Seismic Fragility Analysis of a CANDU Containment Structure for Near-Fault Ground Motions

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1. Introduction

The R. G. 1.60 spectrum [1] used for the seismic design of Korean nuclear power plants provides a generally conservative design basis due to its broad-band nature. A survey on some of the Quaternary fault segments near Korean nuclear power plants is ongoing [2]. It is likely that these faults will be identified as active ones. If the faults are confirmed as active ones, it will be necessary to reevaluate the seismic safety of the nuclear power plants located near these faults. The probability based scenario earthquakes were identified as near-field earthquakes [3].

In general, the near-fault ground motion records exhibit a distinctive long period pulse like time history with very high peak velocities. These features are induced by the 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 the structure to a high input energy at the beginning of the motion. It is necessary to estimate the near-fault ground motion effects on the nuclear power plant structures and components located near the faults.

In this study, the seismic fragility analysis of a CANDU containment structure was performed based on the results of nonlinear dynamic time-history analyses.

2. Fragility Analysis Method

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

$$P_f = \phi\left(\frac{\ln(a/a_m) + \beta_U \phi^{-1}(Q)}{\beta_R}\right) \tag{1}$$

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, a_m is the median ground acceleration capacity, 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 non-linear seismic response analyses. For a variate a which follows a log-normal distribution, the median value a_m and the log-normal standard deviation β_a can be expressed by its mean μ_a and the coefficient of variation δ_a [4].

$$a_m = \frac{\mu_a}{\sqrt{1+\delta_a^2}} \tag{2}$$

$$\beta_a^2 = \ln\left(1+\delta_a^2\right) \tag{3}$$

3. Fragility Analysis of a Containment Structure

3.1 Input Ground Motions

Total number of 30 sets of the near-fault earthquake records were used for the nonlinear time history analyses of the containment structure. Figure 1 shows the acceleration response spectra of the near-fault ground motions.

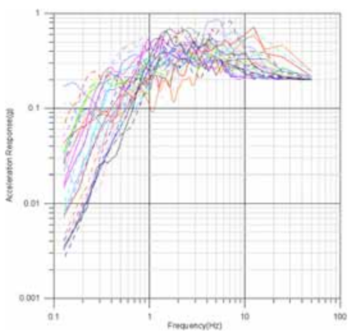


Fig. 2. Acceleration Response Spectra of Near-Fault ground Motions

3.2 Nonlinear Seismic Analyses

The CANDU containment building in Korea, which houses the nuclear reactor and safety related equipments, is a prestressed, post tensioned reinforced concrete structure. The containment consists of a base slab, perimeter wall, ring beam and upper dome. The CANDU containment structure contains the dousing water in an elevated tank around the building dome for a powerful pressure suppression, not like the PWR sprays.

Fig. 2 shows lumped mass model of the containment structure and the hysteretic rule, maximum point oriented model, for the non-linear seismic analyses.

3.3 Failure Modes for Fragility Calculation

In the fragility analysis, it is very important to estimate various failure modes. The ultimate shear stress and bending moment capacity at the lower part of the containment shell were used as the dominant failure modes of the containment structure. This conventional method was based on the linear elastic seismic analysis. In this study, the non-linear seismic time history analyses for the near-fault ground motions were performed to estimate the non-linear behavior of the containment structure for the strong ground motions.

The top displacement is used as the damage index of the containment structure. The damage index of the containment structure is obtained from the results performed by Koh et al. [5]. Koh et al. performed a push over analysis of the containment structure for a static load condition and identified the yielding and ultimate displacement of the containment shell.

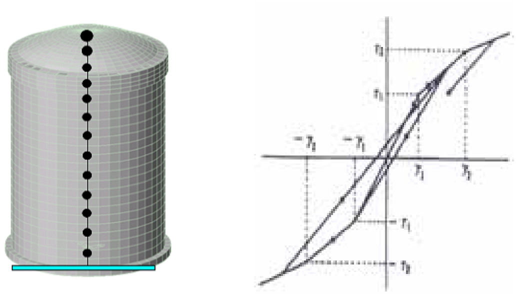


Fig. 2. Lumped Mass Model of Containment Building and Hysteretic Rule for Seismic Analyses

3.4 Fragility Curves for the Containment Structure

Figure 3 shows the fragility curves of the containment structure. Figure 3 (a) is a set of fragility curves for the yielding of the containment shell. The concrete yielding means that a crack occurs in the containment shell. The yielding displacement of the containment structure was 1.31cm at the top [5]. The HCLPF (High Confidence of Low Probability of Failure) is 0.27g for the cracking mode.

Figure 3 (b) is a set of fragility curves for the failure of the containment shell. In this study, the failure of the containment structure is defined as when the containment shell reaches the ultimate displacement. The ultimate displacement of the containment structure was 7.6cm at the top [5]. The HCLPF (High Confidence of Low Probability of Failure) is 1.45g for the cracking mode.

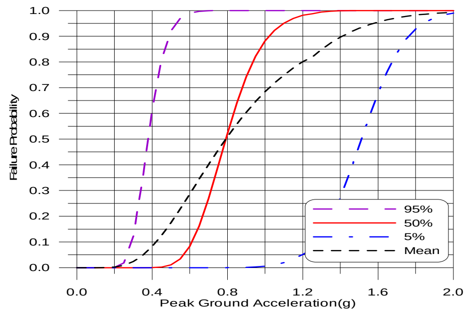
4. Conclusion

In this study, the seismic fragility of the CANDU containment structure was performed for the near-fault ground motions. The displacement based seismic fragility analysis was performed to estimate the seismic margin of the containment building when considering the nonlinear dynamic behavior.

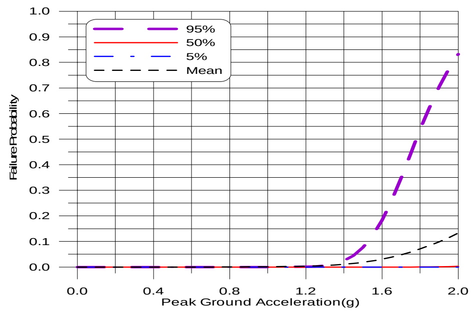
The HCLPF (High Confidence of Low Probability of Failure) is 0.27g and 1.45g for the cracking and failure mode, respectively.

The displacement based seismic fragility analysis method is suitable for considering the non-linear hysteretic seismic behavior of a concrete containment structure.

For the exact evaluation of the seismic fragility of a concrete structure, it is necessary to evaluate the ultimate displacement capacity and its variation based on the seismic tests and analyses results.



(a) Crack



(b) Failure

Fig. 3. Fragility Curves of the Containment Structure

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