Preliminary Study on Evaluation of Impact Resistance Performance of Fiber Reinforced Concrete Walls

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1. Introduction

As the safety assessments of nuclear power plants for the hypothetical large civil aircraft crash should be made mandatory, studies on large aircraft-nuclear power plant impact analyses and assessments studies are actively in progress. For the safety assessment of nuclear power plants against large civil aircraft crash, it is practically impossible to conduct full-scale experiments. Therefore, analysis using general purpose numerical analysis program accompanied by scale model experiments and element experiments has been adopted for the safety assessment [1, 2]. The safety of nuclear power plants against large civil aircraft crash is able to be accomplished by enhancement of the impact resistance performance, such as increasing the wall thickness, increasing the strength of concrete and using the fiber reinforced concrete which is able to be acquired by relatively simple process of adding fibers to a concrete mix without significant change of design and construction. A research for the enhancement of impact resistance performance depending upon design parameters for fiber reinforced concrete, such as type of fibers and application rate, is in progress. In this study, before the safety assessment of nuclear power plants against large civil aircraft crash, we assess the impact resistance performance of concrete wall depending upon type of fibers and impact velocity of objects.

2. Objective Concrete Wall for Impact Resistance Performance and Impacting Missile Body

2.1 Impacting Missile Body

VTT, Technical Research Centre of Finland, conducted an experiment for the safety assessment of concrete wall against the impact of various missiles [3]. A missile of approximate weight 50kg and length 1.5m is shown in the Fig.1. The missile is supposed to be made of aluminum and steel, and perfect elasto-plastic behavior is assumed.

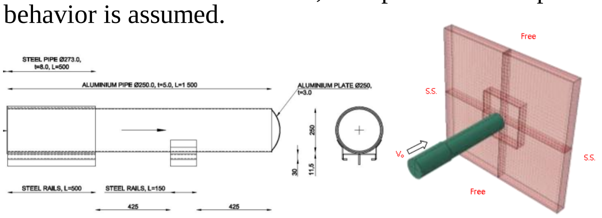

Fig.1. Missile and concrete wall configurations.

2.2 Concrete Wall and Material Characteristics

The objective concrete wall of assessment of impact resistance performance has the same dimensions of the object of the impact test of VTT. The concrete wall is 2.2m wide, 2.3m high and 0.15m thick, and reinforcement ratio is 0.767 % (D8@50mm). The boundary conditions are two edges simply-supported and other two edges free. The tensile behavior of normal concrete (NORM), concrete mixed with 1% of steel fiber (S1), and concrete mixed with 2% of polyamide fiber (PA2) are exhibited in Fig.2.

The impact area of the concrete wall, where the direct contact with the missile occurs, is modeled with fine mesh of 6mm size, and the numbers of the elements of the other part was restricted for the efficiency. The reinforcing bars are modeled with embedded rebar where truss element is used. The compressive behavior of the concretes, independent of the fiber reinforcement, follows the behavior of the normal concrete of compressive strength of 42MPa(6,000psi), shown in the Fig.2.

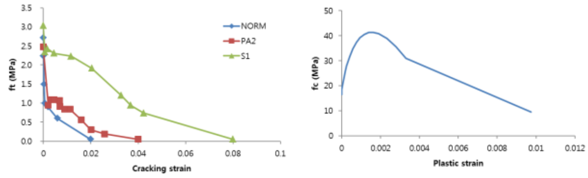

Fig.2. Tensile and compressive behavior characteristics.

3. Missile-Structure Interactive Impact Responses of Fiber Reinforced Concrete Walls and Results

Impact resistance performance depending on the type of concrete is estimated considering the missile-structure interaction. From the base velocity 100m/sec, four impact velocities, 50, 70, 100 and 127 m/sec, are chosen to coincide with the kinetic energy ratio 0.25, 0.5, 1.0, and 1.6, respectively. ABAQUS/Explicit, an explicit analysis program, is used for the finite element analysis, and damaged plasticity model is adopted for the concrete. Although the strain-rate effect of missile impact object is considered according to ACI-349, the strain-rate effect of concrete is not considered. Element deletion by crushing and rupture of the materials are not taken into account. Fig.3 shows maximum displacement at the opposite side of missile impact depending on the velocities of the missile and the type of fibers.

Fig.4, the displacement ratio divided by the maximum displacement of normal concrete wall, shows that the displacement of the concrete wall is in proportion to the square of velocities. The maximum displacements of concrete wall decreased approximately 10~35% in the case of concrete mixed with polyamide fiber 2%, and approximately 50% concrete mixed with steel fiber 1%.

Table I summarizes results on energy balance, such as kinetic energy, plastic dissipation energy and elastic strain energy, etc. Fig.5 shows plastic dissipation energy depending on the impact velocities. The results of Table I exhibit that the 89%~95% of kinetic energy of the missile is transformed into plastic dissipation energy. Missile impacts incur inelastic behavior, of which quantitative results is able to be considered as plastic dissipation energy. Fig.6-7 shows the ratio of plastic dissipation energy of concrete and missile. In the missile-structure interactive impact system, where total energy is constant for each missile impact velocity case, the smaller plastic dissipation energy of concrete wall means the higher impact resistance performance. The quantitative impact resistance performance comparing with normal concrete is shown in Fig.8, and the impact resistance performance of the fiber reinforced concrete is much higher in the case of higher missile impact velocity.

