INFLUENCE OF STIRRUPS ON RESIDUAL LOAD CAPACITY OF RC BEAMS WITH CORROSION

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1. INTRODUCTION

Many built infrastructure facilities are deteriorating. One major cause is the corrosion which most often affects the residual strength of reinforced concrete (RC) structures. With the period of establishing new civil engineering infrastructures shifting to the period of maintenance, it is important to clarify the fracture mechanism and to accurately predict the residual ultimate load carrying capacity of RC beams, which are basic structure elements. Additionally, the shift of mechanism comes into notice.

Based on this background, the objectives of this study are to investigate the influence of stirrup on residual load.

2. EXPERIMENTAL PROGRAMS

2.1 Specimens and Parameters

The specimens shown in Fig. 1 are rectangular RC beams having width 240mm, height 340mm and length 2400mm or 2950mm. The tensile reinforcements used are 3D16(SD295A) deformed bars at 60mm intervals, and stirrups are D6(SD295A) deformed bars. The parameters are shown in Table 1. The mix proportion is given in Table 2, with design strength of concrete is 30MPa. Moreover, 5% *Nacl* solution is used as mixing water, in order to accelerate the galvanic corrosion. Additionally, in the name of beams, F means steel plate.

2.2 Details of Corrosion

In this study, the method of accelerated galvanic corrosion test is adopted [1]. The whole length of beams of series S and the shear span of series L are deposited in water trough filled with 5% *Nacl* solution. Furthermore, the reinforcements in anchorage region are coated with epoxy to keep it away from corrosion.

2.3 Flexural Loading Test and Measurement

All the beams are tested till failure with four-point flexural loading. The loading span and support span are 350mm and 1800mm respectively. The load speed is at the value of 0.5mm per minute. The items to be measured are load, beam deflection in the constant moment region, and the axial strain of middle tensile reinforcement.

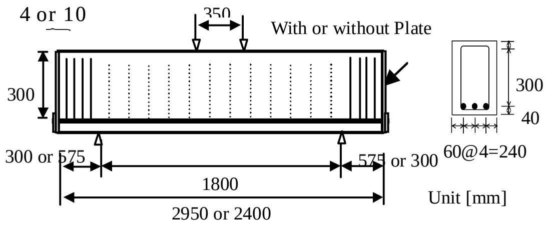

Fig.1 Layout of specimens

Table 1 Test Variables

Series	Specimens	Aimed corrosion Rate (%)	Shear reinforcement Spacing	Number of stirrup in anchorage	Length of anchorage	Steel plate	Ultimate Load (kN)
S	S4	S4-0	0	-	4	300mm	No	174.3
		S4-10	10					209.5
		S4-20	20					236.5
	S150	S150-0	0	150mm				276
		S150-10	10					302.7
		S150-20	20					221.7
	S300	S300-10	10	300mm				206.5
L	L10	L10-10F	10	-	10	575mm	Have	251.7
		L10-20F	20					296.2
	L150	L150-10F	10	150mm				245
NB		S4-0NF	0	-	4	300mm		360.4
		S150-0NF	0	150mm				369.6

Table 2 Mix proportion of concrete

Gmax (mm)	W/C (%)	SL (cm)	Air (%)	Unit weight (kg/m^3)					
				W	C	S	G	Admixture	NaCl
20	60	10	5	168	280	826	996	2.8	8.8

3. RESULTS

3.1 Corrosion Pattern

The average corrosion rates of tensile reinforcements and the stirrups including the bottom part are shown in Table 3, and the partial plot of load versus mid-span deflection is shown in Fig. 4 and 5. The tensile reinforcements are uniformly corroded, but the stirrups are un-uniformly corroded. For one example, the distribution of beam S150-20 is shown in Fig.2. About the partly corroded beams of series L, tensile reinforcements and the stirrups in anchorage near support are little corroded, and reinforcement in shear span corroded uniformly.

3.1 Stirrups in Anchorage

Keywords: load-carrying capacity, bond stress, arch action, stirrup
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Table 3 Average corrosion rate of reinforcements

Series	Specimen	Tensile reinforcements corrosion (%)	Sturrup (%)							
			Left anchorage		Shear span		Right anchorage		Max in anchorage	
			Whole	Bottom	Whole	Bottom	Whole	Bottom	Whole	Bottom
S4	S4-10	6	36.5	32.6	-	-	33.4	13.3	36.5	32.6
	S4-20A	12	45.7	50.8	-	-	45.1	26.4	45.7	50.8
S150	S150-10	4	34.8	15.3	36.2	12.4	32.6	9.1	34.8	15.3
	S150-20	11	35.1	72.8	36.7	37.8	33	22	35.1	72.8
S300	S300-10	9	40.9	16.32	51.8	52.3	46.1	52.9	46.1	52.9
L10	L10--10F	9	-	-	-	-	-	-	-	-
	L10--20F	13	-	-	-	-	-	-	-	-
L150	L150-10F	7	-	-	-	-	-	-	-	-

