Study on Tenancy Reinforcement Using Aramid Rope for RC Bridge Piers with a Reinforcement Termination Point

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Abstract

In recent years, seismic reinforcement has been conducted for many existing bridges under a three-year national program for the seismic reinforcement of such structures along emergency transportation roads. The need for this type of work is expected to continue increasing in the future. However, in cold and snowy regions where the conditions for antiseismic work are disadvantageous (including low temperatures and limited construction periods), it is necessary to introduce new reinforcement methods to be used in addition to existing ones. In this study, positive/negative cyclic loading tests were conducted in the horizontal direction of RC columns that have a reinforcement termination point to examine the feasibility of strengthening using aramid rope as a new seismic reinforcement construction method. As a result, it was confirmed that reinforcement with this type of rope was effective in improving the ductility and toughness of RC columns.

Introduction

Japan has implemented seismic reinforcement projects for existing bridges along emergency transportation roads since the 1995 South Hyogo Prefecture Earthquake, and an intensive program of such work is currently under way for bridges along other roads. The cold and snowy climate of Hokkaido (Fig. 1) means that its conditions, including a low-temperature environment and short construction periods in winter, are disadvantageous for seismic reinforcement work (Photo 1). To conduct seismic strengthening for a large number of bridges effectively and economically, it is necessary to examine and adopt new antiseismic construction methods to be used in addition to existing ones.

Fig. 1 Hokkaido

Photo 1 Seismic reinforcement work in winter

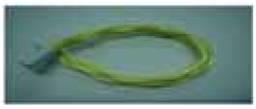

Photo 2 Aramid rope

1. Reinforcement by winding with aramid rope

RC, steel plates and continuous fiber sheets are methods of lining existing structures using concrete, mortar and resin, respectively. In Hokkaido and other cold and snowy regions, meanwhile, bridges reinforced using these methods need to be protected from the cold and cured before and after reinforcement work. Due to the limited construction periods in winter there, it is also difficult to implement year-round construction work. Since relying solely on existing methods involves risks including high costs and reduced construction efficiency, it is necessary to use more effective methods for seismic reinforcement in these regions.

Given these circumstances, the authors paid attention to reinforcement using aramid rope, which has

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become the subject of studies in recent years. This method, which maximizes the locking properties of the rope, involves the improvement of quake resistance by winding continuous aramid fiber material (Photo 2) around existing parts to prevent concrete from falling. Aramid rope is effective in reinforcing structures whether or not it is impregnated with resin, and can also be tied manually. The method therefore eliminates the need for cold protection and curing, and provides a high level of construction efficiency. The present study aims to examine the feasibility of seismic reinforcement using this rope.

2. Reinforcement mechanism using aramid rope

When positive/negative forces are applied repeatedly to common reinforcing concrete structures, bending cracks tend to occur in areas of concrete where reinforcements end in the elastic region. These cracks change to shear cracks in the course of repeated loading, causing concrete to detach and fall. In the final stage, the exposed reinforcing bars become compressed and fail.

When a structure is wound with aramid rope, meanwhile, bending cracks also occur on the concrete in the elastic region, but subsequent concrete detachment/falling and shear cracks are restrained, resulting in an increased displacement magnitude in the final stage. This method is therefore effective in enhancing ductility and toughness (Photo 3).

