Review on Seismic Analysis for Seismic Probabilistic Risk Assessment

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1. Introduction

Since 2000, there has been lots of earthquakes beyond the 5.0 magnitude in Republic of Korea. As results, the public concerns are increased and Korean government also try to release these concerns nowadays. Nuclear Power Plant (NPP) is a one of most important national energy production facility. Therefore, it is necessarily required to secure safety under severe seismic loading condition.

Generally, seismic analysis procedures of design and Seismic Probabilistic Risk Assessment (SPRA) are same basically except ground motion generation. So, differences of seismic ground motion generation between design and seismic SPRA are described and common theoretical backgrounds of analysis are also explained.

Furthermore, this study represents the comparison of seismic analysis methodology between SPRA and Design. Simply example is also presented briefly.

2. Seismic Analysis

2.1 Seismic Ground Motion

Ground Motion means the movement of the earth's surface from earthquake. Ground Motion shall be justified at the seismic analysis. For design, the Design Ground Response Spectra (DGRS) are developed using U.S. NRC Regulatory Guide 1.60 [1] which also present Safety Shutdown Earthquake (SSE). For SPRA, five sets of actual earthquake ground motion called "seed motion" are selected according to U.S. NRC Standard Review Plan (SRP) 3.7.1 [2] as shown in Table 1. NUREG/CR-0098 [3] response spectrum shape is chosen as a Reference Level Earthquake (RLE), in other word "target spectra", for applicability of seed motion to SPRA seismic analysis. Selected five sets of seed motion are compared with RLE as per SRP 3.7.1 as shown in Table 2. Site condition are assumed Western Unite States (WUS) Rock area which has similarity movement with RLE according to NUREG/CR-6728.

Table 1. Seed Motion Case

Case	Magnitude	Site Condition
1	6.6	WUS*, Rock
2	6.7	
3	6.7	
4	7.1	
5	7.6	

* Western United States

Table 2. Comparison of Input Seismic Ground Motion [4]

	Design	SPRA
PGA*	0.3g (SSE)	0.5g
Ground Motion	RG 1.60	Actual (5 sets)
Damping	Multi-damping	5%
RLE	-	NUREG/CR-0098
Criteria	SRP 3.7.1	

* Peak Ground Acceleration

2.2 Site Response Analysis

Site response analysis is performed on the assumptions that the site soil/rock profile is locally horizontally layered and the seismic waves propagating upward from rock at depth at the site are plane waves propagating vertically toward the ground surface. Furthermore, the nonlinear soil/rock material behavior at the site can be approximated by their equivalent linear properties. Based on these assumptions, site response analysis can be performed using a 1-D equivalent linear soil/rock column model and a 1-D wave propagation analysis scheme.

The seismic input to the site response analysis is horizontal or vertical ground motion time histories prescribed as outcrop motions at the control motion elevation. For the horizontal site response analysis, shear-strain-compatibility iterations are required. The shear-strain-compatible shear modulus and damping values are obtained from the horizontal site response analysis of the soil/rock column model. The computed shear-strain-compatible soil properties (shear modulus and damping values) based on the both horizontal components of control motion are computed.

For the vertical site response analysis, the soil/rock compression wave velocity profile is generated using the horizontal site response analyses results. The compression wave velocities are calculated using the averaged shear-strain-compatible shear wave velocities obtained from the horizontal site response analyses and the Poisson's ratios obtained from the low-strain shear and compression wave velocities. The following relationship is used for calculating the compression wave velocity values.

$$V_p = V_s \, [\, (2 - 2\mu) / (1 - 2\mu) \,]^{1/2}$$

V_p : Compression Wave Velocities

V_s : Averaged Strain-compatible Shear Wave Velocities

μ : Poisson's Ratios of Low-strain Shear and Compression Wave Velocities

2.3 Soil-Structurer Interaction analysis

Linear finite element computer program ACS SASSI [5] which is a SASSI family of code is used to obtain the seismic response. The basic method of analysis adopted by the computer program SASSI/ACS SASSI is based on a multiple-step sub-structuring method, called the flexible volume sub-structuring method, formulated in the frequency domain.

