CFRP Strengthened RC Beams Subjected to Impact Loading

National Defense Academy Student member ○Sam Soeun Member Kazunori Fujikake
Toray Industries Inc. Member Takahiro Matsui Member Kenji Suzukawa

1. Introduction

Carbon fiber reinforced plastic (CFRP) materials are being increasingly used to repair bridges and buildings for main advantages of CFRP including high strength, light weight, high resistant to corrosion, light weight and ease of application. However little is known about the effect of impact loads on reinforced concrete (RC) structures strengthened with the CFRP materials. Therefore, the aim of this study was to experimentally examine the impact behaviors of RC beams strengthened with CFRP and to find out the strengthening method efficiency under impact loadings.

2. Experimental Program

2.1 Test specimens

Twenty RC beams with a cross-section of 160×170 mm and a length of 1,700 mm were prepared as shown in Fig.1, of which sixteen RC beams were strengthened with CFRP materials; and four RC beams were unstrengthened as the control. The RC beams were reinforced with two D10 deformed bars with the yield strength of 382 MPa in both tension and compression. Stirrups using D6 deformed bar were provided at a uniform spacing of 60mm, so that the RC beams might exhibit overall flexural failure. The concrete compressive strength at the time of testing was 41.9 MPa.

To strengthen the RC beams in flexure, two kinds of CFRP materials, namely sheets and laminates in which physical properties are shown in Table 1, were employed in this study. Four types of CFRP bonded RC beams, TCN, TCC, TLB and TLC, were prepared as shown in Fig. 2. In TCN and TCC, unidirectional CFRP sheets were bonded to the soffit of RC beams. The differences of TCN and TCC were with or without unidirectional CFRP U-wrap sheets at the both ends of the longitudinal CFRP sheets for anchorage improvements. In TLB and TLC, unidirectional CFRP laminates were bonded to the soffit of RC beams. To improve the anchorage of CFRP laminate at the both ends, anchor bolts and cover plates were provided for TLB, while CFRP U-wrap sheets were bonded for TLC.

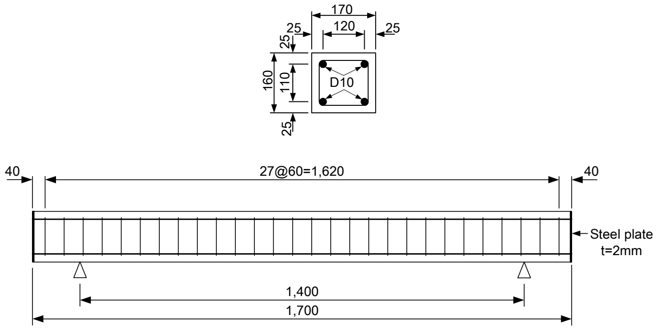
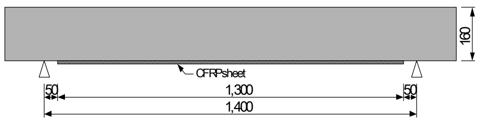


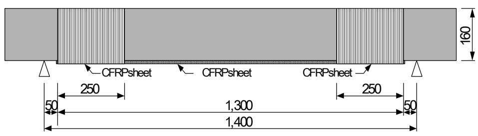
Fig.1 RC beam detail

Table 1 Physical properties of CFRP

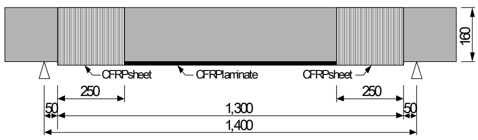
	For flexural strengthening		For anchorage strengthening
	CFRP laminate	CFRP sheet	CFRP sheet
Thickness (mm)	1.0	0.222	0.111
Width	50	150	250
Density (g/cm^3)	1.60	1.80	1.80
Tensile strength (MPa)	2400	3400	3400
Elastic modulus (GPa)	156	245	245



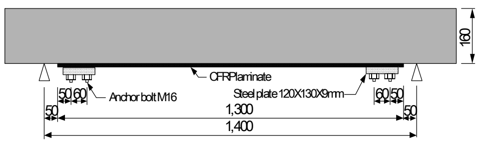
(a) TCN



(b) TCC



(c) TLC



(d) TLB

Fig.2 CFRP sheet and laminate applications

Keywards CFRP, RC beam, flexural strengthening, impact loading
Address 1-10-20 Hashirimizu, Yokosuka, Kanagawa, 239-8686 National Defense Academy TEL046-841-3810