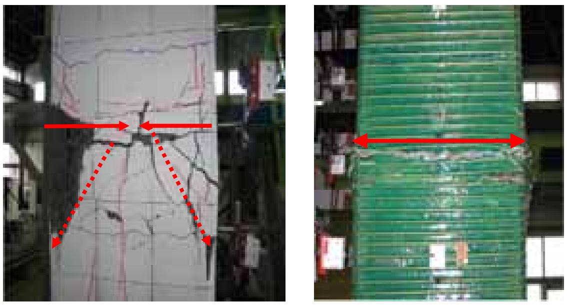

Photo 3 Crack condition

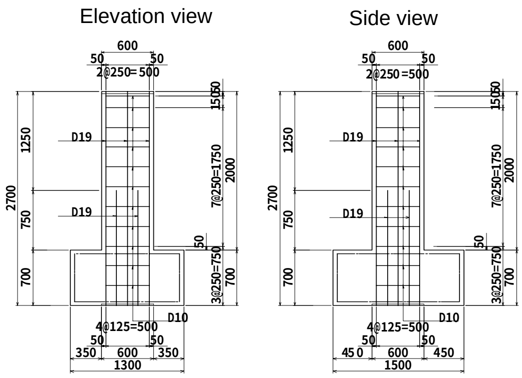

Fig.2 Size and bar arrangement of the test specimen

3. Summary of experiment

3.1 Test specimen

Many existing bridges in Japan have RC bridge piers with termination of axial reinforcements for reasons of economy. Experiments were therefore conducted to examine the effectiveness of winding aramid rope around existing RC bridge piers that have termination of axial reinforcements. The test specimen was a quarter of the size of an actual structure, and had a column with a height of 0.6 meters and a cross section of 2.0 x 2.0 meters. The termination point of axial reinforcement was established at a height of 0.75 meters from the foundation. Fig. 2 shows the size and bar arrangement of the test specimen.

The compressive strength of the concrete was fc = 24 MPa. SD345 was used for the reinforcing bars, D19 for the axial reinforcements and D10 for the tie hoops. The main tensile reinforcement ratio was P1 = 0.70% at the column foundation, and the volume ratio of the lateral restraining reinforcement was Ps = 0.22%. The structure was designed to show the pattern of failure as it changed from flexural to shear failure at the termination point of axial reinforcement to check its effectiveness for shear reinforcement.

3.2 Experiment case

As shown in Table 1, six cases were assumed in this experiment to check the effectiveness of reinforcement using aramid rope. Case 1 was a basic specimen without reinforcement, while those of Cases 2 to 6 were reinforced with aramid rope. Table 2 shows the specifications of the rope, and Fig. 3 gives an overview of the reinforcement of each specimen. In Cases 2 to 6, the column was reinforced up to 1.6 meters from the foundation by winding the rope at intervals of 25 mm (Cases 2, 3 and 6), 12.5 mm (Case 4) and 50 mm (Case 5). To check the impact of impregnation with resin, the entire rope was impregnated in Case 2, while no impregnation was performed for the specimens of Cases 3 to 6. In Case 6, L-shaped steel plates were installed in the vertical direction on the four corners of the specimen to prevent the aramid rope from cutting into the cracks.

Table 1 Experimental cases

Experimental case	Reinforcement method	Winding		Supplementary
		Intervals (mm)	Cross section (mm2)	
1	Without reinforcement	–	–	–
2	Winding with aramid rope	25	11.5	Inpregnated with resin
3		25	11.5	–
4		12.5	11.5	–
5		50	11.5	–
6		25	11.5	Equal leg angle at the corner

Table 2 Aramid rope specifications

Sectional area (mm^2)	11.53
Tensile force (kN)	28.45
Tensile strength (N/mm^2)	1,810
Elastic coefficient (N/mm^2)	66,715

(Case 1) (Case 2) (Case 3) (Case 6)

