Transactions of the Korean Nuclear Society Virtual Autumn Meeting
October 21-22, 2021

Introduction of Seismic Fragility Gap Analysis for Operating NPPs

Hyoungkeun Yoo[a*], Kyuho Hwang [b], Fred F. Grant [b]
[a]*SI Business Department, KEPCO E&C, 269 Hyeoksin-ro Gimcheon-si Gyeongsangbuk-do, 39660*
[b]*Simpson Gumpertz & Heger Inc., 4695 MacArthur Court Suite 500 Newport Beach, California, CA 92660*
[*]*Corresponding author: yhkeun99@kepco-enc.com*

1. Introduction

A seismic fragility is a part of seismic PSA (probabilistic safety assessment) to estimate HCLPF (high confidence of low probability of failure). A HCLPF is a seismic capacity of SSCs (structures, system and components) mainly based on PGA (peak ground acceleration), which is a realistic seismic capacity at the given PGA to already have an additional margin at design stage. The ASME/ANS PRA Standard 2009 [1] (hereafter, ASME 2009) was issued containing the requirements on seismic hazard, seismic fragility and plant response analysis.

Korean NPPs (nuclear power plants) operating now can be required by ASME 2009 to enhance the safety and soundness based on a new standard. Re-estimation of seismic fragility will be required to meet ASME 2009, but, which takes many times and budget. So, Seismic Fragility Gap Analysis is introduced for operating NPPs.

2. Methods and Results

In this section gap analysis of seismic fragility is defined and case adaption for virtual NPP is performed.

2.1 Seismic fragility model introduction

The objective of fragility evaluation is to estimate the ground acceleration capacity of a given component. This capacity is defined as the peak ground acceleration value at which the seismic response of a given component located at specified point in the structure exceeds the component's resistance, resulting in its failure. The ground acceleration capacity of the component is estimated using information on plant design basis, responses calculated at the design-analysis stage, as-built dimensions, and material properties. The ground acceleration capacity is called HCLPF, a random variable which can be described completed by its probability distribution. However, there is uncertainty in the estimation of parameters of this distribution, the exact shape of this distribution, and in the appropriate failure model for the component. For any postulated failure model and set of parameter values and shape of the probability distribution, a fragility curve depicting the conditional probability of failure as a function of ground acceleration can be obtained.

The entire fragility family for an element corresponding to a particular failure mode can be expressed in terms of the best estimate of the median ground acceleration capacity, Am, and two random variables. Thus, the acceleration capacity, A, is given by

$$A = Am \cdot e_R \cdot e_U$$

in which e_R and e_U are random variables with unit medians, representing, respectively, the inherent randomness about the median and the uncertainty in the median value. In this model, both e_R and e_U are assumed to be log-normally distributed with logarithmic standard deviations, β_R and β_U, respectively.

At each acceleration value("a"), the fragility f′ can be expressed by a subjective probabilistic density function [3].

$$f' = \emptyset[\frac{\ln\left(\frac{a}{Am}\right) + \beta_U * \emptyset^{-1}(Q)}{\beta_R}]$$

where Q is the subjective probabilistic (confidence) that the conditional probability of failure, f, is less than f′ for a peak ground acceleration a.

∅ is standard Gaussian cumulative distribution function.

With perfection knowledge (i.e., only accounting for the random variability, β_R, the conditional probability of failure, f, for a given peak ground acceleration level, a, is given by [3]

$$f = \emptyset[\frac{\ln\left(\frac{a}{Am}\right)}{\beta_R}]$$

The equations above can be expressed by a figure.

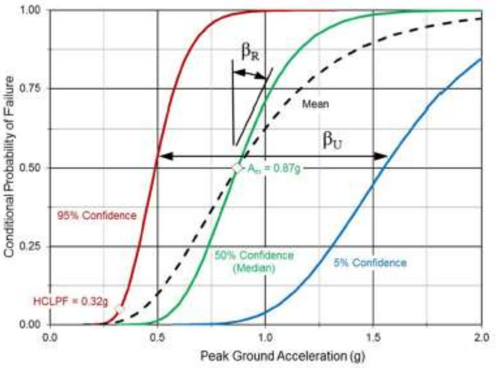

Fig. 1. Example of seismic fragility curve [2]

2.2 Comparison of vintage and current methodology for seismic fragility

The methodology for seismic fragility of vintage operating NPP is based on the study result of U.S documented in Ravindra and Kennedy (1983), PRA Procedure Guide (1983), and Kennedy and Ravindra (1984) and has been developed and applied in over 20 seismic probabilistic risk assessment of nuclear power plants.

