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Investigation on deformational behaviors in shear transfer section of reinforced concrete strengthened with CFRP sheets by x-ray technique using contrast medium

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ABSTRACT: The present study investigates deformational behaviors in the shear plane of reinforced concrete with continuous fiber reinforced plastic (CFRP) sheets using an X-ray technique. In the present study, a shear test was conducted using push-off specimens. X-ray photographs obtained in the experiment revealed a clear discrete diagonal crack (Riedel shear crack) and the cracking zone of concrete that was subjected to shear displacement. Furthermore, the relationship between the cracking zone and the corresponding shear force level depends greatly on the number of CFRP sheets used. The load-carrying mechanism of the CFRP sheets under shear deformation due to the increase in horizontal displacement in shear plane section was determined. Then, The sheet is shared a tensile force during deformation of shear plane.

1 INTRODUCTION

When diagonal cracks occur in RC members, increased shear displacement in the diagonal cracks can cause shear failure. The deformational behavior and the ultimate capacity of such RC members may be considerably affected by the development of diagonal cracks. Therefore, in evaluating the improvement of the shear capacity of RC members through the use of CFRP sheets, the relationship between the diagonal crack behavior and the load-carrying mechanism of the CFRP sheet is important.

In the present study, the effect of improving shear capacity using CFRP sheet is evaluated for a predominant crack during shear displacement. According to Mattock and Hawkins[1)], the existence of a discrete crack was assumed in a part of predominant crack. This crack behavior has an effect on the load-carrying mechanism of RC members. However, this type of discrete crack has not been visually observed in internal cracks. Therefore, internal cracks are herein visualized using an X-ray technique. First, the behavior of the shear cracks and the crack region are observed by the X-ray technique. Next, the relationship between the amount of CFRP sheet strengthening and the crack region, as well as the influence of the shear crack region for the maximum load, is investigated. Finally, the displacement of the shear crack and the CFRP sheet strain are determined. Push-off specimens were used in this experiment. In reference to the field of geotechnics, the shear crack is referred to herein as a Riedel shear crack[2)].

Table 1. Details of specimens.

Series	No.	reinforcing var	P_s (%)	P_{cf} (%)	Type of sheet	Sheet Wide (mm)
X	01-1	SD295A D10	0.815	-	-	-
	01-2			-	-	-
	C1			0.153	Carbon	40
	C2			0.305		80
P	N	SD295AD10	0.317	-	-	-
	C			0.238	Carbon	80

2 EXPERIMENTAL PROGRAM

2.1 *Specimens*

Figure 1 shows the push-off specimens used in the experiment. Two sizes of specimens were used. (1) The 600 mm × 450 mm × 70 mm (height × width × depth) specimen was used to obtained for internal cracks by X-ray technique (X series), (2) The 1,200 mm × 800 mm × 150 mm (height × width × depth) specimen was used to measure the strain behavior of the CFRP sheets (P series). The shear reinforcements were arranged so as to intersect the shear plane at right angles. The CFRP sheets were externally bonded to the side surfaces of specimens, as shown Figure 1. The experimental parameters were the shear reinforcement ratio ρ_s and the CFRP sheet ratio, ρ_{cf} (Table 1). ρ_s is calculated by dividing by the gross sectional area of the shear reinforcement bars by the entire shear plane, and ρ_{cf} is calculated by dividing by the gross sectional area of the CFRP sheets by the entire shear plane. The nominal diameter of the shear reinforcement was 9.53mm, and the widths of the CFRP sheets were 40 mm and 80 mm.

