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Contrast Experimental Analysis of Seismic Performance of Steel Beam Node and Rectangular Steel Tube Recycled Concrete Beam Node

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Abstract. The context makes pseudo-static test of two square steel tube recycled concrete column - steel beam nodes and two square steel tube recycled concrete column-rectangular steel tube recycled concrete beam nodes, taking axial compression ratio and beam column linear stiffness ratio as experimental parameter, and studies the characteristics and mechanisms of destruction, hysteresis curves, ductility and stiffness degradation and other seismic performance. The results showed that, compared with the steel beam joint, hysteresis curve of rectangular steel tube recycled concrete beam nodes are fuller, its energy dissipation capacity is relatively strong, its displacement ductility factor can reach 4.32, but the beam joint only can reach 3.51, so its ductility and deformation capacity are pretty good, the degree of stiffness degradation is smaller. As we can know, the seismic performance of rectangular steel tube girder recycled concrete beam node is better than that of steel beam node, it is worthy of further promotion applications.

Keywords: Recycled concrete filled steel tube beam joint; seismic performance; energy dissipation; ductility; stiffness degradation.

1. Introduction

The frame node is the most key part of the frame connection, its mechanical model and failure characteristics are more complicated than the beams and columns in general, especially in the strong earthquake, after the frame structure entering elastic-plastic stage, nodes plays an important role in the stability of the structure and integrity [1-4]. Therefore , failure mechanism and seismic performance of the node should be given enough attention.

At present, the domestic and foreign experts and scholars made some research on the stress of the frame node performance[5-9], get some useful results, but relatively fragmented, and contrast analysis of the mechanical properties of various nodes is more rare. In this paper, on the basis of home and abroad analyzing and summarizing the status of research[10-11], and application on the concrete filled square steel tube columns and H shape steel beams and recycled concrete-filled rectangular steel tube frame joints, through the method of testing and theoretical analysis, we do pseudo static test on the two steel

girder node model (JD1 and JD3) and two rectangular steel tube concrete beam node model (JD2 and JD4) respectively, compared failure mechanism, hysteresis property, energy dissipation capacity, ductility and stiffness degradation of the two kinds of nodes in different axial compression ratio and beam line stiffness ratio , provides experimental and theoretical basis for perfecting the design method of rectangular recycled concrete-filled steel tube node.

2. Test situation

2.1. Specimen design and production

The test made four nodes specimen model, Table 1 shows the parameters of the framework for each node. JD1 and JD3 are the concrete filled square steel tube columns — H shape steel beams nodes, JD2 and JD4 are the recycled concrete filled square steel tube columns—rectangular steel tube recycled concrete beam nodes, and the connection form of four nodes are all external reinforcement ring. Material test results of the two materials are shown in Table 2.

**Table 1.** Properties of specimens

Specimen number	Column section (mm)	Column length(mm)	Beam section (mm)	Beam length (mm)	Beams line stiffness ratio	Axial compression ratio (n)	Axial force (kN)
JD1	200×200×5.5×5.5	2200	H250×140×6×8	1650	0.61	0.1	330
JD2	200×200×5.5×5.5	2200	200×140×5.5	1650	0.61	0.1	330
JD3	200×200×5.5×5.5	2200	H300×140×6×8	1650	1.12	0.3	992
JD4	200×200×5.5×5.5	2200	250×140×5.5	1650	1.12	0.3	992

Table 2. Material test results of steel and recycled concrete

Materia type	f_y (N/mm²)	f_u (N/mm²)	E_s (Mpa)
Steel plate	352.1	501.2	2.01×10⁵
Recycled concrete	28 days cube compressive strength(N/mm²)	the cube compressive test strength(N/mm2)	E_c (Mpa)
	42.6	63.3	3.65×10⁴

