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Assessment of the Effect of Structure Degradation on In-structure Response and Seismic Fragility of Cabinet-type Nuclear Power Plant Equipment

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1. Introduction

Due to changes in the seismic environment in South Korea, such as the Gyeongju earthquake in 2016 and the Pohang earthquake in 2017, public awareness of the importance of nuclear power plant safety is growing. In particular, to accurately evaluate the seismic safety of an operating nuclear power plant, it is necessary to evaluate seismic performance taking into account the age-related degradation of major structures and equipment. The aging of operating nuclear power plants causes degradation over time due to long-term operation, resulting in degradation of the soundness of structures and equipment and the occurrence of defects [1].

A representative method for deriving the seismic performance of nuclear power plant structures and equipment is the seismic fragility assessment method. Through seismic fragility assessment, the seismic performance of major SSC is probabilistically derived, and the results are used as input data for the level 1 seismic probabilistic safety assessment (SPSA) to derive the core damage frequency.

The main factors in assessing the seismic fragility of equipment include the structure's response, the equipment's response, and the equipment's capacity. Degradation of a structure changes its dynamic characteristics and thus affects in-structure response. Degradation of equipment can change its dynamic characteristics, affecting its response or directly affecting its capacity.

In this study, we evaluate the effect of structural degradation on the seismic fragility of cabinet-type equipment such as motor control center (MCC). The in-structural responses due to changes in dynamic characteristics that occur as the structure degrades are derived, and the effect on the seismic capacity of the equipment is evaluated.

2. Methods and Results

This section describes the basic variables of the separation of variable (SOV) method for seismic fragility assessment, the derivation of internal structural responses spectrum considering structural degradation, and the evaluation of equipment fragility of the motor control center (MCC).

2.1 SOV method for seismic fragility

The SOV method is a representative methodology for developing seismic fragility curves. It derives seismic capacity by evaluating the median safety factors and variability of the factors affecting the response and capacity of structures and equipment. The seismic fragility curve is defined as a double lognormal distribution and can be determined by the median capacity (A_m) and variability related to uncertainty and randomness (β_U, and β_R).

For the equipment-based seismic fragility assessment, the median capacity (A_m) is calculated using the following equation.

$$A_m = \frac{TRS_C}{RRS_C} F_{RS} PGA_{RE} \quad (1)$$

where TRSc is the test response spectrum representing the equipment capacity, RRSc is the required response spectrum representing the equipment demand, F_{RS} is the structure response factor, and PGA_{RE} means the PGA level of the reference earthquake.

2.2 In-structure Response Considering Degradation

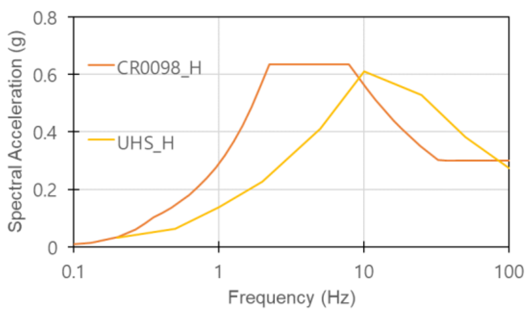
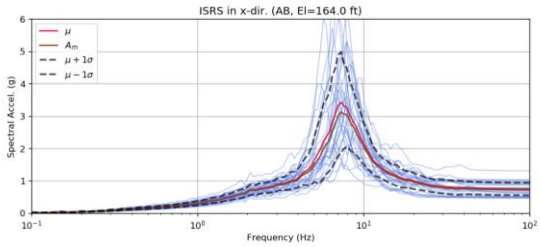


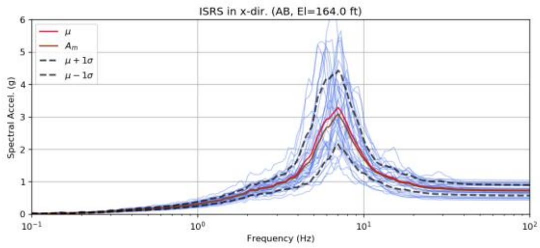
Fig. 1. NUREG/CR0098 and uniform hazard spectrum (UHS) for Uljin site

The internal responses of the structure are derived by considering the structural degradation. The auxiliary building of a representative domestic nuclear power plant is selected as the target structure, and the responses on the floor where the motor control center is located are derived. It is assumed that the stiffness of the structural components changes according to the level of structural degradation, and the responses are derived by changing the stiffness to a somewhat excessive degree in order to identify the overall trend according to the degradation.

