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SHEAR REINFORCEMENT OF RC BEAMS WITH CONTINUOUS FIBER ROPE

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Abstract: In this study, continuous fiber ropes were applied for shear reinforcement of RC members. The effect of adhering and covering materials for the rope on concrete surface and the spacing of winding rope on the shear behavior of RC beams was examined. Shear loading tests were conducted on RC beams reinforced with a continuous fiber rope. The continuous fiber ropes were efficient for shear reinforcement of RC beams. In order to utilize continuous fiber ropes for shear reinforcement of RC beams, we proposed a method to adhere ropes with acrylic resin and then to cover them with SHCC (Strain-Hardening Cement Composites) on concrete surface.

1 INTRODUCTION

In Japan, many reinforced concrete structures built before 1980 are deficient in shear capacity due to insufficient shear reinforcement. To cope with this problem, a variety of retrofitting methods have been adopted for shear strengthening of reinforced concrete members since the 1995 Hyogoken-Nanbu Earthquake. For reinforced concrete beams and columns, these methods include jaketing with steel plates, reinforced concrete, and continuous fiber sheets [1].

In addition, a research is underway on a method involving continuous fiber ropes winding [2]. This is a method in which continuous fiber rope braided to 4 mm diameter are wound around structures for strengthening. It is expected to be effective with the following features:

- Additional burdens on existing structures are marginal because of the light weight of the material.
- The ropes can be manually wound without heavy machinery, requiring only a small working space.
- The light weight allows easy hauling and handling.
- Work can be completed in a short period.
- The ropes facilitate length adjustment at the jobsite.
- Adaptable to complicated shapes and

irregular surfaces of the structure.

A design standard is currently available only for the aramid fiber ropes [3]. This standard covers only fiber ropes that are applied to bridge piers for seismic retrofitting to prevent spalling of cover concrete and enhance ductility, while no shear strengthening is expected. Also, this standard requires surface covering of ropes with polymer cement mortar, etc., from the aspect of facilitating maintenance but does not require resin impregnation or adhesion to concrete surface.

This study [4] is intended to apply continuous fiber ropes for shear strengthening of concrete members to widen the application of such ropes for strengthening and effectively utilize surface covering, which is necessary for maintenance including rope protection.

