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Seismic Characteristics of Vacuum Rupture Valve Based on PEER Seismic Database

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Abstract

In this paper, based on the target response spectrum of seismic load, using the seismic record search engine of peer seismic database, the characteristic parameters of seismic load for the seismic analysis of vacuum rupture valve engineering structure are obtained as the transient dynamic load for the research of seismic performance analysis. Meanwhile, the time history (transient) analysis method and peer seismic data separation principle are applied, and ANSYS is used The transient dynamic Newmark - β analysis and calculation module of workbench software is used to analyze and calculate the stress-strain and its variation law of the vacuum breaking valve installation structure. The results show that the maximum equivalent stress of the valve occurs at the lower neck of the valve body at 0.22s after the earthquake, where the membrane stress is 0.53mpa, the membrane + bending stress is 1.14mpa, and the maximum deformation is 0.0053mm. According to JB According to 4732-2005 "steel pressure vessels - Analysis and design standard", the vacuum rupture valve meets the requirements of seismic performance design. The selection and determination of seismic load and the transient dynamic analysis method for seismic performance of engineering structure are adopted, which provides a reference for the seismic performance analysis and research of thermal power / nuclear boiler equipment and components in the future.

Keywords

PEER seismic database; Time history (transient) analysis method; Newmark - β module; Seismic characteristics of vacuum rupture valve.

1. Introduction

The vacuum control system installed in the steam turbine of thermal power / nuclear power boiler is one of the key systems to ensure the low back pressure and condenser vacuum degree of the steam turbine, and to ensure the efficiency of the steam turbine. In addition to regulating and ensuring the operating vacuum degree of the steam turbine, the vacuum breaking valve can automatically destroy the low back pressure and the vacuum degree of the condenser during the normal shutdown or emergency shutdown of the steam turbine In order to ensure the safe operation of the system, the rotating speed of the steam turbine and the idling time of the rotor are reduced rapidly. Therefore, for the large-scale ultra supercritical thermal power / nuclear power boiler, in order to improve the operation reliability of the boiler and steam turbine system, and improve the safety against natural disasters and emergencies, higher requirements are put forward for a large number of boiler and steam turbine system key parts and accessories in the design and engineering demonstration verification, and vacuum rupture valve is one of them.

Based on the above technology development and market demand, the research topic on seismic characteristics of vacuum rupture valve for thermal power / nuclear power boiler is proposed. In view of the randomness of earthquake natural disasters, even under the same magnitude conditions, due to

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different site area types, earthquake grades and other conditions, the characteristics of ground motion (i.e., amplitude, duration, frequency spectrum) and geological damage degree are also different [1]. In addition, the occurrence of earthquakes exists in the continuous process of short-term high-energy impact. According to the national standard GB / t50083 [2], the "seismic force" is a comprehensive description of seismic acceleration, velocity and dynamic displacement of components, namely ground motion. Therefore, how to determine the seismic load reasonably and effectively is the key to carry out the research on seismic characteristics of vacuum rupture valve.

In this paper, we use the peer seismic source database (Pacific Earth Engineering Research) Center), the load rule and parameters of the target response spectrum are determined by searching and fitting the load evaluation definition selection method which is close to the recorded "ground motion". At the same time, the seismic characteristic time history analysis method recommended by "code for seismic design of buildings" (GB 50011-2010) [3] is adopted, and ANSYS is applied Transient dynamic analysis method of workbench The three-dimensional numerical model of vacuum rupture valve of thermal power / nuclear power boiler is established, and then the transient dynamic characteristics under seismic load are analyzed and calculated. Finally, according to the analysis and design evaluation specification of "steel pressure vessel - Analysis and design" standard JB / t4732-2005 [4], the ability of thermal power / nuclear power boiler vacuum rupture valve to resist earthquake disaster is evaluated.

2. The selection of target response spectrum

One The selection of the target response spectrum of ground motion has made certain provisions and requirements for the selection of seismic records in the seismic codes of various countries, but the randomness of the seismic load and the complexity of the destructive effect of the engineering structure, the selection and definition of the seismic load parameters can reflect the destructive effect of the seismic load more effectively, which is the key point for the research and evaluation of earthquake and seismic characteristics In. In the research of the seismic performance of mechanical equipment and engineering structure system, few research literatures generally define the seismic load as the impact failure of static peak acceleration, and the results are quite different from the actual seismic damage. In this paper, the characteristics of ground motion are characterized by amplitude, frequency spectrum and duration.

