % of the total mass as most codes utilize this as a prerequisite for the RS analysis.

The effective mass participation factor, EMPF (also known as mass participation factor) gives a measure of the energy contained inside each resonant mode, since it says the amount of system mass involved in a particular mode. Therefore the following ideas are considered:

– A mode with a vast effective mass is normally a significant contributor to the response of the system.
– It is possible to calculate a EMPF for a particular direction (x, y or z)
– The aggregate of the effective masses for all modes in a given response direction must equal the total mass of the structure.

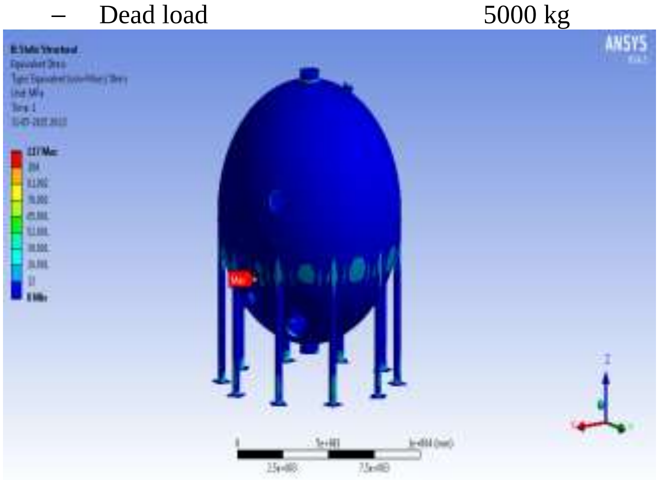
To incorporate the response spectre data, which contains the relation between structural acceleration and the structural frequencies, the tool called RS acceleration is inserted in to ANSYS which includes earthquake data as a table (frequency v/s acceleration).

B. *Load Conditions*

1) *Design Condition without Cross Bars*

Boundary conditions and loads

– Internal pressure	0.125 MPa
– External pressure	0.10134 MPa
– Temperature	70^{o}c
– Convection	2*10^{-5} W/mm^2 ^{o}c
– Standard earth gravity	9806.6 mm/s^2
– Dead load	5000 kg



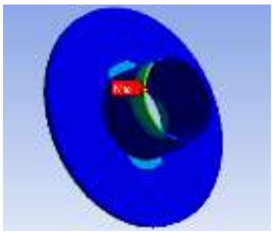


Fig. 4: stress, condition I

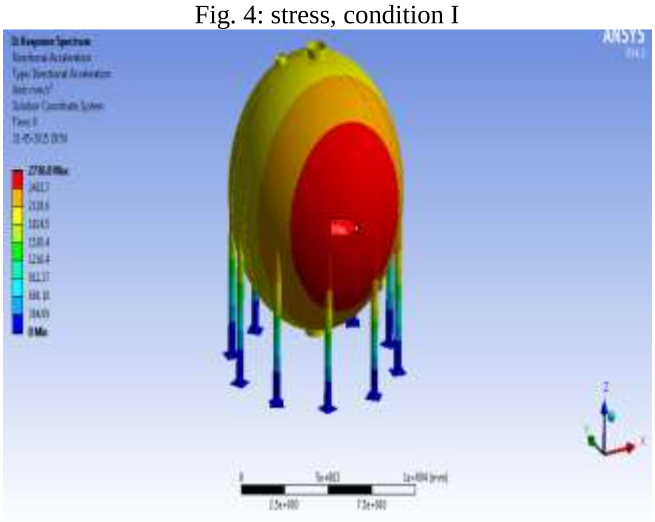
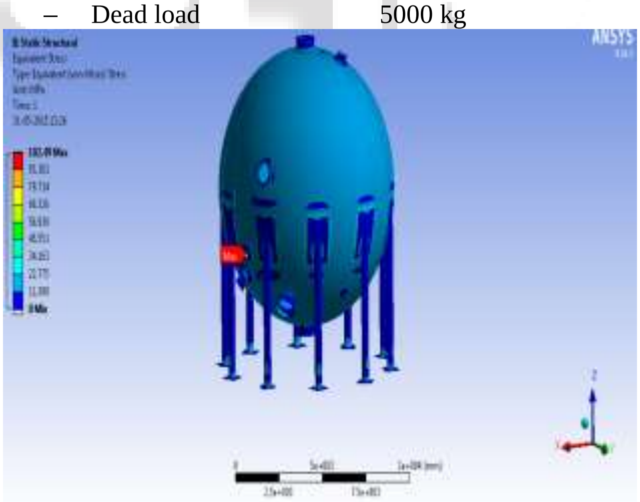