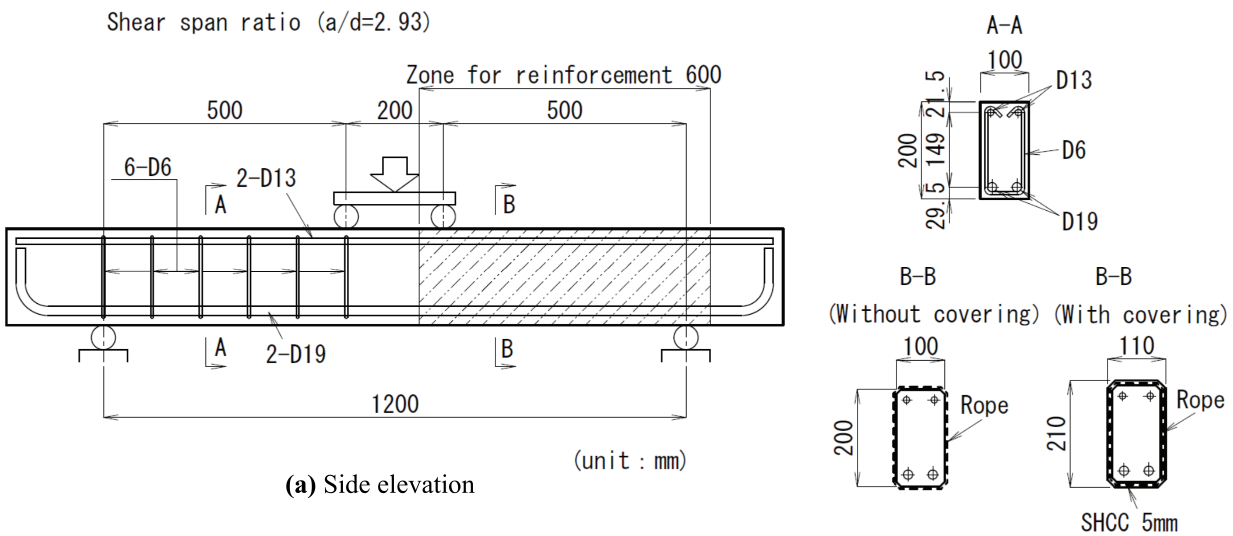
2 EXPERIMENTAL PROGRAM

2.1 Experiment overview

Loading tests were conducted on beam specimens shown in Fig. 1 and Table 1.

As shown in Fig. 1, the left span of each specimen was shear-reinforced using stirrups, while the right span was strengthened under different conditions. Eleven specimens were prepared with different sets of conditions as given in Table 1. Three winding spacing of continuous ropes were selected: 20 and 40 mm to intend flexural failure and 100 mm to intend shear failure.

Specimen N00 is a reference specimen with



(a) Side elevation

(b) Cross sections

Figure 1: Dimension and configuration of specimens

Table 1: Summaries of RC beam specimens

Specimen	Rope		Resin		Surface covering		Remarks
	Material	Winding spacing (mm)	Fixing materials	Amount (g/m^2)	Material	Thickness (mm)	
N00	–	–	Reference beam without shear reinforcement				
S10		–	Reference beam with stirrups over the whole length				
R02	PE	20	–	–	–	–	Effect of rope winding
R02A			Resin A	460	–	–	Effect of adhering material
R02B			Resin B	130	–	–	
R02H			–	–	SHCC	5	
R02AH			Resin A	460	SHCC	5	Effect of covering material
R04A		40	Resin A	420	–	–	Effect of winding spacing
R04AH					SHCC	5	
R10A		100	Resin A	360	–	–	
R10AH					SHCC	5	

no shear reinforcement. Specimen S10 is another reference specimen having standard stirrups over the whole length at 100 mm spacing. Note that a fiber rope was manually wound around each specimen without using any special equipment, while applying tension to avoid slacking.

Two resins were compared as materials for adhering continuous fiber ropes to concrete surfaces. Resin A is an acrylic impregnating resin normally used for strengthening concrete using continuous fiber sheets. Resin B is an acrylic primer normally used for improving the bond at concrete construction joints. Though its tensile strength is as low as 1 MPa when compared with Resin A with a tensile strength of 15 MPa, Resin B is easy to apply and economical due to being a one-component resin.

A strain-hardening cement composite (SHCC) [5] was used as the surface covering material for continuous fiber ropes to ensure

Table 2: Mix proportions of concrete and SHCC

	W／C (%)	Unit weight [kg/m^3]							
		Water	Cement	Expansive agent	Fine aggregate	Coarse aggregate	Fiber	Water-reducing agent	Viscosity enhancer
Normal concrete	45	166	368	—	731	1034	—	Ad 1.027	—
SHCC	30(W/B)	380	1188	76	392^{*1}	—	14.6	Sp 37.9	0.900

Note: Ad: Air-entraining and water-reducing agent   Sp: Air-entraining and high-range water-reducing agent

Fiber: High-strength Polyethylene Fiber (Diameter: 12μm, Length: 12mm, Tensile strength: 2.6GPa, Young's modulus: 88GPa)

W/B: Water–binder ratio

*1 : Quartz sand

Table 3: Mechanical properties of cement composites

Materials	Compressive strength (MPa)	Flexural strength (MPa)	Tensile strength (MPa)	Young's modulus (GPa)	Materials Age (day)	Tensile testing method
Normal Concrete	41	4.3	3.1	31.0	27	Splitting
SHCC	75	—	7.4	22.0	8	Uniaxial

