Finite Element Analysis of Ball Valve Assembly for Earthquakes

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ABSTRACT

Equipment used at nuclear power plants requires robust and reliable designs because in case of disaster, such as earthquake, small damage can turn into an unpredictable result. Valve assembly structure used at nuclear power plants is important because of such reason. Ball valves are used when a straight-line flow of fluid and minimum restriction is desired. Ball valves are the parts that either stop or allow flow of fluid through the valve acts somewhat like the opening or closing of a gate.

The primary objective of this project includes evaluating the seismic response of the system under Operation Basis Earthquake (OBE) and Safe shutdown earthquake (SSE) and validating the results as per ASME section-III, sub-sections NF for the above load cases. The response spectra used for OBE and SSE in X, Y, Z directions are given as input using ANSYS software. Modal analysis was performed in order to determine the first natural frequency, and the way the valve tends to deform. Next, a Quasi-static structural analysis accomplished applying the seismic accelerations. The critical components in the Ball Valve are Body, Stem and valve ball.

Meshing will be carried using Hypermesh v11.0. Model will be meshed with second order tetra elements. Analysis will be carried out using CAE tool Ansys™ 12.0 Classic. Finally, the result obtained from FEM software, theoretical results and research paper are compared.

Keywords***: LNG, Ball valve, OBE and SSE, Modal analysis.***

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1. INTRODUCTION

Earthquake is a natural phenomenon, which result from fracturing or faulting of the earth's crust. The failure of the crust gives rise to sudden release of strain energy, which is transmitted in the form of seismic waves, generating ground vibrations. These ground motions are transmitted to all parts of the buildings, structures, systems and equipment that are mounted on the floors or walls of the building. Historically, the seismic design of mechanical equipment was primarily focused on the equipment supports, and the attachments. The intent of the seismic design provisions in building codes was to reduce the hazard to life by sliding or falling equipment during an earthquake.

Today, mechanical systems often serve vital functions in critical building facilities such as hospitals, communication centres, nuclear plants and emergency response centres. The mechanical systems serving these types of facilities must be operational after an event, as non-functioning equipment could constitute a hazard to life. Therefore, the seismic design for this higher level of earthquake safety must assure functionality as well as position retention. So the structures, system and equipment which are used in earthquake prone area shall be designed to resist these earthquake loads along with other loads, viz., pressure, thermal and gravity loads.

In this study, a numerical analysis is conducted for the structural safety, in order to assess the safety and reliability of the ball valves for LNG to provide a basis for the design and manufacturing of products which are safe from leakage under conditions of extreme temperature variance.

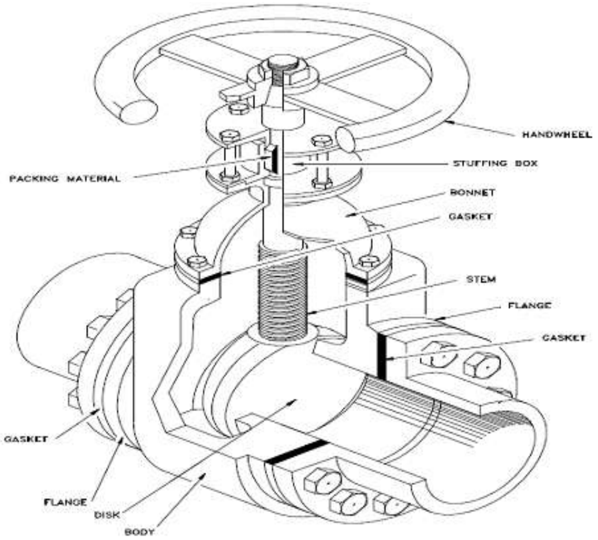


Fig. 1: Schematic illustration of a basic valve.

2. LITERATURE REVIEW

Dr. K.H. Jatkar[2] The submitted article discusses basics of gate valves, its general arrangements, functions, its basic parts and applications. Cryogenic ball valve is a valve that opens by lifting a round or rectangular gate or wedge out of the path of the fluid. This ball valve is used in a transportation system which carries Liquefied Natural Gas (LNG) over long distances through pipelines. A typical Gate valve consists of bonnet, body, stem and ball, packing and bushing as its major components. Valve body consists of a ball valve with a spherical disc which controls flow of fluid through it. Bonnet provides leak proof closure for the valve body. Bonnet positioned at the central axis of a valve connects the handle and ball. Valve body has a rising or non-rising stem for operating the valve.

