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Follow-up Study of FRP Bonding Method through Exposure Test

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ABSTRACT

NEXCO has applied to FRP bonding method to prevention of falling concrete peaces near the PC anchorage. FRP is made of aramid and nylon hybrid fiber sheet, which have high strength and high elongation performance. This paper evaluates durability of FRP by exposure test. Exposure test's locations were selected considering various environmental conditions in Japan, which were Tokyo, Niigata, and Okinawa. The results of investigations of FRP after 12 year exposure show that FRP have maintained good performances either on bond strength between FRP and concrete, FRP tensile strength, and/or FRP tensile elongation.

Keywords. FRP Bonding Method, Aramid and Nylon Hybrid Fiber Sheet, Grout for PC tendon

INTRODUCTION

At PC bridges under control of Nippon Expressway Company Ltd. (NEXCO), a continuous fiber-reinforced plastic (FRP) bonding method is applied as the preventive measure against the fall of cover concrete pieces, which often occurs near the anchorages of transverse prestressing PC tendons. As FRP sheet, aramid-nylon hybrid fiber sheet, which has high strength and excellent deformation characteristics, is adopted. FRP is bonded on the surface of concrete using a synthetic resin adhesive.

In this study, for confirming the durability of the FRP bonding method, exposure test was performed as follow-up study. In order to represent Japan's typical deteriorating environmental conditions, Tokyo Metropolitan, Niigata Prefecture, and Okinawa Prefecture were chosen as exposure sites. The 12 years of exposure survey results revealed that although slight deterioration in performance was found, there were no problems in adhesion with concrete, as well as the tensile strength and ultimate strain of FRP. Thus, we have confirmed that FRP has the excellent durability even after 12 year exposure in various environmental conditions in Japan.

PROCEDURES OF EXPOSURE TEST

As the sites for outdoor exposure test, three spots shown in Table 1. were chosen as the representatives of environmental conditions in Japan. An example of the setup appearance of test samples is shown in Photo 1. At the spots in Tokyo and Okinawa, there was nothing to prevent sunshine. At the spot in Niigata, setup was under an elevated bridge as shown in Photo 2, so the effect of sunshine was smaller than those of other 2 areas. As shown in Fig. 1, the test sample for bonding strength was made by attaching two layers of aramid-nylon hybrid fiber sheets on a concrete plate of compressive strength of 50 N/mm^2. The second layer was applied 25mm narrower than the first layer so the stepwise application was conducted. The edges of the sheets were sealed by epoxy putty and the whole surface was coated by a few types of finishing materials.

Table 1. Outdoor Exposure Sites

Site name	Spot	Environmental condition	Annual precipitation (mm)	Annual temperature (° C)	Maximum/ minimum values of monthly mean temperature (° C)	Annual sunshine hours (hr)
Tokyo	Tokyo NEXCO-RI, Roof yard	Inland and temperate region	1730	15.3	31.2/-0.7	1849
Niigata	Niigata Hokuriku Expressway, Oyashirazu IC, under elevated bridge	Seaside and snowy cold region	2835	14.3	30.3/0.6	1590
Okinawa	Okinawa Okinawa Expressway, Kyoda IC yard	Sea-salt particle incoming semitropical region	2819	22.6	31.8/13.5	1764

*Precipitation, temperature, and sunshine hours are the meteorological data near exposure sites obtained by Japan Meteorological Agency

Photo 1. Example of outdoor exposure spot (Tokyo)

