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Repair and Strengthening of RC Member Damaged by Steel Corrosion and Verification of Re-deterioration Behavior

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ABSTRACT

This paper will be focused on strengthening effect of RC member damaged by steel corrosion, and verified the possibility of re-deterioration after strengthening by using FRP sheet. To conduct experimental work, seven specimens were prepared. Steel corrosion was forced by electrical corrosion test. Corrosion mass loss ratio was less than about 10 percent. The damaged specimen was strengthened by carbon or aramid FRP sheet. To improve the flexural behavior, the sheet bonded underneath RC beam. Then, electrical corrosion test conducted for strengthened beams again. After that all specimens were loaded as simply supported beams. As a result, Strengthened specimens showed a good strengthening effect without repairing such as crack injection or repair patch. On the other hand, it is unlikely that re-deterioration of salt attack occur in the retrofitted RC beam. However, the bonded sheet will be debonded by the re-deterioration test before loading. That depends on the type of fiber.

Keywords. Corrosion, Strengthening, FRP sheet, Recover, Short-term

INTRODUCTION

Repair or strengthening technologies for steel corroded reinforced concrete structures are improved by summarizing the study results in recent. In this paper will be focused on the structural behavior of the corroded reinforced concrete beam strengthened with FRP sheet. In the previous studies, strengthened structural behavior has been discussed about short term performance (Yamamoto et al., 2003). Furthermore previous studies did not consider time-dependent deterioration such as steel corrosion after strengthening. Based on the above discussion, the authors will study as follows:

(1) Reinforced concrete beams damaged by the electrical corrosion test are strengthened by carbon or aramid FRP sheet.

(2) Reinforced concrete beams which have corroded main reinforcement are strengthened by FRP sheet without crack injection or patch repair. The main bar corroded almost 10% mass loss.

(3) The electrical corrosion test conducted to strengthen beams. This aims to verify the re-deterioration for main bar corrosion.

(4) After that, flexural loading tests are conducted for all beams.

The authors will discuss improvement short-term performance by strengthening FRP sheet, and possibility of the the re-deterioration of the main bar after strengthening.

EXPERIMENTAL STUDY

Outline of specimens is shown in Table 1. Experimental parameters include the corrosion mass loss ratio of electrical corrosion test (0 to 10%) and fiber type of FRP sheet (carbon or aramid). Experimental flow is shown in Figure 1.

Table 1. Experimental parameters and measured mass loss

Specimen	Target mass loss ratio	FRP sheet	Measured mass loss ratio (%)
No.1	0%･Control	None	-
No.2	3%	None	3.0
No.3	10%	None	11.1
No.4	3%	Carbon	2.4
No.5	10%	Carbon	13.0
No.6	3%	Aramid	4.8
No.7	10%	Aramid	7.9

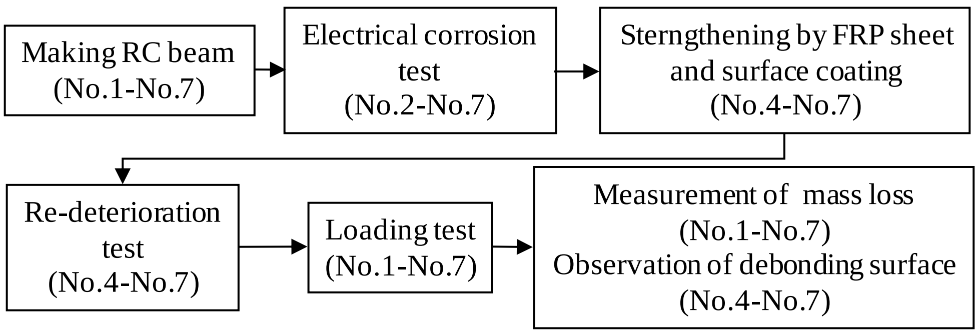

Figure 1. Experimental flow

Specimens. A schematic view of specimen is shown in Figure 2. The cross-sectional dimension is 140mm in height and 80mm in width. The effective depth is 114mm. The span is 1460mm. The main bar is deformed reinforcement which has 13mm diameter, and the stirrup is also deformed one which has 6mm diameter. The main bar is just arranged on the tension side. To prevent stirrup corrosion, all of stirrups were insulated from the main bar. That means just main bar corroded by electrical corrosion test. The mixture proportion of concrete is shown in Table 2. Using cement is early-strength cement, also the water cement ratio is 54.6%. The concrete strength that is measured by end of loading test is 34.2N/mm^2. The yielding strength of the main bar is 373 N/mm^2.

