Research on restoring force model of concrete restrained by corroded stirrup

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Abstract. In order to establish a restoring force model considering rusted RC columns with stirrup, 8 inverted T-shaped RC columns were subjected to accelerated corrosion tests, and then to low-cycle reciprocating load tests. In view of the problems of strength decay and stiffness degradation caused by cumulative damage, the cyclic degradation index β_i was introduced to establish a restoring force model for RC columns after stirrup corrosion. By comparing the restored force model with the hysteretic curve of the test, the agreement is good, indicating that the restored force model has high accuracy and strong applicability, and can be used to clarify the hysteretic characteristics of RC column after the stirrup corrosion. The research results can provide theoretical basis for dynamic elastic-plastic analysis of rusted RC structures and reference for practical engineering applications.

Keywords: Stirrup corrosion; low-cycle reciprocating load test； Stiffness degradation; Intensity attenuation; Restoring force model

1 Introduction

In order to solve the problem of deformation resistance of structures subjected to reciprocating loads in earthquakes, a restoring force model was proposed. Based on low cyclic load test and extensive research on restoring force models, more competitive restoring force models are obtained. The folded line model can not only meet the actual accuracy requirements, but also be easy to use[1]. The accuracy of the curved model is higher than that of the broken line model, but there are shortcomings in the consideration of degradation factors[2]. For practical considerations, the broken line model has a wider application range, so this paper adopts the broken line restoring force model as the basis. The current study[3-8] lacks a reasonable description of strength attenuation and stiffness degradation under low-cycle reciprocating loads.

To solve the above problems, a three-fold model for calculating the skeleton curve of rusted RC columns with different stirrup corrosion rates and stirrup spacing was constructed based on the results of low-cycle reciprocating load tests. In view of the problems of strength decay and stiffness degradation caused by cumulative damage, the cyclic degradation index β_i was proposed, and a restoring force model was established

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considering the corrosion factors of stirrup. Finally, in order to verify the accuracy of the restoring force model.

2 Experimental Overview

2.1 Design and Fabrication of Test Specimens

In this experiment, 8 reinforced concrete column specimens were made. The effects of stirrup spacing and stirrup corrosion rate on the seismic performance of RC columns were considered. The detailed information is shown in Figure 1 and Table 1.

Table 1. Test Specimen Design Parameters

Specimen number	stirrup spacing	Average stirrups weight loss rate	Maximum stirrups weight loss rate
XRC-1	70 mm	—	—
XRC-2	70 mm	13.50%	17.63%
XRC-3	70 mm	21.45%	35.79%
XRC-4	70 mm	25.46%	42.77%
XRC-5	90 mm	13.58%	20.93%
XRC-6	90 mm	20.64%	29.54%
XRC-7	120 mm	22.68%	35.94%
XRC-8	120 mm	26.07%	52.42%

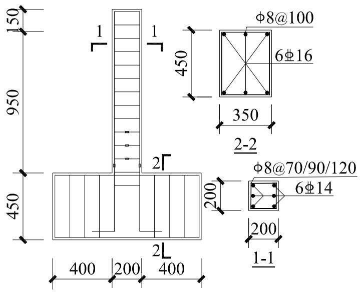


Fig. 1. Dimensions and Reinforcement Arrangement of the Test Specimen

2.2 Material Mechanical Properties

The concrete adopts C30 grade, and the compressive strength of concrete is 35.58 MPa. The mechanical properties of rebar are shown in the table2.

Table 2. Test Specimen Design Parameters

Steel bar type	Yield strength /f_y (MPa)	Ultimate strength /f_u (MPa)	Elongation
A8	390	500	25.5%
C14	480	590	18.8%

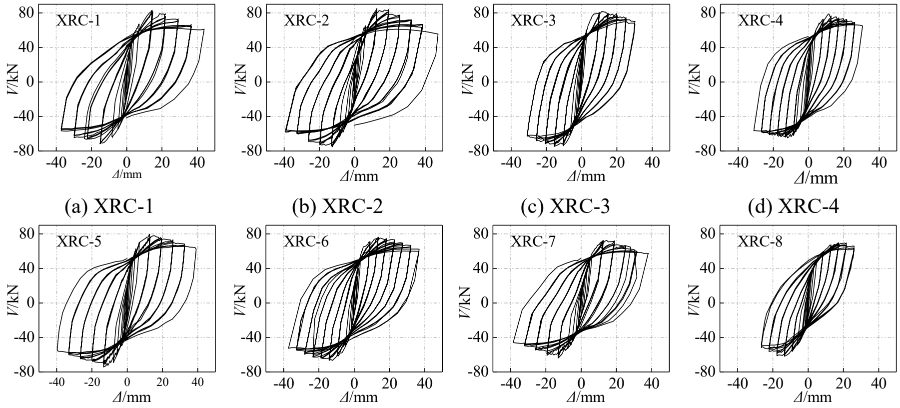
2.3 Test Loading Device and Protocol

The selective force and the moving force are controlled comprehensively. Fixed axial load 200kn, specified horizontal force load from the cylinder 15mm point. Horizontal load control is used to classify loads. 10 kN is used at level 1, and then reloaded into the loop control loop. Once the load drops to 70% of the peak load, the upload is stopped[9].

