Parametric Study on Floor Response Spectra of Nuclear Structure subjected to Aircraft Impact

Sang Shup Shin[a*, b], Daegi Hahm [a], Min Kyu Kim[a]
[a] *Korea Atomic Energy Research institute, 1045 Daedeok-daero, Youseong, Daejeon, 305-353*
[b] *Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul, 133-791*

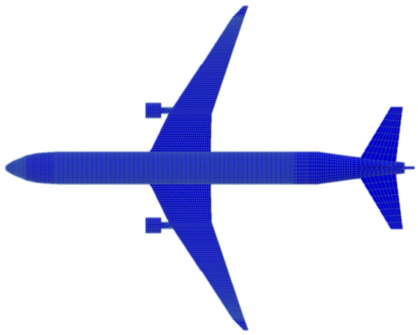
[*] *Corresponding author:ssshin@kaeri.re.kr*

1. Introduction

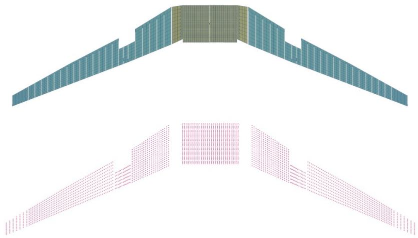
After the World Trade Center (WTC) accident on Sept. 11, 2001, the aircraft crash has attracted the public concern to the potential threat into nuclear power plants. The nuclear structure subjected to aircraft crash will take a severe damage caused by the extreme loads. Even if the external wall of target structure has been protected from the aircraft impact (AI), the internal equipment can be affected by the shock vibration through the walls, floors and ceiling. Thus, the damage induced by vibration should be estimated in order to determine the potential for affecting safe shutdown. Although safety-related equipment has been qualified for the seismic design criteria, the safety assessment for safety-related equipment from the shock vibration caused by AI is also necessary [1]. A parametric study on floor response spectra of nuclear structure subjected to AI was performed in this study. In order to find the floor response spectra of nuclear structure, the variation of impact velocity and analysis methods were considered in the AI simulation analyses. It is expected that the results of this study will be used for the base data of safety assessment for safety-related equipment into nuclear structure from the shock vibration.

2. Modeling of Aircraft and Nuclear Structure

The aircraft model referred by EPRI report [2] and Boeing website [3] was developed as shown in figure 1. The aircraft fuselage, wings, fuel tank and engines are modeled with shell elements and the landing gear is modeled with beam elements. The airframe was modeled with the MAT_PLASTIC_KINEMATIC material model in LS-DYNA [4]. The jet fuel was modeled as a liquid using MAT_NULL material model in LS-DYNA [4], which behaves with fluidlike characteristics.



(a) Aircraft finite element model



(b) Jet fuel tank and particles

Fig. 1. The modeling of aircraft and jet fuel

Figure 2 shows the nuclear building with characteristics similar to primary auxiliary building. The plan dimensions are 67.7m×74.6m and height is 37.9m, divided to six elevations. The solid element mesh was employed in the nuclear building. The Mat_Cscm_Concrete model in LS-DYNA [4] was applied to the solid elements. The value of concrete strength was used to 5.574E7 (Pa) by the consideration of the dynamic increase factor (DIF) and the concrete aging effect, referred by NEI 07-13 revision 8 [5]. Also, to consider the various failure modes for concrete, the Mat_Add_Erosion option was set to 1.05.

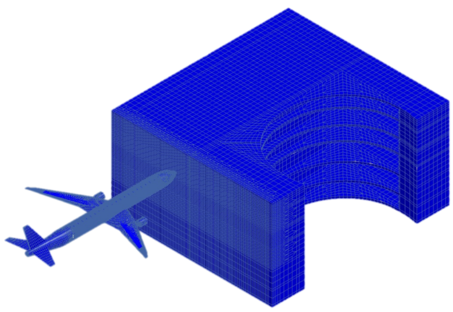


Fig. 2. Finite element model of and nuclear structure

3. Aircraft Impact Loads

For the analysis of the floor response spectra with respect to the variation of impact velocity, we selected three reference impact velocities. Table 1 shows all analysis cases used in this paper. In case 1, 2, 4, 5, 7 and 8, the normalized force value was filtered at 100 Hz to remove the noise in the aircraft impact force in figure 3.

