STRENGTHENING EFFECTS OF BONDING AFRP PLATE ON FLEXURAL CAPACITY OF RC BEAMS FOR SUBMERGED APPLICATION

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ABSTRACT

Bonding a Fiber Reinforced Polymer plate (FRPp) is considered for flexural reinforcing of submerged Reinforced Concrete (RC) structures. In this paper, some static four-point loading tests on reinforced RC beams strengthened with an Aramid FRP plate (AFRPp) were conducted taking with/without sand coating treatment of the bonding surface of the plate as a variable. The RC beams used here have a rectangular cross section of 150 × 150 mm and a clear span of 1.8 m. From this study the following results were obtained: 1) flexural capacity of the beams can be effectively improved by applying a sand coating treatment to the bonding surface of the plate; 2) AFRPp may be debonded due to a peeling action at the critical diagonal crack developed in the lower concrete cover near the loading points; and 3) the bonding strength between the adhesive layer and the AFRPp can be improved by applying the sand coating treatment to the surface of the plate and debonding of the AFRPp may be initiated from the interface between the bonding surface of the beam and the adhesive layer.

Keywords: RC beam, flexural strengthening, AFRP plate, submerged bonding method, peeling action

1. INTRODUCTION

Recently, the Fiber Reinforced Polymer sheet (FRPs) bonding method has been widely used as one kind of seismic reinforcing method for existing Reinforced Concrete (RC) structures. Generally, strengthening work has been conducted under dry conditions, even if the structures were constructed within the water. In the case of strengthening submerged RC structures, the surroundings of the structure were dried by pumping out the water after enclosing the structure by sheet piles. Therefore, the strengthening work for the submerged structures will result in a higher cost compared with for structures surrounded by air. Therefore, seismic strengthening works for existing submerged RC bridge piers have not progressed as much as expected.

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To improve this kind of situation, the authors have proposed the FRP plate (FRPp) bonding method. If the proposed strengthening method were established, the bridge piers constructed in the river and/or sea might be effectively strengthened without any enclosing and drying works. The strengthening works for those structures too can be economical. However, the strengthening effects of the proposed method are not very clear.

Therefore, to investigate the strengthening effects of the proposed method for submerged RC structures, static four-point loading tests were conducted on submerged reinforced RC beams with Aramid FRPp (AFRPp) . In this experiment, to improve the bonding strength between the AFRPp and the adhesive layer, sand coating treatment was applied to the bonding surface of the AFRPp.

2. EXPERIMENTAL OVERVIEW

2.1. Specimen

In total the three specimens listed in **Table 1** were used for this study, in which bonding conditions and with/without sand coating treatment of the bonding surface of the AFRPp were taken as variables. The nominal name of each beam was designated using the particular conditions of bonding (A: in the air, and W: in the water), and with/without sand coating treatment (N: without, and S: with the treatment). To improve the bonding strength between the AFRPp and the adhesive layer, sand coating treatment was applied to the bonding surface of AFRPp using silicate sand of 500 g/m^2.

Figure 1 shows a schematic diagram of the cross section for the interface between the AFRPp and the bottom surface of RC beam. In this experiment, to remove the laitance and to improve the bonding capacity of the adhesive, grid-blasting treatment was applied to the concrete surface for all specimens. In the case of the AFRPp bonding method in the air, a primer was applied to the concrete surface. On the other hand, in the case of bonding the plate underwater, AFRPp was directly bonded to the submerged adhesive without any primer treatment. The procedures for the submerged bonding method are explained later in detail.

