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Experiment on Restoring Force Model of RAC Beam Column Joints

Chao Liu[a,b,*], Huawei Liu[a], Chao Zhu[a], Zhenyuan Lv[a], Zonggang Quan[c], Guangming Fu[c]

[a]Xi'an University of Architecture and Technology, Xi'an 710055, China
[b]Xi'an Engineering Research Center, Xi'an 710055, China
[c]Xi'an Research & Design Institute of Wall & Roof Materials, Xi'an 710000, China
chaoliu@xauat.edu.cn

The purpose of this paper is to analyze component failure mode under different working conditions and based on this, this paper mainly studies the restoring force model of RAC beam column joints by carrying out an experimental research on the restoring force model of four frame beam column joints with different axial compression ratio (1.5, 2.5) and different recycled coarse aggregate substitution rate (0%, 50%, 100%). The analysis of the result of the experiment shows that the failure process of the RAC beam column joints was similar to that of the common concrete joints, and both experienced four stages of initial crack-crack-limit-failure. Through a comparative analysis of the characteristics of the hysteresis curve and the skeleton curve of the RAC beam column joints, and based on experimental data fitting and theoretical analysis and calculation, the restoring force skeleton curve model of the RAC beam column joints with different substitution rates and the restoring force model of the RAC beam column joints with rigidity degradation law were established.

1. Introduction

The performance of recycled concrete has been widely studied (Liu and Leng, 2007; Li and Song, 2008; Li et al., 2008; Xiao et al., 2008). As a green material, the recycled concrete not only can consume building rubbish and turn the building rubbish into treasure, but also can realize the cyclic development of building material recycling. However, less research has been done on the application in the structure, especially the application of the recycled concrete in areas where seismic fortification is required (Hu and Lu, 2012; Guo and Zhou, 2003). Since earthquake is a kind of cyclic reciprocating motion, the beam column joints of RAC (Recycled aggregate concrete) have to bear the impact of reciprocating load. Therefore, the restoring force model of the RAC beam column joints is proposed to more deeply study elastic and plastic properties, joint strength and rigidity degradation law of the internal force of the beam column joints in low cycle reciprocating load.

At present, domestic and overseas scholars have studied the restoring force model of different types of specimens, such as common concrete beams, columns and joints (Liu et al., 2018; Liu et al., 2013). However, the traditional restoring force model is no longer suitable for recycled concrete structures. Based on the hysteretic curve and the skeleton curve of the RAC beam column joints under different coarse aggregate substitution rates in combination with the experimental research of the RAC beam column joints and theoretical analysis and experiment fitting, this paper put forward the restoring force model of the RAC beam column joints.

2. Methods

2.1 Material properties

In this experiment [9], the recycled coarse aggregate is selected from Xinshengyuan Muck Recycling Co. LTD. Its composition and index of the material properties are shown in Tables 1-3 in detail.

Table 1: Recycled aggregate composing component

Raw material pebbles (%)	Secondary aggregates (%)	Mortar blocks (%)	Impurities (%)
35	56	7	2

Table 2: Material property contrast table of recycled aggregate and natural aggregate

Aggregate type	Apparent density(kg/m3)	Bulk density(kg/m3)	Compact density (kg/m3)	Crush index (%)	Water absorption (%)	Moisture content (%)	
						Maximum and minimum	
Recycled aggregate	2601	1314	1459	18.3	4.67	5.86	2.53
Natural stones	2658	1438	1593	10.6	0.69	0.94	0.35

Table 3: Mechanics performance of reinforcement (HRB335)

Type of steel bar	Elongation	Yield stress (MPa)	Limit stress(MPa)	Elasticity modulus(MPa)
□22	1.31	342	544	2.0×10^5
□20	1.30	360	552	2.0×10^5
□16	1.25	363	559	2.0×10^5
□8	1.19	—	545	2.0×10^5

2.2 Specimen design

In the experiment, four RAC beam column joints were designed, the substitution rates of the recycled coarse aggregate thereof are 0%, 50% and 100% respectively, and the specimen size and reinforcement are the same, as shown in Figure 1. Specimens are designed with a strength grade of concrete of C35, the mix ratio is shown in Table 4. Strength of the test block meets the requirements.

