Modeling of Human Error Probability Dependent on Seismic Intensity

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1. Introduction

Accidents in the nuclear power plant are recovered by safety equipment systematically or an operator's action. However, theses recovery could not work normally under the accident such as an earthquake event. So, the failure probabilities of them should be defined to evaluate the plant level risk. The failure probabilities of equipment or structures used to be represented as a fragility curve for natural hazards. On the other hand, the human operation error is not well defined for such accidents like earthquake event. In this study, several human error models for the seismic event were reviewed and compared by the example analysis.

2. Human Error Probability Model

Human error rate in the internal Probabilistic Safety Assessment (PSA) is very small value with an order of 10e-2 or 10e-3. For the Korean nuclear power plant, it used to be about 0.001. For the seismic PSA, human error rate was considered as 10 times of the value in the internal PSA. However, the human action also can be a function of a seismic intensity because an operator may have misjudgment by high stress or cannot take a measure blocked by structural obstacles. There are several human error probability models considering seismic intensity applied to existing nuclear power plants.

In the seismic PSA of Diablo Canyon nuclear power plant, human action errors are defined by the factor multiplied to the value in the internal PSA. These factors are dependent on the seismic intensity. In this model, the seismic intensity is defined by spectral acceleration level at 3 to 8.5 Hz frequency. The factors are categorized by 3 levels of intensity with the value of 1, 5 and 30. Assuming the ratio of the spectral acceleration to the peak ground acceleration as 4.0, the human error probability multiplied by the internal value of 0.001 is plotted as in Fig 1.

In the seismic PSA of Kewaunee nuclear power plant, human error probabilities are defined for 3 acceleration levels. Less than 0.12 g, it is the same as that in internal PSA. At the range from 0.12 g to 0.36 g, it increases linearly to the factor of 10 at 0.36 g. At the range larger than 0.36 g, the human error probability is assumed to be 1.0. These values are also plotted in Fig 1.

Human responses during an earthquake were surveyed by the questionnaire method in Japan [1]. It was not for the operator in nuclear power plant, but this report shows that the probability of a human response beyond control can approach to 1.0 under the high seismic intensity.

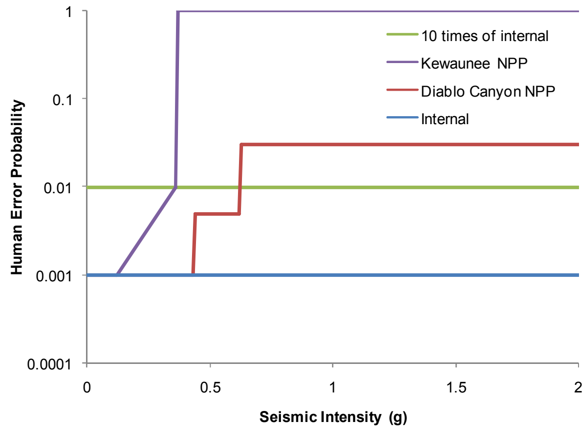

Fig. 1. Human error probability models

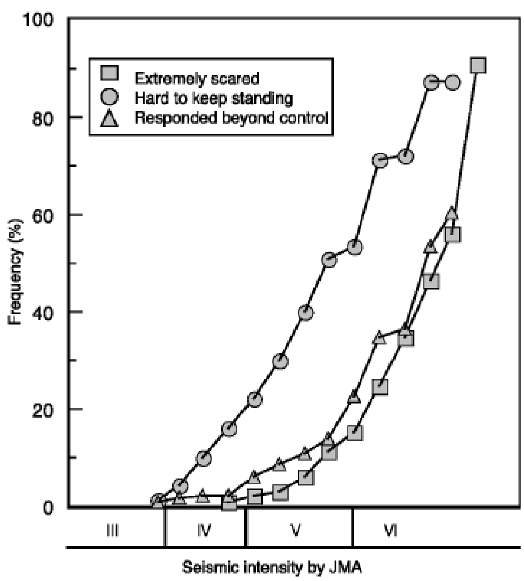

Fig. 2. Human response during earthquake [1]

3. Example Analysis

3.1 Analysis Model

For the example analysis of the nuclear power plant, the seismic PSA model was constructed. In this example, only the Loss of Essential Power (LEP) sequence was modeled because its contribution to the core melt frequency is usually large and it has a human operation component in the fault tree as shown in Fig 3. For the modeling of other components, the fragility curve of a cumulative double lognormal distribution model was used. The parameters of these fragility curves are summarized in Table I.

