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Residual load capacity of corroded reinforced concrete beam undergoing bond failure

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ABSTRACT

20 rebar reinforced concrete beams, including 3 non-corroded beams, 3 unbonded beams, 9 fully corroded beams and 5 partly corroded beams, are loaded under four point static bending test. As a result of the experiment, the unbonded beams suffer arch action at any load level, and the load resisting mechanism of the 13 corroded beams which undergo bond failure changes to arch action near the later loading stage. The 13 corroded beams in the experiment fails as the maximal bond stress in the anchorage region reaches its critical value which cannot keep the balance of the arch rib. The maximal bond force in the anchorage region is taken into account as a key factor in the prediction method, as it has a great effect on the residual load capacity of the corroded beam undergoing bond failure. Based on the experimental result, the maximal bond force in the anchorage region and the residual load capacity are normalized by the values of the unbonded beam, and a model is proposed to predict the residual load capacity of the corroded beam undergoing bond failure based on arch action.

1. Introduction

Corrosion of rebar has been deemed as a serious factor, which can lead to not only the loss of cross sectional area of rebar but also the degradation of the bond [1–3]. It is known that the load capacity will be decreased and that the failure mode can be changed due to the corrosion of rebar embedded in concrete beam. Lachemi et al. [4] evaluated the effect of corrosion on shear behavior of self-consolidating concrete beams and normal concrete beams, and concluded that the degree of corrosion has a major effect on the change in the failure mode. Zhu et al. [5] loaded the reinforced concrete beams corroded in chloride environment for 26 years, and the results showed that the corrosion has very important effect on the mechanical behavior of the short-span beams, leading to the changing of the failure mode. Wu et al. [6] found that the failure mode of beams changed from the crushing of compression concrete to the yielding of rebar. Wei et al. [7] tested the corroded reinforced concrete beams with different degree of corrosion of main rebar and stirrups, and it is found that reinforced concrete beam specimens with the same longitudinal steel ratio and the same shear span ratio have three kinds of failure mode, i.e. bending failure, shear-compression failure and bond-shear failure. Yoon et al. [8] tested corroded beam at various loading levels with different loading histories, and it is found that the failure mode appears to shift from a shear failure of concrete to bond splitting as the degree of corrosion increases. Dong et al. [9] tested the non-corroded beam designed as diagonal tension failure and the corroded beams with the same dimension as the non-corroded beam. As a result of the experiment, the load capacity of some corroded beams is higher than the non-corroded beam, and its failure mode shift to bond failure. Dong et al. [10] tested the corroded beams with different degree of corrosion and different stirrup spacing. The beams were designed as flexural failure, but they underwent bond failure as the stirrups were extremely corroded. In addition, the failure mode of one corroded beam, whose main rebars were anchored well with both stirrups and steel plates, shift from bond failure back to flexural failure.

The prediction methods of flexural failure [11–14] and shear failure [15–18] have been widely studied. However, there is limited experimental study regarding the residual load capacity of the corroded beam undergoing bond failure, and there is a lack of applicable model to predict its residual load capacity. From the reference study, it is reported that the bond stress in the

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Nomenclature

x	position of a cross section in the support span	T_{cor}	the maximal bond force in the anchorage region of corroded beam
$M_{(x)}$	bending moment at the cross section x	P_{arch}	load capacity of unbonded beam
P	applied load, 2 times the shear force	T_{arch}	the maximal bond force in the anchorage region of unbonded beam
$z_{(x)}$	moment arm at the cross section x	a/d	shear span-to-effective depth ratio
$T_{(x)}$	rebar force at the cross section		
P_{cor}	the residual load capacity of the corroded beam		

anchorage region has a great effect on the residual strength of the corroded beam undergoing bond failure [10,19], and it should be taken as a key parameter in predicting the residual load capacity. Thus the object of this paper is to propose a model to predict the residual load capacity of the corroded beam undergoing bond failure.

