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Parametric Study of SC Panel Subjected to Impact Loading

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1. Introduction

Since the terrorist attacks at the World Trade Center in New York City in 2001, in which aircraft was used to destroy buildings, safety assessment of NPP (Nuclear Power Plant) structures subjected to impact loading have been actively performed. FE analysis with impact test for small scale structure is necessary, because it is impossible to perform full scale test for safety assessment of NPP structures. Analysis factors such as erosion value, strain rate effect, and material model of concrete and steel can influence the analysis results. In this paper, the effects of concrete fracture energy and erosion in material model on FE results of SC panel subjected to impact loading are evaluated using a commercial program LS-DYNA. The analysis results are compared with impact test for SC panel conducted by other researchers [1].

2. FE model

SC panel presented by J. Mizuno et al. [1] is used for the impact analysis. The plan dimension and the thickness of SC panel are 1.8m square and 80mm respectively. The unconfined compressive strength of concrete and the yield strength of steel plate are 39.6MPa and 346MPa respectively. The FE model of SC panel, the support beam, the steel frames, and the bolts is shown in Fig. 1. The Winfrith Concrete model (MAT_84) and the Piecewise Linear Plasticity model (MAT_24) are used as the material model for concrete and steel respectively.

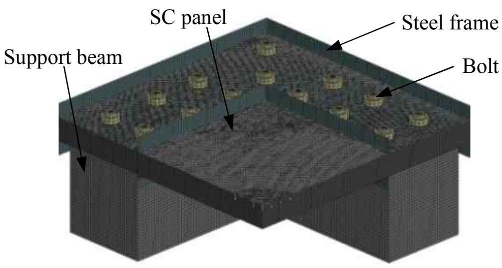


Fig. 1. FE model of SC panel

To reduce the analysis time, the impact force according to time history is applied instead of modeling the aircraft. The impact force-time history is estimated using the Riera function presented by T. Sugano et al. [2]. The Riera function is given as :

$$F\,(t) \;=\; P_c\,[x(t)] \;+\; \alpha_r\,\mu\,[x(t)]\,V^2\,(t) \qquad (1)$$

Where, P_c is the load necessary to crush the fuselage at the impact interface (Axial strength), α_r is a coefficient determined experimentally (α_r = 0.9), $\mu(x)$ is mass per unit length of the uncrushed portion, V is velocity of the uncrushed portion, and $x(t)$ is the distance from nose of the aircraft. Fig. 2 shows the impact force-time history estimated using the axial strength and the mass distribution of the aircraft model. The maximum force was about 548kN.

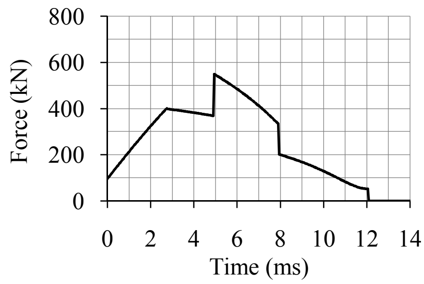


Fig. 2. Impact force - time history

3. Verification of FE model

The displacement history according to distance from center of rear face steel plate is shown in Fig. 3. The analysis result agreed well with the test result performed by J. Mizuno et al. [1]. Aside from the displacement of rear face steel plate center, the corresponding out-of-plane displacements closely matched that of the test results.

