Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 25-26, 2012

A Dependency Test of Shear Strain and Compressive Stress of Full-Scale Lead Rubber Bearings for Nuclear Power Plant

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1. Introduction

Given the critical importance of nuclear power plants, seismic isolators must have been tested for reliability before applying to nuclear facilities. Rubber bearings are a good example of seismic isolators recommended for nuclear power plants. Among the different types of rubber bearings, lead rubber bearings (LRB) deform according to shear strain during an earthquake, and absorb energy due to the plastic behavior of lead core. When an earthquake occurs, the flexibility of LRB is used to lengthen the period of a seismically isolated structure, thus reducing seismic force exerted on the superstructure. For energy dissipation, a cylindrical lead is inserted into the rubber bearing, contributing to the attenuation performance of the seismically isolated structure based on the plastic behavior of lead. This prevents excessive change in the seismically isolated device and reduces seismic force exerted on the superstructure. In this study, we applied seismic isolation to APR1400 to derive characteristic values from a preliminary design of the seismic isolation system, and created actual test specimens to analyze the dynamic behavior of LRB.

2. Design and Dimensions of LRB

2.1 Dimensions of Full-scale LRB specimen

To carry out a characteristic test of LRB, we designed and created two full-scale LRB specimens. Overseas seismic isolation technology for nuclear power plants was used to set the target cycle of specimens. The specifications are 1120 mm in external diameter (rubber bearing external diameter: 1100mm, thickness of rubber coating: 20mm), 240 mm for the lead core, and G=0.392MPa. Depending on the environment temperature during use, a temperature correction factor must be applied to LRB. For our specimens, we applied a characteristic value for 20℃. In general, the first shape factor related to the verticality and flexural stiffness of LRB is 20~35, and the second shape factor of form related to buckling is greater than 5. In accordance, the first and second shape factors of form used in this study are 39.3 and 4.9, respectively.

2.2 Properties of Natural Rubber

We carried out a characteristic tests on the rubber used in full-scale LRB specimens. The characteristic tests were conducted to check the required physical properties outlined in ISO22762 [1]. As shown in Table 1, the specimens were found to meet the minimum requirements of ISO22762.

Table I: Test Results of Rubber Material Properties

Item	ISO22762 Specification	Specimen
Hardness	35±5	39.20
Tensile strength (MPa)	14	23.27
Elongation (%)	600	635.80
Bbonding strength (kN/m)	6R	8.6R

3. Experimental Program and Results

3.1 Test Equipment

The test equipment used in the characteristic tests of our LRB specimens is shown in Fig. 1. It can accommodate a maximum vertical load of 30,000kN. It has a maximum vertical acceleration of 20mm/sec, and a maximum vertical displacement of ±1,000mm.

Fig. 1. The compression-shear test machine.

3.2 Experimental Program

To determine the equivalent damping ratio and dependency resulting from the compressive stress of LRB, we carried out various compressive stress tests at 5MPa, 10MPa, 13MPa, 15MPa, and 20MPa. Also, to determine the change in shear stiffness and damping ratio caused by shear strain, we conducted compressive stress tests with a shear strain of 50%, 100%, 150%, and 200% while maintaining a constant vertical load [2].

3.3 Result of Compressive Stress dependency test

Fig. 2 presents force-displacement hysteresis loops of specimens under various compressive stress conditions.

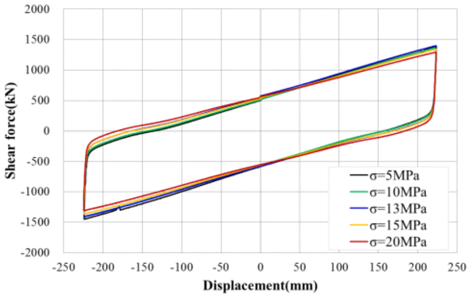

Fig. 2. Hysteresis loops of the specimen under various compressive stress conditions (5, 10, 13, 15, 20MPa).

