CONSECUTIVE IMPACT LOADING TEST OF RC BEAMS STRENGTHENED WITH AFRP SHEET

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1. INTRODUCTION

Recently, Fiber-Reinforced Polymer (FRP) sheet bonding method has been widely applied to strengthen Reinforced Concrete (RC) members because of many advantages such as corrosion resistance, high strength-to-weight ratio, and easy installation. The authors have experimentally investigated the applicability of Aramid FRP sheet for strengthening the RC beams under impact loading. Nevertheless, the design specifications for RC members strengthened with FRP material have not been established yet, and further studies are required.
From this point of view, in this paper, in order to investigate impact-resistant characteristics of the RC beams strengthened with AFRP sheet, consecutive fall-weight impact loading test was conducted. Here, an impact-resistant capacity of the beam and strengthening effects of the AFRP sheet were discussed.

2. EXPERIMENTAL OVERVIEW

A total of six specimens were used in this study. Fall height of the weight, input impact energy, compressive strength of concrete, and yield strength of the axial rebar are listed in Table 1. In this table, nominal name of the specimen was designated in the order of reinforcing material (N: none and AS: AFRP sheet with a 1660 g/m^2 mass), loading method (CI: consecutive impact loading), and set fall height (H*m*-*n*) (*m* and *n*: fall height for the initial and subsequent loadings, respectively, in metric unit) of the weight.

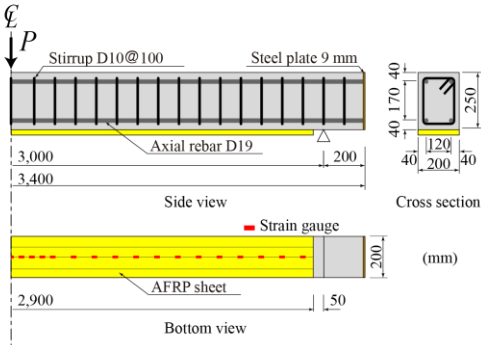

Fig. 1 Dimensions of specimens.

Photo 1 Test setup for fall-weight impact loading.

Figure 1 shows the dimensions of the specimens and layout of the rebars and AFRP sheet. All beams have a rectangular cross section of 200 mm width, 250 mm depth, and 3 m clear span length. The axial rebars were welded to the steel plate at the ends of the beams, stirrups were placed at intervals of 100 mm, and the AFRP sheet was bonded to the tension-side surface of the beam leaving 50 mm between the end of the sheet and the supporting point.
Fall-weight impact tests were conducted by dropping a weight (mass: 300 kg) from the predetermined height onto the mid-span of the beam using the impact test apparatus as shown in Photo 1. Fall height was set in the order of 1, 2, 2.5, and 3 m until the beams reached the ultimate state due to the AFRP sheet debonding/fracturing. The RC beams were placed on the supports equipped with load cells for measuring the reaction forces and were clamped at their ends using cross beams to prevent lifting off. The supporting jigs were able to rotate freely while restraining the horizontal movement of the beam.
Measuring items were: time histories of the impact force P, the reaction force R, and the mid-span deflection (hereinafter, deflection) δ, and the axial strain distribution of the AFRP sheet. The deflection was measured by using a laser-type Linear Variable Displacement Transducer (LVDT). After each test, the residual deflection was measured, and the crack patterns were observed on one side surface of the beam were sketched.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

Figure 2(a) shows the experimental results for Beam N-CI-H1-

Table 1 List of specimens.

Experimental case	Set fall height of weight H (m)	Mea-sured input impact energy E_i (kJ)	Com-pressive strength of concrete f'_c (MPa)	Yield stress of axial rebar f_{ya} (MPa)	Debond-ing of AFRP sheet
N-CI-H1-1	1	2.97			-
N-CI-H1-2	2	5.85			-
AS-CI-H1-1	1	2.97			No
AS-CI-H1-2	2	5.85			No
AS-CI-H1-2.5	2.5	7.33	33.7	371.0	Yes
AS-CI-H2-2.0	2.0	5.85			No
AS-CI-H2-2.5	2.5	7.69			Yes
AS-CI-H2.5	2.5	7.33			Yes
AS-CI-H3.0	3.0	8.95			Yes

Keywords: FRP sheet, flexural strengthening, consecutive impact loading, RC beams, sheet debonding
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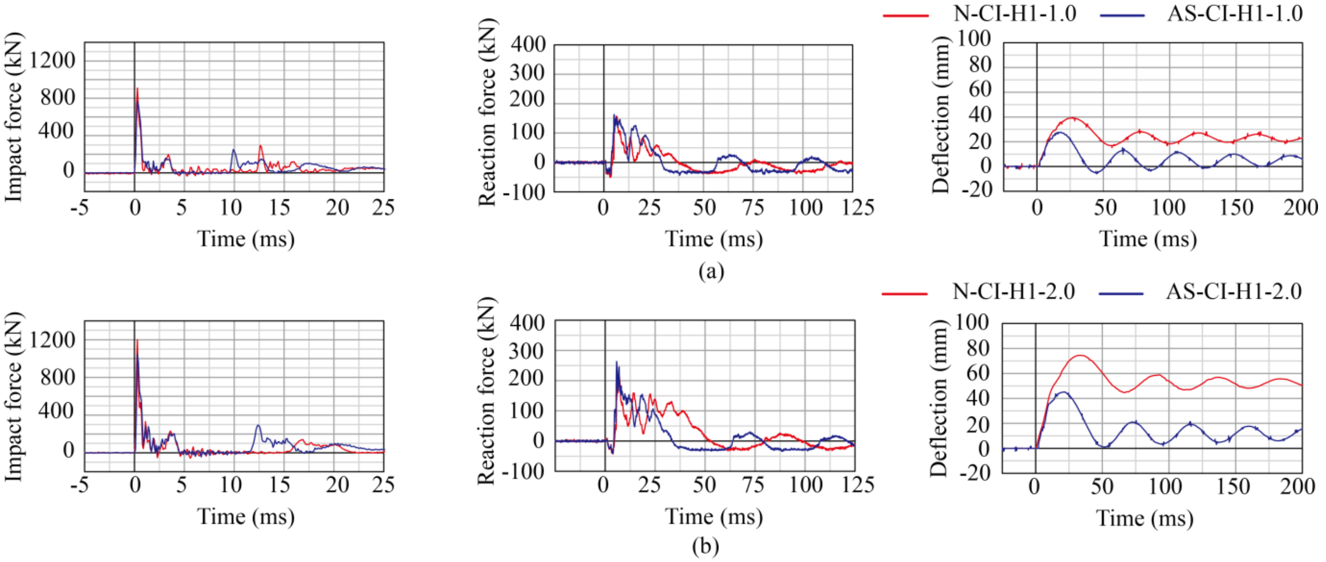

