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Analysis of Horizontal Hysteretic Behavior of LRB in Two-Dimensional Large Deformation Behavior

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1. Introduction

Dynamic characteristic tests of full scale lead rubber bearing were already performed for the evaluation of performance criteria of isolation system for nuclear power plants. For the dynamic test for a full scale rubber bearing, two 1500mm diameter lead rubber bearings were manufactured.

The viewpoints of this dynamic test were determination of an ultimate shear strain level of lead rubber bearing, behavior of rubber bearing according to static and dynamic input motion, sinusoidal and random (earthquake) motion, and 1-dimentional and 2-dimensional input motion.

In this study, only 2-dimensional behaviors of LRB are considered for the evaluation of numerical model for LRB. A longitudinal and lateral strain behaviors are considered.

2. Overview of Test

For the evaluation of a dynamic characteristic test, two full scale isolation devices were manufactured. The diameter, total rubber thickness diameter of lead core are 1500mm, 224mm, 320mm, respectively. The drawing and figure of lead rubber bearing is shown in figure 1.

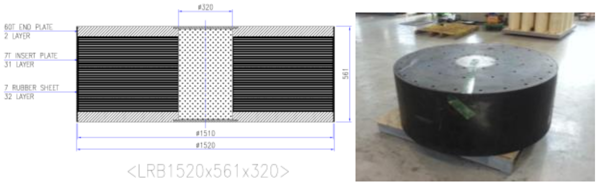


Figure 1. Drawing and LRB for Mechanical property test

Our previous study, only 2 dimensional effect to the longitudinal behavior was considered, but in this study, a lateral strains are also considered.

For the considering two dimensional input motion, a dynamic input motions were generated. In the case of generating input motion, a capacity of test machine should be considered. For the 100% and 200% shear strain level test, seismic input motions were considered but over 300% shear test, only elliptical motions were considered because of the limit displacement of test machine in UCSD. The seismic input motion for 100% and 200% shear strain level, 300% and 400% shear strain level test motions are shown in figure 2 and 3, respectively.

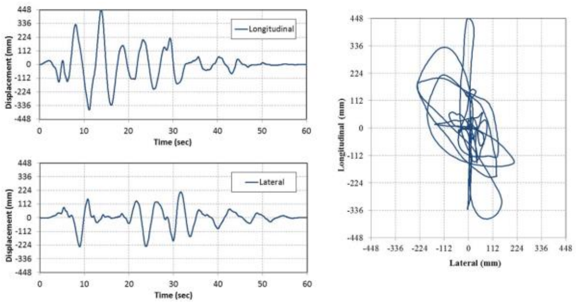


Figure 2. Seismic input motion for 100% and 200% shear test

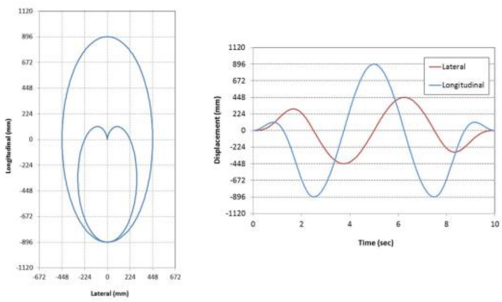


Figure 3. 300%, 400% Elliptical Trace Sinusoidal Motion

A test protocol was decided for considering a dimension of test and shear strain level of test. All the test protocols are summarized in table 1.

Table 1. Test protocol for2-dimensional behavior dynamic characteristic test of lead rubber bearing

Run #	Strain (%)	Disp (mm)	Freq (Hz)	Load shape	Directi on
6	100%	224		EQ 2D	xy
9	200%	448		EQ 2D	xy
11	300%	672	0.2	2D sinusoidal	x
13	400%	896	0.2	2D sinusoidal	x

3. Test Results

Generally a force-displacement relation of LRB is shown in Figure 4. But when the strain is increased, a hardening effect occurred.

