



Study on the skeleton curve model of corroded stirrup confined concrete column

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Abstract. In order to establish a trilinear skeleton curve model of RC columns considering stirrup corrosion, accelerated corrosion tests were carried out on 8 inverted T-shaped RC columns, and then low-cycle reciprocating load tests were carried out. The influence of stirrup corrosion on the seismic performance of RC columns is analyzed by comparing the factors such as different stirrup spacing and corrosion rate. Combined with the characteristic point parameters of the skeleton curve of the uncorroded RC column, a three-line skeleton curve characteristic point calculation model suitable for the corroded RC column is obtained. The calculation results are compared with the experimental data, and the basic error range is within 6 %, indicating that the fitting formula has great accuracy.

Keywords: Stirrup corrosion; low-cycle reciprocating load test; skeleton curve; trilinear skeleton curve model.

1 Introduction

Structural members are affected by various factors such as environment and load in the design reference stage, which will inevitably cause a certain range of damage. The most common problem is that their appearance is corroded by chloride, resulting in a decrease in the seismic capacity of the members, thus damaging the overall safety^[1]. China is an area where earthquake disasters occur frequently and a large number of buildings are subject to environmental corrosion. A large number of studies have shown that^[2], steel corrosion is an important factor affecting the seismic performance of concrete structures. Therefore, in the concrete structure, the role of stirrups can not be ignored. It is of practical engineering significance to study the skeleton curve model of stirrups corroded concrete columns.

In view of the problem of resistance to deformation when the structure is subjected to reciprocating load in earthquake, scholars have proposed a trilinear skeleton curve model in the past. This model can not only meet the actual accuracy requirements, but also has small calculation difficulty and is easy to use^[3].

Therefore, based on the low-cycle reciprocating load test results of 8 RC columns with different stirrup corrosion rates and stirrup spacing, a trilinear model for calcu-

lating the skeleton curve of corroded stirrup RC columns is constructed. Finally, in order to verify the accuracy of the constructed trilinear skeleton curve model, it is compared with the experimental results, and the results are in good agreement.

2 Experimental Overview

2.1 Design and Fabrication of Test Specimens

In this experiment, 8 reinforced concrete column specimens were made. In this study, the effects of stirrup spacing and stirrup corrosion rate on the seismic performance of RC columns were considered. The design axial compression ratio of the specimen is 0.3. 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
RC-1	70 mm	—	—
GRC-2	70 mm	13.50%	17.63%
GRC-3	70 mm	21.45%	35.79%
GRC-4	70 mm	25.46%	42.77%
GRC-5	90 mm	13.58%	20.93%
GRC-6	90 mm	20.64%	29.54%
GRC-7	120 mm	22.68%	35.94%
GRC-8	120 mm	26.07%	52.42%

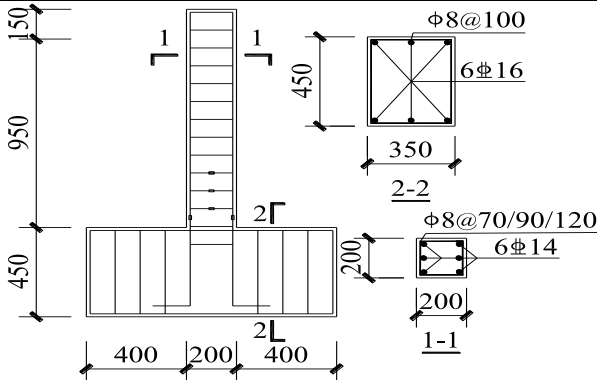


Fig. 1. Dimensions and Reinforcement Arrangement of the Test Specimen

2.2 Material Mechanical Properties

The concrete adopts C30 grade, and the compressive strength of concrete is 35.58 MPa. The yield strength of the stirrup with a diameter of 8mm is 390 MPa, the ultimate strength is 500 MPa, and the elongation is 25.5 %. The yield strength of the longitudinal

bar with a diameter of 14 mm is 480 MPa, the ultimate strength is 590 MPa, and the elongation is 18.8 %.

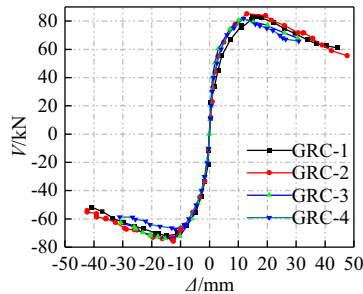
2.3 Test Loading Device and Protocol

The loading mode of the test process selects the hybrid control of force and displacement. Fixed axial load of 200 kN, 15 mm away from the top of the column is specified as the horizontal force loading point. First, the horizontal load control is used for graded loading. 10 kN is the first level, loaded until the specimen yields, and then the displacement control cyclic graded loading is used. After the load is reduced to 70 % of the peak load, the loading is stopped^[4], and the test is completed.

