Experimental study on seismic behavior of recycled concrete filled square steel tubular column and steel beam joints with reinforcing ring

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Abstract. In order to study the influence of strengthening ring on the seismic performance of the recycled concrete filled steel tubular column and steel beam joints. In this paper, reinforcement ring, reinforcing ring extending length, thickness as the test parameters, a total of 4 recycled concrete filled square steel tubular columns and steel beam composite joints were designed and manufactured on this experiment. And the low cycle repeated load test is carried out to study the failure process and characteristics of this kind of joints, hysteretic curve, bearing capacity, ductility and so on. The results show that: strengthen ring can effectively limit the joint core area of steel pipe drum deformation, improve the joints seismic bearing capacity, deformation behavior and hysteretic curve of the full extent of the node; Weld quality has great influence on recycled concrete filled square steel tubular columns and steel beam composite joints. In a certain range, with the strengthening ring overhanging length increases, hysteresis curves are more full and the seismic bearing capacity will also increase, and the ductility coefficient will decrease, but reduced amplitude is relatively small; The thickness of the strengthening ring has little influence on the seismic performance of the joints.

Introduction

It’s well known that our country is an earthquake-prone country and frequent earthquakes each year brings to our country a serious loss of life and property [1]. Numerous studies show that a large part of the earthquake damaged houses is due to the destruction of the beam-column joints [2,4]. Therefore, to design the beam-column joints which has good seismic performance is particularly important. To the end, domestic and foreign scholars have proposed a lot of Concrete filled steel tubular column-Steel beam joint and do research [5,9]. The results show that this type of node has good seismic performance. At the same time, with people's awareness of environmental protection and the pursuit of sustainable development, many scholars try to fill the recycled concrete into the steel pipe then form of recycled concrete structure [10,11]. On the basis of this background, this article conduct research on the seismic performance of joints of the recycled concrete-filled square tubular column-steel beam with reinforcement ring to provide experimental and theoretical basis for the improvement and optimization of such nodes.

Test survey

Design and Production of Test Specimen. A total of 4 recycled concrete filled square steel tubular columns and steel beam composite joints were designed and manufactured on this experiment. The relevant design parameters and dimensions are shown in Table 1 and Fig. 1. The column is filled with square steel tubular column and the replacement rate of recycled concrete was 100% .The mechanical properties of steel and concrete are shown in Table 2.

Loading System and Loading Device. Load and displacement mixed control loading mode is used in this experiment. First of all, the constant axial force is applied at the top of the column according to the determined axial compression ratio by hydraulic jacks. Then, through the 25t electro-hydraulic servo as actuator to the end of column applied horizontal low cyclic loading. At the beginning of loading by load control method of grading loading, each level 5kn, each load cycle once, until the entire component yield. Then the displacement controlled loading is used to the test, displacement increment is yield displacement Δ multiples, each load cycle three times, until the load down to 85% of the maximum load or cannot continue loading when the end of the experiment. The loading device is shown in Fig. 2.

Table 1 The design parameters of specimens

Trial Part Number	Column cross section (mm)	Beam cross section (mm)	Thickness of strengthen ring (mm)	Extended length of reinforcing ring(mm)	Axial compress ion ratio n	Axial force N(kN)
JD1-0-0	150×150×6	I 18	0	0	0.25	400
JD2-10-50	150×150×6	I 18	10	50	0.25	400
JD3-10-100	150×150×6	I 18	10	100	0.25	400
JD4-15-100	150×150×6	I 18	15	100	0.25	400

Note: strengthen ring thickness and overhang length for 0 represents the nodes without stiffening ring, column section dimensions: length ×length × thickness, the thickness of thick wall steel pipe; axial compression ratio $n=N/(A_c f_c+A_s f_y)$

