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A Study on the Effect of Nonlinear Response of Containment Building on Floor Response Spectrum

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1. Introduction

The floor response spectrum (FRS) has been used to design the equipments in nuclear power plants. Because the seismic safety of equipments may be important to successful operation for the critical facilities such as the nuclear power plants (NPPs).

In the Diablo Canyon Power Plant seismic probabilistic risk assessment (SPRA), the median and uncertainty of structural response factor was assumed without performing the nonlinear analysis for the seismic fragility of equipments. But assuming the nonlinear behavior of structure may lead to unrealistic and unreliable conclusions.

The response of equipment mounted on structures which are subjected to dynamic excitation has received much attention in previous research [1]. If the input earthquake is greater than the SSE (safety shutdown earthquake) level of NPPs, the inelastic deformations of the structure may be occurred. In this case, the nonlinear behavior of the structure will affect the response of equipments.

Therefore, it is needed that the factors influencing floor response spectrum is identified for accurately evaluating the seismic capacity of equipments and the important parameters for the seismic fragility should be defined among the parameters by performing a quantitative assessment.

2. Parameters subjected to equipment response under the nonlinear behavior of structure

From the results of Robert et. al.[2], it was reported that the input spectrum, hysteretic model of structure elements, location of equipments and structure damping have effect on the response of equipments under nonlinear behavior of structure.

The FRS can be changed by the spectrum shape of input motions. The hysteresis model for structural elements and the damping for the structure are closely related with the energy absorption of structure. The pinching effect was considered for identifying FRS by the hysteresis model. The FRS of structure changes generally according to the structural damping. From the TR 103959[3], the damping of containment building for elastic and beyond yield region was defined 5% and 10%, respectively.

From this point of view, the parameters in this study were selected as shown in table I.

Table I: Parameters for the analysis

Input spectrums	NRC, UHS
Hysteresis model	Pinching effect
Structural damping	5%, 10%

3. Example model and input motion

3.1 Analytical model

For the structure analysis, containment building (APR1000) was modeled by lumped mass as shown in figure 1. The fundamental frequency of this building is to 4.56Hz.

The shear wall of containment building behaves nonlinear under the strong earthquake. In this study, the hysteretic model of OpenSEES (Open System for Earthquake Engineering Simulation) [4] was used for considering the damage of shear wall while the force-displacement relationship of dome is assumed as linear elastic as shown in figure 1.

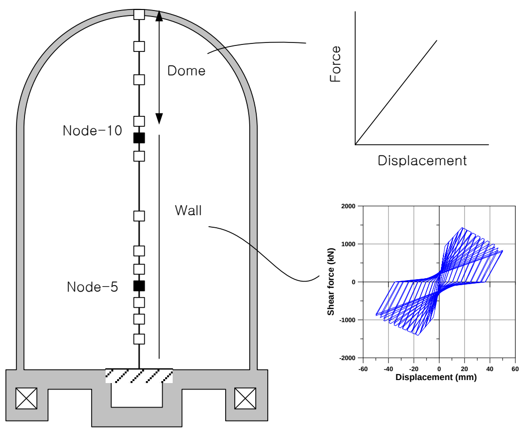


Fig. 1. Containment building model

The regenerative heat exchanger and polar crane are selected for identifying change of the floor response spectrum of containment building according to the frequency of equipments and the elevation level of that. The fundamental frequency for the regenerative heat exchanger and polar crane is 33Hz and 2.6Hz, respectively. The height of two equipments is 14.93m and 52.42m, respectively.

3.2 Input motion

In this study, two input motion was used for analyzing the change of FRS by the spectrum shape. The spectrum proposed by NRC Reg. guide 1.6 was generally used for evaluating the seismic safety of NPPs. An artificial seismic wave based on site specific Uniform Hazard Spectrum (UHS) for the Korean NPP was used.

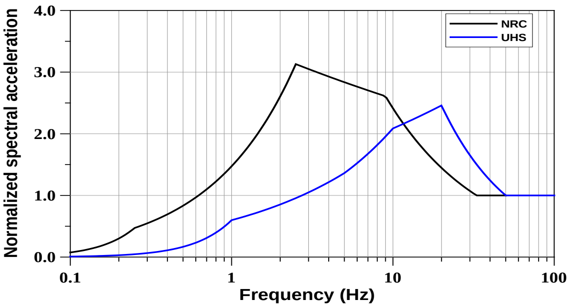
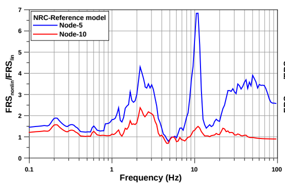


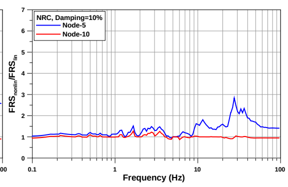
Fig. 2. Input spectrums for the seismic response analysis

4. Comparison of floor response spectrums ratio by structural nonlinearity

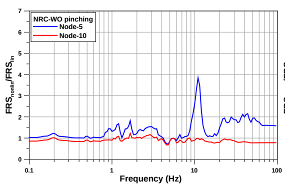
The nonlinear analysis and linear analysis were performed for comparing the change of FRS by the nonlinear behavior of example model. The floor response spectrum ratio (FRSR) was obtained by normalizing the FRS from nonlinear analysis by the FRS from linear analysis.



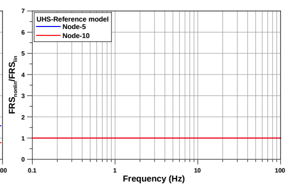
(a) Reference model



(b) Damping=10%



(b) Without pinching



(d) UHS motion

Fig. 3. FRSR for the PGA of 1.0g

For identifying the increase/decrease of FRS by the nonlinear behavior of containment building, the peak ground acceleration (PGA) of 1.0g was used as shown in figure 3. The damping of reference model is 5% and the hysteresis model considering a pinching effect was used for the reference model. The FRS at the node-5 and node 10 was plotted considering the level of two equipments. For the node-5, the FRSR below 1 Hz was similar to the unity while the FRSR over 20 Hz was higher than the unity. For the node-10, the FRSR over the 10Hz was lower than the unity. Since the FRS of lower location was greatly affected by the higher mode due to the nonlinear behavior of structure, it was represented that the FRSR of node-5 was increased near the 10Hz.

A stiffness of structures will be decreased by nonlinear behavior of structure. As a result, the dominant frequency of FRS for nonlinear response was shifted to the low frequency. Therefore it was showed that the FRSR of reference model at 2Hz was about 4.

The energy dissipation capacity of structure is closely related to the structural damping and the hysteresis model. Therefore the increase of damping and hysteresis area caused the decrease of FRS.

It was represented that The FRSR for the UHS input motion was the unity because the example model behaves linear for the UHS motion.

5. Conclusions

When the earthquake exceeds the SSE, the structure of NPPs can be damaged. The nonlinear behavior of containment building causes the change of the FRS.

Although the maximum acceleration of low floor is lower than that of high floor, the FRS of low floor has a significant effect on the nonlinear response of structure. Therefore, it was recommended that the seismic capacity for the equipments located on the low floor was reviewed by performing the nonlinear analysis considering the uncertainty for the hysteresis model and the structural damping instead of the linear analysis assuming the nonlinear behavior.

Acknowledgement

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