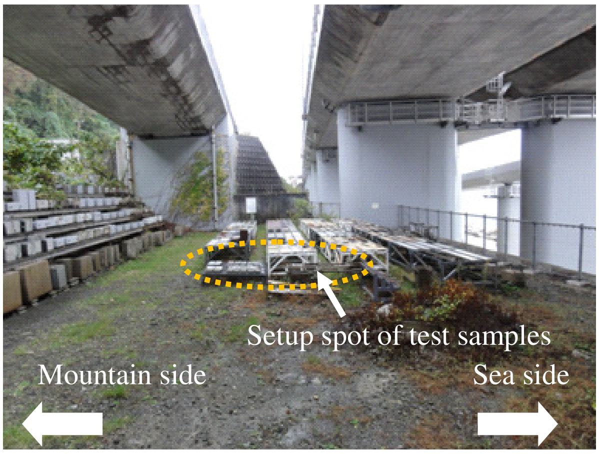
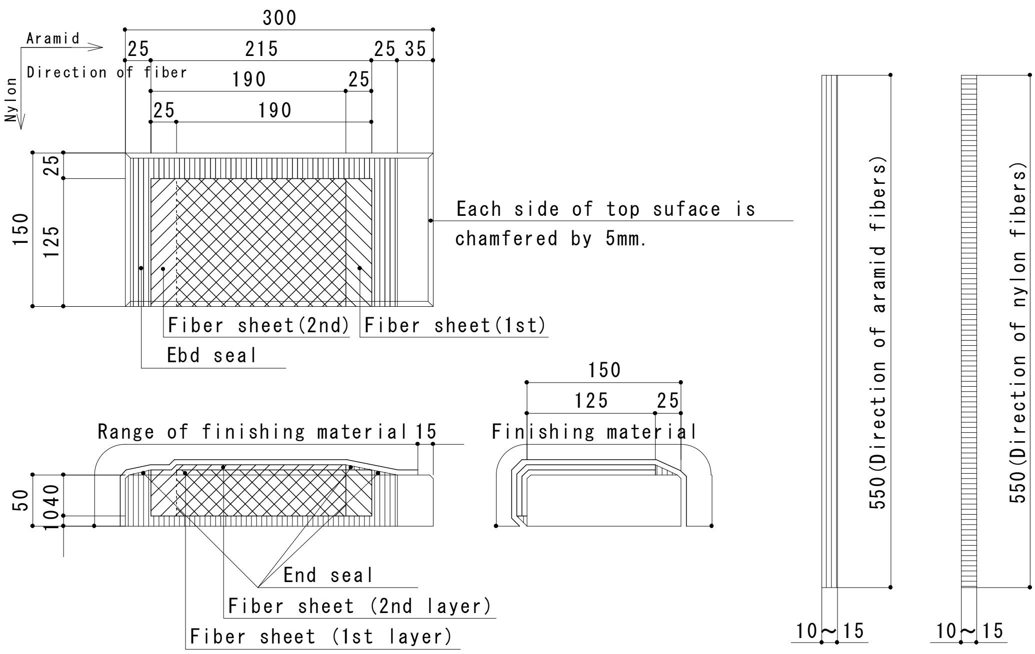


Photo 2 Setup state of test samples in Niigata



Concrete test sample **FRP test sample**

Fig. 1. Specification for test samples

The test specimen for tensile strength and ultimate strain tests was 10-15 mm in width and 550 mm in length. Since this FRP is hybrid fiber sheet, where warp fiber is aramid and woof fiber is nylon, two types of sheets were prepared in order to investigate the properties of both (warp and woof) directions. Application resin was coated on the both faces of the fiber sheet for impregnation and after curing, finishing material was applied on both faces to complete test specimen.

The specifications of fiber sheets are listed in Table 2. The types of finishing materials and the number of prepared test samples (test plates and test specimens) are shown in Table 3. Since this is the follow-up study on durability, test items shown in Table 4 were conducted at the points of 0, 1, 2, 3, 5, 8, and 12 years after the start of exposure test (November 1999).

Table 2. Specifications of the fiber sheet

Item	Unit, etc.	Specifications
Orientation of reinforcing fiber		Two directional
Type of fiber	Horizontal / Vertical	Aramid / Nylon
Mass of fiber	g/m^2	240 / 380 or more
Tensile strength	N/mm	350 / 160
Ultimate strain	%	2.2 / 27
Bonding strength (FRP)	N/mm^2	1.5
Bonding strength (finishing material)	N/mm^2	1.0

Table 3. Types of test samples

Symbol	S	P	F	N
Type of finishing material	Silicone resin	Polyurethane resin	Fluorine resin	Non-coating
Concrete test plate	8 time spans * 3 sites * 4 finishing materials * 1 piece/test = 96 pieces			
FRP test specimen	7 time spans * 3 sites * 4 finishing materials * 2 directions * 4 pieces/test = 672 pieces			

Table 4 Test item

Test item	Test method	Test sample
Bonding Strength	BRI (Building Research Institute) bonding test	Concrete test plate
Tensile strength, strain	JIS A 1191	FRP test specimen

EXPERIMENTAL RESULTS

Bonding Strength. The results of bonding strength test are shown in Table 5 and Table 6. Tests were conducted under two conditions: (1) as exposed (without removing the finishing materials), and (2) after removing the finishing materials. Failure modes were expressed by area ratio of concrete failure and others (interface failure, finishing material failure, and others). As for the results of bonding strength on case (2), although some test values in Tokyo did not pass the specified value, these data were the results of concrete failure, and the average values of three testing points passed the specified value. On the other hand, all of the bonding strength of samples tested after removing the finishing material passed the specified value, which proved the soundness of bonding strength.

