Case Study for CDF Calculation based on Seismic Margin Assessment

Dong-Won Lee[a,b], Nam-Heoyng Lim[a]
a. Dept. of Civil Engineering, Chungnam National University
b. Dept. of Severe Accident and Risk Assessment
dwlee@kins.re.kr

1. Introduction

The seismic margin assessment is conducted for the safety assessment of some of the nuclear power plant not seismic PRA. In this case, the seismic capacity would provide but, it is difficult to know how the risk in in the NPP.

2. Safety Assessment Methodology

There are two different methodology such as below.

- Seismic Margin Assessment : To know how strong the power plant is against the earthquake
- Seismic PRA : To know how risk the power plant is against the earthquake

2.1.Seismic Margin Assessment Methodology

The seismic margin assessment is utilized for the 58% of the NPP in US[1], it is performed with 2 different success scenario to safe shutdown the NPP when the beyond design basis earthquake is occurred. That is the deterministic methodology to find the plant level seismic acceleration capacity (PGA, peak ground acceleration). The following figure 1 shows the example of 2 success path.

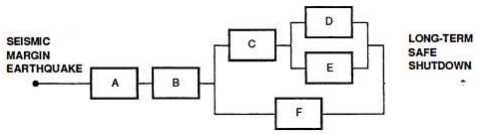

Fig. 1. Example of 2 Success Path

2.1.Seismic PRA Methodology

Seismic PRA is consist of 3 major analysis like as following.

- Seismic Hazard Analysis: The objective of probabilistic seismic hazard analysis (PSHA) is to estimate the probabilities of occurrence of different levels of earthquake ground motion at the plant site taking into account the earthquake history, seismology and geology of the region.
- Seismic Fragility Analysis: Safety related structures and equipment in the plant are designed to withstand the SSE. There are intentional conservatisms introduced in the design, analysis, qualification testing and construction of these structures and equipment such that we can state with high confidence that they will not fail to perform their intended function if earthquakes moderately larger than an SSE occurs
- System Analysis : the structures and equipment list that the fragility analyst should evaluate, constructs the event and fault trees reflecting the unique features of seismic events, and integrates the outputs of seismic hazard analysis and fragility analysis using specialized risk quantification software.

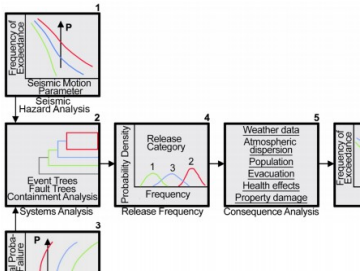

Fig. 2. Seismic PRA Assessment Procedure

3. Simple Convolution Analysis

EPRI[1] provide the simple CDF calculation method based on the SPRA which make the easy to convert seismic margin to CDF. In this paper, this method were used to check the applicability to domestic SMA result. The conditional core damage frequencies (CDF) can be convoluted with Boolean expression, system analysis and conditional failure probability[1].

$$CDF = -\int_0^{\infty} (P_{CDF/a})(dH/da)da \quad (1)$$

If the two independent component failure in NP can be expressed by Boolean expression, it can be calculated like as CD = A+B. And also A can be expressed as the conditional failure probability $P_{A/a}$ for certain earthquakes "a". B also have same meaning.

$$P_{CDF/a} = P_{A/a} + P_{B/a} - P_{A/a}P_{B/a} = 1-(1-P_{A/a})(1-P_{B/a}) \quad (2)$$

dH/da in equation (1) is the mean seismic hazard, a is the peak ground acceleration (PGA)[4,5].The lognormal distribution of fragility can be expressed like as following.

$$dP_{A/a} = [1/\sqrt{2\pi}\beta_c a]e^{-\xi^2/2} \quad (3)$$

And Eq. (3) can be expressed like as following.

$$dP_{CDF\alpha}/da = \sum_{j=1}^{n}[(dP_{Aj/\alpha}/da)\prod_{k\neq j}^{n}(1-P_{Aj/\alpha})] \quad (4)$$

Where, $t_0 = [\ln(a/\hat{a})/\beta_c$,
$\hat{a}$ is median seismic capacity acceleration

The Boolean expression with the combination of several single component is following.

$$CD = \bigcup_{i=1}^{n} A_i \quad (5)$$

$$P_{CDF\alpha} = 1-\prod_{i=1}^{n}(1-P_{Ai/\alpha}) \quad (6)$$

Eq. (5) and (6) can be expressed like bellow.

$$dP_{CDF\alpha}da = \sum_{j=1}^{n}(dP_{Aj/\alpha}/da)\prod_{k\neq j}^{n}(1-P_{Aj/\alpha}) \quad (7)$$

Lastly, if $P_{Ai/\alpha}$ is very small, then $\prod_{k\neq j}^{n}(1-P_{Aj/\alpha}) \approx 1$ is can be expressed like as following.

$$CDF \leq \sum_{i=1}^{n}\int_{0}^{\infty} H(dP_{Aj/\alpha}/da)da = \sum_{i=1}^{n}\Delta CDF_i \quad (8)$$

4. Case Study

4.1.HCLPF calculation with hybrid method

APR1400 NPP had been obtain the design certification by US NRC, but the characteristics of DC plant is that the specific site to construct is not decided. Therefore, the seismic safety assessment of this plant usually conducted thorough the seismic margin assessment. In accordance with this background, the plant level seismic capacity for APR1400 is developed to 0.5g which is 1.67 times to certified site design ground motion 0.3g[6]. The estimation of fragility is based on the hybrid fragility methodology[1], the composite variability value of βc is assumed to be 0.3. Table 1 show the example of fragilities from APR 1400 NRC DC NPP[6].