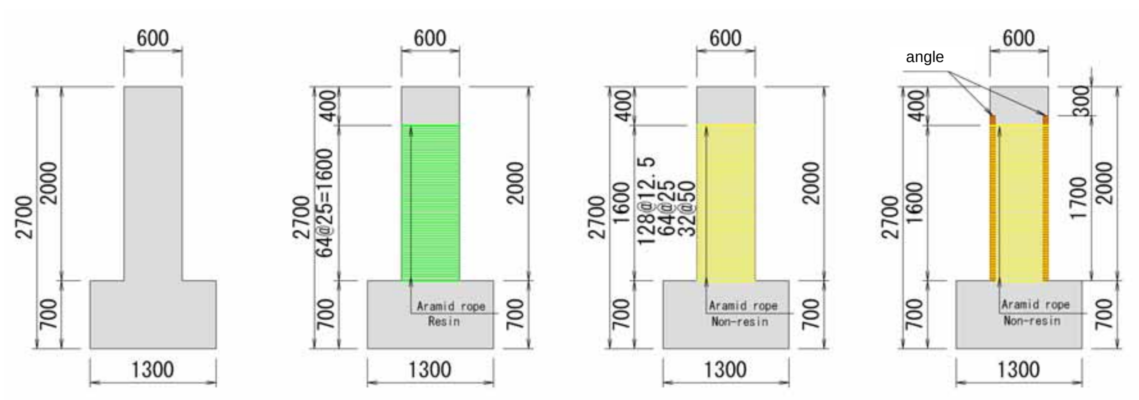

Fig. 3 Overview of specimen reinforcement

3.3 Experimental method

Fig. 4 shows the test specimen. Positive/negative forc were applied repeatedly in the horizontal direction using a horizontal jack. To represent the superstructure's dead loa an axial force of 120 kN (333 kN/m2) was constantly applied using a vertical jack during the loading. The loadi displacement and load when the axial reinforcement reach the yielding point were assumed to be δ_y (yield displacement) and P_y (yield load), respectively, and the forces were applied repeatedly by gradually increasing th displacement amplitude ($2\delta_y$, $3\delta_y$, etc.). Loading was conducted three times per displacement amplitude, and w assumed to be complete when the horizontally loaded weight fell below the yield load.

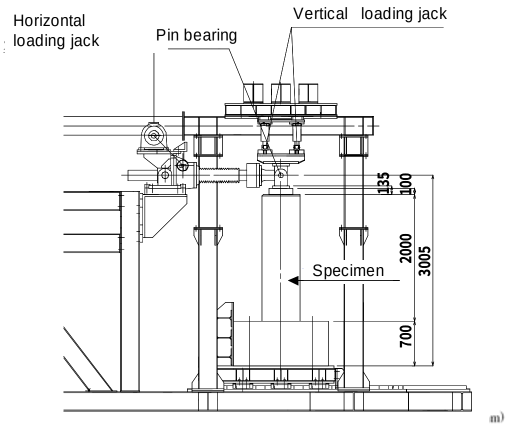

Fig. 4 Experimental setup

4. Experimental results

4.1 Cracks and failure

Photo 4 shows the cracks in the test specimens of Cases 1 and 3, and Photo 5 shows the deformation of the rope. Figs. 5 to 7 present load-deformation hysteresis curves.

In the specimen without reinforcement (Case 1), several horizontal cracks occurred at the termination of reinforcement point with a load of 1δ_y, and damage primarily occurred there at 2δ_y and thereafter. Oblique cracks became significant from 3δ_y, and the cover concrete detached at 4δ_y , after which resistance decreased rapidly and fell below the yield resistance at a load of 6δ_y. All the specimens reinforced with aramid rope (Cases 2 to 5) showed a similar level of damage, with several horizontal cracks occurring at the termination of reinforcement at a load of 1δ_y. At 2δ_y and thereafter, damage began to be observed primarily at the termination of reinforcement. The cover concrete swelled and detached from around 3δ_y to 5δ_y, after which resistance decreased rapidly and fell below the yield resistance at a load of 8_y. Almost no damage was observed in the column foundation.

(Case 1) (Case 2) (Case 3) (Case 6)

Photo 4 Crack conditions

(Case 3) (Case 6)

Photo 5 Rope deformation

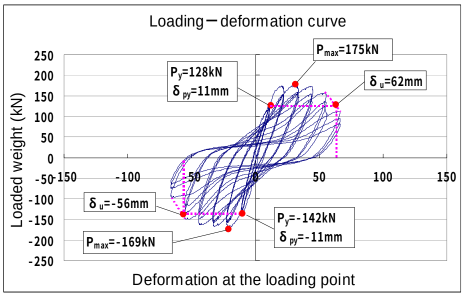

Fig. 5 Load-displacement curve (Case 1)

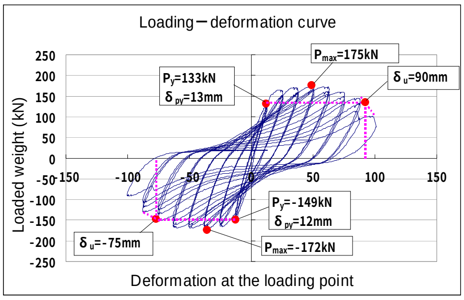

Fig. 6 Load-displacement curve (Case 3)

