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PROTECTIVE EFFECTS OF DOUBLE-LAYERED RC PLATES ON LOCAL DAMAGE BY PROJECTILE IMPACT

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1. INTRODUCTION

The establishment of a design method for reinforced concrete (RC) structures subjected to impact load has recently become a topic of high priority in the nuclear, chemical and heavy industries, especially for which high-safety requirements have to be applied besides the conventional structural design methods.

There are several ideas to improve impact resistance of RC structural members as, for example, 1) lining a steel plate on the rear face of RC plate, 2) use of double-layered RC plates with some elastic material like a rubber as an absorber between the two RC plates, and 3) use of fiber reinforced concrete etc. A double-layered structural system with an absorber is considered to be an effective device to prevent local damage, particularly scabbing of concrete. Thus, this study deals with the double-layered structural system among the ideas mentioned above and is to investigate experimentally the effects of parameters: the thickness of RC plates and absorber, and the existence of absorber, on the impact resistance.

In the impact test, a cylindrical mild steel and stainless steel projectiles with a mass of 0.43kg, a diameter of 39.5mm, were shot from an air gun and impacted on the center of RC specimens. The projectile velocity at impact was about 170m/sec. RC plates were 0.6m square with thicknesses of 3 to 10cm. A total of 46 specimens with various combinations of RC plates and absorber was provided for the impact test to investigate the effect of an absorber on the extent of local damage.

2. EXPERIMENTAL PROCEDURES

2.1 Specimen

Figure 1 outlines the dimensions of the specimens employed for a concrete target. They are 0.6m-square reinforced concrete plates with thicknesses ranging from 3 to 10cm. All plates are single reinforced with deformed rebars of 6mm in diameter. The average compressive strength of concrete was 30.6MPa. In this study, RC plates with the thicknesses of 8, 9 and 10cm are set as standard specimens for the experiments. The difference in the total thickness of the composite double-layered RC plates, the impact absorption capacity and thickness of the absorber are investigated for their combined effects on impact resistance.

2.2 Properties of absorber

To improve impact resistance of RC plates, it is important to prevent concrete scabbing. For this purpose, it is necessary to design structures that could reduce or isolate the propagation of stress waves. The structural system of double-layered RC plates with shock absorber is one of the methods designed to attain this objective. Herein, hard urethane foam was employed for a shock absorber, and scabbing prevention by cutting off the stress wave propagation is examined.

2.3 Types of specimens

As shown in Table.1, three types of specimens were arranged, that is, Type-B: double-layered RC plates without absorber, Type-C: double-layered RC plates with absorber, and Type-A:

standard RC plate. In this test, the thicknesses of Type-A specimens(8,9 and 10cm) are considered to be standard, and the thicknesses of the front and rear plates in Type-B and C specimens are combined in such a way that the sum of the front and rear plate thicknesses be equal to that of the standard ones.

2 . 4 Configurations of projectiles

Two types of projectiles were used in this test as shown in Fig.2. Both projectiles have the same weight of 430g but different magnitude of axial strength, and consisted of three parts: a head, a body and a tail. The head is a mild steel having a weight of 160g and a flat nose shape. The tail is made of plastic and this part is used for placing the projectile in the launch tube by press ring. Two kinds of pipes: mild steel and stainless steel pipe with the same weight of 173g, were employed as bodies. The dimensions and material properties of the body are given in Table 2. As shown, the static axial strengths of the bodies are 186.4 and 50.0 KN, respectively. Therefore, they can be defined as a hard and a soft projectile, respectively.

2 . 5 Measuring instrumentation

As shown in Figure 3, accelerations and displacements at different locations of the surface of targets are measured by installing 7 accelerometers(500-100,000G) on the back face and 4 non-contacting eddy-current transducers on the front face, respectively. The displacement at the impacted point is measured by an optical displacement sensor. The time interval for data sampling is kept at 5μsec.

