

## Effects of the Different Seismic Input Generation Method and Strong Ground Motion Duration on the Behavior of a Seismically Isolated NPP Structure

Hyunuk Kim<sup>1</sup>, Kwangho Joo<sup>2</sup>, Sanghoon Noh<sup>3</sup>, and Junsang Yoo<sup>4</sup>

<sup>1</sup> Researcher, Central Research Institute of KHNP, Daejeon 305-343, Korea (gomzee@khnp.co.kr)

<sup>2</sup> Principal Researcher, Central Research Institute of KHNP, Daejeon 305-343, Korea

<sup>3</sup> Senior Researcher, Central Research Institute of KHNP, Daejeon 305-343, Korea

<sup>4</sup> General Manager, Civil & Architectural Engineering Team of KHNP, Gyungju 780-935, Korea

### ABSTRACT

In this paper, firstly, acceleration-time histories were generated by varying strong motion duration in the frequency domain for application to a seismically isolated nuclear power structure, so as to examine the effects of strong motion duration on the behavior of the structure. Secondly, real recorded earthquakes were modified to match the target response spectrum based on the revised SRP 3.7.1(2007) and the modified time histories were applied to the analysis of a seismically isolated nuclear power structure. The obtained values of acceleration and displacement responses of the structure were, finally, compared with the values obtained in case of applying acceleration-time histories generated in the frequency domain to the structure.

### INTRODUCTION

The input motion used in seismic analysis of nuclear power plant structures should be matched to the target response spectrum and has sufficient energy. Further, it is determined by various conditions that reflect the realistic factors of real earthquake. US NRC SRP 3.7.1 (1996) and other international seismic analysis regulations contain various prerequisites related to the generation of input motion, but most of them do not provide specific guidelines on strong motion duration and envelop function.

The revised SRP 3.7.1 of 2007 prohibits the use of acceleration-time histories that have been generated by purely artificial means instead of being based on real recorded earthquakes. In general, frequency content varies over time due to the non-stationary characteristic of real earthquake waves, but this non-stationary characteristic is not taken into account when an acceleration-time history is generated in the frequency domain.

### INPUT MOTION GENERATION IN FREQUENCY DOMAIN

Considering the parameters of the trapezoidal envelope function by magnitude ranges specified in ASCE 4-98 (1999) and the minimum strong motion duration of 6 seconds for input motion in US NRC SRP 3.7.1 (1996), the envelop functions can be summarized as shown in Table 1. Here, the strong motion duration ( $t_m$ ) is the time taken for arias intensity, as defined in US NRC SRP 3.7.1, to increase from 5% to 75%. When parameters of the compound envelop function are determined according to energy distribution rate, rise time ( $t_r$ ), decay time ( $t_d$ ) and the resulting total duration ( $T_d$ ) differ from those of the trapezoidal envelop function as shown in Table 1. Energy distribution in the  $t_r$  and  $t_d$  ranges of the compound envelope function was considered by using Eq. 1 and Eq. 2 presented by Jennings et al. (1968).

$$I_{(t)} = \left[ \frac{t}{P_1^2} \right] \quad (1)$$

$$I_{(t)} = e^{-c(t-P_2)} \quad (2)$$

In this research, acceleration-time histories were matched to the RG 1.60 design response spectrum of US NRC, and five of each following the compound envelope function were generated for each magnitude range as shown in bold in Table 1. The PGA of the generated time histories was 0.3 g. The values in parenthesis represent the parameters of the compound envelope function based on NUREG/CR 6922 (2006).

Table 1: Strong Motion Duration and Envelope Function Parameters for Each Case.

M	$t_r$ (sec)		$t_m$ (sec)		$t_d$ (sec)		$T_d$ (sec)	
	Trap.	Comp.	Trap.	Comp.	Trap.	Comp.	Trap.	Comp.
7.0~7.5	2	<b>2.8</b> (2.2-3.0)	<b>13</b> (9.8-12.9)		9	<b>21.6</b> (-)	24	<b>37.4</b> (-)
6.5~7.0	1.5	<b>2.1</b> (1.8-2.2)	<b>10</b> (7.4-9.8)		7	<b>16.6</b> (-)	18.5	<b>28.8</b> (-)
6.0~6.5	1	<b>1.5</b> (1.5-1.8)	<b>7</b> (5.9-7.4)		5	<b>11.6</b> (-)	13	<b>20.1</b> (-)

## MODELING OF THE STRUCTURE

In this research, the mass and stiffness information of the APR 1400 nuclear power structure was modified to represent translational motion only. The natural frequency in the first mode was 0.19 seconds in the fixed base condition, and 2.0 seconds in case of base isolation.

