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Erosion Sensitivity Assessment of SC Walls under Aircraft Impact

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ABSTRACT

Since the terrorist attacks at the World Trade Center in New York City in 2001, in which aircraft was used to destroy buildings, safety assessments of nuclear containment buildings for aircraft impact have been actively performed. Analysis factors such as erosion value, strain rate effect, and material models of concrete and steel can all influence the analysis results. In this paper, a sensitivity assessment which both considers and ignores erosion effects is performed for SC(Steel Plate Reinforced Concrete) walls. The aircraft model is developed and verified using the impact force-time history curve created by the Riera function. A sensitivity assessment is performed according to the erosion value of concrete using an aircraft model.

INTRODUCTION

Safety assessments of nuclear containment buildings for aircraft impact were performed by Park, D. H. et al.(2011) using AUTODYN-3D and Jin, B. M. et al.(2011) using ABAQUS/Explicit. Also, a sensitivity study according to erosion value was performed by G. Sagals et al.(2011) using missile impact tests. Due to the characteristics of impact analysis, however, the kind of finite element program and analysis factors such as erosion value, strain rate effect, and the material model of concrete and steel can influence the analysis results. In this paper, a sensitivity assessment of SC walls is performed according to the erosion value of concrete using a commercial program LS-DYNA. Erosion options in LS-DYNA are defined such that once any one of the failure criteria, such as strain, stress, pressure, etc. is satisfied, the element is deleted from the calculation. The considered failure criteria in this paper are the maximum principal strain and plastic strain for concrete and steel respectively.

FE Model

Aircraft (Boeing 767-400)

The aircraft used for impact simulation is a Boeing 767-400 used in safety analyses of nuclear power plants in the U.S.(EPRI, 2002). The dimensions of the aircraft are 61.3m long, 51.9m wide, and 16.8m high. The maximum takeoff weight of the aircraft including the maximum fuel weight of 90,770L is 204.12ton. The mass distribution of the aircraft excluding engine weight and fuel is determined by trial and error using the thickness of the shell element and lumped mass.

Aluminum alloy AL2024-T351 composed of yield stress 290MPa, elastic modulus 73,100MPa, and density 2.8375ton/m^3 is used for the aircraft material. The FE model of the aircraft is modeled using a shell element of 32,203 as shown in Fig. 1.

Figure 1. Boeing 767-400

SC Wall

The concrete is modeled using solid elements. MAT_159(MAT_CSCM_CONCRETE) properly considers strain rate effects according to large impact forces such as an aircraft impact, and is used as the material model for the concrete. Using CSCM concrete, tensile and compressive failure phenomena can be shown by applying the adequate values onto the erosion parameters. The element erosion happens when the erosion parameter is greater than 0.99 and the maximum principal strain is greater than a user supplied input value(LSTC, 2012). In other words, if the erosion parameter is 1.3, the element is deleted from the calculation at the time of the maximum principal strain of 30% of the element. More realistic and accurate analysis results can be obtained by determining accurate erosion values using impact tests.

Steel plate is modeled using a shell element and MAT_24(MAT_PIECEWISE_LINEAR_ PLASTICITY) is used as material model for it. A plastic strain of 13% according to failure criteria considered in the material model is applied. Steel plating that is fully attached to the concrete is shown using a CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_TIEBREAK option as the contact condition.

VERIFICATION OF IMPACT FORCES ACCORDING TO TIME HISTORY OF AIRCRAFT

The Riera function referred in a guideline for aircraft impact assessment(NEI 07-13, 2009) is given by :

$$F(t) = P_c(x) + \alpha_r\, \mu(x)\, (dx/dt)^2$$

Where, $P_c(x)$ is the static force required to crush a lamina of the airframe axially at location x, α_r is a coefficient determined experimentally, $\mu(x)$ is the mass per unit length at location x, and dx/dt is the impact velocity.

According to the basic assumption of the Riera function, the aircraft perpendicularly impacts against the rigid wall as shown in Fig. 2. The impact velocity is 150m/s and the thickness and the lumped mass of the aircraft are determined by trial and error so that the simulation result is similar to the impact force-time history created by the Riera function.