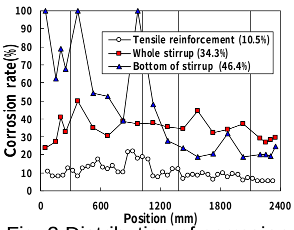

Fig. 2 Distribution of corrosion

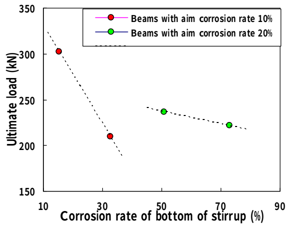

Fig. 3 Load vs. corrosion

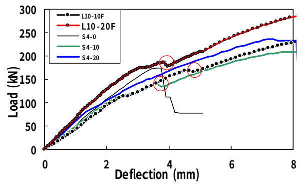

Fig. 4 Series S4

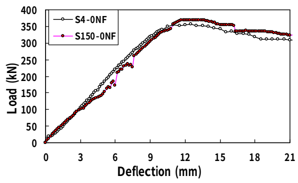

Fig. 5 Series NB

The relationship between load and the maximum corrosion rate of bottom stirrups in anchorage is shown in Fig. 3, both on the situation of aim corrosion rate 10% and 20%, the average corrosion rate of tensile reinforcements are almost the same. When the corrosion rate of bottom of stirrups is less, the ultimate load is higher, for the stirrups in anchorage can prevent tensile reinforcement from being pulled out. Therefore, the stirrups in anchorage can upgrade the residual load capacity.

3.2 Stirrups in Shear Span

The maximum average corrosion rates of bottom stirrup for beam S4-10 and S300-10 are 50.8% and 52.9%, and the average corrosion rate of reinforcement are 12% and 9%, respectively. But the ultimate load of beam S300-10 is 30kN lesser. So it can be concluded that shear reinforcements have disadvantage in forming arch action for the load can not be transferred to anchorage smoothly. In other words, the more the corrosion rate of stirrups in shear span is, the easier the arch action forms.

3.3 Arch action with stirrup when there is no bond stress

In series BN shown in Fig. 5, there is no any bond stress in shear span, and there is no bond stress between tensile and shear reinforcements, too, for tensile reinforcement is wrapped with wax and tape, and tensile reinforcement and stirrup do not contact with each other. The load-carrying capacity is almost the same, and the distribution of strain has the same properties. So, it seems that stirrups in shear span make no contribution to load capacity, when there is no any bond stress between tensile and shear reinforcement.

3.4 Failure Mode Shift

About beam L10-10F, two diagonal cracks appear, when the load reaches the number expressed in Fig.6. Generally speaking, the loads increase linearly. When the crack with green line appears, the load decreases a little transitorily showed in Fig. 4, and then rises again. It indicates that truss action shift to arch action. In the corroded beams, with no shear reinforcements, the same phenomenon appears, except beam S4-20. It can be attributed to the larger corrosion rate, and it performs arch action at the beginning of loading. And then bond failure crack appears, by which the residual bond stress is removed, and then crack with red line appears, therefore compressive zone of arch action forms.

But if there are stirrups in shear span, there is no this kind of phenomenon, because when cracks appear, the stirrups can connect concrete, and prevent load from dropping suddenly, accordingly it is difficult to form compressive zone, and it is not easy to form firm arch action.

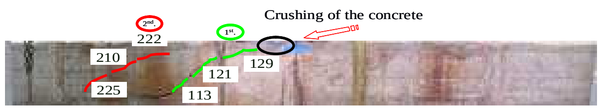

Fig.6 Final stage cracks of beam L10-10F

4. CONCLUSIONS

1) The load-carrying capacity of corroded beams can be increased when stirrups in anchorage perform well.

2) Stirrups in shear span makes disadvantage in load capacity, in the situation of arch action.

3) When there is no any bond stress between tensile reinforcement and shear reinforcement in shear span, the shear reinforcement makes no contribution to load capacity.

4) When there is no shear reinforcement, the load decrease transitorily, during truss mode shift to arch mode

REFERENCES

1) Yuki Murakami, Tetsuhide Kinoshita, Shuichi Suzuki, Yukinari Fukumoto, Hideki Oshita. (2006) "Study on the residual strength for corroded reinforcement beam." Journal of Japan JCI, 17(1), 61-74