Investigation of Existing Researches for Seismic Fragility Assessment of Fuel Assembly in NPPs

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1. Introduction

The seismic safety of NPP(Nuclear Power Plants) is regarded as an important issue. After the Fukushima Daiichi nuclear accident in Japan (2011), as the earthquake consecutively occurred in Gyeongju (2016) and Pohang (2017) in South Korea, the concerns about earthquake has increased. To probabilistically evaluate the structural damage and risks caused by earthquake, the seismic fragility analysis, one of the major components of the PSA (Probabilistic Safety Assessment), is performed. The fragility analysis for various SSC (Structures, Systems and Components) of NPP was conducted, but for the FA (Fuel Assembly) isn't done yet. The FA is directly related to safety because it contains nuclear fuel in which fission occurs. Therefore, it is necessary to develop the methodology for evaluating seismic fragility of fuel assembly.

2. Review of Existing Researches

To develop the methodology for fragility analysis, the existing researches of the FA, RVIs (Reactor Vessel Internals) and the control rod insertion were investigated. And these researches are summarized in this section.

2.1 Relevant Failure Modes

In general, the failure modes of FA is determined based on the failure of reactor trip and FASG (Fuel Assembly Spacer Grid). Manuel et al. [1] classified the failure mode focusing on the reactor trip. When the reactor trip is occured, all control rod have to be fully inserted into the reactor core within required time. From this perspective, the classified failure modes are as follows:

- Excessive deformation of the CRDM (Control Rod Drive Mechanism)
- Excessive relative displacement of the RVIs
- Excessive deformation of the FA

The failure modes listed above are illustrated in Fig. 1. These failure modes are related to permanent deformation, and it can also be defined for other criteria.

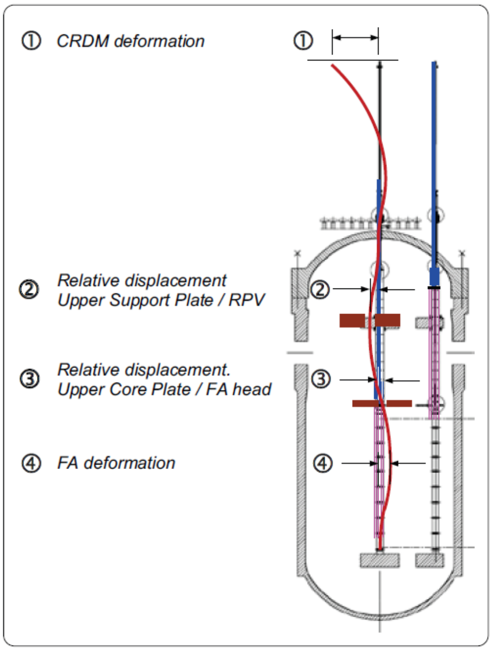

Fig. 1. Potential failure modes of FA related to permanent deformation [1]

2.2 Seismic Analysis of FA and RVIs

First, researches on structural integrity evaluation conducted to secure seismic safety of FA and RVIs supporting, guiding and protecting the reactor core were reviewed.

It is necessary to develop the proper analysis model to obtain a sufficiently accurate structural response. Jhung [2] developed a method for the dynamic analysis of reactor core. In this research, the accurate structural response of FA is obtained from using these models; simplified model, lumped model and detailed model. The analysis are performed under the condition of OBE and SSE. And the structural integrity of FA is evaluated through the dynamic responses such as FA shear force, bending moment, axial force and displacement and FASG impact load. Choi et al. [3] employed the detailed 3-D model to the seismic analysis in order to obtain the reliable dynamic response. In order to reduce the computation time for the detailed model the model reduction method is used. Also to consider the dynamic response when the RVIs is immersed in the coolant, the FSI effect is used. As a results, the structural integrity of RVIs is evaluated by seismic analysis.

2.3 Evaluation of Control Rod Insertion

Kansai Electric Power Company [4] performed the evaluation of control rod insertion. When the shutdown of the reactor occurred by an earthquake, the time of the control rod to be inserted into the core to the point of 80% is evaluated in two method; response magnification method and detailed analysis method. The response magnification method needs existing results. Because the insertion time is calculated by the ratio of the response acceleration between previous reference earthquake and new reference earthquake in this method. In the detailed analysis method, the insertion time is extracted by calculating the dead weight of the control rod cluster and the resistance force generated during the fall. From these methods, the control rod insertion time during the earthquake is calculated. And the safety margin of the evaluation criteria for insertion time is also discussed in this research.

2.4 Fragility analysis of FA and RVIs

Lastly, the researches performed the fragility analysis of FA and RVIs are reviewed. Manuel et al. [1] presented the probabilistic seismic hazard analysis for Gösgen NPP of Swiss. In this research, the preliminary hazard data generated by Latin-Hypercube Sampling scheme is used, and the HCLPF (High Confidence of Low Probability of Failure) capacity of reactor trip are estimated by two approaches; CDFM (Conservative Deterministic Failure Margin) and fragility analysis by separation of variables. In the CDFM method, the HCLPF capacity of the FASG and the CRDM is estimated. These are related to the failure mode ④ and ① of Fig. 1 respectively. And through the separation of variables approach, the fragility of RVIs, including FASG, and CRDM is determined and also the HCLPF capacity is estimated. These are related to all failure modes in Fig.1. Manuel et al. [5] conducted the additional research that extends the previous conclusions. In this research, the statistical analysis is performed for the limited criteria related to permanent deformation and impact force. The variability parameter of the impact force is quantified and the relation between the permanent deformation level of FASG and the cumulative variability of the seismic capacity is presented.

3. Conclusions

By referring to above researches, it is expected that a methodology for evaluating the seismic fragility of fuel assembly of NPP in Korea can be developed.

To analyze the fragility, the failure modes should be defined first, for failure of reactor trip and FASG or for other perspectives. And, by the researches for dynamic analysis of FA and RVIs, the responses related to the failure mode can be obtained. Also, these responses can be used to the evaluation of control rod insertion and to obtain the reliable results. Consequentially, through these researches, it is expected that the fragility analysis can be performed with reference to the case of the Gösgen NPP.

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