2B23

A study on dynamic behaviors of integrated reactor internals about an earthquake

Author Youngin Choi*, Author No-Cheol Park*, Author Young-Pil Park* and Author Kyeong-Hoon Jeong**

* Department of Mechanical Engineering, Yonsei University
50 Yonsei-ro, Seodaemun-gu, Seoul 120-749, Republic of Korea
E-mail: pnch@yonsei.ac.kr

** Korea Atomic Energy Research Institute
1045 Daedeokdaero, Yuseong, Daejeon 305-303, Republic of Korea

Abstract

Reactor internals show dynamic behaviors when they are affected by various dynamic loads such as earthquakes and flow induced vibration (FIV). The structural integrity assessment evaluates these response behaviors in order to prevent accidents and the seismic analysis identifies the dynamic behaviors from the seismic loads. The seismic analysis should be performed during the design process in order to secure safety of the reactor internals and the reactor should be manufactured considering the results of the seismic analysis. The System-Integrated Modular Advanced Reactor (SMART) developed in Korea is an integrated pressurized water reactor which contains main components in the one reactor vessel. In this research, a methodology of the seismic analysis with the integrated reactor internals is suggested. The simplified finite element (FE) models, which reflect dynamic characteristics of the reactor internals, are constructed for the seismic analysis. In order to validate these simplified models, the reliable dynamic characteristics of the reactor internals extracted from the scale-down model are used. Moreover, the time history analysis is conducted with the verified seismic model in order to obtain the dynamic behaviors of the reactor internals. These results are used to evaluate the structural integrity of the reactor internals.

Keywords : Scale Down Model, Integrated Reactor, Earthquake, Fluid Structure Interaction, Time History Analysis

1. Introduction

The SMART is the next generation integral type reactor which is the energy source for generating electricity and desalinating the seawater. It can provide 90 MWe of electricity and 40,000 tons of fresh water a day for a city with a population of 100,000. Moreover, it has the advantage in the safety by preventing large break loss of coolant accidents (LBLOCA). In the development steps, new reactor needs to evaluate structural integrity in order to verify the safety before construction. One of the processes in the structural integrity evaluation, the seismic analysis is carried out for obtaining the structural responses of reactor internals about the earthquake and it calculates that structures can endure the seismic load. In the past, several researches are performed with similar method because conventional pressurized reactor internals have similar inner structures (Jhung and Hwang, 1996). However, the small modular integral reactor, which shows new concept of design, needs new criteria in the seismic analysis because it shows different dynamic behaviors compare with the general reactor internals. In general, the natural frequencies of the submerged structures decrease according to the added mass effect from the fluid structure interaction (FSI). In case of the integral reactor, the reactor internals, which are the CSB assembly and UGS assembly, are arranged close together and gap fluid is located between them. This gap fluid affects greatly to the dynamic characteristics of the submerged structures by increasing the added mass effect and coupling the dynamic behaviors between the adjacent cylinders (Fritz, 1972). When building up the seismic analysis model, it needs to consider the exact dynamic characteristics of the reactor internals in order to identify the reliable dynamic behaviors.

In this research, we suggest the seismic analysis with the verified analysis model by applying the reliable dynamic characteristics from the scale-down model. We apply this method to the SMART internals and manufacture the

scale-down model for extracting the dynamic characteristics considering the fluid-structure interaction effect (Choi, et al., 2013). And then, we construct the seismic analysis model using these extracted dynamic characteristics. The seismic analysis model is simplified with the one dimensional (1D) beam model in order to perform the high-cost seismic analysis efficiently. And then, the time history analysis is performed with this simplified model using the generalized seismic input in order to obtain the dynamic behaviors of the structures.

2. Seismic Analysis

2.1. Seismic Analysis of Reactor Internals in SMART

Different with the general pressurized reactors, main components in the SMART are concentrated in the pressure vessel likes the Fig. 1. According to the integrated structure of the SMART, the reactor internals, which are the CSB assembly and UGS assembly, are arranged with the narrow gap. These two co-axial cylindrical structures have large slenderness ratio that makes low frequency bending modes (i.e. translational movement of cylinders under fixed-free boundary conditions). These modes are easily affected by the seismic input because they have large effective masses about the input direction. In addition, the decrease in the overall natural frequencies from the added mass effect caused by the inner coolant makes that structures are affected by the seismic input greatly. In the seismic analysis, the response behaviors of these cylindrical structures against the seismic input are identified focusing on the low frequency bending modes.

Fig. 1 Inside of the reactor vessel, main components of the SMART are arranged compactly. It also includes the reactor internals the CSB assembly and UGS assembly.