Fig. 5: Directional acceleration, condition I

2) *Operating Condition without Cross Bars*

Boundary conditions and loads

– Internal pressure	1*10^{-5} MPa
– External pressure	0.10134 MPa
– Temperature	60^{o}c
– Convection	2*10^{-5} W/mm^2 ^{o}c
– Standard earth gravity	9806.6 mm/s^2
– Dead load	5000 kg



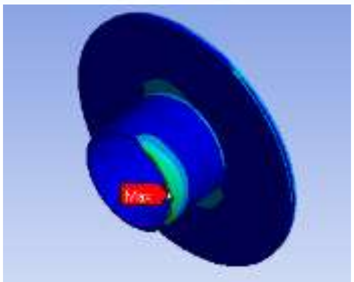


Fig. 6: stress, condition II

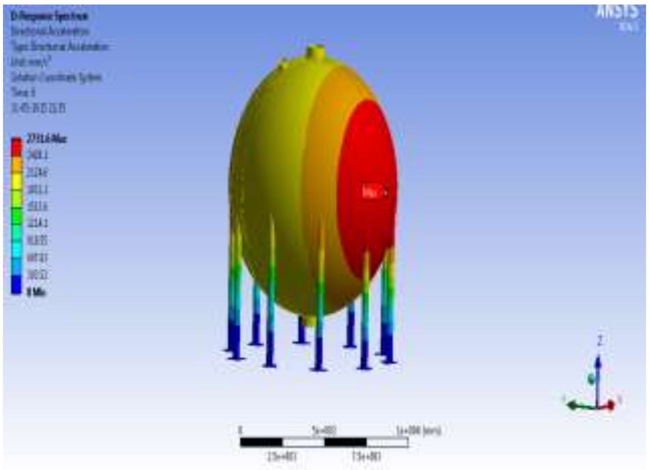


Fig. 7: Directional acceleration, condition II

3) Design Condition with Cross Bars

Boundary conditions and loads

- Internal pressure 0.125 MPa
- External pressure 0.10134 MPa
- Temperature 70^{o}c
- Convection $2*10^{-5}$ W/mm^{2} ^{o}c
- Standard earth gravity 9806.6 mm/s^{2}
- Dead load 5000 kg