The charts of the yearly changes of bonding strength are shown in Fig. 2 and Fig. 3. Although some data without the finishing material did not pass the specified value after three years, all of the succeeding test results passed the specified value, showing no problem. As for the results of case (2), some data in the initial stage did not pass the specified value where the failure occurred in finishing material, the cause of which was considered to be the insufficient curing of polymer cement mortar as an intermediate coating material. As the time passed for the curing, the data came to pass the specified value, which showed that no problem is considered.

Table 5. Bonding strength (without finishing material)

Test Plate		Niigata		Okinawa		Tokyo	
T	No.	Bonding strength N/mm^2	Failure mode Concrete/ Others	Bonding strength N/mm^2	Failure mode Concrete/ Others	Bonding strength N/mm^2	Failure mode Concrete/ Others
F	1	2.34	80/20	2.54	60/40	2.12	97/3
	2	2.24	98/2	2.77	97/3	2.21	98/2
	3	1.63	97/2	1.52	97/3	2.47	98/2
	Ave.	2.07		2.28		2.27	
P	1	1.65	95/5	2.54	85/15	1.83	95/5
	2	2.30	100/0	2.83	90/10	2.23	100/0
	3	2.30	70/30	2.53	97/3	2.63	98/2
	Ave.	2.08		2.63		2.23	
S	1	2.39	80/20	2.30	100/0	2.38	75/25
	2	3.18	70/30	3.33	97/3	2.54	95/5
	3	3.46	5/95	3.18	100/0	2.21	100/0
	Ave.	3.01		2.93		2.38	
N	1	2.44	85/15	2.54	95/5	1.61	95/5
	2	1.97	70/30	2.77	100/0	2.18	90/10
	3	2.44	60/40	1.52	70/30	2.32	0/100
	Ave.	2.28		2.28		2.04	

*Failure mode: Concrete/Others means the ratio of failure modes between concrete and other parts (primer interface, etc.).

Table 6. Bonding strength (on finishing material)

Test Plate		Niigata		Okinawa		Tokyo	
T	No.	Bonding strength N/mm^2	Failure mode Finishing/ Others	Bonding strength N/mm^2	Failure mode Finishing/ Others	Bonding strength N/mm^2	Failure mode Finishing/ Others
F	1	2.63	0/100	3.67	0/100	2.33	0/100
	2	2.58	0/100	3.52	0/100	1.16	0/100
	3	3.21	0/100	1.99	0/100	2.42	0/100
	Ave.	2.80		3.06		1.97	
P	1	3.24	0/100	2.98	0/100	1.86	0/100
	2	3.76	0/100	2.38	0/100	1.83	0/100
	3	2.30	0/100	2.36	0/100	1.64	0/100
	Ave.	3.10		2.57		1.78	
S	1	2.60	0/100	1.55	0/100	1.64	0/100
	2	2.04	0/100	3.13	0/100	2.59	0/100
	3	2.84	0/100	3.07	0/100	3.06	0/100
	Ave.	2.49		2.58		2.43	

*Failure mode: Finishing/Others means the ratio of failure modes between finishing material and other parts (primer interface, etc.).

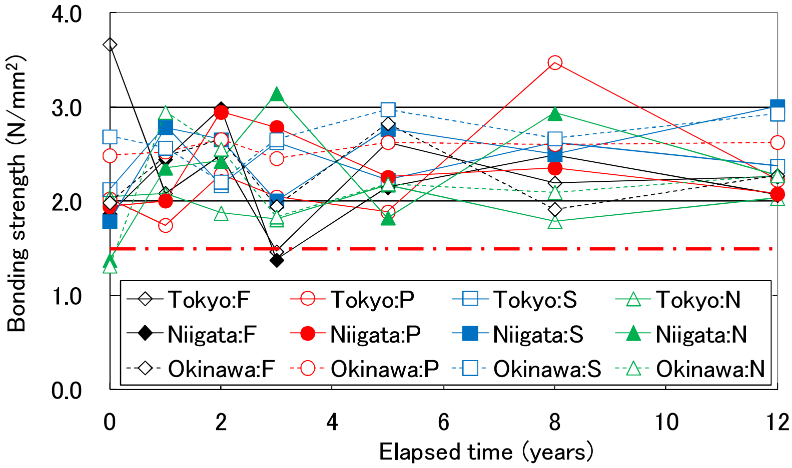


Fig. 2. Temporal change of bonding strength (without finishing material)