2 . 6 Projectile launcher facility

Figure 4 is a schematic view of the impact test set-up. The detail of the projectile launcher facility used here was already presented in Ref. 1. The impact testing facility consists of a high-speed loading machine with a loading capacity of 490kN and a maximum loading velocity of 4.0m/sec and a projectile launching apparatus capable of launching 40mm-caliber projectiles with a mass of about 0.5kg at a velocity of about 200m/sec. The projectile within the launching tube is ejected by high-pressure air. That is, the air pressure in the high-speed loading machine is increased almost instantaneously by the piston in the chamber of the air-jack with the speed of about 4.0m/sec. The striking velocity of projectile is obtained by measuring the time duration in which the projectile passes through the optical velocity meters set in the tube. The concrete target is suspended vertically at a distance of 1.2m from the muzzle by two steel slings to allow free movement after impact.

3. TEST RESULTS

3 . 1 Reduction of local damage by making double-layered RC plates

Figure 5 shows comparisons of the extent of local damage observed in each type of specimens after the impact of steel projectile. The diameter of scabbing damage measured in Type-A was 31cm. Those in Type-B were less than 20cm, and those in Type-C were less than about 27cm. No scabbing can be observed in both Type-B and C, for which the front plate(first RC plate) is thicker than the rear plate. That is , for the case of equal thickness with single RC plate(Type-A) whose thickness is enough to cause no perforation but only scabbing, the extent of local damage can be decreased by using a double-layered structural system. Accounting for the fact that scabbing is caused by the propagation and reflection of the stress wave after impact, it can be recognized that structural system of double-layered RC plates either with or without shock absorber has the effect of reducing scabbing by cutting off and/or reducing the transmission of applied forces and the propagation of stress wave to the rear plate.
The test results showed that the restraining effect of rear RC plate on the local damage in Type-B specimens without absorber was a little larger than that in Type-C specimens with absorber. Though this reason has not yet been completely understood, it may be due to uncertainty of force transmitting mechanism from the first plate to the second, and depends on the characteristics of material properties of the absorber.

3 . 2 Effects of plate thickness

As seen from Figure 5, the projectiles perforated the two RC plates in the case that the thickness of the first plate is equal to or thinner than that of the second plate in Type-C specimens, and

perforated only the front plate when the thickness of the first plate is thicker than that of the second plate.
For Type-B specimens, the projectile perforated both two plates with equal thickness(5cm), and perforated only the first plate when the thickness of the first and second plates is different. The extent of local damage in Type-B specimens is similar to that in Type-C specimens.
It may be concluded that when the total thickness of the first and second RC plates is kept constant, scabbing and perforation can be restrained by thickening the first plate more than the second one.

3 . 3 Effects of hard urethane foam as absorber
It can be seen from the results in Figure 5 that the extent of local damage in Type-B is smaller than that in Type-C. This tendency becomes particularly remarkable for the impact of a stainless steel projectile. Under high-speed impact conditions, hard urethane foam can not be expected to be effective as an absorber that will resist to perforation of a projectile. The test results for specimens without absorber would rather show desirable than those with it. Therefore, it was found that perfect separation of two RC plates without absorber is one of effective ways to prevent scabbing and/or perforation by restraining from the transmission of force and the propagation of stress wave.

3 . 4 Local response
Figure 6 shows an example of the acceleration response of Type-A specimen with the plate thickness of 10cm for the impact of steel projectile. Time duration of acceleration is 0.1 to 0.25 msec. In fact, time of the maximum response at each measuring point is lagged with the distance from the impacted point becomes larger. The maximum difference of times at which the maximum accelerations occurred in the impacted point(G1) and the point(G4) was about 0.26 msec.
Figure 7 shows the relation between the maximum value of acceleration on the rear face of specimens and the distance from the impacted point(G1). For the impact of both steel and stainless steel projectiles, the maximum acceleration responses of Type-B and C are smaller than those of Type-A. The value of maximum acceleration at the point(G4) located 15cm from the impacted point is reduced to about 1/10 to 1/15 of that at the impacted point. That is, the magnitude of the maximum acceleration remarkably decreases as the distance from the center becomes large. This tendency was observed in all types of test. This means that local response may be limited within the range of 30cm in diameter.

