Seismic Base Isolation Analysis for PASCAR Liquid Metal Reactor

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1. Introduction

This paper presents a study for developing a seismic isolation system for the PASCAR (Proliferation-resistant, Accident-tolerant, Self-supported, Capsular and Assured Reactor) liquid metal reactor design [1]. PASCAR use lead-bismuth eutectic (LBE) as coolant.

Because the density (10,000kg/m^3) of LBE coolant is very heavier than sodium coolant and water, this presents a challenge to designers of the seismic isolation systems that will be used with these heavy liquid metal reactors.

Finite element analysis is adapted to determine the characteristics of the isolator device. Results are presented from a study on the use of three-dimensional seismic isolation devices to the full-scale reactor. The seismic analysis responses of the two-dimensional and the three-dimensional isolation systems for the PASCAR are compared with that of the conventional fixed base system.

2. Finite Element Model for Seismic Analysis

The system of PASCAR is shown in Fig. 1. The geometry of PASCAR and the FE model are shown in Fig. 2. The thickness of reactor vessel is 5cm, the diameter is 1.798m and the height is 8.22m. The material of reactor vessel is SS316L. The elastic modulus and the density of SS316L on 400^{o}C are 169GPa and 8,000kg/m^3, respectively. The mass of the vessel and LBE is 123,794kg and 369,575kg, respectively. It is assumed that the total mass of nuclear island is 5,000 ton and the nuclear island is rigid.

Fig. 2 depicts the FE models. The FE stick model composed of beam element and lumped mass is developed for the efficiency of the analysis. And the 3D shell model is developed for the time and stress analysis.

The two-dimensional and the three-dimensional isolation systems are properly modeled by the equivalent stiffness and the equivalent viscous damping to represent mechanical properties of the isolators.

The commercially FE software ABAQUS v6.7 was used for the finite element analysis.

3. Seismic Base Isolation System for PASCAR

Two cases were considered for the base isolation systems of the PASCAR concept: one for a two-dimensional seismic isolation system using horizontal laminated rubber bearings and the other for a three-dimensional seismic isolation system.

In the two-dimensional seismic isolation system, high damping laminated rubber bearings, similar to that in KALIMER [2] are used. The horizontal isolation frequency and the vertical frequency were determined to be 0.5 Hz and 21 Hz, respectively [2]. The design targets for the isolators are 12% above the damping coefficient and 300% above the maximum shear displacement.

The conceptual design for a three-dimensional isolator is shown in Fig. 3. The three-dimensional isolator has a high damping laminated rubber bearing adapted to isolate horizontal seismic loadings. And this isolator cooperates with a vertical isolation device employing a series of disc springs effective for isolating vertical seismic loadings. The horizontal isolation frequency is 0.5 Hz as same as the two-dimensional isolator. But the vertical isolation frequency is determined to be 1.1Hz and the damping coefficient is 8%.

4. Seismic Response Analysis for PASCAR

4.1 Time History Analysis for Reactor Vessel

The input motions used for the time history analyses contain three components of the artificial time history (ATH). The ATH used in the FE analysis is the time history for the safe shutdown earthquake (SSE) condition. The maximum accelerations of the ground motion for the SSE are 0.3g in horizontal direction and 0.2g in the vertical direction. It is assumed that the damping coefficient of the reactor vessel is 4%.

The natural frequencies for the fixed base, the two-dimensional and the three-dimensional isolation case are calculated by a mode analysis. The natural frequencies of the fixed base are 5.1Hz in the horizontal directions and 13.4Hz in the vertical direction, respectively. These frequencies exist within the seismic frequency, and this reactor vessel for the fixed base is very weak for an earthquake.

Fig. 4 compares the acceleration response spectra at a damping value of 4% at the bottom of the reactor vessel. In the horizontal direction, the accelerations for the two-dimensional and the three-dimensional isolation cases become much lower than those of the fixed base case such that reductions from 17g to 0.3g are obtained. In the vertical direction, the acceleration of the three-dimensional case is reduced much lower than those of the two-dimensional and the fixed base cases. The accelerations for the two-dimensional case are same as those of the fixed base case. The reduction of accelerations of the three-dimensional isolation system is from 7.0g of the fixed base to 1.4g.

