Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 9-10, 2024

Generation of Earthquake Input Ground Motions for Seismic Risk Evaluation

Hae Yeon Ji [a], Jung Han Kim [a*]
[a]*Department of Civil Engineering, Pusan National University, 2, Busandaehak-ro 63beon-gil, Geumjeong-gu, Busan, Republic of Korea*
[*]*Corresponding author: jhankim@pusan.ac.kr*

***Keywords :** input ground motion, seismic risk, seismic fragility, ground motion time history, response spectra

1. Introduction

Evaluation of input earthquake in seismic design is an important task to determine seismic loads. In general, there are detailed criteria of input ground motion evaluation procedures for design purpose. On the other hand, when risk assessment is performed, it is difficult to establish specific criteria because realistic input values are required.

The most obvious difference between the input earthquakes for design and that for risk assessment is the difference in the assumed earthquake intensity. In particular, in the case of nuclear power plants, the risk occurs when the seismic load is greatly exceed the design value, therefore the difference will be larger. As the earthquake intensity increases, ground motions do not simply scale up, and the response spectrum or time history characteristics change. These changes mean that the structure response may also not simply scale up. In this study, the appropriate seismic intensity required for risk assessment was estimated and the difference from the design earthquake was analyzed.

2. Seismic Intensity Level for Risk Assessment

The Design Response Spectrum (DRS) is presented as a Uniform Hazard Spectrum (UHS) of 1E-04 AFE (Annual Frequency of Exceedance), which is the design seismic intensity. This is a conservative estimate considering the seismic margin of the structures. According to ASCE/SEI 43-05 [1], Shape of DRS is defined as Ground Motion Response Spectrum (GMRS), which is a value between mean 1E-04 UHS and 1E-05 UHS.

The seismic intensity level with the largest risk contribution was estimated using the slope of the seismic hazard and the standard deviation of seismic fragility assumed in ASCE 43-05. For the estimation of the ratio between design level (1% HCLPF) and the largest risk contribution level, it was simply assumed that the seismic intensity of 1.0g corresponds to AFE 0.2E-04 and the median capacity of fragility curve is 1.0g. From Fig. 1 and Fig. 2, the seismic intensity with the highest risk contribution when evaluating seismic risk corresponds to AFE 0.2E-04, which is the range between 1E-04 and 1E-05 UHS (Fig. 3). Therefore, it is necessary to generate input ground motions for seismic risk evaluation that consider the difference in seismic intensity and response spectrum between design and risk evaluation.

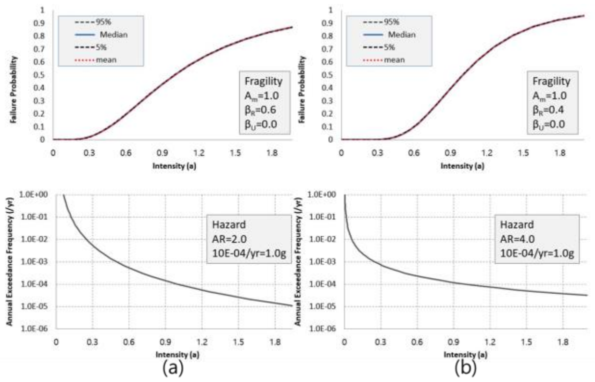

Fig. 1. Example fragility and hazard curve (a) 1% HCLPF = 0.25g, 50% Cumulative Risk = 0.34g (b) 1% HCLPF = 0.39g, 50% Cumulative Risk = 1.12g

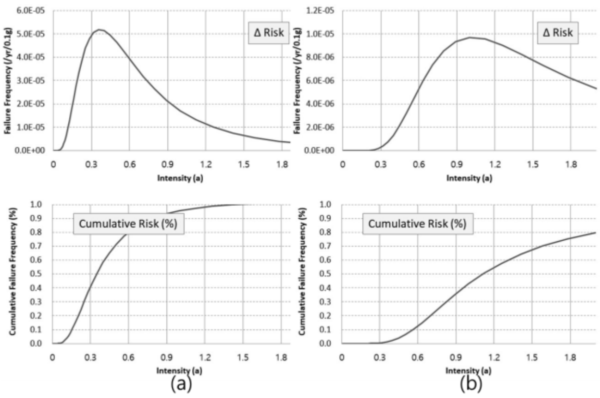

Fig. 2. Risk contribution along seismic intensity (a) 1% HCLPF = 0.25g, 50% Cumulative Risk = 0.34g (b) 1% HCLPF = 0.39g, 50% Cumulative Risk = 1.12g

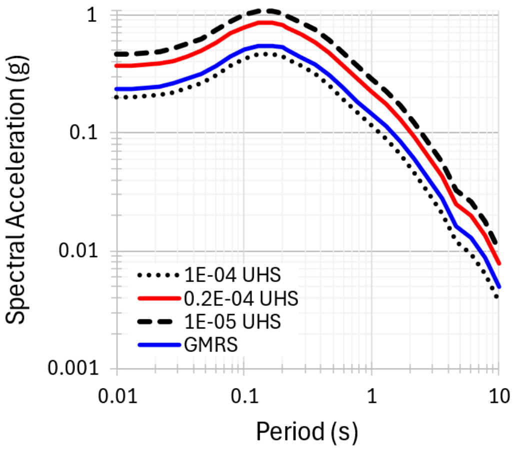

Fig. 3. UHS with AFE of 1E-04, 0.2E-04 and 1E-05, and GMRS

3. Characteristics of Response Spectrum for Seismic Risk Assessment

The UHS represent the spectral acceleration result of probabilistic seismic hazard analysis (PSHA) for each frequency. It does not indicate any specific earthquake magnitude-distance. Therefore, the method of de-aggregation of seismic hazard derived from PSHA, has been developed for selecting the input ground motion. However, UHS assumes the same AFE at all periods and envelopes the ground motions which have different predominant frequencies in one spectrum. This means that UHS has large conservatism by constructing same hazard level at all frequencies even though spectral acceleration of each frequencies is not completely correlated in realistic aspect. Therefore, CMS (Conditional Means Spectrum) with reduced conservatism was presented as the spectrum shape [2].

