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Study on Quantification for Multi-unit Seismic PSA Model using Monte Carlo Sampling

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1. Introduction

The purpose of this paper is to suggest method for quantifying multi-unit seismic PSA model and to perform quantification for example model

Quantification for all of combinations by increase of unit number is one of the significant issues in multi-unit PSA. In existing PSA, frequency for accident sequences occurred in single-unit has been estimated. While multi-unit PSA has to consider various combinations because accident sequence in each units can be different. However, it is difficult to quantify all of combination between inter-units using traditional method such as Minimal Cut Upper Bound (MCUB). For this reason, we used Monte Carlo sampling as a method to quantify multi-unit PSA model.

2. Quantification for Multi-unit Seismic PSA model

Traditional quantification method such as Rare Event Approximation (REA) and Minimal Cut Upper Bound (MCUB) has conservative value when a probability of each event is larger than 0.1 [1, 2]. In case of seismic event, there are many events which have high failure probability. For this reason, we have performed quantification of multi-unit seismic PSA model using FTeMC [3] developed by KAERI. FTeMC, which is based on Monte Carlo method, can calculate nearly exact value for each sequence compared to other method and addresses huge fault tree.

2.1 Multi-unit Seismic PSA model

Multi-unit seismic PSA model was based on single-unit model. Basic assumptions used in this paper were 1) six identical units in a site, 2) use of same hazard/fragility curve in each unit (neglects difference of seismic response by position of each unit). Other considerations are as follows.

- Modification of rate event for MC sampling

Core damage frequency caused by seismic event can be represented by Eq.1

$$\mathrm{CDF} = \sum(\%IE_i \cdot \sum S_{i,j})$$

where,
IE_i: i-th initiating event frequency caused by seismic
$S_{i,j}$: j-th sequence of i-th initiating event

Equation 1 was modified for multi-unit PSA model under seismic event. Existing initiating frequency including seismic and initiating event was divided into two parts (seismic frequency and conditional probability of initiating event caused by seismic).

$$\mathrm{CDF} = \%\mathrm{E} \cdot \sum(P_i \cdot \sum S_{i,j})$$

where,
%E: frequency of seismic
P_i : conditional probability of i-th initiating event under seismic

If there are n units in a site, multi-unit CDF can be derived from equation 2 as follows.

$$\mathrm{MUCDF}_k = \%\mathrm{E} \cdot \binom{n}{k} \cdot \prod\left(\sum(P_i \cdot \sum S_{i,j})\right)_k$$

where,
MUCDF_k : multi-unit core damage frequency including k out of n units

Figure 1 shows structure for quantification model.

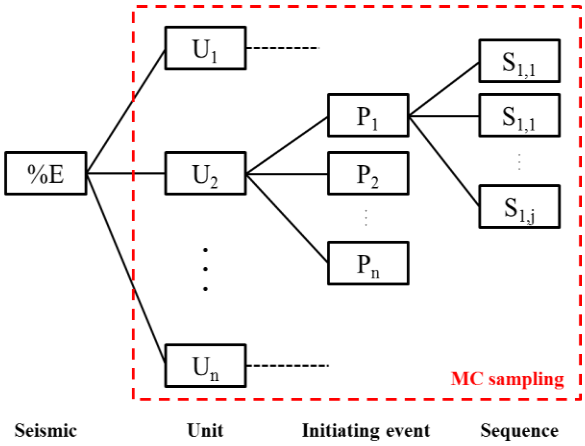

Fig. 1 Structure of quantification using MC

- Common Cause Failure

A result of quantification can be changed by CCF factor between inter-units. To check effect of CCF, we used imaginary value as a CCF factor. These factors were applied in both initiating event and SSCs failure. In SSCs, five major components, which had most dominant effect in single-unit model, were considered.

2.2 Quantification for Multi-unit Seismic PSA model

Existing FTeMC provided top event probability as a result. For quantifying all of combinations, FTeMC was modified as follows.

- The information for all of sequences, which are generated by Monte Carlo sampling in each runs, was provided as a result. In other words, gate name was recorded in FTeMC result file

- The probability of each sequences were estimated by statistical analysis of FTeMC results

Figure.2 shows the example of FTeMC result. Run 4, which is 4-th sampling result, means total two units failed in site and MLOCA-07 sequence occurred in both unit 1 and unit 6. If all of information recorded in result file was arranged, probability of combination for various sequences can be estimated.