Paper [1] discusses how the finite element modelling and its boundary conditions were conducted with the conditions for earthquake-proof. The load conditions were classified into the empty weight of the device, internal pressure, temperature, Operating Basis Earthquake (OBE), and Safety Shutdown Earthquake (SSE). The OBE is an earthquake that does not force the LNG facility to stop operation. Therefore, the maximum stress exerted under an OBE is less than the elastic limit. The SSE, however, is a strong earthquake that may occur once throughout the lifespan of the facility. The device was applied with maximum acceleration in the x, y, and z directions. In this paper, the cases of the OBE and SSE include the earthquake accelerations in the vertical and horizontal directions, which are 2.0g, including the device weight, and 1.5g, in the vertical and x-y directions respectively. In this study, the loading conditions of an SSE were applied to obtain a conservative result.

K V Satyavathi, N Jeevan Kumar [3] and Bang Hyun Cho, Hoon Hyung Jung [4] explains the different steps to follow in carrying out seismic analysis and its methodology. The analysis approach differs based on whether the equipment is rigid or relatively flexible. The statistical data shows that the frequency contents of the Raw Signal during earthquake is in lower range i.e. maxima occurring in the frequency range of 1 Hz to 30 Hz. Hence 33 Hz is designated as threshold frequency. If the lowest natural frequency of the system is more than the threshold frequency, the system is considered to be rigid and an equivalent static analysis is carried out considering Zero Period Accelerations as the seismic load. The accelerations applied as body loads in this case are 1.5 times the ZPA values. When the lowest natural frequency falls below 33 Hz, the system is considered flexible and a dynamic analysis approach needs to be adopted. Either response spectrum analysis or a time history analysis can be carried out for the above purpose.

The sourcebook, ‘Finite Element Method’, by S. S. Rao [9] explains thoroughly what exactly a finite element method concept is. He explained this method by step by step procedure, and then explained each step by devoting a separate chapter for each step. Author gives the detail explanations about how to solve the governing equation with three methods i.e. direct approximate, weighted residual and Raleigh Ritz method.

Practical Finite Element Analysis by N S Gokhale [10] explains the various types of analysis solved by FEM method. Author explains the solution technique and general procedure to solve the non-linear analysis.

Descretization process is well explained and this helps for element type selection, meshing pattern selection and controlling the quality of mesh.