Table 1: List of specimen

Specimen	Treatment for bonding surface of the AFRPp	Kind of adhesive	Operating and curing conditions
A-N	-	Widely used adhesive	In the air
W-N	-	Adhesive for submerged application	In the water
W-S	Sand coating		

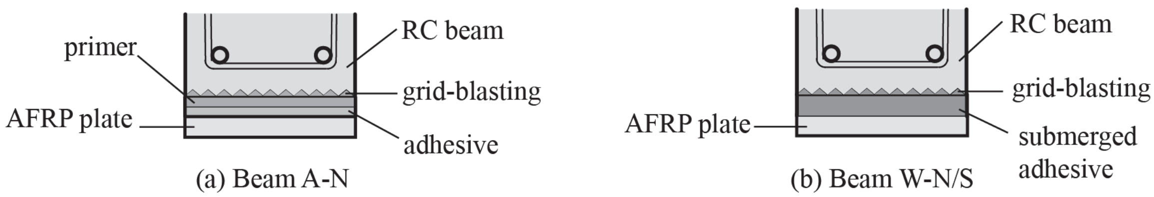


Figure 1: Schematic diagram of cross section

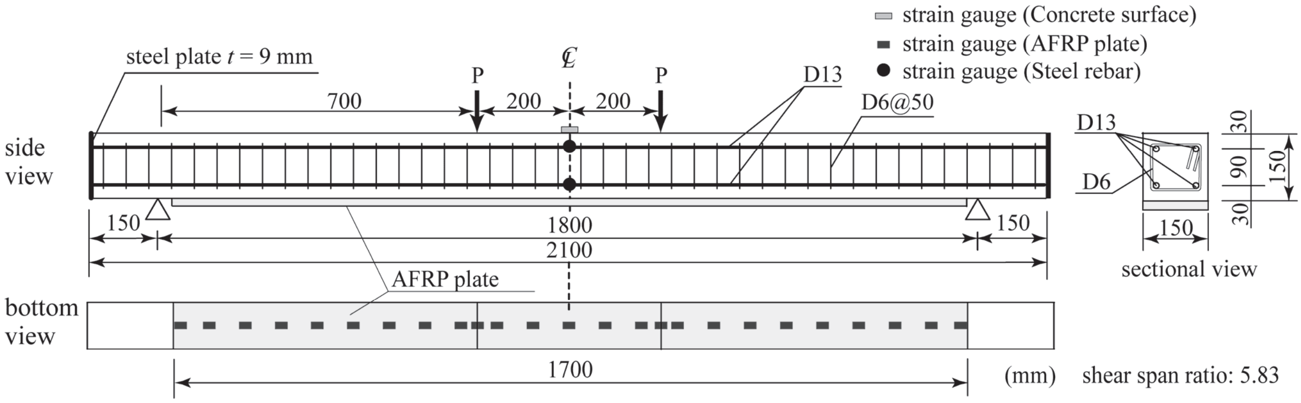


Figure 2: The layouts of the reinforcement and the AFRPp

Table 2: Mechanical properties of adhesive for a submerged application

	Nominal value (MPa)	Testing guideline
Compressive strength	53.0	JIS K - 6911
Flexural strength	32.4	JIS K - 6911
Tensile strength	15.0	JIS K - 6911

The layouts of the reinforcement and the AFRPp are shown in **Fig.2**. The beams have a rectangular cross section of 150 × 150 mm (height × width) and a clear span of 1.8 m. Steel rebars of diameter ϕ = 13 mm were placed at the upper and lower edges. Stirrups of diameter ϕ = 10 mm were placed at intervals of 50 mm. The AFRPp was bonded onto the tension-side surface leaving 50 mm between the supporting point and the end of the sheet as shown in **Fig.2**. The nominal tensile strength of the AFRPp is 392 kN/m.

2.2. Mechanical property of adhesive for submerged application

The adhesive for a submerged application used in this study is of the putty-like epoxy resin type that can be used by mixing base resin and hardening agent. **Table 2** shows mechanical properties of adhesive. The bonding capacity of this adhesive was evaluated referring to the "Test method for direct pull-off strength of continuous fiber sheets with concrete" (JSCE 2001) in this study. As a result, it was found that the failure mode was tensile failure of the concrete for all cases. The average strength in the pull-off test was 2.6 MPa. This value is greater than the 1.5 MPa of the reference value for repairing materials for existing concrete structures (JSCE 2006). Thus, it is seen that the adhesive used in this study can be applied as bonding material for strengthening work with existing submerged concrete structures.

2.3. Outline of submerged bonding method

Procedures for proposed submerged bonding method are as follows.

