Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2023

Re-evaluation of Seismic Fragility of Internal Equipment Considering Probabilistic In-structure Response Spectrum

Jae-Wook Jung [a*], Jeong-Gon Ha [a], Junhee Park [a], In-Kil Choi [a], Hong-Pyo Lee[b]
[a]*Korea Atomic Energy Research Institute, Structural and Seismic Safety Research Division, 111, Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon, 34057, Korea*
[b]*Korea Hydro & Nuclear Power Co. Ltd. - Central Research Institute, Yuseong-daero 1312 beon-gil 70, Yuseong-gu, Daejeon, 34101, Korea*
[*]*Corresponding author: jaewook1987@kaeri.re.kr*

***Keywords :** Probabilistic seismic response analysis, in-structure response spectrum, seismic fragility, seismic PSA, separation of variable

1. Introduction

Due to the 2011 Fukushima nuclear power plant accident and the 2016 Gyeongju earthquake, securing the safety against external hazards such as earthquakes of nuclear power plants has become an important issue. A method that can probabilistically evaluate the safety against the potential effect of such an earthquake has been developed and performed, and this is called a seismic probabilistic safety assessment (seismic PSA) [1-2]. Seismic fragility assessment is a major component for performing seismic PSA, and can be used as input data for level 1 PSA to derive core damage frequency (CDF). In this study, the previously performed seismic fragility is re-evaluated by applying the probabilistic in-structure response spectrum (ISRS) and the results are compared.

2. Methods and Results

In this section, the basic variables and variability of separation of variable (SOV) for seismic fragility assessment are described, and the probabilistic ISRS development procedure and seismic fragility re-evaluation results are described.

2.1 Seismic Fragility by SOV

The SOV method is a representative seismic PSA methodology for developing a fragility curve [3-4]. For each variable that affects response and capacity, the median safety factor and the corresponding logarithmic standard deviation (β_r and β_u) are evaluated. The first purpose of the SOV method is to estimate the median of the realistic ground acceleration capacity (A_m). The median capacity can be evaluated by separating it from the product of several variables as shown in Eq (1).

$$A_m = F_c F_{er} F_{rs} PGA_{RE} \qquad (1)$$

The variables F_c, F_{er}, F_{rs}, and PGA_{RE} are capacity factor, equipment response factor, structure response factor, and PGA level of reference earthquake, respectively. The median of the capacity/response factor is used to eliminate conservatism and non-conservatism in the capacity and response analysis of the SSCs. The logarithmic standard deviations, β_r and β_u corresponding to each response factor represent randomness and uncertainty. Using the median capacity (A_m) and corresponding variabilities (β_r and β_u), the fragility curve of SSCs can derived and the HCLPF that can represent seismic performance can be evaluated.

2.2 Development of Probabilistic ISRS

Probabilistic ISRS can be derived through probabilistic seismic response analysis. Probabilistic seismic response analysis is the preferred method for estimating the median response of SSCs together with the variability of the seismic response, including the variability of the input earthquake, the variability of soil properties, and the variability of the structure. This method can derive lower variability compared to deterministic seismic response analysis and scaling methods. The combination of each parameter including variability is made through LHS sampling. In this study, a probabilistic ISRS including the variability of the input earthquake and the variability of the structure is derived by assuming fixed ground conditions.

2.3 Probabilistic ISRS of EWS building

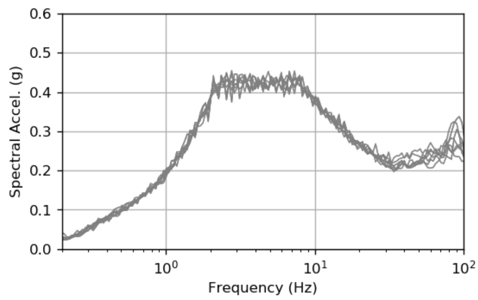

Fig. 1. Response spectrum of NUREG/CR-0098 spectrum matched input earthquakes

The emergency water supply (EWS) building is selected as a target structure for deriving the probabilistic ISRS. The target spectrum of the input earthquake is NUREG/CR-0098 [5] spectrum, and a set of 30 input earthquakes is utilized for the seismic response analysis.

The response spectrum of the 30 input earthquakes are shown in Fig. 1.

