Seismic Response Analysis of Isolated Nuclear Power Plant with Experiment-Based Bearing Models

Gyeong Hee An [a*], Min Kyu Kim [a]
[a]*Structural Safety & Prognosis Research Division, Korea Atomic Energy Research Institute, 111, Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon, 34057, Korea*
[*]*Corresponding author: akh425@kaeri.re.kr*

1. Introduction

Seismic response of base isolated nuclear power plant (NPP) is naturally affected by the modeling method of the isolators. The inelastic behavior of isolation system, however, is not simple, so it is hard to make reasonable numerical models. An experiment using full scale lead rubber bearing(LRB) was conducted to evaluate the performance criteria of isolation system for NPP [1]. The numerical bearing models were developed in OpenSees based on the experimental results [2]. In this study, this experiment-based LRB models are implemented in one of the structural model of APR 1400 and floor response spectra(FRS) of NPP are analyzed. Maximum displacement response is also analyzed to make basis of the clearance to hard stop(CHS).

2. Model

In this section, some information for the analysis such as ground motions, isolator models, and nuclear power plant model are described.

2.1 Ground Motions

Ground motions used in this study are shown in Fig. 1. In the previous study by PEER center, the 20 ground motions are scaled to spectrally match a 5% damped USNRC 1.60 target spectrum with a PGA of 0.5g [3].

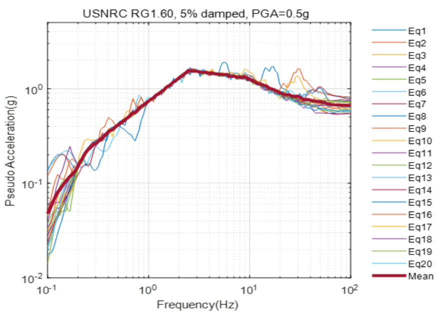

Fig. 1. Pseudo acceleration response spectra of 20 spectral matched motions

2.2 Isolator Model

Bearing models are suggested based on the experiments conducted at SRMD center of UCSD in 2014 [1]. Two full scale lead rubber bearings(LRB) were tested. The diameter and total rubber thickness of the bearings are 1500mm and 224mm respectively.

The final model was developed by combining three types of elements in OpenSees which can capture the characteristics of inelastic behavior of LRBs as depicted in Fig. 2 [2].

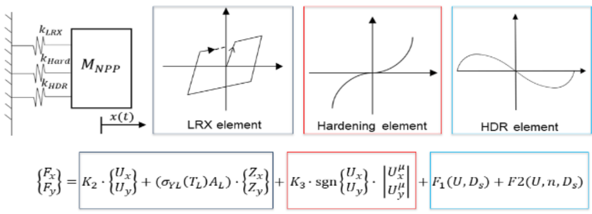

Fig. 2. Parallel numerical bearing model [2]

SDOF analysis result of the isolation system is shown in Fig. 3. Force-displacement relations of each element and the final HHHDR model for the sinusoidal motion used for 500% shear test are presented. The normalized root mean squared error from the test result and the final HHHDR model is less than 6% [2].

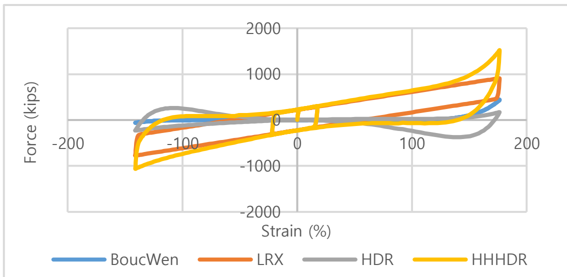

Fig. 3. Parallel numerical bearing model

2.3 Structural model

The structural model of APR 1400 was initially developed by KEPCO E&C in SAP2000 and converted to OpenSees during the previous research project. Bearing model explained above is implemented for 486 isolators in this model as shown in Fig. 4. This model can analyze the effect of moat wall on the seismic response.

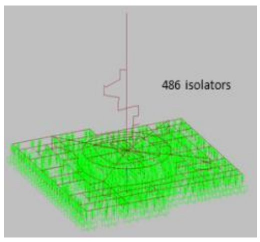

Fig. 4. ANT model with 486 isolators

3. Analysis Results

3.1 Floor Response Spectra

Five locations in auxiliary building, from the height of 100ft to 172ft are selected to analyze FRS of isolated NPP based on fragility analysis results [4].

Fig. 5 and Fig. 6 show some of the response spectra of non-isolated NPP and isolated NPP with HHHDR bearing model at the height of 120ft and 172ft without moat wall. The acceleration of isolated NPP is much less than non-isolated NPP as expected. Also, the peak frequency because of the bearing is observed.