1) The AFRPp was fabricated by impregnating AFRPs using epoxy-resin and then cured. In the case of Beam A-S, the bonding surface of the AFRPp was coated with silicate sand.

Table 3: The material properties of the AFRPp

Mass (g/m^2)	Nominal tensile capacity (kN/m)	Thickness (mm)	Tensile strength (MPa)	Elastic modulus (GPa)	Ultimate elongation (%)
280	392	0.193	2.06	118	1.75

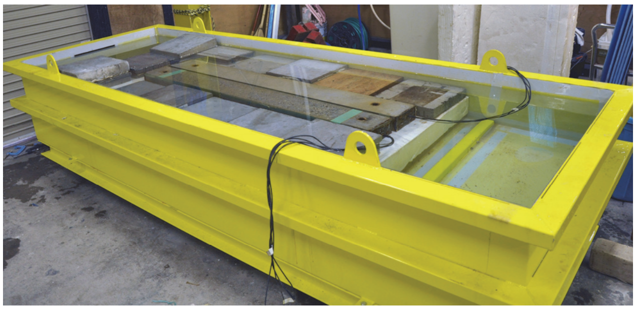


Photo 1: RC beam placed in water

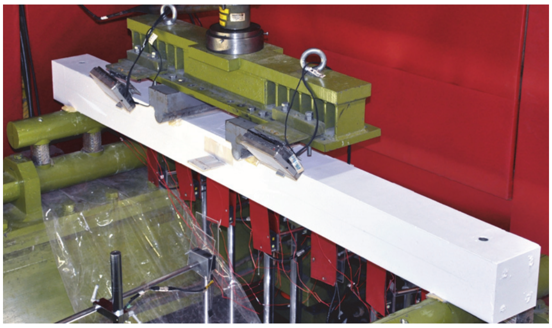


Photo 2: Experimental setup

2) The bonding surface of the RC beam was grid-blasted to improve the bonding capacity, and then the beam was placed in the water (see **Photo 1**).

3) The adhesive for submerged application was prepared by mixing a base resin and a hardening agent, and was formed like a plate with about 4 mm thickness;

4) The adhesive was applied to the AFRPp and then pressure was applied to ensure bonding to the plate;

5) The AFRPp with the adhesive was put onto the tension-side surface of the RC beam, placed in water and pressure was applied for complete bonding to the RC beam;

6) After 7 days of curing, the reinforced RC beam was taken out of the water and was placed in the testing apparatus.

2.4. Measuring items and material properties

Static four-point loading tests were conducted using a hydraulic jack of 500 kN loading capacity. **Photo 2** shows the experimental setup. The measured quantities were the surcharge load, the mid-span deflection (hereinafter, deflection), and the axial strain distribution of the AFRPp. The progress of cracking and debonding of the AFRPp was recorded using digital cameras. The material properties of the AFRPp are listed in **Table 3**. At the commencement of this experiment the average compressive strength of the concrete was 28.0 MPa. The yield strength of the main rebar was 395 MPa.

3. EXPERIMENTAL RESULTS

3.1. Load-deflection curve

Comparisons of the load-deflection relationship between experimental and numerical results are shown in **Fig.3**. In this study, a multi-section method was employed to numerically evaluate the