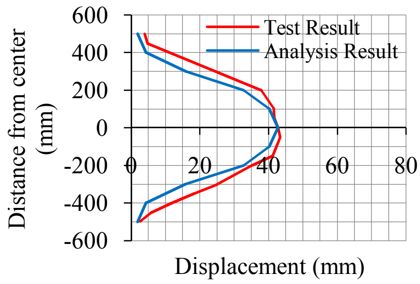


Fig. 3. Distance from center of rear face steel plate - displacement history

4. Parametric study

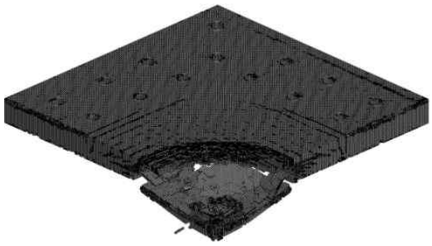
4.1. Effect of concrete fracture energy

A parametric study is performed to evaluate the structural behavior of SC panels according to the fracture energy of concrete. The fracture energy is derived using the function referred in CEB-FIP model code [3]. The analysis cases according to the fracture energy of concrete are summarized in Table I. The erosion values of ±7% for tension and compression of concrete are applied to all analysis cases.

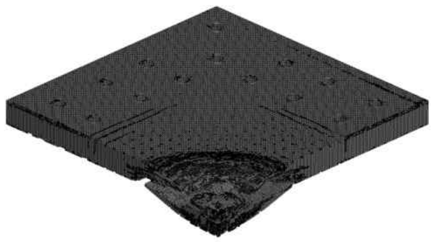
Table I : Analysis cases according to fracture energy

Case	Compressive strength of concrete (MPa)	Maximum aggregate size, d_{max} (mm)	Fracture energy, G_F (N/mm)
Case1-1	39.6	8	0.066
Case1-2		16	0.079
Case1-3		32	0.152

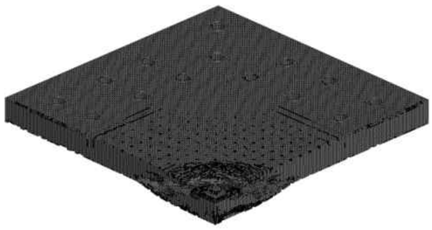
Fig. 4 compares the failure shapes of concrete according to the fracture energy. It is observed that as the fracture energy of concrete increased, the number of elements eroded and cracked decreased significantly.



(a) Case1-1



(b) Case1-2



(c) Case1-3

Fig. 4. Failure shapes of concrete according to fracture energy

4.2. Effect of erosion

A parametric study is performed to evaluate the structural behavior of SC panels according to erosion values of concrete and steel. The considered failure criteria in this study are the maximum/minimum principal strain and the plastic strain for concrete and steel respectively. The analysis cases are summarized in Table II. A fracture energy of 0.152N/mm is applied to all analysis cases.

Table II : Analysis cases according to erosion values

Case	Erosion value (%)	
	Tension and compression of concrete	Steel
Case2-1	±3 ~ ±16	47 (Fixed)
Case2-2	±7 (Fixed)	23 ~ 65

Fig. 5 shows the maximum displacement of rear face steel plate - erosion value history. As shown in Fig. 5, as erosion value of concrete increased, the maximum displacement of rear face steel plate decreased. However, the erosion of steel had not influenced the structural behavior, because the failure mode of SC panel is non-perforation.

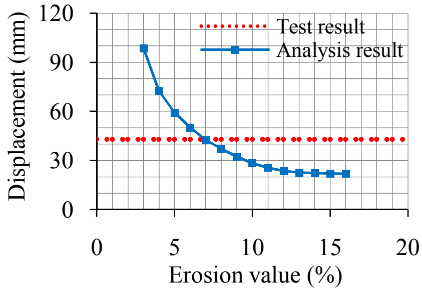


Fig. 5. Max. displacement of rear face steel plate - erosion value history

5. Conclusions

Parametric studies were performed to evaluate the structural behavior of SC panels according to the fracture energy of concrete and erosion values of concrete and steel. Based on these studies, the following conclusions have been obtained :

(1) SC panel with an applied erosion value of ±7% for tension and compression of concrete agreed well with the test result.
(2) The erosion of steel had not influenced structural behavior, because the failure mode of SC panel is non-perforation mode.
(3) SC panel using the concrete fracture energy of 0.152N/mm corresponding to the maximum aggregate size of 32mm showed a good agreement with the test result.

ACKNOWLEDGEMENT

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