An Improved Seismic PRA Method for a Korean NPP Site

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1. Introduction

The safety of a Nuclear Power Plant (NPP) can be evaluated by the Core Damage Frequency (CDF). For the calculation of the CDF, seismic hazard evaluation results, seismic fragility analysis results and plant system information are needed. Using this information, an accident scenario through a core damage can be analyzed and finally the CDF can be determined. The well known CDF calculation program is EQESRA (1995) which was developed by EQE International INC. The EQESRA is widely used for a seismic probabilistic risk analysis (PRA) in a Korean NPP site. In this study, a new methodology for the CDF calculation was developed. For a validation about the developed method, an analysis was performed and compared to that of the previous results. Finally, the developed method was applied to the Yonggwang 5,6 unit in the case of an isolated EDG system.

2. Development of a System Analysis Program

The system analysis program which name is CRIEPI_SRAv60K was developed in this study. This program was developed as a result of a KAERI-CRIEPI collaboration research program during 2003 to 2006. The developed program needs component fragilities, accident sequences and seismic hazard curves for a calculation. The system fragility curves and CDF were produced from the calculation results. The basic concept is the same as EQESRA. An outline of the developed computer program is shown in Figure 1.

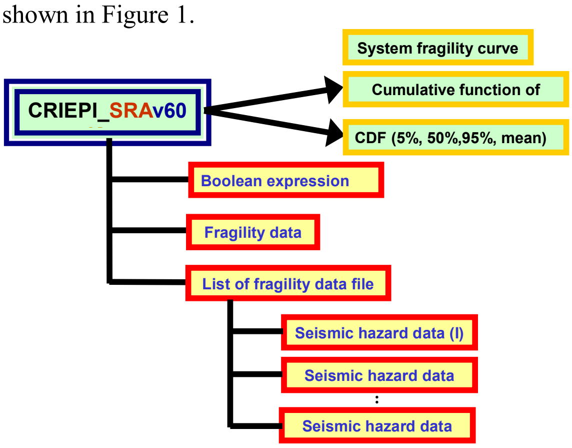


Figure 1. The Outline of Developed Program for PRA

EQESRA uses the method of Kaplan and Lin (1987) for the Boolean algebra operation. A complete enumeration (grid search) is used for an evaluation of the Boolean operations. But the CRIEPI_SRAv60K uses the Latin Hypercube Sampling (LHS) which is used for an evaluation of the Boolean operations. The discrete fragility curves and vertical condensation should be repeatedly executed in case of the Kaplan's method. The number of calculations is decreased by using the LHS method. However, the results depend on a random seed.

3. Verification of the Developed Program

For the verification about the developed computer program, the analysis performed and compared to that of the results of the Ellingwood (1989). Table 1 shows the parameter of the component fragility curves and Figure 2 shows the seismic hazard curves for an analysis. The fragility results are shown in Figure 3.

Table 1. Parameters for the Component Fragility

	Component	Am	β_R	β_U
1	Off Site Power (500/230 KV SW)	0.2	0.2	0.25
2	Reactor Internals	0.67	0.28	0.32
3	Reactor Enclosure Structure	1.05	0.31	0.25
4	Reactor Pressure Bessel	1.25	0.28	0.22
5	SLC Tank	1.33	0.27	0.19
6	440KV BUS/SG Breaker	1.46	0.38	0.44
7	440KV BUS Transformer Breaker	1.49	0.36	0.43
8	125/250V DC BUS	1.49	0.36	0.43
9	4KV BUS/SG	1.49	0.36	0.43
10	Diesel Generator Circuit	1.56	0.32	0.41
11	DG Heat and Vent	1.55	0.28	0.43
12	RHR Heat Exchangers	1.09	0.32	0.34
13	DG Common Mode	1.25E-03	-	-
14	Containment Heat Removal	2.60E-04	-	-
15	Scram System Mechanical Fail	1.00E-05	-	-
16	Standby Liquid Control	1.00E-02	-	-

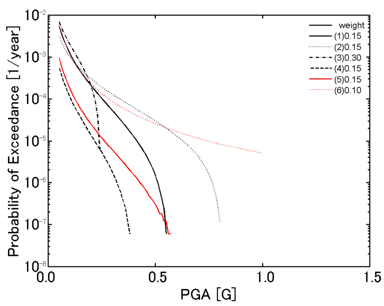


Figure 2. Seismic Hazard Curves for the Verification Analysis

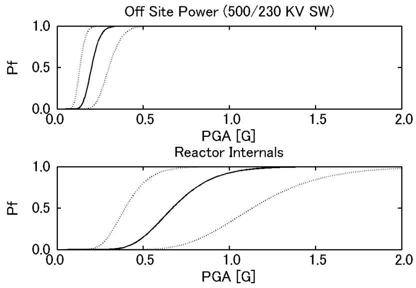


Figure 3. The Component Fragility Curves of the Analysis Result

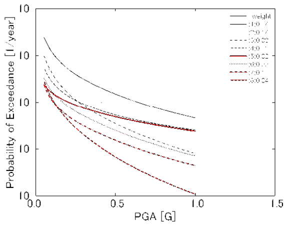
The calculation was performed for a number of LHS and a division of the fragility curves as a parameter. The initial parameter was changed 5 times for the calculation because the results were affected by the initial parameter. One analysis result is shown in Table 2. There results were compared with the results of EQESRA and Ellingwood. The results are affected by the division number in the case of the fragility analysis but the HCLPF and CDF are not affected by the division number.

