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HIGH FREQUENCY GROUND MOTION EFFECT ON THE SEISMIC INTEGRITY OF ANCHORAGE SYSTEM

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ABSTRACTS

Recently, strong earthquakes that affect the operation of close nuclear power plants occurred in Korea. The Gyeongju earthquake, M5.8, occurred in 2016, and followed by the Pohang earthquake, M 5.4, in 2017. The recorded earthquake ground motions from both earthquake events show the typical characteristics of a high frequency ground motion, which is different from that of the response spectrum used for the seismic design of Korean nuclear power plants. A high frequency ground motion can cause various effects on the safety of nuclear power plants. To resolve the high frequency issue, a research program was launched after the Gyeongju earthquake event. In this study, several tasks to resolve the high frequency issue were performed. In this paper, the effect of a high frequency ground motion on the anchorage systems for a component was estimated by experimental and numerical studies.

INTRODUCTION

The Gyeongju earthquake, M 5.8, which occurred in 2016 is the largest earthquake that occurred in Korea since the earthquake observation started in 1910. Due to this earthquake, 4 unit of nuclear power plants located 28km from the epicentre were manually shut down. The measured peak ground acceleration at the nuclear power plant site was 0.098g. Despite the measured peak acceleration being smaller than the operating basis earthquake (OBE), the spectral acceleration in the high frequency range exceed the OBE spectrum. The exceedance of the spectral acceleration in high frequency range was caused by the high frequency ground motion characteristics.

The earthquake ground motions recorded from the Gyeongju earthquake and Pohang earthquake show the typical characteristics of a high frequency ground motion. The frequency contents of those earthquakes are very similar to that of a typical Central and Eastern United States (CEUS) site earthquake ground motions.

A research program was started to resolve the high frequency ground motion issue and to secure the seismic safety of the nuclear power plants. The high frequency ground motion was issued in the United States, and various research programs were performed to resolve this issue. The approach to resolve the high frequency issue in the US included several tasks for the high frequency sensitive components and structures, which is important to the safety of nuclear power plants. One of the task to be resolved in the US program is the structural adequacy of anchorage/mounting and supports of the high frequency sensitive components (Ostadan et al., 2017).

The main topics of the Korean high frequency research program include the following:

- Soil-structure interaction effect considering the high frequency ground motions

- Ground motion development for tests and analyses considering Gyeongju earthquake
- Experimental study on the ultimate seismic capacity of safety related equipment considering high frequency ground motion effect
- High frequency ground motion effect to the reinforced concrete shear wall structures and anchorage

In this paper, the high frequency ground motion effects on the anchorage were estimated by a shaking table test. An example fragility analysis was performed to estimate the high frequency ground motion effects by comparing the fragility results against the design earthquake and site-specific uniform hazard spectrum, which shows the typical characteristics of high frequency motions.

CHARACTERISTICS OF RECORDED GROUND MOTIONS

The recorded ground motions from the Gyeongju and Pohang earthquake show typical characteristics of the high frequency ground motions. The recorded acceleration time histories show very short strong motion duration and very high peak acceleration. The highest peak ground acceleration measured at near the epicenter is 0.42g.

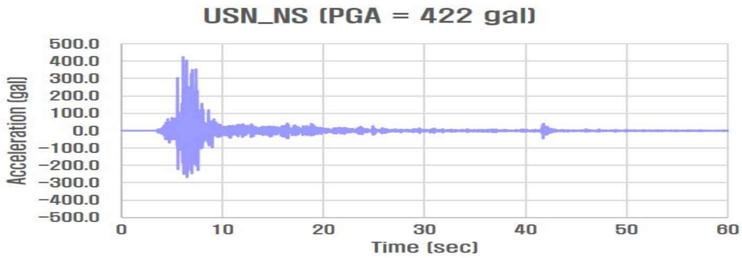


Figure 1. Typical acceleration-time history of Gyeongju earthquake.

Figure 2 shows the comparison of the acceleration response spectra of the recorded earthquake ground motions from two earthquake events and the design response spectrum (USNRC, 2014) which is used for the seismic design of most of the Korean nuclear power plants. As shown in this figure, the high frequency contents of the recorded earthquake are rich compared to the design earthquake.

