Seismic Fragility Assessment of Fuel Assembly for Seismic Probabilistic Safety Assessment

Jae-Wook Jung [a*], Min Kyu Kim [a]
[a]*Korea Atomic Energy Research Institute, Advanced Structures and Seismic Safety Research Division, 111, Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon, 34057, Korea*
[*]*Corresponding author: jaewook1987@kaeri.re.kr*

1. Introduction

According to regulatory guidelines related to nuclear power plant design, safety-related devices of the nuclear power plant, including nuclear fuel assemblies, are required to evaluate seismic fragility based on a probabilistic evaluation methodology [1]. The seismic vulnerability of a nuclear fuel assembly and its variability directly affect the results of probabilistic seismic safety assessment. Since the reactivity control by inserting the control rods of the nuclear fuel assembly is essential for the safe shutdown of the power plant, the probability of failure in fuel assembly should be extremely low. In this study, seismic fragility assessment of fuel assembly is performed by applying the separation of the variable method suggested by EPRI [2].

2. Methods and Results

The separation of variable (SOV) method suggested by EPRI [2] is a representative method for performing fragility assessment on the SSCs of nuclear power plants. The seismic fragility of the nuclear fuel assembly is derived based on the experimental and analysis data by joint research with KHNP CRI, KEPCO SD, and KNF.

2.1 Failure Modes of Fuel Assembly

The failure mode of the nuclear fuel assembly can be divided into categories related to CRDM, fuel assembly, pressure vessel, and control rod. In this study, the capacity factors are derived based on the results of fuel assembly analysis by KEPCO SD [3] and the spacer grid impact test by KNF [4].

Table I: Primary failure modes of the fuel assembly

Category	Failure mode
CRDM	Bending of CRD housing Failure of housing support Deformation/failure of guide tube
Fuel assembly	Buckling of spacer grid Failure of fuel components
RPV internals	Damage at core support Damage at shroud support Damage at lower support
Control rod insertion time delay	Insertion time limit excess

2.2 Structure Response Factor

In seismic fragility assessments, the structure response factor consists of coefficients and variability related to spectral shape, maximum horizontal response, vertical component response, structure damping, structure modeling, mode combination, soil-structure interaction, etc.

In particular, in order to evaluate the conservatism of the design ground response spectrum in the process of calculating the structure response factor, a site-specific response spectrum that can occur at the site is required. In most of the fragility assessments conducted in Korea in the past, the ground response spectrum provided in NUREG/CR-0098 [5] was assumed to be the site-specific ground response spectrum of the Korean Peninsula. However, for actual seismic fragility assessment, the site-specific spectrum obtained through seismic probabilistic hazard analysis for the site or the uniform hazard spectrum should be used.

The ground response spectrum used in the fragility assessment directly affects the spectral shape factor. Here, fragility assessment is performed using the CR-0098 spectrum and the uniform hazard spectrum (UHS) prepared for the Uljin site [6]. Through this, it is possible to quantitatively derive the conservatism of the previously used ground response spectrum and confirm the potential seismic performance of the nuclear fuel assembly.

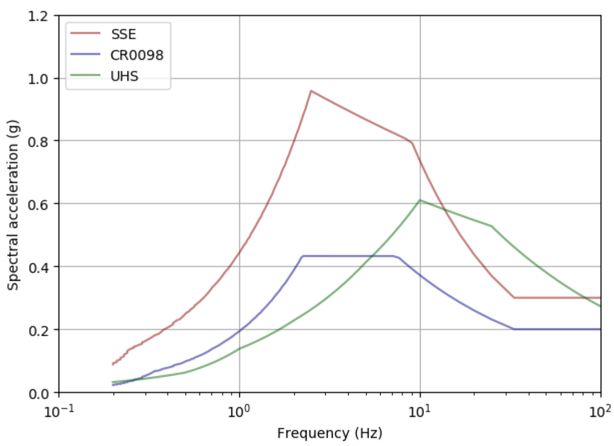

Fig. 1. Ground response spectrum in NUREG/CR-0098 and uniform hazard spectrum for Uljin site.

2.3 Equipment Response Factor

The equipment response factor consists of coefficients and variability related to qualification method, equipment damping, equipment modeling, mode combination, seismic component combination, etc. Equipment response factor and variability are calculated according to the procedure presented in EPRI [2] and used for fragility assessment.

