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CFRP strengthened RC beams subjected to impact loading

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Abstract

This paper examines the impact responses of CFRP strengthened reinforced concrete (RC) beams through an experimental study. The experimental study involves a drop hammer impact test that investigates the influence of drop height, number of blows and CFRP strengthening scheme on its response. Four different types of CFRP strengthening schemes are applied to RC beams. This experimental study reveals that the RC beams strengthened with CFRP are significantly improved in the resistance to impact loadings.

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Keywords: CFRP; flexural strengthening; impact loading; maximum midspan deflection

1. Introduction

Impact loading can be induced on reinforced concrete (RC) structures on various instances in their service life. They include crashing vehicles, ships, airplanes, rocks, explosions and even avalanches to name a few. As seismic strengthening should be applied to RC structures without sufficient earthquake resistance, RC structures without proper impact resistance should be strengthened to improve their impact performance. Carbon fiber reinforced polymer (CFRP) materials are being increasingly used to repair and strengthen bridges and buildings for major advantages of CFRP including high strength, high fatigue strength, high stiffness, high resistant to corrosion, light in

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weight, ease of application and high durability. However, little is known about the effect of impact loads on RC structures strengthened with the CFRP materials [1]-[3].

The behavior of a RC member under impact loading may consist of two response phases; one is the local response mainly due to the stress wave that occurs at the loading point during a very short period after impact, and the other is the overall response with a free vibration effect due to the elastic-plastic deformation that occurs in the whole structure member over a long period after impact. The overall response strongly depends on the quasi-static behavior with loading rate effect of the RC member. Overall failure tends to be a major issue concerning RC beams subjected to impact loading. In contrast, local failure such as penetration, scabbing, perforation and/or punching shear tends to be the predominant mode of failure for RC plates subjected to impact loading.

Therefore, the aim of this study was to experimentally examine the overall impact responses of RC beams strengthened with CFRP materials.

2. Experimental programs

2.1. Specimen preparation

Twenty RC beams with cross-sectional dimensions of 160×170 mm and lengths of 1,700 mm as illustrated in Figure 1 were cast using the ready-mixed concrete. The RC beams were reinforced with two 10mm deformed bars with a yield strength of 382 MPa in both tension and compression. The stirrups were provided with 6mm deformed bar with yield strength of 295 MPa and spaced 60 mm apart. The maximum aggregate size was 10mm, taking into account the minimum clearance of rebar. The concrete compressive strength at the time of testing was 41.9 MPa. The design shear resistance of the RC beam was more than 47.5 kN. Therefore, the RC beams strengthened with CFRP reinforcement would be weaker in flexure.

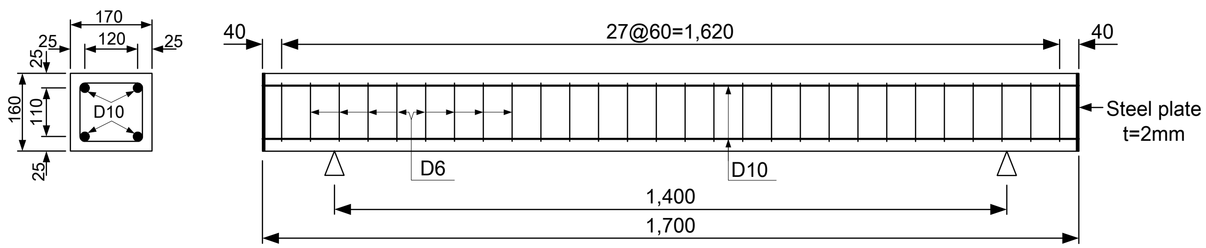

Fig.1. RC beam detail.

To strengthen the RC beams in flexure, two kinds of CFRP reinforcement, i.e., unidirectional sheets and unidirectional pultruded laminates, were employed. The CFRP sheets had a maximum tensile strength of 3,400 MPa and an elastic modulus of 245 GPa, while the CFRP laminates had a maximum tensile strength of 2,400 MPa and an elastic modulus of 156 GPa. Of the twenty RC beams, four RC beams were not strengthened as Control specimens, and sixteen RC beams were strengthened with the CFRP reinforcement. Four different types of CFRP strengthening schemes, TCN, TCC, TLB and TLC were applied to the RC beams as shown in Figures 2 to 5, for each of which four specimens were prepared. For TCN and TCC, CFRP sheets with a thickness of 0.222mm and a width of 150mm were bonded to the soffit of the RC beams as shown in Figures 2 and 3. For TCC, a CFRP sheet with a thickness of 0.111mm and a width of 250mm was installed at the ends of the soffit CFRP sheet with the direction of the fibers perpendicular to the longitudinal beam axis to improve the anchorage of the CFRP strengthening system, while no end anchors were used for TCN. For TLB and TLC, CFRP laminates with a thickness of 1.0mm and a width of 50mm were bonded to the soffit of the RC beams as shown in Figures 4 and 5. To improve the anchorage of the CFRP laminates at the both ends, steel anchor bolts with a diameter of 16 mm and steel cover plates with a thickness of 9 mm were provided for TLB, while CFRP U-wrap sheets with a thickness of 0.111mm and a width of 250mm were bonded for TLC. The CFRP sheets and laminates bonded to the soffit of the RC beams were designed to have approximately the same tensile rupture load.