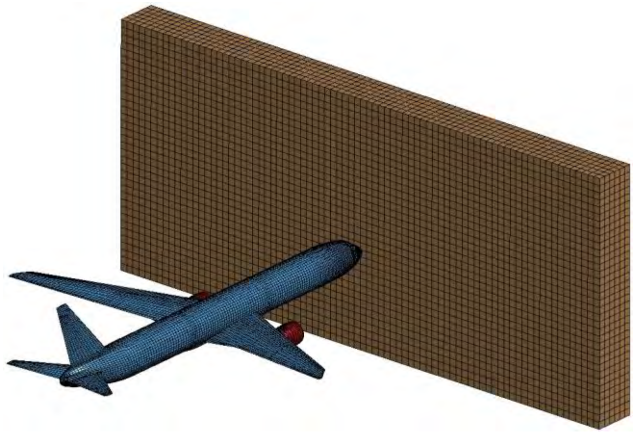


Figure 2. Impact simulation to rigid wall

The impact force-time histories by the Riera function (Park, D. H. et al., 2011) and impact simulation are shown in Fig. 3. Overall, the simulation result shows similar behavior compared with that of the Riera function. The area under the two impact force-time history matches within 9%. However, the occurrence time of maximum force shows a difference of about 0.025s.

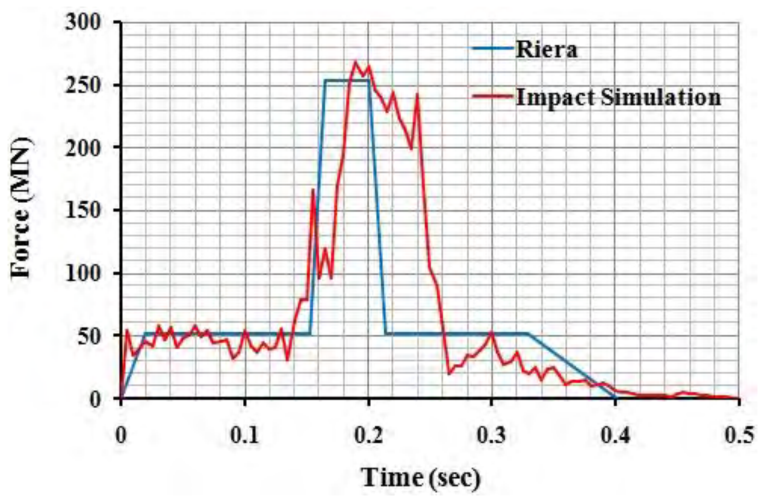
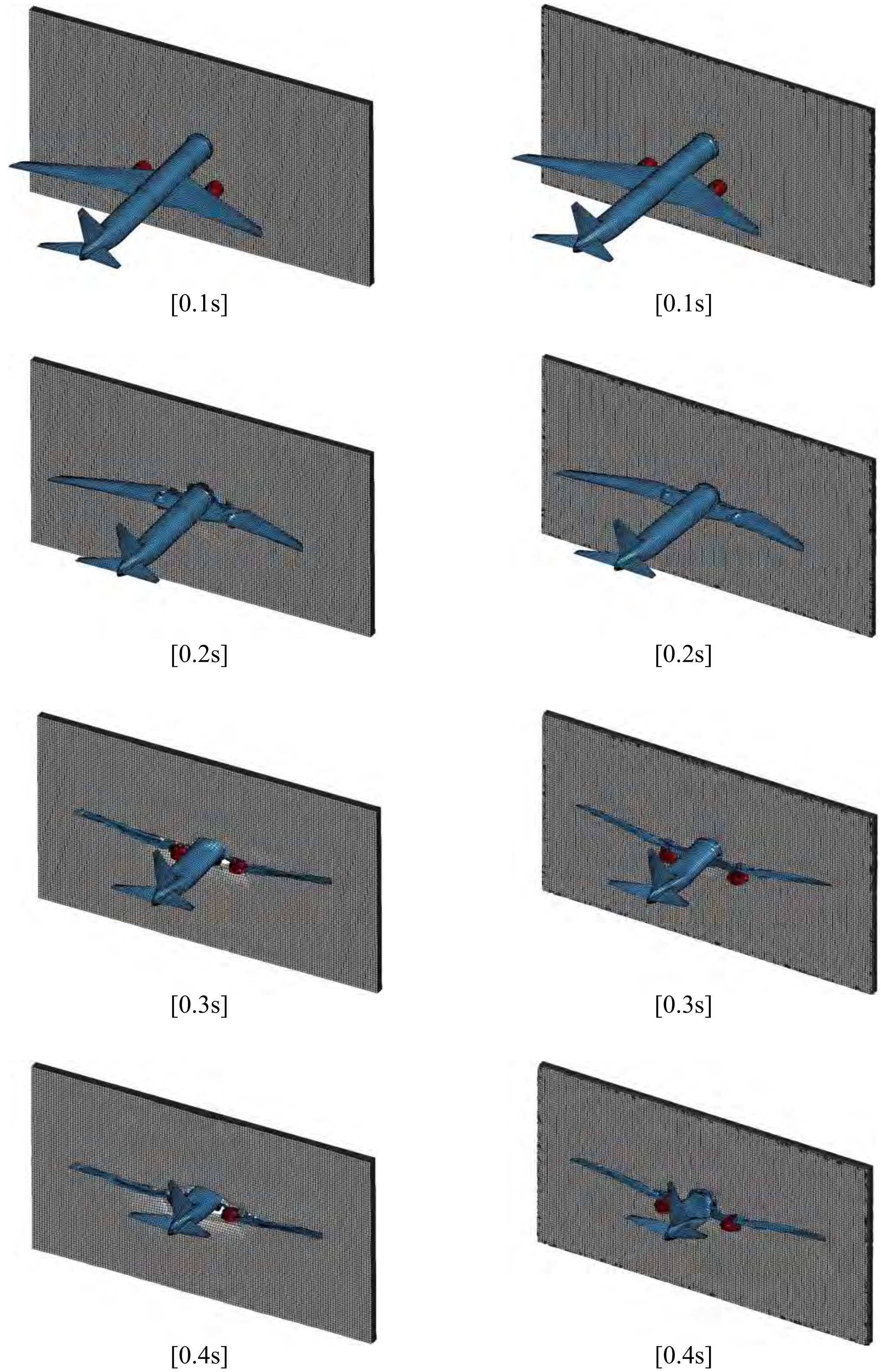


