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Local Impact Simulation of SC Wall Structures using Aircraft Engine Projectile

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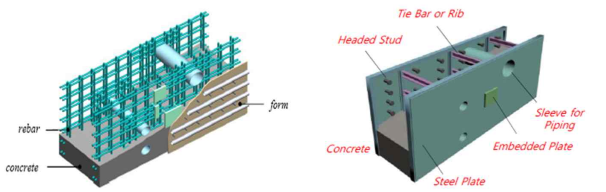
1. Introduction

SC wall structure developed for nuclear power plant buildings consists of plain concrete and two steel plates on both surface of the concrete, while RC structure consists of rebar and concrete as shown in Fig. 1. SC structure has higher scabbing resistance than RC structure due to the action of steel plate on the rear side of impact. Therefore SC structure is known as more effective structure from the viewpoint of aircraft crash than RC structure[1]. However, most of the recent researches and experiments about local impact damage deal with RC structures, and the effect of rebar and steel plate is not considered reasonably. Although Walter et al.[2] and Morikawa et al.[3] suggested a formula for evaluating perforation depth of steel plate covered RC walls, most of the previous researches about SC structure are focused on perforation and scabbing due to the impact of hard projectile, rather than soft projectile such as an aircraft. In this research a soft projectile, i.e. aircraft engine, is utilized for impact simulation of RC and SC walls. To evaluate local damage of SC wall structures, parametric study with the variables of wall thickness and steel ratio of the cover plate is performed, and the results are compared with those of RC structures.



(a) RC wall (b) SC wall
Fig. 1 Section shapes of nuclear power plant wall structures

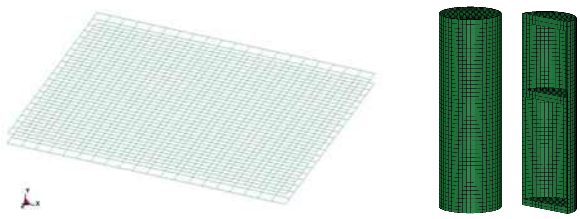
2. Impact Simulations

A series of impact simulations of a total of 30 numerical models consist of 15 SC structures and 15 RC structures are performed to investigate the effect of the wall thickness and steel ratio when an aircraft engine projectile impacts on an SC wall structure. Three cases of wall thickness such as 800mm, 940mm, and 1220mm are considered, and the steel ratio, ρ_p varied from 1.0% to 3.0%. Idealized F-4D engine projectile suggested by Sugano et al.[4] and general FE analysis software, LS-DYNA were adopted for the impact simulations.

2.1 FE Modeling

Longitudinal and lateral dimension of the walls of numerical impact simulations are both 14,000mm, and the nodes on the four edges of the rear side wall are all fixed. 8-node solid elements are used for concrete and steel plates, and perfect bonding condition between concrete and steel plates are assumed. Rebars in RC walls are modeled with truss elements, and located in lattice shape on both upper and lower part of the walls. #14 rebars (d=43.0mm, A=1,452mm^2) are used and the reinforcement ratio of RC structures are equalized with the steel ratio of SC structures. Idealized aircraft engine projectile (d=760mm, M=1463kg) is modeled with 8-node solid elements, and the impact speed is assumed as 150m/sec, which is normal navigation speed of civil aircrafts. The shapes of FE models are shown in Fig. 2.

(a) concrete wall



(b) rebars (c) projectile
Fig.2 Finite Element Model

Table I: Material Properties of Steel Parts

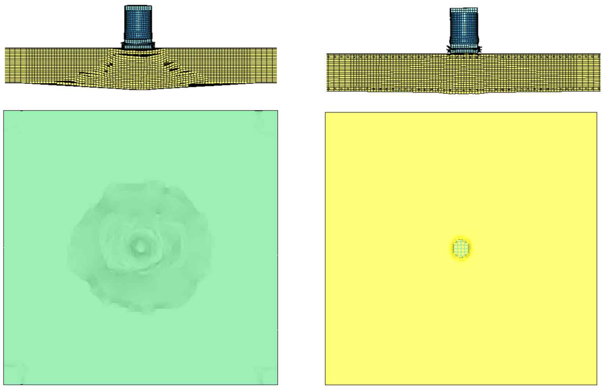
	Elastic Modulus (GPa)	Poisson Ratio	Yield Stress (MPa)	Failure Strain
Steel plate	200	0.3	310	0.15
Rebar	200	0.3	410	0.15
Projectile	201	0.3	349.1	-

2.2 Material Models

According to the previous research by Chung et al. [6], CSCM(continuous surface cap model) concrete model(#159) and plastic kinematic model(#3) are applied for concrete and steel parts respectively. Strain rate effect is considered, input value of concrete compressive strength is 40MPa, and the input material properties of the steel parts are listed in Table. 1.

3. Simulation Results

In every simulation case of the SC structure, penetration damage was observed and no scabbing was occurred due to the action of rear steel plate. Shear cone type damage was observed in concrete section, and the extent of damage decreased due to the increase of wall thickness and steel ratio. On the other hand, scabbing type damage was occurred in RC structures, and the area of the scabbing also decreased due to the increase of wall thickness and reinforcement ratio. Typical damaged shapes are shown in Fig. 3.



(a) SC Structure (b) RC Structure

Fig. 3. Section and bottom surface shapes after impact (t_c=940mm, ρ=2.0%)

Variation of penetration depth of SC and RC walls according to the steel ratio and wall thickness is comparatively shown in Fig. 4. Overall decreasing tendency is observed due to increasing wall thickness and steel ratio as shown in the figure, and this tendency is clearer especially in SC structures. Also, as shown in SC_tc1220mm case, penetration depth does not largely change due to the increasing steel ratio when the wall thickness is larger than a certain value, since the relative portion of impact resistance of the steel part becomes negligible to that of concrete part when the concrete thickness reaches a certain value.

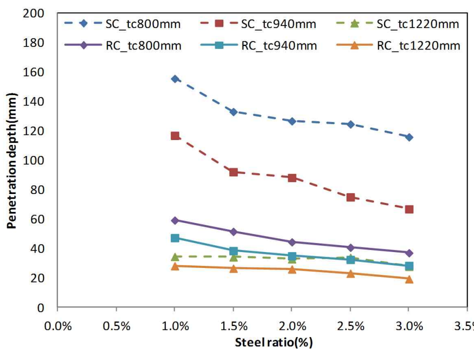


Fig. 4 Comparison of penetration depth between RC and SC structures

When the wall thickness and steel ratio are identical, penetration depth of RC structure is lower than that of SC structure. The cause of this result is that the impact speed reducing capability of SC structure is relatively lower since the thickness of the steel plate is smaller than the diameter of rebars even though the steel ratio is identical. However, when the wall thickness reaches a certain value SC and RC walls shows similar results as shown in the case of SC_tc1220mm and RC_tc1220mm.

4. Conclusions

Since scabbing was prevented by the steel plates, penetration mode of damage was observed in SC walls while scabbing damage was occurred in RC walls. It is confirmed that the rear steel plate not only contains concrete debris, but also reduces the internal damage of the concrete walls.

Penetration depth of SC walls did not largely vary due to the increasing steel ratio, and similar results to RC walls were observed when the wall thickness is larger than a certain value since the impact resistance of SC wall is mainly governed by the thickness of concrete part. Therefore, it is expected that similar level of impact resistance to RC structure can be produced with the minimum thickness of steel plates of SC structure.

According to these results, SC structure is effective for buildings of nuclear power plants since it can prevent scabbing of concrete, damage of internal facilities due to concrete debris, and radiation leak due to concrete cracks.

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