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Shear Reinforcing Effect of Continuous Fiber Rope on Reinforced Concrete Beams

Kenzo SEKIJIMA[1], Masatoshi SATOH[2] and Junich IZUMO[3]

[1]*Institute of Science and Technology, Kanto Gakuin University, Japan*
[2,3]*Department of Civil and Environmental Engineering, Kanto Gakuin University, Japan*
[1,2,3]*Mutsuurahigashi 1-50-1, Kanazawa-ku,Yokohama-shi, Kanagawa 236-8501, Japan*
[1]*r069009@kanto-gakuin.ac.jp*
[2]*m1245001@kanto-gakuin.ac.jp*
[3]*izumo@kanto-gakuin.ac.jp*

ABSTRACT

Continuous Fiber Rope (CF Rope) made of Aramid fiber or Vinylon fiber has been developed to apply for the reinforcement of concrete members. It is characterized by a lightweight, a high tensile strength and an excellent durability compared with reinforcing steel bar. It has also a good transportability, and it is flexible to be easily arranged at a construction site. The purpose of this study is to investigate the shear reinforcing effect of CF Rope. First, the reinforced concrete (RC) beams without shear reinforcement were tested. Then, the RC beams wound with CF Rope at shear span were tested. Moreover, the shear reinforcing effect of CF Rope on the RC beams that were pre-damaged in shear assuming seismic retrofitting was also investigated. Through the test results, it was confirmed that CF Rope was effective for the RC beams without shear reinforcement and the pre-damaged RC beams in shear.

Keywords. Continuous Fiber Rope, Vinylon fiber, Aramid fiber, Reinforced concrete beam, Shear reinforcing effect

INTRODUCTION

Japan has experienced the big earthquakes such as Kobe Earthquake (1995), Chuetsu-oki Earthquake (2007) and Great East Japan Earthquake (2011). Moreover, the M7 scale epicentral earthquake directly under the capital is assumed in the future. Many reinforcing and restoring methods of RC structures and members have been developed so far. However, it is also required to develop the engineering method that is economical and applicable to shortening the construction period compared to the conventional method in order to minimize the extensive damage.

Continuous Fiber Rope (CF Rope) made of Aramid fiber or Vinylon fiber has been developed to apply for the reinforcement of concrete members. It is characterized by a lightweight, a high tensile strength and an excellent durability compared with reinforcing steel bar. It has also a good transportability, and it is flexible to be easily arranged at a construction site.

The authors have already investigated the tensile properties of CF Rope (Sekijima, Izumo, 2008), the capacities of some kinds of splice of CF Rope (Sekijima, Kawakami, Izumo, 2009) and the bond properties between CF Rope and concrete (Sekijima, Kawakami, Izumo, 2012).

When the reinforced concrete (RC) structure lacking of shear capacity is reinforced in shear with CF Rope, a safety of the RC structure will be improved. The purpose of this study is to investigate the shear reinforcing effect of CF Rope. First, the RC beams without shear reinforcement were tested. Then, the RC beams wound with CF Rope at shear span were tested. Moreover, the shear reinforcing effect of CF Rope on the RC beams that were pre-damaged in shear assuming seismic retrofitting was also investigated.

SPECIMEN

Outline of Specimen. The specimens were rectangular beams with double reinforcement, and the dimension was 150 mm wide, 200 mm high and 1,500 mm long. The tension and compression reinforcement of the specimen were the deformed steel bar which nominal diameter was 13 mm (D13). The erection bar was a closed shape and its nominal diameter was 10 mm (D10). The dimension of the specimens, the arrangement of the main reinforcement and the erection bar are shown in Figure 1. Four corners of the section of the specimen were chamfered in order to prevent CF Rope from being damaged when it was wound around the specimen. The number of the specimens was four. Two specimens did not have any shear reinforcement (No.1, No.2), and the others were wound with Vinylon fiber rope or Aramid fiber rope at shear span (No.3, No.4) as shown in Figure 2. Moreover, after No.1 and No.2 had failed in shear, they were wound with Vinylon fiber rope and Aramid fiber rope at shear span, respectively (No.5, No.6). The shear span ratio a/d of all specimens was 2.3. The list of the specimens is shown in Table 1.

