A simple case study of multi-unit seismic PSA for seismic dependency

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1. Introduction

After the Fukushima Dai-ichi accident, multi-unit accidents at a site have been under consideration. Many countries which have multi-unit sites have tried to manage the risk by multi-unit accidents [1-3]. For the management of multi-unit risk, the technique of probabilistic safety assessment (PSA) which have been widely accepted for single unit risk assessment [4] has been employed.

Korea is one of the countries which concerns multi-unit risk. Korean nuclear regulatory authority, Nuclear Safety and Security Committee (NSSC), has started an R&D project for development of multi-unit risk regulation. However, there has been no technically matured approach and results of multi-unit probabilistic risk assessment (MUPRA) in the world, yet.

Among the many issues of MUPRA, seismic dependency between units nearly located within a site is one of the issues being actively studied as well as discussed. However, many results of recent studies show it is practically difficult to resolve the issue [4].

This study is a very simple case study of multi-unit seismic risk to represent the impact of seismic dependency on seismic risk. The results can be a basis to resolve the seismic dependency in multi-unit risk. PRASSE [5] is employed for this study, which can derive system level fragility curve using component fragility.

2. Case 1

For Case 1 study, let's assume same fragilities for three components, S1, S2, and S3, as below, Table 1.

Table 1. Assumed Fragilities for S1, S2, and S3.

	Am(g)	β_R	β_U	HCLPF(g)
S1	1.27	0.28	0.28	0.50
S2	1.27	0.28	0.28	0.50
S3	1.27	0.28	0.28	0.50

Using the fragilities, several combinations of seismic induced failures of components, union and intersection, are examined. The following Table 2 show the results of combinations of seismic induced failures. "U" means "Union of events," while "I" means "Intersection of events." For example, "U-S1S2" means union of S1 failure event and S2 failure event due to single earthquake.

All analysis is performed under seismically independent assumption. And combinations of S1S1 means total dependency between S1 and S2.

Table 2. Fragility of combinations of events. (Seismic induced failure probability)

	Ground Acceleration				
	0.3(g)	0.5(g)	0.7(g)	0.9(g)	1.1(g)
S1	1.03E-04	9.53E-03	6.81E-02	1.95E-01	3.60E-01
U-S1S2	2.05E-04	1.90E-02	1.32E-01	3.56E-01	6.00E-01
U-S1S2S3	3.08E-04	2.84E-02	1.92E-01	4.79E-01	7.36E-01
I-S1S2	6.81E-10	4.14E-05	3.61E-03	3.34E-02	1.20E-01
I-S1S2S3	5.64E-15	1.79E-07	1.91E-04	6.08E-03	4.32E-02
U-S1S1	2.05E-04	1.81E-02	1.18E-01	3.06E-01	5.15E-01
I-S1S1	3.79E-07	9.69E-04	1.85E-02	8.37E-02	2.05E-01

From the results above, intersection fragilities, e.g., I-S1S2, are lower than independent events probability calculation; e.g., 4.14E-5 vs. 9.08E-5. For totally dependent components, I-S1S1 is much higher than I-S1S2, while U-S1S1 is a little bit lower than U-S1S2.

It can be interpreted, the failure probability of system which has dependent components should be calculated using a seismic code, such as PRASSE, being able to calculate system fragility. In other words, all fragilities in a cutset from seismic PRA should be calculated by seismic code, altogether.

3. Case 2

For Case 2 study, let's assume simple seismic PRA event tree, like Fig. 1. (In this study, sample seismic PRA model in PRASSE code [5] is used.) In the event tree, sequences 1 to 4 are transferred to detailed event trees which consider random failure basic events. For simplicity, only sequences 5 to 8 are considered for this study. It is reasonable approach because CDFs from transferred sequences are generally not high compared to non-transferred sequences.

Based on the event tree given above, two event trees are developed, depending on seismic dependency. In these event trees there are 25 sequences, which are three sequences of unit 1 core damage, three sequences of unit 2 core damage sequences, and 18 sequences of units 1 and 2 core damage. There is one OK sequence.