The current domestic methodology for seismic fragility is standardized by ASME/ANS PRA Standard 2009[1] which are developed and being updated from past 20 years until now.

There are about 17 parameters in both structural and equipment response when performing seismic fragility. Only relevant parameters which have the gaps between the vintage and current methodology have been shown in Table I, and the others to have no gaps are ignored.

The existing gaps between vintage and current methodology for seismic fragility are presented Table I.

Table I: Major Gaps in Vintage and Current Methodology for Seismic Fragility Parameters

Variable	Vintage	Current
Test Response Spectra Capacity	*No spectral clipping *No capacity increase factor *Device capacity factor outdated	*Spectral clipping *Capacity increase factor *Device capacity factor updated
Ground Motion Input Scaling	EQE spectrum	NUREG/CR-0098
Structure Damping	Median damping : 7%	Median damping: 5% (at structure half-yield level)
Structure Modeling	*Simple lumped stick model *Frequency variation is conservatively high.	Input motion is very broad band, which reduces the significance of structure frequency variation.
Ground Motion Incoherency	At component frequency	At component and structure frequency
Multi-Directional Effects	Tri-axial tests were treated as median-centered for function-after evaluation, and biaxial tests were as treated median-centered for function-during evaluation in vintage fragilities	For multi-axis TRS applied to single-axis response component, EPRI TR-103959[3] recommends a median factor of 1.2, that is, the TRS can be increased by 1.2.
In-Structure Response Clipping	No spectral clipping	Spectral clipping
Equipment Demand Reduction	Not applied	Applicable for single time-history response analysis, and equipment mounted high up in the structure (not on grade)

2.3 Case analysis for feasibility

For the feasibility of gap-adjustment approach, sample detailed calculation and the gap-adjustment results are compared.

The broad classification of equipment is taken into account, composed of tanks, pumps, generators, electrical equipment. Comparison results for feasibility is presented in Table II.

Table II: Comparison Results for Feasibility

Equipment	Increase/Decrease Percentage (Gap adjustment/Sample Calc.)
Tanks	8% increase
Pumps	2% increase
Mechanical Equipment	8% decrease
Generators	30% decrease
Electrical Equipment	**13% increase**
Distribution Sys.	22% decrease

As a result, the ratio of Gap adjustment/Sample detailed calculation less than 1.1 except electrical equipment is considered to represent consistency with real calculation.

The uncertainties in natural frequencies of electrical equipment are estimated to be main cause to induce deviation bigger than 1.1 ratio. Except an electrical equipment, the gap analysis results of others are evaluated conservative.

3. Conclusions

There are no enough options to re-estimate the seismic fragility for the new standard to revise outdated one in limited time. So, gap analysis is suggested to reasonably re-estimate seismic fragility in limited time and effort, and the results of it are around 10% matched to real calculation. But, this attempt is limited to guess the result and identify the trend for the gap between the old and new standard.

REFERENCES

[1] ASME, Addenda to ASME/ANS RA-S-2008 Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Application, ASME/ANS RA-Sa-2009, 2009.

[2] EPRI, Seismic Fragility and Seismic Margin Guidance for Seismic Probabilistic Risk Assessments, EPRI-3002012994, 2018.

[3] EPRI, Methodology for Developing Seismic Fragilities, TR-103959, June, 1994.

[4] Ravindra, M. K., and R. P. Kennedy, "Lessons Learned from Seismic PRA Studies." Paper M6/4. In Proceedings of the Seventh Conference on Structural Mechanics in Reactor Technology, Chicago, Illinois, August, 1983.

[5] PRA Procedure Guide, NUREG/CR-2300, Volume 2, January, 1983.

[6] Kenedy, R. P., and M. K. Ravindra, "Seismic Fragilities for Nuclear Power Plant Risk Studies.", Nuclear Engineering and Design 79, No. 1 (May (I) 1984): 47-68, 1984.