Table 4: Quality mixture ratio of concrete and compressing strength result

T specimen	substitution rates of recycled aggregate (%)	Quality mix ratio cement: water: sand: natural aggregate: recycled aggregate	Cube compressive strength $f_{cu,m}$ (Mpa)	Axial compressive strength f_{cu} (Mpa)	Axial compression ratio
J-0	0	475: 163: 540: 1180:0	50.18	33.56	1.5
J-50	50	475: 184: 540: 590: 590	50.89	34.03	1.5
J-100-1	100	475: 203: 540: 0: 1180	44.79	29.95	1.5
J-100-2	100	475: 203: 540: 0: 1180	44.62	29.84	2.5

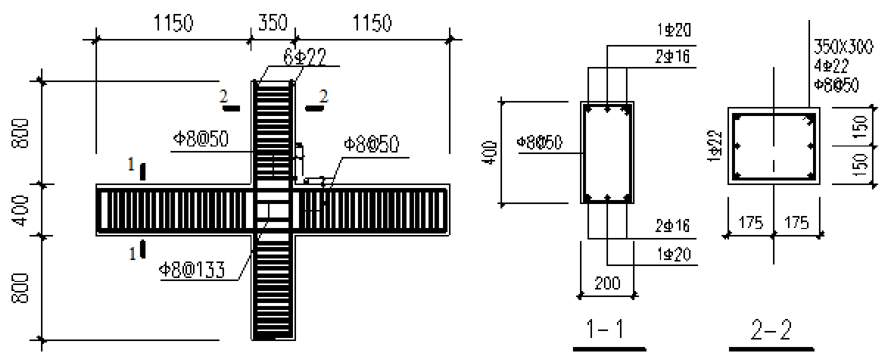


Figure 1: Dimensions and reinforcement details of specimens

2.3 Experiment plan

In order to study the seismic property of RAC beam column joints under a horizontal earthquake action, the quasi-static loading scheme was adopted in this experiment. The beam column joint model was completed on a 12.5m high two-way L-shaped reaction wall-pedestal..

3. Results

3.1 Loading process and failure

It can be seen from the experiment results that the failure process of the RAC beam column joints with substitution rates of 50% and 100% was similar to that of the common concrete beam column joints, that is, they both experienced four stages of initial generation of cracks, crack development, ultimate load and specimen destruction: 1) at the initial stage of loading, due to the small load, the specimen joint was in an elastic state; when the load was increased, the first crack appeared on the beam end surface near the core area of the joint, and then more cracks spread to the core area of the joint; 2) As the experiment was carried on, a number of diagonal cracks intersecting with each other appeared in the core area of the joint, wherein a pair of diagonal cracks going through the core diagonal of the joints were main diagonal cracks; 3) after the main diagonal cracks were formed, the load was increased continuously and the cracking of the cracks in the core area was aggravated and the specimen joints were in a plastic state, at this moment, the bearing capacity reaches a peak value; 4) the load remained unchanged, the displacement was increased, and the concrete on the surface of the core area was damaged, the bearing capacity decreased, and the joints were destroyed.