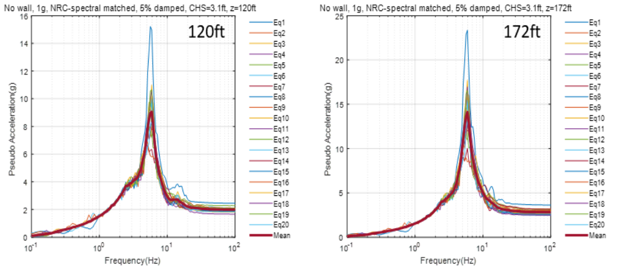

Fig. 5. Response spectra of non-isolated NPP (PGA=1.0g)

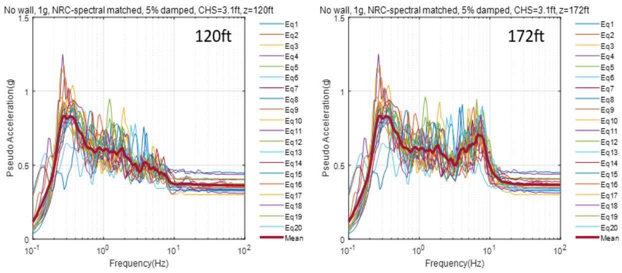

Fig. 6. Response spectra of isolated NPP (PGA=1.0g, HHHDR_damage)

3.2 Maximum Displacement

The maximum displacement at ground is dependent on the ground motion and bearing model as shown in Fig. 7.

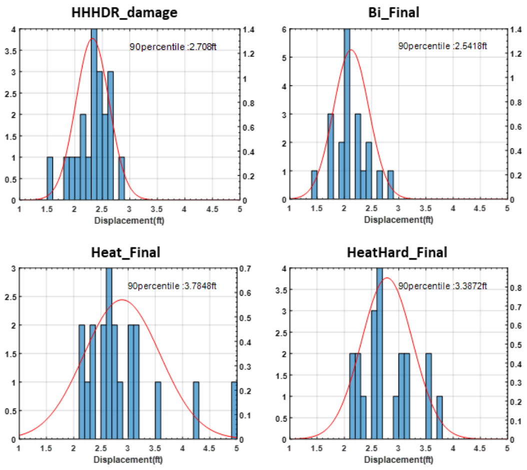

Fig. 7. Maximum displacement distribution (PGA=1.0g)

The 90th percentile displacement varies from 2.5ft to 3.8ft depending on the bearing models. According to ASCE 4-16, CHS is the maximum horizontal distance between the superstructure and the stop, which can be no less than the 90th percentile displacement for 150% DBE shaking [5].

If there is moat wall and the CHS is set to be 3.1ft, the displacement changes over PGA 1.0g. Fig. 8 shows the effect of moat wall. It is also affected by modeling method of bearing and moat wall.

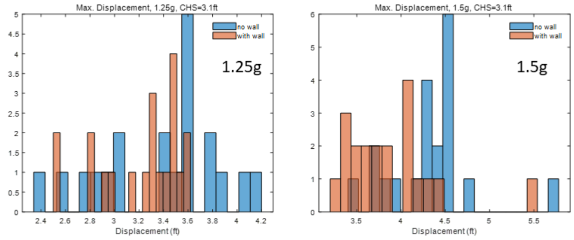

Fig. 8. Effect of moat wall (isolator model: HHHDR, CHS=3.1ft)

4. Conclusions

In this study, seismic response of isolated NPP is analyzed using the experiment base isolator models and the structural model of APR 1400. Floor response spectra and the maximum displacement are analyzed to capture the seismic response characteristics and utilize for the seismic risk assessment of isolated NPP. Further studies for the decision of CHS and the failure mode are necessary to make reasonable risk assessment.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (NRF-2017M2A8A4014827).

REFERENCES

[1] Minkyu Kim, Jung-Han Kim, and In-Kil Choi, Dynamic Performance Characteristic Tests of Real Scale Lead Rubber Bearing for the Evaluation of Performance Criteria, Proceedings of KNS 2014 Fall Meeting, 2014.
[2] Patrick Hughes, Joaquin Marquez, and Gilberto Mosqueda, Advanced Numerical Modeling of Seismic Isolation Bearings and Moat Walls for Impact Simulations to Evaluate Beyond Design Basis Shaking of Base Isolated Nuclear Power Plants, Progress Report, 2019.
[3] Andreas Schellenberg, Jack Baker, Stephen Mahin, and Nicholas Sitar, Investigation of Seismic Isolation Technology Applied to the APR 1400 Nuclear Power Plant (Volume2: Selection of Ground Motions), Technical Report, 2014.
[4] KEPCO and KHNP, Probabilistic Risk Assessment Summary Report, Technical Report, 2013.
[5] ASCE 4-16, Seismic Analysis of Safety-Related Nuclear Structures, 2017.