A Study on the Reduction Effect for Seismic Isolation System of Nuclear Power Plant

Hong-Pyo Lee & Myung-Sug Cho
Plant Construction & Engineering Lab., KHNP-Central Research Institute, Republic of Korea

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SUMMARY:
Seismic isolation systems which performance was verified from many experimental studies has been used general industry structures such as bridges, LNG tank and architecture structures to protect the structures from the destructive earthquake. There are so many advantages when using seismic isolation to construct civil structure against strong earthquake area. However, seismic isolation system in nuclear power plant is adapted with limitation because of a field of insufficiency study in nuclear facilities. In point of view, a study on the development of seismic isolation system in nuclear power plant is being started in Korea. The target nuclear power plant is Advanced Power Reactor 1400. In this paper, reduction effects by seismic isolation device, LRB of earthquake load are described, in brief.

Keywords: seismic isolation system. Nuclear power plant, earthquake

1. INTRODUCTION

Seismic isolation systems which performance was verified from many experimental studies has been used general industry structures such as bridges, LNG tank and architecture structures to protect the structures from the destructive earthquake. There are so many advantages when using seismic isolation to construct civil structure against strong earthquake area. However, seismic isolation system in nuclear power plant is adapted with limitation because of a field of insufficiency study in nuclear facilities. In point of view, a study on the development of seismic isolation system in nuclear power plant is being started in Korea. The target nuclear power plant is Advanced Power Reactor 1400.

When a seismic isolation system is applied underneath a nuclear structure, the inertial forces occurring at the upper and lower structures diminish but the displacements increase, and the increased displacements are mostly accepted by the seismic isolator which is made to receive a large axial load at a large lateral displacement.

Fig. 1.1 shows a concept of the seismic isolation development on this research. It consist of four parts, (1) seismic resistance design, (2) reduction of earthquake load, (3) seismic isolation devices, (4) seismic isolation monitoring.

Briefly, this paper describes the numerical analysis result on the reduction effectiveness of earthquake load for a seismically isolated nuclear containment.

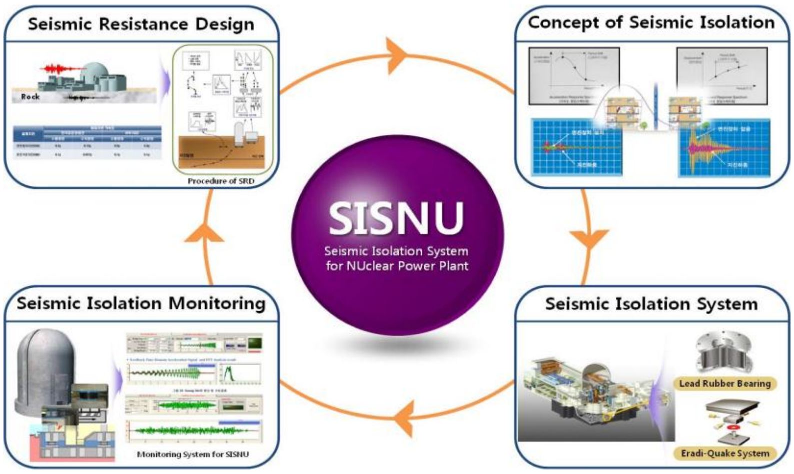


Figure 1.1. Layout of seismic isolation system

2. SEISMIC ISOLATION ANALYSIS MODEL

2.1. Free vibration analysis model

The nuclear containment building used for the seismic isolation analysis is a prestress concrete building consisting of 3m-thick foundation mat, 1.2-thick cylindrical wall system and 1.07m-thick, hemispherical dome. It is 76.7m tall from the foundation mat to the top of the dome (Korea Hydro & Nuclear Power Co., Ltd, 2009). Major structural materials include concrete, rebar tendons, and liner plates. A 3D lumped mass model was established to perform an analysis on the application of the seismic isolation system. To validate dynamic characteristics of the established 3D lumped mass model, a 3D finite element model (Lee Yong-tae et al., 2009) and major modes were compared. Fig. 2.1 shows the model based on 3-D lumped mass and finite element.