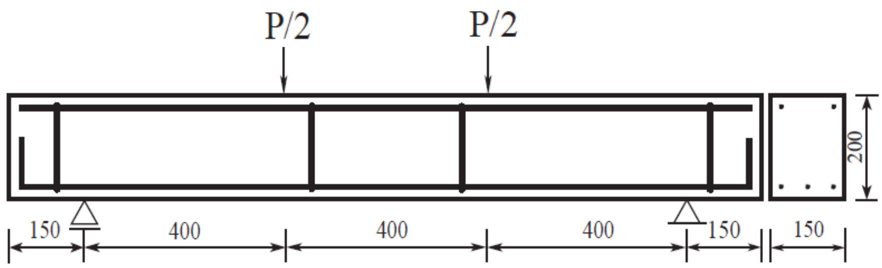

Figure 1. Dimension of specimen (No.1, No.2)

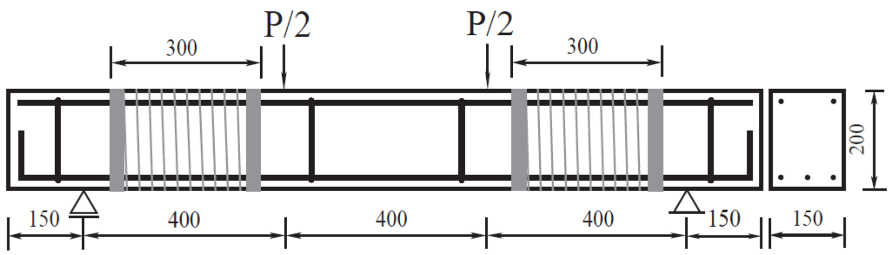

Figure 2. Dimension of specimen (No.3, No.4)

Table 1. List of specimen

Specimen	Pre-damaged in shear	Type of rope	Interval of rope
No.1	No	-	-
No.2	No	-	-
No.3	No	Vinylon fiber	25 mm
No.4	No	Aramid fiber	25 mm
No.5	Yes	Vinylon fiber	25 mm
No.6	Yes	Aramid fiber	25 mm

The 300 mm long part of the shear span that was 50 mm inside between the support and the loading point was wound with CF Rope with an interval of 25 mm as shear reinforcement. CF Rope was anchored as shown in Photo 1. Namely, at the starting point CF Rope was wound three times and three ropes were fixed with annealed steel wire at three spots. At the ending point the same procedure was adopted.

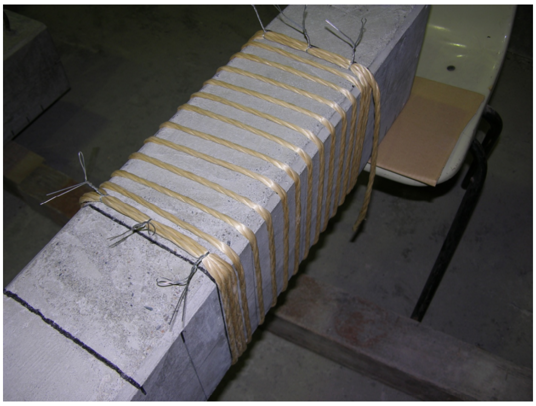

Photo 1. Starting and ending point of CF Rope at shear span

Materials. The specification of the main reinforcement D13 was SD295 (nominal yield strength was 295 N/mm^2). The average yield strength was 349 N/mm^2 by the tension test.

