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Development of Simplified and High Fidelity FE Model of Single Door Electrical Cabinet

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ABSTRACT

The electrical cabinet as a safety-related equipment is the essential system for operational support and power distribution in nuclear power plants. Most existing structural and nonstructural components in nuclear power plants was designed by the frequency range of 2 Hz to 10 Hz based on Regulatory Guide 1.60 (EPRI 2007). In a recent year, high frequency earthquake including over 10Hz, however, was occurred around GyeongJu area in Korea. Therefore, seismic qualification and demands of the mechanical and electrical equipment must be evaluated for the high frequency earthquake. This study presented the dynamic characteristics of single door electric cabinet through the experimental test and analytical analysis. In particular, to generate the accurate in-cabinet response spectra (ICRS) of the cabinet system, this study constructed the simplified finite element (FE) model and high fidelity (HF) FE by model using ABAQUS platform of the electric cabinet based on the experimental test data. Consequently, the global and local modes of the electric cabinet obtained from HF simulation and simplified FE model was an extremely good agreement with the data from the experimental tests. As a result, the dynamic characteristics of the two different FE model was validated in this study.

INTRODUCTION

To verify the seismic qualification of the electrical cabinet in nuclear/nonnuclear power plants, seismic demands on in-cabinet response spectra of the electrical cabinet system have been addressed (Jeon et al. 2021, Cho and Salman 2021, Tran et al., 2021, Latif et al. 2021), since the electrical cabinet system related to the operation and functionality in NPPs. In addition, through the strong ground motions, the earthquake damage of the cabinet such as overturning modes, rocking modes, and anchor failure modes was reported. Also, Gupta et al. (2019) presented that safety-related equipment such as relays, breakers and switches can be loss of functionality under high frequency earthquakes. On the other hand, the design frequency of most existing nuclear power plants was 2 Hz to 10 Hz (EPRI 2007) but the deterministic seismic design intensity corresponding to R.G. 1.60 was exceeded from the 2016 Gyeongju earthquake including high-frequency earthquake components in Korea (Kwag et al 2020, USNRC RG1.60), as shown in Figure 1. Such high-frequency earthquake can cause the impact or unexpected strong vibration to the safety-related electrical and mechanical equipment in the cabinet system. Therefore, this study presented the dynamic characteristics of the electrical cabinet on a shaking table test, and then the results obtained from the simplified and high fidelity FE model of the cabinet system test was reconciled with the data from the experimental test.

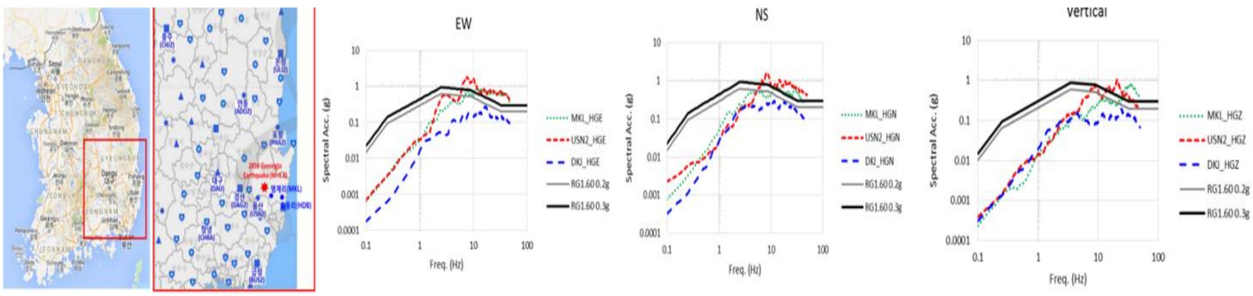


Figure 1. 2016 Gyeongju earthquake with Reg. 1.60 (after Kwag et al., 2020).