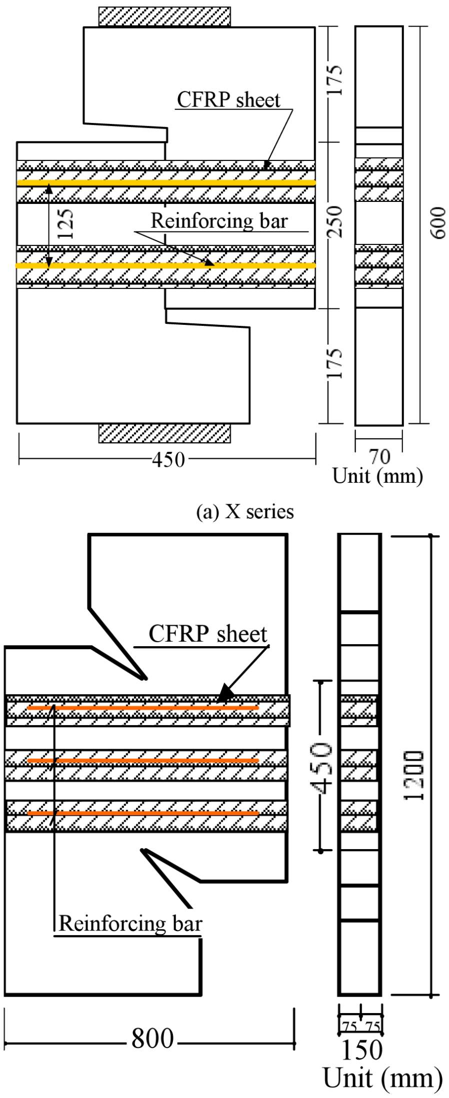


Figure 1. Type of specimens.

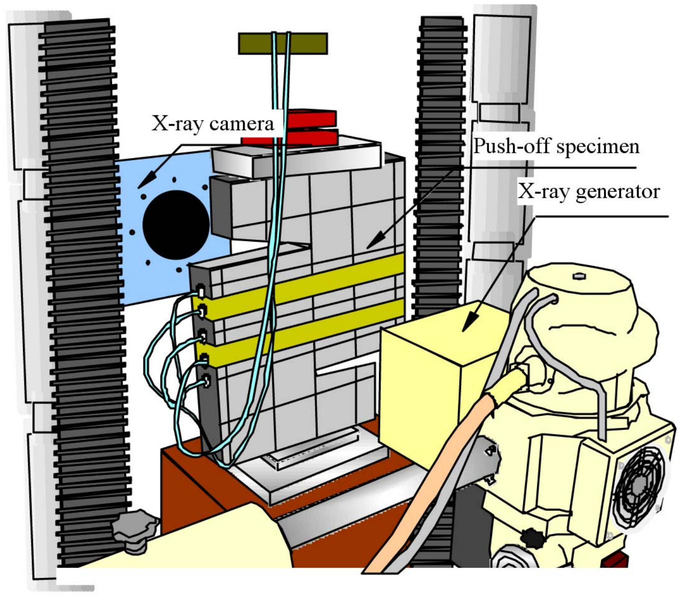


Figure 2. Loading equipment and X-ray generator.

2.2 *Test procedures*

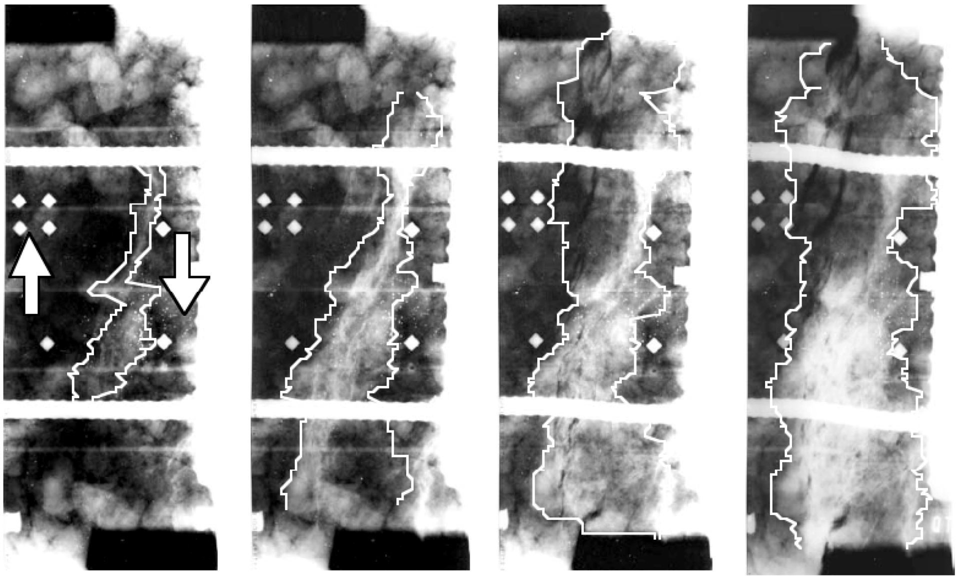
Figure 2 shows a schematic diagram of the combination of the shear test using a push-off specimen and the X-ray technique. The internal crack was observed by radiography using a contrast medium. The loading test was conducted by injecting a contrast medium into the push-off specimen through injection holes (φ = 2 mm). Cesium carbonate solution was used as the contrast medium[3)].