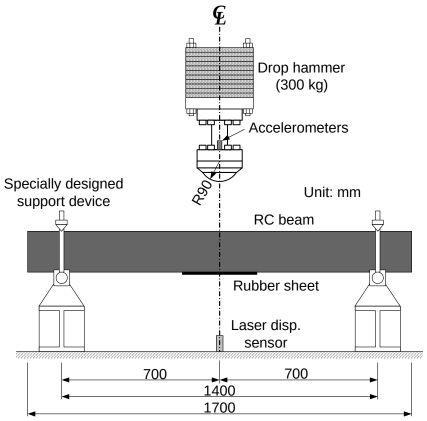


Fig.3 Impact loading machine

2.2 Impact loading test and experimental detail

Two types of impact loading tests were performed. One was single impact test; the other was repeated impact test. A drop hammer impact loading machine was used for the both tests as shown in Fig.3. In the test, the RC beam was simply supported over a span of 1,400 mm. The drop hammer with a 300 kg was dropped freely onto the RC beam at midspan. In the single impact test, the drop heights were 0.1, 0.2 and 0.4m. In the repeated impact test, the drop hammer was repeatedly dropped. The initial drop height was 0.05m, and then the drop height was doubled after every two hundred drops. The contact force developed between the hammer and the RC beam was measured using two accelerometers. The midspan deflection response of the RC beam was measured using a displacement laser sensor.

3. Experimental Results

3.1 Failure mode

In the single impact loading test, the extent of damage of the strengthened and unstrengthened RC beams increased with increases in drop height. Fig. 4 shows failure modes obtained at the drop height of 0.4 m. The RC beams strengthened with CFRP performed well. Control exhibited flexural failure with compression crushing of concrete. TCC had a partial delamination of CFRP sheet due to U-wrap anchoring, while TCN exhibited the complete delamination of CFRP sheet. TLB and TLC failed with slips of CFRP laminate of 8 and 10 mm respectively at one end.

In the repeated impact test, TCC and TLB showed a significant reduction in the deflection, crack width and formation of new cracks.

3.2 Maximum midspan deflection

Fig. 5 shows the relation between the maximum midspan deflections and drop heights in the single impact test. At the drop height of 0.4m, TCC had the smallest deflection. The maximum midspan deflection of TCC was 50% smaller than that of Control. Fig. 6 shows the number of blows required to reach a midspan deflection of 28 mm, corresponding to 2% of the span, in the repeated impact test. It can be said that the RC beams strengthened with CFRP are significantly improved in the resistance to repeated impact loadings. Specifically, TCC and TLB perform well.

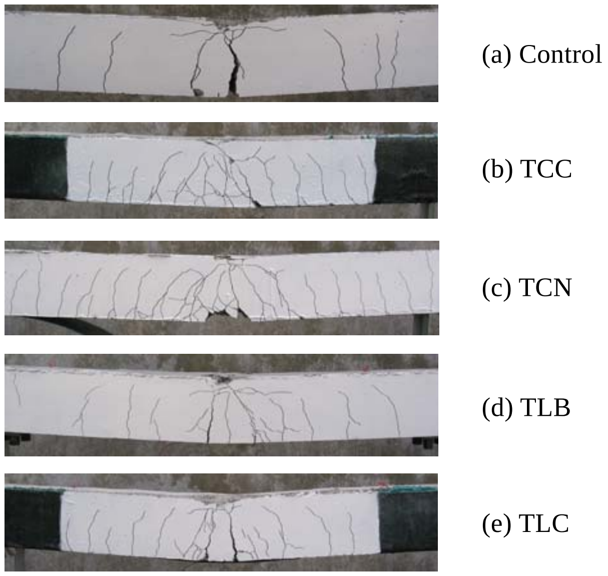


Fig.4 Typical failure modes at a drop height of 0.4m

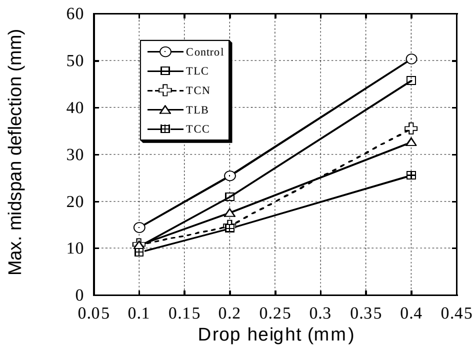


Fig. 5 Relation between max. midspan deflection and drop height in single impact test

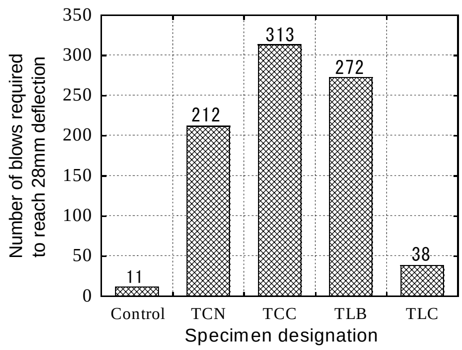


Fig. 6 Number of blows required to reach 28mm midspan deflection