Figure 3. Impact force-time history

ANALYSIS RESULTS

The impact simulation is performed using an aircraft model. The concrete thicknesses of SC walls are 1200mm and 1500mm and the thickness of the steel plate is 15mm. A sensitivity assessment is performed according to the erosion values of the concrete part of the SC wall. The impact velocity of the aircraft is 150m/s. In the case of the impact angle, because nuclear power plant structures are generally a relatively height from ground, the possibility that the aircraft will impact the structure perpendicularly is very low. However, a perpendicular impact that has the largest impact effect is conservatively considered as the impact angle. The analysis result considering erosion is shown in Fig. 4(a), while the one ignoring erosion is shown in Fig. 4(b).

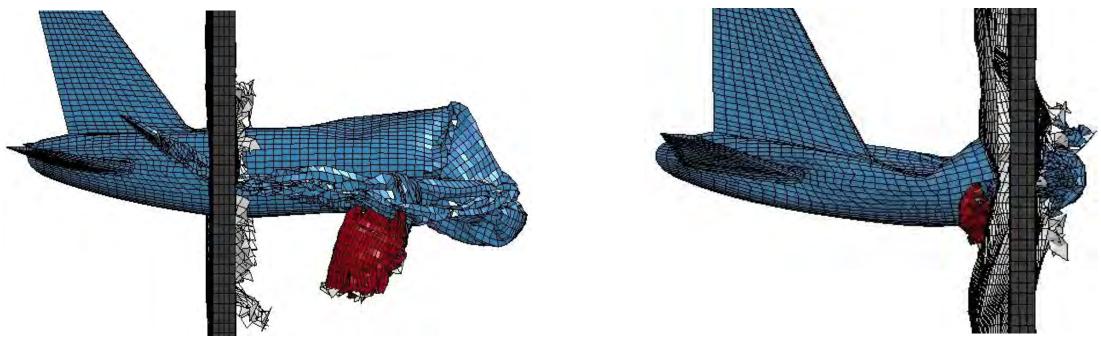


(a) Considering erosion (Erosion value 1.1) (b) Ignoring erosion

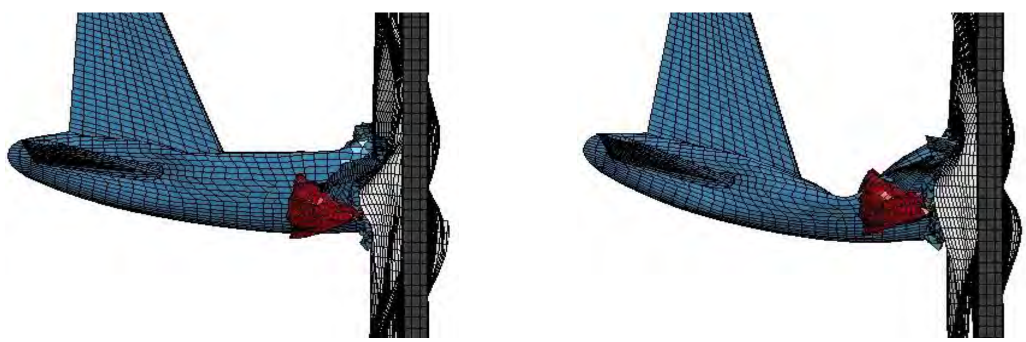
Figure 4. Behavior of SC walls (SC walls of 1,530mm thickness)

In the case where erosion was considered, when the thickness of the SC wall was 1,230mm, failure shapes of SC walls were different according to erosion values as shown in Fig. 5. SC walls with an applied erosion value of 1.1 and 1.2 to its concrete part were perforated as shown in Fig. 5(a) and (b). Also, as shown in Fig. 5(c) and (d), although the tearing phenomenon of the rear-face steel plate occurred beyond a steel failure strain of 13% and the concrete part has partially failed, SC walls with an applied erosion value of 1.3 and 1.4 were not perforated. On the other hand, when the thickness of an SC wall was 1,530mm, SC walls with an applied erosion value of 1.1 and 1.2 were perforated. SC walls with an applied erosion value of 1.3 and 1.4 were not perforated and the tearing phenomenon of the rear-face steel plate did not occur.

In the case where erosion was not considered, the displacement of the SC wall with a 1,230mm thickness was 687mm and the displacement of the SC wall of 1,530mm thickness was 616mm. Also, a maximum strain of the rear-face steel plate portion of the SC wall with thicknesses 1,230mm and 1,530mm were 10.3% and 9.9% respectively, and the 13% failure strain was not exceeded.