Step 1: according to the standard of code for seismic design of buildings (GB 50011-2010), the seismic grouping coefficient is 3, the site classification coefficient is 3, and the maximum value of horizontal seismic influence coefficient a m is 0.12.

Step 2: the target response spectrum of seismic load [5] is obtained by the corresponding program provided by the building structure Professional Committee of Yunnan Society of civil engineering and architecture and Kunming University of science and technology as the basis for selecting the seismic load. The response spectrum acceleration curve is shown in Fig. 1.

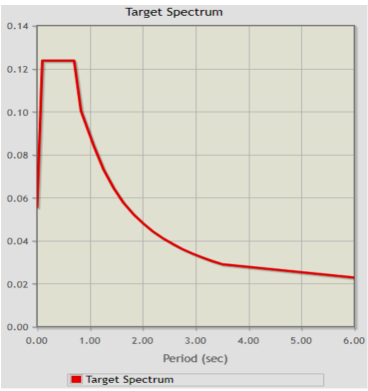

Fig. 1 Acceleration Curve of the Target Spectrum

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Step 3: in order to obtain the seismic characteristic parameters of the engineering structure damage caused by the global earthquakes which are close to the target spectrum of the earthquake load studied in this paper, we make full use of the peer seismic database and its record search engine. By setting the source level (6.5 ~ 7.5), the horizontal distance between the action point and the source (10 ~ 30 km), the depth of the action point (10 ~ 30 km), the source is determined The shear wave velocity of ground motion is set at 250m / S ~ 500m / s [6], as shown in Figure 2. More than 30 corresponding seismic records can be obtained by searching the record search engine of peer seismic database. In this paper, the characteristic parameters of 7.2 earthquake occurred at 8:43 a.m. on June 14, 2008 in Iwate Prefecture, Japan were selected as the seismic load for seismic analysis of vacuum rupture valve engineering structure. The shear wave velocity of the engineering structure site was 477.55m/s. The corresponding curve of seismic wave shape and target response spectrum acceleration is shown in Figure 3. Red is the target response spectrum acceleration curve, and black is black It is the acceleration curve of seismic wave in Yanshou county.

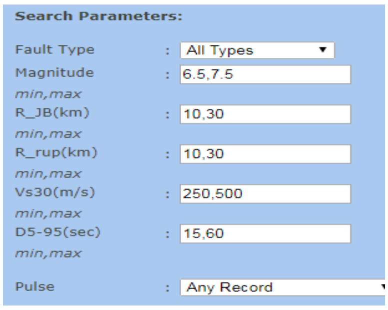


Fig. 2 Seismic Record Parameter Setting Interface

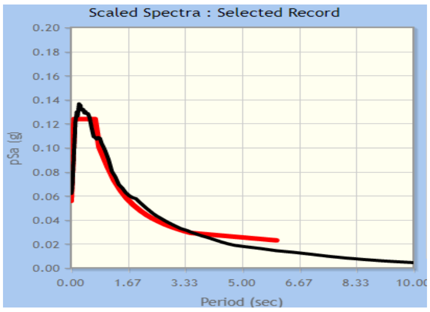
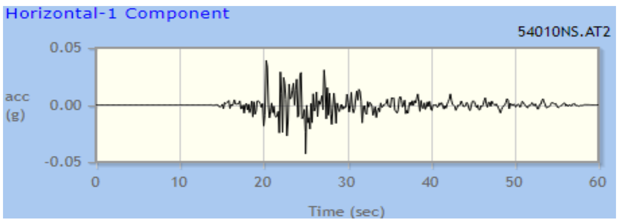
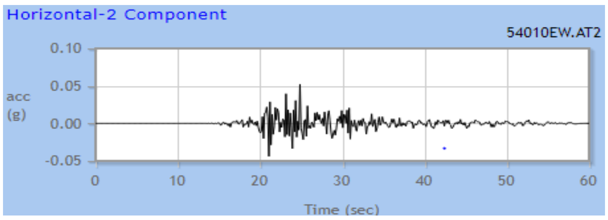


