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Seismic Risk of the Base Isolation System Protected by the Hard Stop

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1. Introduction

A seismic base isolation system is introduced in high seismicity regions to secure the seismic safety of nuclear power plants recently. It is also required for the seismic design of next generation nuclear power plants. Several guidelines for base isolated nuclear power plants are being developed in many countries. These guidelines suggest that a hard stop should be installed around the base isolation system to protect a shear failure of isolators.

The concept of base isolation is to permit the deformation of isolator for absorbing seismic input wave from the ground. In a nuclear power plant design, allowable shear deformation of isolators should be enough to absorb the displacement response by extended design basis (EDB) ground motions. However isolators cannot resist over its displacement capacity. So, the clearance of hard stop (CHS) needs to be set between the response of base isolation system excited by the EDB ground motion and the displacement capacity of isolators. The isolation system must survive with high confidence in any seismic accident because it is a non-redundant system. Therefore, the CHS should be determined carefully based on the failure risk of base isolation system considering the uncertainties of earthquake responses and isolator capacities.

2. Fragility Curve of the Base Isolation System

2.1 Acceleration Based Fragility Curve of a Base Isolation System

For a quantification of the failure risk for a base isolation system, the failure probabilities of an isolator for various seismic intensity levels need to be calculated. It is evaluated as the probability when the seismic response of the isolation system exceeds the failure criteria of isolators. This failure probability plotted with regard to the seismic intensity is a fragility curve. The type of base isolator appropriate for a nuclear power plant structure is thought to be a lead rubber bearing (LRB). The failure criteria of a LRB can be defined as an ultimate horizontal displacement. However, the seismic intensity used to be peak ground acceleration (PGA) or spectral acceleration (SA) because most of hazard curves are expressed by these parameters.

Frist of all, the procedure to express a fragility curve by ground a motion parameter, PGA was developed. The displacement response is not proportional to the ground motion intensity because of the nonlinear behavior of the LRB system. In the analysis results, the displacement response increases about 3 times when an input ground motion increases 2 times. For simplicity, the displacement response is assumed to be linear in the range from the design basis ground motion level to the EDB. The uncertainty variation to the displacement response is about 0.12 ~ 0.15 and it was assumed to be 0.143 in this study. Let the PGA of a design ground motion be 0.5 g and its displacement response be 25 cm which is appropriate for the LRB design displacement of nuclear power plants. If the EDB is twice of the design ground motion, then the EDB displacement is 75 cm and the 90%-ile EDB displacement is 90 cm on the assumption.

The prototype isolators need to be proven safe at the 90%-ile EDB displacement which is minimum CHS in recently developed seismic base isolation criteria [1]. Based on this, the displacement capacity of isolators can be 90 cm if there is no uncertainty in the capacity of isolators. However it may have uncertainty and this standard deviation should also be included in the fragility curve. Figure 1 shows the acceleration based fragility curve of the isolator with the displacement capacity of 90 cm. And the fragility curve on the assumption of the standard deviation of the isolator capacity as 0.1 is plotted also.

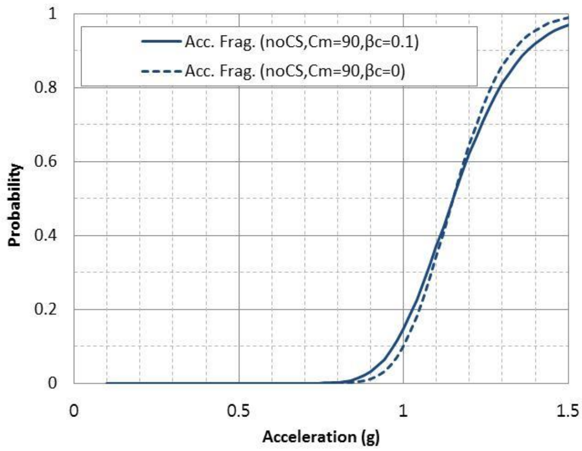

Fig. 3. Acceleration based fragility curve of the base isolation system

2.2 Fragility Curve Considering a Hard Stop

The purpose of a hard stop is to prevent the isolation system from the shear failure. It can simply be regarded that the displacement response of isolators cannot exceed the CHS by impact, so it has no failure when the capacity of an isolator is larger than the CHS. Then the isolation failure will occur in the cases below. The fragility curves of each case are plotted in figure 2. The third case is included in the second case.