Table 2 Material properties of steel and concrete

Material	Species	yield strength $f_y(\mathrm{N\cdot mm^{-2}})$	ultimate strength $f_u(\mathrm{N\cdot mm^{-2}})$	modulus of elasticity E/MPa	Cube compressive strength $f_{cu}(\mathrm{N\cdot mm^{-2}})$
Steel pipe	Q235	275	416	1.9×10^5	——
Steel beam(flange)	Q235	330	390	2.18×10^5	——
Steel beam(plate)	Q235	313	345	2.07×10^5	——
Concrete	C50	——	——	3.55×10^4	56

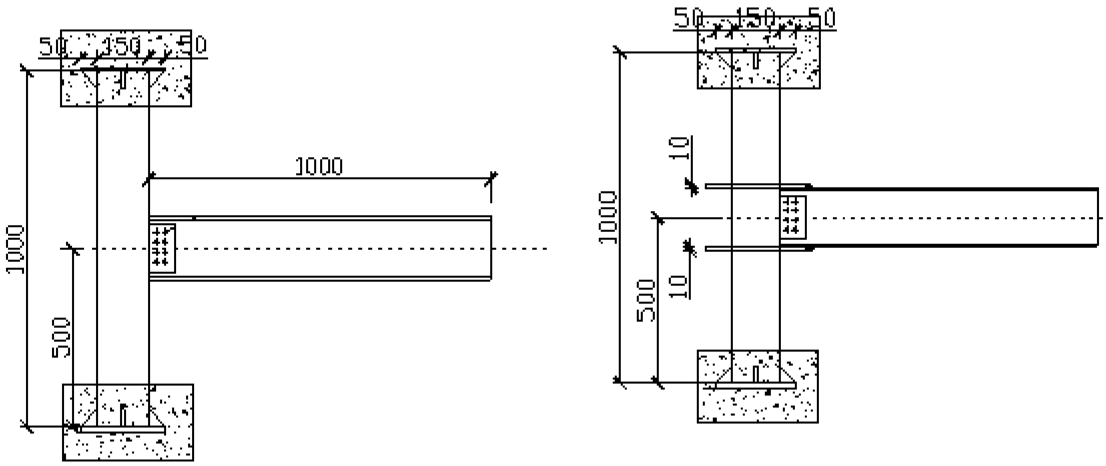

Fig. 1 The shape figures of the specimen

Fig. 2 Loading device

Test Results and Analysis

Failure Process and Damage Form. In the load control stage, the test pieces are in the elastic working stage, there are no obvious signs of deformation and failure, and then enter the stage of displacement control.JD1-0-0 test piece of non reinforcing ring,in the 2Δ first cycle control bit, the yield phenomenon occurred in the flange of the steel beam near the wall of the steel tube. With the increasing of load displacement, yield point increased.in the 3Δ second cycle control bit, node area began to appear in the yield.In the 6Δ first cycle, deformation zone node of steel tube drum, steel web yield, weld slight crack, and specimen damage.For JD2-10-50, JD3-10-100, JD4-15-150, due to the presence of strengthening ring hoop function, the test node region of steel drum did not occur, and close to the strengthening ring at the flange of the steel beam yield firstly, then the web yield. But JD2-10-50 JD3-10-100 respectively in 2Δ in the third cycle and 3Δ in the first cycle and strengthen ring began to wave drum, then respectively in 3Δ in the third cycle and 4Δ in the first cycle and steel beam flange and strengthen ring weld was torn, specimen bearing force suddenly reduces brittle failure, and JD4 -15-150 destruction forms of 5Δ beam buckling of web plate and steel beam flange local buckling failure mode. The specimen failure mode are shown in Fig. 3.

From the failure process and failure mode can be seen: strengthen the rings in the presence of core area of joint deformation has obvious constraints, it can effectively limit the node area of steel pipe drum deformation; In addition, the weld quality has great influence on recycled concrete filled square steel tubular columns and steel beam composite joints.

