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A study on time-history input generation method for nuclear power plant components using floor response spectra

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1. Introduction

Structures, systems, and components (SSCs) critical to the safety of nuclear facilities are categorized by safety grades, and numerical seismic analysis is one of the methods to ensure their integrity. The floor response spectra (FRS), used as input loading for the seismic analysis of SSCs, include conservatism introduced during the earthquake input generation process due to the peak smoothing procedure et all. Moreover, seismic analysis of components applies a conservative approach, especially for analysis targets with multiple supports, where both relative displacements between supports and inertial loads are considered [1-2].

Seismic integrity assessments should account for both responses, with structural analysis typically based on FRS obtained from dynamic simulations [3]. The uniform support motion (USM) method addresses inertial responses independently by enveloping all spectra across different height levels, while the static response, represented by seismic anchor motion (SAM), is combined under the most unfavorable conditions. The U.S. NRC Standard Review Plan 3.7.1 acknowledges that this conservative combination of static and inertial responses may lead to overly cautious evaluations. As an alternative, the independent support motion (ISM) method applies independent inputs at each support, enabling simultaneous calculation of both responses.

In this research, we studied the ISM time history analysis as an alternative to the NRC-recommended response spectrum analysis. Specifically, we investigated the generation of artificial seismic loads using algorithms that create time histories based on the response spectrum inputs commonly used in the industry.

2. Methods and Results

We considered the frequency interval for generating time history loads as a critical factor. Table 1 shows the magnitude of the frequency interval of time history load generation for the ground. The time history loads outlined in SRP 3.7.1 pertain exclusively to seismic load generation for the ground and do not include methodologies for generating time history loads for varying elevation levels.

Table 1: Problem Description

Frequency range [Hz]	Increment [Hz]	Frequency range [Hz]	Increment [Hz]
0.2 - 3.0	0.10	8.0 - 15.0	0.50
3.0 - 3.6	0.15	15.0 - 18.0	1.0
3.6 - 5.0	0.20	18.0 - 22.0	2.0
5.0 - 8.0	0.25	22.0 - Highest freq. of interest	3.0

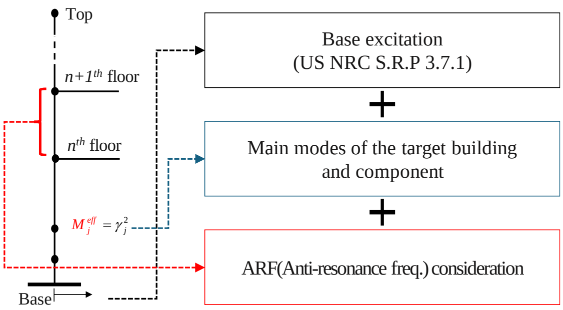
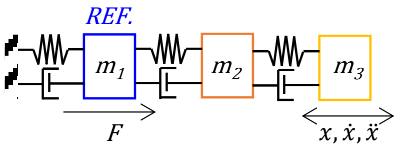
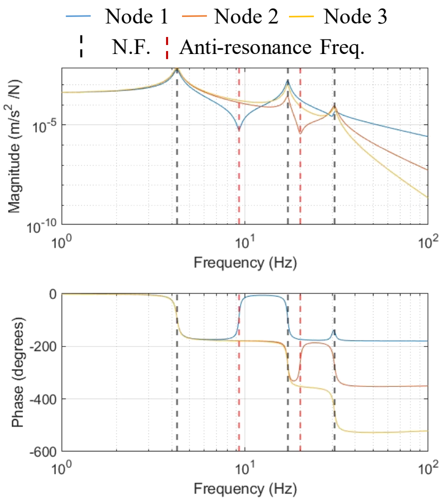


Fig. 1. Schematic of frequency interval considerations of generating time-history ISM loading

However, when supports are installed at multiple heights, as with components, it is essential to develop time history loads for each distinct elevation. Furthermore, the loads at different heights must incorporate the dynamic characteristics of the system in which the component is installed, in addition to the ground load generation. Therefore, this study suggests that the selection of frequency intervals should be accompanied by consideration of the three items shown in Figure 1. First, the frequency interval selection in Table 1, which is considered when generating the ground load, is adopted, and the selection of frequency intervals including the main modes of the target component and structure is asserted [4]. This paper intends to deal with the consideration of the difference in response according to the existence of the anti-resonant frequency (ARF), which corresponds to the third item. In order to analyze the difference in response when generating the load of each layer height according to the presence or absence of the anti-resonance point, a simple 3 DOF system with a natural frequency of 4.2 Hz, 17.1 Hz, and 30.7 Hz was constructed as shown in Figure 2(b).



(a) Schematic diagram of 3 DOF system



(b) Frequency responses of each node

Fig. 2. Configuration of 3 dof system and frequency response for analysis according to the presence of ARF

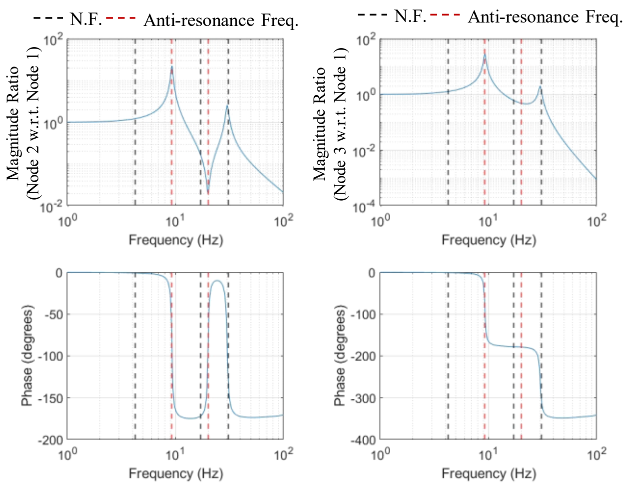


Fig. 3. Frequency responses with respect to reference height (node 1)

Table 2: Problem Description

		w/o ARF	w/ ARF	Diff.
Peak Acc [m/s²]	Node2	7.004E-03	7.044E-03	0.5711%
	Node3	7.949E-03	7.925E-03	-0.3140%
Arias intensity [sec]	Node2	1.057	1.163	10.00%
	Node3	1.057	1.163	10.00%

The frequency response function (FRF) of node 1, which is the reference height, has an ARF between the 1st and 2nd natural frequencies, and thus has a phase difference at the 2nd natural frequency, unlike other heights as shown in Figure 3. Since the phase difference according to the height of the layer occurs, the time history load near the corresponding frequency should be able to reflect this frequency-based change. For components within 100 Hz, a time-history load generated through artificial earthquakes was generated, and the results of comparing the peak value of the acceleration signal according to the presence or absence of ARF with the Arias intensity represented by the earthquake duration are shown in Table 2. By generating a time history load including the anti-resonance point, it is confirmed that there is a 10% increase in the time to intensity compared to the original input load, and this increase in the intensity of the input load will have a difference in the effect on the subject.

3. Conclusion

In this paper, we aim to generate time history loads reflecting the SAM effect based on FRS. Specifically, there is no indication regarding the selection of frequency points where time history loads are generated. To address this, we examined the changes in input loads with and without anti-resonance points. As a result, we found that when anti-resonance points exist in the FRF at the reference height, the difference in load magnitude generated at other heights is pronounced. Consequently, incorporating this effect highlights significant differences in strong motion duration. Therefore, we have identified important factors not only for generating time history loads for the ground but also for analyzing time history load generation for components.

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