Experimental Study of Local Behavior of Reinforced Concrete Plates to Missile Impact

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1. INTRODUCTION

Empirical formulas for design of reinforced concrete slab thickness have been proposed by Degen (1980), Chang (1981), and others regarding designs for local protection against impact of missiles. These formulas had assumed impact of missiles having hard noses. On the other hand, Alderson (1977) and others reported on experimental studies concerning impact of missiles with noses that were deformable when they hit.

This paper reports experimental studies about protection against missiles with reinforced concrete slabs focusing on (1) reduction in slab thickness in case of deformable missiles, (2) the reinforcing effect of steel lining provided at the back face, and (3) the protective effect in case of double plates of reinforced concrete slabs.

2. OUTLINE OF EXPERIMENTS

The method of testing is shown in Fig.1, consisted of making steel missiles collide against reinforced concrete slabs. A total of 12 tests were performed varying the specimen and missile conditions. Conditions of each tests are summarized in Table 1.

Target specimens were of three types; (1) single-layer reinforced concrete slab (Fig.2-a), (2) double-layer reinforced concrete slab (Fig.2-b), and (3) reinforced concrete slab having a steel lining at its back face (Fig.2-c). Example of target specimen is shown in Fig.3. Each slab was a square plate with sides 1.2m in length attached to a supporting base with prestressing steel rods so that spans would be 1.0m. The concrete slabs were of five different thicknesses, from 6cm to 24cm. The reinforcement ratios of the slabs were 0.6% on one side for both longitudinal and transverse bars and steel linings used at back faces were 3.2mm thick. The steel linings were connected to concrete by stud bolts 60mm long. The materials used for the targets were concrete corresponding to 240kg/cm^2 in compressive strength and reinforcing bars corresponding to yield strength of 3,500kg/cm^2.

As shown in Fig.4-a and Fig.4-b, missiles were of two kinds; those with hard noses that were solid (hard missile) and those with soft noses that were hollow (soft missile). Each missile weighed 2kg, was 6cm in diameter, and had a steel nose hemispherical in shape. The collision velocity was mainly 200m/sec, but 150m/sec and 100m/sec were also used.

Projection of missiles was done using launcher. Missile velocity was determined by the time of flight and distance between two reference points. Reactions of specimens were measured by load cells set at the supports in the four corners. In addition, two high-speed 16mm cameras recording 2,000 frames each second were set up so that the behavior could be observed.

3. TEST RESULTS AND DISCUSSIONS

The failure conditions were compiled in Table 2, while representative photographs showing the failure conditions of missiles and targets were shown in Photo.1 - Photo.4. The influences of the various parameters on the failure properties of the reinforced concrete slabs were as follows;

3.1 Influence of Thickness of Target

In the tests in which only slab thicknesses were varied with missile velocity and hardness as conditions in common, perforation occurred with specimen R-12-X, scabbing occurred at the back face of R-18-X, while there was only cracking at the back face of R-24-X. These results clearly showed that the thickness of the reinforced concrete slab had a great influence on failure properties. A conspicuous feature was that, whereas depth of penetration became shallower with increase in slab thickness, the size of spalling area was larger the greater the thickness. It is thought this was because concrete cover was larger the thicker the slab, making it easier for spalling to occur.

3.2 Influence of Velocity of Missile

The specimens R-12-X, R-12-Y, and R-12-Z were tested with only missile velocity varied. The degrees of damage were perforation, scabbing, and scabbing partially, and the missile velocity clearly had a great influence on the failure condition. The sizes of the areas of spalling and scabbing were smaller with lower velocity of missile. In addition, quantity of concrete spalled off at the back are fewer and their velocity were slower with lower velocity of missile.

3.3 Influence of Hardness of Missile

Soft-nosed missiles all buckled in the tests (Photo.1). In the tests with R-18-X and R-18-S where only the hardness of the missile differed, the results were that the former showed scabbing partially while the latter only cracked. For R-12-X and R-12-S, the results were perforation and scabbing, respectively. The number of reinforcing bars ruptured, depth of penetration, size of spalling area showed trends of becoming smaller with the soft-nosed missile. The degree of damage with impact at a velocity of 199m/sec with R-12-S (Photo.2) was about the same as for R-12-Y (Photo.3), a hard-nosed missile with impact at 164m/sec. It was considered from these results that the effects of the soft-nosed missile on reinforced concrete slabs are considerably smaller compared with a hard-nosed missile.