The shear displacement and the horizontal displacement were measured at the shear plane by displacement transducers. In addition, the horizontal strain of the CFRP sheet at the CFRP sheets was measured by the P series. This strain was measured by using electric strain gauges attached to the surface of CFRP sheet at central location.

3 RESULTS AND DISCUSSION

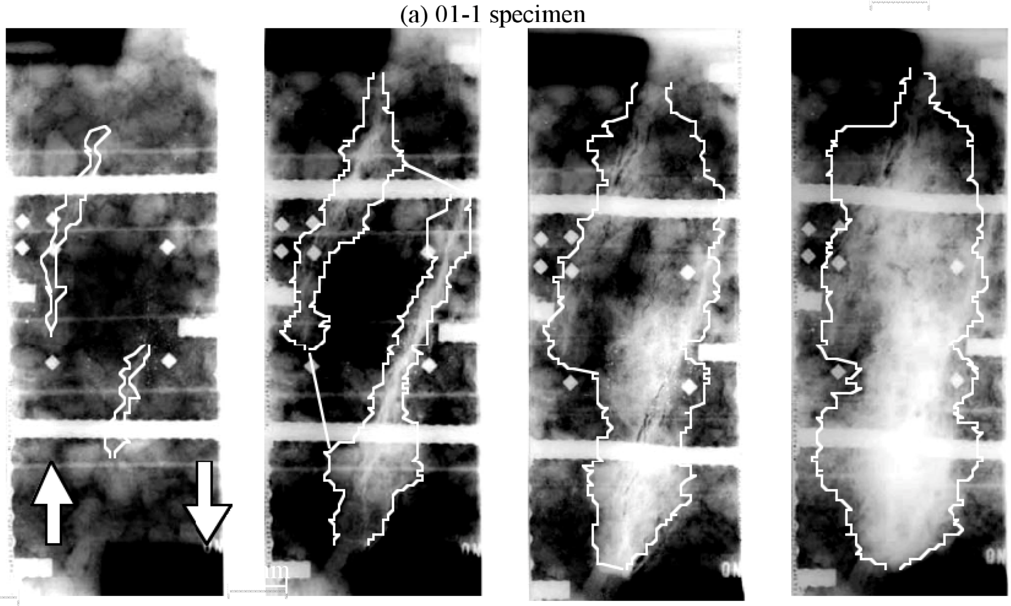
3.1 *Riedel shear crack observed by X-ray photography*

Figure 3 shows the X-ray photographs of the entire shear plane captured by the X-ray technique. As shown in these photographs, initial cracks were observed as diagonal discrete cracks. Thus, the Riedel shear crack formed in the concrete was revealed by the X-ray technique. These cracks propagated as vertically increasing cracks from the position between the shear reinforcements with increasing load. In addition, fine cracks[4)] were observed around the Riedel shear cracks, and the shear plane formed in the crack zone. The X-ray photographs clearly showed the cracking zone. The crack zone then expanded as the load increased, and the tendency became remarkable as the CFRP sheet ratio increased.



