Development of a Seismic Risk Assessment Program

In-Kil Choi [a*], Do-Yeon Kim [b], Jin-Hee Park [a]
[a] *Integrated Safety Assessment Division, Korea Atomic Energy Research Institute, Daejeon, Korea*
[b] *Korea Institute of Construction Materials, Daegu, Korea*
[*] *Corresponding author: cik@kaeri.re.kr*

1. Introduction

The final result of a seismic probabilistic safety assessment (SPSA) is expressed as the frequency of adverse consequences, such as core damage, due to the potential effects of earthquakes. In this study, a seismic risk quantification software was developed using the LHS (Latin Hypercube Sampling) method.

2. Seismic Risk Assessment

The purpose of a SPSA is to determine the probability distribution of core damage due to the potential effects of earthquakes [1,2]. SPSA is performed based on four steps, seismic hazard analysis, component fragility evaluation, plant system and accident sequence analysis, and consequence analysis.

2.1 Seismic Hazard Analysis

A probabilistic seismic hazard analysis is to develop the frequencies of the occurrences of different levels of ground motion parameters (such as peak ground acceleration, peak ground velocity, spectral acceleration, etc.) at a site. In this step, a series of seismic hazard curves are developed by using seismic source models and attenuation equations with considering the uncertainties of the hazard parameters.

2.2 Seismic Fragility Evaluation

A seismic fragility evaluation is to estimate the conditional probability of a failure of important structures and equipments whose failure may lead to unacceptable damage to a plant. The component fragilities are needed in a SPSA to estimate the conditional probabilities of an occurrence of initiating events and the conditional failure probabilities of different mitigating systems.

2.3 Plant System and Accident Sequence Analysis

In this step, the modeling of the various combinations of the structural and equipment failures that could initiate and propagate a seismic core damage sequence is performed. Event and fault trees are constructed to identify the accident sequences that may lead to severe core damage and a radioactive release. Based on the core damage sequences, Boolean expressions are developed for each release category.

Plant level fragility curves are obtained by combing the fragilities of individual components according to Boolean expressions.

2.4 Consequence Analysis

The plant damage state frequency is obtained by convolving plant level fragilities with the seismic hazard curves. The probability distribution for the unconditional frequency of core damage can be obtained by the following equation.

$$P_f = \int_0^\infty H(a)\left(\frac{dF(a)}{da}\right)da = \int_0^\infty F(a)\left(\frac{dH(a)}{da}\right)da \quad (1)$$

Here, $H(a)$ represents the seismic hazard curve, and $F(a)$ represents the plant level fragility curve.

3. Program Development

A seismic risk quantification program was developed to calculate the initiating event frequencies.

3.1 Verification of System Fragility

Plant level fragility curves are obtained by the Boolean equations using a Monte Carlo simulation (MCS) or a Latin Hypercube Sampling (LHS) to consider the uncertainties. In this study, the LHS method was used for an efficient and rapid calculation. Figure 1 shows the comparison of the sample calculation results using MCS and LHS. The calculation time of the MCS was about 50 times more than the LHS to obtain smooth curves.

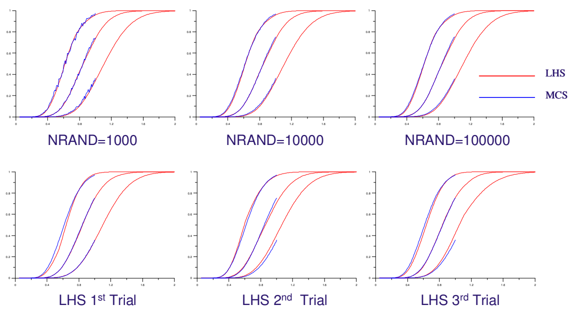


Fig. 1. Comparison of the sample calculation using MCS and LHS.

A sample problem in a reference [3] was calculated using two programs which were used for the past SPSAs and the newly developed program in this study. Figure 2 shows the calculated results for a sample Boolean equation (Union of three independent components).