3.4 Effect of Reinforcing Back Face with Steel Lining

Whereas R-12-X and R-18-X without steel linings at the back face were perforation and scabbing partially, L-12-X and L-18-X with steel linings showed no cracking or perforation of the steel plates and the effectiveness of the reinforcement with lining was clearly seen. On cutting the specimens after testing to see how they looked inside, it was found that concrete parts were damaged to about the same degree with or without steel lining (Photo.4). It was learned from these observation results that providing steel lining at the back face could prevent perforation by the missile and scabbing of the back face which would be a factor causing a secondary shrapnel effect.

3.5 Impact Resistance of Double-Layer Reinforced Concrete Slab

Impact tests were performed on reinforced concrete slabs in two layers each 9cm thick, or one layer 6cm and the other 12cm, for a total thickness equaling a slab of 18cm. In case of a hard-nosed missile, whereas with the reinforced concrete slab R-18-X in a single layer part of the back face was scabbed, in the tests on W-09-X and W-12-X, the second layers of both were scabbed over wide areas. According to these results, it was thought that in case of a hard-nosed missile, a single-layer slab would have a superior impact resistance compared with a double-layer slab. On the other hand, in case of a soft-nosed missile, R-18-S of single layer and the second layer of W-12-S showed about the same degree of damage, which were cracking only, and it was thought that in case of a soft-nosed missile, double-layer reinforced concrete slab would have roughly the same impact resistance as a single reinforced concrete slab of equal total thickness.

3.6 Comparisons with Prior Evaluation Formulas

Many formulas have been proposed for evaluating the critical slab thickness at which perforation and scabbing of reinforced concrete occur when an object flying in from the outside collides with the concrete. Degen's formula for perforation thickness and Chang's formula for scabbing thickness are considered to be comparatively accurate. In this section, these two formulas are considered to evaluate the test results.

The slab thicknesses required according to the two formulas and the test results were compared regarding perforation (Fig.5) and scabbing (Fig.6) and graphs were respectively drawn. In both cases, the necessary slab thicknesses calculated by the formulas to check the degrees of safety of the formulas were simply multiplied by coefficients and the curves thus obtained are shown on the graphs. These graphs indicate that both of the formulas give slab thicknesses on the conservative side regardless of the hardness of the missile's nose.

Judging by the results of comparisons regarding the critical slab thickness against perforation, in case of a hard-nosed missile, about 0.75 to 0.90 of the required thickness according to Degen's formula is the critical slab thickness against perforation. In case of a soft-nosed missile, it is even less and thought to be 0.80 or under. In the same way, with regard to the critical slab thickness against scabbing, in case of a hard-nosed missile, it is 0.75 to 0.90 of the slab thickness required according to Chang's formula, while in case of a soft-nosed missile, it is thought the critical thickness against scabbing would be not more than 0.65.

4. CONCLUSIONS

Regarding the behaviors of reinforced concrete slabs subjected to impact loads, following conclusions were obtained by these tests.

- The effects of soft-nosed missiles are considerably less than those of hard-nosed missiles.
- The provision of a steel lining at the back face is effective for the prevention of perforation and scabbing.
- The impact resistance of a double-layer reinforced concrete slab to a missile striking against it is inferior to the resistance of a single-layer reinforced concrete slab in case the missile's nose is hard, and equal in case it is soft.
- The existing formulas for evaluating critical thicknesses against perforation and against scabbing give slab thicknesses on the conservative side compared with test results regardless of the conditions concerning target specimens and missiles. When the missile noses are deformable, this is even more pronounced.

REFERENCES

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Chang,W.S.(1981), "Impact of Solid Missiles on Concrete Barriers." Journal of the Structural Division (ASCE), Vol.107, No.ST7, pp.257-271.