Table 2. The results of Verification Analysis

Number of fragility division for LHS	Number of fragility division for Convolution	Trial	Fragility Curve			HCLPF [G]	Plant damage frequency [1/year]			
			Am	br	bu		5%	50%	95%	mean
30	30	1	0.649	0.239	0.158	0.30	2.2E-08	7.0E-07	2.6E-05	5.2E-06
		2	0.648	0.234	0.168	0.32	1.9E-08	6.4E-07	2.6E-05	5.2E-06
		3	0.641	0.238	0.144	0.31	2.3E-08	7.6E-07	2.6E-05	5.3E-06
		4	0.650	0.235	0.162	0.32	2.1E-08	6.8E-07	2.6E-05	5.2E-06
		5	0.640	0.240	0.136	0.31	2.1E-08	7.8E-07	2.6E-05	5.4E-06
min			0.640	0.234	0.136	0.30	1.9E-08	6.4E-07	2.6E-05	5.2E-06
max			0.650	0.240	0.168	0.32	2.3E-08	7.8E-07	2.6E-05	5.4E-06
mean			0.645	0.237	0.153	0.31	2.1E-08	7.1E-07	2.6E-05	5.3E-06
Ellingwood's *1			-	-	-	0.32	2.7E-08	7.2E-07	2.4E-05	5.0E-06
EQESRA*2			0.647	0.259	0.121	0.32	2.0E-08	6.2E-07	1.9E-05	4.6E-06
Ratio	Present/Ellingwod's		-	-	-	-	0.787	0.988	1.079	1.055
	Present/EQESRA		0.998	0.916	1.268	0.966	1.062	1.147	1.363	1.147

4. Application to the Korean NPP Site

The developed seismic PRA methods were applied to a Korean NPP site. The parameter of the fragility curves of each component as Am, β_U and β_R were used as existing values. The seismic hazard curves for the analysis and the Boolean equation of a Korean NPP site are shown in Figures 4 and 5, respectively.



(SDGSF
+ SSWIT
+ SHVAC
+ (SSWRC * OP-HR)
+ (SLCRC * OP-HR)
+ (SBCRC * OP-HR)
+ (SINRC * SRTRC * OP-HR)
+ SDCSF
+ SBCSF
+ SBRSF)

Fig 4. Seismic Hazard Curves Fig. 5. Boolean Equation

Table 3 and Figure 6 show the results of an application analysis. In this case, the CDF and HCLPF values were shown according to an increase of the seismic capacity of EDG (Am). As shown in Table 3 and Figure 6, a 40% seismic capacity increase is effective for the CDF and HCLPF. If the seismic capacity of the EDG system can increase to 40%, the HCLPF is improved by 15% and the CDF is decreased by 33%.

Table 3. The CDF and HCLPF variation according to the Increase of Seismic Capacity

ケース番号	耐力の上昇率 %			Am [G]			CDF [1/year]				HCLPF [G]
	OP	EDG	CST	OP	EDG	CST	5%	50%	95%	mean	
0	0	0	0	0.30	1.13	0.91	2.49E-07	2.38E-06	2.91E-05	7.79E-06	0.378
1	0	10	0	0.30	1.24	0.91	2.36E-07	1.99E-06	2.64E-05	6.74E-06	0.395
2	0	20	0	0.30	1.36	0.91	2.03E-07	1.79E-06	2.41E-05	5.99E-06	0.408
3	0	30	0	0.30	1.47	0.91	1.89E-07	1.71E-06	2.26E-05	5.54E-06	0.427
4	0	40	0	0.30	1.58	0.91	1.71E-07	1.59E-06	2.13E-05	5.23E-06	0.433
5	0	50	0	0.30	1.70	0.91	1.64E-07	1.53E-06	1.90E-05	5.00E-06	0.433
6	0	60	0	0.30	1.81	0.91	1.51E-07	1.51E-06	1.82E-05	4.85E-06	0.433
7	0	70	0	0.30	1.92	0.91	1.43E-07	1.48E-06	1.79E-05	4.75E-06	0.433
8	0	80	0	0.30	2.03	0.91	1.40E-07	1.47E-06	1.76E-05	4.68E-06	0.433
9	0	90	0	0.30	2.15	0.91	1.37E-07	1.46E-06	1.75E-05	4.62E-06	0.433
10	0	100	0	0.30	2.26	0.91	1.36E-07	1.46E-06	1.74E-05	4.58E-06	0.433

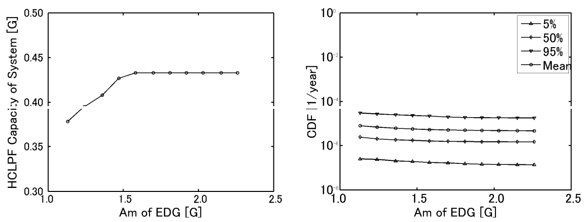


Figure 6. HCLPF and Am of EDG

5. Conclusion

In this study, a new computational method for a seismic PRA was developed. The developed method can calculate the seismic risk of a NPP faster and more accurately. For a validation of the presented method, an analysis was performed and its results were compared to previous results. The developed method can successively be applied to the Korean NPP site.

ACKNOWLEDGEMENT

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