A study on Beyond Design Basis Earthquake Evaluation Methodology of the U.S and Japan

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1. Introduction

The earthquake that happened on Sep 12, 2016 with Magnitude 5.8 was the biggest earthquake ever in South Korea. After the 9.12 earthquake happened, Korean people's interest in the safety of nuclear power plants (NPPs) against earthquakes significantly increased. In Dec, 2016, Korean government made clear to the public that the government would take actions to enhance the existing NPPs' safety against the earthquakes above the designed level.

This study was conducted as a part of study to enhance the safety of the existing NPPs from earthquakes exceeding the design basis. This includes review on evaluation methodologies/procedures for beyond design basis earthquakes (BDBE) in the U.S and Japan and research on regulation requirements about safety of BDBE for NPPs in the two countries. Also, through this study we aim to make ways to strengthen seismic safety by means of methodology, which we will come up with, to improve the seismic design and/or performance against BDBE.

2. Methods and Results

2.1 U.S

Following the accident at the Fukushima Daiichi NPPs resulting from the 11 March 2011, Great Tohoku Earthquake and subsequent tsunami, the U.S. Nuclear Regulatory Commission (USNRC) established a Near Term Task Force (NTTF) to conduct a systematic review of USNRC processes and regulations. The NTTF developed a set of recommendations intended to clarify and strengthen the regulatory framework for protection against natural phenomena. Subsequently, the USNRC issued a 10 CFR 50.54(f) Letter [1] that requests information to ensure all the U.S NPPs address these recommendations. This letter requests that licensees and holders of construction permits under 10 CFR Part 50 reevaluate the seismic hazards at their sites against present-day USNRC requirements and guidance.

The Electric Power Research Institute (EPRI) project team formulated guidance for the seismic evaluations through a series of expert meetings, supplemented by analytical research to evaluate selected criteria. The approach was documented in *Seismic Evaluation Guidance: Screening, Prioritization and Implementation Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic* in 2013 (EPRI 1025287) [2]. Previous seismic evaluations are described and applied to the extent applicable. Screening methods are described for evaluating newly calculated seismic hazards against previous site-specific seismic evaluations, as well as for determining the structures, systems, and components (SSCs) appropriate for modeling in a seismic probabilistic risk assessment (SPRA). A number of public meetings were held with the USNRC during development of the guidance to discuss evaluation criteria and to ensure the guidance meets the requirements of NTTF Recommendation 2.1: Seismic.

SPID consists of four major tasks area: (1) developing updated ground motion response spectra (GMRS) based on RG 1.208 [3], (2) comparison GMRS vs safe shutdown earthquake (SSE) and plant screening, (3) prioritization of risk assessments, (4) performing seismic risk evaluation (SPRA/SMA). Figure 1 (taken from the SPID) illustrates the process for employing this approach.

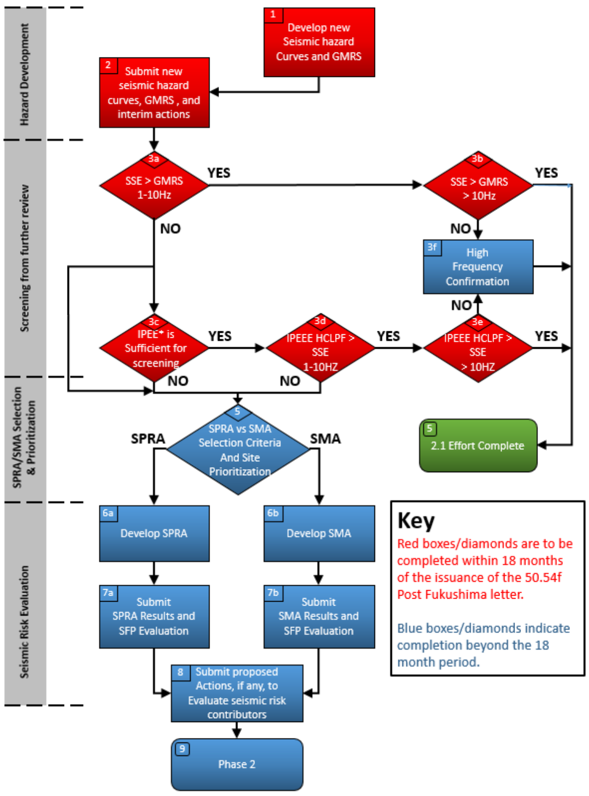

Figure 1. Recommended Approach to Respond to NTTF 2.1 Seismic

A total of 102 units located at 63 U.S. NPP sites are reviewed for the NTTF Recommendation 2.1 Seismic. Of the 63 sites, 22 sites are required to perform additional risk analysis and other activities. More detailed information is provided in Table 1 and Figure 2 below.