Table 1. Example of Seismic Fragility

Description	βc	HCLPF	Am
LOOP	0.5	0.09	0.3
SIP Failure	0.3	0.5	0.82
MOV Failure	0.3	0.5	0.82
CS Pump Failure	0.3	0.5	0.82

4.2.Seismic Hazard for Case Study

Seismic Hazard curve from Catawba NPP[1] is used for the case study. Because seismic hazard of APR1400 NRC DC NPP[6] is not decided yet, that's why the assumption is needed to conduct the simplified CDF assessment. The figure 3 depict Catawba PSHA curve.

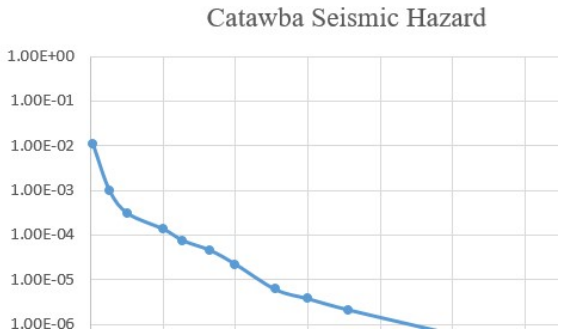

Fig. 3. Catawba Plant Seismic Hazard

4.3.Plant Response Analysis for Case Study

In this paper, Eq (9) is utilized to have the CDF based on seismic margin assessment of APR1400[6], The representative accident sequence of APR1400 among the more than 1,000 is following.

$$CD = SLOOP*SIPP*AFMP*CSPP \quad (9)$$

When the user wants to have the accurate result then all of the cutsets in the APP 1400 NRC DC[6] need to be convoluted with PSHA, HCLPFs of SCCs. There might include the rate of operator failure, nonseismic failures, so this methodology can produce the total core damage frequency and insights from the results.

4.4. Simplified CDF Assessment Procedure

The calculation of simplified CDF is calculated by following procedures.

a. Calculated the Am based on HCLPF with generic βc
b. Calculated the d(PF/a)/da
c. Convolute the results f(a) = H[d(PF/a)/da]
d. Calculated $\Delta an = a_n - a_{n-1}$
e. $\Delta CDFn = \int f(a)da$
f. CDF = ΔCDFn

By following above procedures, the simplified CDF based on the suggested information above can be obtained. The cutset from equation (9) can be transform to the Boolean expression which is the probability of failure and last line of table 2 show the result of single CDF from equation (9). The following table 1show the result of CDF.

Table 2. CDF result based on Seismic Margin Assessment

Event	Description	β_c	HCLPF	Am	PF
LOOP	Loss of offsite power	0.5	0.09	0.3	1.29E-04
SIPP	SI pump	0.3	0.5	0.82	9.54E-06
MOV	MOV	0.3	0.5	0.82	9.54E-06
CSPP	CS pump	0.3	0.5	0.82	9.54E-06
CD = LOOP*SIPP*AFMP*CSPP				Total CDF	3.69E-09

5. Conclusion

Some of the NPP in domestic and foreign is constructed on the low seismic risk zone before Fukushima NPP accident, so the seismic safety assessment of these NPP is conducted by seismic margin assessment. However, some of the site have the new seismic source which is provide higher than the original design seismic demand, so these plant need to have the new detail safety assessment. In this paper, the case study was performed based on methodology in reference [1], APR1400 NRC DC seismic margin assessment result[6] and seismic hazard curve in Catawba [1]. The result of CDF is 3.69E-09/yr based on the single representative seismic accident sequence. The result might have the difference from when the CDF from the full sequences are summed. But the calculation of full CDF sequences is not difficult, because the MS Excel commercial software or others might make them easy to provide the results. Based on the result, if some plant which performed by seismic margin assessment need to have CDF, this methodology expected to be helpful.

REFERENCES

[1] EPRI 1003121, "Methodology and Case Study for Use of Seismic Margin Assessments in Quantitative Risk-Informed Decision Making", EPRI, 2004
[2] Electric Power Research Institute, EPRI NP-6041SL, “A Methodology for Assessment of Nuclear Power Plant Seismic Margin (Revision 1),” EPRI, 1991.
[3] Electric Power Research Institute, “Seismic Probabilistic Risk Assessment Implementation Guide”, EPRI, Palo Alto, CA: 2003.1002989.
[4] Electric Power Research Institute, EPRI NP-6395-D, “Probabilistic Seismic hazard Evaluation at Nuclear Plant Sites in the Central and Eastern United States: Resolution of the Charleston Issue,” April 1989.
[5] NUREG/CR-1488, “Revised Livermore Seismic Hazard Estimates of 69 Nuclear Sites East of the Rocky Mountains,” prepared by Lawrence Livermore National Laboratory for the U.S. Nuclear Regulatory Commission, April 1994.
[6] APR1400 NRC DC, “Chapter 19, Probabilistic Safety Assessment and Severe Accident Evaluation", APR1400-K-X-FS-14002-NP, Rev03, 2019