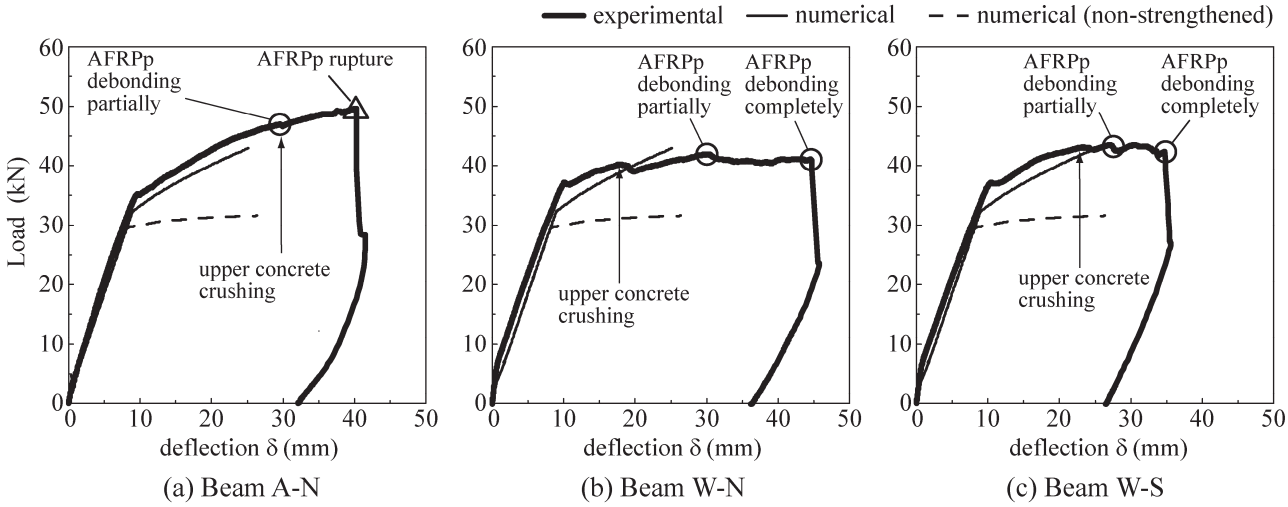


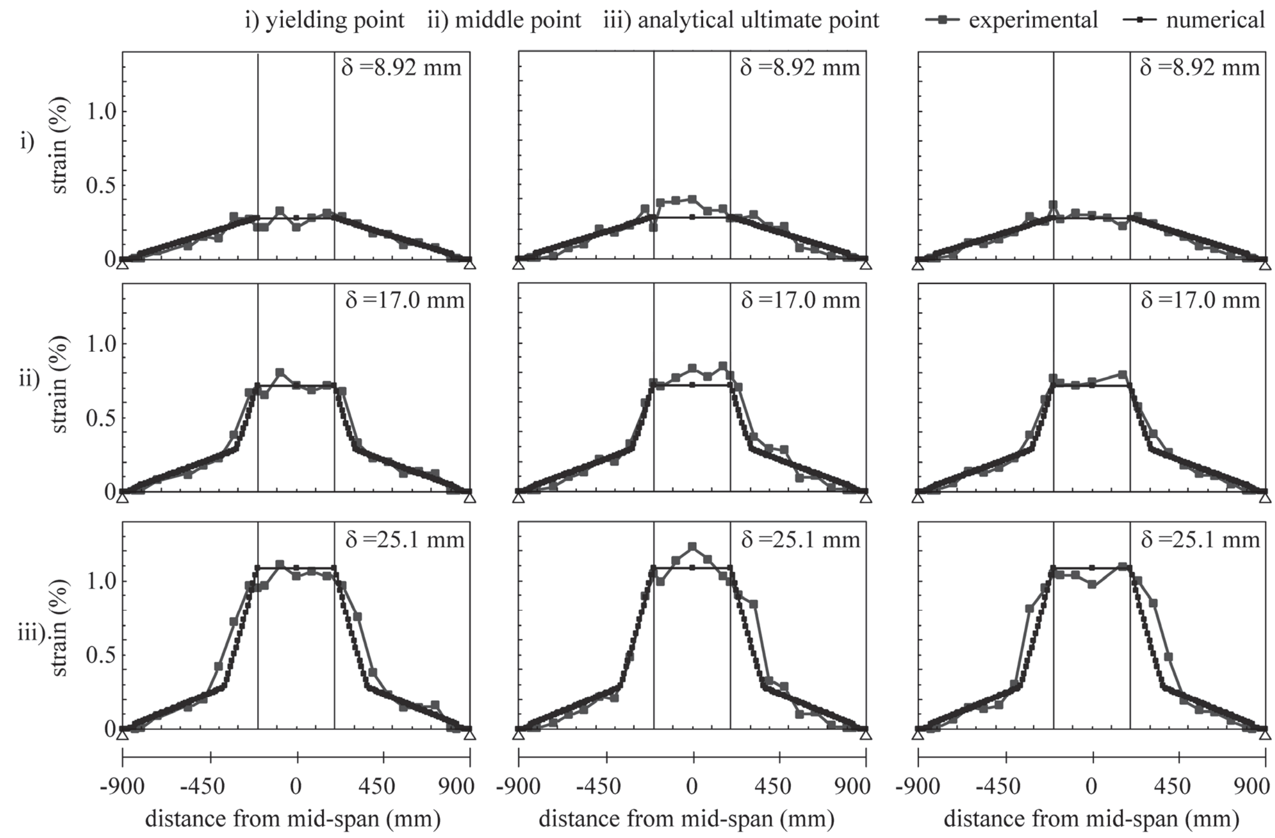
Figure 3: Comparisons of the load-deflection relationship for the experimental and numerical results