## NONLINEAR TIME DOMAIN ANALYSIS (I)

Structural analysis was carried out using totally fifteen acceleration-time histories generated for 3 cases. Based on the median and mean of displacement and acceleration response, the effects of strong motion duration on the response of a seismically isolated nuclear power structure were analyzed. Excitation was applied to a single direction for the target structure. Since the first mode shape was a translation in the x-direction, analysis was limited to x-directional excitation.

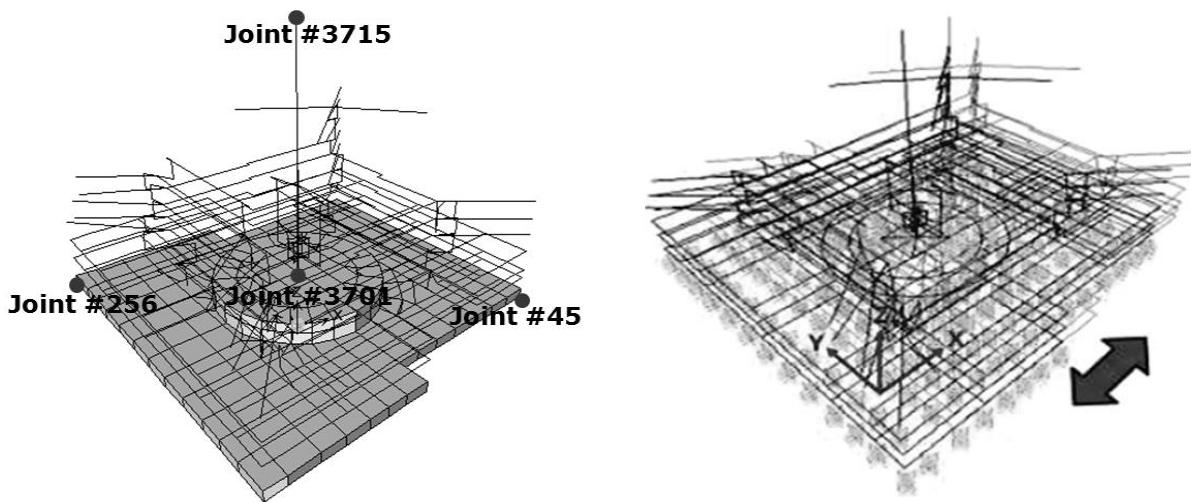


Figure 1. the Analysis Model and 1<sup>st</sup> Mode Shape of the Seismically Isolated Nuclear Power Structure.

During the generation of acceleration-time history, the difference in total duration by case leads to a difference in time interval of acceleration-time histories because the amount of data generated from

inverse fourier transform in the frequency domain is applied as  $2^n$ . To examine the effects of the difference in time interval on acceleration and displacement responses, comparative analyses using each generated acceleration-time history at a time interval of 3.5 ms and 7.0 ms when magnitude was between 6.5 and 7.0 were conducted. As indicated in Table 2, the analysis results for Joint 3715 show that the difference in time interval hardly affects displacement and acceleration response of the target structure.

Table 2: Evaluation of the Effect of the Time Interval on Structural Responses.

	No.	Displacement (cm)		Acceleration (g)	
		$\Delta t=3.5$ (ms)	$\Delta t=7.0$ (ms)	$\Delta t=3.5$ (ms)	$\Delta t=7.0$ (ms)
M 6.5-7.0 (10 sec)	1	10.4		0.159	
	2	13.1		0.169	
	3	13.9		0.167	
	4	14.0		0.167	
	5	14.3	14.2	0.169	

Table 3 shows the results of analyzing a seismically isolated nuclear power structure (Joint 3715) using totally ninety acceleration-time histories generated for 3 cases. Even though the strong motion duration increases, the displacement and acceleration responses did not show remarkable trends. All the results may be due to the limited data, but it can be concluded that longer strong motion duration does not necessarily produce conservative results for artificial time histories, which exceed the minimum requirement of 6 seconds specified in US NRC SRP 3.7.1.