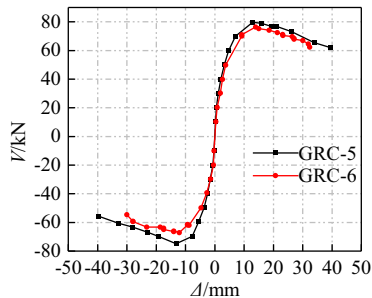
3 Skeleton curve model

3.1 Skeleton curve analysis

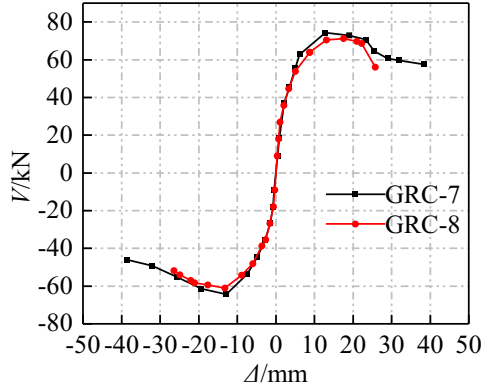
From the skeleton curve of each specimen in Fig.2, it can be seen that, it can be seen that: In the initial stage of loading, the corroded skeleton curve is basically overlapped with the uncorroded skeleton curve, indicating that the corrosion damage has no significant effect on the bearing capacity of the structure at this stage. When the loading continues, the constraint of the corroded stirrups gradually yielding on the core concrete is weakened. Therefore, the higher the corrosion degree of stirrups, the faster the yield, peak and ultimate load values decrease, and the weaker the seismic performance.



(a) Stirrup spacing 70mm specimen



(b) Stirrup spacing 90mm specimen



(c) Stirrup spacing 120mm specimen

Fig. 2. Skeleton curve of specimen

3.2 Establishment of Skeleton curve

The advantage of the degenerated trilinear restoring force model is that it can reflect the negative stiffness section of the compression-bending member^[4,5]. The main difference is that the characteristic points of the skeleton curve caused by the stirrup corrosion change, which affects the curve characteristics. According to the research direction of this paper, the three-line model can more accurately express the research content and model.

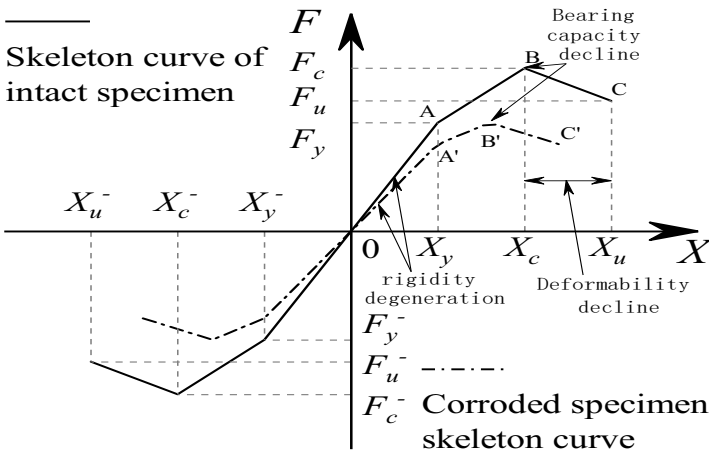


Fig. 3. Trilinear skeleton curve

According to Fig 3, yield load, displacement (F_y 、 X_y), ultimate load, displacement (F_c 、 X_c) and failure load, displacement (F_u 、 X_u), and determine the parameters according to the method of Reference^[6].

$$F_y = (0.14x^2 - 0.351x + 1.007)F_y^{\wedge} \quad (1)$$

$$X_y = (2.325x^2 - 1.428x + 0.999)X_y^{\wedge} \quad (2)$$

$$F_c = (-1.069x^2 + 0.505x + 0.997)F_c^{\wedge} \quad (3)$$

$$X_c = (1.458x^2 - 0.885x + 0.996)X_c^{\wedge} \quad (4)$$

$$F_u = 0.85F_u^{\wedge} \quad (5)$$

$$X_u = (-0.902x^2 - 0.635x + 1.021)X_u^{\wedge} \quad (6)$$

All are the yield load, displacement (F_y^{\wedge} , X_y^{\wedge}), ultimate load, displacement (F_c^{\wedge} , X_c^{\wedge}) and failure load, displacement (F_u^{\wedge} , X_u^{\wedge}) of uncorroded specimens.