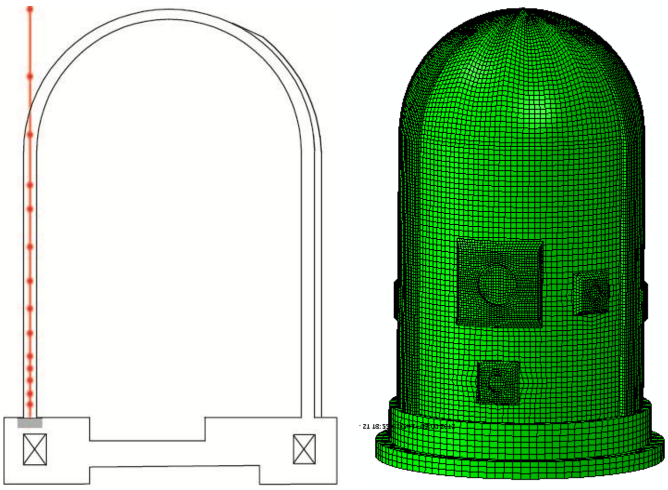


Figure 2.1. Free vibration analysis model

2.2. Seismic isolation analysis model

The seismic isolator was installed at the bottom of the lumped mass, which was established in order to evaluate seismic reduction effect by the seismic isolator, and a general-purpose finite element program, SAP2000 (Computers & Structures, 2011) was used to perform non-linear seismic isolation analysis. Upon analysis, the total weight of the nuclear containment building was 33,190 tons, the target period was 3 sec, and the maximum acceptable displacement was 30cm. Only the effect in the horizontal direction was considered for the seismic isolator, and the bottom of seismic isolation bearings were assumed to have a fixed end. When the lead rubber bearings (LRBs) were applied under these conditions, the effective stiffness was K_B=153.6kN/mm, K_1=794.8kN/mm, K_2=76.4kN/mm and Q_d=377.1kN, and the hysteretic behavior was as shown in Fig. 2.2.

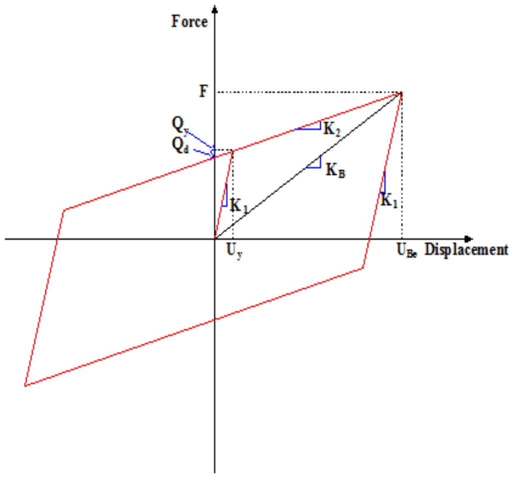


Figure 2.2. Force-displacement curve

The incident seismic waves used in the seismic isolation analysis cross at right angles, and artificial acceleration in which three statistically independent time histories were generated as a single set was also used. The peak ground acceleration (PGA) of the safe shutdown earthquake at the target nuclear containment building was 0.3g, and the acceleration-time history generated for three directions is shown in Fig. 2.3.

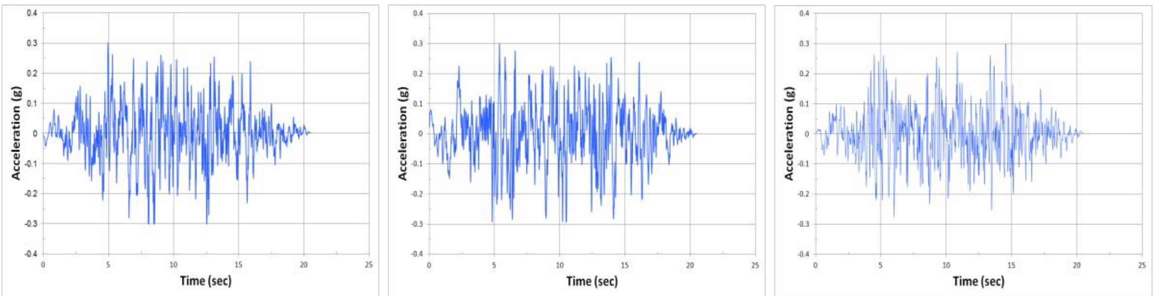
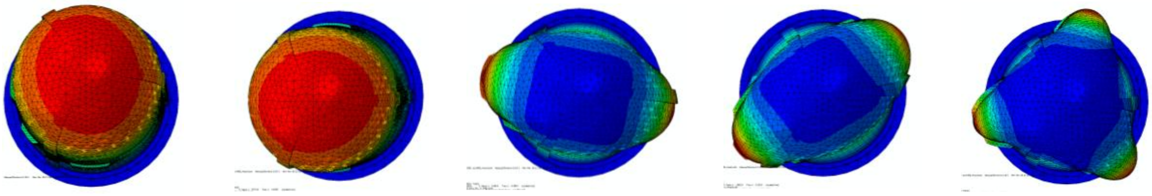


Figure 2.3. Artificial earthquake acceleration

3. RESULTS OF SEISMIC ISOLATION ANALYSIS

3.1. Results of free vibration analysis

The free vibration analysis found that the fundamental mode (Mode 1) of the lumped mass was 3.84Hz and the finite element model was 3.65Hz, which are very similar. While a slight difference was found as it advanced to higher modes, this was presumably due to the difference between analytical models. The free vibration analysis on the lumped mass model to which the seismic isolator proposed in Chapter 2.2 was applied found that the primary mode (Mode 1) was 0.34Hz (2.9sec), sufficiently satisfying the target 3sec period. In the seismic isolation analysis, modes higher than the tertiary mode (Mode 3) reflect structural characteristics, and a high frequency of over 10Hz was measured. In Fig. 3.1 and Table 3.1, the mode shapes of the finite element model and up to the mode 5 of each model were compared.



