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# Experimental Study on the Ultimate Property Diagram of Base Isolators

Jung Han Kim [a*], Min Kyu Kim [a], In-Kil Choi [a]
[a] *Korea Atomic Energy Research Institute, 1045 Daeduk-daero, Dukjin-dong, Yuseong-gu, Daejeon, 305-303*
[*] *Corresponding author: jhankim@kaeri.re.kr*

## 1. Introduction

In recent, a seismic base isolation system is raised to secure the seismic safety of nuclear power plants. The guideline for base isolated nuclear power plants is being developed in many countries and several design examples were tried. Because the nuclear facilities must have enough capacity even under the extreme earthquake event, the safety of an isolation system needs to be verified in the design procedure. Therefore, the study on the limit state of an isolator is required prior to the safety evaluation of the isolation system.

The type of base isolator appropriate for a nuclear power plant structure is regarded as an elastometric rubber bearing with a lead core. The failure limit of the lead-rubber bearing (LRB) is not easy to be predicted because of its high nonlinearity and complex loading condition by an earthquake excitation. Furthermore, the failure mode of a LRB can be affected by the vertical load, shape factor, material property of rubber, and manufacturing quality etc. Therefore, a simplified and efficient test approach to evaluate the failure state of a base isolator is necessary. From this point of view, the experimental test to determine all possible failure modes and its limit state was performed in this study.

## 2. Ultimate Capacity of a Base Isolator

### *2.1 Failure Mode of a Base Isolator*

A laminated rubber bearing, including the LRB, has high stiffness and strength in the vertical direction compared to those in the horizontal direction. The critical axial load capacity of the LRB used to be several times of the design axial load. However, the axial load can be applied excessively at the edge of the basemat by the overturning moment or a vertical ground motion can increase axial load of entire isolators. Therefore, the failure criteria need to be determined by axial load and shear strain relationship. This relationship is represented as three types of the failure mode as follows.

- ✓ Shear fracture: a fracture by a large horizontal displacement with a relatively low axial load around the design axial load
- ✓ Buckling: compressive failure by a high axial load with a small effective area resisting the axial force
- ✓ Tensile failure: failure by the uplift tensile force which is prohibited in the LRB design because of its low strength

The failure criteria of the LRB can be represented by the Ultimate Property Diagram (UPD), which shows the relationship between an axial load and a horizontal displacement of the limit state [1]. It represents these three failure mode of an isolator.

### *2.2 Limit State of a Base Isolator*

In the performance based design guideline of base isolated nuclear power plants, unacceptable behaviors of a base isolator are defined. The most important function of isolators is surviving without loss of gravity-load capacity at the displacement under extended design basis earthquake loading. It can be demonstrate that a minor damage is acceptable but load-carrying capacity must be maintained under the probable axial load.

Another concern is the re-centering capacity of a base isolator under the given axial load when the horizontal deformation occurs. This performance can be proven by the load-displacement hysteresis curve which does not have a minus stiffness.

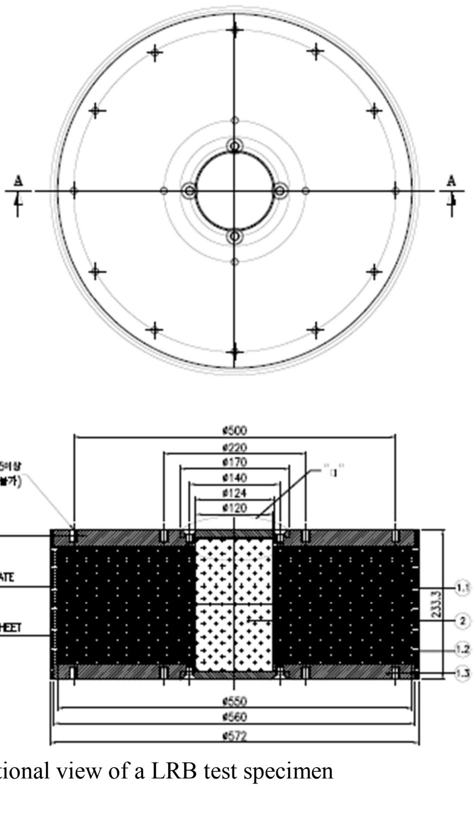



Fig. 1. Sectional view of a LRB test specimen

## 3. Ultimate Property Diagram Test

### *3.1 Test specimens*

The LRBs used in this experiment have 550 mm diameter and the total height of rubber is 112 mm as shown in Fig 1. The diameter of lead core is 120 mm. For constructing of the ultimate capacity diagram, fifteen LRB specimens were used. These LRBs had experienced different horizontal loading by previous experimental test. Most of all experienced 300% shear strain, which is referred as Moderate Damaged (MD) specimen. There is some Low Damaged (LD) specimen by 100% shear strain and some High Damaged (HD) specimen by 400% shear strain. Each test is performed by horizontal displacement control loading under the various axial load conditions as shown in Fig 2.

