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Local Impact Damage Response of CFRP Strengthened Concrete Slabs

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Abstract

The effectiveness of carbon fiber reinforced polymer (CFRP) strengthening is well established for seismic retrofitting and structurally deficient RC members, however their response to impact loads is not well known. This paper attempts to investigate the local damage behavior of CFRP strengthened RC slabs against projectile impact. In the present study, CFRP strengthened RC slabs were tested under the impact of 40 mm diameter projectile with hemispherical nose and the response was compared with the control. The test specimens were 600 mm square, 90 mm thick RC slabs reinforced with 8 mm diameter steel rebars. The velocity of steel projectiles was varied within sub-ordinance range and the projectile was made to strike normal to the slab using a gas gun. The slabs were also tested under quasi-static load for establishing their punching resistance against the same projectiles. The test results illustrate that CFRP strengthening is effective in reducing the local damage from front and rear faces of RC slabs. Moreover, the strengthening increases the ballistic limit velocity by 18% and the energy absorption in quasi-static punching by 65.5%. The CFRP strengthening is also effective in reducing the flying of concrete fragments from the rear face.

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Keywords: Local damage; Punching strength; CFRP; Slab; Projectile impact

1. Introduction

Structural impact problems have become increasingly important for the construction industry. In the design of reinforced concrete (RC) strategic structures, account is taken of accidental loads such as dropped objects, collisions, explosions, aircraft crash and penetration of fragments. Some of these accidental loads are also pertinent in the

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design of protective structures which are mainly of RC in the process industry [1-3] or fortification installations. The general public is increasingly concerned about the safety of their structures, especially after September 11, 2001 attack on world trade center, against impact loads. Therefore, it is necessary to ensure the safety of various RC structures and their components, when impacted by a mass or a projectile.

One of the impact loads that RC structures should be protected against is the localized impact from high-velocity projectiles caused by small arms or blast-induced fragments. Many strategic RC structures have been found deficient against such impact loads and are often required to be strengthened for which different techniques exist.

The quasi-static behavior of flexural members strengthened with carbon fiber reinforced polymer (CFRP) laminates has been well documented covering flexure, shear and bond studies [4] and lately their applications for impact situation have also been investigated [5-10]. Cantwell and Smith [5] conducted drop hammer scaled model tests on CFRP strengthened concrete beams and observed significant increase in their load carrying capacity. Erki and Meier [6] compared the impact response of beams strengthened with CFRP laminate and steel plate. They observed that the beams externally strengthened with CFRP laminates performed well under impact loading, although they could not provide the same energy absorption as the beams externally strengthened with steel plates due to the loss of anchoring at the ends of the CFRP laminates. Parretti et al. [7] used CFRP laminates to restore the original capacity of impacted prestressed and RC girders of a bridge. Serrano-Perez et al. [8] evaluated the low velocity impact response of autoclaved aerated concrete strengthened with CFRP laminates. In another study, Tang and Saadatmanesh [9] conducted drop weight test on concrete beams strengthened with FRP laminates and observed significant improvement in their performance. It increased cracking and flexural strength, as well as residual stiffness of the beams. Furthermore, it reduced a number of cracks, crack widths, and the maximum deflection. Almusallam et al. [10] experimentally studied the impact response of CFRP-strengthened RC slabs under the strike of non-deformable hemispherical steel projectiles at varying impact velocities. The same slabs were also analyzed numerically using LS-DYNA program. They observed that CFRP-strengthening (i) increases the ballistic limit velocity by 18% and perforation energy by 56.7% (ii) reduces the crater damage and (iii) contains the flying concrete fragments effectively. Siddiqui et al. [11] first experimentally studied the response of RC shielded steel plates against impact of ogive and bi-conical nose shape projectiles and then presented a probabilistic procedure for reliability analysis of same RC shielded steel plate against the impact loads. The results of the reliability analysis were then used to relate the probability of failure with different scenarios of the failure of the specimens. Almusalllam et al. [12] studied the effectiveness of hybrid-fibers (a combination of steel and plastic fibers) in improving the impact resistance of slabs through a detailed experimental program. The test results showed that the hybrid-fibers in the concrete lead to smaller crater volumes and reduce the spalling and scabbing damage. The hybrid-fibers arrest the crack development and thus minimize the size of the damaged area. They also predicted the penetration depth and perforation thickness by modifying the impact function of NDRC equation to incorporate the effects of hybrid-fibers. The ballistic limit was also predicted. A simple formulation was then proposed for the prediction of the ejected concrete mass from the front and the rear faces of the specimens. Predictions matched well with the experimental observations. Almusallam et al. [13] extended their earlier work [12] to increase the confidence on hybrid-fibers in improving the impact resistance of RC slabs plates. The earlier proposed expressions for the penetration depth and the ballistic limit were generalized to incorporate the effect of hybrid-fibers made up of *n*-types of fibers. The generalized equations were developed using a larger set of data containing their present as well as earlier test data. The prediction was compared with the current and other test data available in the literature covering a wide range of fibers and their combinations in different proportions. A good match was observed again between the generalized prediction and the test results.

The present study was carried out with the objective of studying the local damage behavior of CFRP strengthened RC slabs against projectile impact. RC slabs with and without strengthening of CFRP sheets were tested under the impact of 40 mm diameter projectile with hemispherical nose. The slabs were also tested under quasi-static load for establishing their punching resistance against the same projectiles.