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EXPERIMENT AND SIMULATION OF DOUBLE-LAYERED RC PLATES UNDER IMPACT LOADINGS
PART 1: IMPACT TESTS FOR DOUBLE-LAYERED RC PLATES

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1 INTRODUCTION

At a nuclear power plant facility, it should be of interest and important problem to ensure structures against impact loads induced by projectile impacts or plant-internal accidents. It has been well known that local damage consists of spalling of concrete from the impacted area and scabbing of concrete from the back face of the target together with projectile penetration into the target. There are several techniques for improving the impact resistance of RC slabs, that is, lining with a steel plate on the impacted and/or rear face of the slab[1], [2],[3], making the slab a double-layered composite slab with an elastic absorber[4],[5] and employing a fiber reinforced concrete[6] or a high-strength concrete as the slab materials. Of the many measures available for withstanding impact loads, the use of a double-layered RC slab with absorber is expected to have the higher resistance in reducing or preventing local damage. This paper presents the results of an experimental investigation on the impact resistance of double-layered RC plates subjected to the impact of projectile. In the experiment, the effects of two parameters; the combination of two RC plates having different thicknesses and the existence of an absorber in the middle layer, are mainly investigated. And, the effects of the concrete thickness(7, 9 and 11cm) and the concrete strength(a normal-:35MPa, a lightweight-:40MPa and a high-strength:57MPa) of target were also examined. RC plates, 0.6m-square, were used for test specimens. The projectile has a mass of 0.43kg, made of steel with a flat nose. An average projectile velocity was about 170m/sec. A rubber plate shaped into a square with the same size of RC plate was used for a double-layered specimen as an absorber which was put between two RC plates.

2 OUTLINE OF IMPACT TEST

2.1 Impact Testing Apparatus

Figure 1 is a schematic view of the impact test set-up. The impact testing facility consisted of a high-speed loading machine, which has a loading capacity of 490kN and a maximum loading speed of 400cm/sec, and a projectile launching apparatus, which is a 40-mm smooth-bore airgun and has a capable of launching 40-mm caliber projectiles with a mass of about 0.5kg at a velocity of approximately 200m/sec. The projectile within the launching tube is ejected by high-pressure air.

2.2 Projectiles

In this impact tests, a projectile of a mild steel tube, mass of 0.43kg, flat nose, was used and launched to striking velocity of about 170m/sec. A projectile is consisted of the three parts as head, body and tail as shown in Fig.2. The head is made of steel having the mass of 160g. The dimensions and material properties of the body are given in Table 1. As shown, the static

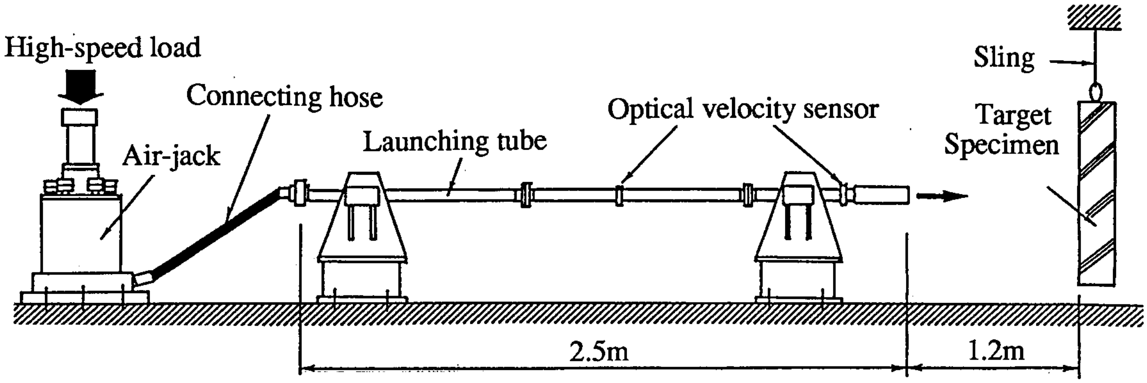

Fig.1 Schematic view of impact test set-up.