3. Project Methodology

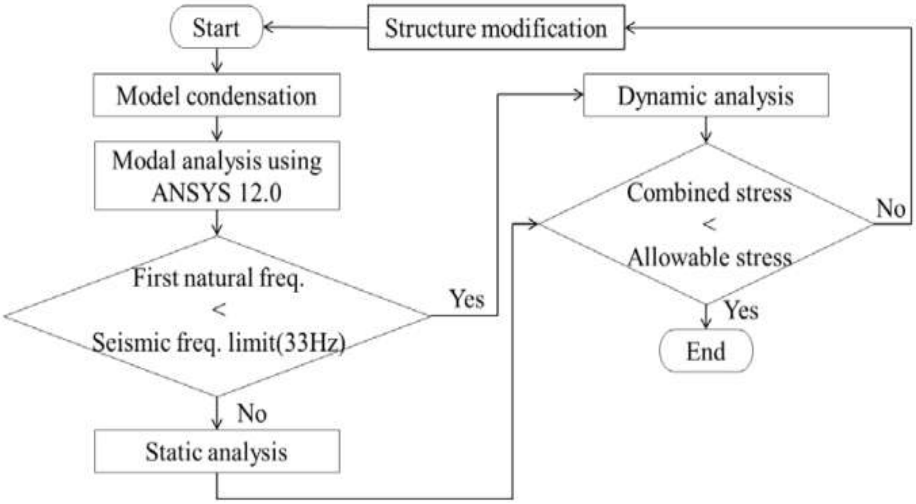


Figure2. Project Methodology

4. Finite Element Methodology

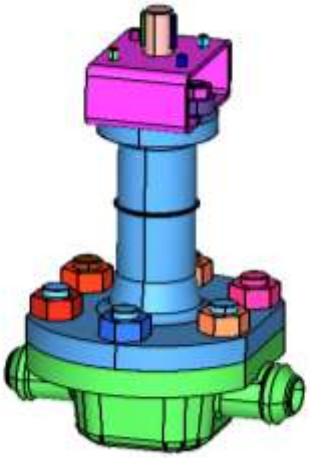


Figure3.CAD Model

Figure4.Meshed Model

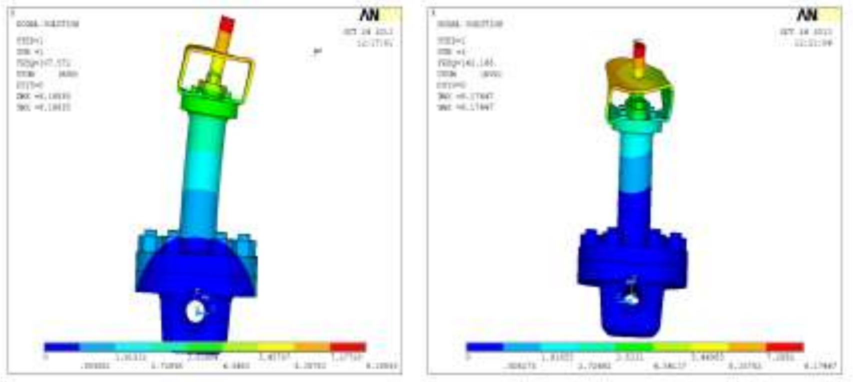
In order to conduct the optimal simulation of a real cryogenic ball valve with the FEA model, a tetrahedron solid element was used and the solid92, which is an element for isotropic materials. The solid elements have an average size of 10mm and comprise 150,934 elements and 246,629 nodes. The x, y, and z axes were defined to represent the lateral, longitudinal and vertical coordinates, respectively.

5. MODAL ANALYSIS

For the purpose of finding out the first natural frequencies and their corresponding modes, a modal analysis was performed. This enables a better understanding of how the valve deforms. On top of that, a modal analysis is a necessary previous step for the further analysis. In this analysis the finite element model was used. Contact nonlinearities are allowed, and the linear material properties are used. On top of that, the flanges where the piping is connected were fixed, that is, the degrees of freedom of the nodes on the flange were set to 0.

Modal Analysis Result

The first mode of vibration (107Hz) The second mode of vibration (142Hz)



The third mode of vibration (299Hz) The fourth mode of vibration (330Hz)

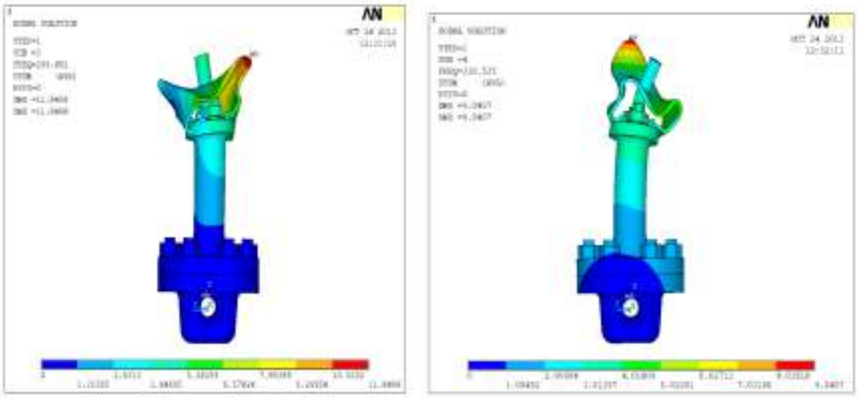


Figure5. Modal Analysis Result (frequency)

As the lowest natural frequency of the system is 107 Hz which is more than the threshold frequency 33Hz [4], the system is considered to be rigid and an equivalent static analysis is carried out.

6. Equivalent Static Analysis

Instead of conducting a spectral analysis, the maximum spectral acceleration shall be considered in the analysis. Thus, a quasi-static analysis is carried out with the maximum spectral acceleration applied to the death weight of the valve. The acceleration is applied to the general coordinate system. The valve is fixed to this system by means of the body ends and inertial properties of the valve are defined through material density data input. The seismic forces are then obtained by multiplying the mass by the appropriate acceleration and applying it at the centre of gravity of the mass.

