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# Evaluation of Isolator Capacity and Seismic Response of an Isolated Nuclear Power Plant for Clearance to Stop Requirements

Gyeonghee An [a], Minkyu Kim [a*]
[a]*Smart Structural Safety and Prognosis Research Division, Korea Atomic Energy Research Institute, 111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, 34057, Korea*
[*]*Corresponding author: minkyu@kaeri.re.kr*

## 1. Introduction

Seismic isolation systems represent a promising strategy to improve the seismic performance of a nuclear power plant(NPP) under strong ground motions that reduces the vibration transferred to the structure by inserting a flexible isolation layer at the base that can sustain large displacements [1]. As expected, seismic response and capacity of an isolated NPP are different from the non-isolated NPP, and a physical stop is necessary to ensure the mean annual frequency of failure is very small. In this research, both analytical response and experimental capacity are considered to evaluating the clearance to the stop(CS), which refers to the horizontal distance between the isolated NPP and the physical stop.

## 2. Capacity of the Isolation System

In order to test the capacity of isolation system, 15 lead rubber bearings(LRBs) in Table 1 having the diameters of 550mm, lead core diameters of 120mm, and total rubber thickness of 112mm were tested until failure. These specimens had experienced horizontal loading prior to the failure test, and could have been damaged. $P/P_d$ in Table 1 represents the ratio of the axial load for test to the design axial load [2-3].

Table 1. Specimens and results of the ultimate property test

| Test No. | Specimen Tag | $P/P_d$ | Buckling Load(kN) | Failure Load(kN) | Failure Disp.(mm) | Failure Disp.(%) |
|---|---|---|---|---|---|---|
| #1 | MD-P1.0 | 1.0 | | 683 | 457 | 408 |
| #2 | MD-P1.0 | 1.0 | | 762 | 462 | 412 |
| #3 | LD-P1.0 | 1.0 | | 460 | 389 | 348 |
| #4 | HD-P1.0 | 1.0 | 236 | 583 | 478 | 427 |
| #5 | MD-P1.0 | 1.0 | | 777 | 470 | 419 |
| #6 | LD-P6.0 | 6.0 | | 245 | 67 | 60 |
| #7 | MD-P2.0 | 2.0 | 232 | 766 | 480 | 429 |
| #8 | MD-P3.0 | 3.0 | 311 | 666 | 476 | 425 |
| #9 | MD-P1.5 | 1.5 | 287 | 761 | 467 | 417 |
| #10 | MD-P2.5 | 2.5 | 214 | 614 | 457 | 408 |
| #11 | MD-P4.0 | 4.0 | 180 | 594 | 460 | 410 |
| #12 | MD-P5.0 | 5.0 | 126 | 666 | 483 | 431 |
| #13 | MD-P0.0 | 0.0 | | 782 | 463 | 413 |
| #14 | HD-P0.0 | 0.0 | | 597 | 477 | 426 |
| #15 | MD-P0.5 | 0.5 | | 763 | 469 | 419 |

The failure criteria of the LRBs can be represented by an ultimate property diagram (UPD). UPD in Fig. 1 shows the relationship between the axial load and the shear strain of the limit state as shown in Table 1.

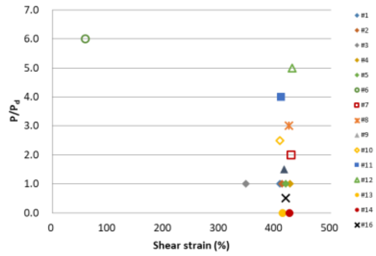



Fig. 1. Ultimate Property diagram in shear strain (%)

## 3. Seismic Response of an Isolated NPP

### *3.1 Ground Motions*

Ground motions used for this research were selected from the PEER NGA-West1 database, such that they match the mean and dispersion of a target response spectrum [4]. Fig. 2 shows the 20 ground motions used for this research, with the mean spectrum matched to the 5% damped USNRC RG1.60 target spectrum.

