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Seismic Evaluation by Using Composite Standard Deviation

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1. Introduction

For the seismic evaluation of nuclear facilities, the seismic margin assessment (SMA) and the seismic probabilistic safety assessment (SPSA) have been widely used. The system level HCLPF is the criterion in the SMA methodology developed by NRC. The estimation of the system fragility is necessary in the procedure of the SPSA. Therefore, the modeling of a system fragility curve is important in these two methods. In this research, the estimation of system fragility by using composite standard deviation was studied.

2. System Fragility Curve Evaluation

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 of a component is modeled as a cumulative lognormal distribution along the intensity parameter. Accordingly fragility curve can be defined by 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.

2.2Estimation of HCLPF capacity

HCLPF capacity is defined as the 95% confidence of a 5% probability of exceedance level in the fragility curve. An alternative way to estimate HCLPF capacity is to obtain from the composite fragility curve [1]. The composite standard deviation, β_C is calculated as the square root of sum of squares of the two standard deviations, β_R and β_U as defined in Equation 2.

$$\beta_C = \sqrt{\beta_R{}^2 + \beta_U{}^2} \quad (2)$$

The HCLPF capacity defined as the 5% failure probability of 95% confidence level is estimated by the 1% failure probability level on the composite fragility curve. This alternative HCLPF is almost equal to the original one when β_R and β_U are same. Figure 1 shows the ratio between the two HCLPF capacities with different β_R and β_U. The HCLPF of 1% probability of composite curve is always less than 95%-5% HCLPF and larger than 0.9 times of that in the range of β_R less than 0.3 and β_U of 0.5~2.0 β_R. Therefore HCLPF estimation method by composite curve could be a little conservative way.

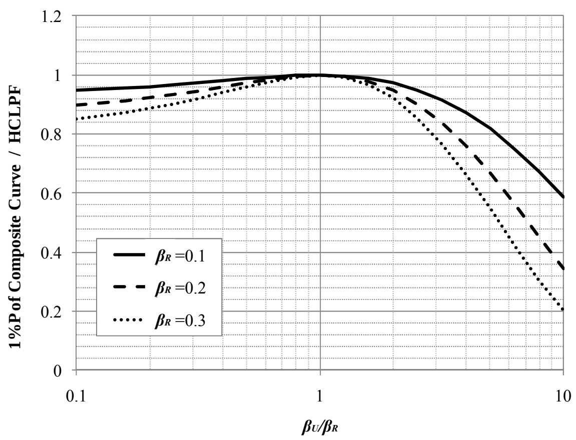

Figure 1. The ratio of the 1% probability HCLPF by composite fragility curve to the 95% confidence of a 5% probability HCLPF according to the various β_R and β_U.

2.3 System HCLPF capacity

The system fragility curve is composed of component fragilities by the Boolean equation of inducing core damage. The uncertainty analysis of the system fragility curve is necessary to estimate the system HCLPF. In this study, the alternative HCLPF capacity was calculated by the component fragilities expressed by composite standard deviation for simplified way to avoid the uncertainty analysis.

For the example of the system, the seismic safety assessment of the Limerick Generating Station (LGS) was solved. The parameters of the components and the Boolean equations of the core damage sequences were stated in NUREG/CR-3493 report [2]. The component composite fragilities converted by the two standard deviations and the random failure rates were used to calculate the composite system fragility curve. Figure 2 shows the composite system fragility curve and the system fragility curve by sampling based uncertainty analysis for CM sequence. The composite fragility curve is mathematically equivalent to the mean curve expressed by separate standard deviation in single component [2]. In this figure, the composite fragility curve was almost identical with the mean fragility curve obtained by uncertainty analysis in the system level also. The HCLPF capacity by uncertainty analysis was obtained as 0.291g and that by the composite system fragility was obtained as 0.281g. The difference of the two system HCLPF capacities could be explained by the difference of β_R and β_U of the system level in the same way as the component level fragility.