2.4 Fragility Assessment of Fuel Assembly

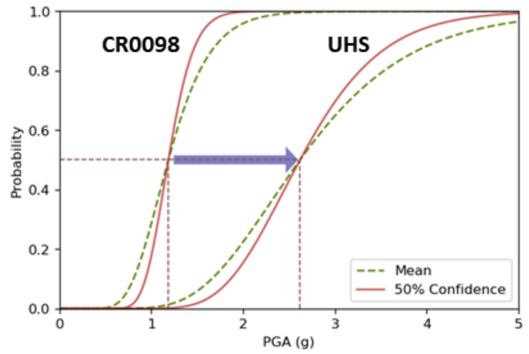

Fig. 2. Fragility curves for the through-grid impact of spacer grid in nuclear assembly using CR-0098 and UHS response spectrum.

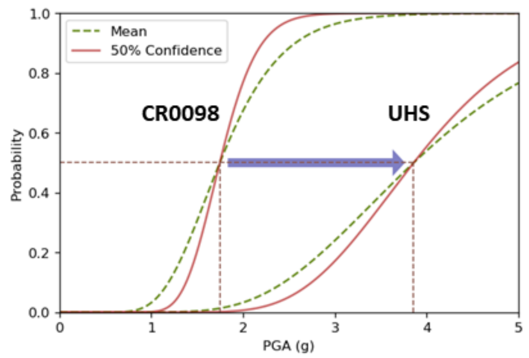

Fig. 3. Fragility curves for fuel rod in nuclear assembly using CR-0098 and UHS response spectrum.

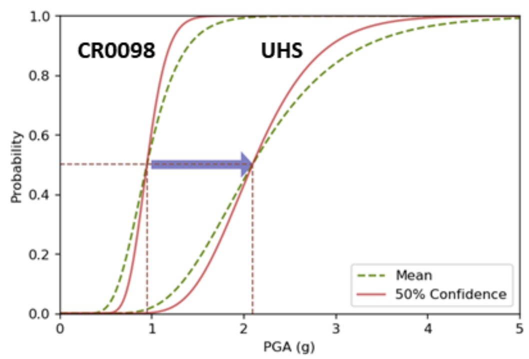

Fig. 4. Fragility curves for guide tube in nuclear assembly using CR-0098 and UHS response spectrum.

Fragility assessment of the nuclear fuel assembly is performed according to the procedure described above. The seismic fragility is derived considering the failure modes for the spacer grid impact and the fuel component of the nuclear fuel assembly.

Figs 2-4 show the fragility curves using CR-0098 and UHS response spectrum for the failure modes of spacer grid impact, fuel rod, and guide tube, respectively. The dominant failure mode is the through-grid impact, and the HCLPF is calculated as 0.467 g from the CR-0098 spectrum and 0.905 g from UHS. It is confirmed that the seismic performance could be significantly improved as a result of using the uniform hazard spectrum compared with the results from the CR-0098 spectrum. The reason is that due to the lower spectral acceleration in the low-frequency range of UHS, the change in the spectral shape factor has a major effect on the fragility assessment results.

3. Conclusions

In this study, the seismic fragility of nuclear fuel assemblies is evaluated. Fragility assessment results are derived by considering the spacer grid impact and the fuel components. In particular, a higher HCLPF value is confirmed in the results using the UHS spectrum. If the characteristics of domestic earthquakes, where high-frequency components are dominant, are considered, it is expected that additional seismic margins can be derived due to the characteristics of fuel assemblies with low natural frequencies.

REFERENCES

[1] K. S. Kim, A Study on the Seismic Fragility Assessment Methodology of the Nuclear Fuel Assembly, Proceedings of the Korea Concrete Institute Conference, 2021.

[2] S. H. Eem and I. K. Choi, A Shape of the Response Spectrum for Evaluation of the Ultimate Seismic Capacity of Structures and Equipment including High-frequency Earthquake Characteristics, EESK Journal of Earthquake Engineering, Vol.24, pp.1-8, 2020.

[3] 핵연료집합체 지진취약도 평가관련 9 월 기술회의 Action Item 2 후속조치를 위한 자료송부, 한국전력기술㈜, 기계설계그룹-128, 2021. 9. 15.

[4] 핵연료집합체 지진취약도평가 관련 연계자료(2 차) 송부, 한국수력원자력㈜ 중앙연구원, 연구원(SMR 기)-1245, 2021. 10. 12.

[5] EPRI 3002012994, Seismic Fragility and Seismic Margin Guidance for SPSA (TR-3002012994), 2017.

[6] U.S. Nuclear Regulatory Commission, Development of Criteria for Seismic Review of Selected Nuclear Power Plants, NUREG/CR-0098, 1978.