Fig. 3 Geoseismic Curve and Target SpectrumAcceleration Curve of Iwate Prefecture

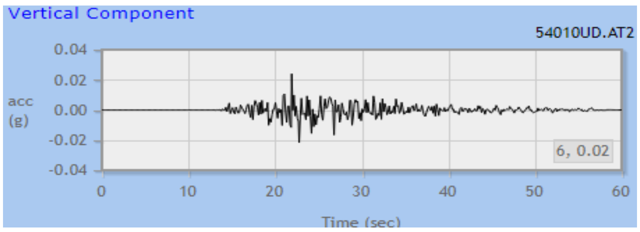
Step 4: in fact, the ground motion of the same particle is a vector. In order to carry out structural analysis, it is necessary to decompose the vector into two horizontal and one vertical components which are perpendicular to each other. In structural analysis, the ground motion vector is usually decomposed according to the ratio of AV: ah = 1:2 vertical ground motion acceleration and horizontal ground motion acceleration. The waveform curves of ground motion acceleration characteristics during the occurrence of the 7.2 earthquake in Iwate Prefecture, Japan are shown in Fig. 4.Where a, B and C are acceleration data in two horizontal directions and one vertical direction respectively.



(a)



(b)



(c)

Fig.4 Acceleration Curve of Horizontal and Vertical Component

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3. Time history analysis method and seismic load separation

3.1 Time history analysis method based on peer seismic database

Based on the research on seismic characteristics of vacuum rupture valve of thermal power / nuclear power boiler based on peer ground motion, the selected and induced seismic target response spectrum is applied to the analysis load of the strong earthquake ground motion acceleration waveform characteristic parameter of the Iwate earthquake of M = 7.2 in Japan. Under this condition, the engineering structure object is analyzed, and the seismic action shows that the structure may enter the stage of elastic-plastic deformation Due to the geometric nonlinear characteristics of excessive structural displacement, the stress superposition principle adopted by response spectrum analysis method has limitations [8]. With the development of computer technology and structural dynamics, the time domain direct digital calculation method, also known as time history analysis method or time history step-by-step integration method, has been developed and applied with the development of computer technology and structural dynamics The deformation of the image is elastic deformation. The dynamic characteristic response in each discrete interval is analyzed. Finally, the dynamic characteristic response law of engineering structure with the time history of ground motion is summarized. The most important feature of this method is that the time domain response results of ground motion to engineering structure can be obtained directly.

3.2 Dynamic equation and mathematical model

Based on the randomness and complexity of ground motion, the simplified dynamic discrete model of actual engineering structure is characterized by multi degree of freedom dynamic motion equation

$$M \ddot{x} + C \dot{x} + K x = -M \ddot{x}g \tag{1}$$

Where: X, $\dot{x}$, $\ddot{x}$ and $\ddot{x}$ G are the displacement, velocity, acceleration and ground motion acceleration vectors of the structure respectively; m, C and K are the mass matrix, damping matrix and stiffness matrix of the structure system respectively.

In the time history analysis method, it is assumed that the engineering structure object is defined as a linear system in the discrete range of seismic load, and the algorithm is characterized as no damping, so it is unnecessary to consider the oscillation caused by high mode response. Although the corresponding analysis software provides a variety of dynamic analysis and calculation mathematical models, through analysis and comparison, Newmark - β analysis and calculation mathematical model is used in this paper.

3.3 Seismic load separation

In view of the time acceleration law of ground motion recorded in peer seismic database, the time interval is about 0.005s within 0 ~ 1s, 0.2S within 1 ~ 5S, 0.5s between 5 ~ 10s, 1s between 10 ~ 15s, and 5S within 15 ~ 20s. Therefore, the dynamic load response characteristics (structural displacement, velocity and acceleration) of each discrete interval can be analyzed and calculated for the thermal power / nuclear power boiler vacuum rupture valve engineering structure under seismic load by using the time history analysis method. Finally, the response results of earthquake ground motion on the engineering structure are obtained through the post-processing and inductive analysis.