2.2. The test device and loading system

Loading test setup and test equipment are used in this test as shown in figure 1 and figure 2.
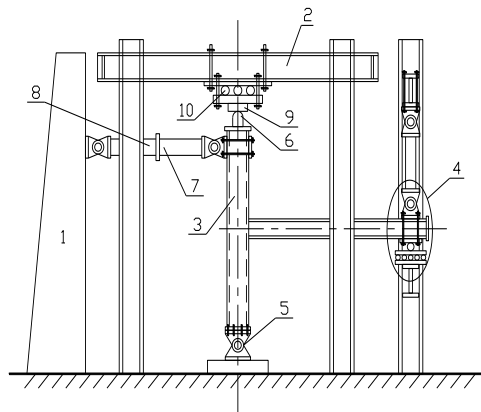
Fig.1 Test setup Reaction wall 2. Reaction frame 3. Specimen 4. Specimen beam end support 5. Hinge support 6. The sensor 7. The sensor 8. Tension and compression jack 9. Jack 10. Sliding roller

Fig. 2 Test equipment

Throughout the test, the applied load is divided into vertical load and horizontal load. Vertical load is constant loads and once applied to complete; horizontal load is low cyclic loading, according to the regulation [12], we adopt the load - displacement mixed loading. When beginning to load, we use load control, taking 10kN as the load differential loading, cyclic loading at a time until the specimen yield; After the surrender, we use displacement control, taking 0.25 times the yield displacement as the differential graded loading, repeated three times, until specimen damage.

## 3. Experimental results and analysis

3.1. Hysteresis curve

(a)JD1

(b)JD2

(c)JD3

(d)JD4
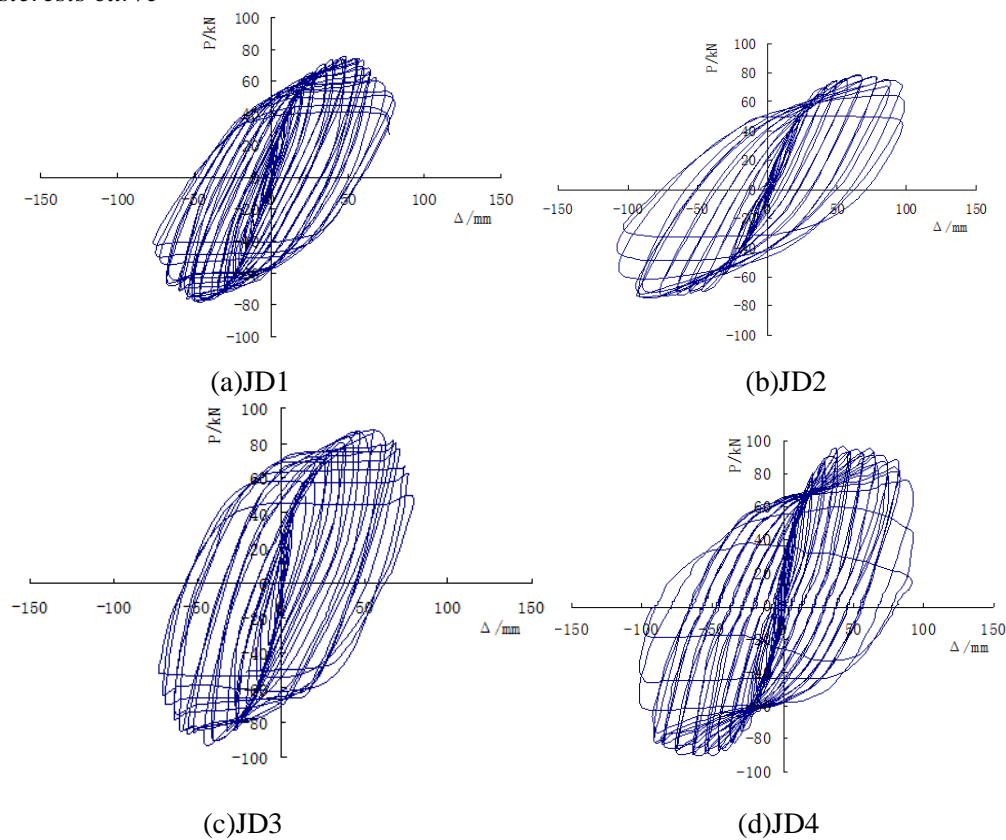
Fig.3 P-Δ hysteretic curves of the specimens

