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Generalized Approach to Consider the Seismic Failure Correlation of Components for MUPSA

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1. Introduction

The seismic failure correlation of structure, system and components (SSCs) in nuclear power plant (NPP) is an important issue for the seismic risk of a nuclear power plant site. In this study, a simplified approach to estimate the seismic failure correlation of SSCs in a NPP or in several power plant units. This is based on the separation of fragility parameters which is proposed by Reed et al. [1]. To apply this methodology, the current status of seismic fragility methodology used in our country should be considered. In this study, the simplified approach considering the current fragility data in our country is proposed for the multi-unit seismic risk assessment.

2. Estimation of Seismic Failure Correlation

Probabilistic seismic risk assessment has been used as a systematic approach to estimate the earthquake risk of a nuclear power plant. Recently, many nuclear power plants, more than 8 units, has been constructed in a site for a long period. The seismic risk of a nuclear plant site became an important issue after recent major earthquake event in our country. An extreme natural hazard, such as earthquake, tsunami, super typhoon, can cause a common cause failure of multiple units of nuclear power plants in a site.

In this study, the simplified approach to consider the seismic failure correlation due to the extreme earthquake event is proposed to apply a multi-unit probabilistic seismic safety assessment.

2.1 Reed-McCann Methodology

In general, the seismic failure correlation of SSCs has been conservatively assumed to be independent or fully dependent. Several researchers proposed the methodology to estimate the seismic failure dependency for the seismic PSA [2]. A numerical approach was also proposed by some researchers [3,4]. The numerical approach need much time and effort to obtain the correlation coefficient for each pair of components. So the simplified approach is needed for the multi-unit PSA.

The basic equation to calculate the seismic failure correlation between any two components is as follows,

$$\rho_{12} = \frac{\beta_{R1}\cdot\beta_{R2}}{\sqrt{\beta_{R1}^2+\beta_{S1}^2}\cdot\sqrt{\beta_{R2}^2+\beta_{S2}^2}}\cdot\rho_{R1R2} + \frac{\beta_{S1}\cdot\beta_{S2}}{\sqrt{\beta_{R1}^2+\beta_{S1}^2}\cdot\sqrt{\beta_{R2}^2+\beta_{S2}^2}}\cdot\rho_{S1,S2}$$

In which,

ρ_{12} : Correlation coefficient between the failure of components 1 and 2

β_{R1}, β_{R2} : Logarithmic standard deviation of the response of components 1 and 2

β_{S1}, β_{S2} : Logarithmic standard deviation of the capacity of components 1 and 2

ρ_{R1R2} : Correlation coefficient between the response of component 1 and 2

ρ_{S1S2} : Correlation coefficient between the capacity of component 1 and 2

The first part of the equation is related to the plant response correlation, and the second part of the equation is related to the plant capacity correlation. The capacity correlation is generally very smaller than that of response [3], and it is very difficult to estimate.

The Reed-McCann proposed a procedure to estimate dependency between component failure by identifying the common source of variability in the response and strength calculation. The response and capacity correlation coefficient between component 1 and 2 can be obtained from the following equation.

$$\rho_{R1R2}, \rho_{S1S2} = \frac{\beta_{C12}}{\beta_1\cdot\beta_2}$$

where, β_{C12} is the common variability of the two components, and β_1 and β_2 are the total variability of component 1 and 2, respectively.

Ohtori et al. proposed the practical frame work for the application of Reed-McCann method [5]. In this study, this method and generalized common variability were used to calculate the response correlation coefficient between two components.

2.2 Seismic Fragility Parameters

The variable separation method has been used for the seismic fragility analysis of SSCs. To apply the Reed-McCann method, the variability of fragility parameter should be known. However, in some case, it is not easy to separate all of the variability form the various fragility parameters.

The general recommended logarithmic standard deviations, proposed in the EPRI report [6], to use in the hybrid fragility analysis can be used for the calculation of the variability of the response parameters.

Table 1: Recommended Logarithmic Standard Deviation [6]

SSCs	β_C	β_R	β_U
Structures & major passive mechanical components mounted on ground or at low elevation with structures	0.35	0.24	0.26
Active components mounted at high elevation in structures	0.45	0.24	0.38
Other SSCs	0.40	0.24	0.32

2.3 Example Calculation

An example study was performed by using the method proposed by Ohtori et al. [5]. In a NPP site, it was assumed that there are two buildings, and four components in the two building as shown in Fig. 1. The assumed variability parameters of the components are shown in Table 1. $F_{R(1)}$ is related to the earthquake ground motion. $F_{R(2)}$ is related to the site response. In our country, the fragility analysis did not consider the site response and soil-structure interaction effect. So, the variability of related fragility parameter, $F_{R(2)}$ is zero. $F_{R(3)}$ and $F_{R(4)}$ are related to the response of structure and components, respectively.

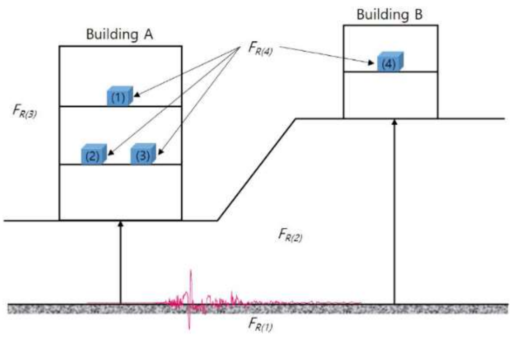

Fig. 1. Grouping of the seismic fragility variables for intra- and inter-unit components.

In the past seismic fragility, the variability of earthquake ground motion was 0.19 and 0.06 for randomness and uncertainty, respectively. Based on the general recommended value and ground motion variability in Table 1, the response variability of structure and component can be obtained. Table 2 show the example calculation of variability of response parameters.

Table 2: Variability of Response Parameters

Comp.	Var.	$F_{R(1)}$	$F_{R(2)}$	$F_{R(3)}$	$F_{R(4)}$
1	β_r	0.19	0.00	0.10	0.10
	β_u	0.06	0.00	0.26	0.26
2	β_r	0.19	0.00	0.10	0.10
	β_u	0.06	0.00	0.26	0.26
3	β_r	0.19	0.00	0.10	0.10
	β_u	0.06	0.00	0.26	0.26
4	β_r	0.19	0.00	0.10	0.10
	β_u	0.06	0.00	0.26	0.26

The calculated example response correlation coefficients are shown in Table 3. The seismic failure correlation can be obtained by assuming the seismic capacity variability.

Table 3: Example Response Correlation Coefficient

		Component			
		1	2	3	4
Component	1	1.000	0.205	0.205	0.205
	2		1.000	0.602	0.205
	3	symm.		1.000	0.205
	4				1.000

3. Conclusions

In this study, the generalized approach to estimate the seismic failure correlation. This approach can be used for the seismic probabilistic safety assessment for a unit and multiple units. The generalized response coefficient for the seismic failure correlation can be used for the preliminary evaluation for the sensitivity study to consider seismic failure correlation.

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