The SASSI/ACS SASSI system is idealized using a finite element model, with complex material moduli coupled with free-field soil impedance functions obtained by inverting the dynamic Green' s functions developed for the free-field soil/rock half-space medium. The resulting solution in the frequency domain in the form of complex frequency-response functions is then inverse Fourier-transformed to the time domain to give the desired dynamic response time histories using the well-known Fast Fourier Transform algorithm.

The SASSI/ACS SASSI consists of a number of program modules used to solve dynamic SSI problems in a seismic environment. For this analysis, the seismic environment is defined by the vertically propagating S-waves for the horizontal excitation, and by the vertically propagating P waves for the vertical excitation.

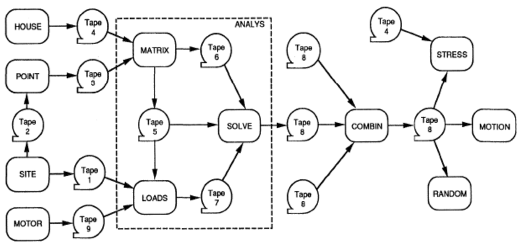

Figure 1. Layout of Computer Program SASSI/ACS SASSI

3. Example Analysis

Example analysis is conducted to see how differential trends of result are existed between SPRA and Design. APR1400 Auxiliary Building (AB) is selected as sample structure because AB contains lots of safety related equipment and SSCs in the view of SPRA. Figure 2 shows the plan layout of basemat of sample AB.

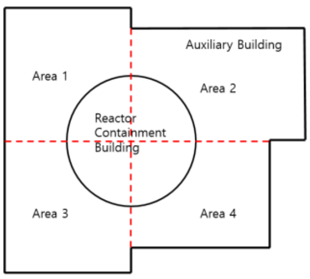

Figure 2. Plan Layout of AB at Basemat

Force and moment comparisons could be obtained from the analysis results. Force and moment of SPRA with PGA 0.5g shows higher value about 130% (SPRA/Design) than those of Design. And then, we are also able to check SPRA results are enveloped (71.0% ~ 90.2%, SPRA/Design) by Design results if 0.5g PGA scaled down to 0.3g SSE level as shown in Table 3.

Table 3. Force and moment comparison (SPRA/Design)

PGA	Force			Moment		
	X(kip)	Y(kip)	Z(kip)	Mxx(kip-ft)	Myy(kip-ft)	Mzz(kip-ft)
0.3g ※ Down Scaling to SSE Level	77.6%	82.8%	88.8%	87.2%	86.8%	90.2%
	74.5%	79.8%	69.3%	76.1%	75.2%	77.4%
	72.5%	79.4%	69.2%	80.2%	74.4%	79.4%
	71.3%	79.0%	71.8%	81.3%	73.6%	81.2%
	71.6%	78.0%	73.2%	82.3%	73.1%	84.3%
	71.0%	77.1%	74.5%	81.8%	72.3%	84.7%
	73.1%	76.7%	75.6%	80.6%	71.6%	84.4%
	77.6%	75.6%	78.3%	79.1%	71.0%	84.2%
	78.4%	78.1%	80.0%	78.3%	71.4%	83.6%
	78.5%	79.0%	81.3%	77.0%	71.7%	82.7%

4. Conclusion

In this study, SPRA seismic analysis procedure is shown and sample analysis is also done. Five sets of actual ground motion could be selected and be modified as per SRP 3.7.1 successfully. Comparative reviews are done between the analysis results of ground motion by NUREG/CR-0098 and RG 1.60.

From those results, we can have some insights for SPRA methodology at NPP. Stress resultants of SPRA shows lower value (71.0% ~ 90.2%) than those of Design under 0.3g PGA. From this, we can expect the existing APR1400 type AB may have enough seismic load carrying capacity with safety margin about 1.28.

This study shows only seismic analysis procedure and characteristics of SPRA to see trends of analytical results but not included all the details. Moreover, the all analytical results show lower value than design value. This is due to selection of five sets ground input motion. So, Further study related details of engineering calculation work and more various type of ground motions shall be followed.

REFERENCES

[1] U.S. NRC, Guide 1.60, Design Response Spectra for Seismic Design of Nuclear Power Plants, Rev.1, December 1973.
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[3] N.M. Newmark, and W.J. Hall, Development of Criteria for Seismic Review of Selected Nuclear Power Plants, NUREG/CR-0098, May 1978.
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[5] Computer Program ACS SASSI User's Manual