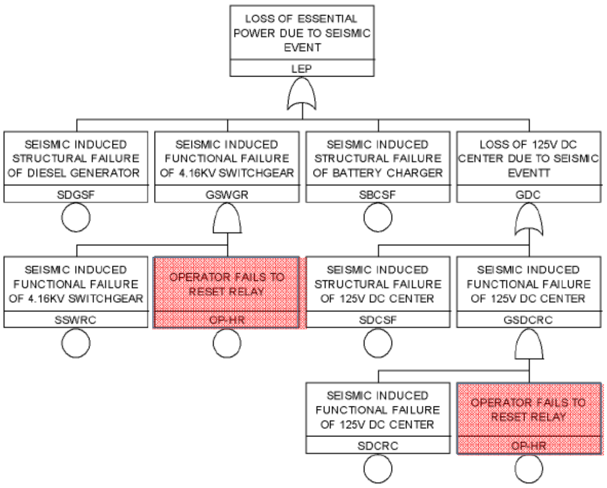

Fig. 3. Example fault tree for the LEP sequence

Table I: Component fragility parameters

Description	Title	A_m	β_R	β_U
Diesel Generator	SDGSF	0.92g	0.30	0.20
4.16kV SWGR	SSWRC	1.33g	0.33	0.29
Battery Charger	SBCSF	1.35g	0.29	0.31
125V DC Control Center (Structure)	SDCSF	1.12g	0.29	0.30
125V DC Control Center (Function)	SDCRC	0.75 g	0.29	0.27

For the seismic PSA analysis, a computer code PRASSE was used to calculate the event frequencies [2]. The human error probabilities of 0.0 and 1.0, were applied in this model to check the lower and upper limit of the core damage frequency. For using the four models represented in previous section, the error factor, which is the ratio of 95% confidence probability to the median, was applied as 5.0. The human error probability larger than 1.0 caused by the positive error factor was prevented by the ceiling of 1.0.

3.2 Analysis Result

Table II shows the results of 6 cases. For each case, the plant level High Confidence of Low Probability of Failure (HCLPF) capacity and the event frequencies of 5%, 50%, 95% and mean probability were calculated. In this model, the recovery by human action reduces core damage frequency by the factor of 2 if it always succeeds. The result using the human error probability used in the internal PSA is almost the same as the result of the lower limit. Even with the 10 times of internal human error probability, the mean frequency was not changed. It is because the failure probability of other equipment by seismic accidents is large enough to hide the random error effect.

For the case of the model used in Diablo Canyon nuclear power plant, the human error probability in the high seismic intensity range was calculated as 0.03. This value also cannot affect to the mean frequency. However for the model used in Kewaunee nuclear power plant, the mean frequency was estimated as the middle between the upper and lower limit.

Table II: Plant level HCLPF and event frequency for the LEP sequence with different human error models

OP-HR Model	HCLPF	5% PF	50% PF	95% PF	Mean PF
0.0	0.376 g	3.01E-06	8.47E-06	1.93E-05	1.04E-05
1.0	0.296 g	7.85E-06	1.74E-05	3.93E-05	1.98E-05
Equal to internal	0.376 g	3.02E-06	8.48E-06	1.93E-05	1.04E-05
10 times of internal	0.372 g	3.05E-06	8.58E-06	1.96E-05	1.05E-05
Diablo Canyon	0.376 g	3.18E-06	8.71E-06	1.97E-05	1.06E-05
Kewaunee	0.323 g	4.31E-06	1.23E-05	3.12E-05	1.48E-05

4. Conclusions

In this study, several human error probability models were compared by example analysis. With an error probability less than 0.1, the damage frequency caused by seismic events is not affected by the human error. However if the human error is assumed to be nearly 1.0 for the high seismic intensity, the damage frequency increases remarkably. Therefore, the further study for the reasonable modeling of a human error is necessary.

ACKNOWLEDGEMENT

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