load-carrying behavior under the assumptions that: i) cross-section remained plane under the deformation of the beam; and ii) the AFRPp was perfectly bonded to concrete surface up to the ultimate state of the beam. The strain at the compressive failure of the concrete was assumed as 3,500 μ based on the Japanese Concrete Standards (JSCE 2002). The mechanical properties and the thickness of the adhesive were ignored.

From this figure, it is observed that the load-carrying capacity of all the RC beams considered here can be improved by bonding AFRPp under the water. In the case of Beam A-N, the experimental result corresponded better with the numerical one up to the theoretical ultimate state. The AFRPp debonded partially when the deflection reached 30 mm, which is larger than the theoretical ultimate deflection. Here, the debonding of the AFRPp resulted from a peeling action of the critical diagonal crack (CDC) developed in the lower concrete cover near the loading point. Finally, the AFRPp ruptured.

In the case of Beam W-N, the experimental results corresponded well with numerical ones until the beam reached theoretical yield point. After that, the gradient of the curve for the experimental results decreased due to the upper concrete cover crushing at a deflection of δ = 18 mm. Also, the load-carrying capacity for the experimental results was lower than that for the numerical one.

In the case of Beam W-S with sand coating treatment, the experimental results were in good agreement with the numerical ones up to the theoretical ultimate state. The upper concrete cover was crushed close to the theoretical ultimate deflection. After that, the AFRPp gradually debonded due to the peeling action mentioned above. Finally, the AFRPp completely debonded at a deflection of δ = 35 mm. The load-carrying capacity of Beam W-S was greater than that of Beam W-N.



(a) Beam A-N (b) Beam W-N (c) Beam W-S

Figure 4: Comparisons of the strain distributions in the AFRPp between the experimental and numerical results

From these results, it is seen that bonding capacity of the interface between the adhesive layer and the AFRPp can be improved by means of a sand coating treatment of the bonding surface of the AFRPp.

3.2. Strain distributions in the AFRPp

Comparisons of the strain distributions in the AFRPp between the experimental and numerical results at the points: i) rebar-yielding point; ii) the middle point between rebar-yielding and ultimate deflection (hereinafter, middle point); and iii) theoretical ultimate point are shown in **Fig 4**. Here, the numerical results were evaluated by means of the multi-section method mentioned above.

From these results, it is observed that in the case of Beams A-N and W-S, both experimental and numerical strain distributions were quite similar up to the theoretical ultimate state. This means that the AFRPp may be perfectly bonded to the concrete surface.

In the case of Beam W-N, the strains in the equi-bending span of the experimental results were larger than those of the numerical ones in spite of the magnitude of the loading level. This means that the AFRPp may be strongly influenced by the opening of flexural cracks. At the theoretical ultimate point, the strains in the right-hand side of the equi-shear span of the experimental results