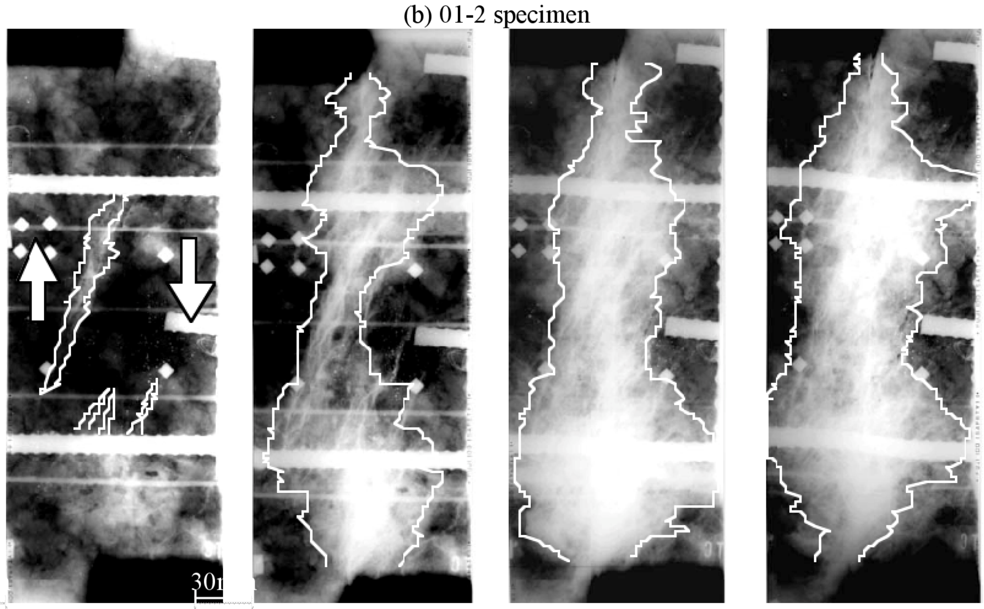
1) Initial Crack 2) Maximum load 3) shear displacement 3 mm 4) shear displacement 5 mm

(a) 01-1 specimen



1) Initial Crack 2) Maximum load 3) shear displacement 3 mm 4) shear displacement 5 mm

(b) 01-2 specimen



1) Initial Crack 2) Maximum load 3) shear displacement 3 mm 4) shear displacement 5 mm

(c) C1 specimen

Figure 3. The X-ray photographs of shear plane.

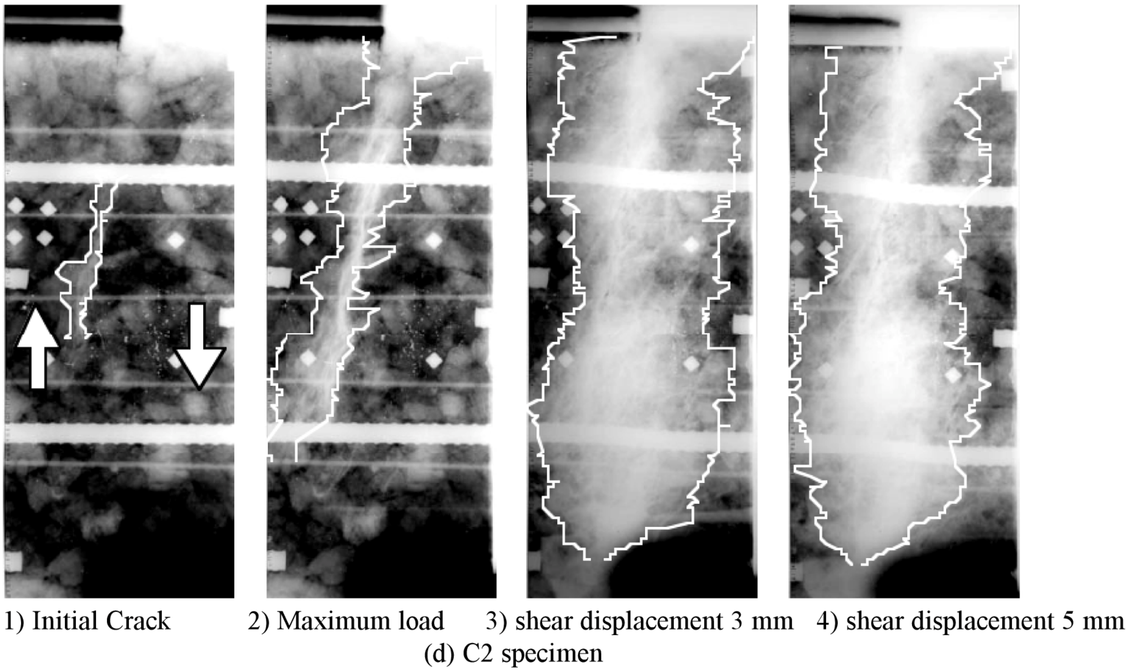


Figure 3. The X-ray photographs of shear plane.

