Experimental study on compressive properties of round steel tube recycled concrete columns

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Abstract: In order to study the compressive performance of circular steel tube recycled concrete columns, four circular steel tube recycled concrete columns are designed and manufactured, and subjected to a monotonic static compression test. Consider the eccentricity and the slenderness ratio, this paper observes the whole process of the specimen and the failure mode, and analyses the ultimate bearing capacity, deformation curve, load-deformation relationship, and load-strain relationship. The experimental research shows that the failure process and failure mode of the round steel tube recycled concrete column are similar to those of the ordinary round steel tube concrete column. Similarly, the bearing capacity of the test piece decreases with the increase of the slenderness ratio and eccentricity, and the ultimate failure form is mainly the overall instability failure.

1. Introduction
In recent years, the research and application of recycled concrete technology [1] has increased the effective utilization of construction waste resources. Recycled aggregate concrete (RAC) refers to recycled concrete aggregates that have been crushed from waste concrete and partially or completely replaced with natural aggregates. However, since a large part of the raw materials in the RAC are derived from the existing buildings with lower strength grades of the removed concrete, and the recycled aggregates are in the process of crushing, a large number of micro cracks or cracks appear inside the aggregates, correspondingly from the regenerated bones. The concrete prepared by the material has low compressive strength and low elastic modulus, so that RAC is generally applied to non-load-bearing or load-bearing structures such as roadbed backfilling. Therefore, the application of RAC to the load-bearing structure will be an important issue for researchers [2].

Concrete-filled steel tubular structures are widely used in single- and multi-layer industrial buildings, high-rise and super-tall buildings, as well as equipment structures and supports, due to their high bearing capacity and good seismic performance [3]. The structure of the recycled concrete filled steel tube (RACFST) [4] is a new combined structure formed by pouring RAC into the inside of the steel pipe. At present, domestic and foreign scholars have studied the steel pipe recycled concrete structure [5-6] mainly in the static compression performance. In terms of seismic performance, the literature [7] used the beam loading method to test the seismic performance of 15 square steel tube recycled concrete columns, and studied the effects of the parameters such as the replacement ratio of the coarse aggregate and the axial compression ratio on the seismic performance of the test piece. The results show that the seismic performance of the square steel tube recycled concrete column is similar to that of ordinary steel tube concrete, and the square steel tube regenerative concrete column exhibits high ductility and horizontal bearing capacity.

In order to better understand the failure morphology and bearing capacity characteristics of circular
steel tube recycled concrete columns under static pressure, this study carried out static analysis on 4 circular steel tube recycled concrete columns by changing two parameters of eccentricity and slenderness ratio. The compressive load test analyzed the effects of various parameters on the static mechanical properties of the test piece.

2. Test overview

2.1. Test material
The test steel pipe material is seamless round steel pipe, 42.5R ordinary Portland cement, ordinary natural river sand, 5-14mm continuous grade natural gravel, recycled coarse aggregate and high-efficiency water reducing agent. The mix ratio is shown in Table 1. The concrete compressive strength is measured by a 150X150X150mm cube standard test block which is molded and cured under the same conditions as the test piece. The test method is based on the "Test Method for Mechanical Properties of Ordinary Concrete" (GB50081-2002, 2003), and finally takes the average value of the measured strength of each of the three test blocks. The average compressive strength of concrete measured at 28 days was 41.2 MPa when the substitution rate was 70%.

| Replacement rate (%) | Material usage (kg/m³) |
|----------------------|------------------------|
|                      | Water | Cement | Sand | natural Coarse aggregate | Recycled coarse aggregate | Nickel iron slag | Silica fume | Water reducing agent |
| 70                   | 188.77 | 382.2 | 604.44 | 322.4 | 752.2 | 109.2 | 54.6 | 6.55 |

2.2. Component design and production
Design and manufacture four components which numbered 1 ~ 4 respectively. The detailed parameters of each test piece are shown in Table 2. In the table, L is the length of the component, and D is the outer diameter of the steel pipe, and t is the wall thickness of the steel pipe, and fcu is the cubic concrete compressive strength measured by the core concrete, and fy is the yield strength of the steel tube, and λ is the aspect ratio (length / diameter), and e is the eccentricity.

| Number | L/mm | t/mm | D/mm | fcu/MPa | fy/MPa | e/mm | λ |
|--------|------|------|------|---------|--------|------|---|
| 1#     | 840  | 4.5  | 140  | 37.7    | 386    | 0    | 6 |
| 2#     | 840  | 4.5  | 140  | 41.2    | 386    | 50   | 6 |
| 3#     | 1008 | 5    | 168  | 41.2    | 326    | 50   | 6 |
| 4#     | 1120 | 4.5  | 140  | 41.2    | 386    | 75   | 8 |

2.3. Loading device and measuring method
The test was carried out using a 5000kN hydraulic long column tester. The lateral displacement of the test piece was measured by five equally spaced displacement meters. The microstrain on the surface of the steel pipe was measured by the axial and hoop strain gauges attached to the middle. The strain collection box which named DH3816N was used for strain collection. The test device and measuring point arrangement are shown in Fig.1.

