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Analysis of an NPP Structure subjected to Vibrations Induced from Airplane Crashes

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1. Introduction

After the terrorists' attacks with civilian airplanes on September 11, 2001, special attention has been paid to the potential for an airplane crash into a Nuclear Power Plant (NPP) as a man-made hazard. An airplane crash (APC) into an NPP has the potential to damage the roofs and walls of these structures, as well as other systems and components such as pipelines, electric motors, power supplies, power cables of electricity transmission that are important for safety. Therefore, an evaluation of the structural response to an APC is important for the safety of NPPs to be confirmed.

A structural integrity analysis was carried out focusing on the vibration effects of an APC on an NPP structure. The NPP structure under consideration has been conceptually redesigned based on APR1400 to have double containments for the purpose of a feasibility study to meet European requirements. The finite element method was used for the structural analysis of the NPP, and the computer code ABAQUS was employed for this analysis.

2. Inputs for the APC Evaluation

In this section, the inputs for the APC evaluation, including the properties of an NPP and those of airplanes, are described.

2.1 Details of the evaluated NPP containment structure

In case of an airplane crashes to an NPP with double containments, it is expected that a secondary containment protects the plant safety-related systems and components. A cross section view of the secondary concrete containment wall of an NPP with embedded rebars is shown in Fig. 1. The geometrical design values for the secondary containment system and the properties of its structures are listed in Table 1.

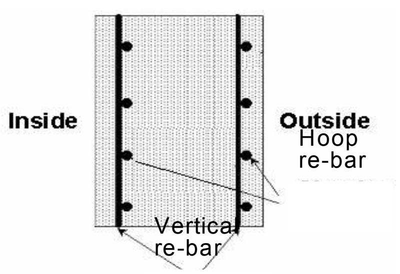


Fig. 1 Configurations of secondary containment

Table 1 Specifications of secondary wall of the containment

Items	Design values
Wall thickness	1.5m
Dome thickness	1.5m
Concrete design strength	422 kgf/㎠
Reinforcing bar yield strength	4,200 kgf/㎠

2.2 Parameters of the airplanes

Large/commercial airplanes must be considered in the safety assessment of NPPs according to European requirements and regulations concerning APC[1]. However, detailed airplane parameters that are appropriate for use in the requirements are not publicly available because of their potential value to terrorists.

For the same reason, the parameters considered in this study are not specifically but restrictively described, as given in Table 2.

Table 2 Parameters of commercial airplane

Items	Commercial airplane
Missile mass	4,300 kg
Missile velocity	150 m/s

2.3 Impact Conditions

A global response analysis was performed for two cases according to impact location: one is on the mid-wall and the other is on the connecting part of the wall and dome of the containment section, as shown in Fig. 2.

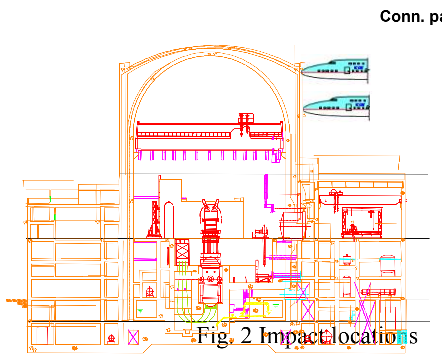


Fig. 2 Impact locations

3. Performed analysis and results

3.1 Modeling of the secondary containment and auxiliary building

The secondary containment and auxiliary building are modeled as shown in Fig. 3.

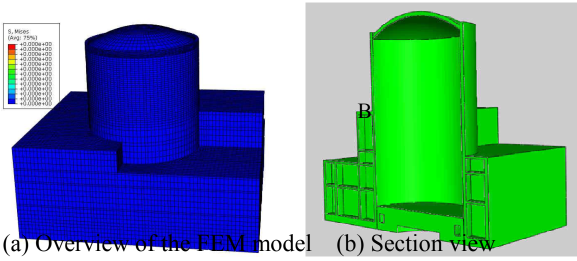


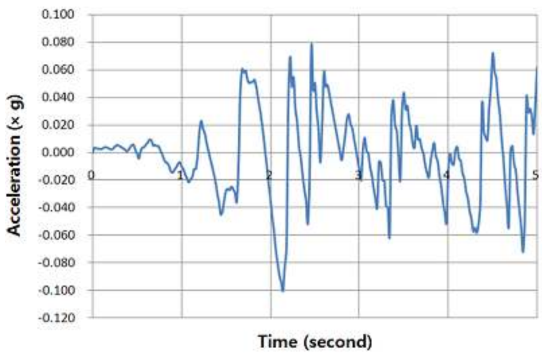
Fig. 3 FEM modeling of the secondary containment and auxiliary building

In the material modeling of the model, a damaged plasticity model [2] was defined to simulate the material non-linearity of concrete with strain hardening and tension stiffening. The von Mises failure criterion was used for the steel materials.

3.2 Performed analysis

The impact force-time history based on the parameters of a commercial airplane considered was applied as airplane crash loadings in two load cases, as shown in Fig. 2.

In addition, in order to evaluate which load governs the vibration effects on the systems and components between an APC and an earthquake, a third load case was considered with a seismic spectrum modeled based on the El Centro earthquake to reflect the 0.1g of horizontal direction. The spectrum is suggested in an IAEA safety standard [3] to which many regulations of EU nations including YVL of Finland [4] refer. The spectrum is shown in Fig. 4.



3.3 Results of the analysis

In order to evaluate the vibration effects induced by an APC and an earthquake on the safety-related systems and components encased in the auxiliary building, the displacements at the locations marked as A and B on the auxiliary building floor were compared for each load case as shown in Fig. 3(b).

In the comparison of the results of the two APC load cases, the displacement by an APC on the mid-wall is larger than that by an APC on the connecting part of the wall and dome; hence, the vibration effect induced by an APC on the mid-wall was compared with that effect induced by an earthquake in terms of the displacement. The displacement induced by an APC is smaller than that induced by an earthquake at both locations of A and B. Their results are shown in Fig. 5.

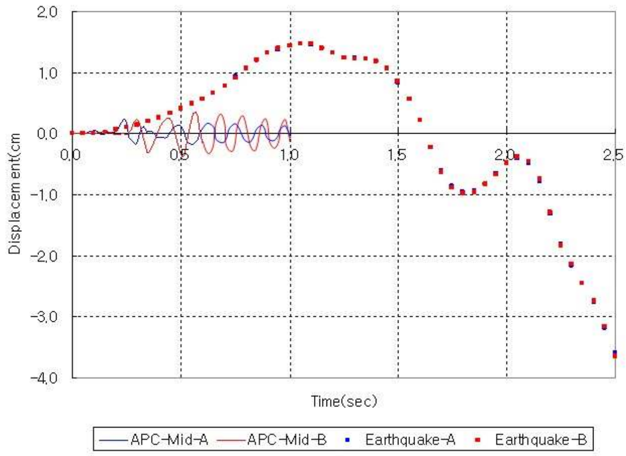


Fig. 5 Displacements at A and B locations for each APC loading and earthquake loading

4. Conclusions

Based on the analysis results, it was determined that an earthquake load governs the vibration effects on the safety-related systems and components encased in auxiliary building.

Considering that the vibration effect of an APC was smaller than that effect by an earthquake with 0.1g, it is expected that APR1400 designed based on a seismic load of 0.3g will sufficiently cover the vibration effect subjected to an APC loading.

Acknowledgement

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