Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 7-8, 2015

Variation Limits in Mechanical Properties of Seismic Isolation Systems Subjected to Long-Period Ground Motions

Young-Sun Choun*, Junhee Park
Integrated Safety Assessment Division, Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Daejeon, 305-353, Republic of Korea
**Corresponding author: sunchun@kaeri.re.kr*

1. Introduction

The mechanical properties of rubber bearings have inherent variations owing to the variability in rubber materials and manufacturing processes. After installation, the properties of the rubber bearings constantly change due to aging and environmental effects for long-term service life. ASCE-4 [1] restricts the greatest variability in the mechanical properties within 20%, with 95% probability, for seismically isolated, safety-related nuclear structures to account for all variations in material properties during manufacturing, construction, and long-term operation.

The effects of the mechanical property variability of rubber bearings on the response of base-isolated structures will be greater during long-period ground motions than short-period ground motions [2]. It is necessary to evaluate the limits of variability in the mechanical properties of rubber bearings when subjected to ground motions with relatively low peak ground acceleration to velocity (A/V) ratios.

2. Response to Ground Motions with Different A/V Ratios

The response of an isolation system is quite different for A/V ratios of input ground motions. In addition, the effect of the stiffness variation of the isolators on the response of the isolation system is highly sensitive to peak A/V ratios of the ground motions. The peak displacement of the isolation system is significant for ground motions with low A/V ratios as shown in Fig. 1 [2]. The large displacements of isolators cause huge shear strains in isolation bearings as shown in Fig. 2.

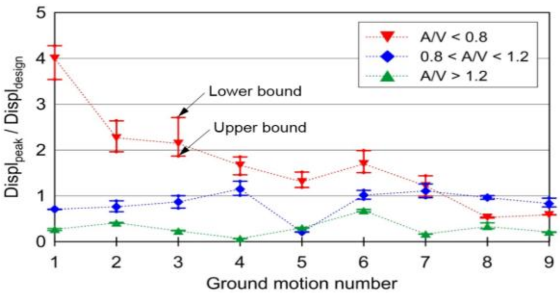

Fig. 1. Ratios of peak displacements to design displacement of isolators for ground motions with different A/V ratios.

The stiffness variations of isolation bearings can cause damage to the isolation system during ground motions with low A/V ratios.

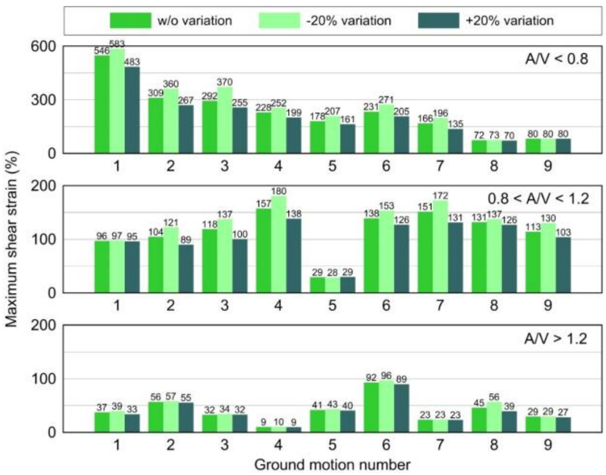

Fig. 2. Maximum shear strains of isolators for different stiffness variations in isolators and A/V ratios of ground motions.

3. Response to Long-Period Ground Motions

The variation limits in the mechanical properties of lead rubber bearing (LRB) system are evaluated for ground motions with low A/V ratios.

2.1 Structural Model

The structural model for a nuclear island that is supported by the LRB base isolation system is considered. The fundamental periods of the structural model in the orthogonal directions are $T_x = T_y = 2.10$s. The LRBs were designed to have an outside diameter of 1,500 mm, with 30 layers of 7 mm thick rubber and four lead cores of 400 mm diameter. The effective horizontal stiffness of a bearing is 9.03 kN/mm and the vertical stiffness is 12,896 kN/mm. A standard design response spectrum defined in the Regulatory Guide 1.60 [3] was employed, and a peak ground acceleration (PGA) of 0.5g was used for the seismic design. The design displacement at the base isolation level was assumed to be 210 mm in horizontal directions. The nonlinear behavior of LRBs was modeled by a bilinear model. The parameter values used to define the bilinear model are 544.93 kN/mm for the initial stiffness, 4.26 kN/mm for the post-yield stiffness, and 1,001.77 kN for the characteristic strength. The horizontal and vertical behaviors of the isolation bearing were modeled based on the bilinear model and linear model, respectively.

2.2 Ground Motion Inputs

To evaluate the response of seismically isolated nuclear structures for long-period ground motions, 30 earthquake record sets that were modified to match the design response spectral shapes in the long period range were used, shown in Fig. 3. The earthquake records have PGAs ranging from 0.480 to 0.895g, PGVs ranging from 0.572 to 1.134 m/s, and peak A/V ratios from 0.54 to 1.22 g/m/s. Two horizontal components (X and Y) and one vertical component of the ground motions were used for a seismic response analysis.