Table II: Test results of compressive stress dependency

σ (MPa)	Shear stiffness (k_h)	Damping Ratio (h_{eq})
5	3.109kN/mm	0.253
10	3.059kN/mm	0.254
13	3.029kN/mm	0.271
15	2.990kN/mm	0.264
20	2.884kN/mm	0.277

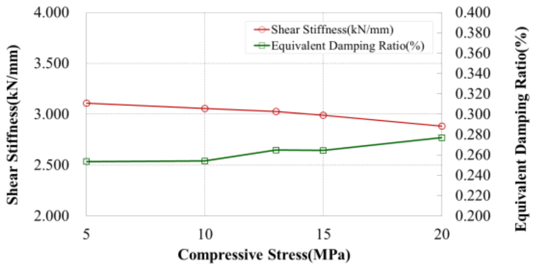

Fig. 3. Results of compressive stress dependency.

Fig. 3 gives the change in shear stiffness and equivalent damping ratio. As shown in Fig. 3, the shear stiffness decreases with an increase in compressive stress, whereas the equivalent damping ratio rises with higher compressive stress. With the design compressive stress (13 MPa) as a reference, we found a 2.6% change at 5 MPa, and 4.8% at 20 MPa.

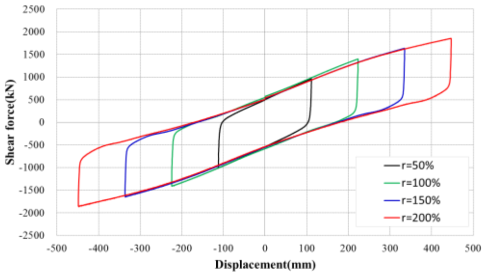

Fig. 4. Hysteresis loops of the specimen under various shear strain conditions (50, 100, 150, 200%).

3.4 Result of Shear Strain dependency test

Hysteresis loops obtained from shear strain dependency tests are shown in Fig. 4. The change in shear stiffness and damping ratio according to shear strain can be observed in Fig. 5. For a shear strain in the range of $0.5\gamma_0$ ~ $2.0\gamma_0$, both shear stiffness and equivalent damping ratio decrease while shear strain increases. The specimens were found to have a high shear strain dependency. Results for the equivalent damping ratio were similar to the change in shear stiffness.

Table III: Test results of shear strain dependency

Shear strain(γ_0)	Shear stiffness (k_h)	Damping Ratio (h_{eq})
50%	4.408kN/mm	0.325
100%	3.098kN/mm	0.265
130%	2.411kN/mm	0.223
150%	2.047kN/mm	0.201

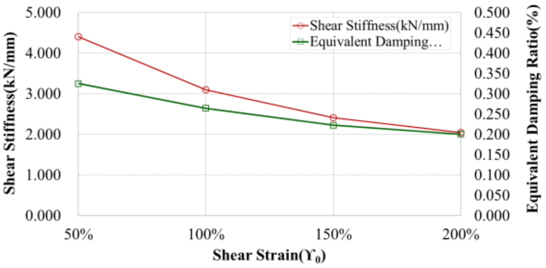

Fig. 5. Results of Shear strain dependency.

3. Conclusions

To assess the performance of LRB specimens as seismic isolators of nuclear facilities, we evaluated the compressive stiffness, shear stiffness, and equivalent damping ratio. This was followed by a test of bearing and shear strain dependency. When the vertical load exerted on LRB becomes higher, the effective stiffness gradually decreases while the equivalent damping ratio increases. With an increase in shear strain, the effective stiffness and equivalent damping ratio drops significantly, indicating a high dependency on shear strain. Thus, we can see that LRB characteristics are greatly affected by varying compressive stress and shear strain. To apply LRB in nuclear power plants, we will have to reflect accurate characteristic values for vertical load, design variables, and other factors affecting mechanical characteristics.

ACKNOWLEDGMENT

This work was supported by the Energy Efficiency & Resources of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy (No. 2011T100200081)

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