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Probabilistic Seismic Risk Analysis of a Wolsung NPP Containment Building for Near Fault Ground Motions

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1. Introduction

In this study, a probabilistic seismic risk analysis of the Wolsung NPP containment building was performed by a seismic hazard analysis and a seismic fragility analysis based on the nonlinear dynamic time-history analyses. The conventional seismic fragility analysis of the safety related structures in a NPP have been performed by using the linear elastic analysis results. The probabilistic seismic risk of the containment building was 5.19e-8.

2. Seismic Hazard

The probabilistic seismic hazard analysis (PSHA) was performed for the NPP site. In this study, four seismic source models proposed by the seismologists were used for the seismic hazard analysis. Fig. 1 shows one of the seismic source maps which was used for the evaluation of the seismicity. The ground motion attenuation equation used in this study is developed by using the recorded earthquake data in Korea [1].

$$\ln(Y(PGA(g))) = C_1 + C_2 * M_w + (C_3 + C_4 * M_w) * a\log(R_{epi} + \exp(C_5)) + C_6 * (M_w - 6.0) * (M_w - 6.0) + C_7 * \ln(\min(R, 50)) + C_8(\max(R, 50)) \quad (1)$$

$$R = \sqrt{R_{epi}^2 + 9.8^2} \qquad (Mw \le 6.5)$$

$$= \sqrt{R_{epi}^2 + 9.8^2 * \exp(2.0 * (-1.25 + 0.227 * Mw))} \qquad (Mw > 6.5)$$

where, M_w and R_{epi} denote the earthquake magnitude and the epicentral distance (km), respectively. $C_1 \sim C_8$ are the constants for the attenuation equation. Fig. 2 shows the characteristics of the ground motion attenuation equation according to the earthquake magnitude. Using these PSHA input data, the PSHA was performed for the site.

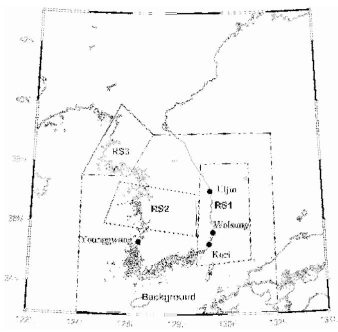

Fig. 1 Example Seismic Source Model for PSHA

3. Seismic Fragility Analysis

3.1 Input Ground Motions

In this study, 30 sets of near-fault ground motion records which have occurred throughout the world were used [2].

Near-fault ground motions are the ground motions that occur near an earthquake fault. In general, the near-fault ground motion records exhibit a distinctive long period pulse like a time history with very high peak velocities. These features are induced by a slip of the earthquake fault. Near-fault ground motions, which have caused much of the damage in recent major earthquakes, can be characterized by a pulse-like motion that exposes a structure to a high input energy at the beginning of a motion.

3.2 Nonlinear Response Analysis

A response spectrum analysis method is generally used for the seismic design of a NPP containment building. In the design stage, an elastic time history analysis is performed to obtain the member stress and floor acceleration. But, in this study, nonlinear inelastic dynamic analyses of the containment building were performed to consider the nonlinear response of a containment building subjected to strong ground motions.

The seismic responses for the input ground motions up to 1.8g PGA (Peak Ground Acceleration) were calculated for the seismic fragility analysis. Fig. 2 shows the maximum displacement response of the containment building at the top according to the PGA of the near fault ground motions.

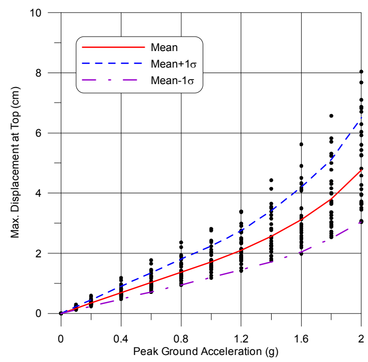

Fig. 2 Maximum top displacement for the near-fault ground motions

3.3 Fragility Calculation

The probability of a failure of a structure P_f at any non-exceedence probability level Q can be obtained from the following equation.

$$P_f(a) = \phi\left(\frac{\ln(S_m(a)/C_m) + \beta_U \phi^{-1}(Q)}{\beta_R}\right) \quad (2)$$

where, $\phi(\cdot)$ is the standard Gaussian cumulative distribution function, a is a peak ground acceleration as a ground motion parameter, $\phi^{-1}(\cdot)$ is the inverse of the standard Gaussian cumulative distribution function, $S_m(a)$ and C_m are the median seismic responses at a given ground acceleration a, and the median seismic capacity, respectively, and β_R and β_U are the lognormal standard deviations of the randomness and uncertainty, respectively.

The median ground acceleration capacity can be obtained from the result of the nonlinear seismic response analyses. For a variate a which follows a log-normal distribution, the median response S_m and the log-normal standard deviation β_a can be expressed by its mean μ_a and the coefficient of a variation δ_a [3].

The top displacement is used as the damage index of the containment building. In this study, the failure of the containment building is defined as when the containment shell reaches an ultimate displacement. The ultimate displacement of the containment building was 7.6cm at the top [4].

Figure 3 shows a set of fragility curves for the failure of the containment shell [5].

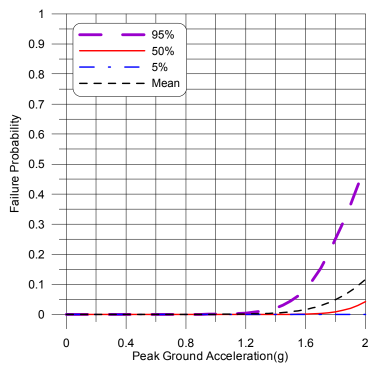

Fig. 3 Fragility curves

4. Probabilistic Seismic Risk

For a nuclear power plant component, a mean probability of the unacceptable performance can be obtained by a convolution of the seismic hazard and fragility curves.

$$P_F = -\int_0^\infty \left(\frac{dH(a)}{da}\right) P_f(a) da \quad (3)$$

Where $H(a)$ is the seismic hazard curve and $P_f(a)$ is the probability of a failure (fragility) for a given ground motion amplitude a, which captures both the response and capacity uncertainties. The seismic risk of the containment building was evaluated for the four seismic hazards. The largest failure frequency for the collapse is about 37 times that of the smallest one. The mean frequency of the collapse is 5.19e-8/year.

5. Conclusion

The probabilistic seismic risk analysis of the Wolsung NPP containment building was estimated based on the nonlinear seismic response and the up to date seismic hazard. It is very important to secure the seismic safety of the containment building for the potential earthquake ground motions which can occur near from the NPP site, since the near-fault ground motion can cause severe damage to the safety related structures and components.

From this study, it is concluded that the containment building has enough safety margin for near fault ground motions. The mean collapse frequency of the containment building is estimated as 5.19e-8/year.

ACKNOWLEDGEMENT

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