Degen,P.P.(1980), "Perforation of Reinforced Concrete Slabs by Rigid Missiles." Journal of the Structural Division (ASCE), Vol.106, No.ST2, pp.1623-1642.

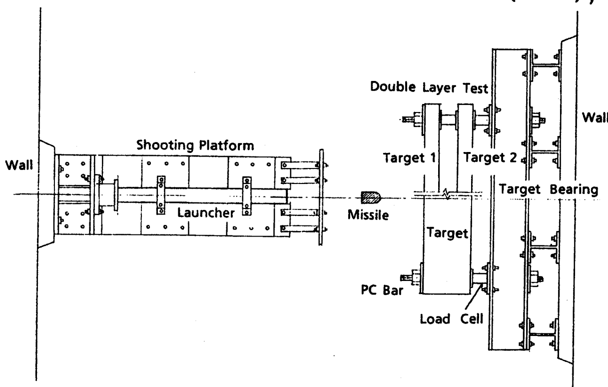

Fig.1 Impact Test Apparatus (Plan)

Table 1 List of Specimens

SPECIMEN	TARGET				MISSILE	
	Thickness (cm)	Remark	Re-bar Ratio(%)	Re-bar Type	Velocity (m/sec)	Type
R - 24 - X	24		0.59	D13	200	HARD
R - 18 - X	18		0.61	D10	200	HARD
R - 12 - X	12		0.59	D10	200	HARD
R - 12 - Y	12		0.59	D10	150	HARD
R - 12 - Z	12		0.59	D10	100	HARD
R - 18 - S	18		0.61	D10	200	SOFT
R - 12 - S	12		0.59	D10	200	SOFT
W - 09 - X	9 9	Double Layer	0.59 0.59	D6 D6	200	HARD
W - 12 - X	6 12	Double Layer	0.59 0.59	D6 D10	200	HARD
W - 12 - S	6 12	Double Layer	0.59 0.59	D6 D10	200	SOFT
L - 18 - X	18	Liner	0.61	D10	200	HARD
L - 12 - X	12	Liner	0.59	D10	200	HARD

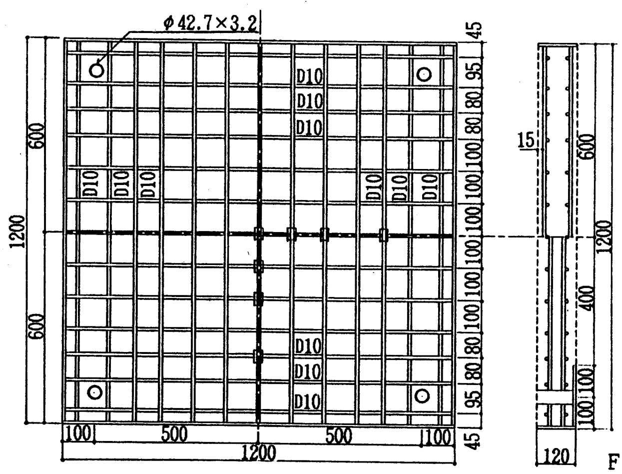

Fig.3 Example of Target (12cm Thickness)

