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Comparative Assessment of Impact Resistance Capacity for SC and RC Panels Using Numerical Simulation

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ABSTRACT

In this paper, the impact resistance of steel-plate concrete (SC) and reinforced concrete (RC) panels is evaluated using the commercial software LS-DYNA. The structural components and their contacts are fully modelled. The material nonlinearity and strain rate effect for concrete and steel are considered in the analysis. The impact analysis according to four different concrete thicknesses with five different steel ratios respectively is performed in order to compare the impact resistance of the SC and RC panels. Failure mode, damage size, and displacement of the SC and RC panels, and residual velocity of missile are investigated.

INTRODUCTION

After the terrorist attack on the World Trade Center using aircraft in New York City in 2001, safety assessments of nuclear power plant (NPP) structures subjected to impact loading have been actively performed. NPP structures have been generally constructed using RC structures. In recent studies, however, it has been confirmed that SC structure has a much better impact resistance than the RC structure. Several impact tests have been performed to compare the impact resistance of the SC and RC structures under impact loading. The impact test for the SC structure with the different thicknesses of concrete and steel plate was performed by Mizuno et al. (2005). The impact resistance of the SC structure was compared with impact test of the RC structure performed by Tsubota et al. (1999). Also, the impact resistance of the SC and RC structures using impact test was compared by Hashimoto et al. (2005). The impact tests can provide reliable results on behavior of structures. However, since impact tests are possible for small-scale structures but not full-scale structures, FE analysis is necessary to predict reliable behaviour of structures. In this paper, the impact analysis according to four different concrete thicknesses with five different steel ratios respectively is performed in order to compare the impact resistance of the SC and RC panels.

VERIFICATION OF FINITE ELEMENT MODELS

The impact test performed by Mizuno et al. (2005) is used to verify FE models. The FE models of SC and half-steel plate concrete (HSC) panels are shown in Figure 1. The concrete thickness of the SC and HSC panels is 80 mm, and the thickness of steel plate is 1.2 mm. The rebar diameter of the HSC panel is 6 mm. The Winfrith Concrete model (MAT_WINFRITH_CONCRETE, MAT_84) is used as the material model for concrete. The Piecewise Linear Plasticity model (MAT_PIECEWISE_LINEAR_PLASTICITY, MAT_24) is used as the material model for steel. The material properties of panels are listed in Table 1. To reduce the analysis time, the impact force-time history is applied on the SC and HSC panels instead of modeling an aircraft.

Concrete Steel plate and stud

(a) SC panel

Concrete Steel plate, stud, and rebar

(b) HSC panel

Figure 1. FE models of SC and HSC panels

Table 1: Material properties of SC and HSC panels

Analysis case		Comp. strength (MPa)	Tensile strength (MPa)	Yield strength (MPa)	Elastic modulus (MPa)	Density (ton/m^3)	Poisson's ratio
SC-80	Concrete	39.6	3.76	-	17,700	2.30	0.2
	Steel plate	-	-	346	206,000	7.69	0.3
HSC-80	Concrete	38.1	3.66	-	17,700	2.30	0.2
	Steel plate	-	-	346	206,000	7.69	0.3
	Rebar	-	-	361	206,000	7.69	0.3

The analysis results agreed well with the test results as shown in Table 2.

Table 2: Comparison between test and analysis results

Case		Max. displacement (mm)	Residual displacement (mm)	Failure mode
SC-80	Test result	43.0	30.0	Non-perforation
	Analysis result	42.7	28.3	Non-perforation
HSC-80	Test result	78.0	70.0	Non-perforation
	Analysis result	86.6	70.7	Non-perforation

COMPARISON ON IMPACT RESISTANCE OF SC AND RC PANELS WITH DIFFERENT STEEL RATIOS

The four categories (Concrete thickness: 80 mm, 120 mm, 160 mm, and 200 mm) of SC and RC panels, modified from the SC and HSC panels are used for the impact analysis. The impact analysis cases corresponding to four different concrete thicknesses with five different steel ratios respectively are summarized in Table 3. Also, the missile is modelled to evaluate the residual velocity. The impact velocity of missile is 110 m/s.

