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Fragility Assessment of Rerouted Piping Systems in Seismically Isolated Nuclear Power Plant

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1. Introduction

Recently, to design the nuclear power plants (NPPs) more efficiently and safely against the strong seismic load, many researchers focus on the seismic isolation system. For the adoption of seismic isolation system to the NPPs, the seismic performance of isolation devices, structures, and components should be guaranteed firstly. Hence, some researches were performed to determine the seismic performance of such items [1,2]. For the interface piping system between isolated structure and non-isolated structure, the seismic capacity should be carefully estimated since that the required displacement absorption capacity will be increased significantly by the adoption of the seismic isolation system. A rerouting of piping systems can be an adequate alternative to avoid the excessive strain response and functional failures of interfacing piping systems. Hence, in this study, we analyzed the effects of rerouted piping systems and evaluated the probabilistic performance of the rerouted interface piping system. The detailed procedure and main results are summarized in next section.

2. Methods and Results

2.1 Effect of Rerouting of Pipings

A reroute of the piping system can be adding an adequate flexibility to absorb the large seismic anchor motion displacements. However, the performance of rerouted piping systems are not evaluated quantitatively yet. Therefore, we adopted a simple example piping system, and estimated the quantitative performance of the rerouting of pipings. The example piping and rerouted pipings are depicted in Figure 1.

The pipes are designed by the ASME " Boiler & Pressure Vessel Code" Section III, IX. Internal pressures of pipes are 19.0 MPa. Each of the maximum strain response under the seismic loading of PGA 1.0g is estimated and illustrated in Figure 2. In this figure, it can be seen that the maximum strain response decrease rapidly as the rerouted lengths of pipes are increased. Also the seismic performances of the pipes are increased as the complexity of rerouting system is increased.

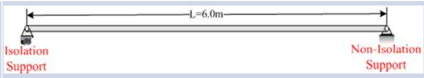
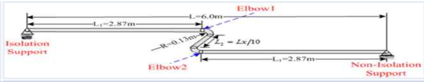
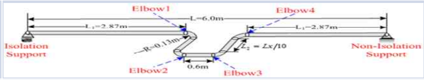
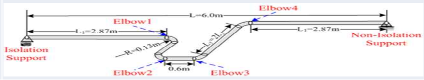
Case	Pipeline Configuration	L_2 (m)
Base		-
1		0.6 1.2 2.0 3.0
2		0.6 1.2 2.0 3.0
3		0.6 1.2 2.0 3.0

Fig. 1. An example pipe and rerouted pipes.

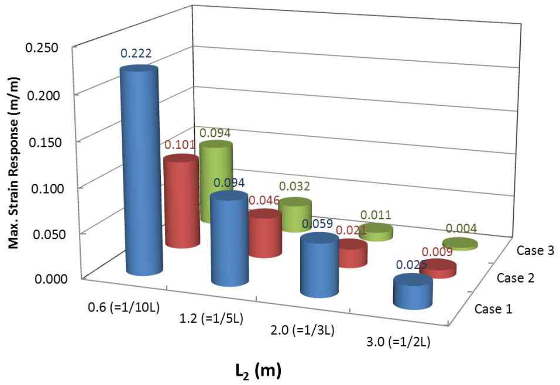


Fig. 2. Maximum strain responses of rerouted pipes

2.2 Probabilistic Performance Evaluation Method

The target performance goal of umbilical lines under EDB loading is greater than 90% confidence that each type of safety-related umbilical line remains functional for the CHS displacement. Also, qualification of the reliability of umbilical lines by numerical analysis will require development of fragility functions that plot probability of failure against an appropriate seismic demand (e.g., lateral displacement for displacement-sensitive umbilical lines). For the probabilistic performance evaluation of umbilical lines under EDB loading, we proposed the appropriate procedure which was demonstrated in Fig. 3. To performing the seismic analysis and estimate the displacement response, we modeled the target NPP, APR1400, and isolation system. The target design frequency of isolated nuclear island is determined to 0.5 Hz. Fig. 4 depicts the auxiliary building structure model of APR1400 NPP.

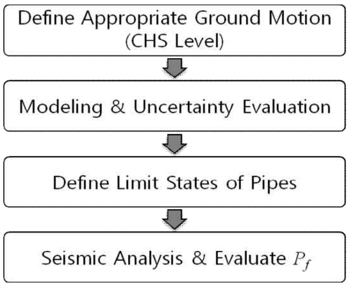


Fig. 3. Procedure to evaluate the probabilistic performance.

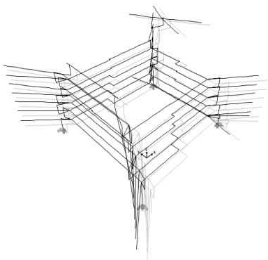


Fig. 4. Modeling of auxiliary building structure.

To apply the performance evaluation method and estimate the effect of rerouted piping systems, we selected the example piping system which was demonstrated in Fig. 5. We assumed that one end of it is attached at the non-isolated turbine building, and another end of it is fixed at the isolated auxiliary building.

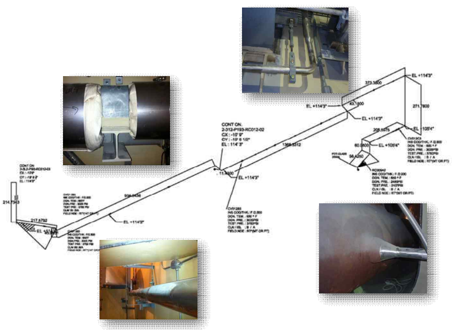


Fig. 5. Iso-drawing and pictures of the example piping system.

The limit state of piping system is determined to strain level of 0.31 based on the test results by Chitoshi et al.. They carried out the opening & closing bending tests for 21 specimens and reported the critical strains for each failure mode. To perform the uncertainty analysis, we assumed that the probabilistic distribution of response will follow the lognormal distribution, and its lognormal standard distribution will be 0.10. With this assumption, we could illustrate the PDF w.r.t the strain level. From this PDF, we could figure out that the confidence of the example umbilical line is 56.5%, which is smaller than the performance goal, 90%.

Therefore, we adopted the reroute of the pipe to decrease the strain response of the target piping system. From the fragility analysis, the median capacity and lognormal distribution of the original piping system is evaluated as Figure 6. However, as the reroute lengths of pipes are increased, we found that the median displacement performance of the target piping system is also increased drastically and the performance goal in NUREG draft can be fulfilled.

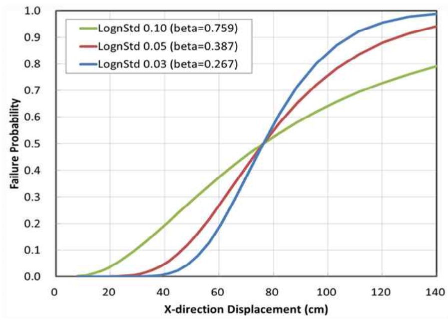


Fig. 7. Fragility curves w.r.t. assumed distributions.

3. Conclusions

For the interface piping system, the seismic capacity should be carefully estimated since that the required displacement absorption capacity will be increased significantly by the adoption of the seismic isolation system. A reroute of the piping system can be adding an adequate flexibility to absorb the large seismic anchor motion displacements. In this study, we analyzed the effects of rerouted piping systems and evaluated the probabilistic performance of the rerouted interface piping system. For EDB level earthquakes, the target performance goal can be fulfilled with the adoption of the reroute of the piping system even though the seismic performance of the original piping system is relatively poor.

Acknowledgement

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