2. Experiment

2.1. Test specimens

The details of the 20 tested beams are presented in Fig. 1, and the parameters and the test results in Table 1. The beams were 1950 mm in length and 180 mm in width, and the effective depths were 240 mm, 180 mm and 130 mm. The concrete cover under the rebar was 40 mm in most beams, however, it was also set to 50 mm or 60 mm in some beams with similar degree of corrosion to make the bond stress changes in a wide range. The loading span and the support span were 200 mm and 1350 mm, respectively. The beams were divided into three series according to their shear span-to-effective depth ratios (a/d), 2.40, 3.19 and 4.42, each series contained one non-corroded beam, three fully corroded beams, one or two partly corroded beams and one unbonded beam. The non-corroded beam, whose main rebars were anchored with closely spaced stirrups (see Fig. 1(c)) and steel plates at the beam ends, was designed as diagonal tension failure. The fully corroded beams, whose main rebars were not anchored, were corroded all over the length to the degree of corrosion less than 10%. The partly corroded beams, whose main rebars were anchored the same as the non-corroded beams, were only corroded in the support span to the degree of corrosion higher than 10%. Apparently enough, the bond in the anchorage region of fully corroded beams were degraded more significantly than that of the partly corroded beams, and thus, the effect of bond in the anchorage region can be investigated at an extensive range. Regarding the unbonded beam whose main rebars were also anchored the same as the non-corroded beams, the bond in the support span was removed artificially [9] to simulate the beam whose bond in the anchorage region was completely not degraded due to corrosion.

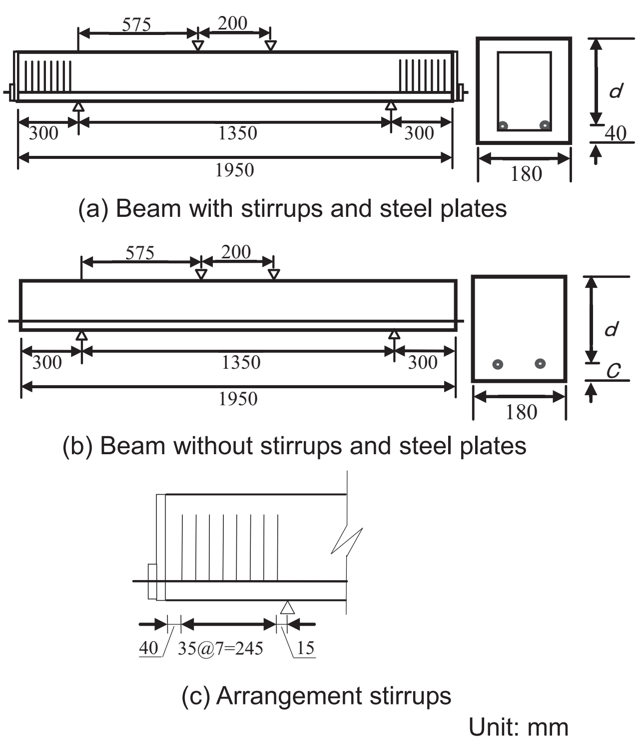

Fig. 1. Beam dimension and arrangement of rebars.

The mixture proportion of concrete is given in Table 2, and the compressive strengths at the loading stage are shown in Table 1. The non-corroded beams, the partly corroded beams and the unbonded beam was fabricated with ordinary Portland cement in winter. To investigate the effect of the bond in the anchorage region at an extensive range, the fully corroded beams were added and fabricated with high early strength cement in summer. Thus, the compressive strengths of the fully corroded beams were higher due to the effects of the type of cement, the temperature of materials, the curing temperature, and the temperature of salt solution used in corrosion test. The uniaxial tensile strengths of the rebar are shown in Table 3. Considering that the degree of corrosion of the partly corroded beams with the a/d of 2.40 was higher, D22 was used as main rebar to prevent yielding. However, the experiment result showed that the local strains were extremely lower than the yield strain, and then D19 was used as main rebar in the beams fabricated later. D6 was used as stirrups in all the beams. An electrochemistry accelerated corrosion method was adopted for the preparation of the corroded beams [10,20,21]. Two rebar acted as the anode, and a copper plate as the cathode. 12.6 A direct current flowed through the two electrodes until the amount of electricity achieved a given value. The scene of partly corrosion test is shown in Fig. 2; only the support span was immersed in the 5% salt solution. Thus, the degree of corrosion of main rebar in the support span was more serious than the degree in the anchorage region.

2.2. Loading test and measured items

Four-point static bending tests were conducted under displacement control at the speed of 0.5 mm/minute as shown in Fig. 3. The measured items included degree of corrosion, deflection and the longitudinal strains of the main rebar. After the loading test, the corroded beams were demolished, then the main rebars were extracted and immersed into 10% diammonium hydrogen citrate solution for 24 h to make the rust dissolve, finally the corroded main rebars were cut into parts with a length of 50 mm (partly corroded beam) or 100 mm (fully corroded beam). The degree of