4. Conclusions

Studies on the safety assessments on nuclear power plants against large civil aircraft crashes are ongoing actively. As a step of evaluating the applicability of fiber reinforced concrete in means of ensuring more structural safety against impact, the impact resistance performances for the 1% steel fiber added and 2% polyamide fiber added fiber reinforced concretes has been evaluated. It is also considered that more advanced structural safety assessments of NPP against large civil aircraft impacts are possible by remedying the material characteristics of FRC and adopting more improved material model in near future.

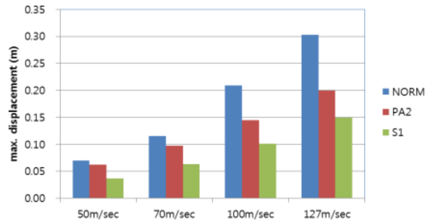

Fig.3. Maximum displacements of concrete wall according to the missile impact velocities.

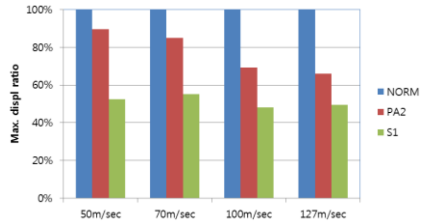

Fig.4. Maximum displacement ratios according to the missile impact velocities

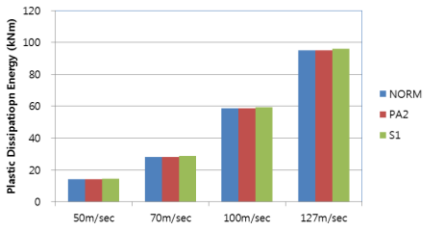

Fig.5. Plastic dissipation energies of total system (missile + concrete wall + rebar)

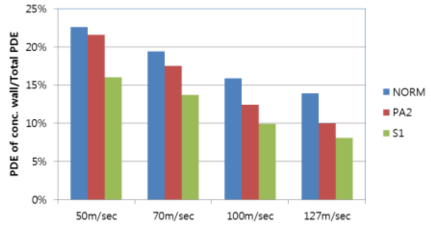

Fig.6. Ratios of plastic dissipation energy of concrete walls to total plastic energy

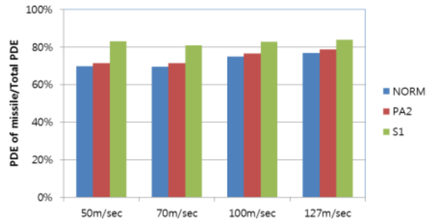

Fig.7. Ratios of plastic dissipation energy of missile to total plastic energy

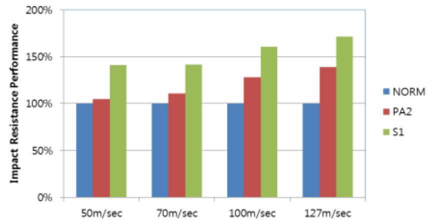

Fig.8. Resulting impact resistance performances

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Table 1: Comparison of resultant energies

Impact Velocity (m/sec)	FRC Type	Total Energy (J)	Plastic Dissipation Energy (PDE, J)				Elastic Strain Energy (J)	Artificial Energy (J)
			missile	rebar	slab	Sum		
50	Norm	1.59E+04	9.86E+03 69.7%	1.10E+03 7.8%	3.19E+03 22.6%	1.42E+04 89.0%	6.73E+02 4.2%	9.73E+02 6.1%
	PA2		1.02E+04 71.5%	9.78E+02 6.9%	3.08E+03 21.6%	1.43E+04 89.7%	6.85E+02 4.3%	8.68E+02 5.5%
	S1		1.21E+04 82.9%	1.63E+02 1.1%	2.33E+03 16.0%	1.46E+04 91.8%	6.97E+02 4.4%	6.23E+02 3.9%
70	Norm	3.11E+04	1.96E+04 69.5%	3.14E+03 11.1%	5.46E+03 19.4%	2.82E+04 90.7%	9.13E+02 2.9%	1.79E+03 5.8%
	PA2		2.02E+04 71.5%	3.11E+03 11.0%	4.95E+03 17.5%	2.83E+04 90.9%	9.06E+02 2.9%	1.75E+03 5.6%
	S1		2.33E+04 80.9%	1.54E+03 5.3%	3.96E+03 13.7%	2.88E+04 92.6%	9.27E+02 3.0%	1.35E+03 4.4%
100	Norm	6.35E+04	4.40E+04 74.9%	5.37E+03 9.2%	9.33E+03 15.9%	5.87E+04 92.4%	1.13E+03 1.8%	3.09E+03 4.9%
	PA2		4.48E+04 76.4%	6.53E+03 11.2%	7.26E+03 12.4%	5.86E+04 92.3%	1.18E+03 1.9%	3.26E+03 5.1%
	S1		4.90E+04 82.7%	4.34E+03 7.3%	5.89E+03 9.9%	5.92E+04 93.3%	1.20E+03 1.9%	2.63E+03 4.1%
127	Norm	1.02E+05	7.28E+04 76.7%	8.93E+03 9.4%	1.32E+04 13.9%	9.49E+04 93.1%	1.39E+03 1.4%	4.68E+03 4.6%
	PA2		7.48E+04 78.6%	1.08E+04 11.4%	9.48E+03 10.0%	9.51E+04 93.2%	1.44E+03 1.4%	4.74E+03 4.6%
	S1		8.04E+04 83.8%	7.76E+03 8.1%	7.79E+03 8.1%	9.60E+04 94.1%	1.62E+03 1.6%	3.97E+03 3.9%