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An experimental study on the local failure of prestressed concrete panels due to collision

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ABSTRACT

There are various types of collisions on concrete structures, such as bombing by terrorist action and hurricane born missiles. Local failure would occur on concrete members especially in the event of a high-velocity collision (Kennedy, 1966). However, research on the characteristics of local failure of prestressed concrete members is still lacking. In this study, 2,000 x 2,000 x 500 mm prestressed concrete panels were impacted by steel missiles with a mass of 50 kg and a velocity of 240 m/s. The effect of prestressing on perforation and scabbing resistance performance of concrete members was discussed.

1. INTRODUCTION

Researches on the impact resistance performance of concrete panels have been conducted since the 19th century. While most studies have ignored the effects of rebar, it could not be appropriate in structures with high rebar ratios, such as nuclear power plants. In addition, the effect of prestressing on impact resistance performance has not been sufficiently verified. In this study, the impact resistance performance of prestressed concrete panels with high rebar ratio was verified. Experiments were carried out using Middle Velocity Propulsion Impact Machine at Extreme Performance Testing Center (EPTC) at Seoul National University (note that there are two more high-velocity machines capable of launching a projectile with higher velocity). Two types of projectiles, hard (non-deformable or rigid) and soft (deformable), crashed into concrete panels of 2000 × 2000 × 500 mm.

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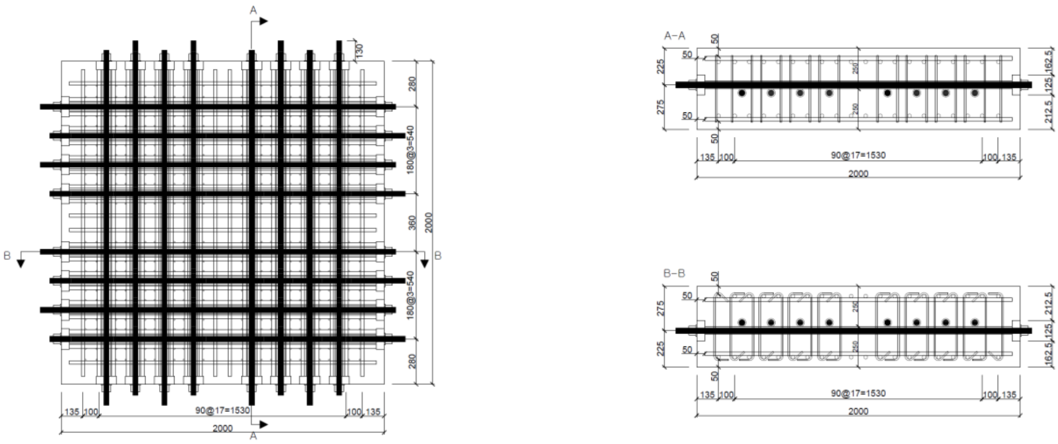
2. RESERCH METHODOLOGY

Reinforced concrete panels and post-tensioned panels with prestressing force of 536 and 1608 kN were used to determine the effect of prestressing force on impact resistance performance. Biaxial steel threaded bars were placed as shown in Fig. 1, to apply uniform in-plane prestressing stress on the post-tensioned concrete panels. As shown in Fig. 2, the specimens were made with longitudinal reinforcement ratio of 1.55% and shear reinforcement ratio of 0.578% to clearly compare the impact resistance performance of the structures with different rebar ratios.

(a) Placement of rebars and ducts (b) Concrete panel in the impact machine

Fig. 1 Biaxially post-tensioned unbonded concrete panel



(a) Plan (b) Sections

Fig. 2 Details of unbonded post-tensioned concrete panel

Two types of flat nose projectiles with a mass of 50 kg and a diameter of 150 mm were used in the impact tests: 1) hard projectiles (Fig. 3(a)) and 2) soft projectiles (Fig. 3(b)). To equalize the mass of the two types of projectiles, the length of soft projectiles having hollow section was 1000 mm, longer than the hard projectiles (360 mm). The Middle Velocity Propulsion Impact Machine was used to impact projectiles aimed at impact velocity of 240 m/s onto the center of concrete panels. The actual impact velocity of projectiles was measured using two laser sensors. The variables of specimens are summarized in Table 1.

(a) Hard projectile

(b) Soft projectile

Fig. 3 Two types of projectiles

Table 1 Details of the experimental program

Specimen	Panel type	Projectile type	Prestressing force [kN]	Impact velocity [m/s]
RC_SOFT	Reinforced concrete	Deformable	-	241.5
PSC_SOFT_1	Unbonded post-tensioned concrete	Deformable	536	235.5
PSC_SOFT_2	Unbonded post-tensioned concrete	Deformable	1608	234.1
RC_HARD	Reinforced concrete	Rigid	-	231.3
PSC_ HARD _1	Unbonded post-tensioned concrete	Rigid	536	237.0
PSC_ HARD _3	Unbonded post-tensioned concrete	Rigid	1608	235.5

3. EXPERIMENTAL RESULTS

The failure mode of concrete panels was generally similar (i.e., local failure, as shown in Fig. 4). Although the same impact conditions (projectile mass, diameter, and impact velocity) were applied, the results of experiments differed greatly depending on the deformation of the projectile. All concrete panels impacted by hard projectiles had perforation, but concrete panels by soft projectiles did not. Only the penetration and scabbing of the panel occurred in PSC_SOFT_1 and PSC_SOFT_2 specimens, while no scabbing occurred in RC_SOFT specimen. The perforation limit and scabbing limit thicknesses were calculated 530 mm and 682 mm, respectively, according to NDRC formulae for reinforced concrete with compressive stress of 45 MPa (NDRC, 1946). The accuracy of NDRC formulae can be verified using the reinforced concrete specimens. On the other hand, the results from the 500 mm thick post-tensioned panels that showed scabbing implied that prestressed concrete panels might need to be evaluated with different formulae.

(a) RC_SOFT (b) RC_HARD

Fig. 4 Fracture mode of RC specimens

Fewer cracks were observed in the post-tensioned panels than reinforced panels. As prestressing force increased, the number of cracks on the front and rear sides of concrete panels decreased. The spalling area of the concrete panels showed a tendency for specimens using soft projectiles to be less than specimens using hard projectiles.

Two types of projectiles showed significant difference in the fracture mode. While the hard projectiles did not show major deformations except the front edge part, fracture and large deformation (local buckling) occurred at the hollow section. Because part of kinetic energy of the projectile was converted to projectile deformation and fracture, less energy was converted to concrete panel, resulting in less concrete failure.

5. CONCLUSIONS

In this study, impact experiments on reinforced concrete and unbonded post-tensioned concrete were conducted using hard and soft projectiles. Based on the experimental results, the following conclusions were obtained.

1. The response of concrete members by impact loading varied depending on the

cross-sectional characteristics of projectiles. In the case of soft projectile impact, the energy was dissipated during projectile deformation and fracture, reducing the energy converted to concrete panel. Failure mode is affected by the distribution of projectile mass, and various soft projectile impact experiments are needed to clearly understand the effect of mass distribution.

2. The response of prestressed concrete panels by the impact was somewhat different (more deteriorated) from that of reinforced concrete panels. Existing local failure formulae, such as NDRC formulae, do not accurately predict the response of prestressed concrete panels.

3. Prestressing force reduces the number of cracks in the event of impact load. In other words, prestressing force is considered to improve the durability and global resistance of the structures against impact load.

REFERENCES

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