Loads & Boundary conditions

The load conditions were classified into the empty weight of the device, internal pressure, temp, Operating Basis Earthquake (OBE), and Safety Shutdown Earthquake (SSE). The OBE is an earthquake that does not force the LNG facility to stop operation during the lifespan of the facilities. Therefore, the maximum stress exerted under an OBE is less than the elastic limit. The SSE is a strong earthquake that may occur once throughout the lifespan of the facility. The valve assembly will be applied with maximum acceleration in the x, y, and z directions, as the cases of the OBE and SSE include the earthquake accelerations in the vertical and horizontal directions respectively.

Here three main loads are applied as internal pressure, bolt pretension, directional acceleration for SSE and OBE.

1] Internal pressure = 16.475 Mpa

2] Bolt pretension, also called preload or pres-tress, comes from the installation torque T you applies when you install the bolt. The inclined plane of the bolt thread helix converts torque to bolt pretension. Bolt preload is computed as follows.

Pi = T/(K D)

where Pi = bolt preload (called Fi in Shigley).
T = bolt installation torque.
K = torque coefficient.
D = bolt nominal shank diameter (i.e., bolt nominal size).

Bolt installation torque T = 265440 N-mm

Bolt nominal dia. = 35 mm

Hence we get, F = 25280 N

3] Directional acceleration for SSE = 2g = 2*9810 = 19620 mm/sec2

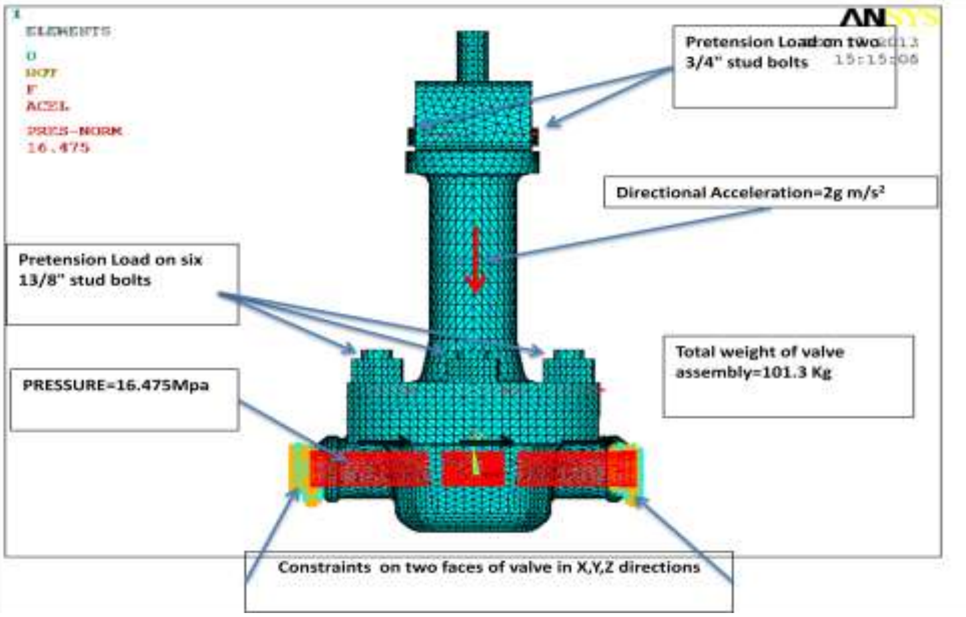


Figure6. Loads & Boundary conditions

Seismic classification and verification criteria

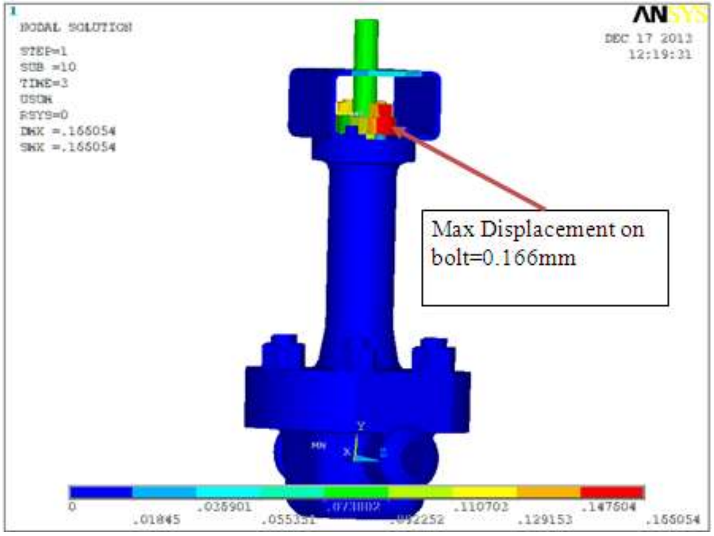
The valves are classified according to different seismic categories. Depending on the category, the verification criteria is defined.