2.2. Analysis Model Design

In the seismic analysis of the SMART internals, the simplified FE model, which is composed of the 1D elements, is developed using the finite element analysis program ANSYS. This simplified model can reduce the analysis time and cost greatly and it also provides the dynamic behaviors about the seismic input efficiently. The validity of the analysis model is verified with the reliable extracted dynamic characteristics from the scale-down model (Choi, et al., 2013).

In order to construct seismic analysis model, the Timoshenko beam element, which is the BEAM188, is adopted to the structures considering the shear deformation. The reactor vessel, CSB assembly, UGS assembly and FMHA are included in the structure models. The beam elements divided into several parts in order to reflect the detailed geometric

information of the structures which can affect to the dynamic characteristics by changing the stiffness of the structures. The detailed structures in the CSB assembly and UGS assembly are simplified considering the inertial mass. In the SMART, reactor internals are assembled to the upper flange of the reactor vessel. This boundary condition has dominant influences in the bending modes of the structures. The boundary condition in the simplified seismic model is modelling with the spring element (COMBIN14 in ANSYS) considering the deflection of flange and hold-down ring. The spring constant is calculated from the results of the 3D FE model. The inner coolant in the reactor vessel is modelled by the lumped mass elements (MASS21) regarded as the added mass. And fluid elements (FLUID38) are adopted for the inner coolant located in the narrow gap between the barrel structures taking account of the coupling effect by the FSI. Figure 2 demonstrates the established simplified seismic model of the SMART internals.

Fig. 2 The simplified seismic analysis model is built up with the spring, beam, lumped mass and fluid elements reflecting original geometry and boundary conditions of the SMART internals.

2.3. Time History Analysis

The time history analysis is the most commonly used method in the seismic analysis in order to obtain the response behaviors of the structures when they are affected by the seismic load. It uses the acceleration time histories of the general earthquake as the base excitation and calculates the responses at the interested locations of the structures. In this research, the north-south El Centro earthquake input is used as the base excitation. Figure 3 shows the time histories and response spectrum (3% damping) of the El Centro earthquake. The base excitation is applied to the base of the reactor corresponding horizontal direction using the large mass method. The large mass method is an indirect technique used in the structural dynamic analysis when excitation forces are hardly be measured. The large mass method assumes the ground as the large mass and the whole structures are connected to the ground. It shows reasonable results when the large mass is sufficiently large comparing with the total mass of the whole structures.

In the time history analysis, the response histories (displacement, velocity and acceleration) against to the seismic input at the interest points are identified. The top, middle, and bottom points of the CSB assembly and UGS assembly are selected as interest points.

Fig. 3 Time Histories of the north-south El Centro earthquake with 0.02s time step (left) and response spectrum (right)

2.4. Results

Figure 4 and Fig. 5 shows the response histories at the interest points (i.e. top, middle and bottom) of the CSB assembly and UGS. As shown in the figures, the CSB assembly and UGS assembly show the largest deformation at the bottom of the barrel. It shows that the peak displacement at bottom of the CSB assembly is 12.531mm at 11.70 second and the UGS assembly is 13.434mm at 12.88 second. On the other hand, the deformations at the middle and top of the structures show inconsiderable values below 4mm. Thus, it needs to observe the deformation in the bottom of the structures whether they interfere each other or not. The maximum value of the relative displacement between the CSB assembly and UGS assembly is 7.25mm at the bottom of the UGS assembly. It shows that the gap between the CSB assembly and the UGS assembly (141mm) is sufficiently wide than the maximum relative displacement of these structures. In addition, the bottom of the CSB assembly does not collide with the FMHA considering the space between the two structures (36mm). As shown in the results of the displacement response histories, the reactor internals satisfy the design acceptance.

In the case of the acceleration, the bottom parts of each structure also show largest value as depicted in Fig.4 and Fig.5. The peak acceleration at the bottom of the CSB assembly is 18.644 m/s^2 at 11.88 second and the UGS assembly is 18.270 m/s^2 at 12.38 second. It shows that the acceleration is amplified about 5 times compared with the original maximum input (0.348 g).

Fig. 4 Response Histories (Displacement and Acceleration) of the CSB assembly at the top, middle, and bottom points

Fig. 5 Response Histories (Displacement and Acceleration) of the UGS assembly at the top, middle, and bottom points

3. Conclusion

In this research, the seismic analysis of the SMART is performed in order to obtain the dynamic behaviors of the specific reactor internals. In order to carry out the analysis, the simplified seismic analysis model is established reflecting the reliable dynamic characteristics extracted from the scale-down model. The results show that the analysis model provides the dynamic behaviors of the reactor internals affected by the seismic input clearly.

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