(a) JD1-0-0 (b) JD2-10-50 (c) JD3-10-100 (d) JD4-15-150

Fig. 3 Failure mode of the specimens

The Hysteretic Curves. For all the tested elements, the lateral loads (P) versus lateral displacement (Δ) hysteretic curves gotten experimentally shown in Fig. 4. As seen in Fig. 12, the hysteretic curves of all specimens gotten experimentally are spindle-shaped, indicating that recycled concrete filled square steel tube column-steel beam joint with good seismic performance and energy dissipation capacity. The hysteresis curve of JD2-10-50, JD3-10-100 and JD4-15-150 was significantly plumper than that of JD1-0-0, which fully demonstrates the presence of the reinforcement ring can greatly improve the seismic node energy dissipation capacity and deformation capacity. With the increase of the length of reinforcing ring, the hysteresis curve was getting more and more plump. However, The thickness of the ring did not significantly affect the hysteresis curve.

The Envelope Curves. The P–Δ envelope curves, which were engendered by connecting the peak point of each loading cycle on the hysteretic curves, are also shown in Fig. 4. As seen in Fig. 4, the peak load of JD4-15-100, JD3-10-100 and JD2-10-50 was far greater than that of JD1-0-0, it showed that the reinforcing ring can significantly enhance seismic bearing capacity of the nodes. Within a certain range, bearing capacity was increased with increase of the length of the ring while the thickness of the ring has no significant impact.

Bearing capacity and deformation capacity. The eigenvalue of each specimens are shown in Table 3. Yield load P_y and yield displacement Δ_y are solved using energy equalization method [12].

The initial defect of specimen and other reasons, led to the asymmetric bearing capacity of forward and backward during the loading process. For analyses convenient, unify to take the specimen forward loading bearing capacity to carry out comparative analysis, seen from the values in the table:

(1) The yield load of JD2-10-50, JD3-10-100 and JD4-15-100 are respectively 2.2, 2.8 and 3.3 times of JD1-0-0, the peak load are respectively 2.1, 2.8 and 2.9 times of JD1-0-0. Therefore, stiffening ring can greatly improve the seismic bearing capacity of the joints. The yield load and the peak load of JD3-10-100 is respectively 1.26, 1.36 times of JD2-10-50; The yield load and the peak load of JD4-15-100 is respectively 1.17, 1.02 times of JD3-10-100. Therefore, in a certain range, the seismic bearing capacity of the joints increases with the stiffening ring length increase, whereas subject to less thickness influence.

(2) The forward yield displacement of JD2-10-50, JD3-10-100 and JD4-15-100 are respectively 2.0, 1.8 and 1.7 times of JD1-0-0, the backward yield displacement are respectively 2.01, 1.72 and 1.64 times of JD1-0-0. Thus, stiffening ring can greatly improve the elastic deformation of specimen.

(3) In addition to the ductility factor of JD1-0-0 is less than 3, the ductility factor of the remaining3 specimens that add stiffening ring joints are all more than 3. So, stiffening ring can greatly improve the deformation capacity of specimen. But, overall, the length and thickness of the stiffening ring don't have a significant effects on the ductility factor of the joints.