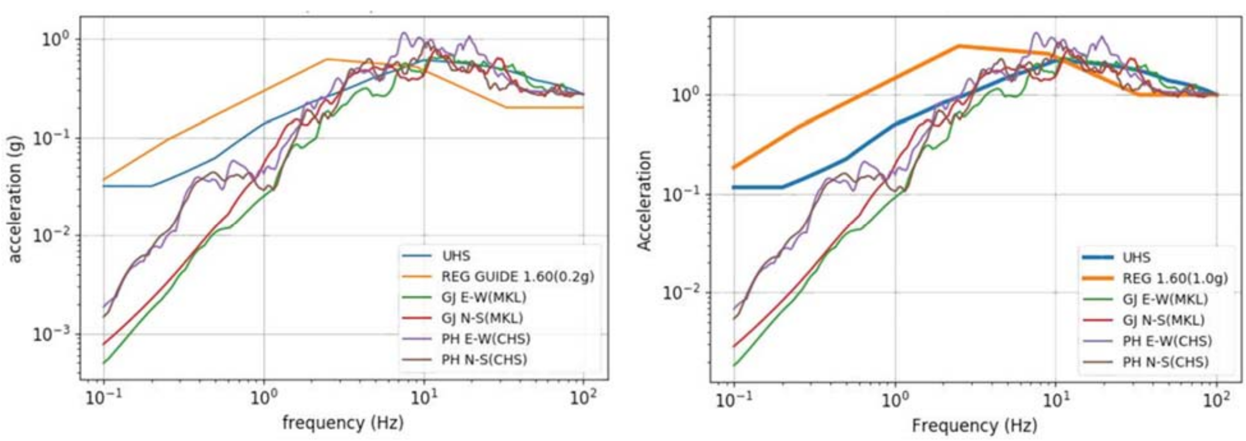


Figure 2. Comparison of the acceleration response spectra.

SHAKING TABLE TEST OF ELECTRICAL CABINET

In general, the high frequency ground motion does not affect seismic safety of nuclear power plant structures since most of the fundamental frequencies of nuclear power plant structures are not so high. The most important effect of a high frequency ground motion is the functional safety of high frequency sensitive components, such as electrical equipment in a nuclear power plant. However, the potential effect of the high frequency ground motions on the seismic safety of a nuclear power plant should be reviewed and confirmed.

There are several kinds of potential high frequency ground motion effects on the seismic safety of safety related SSCs:

- Effects on the structural safety of a stiff structure and the out-of-plane response of a wall and slab
- Structural integrity of equipment anchorage
- Structural and functional safety of active components, especially on the functional safety of electrical equipment
- Structural effect on stiff components, such as stiff pipe systems and their support structures

In this study, a shaking table test was performed to estimate the high frequency motion effect on the anchorage system for an electrical cabinet.

Test Model and Setup

Figure 3 shows the electrical cabinet and its dimension for the shaking table test. The internal structure is also shown in this figure. The total weight of the cabinet is 549 kg, and the dimension of the cabinet is 1,200x600x2,450 mm.