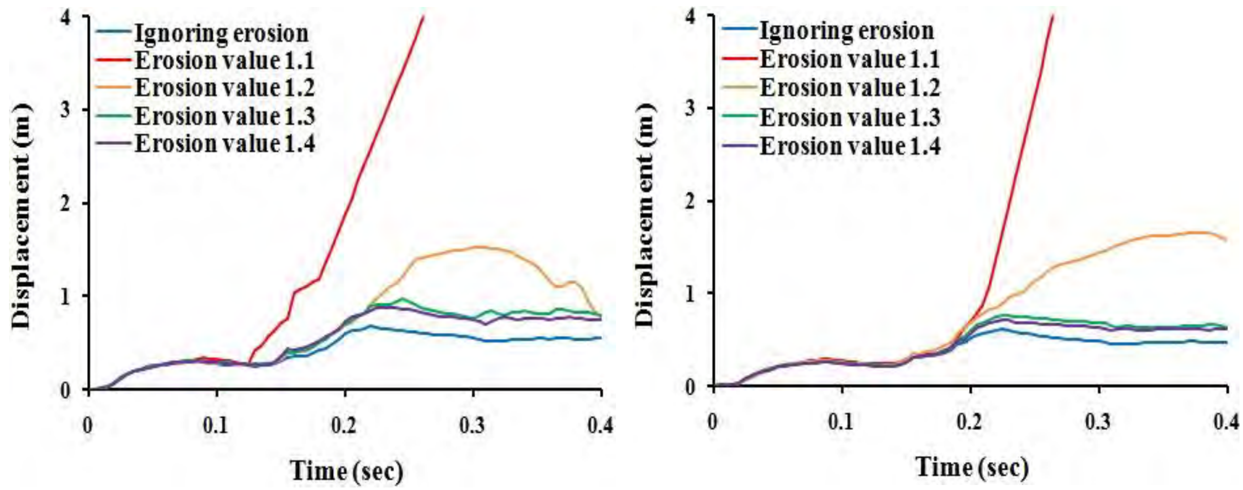
(a) Erosion value 1.1 (b) Erosion value 1.2



(c) Erosion value 1.3 (d) Erosion value 1.4

Figure 5. Failure shapes of 1,230mm thick SC walls (0.4s)

The displacement-time history of the rear-face steel plate is shown in Fig. 6 and the results of the impact analysis are summarized in Table 1. The reason behind the occurrence of abnormal displacement pertaining to erosion values 1.1 and 1.2 in Fig. 6(a) and (b) is the phenomenon that eventuated after elements have been deleted or fallen from the rear-face steel plate. Also, the results indicated that the displacements of the analysis cases ignoring erosion were lower than that which considered erosion. When erosion was ignored, although the concrete elements were beyond the failure strain applied only in analysis cases considering erosion, the elements were not deleted from the calculation. Therefore, the elements ignoring erosion were subjected to a larger impact force as compared to the elements considering erosion. This indicates that the stiffness of the SC walls considering erosion decreased overall.



(a) SC walls of 1,230mm thickness (b) SC walls of 1,530mm thickness

Figure 6. Displacement-time history of rear-face steel plate

Table 1: Summary of analysis results according to erosion value

Erosion value	Maximum displacement of rear-face steel plate in displacement-time history	
	Thickness 1,230mm	Thickness 1,530mm
Ignored	687mm	616mm
1.1	Perforation	Perforation
1.2	Perforation	Perforation
1.3	980mm (Tearing on rear-face steel plate)	765mm
1.4	886mm (Tearing on rear-face steel plate)	715mm

CONCLUSIONS

In this paper, a sensitivity assessment was performed according to erosion values of the concrete part of an SC wall. In the case where erosion was considered, when the thickness of the SC wall was 1,230mm, the failure shapes of the SC walls were different according to the erosion values. SC walls with an applied erosion value of 1.1 and 1.2 to its concrete part were perforated. Also, although the tearing phenomenon of the rear-face steel plate occurred beyond a steel failure strain of 13% and the concrete part has partially failed, SC walls with applied erosion value of 1.3 and 1.4 were not perforated. On the other hand, when the thickness of the SC wall was 1,530mm, the SC walls with an applied erosion value of 1.1 and 1.2 were perforated. SC walls with an applied erosion value of 1.3 and 1.4 were not perforated and the tearing phenomenon of the rear-face steel plate did not occur. In the case where erosion was not considered, the displacement of the SC wall with 1,230mm thickness was 687mm and the displacement of the SC wall with 1,530mm thickness was 616mm. Also, a maximum strain of the rear-face steel plate portion of the SC wall with thicknesses of 1,230mm and 1,530mm were 10.3% and 9.9% respectively, and the 13% failure strain was not exceeded. It is concluded that erosion is a very important factor to get accurate behavior. Further studies determining accurate erosion values using impact experiments are necessary.

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