Run	Sequence Information			
1	MUCDF-TOP	MU-1FAIL-T	4GIE-LOOP-32	
2	MUCDF-TOP	MU-1FAIL-T	4GIE-TLOCCW-16	
3				
4	MUCDF-TOP	MU-2FAIL-T	1GIE-MLOCA-07	6GIE-MLOCA-07
5	MUCDF-TOP	MU-2FAIL-T	5GIE-SLOCA-07	6GIE-LSSB_OUT-08

Fig. 2 Example of FTeMC result

Sensitivity assessment for four cases was assessed as follow

- Case 1 (Base): no CCF between units
- Case 2 (IE): CCF considered in only IE
- Case 3 (SS): CCF considered in both IE and SSCs
- Case 4 (SS-no IE): CCF considered in only SSCs

Result of each case is given in Table.1 and Fig.3, 4.

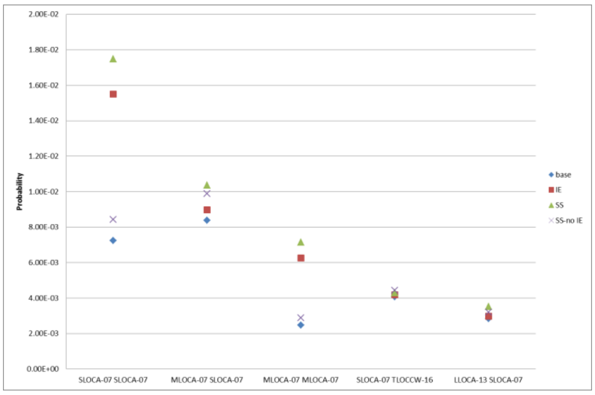

Fig. 3 Top sequence – more than 2 units

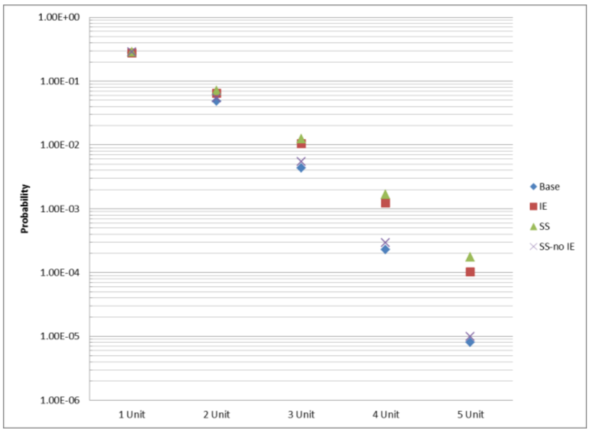

Fig. 4 Quantification result of example model using MC sampling

Table.1 Quantification result of example model using MC sampling

Case	Base	IE	SS	SS-no IE
10^6 sampling				
P (1unit)	2.76E-01	2.75E-01	2.84E-01	2.87E-01
P (2unit)	4.80E-02	6.42E-02	7.12E-02	5.44E-02
P (3unit)	4.35E-03	1.04E-02	1.24E-02	5.50E-03
P (4unit)	2.30E-04	1.22E-03	1.66E-03	2.91E-04
P (5unit)	8.00E-06	1.02E-04	1.74E-04	1.00E-05

These results mean conditional probability under occurrence of seismic. Each value had been calculated by summing the values of all units.

Let me summarize the results as follow.

- In case of more than 3 units, effect of CCF increases.
- CCF effect applied in IE was greater than that of CCF applied in SSCs. However, this model does not consider CCF for all SSCs which were affected by seismic.

3. Conclusions

In this paper, Monte Carlo method was used to quantify multi-unit PSA model. The advantage of this method is to consider all of combinations by the increase of number of unit and to calculate nearly exact value compared to other method. However, it is difficult to get detailed information such as minimal cut sets and accident sequence. To solve partially this problem, FTeMC was modified.

In multi-unit PSA, quantification for both internal and external multi-unit accidents is the significant issue. Although our result above mentioned was one of the case studies to check application of method suggested in this paper, it is expected that this method can be used in practical assessment for multi-unit risk.

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