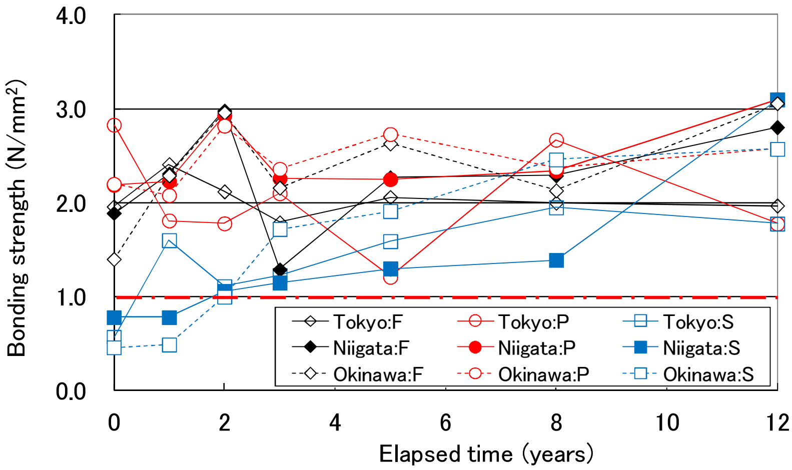
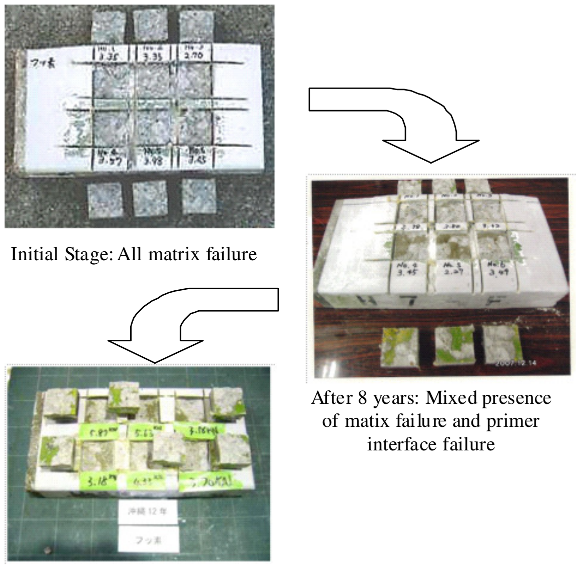


Fig. 3. Temporal change of bonding strength (on finishing material)

As for failure mode, although the results after 12 years were still largely concrete failure mode, those in the initial stage were nearly completely concrete failure mode. In other words, as exposure years elapsed, failure mode tended to shift from the failure at concrete to the failures at interface between concrete and primer or at interface between primer and adhesive resin. As an example of the shift of failure mode, the example of fluorine coating in Okinawa is shown in Fig. 4. This trend was found in any of exposure test sites and any types of finishing materials to a greater or lesser extent, and the trend was the strongest in Niigata where samples were placed under an elevated bridge with the least sunshine time. From this fact, it was inferred that the shift of this failure mode was not considered due to the effect of ultraviolet rays, and that the penetration of moisture and the repetition of warm-cold period may have caused the progress of deterioration. However, during 8 years and 12 years, there were no remarkable changes in failure modes. It is predicted that rapid deterioration would not occur in the future. In addition, the bonding strength after 12 years sufficiently satisfied the specified value. Therefore, the bonding strength is considered to have sustained the initial performance of FRP.

