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Construction of Site Risk Model using Individual Unit Risk Model in a NPP Site

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1. Introduction

Since Fukushima accident, strong needs to estimate site risk has been increased to identify the possibility of re-occurrence of such a tremendous disaster and prevent such a disaster. Especially, in a site which has large fleet of nuclear power plants, reliable site risk assessment is very emergent to confirm the safety. In Korea, there are several nuclear power plant site which have more than 6 NPPs. In general, risk model of a NPP in terms of PSA is very complicated and furthermore, it is expected that the site risk model is more complex than that. In this paper, the method for constructing site risk model is proposed by using individual unit risk model

2. Methods and Results

In this section overall procedures and the methods for constructing site risk model are described. In Section 2.1 overall procedure of the proposed method is described. Section 2.2, 2.3, and 2.4 explain the details to construct site risk model. Finally, the quantification of the site risk model are discussed to show example using one of the proposed methods.

2.1 Overall procedure for the site risk assessment

The site risk model may be similar to a unit PSA model if a system which one want to know its risk is replaced a NPP with a site which have several NPPs. If it is, the following general procedures can be applied to construct site risk model

a. Define site risk
b. Construct top logical structure of site risk model
c. Develop individual unit logical risk model
d. Treat dependencies among units
e. Quantify site risk

Each procedure is explained in the following sub-section, 2.2 to 2.4

2.2 Definition of site risk

At the level of site, one can regard an event as a site damage event if one or more than one unit in the site has a damage event. Let U_i be a damage event in the i'th unit in a site. Using Boolean expression, site damage event can be expressed as follows

$$S = \sum_{i=1}^{n} U_i \quad (1)$$

Where *S* is site damage event and n is the number of NPPs in a site

According to the definition of a damage event in a unit, *S* may means a site core damage event or site radioactivity release event.

2.3 Top structure of site risk model

Eq. (1) shows that a site risk can be obtained by Boolean summation of unit risk models. If one wants to know the site risk by simply estimating a frequency of site damage event, the procedure may be similar to the conventional fault tree quantification under the condition that the unit PSA model in terms of FT constructed and the dependencies among units are sufficiently considered.

In case that a damage state of a site should be identified to consider the consequence of each damage state, simple frequency calculation may not be applied since direct FT calculation generate minimal cut-set (MCS) which multiple units failures are subsumed to a simple minimum failure scenario. To overcome this faculty, Eq. (1) should be decomposed to the set of exclusive events.

Figure 1 shows an example of decomposition for three events using Venn diagram

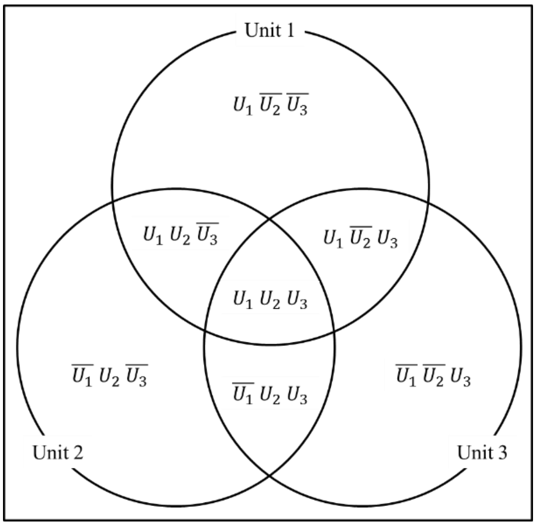

Fig. 1. Decomposition of three event

For the site of n units as shown in Eq. (1), the decomposition can be expressed as follows

$$S = \sum_{i=1}^{m} U_i$$
$$= \sum_{i=1}^{m}\left(U_i \cdot \prod_{\theta \neq i}^{m} \overline{U_\theta}\right) + \sum_{i=1}^{m}\sum_{j=i+1}^{m}\left(U_i \cdot U_j \cdot \prod_{\theta \neq i,j}^{m} \overline{U_\theta}\right) + \cdots$$
$$+ \sum_{i=1}^{m} \cdots \sum_{l=k+1}^{m}\prod_{\rho=i}^{l} U_\rho \cdot \prod_{\theta \neq i,\cdots l}^{m} \overline{U}_\theta + \cdots + \prod_{\rho=1}^{m} U_\rho \quad (2)$$

As shown in Eq. (2), if one wants to quantify the site damage frequency with the damage state, 2^n-1 times of independent FT quantifications are required.