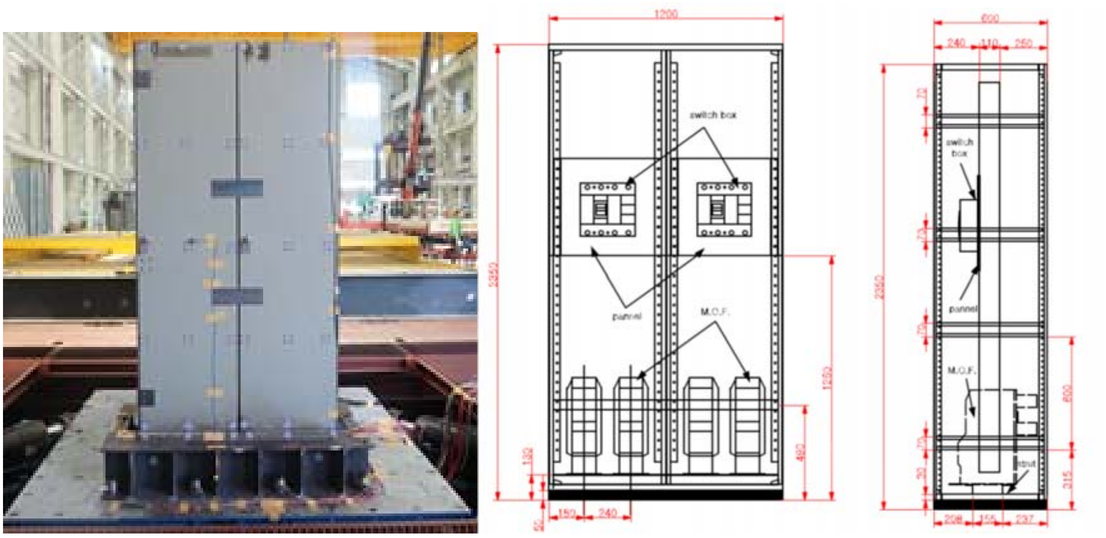


Figure 3. Test model of an electrical cabinet for shaking table tests.

As shown in Figure 3, the test cabinet is installed on the jig which is a stiff structure to fix the cabinet to the shaking table. The cabinet is welded to the jig, and the jig is fixed to the table by bolts. Six accelerometers (A1-A6) were installed to measure the acceleration response of the cabinet. Two accelerometer (A5 and A6) were installed outside of the cabinet to measure the global response of the cabinet. In addition, two accelerometers (A3 and A4) were installed inside of the cabinet to measure the local response of the panel that was installed to attach a device. A1 and A2 are installed on the table and on the top of the jig to measure the acceleration subjected to the cabinet. Eight load cells were installed between the shaking table and the jig to measure the reaction forces. Figure 4 shows the locations of the accelerometers and load cells.

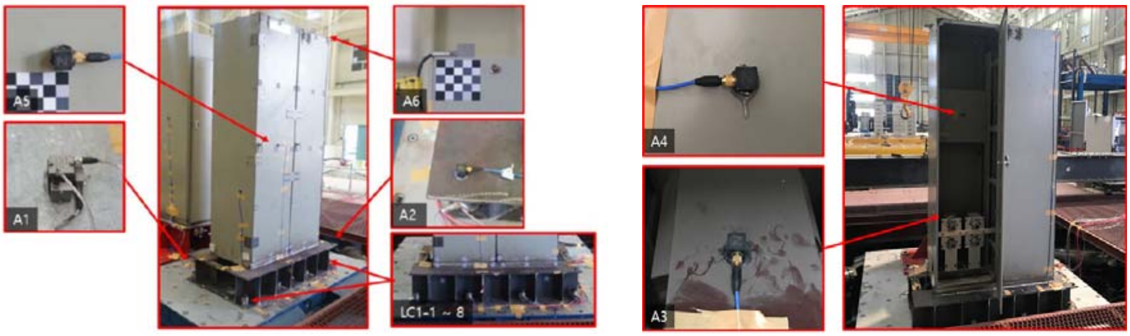


Figure 4. Location of the sensor for acceleration measurements inside of the cabinet.

Input Motions for Shaking Table Tests

In this study, two kinds of acceleration response spectrum were considered for the shaking table test: The standard design response spectrum proposed by US NRC (Nuclear Regulatory Commission) (US NRC, 2014) and site-specific Uniform Hazard Spectrum (UHS) for a nuclear power plant site (Choi et al., 2017).

The UHS was developed based on the results of probabilistic seismic hazard analysis for a NPP site. Figure 5 shows an example seismic source map for Korean peninsula that used for the PSHA (Probabilistic Seismic Hazard Analysis) and the seismic hazard curves for a NPP site. The developed UHS is shown in Figure 6 with the design response spectrum. As shown in this figure, the frequency contents of UHS showed typical characteristics of a high frequency ground motion, and the frequency contents were much different from the design spectrum. The floor response spectrum for the two earthquakes was developed to consider that the electrical cabinet is generally installed inside of buildings. In Figure 6, the floor response spectrum for design earthquake and UHS is compared.

