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Aircraft Impact Assessment of APR1400 Reactor Containment Building

Ilhwan Moon, Do Yeon Kim, and Jae Hee Kim
KEPCO E&C Company Inc., Seongnam, Gyeonggi-do, Korea
Sang Yun Kim
Korea Institute of Nuclear Safety (KINS), Daejeon, Korea
Tel: 82-31-8021-6104, Fax: 82-31-8021-6256, E-mail: youmoon@kepco-enc.com

1. Introduction

The implementation of a protection to withstand aircraft impact on safety-related structures and systems is basically based on a probabilistic evaluation for each site, if the licensing body doesn't require a deterministic approach. Existing nuclear power plants in Korea were designed based on the probabilistic approach, and the aircraft impact hazard remained less than a probability of 10^{-7}. However, a man-made aircraft impact have been considered as a possible external accident for the nuclear power plant.

New plant designs that are to be constructed in the U.S. after July 2009 must consider the effect of impact from a large commercial aircraft according to the requirements of 10 CFR 50.150. Especially, Reactor Containment Building (RCB) housing the safety-related equipments and fuels should be protected safely against aircraft crash without perforation and scabbing failure of external wall.

APR1400 RCB is constructed as a prestressed concrete containment vessel (PCCV) which is surrounded by the auxiliary building housing additional safety-related equipments and other systems.

In this study, the aircraft impact analyses for the RCB are carried out using Riera forcing function and aircraft model. Considered external wall thickness is 4 ft 6 in. for the cylindrical wall and 4 ft for the dome. Actual strengths of concrete and steel are considered as the material properties. For these analyses, the dynamic increment factor and concrete aging effect are considered in accordance with NEI 07-13(2011).

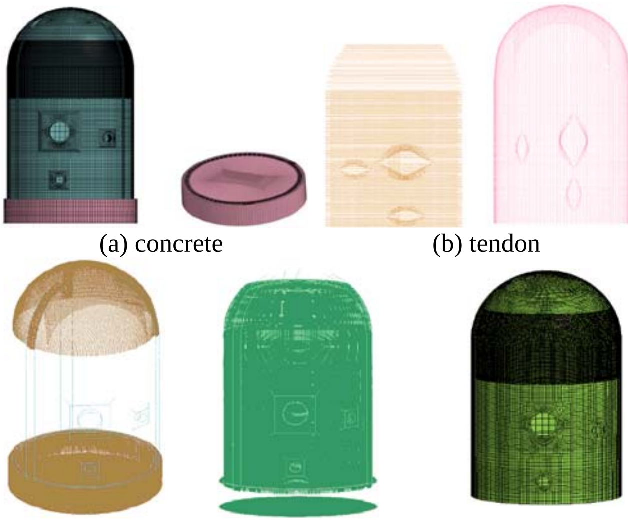
2. PCCV Finite Element Model

The RCB consists of various materials such as concrete, prestressing tendon, reinforcing steel, and liner plate, and this building is regarded as a robust structure due to the shape characteristics and its material properties.

Three-dimensional finite element models for the RCB are developed for the aircraft impact analysis as shown in Fig. 1. Concrete part is idealized using a 8-node solid element, and the reinforcing steel and tendon are modeled using a 2-node truss element. The liner plate is modeled using a 4-node shell element. The concrete element size around impact area is decided to be less than 6 in. to consider out-of-plane bending or punching shear behavior.

The RCB is considered to be a free standing structure because the external wall is separated from its internal slab and the auxiliary building due to the required seismic gaps. Fixed boundary conditions are enforced at the bottom of the basemat or the wall base. The boundary condition might be conservative because it neglects the deformation of the basemat.

ANACAP-U and Winfrith concrete model are applied to these analyses and these constitutive models are subsequently sanctioned in the NEI guidelines. Yielding in the steel material is treated using the von Mises plasticity formulation with isotropic hardening.



(a) concrete (b) tendon

(c) reinforcing steel (d) liner plate

Fig. 1 Finite Element Model

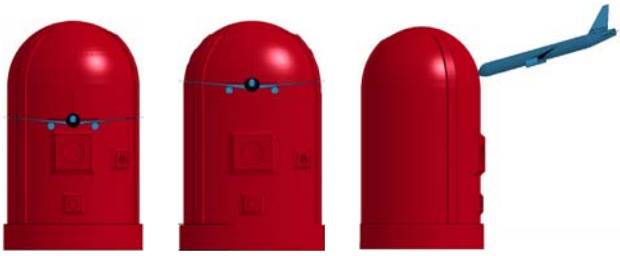
3. Strike Locations

In the aircraft impact assessment requirements in the 10 CFR 50.150 and NEI 07-13, it must be demonstrated that the primary containment boundary is not perforated in order to prevent fire inside containment as part of the requirement for continued core cooling. Based on the exposed configuration of the reactor containment building above the auxiliary building and associated structural vulnerability, 3 strike locations for detailed analyses are identified.

