

A study on seismic behavior of nuclear power building in strong nonlinear area and fragility evaluation using 3 dimensional FEM Part-2 Fragility evaluation

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Keywords: Seismic PSA, 3D FEM, Nonlinear analyses, Soil-structure interaction, Basemat uplift, Lumped mass model

1 ABSTRACT

The evaluation based on the probabilistic safety assessment (PSA) is expected for nuclear power buildings because the risk of the occurrence of the seismic ground motions beyond the design assumption cannot be denied. In this paper, the building fragility evaluation of the seismic PSA was carried out using the 3 dimensional nonlinear FEM model based on the result of part-1.

As the fracture modes, the shear failure of the web wall and the flexural failure and the compressive failure of the flange wall were assumed. The fragility curves of the FEM model and lumped mass model in each analysis case were calculated as follows. First, the failure probability was plotted on a diagram for each input acceleration level where analysis was conducted. The failure probability is calculated by considering the aleatory uncertainty of the response and strength value. The plotted points are approximated by a lognormal cumulative distribution function using the least squares method, which is taken to be the fragility curve.

2 INTRODUCTION

The September 2006 revision of the Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities Nuclear Safety Commission of Japan, (2006) noted the existence of risk (residual risk) arising from the seismic ground motion exceeding the design basis ground motion. This has created demand for the proactive introduction of evaluation methods for quantitatively evaluating this risk based on the most up-to-date techniques, such as probabilistic safety analysis (PSA), and aggressive efforts for establishing these methods.

For the purpose, in the previous paper (part-1), a nonlinear 3D FEM model (Figure 1) was used to conduct seismic response analysis of large inputs to a nuclear power plant building and estimated the seismic ultimate behavior. First, response analysis was conducted by increasing the maximum horizontal acceleration up to 3500 Gal, and the effects of vertical input motion and basemat uplift on the response characteristics were evaluated. A comparison was also made with SR model response results.

In this paper, the building fragility evaluation of the seismic PSA was carried out using the 3 dimensional nonlinear FEM model based on the result of part-1. At building fragility evaluation, shear failure of web walls and compression crash of flange walls was assumed (except in the lumped mass SR model, where only shear failure was assumed), and the failure probability was calculated and the building fragility curve was determined.

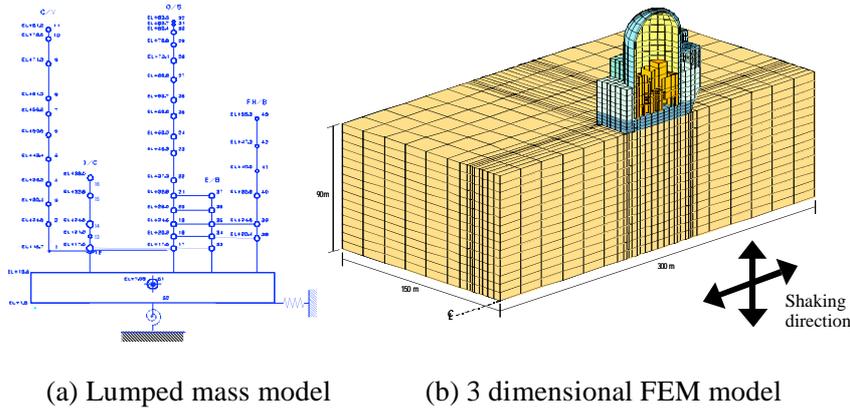


Figure 1. Analysis models

3 ANALYTICAL MODEL AND ANALYSIS CONDITIONS

Figure 1 shows the 3D FEM model and the lumped mass model that was used in the investigation. It is the same as part-1. Material Properties, Input seismic motion, Analysis condition are the same as part-1, too.

The building is a PWR type reactor building (R/B). This building is a compound building consisting of an outer shield (O/S), inner concrete (I/C), fuel handling building (FH/B), enclosure building (E/B), and a containment vessel (C/V). Figure 2 shows the locations of each building and Table 1 shows the abbreviations and materials of these buildings.