This study was prepared by considering the shape of CMS based on seismic hazard de-aggregation for UHS corresponding to PSHA and 0.2E-04 AFE to generate input ground motions for risk evaluation. Considering that the natural period of nuclear power plant structures mostly corresponds to the short period band (0.2-0.05s), the period of interest was calculated as 0.2s when calculating CMS. This study present the feasibility of the approach to generate input ground motions, therefore a simplified PSHA was performed for research purpose. The input parameters for simplified PSHA and de-aggregation are provided in Table I, and the de-aggregation results are shown in Fig. 4. The UHS and the CMS are shown in Fig. 5(a).

Table I: Seismic Hazard Parameter used in PSHA and de-aggregation

Parameter		Value
Seismic Source Model		10,000 km^2 Area Source
Gutenberg-Richter Law	a-Value	3.027
	b-Value	1.0
	Magnitude $_{MIN}$	5.0 M_W
	Magnitude $_{MAX}$	7.0 M_W
Ground Motion Prediction Equation		Boore and Atkinson (2008)
Annual Frequency of Exceedance		0.2E-04 (/yr)

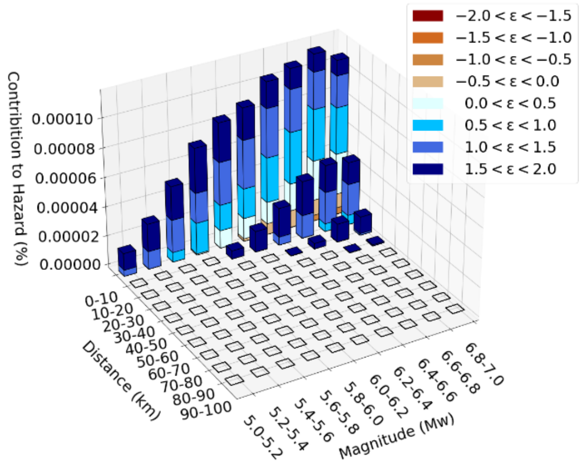

Fig. 4. Result of de-aggregation for Magnitude, Distance, and epsilon at spectral period 0.2s

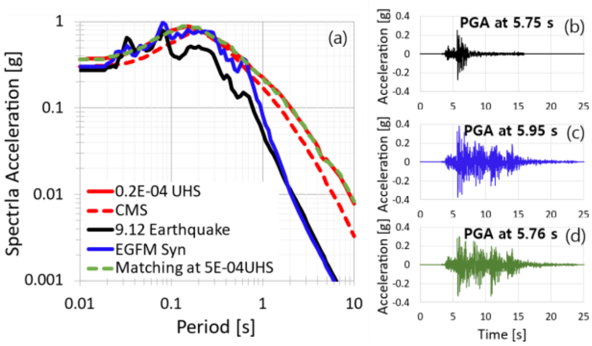

Fig. 5. (a) Response spectra of recorded ground motion and synthesized ground motion with CMS and 0.2E-04 UHS. (b) Ground motion time history of observed ground motion. (c) Synthesized time history by EGFM. (d) Matched time history for UHS

The recorded ground motion used to generate the input ground motion used the NS component of the 9.12 Gyeongju earthquake recorded at the MKL seismic station located on rock site condition. In addition, the virtual fault was modeled using the Empirical Green's Function Method (EGFM) [3] to generate ground motions that are consistent in terms of magnitude and distance, corresponding to the seismic hazard de-aggregation results. After synthesizing the time history using EGFM, this study selected the time history with the response spectrum that most closely resembles CMS. It was subsequently modified to be compatible with the UHS using the spectral matching method [4] in the time domain. The time history of ground motion at each step are shown in Fig. 5(b)-5(d), respectively, and its response spectra is presented in Fig 5(a).

4. Conclusions

In this study, the seismic hazard was calculated through the assumption of a simplified seismic source and attenuation equation, and based on this, the ground motion characteristics appropriate for the seismic intensity appropriate for risk assessment were analyzed. In order to determine realistic ground motion for risk assessment, several steps were required related to hazard analysis. There will be a difference between the input ground motions obtained in this way and that for seismic design. Further research is needed to examine how this difference affects the behavior of the structure. If there is a meaningful difference, the guidelines for input ground generation method in risk assessment need to be established.

Acknowledgements

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. RS-2022-00144482).

REFERENCES

[1] American Society of Civil Engineers, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities, ASCE/SEI 43-05, p. 96, 2005.
[2] J.W. Baker, Conditional Mean Spectrum: Tool for Ground-Motion Selection, Journal of Structural Engineering, Vol.137, pp. 322-331, 2011.
[3] K. Irikura, T. Kagawa, and H. Sekiguchi, Revision of the Empirical Green's Function Method, Programme and Abstracts. The Seismological Society of Japan, Vol.2, pp. 1-4, 1997.
[4] L. Al Atik, and N. Abrahamson, An improved method for nonstationary spectral matching, Earthquake spectra, Vol.26, pp. 601-617, 2010.