Response Spectrum Analysis of Pressure Vessel with Vertical Orientation

Vipul J. Solanki[1] Prof.D.A.Patel[2]
[1]P.G. Student [2]Associate Professor
[1,2]Department of Mechanical Engineering
[1,2]SPCE Visnagar, GTU, Gujarat, India

Abstract— Pressure vessels are widely used in private sectors and industries all over the world. Its safety and quality is major issues to avoid the failure of the system. In this paper response spectrum analysis of pressure vessel with vertical orientation is carried out. Vertical orientation pressure vessel is 6m in height and support height is above 1m. To understand the dynamic behaviour of the pressure vessel in actual conditions response spectrum analysis is performed in mastering software ANSYS 15.0. Manual calculation is carried out for seismic evaluation based on Indian Standards Codes IS: 1893 to validate the results.

Key words: Vertical Pressure Vessel, IS: 1893 RSM, ANSYS 15.0, Response Spectrum Analysis

I. Introduction

Pressure vessels are the container for fluid and gases under high pressure. Due to high pressure, stresses are induced in pressure vessel, if this stresses are more than the permissible stresses then the failure of pressure vessel occurs. The wind and seismic design is a major requirement in oil and gas industries equipment design. Normally oil and gas plants are away from the residential area. However if heavy earthquakes or wind emerge, that will cause disaster due to failure of equipment as these plants are handling many harmful toxic fluids and gases. Many disasters have happened all over the world in these industries due to excess wind and seismic effects. So it is necessary to manufacture pressure vessels under standard codes.

II. Literature Survey

Authors have analyses were carried out on head, shell, nozzle and saddle. The input parameters are type of material, pressure, temperature, and diameter and corrosion allowance. Analysis performed the calculations of internal and external pressure, weight of element, allowable stresses, vessel longitudinal stress check, nozzle check and saddle check. The high stresses at intersections are caused by discontinuity shear stresses and moments which exist to maintain compatibility at the junctions. Research can be explored to into account other parameters. Selection material referring to ASME, standard can also been developed. There are other parameters that are not considered such as thermal loads, wind loads, seismic loads, transportation load, erection load and fabrication methods etc. This can be done by mastering software like ANSYS. Another probabilistic design of pressure vessels using ANSYS PDS feature is carried out in paper [1]. Probabilistic design uses Gaussian distribution for various input parameters and simulation uses Monte Carlo simulation technique for sampling. Monte Carlo simulation approach and analysis was looped through 100 samples points considering the variations defined in the input variables and the corresponding statistical analysis of the output parameters.

The wind and seismic design is a major requirement in oil and gas industries equipment design. Normally oil and gas plants are away from the residential area. However if heavy earthquakes or wind emerge, that will cause disaster due to failure of equipment as these plants are handling many harmful toxic fluids and gases. The seismic design based only on analytical approach does not give exact solution all the time and it is not suitable for all types of vessel geometry. [5]The FEM is required with analytical approach to ensure the design is safe. They found that the passed analytical saddle design is failing during FEM simulation and it requires more thickness to with stand the external forces based on FEM. Accordingly thickness has been improved as 16mm and the FEM was redone and found that the saddle is safe with 16mm shell thickness. Here further fabricator can use external or internal stiffening rings wherever required for saving the vessel from excess external and internal loading conditions. The behaviour of a structure system in an earthquake or seismic is one of vibration under variable conditions of acceleration [6]. The usual normal simplified approach to the problem is based on the assumption that the structural system is a rigid body which undergoes the accelerations of the supporting ground on which it’s standing. The horizontal force which acts on the structure are equal to its mass times the ground acceleration, and has the same ratio to the weight as the ground acceleration has to that of gravity [7]. These structural codes give values of this ratio that are based on engineering experience and judgment.

III. Objective of Paper

The salient points of the proposed problem are as follows:

- To identify the design capacity level of pressure vessel structure and maximum allowable lateral force based on shear coefficients of seismic loadings by perform the response spectrum analysis.
- To specify the damage level of pressure vessel structure by performs the response spectrum analysis in ANSYS 15.0.
- IS: 1893 codes are performed to evaluate the seismic response of structure.
- To obtained the natural frequency response of structure with mathematical and software approach.