Table 3: Comparison of Responses by Varying Strong Motion Duration

	No.	Displ. (cm)	Acc. (g)	No.	Displ. (cm)	Acc. (g)	No.	Displ. (cm)	Acc. (g)	Min. / Max. (Mean)	
										Displ. (cm)	Acc. (g)
M 6.0-6.5 (7 sec)	1	13.9	0.153	11	11.9	0.144	21	13.7	0.165	9.7 / 14.4 (12.5)	0.129 / 0.165 (0.149)
	2	14.4	0.157	12	12.5	0.148	22	9.7	0.129		
	3	14.4	0.165	13	12.8	0.151	23	9.8	0.131		
	4	12.3	0.139	14	13.2	0.155	24	10.0	0.134		
	5	12.4	0.145	15	13.5	0.158	25	10.2	0.136		
	6	12.0	0.148	16	13.9	0.162	26	10.4	0.136		
	7	11.6	0.146	17	13.8	0.163	27	12.6	0.160		
	8	11.4	0.135	18	13.7	0.164	28	14.3	0.152		
	9	11.2	0.136	19	13.4	0.164	29	12.8	0.143		
	10	11.5	0.141	20	13.7	0.165	30	12.9	0.144		

	No.	Displ. (cm)	Acc. (g)	No.	Displ. (cm)	Acc. (g)	No.	Displ. (cm)	Acc. (g)	Min. / Max. (Mean)	
										Displ. (cm)	Acc. (g)
M 6.5-7.0 (10 sec)	1	10.4	0.159	11	12.2	0.160	21	11.2	0.136	8.5 / 16.6 (12.7)	0.130 / 0.178 (0.154)
	2	13.1	0.169	12	12.3	0.160	22	10.6	0.154		
	3	13.9	0.167	13	12.2	0.160	23	8.5	0.130		
	4	14.0	0.167	14	16.6	0.176	24	10.7	0.141		
	5	14.3	0.169	15	16.5	0.178	25	9.5	0.134		
	6	15.1	0.166	16	11.6	0.135	26	16.5	0.178		
	7	14.5	0.161	17	11.4	0.138	27	12.5	0.139		
	8	13.3	0.157	18	10.6	0.142	28	13.6	0.151		
	9	13.2	0.157	19	11.3	0.139	29	14.5	0.156		
	10	12.1	0.158	20	11.8	0.140	30	11.6	0.135		
M 7.0-7.5 (13 sec)	1	10.3	0.142	11	11.2	0.150	21	10.6	0.144	10.3 / 14.2 (11.5)	0.135 / 0.167 (0.151)
	2	11.7	0.135	12	11.1	0.151	22	10.9	0.145		
	3	13.2	0.159	13	11.1	0.158	23	11.5	0.147		
	4	13.9	0.166	14	11.4	0.161	24	11.5	0.148		
	5	14.2	0.167	15	11.7	0.158	25	11.3	0.152		
	6	11.2	0.147	16	11.7	0.154	26	11.1	0.153		
	7	10.3	0.140	17	11.6	0.150	27	11.1	0.151		
	8	12.8	0.153	18	11.5	0.149	28	11.0	0.151		
	9	12.5	0.155	19	11.4	0.149	29	10.9	0.149		
	10	12.0	0.153	20	11.3	0.148	30	10.7	0.148		

## INPUT MOTION GENERATION IN TIME AND FREQUENCY DOMAIN

One method of generating an acceleration-time history in the time domain is the nonstationary spectral matching technique, proposed by Lihanand & Tseng (1987; 1988). This technique involves modification of real recorded earthquakes of which response spectra do not matched to the target response spectrum. The modified acceleration-time histories maintain similar nonstationary characteristics to real earthquakes,

and the response spectra of the time histories have the same amplitude as the target response spectrum in all frequency ranges. In other words, the change in response spectrum ( $\delta R_i$ ) arising from adding an acceleration-time history  $\delta a(t)$  for modification at a certain time ( $t_i$ ) becomes equal to the difference between the target response spectrum and response spectrum of considered time history ( $\Delta R_i$ ). Under this technique, the wavelet function can be seen as the key determinant of  $\delta a(t)$ . In this study, RSP Match -09 was used in the matching of acceleration-time histories to the target response spectrum. The wavelet function was an improved tapered cosine wavelet, which does not lead to drifts in velocity and displacement. Based on the 1999 Chi-Chi earthquakes of Taiwan and the 1999 Cape Mendocino earthquakes, the nonstationary spectral matching technique was applied to generate acceleration-time histories to match the US NRC RG 1.60 design response spectrum. The PGA of time-histories was scaled to 0.3 g. Table 4 summarizes the information of real earthquake waves used in this study including station name.