Experimental Test

Typically, the electrical cabinet consisted of a complicated system including in-cabinet equipment, bracing frames and panels. Therefore, the experimental test must be performed to understand the complicated behaviour of the cabinet system subjected to a ground motion. The existing cabinet composed of 2350 mm high, 800 mm wide, and 800 mm deep was selected in this study and the cabinet was anchored by eight M-16 hex-head bolts between a jig-plate. Then, accelerometers (A6, A7, and A8) on the outside of the cabinet were attached and in order to evaluate the seismic performance of in-cabinet equipment of the cabinet, another three accelerometers were installed, as shown in Figure 2.

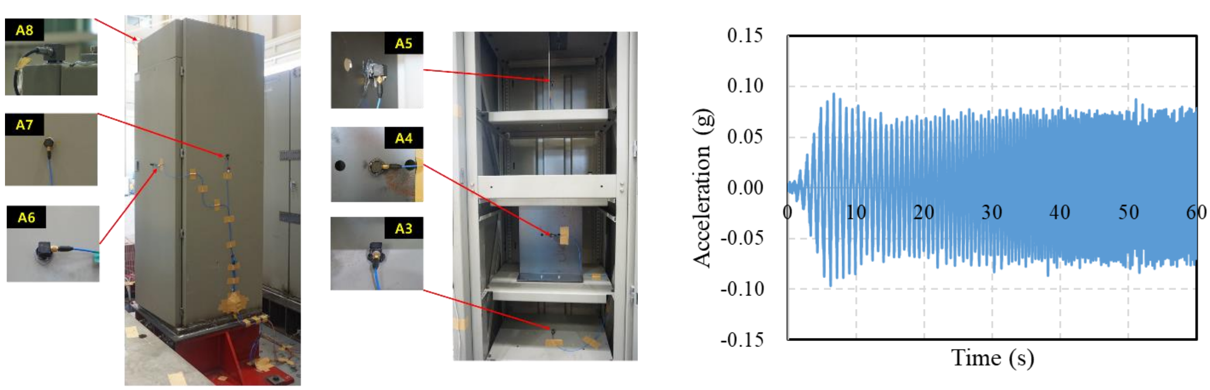


Figure 2. Experimental test set up and loading protocol of single-door electrical cabinet

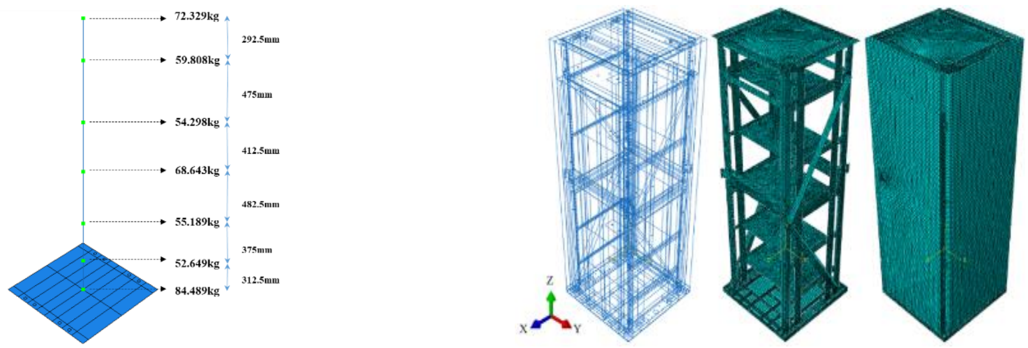
In addition, the Seismic Simulation Test Center at Pusan National University in Korea conducted the shaking table test of the electrical cabinet by using 6-DOF equipment. The resonance search test based on the loading protocol shown in Figure 2 was carried out for the evaluation of dynamic characteristics of the electrical cabinet, and the sinusoidal sweep wave corresponding to 2 Oct/min was applied. In addition, the maximum acceleration of the loading protocol was 0.07g to minimize the damage from the experimental test and the frequency must be considered from 1.3 Hz and 33.3 Hz. Therefore, the sinusoidal sweep wave was composed of 1 Hz and 50 Hz. Based on the installation of the resonance search tests, the first resonance test without any reinforcement was conducted, as a result, the frequency over 40 Hz associated with the influence of impact during the test was detected, as listed in Table 1. It was revealed that the boundary conditions of the cabinet must be enhanced to mitigate the impact influence for the test. After strengthening, the accurate frequency of the electrical cabinet was obtained from the second resonance search test, as given in Table 1.