Since the cover for embedded bars was small, mortal was adopted to manufacture the specimen instead of concrete. The mix proportion of mortar is shown in Table 2. The loading tests were carried out at 28 days and 30 days. The compressive strength and the tensile strength at 28 days and 30 days were 48.3 N/mm^2 and 43.3 N/mm^2, 3.6 N/mm^2 and 3.3 N/mm^2, respectively.

Table 2. Mix proportion of mortar

Water cement ratio W/C (%)	Sand-coarse aggregate ratio s/a (%)	Unit weight (kg/m^3)		
		Water W	Cement C	Sand S
60	100	270	450	1508

CF Rope was stranded by Vinylon fiber or Aramid fiber, and only the surface of CF Rope was coated with urethane resin. Through coating with urethane resin, the fibers were prevented from being unbraided, moreover CF Rope became a little harder and easy for handling. Table 3 shows the properties of two types of CF Rope (Sekijima, Izumo, 2008). The sectional area shown in Table 3 does not include urethane resin.

Table 3. Properties of CF Rope

Type of rope	Diameter (mm)	Sectional area (mm^2)	Tensile strength (N/mm^2)	Young' modulus (kN/mm^2)
Vinylon fiber	6.0	12.3	851	19.3
Aramid fiber	6.0	11.5	2414	45.7

LOADING TEST

Test Method. The specimen was loaded with 1,200 mm of span. The load was increased at the interval of 5 kN. After bending cracks occurred, the load was decreased to 5 kN. Then the load was gradually increased until failure. The displacement of midspan and both supports, and the load were measured during the test duration.

Crack. In case of No.1 and No.2, bending cracks occurred at 20 to 30 kN of load, and diagonal tension cracks occurred at shear span at 45 to 55 kN, then the tests were finished. Photo 2 shows the diagonal tension crack of No.1. In case of No.1, a diagonal tension crack occurred only at right shear span. However, in case of No.2, diagonal tension cracks occurred at both shear spans. The width of the diagonal tension cracks measured by a crack scale was approximately 0.3 to 1.0 mm.

In case of No.3 wound with Vinylon fiber rope, diagonal tension cracks of approximately 0.4 mm wide occurred at both shear spans at 55 kN. Then, the tension reinforcement yielded at 101.5 kN, and a flexural tension failure occurred at 114.0 kN. In case of No.4 wound with Aramid fiber rope, a diagonal tension crack occurred at right shear span at 49 kN. Then, a diagonal tension crack also occurred at left shear span. The tension reinforcement yielded at 96.4 kN, and a flexural tension failure occurred at 110.9 kN. Photo 3 shows the diagonal tension crack of No.4. The width of the diagonal tension crack of No.3 wound with Vinylon fiber rope with low Young’s modulus was larger than that of No.4 wound with Aramid fiber rope with high Young’s modulus.

In case of No.5 that was No.1 itself wound with Vinylon fiber rope after the test, a diagonal tension crack occurred at left shear span at 45 kN. Then, the tension reinforcement yielded at 100.7 kN, and a flexural tension failure occurred at 111.2 kN. In case of No.6 that was No.2 itself wound Aramid fiber rope after the test, the diagonal tension crack at right shear span extended to the support at 50 kN. Then, the tension reinforcement yielded at 101.7 kN, and a flexural tension failure occurred at 111.7 kN. The diagonal tension cracks of No.5 and No.6 after the flexural failure were shown in Photo 4 and Photo 5, respectively. When the specimen was wound with CF Rope, CF Rope carried the shear force after diagonal tension cracking, consequently the specimen failed in flexure but not in shear. The initial interval of CF Rope of No.3 to No.6 was not change through the test.