4. Modal analysis

4.1 Structure and working condition of vacuum breaking valve

(1) Structure of vacuum breaking valve

It is mainly composed of valve body, valve seat, valve core, valve cover and valve seat cover. The upper part of the valve is connected with the discharge medium, and the lower part of the valve is

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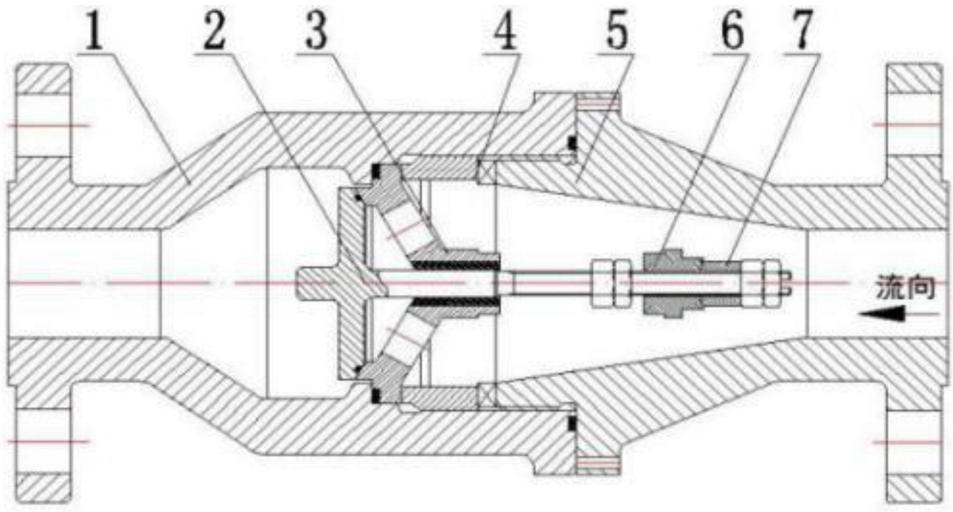
connected with the discharge system. The valve height is 220mm, the inlet and outlet diameter is 27mm, and the minimum wall thickness is 12mm.As shown in Figure 5.



1. Valve body; 2. Valve core; 3. Valve seat; 4. Valve seat cover; 5. Valve cover; 6. Spring compression sleeve; 7. Guide sleeve

Fig.5 Schematic diagram of the vacuum damage valve

(2) Service conditions

Medium: air; discharge temperature: 79.4 ℃; discharge pressure: -6.89kpa; rated suction capacity: 48.2m3/h.

(3) Material properties of main structural parts

Tab.1 Material Performance

Material	Elastic modulus E(MPa)	Poisson's ratioμ	density ρ(kg/m^3)	yield strength Sy(MPa)	tensile strength S_u(MPa)	Allowable stress S(MPa)
F316L	2.0×10^5	0.28	7960	173	483	108
316L	2.0×10^5	0.28	7960	173	483	108

(5) Establishment of finite element model of vacuum breaking valve

During the modeling process, the chamfering, fillet, connecting bolt / nut, sealing ring, threaded hole and other parts and features that have little influence on product analysis are ignored. According to JB / t5296-1991 test method for general valves, flow coefficient and flow resistance coefficient, in order to reduce the influence of analysis, calculation and test constraints on the structural stress characteristics of valves, the constraint point surface should be more than 10 times the pipe diameter length away from the valve inlet and outlet. Therefore, when using SolidWorks software to build the 3D model of vacuum breaking valve, the length of the pipeline is increased, as shown in Fig. 6.

The finite element mesh generation model is established by using free mesh generation technology and solid186 solid element type, as shown in Figure 7, with 58546 mesh elements and 158728 nodes. In this case, the grid independence check is adopted, and it is found that the accuracy of the calculation results will not be further improved with the increase of the number of grids, so the grid generation is reasonable.

