Uncertainty Analysis for Multi-unit Seismic CCDP model using BBN

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1. Introduction

Earthquake is an external event that starts at one point (seismic center) and affects all buildings and components in a site. A nuclear power plant (NPP) has also developed safety assessments for earthquakes, and it is still underway [1]. While research on multi-unit probabilistic safety assessment (PSA) is actively being conducted, research on seismic multi-unit PSA is also conducted. A safety assessment for seismic event is necessary because an earthquake can affect all units in a site. To this end, various methodologies for seismic multi-unit PSA are being studied. However, earthquakes show different frequencies depending on the size of the earthquake, but there is not enough data because earthquakes with a huge size expected to have a large impact on the safety of a multi-unit site have a very low frequency. Therefore, it can be said that uncertainty analysis is essential when analyzing the results of seismic multi-unit PSAs to be built in the future. Accordingly, this paper intends to raise the importance of uncertainty analysis by analyzing variables using the existing multi-unit seismic conditional core damage probability (CCDP) model using Bayesian belief network (BBN).

2. Model

The model used for uncertainty analysis in this paper is a model that derives a multi-unit seismic CCDP using BBN [2]. The components to be reflected in the model are filtered and selected through the importance analysis of the existing single unit PSA model, and each component forms one leaf node. In addition, the event tree of the single unit PSA model is analyzed to construct a system according to the sequence, and the TOP node is calculated accordingly. The target of this paper is the seismic LOOP CCDP of the identical twin unit, and the TOP node means it.

The input data inserted in the model is as follows.

$$Input\ data = random\ failure + seismic\ failure$$
$$random\ failure = p(r) * alpha\ factor\ inter\ unit\ CCF$$
$$seismic\ failure = p(s)\big(1 - p(s)\big) * C + p(s)^2$$

$p(r) = random\ failure\ probability\ of\ component$
$p(s) = seismic\ failure\ probabilty\ of\ unit$
$C = seismic\ inter - unit\ correlation\ factor$

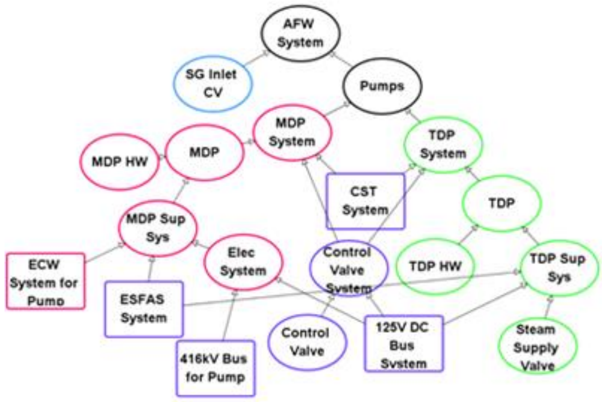

Figure 1. BBN modelling example of auxiliary feed water (AFW) system. Purple colored nodes mean shared components between components.

The input data considered both random and seismic failure. Radom failure means that all components in the twin units fail. For representing that, the alpha factor CCF is calculate which is consider inter-unit common cause component group. On the other hand, seismic failure consists of inter-unit correlation factor and seismic failure probability of one unit (p(s)). In addition, the seismic failure includes both dependent and independent failure by representing the correlation between the units. The seismic failure probability for the twin units are defined as Figure 2.

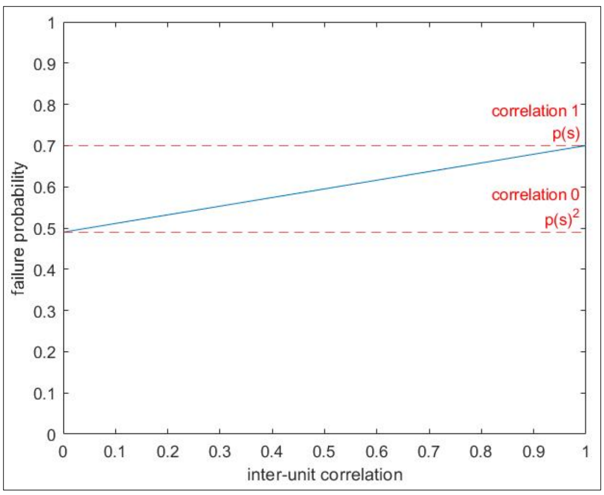

Figure 2. Example of seismic failure probability when p(s) = 0.7. It shows the changes of inter-unit seismic probability according to inter-unit correlation.

The inter-unit correlation factor defines the failure probability of twin units as failure probability of one unit when correlation is 1 which means the twin units are failed simultaneously, and when the correlation is 0, it is defined as the square of the probability of failure to consider both independent failure and dependent failure.