Electrical corrosion test. Six reinforced concrete beams was provided to electrical corrosion test to corrode main bar. Figure 3 shows outline of that test. In this test, current density for main bar is 9.81A/m^2, therefore current of electricity adjust 0.68A under constant current conditions. To estimate the corrosion mass loss ratio by using integrated current value, Equation (1) is used (Tamori et al., 1988):

$$W = 0.766\sum\left(I \cdot T\right) \quad (1)$$

Where, W is corrosion mass loss [g], I is current of electricity [A] and T is applying current time [hour]. Applying current time is estimated by Equation (1) before the start of electrical corrosion test.

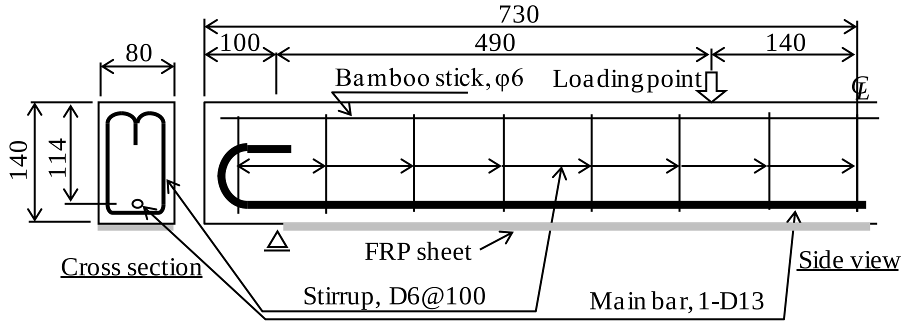

Figure 2. schematic view of specimen

Table 2. mixture proportion of concrete

Gmax (mm)	Slump (cm)	W/C (%)	Air (%)	s/a (%)	Unit weight (kg/m^3)				AE (Kg/m^3)
					W	C	S	G	
25	14	54.6	5.6	43.4	131	295	796	1077	2.95

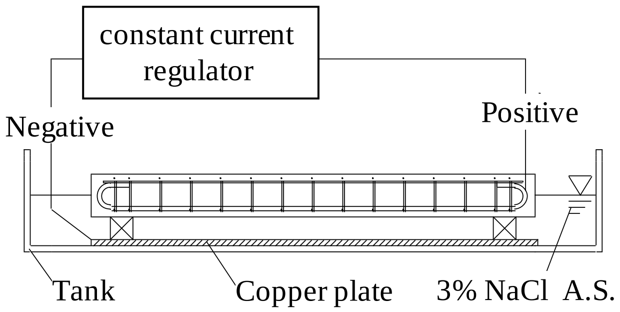

Figure 3. Outline of electrical corrosion test

Strengthening method. After finished electrical corrosion test, the beams are strengthened by FRP sheet. The drying time for the beam is 7days. All of the beams have dried naturally. Material property of FRP sheet is shown in Table 3. The fiber direction of FRP sheet arranged one way. This test program aimed to flexural strength of the beam, so that FRP sheet was bonded underneath of the beam by using epoxy resin. The sheet dimension is 80mm in width and 1220mm in length. The underneath of the beam was drained and primed prior to boding the sheet. The concrete surface of the deteriorated specimens polished by electrical grinder at attaching FRP sheets.

The strengthened specimens will be provided to electrical corrosion test due to verify re-deterioration of the main bar. Therefore, chloride ion should not penetrate from corrosion crack which occurred out of the span or lateral side of the beam. To prevent such penetration, the paper waste cloth was bonded on that crack by using epoxy resin. The reason why the cloth is bonded is because the cloth cannot carry the tensile force during flexural loading test. Also, the lateral side of the specimen was coated with epoxy resin.