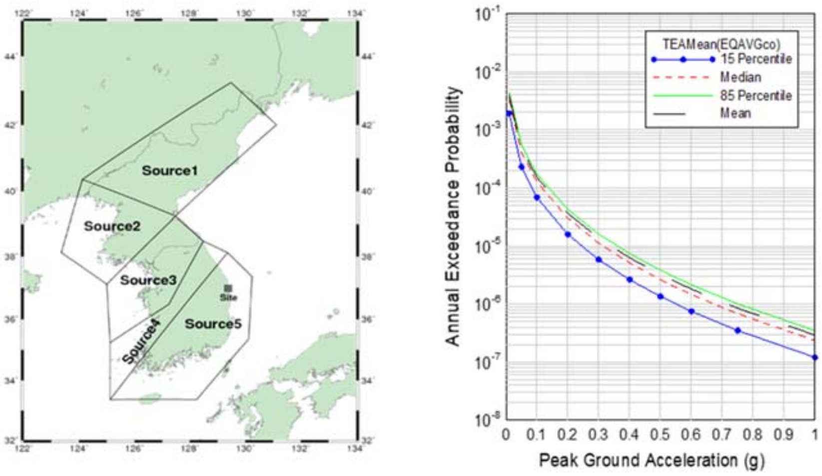
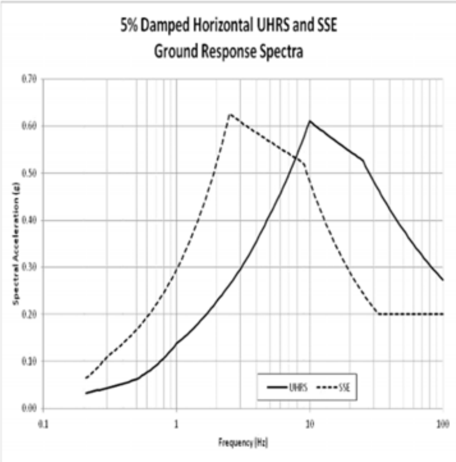


Figure 5. Example seismic source map used for the PSHA and probabilistic seismic hazard curves.



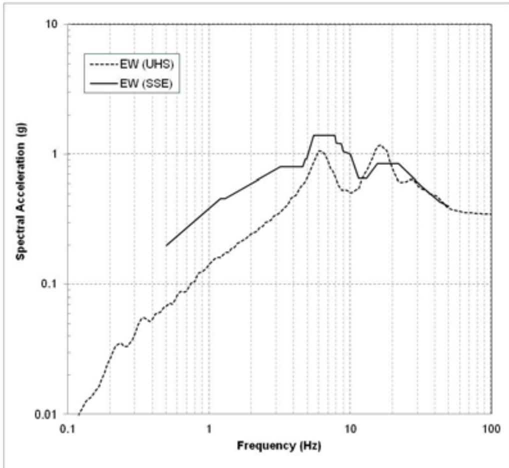


Figure 6. Input ground motion response spectrum and corresponding floor response spectrum for Shaking Table Tests (Horizontal Direction).

Resonance Test

To estimate the dynamic characteristics of the test cabinet, the resonance tests were performed before the test. In addition, the resonance tests were performed after the tests to check the change of the dynamic characteristics due to the aging effect from the repeated tests. The fundamental frequency of the cabinet was 15Hz and 20.5Hz in the front-to-back direction and side-to-side direction, respectively. Figure 7 shows the transfer function from the resonance test to identify the natural frequency of the test cabinet.

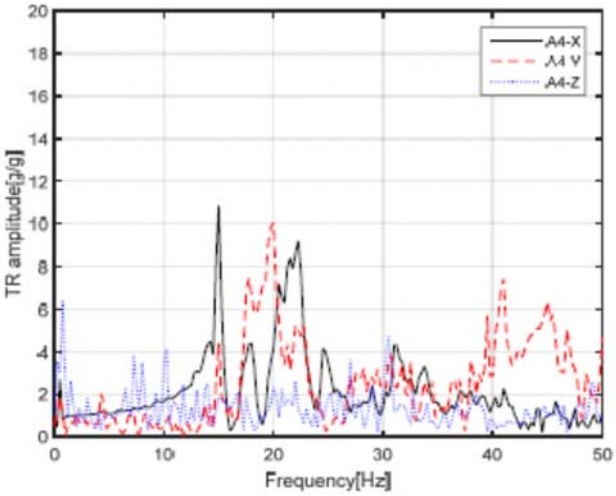


Figure 7. Resonance test results for front-to-back, side-to-side, and vertical direction.

Test Procedure

Table 1 shows the test procedure. Before the earthquake motion test, the first resonance test was performed for three directions. Shaking table test was performed for four different input motions with a multi-axis time history. After the test, a resonance test was performed to check the changes in the dynamic characteristics of the cabinet.