IV. Project Approach

In this paper, to understand the dynamic behaviour of pressure vessel response spectrum modal analysis is carried out in ANSYS 15.0 and results are generated based on that. The work is done on the case study given by Air and Gas Process Technologies Pvt. Ltd. Vatva GIDC, Ahmedabad. This work is based on the vertical orientation pressure vessel of air receiver. Company has provided the details of current vertical pressure vessel of air receiver.

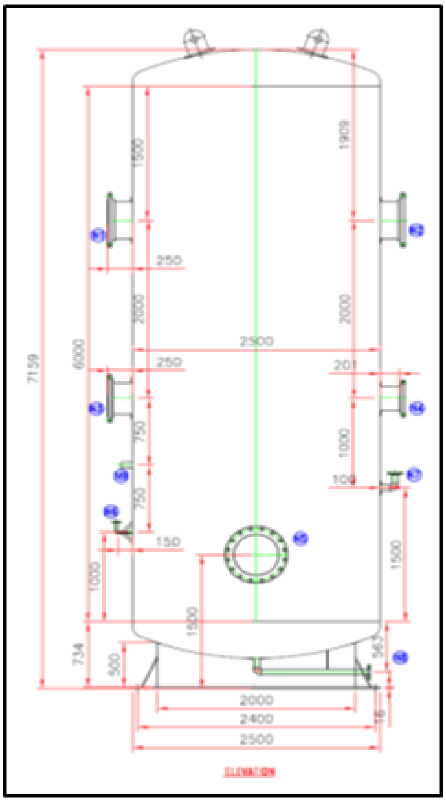

Fig. 1: Elevation of pressure vessel

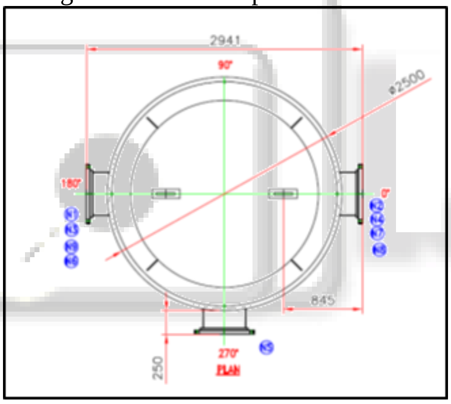

Fig. 2: Top view of pressure vessel

Size	2500 X 6000
Quantity	1 No.
Design Code	ASME Sec VIII Div I
Material of Construction	SA 516 Gr 60
Shell Thickness	6 mm
Dish Thickness	8 mm
Corrosion Allowance	1.5 mm
Working Pressure	4.59 kg/cm²g
Design Pressure	5.1 kg/cm²g

Table 1: Detail Input of pressure vessel system

V. MATHEMATICAL APPROACH

Mathematical approach for seismic calculations is carried out based on Indian Standard criteria for earthquake resistant design of structures PART 1 GENERAL PROVISIONS AND BUILDINGS (Fifth Revision)

- Lateral Load Distribution with Height by the Static Method:
- Vessel location: Vatva, Ahmedabad, Gujarat, India

The approximate fundamental natural period of vibration (T), in seconds, of a moment-resisting frame building without brick panels may be estimated by the empirical expression: for steel frame building.

$$T_a = 0.085 \times h^{0.75}$$

T_a = 0.32 seconds

(Ref. Clause 7.6.1 IS: 1893)

Design seismic base shear, $V_b = A_h \times W$ = 5820.53 Kg

Where, $W = \sum W_i$, Ah = Design horizontal acceleration spectrum value as per 6.4.2 (IS: 1893), using the fundamental natural period T, as per 7.6 in the considered direction of vibration.