Table 4: Mechanical properties of reinforcing bars

	Quality of materials	Diameter	Yield strength (MPa)	Tensile strength (MPa)	Young's modulus (GPa)
Tension bar	SD345	D19	396	574	200
Compressive bar	SD345	D13	380	539	200
Stirrup	SWM-R	D6	481	600	200

Table-5: Mechanical properties of reinforcing ropes

Material form	Item	Properties
PE fiber Basic properties	Tensile strength	2600 MPa
	Young's modulus	79 GPa
	Fracture elongation	3～5%
PE fiber rope Φ3mm Plaited cord Testing method：JIS L 1013 Tensile speed 20cm/min Mesurement length 20cm	Fracture load	6.44kN
	Fracture elongation	15.5%
	Sectional area	4.37mm^2
	Tensile strength	1473 MPa
	Young's modulus	8.89 GPa

Table-6 Mechanical properties of adhering materials

Fixing materials	Strength	Mesured value (MPa)	Testing methods	Remarks
Resin A	Bond Strength on concrete	2.5	JIS A 6909	Manufacturer's catalog values
	Compressive strength	70	JIS K 7208	
	Compressive young's modulus	940	JIS K 7208	
	Flexural strength	30	JIS K 7203	
	Tensile strength	20	JIS K 7113	
	Tensile shear strength	19	JIS K 6850	
	Tensile strength	15	Measured in this study	
Resin B	Tensile strength	0.8		

long-term durability.

2.2 Material properties

Table 2 gives the mix proportions of concrete and SHCC for specimens. Tables 3 to 6 give the strength properties of materials.

2.3 Loading test procedure

Loading tests were conducted by four-point loading as shown in Fig. 1. The load and specimen displacement were measured. The deflection at the two loading points and two support points were measured to determine the average deflection at the loading points by excluding the effect of the displacement at support points. The loading rate of the tests was approximately 0.75kN/sec.

3 RESULTS AND DISCUSSION

Table 7 summarizes the test results including the shear force and average deflection at the maximum load and the failure mode in the ultimate state of each specimen.

3.1 Effect of rope winding

Figure 2 compares the loading test results of N00 having no shear reinforcement, S10 having standard stirrups at 100 mm spacing, and R02 having a rope wound at a 20 mm spacing, to examine the shear strengthening with a rope winding in the RC beam. The vertical and horizontal axes represent the shear force (1/2 of the load) and the average deflection at the loading points, respectively.

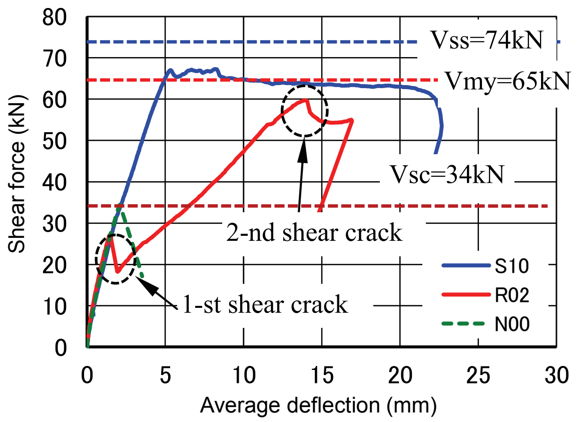
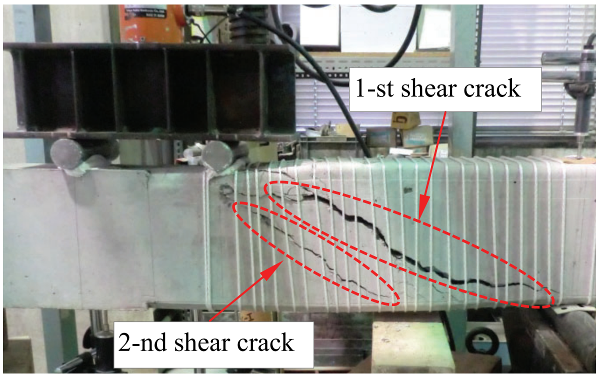