Table 3: Summary of analysis cases

Analysis case	Concrete thickness (mm)	Steel ratio (%)	Steel plate thickness (mm)	Rebar diameter (mm)
SC-80	80	1.0 ~ 3.0	0.38 ~ 1.18	-
RC-80			-	5.76 ~ 9.97
SC-120	120	1.0 ~ 3.0	0.58 ~ 1.78	-
RC-120			-	7.05 ~ 12.21
SC-160	160	1.0 ~ 3.0	0.78 ~ 2.38	-
RC-160			-	8.14 ~ 14.10
SC-200	200	1.0 ~ 3.0	0.98 ~ 2.98	-
RC-200			-	9.10 ~ 15.76

Table 4 summarizes the failure modes of the SC and RC panels corresponding to the analysis cases. In this study, the failure modes for the SC panels are classified into five types such as perforation, splitting, bulging*, bulging, and penetration. The bulging* is defined as the failure mode of when the missile stopped at the rear face steel plate. The failure modes for the RC panels are classified into four types such as perforation, perforation*, scabbing, and penetration. The perforation* is defined as the failure mode of when the missile stopped at the rear rebar.

Table 4: Summary of failure mode

Analysis case	Failure mode				
	Steel ratio 1.0%	Steel ratio 1.5%	Steel ratio 2.0%	Steel ratio 2.5%	Steel ratio 3.0%
SC-80	Perforation	Perforation	Perforation	Perforation	Bulging*
RC-80	Perforation	Perforation	Perforation	Perforation*	Perforation*
SC-120	Perforation	Perforation	Bulging*	Bulging*	Bulging*
RC-120	Perforation*	Perforation*	Perforation*	Scabbing	Scabbing
SC-160	Bulging	Bulging	Bulging	Bulging	Bulging
RC-160	Scabbing	Scabbing	Scabbing	Scabbing	Scabbing
SC-200	Penetration	Penetration	Penetration	Penetration	Penetration
RC-200	Penetration	Penetration	Penetration	Penetration	Penetration

Figure 2 shows residual velocities of missile corresponding to the different steel ratios for SC-80 and RC-80 at the time of 20 ms. In case of the perforation failure in both the SC and RC panels, the residual velocities of the missile for the SC panels were larger than those of the missile for the RC panels.

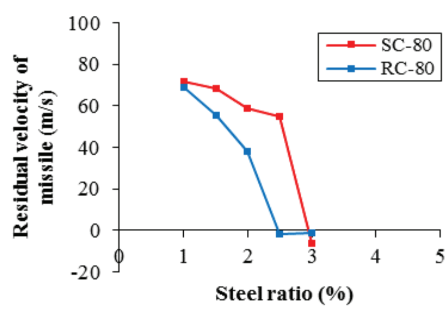
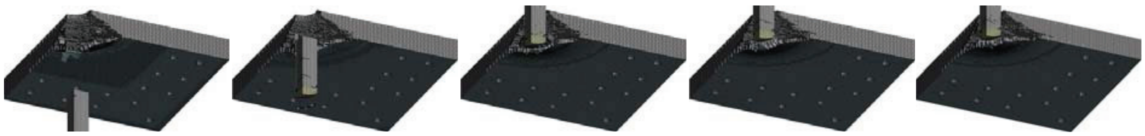
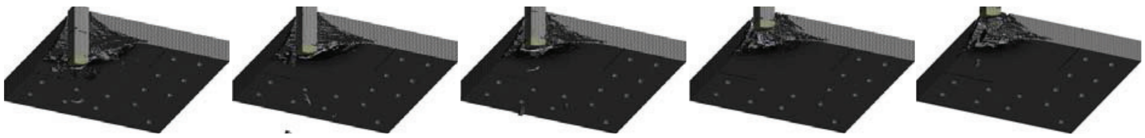


Figure 2. Residual velocity of missile for SC/RC-80

Figure 3 compares the failure modes of SC-120 and RC-120 corresponding to the different steel ratios. The analysis results showed that the SC panels were not perforated when the steel ratio was 2.0% and more, while the RC panels were not perforated when the steel ratio was 2.5% and more.