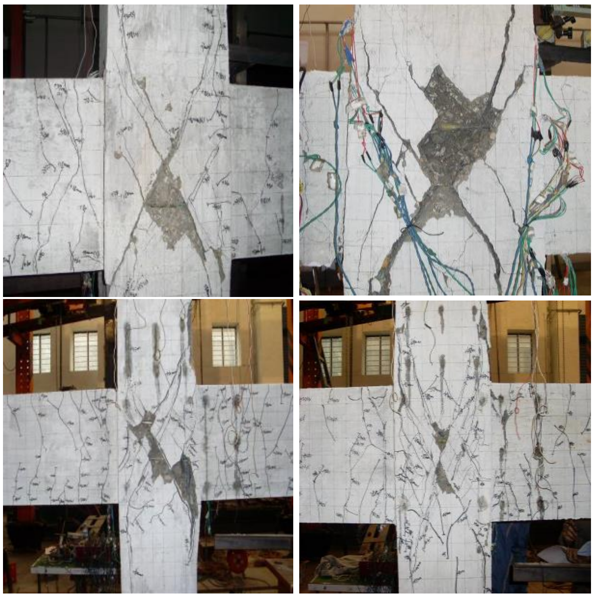


Figure 2: Failure mode of joints

3.2 Load--displacement hysteretic curve

Figure 3 shows a load-displacement hysteretic curve of four beam column joints. It can be seen from the figure that at the initial stage of loading in the experiment, hysteretic curve was almost cycling along a straight, at this moment, the beam column joints were in an elastic state; when a yield was reached, cracks appeared in the joints and larger residual deformation appeared. After the specimen yielded, the method for loading was changed and was controlled by the displacement; the hysteretic curve drew close to the horizontal displacement axis, and the rigidity, strength and energy-dissipating capacity of the joints were degraded accordingly.

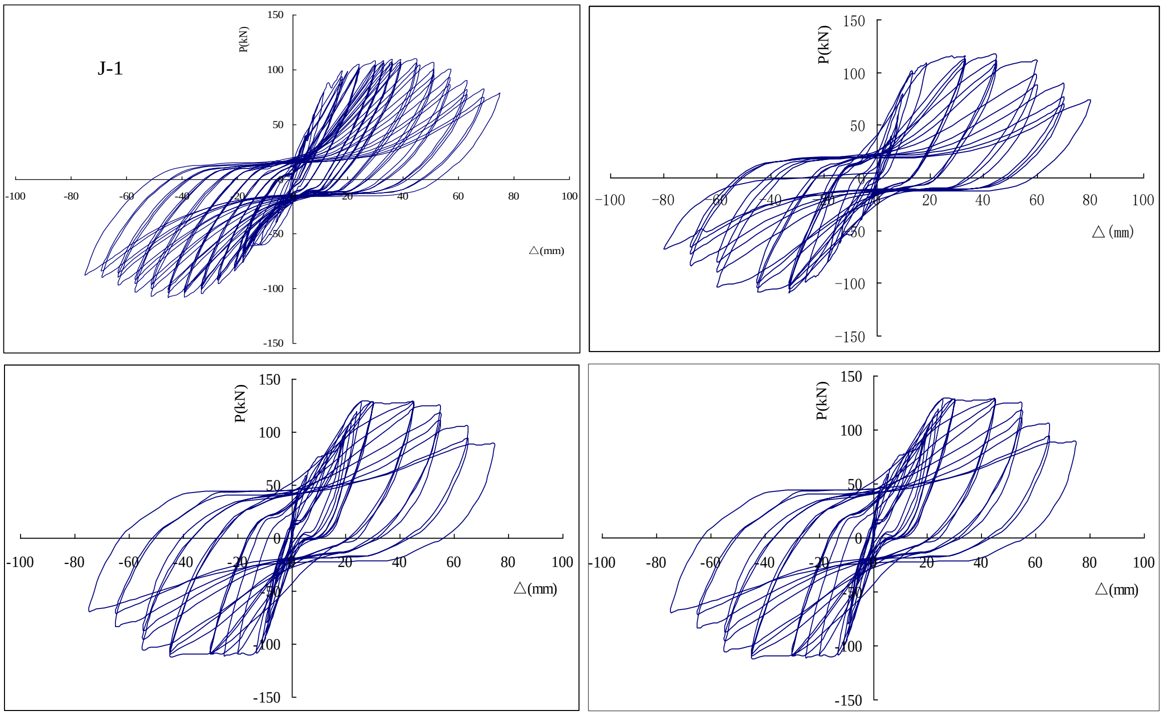


Figure 3: Hysteretic curves

3.3 P-∆ restoring force model of RAC beam column joints

3.3.1 Rigidity degradation law

By analyzing the hysteresis and skeleton curves obtained in the experiments, it was found that the loading rigidity and unloading rigidity of the specimens were all degraded. Without consideration of the influence of rheostriction effect in the hysteresis curve, and according to the hysteresis curve obtained from the experimental study, this paper provided rigidity degradation law of loading and unloading state under the cyclic load action.