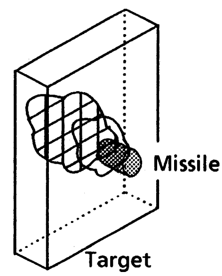

Fig.2-a Single-Layer Reinforced Concrete Slab Test

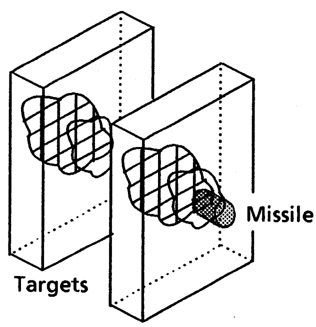

Fig.2-b Double-Layer Reinforced Concrete Slab Test

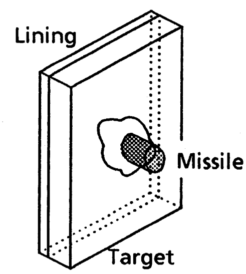

Fig.2-c Test of Reinforced Concrete Slab with Lining

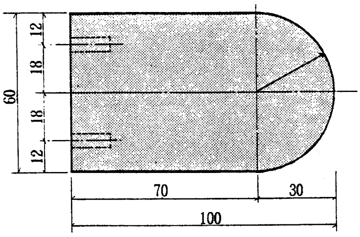

Fig.4-a Hard Missile

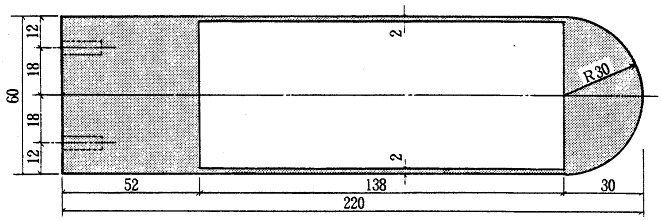

Fig.4-b Soft Missile

Table 2 Summary of Test Results

Specimen	TARGET					MISSILE			Maximum Reaction Force (t)	Damage
	Penetration Depth (mm)	Opening (mm×mm)	Spalling (mm×mm)	Scabbing (mm×mm)	No. of Re-bar Ruptured	Velocity (m/sec)	Type	Damage		
R - 24 - X	60		317×305		1	209	hard	none	34.7	PENETRATED
R - 18 - X	78		282×217	445×435	2	211	hard	none	23.0	SCABBED
R - 12 - X		80×100	205×226	720×428	3	215	hard	none	10.6	PERFORATED
R - 12 - Y	100	83×100	189×203	561×480	1	164	hard	none	11.8	SCABBED
R - 12 - Z	44		162×146	455×512	0	95	hard	none	14.5	SCABBED
R - 18 - S	35		180×200		0	214	soft	buckled	27.7	PENETRATED
R - 12 - S	92	95×100	208×215	764×395	1	199	soft	buckled	15.2	SCABBED
W - 09 - X	106	82×90 90×80	185×180 123×110	553×325 715×455	3 3	210	hard	none	11.7	PERFORATED SCABBED
W - 12 - X	59	100×85 90×85	170×165 155×180	295×495 545×410	4 1	206	hard	none	19.5	PERFORATED SCABBED
W - 12 - S	25	86×85	140×154 105×110	339×604	4 0	202	soft	buckled	20.8	PERFORATED PENETRATED
L - 18 - X	66		315×268		1	206	hard	none	25.8	PENETRATED
L - 12 - X	125		228×255		2	212	hard	none	18.8	PENETRATED

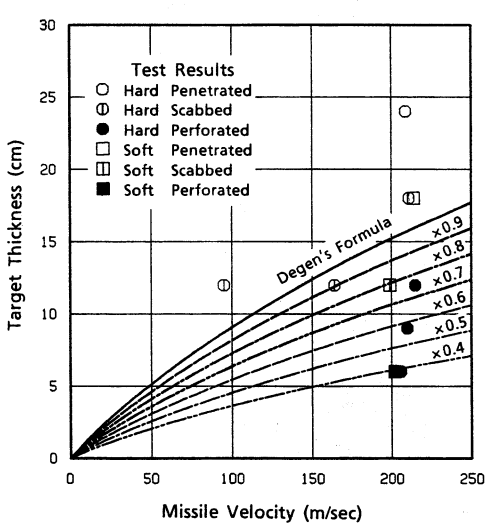

Fig.5 Comparison of Test Results to Predicted Perforation Thicknesses using Degen's Formula

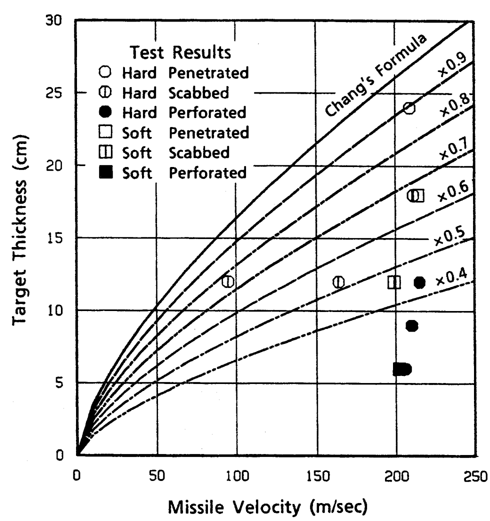

Fig.6 Comparison of Test Results to Predicted Scabbing Thicknesses using Chang's Formula

