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Experimental research on hysteretic behaviors of corroded reinforced concrete columns with different maximum amounts of corrosion of rebar

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HIGHLIGHTS

- The hysteretic experiments of five groups of corroded RC columns were designed.
- The effects on the degradation for the corroded RC columns were studied.
- The critical maximum amount of corrosion of rebar and dilation crack width were explored from the experiments.

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ABSTRACT

The reinforced concrete (RC) columns infiltrated by chloride ion in marine environment are much vulnerable under seismic loading. In this paper, the hysteretic behaviors of corroded RC columns were studied, which were considered as the condition of tide region or splash zone. Experiments were designed for five groups of corroded RC columns with different maximum amounts of corrosion of rebar under cyclic lateral loads combined with a constant vertical load. The traditional soaking method was replaced by a new wrapping method in order to obtain the desired amount of corrosion of rebar that was similar with the environment condition. The results showed that the flexural strength, the circular stiffness, the ductility, and the energy absorption of corroded RC column degraded with the increase of the maximum amount of corrosion of rebar. The maximum amount of corrosion of 13.25% and the dilation crack width of 1.2 mm were two important critical parameters.

1. Introduction

The corrosion in the RC column reduces the diameter of steel bar and influences the bond force between steel bar and surrounding concrete, which makes RC structures much dangerous under the earthquake load. Till now, lots of researches have been done to study the behaviors of corroded bare rebars and corrode RC structures. Based on the experiments of corroded bare rebars, some researchers [16,7] regarded that the corroded bare rebars had worse mechanical properties than those without corrosion. In the literatures [13,2,5,4,1], the flexural strengths and the ultimate displacements for corroded RC beams were found to be obvious decrease from experimental results. Du et al. [5] also thought the beams with short corrosion lengths have worse mechanical behaviors than those with long corrosion lengths through the experiments of corroded RC beams. Some researchers [17,14] considered that the depth of pitting corrosion was the most important parameter which affected the flexural load capacities of corroded RC beams. Other researchers [9,11] paid their attentions to the hysteretic behavior of corroded rectangular RC columns. They revealed that the flexural strengths and the ductility of corroded RC columns were reduced with the increases of the amount of corrosion of steel bar, and the large amount of corrosion could change its failure modes. The similar conclusions were arrived by the studies on corroded circular RC columns [12,10]. Lots of researchers [16,6,18,15] orientated their targets on the researches of the rectangular RC columns with partial corrosions, and the results showed that the partial corrosion zones influenced greatly the flexural strengths of corroded RC columns. However, little researches

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were found on the corroded RC columns located in tide region or splash zone.

In this paper, the hysteretic behavior of corroded RC columns with different maximum amounts of corrosion of rebar were studied, which were corresponded to the columns located in the tide regions or the splash zones in marine environment under earthquake loads. Five groups of corroded RC columns with different maximum amounts of corrosion of rebar ranging from 0% to 20% were designed and a new wrapping method was applied in the experiments. Based on the experimental results, the degrading rules of the flexural strength, the circular stiffness, the ductility and the energy absorption capacity for the corroded RC columns with the maximum amount of corrosion of rebar were proposed. The critical maximum amount of corrosion of rebar as well as the critical maximum dilation crack width was specified.

2. Experiment

2.1. Specimens

Five cantilever RC columns with the expected amounts of corrosion of rebar of 0%, 5%, 10%, 15%, and 20% were utilized and were named as ZZ-1, ZZ-2, ZZ-3, ZZ-4, ZZ-5, respectively. The axial load ratio n_o of 0.18 and the shear span ratio λ of 5.26 were applied to five column specimens. The n_o is defined as $n_o = N/(f'_c A_g)$, where N is the actual axial load, A_g is the cross sectional area of specimen, and f'_c is the actual cylinder compressive strength for concrete. Usually, it is noted that has $f'_c = 0.8 f_{cu}$ [8], where f_{cu} is the actual cubic compressive strength of concrete.

All five specimens had same cross-sections and cantilever heights, and were reinforced with identical longitudinal rebar and transverse stirrups. Details for the specimens are shown in Fig. 1. Each specimen was 210 mm wide by 210 mm deep and was reinforced with 4 Φ18 mm rebar and Φ6@90 mm stirrups. The heights for all cantilever parts of specimens were 1000 mm. The footings were heavily reinforced with 6 Φ18 mm rebar and Φ8@100 mm stirrups to avoid failure during the tests.

The strength grade for concrete was C40, and the mix proportion in weight was Cement:Water:Sand:Gravel = 1:0.55:1.66:3.09. *NaCl* was added by the value of 4.2% in the cement weight to accelerate the steel bar corrosion.

2.2. Material property

Material tests were carried out to determine the mechanical properties of concrete and steel bar. The compressive strength with the value of 46.4 MPa, was obtained from the compression tests of standard concrete cubic blocks. Stress-strain relationships of the reinforcing steels were obtained from tensile tests. The yield strength and the tensile strength of the rebar were 372 MPa and 573 MPa, respectively. The yield strength and the tensile strength for the stirrup were 607.4 MPa and 727.5 MPa, respectively.