Sr. No.	Parameters	Value
1	Zone Number	III
2	Zone Factor	0.16
3	Soil Type	Medium Soil
4	Period of Vibration	0.32 Sec
5	Value of Sa/g	2.50
6	Damping Factor	2.00
7	Importance Factor	1.00

Table 2: Input parameters for seismic data

Level	w_i (N)	h_i (m)	$w_i h_i^2$	$\frac{w_i h_i^2}{\sum w_i h_i^2}$	Lateral force at each level (N) $V_b \frac{w_i h_i^2}{\sum w_i h_i^2}$
6	13894	6	68.18	0.052	303
5	22.903	5	572.57	0.4312	2510
4	22.903	4	366.45	0.2759	1606
3	22.903	3	206.13	0.1552	903
2	22.903	2	91.61	0.0689	401
1	22.903	1	22.903	0.0172	100
			Total = 1327.8		

Table 3: Vertical distribution of design force at each level

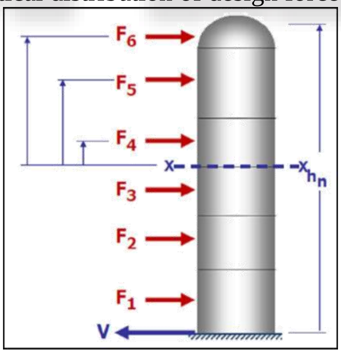

Fig. 3: Diagram for lateral force in vessel at different level

A. *Frequency Calculation*

Loading condition of vertical pressure vessel under seismic forces is similar to that of a cantilever beam when the load increases uniformly toward the end.

1) *Step 1: Moment of inertia*

$$I = \frac{\pi}{4}({r_o}^4 - {r_i}^4) = 0.01833\ m^4$$

2) *Step 2: Force or weight of vessel*

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

F = 141130.44 N

3) *Step 3: Deflection of pressure vessel system*

$$\delta = \frac{\omega \times L^3}{8 \times E \times I} = 1.19 \times 10^{-3} m$$

4) Step 4: Natural frequency of vessel system

$$f = \frac{1}{2\pi}\sqrt{\frac{g}{\delta}} = 14.44\ Hz$$

Hence, the natural frequency of vessel system is found to be 14.44 Hz by mathematical approach. Vertical distribution of lateral force at each level is presented here with mathematical calculation as well as stress calculation in vessel structure is presented.

VI. SOFTWARE APPROACH

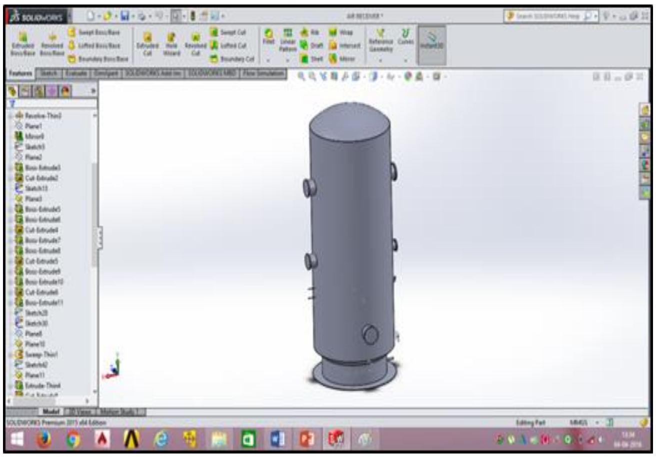

Fig. 4: Modelling of air receiver solid works

VII. ANSYS 15.0 SOFTWARE

A. *Modal Response Spectrum Analysis*

We apply modal analysis to conclude the vibration characteristics like mode shapes and natural frequencies of a construction component while it is being planned. It also can be starting points for another analysis like dynamic analysis, such as a spectrum analysis, transient dynamic analysis, or a harmonic response analysis. The mode shapes and natural frequencies are vital parameters in the design of a structure for dynamic load environment. It is also required if we want to do a spectrum analysis or a mode superposition transient or harmonic analysis. Modal analysis is done on a pre-stressed construction. Modal analysis in the ANSYS relations of parts is a linear analysis.

A response spectrum analysis in which the outcome of a modal analysis are used to recognized spectrum for estimate stresses and displacements in the model. It is mostly used in position of a time-history analysis to establish the response of systems to time-dependent or random loading situation like seismic, ocean wave loads, wind loads, rocket motor vibrations, and jet engine thrust and so on.

The method for a Single-point response spectrum analysis done by following steps:

1) Set up the model.
2) Apply loads and find the solution.
3) Find the Model result.
4) Find the spectrum result.
5) Develop the Modes.
6) Merge the Modes.
7) Review the results.