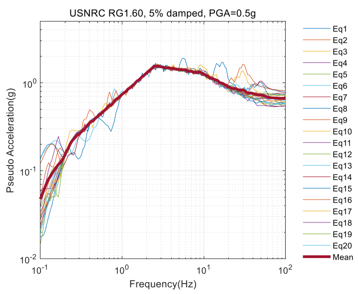



Fig. 2. Acceleration response spectra for 20 motions

### *3.2 Models for Analysis*

The structural model of the APR1400 including a seismic isolation system consisting of 486 bearings was initially developed in SAP2000 by KEPCO E&C. The superstructure is modeled as beam–stick elements with lumped masses and the base mat is modeled using solid elements. The isolators are attached at the bottom of the base mat. This SAP2000 model was then converted to an OpenSees format [5] and used for this research.

A parallel numerical model of an isolator representing an LRB was suggested by Mosqueda, Marquez, and Hughes [6] based on the full-scale tests of LRBs conducted by KAERI in 2014. The characteristic behaviors of the LRBs, such as a reduction in strength due to the heat of the lead and hardening at large strain are modeled using three elements: an LRX element, a Bouc–Wen (hardening) element, and an HDR element, which are all separately available in OpenSees [7].

### *3.3 Response of an Isolated NPP*

Fig. 3 shows the acceleration and displacement response of NPP subjected to one of the ground motions with PGA=1.0g. Fig. 4 shows the force-displacement relation of an LRB subjected to the same ground motion but at various PGA levels. The bearing model shows nonlinearity as modeled.

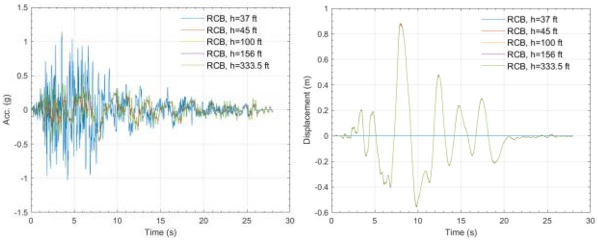



Fig. 3. Acceleration and displacement response of NPP

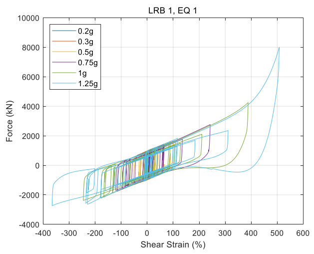
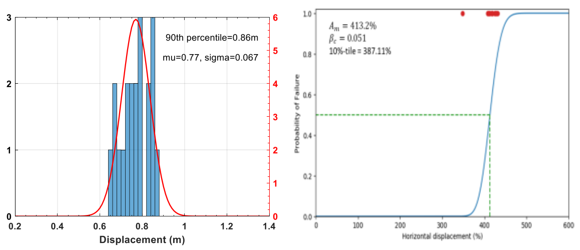



Fig. 4. Hysteresis of LRB #1

## 4. Clearance to Stop

The performance criteria for seismically isolated NPP has been suggested in NUREG/CR-7253 [8]. Isolation systems need to have 90% confidence of surviving, and the superstructure needs to have less than a 10% probability of contacting with a hard stop (moat wall) under beyond design basis earthquake ground motion response spectra (BDBE GMRS) loading. To satisfy the criteria, the CS has to be greater than the 90th percentile displacement of the structure under BDBE GMRS loading, and the isolation system need to be designed to have 90% confidence or higher for the CS.




(a) (b)

Fig. 5. Evaluation of Clearance to the Stop (CS): (a) Maximum Displacement Distribution under BDBE GMRS (b) Empirical fragility curve of LRBs

## 5. Conclusions

In this study, the experimental capacity of LRB, analytical response of a seismically isolated NPP, and clearance to the stop based on the performance criteria were investigated. When the RG1.60 design spectrum with PGA = 1g was used for BDBE GMRS, clearance to the stop was evaluated as 0.87m (387% shear strain for LRB) in this research. However, further research is necessary to reflect more realistic behavior of an isolated NPP under seismic loading.

## ACKNOWLEDGEMENTS

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