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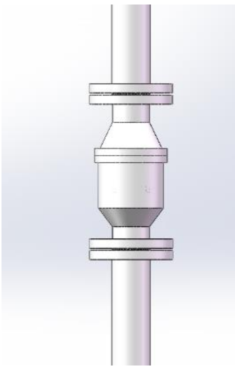

Fig.6 Three-dimensional solid model of the vacuum

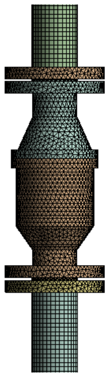

Fig.7 Finite element calculation model

(6) Constraints and loads

Constraint conditions: fixed constraints are applied to the end faces of the sleeve.

Load condition: according to the design function and actual working condition of vacuum breaking valve, the internal pressure of valve body is - 5.8kpa. According to the material and geometric properties of the valve body, the dead weight load of the valve body is automatically processed and loaded by ANSYS Workbench software.

4.2 Modal analysis

Modal analysis is the basis of dynamic method[7]. Each natural frequency corresponds to a mode. Under the condition that the system does not resonate (the natural frequency is greater than 33hz), the first and second order modes are selected. The significance of selecting these two order modes is: 1. The fitting degree of the ground motion curve and the target response spectrum curve near the two periodic points are compared, and the fitting degree of the two curves is similar, and the curve can be used as the ground motion input in this paper; 2. The initial time step is estimated by using the formula, and the initial step size is s.

The first six modal frequencies of vacuum breaking valve are calculated by ANSYS, as shown in Table 2.

Table 2 the first six natural frequencies and vibration modes of the system

Mode shapes	Mode frequency (Hz)	Maximum amplitude (mm)	Mode description
1	127.3	0.373	Deformation of ball valve along X direction
2	175.42	1.11	Deformation of pipeline on the right side of valve along X direction
3	185.55	1.15	Deformation of pipeline on the left side of valve along X direction
4	285.17	0.63	Wave deformation of pipes on both sides of valve along z direction
5	316.67	0.613	Wave deformation of pipes on both sides of valve along Y direction
6	343.4	1.09	Torsion of the pipe on the right side of the valve along the x-axis

(1) It can be seen from table 2 that the minimum natural frequency of the first six orders of the system is greater than 33 Hz, and the installation and use structure of all welded ball valve and pipe fitting system will not occur resonance in case of earthquake, which is the basis and premise for subsequent dynamic analysis [8,9,10];

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(2) Using the formula$\Delta t=1/20f$, the first frequency is selected, and the time step Δ t = 0.001 s is obtained;

(3) The damping form adopted in this paper is Rayleigh damping, C=αM+βK., where sum is the constant calculated according to the material and result characteristics, m and K are the mass matrix and stiffness matrix of the structure respectively. Using the formula [11]:

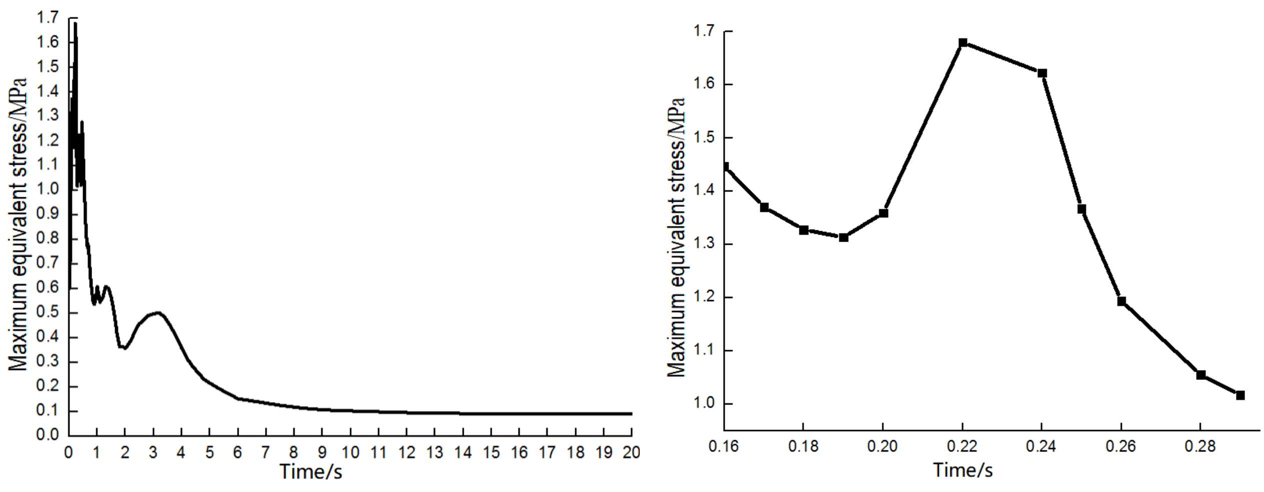
$$\alpha = \zeta \frac{\omega_i \omega_j}{\omega_i + \omega_j} \tag{2}$$