Table 1. Analysis cases with respect to the variation of impact velocity and analysis methods

Case	Impact Velocity (m/s)	Missile-Target Interaction Method		Force-Time History Method
		SPH Method	Added Mass Method	
Case 1	150	○		
Case 2	150		○	
Case 3	150			○
Case 4	100	○		
Case 5	100		○	
Case 6	100			○
Case 7	50	○		
Case 8	50		○	
Case 9	50			○

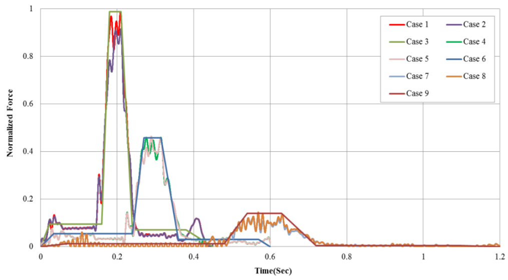
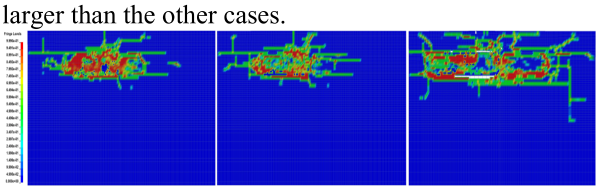


Fig. 3. Force-Time history for impact velocity (50, 100, 150m/s)

4. Numerical Analysis Results

Figure 4 shows the plastic strain contours on the external wall at the maximum force occurrence times, which are 0.2 second for case 1, 2 and 3. The plastic strain contour was differently occurred from the difference of analysis methods. The perfectly damaged areas in case 1 are larger than the case 2 and 3. However, the partially damaged areas in case 3 are larger than the other cases.



Case 1 Case 2 Case 3

Fig. 4. Plastic strain contour in case 1, 2 and 3 at 0.2sec

Figure 6 shows the floor response spectra for P1 in figure 5. Figure 6 shows the floor response spectra for Case 1 with respect to the variation of an aircraft impact velocity at P1.

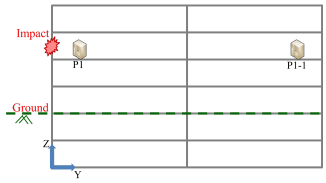


Fig. 5. The position at which responses were calculated.

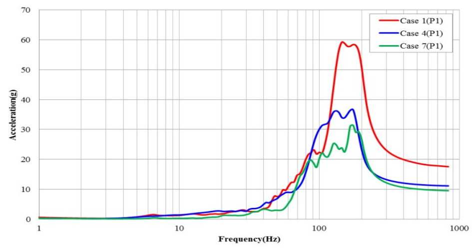


Fig. 6. Floor response spectrum for the impact velocity (50, 100, 150m/s) at P1

When the aircraft impact velocity had been increased by 100% (50m/s to 100m/s), the maximum acceleration response at P1 was raised by about 15%. The maximum acceleration response at P1 was raised by about 88% when the aircraft impact velocity had been increased by 200% (50m/s to 150m/s). As shown in figure 6, the maximum acceleration response at P1 shows a tendency to rise for the increase of impact velocity, but the maximum acceleration response for the increase of impact velocity is not meant to be increased linearly.

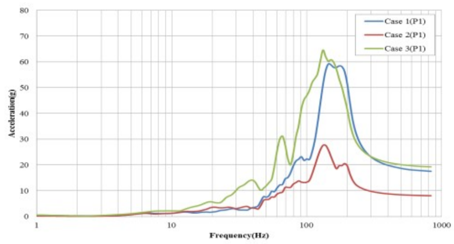


Fig. 7. Floor response spectrum for the impact velocity (50, 100, 150m/s) at P1

Figure 7 show the floor response spectrum at P1 for aircraft impact analysis methods. As shown in figure 7, the maximum acceleration response at P1 which is corresponding to the added mass method show smaller 54% and 58% as compare with the SPH method and Riera method, respectively.

5. Conclusions

In order to obtain the floor response spectra with respect of nuclear structure, we considered the variation of impact velocity and analysis method. In case of impact velocity 150m/s, the plastic strain contours in case 2 are underestimated than the case 1 and 3 regardless of the perfect and partial damage. Also we know that the margin of maximum acceleration response is increased with the increase of the aircraft impact velocity because the nonlinearity for structural response is raised with the increase of the aircraft impact velocity.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. 2012M2A8A4009710)

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY., “Safety Aspects of Nuclear Power Plants against Human Induced External Events: Assessment of Structures,” Draft Safety Report No. 1087-7.2, IAEA, Vienna, 2014.
[2] Electric Power Research Institute (EPRI)., “Deterring Terrorism: Aircraft Crash Impact Analyses Demonstrate Nuclear Power Plant’s Structural Strength”, 2002.
[3] Boeing website., http://www.boeing.com
[4] Hollquist, J., “LS-DYNA Theory Manual”.
[5]Nuclear Energy Institute (NEI 07-13), “Methodology for Performing Aircraft Impact Assessments for New Plat Designs”, 2011.