Table 3. Material property of FRP sheet

Fiber	Density (g/m^2)	Tensile strength (N/mm^2)	Elastic modulus (kN/mm^2)
Carbon	212	4420	252
Aramid	291	3250	133

Verification of re-deterioration test. The test is conformed electrical corrosion test as shown in the previous section (see **the Electrical corrosion test.**) However, the electric resistance of specimen surface is improved by coating material which includes FRP sheet and epoxy resin. So, the electrical current applied same value under constant power voltage (Shimomura, et al., 2005). The voltage value is 15V and applying current time is 15days.

Flexural loading test. After completing for electrical corrosion testing, loading test was conducted such as Figure 2. In that test, load, deflection at mid span, strain of concrete at upper edge ware measured. The strain of FRP sheet was not measured due to a problem in data acquisition system.

Measurement of corrosion mass loss and observation of debonding surface. Main bar was excavated from each beam, and then corrosion mass loss of the bar was measured. The corrosion product on the surface of the bar was dissolved by diammonium hydrogen citrate aqueous solution. Also, the diameter of main bar which was removed corrosion product was measured by using vernier calipers. The FRP sheet which debonded by flexural loading was observed by visual contact.

EXPERIMENTAL RESULT AND DISCUSSION

Corrosion mass loss of main bar. The average corrosion mass loss ratio is shown in Table 1. From that result, the observed ratio is in almost agreement with the estimated one. The diameter distribution after corrosion between each supporting point is shown in Figure 4. The diameter distribution shows small variability. Especially, such variability is noted among the specimens (No. 3, No. 5, and No. 7) which had about 10% corrosion mass loss ratio. However, there is no tremendous dimension loss.

Verification re-deterioration. Table 4 shows integrated current value and the estimation of the corrosion mass loss ratio during the re-deterioration test. The estimated ratio was obtained by Equation (1). We now know that main bar did not corrode during the re - deterioration test. Such behavior did not depend on types of fiber for FRP sheet. Therefore, strengthening by FRP sheet and surface coating reduce the risk of re-deterioration. In this study, the concrete did not desalinate, and cover concrete was still damaged by expansion due to corrosion. As a result, main bar corrosion by re-deterioration can be controlled, if the resistant quality of ion penetration is improved by bonding FRP sheet and surface coating.

Furthermore, the authors propose that FRP sheet strengthening apply for short term upgrading without crack injection or patch repair.

Flexural behavior. The load and deflection curves are shown in Figure 5, also the maximum capacity is summarized in Table 5. The flexural stiffness or the capacity is improved by strengthening without crack injection or patch repair. That did not depend on the type of FRP sheet. The specimens which were strengthened by FRP sheet showed debonding the sheet when the load reached to maximum value. That failure mode is shown in Figure 6. In this experimental study, the corrosion mass loss ratio of all specimens is less than about 10%, also fasting corroded bar end is sufficient. Strengthening by FRP sheet will improve the flexural stiffness and maximum capacity without crack injection or patch repair within such condition.

