Shaking Table Tests for Amplification Ratio Estimation of Electric Cabinet for Nuclear Power Plant under Seismic Loading

Chae-Been Lee [a], Bub-Gyu Jeon [a], Sung-Wan Kim [a], Dong-Wook Park, Sung-Jun Lee [b]
[a]*Pusan National University, Seismic Research and Test Center, 49 Busandaehak-ro, Yangsan 50612, Korea*
[b]*Korea Hydro and Nuclear Power Co, LTD, Yuseong-daero 1312beon-gil, Yuseong-gu, Daejeon, Korea*
beenee2@pusan.ac.kr

1. Introduction

In nuclear power plants, damage to safety-related equipment is directly related to safety accidents such as radioactive leakage. Loads acting on equipment in nuclear power plants include environmental loads such as natural aging, radiation aging, thermal aging, vibration, and abrasion. To evaluate the performance of safety-related devices, it is necessary to verify qualification considering these loads. In the case of a nuclear power plant nearing the end of its design life, it is necessary to choose whether to permanently shut down or extend the operating period [1]. A revaluation of the performance of safety-related equipment may be required to determine this. In order to evaluate the earthquake safety of nuclear power plants, various studies have been conducted to predict the behavior characteristics and internal response of electrical cabinets by seismic loads[2,3]. However, while finite element analysis is performed with the cabinet ideally fixed to the floor, ideal fixation is difficult in actual experiments. In addition, the effect of cracks in the concrete foundation on the response of the appliance in the anchored electrical cabinet was not considered. That is, there is a limit to accurately representing the damage of the electric cabinet due to the earthquake load. In this study, the seismic behavior of the electric cabinet was analyzed considering the anchor standard and cracks in the concrete foundation, and a 3-axis shaking table test was conducted to evaluate the seismic performance. The dimensions of the anchor and the size of the concrete crack were determined by referring to the results of the field investigation of the nuclear power plant and the anchor test standard. The electric cabinet was manufactured with a steel frame to minimize experimental variables, and the steel frame was designed through numerical analysis to simulate the cabinet used in a nuclear power plant.

2. Model

It is ideal to perform shaking table test with equipment in a nuclear power plant. In this study, a pre- experiment was conducted to derive a method for evaluating the seismic performance of a cabinet installed in a power plant. In order to consider deterioration, the crack of the concrete foundation was assumed as a variable, and the effect of deterioration was analyzed through experiments. Based on the results of the field investigation, in the experimental study, the crack of the concrete foundation was determined to be 0.5 mm and 1.0 mm, and four anchor bolts, the most vulnerable condition, were applied as the fixing condition. Also, four cracks simulated in the anchor are all in the same direction (X-dir). The cabinet model was designed by referring to the results of shaking table tests and field investigations, and the load was distributed over multiple floors as shown in Fig. 1 with reference to the composition of the MCC (Motor Control Center).

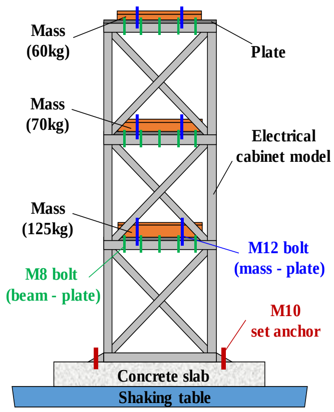


Fig. 1. Unit Under Tests(UUT)

3. Input motion

The RRS (Required Response Spectrum) for the shaking table test is shown in Fig. 2. The horizontal direction (x, y) and vertical direction(z), the damping ratio is 5%. The acceleration time history was prepared by referring to IEEE 344. The vibration duration is 30 secs, the strong motion duration is 20 secs, and the cross-correlation function is less than 0.3.