3. Uncertainty Analysis

For uncertainty analysis, all input variables are assumed to be distributions. Random failure is assumed to be log-normal distribution. Since the selection of distribution for certain variable depends on the characteristic of the probability and quantity of the data which are not carefully considered in this paper, it is assumed to the general case for component failure probability in nuclear power plant in the manner of WASH-1400. Seismic failure and correlation are assumed to be normal distribution. The distribution for seismic failure in certain seismic size and correlation factor is not generally defined yet. Since it is defined by mean and standard deviation (SD) and is the most common probabilistic distribution, normal distribution represents seismic failure and correlation factor. For each variable, SD is assumed to component specific value. In addition, it is assumed to be the order of mean for each failure probability inserted into the distribution. Moreover, the order of SD is changed to show the change in the uncertainty. Distribution is as follows.

Normal:

$$y(\mu,\tau) = \left(\frac{\tau}{2\pi}\right)^{\frac{1}{2}} exp\left(-\frac{\tau}{2}(x-\mu)^2\right)$$

Log-normal:

$$y(\mu,\tau) = \left(\frac{\tau}{2\pi}\right)^{\frac{1}{2}} \left(\frac{1}{x}\right) exp\left(-\frac{\tau}{2}(logx-\mu)^2\right)$$

$\tau = standard\ deviation$
$\mu = mean$

In this uncertainty analysis, 0.707 g and 0.122 g of seismic sizes are used, and the correlation factor is assumed to be 0.9 for high correlation and 0.1 for low correlation. Uncertainty analysis is performed through two variables assumed to be distribution (seismic failure and seismic inter-unit correlation factor). In addition, the BBN model is calculated using Monte Carlo update. The sampling is generated 1500 times. In addition, the distributions are truncated for following value 0~1 and area 1.

4. Result

First, the correlation factor is analyzed for SD. The mean of each distribution increases as decreasing of SD for 0.707 g and 0.122 g high correlation while the change rates of mean show different amount of change (see Table 1.). For 0.707 g, change rates of mean are about 21 % and 24 % and for 0.122 g, about 4%. The correlation factor is applied for same value and same SD in same formula of different seismic size. It represents the impact of SD for higher seismic size is larger than lower seismic size.

Table 1. Multi-unit seismic CCDP distribution mean and the change rate according to SD of correlation factor.

	Corr. Factor	Mean	Change rate
0.707 g High corr.	SD 1E-1	0.1628	0.00%
	SD 1E-2	0.1975	21.31%
	SD 1E-3	0.2023	24.26%
0.122 g High corr.	SD 1E-1	0.001684	0.00%
	SD 1E-2	0.001749	3.86%
	SD 1E-3	0.001754	4.16%

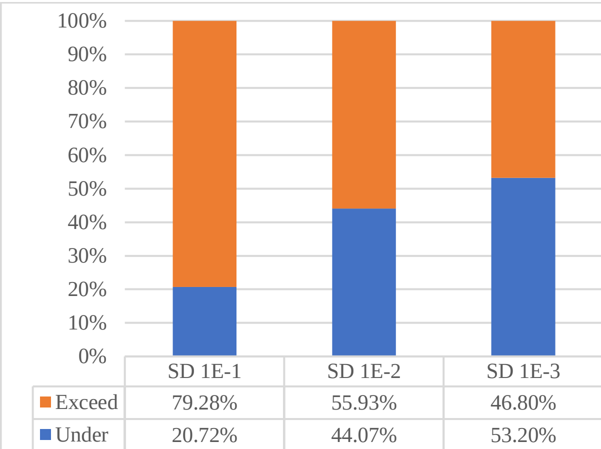

Figure 1. Distribution region comparison when 0.707 g and low correlation according to correlation factor SD.

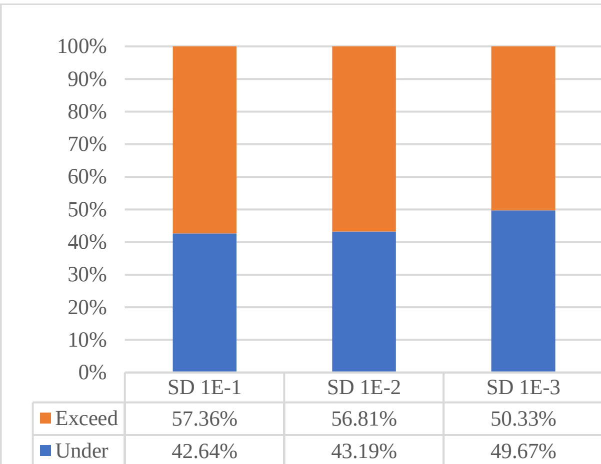

Figure 2. Distribution region comparison when 0.122 g and low correlation according to correlation factor SD.

On the other hand, the cases for low correlation of 0.707 g and 0.122 g show decrease as decreasing of SD and the 0.707 g case of low correlation has larger change than 0.122 g. The uncertainty of high correlation which has factor 0.9 produces increase of multi-unit seismic CCDP while the low correlation makes decrease of the CCDP.