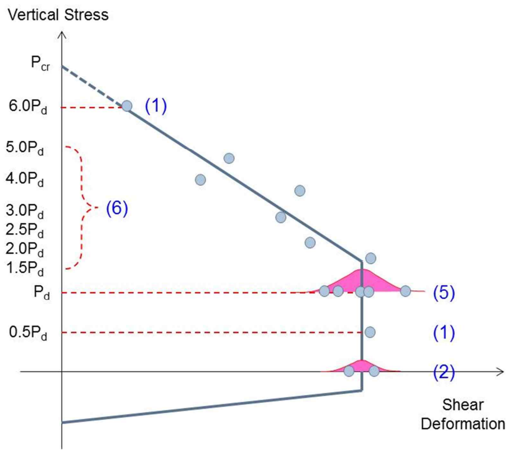


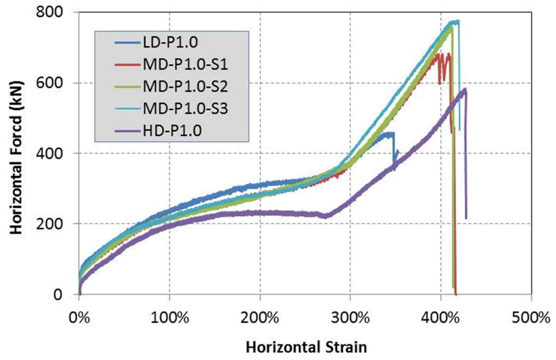

Fig. 2. Test cases and expected ultimate property diagram

### *3.2 Test Results*

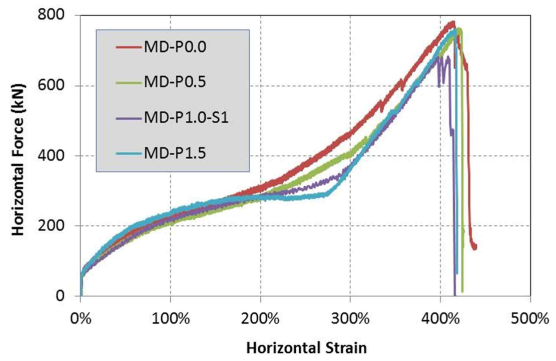
Horizontal strain-force curve by the test are depicted in Fig 3. The MD specimens under the 1.0 Pd (design axial force) show consistence results, but the HD specimen has decreased stiffness. Nevertheless, the failure strain by shear behavior is almost same. The results up to the 1.5 Pd are not much different also. One exceptional case was the LD specimen under the 1.0Pd which could be a defective product. When the axial load is more than 2.0 Pd, the buckling had occurred with minus stiffness and it causes significant decrease of displacement capacity.

## 4. Conclusions

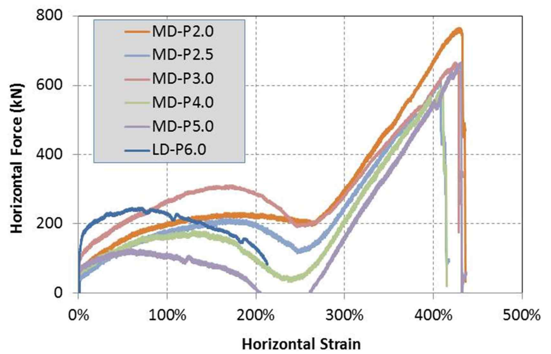
This is an experimental study for construction of the UPD to define the ultimate capacity of an isolator. The result could be different when another shape factor is used. Even though this limitation, the experimental methodology can be applied for all types of isolators. In future research, the limit state needs to be defined more clearly.




(a) Pd=1.0




(b) Pd=0.0~1.5




(c) Pd=2.0~6.5

Fig. 3. Horizontal strain-force curve of base isolators

## ACKNOWLEDGEMENT

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## REFERENCES

[1] Japan Electric Association (JEA), Nuclear Standard Committee of JEA, Design and Technical Guideline of Seismic Isolation Structure for Nuclear Power Plant, JEAG 4614-2000, (in Japanese, only).