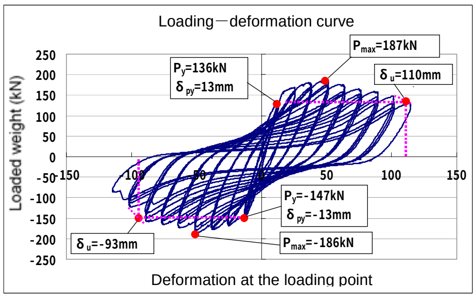

Fig. 7 Load-displacement curve (Case 6)

Compared to Case 1, concrete falling was prevented in Cases 2 to 5 in which the cracked concrete was bound with aramid rope. The conditions of the test specimen for Case 2, in which the rope was impregnated with resin, were similar to those of Cases 3 to 5 that had no resin impregnation. The winding interval of the aramid rope was varied in Cases 3, 4 and 5 (25/12.5/50 mm, respectively), but no concrete falling was observed in any of these cases, indicating that the rope interval does not affect the structure's tenancy.

4.2 Maximum resistance

Table 3 shows the maximum resistance of each specimen. The results of Cases 2 to 5 indicate that reinforcement with aramid rope does not work to raise the level of maximum resistance. Meanwhile, the maximum resistance slightly increased in Case 6, probably due to the properties of the steel members installed on the corners of the structure (Photo 5).

Table 3 Maximum resistance

Experimental case		1	2	3	4	5	6
Maximum resistance P_{max}(kN)	Positive	175	179	175	184	186	187
	Negative	-169	-179	-172	-185	-185	-186
Ratio to Case1	Positive	—	1.02	1.00	1.05	1.06	1.07
	Negative	—	1.06	1.02	1.09	1.09	1.10

4.3 Ductility

Table 4 summarizes the tenancy ratio expressed along with that of the final displacement to the yield displacement to allow comparison of each specimen's ductility.

Compared to Case 1, the tenancy was 1.2 times higher in Cases 2 and 3, 1.5 times in Cases 4 and 5, and 1.6 times in Case 6, indicating that reinforcement with aramid rope contributed to higher ductility. The specimens of Cases 2 and 3 shared the same tenancy ratio, indicating that the level of toughness may not be affected by resin impregnation. The winding interval of the aramid rope was changed in Cases 3 to 5, but no correlation was found between the interval and the toughness. The tenancy ratio was 1.2 in Case 3 and 1.5 in both Cases 4 and 5, even though the winding interval was narrower in Case 4 and wider in Case 5 than in Case 3.

These results indicate that, under the conditions of this experiment, the impact of the winding interval of the aramid rope on tenancy was small. This was probably due to the size of the concrete pieces, the smallest of which were approximately 50 mm, meaning that they did not fall in this experiment with winding intervals of 12.5, 25 and 50 mm. This suggests that an important parameter in aramid rope reinforcement is the winding interval rather than the cross-sectional area of the reinforcing material, and that the interval needs to be set at a level that prevents concrete pieces from falling.

The tenancy ratio was higher in Case 6, in which steel members were installed on the corners, than in other cases where the structure was reinforced with aramid rope alone, indicating the effectiveness of reinforcement with steel members (Photo 5).

Table 4 Tenancy ratio

Experimental case		1	2	3	4	5	6
Yield displacement δ_{py}(mm)	Positive	11	13	13	10	10	13
	Negative	-11	-12	-12	-11	-10	-13
Final displacement δ_u(mm)	Positive	62	90	90	83	82	110
	Negative	-56	-82	-75	-85	-78	-93
Tenancy ratio δ_u/δ_{py}	Positive	5.6	6.9	6.9	8.3	8.2	8.5
	Negative	5.1	6.8	6.3	7.7	7.8	7.2
Ratio to Case1	Positive	—	1.23	1.23	1.48	1.46	1.67
	Negative	—	1.33	1.24	1.51	1.53	1.41

4.4 Energy absorption

Fig. 8 shows the accumulated values of the hysteretic energy absorption in each case, and indicates that the absorption increased in Cases 2 to 6 compared to Case 1, probably due to the improved ductility from aramid rope reinforcement. The energy absorption in Case 6 was slightly higher than in Cases 2 to 5, probably because the steel members installed on the corners worked to absorb energy.

