Seismic Fragility Evaluation for Main Steam Line of Seismically Isolated APR1400 NPP

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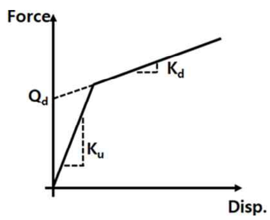
1. Introduction

In this study, seismic fragility analysis was performed with seismically isolated APR1400 nuclear power plants and main steam line. The main steam line is the interface pipe connecting the base-isolated auxiliary building and the turbine building. The failure mode for seismic fragility analysis was defined as leak-through crack. Leak-through crack point was quantified as a damage index through experimental and numerical analysis results and used as a failure criterion for seismic fragility analysis. Seismic fragility curves were suggested based on PGA and Relative displacement between isolated-non isolated building.

2. Input motion

The crossover piping system which is connecting isolated structures and non-isolated structure could be damaged by relative displacement. Therefore, this paper conducted seismic response analysis of isolated structure and relative displacement was calculated. A seismic responses of isolated structure is dominant by isolatory behavior, therfore an upper structure was simplified to a point-mass with 2 degree of freedom in two directions (x, y). A seismic response analyses were performed using the Opensees program[1].

The target NPP is APR1400 which is a Korean standard NPP. It was assumed that the isolation system was applied to nuclear island which is the foundation of the containment and auxiliary buildings. It was assumed that the isolation system has bilinear characteristics as shown in Fig. 1. The isolation system had an effective period of 2.5 sec and a damping ratio of 20% for a PGA of 0.5 g as design levels.



Parameters	Values
K_{eff}	2939.72 MN/m
K_u	19620.51 MN/m
K_d	1962.05 MN/m
Q_d	329.43 Mn

Fig. 1. Mechanical properties of the isolation system

Input earthquakes were modified to satisfy the response spectrum of Reg. Guide 1.60 using the RSPmatch program, with the seismic records provided by the Pacific Earthquake Engineering Research Center (PEER). The input earthquake was composed of a total of 30 sets from EQ1 to EQ30 in horizontal bi-directions (x, y), and artificial earthquakes were generated in units of 0.5 g from 1.0 g to 3.0 g with PGA level. Fig. 3 shows a response spectrum for each direction of the generated input earthquake.

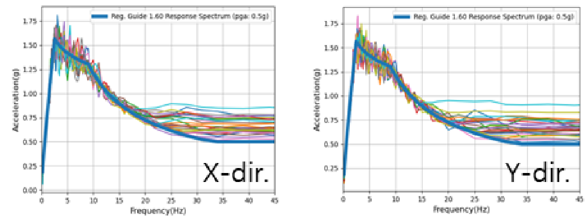


Fig. 2. Response spectrums

3. Seismic Response Analysis

In this paper, the crossover piping system is a main steam line with multiply supported and arranged by an auxiliary building on the isolated APR1400 NPP nuclear island and a turbine building which is a non-isolated structure. A finite element model of the piping system is modeled using ABAQUS 6.14[2]. Fig. 3 shows the crossover piping system which is the main steam line of APR1400 NPP. The material of pipe is assumed to be carbon steel SA106 and Grade B of ASME B36.10M, which are commonly used in NPPs.

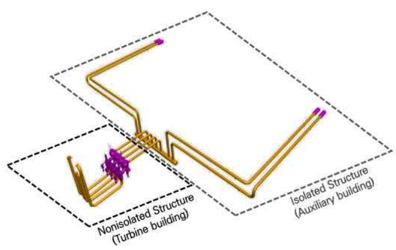


Fig. 3. Main steam line of isolated APR1400 NPP

The finite element model of connection pipes was modeled using the shell element, so that the effect of elliptical deformation of pipes could be considered. Nonlinear seismic response analysis was performed by the direct integration method while applying pressure inside the crossover piping system and maintaining the stress caused by internal pressure. In consideration of the reliability and convergence of the analysis, the input earthquake was used as input displacement, and the stress and strain in the circumferential direction were obtained from elbow's crown in Fig. 4.