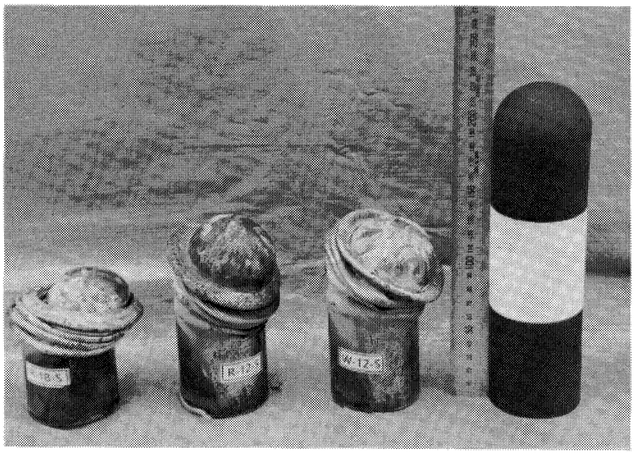

Photo.1 Buckling of Soft Missiles

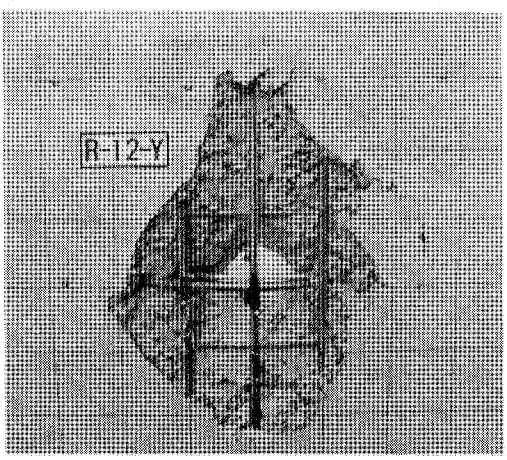

Photo.2 Back Face of 'R-12-Y'

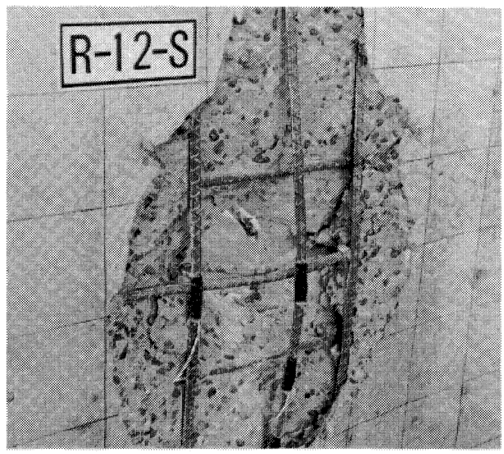

Photo.3 Back Face of 'R-12-S'

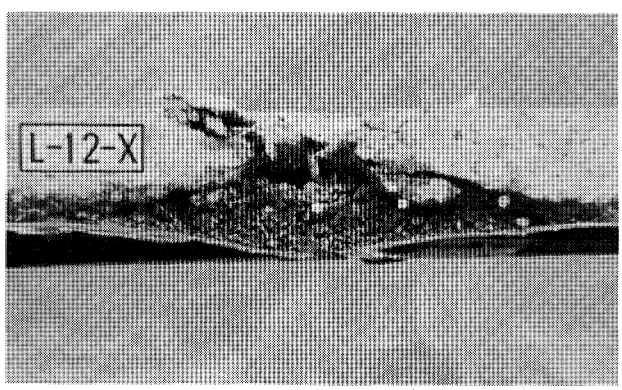

Photo.4 Section of 'L-12-X'