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Aircraft Impact Assessment for a Base-Isolated Nuclear Power Plant Structure

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ABSTRACT

Seismic isolation (SI) is a type of earthquake-resistant design that is based on the concept of reducing the seismic demand rather than increasing the resistance capacity of the structure and related systems. Appling 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).

Such an incident has the potential to damage the structures of an NPP as well as other systems and components, such as pipelines, electric motors, power supplies and power cables for electricity transmission, which are all important for safety.

This paper analyzes the impact of an ACC on NPP structures with and without SI. The analysis of an aircraft impact into nuclear power plant structures is discussed while utilizing a simplified model of a "fictitious nuclear structure" developed based on a typical NPP to perform the analysis.

The main point of the discussion is a comparison of structural responses between NPP structures with or without SI system against an ACC loading.

1. INTRODUCTION

The structures of an NPP must be designed to withstand the impact of an aircraft crash or the debris from such a crash. The problem is of strategic significance because the structural damage caused by such an incident may lead to the leakage of nuclear radiation.

In many parts of the world, including the USA and the EU, the design requirements for an

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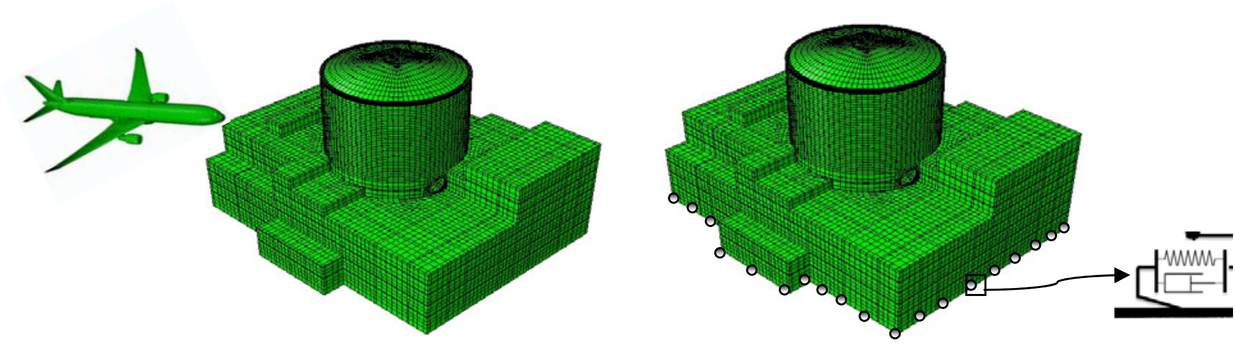
aircraft crash have been revaluated and reinforced since the terrorist attacks in the US on September 11, 2001. The US Nuclear Regulatory Commission recently determined that the impact of a large commercial aircraft was a beyond-design-basis event and published a new set of regulations (10CFR50.150, 2009).

In this paper, an analysis of an aircraft impact into nuclear power plant structures is conducted while utilizing a simplified model of a "fictitious nuclear building" using ABAQUS software to check the effects of introducing the SI system to an NPP structure.

The fictitious nuclear building under consideration was conceptually redesigned based on the typical pressurized water reactor (PWR) buildings of quadrant-arranged auxiliary buildings around the containment with a double-walled containment for the purpose of a feasibility study to meet the needs of several European nations.

2. FINITE ELEMENT MODEL

Fig. 1 shows the models of the fictitious nuclear building. The buildings have typical features of NPP buildings.