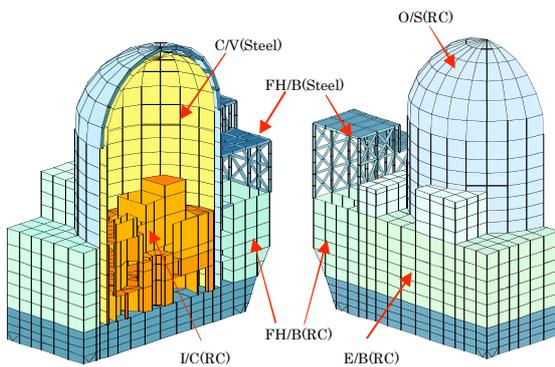


Figure 2. Position of each building consists of the reactor building

Table.1. Abbreviations and materials

Building		Abbreviation	Material
Outer Shield		O/S	RC
Inner Concrete		I/C	RC
Fuel Handling	Upper	FH/B	Steel
	Lower	FH/B	RC
Enclosure Building		E/B	RC
Containment Vessel		C/V	Steel

4 BUILDING FRAGILITY EVALUATION PARAMETER CONDITION

4.1 Consideration of Variations in Response

Variations in the response were generally considered by dividing them into aleatory uncertainty (β_r) and epistemic uncertainty (β_u). The former corresponds to the randomness of materials, and the latter corresponds to the unknown of the analysis, mainly. In this study, only β_r are considered to evaluate the building fragility as follows.

In Japanese PSA study, the concrete strength, concrete damping coefficient, and soil shear wave velocity etc. are generally considered as variable parameters for β_r . Miake et al. (2005) conducted a study on the value of β_r for the building response considering these variable parameters, and showed that the value of β_r of the maximum response shear strain was approximately 0.2. Based on this, the value of β_r of the maximum response shear strain is taken to be 0.2 in this study. Furthermore, the value of β_r of the maximum response vertical stress was also taken to be 0.2.

4.2 Failure Mode and Strength Settings

In the explanatory note 66 of the PSA standard, shear failure of shear walls is given as the dominant failure mode for Japanese general nuclear power plant buildings. Furthermore, the effect that local damage has on the building is relatively small, compared to entire destruction of the story of the building.

In this study, bending failure and compressive failure are considered as building failure modes in addition to shear failure (refer to Table 2). In order to evaluate the damage to an entire story instead of the damage at the local element level, evaluation was made by averaging the shear strain and axial stress of each story across the corresponding web and flange regions. The averages of flange regions were calculated separately on the northern and the southern side.

Table 3 shows the mean value and variation of the ultimate shear strain of shear walls and the compressive strength of concrete. They are used as the strength values for the damage probability calculation based on Appendix 5 (regulations) and Appendix 9 (regulations) of the PSA standard. Because the shear walls are modeled using layered shell elements, the response values for concrete in the outermost layer are used in all cases.

Table.2. Fracture modes considered in this paper

Direction of input ground motions	Failure modes for shear walls	Index for response for shear walls	Index for strength
Horizontal only or simultaneous horizontal and vertical	Shear failure in web parts	Averaged shear strain	Ultimate shear strain of shear walls
	Bending failure in flange parts	Averaged axial force	Compressive strength of concrete
Vertical only or simultaneous horizontal and vertical	Compressive failure		

Table.3. Fracture modes considered in this paper

Index for strength		Mean	Coefficient of variation	Median	Logarithm standard deviation
Shear stress	Box walls	5.36×10^{-3} rad	0.24	5.21×10^{-3} rad	0.24
	Cylindrical walls	9.77×10^{-3} rad	0.32	9.30×10^{-3} rad	0.32
Compressional strength		34.0 N/mm ²	0.13	33.7 N/mm ²	0.13

4.3 Fragility Curve Calculation

The fragility curves of the FEM model and lumped mass model in each analysis case are calculated as follows. First, the damage probability was plotted on a diagram for each input acceleration level where analysis was conducted. The damage probability is calculated by considering the β_r of the response and strength value. The plotted points are approximated by a lognormal cumulative distribution function using the least squares method, which is taken to be the fragility curve.

5 BUILDING FRAGILITY EVALUATION

Figure 3 shows the curves with the highest damage probability for the O/S and E/B from among the fragility curves calculated for each story of the web regions in the O/S and E/B in the basic case. Among these, the O/S at the height around EL.+45.3m is critical.

Figure 4 shows a comparison of the fragility curves for horizontal input only and for simultaneous horizontal and vertical input, and Figure 5 shows a comparison between the case where uplift was considered and when uplift was ignored. In both figures, differences in the fragility curves of the critical O/S are small. This shows that the effects of vertical motion and basemat uplift on the building fragility evaluation were relatively small.

Figure 6 shows a comparison between the basic case using the FEM model and horizontal input only using the lumped SR model. In the lumped mass SR model results, the damage probability is overall larger than the FEM model results for the same input. Furthermore, the E/B is more easily damaged than the O/S, and this tendency is thought to correspond with the results shown in Figure 13(b) of Part-1. In the above results, the fragility curve of the lumped mass SR model exhibited a tendency to estimate the damage larger when compared to the FEM model, and the difference was particularly large in the E/B.