	Seismic Class		
Verification	A	B	C
Functionality	SSE	OBE	OBE
Integrity	SSE	SSE	OBE*

The class A valves shall remain operational for both OBE and SSE earthquake. The class B valves shall remain operational after an OBE and shall keep their integrity in case of SSE. The class C valves shall remain operational after OBE and shall not fall on or impact other classes and components after SSE.
A valve is considered to remain operational if the stresses are kept under the Yield Strength, and the integrity is maintained if the stresses are kept under the Ultimate Stress.

Equivalent Static Analysis

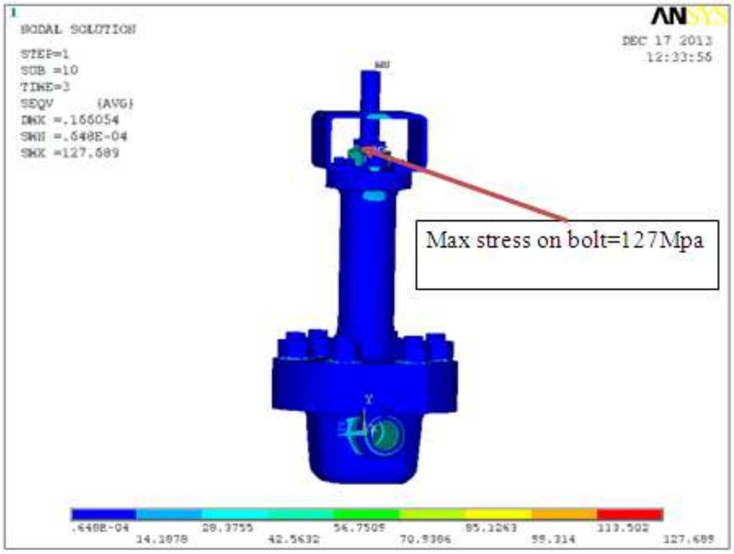
STRESSES SSE Y DIRECTION (Ax=0; Ay=2g; Az=0)
Displacement Plot(Assembly):



Max Displacement on bolt=0.166mm

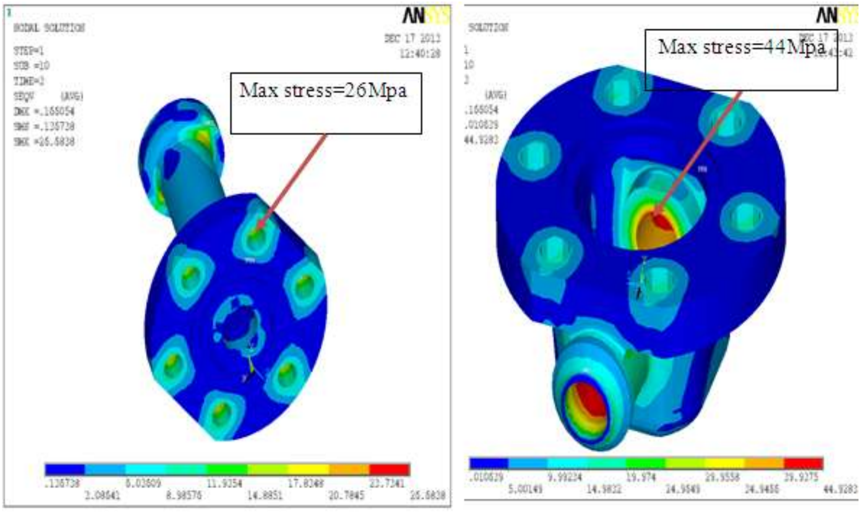
Figure7. Displacement plot of Valve Assembly

STRESSES SSE Y DIRECTION FOR (Ax=0; Ay=2g; Az=0)
Von-Mises Stress Plot(Assembly):