$$\beta = \zeta \frac{2}{\omega_i + \omega_j} \tag{3}$$

The damping ratio of the system is ζ = 0.05, and the first and second natural frequencies of the system are taken as ω I and ω J respectively, and α = 3.453, β = 0.00073 .

5. Seismic analysis and calculation of vacuum breaking valve

The dynamic analysis module transient structural in ANSYS is used for analysis and calculation, and the seismic acceleration data is imported into the module, and the valve working pressure pressure pressure of -5.8kPa is added According to the actual installation position, fixed constraints are added to the bottom surface of the valve seat and both ends of the pipe; the initial time step Δ t = 0.01s is set and the automatic time step of the time step option is turned on, which can automatically adjust the time step according to the frequency response and nonlinear response and shorten the calculation period; the structural damping coefficient α and β are set; finally, the solution method is Newmark - β method;According to the time history separation method of peer seismic load database, the seismic load data (two horizontal and one vertical time acceleration curves) of vacuum rupture valve are analyzed and calculated as shown in Figure 4. When the finite element external load is loaded, the seismic acceleration at the separated time is loaded respectively, and the corresponding structural stress and strain are analyzed and calculated After obtaining the results of the structural stress-strain analysis and calculation under the external load at the separation time, the corresponding relationship between the maximum equivalent stress and the separation time is summarized on the basis of the structural stress-strain analysis and calculation results of the external load at each separation time [12,13], as shown in FIG. 8.



(a) (b)

Fig.8 Time-mises equivalent stress value curve

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By analyzing the maximum equivalent stress value curve figure 8, it can be concluded that the maximum equivalent stress value of vacuum damage valve body is 1.6802Mpa when the earthquake occurs 0.22s, which appears in the neck of the valve body, as shown in Figure 9.