3 . 5 Displacement response
The displacement on the impacted face does not occur instantly after impact, and is less than 4mm at which impact terminates. Figure 8 shows an example of acceleration- and displacement-time histories at the reverse point of impacted one on the rear plate. It can be seen that there exists a time lag of about 0.82msec between the times at which the acceleration and displacement responses were appeared, respectively.

4. CONCLUSIONS
Results obtained from this test can be summarized as follows:
(1) Local damage of scabbing and/or perforation can be reduced by employing a structural wall system composed of double-layered RC plates. When the total thickness of the first and second RC plates is kept constant, the thicker the first plate is, the more effective the scabbing of rear plate can be restrained.
(2) Hard urethane foam did not work as an absorber against the high-speed impact of projectile. From the viewpoint of cutting off stress wave, a double-layered RC plate without any absorber, that is, two plates are completely separated, is expected to be more effective. If attention would be focused on the reduction of impact force and the prevention of perforation, it is desirable to employ an absorber with high ductile material like an soft rubber.
(3) From the results of acceleration distributions, it was found that RC plate under high-speed projectile impact behaves locally in the area of 30cm in diameter(that is, about 8.6 times of a projectile diameter) from the impacted point. From the viewpoint of displacement response, it was also found that RC plate will not deform immediately after impact, but may begin to deform

according to the progress of penetration after impact.

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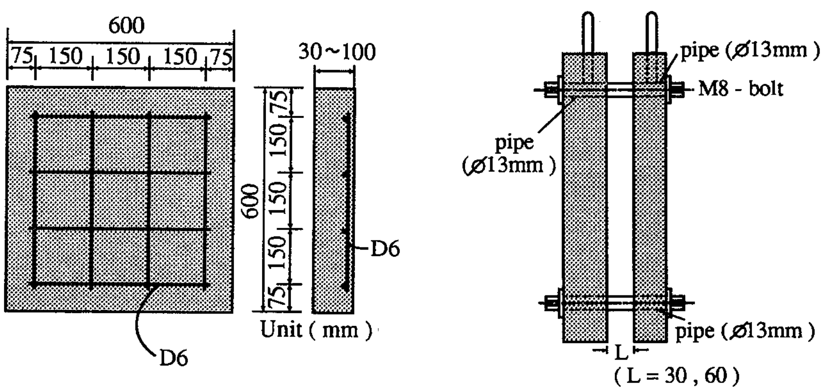