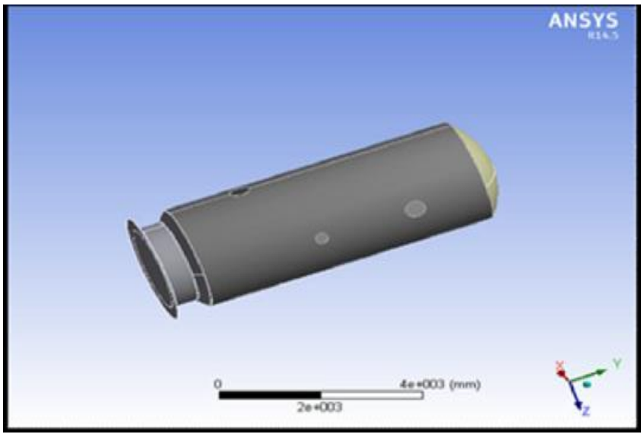

Fig. 5: 3D model in ANSYS Workbench 15.0

B. *Meshing Details*

Name of Element = 1 x 1 Square
No. Of nodes = 47504
No. Of elements = 23627

C. *Result of Frequency Response*

Frequency value = 10.568 Hz

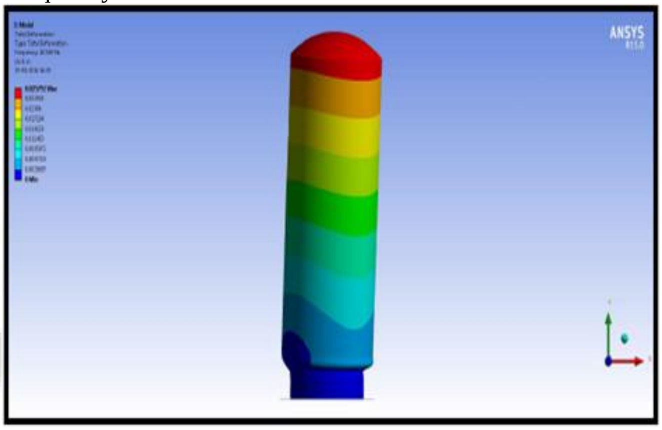

Fig. 6 Natural frequency result

Sr. No.	Frequency (Hz)	Displacement (mm)
1	1	10
2	3	20
3	25	30

Table 5: Displacement value with respect to Frequency

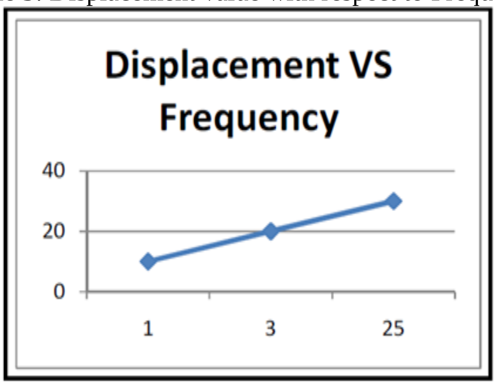

Fig. 7: Displacement VS Frequency

Sr. No.	Parameter	Mathematical approach IS: 1893	Software approach ANSYS 15.0
1	Natural frequency	14.44 HZ	10.56 Hz

Table 6: Validation for natural frequency

VIII. Conclusion

- Natural frequency value for vertical pressure vessel is estimated as mathematical value found to be 14.44Hz, and ANSYS 15.0 modal analysis observed the result of natural frequency as 10.56Hz. This natural frequency value specifies the damage level of pressure vessel structure.
- Structure displacement found to be 10mm, 20mm and 30mm for natural frequency value of 1Hz, 3Hz and 25Hz respectively.
- Mathematical approach to evaluate dynamic behaviour of structure is performed by IS: 1893 codes & standards which shown the seismic response of structure. Maximum allowable lateral force at each level in vessel system is calculated.
- To consider the wind load as a alternate to seismic load condition, future work can be possible with Dynamic Wind Analysis. In mastering software ANSYS computational fluid dynamics (CFD) can be performed to evaluate wind load results.

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