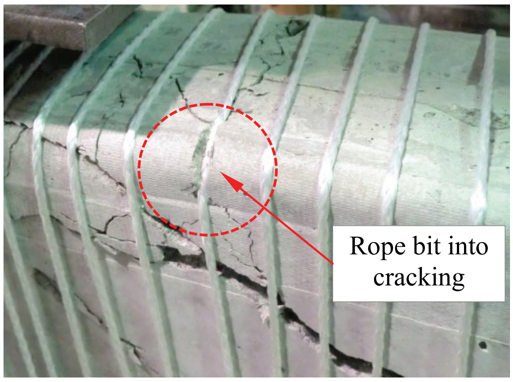
Figure2: Effect of rope winding

Table 7: Summaries of test results

Specimen	Maximum shear force (kN)	Average deflection (mm)	Failure mode
N00	34.4	2.1	Shear failure (diagonal tension failure)
S10	67.3	8.2	Flexural failure(concrete compression failure)
R02	59.7	13.9	Shear failure (diagonal tension failure)
R02A	67.2	9.7	Flexural failure(concrete compression failure)
R02B	60.8	13.9	Shear failure (diagonal tension failure)
R02H	69.7	12.9	Flexural failure(concrete compression failure)
R02AH	68.0	5.6	
R04A	57.1	9.6	Shear failure (Rupture of rope)
R04AH	68.6	8.6	Flexural failure(concrete compression failure)
R10A	40.4	12.2	Shear failure (Rupture of rope)
R10AH	54.3	4.9	



(a) Shear crack at fracture mode



(b) Corner of the upper edge

Figure 3: Failure mode of R02 beam

This figure also includes the diagonal cracking capacity *Vsc*, flexural yielding capacity, *Vmy*, and shear capacity incorporating stirrups, *Vss*.

Shear cracking occurred in Specimen N00 leading to shear failure (diagonal tension failure). Specimen S10 underwent concrete crushing at the upper edge after yielding of tensile reinforcement, reaching the ultimate state.

In Specimen R02 having rope strengthening alone, the first shear crack occurred as shown in Fig. 3(a) with a temporary reduction in the load as shown in Fig. 2. Rope-strengthening then took effect as the crack widened with increase of the load. The maximum capacity was attained when the second shear crack occurred. Deformation of this specimen rapidly increased as the rope bit into cracking at the corner of the upper edge as shown in Fig. 3(b).

These results revealed the continuous rope could be used for shear strengthening of reinforced concrete beams, wheareas it was necessary to prevent the temporary decrease of load until the rope begins to function after the occurrence of shear cracks.

3.2 Effect of adhering material

As to the effect of adhering the rope to the concrete surfaces, Fig. 4 shows the results of loading tests on R02A and R02B, to which the ropes were adhered using Resins A and B, respectively, and R02H, which was covered with the SHCC without resin adhering, in comparison with the results of R02 without adhering material.

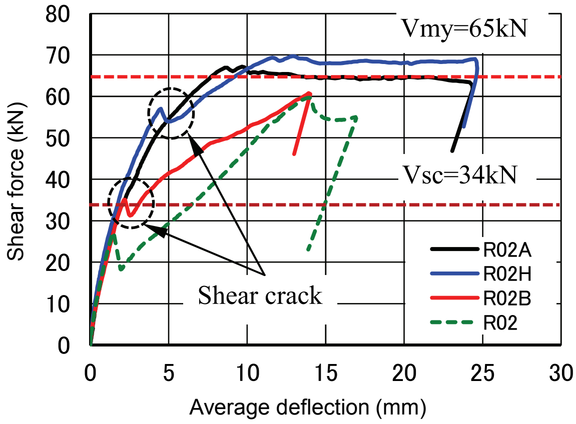


Figure 4: Effect of adhering material

Regarding R02A, shear cracks with a maximum crack width of 0.3 mm occurred as deformation increased after the yielding of tensile reinforcement, but concrete of the upper edge was ultimately crushed to reach the ultimate state.