Fig.1 Dimensions of concrete target

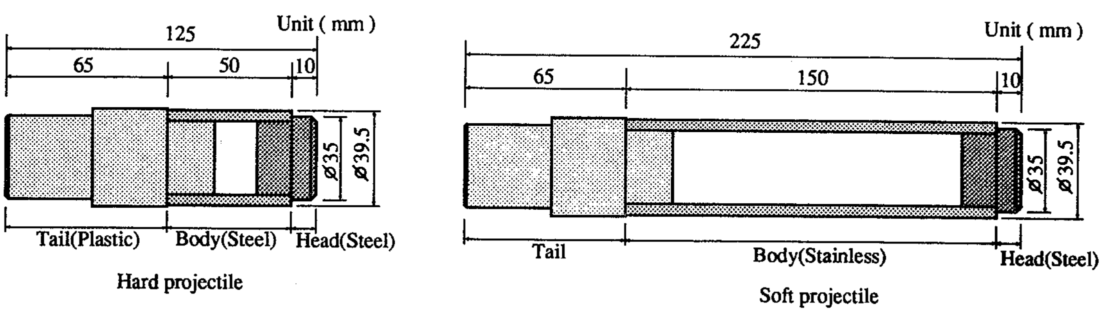


Fig.2 Configuration of projectiles

Table.1 Types of specimens

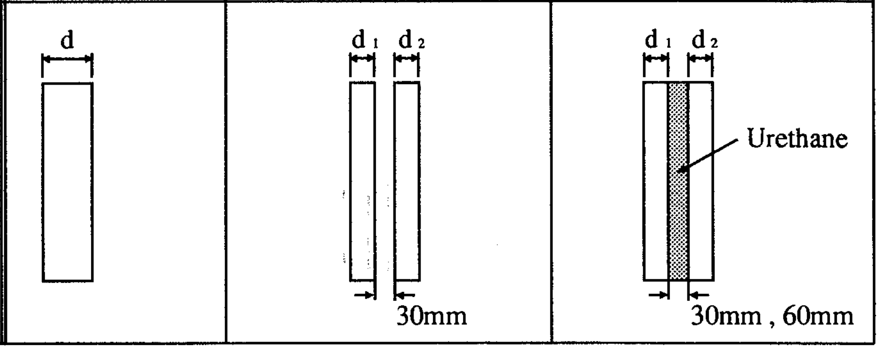
	Standard RC Plate (Type-A)	Double - layered RC Plate without Absorber (Type-B)						Double - layered RC Plate with Absorber (Type-C)					
		$d_1 = d_2$		$d_1 > d_2$		$d_1 < d_2$		$d_1 = d_2$		$d_1 > d_2$		$d_1 < d_2$	
Combinations of Thickness (mm)	80	40	40	50	30	30	50	40	40	50	30	30	50
	90	45	45	60	30	30	60	45	45	60	30	30	60
	100	50	50	70	30	30	70	50	50	70	30	30	70
Side View													

Table.2 Dimensions and material properties of projectile bodies

Material of body	Length (cm)	Thickness (cm)	Outer Diameter (cm)	Axial Strength (kN)
Steel	5.0	0.42	3.83	186.4
Stainless steel	15.0	0.15	3.41	50.0