(a) mode 1 (b) mode 2 (c) mode 3 (d) mode 4 (e) mode 5

Figure 3.1. Mode shapes of the 3D finite element model

Table 3.1. Result of free vibration (unit: Hz)

Mode	Non-seismic isolation lumped mass	Non-seismic isolation finite element model	Seismic isolation-applied lumped mass
Mode 1	3.84	3.65	0.34
Mode 2	3.84	3.65	0.34
Mode 3	8.37	6.28	10.4
Mode 4	11.0	6.33	10.7
Mode 5	11.6	7.3	10.7

3.2. Acceleration and displacement response

Fig. 3.2 shows incident seismic waves in the horizontal direction, and acceleration-time history at the upper part of the seismic isolator. As a result of seismic isolation, the input ground motion decreased by about 60% in both east-west direction and north-south direction. It should be noted that this study examined two dimensional planes when a seismic isolation system must ultimately consider three dimensions.

The displacement hysteretic behavior of the seismic isolator is illustrated in Fig. 3.3. The maximum target displacement is 200mm and the maximum displacement of the seismic isolator was calculated to be 170mm, demonstrating the validity of the design and the analysis.

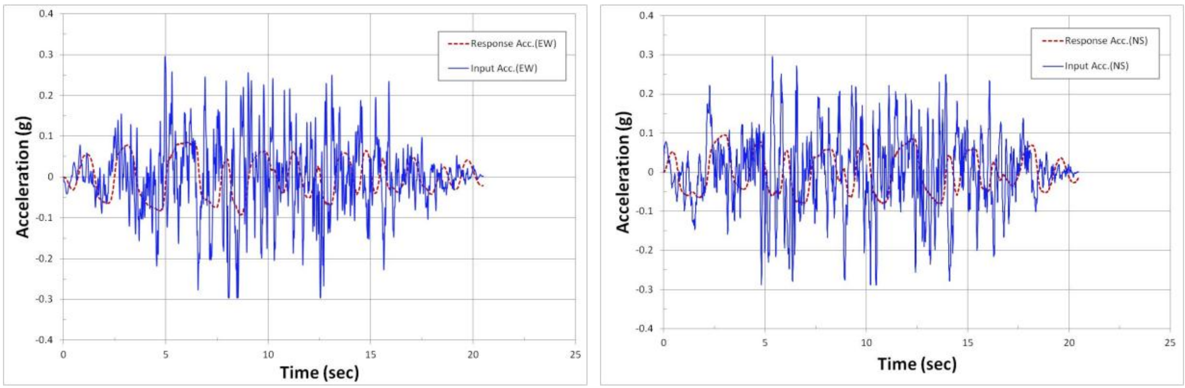


Figure 3.2 Acceleration responses by the seismic isolator: (Left) EW direction, (Right) NS direction

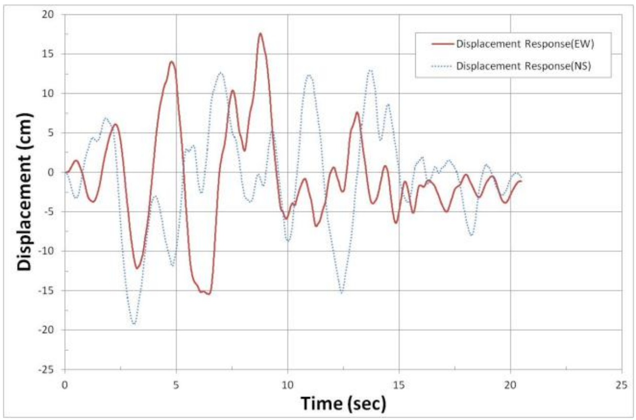


Figure 3.3 Displacement responses by the seismic isolator

4. CONCLUSION

In this study, the free vibration mode and the seismic reduction effect of a nuclear containment building as a result of seismic isolation were evaluated in order to develop a seismic isolation system to be applied to nuclear power plants. The target containment building is a domestic nuclear power plant and the lumped mass model was used to evaluate the reduction effect. Artificial seismic waves used for seismic analysis of Korean nuclear power plants were applied as the input ground motion of the seismic isolation analysis, and LRB seismic isolation bearings were introduced. The analysis found that the seismic isolator reduced the acceleration by about 60% compared to the input ground motion, and the maximum displacement of the seismic isolator was smaller than the target displacement at 170mm. Therefore, the seismic isolation analysis technique developed in this study can be expected to be used as reference when designing a seismic isolator for nuclear containment buildings in the future.

ACKNOWLEDGMENT

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