2.4 Development of individual unit risk model

As shown in Eq. (1), to develop site risk model, individual unit damage model in term of FT should be developed. A unit damage model is basically constructed for the operation mode of a NPP. By considering operation model, unit damage model can be described as follows

$$U_i = \sum_{j=1}^{nm(i)} m_{ij} \cdot U_{ij} \quad (3)$$

Where *nm(i)* means the number of operation mode for i'th unit as a function of I, m_{ij} is the event that I'th unit is in operation mode j, and U_{ij} is the damage event of unit i in operation mode j.

Furthermore, a unit may experience variety of initiating events depending on the root causes of hazards. For example, a unit may experience damage event internal cause, external causes from seismic event, flooding, and so on.

Considering such an event types, a unit damage event of i'th unit in operation mode j can be expressed as follows

$$U_{ij} = \sum_{k=1}^{nc(j)} U_{ijk} \quad (4)$$

Where *nc(j)* is the number of hazard of unit I in operation mode j as a function of j, and U_{ijk} is the damage event of unit I in operation mode j by hazard k.

Integrating Eq. (3) and (4), the structure of unit damage event can be obtained as follows

$$U_i = \sum_{j=1}^{nm(i)}\left(m_{ij} \cdot \left(\sum_{k=1}^{nc(j)} U_{ijk}\right)\right) \quad (5)$$

By the practice of conventional PSA model development, full power and low power & shutdown (LPSD) PSA model is developed for a NPP as an operation mode. For the hazard type, an internal event, fire, flooding PSA model are considered. However, as experienced in the Fukushima accident, external event such as seismic and Tsunami is very important hazards to estimate site risk. As for the Korea, it is very important to identify Korea specific external events which has possibility of multiple unit failure

2.5 Treatment of dependencies among units

Once a unit damage model has been developed, dependencies among unit damage event is important factor to develop site damage event model. Dependencies should be treated manly for the followings

a. Initiating event
b. Common SSC
c. Common cause failure(CCF)

For most of external event, the effect of this event may reach all the unit in a site. In such cases, initiating event at each unit's damage event model have dependency. Common SSC may also make dependencies in the initiating event and failure event in the accident scenarios. When modeling site damage event model, CCF make a problem more complicated. As a typical example, when a site is regarded as a whole system, the number of SSCs to be modeled as a CCF group increases to make logical model be complex. Also, in the seismic PSA model, seismic correlation is difficult to be considered realistically.

2.6 Quantification of site damage model

The quantification of site damage model may have some problems as follows

- Size of logical model
- Resolution
- Error of estimation

As expected from Eq. (1) and (5), site damage model may be more complicated compared to unit damage model. By this reason, although the site damage model may be computable, calculation resource mainly in terms of calculation time may increase.

As mentioned in Section 2.3, to distinguish the damage state from the site damage events (see Eq. (1)), the calculation loads increase exponentially. Also, the generation of logical model may not be easily handled manually.

Finally, there may be some problem in quantifying the site damage event frequency when applying conventional approximation method such as rare event approximation. As an example, when developing site damage model by seismic event, it is not easy to quantify the frequency using conventional FT quantifying program such as AIMS-PSA [1]. It is due to the failure event probability to be fairly large compared to other random failure event.

In this paper, two types of quantification methods are proposed

One is to use Monte Carlo sampling of FT. This method is to calculate top event probability of a FT by sampling basic events in the FT. This method can calculate the damage frequency exactly under the condition that the sampling number is sufficiently large. However, since this method cannot generated accident scenarios such as MCS, detailed information for the improvement the site safety may be handled.

The other is to use conventional FT quantifying program. As mentioned in Section 2.3, to apply this method, decomposition of an event should be proceeded to identify damage state. When NPPs in a site increase, it is not easy to treat this work manually. It is recommended to develop a computational program to treat this problem effectively

3. Conclusions

Procedure for the development of site damage (risk) model was proposed in the present paper. Since the site damage model is complicated in the sense of the scale of the system and dependency of the components of the system, conventional method may not be applicable in many side of the problem. Although pilot application was completed and make successful results using the proposed method [2], it is expected to make more effort to develop the methodology for the realistic site damage model.

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REFERENCES

[1] S. H. Han et al, Comparison of Various Methods to Quantify a Fault Tree for Seismic PSA, Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, 2015

[2] G. M. Oh., Study on Quantification for Multi-unit Seismic PSA Model using Monte Carlo Sampling, Transactions of the Korean Nuclear Society Automn Meeting, Jeju, Korea, 2015.