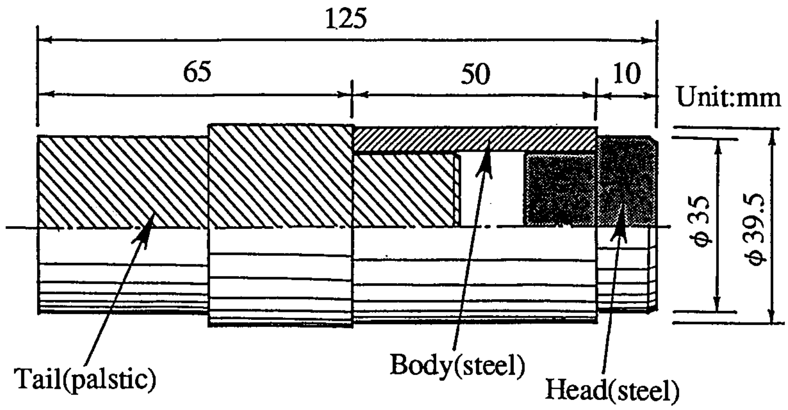

Fig.2 Configurations of a projectile.

Table 1 Dimensions and material properties of projectile body.

Material	Length	Thickness	Outer diameter	Axial strenth
Mild Steel	50mm	4.2mm	39.5mm	186.4kN (19.0tonf)

compressive strength of the body was 186.4kN. This may be defined as a hard or rigid projectile based on previous test results. The tail is made of a plastic and this part is used for placing the projectile itself within the launch tube by a press ring.

2.3 Target Specimens

Figure 3 outlines the dimensions of the specimens for a concrete target. The size of all RC target plates were 0.6m square, scaled down by about 1/10 of prototypes. Two of RC plates with the different three thicknesses of 3.0, 4.5 and 6.0cm were combined as to sum in 9.0cm and, thus, these are called the double-layered RC targets. As shown in Fig.4, three types of double-layered RC targets(C1,C2 and C3-types) with or without absorber between two plates, were employed. And, to examine the effects of double-layering, the standard RC targets(M1,M2 and M3) with the thickness of 9.0cm were also tested. The target was located 1.2m from the end of the gun barrel and suspended by two steel slings so as to enable the target to move freely after the impact of projectile. A total of 28 specimens were used for impact tests.

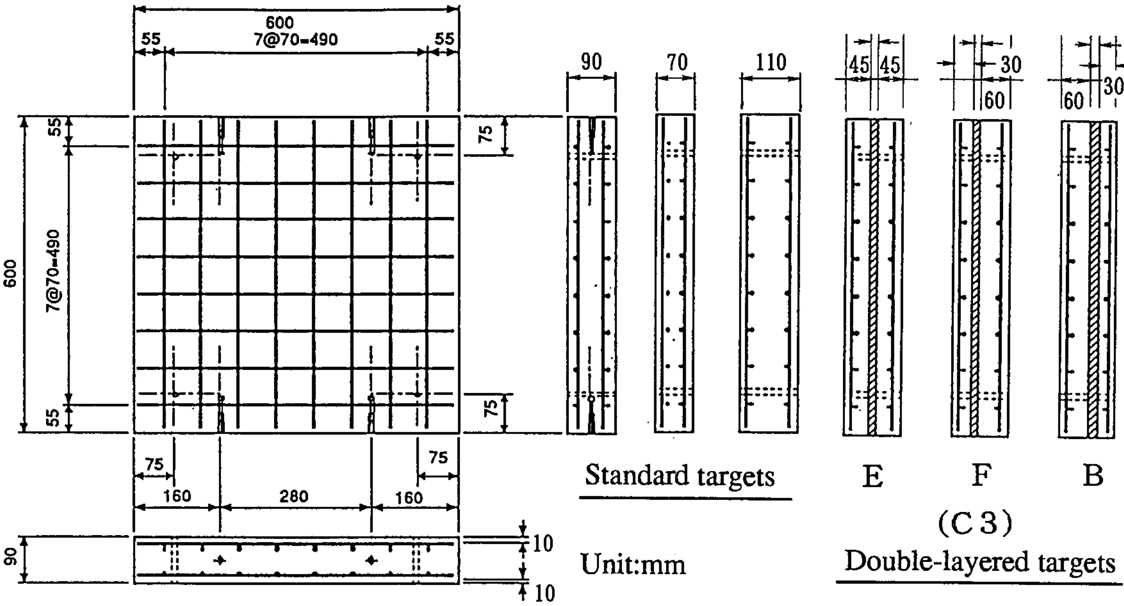

Fig.3 Dimensions of RC targets.