(a) without the SI system (b) with the SI system (conceptual)

Fig.1. Models of the "fictitious nuclear building" and of the aircraft

2.1 Method of Analysis

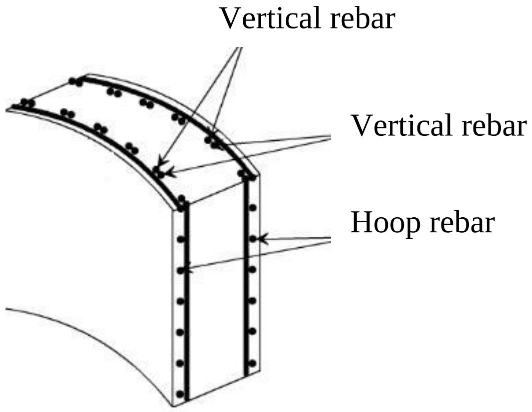
Impact analysis is a means of evaluating the global structural damage of a target structure. The 'Force Time-History Analysis Method' was used in this analysis. In this method, the impact force time-history is first determined based on the aircraft crushing strength information and on impulse conservation 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.

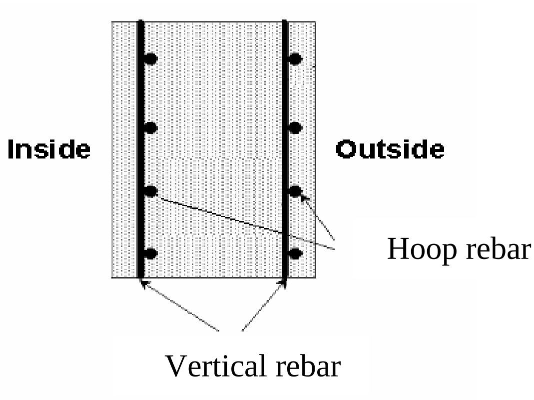
2.2 Impacted walls of each NPP structure

Fig. 2 shows a cross-sectional view of the outer wall of the containment building and the wall of an auxiliary building of an NPP with an embedded rebar.

2.3 Description of the finite element model

As shown in Fig. 2, the impacted walls of the NPP structures have two main structural components: concrete and reinforcing bars. Several types of elements are needed to model the wall structure properly. The ABAQUS elements used for this analysis included an eight-node hexahedral solid element for the concrete modeling and an embedded shell element with a rebar layer option for the rebar.





(a) outer wall of the containment (cylindrical) (b) outer wall of the auxiliary building

Fig. 2 Typical section of outer walls

2.4 Seismic isolation type and modeling

Various types of elastomeric bearings are differentiated by their methods of energy dissipation. Low-damping rubber (LDR) bearings use natural rubber with very little inherent damping. Considering the energy dissipation and induced displacement due to an aircraft loading, LDR bearings are expected to be disadvantageous compared to other bearing with more damping.

In this paper, a LDR bearing is adopted as the SI unit as a conservative evaluation. The 100% shear strain level of the SI unit is 280mm. SI units are modeled with 400 connector elements based on typical rubber bearing properties for the analysis of the NPP with SI. The isolation frequency used in the analysis is 0.5 Hz and the equivalent damping coefficient for the isolation system is 0%.

2.5 Nonlinear constitutive model

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

3. ANAYSIS 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 1. 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 compared to the 100% shear strain level of the SI unit (280mm).

Table 1. Comparison of the structural responses

Case	Concrete compressive stress (normalized)	Rebar tension stress (normalized)	Maximum displacement at impact point [mm]
with SI	0.83	0.443	77.4
without SI	0.83	0.442	71.3

The maximum displacement calculated at the impact point of the NPP with SI is larger than that of the NPP without SI by 6mm, which is larger than the maximum horizontal displacement right above the SI (2mm) due to the effects of torsional displacement.

CONCLUSIONS

- The structural responses of an NPP with the SI system of bearings with no damping are nearly identical to those of an NPP without the SI system in terms of the induced stresses of structures by an aircraft crash loading.
- The displacement in an NPP with the SI system induced by an aircraft loading is much less than the 100% shear strain level of the SI unit (280mm), indication that the probability of the failure of the SI system due to excessive displacement by aircraft loading is very low.

Further studies of an aircraft impact on base-isolated nuclear power plants are needed to evaluate the following :

- The effects of various impact locations and impacted angles
- The effects of aircraft crash-induced fires
- The characteristics of vibratory responses for locations in which safety related equipment and systems are located.

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