For an in-depth study, several regions of distribution are conducted. The regions are calculated to make each 'Exceed area' and 'Under area' with reference point, which is the mean of medium value of SD, 1E-2. If the distributions are spread widely, the disparity of ratio for each area is large. As Figure 3 and 4., the disparity of 0.707 g is larger than 0.122 g. It means the SD of correlation factor is more sensitive for multi-unit seismic CCDP than 0.112 g.

Moreover, Table 1, Figure 3 and 4 shows the smaller SD, the larger multi-unit seismic CCDP. The small SD means more precise data. Thus, it is represented the uncertainty of data which shows not precise values may make underestimation of the CCDP.

In addition, the seismic failure probability shows large different distribution according to the SD (see Figure 5 and 6). The SD of seismic failure probability increases and decrease in 10^{-1}. For example, the default SD of certain component which has 0.002 mean is 0.001 and the control SDs are 0.01 and 0.0001. As different as the correlation factor cases, the larger SD shows the larger mean and wider distribution of multi-unit seismic CCDP. It can cause overestimation of multi-unit seismic CCDP. In addition, 0.707 g case represent larger disparity than 0.122 g. It means that the uncertainty of seismic failure probability is more affective to large seismic size than small seismic size.

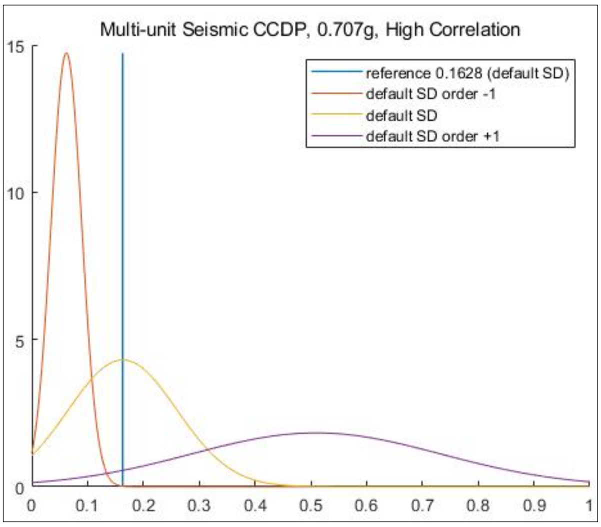

Figure 3. Multi-unit seismic distribution according to seismic failure probability SD when 0.707 g and high correlation.

5. Conclusion

In this paper, comparative analysis is conducted for SD in two seismic size and two inter-unit seismic correlation factor. As a result, the change of SD of correlation factor and seismic failure probability is more sensitive to larger seismic size. In addition, for seismic correlation factor, the larger SD which means that the CCDP distribution is spread widely shows the smaller CCDP. It may cause underestimation of multi-unit seismic CCDP. On the other hand, for seismic failure probability, the larger SD represent the larger CCDP. Therefore, it can cause overestimation.

If the seismic size is large, the frequency of earthquake is low and the data for PSA is not enough. Therefore, uncertainty may be large. Thus, it is confirmed that the multi-unit seismic PSA should increase the reliability through uncertainty analysis since the change in CCDP due to uncertainty which is represented SD in this paper increases when the seismic size is large.

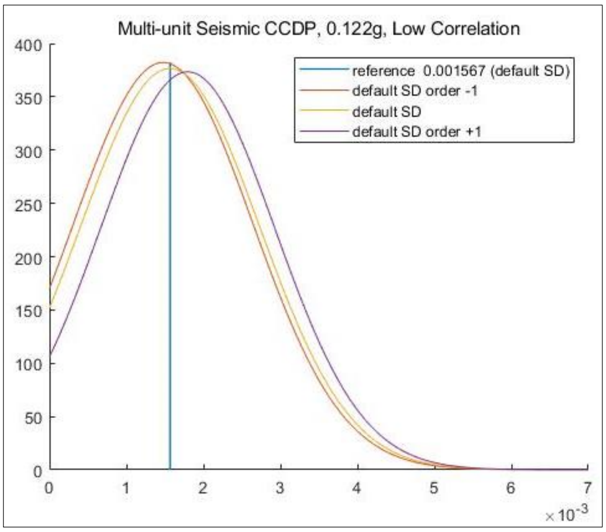

Figure 4. Multi-unit seismic distribution according to seismic failure probability SD when 0.122 g and low correlation.

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[1] Jung, Woo Sik, "Conversion of Seismic Correlation into Seismic CCFs and Its Application to Multi-Unit PSA", ASRAM 2019

[2] Heo, Yunyeong, Seung Jun Lee, "Framework of Simplified Method Evaluating Seismic Conditional Core Damage Probability for Multi-unit', ASRAM 2019