The test uses a constant-rate displacement-controlled continuous loading method. The ascent rate is 0.5mm / min, and the descending rate is 1.0mm / min. All the data (load data from the press, displacement data from the displacement gauge, and strain gauge strain data) are finally made by DH3816N collection box collects data to ensure data synchronization. When the bearing capacity drops
to 85% of the ultimate load, the loading is stopped and the test is over. The loading device is shown in Fig. 2.

3. Test phenomenon
The stress process of all the specimens is basically similar: the specimen is in the elastic stage at the beginning of loading, and the stress between the steel pipe column and the recycled concrete is small; when the load continues to increase to 75% Pu, the lateral deformation of the recycled concrete gradually increases and subject to the restraint of steel pipe columns, the steel pipe appears to rust; as the load increases to near 90% Pu, the deformation of the central part of the steel pipe increases; when the load is about to reach the limit bearing capacity Pu, the round steel pipe affects the core concrete. Constraint effect which affected by the slenderness ratio is strong, the damage occurred in the middle of the specimen. When the component is damaged, the overall buckling and instability of the test piece, but the steel tube has reached the yield strain, and its failure form is elastoplastic instability.

4. Test results and analysis

4.1. Load-displacement relationship curve
The load-span lateral displacement curve of the biased test piece measured in the test is shown in Fig. 3. It can be seen from the figure that the eccentric moment affects the eccentric compressive load-bearing performance of the steel tube recycled concrete column. The specimen with a large eccentric distance has a smaller ultimate bearing capacity, and the descending section after the peak load is steeper and the ductility becomes worse.
4.2. Load-axial strain curve

The axial strain in the loading process of the biased specimen can be obtained through the strain gauge attached in the middle. The measured load-axial strain curve is shown in Fig.4. As can be seen from Fig.4: due to the large eccentricity, $e = 50$ and $e = 75$, at the beginning of loading, the steel pipe on one side of the specimen is under tension and the strain is positive. The side tension strain continued to increase, and the compressive side compressive strain also increased simultaneously. When the peak load was reached, the compressive strain value of the compressive side steel pipe reached 10,000 $\mu \varepsilon$. 
4.3. Load-circle strain relationship curve

The hoop strain value of the biased specimen during the stress was obtained by the hoop strain gage stuck in the middle of the test piece. The measured load-hoop strain curve in the test is shown in Fig.5.

It can be seen from the figure that when the load is small, the linear relationship between the load and the circumferential strain of the steel tube is basically maintained, but when the load approaches the peak load of 0.8 to 0.9, it starts to change to non-linear. Due to the large eccentricity of the test piece, the steel pipe on one side of the test piece is always under tension, and the circumferential strain direction is always under pressure. When the specimen reaches the peak load, the circumferential tensile strain value of the steel tube under the biased specimen can reach yield. It can be seen that despite the eccentric compression, the steel tube's restraining effect on the internal concrete ferrule is still obvious.

5. Conclusion

(1) The process of eccentric compression and compression of long steel tubular recycled concrete columns is similar to that of ordinary steel tubular concrete, and they all have undergone the elastic phase, elastoplastic phase, and failure phase. After reaching the peak load, the decline is relatively gentle and the ductility is good.

(2) The compression strain value of the steel tube on the compression side reached the peak load of 10,000 με when the circular steel tube recycled concrete biased column reached the peak load, far exceeding the limit compressive strain value of ordinary reinforced concrete. The restraint effect of concrete is obvious.

(3) The slenderness ratio has a significant effect on the ultimate bearing capacity of the round steel tube recycled concrete columns. As the slenderness ratio increases, the bearing capacity nonlinearity
gradually decreases.

(4) The eccentricity is sensitive to the bearing capacity of steel tube recycled concrete. As the eccentricity increases, the bearing capacity decreases non-linearly.

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