Seismic Analysis of Nuclear Power Plant Structures to High-frequency Earthquakes Considering Crack Effects

Jae-Wook Jung [a*], Jeong-Gon Ha [a], In-Kil Choi [a]
[a]*Structural Safety & Prognosis Research Division, Korea Atomic Energy Research Institute, 111, Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon, 34057, South Korea*
[*]*Corresponding author: jaewook1987@kaeri.re.kr*

1. Introduction

In September 2016, an earthquake with a magnitude of 5.8 occurred in Gyeongju, South Korea, and the Wolseong nuclear power plant located near the epicenter was manually stopped. In particular, it was found that the high-frequency components of the earthquake exceeded the Regulatory Guide 1.60 [1] design spectrum proposed by the US NRC used in the design of the Korean nuclear power plant (NPP). Accordingly, securing safety against high-frequency earthquakes in operating nuclear power plants has emerged as an urgent problem. In addition, the recently published technical report by EPRI [2] suggests the use of an analysis model representing the extent of cracks for calculating the seismic demand for structure seismic fragility evaluation. Therefore, seismic response analysis considering the effects of cracks as well as high-frequency characteristics is required. In this study, the seismic response analyses considering crack and high-frequency components are performed on a Korean standard nuclear power plant, and its effect is evaluated.

2. Methods and Results

2.1 Seismic Response Analysis of NPP

Seismic response analyses NPP are performed by selecting a Korean standard nuclear power plant as a target model to calculate the seismic demand. Among the buildings constituting a nuclear power plant, an assembly of auxiliary buildings where many equipment are located was set as the target structure. Fig. 1 shows the auxiliary-turbine-access control building complex modeled with the SAP2000 program.

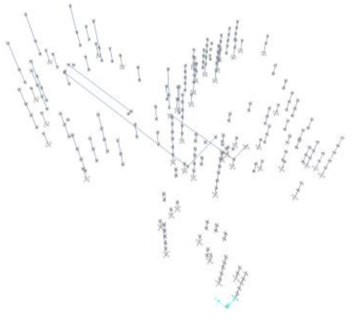


Fig. 1. Auxiliary-turbine-access control building complex.

In order to perform the analysis considering the crack effect, a two-step analysis procedure is required. First, through the seismic response analysis of the uncracked model, it is determined whether the shear wall inside the structure exceeds the criteria suggested by the EPRI technical report and ASCE/SEI 4-16 [2-3]. After that, the elements determined to have cracks are selected, the model to which the effect of reducing the stiffness of concrete due to cracks is applied is reconstructed, and secondary analysis is performed. Fig. 2 shows the cracking elements after the first analysis. Inefficient efforts are required to select the cracked element and apply the stiffness reduction effect on the model for secondary analysis. Therefore, in this study, the analyses are performed by linking the SAP2000 program with the programming language Python using Open Application Programming Interface (OAPI). A series of seismic response analysis, crack classification, application of stiffness reduction effect, secondary analysis, and data post-processing are unified and analyzed using Python programming language.

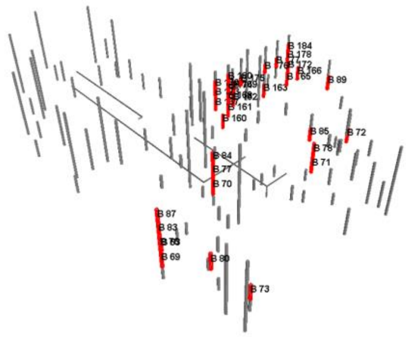


Fig. 2. Cracked element after seismic analysis.

2.2 Input Earthquake

For seismic response analysis, the uniform hazard spectrum of Uljin area was used to reflect the earthquake characteristics of South Korea. In order to consider the variability of earthquakes, 30 earthquake sets satisfying the target spectrum were constructed using the P-CARES program, and are shown in Fig. 3.

