CONSTANT LOW-ENERGY CONSECUTIVE DROP-WEIGHT IMPACT LOADING FOR RC BEAMS STRENGTHENED IN FLEXURE WITH LARGE-VOLUME OF AFRP SHEETS

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1. INTRODUCTION

The fiber-reinforced polymer (FRP) sheet bonding methods are sometimes used to upgrade impact-resistant capacities of the RC members because of the unique advantages of the FRP materials such as corrosion resistance, high strength-to-weight ratios, and relatively easy to install. To establish an adequate strengthening method for upgrading impact-resistant capacities of the RC structures, many drop-weight impact tests for the RC beams strengthened by bonding FRP sheets to tension-side surface were carried out by the authors. In this paper, in order to evaluate impact-resistant capacities and to identify the failure mode of the RC beams strengthened in flexure with FRP sheets, consecutive drop-weight impact loading with constant low-energy for the beam with Aramid FRP (AFRP) sheets was conducted. Input impact energy was decided as to be one-sixth and/or one-third that of the beams collapsed under single impact loading. A static loading test was also carried out to compare the failure mode of the beam.

2. EXPERIMENTAL OVERVIEW

Specimens used in this experiment were listed in Table 1. In this table, the nominal name of the specimen was designated in the order of strengthening material (A: AFRP), loading method (S: static loading, and C: constant-energy consecutive-impact loading), and drop height of the weight H*n* (*n*: drop height in metric unit) with a hyphen. The estimated drop height of the weight *H'* was evaluated using the measured drop velocity.

Figure 1 shows dimensions of the specimens and layout of the rebars and AFRP sheets. All beams have a rectangular cross-section of 200-mm width, 250-mm depth, and 3-m clear-span length. The AFRP sheet was bonded to the tension-side surface leaving 50 mm between the end of the sheet and the support point. The beam was strengthened by bonding two-ply AFRP sheets, in which one-ply has 830 g/m^2 mass. The AFRP sheet has material properties of the tensile strength of 2.1 GPa, the elastic modulus of 118 GPa, and the fracture strain of 1.75%.

Table 1 List of specimens

Specimen	Set drop height of weight H (m)	Measured drop height of weight H' (m)	Measured input impact energy E_i (kJ)	Comp. strength of concrete f'_c (MPa)	Yield strength of main rebar f_y (MPa)
A-S	Static loading	-	-	33.7	371.0
A-C-H0.5	0.5	0.56*	1.65	34.3	393.7
A-C-H1.0	1.0	1.137*	3.35		

* Average value for whole tets of specimen

Figure 2 shows a view of setup for drop-weight impact loading. Herein, impact load was applied by freely dropping a 300-kg steel-weight from a predetermined height onto the mid-span of the beam. The RC beams were placed on the supports equipped with load cells for measuring the reaction forces and clamped at their ends using cross beams to prevent lifting off. The supports are able to rotate freely while restraining horizontal movement of the beam. The weight was vertically dropped via the guide rails at the mid-span of the beam. Two kinds of drop height were selected: H= 0.5 m; and 1.0 m, which are 1/6 and 1/3 impact energy, respectively, referring to that of the beam reaching the ultimate state with single impact loading.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

Figure 3 shows comparisons of the static load-deflection curves for Beam A-S between experimental and numerical