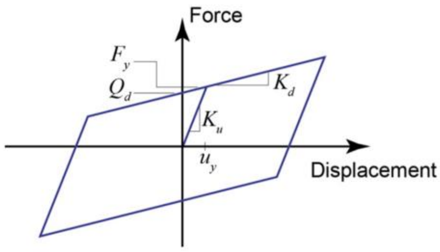


Figure 4. Typical Force-Displacement relation of LRB (USNRC, 2019)

The force-displacement relations for 200% shear strain level earthquake motion are shown in Figure 5. As shown in Figure 5, even though the force-displacement relations shapes are not exactly follow the typical shape of LRB but generally not many differences between typical shapes of the force-displacement relations.

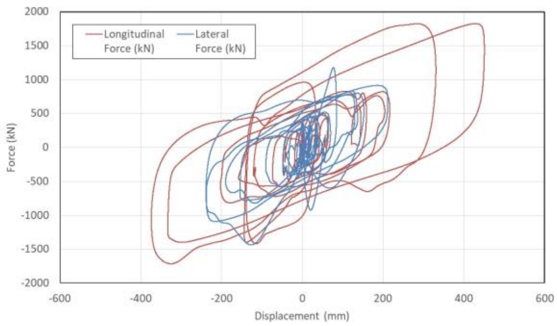
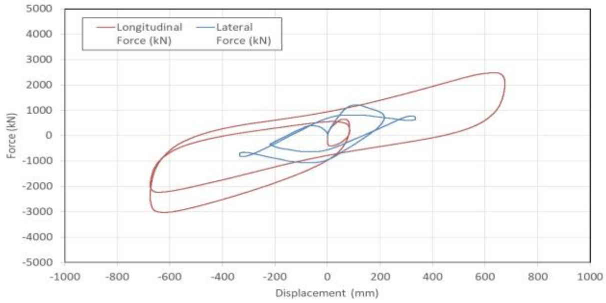


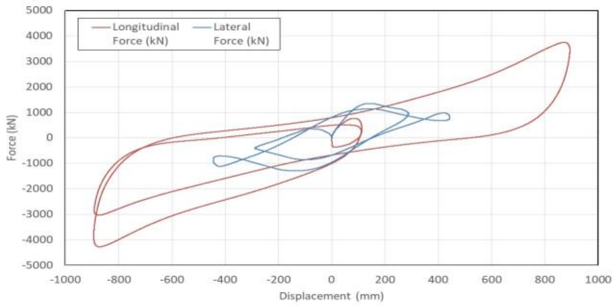
Figure 5. Force-Displacement relations for 200% shear strain level earthquake motion (Benzoni et al, 2014)

The force-displacement relations for 300% and 400% shear strain level characteristic test results are shown in Figure 6. As shown in figure 6, the force-displacement relations of lateral direction are totally different that of typical behavior of LRB. Even a negative stiffness occurred. Otherwise, a longitudinal directional behaviors follows a typical LRB shear behavior. The 300% shear strain level is not a normal situation for conventional structure. But in the case of nuclear power plants, isolator behavior should be considered until shear failure. Therefore, if we want to simulation numerical analysis for low strain level as 200% shear strain level, we don't need to consider this kind unexpected behavior. But if we want to expect large strain level behavior of seismic isolated NPP structure, we should consider the force-displacement relation as shown in Figure 6. If 300% or more of shear deformation occurs, numerical analysis is performed by applying the force-displacement relation in the longitudinal direction to the force-displacement relation in the lateral direction, and the numerical analysis results will lead to incorrect results.

In order to accurately determine the effect of this unpredictable lateral directional isolation behavior, a numerical analytical study using each force-displacement relationship should be additionally performed.



(a) force-displacement relation for 2 dimensional 300% shear strain level test



(b) force-displacement relation for 2 dimensional 400% shear strain level test

Figure 6. Characteristic test results for LRB (Benzoni et al, 2014)

4. Conclusions

In this study, seismic isolation device tests were performed for the evaluation of 2-dimentional large shear strain level behavior. Through this test, it can be recognized that unpredictable lateral force-displacement relation should be considered for over 300% shear strain level behavior.

ACKNOWLEDGEMENT

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