The maximum displacement is 26.6cm in the horizontal direction and 5.0cm in the vertical direction for the three-dimensional isolation system.

4.2 Stress Analysis for Reactor Vessel

The stress analysis for the three-dimensional reactor vessel has been investigated using the response spectra which are obtained in the acceleration analysis.

The seismic margin evaluations are performed using the stress limit conditions of ASME Code, Section III, NB, Rules for Evaluation of Service Loadings with Level D Service Limits. The seismic margin is calculated by following equation.

$$\text{Margin} = \frac{\sigma_{SSE}}{P_L + P_b} - 1.0 \qquad (1)$$

P_L and P_b are the local primary membrane stress intensity and the primary bending stress intensity, respectively. σ_{SSE} is the total stress intensity for horizontal and vertical SSE loads. The square root of sum of square (SRSS) method is used for the summation of stresses in each direction.

The maximum stress occurs at point A (Fig. 2(b)) of reactor vessel. At Point A, (P_L+P_b) is 298MPa and σ_{SSE} is 400MPa. And the seismic margin is 0.34. It means that the reactor vessel supported by three-dimensional isolation system is safe for SSE seismic loads.

5. Conclusions

The three-dimensional isolation system for PASCAR is effective to reduce both vertical and horizontal seismic loadings to insure the structural integrity of the reactor structure enhancing structural safety margin as well as the economic competitiveness.

Acknowledgement

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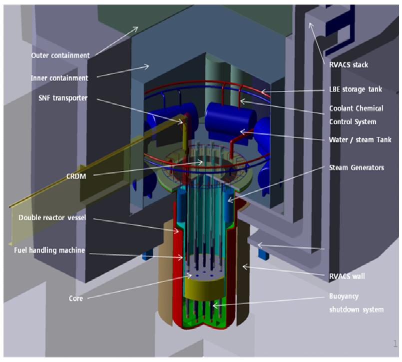
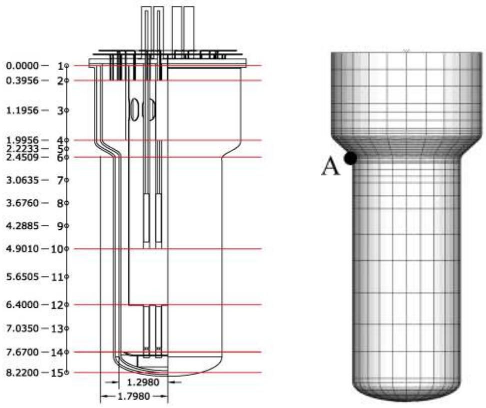


Fig. 1 Schematics for PEACER



(a) (b)

Fig. 2 (a) stick model and reactor vessel, (b) 3D shell model

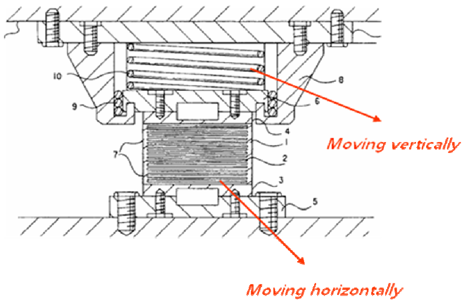
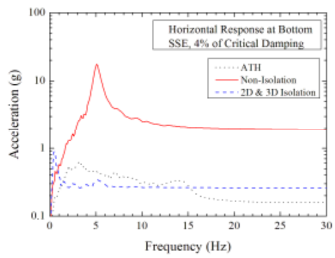
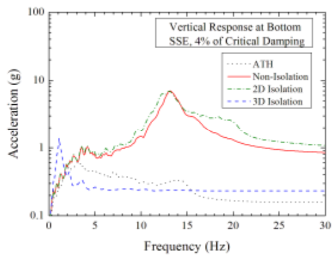


Fig. 3 Schematics for Seismic Isolator



(a)



(b)

Fig. 4 Acceleration Response