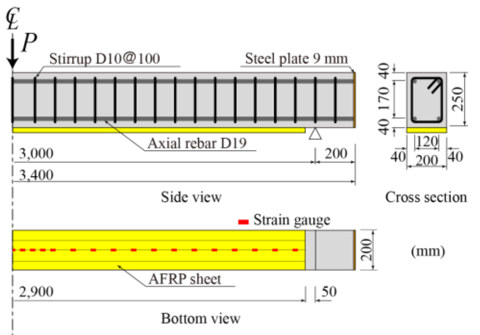

Fig. 1 Dimensions of specimen

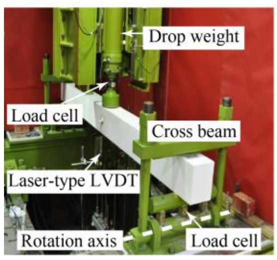

Fig. 2 Experimental setup

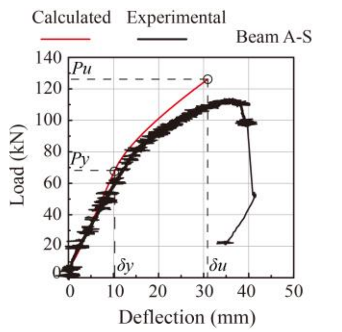

Fig.3 Static load-deflection curves

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

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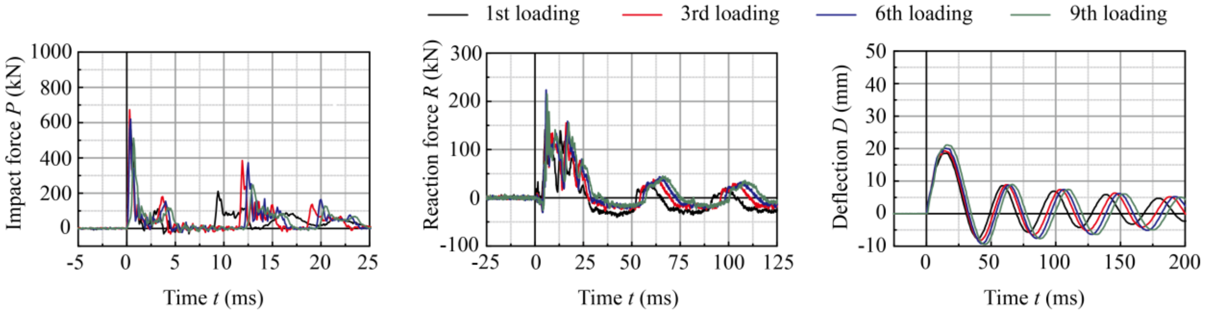

Fig. 4 Time histories of dynamic response wave for Beam A-C-H0.5

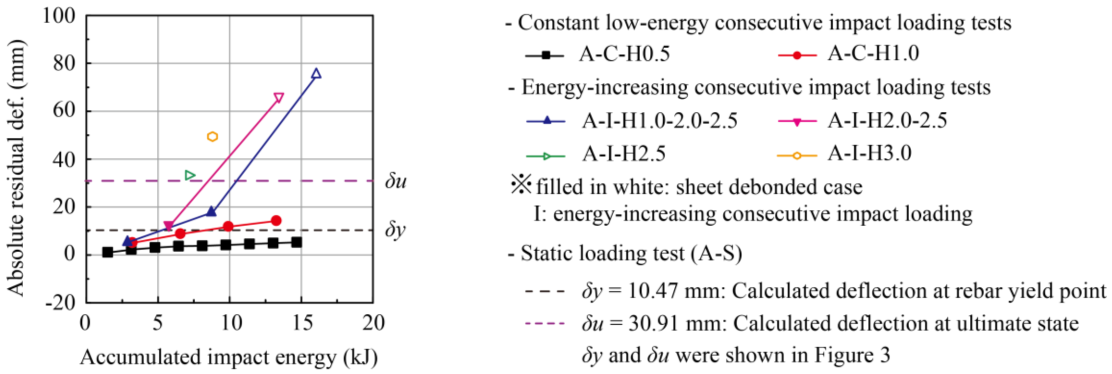

Fig. 5 Relationships between absolute residual deflection and accumulated impact energy

results. From this figure, it is observed that the maximum load obtained from the experimental result was smaller than that of the calculated one. The experimental results could not ensure the calculated ultimate state because of the sheets gradually debonding after the rebar yielded. The beam reached the ultimate state with the sheet debonding.

Figure 4 shows the time histories of the impact forces *P*, the total reaction forces (hereinafter, reaction force) *R*, and deflections *D* at 1st, 3rd, 6th, and 9th loading for Beam A-C-H0.5. The number of times of loading at reaching the ultimate state for Beams A-C-H0.5 and A-C-H1.0 was 9 and 4 times, respectively. These failed without sheet debonding, but with the loading area being severely damaged.

From the results for impact force *P*, following findings can be observed: (1) maximum impact force at each loading step gradually decreased and (2) the response time for the second wave around 10-15 ms tends to be delayed for a few milliseconds with increasing the number of times of loading.

In terms of the reaction force *R*, it is observed that: (1) the maximum reaction force tends to increase gradually with increasing the number of times of loading and (2) natural vibration period of the beam after unloading tends to be prolonged.

From the results for the deflection *D*, this finding indicates that: (1) maximum and residual deflections were approximately the same irrespective of the number of times of loading and (2) however, the natural vibration period of the beam after unloading tends to be prolonged.

Although the experimental results for Beam A-C-H1.0 cannot be shown here, similar results to those for Beam A-C-H0.5 were obtained.

Figure 5 shows the relationships between experimental absolute residual deflection and accumulated input impact energy, including the results for energy-increasing consecutive impact loading tests (Le Huy et al., 2019). From this figure, the following results can be observed: (1) the sheets were debonded at that the absolute residual deflection was greater than the calculated deflection δ_u at the ultimate state and (2) the sheets did not debond when the absolute residual deflection was less than the deflection δ_u, even the energy was greater than that at sheet debonding under the energy increasing-consecutive impact loading.

4. CONCLUSIONS

1) In the cases of energy-increasing consecutive and single impact loading, the beams reached the ultimate state with the sheet debonding;
2) In the case of constant low-energy consecutive impact loading, the sheet did not debond and the concrete around the loading point crushed due to accumulated damages; and
3) The sheet tends not to debond when the absolute residual displacement of the beam was less than the calculated deflection at the ultimate state under static loading.

REFERENCES

Le Huy, S., Komuro, M., Kishi, N., and Kawarai, T.: Experimental Study on Dynamic Behaviors of Flexural Strengthened RC Beams with AFRP Sheet Having 1660 g/m^2 Mass under Consecutive Impact Loading, 16th East Asia-Pacific Conference on Structural Engineering & Construction (EASEC16), P135, Brisbane, Australia, 2019.