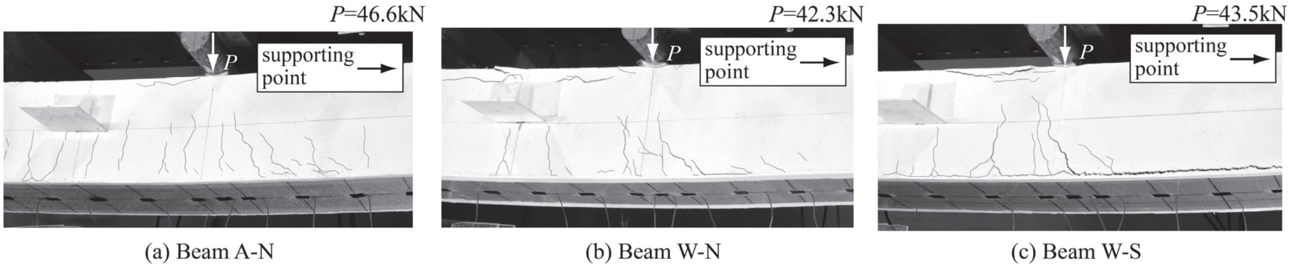


Photo 3: Crack patterns on the side-surface of the beams at the ultimate state

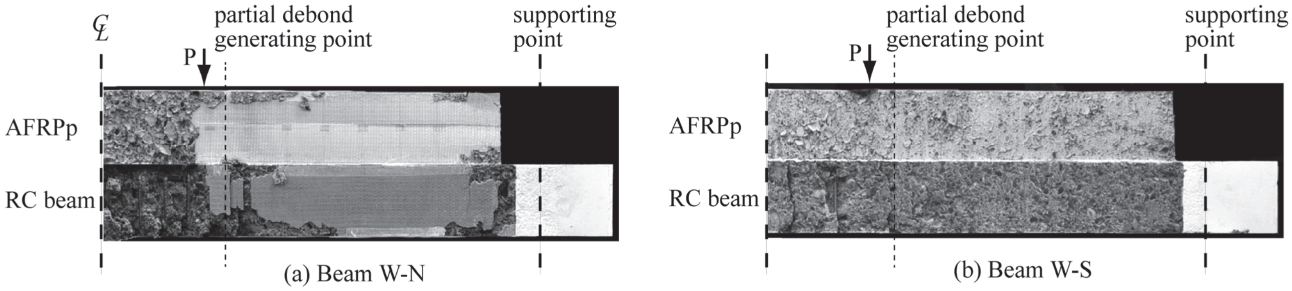


Photo 4: The bonding interface between the RC beam and the AFRPp after experiment

were larger than those of the numerical ones. This implies that the AFRPp may be debonded partially due to the peeling action. Thus, it is seen that Beam W-N tends to fail more easily with the debonding of the AFRPp than is the case for Beams A-N and W-S.

3.3. Crack patterns

Crack patterns on the side-surface of the beams at the point of reaching the deflection of δ = 30 mm are shown in **Photo 3**. From these photos, it is seen that the AFRPp's for all specimens were partially debonded due to the peeling action of the CDC.

Photo 4 shows the bonding interface between the tension-side surface of the RC beam and the AFRPp for the Beams W-N/S. From these photos, it is observed that in the case of Beam W-N, the AFRPp debonded at the interface between the AFRPp and the adhesive. On the other hand, in the case of Beam W-S, the AFRPp with adhesive was debonded at the surface of the concrete. This means that the bonding strength between the adhesive layer and the AFRPp can be improved by applying the sand coating treatment, and then the debonding of the AFRPp may be initiated from the interface between the bonding surface of the concrete and the adhesive layer.

4. CONCLUSIONS

In this study, in order to investigate the strengthening effects of the FRPp bonding method for the submerged application for existing RC structures, static four-point loading tests on reinforced RC beams were conducted. Sand coating treatment was applied to the bonding surface of the AFRPp to improve the bonding strength between the AFRPp and the adhesive layer. The results obtained from this experiment are as follows:

1) The flexural load-carrying capacity of the beams can be effectively improved by applying a sand coating to the bonding surface of the AFRPp;

2) The AFRPp may debond due to a peeling action at the critical diagonal crack developed in the lower concrete cover near the loading points; and

3) The bonding strength between the adhesive layer and the AFRPp can be improved by applying the sand coating treatment to the surface of the plate and the debonding of the AFRPp may be initiated from the interface between the bonding surface of the concrete and the adhesive layer.

5. ACKNOWLEDGMENTS

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