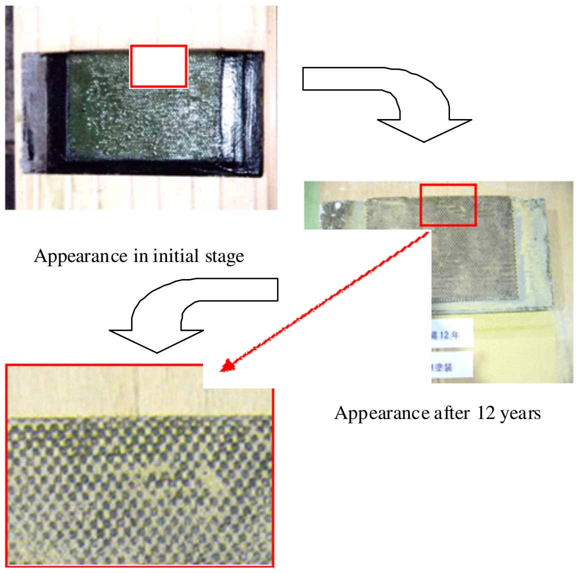


Initial Stage: All matrix failure

After 8 years: Mixed presence of matix failure and primer interface failure

After 12 years: Partly primer interface in all samples

Fig. 4. Example of shift of failure mode



Appearance in initial stage

Appearance after 12 years

Exposure of fibers after deterioration of epoxy resin

Fig. 5. Example of external change of non-coating test sample (Okinawa)

Tensile Strength and Elongation. The external appearance of test samples with finishing material has not much changed from setup time except pollution in every setup sites. On the other hand, in the test samples without coating, discoloration was seen in all test samples, and the exposure of the fibers was seen in some of the test samples in Tokyo and Okinawa. In the test samples without coating, impregnated resin adhesive was partly depleted due to sunshine beam and weathering. On the surface of impregnated resin adhesive of the test samples in Niigata, whitish powdery material covered the surface. The external state change of the test samples in Okinawa after 12 years of exposure was shown in Fig. 5, in comparison with the external appearance of initial setup time.

The test results of tensile strength and ultimate strain are shown in Figs. 6-9. As for aramid fiber (warp direction), the test samples with the finishing material satisfied the specified values of both tensile strength and ultimate strain. In contrast, as for the test samples without finishing material, many samples did not satisfied the specified values of both tensile strength and ultimate strain. On the other hand, as for nylon fibers, even with finishing material, most test samples resulted in smaller than the specified value in tensile strength. However, the ultimate strain of the test samples with the finishing material satisfied the specified value. Considering the main load bearing performance relied on aramid fiber, it is considered the FRP has maintained the sufficient performance.

As for the test samples without coating, both of the tensile strength and ultimate strain of aramid fibers and nylon fibers showed remarkable decreasing trend. These deterioration degrees are same in Tokyo and Okinawa, and less in Niigata than other areas. Since direct sunlight hours were little in Niigata, where the setup spot was under an elevated bridge, ultraviolet rays are considered to have largely contributed to the progress of deterioration of each fiber.