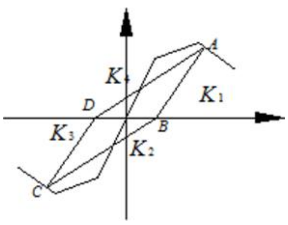


Figure 4: Rigidity in different stages

Before yielding, the specimen was in an elastic state, and the unloading rigidity and loading rigidity were the same, and the rigidity was degraded after yielding. According to the characteristics of repeated loading, the hysteresis loop was divided into four sections, and correspondingly the rigidity of the specimen was divided into four stages to study. Figure 4 shows the rigidity of the forward unloading stage K1 (AB section), the rigidity of the reverse loading stage K2 (BC section), the rigidity of the reverse unloading stage K3 (CD section) and the rigidity of the forward loading stage K4 (DA section). According to the analysis of scatter regression of the hysteresis curve, the rigidity degradation law of the four stages can be derived. Here the rigidity referred to secant rigidity of loading (unloading) point.

(1) Degradation law of forward unloading rigidity K1

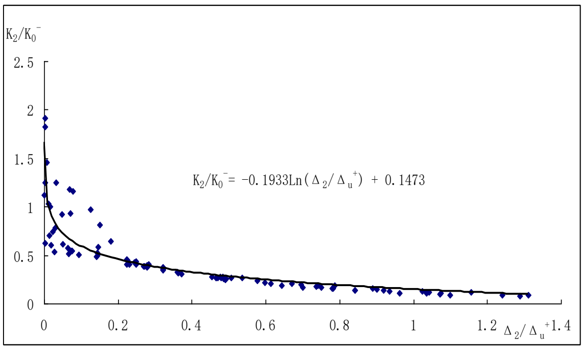
As shown in Figure 5, the line segment AB represented that AB was obtained by connecting the forward unloading point A to the point B at which the unloading force was zero along the unloading line segment in the forward direction. Its slope was the forward unloading rigidity K1 of the specimen. A relation curve between K1/K0+ and Δ1/Δu+ can be obtained through regression analysis. K0+ represented elastic rigidity of the joint under forward loading, and Δ1 represented the displacement corresponding to the forward unloading. The mathematical equation for the forward unloading rigidity degradation curve was:

$$K_1/K_0^+ = -0.53\ln(\Delta_1/\Delta_u^+) + 0.43 \quad (1)$$

(2) Degradation law of reverse loading rigidity K2

The reverse loading line segment BC was obtained by connecting the forward loading residual point B and the reverse unloading point C, its slope was the reverse loading rigidity K2 of the specimen, and it was related to the number of cycles of the specimen horizontal load, residual deformation Δ2 generated during forward unloading and initial rigidity of reverse loading; through regression analysis, a relation curve (Figure 6) between K2/K0- and Δ2/Δu+ can be obtained, wherein K0- represented the initial rigidity during reverse loading. The mathematical equation of reverse loading rigidity degradation curve was:

$$K_2/K_0^- = -0.19\ln(\Delta_2/\Delta_u^+) + 0.15 \quad (2)$$



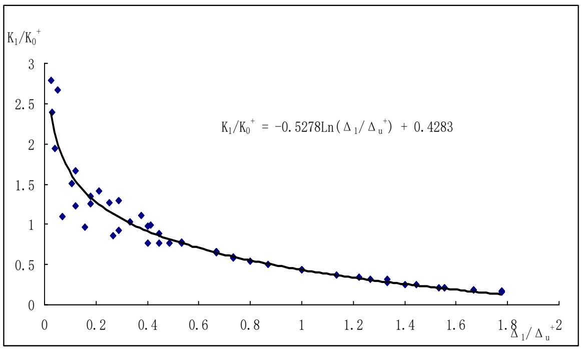


Figure 5: Forward unloading rigidity degradation curve

Figure 6: Reverse loading rigidity degradation curve

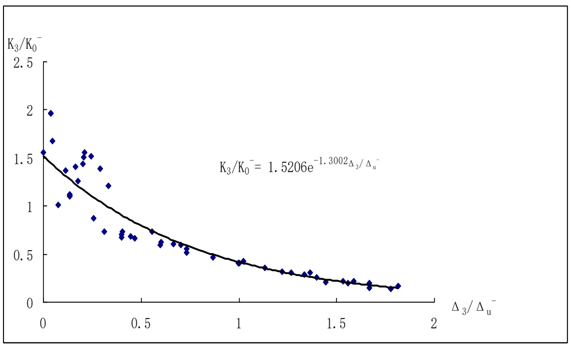
(3) Degradation law of reverse unloading rigidity K3

The reverse unloading line segment CD was obtained by connecting the reverse unloading point C and unloading-to-zero point D, its slope was the reverse unloading rigidity K3 of the specimen. A relation curve (Figure7) between K3/K0- and Δ3/Δu+ can be obtained through regression analysis., where Δ3 represented the displacement corresponding to the reverse unloading. The mathematical equation of reverse unloading rigidity degradation curve was:

$$K_3/K_0^- = 1.52e^{-1.3\Delta_3/\Delta_u^-} \quad (3)$$

(4) Degradation law of forward loading rigidity K4

The forward loading line segment DA was obtained by connecting the reverse unloading residual point D and the forward unloading point A, its slope was the forward loading rigidity K4 of the specimen. A relation curve (Figure 8) between K4/K0+ and Δ4/Δu+ can be obtained through regression analysis., where Δ4 represented the displacement corresponding to the reverse unloading to zero. The mathematical equation of forward loading rigidity degradation curve was:



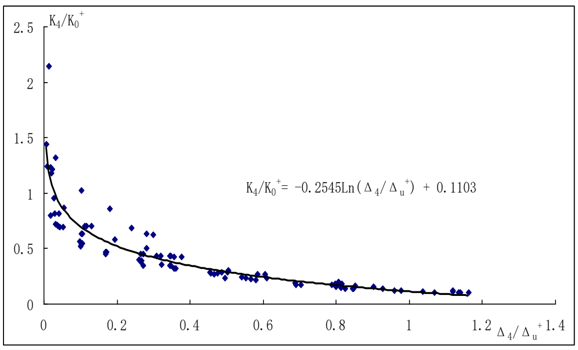


Figure 7: Reverse unloading rigidity degradation curve

Figure 8: Forward loading rigidity degradation curve

$$K_4 / K_0^+ = -0.25 \ln(\Delta_4 / \Delta_u^-) + 0.11 \quad (4)$$

4. Conclusion

Through an experimental research on the quasi-static anti-seismic property of the joints in the RAC beam column, this paper conducts a comparative analysis on the difference in anti-seismic property of beam column joints between recycled concreate with different substitution rates and common concrete, and puts forward restoring force model of RAC beam column joints in combination with experiments. Through a comparison between theoretical analysis and experimental results, the following conclusions can be drawn:

(1) Under the action of low cyclic repeated loading, similar to the common concrete beam column joints, the RAC beam column joints have undergone four stages: elastic stage, elastic-plastic stage, plastic stage and final failure.

(2) The anti-seismic property of the joints shows difference under different axial compression ratios. In particular, the anti-seismic property of the RAC beam column joints is inferior to common concrete, but can still be applied to buildings in areas with seismic fortification requirements through reasonable design.

(3) It should be pointed out that the restoring force model of RAC beam column joints with different substitution rates under repeated loading is a complicated issue. Factors such as the external load applied during the experiment, the reinforcement of the specimen and the earthquake effect actually produced will all have impacts on the restoring force model. Therefore, there is a need to further conduct a deep study on relevant research on the RAC beam column joints.

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