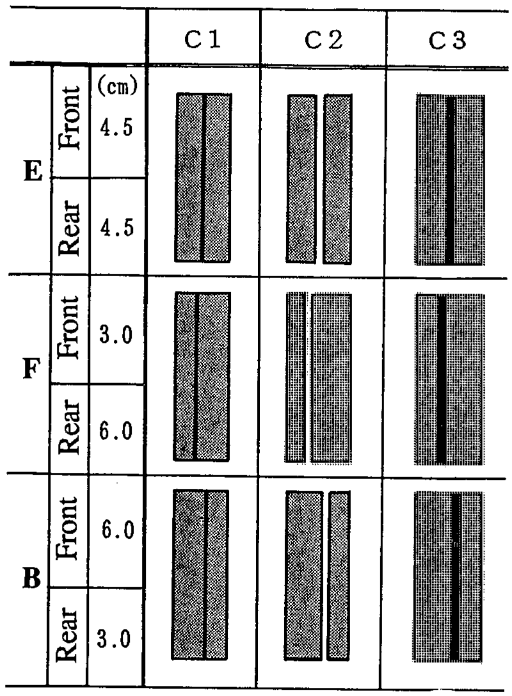

Fig.4 Types of double-layered RC targets.

2.4 Measuring Instrumentation

To examine the target response to projectile impacts, displacement, acceleration and strains at some points of the target were measured. The time interval for data sampling was kept at 5 μsec.

3 TEST RESULTS

As a typical example of test results, post-test figures of the impacted and rear surfaces in the different three types of targets: double-layered RC targets without and with an absorber and standard RC plates with the thickness of 9.0cm, are shown in Fig.5 and the extent of local damage in double-layered RC targets are summarized in Table 2.

Table 2 Summary of extent of local damage in RC targets.

Name of specimen	Thickness of concrete(cm) Front	Thickness of concrete(cm) Rear	Extent of local damage (Heavy ←): Perforation	Scabbing, Size of scabbing 40(cm)–30	Scabbing, Size of scabbing 30–20	Scabbing, Size of scabbing 20–10	Scabbing, Size of scabbing 10–0	(→ Light) Scabbing-limit
C1E	4.5	4.5			●	○		
C1F	3.0	6.0	○	●				
C1B	6.0	3.0			●			○
C2E	4.5	4.5	○1○2●1					●2
C2F	3.0	6.0	○1○2		●1	●2		
C2B	6.0	3.0	○1○2●1●2					
C3E	4.5	4.5	○1	●2		○2		●1
C3F	3.0	6.0	○1○2○3					●1●2●3
C3B	6.0	3.0	○3		●2●3	○1○2		●1
M1	9.0	normal-		●2	●1			
M2	9.0	high-						●1●2
M3	9.0	lightweight-	●2		●1			

[Note/○ : Front plate, ● : Rear plate, Number: No. of specimen]

3.1 Effect of Concrete Strength on Local Damage

Only a few difference in the extent of local damage of RC target cast in either M1 targets: a normal-(35MPa) or M3 targets: a lightweight-(40MPa) concrete, is observed. Local damage of M2 targets cast in a high-strength(57MPa) concrete were all resulted in the scabbing-limit: a concrete debris is not come off from the back face but circular cracks are clearly observed around the center of the target. Thus, it can be said that the use of the higher strength concrete is effective to reduce the extent of local damage.

3.2 Comparison of Extent of Local Damage in Double-layered RC targets

(1) Double-layered RC plates without absorber and just contacted two plates(C1-types)
Local damage on the impacted face is reduced in size by a thickness increase. Scabbing was occurred on the rear face of every targets, and as the thickness of concrete plate increases the size of scabbing increases. It can be said from the size of local damage on the rear face that it is somewhat advantageous when the thicker concrete plate is used for the impacted face.

