Seismic Fragility Evaluation of NPP Components Based on the Shaking Table Test Data

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1. Introduction

After the Gyeongju earthquake occurred in 2016, concerns about the seismic safety of the operating nuclear power plants have risen significantly. The earthquake records obtained from the Gyeongju and Pohang earthquake which are representative strong earthquake occurred in our country shows typical characteristics of high frequency earthquake ground motion [1].

The fragility has been used as a measure of the seismic safety of a nuclear power plant (NPP). The seismic fragility and corresponding HCLPF (High Confidence Low Probability of Failure) analysis have been performed by using the seismic qualification data. The seismic qualification test is basically up to the design earthquake level. However, there are differences between the seismic qualification level and the ultimate capacity of components.

In this study, the seismic fragility analysis method is proposed for the NPP components which are tested up to the failure level. Example fragility analysis was performed for the tested components.

2. Shaking table test of electrical components

2.1. Component selection for shaking table test

The earthquake response of equipment is very much related to the fundamental frequency of the equipment. High frequency component can be significantly affected by the high frequency ground motions. The high frequency ground motion affects the functional failure of the electrical component due to the malfunction of the relays. In this study, the electrical components which are sensitive to the high frequency earthquake and affect the risk of NPP are selected for the fragility tests [2]. Figure 1 shows the test setup of an electrical component for the shaking table test.

Fig. 1. Test setup of components for shaking table test

2.2. Test response spectrum

Three kinds of input motions, US NRC R.G. 1.60 [3] compatible motion, UHS (Uniform Hazard Spectrum) compatible motion [4], and broad band test motion developed for the test [5], were used for the shaking table test. Figure 2 shows the comparison of the target response spectrum and test response spectrum.

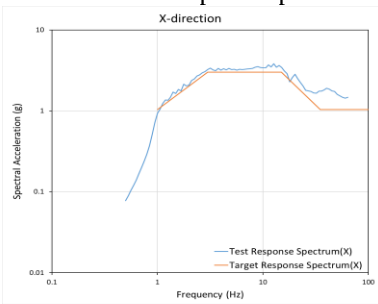


Fig. 1 Comparison of target and test response spectrum for shaking table tests

3. Median capacity of components

The fragility test was performed from the design earthquake level up to the failure level. The interval of the input motion level was determined based on the typical fragility curves for the components. The input motion was increased by 10% of the failure probability of the fragility from the previous level.

Based on the test response spectrum at the failure level, the median seismic capacity of the tested components was evaluated.

4. Seismic fragility evaluation

4.1. Seismic fragility analysis for components qualified by test

The median capacity, A_m, of a component qualified by test can be obtained from the following equation [6].

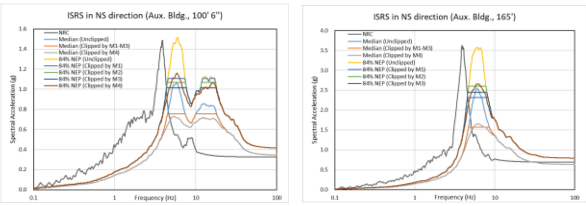
$$A_m = \frac{TRS_C}{RRS_C} \cdot F_D \cdot F_{RS} \cdot PGA \quad (1)$$

Where, TRS_C and RRS_C are Test Response Spectrum Capacity and Required Response Spectrum Demand, respectively. F_D, F_{RS}, and PGA are broad frequency input spectrum capacity factor and structure response factor, peak ground acceleration, respectively.

The capacity margin of a component can be obtained from the ratio of TRS_C and RRS_C. TRS_C was evaluated from the test results, and RRS_C was evaluated by performing probabilistic response analysis of a NPP structure.

4.2. Required response spectrum

The in-structure response spectrum (ISRS) was developed by probabilistic response analysis of a NPP structure considering the variation of structure stiffness and damping [7]. The developed ISRS was used as the required response spectrum for the seismic fragility analysis of the components. Figure 2 shows the developed probabilistic in-structure response spectrum according to the elevation in the building.



(a) El. 100'6" (b) El. 165'

Fig. 2. Probabilistic in-structure response spectra for Aux. building

4.3. Fragility analysis results

Table 1 shows the fragility analysis results. Most of the electrical components show robust seismic capacity. As shown in this table, the natural frequency of the components is much higher than that of the general electrical component used in old plants. The high-frequency earthquake does not affect the seismic fragility of electrical components.

Figure 3 shows an example fragility curve of a component based on the fragility test result.

Table 1: Example fragility analysis results

Component	Freq. (Hz)	A_m(g)	β_R	β_U
Battery Charger	29.0	2.17	0.33	0.42
Inverter	21.0	1.60	0.33	0.40
Switchgear	17.5	1.35	0.33	0.50
Motor Control Center	21.2	1.45	0.49	0.26

5. Conclusion

A seismic fragility analysis has been performed to evaluate the seismic safety of structure, system and component. The HCLPF capacity from fragility analysis has been used as a safety measure of SSCs in NPP for beyond design earthquake. The seismic fragility analysis of equipment has been performed based on the seismic qualification data.

There is a difference between the actual capacity of a component and the estimated capacity based on the seismic qualification data. For the reliable seismic fragility analysis, it is necessary to estimate the realistic capacity of electrical components by fragility test. And the median ultimate capacity of an electrical components should be evaluated based on enough number of test data.

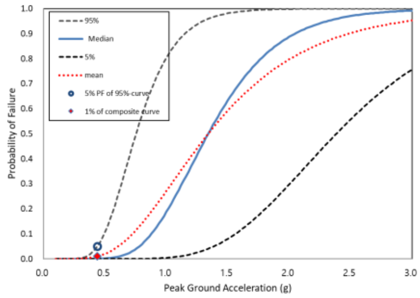


Fig. 3. Example seismic fragility curves of a tested component

Acknowledgment

This work was supported by the KETEP (Korea Institute of Energy Technology Evaluation and Planning) grant funded by the Korea government (MOTIE) (No. 20201510100010)

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