a. Strike just above the equipment hatch, illustrated in Fig. 2(a)
b. Strike between buttresses near the springline, illustrated in Fig. 2(b)

c. Strike on the dome with 15 degrees angle to the horizontal axis, illustrated in Fig. 2(c)

In general, a strike on the dome may be neglected from the analysis case because the area is considered as the lusty part of the containment building due to a hemi-spherical configuration. However, a strike on the dome is necessary to demonstrate its structural integrity because the dome is having less thickness compared to the cylindrical shell. Strike occurring perpendicular to the wall surface will deliver the highest impact energy, therefore the aircraft impact angle is applied as 15 degrees to horizontal axis.



(a) above EH (b) springline (c) dome

Fig. 2 Strike Locations

4. Aircraft Impact Assessment Results

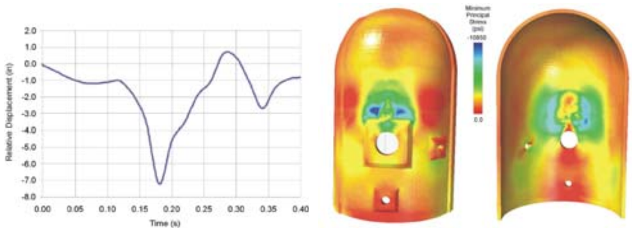
The loading, as a representative of impact from a large commercial aircraft, is developed from calculations using an aircraft model impacting on a rigid wall, consistent with the Riera method(1980). The loading is applied as pressure time histories using the force time histories for fuselage, wing, and engine components distributed over the representative areas.

The missile-target interaction analysis method is an alternative method to use the Riera function methodology. For this method, a combined dynamic analysis model of the aircraft and PCCV is developed, and the dynamic response is determined as an initial velocity problem. The aircraft-rigid wall interaction analysis model is shown to produce a demonstrated equivalence to the Riera force-time history.

Fig. 3(a) and (b) show the results of the analysis using the Riera force-time history. Fig. 3(a) plots the displacement history for a point on the model near the center of the impact location above the equipment hatch. This figure shows a peak displacement of about 7.2 in. and the recovery with perhaps some residual deformation. Fig. 3(b) plots contours for minimum principal stress representative of concrete compressive stress near the time of peak deformation. Some compressive yielding is indicated in the area under the load possibly leading to some post impact spalling of concrete off the front side. The liner will prevent concrete from spalling off the inside surface.

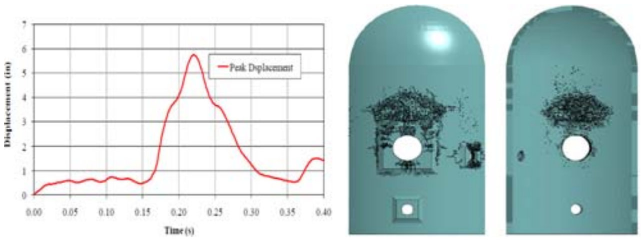
Fig. 4(a) and (b) show the results of the missile-target interaction analysis. Fig. 4(a) plots the displacement history for a point near the center of the impact location above the equipment hatch, and Fig. 4(b) plots the concrete crack pattern. Fig. 4(a) shows a peak inward displacement of about 5.8 in. and then recovered with some residual displacement. The cracks at the aircraft impact area indicate over a large extent, and the liner plate strain is less than 3.6%.

The analysis results using both methods indicate that the maximum strain of the reinforcing steel and liner plate is less than 3.6%, therefore the punching shear or the perforation failure does not develop due to thickened concrete section. In case of the dome strike, the concrete cracks indicate over a fairly large extent without any perforation failure.



(a) displacement history (b) min. principal stress

Fig. 3 Analysis Results using the Riera Method



(a) displacement history (b) crack pattern

Fig. 4 Analysis Results using the Missile-Target Interaction Method

5. Conclusions

In this study, the effectiveness of both aircraft impact assessment methodologies is verified using the explicit dynamic analysis. A peak displacement between both analysis results is slightly different, but the concrete crack pattern and the steel strain are almost the same. Especially, an aircraft strike on the dome should be evaluated because the analyzed damage in this area is more severe compared to other strike areas.

REFERENCES

[1] Nuclear Energy Institute, *Methodology for Performing Aircraft Impact Assessments for New Plant Designs*, NEI 07-13, Rev. 8, April, 2011.
[2] Riera, J. D., A Critical Reappraisal of Nuclear Power Plant Safety Against Accidental Aircraft Impact, Nuclear Engineering and Design, 57, 1980, pp 193-206.