Shear cracks occurred in R02H (maximum crack width: 4 mm) before flexural yielding but did not lead to shear failure due to the rope-strengthening. The specimen reached the ultimate state when concrete on the upper edge crushed after tensile reinforcement yielded.

In regard to R02B, a shear crack appeared similarly to R02, but the strengthening rope took effect as the crack propagated as shown in Fig. 4. The second shear crack then occurred, leading to shear failure.

These results revealed that the shear strengthening effect of rope winding is enhanced by adhesion the rope to the concrete surfaces and that Resin A is effective as a adhering material. The adhering effect of the

SHCC was found evident, though not comparable to the effect of Resin A.

3.3 Effect of covering material

Protective measures including covering are necessary for rope-strengthening from the aspect of ensuring the long-term durability of ropes. Figure 5 shows the results of tests to investigate the influence of covering materials on structural properties.

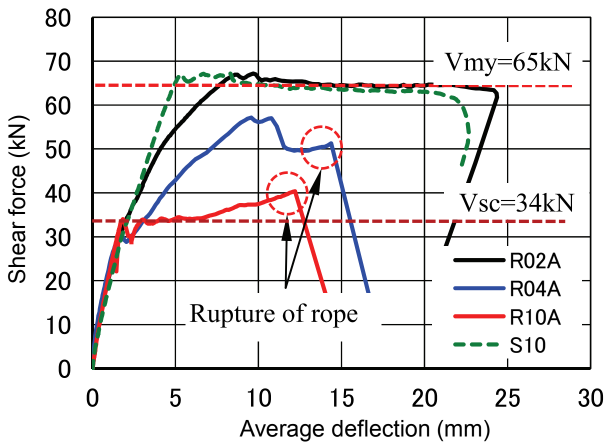
Figure 5(a) shows the results of three specimens having ropes (winding spacing: 20, 40, and 100 mm) adhered using Resin A but not SHCC-cover. Figure 5(b) shows the results of three specimens having both Resin A adhering and SHCC covering.

Among the three specimens with different winding spacing, only R02A demonstrated the effect of shear strengthening, with the upper edge concrete crushing after the yielding of tensile reinforcement to undergo flexural failure. For R04A and R10A, the ropes ruptured as shown in Fig. 6(a) to lead to shear failure, due to insufficient shear strengthening.

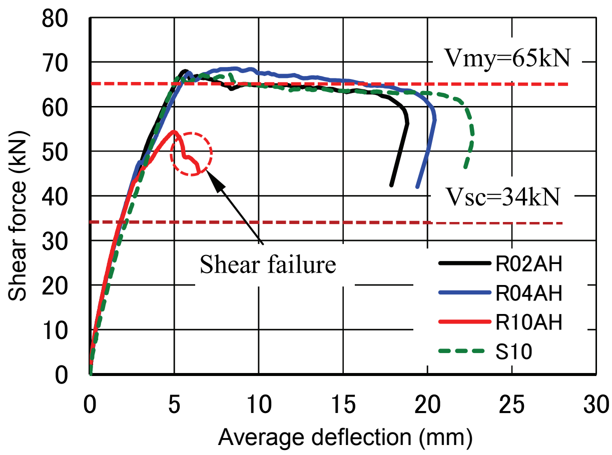
In regard to the latter three with both Resin A and the SHCC, R02AH and R04AH demonstrated the effect of shear strengthening, with the upper edge concrete crushing after the yielding of tensile reinforcement to undergo flexural failure as shown in Fig. 6(b). In R10AH, however, shear cracking expanded to the maximum capacity, leading to shear failure, though the ultimate load increased, due to shear strengthening, when compared with specimens not covered with the SHCC.

Figure 5 also reveals that the rigidity losses after shear cracking of the three SHCC-covered specimens are smaller than those of uncovered specimens.