Table 4: Information about Real Earthquake Waves used in this Study

Name	Year	Station Name	M	D (km)	Site Class	$V_{S30}$ (m/s)	PGA (g)	PGV (cm/sec)	PGD (cm)
Chi-Chi	1999	TCU072	7.6	7.03	C	468.1	0.4033	60.08	36.25
Cape Mendocino	1992	Cape Mendocino	7.0	6.96	C	513.7	1.3455	90.38	27.79

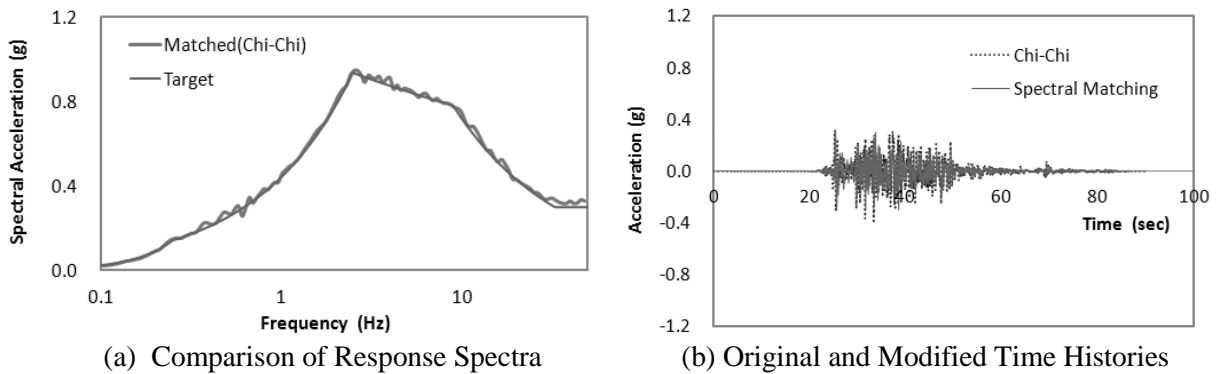
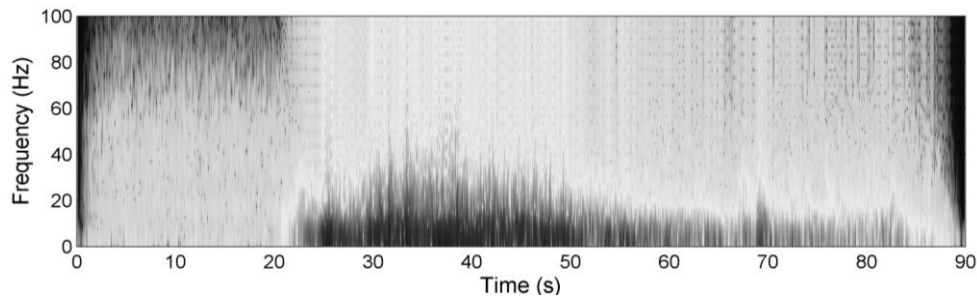
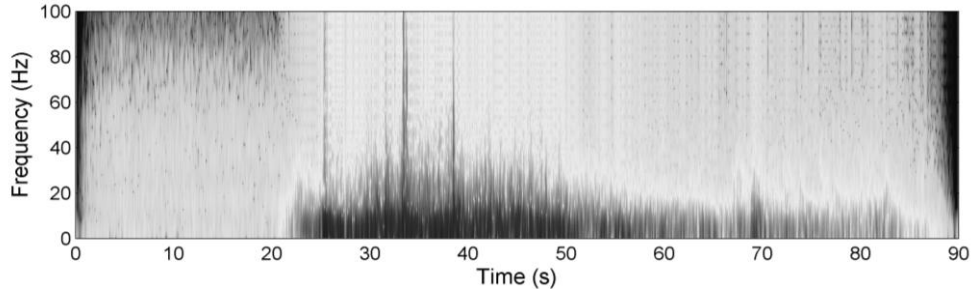


Figure 2. Spectral Matched Results of Chi-Chi Earthquake.