Each input ground motion set is generated using the NUREG/CR0098 [4] spectrum and the Uljin site's uniform hazard spectrum (UHS) as the target spectrum (Fig. 1). The results of deriving the in-structure response spectrum (ISRS) of the initial structure condition and the structure with 20% stiffness reduction due to deterioration using the CR0098 and UHS input ground motion are shown in Fig. 2 and 3, respectively.

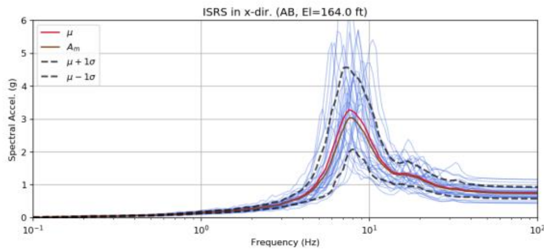


(a)

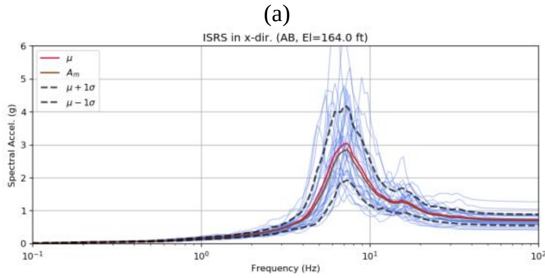


(b)

Fig. 2. In-structure response spectrum at h = 164 ft with (a) 0% and (b) 20% stiffness reduction using CR0098 spectrum



(a)



(b)

Fig. 3. In-structure response spectrum at h = 164 ft with (a) 0% and (b) 20% stiffness reduction using UHS

2.3 Fragility Assessment of MCC

The fragility assessment of MCC is performed using ISRS considering the degradation derived above. High confidence of low probability of failure (HCLPF), which can represent the seismic capacity of the equipment, is summarized according to the degree of degradation (Fig. 4). It is found that the decrease in stiffness due to the degradation of the structure can have a positive effect on the seismic capacity of the equipment. In addition, it is confirmed that the effect of degradation can vary depending on the characteristics of the input earthquake.

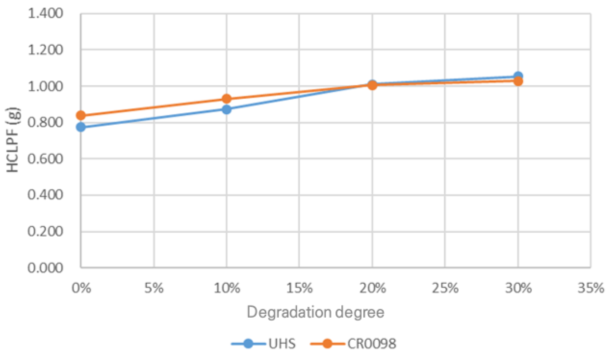


Fig. 4. HCLPF of MCC in accordance with the change in degradation level

3. Conclusions

In this study, the effect of NPP structure degradation on the seismic capacity of MCC is investigated. The internal responses of the structure are derived by assuming that the structural degradation causes a change in the stiffness of the structural elements. It is confirmed that the degradation condition may reduce the structural response and have a positive effect on the seismic performance of the equipment depending on the change in the dynamic characteristics of the structure. However, since these results are limited to specific structures and equipment, the results may vary depending on the target structure and equipment, so it is judged that additional research is necessary in the future.

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