Figure 5(b) shows that a shear-strengthening effect comparable to stirrups can be achieved by winding a rope around

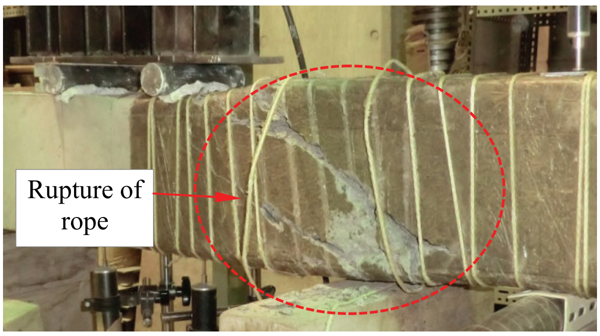


(a) Without covering

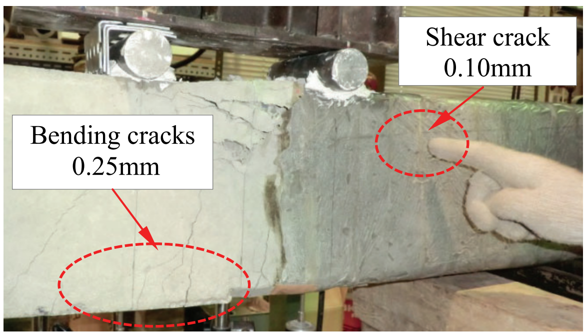


(b) SHCC covering

Figure 5: Effect of covering material



(a) R04A (Rope + Resin A)



(b) R04AH (Rope + Resin A + SHCC)

Figure 6: Failure mode of RC beams with different covering materials (R04A and R04AH beams)

concrete, adhering the rope with such a material as Resin A, and covering the wound concrete with a covering material, such as a SHCC.

4 CONCLUSIONS

The mechanical properties of reinforced concrete members that are shear-strengthened by winding a continuous fiber rope were investigated. The following properties were found:

(1) When using a continuous fiber rope, its load-bearing capacity can be fully utilized for shear strengthening by adhering the rope with such a material as resin and covering the member with such a material as SHCC.

(2) The acrylic resins used for strengthening using continuous fiber sheets are suitable as a material for adhering a rope to concrete surfaces. A SHCC is also effective as a adhering material.

(3) Winding a rope around a concrete member without adhering it to the concrete surfaces does not provide an adequate shear strengthening effect, as the strengthening effect of the rope is brought about after shear cracking has substantially developed.

(4) When the rope is adhered to the concrete surfaces with an acrylic resin, etc., but the member is not covered with a SHCC, etc., a certain shear strengthening effect can be obtained. However, the rigidity of the member decreases when the rope bears the shearing force under a load exceeding the diagonal cracking capacity. A covering material such as SHCC contributes to preventing such reductions in rigidity.

REFERENCES

[1] Concrete Committee, Japan Society of Civil Engineers 2000. Guideline repair and reinforcement of concrete structures using continuous fiber sheets, Concrete Library 101, Mar. 2000. (in Japanese)

[2] Shimomura, T., Fujikawa, H. and Maruyama, K., 2009. Modeling of load bearing mechanism of RC column with external continuous fiber rope under reversed cyclic load, *Asia-Pacific Conference on FRP in Structures (APFIS 2009)*, December 9-11, 2009, Seoul, Korea, pp.137-142.

[3] Nippon Expressway Company 2011. Design guidelines No.2 Bridge maintenance, July 2011, pp.6.44-6.51. (in Japanese)

[4] Hatano, H., Nakashima, T., Yun, H.-D., Uchida, Y. and Rokugo, K., 2012. Shear Reinforcement of RC members with Continuous Fiber Rope. *Journal of materials and concrete structures*, E2, Vol.68, No.4, pp.271-282, 2012. (in Japanese)

[5] Concrete Committee, Japan Society of Civil Engineers 2008. Recommendations for Design and Construction of High Performance Fiber Cement Composites with Multiple Fine Cracks(HPFRCC), Concrete Engineering Series 82, 2008.