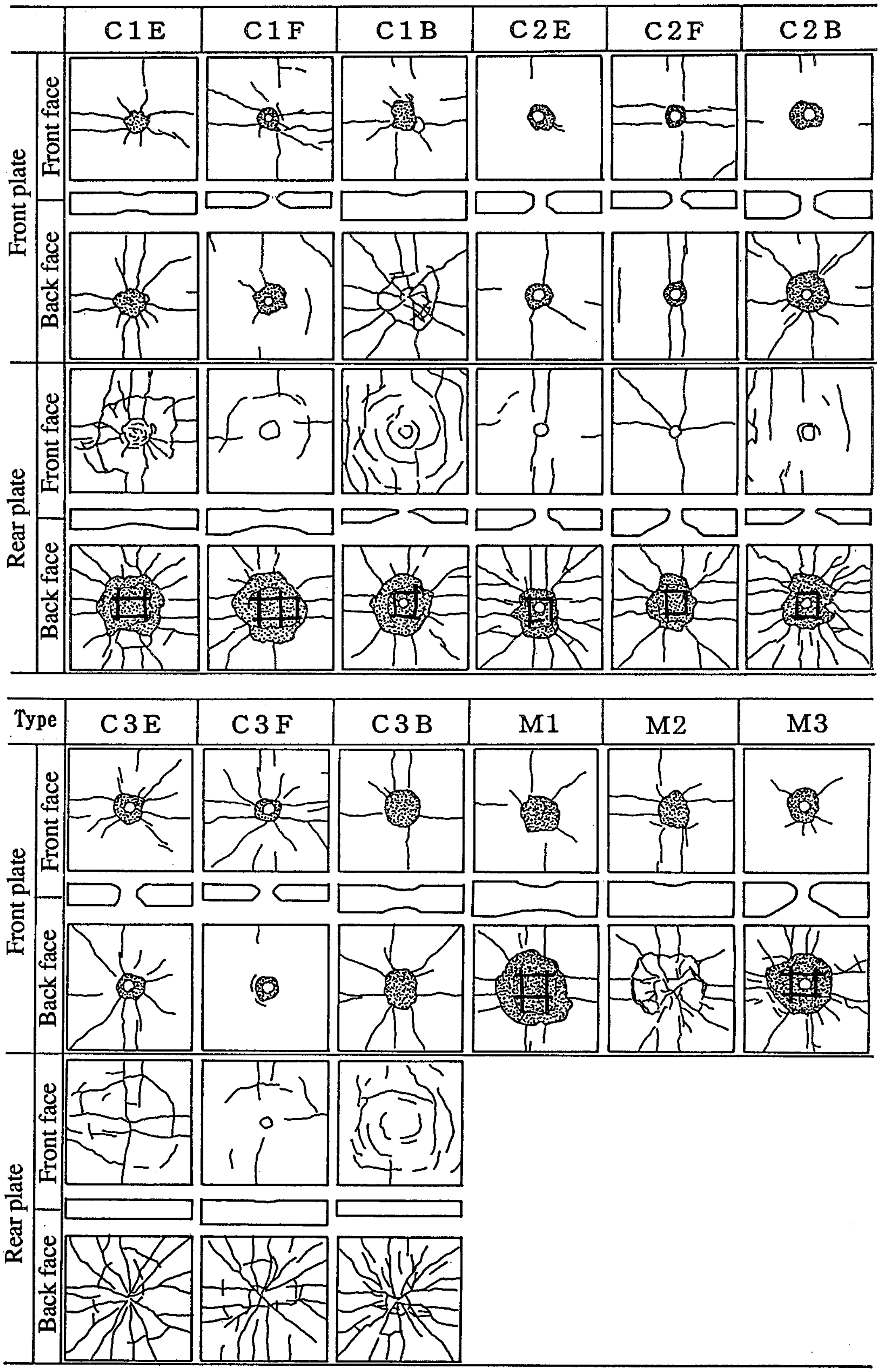

Fig.5 Damage state of RC targets after impact.

(2) Double-layered RC plates without absorber and with 1.5cm interval between two plates(C2-types)
The impacted face of every targets were perforated. Scabbing was resulted only in the target having the thickest concrete plate for the rear. Thus, when the impacted plate of double-layered target without absorber is easily perforated, it may be effective to use the thicker concrete plate for the rear.

(3) Double-layered RC plates with rubber as an absorber(C3-types)
The front plate with the thickness of 3.0cm were all perforated, but both perforation and scabbing were occurred in the front plate with the thicknesses of 4.5 and 6.0cm. Of the local damage in the rear plate, cracks were produced in the targets having the rear plate thickness of 6.0cm and scabbing and/or scabbing-limit were occurred in both the targets having the rear plate thicknesses of 3.0 and 4.5cm. In this case, it can be said that in order to reduce local damage, it is more effective to set up the thicker concrete as the rear plate.

4 CONCLUDING REMARKS

(1) It may be concluded from the test results that double-layering and having an absorber had a considerable effect on an increase in impact resistance of RC plate.

(2) In order to reduce local damage, it is more effective to set up the thicker concrete plate as the rear plate.

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