3.3 Skeleton curve model validation

Comparing the test values and calculated values of the load and displacement feature points of each specimen, see Table 2, Table 3.

Table 2. Load characteristic points of each specimen

Specimen number	Yield load (kN)			Ultimate load (kN)			Failure load (kN)		
	Test	Calculated	error	Test	Calculated	error	Test	Calculated	error
GRC-2	65.00	63.62	0.02	78.29	78.11	0.00	66.55	66.39	0.00
	-60.48	-60.60	0.00	-67.78	-67.93	0.00	-57.61	-57.74	0.00
GRC-3	60.00	60.25	0.00	78.35	77.22	0.01	66.60	65.64	0.01
	-57.59	-57.39	0.00	-67.80	-67.15	0.01	-57.63	-57.08	0.01
GRC-4	59.44	59.13	0.01	76.91	75.48	0.02	65.37	64.16	0.02
	-55.66	-56.32	0.01	-65.50	-65.64	0.00	-55.68	-55.79	0.00
GRC-5	63.74	62.96	0.01	78.98	78.34	0.01	67.13	66.59	0.01
	-59.79	-59.97	0.00	-68.66	-68.13	0.01	-58.36	-57.91	0.01
GRC-6	60.00	61.34	0.02	77.78	78.11	0.00	66.11	66.39	0.00
	-58.61	-58.43	0.00	-67.34	-67.93	0.01	-57.24	-57.74	0.01
GRC-7	60.69	60.23	0.01	76.71	77.19	0.01	65.20	65.61	0.01
	-56.76	-57.37	0.01	-66.35	-67.13	0.01	-56.40	-57.06	0.01
GRC-8	58.85	57.72	0.02	71.16	71.82	0.01	60.49	61.05	0.01
	-54.44	-54.98	0.01	-62.39	-62.46	0.00	-53.03	-53.09	0.00

Table 3. Displacement characteristic points of each specimen

Specimen number	Yield displacement (mm)			Ultimate displacement (mm)			Failure displacement (mm)		
	Test	Calculated	error	Test	Calculated	error	Test	Calculated	error
GRC-2	6.07	6.02	0.01	13.02	13.09	0.01	27.54	25.82	0.06
	-6.71	-6.68	0.00	-12.82	-13.11	0.02	-23.38	-22.54	0.04
GRC-3	5.87	5.77	0.02	12.83	12.81	0.00	21.08	19.88	0.06
	-6.42	-6.41	0.00	-12.77	-12.83	0.00	-16.81	-17.35	0.03
GRC-4	6.09	5.98	0.02	13.24	13.07	0.01	18.33	17.33	0.05
	-6.36	-6.64	0.04	-13.06	-13.09	0.00	-16.67	-15.95	0.04
GRC-5	5.83	5.89	0.01	12.95	12.94	0.00	24.94	24.87	0.00
	-6.41	-6.54	0.02	-13.20	-12.96	0.02	-21.42	-21.71	0.01
GRC-6	5.68	5.73	0.01	12.77	12.75	0.00	20.38	21.62	0.06
	-6.47	-6.37	0.02	-12.68	-12.77	0.01	-19.57	-19.31	0.01
GRC-7	5.56	5.78	0.04	12.89	12.81	0.01	17.26	18.82	0.09
	-6.71	-6.41	0.05	-12.81	-12.83	0.00	-16.38	-17.30	0.06
GRC-8	6.59	6.54	0.01	13.87	13.8	0.01	11.1	12.12	0.09
	-7.21	-7.26	0.01	-13.63	-13.82	0.01	-12.42	-11.26	0.09

The calculation results of the feature points of the skeleton curve are compared with the experimental data, and the error range is within 6 %, indicating that the fitting formula has great accuracy.

4 Conclusion

The analysis of the skeleton curves of each specimen shows that : (1) The corrosion rate of stirrups is small (less than 15 %). Compared with the intact specimen, the skeleton curve basically coincides with the intact specimen. For columns with severe stirrup corrosion (more than 30 %), the higher the degree of corrosion, the more obvious the strength and stiffness degradation of the skeleton curve. (2) On the basis of the experimental results, the calculation method of the characteristic points of the skeleton curve of the RC column with stirrup corrosion is established and compared with the experimental values. The maximum deviation is 9 %, and the basic error range is within 6 %, indicating that the calculation formula has a high accuracy. (3) This model can lay a foundation for the seismic performance of RC structures with corroded stirrups.

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