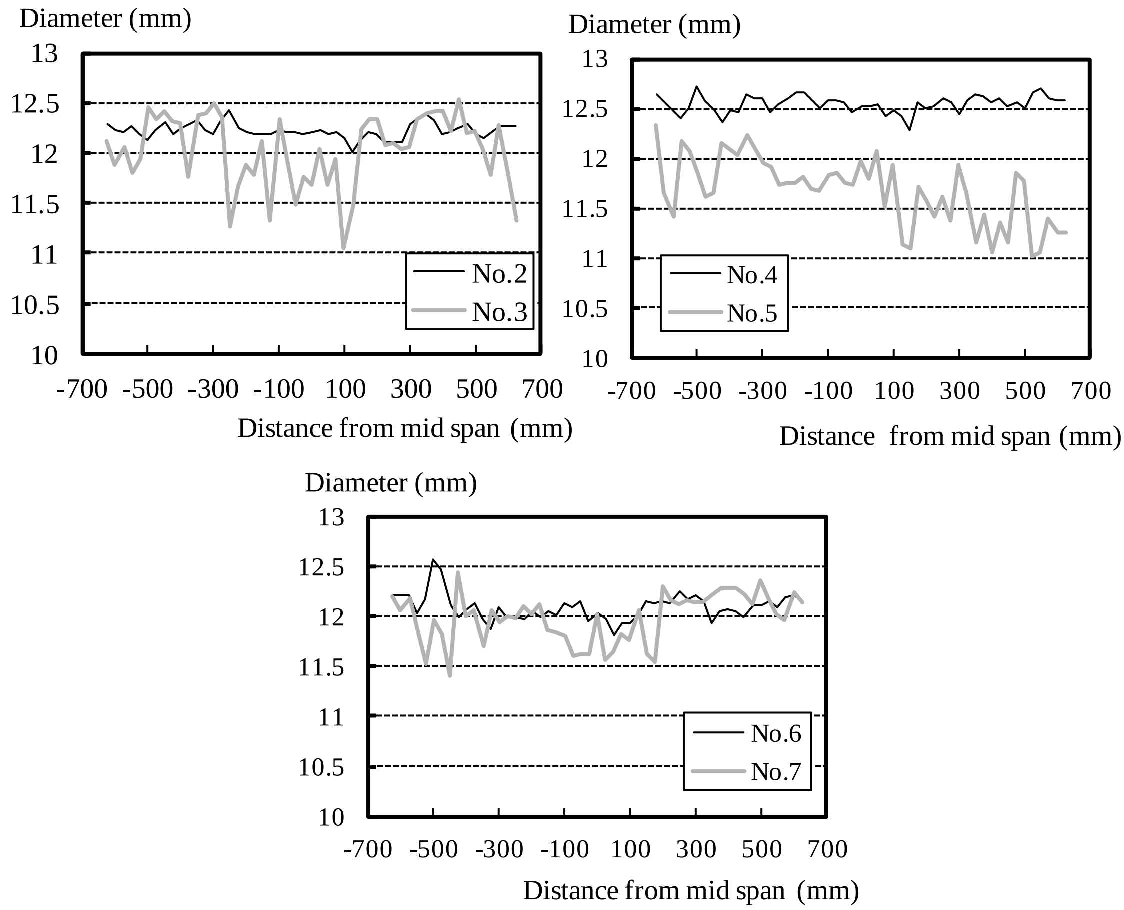

Figure 4. Diameter distribution after corrosion between each supporting point

Estimation results of maximum capacity are shown in Figure 5 and Table 5. The estimation was conformed to Japanese code (JSCE, 2007) which applied some assumption (plain section remains plain, yielding main bar and concrete crushing, and so on). Also estimation for strengthening specimen assumed that FRP sheet never debonded from concrete surface. Even the calculation assumed that the sheet never debond, estimation capacity shows good agreement with observation one. So, the assumption is valid if the main bar was corroded.

Table 4. Result of re-deterioration test

Specimen	Integrated current value (A・hr)	Estimated mass loss ratio (%)
No.4	8.62	0.37
No.5	16.7	0.72
No.6	15.6	0.67
No.7	17.9	0.77