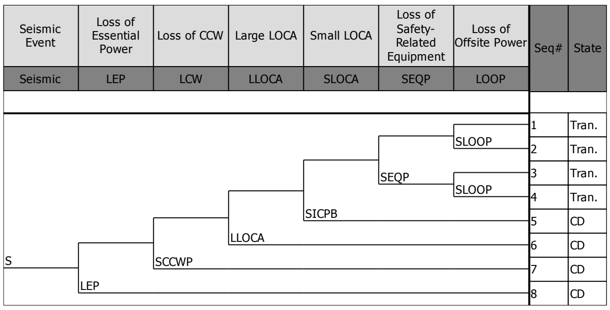

Fig. 1. Assumed Seismic Event Tree.

Table 3 shows summary of Case 2. As expected by many previous studies, at high accelerations, if core damage occurs at unit 1, unit 2 almost always experiences core damage. So, site CDF (②) is almost same as the frequency of simultaneous core damage of units 1 and 2 (①).

Table 3. Results of Case 2.

		Core Damage Frequency (/year)					
	Acc. range (g)	0.1-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0	1.0-1.2
Independent	unit 1	1.03E-09	4.03E-07	1.91E-06	2.21E-06	6.72E-07	9.86E-08
	unit 2	1.18E-09	4.06E-07	1.90E-06	2.28E-06	7.19E-07	9.01E-08
	units 1&2 ①	1.99E-14	4.03E-09	2.43E-07	1.52E-06	1.88E-06	1.12E-06
	site ②	2.21E-09	8.14E-07	4.06E-06	6.00E-06	3.27E-06	1.31E-06
unit 1&2 ③		1.11E-09	4.05E-07	2.14E-06	3.75E-06	2.59E-06	1.22E-06

The results from independent case are compared with totally dependent case results. In the totally dependent case, there is no chance of single unit core damage because if one unit experiences core damage, another unit should experience core damage, too. So, there is no frequency on 6 sequences which result in one unit core damage. Site CDF of dependent case (③) is lower than that of independent case (②). However, it is higher than the frequency of simultaneous core damage of units 1 and 2 (①). The absolute difference between (①) and (③) are big at mid-range of acceleration, where we are mostly interested.

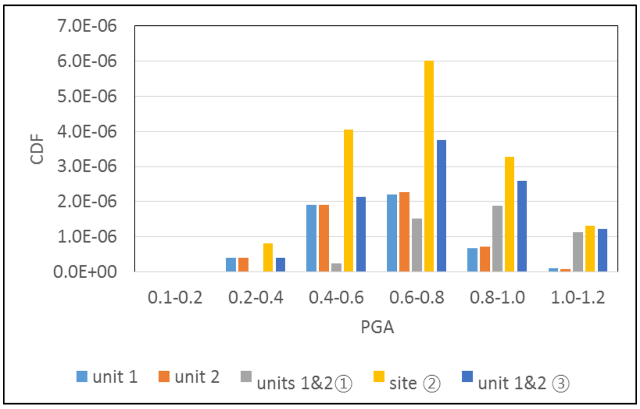

Fig. 2. Results of Case 2.

The results can be interpreted as the real seismic site CDF is located between the results of independent case and dependent case. The site CDF of the independent case (②) represents the upper bound of the real site CDF. Also, total dependent case (③) represents the upper bound of the frequency of simultaneous core damage of units 1 and 2. It can be conservatively suggested that site CDF due to earthquake can be assumed to be independent case site CDF (②), while in the site CDF the frequency of simultaneous core damage of units 1 and 2 can be assumed totally dependent case core damage frequency (③).

4. Conclusions

Until now there are only two multi-unit seismic events. It is practically impossible to establish seismic dependency analysis methodology in near future.

In this study, the impact of seismic dependency on the system fragilities as well as CDFs in multi-unit site is studied by simple model representing bounding cases of dependency. Based on the results, a conservative approach to derive site CDF as well as multi-unit CDF due to earthquake is proposed.

Acknowledgements

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