3.2 *Relationship between the maximum shear stress and the average cracking zone*

Figure 4 shows the relationship between the maximum shear stress, τ_{max}, and the average cracking zone, Ls. The values of Ls are obtained by dividing the cracking zone by shear plane height. The results of the push-off test without the CFRP sheets, experimental parameter was the area of reinforcement, compared in this figure. The numerical value in the figure is the shear reinforcement ratio. The maximum shear stress increased by the average cracking zone increase. As the CFRP sheet ratio increased, the cracking zone increased remarkably. On the other hand, the reinforcement area is not influenced significantly. The average zone was expanded by increasing the CFRP sheet ratio before the maximum load was reached. As a result, the maximum shear stress are increased as in Figure 4.

3.3 *Relationship between shear displacement and horizontal displacement in the shear plane*

Figure 5 shows the relationship between the shear displacement and the horizontal displacement during loading to the maximum load in the P series. After the initial crack initiation, the horizontal displacement was larger than the shear displacement. The shear displacement became large after exceeding 0.1 mm. These displacements increased remarkably in the specimen with the CFRP sheets (C). Thus, the CFRP sheets resist the horizontal displacement that developed in the cracking zone.

Figure 6 shows the relationship between the load and the horizontal displacement of the P series. The initial cracking load is approximately 300 kN, and the specimen without CFRP (N) increased the horizontal

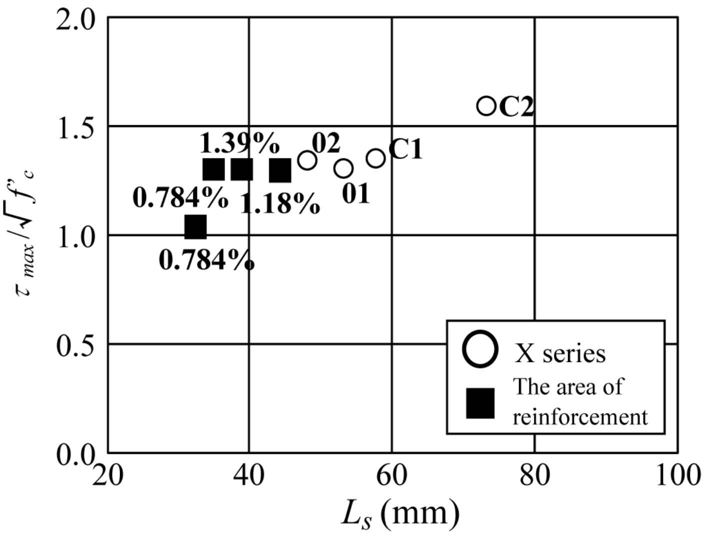


Figure 4. The relationship between the maximum shear stress and the average cracking zone.

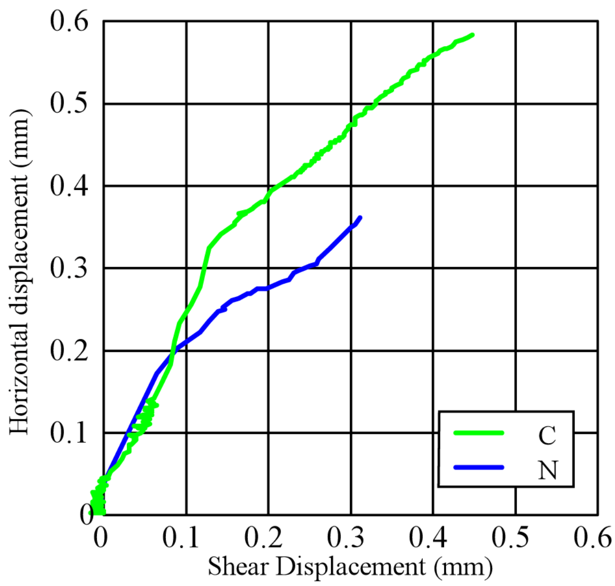


Figure 5. The relationship between shear displacement and the horizontal displacement.