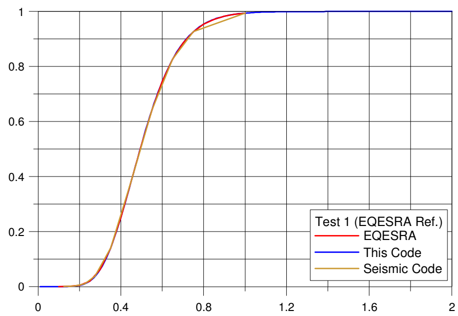


Fig. 2. Plant level fragility curves

3.2 Convolution Methodology

The unconditional frequency of a core damage can be obtained by equation (1). The hazard curve and fragility curve are given as discrete data. Especially, the hazard curve is given at several points. This can cause a different result for the former and latter integral of equation (1). The Simpson's 1/3 integration method was used to reduce the difference of the two integral calculations. As shown in Table 1, the final results from the two equations are very similar.

Table 1. Comparison of the integration results.

Former Integral	Latter Integral
7.7638E-06	7.7637E-06

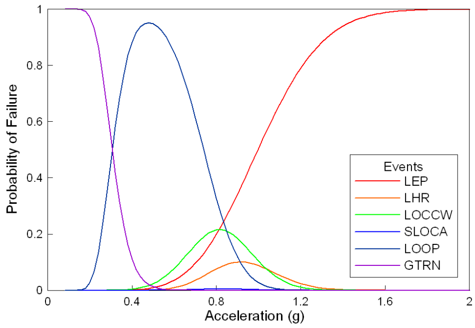
Table 2 shows the convolution results for different seismic hazard curves by LHS and MCS. As shown in this table, the convolution results show some difference due to the number of random number generations.

Table 2. Convolution result for different hazard curves.

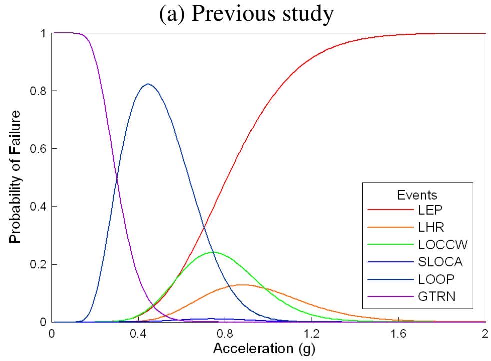
Hazard Curves	This Code (LHS)	Seismic Code (MCS)
HC1	2.171E-06	2.288E-06
HC2	3.263E-06	3.440E-06
HC3	4.809E-06	5.076E-06
HC4	8.774E-07	9.840E-07
HC5	1.151E-06	1.291E-06
HC6	1.822E-06	2.067E-06
HC7	6.972E-06	7.388E-06
HC8	1.013E-05	1.071E-05
HC9	1.458E-05	1.537E-05

3.3 Sample Calculation

The plant level fragility curves for six initiating events were calculated. The Boolean equations were used in the past SPSAs for Ulchin unit 5 and 6 [4]. Figure 3 shows the plant level fragility curves for six initiating events.



(a) Previous study



(b) This study

Fig. 3. Comparison of the plant level fragility curves.

4. Conclusions

A computer program to calculate the initiating event frequencies for seismic events was developed. The uncertainty of the component fragilities was simulated by the LHS method. The calculated plant level fragility curves and initiating event frequencies obtained by convolving the system level fragility with seismic hazard curves shows a good agreement with the reference results. But, for the convolution result it shows some differences with the conventional program used in the past SPSAs.

ACKNOWLEDGEMENT

This research was supported by the Mid- and Long-Term Nuclear Research & Development Program of the Ministry of Education, Science and Technology, Korea.

REFERENCES

[1] John W. Reed and Robert P. Kennedy, Methodology for Developing Seismic Fragility, EPRI TR-103959, 1994.
[2] American Nuclear Society, American National Standard ; External-Events PRA Methodology, ANSI/ANS-58.21, 2007.
[3] EQE International, Inc., EQESRA ; Reference Document, Version 3, 1995.
[4] KHNP, Probabilistic Safety Assessment for Ulchin Uints 5&6(Phase II) : External Event Analysis, 2002.