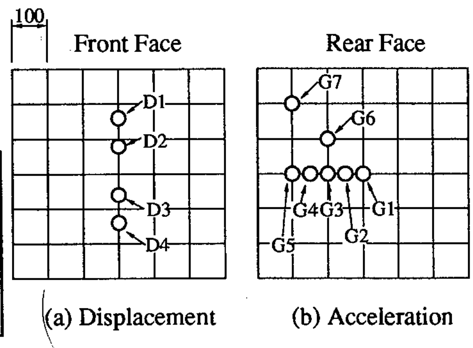


Fig.3 Measuring positions

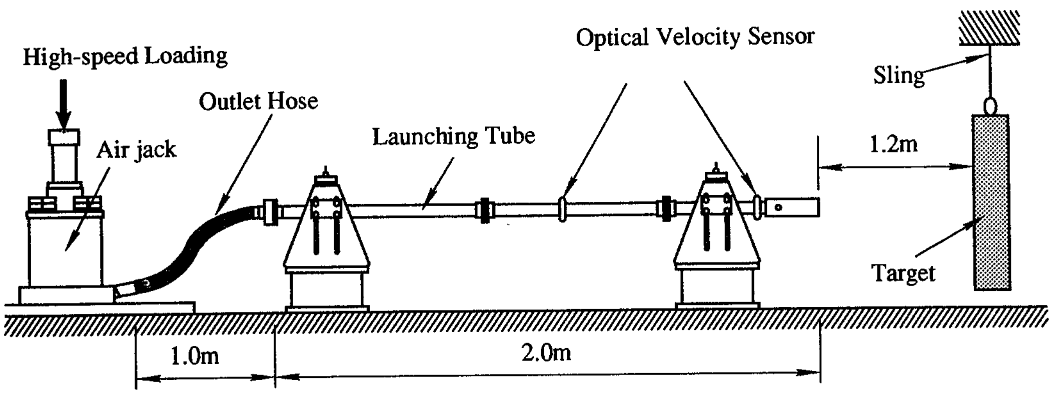


Fig.4 Outline of projectile launcher apparatus

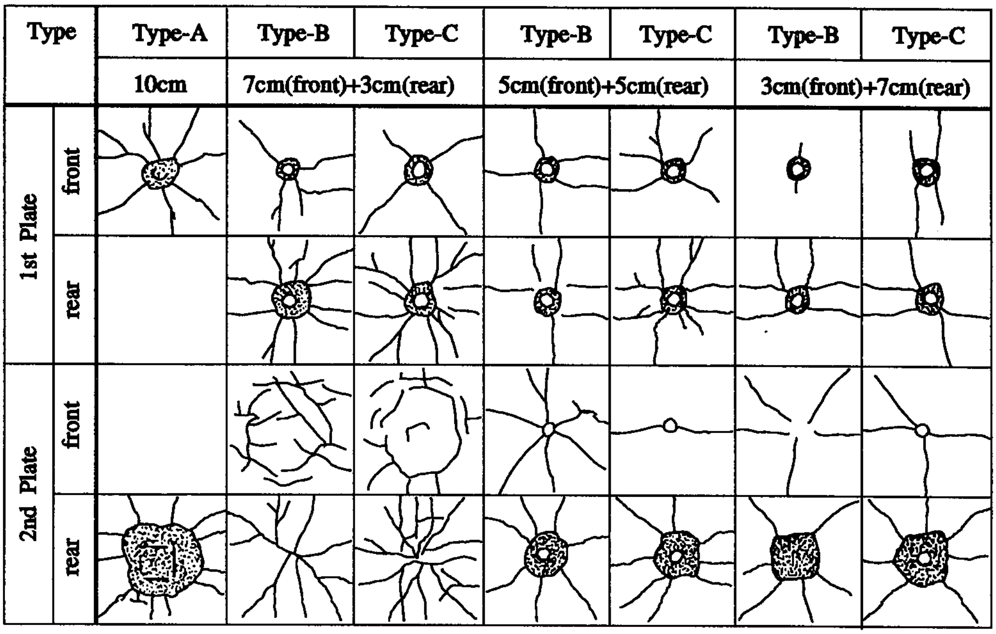


Fig.5 Comparison of local damage state after impact of steel projectile

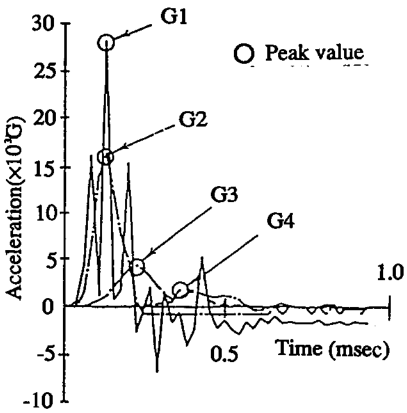


Fig.6 Acceleration time histories at different positions (Type-A, ST1000)

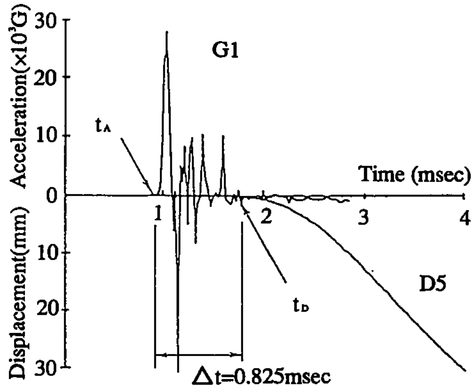
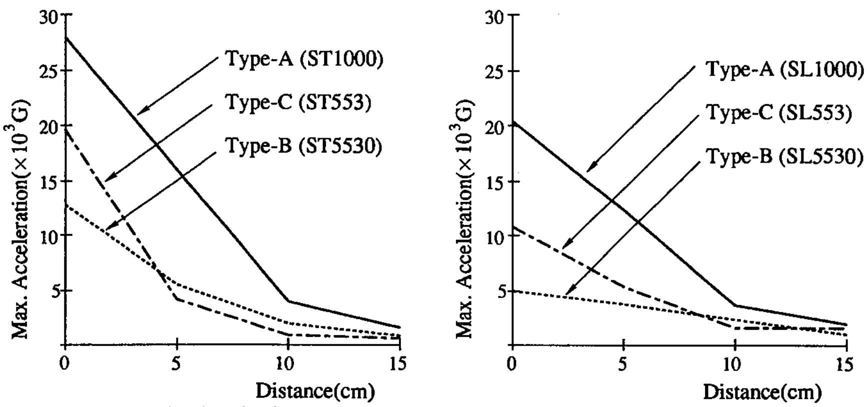


Fig.8 Comparison of the acceleration and displacement responses (Type-A, SL800)



(a) For hard projectiles (steel)

(b) For soft projectiles (stainless steel)

Fig.7 Relation of the maximum acceleration and the distance from the center