Max stress on bolt=127Mpa

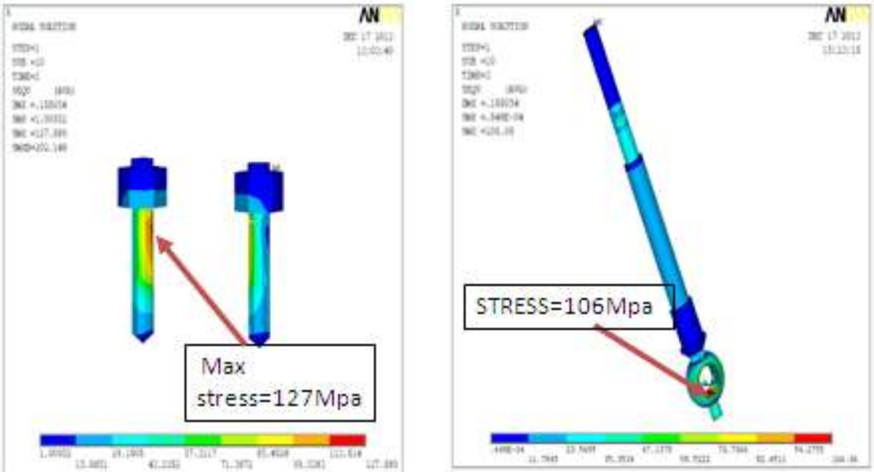
Figure8. Stress plot of Valve Assembly



BONNET

VALVE

Figure9. Stress plot of Valve body and Bonnet



3/4" STUD BOLT

STEM AND BALL

Figure10. Stress plot of Bolt and Stem

7. THEORICAL RESULTS

In order to compare the stress for a point on a spherical body with the theoretical calculation and ANSYS, we used the Von Mises Theorem.

Von Mises Theorem:

$$\sigma = \frac{1}{\sqrt{2}}\left(\sqrt{(\sigma_r - \sigma_z)^2 + (\sigma_z - \sigma_\theta)^2 + (\sigma_\theta - \sigma_r)^2}\right)$$

Firstly, Lames equations were used to calculate the values of the stress used in the equation above:

Hoop stress

$$\sigma_\theta = \frac{P_i}{k^2 - 1}\left(1 + \frac{r_0{}^2}{r_i{}^2}\right)$$

Axial stress

$$\sigma_z = \frac{P_i}{k^2 - 1}$$

Radial stress

$$\sigma_r = \frac{P_i}{k^2 - 1}\left(1 - \frac{r_0{}^2}{r_i{}^2}\right)$$

The values required for the ball valve are follows:

r_0 = 29.5mm	r_i = 25mm	k = r_0 / r_i =1.18	p_I = 16.475 MPa

This gives the follow results:

s_r = -16.475 N / mm^2	sq = 100.44 N / mm^2	s_2 = 41.98 N / mm^2

Finally: s = 101.25 N / mm2

THEORICAL RESULTS

Component	Theoretical stress (Mpa)	ANSYS stress (Mpa)	Error(%)
Ball Valve	101.25	106	4.48

8. DISCUSSION AND COMPARISON OF RESULTS

Seismic analysis of the Valve Assembly was performed for given seismic loading. The stresses and deflections were observed to be below the allowable limits. The maximum stresses in the Valve Assembly are compared against allowable stresses as per ASME section-III, sub-section NF.

Components	Max. Deformation [mm]	Max. Stress [Mpa]	Allowable Stress [Mpa]	Safety Factor
Valve body	0.1	43	205	4.7
Bonnet	0.12	26	205	7.8
Stem	0.04	54	255	4.7
Valve ball	0.14	106	255	2.4
Stud bolt	0.166	127	345	2.7

Hence, Overall Stresses on Valve Assembly are well below the allowable Yield Strength of Material. Hence design is safe for given loading condition.

Conclusion

The maximum stress and translations are well within the acceptable limits of the material. The analysis ensures that the Valve assembly & foundation bolts are safe from the point of structural integrity and operability during a seismic event under specified seismic load prevailing at site. As the factor of safety for both valve body and bonnet is greater, there is a possibility of weight reduction in these components. As the overall stresses on valve assembly in this design are well below the research paper design. Hence the current design is best suited for same loading and boundary conditions of seismic analysis.

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