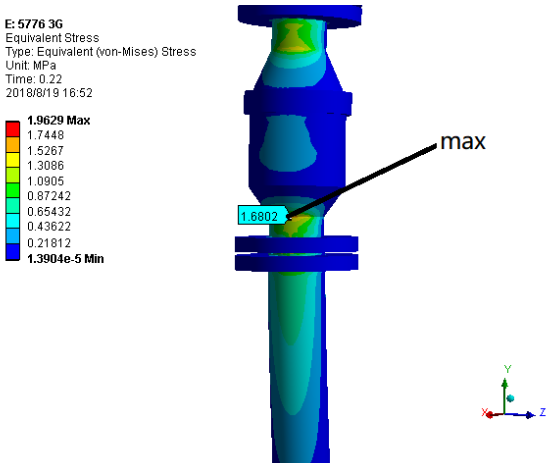

Fig.9 The Max Mises stress

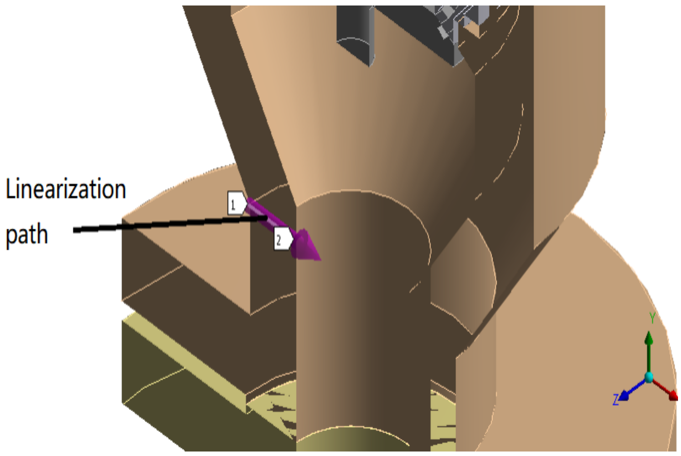

Fig.10 The Max Mises stress and stress linearization path

6. Seismic performance evaluation of vacuum rupture valve

As a steel pressure bearing component, according to the requirements of JB 4732-2005 "steel pressure vessels - Analysis and design standard", the evaluation methods of structural stress intensity are divided into point treatment method and line treatment method. In this paper, the line treatment method is selected, that is, each stress component is homogenized and equivalent linearized along a stress treatment line according to the selected dangerous section [14]. It can be seen from Fig. 9 that the maximum equivalent stress value of 1.6802mpa appears at the neck of the valve body at 0.22s of the earthquake, which is caused by the stress concentration of structural change. Therefore, the stress linearization path is established along the wall thickness at the maximum stress, as shown in FIG. 10.

The stress at this point is linearized to obtain the linearization results of membrane stress and film + bending stress (as shown in FIG. 11).

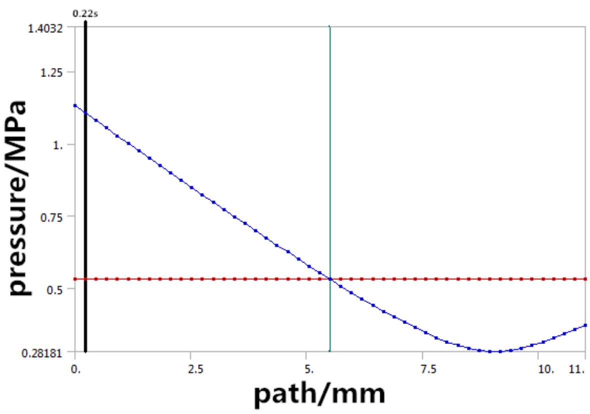

Fig.14 Linearization results of the membrane stress and the membrane stress plus bending stress

According to JB 4732-2005 "[15] steel pressure vessels - Analysis and design standard", the results of primary membrane stress, primary membrane stress plus bending stress and maximum deformation are obtained, as shown in Table 3.

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Table.3 Seismic performance evaluation of the vacuum destruction valve

Type	limit	value calculated	value conclusion
σ_m/MPa	162	0.53	qualified
$\sigma_m+\sigma_b$/MPa	194.4	1.14	qualified
d/mm	0.275	0.0053	qualified

Through the above analysis and calculation results, it is concluded that the structural stress and deformation of vacuum rupture valve under the combined action of seismic load, internal working load and self weight load does not exceed the allowable limit of pressure bearing component material, which indicates that the valve structure design meets the requirements of steel pressure vessel design code and has corresponding seismic capacity.

7. Conclusion

(1) In this paper, the seismic load target response spectrum is applied, and the seismic record search engine of peer seismic database is fully used. The characteristic parameters of ground motion with magnitude 7.2 in Iwate Prefecture, Japan, are selected as the seismic load for the seismic analysis of vacuum rupture valve engineering structure. Time history (transient) analysis method and peer seismic data separation method are used to make the selected seismic load target response spectrum have the following characteristics The reliable basis of recorded load response spectrum of ground motion provides a reference method for the selection of seismic load of research object.

(2) Based on the time history (transient) analysis method and peer seismic data separation principle, the transient dynamic Newmark-β analysis and calculation module of ANSYS Workbench software, and the structural strength of the vacuum rupture valve installation structure under the action of seismic load and so on. The analysis results show that: when the earthquake occurs 0.22s, the maximum equivalent stress of the vacuum valve occurs at the lower neck of the valve body, where the membrane stress is 0.53mpa, the membrane + bending stress is 1.14mpa, and the maximum deformation is 0.0053mm. According to JB 4732-2005 "steel pressure vessels -Analysis and design standard", the vacuum breaking valve meets the seismic performance design requirements, which provides a reference for the seismic performance analysis and research of thermal power / nuclear power boiler equipment and components in the future.

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