Photo 2. Diagonal tension crack (No.1)

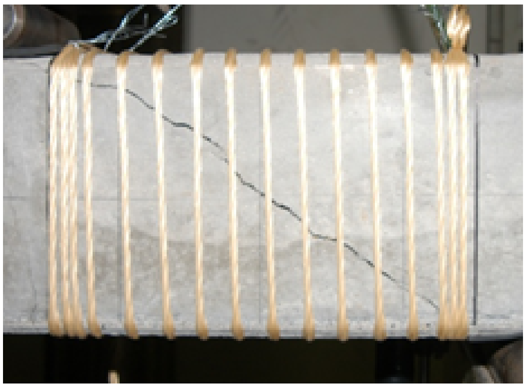

Photo 3. Diagonal tension crack (No.4)

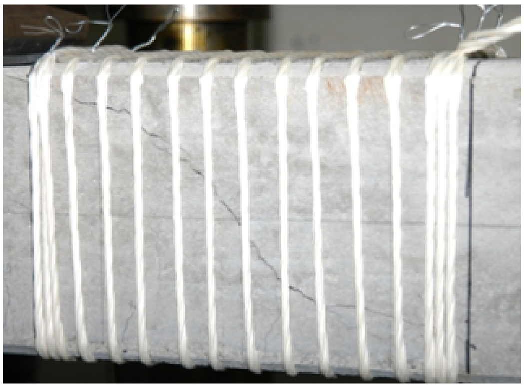

Photo 4. Diagonal tension crack (No.5)

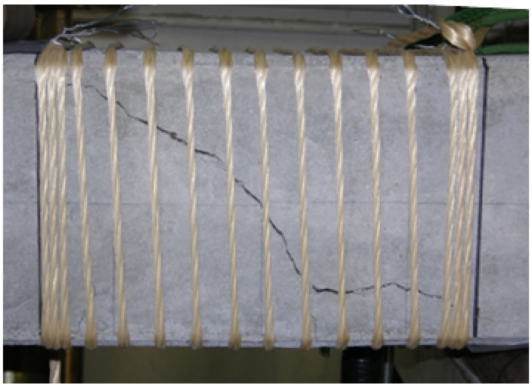

Photo 5. Diagonal tension crack (No.6)

Load bearing capacity. Table 4 shows the test results and the calculated values. The diagonal tension cracking loads were between 45 and 55 kN, and there was almost no difference between those of No.1 and No.2 without shear reinforcement and those of No.3 and No.4 wound with CF Rope. Moreover, there was no difference between the diagonal tension cracking load of No.3 wound with Vinylon fiber rope and that of No.4 wound with Aramid fiber rope. The type of CF Rope had no influence on the occurrence of the diagonal tension crack. The calculated shear capacities in Table 3 were obtained by Niwa's equation related to reinforced concrete beams (Niwa, 2006). Niwa's equation is as follows,

$$V_c = 0.20 f'_c{}^{\frac{1}{3}} \left(100\frac{A_s}{bd}\right)^{\frac{1}{3}} \left(\frac{10^3}{d}\right)^{\frac{1}{4}} \left(0.75 + \frac{1.4d}{a}\right) bd \tag{1}$$

where, f'_c: compressive strength

A_s: sectional area of tensile reinforcement

b: width

d: effective depth

a: shear span

In case of No.1 and No.2 that failed in shear, the ratio of the experimental and calculated values was between 0.61 and 0.67, and the former was lower than the latter. Equation (1) is related to concrete beams, however, the specimen was made of mortar but not concrete, consequently the aggregate interlock decreased and the shear capacity became lower. In case of No.3 to No.6, the flexural capacities were calculated on the assumption of flexural tension failure. The calculated values in Table 1 were obtained by supposing as a rectangular beam with single reinforcement. The ratio of the experimental and calculated values was between 1.03 and 1.06, consequently the experimental and calculated values were almost same.

Since the load bearing capacities of the specimens were almost same, because the failure mode was flexural tension failure though they were wound with Vinylon fiber rope or Aramid fiber rope with an interval of 25 mm. Since the interval of CF Rope will have an influence on the failure mode, the experiment with a parameter of the interval of CF Rope must be necessary from now on.

Through this test, it was confirmed that when the RC beam that was pre-damaged in shear was wound with CF Rope, CF Rope carried the shear force after diagonal tension cracking, consequently the RC beam failed in flexure but not in shear.