3 Restoring force model

3.1 Hysteresis curve analysis

Hysteresis curves of each specimen are shown in Figure 2.



(a) XRC-1 (b) XRC-2 (c) XRC-3 (d) XRC-4

(e) XRC-5 f) XRC-6 (g) XRC-7 (h) XRC-8

Fig. 2. Skeleton curve of specimen

The hysteresis curves of each specimen are given. The hysteresis characteristics of specimens with different stirrup spacing and corrosion rate under the same stirrup diameter are studied in this paper. By comparing and analyzing the characteristics of hysteretic curves of each specimen, the following rules can be obtained: In the process of cyclic load. For each cycle, the residual deflection increases with the increase of cycle frequency. When the stirrup corrosion is about 45% and the member is in the failure stage, the concrete protective layer is basically unable to function, the limiting ability of stirrup corrosion on the concrete in the central area is weakened, and the bearing capacity and stiffness of the specimen gradually decline. Under the action of the same displacement cycle. After yielding, as the stirrup ratio decreases, the bearing capacity of each specimen decreases, the stability of hysteresis ring deteriorates.

3.2 Building of restoring force model

According to this experimental study, both the yield strength and ultimate strength of the member under cyclic loading decrease to varying degrees, and the higher the corrosion rate, the more obvious the correlation is. Therefore, the cyclic degradation index β_i[10], which is considered from the perspective of energy dissipation, is introduced in this paper to characterize the structural strength attenuation and stiffness degradation.

$$\beta_i = \left[E_i/\left(E_t - \sum_{j=1}^{i-1} E_j\right)\right]^{1.5} \tag{1}$$

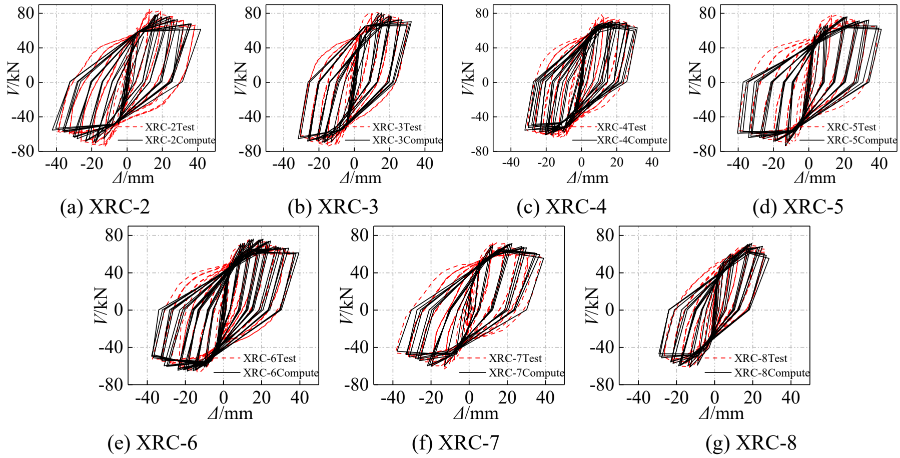
$$E_t = 2.5 I_u \left(F_y X_y\right) \tag{2}$$

$$I_u = \sum_{i=1}^{n} \frac{F_i X_i}{F_y X_y} \tag{3}$$

Where E_i is the hysteretic energy dissipation of the specimen during the i cycle; E_t is the hysteretic energy dissipation capacity of the specimen; I_u is the work ratio coefficient of the specimen; F_i represents the load at the unloading point during the i cycle, and X_i represents the displacement at the unloading point during the i cycle.

3.3 Restoring force model verification

As can be seen from Figure. 3, the model established in this paper can accurately describe the hysteretic characteristics of the rusted RC column.



(a) XRC-2 (b) XRC-3 (c) XRC-4 (d) XRC-5

(e) XRC-6 (f) XRC-7 (g) XRC-8

Fig. 3. Hysteresis curve verification

4 Conclusion

By analyzing the hysteresis curve and restoring force model of each specimen. This paper has built a restoring force model considering rusted RC columns with stirrup. The feature of this model is the introduction of cyclic degradation index β_i, which has the advantage of emphasizing cumulative damage effect, specifying strength attenuation and stiffness degradation. The hysteresis curve calculated by this model is compared with the experiment, which indicates that the restoring force model constructed in this paper has the characteristics of high precision.

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