Effects of Variability of Seismic Fragility Analysis Variables on Seismic Capacity of Structure

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1. Introduction

The seismic probabilistic assessment (SPRA) has been developed to resolve the safety issue and to evaluate the more reasonable seismic capacity of nuclear power plant. The seismic fragility analysis (SFA) is one of separate works included in SPRA, which is a tool to evaluate the seismic capacity of structure.

This paper discussed on variability of basic variables for seismic fragility analysis of structure. The practical guidance presents variability ranges of fragility variables as recommendable value for practical use. The recommended values are presented in this paper. The results of comparative studies are presented to inform quantitatively variation of structural seismic capacity in relation with the degree of variability of the basic fragility variables.

2. Seismic Fragility

The SFA methodology of this study is basically similar to that of US Electric Power Research Institute (EPRI), called "response factor method"[1]. In this method, the response factor is a measure of conservatism included in seismic design and a ratio of design response to actual response. Using peak ground acceleration as ground motion parameter, the seismic fragility of structure as seismic capacity acceleration, A is expressed by equation (1) [2, 3].

$$A = A_m \cdot \varepsilon_R \cdot \varepsilon_U \quad (1)$$

where, A_m : median of seismic fragility

ε_R : random variable for randomness with unit median and β_R of logarithmic standard deviation

ε_U : random variable for uncertainty with unit median and β_U of logarithmic standard deviation

Using the response factor method, an actual seismic capacity, A is obtained by equation (2).

$$A = (\prod_i F_{Ci} \cdot F_{Ri}) \cdot a_{ref} \quad (2)$$

where, F_{Ci} : safety factors for capacity variables

F_{Ri} : safety factors for response variables

a_{ref} : reference ground acceleration (usually, safe shutdown earthquake leve)

The seismic fragility is expressed by a set of probability of failure P_f for a given ground level, a at any non-exceedance probability level as in equation (3) [1].

$$P_f = \Phi\left[\frac{\ln\left(\frac{a}{\bar{A}}\right) + \beta_U \Phi^{-1}(Q)}{\beta_R}\right] \quad (3)$$

where, $\Phi[\ ]$: cumulative distribution function of normal distribution

Q : non-exceedance probability level (5%, 50% or 95% level in usual)

$\Phi^{-1}[\ ]$: inverse of normal function

The HCLPF capacity is defined in SPRA to be the 95% confidence of a 5% probability of exceedanc, which is an index to express the seismic capacity of structure. The HCLPF is calculated by equation (4).

$$HCLPF = A_m \cdot \exp[-1.645(\beta_R + \beta_U)] \quad (4)$$

3. Fragility Variables

The fragility analysis for structures considers both response and capacity variables as basic fragility analysis variables. These variables are represented by safety factors as expressed in equation (2). The response variable accounts for the conservatism of seismic response which may result from the variabilities of design ground motions, damping values, and caused by the techniques of modeling, mode combination, earthquake component combination, soil-structure interaction analysis, and so on. The strength and the inelastic energy absorption capacity of structural members are considered as capacity variables to reflect the actual resistance of structures under the reference earthquake.

The variability of fragility variable may be determined by considering actual experiences and various experimental data. The US practical guidance presents the recommended values about the variability of basic variables. Table I shows the variabilities of fragility variables recommended by US EPRI.

Table 1: Recommended variability of basic variable

variable \ value	β_R	β_U
spectrum shape factor	0.12~0.22	0~0.32
horizontal peak response	0.12~0.14	0
vertical component response	0.22~0.28	0.20~0.26
damping	0	-1σ
frequency	0	0.15~0.35
mode shape	0	0.05~0.15
tensional coupling	0	≤ −2σ
mode combination	0.05~0.15	-
ground motion incoherence	-	≥ 2σ
vertical spatial variation of motion	0.08	
earthquake component combination	≤ 0.45	-

4. Evaluation of Seismic Capacity Variation

This study performs numerical evaluation of seismic fragility of YGN 5&6 containment building structure to analyze quantitatively the variation of seismic capacity in accordance with the variability of fragility variables. The structural model and the fragility variables were referred to reference 4. Table 2 shows the basic fragility variables.

Table 2: Fragility variables for the structural model

variable \ value	Median factor	β_R	β_U
Strength	7.42	0.0	0.15, 0.25
Inelastic energy absorption	2.1	0.22	0.17
Response spectrum shape	1.25	0.18, 0.22	0.05, 0.24
Damping	1.0	0.06	0.06
Modeling	1.0	0.0	0.15, 0.35
Mode combination	1.0	0.05, 0.15	0.0
Earth. comp. combination	1.0	0.05, 0.18	0.0
Soil structure interaction	1.0	0.0	0.0
Ground motion direction	0.9	0.0	0.0, 0.15

Table 3: Fragility analysis results

	Reference 4	Upper value	Lower value
Median factor	17.53	17.53	17.53
A_m	3.51 g	3.51 g	3.51 g
β_R	0.325	0.299	0.394
β_U	0.329	0.283	0.546
HCLPF	1.20 g	1.34 g	0.743 g

Table 3 and Fig. 1 and Fig. 2 show the SFA results obtained by considering the lowest variability and the highest variability of fragility variables, respectively. The HCLPF value can be larger by 12% or be smaller by 35% in accordance with the variability of fragility variable.

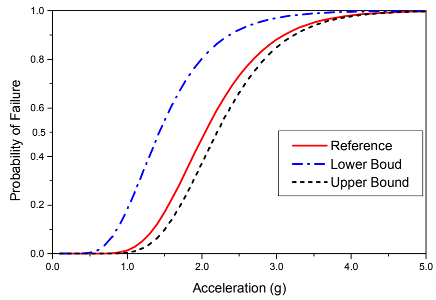

Fig. 1 95% confidence curve of seismic fragility

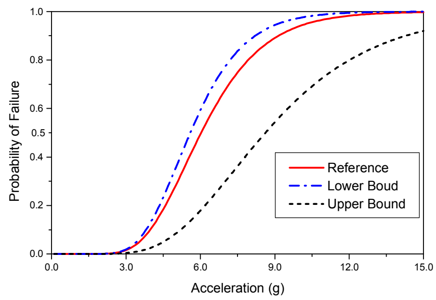

Fig. 2 5% confidence curve of seismic fragility

5. Conclusions

In SFA, the seismic capacity of structures could be over-estimated or under-estimated by applying the lower or the higher recommended values for the variability of fragility variables. Some extended studies should be continued to present more reasonable variability of fragility variables for practical use.

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