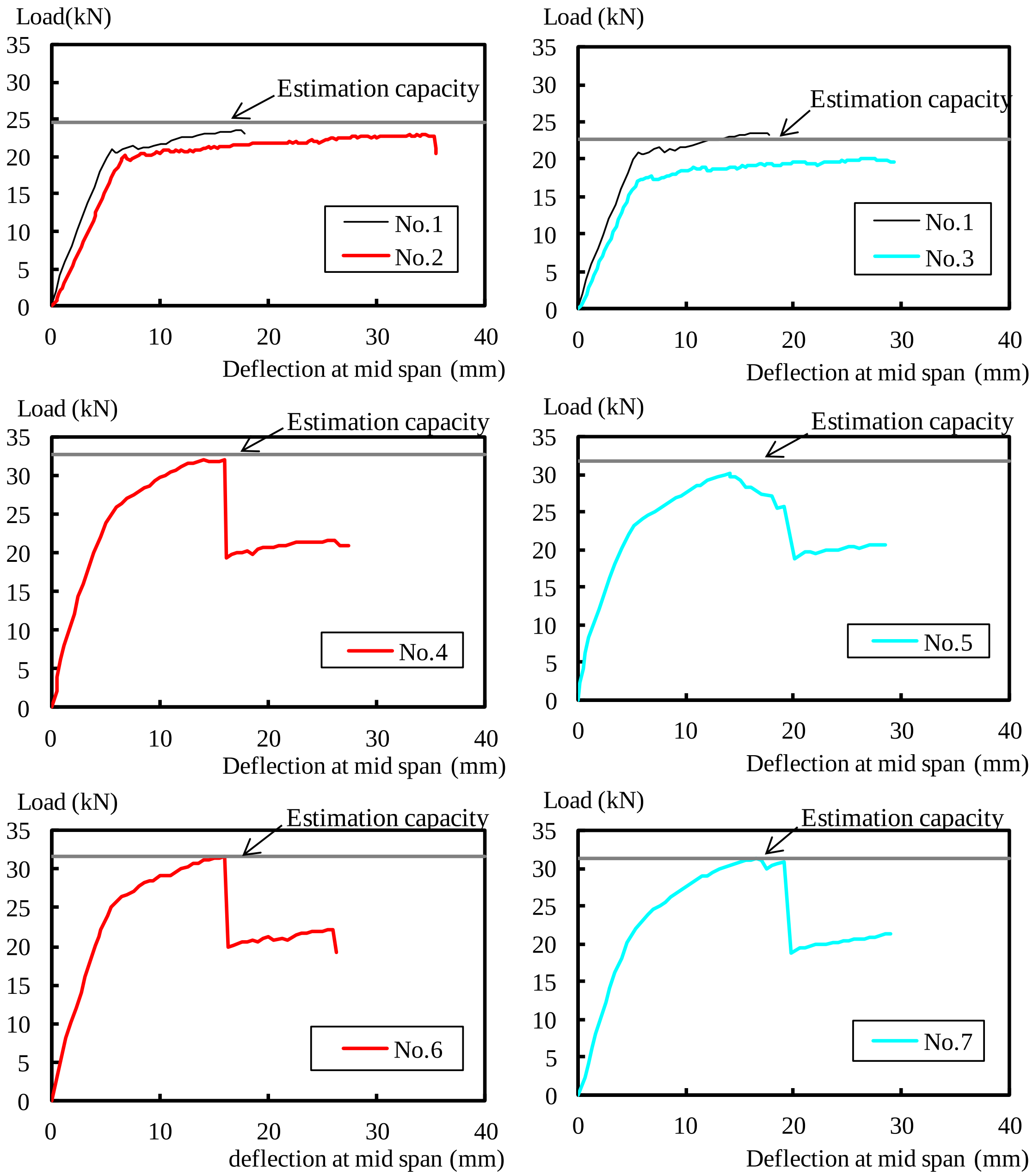

Figure 5. Load and deflection curve

Debonding surface. The Debonding surface of the FRP sheet after the loading test is shown in Figure 7. The corrosion product fluid stuck to the debonding surface in case of the armed fiber FRP sheet. The Aramid fiber sheet was debonded by some kind of actions within re-deterioration test, because the mortar fragment did not stick to such area. Figure 8 shows the fluid area distribution of specimen Nos.6 and 7, which were strengthened by the aramid fiber FRP sheet. The distribution of the debonding caused by re-deterioration test does not have deflection, and, besides, it is indicated that the debonding progressed from the long side end of the FRP sheet. On the other hand, Carbon fiber sheet did not debond by re-deterioration test, because the mortar fragment stuck to debonding surface. In this experimental study, the author did not make clear the debonding mechanism of the aramid fiber sheet which occurred before a loading test. A future study will clarify such mechanism.

Table 5. Result of loading test

Specimen	Observed (kN)	Estimated (kN)
No.1	23.2	25.3
No.2	22.8	24.6
No.3	20	22.7
No.4	32.1	32.8
No.5	29.7	31.8
No.6	31.6	31.7
No.7	31.3	31.4

