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Impact Test of RC Beams Flexurally Strengthened with AFRP Sheet Varying Sheet Volume

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Abstract

In order to investigate an influence of FRP sheet volume on impact-resistant characteristics of the RC beams flexurally strengthened with FRP sheet, drop-weight impact test was conducted taking sheet volume as variable. Here, aramid FRP sheet was applied and an amount of the volume was changed into 3 classes: 415 g/m^2; 830 g/m^2; and 1660 g/m^2, respectively. Impact test was conducted freely dropping a 300 kg steel weight on the RC beams following single loading method. RC beams used here have a rectangular cross section of 200 mm width, 250 mm depth, and 3 m clear-span length. As a reference to failure mode, static loading test was also conducted. The results obtained from this study were as follows: 1) the beams classified as flexural compression failure type under static loading may reach ultimate state with sheet fracture mode under impact loading; 2) the beams belonged to sheet deboning failure type under static loading may reach, with sheet debonding under impact loading; and 3) impact-resistant capacities of the beams may not always be increased with the increasing sheet volume.

Keywords: FRP sheet, impact loading test, RC beams, flexural strengthening

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Introduction

In Japan, after suffering the great Hanshin-Awaji earthquake (January 17, 1995), anti-earthquake strengthening works for reinforced concrete (RC) bridge piers have been conducted nationwide. Normally, steel plate bonding and/or section enlargement methods are applied. However, nowadays, the fibre reinforced polymer (FRP) sheet bonding method has been also applied because of its light weights, high strength to weight ratios, non-corrosive behaviors and relatively easy to install.
On the other hand, this strengthening method may be applicable to strengthen RC members against not only static loading but also blast and impact loading. However, researches on the RC members strengthened with FRP under impact loading are still extremely limited [1].
In this study, in order to investigate flexural strengthening effects of an amount of the FRP material on the impact-resistant capacities of the RC beams, drop-weight impact loading test was conducted. Here, aramid FRP (AFRP) sheet was applied. In this study, static loading test was also conducted to compare the failure mechanisms of the beams under static and impact loading.

Experimental overview

A total of 11 specimens were used in this study. Sheet volume of the AFRP sheet, compressive strength of concrete, and the static flexural and shear capacities of the beams are listed in Table 1. In this table, a specimen name was designated in the order of the strengthening material (N: non, A*m*: AFRP with *m* g/m^2 sheet volume), the method of loading (S: static loading, and I: drop-weight impact loading), and the drop height of the weight (H*n*) (*n*: drop height in metric units). The estimated drop height (*H*') was evaluated by using the measured drop velocity of the weight just before impacting the upper surface of the beam.
The beams have rectangular cross-sections with 250 × 200 mm (height × width) and 3.0 m clear-span lengths. AFRP sheet was bonded to the tension side-surface, and 50 mm was left between the supporting point and the end of the sheet.
Material properties of AFRP sheet used in this study are listed in Table 2 in which these values are nominal ones.
Static loading test was conducted following three-point loading test method. The load was

Table 1 List of specimens

Specimen	Sheet volume (g/m^2)	Set drop height of weight *H* (m)	Measured drop height of weight *H*' (m)	Compressive strength of concrete *f*'c (MPa)	Yield strength of main rebar *fy* (MPa)	Calculated flexural capacity *P*usc (kN)	Calculated shear capacity *V*usc (kN)
N-S	-	Static loading	-	32.4	381.7	55.0	329.0
A415-S	415			33.7	371	81.0	298.8
A830-S	830					99.9	
A1660-S	1660					126.1	
N-I-H2.5	-	2.5	2.29	32.4	381.7	55.0	329.0
A415-I-H2.5	415		2.49	33.7	371	81.0	298.8
A830-I-H2.5	830					99.9	
A1660-I-H2.5	1660					126.1	
A415-I-H3	415	3.0	2.89	33.7	371.1	81.0	298.8
A830-I-H3	830		3.04			99.9	
A1660-I-H3	1660					126.1	

Table 2 Lists of material properties of AFRP sheet

Sheet volume (g/m^2)	Tensile capacity (kN/m)	Thickness (mm)	Tensile strength (GPa)	Elastic modulus *E* (GPa)	Ultimate strain (%)
415	600	0.286	2.1	118.0	1.75
830	1200	0.572			
1660	1800	1.144			

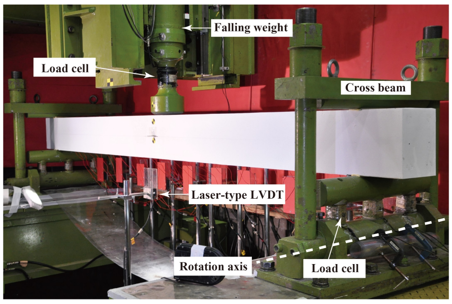

Fig. 1 Test setup for falling-weight impact loading

surcharged through the loading plate with 10 cm length by using hydraulic jack at the mid-span of the beam.