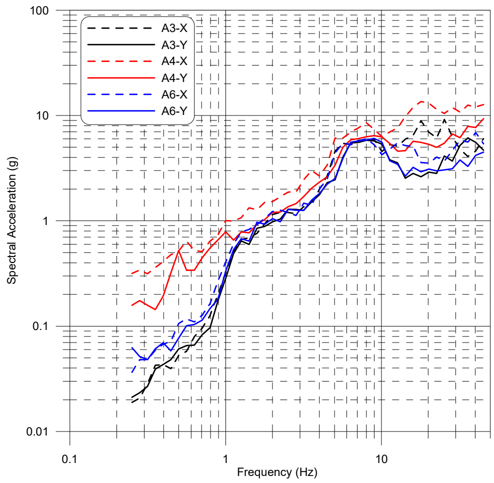
Table 1: Shaking Table Test Procedure.

Step	Test	Input motion	Direction
1	Resonance test	Sine sweep	x
2	Resonance test	Sine sweep	y
3	Resonance test	Sine sweep	z
4	Multi-axis earthquake test	RG-G[1]	x,y,z
5	Multi-axis earthquake test	RG-A[2]	x,y,z
6	Multi-axis earthquake test	UHS-G[3]	x,y,z
7	Multi-axis earthquake test	UHS-A[4]	x,y,z
8	Resonance test	Sine sweep	x
9	Resonance test	Sine sweep	y
10	Resonance test	Sine sweep	z

[1] RG-G: US NRC Regulatory Guide 1.60 at Ground
[2] RG-A: Floor Response at Aux. Building by RG-G
[3] UHS-G: Uniform Hazard Spectrum at Ground
[4] UHS-A: Floor Response at Aux. Building by UHS

Test Results

The shaking table test was performed with 3-directional input motions: two horizontal and one vertical motion, simultaneously. The acceleration responses were measured outside and inside of the cabinet. Figure 8 shows the acceleration response spectrum measured at the outside and inside of the cabinet subjected to the RG-A and UHS-A input motions. As shown in this figure, the measured acceleration subjected to UHS-A is higher than that subjected to the RG-A input motions. It is shown that the high frequency motion can cause higher acceleration response at the electrical cabinet with high fundamental frequency. The acceleration amplification at the inside of the cabinet is higher than that at the outside of the cabinet.



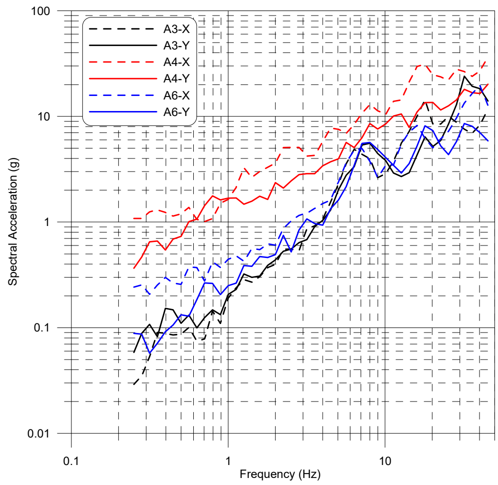


Figure 8. Measured response spectrum of the cabinet subjected to RG-A and UHS-A input motions.

During the shaking table test, the reaction forces at the bolt that connects the test jig and shaking table were measured to estimate the high frequency ground motion effect on the anchorage system. Table 2 shows the measured maximum reaction forces subject to four different input motions. As shown in this table, the total reaction forces for the front-to back and side-to-side directions subjected to the high frequency input motion is slightly greater. However, the shaking table tests were performed with simultaneous three directional input motions. Therefore, it was not easy to identify the relationship between the dynamic characteristics of the cabinet and the frequency content of input motions.

Table 2: Measured maximum reaction forces at the load cells.