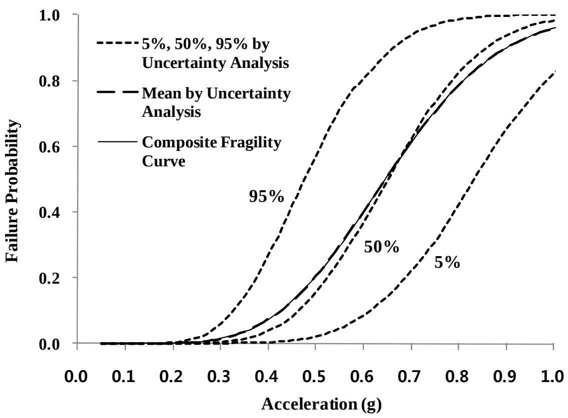

Figure 2. Fragility curves obtained by composite standard deviation and uncertainty analysis

3. Effect of the Ratio of β_R and β_U

For the seismic safety assessment, a fragility curve is usually expressed by uncertainty and randomness standard deviations. But it is difficult to separate these two standard deviations. Therefore, the effect on the system HCLPF and the the core damage frequency (CDF) according to the ratio of β_R and β_U was investigated for fixed composite standard deviation.

Figure 3 shows the 95%-5% HCLPF and alternative HCLPF of the CM event of the LGS for the various ratio of β_R and β_U. The uncertainty analysis estimated the lowest HCLPF capacity at the range of $\beta_U = 1.0 \sim 1.7\beta_R$. The alternative HCLPF was not over the 95%-5% HCLPF for the entire range. In case of SPSA methodology, the variation of uncertainty can affect the distribution of the CDF. Figure 4 shows the 5%, 50%, 95% and mean CDF of the various ratio of β_R and β_U. This represent that the variation of CDF increased as the portion of β_U increased. Nevertheless, the mean CDF did not vary because the mean fragility curve was almost same as the composite fragility curve as depicted in Figure 2.

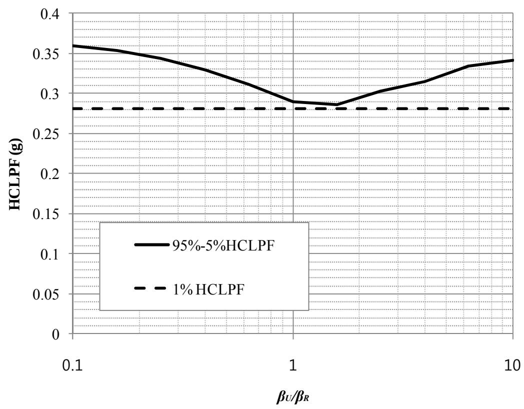

Fig. 3. The HCLPF capacity according to the various β_U/β_R

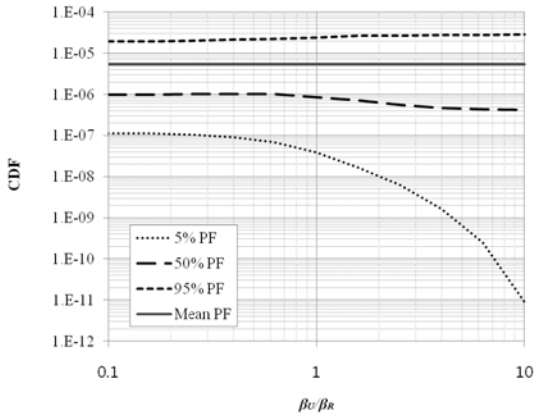

Fig. 4. The CDF according to the various β_U/β_R

4. Conclusions

In this research, the alternative HCLPF capacity was compared with the HCLPF by the uncertainty analysis for the system level. When only the composite standard deviation of components are given, the conservative way is to set β_U same as β_R. And using β_C is more conservative way. The ratio of β_R and β_U did not affect the mean CDF. Therefore, using the composite standard deviation is enough to estimate the mean CDF.

ACKNOWLEDGEMENT

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REFERENCES

[1] Hwang H. H. M. Determination of HCLPF Value For Seismic Margins Study. Transactions, 10th SMiRT, Vol. M: 179-184, 1989.

[2] Azarm, M. A. et al. A review of the Limerick Generating Station severe accident risk assessment, Report NUREG/CR-3493. Washington, DC: U.S. Nuclear Regulatory Commission. 1984.

[3] Kaplan, S., Bier, V. M. and Bley, D. C. A note on families of fragility curves - is the composite curve equivalent to the mean curve? Reliability Engineering and System Safety 43: 257-261, 1994.