On the other hand, the drop-weight impact test was conducted by dropping a prescribed height onto the mid-span of the beam using the impact test apparatus shown in Fig. 1. The 300 kg weight was a solid steel cylinder equipped with load-cell.

Measuring items are: the time histories of the impact force *P*, the reaction force *R,* and the midspan deflection *D,* and the axial strain distribution of the AFRP sheet measured by using digital data recorders with 0.1 ms time intervals; progress of the crack patterns and AFRP sheet debonding around the midspan area took by using high-speed digital cameras at 2000 fps; and the residual deflection and crack patterns sketched after each experiment.

Experimental Results and Discussions

Static loading test

Comparing the static load-deflection curves between Beams N-S and A415/830/1660-S, it is seen that: in the case of Beam N-S, the load gradually increased after rebar yielded and on the other hand, in the cases of strengthened Beams A415/830/1660-S, rebar yielding load and maximum load were improved corresponding to an amount of the sheet volume. Comparing the curves of flexurally strengthened beams between experimental and calculated results, in the case of Beam A415-S, the experimental results were good agreement with the calculated ones up to the calculated ultimate state, in which the authors defined this type of beams as “flexural compressive failure type”. On the other hand, in the cases of Beams A830/1660-S, the experimental results were lower than those of the calculated ones and the experimental results cannot confirm the calculated maximum load. The authors defined these beams as “sheet debonding failure type”. Here, the calculated results can be obtained by means of the elastic load method assuming a plane section of the beam and perfect bonding between concrete and reinforcement including the AFRP sheet.

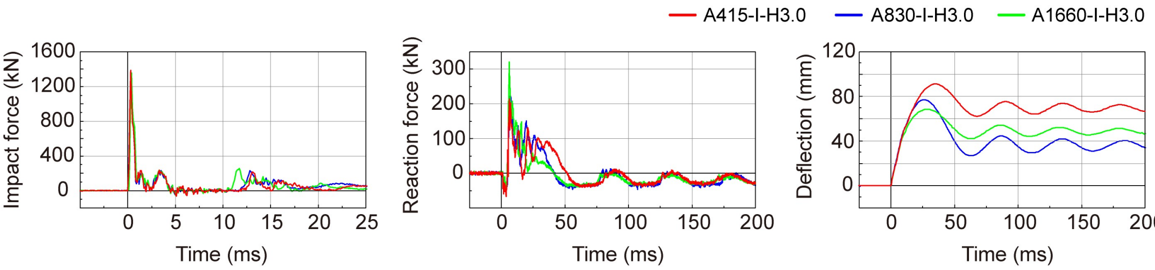

Fig. 2 Comparisons of time histories of impact force *P*, reaction force *R*, and midspan deflection *D* at drop height of *H* = 3 m

Impact loading test

Figure 2 shows comparisons of the time histories of the impact force *P*, the reaction force *R*, and the midspan deflection *D* between Beams A415/830/1660 at drop height of the weight *H* = 3 m. From this figure, it is observed that regarding the impact force *P*, configurations of the time history are similar to each other because of the material properties of the impacted concrete of the specimens being similar.

Regarding the reaction force time history, it is seen that time duration of Beam A415 prolonged about 10 ms comparing with those of Beams A830 and A1660. This may be the reason why the flexural stiffness of Beam A415 was decreased due to the AFRP sheet fracturing. Since time durations of Beams A830 and A1660 are approximately equal, AFRP sheets for both beams may be debonded when the impact load was surcharged.

Regarding the deflection time history, even though the maximum deflection in the case of Beam A1660 is smaller than that in the case of Beam 830, the residual deflection for Beam A1660 is larger than that for Beam A830. This implies that in the case of Beam A1660, AFRP sheet may be perfectly debonded, but in the case of Beam A830, the sheet has still restrained the residual deflection from increasing even though the sheet may be partially debonded.

Since in the case of Beam A415, sheet volume is the smallest among three beams and the sheet was fractured during impact load was surcharged, the maximum and residual deflections for Beam A415 are the largest among three beams.

Conclusions

In this paper, in order to investigate the effects of the sheet volume on impact-resistant capacity of the flexurally strengthened RC beams with AFRP sheet, drop-weight impact loading test was conducted. The results obtained from this study was as follows:

1) the maximum deflection can be restrained corresponding to the sheet volume;
2) the residual deflection cannot be always restrained with the increasing sheet volume;
3) the compressive failure type beams under static loading may reach the ultimate state with the sheet fracturing under impact loading; and
4) the sheet debonding failure type under static loading may reach, with the sheet debonding under impact loading.

Reference

[1] Pham, T. M. and Hao, H., 2016, “Review of concrete structures strengthened with FRP against impact loading.”, Structures, Elsevier, 7, pp. 59-70.