(a) Short Time Fourier Transform of Chi-Chi Earthquake



(b) Short Time Fourier Transform of Modified Time History

Figure 3. Comparison of Nonstationary Characteristics between Original and Modified Time Histories

Acceleration-time histories were generated in the frequency domain to allow comparison with those generated by the nonstationary spectral matching technique in the time domain. The target response spectrum and strong motion duration ( $t_m$ ) were the common denominator, and the compound envelope function was applied. Rise time ( $t_r$ ) and decay time ( $t_d$ ) were determined by the energy distribution rate for an arias intensity of 5-75%. The PGA of the generated acceleration-time histories was scaled to 0.3 g, which coincides with the PGA for those generated in the time domain. The characteristics of the envelop functions are summarized in Table 5.

Table 5: Parameters Determining the Envelope Functions based on Modified Time Histories.

Artificial Time History	$t_r$ (sec)	$t_m$ (sec)	$t_d$ (sec)	$T_d$ (sec)
Based on Chi-Chi	3.1	14.4	23.9	41.4
Based on Cape Mendocino	1.1	5.2	8.6	15.0

## NONLINEAR TIME DOMAIN ANALYSIS (II)

So as to compare structural responses according to the input generation method, structural analyses were performed for a total of ten acceleration-time histories (five for each modified time history) generated in frequency domain and the other analyses were conducted using two modified acceleration-time histories. Mean and median values were obtained for five acceleration-time histories of each case and the results were compared with the results using each modified time history. During nonlinear time domain analysis, excitation was applied in one direction only. Table 6 shows the analysis results. Compared to artificially generated waves in the frequency domain, both displacement and acceleration response were relatively large when the modified Chi-Chi time was applied to the analysis. On the other hand, the modified Cape Mendocino time history with a strong motion duration of 5.2 seconds resulted in a similar displacement but relatively smaller acceleration.

Table 6: Comparison of the Acceleration and Displacement Responses of the Top Points of the Structure

Time History Generation Method		Mean / Median		Remark
		Displacement (cm)	Acceleration (g)	
Frequency Domain	based on Chi-Chi	9.5 / 9.5	0.132 / 0.131	5 Analyses for Each Case
	based on Cape Mendocino	12.9 / 13.2	0.165 / 0.151	
Time Domain	Chi-Chi	14.4	0.158	1 Analysis
	Cape Mendocino	13.3	0.149	

## CONCLUSIONS

Acceleration-time histories were generated by varying strong motion duration in the frequency domain for application to analyses of a seismically isolated nuclear structure. According to the results, it is found that artificial time histories exceeding the minimum strong motion duration of 6 seconds in US NRC SRP 3.7.1 do not necessarily produce conservative results for longer strong motion durations. Next, spectral matching technique was applied to generate time histories matched to the target spectrum while maintaining the nonstationary characteristics of real earthquakes. Time histories, having the same strong motion duration as the modified time histories, were generated in the frequency domain to compare corresponding responses of the seismically isolated nuclear power structure. For long strong motion durations, the results were fairly conservative due to the inclusion of long period components in the modification process. When the strong motion duration was relatively short, no consistency was observed in the acceleration and displacement responses. From the results, it is concluded that enough total duration is needed to generate acceleration-time histories in time domain unlike the case of generating input motions in frequency domain.

## ACKNOWLEDGEMENTS

This work was supported by the Nuclear Research & Development project of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), through a grant funded by the Ministry of Knowledge Economy, Republic of Korea (2011151010010B). This support is gratefully acknowledged.

## REFERENCES

- ASCE (1999), Seismic Analysis of Safety-Related Nuclear Structures and Commentary, ASCE Standard 4-98
- Jennings, P.C., Housner, G.W. and Tsai, N.C. (1968), "Simulated Earthquake Motions", EERL California Institute of Technology, Pasadena, California
- L. Al Atik and N. Abrahamson (2010), "An Improved Method for Nonstationary Spectral Matching", *Earthquake Spectra*, 26(3) : pp. 601-617
- US NRC (2006), NUREG/CR 6922 P-CARES : Probabilistic Computer Analysis for Rapid Evaluation of Structures
- US NRC (1996), Seismic Design Parameters, US NRC Standard Review Plan 3.7.1
- US NRC (2007), Seismic Design Parameters, US NRC Standard Review Plan 3.7.1