Load Cell No.	RG-G (kN)	UHS-G (kN)	RG-A (kN)	UHS-A (kN)
LC1-1	0.1342	0.1725	0.3023	0.2612
LC1-2	0.1155	0.1227	0.2181	0.1644
LC1-3	0.0977	0.0948	0.161	0.1263
LC1-4	0.1164	0.1741	0.2811	0.3662
LC1-5	0.1376	0.1629	0.2565	0.2729
LC1-6	0.0794	0.0884	0.1331	0.1828
LC1-7	0.093	0.1007	0.1032	0.1456
LC1-8	0.1311	0.1969	0.4322	0.387

EXAMPLE FRAGILITY ANALYSIS OF CABINET ANCHORAGE

An example fragility analysis of the electrical cabinet was performed for anchorage failure. It was assumed that the base of the cabinet was very strong, and the anchorage capacity was controlled by the bolt failure. The cabinet was fixed by the expansion anchor bolts attached near each corner of the cabinet. It was assumed that the cabinet is installed at EL. 30.6 m (100’ 6”) of a building in a NPP. The test cabinet was not fully equipped with the electrical components needed for the original function. The fragility analysis was performed by assuming that the weight of the cabinet is 1,100 kg. The anchorage condition and the fragility parameters, except for the cabinet specification and spectral acceleration demand at the base of the cabinet, were assumed to be same as the example shown in Section 9 in the EPRI report (Reed et al., 1994)

Two input ground motions, i.e., the design earthquake of the US NRC standard spectrum (USNRC, 2014) and UHS (Choi et al., 2017), were used for the fragility analysis. The fundamental frequencies of the electrical cabinets were assumed to be 8 and 20Hz. Figure 9 shows the comparison of the fragility curves for the different input motions and different electrical cabinets. As shown in this figure, the high frequency ground motion affects the seismic safety of the anchorage system for the stiff electrical cabinet.

Table 3 shows the comparison of the median acceleration capacity and High Confidence Low Probability of Failure (HCLPF) capacity of the cabinet. As shown in this table, the median and HCLPF capacity is depending on the natural frequency of the cabinet and the frequency contents of subjected floor acceleration.

CONCLUSION

Recent earthquake that occurred in Korea have shown typical high frequency ground motions. In this study, the high frequency ground motion effect on the seismic safety of anchorage system was investigated by numerical and experimental studies. From the shaking table test and example fragility analysis that considered the frequency contents of the input ground motions, it was shown that the high frequency ground motions can affect the safety of anchorage systems needed to anchor the stiff components.

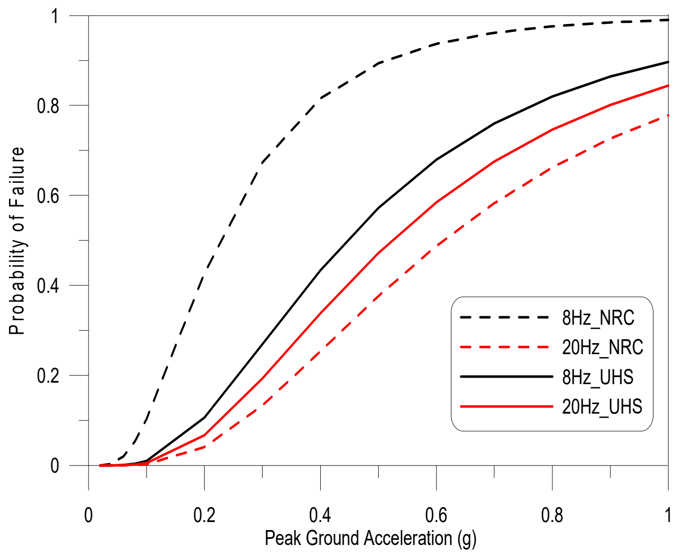


Figure 9. Comparison of the seismic fragility for the low and high stiffness cabinets subjected to the different ground motions.

Table 3: Median and HCLPF acceleration capacities of the example cabinets.

	8 Hz		20 Hz	
	R.G. 1.60	UHS	R.G. 1.60	UHS
Median capacity (g)	0.225	0.445	0.612	0.523
HCLPF (g)	0.056	0.111	0.153	0.131

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REFERENCES

Choi, In-Kil, et al. (2017). “Seismic Fragility Reevaluation of SSCs in NPP with Site-Specific Response Spectrum,” Transactions of the Korean Nuclear Society Spring Meeting.
USNRC (2014). Design response spectra for seismic design of nuclear power plants, Regulatory Guide 1.60.
Reed, John W., and Robert P. Kennedy (1994). Methodology for Developing Seismic Fragilities, EPRI TR-103959.
Ostadan, F., Nan Deng, Tarek Elkhoraibi, Alidad Hashemi, Sanj Malushte, and Jaspal Saini (2017). Advanced Nuclear Technology: High-Frequency Seismic Loading Evaluation for Standard Nuclear Power Plants, EPRI 3002009429.