5. Evaluation of reinforcement effects

The level of improvement in ductility from aramid rope reinforcement was calculated by replacing the improvement value with the increase in the design shear strength. The following formula[4)] was used to calculate the design shear strength of the test specimen without reinforcement (Case 1):

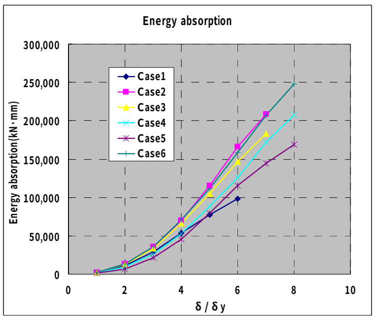

Fig.8 Energy absorption

$$V_{yd1} = V_{cd} + V_{sd} \quad (1)$$

where

V_{yd1}: Design shear strength (kN) of the test specimen without reinforcement

V_{cd} : Design shear strength (kN) of the member of a structure without shear reinforcement steel

V_{sd} : Design shear strength (kN) of the shear reinforcement steel

The hypothetical shear strength, assumed to be equivalent to the tenancy ratio obtained in the experiment, was calculated using the following formulas for ductility[5)]:

$$\mu = 2.2 + 3.2 \times (V_{yd2} \times L_a / M_{ud}) \quad (2)$$

$$V_{yd2} = V_{cd} + V_{sd} + V_{ad} \quad (3)$$

where

μ : Tenancy ratio ($= \delta_u / \delta_y$)

L_a: Shear span (m)

M_{ud}: Design flexural strength (kN/m)

V_{yd2}: Sum of hypothetical shear strength, assumed to be equivalent to the tenancy ratio (kN)

V_{ad}: Of the hypothetical shear strength (assumed to be equivalent to the tenancy ratio), the amount of hypothetical shear strength assumed to have been gained from aramid rope reinforcement (kN)

The tenancy ratio of the reinforcement effect from the aramid fiber sheet was calculated using formula (2). These formulas were therefore utilized to calculate the shear strength obtained from the adoption of aramid fiber sheet, using the deformation performance observed in this experiment that used aramid rope for reinforcement.

Table 5 shows the hypothetical shear strength assumed to have been gained from aramid rope reinforcement (Case 3), calculated using formulas (1) to (3). The level of improvement in tenancy through reinforcement with aramid rope (calculated by replacing the improvement value with the increase in shear strength) was equal to 40% of the shear strength of the tie hoops installed in the test specimen.

Table 3 Calculation of increase in hypothetical shear strength (Case 3)

μ	V_{yd1} (kN)	V_{cd} (kN)	V_{sd} (kN)	L_a (mm)	M_{ud} (kN・m)	V_{yd2} (kN)	V_{ad} (kN)	V_{ad}/V_{sd}
6.9	215	115	100	1.56	272	258	43.2	0.432

6. Summary

To confirm the antiseismic effects gained by winding aramid rope around existing RC bridge piers with termination of reinforcement, cyclic loading tests were conducted in the horizontal direction using rectangular column-shaped RC test specimens. The results are summarized as follows:

(1) The ductility of the RC column was improved by winding aramid rope around it, while the maximum flexural strength remained unchanged. When cases with and without resin impregnation were compared, no difference in the level of ductility improvement was seen.

(2) No impact was observed from differences in the winding interval. Ductility improved when steel members were installed on the corners of one of the test specimens.

(3) When the level of tenancy improvement from aramid rope reinforcement was calculated by replacing the improved value with the shear strength, the value was equivalent to approximately 40% of the shear strength of the tie hoops installed in the test specimen.

The results of this experiment indicated that toughness (ductility) was reinforced by winding aramid rope around structures. This reinforcement method was proved to be effective even in manual winding regardless of whether or not the rope was impregnated with resin. These results confirmed that the method is effective in increasing construction efficiency and eliminates the need for cold protection and curing. It would therefore be feasible to use the method in cold and snowy regions.

In the future, it will be necessary to examine the mechanism of aramid rope reinforcement for damage in the foundations for structures without termination of axial reinforcement.

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