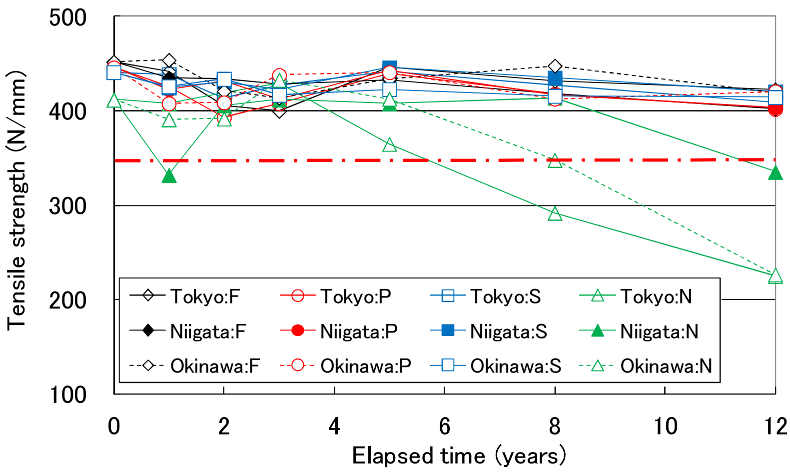


Fig. 6. Temporal change of tensile strength of aramid fiber

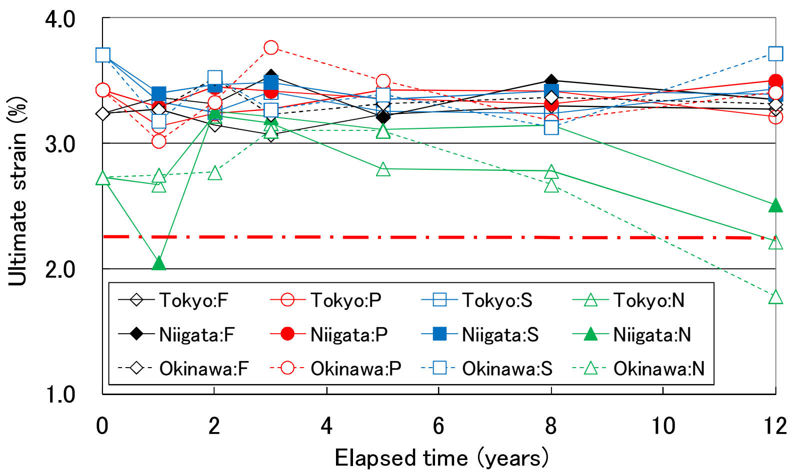


Fig. 7. Temporal change of ultimate strain of aramid fiber

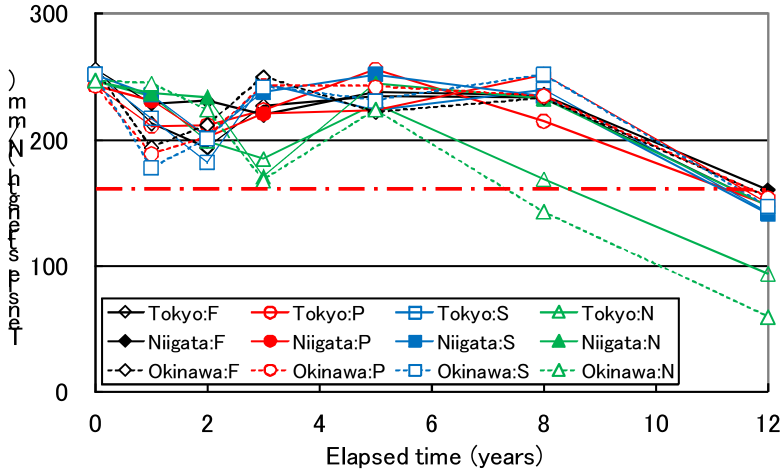


Fig. 8. Temporal change of tensile strength of nylon fiber

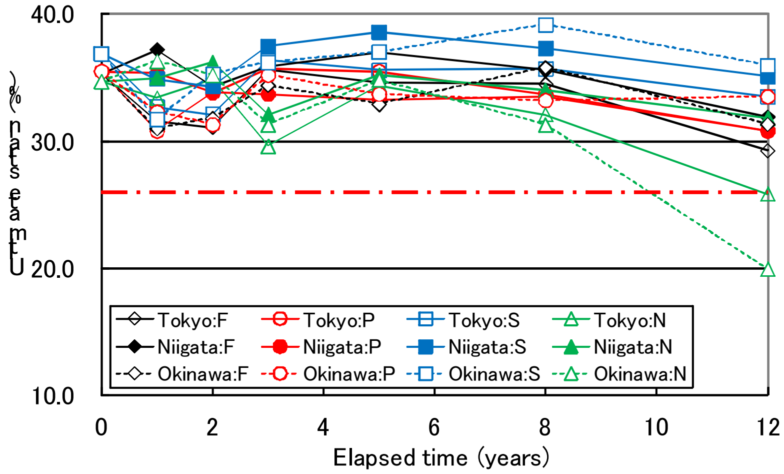


Fig. 9. Temporal change of ultimate strain of nylon fiber

CONCLUSION

From the follow-up study during 12 years of the exposure test of aramid-nylon hybrid fiber FRP sheet, the following conclusions are obtained.

(1) Application of a finishing material to FRP enables to maintain fairly well the bonding strength between concrete matrix and FRP, as well as the tensile strength of aramid fiber and the ultimate strain of both fibers of FRP. Therefore, deterioration in the performance of FRP wouldn't be occurred.

(2) FRP without finishing material deteriorates in performance from the effect of ultraviolet rays, resulting in drop in the tensile strength and ultimate strain of FRP.

Photo 3. Deformation state of crossbeam transverse prestressing anchorage constructed by FRP bonding method

Since the soundness of FRP bonding method has been confirmed at the present moment, confirmation through visual check on the existence of the abnormality of external appearance will be continued, in order to control this FRP bonding method properly. When the abnormality as seen in Photo 3 that does not affect the durability of FRP has been found, it is necessary to take a proper action on a case-by-case basis. In addition, it is necessary to establish the checking technology of the packing degree of PC grout. In case of the insufficient packing of PC grout is found, re-grouting is necessary to secure durability performance. In this way, the further grade-up of maintenance control technology for PC bridges must be attempted.

In addition, it is considered important to do acceleration evaluation and to compare the results to the results of this experiment for obtaining the relation between them. By this, the durability of FRP could be estimated in a short period.