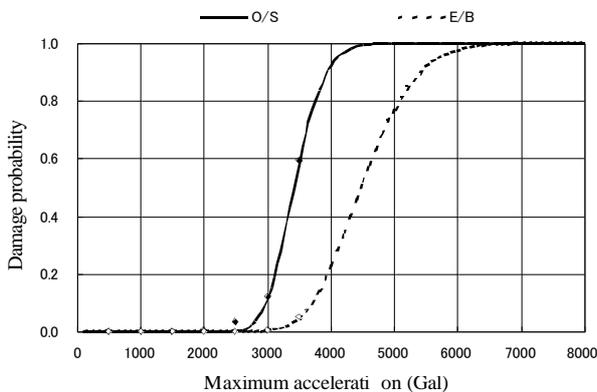


Figure 3. Fragility curves of each position for simultaneous input (considering uplift)

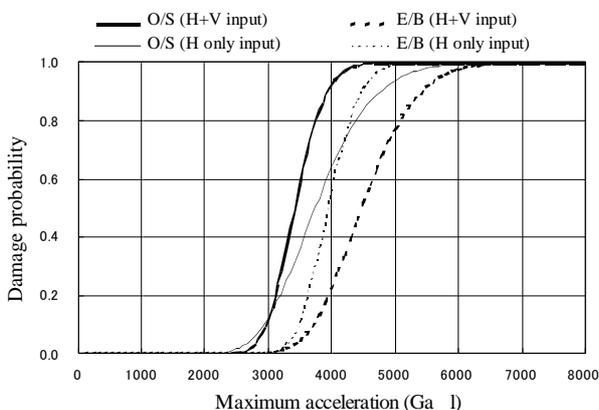


Figure 4. Comparison of fragility curves between simultaneous input and horizontal input only

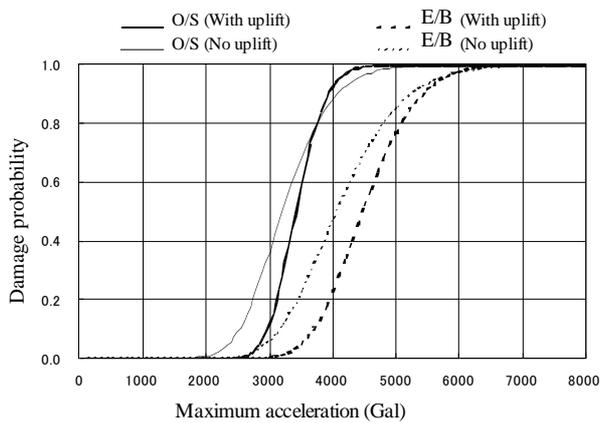


Figure 5. Comparison of fragility curves between when uplift is considered and when neglected

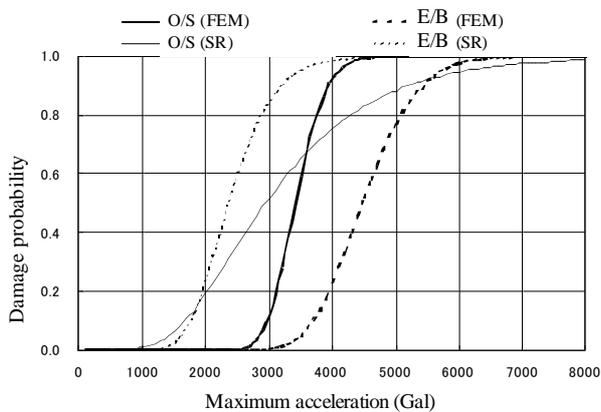


Figure 6. Comparison of fragility curves between 3D FEM model and lumped mass SR model

6 CONCLUSION

In this paper, the building fragility evaluation of the seismic PSA was carried out using the 3 dimensional nonlinear FEM model based on the result of part-1.

As the fracture modes, the shear failure of the web wall and the flexural failure and the compressive failure of the flange wall were assumed. The fragility curves of the FEM model and lumped mass model in each analysis case were calculated as follows. First, the failure probability was plotted on a diagram for each input acceleration level where analysis was conducted. The failure probability is calculated by considering the aleatory uncertainty of the response and strength value. The plotted points are approximated by a lognormal cumulative distribution function using the least squares method, which is taken to be the fragility curve. From the study, the following results were obtained

- (1) In terms of the failure mode of the envisioned reinforced concrete seismic walls, shear failure preceded flexural failure and compressive failure.
- (2) In the evaluation of shear strain, the difference between the fragility evaluations for horizontal input only and simultaneous horizontal and vertical input was small, and thus the effect of vertical input was relatively small.
- (3) The effect of basemat uplift on fragility evaluation was relatively small.
- (4) In the fragility evaluation, the lumped mass SR model exhibited a tendency to estimate damage largely compared to the FEM model.

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