Figure 3 shows that: due to the final failure mode of the four nodes specimens is similar, the shape of the hysteresis curve is basically the same, they show more full of "spindle." When beginning to load, the overall deformation and the residual strain after loading and unloading curve slope of the specimen which are in the flexible working stage are small, after P- Δ hysteretic curves appearing obvious turning point and entering the elastic-plastic stage, the specimen yield, its load grows slowly, but the distortion is growing quickly and the hysteresis loop are increasingly full. But after the load limit is reached, the loads which frame can bear decreases slowly, then that is all kinds of damage, but still show a full "spindle" hysteresis loop. But overall, the peak load and maximum displacement of JD2 and JD4 were higher than JD1 and JD3, and the hysteresis curve of the former are fuller than the latter, the larger envelope area, no obvious "pinch" phenomenon, which shows that energy dissipation capacity of rectangular beam node is superior to that of steel beam node.

3.2. Deformation and ductility

Figure 4 shows that: four nodes which are under load have experienced elastic, elastic-plastic and destroy three stages. The peak load of skeleton curve o JD3 and JD4 f was significantly higher than that of JD1and JD2, and the descending of curve is earlier than the latter, higher peak is due to relatively large load beams linear stiffness, so that the specimen ultimate bearing capacity has increased; decline segment is in advance which is due to the increase of axial compression ratio, so that the displacement ductility decreased. Compared with JD1, the peak load of JD2 is large, the slope of the falling section is relatively small, and the position of the inflection point appears later, Compared with JD3, the peak load of JD4 is large, the relative slope of the falling section is small, the position of the inflection point appears later. This fully shows that: Compared with steel beams node, the bearing capacity of the rectangular steel tube recycled concrete beam node ultimately improved and its ductility increases.
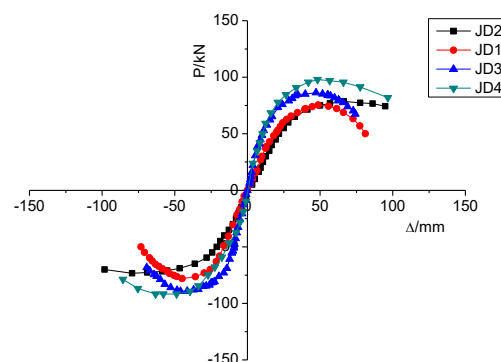
Fig.4 P-Δ skeleton curves of the specimens

As can be seen from Table 3:compared with the recycled concrete filled square steel tube columns-rectangular steel tube recycled concrete beam nodes (JD2 and JD4) , the yield load, limit load and failure load of the recycled concrete filled square steel tube columns- H shape steel beams nodes (JD1 and JD3) are lower, which is due to its relatively large beams linear stiffness,   leading to its bearing capacity increased; the minimum and maximum displacement ductility factor of rectangular beam node are 3.5 and 4.32, respectively, were greater than 3.1 and 3.51 of the steel beam joint, the comparison shows that the displacement ductility factor of rectangular beam nodes are generally higher and its ductility and deformation capacity are better. But the displacement ductility coefficient of steel beam joints are greater than 2, which can meet the requirements of the recycled concrete structure displacement ductility factor.

Table 3. Load and displacement of every stage

| Speci-men no.	Loading stage	Yield load /kN	Yield displacement /mm	Limit load/kN	Limit displacement /mm	Failure load /kN	Failure displacement /mm	Ductility factor
JD1	Forward Load	51.29	20	75.43	48.76	64.11	70.2	3.51
	Negative load	-53.14	-19.2	-78.12	-44.9	-66.40	-63.25	3.29
JD2	Forward Load	61.33	27.59	78.67	67.24	66.9	96.55	3.50
	Negative load	-60	-25.86	-73.33	-69.31	68	-98.28	3.80
JD3	Forward Load	73.2	21.1	86.3	47.2	73.36	68.9	3.36
	Negative load	-76.2	-19.6	-89.28	-46.09	-75.88	-65.2	3.10
JD4	Forward Load	75.35	22.41	96.8	60.34	82.3	96.89	4.32
	Negative load	-73.46	-24.1	-94.9	-55.17	-80.7	-100.1	4.15

