Structural Behavior of SC and RC Panels under Impact Loading

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1. 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 reinforced concrete (RC) structures. In recent studies, however, it has been confirmed that a steel-plate concrete (SC) structures has a much better impact resistance than an RC structure. In this paper, the impact resistance of SC and RC panels is evaluated using the commercial software LS-DYNA. To verify finite element (FE) models, the analysis results for SC and half steel-plate concrete panels under impact loading are compared with the test results conducted in other research [1]. The impact analysis according to the different steel ratios with four different concrete thicknesses is performed in order to compare the impact resistance of SC and RC panels.

2. Verification of finite element models

The impact test performed by J. Mizuno et al. [1] is used to verify FE models. The impact test cases for SC and HSC panels are summarized in Table I. To reduce the analysis time, the impact force-time history is applied on SC and HSC panels instead of modeling an aircraft.

Table I: Summary of impact test cases

Test case	Thickness (mm)		Rebar diameter (mm)	Impact velocity (m/s)
	Concrete	Steel plate		
SC-80	80	1.2	-	146
HSC-80	80	1.2	6	149

Table II shows a comparison between the test and analysis results. Positive agreement had been achieved between the test and analysis results.

Table II: Comparison between test and analysis results

Case		Max. disp. (mm)	Residual disp. (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

3. Comparison on impact resistance of SC and RC panels according to different steel ratios

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

Table III: 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 IV summarizes the failure modes of SC and RC panels corresponding to the analysis cases. In this study, the failure modes for 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 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 IV: Summary of failure mode

Analysis case	Failure mode [a), b)]				
	Steel ratio 1.0%	Steel ratio 1.5%	Steel ratio 2.0%	Steel ratio 2.5%	Steel ratio 3.0%
SC-80	○	○	○	○	◇*
RC-80	○	○	○	○*	○*
SC-120	○	○	◇*	◇*	◇*
RC-120	○*	○*	○*	△	△
SC-160	◇	◇	◇	◇	◇
RC-160	△	△	△	△	△
SC-200	□	□	□	□	□
RC-200	□	□	□	□	□

[a)] SC panel: ○-Perforation, ◎-Splitting, ◇*-Bulging*, ◇-Bulging, □-Penetration
[b)] RC panel: ○-Perforation, △-Scabbing, □-Penetration

Fig. 1 shows residual velocities of missile corresponding to the different steel ratios for SC-80 and RC-80 at the time of 20 ms. For the steel ratios (1.0%, 1.5%, and 2.0%) occurring the perforation failure in both SC and RC panel, the residual velocities of the missile for SC panels were larger as compared with the residual velocities of the missile for RC panels.

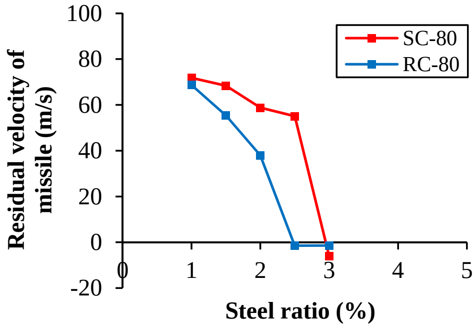
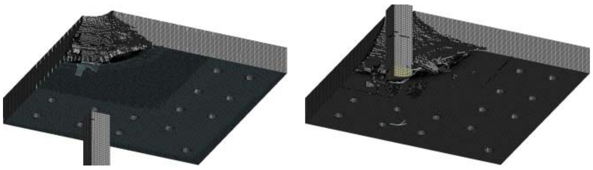


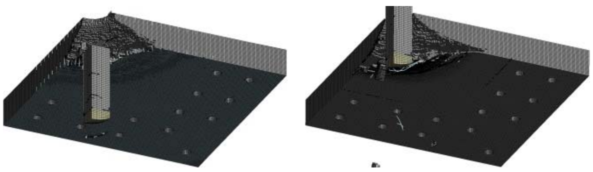
Fig. 1. Residual velocity of missile for SC/RC-80

Fig. 2 compares the failure shapes of SC-120 and RC-120 corresponding to the different steel ratios. The analysis results showed that while SC panels were not perforated when the steel ratio was 2.0% and more, RC panels were not perforated when the steel ratio was 2.5% and more.



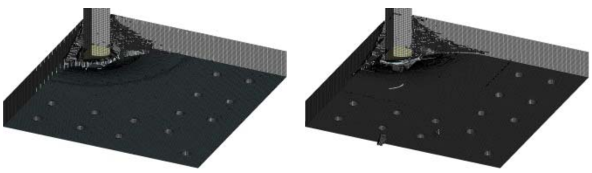
SC-120 (Perforation) RC-120 (Perforation*)

(a) Steel ratio = 1.0%



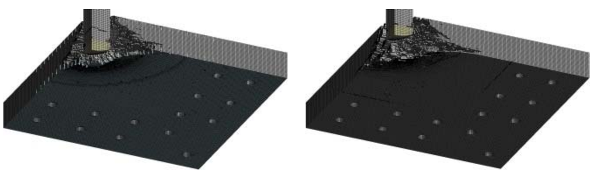
SC-120 (Perforation) RC-120 (Perforation*)

(b) Steel ratio = 1.5%



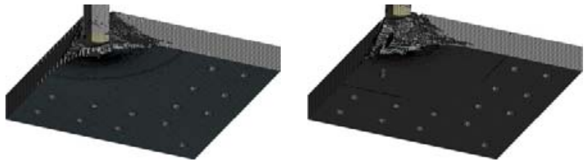
SC-120 (Bulging*) RC-120 (Perforation*)

(c) Steel ratio = 2.0%



SC-120 (Bulging*) RC-120 (Scabbing)

(d) Steel ratio = 2.5%



SC-120 (Bulging*) RC-120 (Scabbing)

(e) Steel ratio = 3.0%

Fig. 2. Failure shapes of SC/RC-120

The maximum displacements of the rear face steel plate for SC-200 and the rear face concrete for RC-200, corresponding to the different steel ratios, are shown in Fig. 3. As the steel ratios of SC/RC panels increased, the maximum displacements of the rear face decreased. However, the maximum displacements of SC panels were smaller as compared with the maximum displacements of RC panels.

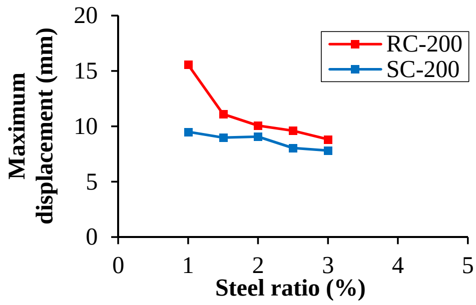


Fig. 3. Maximum displacements of rear face for SC/RC-200

4. Conclusions

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

(1) The rear face steel plate of SC panel plays more important role than the rear rebar of RC panel in preventing perforation.

(2) When the perforation failure occurs, RC panel is more effective than SC panel to reduce the velocity of the missile.

(3) When the penetration failure occurs, the stiffness of SC panel is greater than RC panel.

ACKNOWLEDGEMENT

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[1] J. Mizuno, N. Koshika, Y. Sawamoto, N. Niwa, T. Yamashita, and A. Suzuki, Investigation on impact resistance of steel plate reinforced concrete barriers against aircraft impact, Part1 : Test program and results, Transactions of the 18th SMiRT, Div.J05-1, pp.2566-2579, 2005.