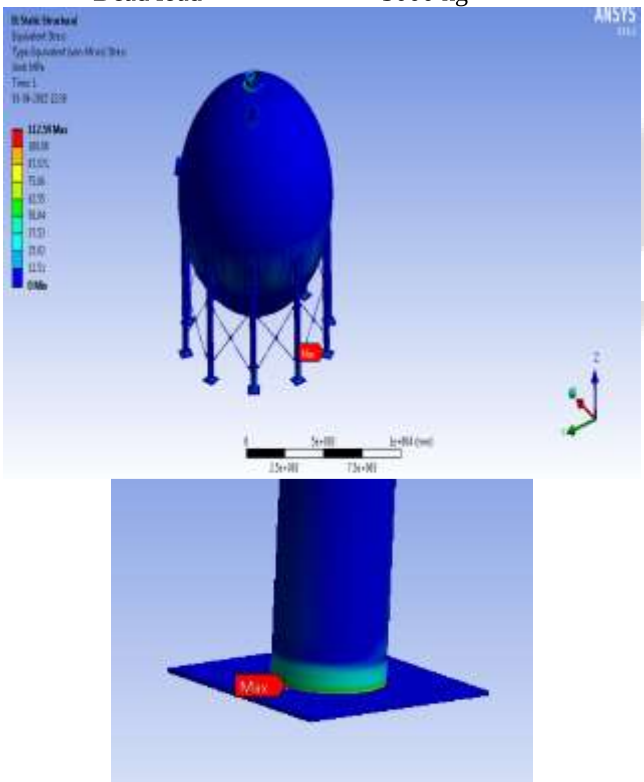


Fig. 8: stress, condition III

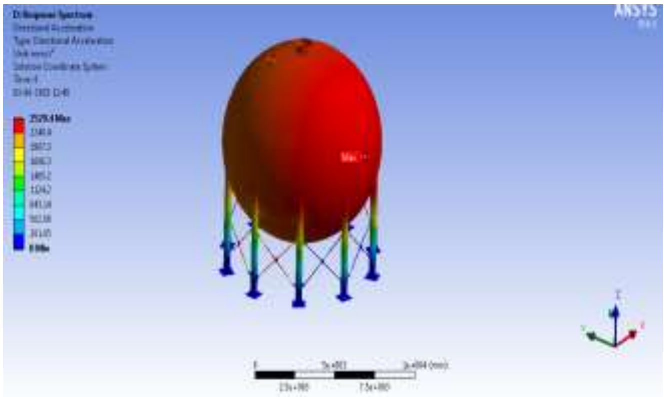


Fig.9: Directional acceleration, condition III

4) Operating Condition with Cross Bars

Boundary conditions and loads

- Internal pressure $1*10^{-5}$ MPa
- External pressure 0.10134 MPa
- Temperature 60^{o}c
- Convection $2*10^{-5}$ W/mm^{2} ^{o}c
- Standard earth gravity 9806.6 mm/s^{2}
- Dead load 5000 kg

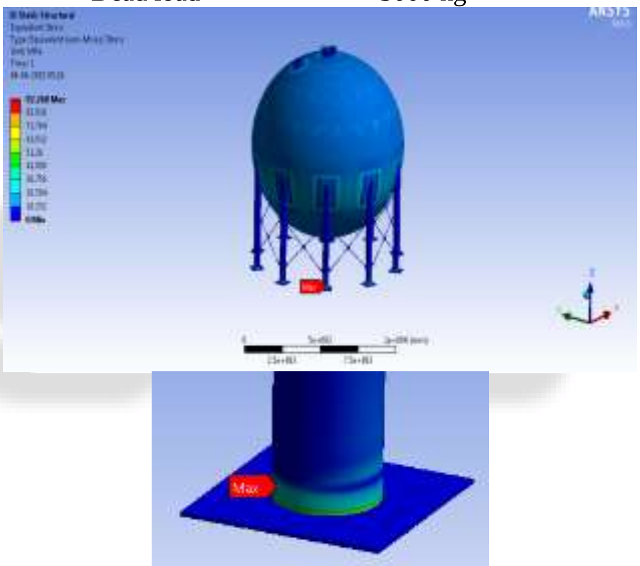


Fig. 10: stress, condition IV

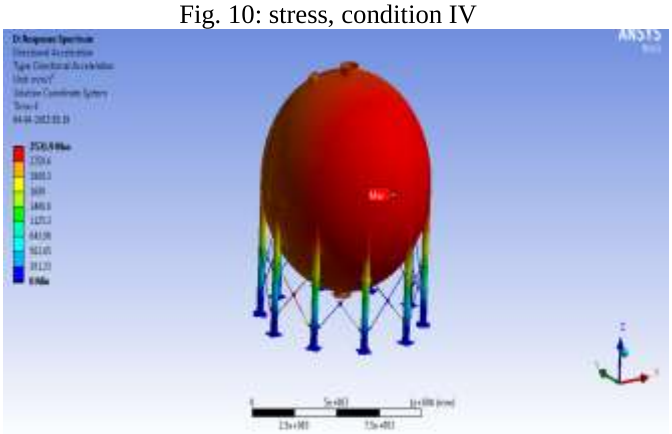


Fig. 11: Directional acceleration, condition IV

VI. RESULTS AND CONCLUSION

A. Analysis Results

	Allowable stress (Mpa)	Stress generated (MPa)	Total deformation (mm)	Directional acceleration (mm/s^{2})
Design condition without cross bars	137.89	117	5.3697	2736.8

Operating condition without cross bars	137.89	102.49	4.3206	2731.6
Design condition with cross bars	137.89	112.59	3.9459	2529.4
Operating condition with cross bars	137.89	92.268	3.3389	2531.9

Table.10: Analysis results

B. Conclusion

- The spherical pressure vessel is designed according to ASME standards and the calculation of thickness for internal and external pressure, nozzle calculations, flange calculations and support calculations are made as per ASME section viii division ii.
- The geometric modelling of the spherical pressure vessel is carried out using software CATIA. Then the spherical pressure vessel model was optimized by redesigning the support columns with the cross bars (brazing).
- The total deformation value for design and operating conditions are in the range of 3mm to 5mm which is considerably low for the spherical pressure vessel of 10m diameter.
- The stress values obtained from the analysis of spherical pressure vessel with and without cross bars are well below the allowable stress value for both design and operating conditions.
- The solution information of the modal analysis shows the effective mass greater than 90% of the total mass, thus the criteria required for the RS analysis is satisfied.
- The directional acceleration obtained from the response spectrum analysis of the vessel is below 3 m/s² which are accepted.
- The analysis of the vessel along with the cross bars shows better results compared to analysis results of the vessel without the cross bars.
- The vessel is validated as per ASME on static and seismic loads.

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