Table 1. Statistics of Final Determination of SPRA and Other Activities

Seismic Issue	Sites	Units	Remark
Screened Out	6	12	Outcome 1
SPRA	22	38	Outcome 3
High Frequency Confirmation	28	40	Outcome 2
Spent Fuel Pool Integrity	43	69	
Low Frequency Issue	1	2	

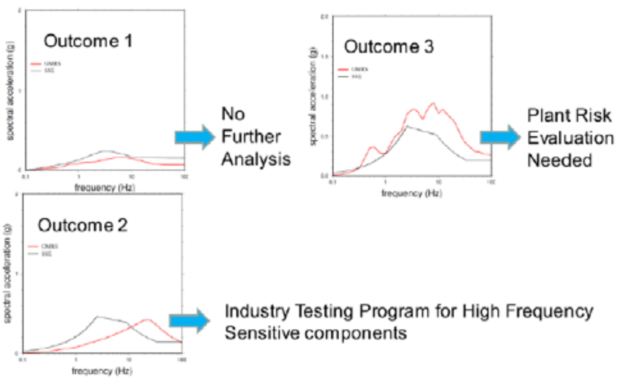

Figure 2. Screening to NTTF 2.1 Seismic

2.2 Japan

Japan has experienced several earthquakes that have directly affected NPPs with ground motions exceeding the design-basis ground motion. However, in these cases, minimal or no damage from strong shaking of safety-related SSCs was observed. This is a testament to the adequacy of the seismic design standards of Japan and field experiments and laboratory testing in Japan over this same period have illuminated aspects of the standards and the conservatism contained therein. The lesson learned from these experiences is that seismic design of NPPs in Japan has been demonstrated to be extremely effective when tested by actual earthquake shaking. However, following the accident at the Fukushima Daiichi NPPs resulting from the 11 March 2011, the most NPPs were shut down and are performing evaluations of seismic safety for new ground motions.

SSCs of Japan NPPs are designed in accordance with JEAG (Japan Electric Association Guide) 4601 [4] and JEAC (Japan Electric Association Code) 4601 [5]. JEAC 4601 is composed of five chapters and seismic design for buildings and structures is described in chapter 3. The key features of JEAG/JEAC 4601 are investigated and as below.

- Two levels of ground motions (Ss, design-basis ground motion, and Sd, elastic design ground motion) are used in seismic design of SSCs and nonlinear analysis is acceptable in Ss design.
- Realistic soil damping and nonlinearity are used in site response analysis.
- Soil spring model considering building sliding and rocking is used in soil-structure interaction (SSI) analysis.
- Ss (Sd) is combined with NOL (Normal Operating Load) without Accidental Loads.

Generally, significant reduction of seismic motions occur in site response analysis due to realistic soil damping and nonlinearity and figure 3 shows an example of Kashiwazaki-Kariwa NPP (KKNPP) Unit 7 which indicates that 1209 gal of level of control point (EL. -155m) is reduced to 814 gal at the bottom of Reactor Building basemat (EL. -13.7m).

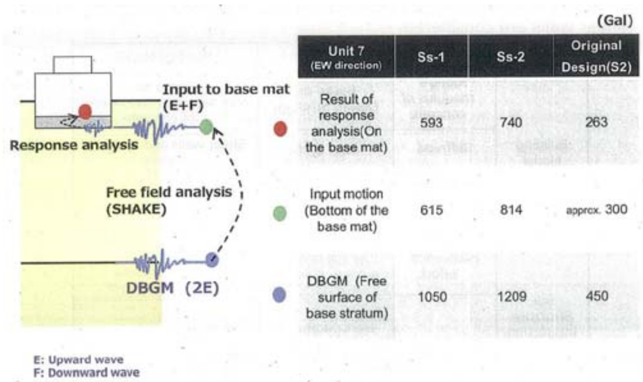

Figure 3. Acceleration Reductions at Each Step in Seismic Analysis of KKNPP Unit 7

3. Conclusions

In this study, BDBE evaluation methods of the US and Japan are analyzed and summarized as below.

- In the U.S, NTTF 2.1 Seismic in accordance with US NRC 50.54(f) Letter is performing to evaluate BDBE. The detail methodology is described in SPID (EPRI 1025287)
- In Japan, new earthquakes ground motions are introduced in JEAG/JEAC 4601. Design for Ss ground motion in the guide and code is similar to evaluation of BDBE in the U.S.
- The detailed BDBE evaluations of the U.S vs Japan are compared in Table 2. Furthermore, BDBE evaluation method of Korea will be prepared in the

future.

Table 2. BDBE Evaluation in the U.S vs Japan

	U.S	Japan
Method	NTTF 2.1 Seismic	JEAG/JEAC 4601
Seismic input	Site-specific GMRS	Site-specific GMRS (Ss)
Return Period	10,000~100,000 years	120,000 ~ 130,000 years
Site Response Analysis	SHAKE (Equivalent Static)	SHAKE (Equivalent Static or 3-D Nonlinear)
	BE, UB, LB	BE
Structural Model	LMSM, FEM	LMSM
Soil Modeling	Soil Layered, 3D Soil	Soil Spring
Structural Analysis	Linear-Dynamic	Bi-linear or Tri-linear
Structural Damping	Best-estimate	5% (Reinforce Concrete)
SSI Analysis	Frequency-domain Analysis (SASSI)	Nonlinear TH Analysis using Soil Spring (Inhouse program)

ACKNOWLEDGEMENT

This study was supported by the Seismic Design /Performance Enhancement Program of KHNP.

REFERENCES

[1] U.S. Nuclear Regulatory Commission, Request for Information Pursuant to Title 10 of the Code of Federal Regulations 50.54(f) Regarding Recommendation 2.1, 2.3, and 9.3, of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident, Letter to All Power Reactor Licensees et al. (ML12053A340), 12 March 2012.

[2] Electric Power Research Institute, Seismic Evaluation Guidance: Screening, Prioritization and Implementation Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic, 1025287, Palo Alto, CA, 2012.

[3] U.S. Nuclear Regulatory Commission, Regulatory Guide 1.208, Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion, Washington, DC, Mar. 2007.

[4] JEAG (Japan Electric Association Guide) 4601-2015.

[5] JEAC (Japan Electric Association Code) 4601-2015.