Table 4. Test result and calculated value

Specimen	Diagonal tension cracking load (kN)	Yielding load (kN)	Experiment (kN)	Calculation (kN)	Experiment / calculation	Failure mode
No.1	55	-	55.2	82.2	0.67	Shear
No.2	45	-	49.9	82.2	0.61	Shear
No.3	55	101.5	114.0	108.0	1.06	Flexure
No.4	49	96.4	110.9	108.0	1.03	Flexure
No.5	-	100.7	111.2	107.0	1.04	Flexure
No.6	-	101.7	111.7	107.0	1.04	Flexure

Load-deflection relationship. The load-deflection relationships measured during the test duration were shown in Figure 3 to Figure 8. No.1 and No.2 without shear reinforcement failed in shear at 49.9 to 55.2 kN, the deflection at midspan was smaller than 2 mm, and the flexural behavior was not good. However, in case of No.3 wound with Vinylon fiber rope, the load bearing capacity became twice higher than those of No.1 and No.2, the deflection at midspan was approximately 14 mm, and it was approximately seven times larger than those of No.1 and No.2. The load-deflection relationship of No.4 wound with Aramid fiber rope showed a similar tendency as that of No.3.

In case of No.5 and No.6 that were No.1 and No.2 themselves wound with Vinylon fiber rope and Aramid fiber rope after the test, the load bearing capacity and the flexural behavior was improved remarkably, and the load bearing capacity became twice higher, moreover the deflection at midspan became seven times larger.

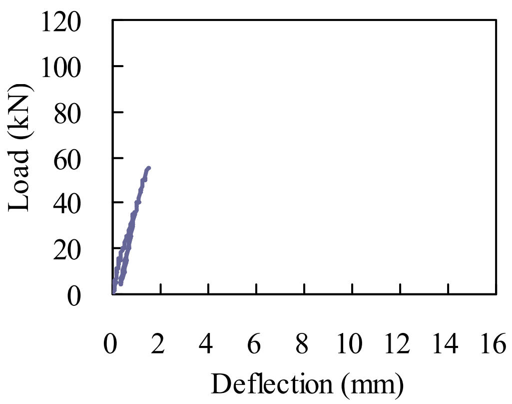

Figure 3. Load-deflection relationship (No.1)

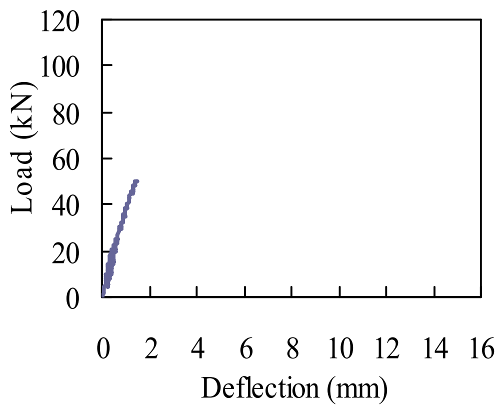

Figure 4. Load-deflection relationship (No.2)

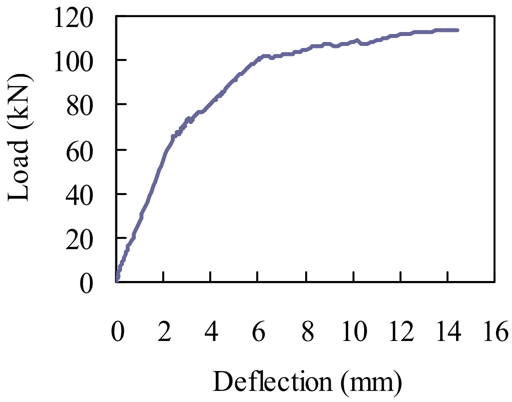

Figure 5. Load-deflection relationship (No.3)