3.3. Stiffness degradation
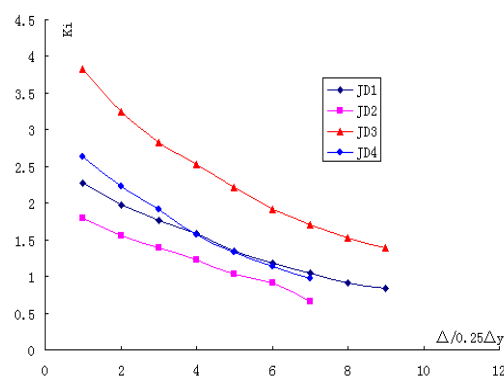
Fig.5 Stiffness degradation curves

Figure 5 shows: four-node specimens both showed obvious stiffness degradation, mainly due to the node yielding, plastic deformation increasing and the cumulative damage exacerbated in the nodes; Compared with JD1 and JD2 , the stiffness degradation curves of JD3 and JD4 are more steeper, so the stiffness degradation of the former are faster than the latter, because the larger axial compression ratio, additional moment caused by the N-Δ effect increases, the envoys of cumulative damage increase after the yield point.   Under the condition of the same level of load displacement increment, the stiffness degradation amplitude of JD3 is 2.44, that of JD4 is 1.66, so the degree of stiffness degradation of JD3 is significantly higher than JD4, while the stiffness degradation amplitude of JD1 is 1.45, that of JD2 is 1.01, so the degree of stiffness degradation of JD1 is also higher than JD2, fully illustrated: degree of stiffness degradation of steel beam joint is more serious.

3.4. Energy dissipation capacity of the structure

In order to evaluate the energy dissipation capacity of nodes, we use the equivalent viscous damping coefficient "he" as measure index, Table 4 for node energy consumption indicators.

Table 4. Energy consumption indicators of specimen

Specimen	JD1	JD2	JD3	JD4
h_e	0.287	0.310	0.336	0.302

Table 4 shows that the equivalent viscous damping coefficient and energy dissipation coefficient of JD2, JD4 were higher than JD1, JD3, and the maximum equivalent viscous damping of rectangular steel tube recycled concrete beam node can reach 0.337, while steel beam node is 0.303, although both have reached the seismic design requirements, but energy dissipation capacity of rectangular steel tube recycled concrete beam nodes is relatively high.

4. Conclusion

Through contrast experimental research of seismic performance of two recycled concrete filled square steel tube columns- - H shape steel beams nodes and two rectangular steel tube recycled concrete beam nodes, we can draw the following conclusions:

(1) The hysteresis curves of a four-node specimens are presented full of "spindle", but relatively speaking, the peak load and maximum displacement of rectangular steel tube recycled concrete beams nodes are larger, envelope area of the curve is bigger, , so the energy dissipation capacity is superior to the steel beam joint.

(2) Skeleton curve of four nodes specimen has yield stage, the ultimate stage and failure stage, the peak load of skeleton curve of recycled concrete rectangular steel tube beam nodes is larger, the slope of its decline segment is relatively small, and the position of the inflection point appears relatively late, this shows that the ultimate bearing capacity and ductility of rectangular steel tube recycled concrete beam node has been enhanced over the steel beams node.

(3) The displacement ductility factor of rectangular steel tube recycled concrete beam nodes can reach 4.32, more than 3.51 of steel beam joints,   ductility coefficient of two kinds of nodes satisfy the requirements of the seismic ductility index, but the deformation capacity and ductility of recycled concrete filled rectangular steel tube beam joint are far more than the steel beam node; The maximum equivalent viscous damping of rectangular beam nodes is 0.337, and the steel beam node is 0.303, energy dissipation capacity of the former is significantly higher than the latter.

(4) From stiffness degradation curve, four nodes has shown significant stiffness degradation, but the degradation curve of steel beams node is more steeper than rectangular steel beams node, so the stiffness degradation degree of the former is greater than the latter. Overall, the seismic performance of rectangular steel tube recycled concrete beam node is better than that of steel beam node, which are worthy of further extending application.

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