Dynamic Responses of Base Isolated NPPs under Seismic Excitations and Aircraft Crashes

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1. Introduction

Seismic isolation (SI) is a type of seismic design that is based on the concept of reducing the seismic demand rather than increasing the resistance capacity of the structure and related systems. Applying this technology leads to improved performance of structures that will remain essentially elastic during a design basis earthquake.

In the application of the system to a nuclear power plant (NPP) structure to gain seismic resistance advantages, other safety issues should also be considered. One of those issues is the safety of an NPP against an aircraft crash (ACC) [1].

In this study, responses of a seismically isolated structure, such as acceleration and displacement, were obtained from a time domain non-linear analysis to check the performance of SI system under seismic excitation. In addition, the dynamic responses of NPP structures with or without SI against an ACC were compared and other considerations are discussed.

2. Dynamic analysis under seismic excitations

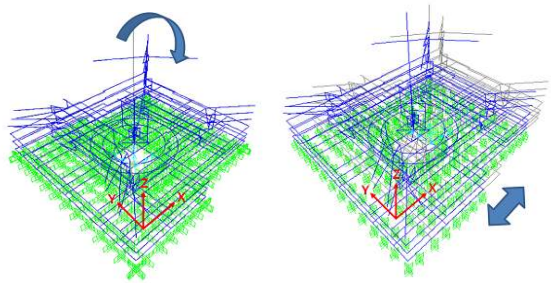
2.1 Analysis model

A fictitious NPP (Nuclear Power Plant) was modeled for the analysis and total weight of the structure used was approximately 4,700,000 kN and isolators (210EA.) were used to support the foundation and superstructure. The damping ratio of the SI system was set at 10 % and effective period of the system used was 2 sec. Analysis were performed with SAP2000 (ver.14).

2.2 Modal Analysis

The superstructure of the target NPP structure was modeled as a lumped mass beam stick and was combined with the finite element mat foundation model. The 1st mode period of the fixed-base structure shown in Fig. 1(a) was about 0.1881 seconds and it shows a rocking mode shape. On the other hand, the 1st mode period of the seismically isolated structure, shown in Fig. 1(b), is about 2.0 seconds and it shows a translational mode shape.

The modal participating mass ratio of translation modes of the base isolated structure are almost 1(0.99998) in each horizontal direction.



(a) Fixed base structure (b)Base isolated structure

Fig.1. 1st mode shapes of structures without or with SI

2.3 Dynamic Analysis under seismic excitations

2.3.1 Seismic input motion

An acceleration time history input motion with two horizontal components and one vertical component, of which the peak ground acceleration was set as 0.3g corresponding to the SSE(Safety Shutdown Earthquake) level, was applied to the model.

2.3.2 Acceleration and displacement responses

Fig.2 shows the sampling location of the response results. The acceleration responses as well as displacement responses were obtained from specific nodes of the finite elements. As for the shear forces of isolators, the analysis results were obtained from link elements(SIx) as shown in Fig 2.

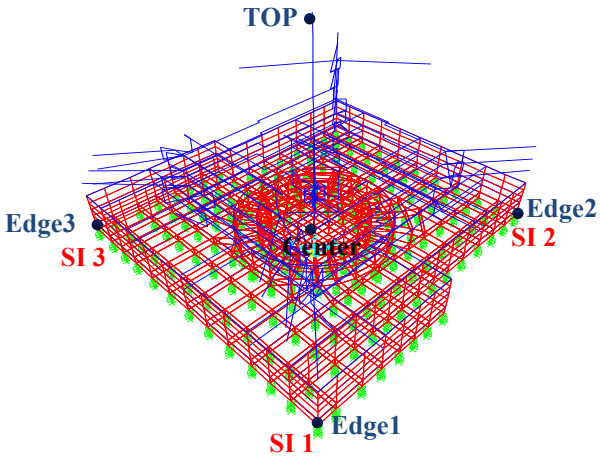


Fig.2. Locations of Sampling Data

Table I shows the absolute maximum acceleration responses and the absolute maximum

displacement responses of the dynamic analysis for concerned locations.

Table I : Absolute Maximum Acceleration and Displacement Responses of Dynamic Analysis

	Max. acceleration	Max. displacement
Top	0.1678 g	110.85 mm
Center	0.1475 g	109.17 mm
Edge1	0.1502 g	108.94 mm
Edge2	0.1469 g	108.92 mm
Edge3	0.1502 g	108.93 mm

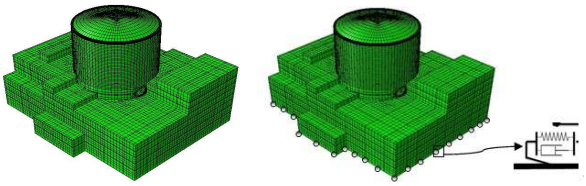
2.3.3 Discussion for the analysis results

Acceleration responses of dynamic analysis showed little differences from top to the bottom of the structure and the values of the structures above the isolators were rapidly reduced compared to the input motion, which means good performance of S.I. system.

3. Dynamic analysis against aircraft crash loadings

3.1 Analysis model

Fig. 3 shows the models of the fictitious nuclear building. The buildings have typical features of NPP buildings composed of RC structures [2].



(a) Fixed base structure (b) Base isolated structure

Fig.3. Models of structures without or with SI

Isolators (210 EA.) were used to support the foundation and superstructure. The damping ratio of the SI system was set at 0 % and effective period of the system used was 2sec. Analysis were performed with ABAQUS (ver.6.7.1).

3.2 Method of analysis and aircraft loading

The 'Force Time-History Analysis Method' was used in this analysis. In this method, the impact force time-history is first determined based on the aircraft crashing strength information and on impulse conservation principles, assuming that the target is rigid. The force time-history so obtained is then applied to a mathematical model of the structure in a time history analysis. The aircraft under consideration in the analysis is Boeing's 767-400.

3.3 Nonlinear Constitutive model

The Concrete Damaged Plasticity Model for concrete was adopted and the von Mises failure criterion is used for the rebar material in the analysis.

3.4 Analysis results

Nonlinear analyses for two NPPs with SI and without SI were performed for the impact locations of the mid-wall above the equipment hatch.

The results are summarized in Table II. The stresses are reported as normalized with Stress/Maximum allowable strengths in the table.

The maximum concrete compressive stresses and maximum rebar tension stresses calculated are nearly identical for the two cases (with or without SI) due to the aircraft loading.

The maximum horizontal displacement calculated at the point right above the SI was 2mm, which is very small shear strain level, about 1%, of the SI unit (300mm).

Table II : Comparison of the structural responses

Case	Concrete compressive stress (normalized)	Rebar tension stress (normalized)
with SI	0.83	0.443
without SI	0.83	0.442

4. Conclusions

The analysis result of performances of a typical base isolated structure under seismic excitations showed the benefits of SI system. The analysis result of another typical base isolated structure against an aircraft crash loading showed almost equal resistance between with SI system and without SI system, under each loading, respectively.

The developments of practical non-linear seismic and aircraft impact soil-structure interaction response analysis of the seismically isolated nuclear power plants are needed in further researches.

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