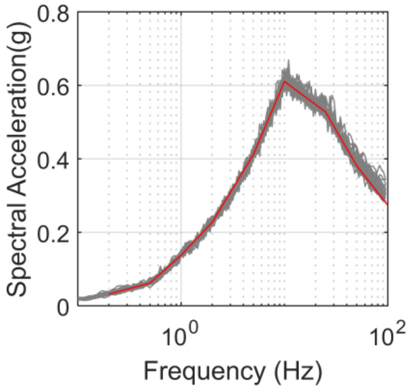
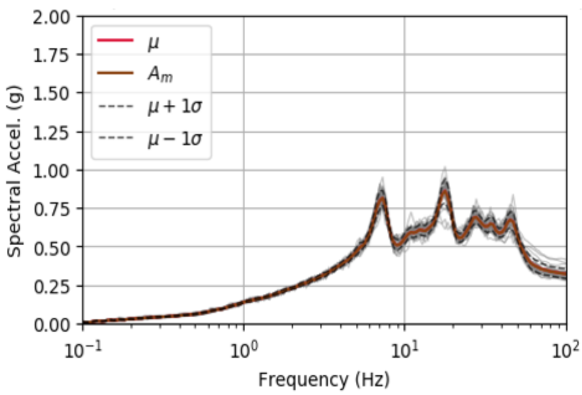


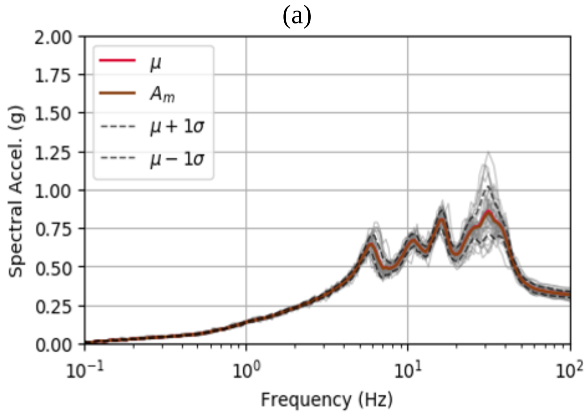
Fig. 3. Target spectrum and response spectrum by 30 sets of earthquakes.

2.3 Seismic Response Considering the Effect of Crack

If the stiffness is reduced due to the occurrence of cracks, the natural frequency of the structure changes, and the location of cracks also vary according to the input earthquake. The spectral acceleration of each seismic response itself does not change significantly, but the overall average decreases due to the variability of the mode frequency. However, if the mode frequency is affected by the spectral shape of the input earthquake, the average of the spectral acceleration may increase.



(a)



(b)

Fig. 4. Floor response spectrum of (a) uncracked and (b) cracked model.

Fig. 4 shows the floor response spectrum and the average for 30 earthquakes before and after cracking at 77 ft of the auxiliary building. It is shown that the response decreases due to the variability by the crack occurrence in the 6-7 Hz range where the first mode occurs. However, in the higher-order mode range of 10 Hz or higher, the response tends to increase by the crack effect. The reason is that the spectral acceleration in uniform hazard spectrum increases if the frequency decreases in the range of more than 10 Hz, and the seismic response also increases by the decrease of mode frequency by the crack effect.

3. Conclusions

In this study, the responses to high-frequency earthquakes of NPP structures considering the crack effect are analyzed. The effect of cracks is analyzed through an analysis process consisting of two steps. In order to select cracked elements and reconstruct the analysis model, the entire analysis process is automated using the OAPI provided by SAP2000, and earthquake response analyses are performed considering the effects of cracks. The average of earthquake responses tends to decrease due to the variability of the mode frequency by cracks, but the results are confirmed that there existed a range in which the opposite shape occurs in the higher-order mode according to the shape of the response spectrum of the input earthquake. Through the results performed in this study, it is expected to be able to understand how the input earthquake considering the earthquake characteristics of Korea affects the response of the cracked nuclear power plant structure.

ACKNOWDGEMENT

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

REFERENCES

[1] US NRC, Design Response Spectra for Seismic Design of Nuclear Power Plants (Regulatory Guide 1.60), 1973.
[2] EPRI, Seismic Fragility and Seismic Margin Guidance for SPSA (TR-3002012994), 2017.
[3] ASCE, Seismic Analysis of Safety-Related Nuclear Structures (4-16), 2017.