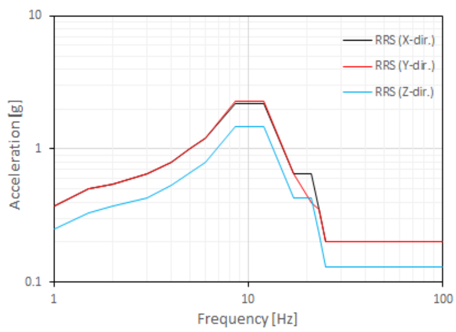
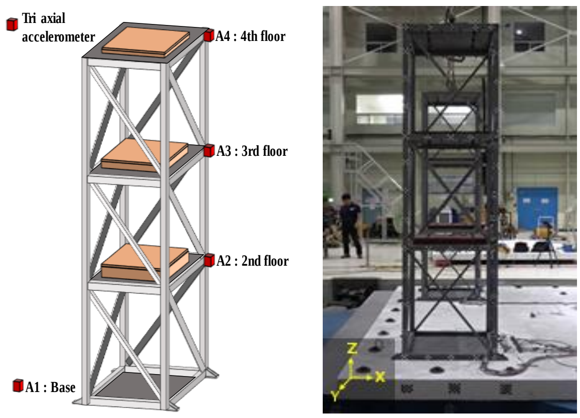


Fig. 2. Required response spectrum

4. Shaking table test

For the seismic simulation test, a tri-axial shaking table test was performed using the acceleration time histories of the axial direction prepared using the RRS in Fig. 2 to simultaneously excite two horizontal directions and one vertical direction. The size of the input signal is RMS (Root Mean Square) 0.1 g. The frequency range of the random wave was 0.5 Hz to 50.0 Hz, and the vibration duration was more than 60 seconds. The resonant frequency search test was conducted before and after the earthquake simulation test. Fig. 3(a) is the installation location of the 3-axis acceleration sensor and Fig. 3(b) is an experimental photo.



(a) Accelerometer location (b) Test photo

Fig. 3. Location of the acceleration sensor

5. Table Result

The shaking table test was performed by increasing the level of input ground motion until damage to the test sample was found. The acceleration amplification trend of the UUTs was compared using the ratio of the acceleration response measured at each floor of the cabinet model and the floor of the shaking table. The ratio of acceleration response spectrum, Ra(i), can be calculated as in Equation (1) [4]. In Equation (1), Sa(Ground) is the TRS of the acceleration response measured on the top of the concrete foundation installed on the shaking table, and Sa(Floor) is the FRS measured on each floor of the test subject. And i is the measurement position.

$$Ra(i) = \frac{Sa(Floor)}{Sa(Ground)} \qquad (1)$$

$$R_{ZPA}(i) = Ra(i) of\ Zero\ Period \qquad (2)$$

$R_{ZPA}(i)$ of UUT 1 without cracks, UUT 2 with 4 cracks of 0.5 mm, and UUT 3 with 4 cracks of 1.0 mm were compared. $R_{ZPA}(i)$ in Equation (2) is Ra(i) of the zero period. Here, the zero period is 45.25 Hz. Since UUT 1 was damaged during the EQ5 experiment, the $R_{ZPA}(i)$ of UUT 1 is shown up to EQ4. Fig. 4 is $R_{ZPA}(i)$ of UUTs. The maximum value of $R_{ZPA}(i)$ of UUT 1 in EQ4 before anchor damage occurs is 6.46. For UUT 2 and UUT 3, the maximum values are 3.48 and 3.84, respectively. The acceleration response of UUT 1 without cracks is mostly greater than that of UUT 2 and UUT 3 with cracks. The acceleration amplification trend of the cabinet models for each UUT can be confirmed.

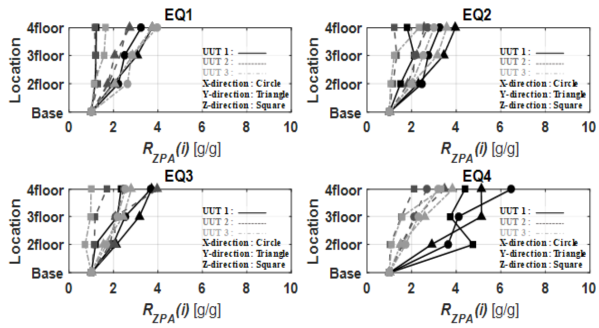


Fig. 4. Ratio of acceleration response spectrum

6. Conclusion

The estimation of the amplification of electric cabinets for nuclear power plants subjected to seismic loads can be one of the safety evaluations of nuclear power plants. In this paper, seismic analysis was performed for electric cabinets for nuclear power plants through shaking table test. For accurate analysis, cracks in the concrete foundation were considered. As a result of the analysis, the $R_{ZPA}(i)$ value of the cracked UUT is smaller than that of the non-cracked UUT. Depending on the $R_{ZPA}(i)$ value, it is possible to determine whether or not the support is damaged.

Acknowledgment

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