Fig 2. Comparisons of time histories of impact force P, reaction force R, and deflection δ:
(a) Beam N-CI-H1-1.0 and AS-CI-H1-1.0; (b) Beam N-CI-H1-2.0 and AS-CI-H1-2.0

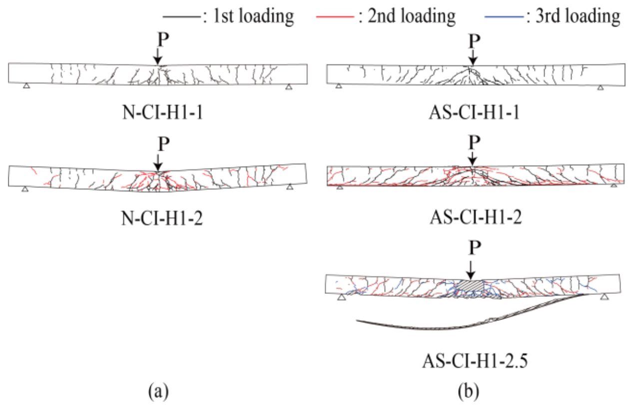

Figure 3. Crack patterns after consecutive impact loading:
(a) Beam N-CI-H1; and (b) Beam AS-CI-H1.

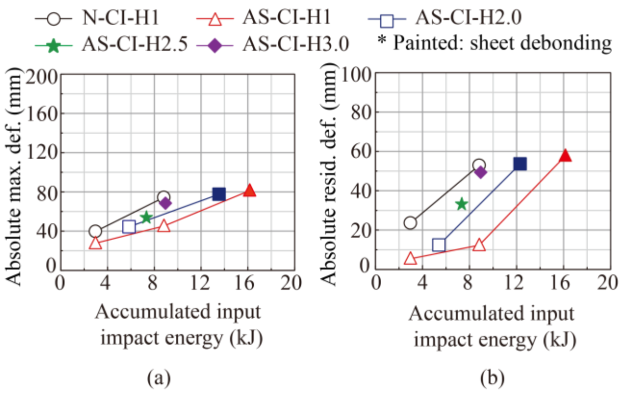

Figure 4. Relationship between absolute maximum response values and accumulated input impact energy E_a: (a) absolute maximum deflection; and (b) absolute residual deflection.

1.0 and AS-CI-H1-1.0. From these figures, comparing the time histories of impact force P and reaction force R for both beams were similar to each other. Regarding the time histories of deflection δ, the maximum and residual deflections of Beam AS-CI-H1-1.0 were smaller than that of Beam N-CI-H1-1.0.

Figure 2(b) shows the experimental results for Beam N-CI-H1-2.0 and Beam AS-CI-H1-2.0. From these figures, it is observed that the time histories of impact force P were also similar to each other. On the other hand, regarding the time histories of reaction force R, time duration of the main response of Beam N-CI-H1-2.0 was prolonged for 25 ms comparing to that of Beam AS-CI-H1-2.0. Regarding the time histories of the deflection δ, it can be observed that the maximum and residual deflections of Beam AS-CI-H1-2.0 were also significantly smaller than those of Beam N-CI-H1-2.0.

Figure 3 shows comparisons of the crack patterns after the tests between the beams with/without strengthening. From this figure, it is observed that: 1) flexural and diagonal cracks developed almost on the whole beams, and area near the loading point was damaged accompanied with compressive failure, irrespective of with/without strengthening; 2) at the fall height H = 2 m, although Beam N reached the ultimate state and was folded near the loading point, Beam AS may not be deformed significantly; and 3) in the case of Beam AS, the sheet was debonded at H = 2.5 m, and reached ultimate state.

Figure 4 shows the relationships between the absolute maximum deflection and the accumulated input impact energy E_a, and the absolute residual deflection and the accumulated input impact energy E_a. In these figures, the painted marks mean that the AFRP sheet debonded. From Figure 4(a), it is seen that the absolute maximum deflections for all Beams AS under consecutive loading may be linearly distributed including the cases of the sheet debonding. From the results for absolute residual deflections as shown in Fig. 4(b), it can be observed that the residual deflections for Beams AS except for the cases of sheet debonding were also linearly distributed. AFRP sheet was not debonded until the accumulated input impact energy E_a was greater than about 7.3 kJ.

4. CONCLUSIONS

The results obtained from this study were as follows:

1) Maximum and residual deflections of the beams considerably decreased by bonding AFRP sheet to the beam bottom tension-side surface; and
2) Absolute maximum and absolute residual deflections increased linearly with accumulated input impact energy.