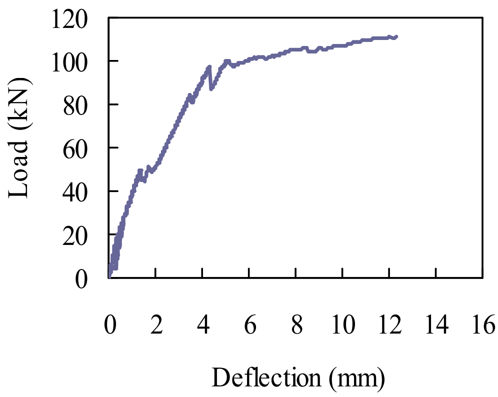

Figure 6. Load-deflection relationship (No.4)

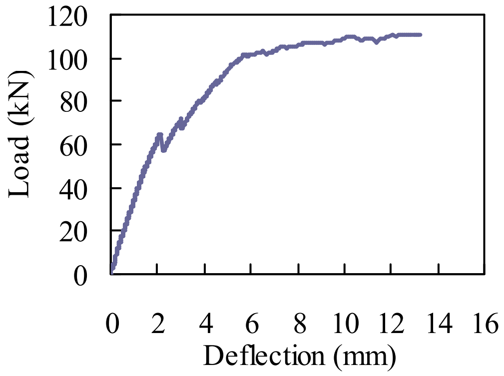

Figure 7. Load-deflection relationship (No.5)

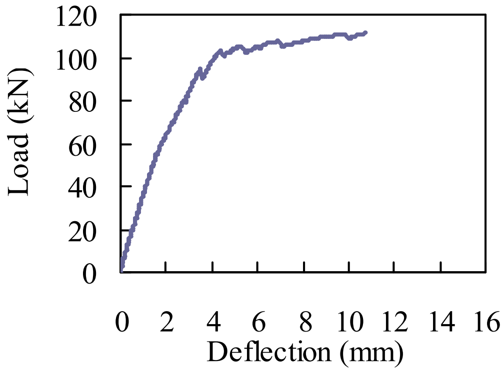

Figure 8. Load-deflection relationship (No.6)

Concerning the flexural rigidity in the load-deflection relationship between 50 kN (diagonal tension cracking) and 100 kN (tension reinforcement yielding), those of No.4 and No.6 wound with Aramid fiber rope were higher than those of No.3 and No.5 wound with Vinylon fiber rope, because Aramid fiber rope with high Young's modulus could suppress the shear deformation more efficiently than Vinylon fiber rope with low Young's modulus.

Through this test, it was confirmed that when the RC beam was wound with CF Rope at shear span, a shear failure was prevented, the load bearing capacity increased up to a flexural failure, moreover the flexural behavior was improved.

CONCLUSIONS

When the RC beam without shear reinforcement was wound with CF Rope at shear span, the shear capacity increased, and then the failure mode changed from a shear failure to a flexural failure.

When the RC beam without shear reinforcement that was pre-damaged in shear was wound with CF Rope, the load bearing capacity increased, moreover the flexural behavior was improved.

The width of the diagonal tension crack of the RC beam wound with Aramid fiber rope was smaller and the flexural rigidity in the load-deflection relationship was higher than those of the RC beam wound with Vinylon fiber rope.

REFFERENCES

Niwa, J. (2006). "Foundation of concrete structures." Surikogakusha.

Sekijima, K., and Izumo, J. (2008). "Evaluation of properties of continuous fibre rope." 5th international conference on advanced composite materials in bridges and structures (ACMBS-V), CD-ROM.

Sekijima, K., Kawakami, K., and Izumo, J. (2009). "Tensile properties of continuous fiber rope." 4th international conference on construction materials: performance, innovations and structural implications (ConMat'09).

Sekijima, K., Kawakami, K., and Izumo, J. (2012). "Bond properties between continuous fiber rope and concrete." The third asia-pacific conference on FRP structures (APFIS2012), CD-ROM.