- ✓ Response exceeds capacity when hard stop is not installed.
- ✓ Response exceeds capacity and the both are less than the CHS. In this case, the impact of hard stop does not occur
- ✓ Response exceeds capacity and only the capacity is less than the CHS. In this case, the impact of hard stop occurs

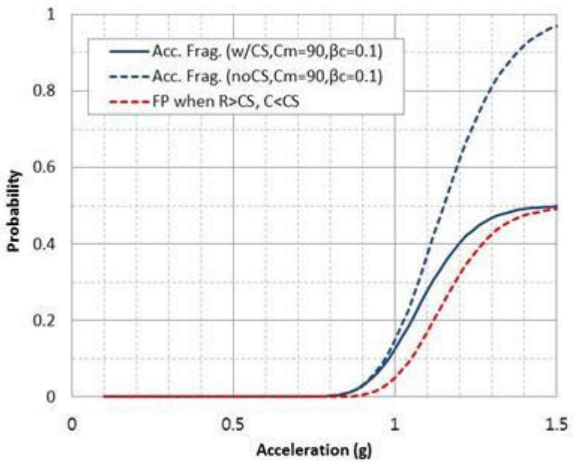

Fig. 2. Fragility curve of a base isolation system with and without hard stop

In this result, the hard stop reduces the failure probability at the range beyond the EDB level. The failure probability does not increase larger than 0.5 because the median capacity of the isolator is equal to the CHS. This means that the median capacity will control the failure risk significantly after the CHS is determined.

3. Failure Risk Assessment of a Base Isolation System

The failure risk of a component is calculated by the convolution of a hazard curve and a fragility curve in full range of seismic intensity. The hazard curve was assumed to decrease linearly when an annual frequency of exceedence is log scale. The capacity of isolator should have sufficient confidence to reduce the failure risk. In here, three confidence levels, 99%, 90%, and 50%, for the safe of isolators at the CHS was examined to understand the effect on the failure risk. The fragility curves were calculated when the median capacity of isolators are 114 cm, 102 cm, and 90 cm, respectively which is correspondent to the confidence level above. Figure 3 shows the fragility curve of a base isolation system with hard stop when these different confidence levels of the isolator capacity are applied. The result of convolution was summarized in Table 1.

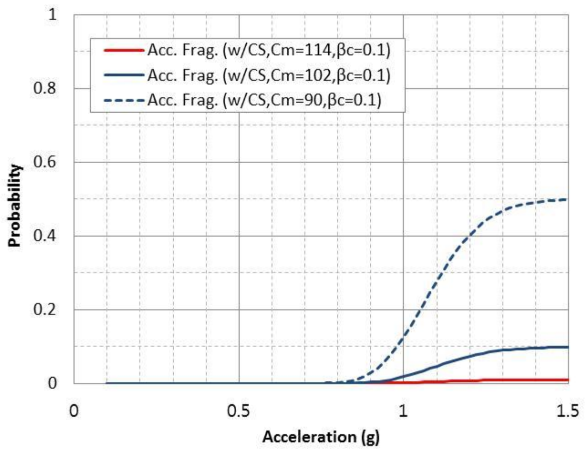

Fig. 3. Fragility curve of a base isolation system with hard stop when different confidence levels of the isolator capacity are applied

Table I: Response of the isolation system

Confidence Level of Isolator Capacity	Median Capacity	Failure Frequency
99% FP	113.7cm	6.22E-08
90% FP	102.4cm	6.65E-07
50% FP	90.0cm	3.85E-06

4. Conclusions

In this research, the fragility curve of isolation system and its failure risk were estimated. The procedure to calculate the acceleration based fragility curve of the isolation system was developed. The fragility curve and failure risk for example case was estimated and its result was compared with different isolator capacities. The hard stop will reduce the failure risk of an isolation system. Nevertheless, the capacity of isolators should be sufficiently larger than CHS to reduce the failure risk to be screened out.

ACKNOWLEDGEMENT

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[1] A. M. Kammerer, A. S. Whittaker, and M. C. Constantinou. Technical Considerations for Seismic Isolation of Nuclear Facilities, NUREG (Draft), U.S. Nuclear Regulatory Commission, 2014.