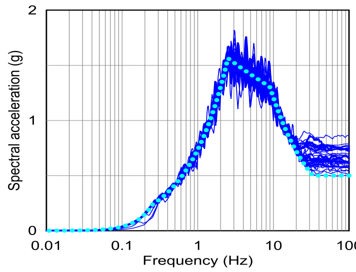

Fig. 3. Spectral accelerations for input ground motions vs design response spectral shape anchored to a PGA of 0.5g.

2.3 Seismic Responses

The long-period ground motions increase the peak displacement of isolation system. It can be found from Fig. 3 that the peak displacements of isolators are larger than the design displacement of 210 mm for many of the input motions. When isolation bearings have variations in their mechanical properties, the response of isolation system varies significantly. Fig. 5 shows the peak displacements and maximum shear strains of isolation bearings for their stiffness variations from -20% to +20%. The effect of the stiffness variations of bearings on the peak displacement of isolation system was significant. The displacement decreased up to 30% for the variation of +20%, but increased up to 50% for the variation of -20%, as shown in Fig.6.

The maximum shear strains in isolation bearings were

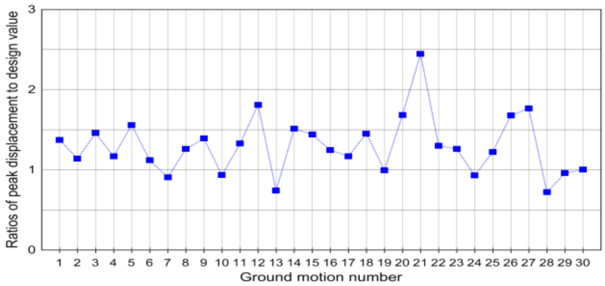

Fig. 4. Ratios of peak isolator displacements to design value.

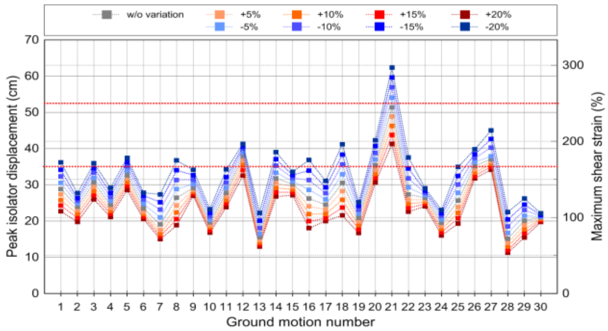

Fig. 5. Peak displacements and maximum shear strains of isolation bearing.

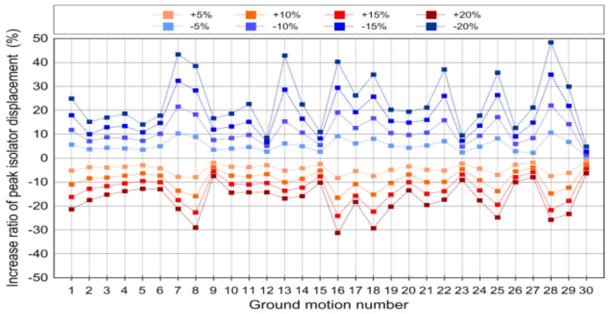

Fig. 6. Increase ratios of peak isolator displacement for different variations in the mechanical properties.

greatly varied by their stiffness variations. When the bearing has a stiffness variation of -20%, the maximum shear strain for ground motion #21 reaches about 300%. The huge shear strain in isolation bearings may exceed the linear strain limit of bearings [4].

4. Conclusions

The peak displacements and maximum shear strains of isolation bearings varied significantly owing to their stiffness variations for long-period ground motions. The variation limits in the mechanical properties of isolation system should be properly determined considering the behavior of isolation system for long-period ground motions.

REFERENCES

[1] American Society of Civil Engineer, Seismic Analysis of Safety-Related Nuclear Structures and Commentary, ASCE-4 Draft, 7.7, 2013.

[2] Y.-S. Choun, J. Park, and I.-K. Choi, Effects of Mechanical Property Variability in Lead Rubber Bearings on the Response of Seismic Isolation System for Different Ground Motions, Nuclear Engineering and Technology, Vol.46, pp.605-618, 2014.

[3] Regulatory Guide 1.60, Design Response Spectra for Seismic Design of Nuclear Power Plants, U.S. Nuclear Regulatory Commission, Washington, D.C., 1973.

[4] The Nuclear Standards Committee of JEA, Seismic Design Guidelines for Base-Isolated Structures of Nuclear Power Plant, JEAG 4614-2013, Japan Electric Association, 2013.