Uncertainty Analysis Methods for Probabilistic Seismic Risk Analysis of NPP

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1. Introduction

For quantification of the seismic risk of nuclear power plants, Seismic Probabilistic Safety Assessment (SPSA) is performed. To achieve this, a computer program (PRASSE : Probabilistic Risk Assessment of Systems for Seismic Events) to calculate the initiating event frequencies for seismic events was developed. Monte Carlo Simulation (MCS) and Latin Hypercube Sampling (LHS) method was used for uncertainty analysis in this code.

2. Evaluation of Seismic Probabilistic Safety Assessment

2.1 Fragility Model

Fragility curve is expressed as a probability of failure versus intensity of ground motion parameter inducing damage. For an earthquake event, these intensity parameters are used to be a spectral acceleration or a peak ground acceleration. The fragility curve is modeled as a cumulative lognormal distribution along the intensity parameter. Accordingly fragility curve can be defined by a median ground acceleration capacity, and two logarithmic standard deviations as expressed in Equation (1).

$$F(a) = \Phi\left[\frac{\ln(a) - \ln(A_m) + \beta_U \Phi^{-1}(Q)}{\beta_R}\right] \quad (1)$$

where, Φ denotes standard Gaussian cumulative distribution function and A_m is a median ground acceleration capacity. Two logarithmic standard deviations represent different kinds of uncertainty. One is a deviation of inherent randomness, β_R, and the other is a deviation of uncertainty, β_U. And the non-exceeding probability level of the median value, Q is introduced to consider the uncertainty in this equation.

2.2 System Level Risk

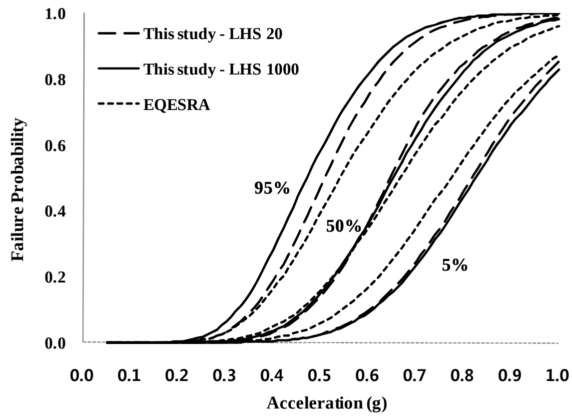
The result of a SPSA is expressed as the frequency of adverse consequences, such as core damage, due to the potential effects of earthquakes. The frequency of the damage is obtained by convolving plant level fragility with seismic hazard curves. This convolution is expressed by Equation (2).

$$P_F = \int_0^{\infty} F(a)\left(-\frac{dH(a)}{da}\right)da \quad (2)$$

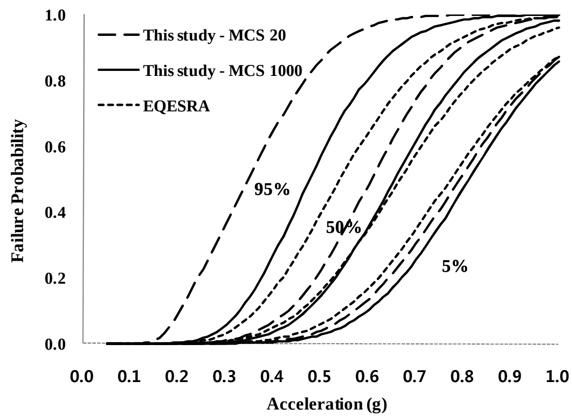
where, *F(a)* is the system fragility at the given acceleration point and *H(a)* is a seismic hazard curve. The term, *-dH/da* means the frequency of the earthquake event in the range of *da* at the level *a*.

3. Example for Verification

By using the developed code, the SPSA example for the Limerick Generating Station (LGS) was solved for verification. The results of a seismic risk assessment for the LGS are published by Ellingwood [1] and EQESRA [2]. In the Ellingwood paper, the uncertainty analysis by LHS method was used and its sampling number was 20. In the EQESRA code, the condensation method is used for the uncertainty analysis.



(a) LHS method



(b) MCS method

Fig. 1. 5%, 50%, and 95% fragility curves of CM failure.

