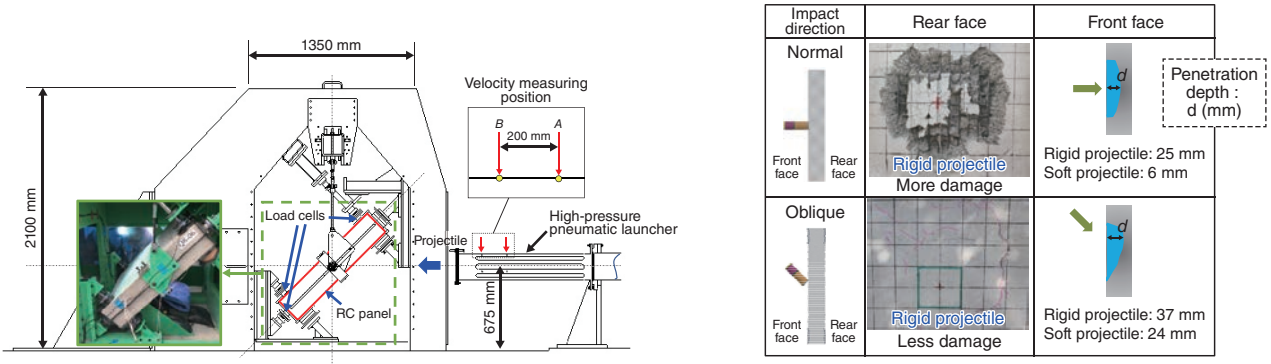
11–2 Clarifying Damage Conditions of Structures Subjected to Projectile Impact

— Investigation of Damage Condition of Reinforced Concrete Panels Simulating Outer Walls of a Nuclear Building —

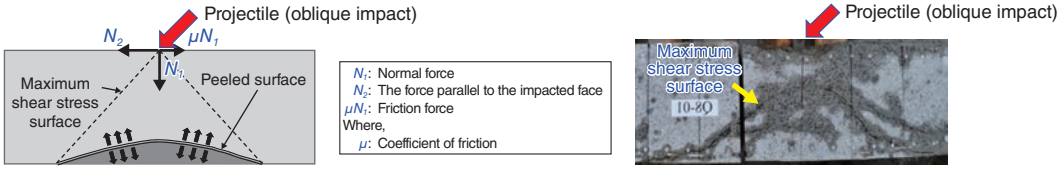


(a) Overview of a projectile impact test (oblique impact)

(b) Comparison of damage state in RC panel

Fig.1 Projectile impact test and damage condition of RC panel

(a) Projectile impact tests were conducted using a high-pressure pneumatic launcher to launch a projectile that collides with the reinforced concrete (RC) panel. (b) The damage conditions of the RC panels were compared between cases of normal and oblique impacts under identical test conditions. Compared to the case of normal impact, the damage to the rear face is less and the penetration depth is greater in the case of oblique impact.



(a) Image of scabbing damage

(b) Cross section of the RC panel (after impact test)

Fig.2 Scabbing damage on the rear face of the RC panel due to stress wave propagation

The test results show that oblique impacts clearly have the same symmetrical conical maximum shear stress surface as normal impacts.

After the 2011 TEPCO's Fukushima Daiichi Nuclear Power Plant (NPP) accident, new regulatory requirements stipulated by the Nuclear Regulation Authority of Japan were introduced in 2013 for the safety evaluation of nuclear facilities subjected to projectile impacts induced by tornadoes or aircraft. To comply with this regulation and ensure the structural integrity of buildings and internal equipment of NPPs, it is important to develop a numerical analysis method and validate it via test data.

So far, most local damage evaluation methods for RC panels, such as outer walls of nuclear buildings, were developed from conservative impact tests based on normal impacts using rigid projectiles. In this study, we assumed scenarios involving projectiles that may deform during the impact (such as aircraft) and oblique impacts originating from different directions depending on the site conditions. The objective of our study was to obtain the test data on realistic impact conditions (e.g., soft projectiles and oblique impacts) and to develop a numerical analysis method and validate it for evaluating the local damage to RC panels using the obtained test data.

We conducted projectile impact tests on RC panels considering two types of projectiles (rigid and soft projectiles), two impact angle conditions (0°: normal impact and 45°: oblique impact), and two RC plate thicknesses (210 and 80 mm) (Fig.1(a)). Differences in the local damage conditions of RC panels due to different types of projectiles and different impact angles were investigated. With regard to the local damage on the rear face of RC panels, the damage was drastically less in the case oblique impact compared to that in the case of normal impact. Furthermore, the penetration depth was greater for oblique impact than for normal impact (Fig.1(b)).

The difference in penetration depth is attributed to the fact that the contact area between the projectile and the RC panel is larger during a normal impact because the nose shape of the projectile is flat during a normal impact, while the nose shape is sharper during an oblique impact, thereby reducing the contact area between the projectile and RC panel. With regard to the reduced damage on the rear face during oblique impacts, based on a detailed investigation of the damage condition of the RC panel, we suggest that only the force normal to the RC panel contributes to scabbing damage during an oblique impact (Fig.2(a)). It is known that the tensile strength of concrete is generally about 1/10th of its compressive strength, and tensile failure is likely to occur. Therefore, scabbing damage on the rear face is caused by the compression stress wave generated by the collision in a direction opposite to the tensile stress wave at the free boundary on the rear face. From the damage condition of the test results, we confirmed that only the normal force contributes to the rear face scabbing damage during an oblique impact or a normal impact. The normal force is smaller during an oblique impact than during a normal impact; hence, the rear face suffered scabbing damage during a normal impact, but this damage did not occur during an oblique impact under identical conditions (Fig.2(b)).

In this study, we conducted projectile impact tests on RC panels and found that in an oblique impact, the damage on the rear face is less and the penetration depth is greater compared to those observed in a normal impact. Based on the obtained test data, we will develop an analysis method and validate it. We will also construct guidelines for the impact evaluation method for projectile impact in the future.

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Reference

Okuda, Y. et al., Experimental Study on Local Damage to Reinforced Concrete Panels Subjected to Oblique Impact by Projectiles, Journal of Nuclear Engineering and Radiation Science, vol.9, issue 2, 2023, 021801, 12p.