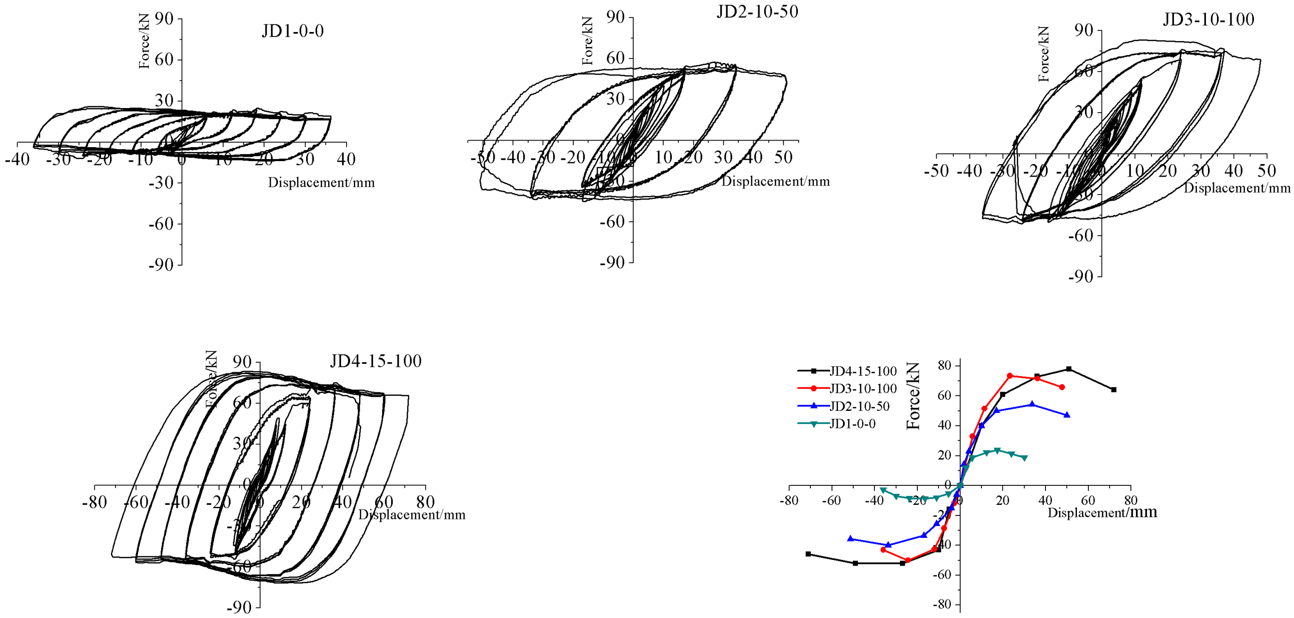

Fig. 4 The hysteretic curves and the skeleton curves of specimens

Table 3 Main eigenvalue of specimen skeleton curve

Specimen No.	Direction	Yield point		Peak point		Limit point		Ductility factor	μ mean value
		P_y(kN)	Δ_y(mm)	P_u(kN)	Δ_u(mm)	P_m(kN)	Δ_m(mm)	$\mu=\Delta_m/\Delta_y$	
JD1-0-0	+	19.3	6.88	26.3	36.17	22.4	20.59	2.99	2.96
	-	6.5	7.76	9.9	23.80	8.4	22.69	2.92	
JD2-10-50	+	42.4	13.60	54.3	33.70	46.2	50.57	3.72	3.43
	-	30.6	15.61	43.4	33.71	36.9	48.96	3.14	
JD3-10-100	+	53.7	12.65	73.6	35.71	65.8	47.75	3.77	3.21
	-	43.4	13.38	50.0	24.62	48.9	35.46	2.65	
JD4-15-100	+	62.9	11.46	75.0	36.16	63.7	42.55	3.71	3.47
	-	45.7	12.71	52.8	27.87	51.1	40.93	3.22	

conclusions

(1) Strengthening rings in the presence of recycled concrete-filled square steel tube column and steel beam joint core zone of deformation has obvious constraints, and it can effectively limit the node area of steel pipe drum deformation; Weld quality of recycled concrete-filled square steel tube column and steel beam joints has an important influence on failure process and form.

(2) In a certain range, with the strengthening ring overhanging length increases, hysteresis curves are more full, and strengthen the cyclic variations in thickness has not significantly affect on the hysteretic curve of degree of satiation.

(3) In a certain range, the seismic bearing capacity of the recycled concrete-filled steel tubular column and steel beam joints can be significantly improved.

(4) The existence of the reinforcing ring can significantly improve the deformation behavior ofrecycled concrete-filled square steel tube column and steel beam joints. However, the influence of the length and thickness of the ring on the ductility coefficient of the joints is not great.

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