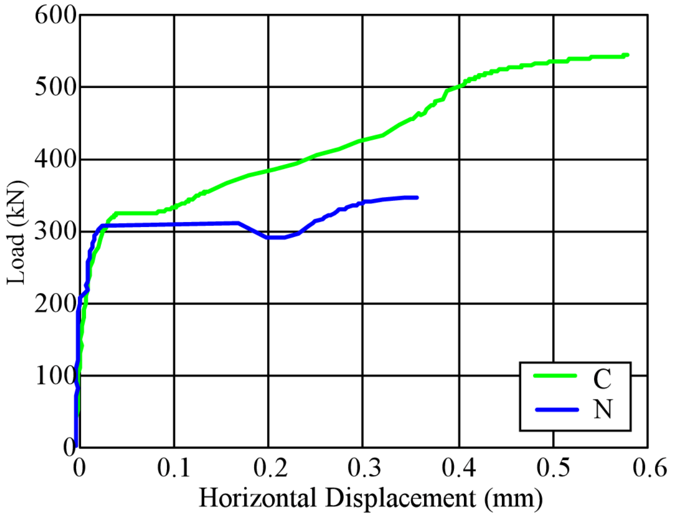


Figure 6. The relationship between load and the horizontal displacement.

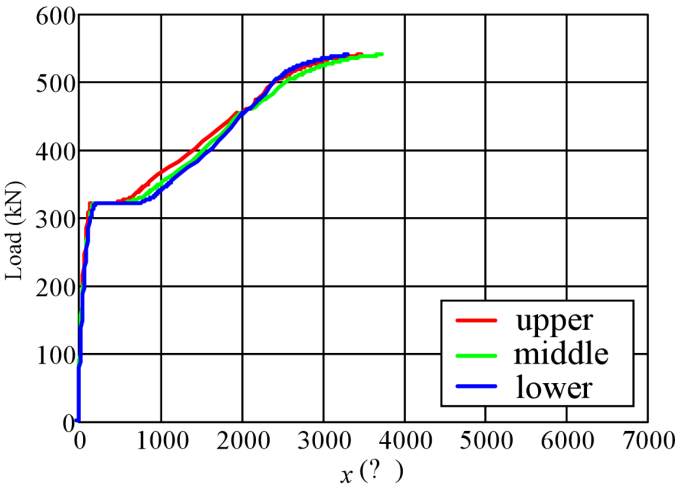


Figure 7. The relationship between load and the horizontal strain in CFRP sheets.

displacement during a load hardly increased. On the other hand, the specimen with CFRP (C) increased the horizontal displacement and the load. The load-carrying capacity of CFRP sheets is the difference in maximum load between C and N.

Increasing the shear load-carrying capacity by adding CFRP sheets has been determined to increase the horizontal displacement.

The carrying load of the strengthening of shear capacity by CFRP sheets under the shear displacement has been determined to the horizontal displacement increasing.

Figure 7 shows the relationship between the load and the horizontal strain in CFRP sheets of P series. The horizontal strain, ε_x, is tensile strain and increased remarkably when the initial crack appeared. This strain behavior of CFRP sheet on the shear plane has a meaning, that the tensile force is shared by the CFRP sheets under the shear displacement.

4 CONCLUSIONS

In the present study, the deformational behavior in the shear plane of reinforced concrete with CFRP sheets was investigated by X-ray radiography and the load-carrying capacity of CFRP sheet was also investigated. The experimental results revealed that the Riedel shear crack in the shear plane was caused by shear displacement. X-ray photographs revealed that the cracking zone of concrete subjected to shear displacement and the shear force level depend greatly on the area of the cracking zone. The CFRP sheet strengthening is expanded of these areas compared to without CFRP sheet. The load-carrying mechanism of CFRP sheets under shear deformation was found to be caused by the increase in horizontal displacement. The CFRP sheet on the shear plane is confirmed to carrying a tensile force, despite the shear deformation increasing.

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