The variability of the input earthquake includes the variability of the ground motion, the variability of the peak response in the horizontal direction, and the variability in the vertical direction. For the variability of structural stiffness and damping, generally available conservative values suggested by EPRI technical report [4] are applied. The PGA level of the reference earthquake is selected as 0.50 g by referring to the past PSA results and the procedure presented in the technical report [4], and seismic response analysis is performed. LHS sampling is applied to construct a set of 30 analysis models combining parameters, and seismic response analysis is performed. The derived probabilistic ISRS and variability are shown in Figs. 2 and 3.

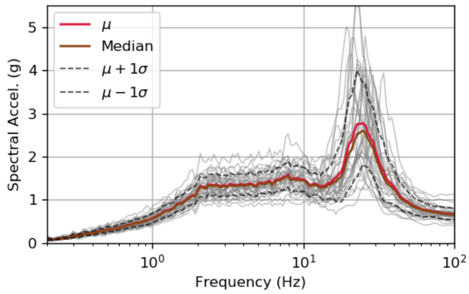

Fig. 2. Probabilistic ISRS of EWS building at El. 100.0 m

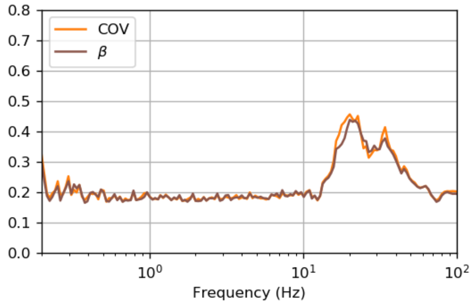

Fig. 3. Variability of probabilistic ISRS of EWS building at El. 100.0 m

2.4 Seismic Fragility Re-evaluation of EWS pump

The seismic fragility is re-evaluated for the EWS pump located in the EWS building. A seismic fragility re-evaluation is performed by applying a probabilistic ISRS using the fragility assessment results from previous seismic PSA as reference data. The seismic demand is derived by re-evaluating the response factors and variability included in the probabilistic ISRS.

Among the response factors and variability used in the existing fragility assessment, the coefficients included and merged in the probabilistic ISRS are the uncertainty of the spectral shape factor, the uncertainty of the structural damping, the uncertainty of the structural frequency, the randomness of the earthquake component combination, and the randomness of the peak response in the horizontal direction. These variabilities are merged into the variability of the probabilistic ISRS. The equipment capacity factor is re-evaluated using a scaling method based on the median of the probabilistic ISRS. Table I shows the results of the seismic fragility re-evaluation of the EWS pump. Based on the value of HCLPF, about 30% of seismic performance is improved.

Table I: Comparison of seismic fragility results for EWS pump

	Seismic fragility from previous seismic PSA	Seismic fragility from re-evaluation
Am (g)	2.36	2.97
β_r	0.26	0.31
β_u	0.54	0.48
HCLPF (g)	0.62	0.81

3. Conclusions

In this study, the re-evaluation of the seismic fragility of internal equipment of structures according to the application of probabilistic ISRS is described. A probabilistic ISRS is derived considering the variability of the input earthquake and the structure, and is used for re-evaluation of seismic fragility. The variables of the SOV method for probabilistic ISRS are derived and the seismic demand is recalculated. In the re-evaluation of the seismic fragility for the EWS pump, an improvement in the seismic performance of about 30% is confirmed. The reason for this result is that the variability is reduced by applying the probabilistic ISRS, and the conservatism of the design spectrum is removed by using the median spectrum. Based on this result, it is considered that the conservatism existing in the past seismic fragility evaluation of SSCs can be removed and additional seismic performance can be secured.

ACKNOWLEDGEMENTS

This work was supported by the Central Research Institute of KHNP (Korea Hydro & Nuclear Power Company) (L21S082000).

REFERENCES

[1] J. Oh, S. Kwag. A study on seismic probabilistic safety assessment for a research reactor, Journal of the Computational Structural Engineering Institute of Korea, Vol. 31, pp. 31-38, 2018.
[2] American Society of Civil Engineers, Seismic analysis of safety-related nuclear structures. ASCE/SEI 4-16, ASCE, 2017.
[3] EPRI, Methodology for Developing Seismic Fragilities, Palo Alto, California, Electric Power Research Institute, EPRI TR-103959, 1994.
[4] EPRI, Seismic Fragility and Seismic Margin Guidance for Seismic Probabilistic Risk Assessments, Palo Alto, California, Electric Power Research Institute, EPRI TR-3002012994, 2018.
[5] US Nuclear Regulatory Commission, Development of Criteria for Seismic Review of Selected Nuclear Power Plant (NUREG/CR 0098), US NRC, 1978.