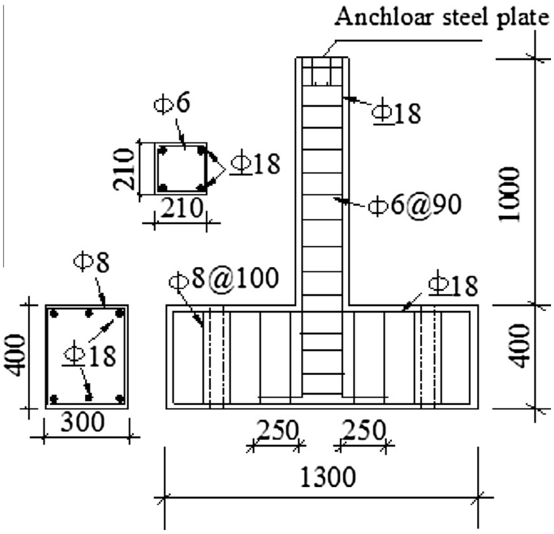

Fig. 1. Details for the specimens.

2.3. Corrosion

The electrochemical method was applied to the corrosion process, and a wrapping method replaced the traditional soaking method in order to simulate the condition of the tide region or the splash zone. The corrosion process was as following: at first, a layer of sponge with 30 mm thickness was wrapped on the specimen. Then stainless steel net was covered on the sponge. The third step was that the plastic film was coated on the stainless steel net in order to avoid the evaporation of the water. The sticky tape was used to fix the film. The 3–5% salt water was poured into the sponge every 2 h from the top of the specimen. It is ensured that the amount of corrosion of rebar is different between the upper and the lower part of specimen, as that salt water accumulated easily on the bottom of the specimen. Current stabilized power is used to provide a constant current. The rebar and the stirrup in the cantilever part were connected to the anode, while the stainless steel net was linked with the cathode. The steel bars in the footing were insulated from those steel bars from the cantilever part. The sketch of corrosion can be found in Fig. 2.

Faraday's law was used for the determination of the theoretical amount of corrosion η_m for the steel rebar, and the conduction time and the corrosion current intensity were two main controlling parameters. The two controlling parameters were recorded for every two hours interval during the corrosion process. The loss factor of 1.25 was employed here to consider the influence of the stirrup [3]. In the experiment, the electric current densities of 609 μA/cm^2 were employed and the similar value was applied to corroded RC columns of Lee et al. [9]. The stabilized current intensities were 2.1 A. The integrated corrosion time was two weeks, four weeks, six weeks and eight weeks for ZZ-2, ZZ-3, ZZ-4 and ZZ-5, respectively. The corrosion processes were ended after the specimens reached its theoretical amounts of corrosion.

2.4. Test

The constant axial load and the cyclic lateral displacement were conducted for each specimen. The loading device is shown in Fig. 3. Two Φ60 mm bolts were used to fixed the footing on the strong floor in order to prevent its rocking. The lateral cyclic displacement was conducted using a MTS testing system, and the vertical constant axial load was exerted by a hydraulic jack.

In order to observe the crack during the whole loading, the rule of lateral displacement which was 0 mm, 1 mm, 2 mm, 4 mm, 6 mm, 8 mm, 10 mm, 14 mm, 18 mm, 22 mm ..., was employed. A representative lateral cyclic load history is shown in Fig. 4.

Due to different cover thickness between in the cantilever part and in the footing, as well wrapping method, there should be differences of amounts of corrosion of steel bar in the specimen. The rebar and the stirrup were divided to four different regions to measure the amounts of corrosion, which are shown in Fig. 5. The first region was within 300 mm height area away from the bottom of the cantilever part, and the second region was within 600 mm height area away from the free end of the cantilever part. Other two regions were 334 mm height straight area and 250 mm bending area in the footing, respectively.

In order to obtain practical mass amount of corrosion η_s, the rebar and the stirrups were taken out of the specimens after the experiments. Then they were put into 10% diluted hydrochloric acid tank for approximate 15 min, and finally Ca (OH)$_2$ powder were spread into the tank for neutralizing the solution. After cleaning, drying and weighting, the practical average mass amounts of corrosion η_s of the rebar and the stirrups were calculated according to the equation,

$$\eta_s = \frac{(g_o - g)}{g_o} \tag{1}$$

where g_o is the weight of the original rebar, g is the weight of the rebar removing rusts.

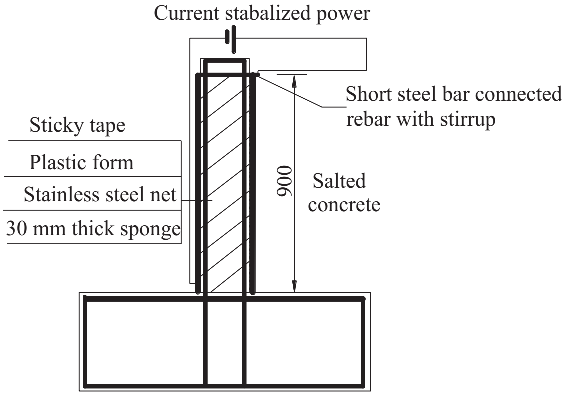

Fig. 2. Sketch of electronic chemical corrosion.