Table 1: Resonance frequencies of a single door electrical cabinet

Location	Resonant Frequency (Hz) Before Reinforcement			After Reinforcement		
	X	Y	Z	X	Y	Z
Inside 1st story (A3)	N/A	44.3	49.8	16.0	16.0	22.3
Inside 2nd story panel center (A4)	15.8	16.0	40.8	16.0	13.8	23.2
Inside 3rd story panel center (A5)	41.0	41.0	17.8	15.8	17.8	16.0
Door center (A6)	N/A	20.3	16.0	16.0	16.3	16.0
Top (A7)	13.5	16.0	N/A	15.3	14.3	16.0
Side panel center (A8)	12.8	16.0	N/A	23.0	14.3	16.0

VALIDATION OF FE MODELS

In order to describe the various conditions of the electrical cabinet system subjected to a strong ground motion, a numerical model based on the experimental test must be developed. Two different FE model was generated in this study. First, over the past decade, to reduce the computational cost of simulation models, a simplified FE model commonly used. Based on the experimental test, the lumped mass with beam-stick model was constructed and the mass was distributed corresponding to the in-cabinet equipment points and essential parts in simplified beam-stick FE model, as illustrated in Figure 3. The beam-stick element of the simplified FE model was also idealized by using a moment of inertia of $9.290\times10^{8}mm^{4}$. Consequently, simplified was a good agreement with the result of experimental test, especially, at the global modes of the cabinet system, as given in Table 2.



(a) simplified model (b) HF model

Figure 3. Electrical cabinet FE models

Table 2: Dynamic characteristics of a single door cabinet caption.

Modes	Experimental Test	Simplified Model	HF model
1st global	16.00 Hz	15.73Hz	16.11 Hz
2nd global	24.00 Hz	24.034Hz	23.86 Hz
1st local	30.50 Hz	N/A	30.81 Hz
2nd local	37.50 Hz	N/A	37.25 Hz

As can be seen in Figure 2 and the data from the analysis of simplified FE model, the result can only represent the global modes in the cabinet system, but in order to obtain the accurate in-cabinet response spectra for the seismic performance evaluation of in-cabinet equipment and consider the effect of impact from the high frequency earthquakes, the FE model of the cabinet needs to develop the high fidelity simulation model for the electrical cabinet. Therefore, the HF simulation FE model using ABAQUS platform was constructed. The partially fixed conditions as a boundary condition was applied to allow the small rotation for anchor systems at the bottom of the cabinet and then shell element (S4R) for bracing member, frame and panels was used in this HF FE model. Further details can be found in Jeon et al. (2021). As a result, the natural frequencies obtained from the HF FE model was an extremely good agreement with the data from the experimental test including the global and local modes. The both FE model can be reliable, since the dynamic characteristics of the cabinet was significantly identical with the experimental test. Especially, for the in-cabinet response spectra and the seismic performance evaluation of the electrical cabinet, the HF FE model can be more reliable, as shown in Figure 3 and Table 2.

CONCLUSION

This Paper showed the dynamic characteristics of the electrical cabinet system under shaking table test. Two different FE models of the electrical cabinet was developed by using ABAQUS platform. In order to reduce the computation cost, the simplified FE model was significantly validated with the experimental test, but it was difficult to show the local modes of the cabinet system in the simplified FE model. Consequently, the first two global modes (16.11 Hz and 23.86 Hz) from the HF simulation model was identical to the data obtained from the experimental test and also the local mode shapes for 30.81 Hz and 37.25 Hz of the HE simulation model was extremely reconciled with the results (30.50 Hz and 37.50 Hz) from the experimental test. Therefore, the HF model can be reliable to identify the in-cabinet response spectra in nuclear power plants and then this model can be used to construct the seismic fragility of the cabinet to mitigate the non-structural earthquake damage.

ACKNOWEDGEMENT

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