SC-120 (Perforation) SC-120 (Perforation) SC-120 (Bulging*) SC-120 (Bulging*) SC-120 (Bulging*)



RC-120 (Perforation*) RC-120 (Perforation*) RC-120 (Perforation*) RC-120 (Scabbing) RC-120 (Scabbing)

(a) Steel ratio = 1.0% (b) Steel ratio = 1.5% (c) Steel ratio = 2.0% (d) Steel ratio = 2.5% (e) Steel ratio = 3.0%

Figure 3. Failure modes of SC/RC-120

Crater sizes of the rear face steel plate for SC-160 and scabbing sizes of the rear face concrete for RC-160 corresponding to the different steel ratios are shown in Figure 4. For analysis cases of SC-160, the crater sizes of the rear face steel plate were 0 mm, because the failure mode of all the SC panels was the bulging. For analysis cases of RC-160, as the steel ratios of the RC panels increased, the scabbing sizes of the rear face concrete decreased.

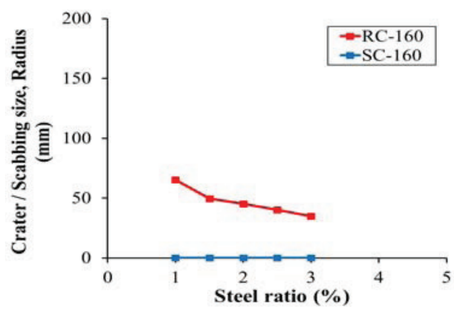


Figure 4. Damage sizes of SC/RC-160

The maximum displacements of the rear face steel plate of SC-200 and the rear face concrete of RC-200 with the different steel ratios are shown in figure 5. When the panel thickness was 200 mm, both the SC and RC panels showed the penetration failure mode regardless of the steel ratio. As the steel ratios of the SC and RC panels increased, the maximum displacements of the rear face decreased. However, the maximum displacements of the SC panels were smaller than the maximum displacements of the RC panels.

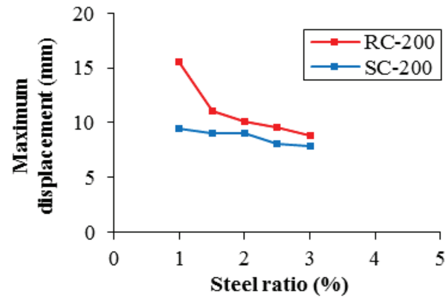


Figure 5. Maximum displacements of rear face for SC/RC-200

CONCLUSIONS

To compare the impact resistance of the SC and RC panels, the impact analyses were performed according to four different concrete thicknesses with five different steel ratios respectively. Based on this study, the following conclusions have been obtained:

(1) For analysis cases of SC/RC-80, the SC panels were not perforated when the steel ratio was 3.0% and more, while all the RC panels were perforated regardless of steel ratio. For analysis cases of SC/RC-120, the SC panels were not perforated when the steel ratio was 2.0% and more, while the RC panels were not perforated when the steel ratio was 2.5% and more.

(2) For analysis cases of SC-160, the crater sizes of the rear face steel plate were 0 mm, because the failure mode of all the SC panels was the bulging. However, for analysis cases of RC-160, the scabbing sizes of the rear face concrete were not 0 mm, because the failure mode of all the RC panels was the scabbing.

(3) The rear face steel plate of the SC panel was more effective than the rear rebar of the RC panel in preventing perforation.

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