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Development of Framework of Seismic PSA using 3D FE model of NNPs

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1. Introduction

A 3D FE model of the nuclear power plant has been developed for the evaluation of structural safety beyond the design level. Developing a FE model is key to the numerical study of nonlinear structural response with the earthquake input ground motion.

Especially the auxiliary building, where most of critical equipment for the seismic PSA are located, is considered to define the failure mode and its measurement. Eventually, this study aims to perfume the probabilistic seismic analysis and develop numerically a fragility curve for the auxiliary building.

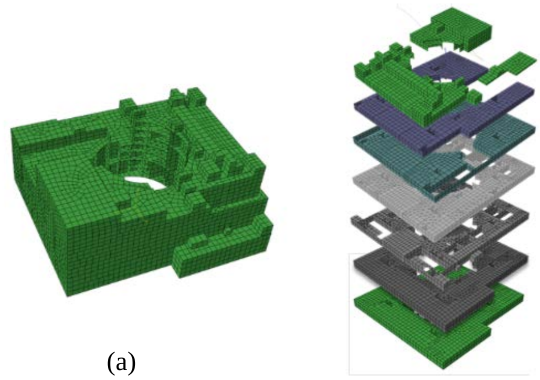
At the end, a framework for the seismic PSA is proposed by integrating the probabilistic seismic hazard analysis and the fragility analysis using a 3D FE model, analysis.

2. Methods and Results

2.1 3D FE Model of APR1400

The 3D FEM model of the APR1400 in ABAQUS includes the containment building and the auxiliary building. The model for containment building is composed of the containment, the internal structures, the reactor coolant system (RCS), and the basemat. The containment has a height of 76 m and a diameter of 45 m. The thickness of the cylindrical wall is 1.37 m while that of the dome is 1.22 m. In modeling, solid elements were used for concrete material and truss elements for tendons and reinforcements. The vertical and horizontal pre-stressing was applied as an initial condition for the wall and the dome.

The auxiliary building has the shape of rectangle with 106 m x 107 m. It has the seven floors from EL. +55ft to EL. +172ft. Each floor is divided into a number of rooms as compartment structures. Considering such complication, the auxiliary building was modeled by shell elements. Then, rebar option with the shell elements was used to model the reinforcements. In addition, the node connectivity between the floors was constrained using the tie option because continuous meshing is not applicable.



(a) (b)

Figure 1. (a) 3D FE model of auxiliary building (b) elevation view of auxiliary building.

2.2 Nonlinear Time History Analysis

An earthquake input ground acceleration from the Kyoungju earthquake data was selected to investigate the response of the containment building. The spectral acceleration was compared as response at the selected locations. Figure 2 shows the simulation with the earthquake input and Fig. 3 shows the comparison between linear and nonlinear simulation.

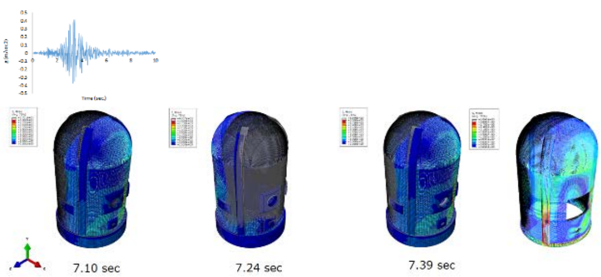


Figure 2. snapshots from dynamic simulation of containment building.

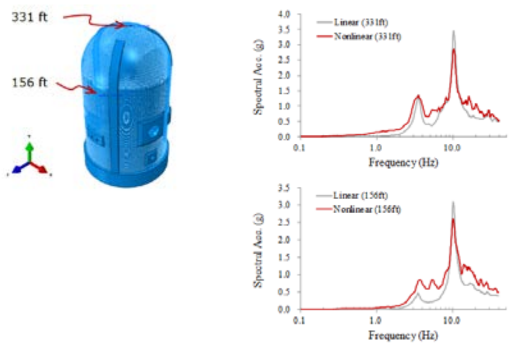


Figure 3. comparison of spectral acceleration between from linear and nonlinear analysis.

2.3 Failure Mode for Auxiliary Building

An x-directional pushover analysis was conducted to evaluate the failure mode because it is the first major mode. The mode shape $\{\varphi_x\}$ from the modal analysis and the mass matrix [M] were multiplied to result in the load vector {F}. Then, the load vector {F} was applied to the 3D FE model for the pushover analysis. The result is shown in Figure 4 and critical areas (F_1W_1~F_1W_6, F_2W_1~F_2W_7, and F_3W_1~F_3W_6) are identified based on the stress concentration (Fig. 5).

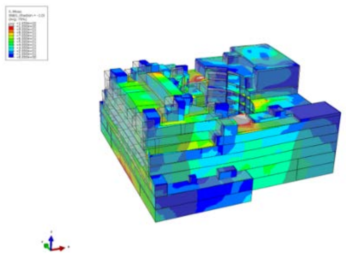


Figure 4. FE result from pushover simulation of auxiliary building.

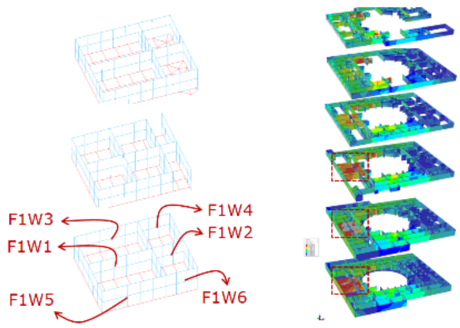


Figure 5. identification of critical shear walls from pushover simulation.

ASCE/SER 41 proposes the critical drift of shear walls from its hysteretic behaviors. A skeleton curve can be obtained from the hysteretic curve of a shear wall. It generally depends on the span-depth ratio, the horizontal-vertical reinforcement ratio, the axial force magnitude, and etc. In this study, the span-depth ratio of 1 was assumed and critical drift 1% (0.01 Height of the shear wall) was selected as an example.

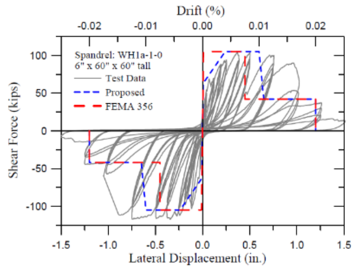


Figure 6. selection of skeleton curve from ASCE/SEI 41

3. Conclusions

In summary, 3D FEM model of the NPP structure was developed and nonlinear time history analysis was verified with the 3D model. The failure mode of the auxiliary building was defined from the push-over analysis in the major mode direction. Then, the fragility curve for the auxiliary building can be constructed from incremental seismic inputs. The integrated framework is proposed as results.

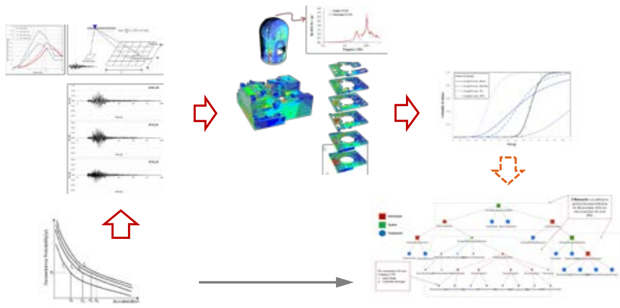


Figure 7. schematic view of integrated framework for seismic fragility

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