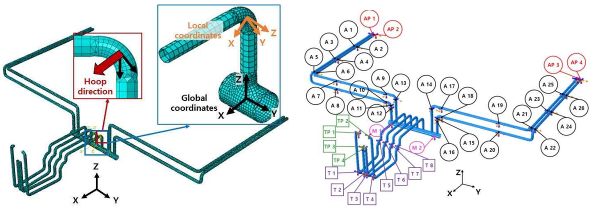


Fig. 4. Finite element model of MS line

4. Failure Criteria

The actual failure to the pipe observed by the test is leakage-through cracks. Therefore, in this paper, leakage-through cracks, which can cause serious damage such as loss of function of pipes and radiation leakage, were defined as failure. In general, failure to pipe elements under repeated large dynamic loading such as a seismic load is LCF(low cycle fatigue failure)[3]. In a previous study, the failure tests by in-plane cyclic loading were conducted on the elbow of carbon steel pipe. As a result, failure of pipe by LCF could be quantificated by using the damage index. Therefore, in this paper, damage index was used for failure criteria of seismic fragility analysis was damage index for leakage [4], It is a 35.25.

5. Performance Evaluation

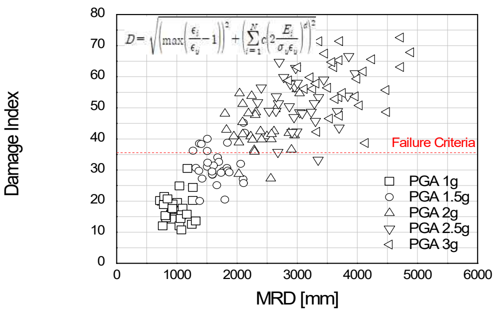


Fig. 5. Damage index

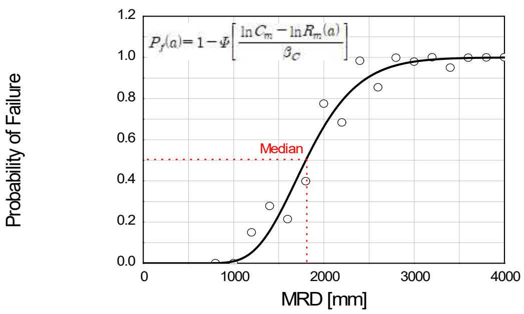


Fig. 6. Fragility curve

Fig. 5 shows the damage index distribution. When MRD is used as a seismic intensity, the maximum response is dispersed according to the size of MRD of each input ground motion as shown in Fig 5. The larger the size of PGA, the wider the distribution of MRD and damage index. In particular, even if the size of the PGA is small, the size of the MRD and the value of the damage index may be larger. For the design of isolation system of NPP, it is necessary to calculate the probability of damage of crossover piping system. Here, MRD is the maximum relative displacements between isolation-non isolation building. Fig. 6 shows the fragility curve prepared using MRD as seismic intensity. The MRD with a 5% probability of damage is 1156 mm, and the median of the seismic fragility curve is 1800 mm.

3. Conclusions

The probability of failure to the seismically isolated pipe could be one of the considerations when designing the seismic isolator of a nuclear power plant. The results of this study can be useful for the design of isolators.
This paper performed the seismic fragility analysis targeted with the main steam line, a crossover piping system of a Korea standard nuclear power plant applied with isolation system. For the accurate seismic fragility analysis, the damage index for leakage-through cracks, which is an Actual failure, was used as the fragility criterion. As a result of nonlinear seismic response analysis, according to the size of MRD of each input ground motion, the damage indices are dispersed. The larger the size of the PGA, the wider the distribution of MRD and damage index. Even if the size of the PGA is small, the size of the MRD and the value of the damage index can be larger. It is necessary to calculate the probability of damage of crossover piping system for the design of isolation system of NPP.

Acknowledgment

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