System fragilities of the Core Melt (CM) failure are combined by the LHS and the MCS methods considering uncertainty of individual component fragilities. The fragilities of 5%, 50% and 95% confidence levels are plotted in Fig. 1. The dashed line with large spacing shows the system fragilities by the LHS method with 20 sampling number, and the solid lines are calculated with 1000 sampling number which is thought to be an enough number for satisfying the convergence of the uncertainty analysis. The result obtained by the code EQESRA is also plotted as the fine dashed lines. As shown in Fig. 1(a), the LHS method with larger sampling number resulted in higher failure probability for the high confidence level and lower failure probability for the low confidence level. It means that the estimated system uncertainty increases as the number of sampling increases. For the MCS method as shown in Fig. 1(b), the result of sampling number 1000 was almost identical comparing with the LHS method. But the difference of fragilities between the small sampling number case with the large number case was larger than that in the LHS method. It represent that the LHS method is more reliable than the MCS method if the sampling number is small.

Event frequencies for core damage sequences were calculated by convolving the system fragility sets with hazard curves. The frequency distribution can be represented as the graph of cumulative frequencies vs. the failure probabilities with ascending order. The information of the six hazard curves at the LGS site was presented in the NUREG/CR-3493 report [3]. Fig. 2 shows the frequency distribution of $T_S E_S UX$ event estimated by the LHS and MCS methods compared with the result in Ellingwood paper. For more accurate estimation, enough sampling number was chosen as 1000 and the acceleration interval for convolution was determined as a small value, 0.01. The result is well matched with Ellingwood result, and the more smooth line was obtained because of the large sampling number.

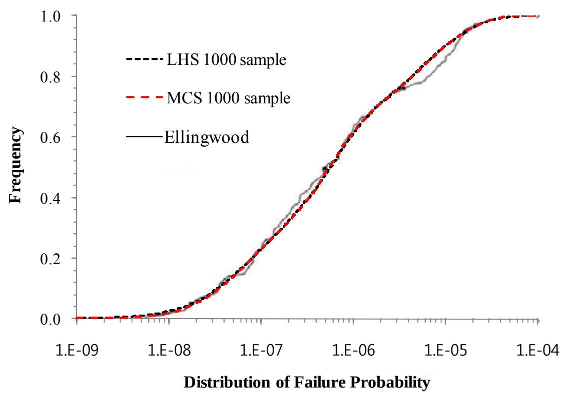


Fig. 2. Frequency distribution of $T_S E_S UX$.

The event frequencies of the CM failure are listed in Table I compared with the results of Ellingwood and EQESRA. The hazard curve contribution to mean frequency of the CM failure is also listed in Table II compared with the result of LGS-SARA in the NUREG/CR-3493. The results estimated by the both methods in this study agree well with the results of other researches.

Table I: Event frequencies of CM failure of LGS

	Elling-wood	EQESRA	PRASSE by MCS	PRASSE by LHS
5%	2.7e-08	2.0e-08	2.99e-08	2.94e-08
50%	7.2e-07	6.2e-07	8.34e-07	8.27e-07
95%	2.4e-05	1.9e-05	2.30e-05	2.31e-05
Mean	5.0e-06	4.6e-06	4.98e-06	5.00e-06

Table II: Hazard curve contribution to mean frequency of CM failure

Hazard Curve	LGS-SARA	PRASSE by MCS	PRASSE by LHS
Piedmont $M_{b, max}$=5.8	5.4e-7	5.83e-7	5.81e-7
Piedmont $M_{b, max}$=6.3	2.3e-6	2.54e-6	2.55e-6
Northeast Tectonic	2.4e-7	2.73e-7	2.74e-7
Crustal Bl. $M_{b, max}$=5.5	1.5e-8	1.79e-8	1.77e-8
Crustal Bl. $M_{b, max}$=6.8	6.2e-8	7.26e-8	7.25e-8
Decollement	2.1e-6	1.49e-6	1.49e-6
Total	5.3e-6	4.98e-6	5.00e-6

4. Conclusions

In this study, the computational code for seismic probabilistic safety assessment, PRASSE, was developed using the LHS method and the MCS method for the uncertainty analysis. The uncertainty estimation of system fragility was performed well by using enough sampling number. Event frequencies were obtained by convolving the system level fragility with seismic hazard curves. The core damage failure event of the nuclear power plant was estimated and it shows a good agreement with the reference results.

ACKNOWLEDGEMENT

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REFERENCES

[1] B. Ellingwood, Validation studies of seismic PRAs, Nuclear Engineering and Design, Vol.123, pp. 189-196, 1990.
[2] EQE International, Inc. EQESRA; Reference Document, Version 3, 1995.
[3] M. A. Azarm, et al. 1984., A review of the Limerick Generating Station severe accident risk assessment, Report NUREG/CR-3493, Washington, DC, U.S. Nuclear Regulatory Commission.