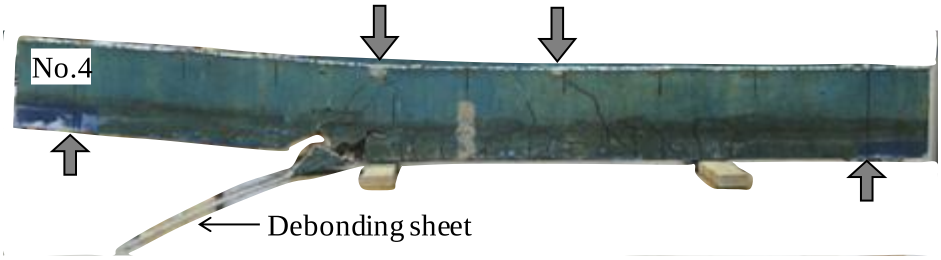

Figure 6. Ultimate failure mode on specimen No.4

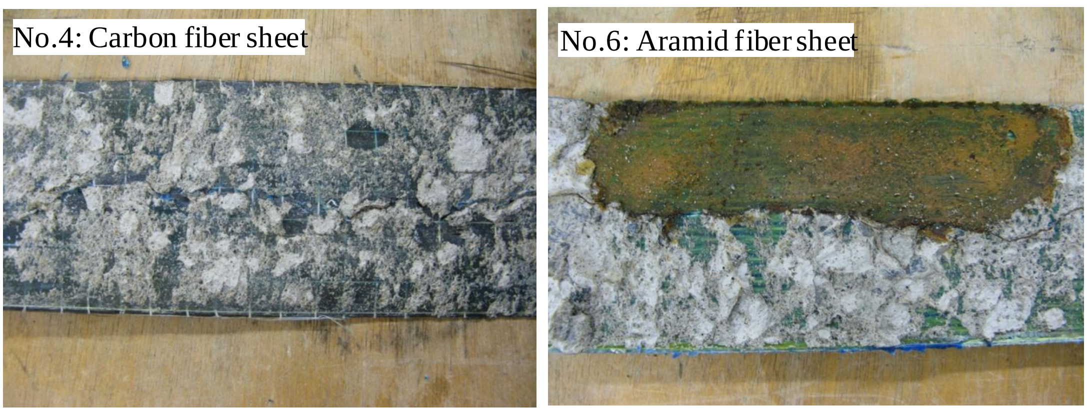

Figure 7. Debonding surface after loading test

Figure 8. Distribution of debonding by re-deterioration test

It is estimated that the debonding of the aramid fiber sheet occurred before a loading test. However, the flexural capacity which strengthened by the aramid FRP sheet is almost same as carbon FRP sheet one as shown in Figure 5 and Table 5. Even if an aramid fiber sheet debonded before a loading test, the debonding area is restricted, and it is thought that debonding does not spread through the whole the bonded width of the sheet.

CONCLUSION

The conclusion can be drawn in this study as follows:

1. Strengthened specimens showed a good strengthening effect without repairing such as crack injection or repair patch. That stands within the terms of that the corrosion mass loss of the main reinforcing bar is less than about 10 percent and fasting of the bar end is sufficient.

2. It is unlikely that re-deterioration of salt attack occur in the retrofitted RC beam.

3. The bonded sheet will be debonded by the re-deterioration test before loading. That depends on the type of fiber. However, the author did not make clear the debonding mechanism. A future study will clarify such mechanism.

This study aimed for the performance recovery in the relatively short-term span, the authors examined a method to utilize a FRP sheet. As a result, short-term performance could be recovered by combining strengthening by FRP sheet and surface coating. On the other hand, It has shown the possibility that a sheet debonding by some kind of action even if excessive load did not act. Such phenomenon depends on a kind of the fiber of FRP sheet. When expecting the cover effect of the deterioration factor as well as structural performance recovery to a FRP sheet, it is thought that a notice is necessary for such debonding.

REFERENCES

Japan Society for Civil Engineer (2007) "Standard Specifications for Concrete Structures - 2007, Design"

Shimomura, T., et al. (2005). "Evaluation of effectiveness of surface protecting materials for concrete by numerical analysis" *Proceedings of the International Workshop on Durability of Reinforced Concrete under Combined Mechanical and Climate Loads"* 153-160

Tamori, K., et al. (1988). "Crack Behavior of Reinforced Concrete Members due to Corrosion of Reinforcing Bars" *Proceedings of Japan Concrete Institute"* 10 (2): 505-510 (In Japanese)

Yamamoto, T., et al. (2003). "Influence of Reinforcing Steel Corrosion on Load-Carrying Behavior of RC Flexural Member Strengthened with CFRP Sheet" *Proceedings of Concrete Structure Scenarios* 3: 357-362 (In Japanese)