

Study on Seismic Behavior of Concrete-filled square steel tube column with core column -Steel Beam Joints

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Summary: This paper has carried out the quasi-static tests of five specimens of FRP-UHPC column-steel beam joints with core columns, and the extensive parameter analysis of the joints by numerical simulation. The results show that the Concrete-filled square steel tube column with core column -Steel Beam Joints have strong bearing capacity. It has excellent deformability, stiffness and energy dissipation capacity, and works well under the condition of high axial compression ratio. The bearing capacity of the replacement beam specimen does not deteriorate significantly, which indicates that the Concrete-filled square steel tube column with core column -Steel Beam Joints is replaceable.

1 Preface

As the most commonly used form of connection in semi-rigid joints, high-strength bolted connections have good seismic performance and manageable quality of connection, and can be processed in advance to realize on-site assembly construction and speed up construction progress [1]. Zong Zhouhong et al. [2] found that the seismic performance of joints with core columns is better than that of ordinary welded joints. Wang Xiantie et al. [3] conducted a seismic test of Concrete-filled square steel tube column with core column -Steel Beam Joints and found that the energy dissipation capacity of thin end-plate joints can be obviously improved by setting stiffeners. At present, the research on the seismic performance of steel-concrete-FRP-UHPC column (SCFU column) -steel beam joints with built-in high-strength core columns has not been carried out.

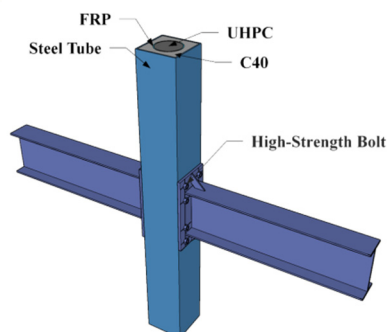


Figure 1 Schematic diagram of joints

In order to solve the problems of high requirements on structural mechanical properties and difficulty in construction of high-rise and super-high-rise buildings, this paper combines the characteristics of new

FRP-UHPC columns such as high ductility, high bearing capacity and convenience for beam-column joint connection, and the assemblability of end-plate-bolt connection joints, and proposes the concrete-filled steel tubular column-steel beam joints with core columns, as shown in Figure 1.

2 Overview of the Tests

2.1. Specimen Design

The FRP-UHPC column is a square section with a sectional size of 250 mm × 250 mm. The outer steel tubular column is 8mm thick and the column height h is 1800mm. The core column uses GFRP tube to constrain UHPC column. The section specification of steel I-beam is HN 300 mm × 150 mm × 6.5 mm × 9 mm, and the length of steel beam is 1100mm. The dimension of the end plate is 480 mm × 250 mm × 25 mm, and that of the end plate stiffener is 90 mm × 90 mm × 5 mm. The joint detail dimensions are shown in Figure 2.

In the paper, four joint specimens were designed for quasi-static loading test based on three parameters: axial compression ratio, number of GFRP tube layers, and presence or absence of core columns to study the influence of each parameter on the seismic performance. A group of replacement beams were set to study the reparability of this structure after earthquake.

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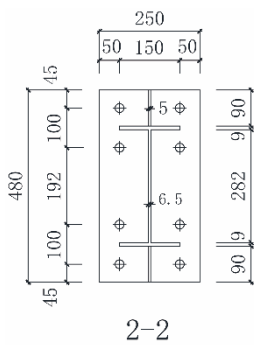


Figure 2 Joint detail dimensions

Table 1 Overview of the specimen

Specimen No.	n	Core column Diameter /mm	FRP Number of Layers	Axial compression Load
100-10-0.3	0.3	100	10	1382kN
100-10-0.6	0.6	100	10	2764kN
100-8-0.6	0.6	100	8	2751kN
100-8-0.6-C	0.6	100	8	2751kN
0-0-0.6	0.6	0	0	2282kN

2.2. Material Properties

The sandwich concrete is C40 concrete with crushed stones, with the three-dimensional compressive strength of 46.5 MPa and elastic modulus of 32.5 GPa. According to the testing method of “Reactive Powder Concrete” GB/T31387 -2015^[4], the compressive strength and elastic modulus of UHPC cube measured are 160.5 MPa and 45.2 GPa. The bolt adopts friction type high-strength bolt with nominal diameter M20 and strength grade 10.9. The steel adopts Q235 steel, and the material property data are shown in Table 2. The winding angle of GFRP tube is 80, and the circumferential tensile test is carried out by splitting disc method. The results are shown in Table 3.

Table 2 Test results of steel properties

Steel thickness /mm	Yield strength f_y / MPa	Tensile strength f_u / MPa
5	272.75	403.78
6.5	289.73	431.51
8	334.99	462.34
9	240.08	392.70
25	307.61	435.89

Table 3 Test results of GFRP properties

Thickness t_f / mm	Circumferential ultimate fracture strain ϵ_h	Circumferential ultimate tensile strength σ_h / MPa	Poisson's ratio ν_h
3.13	0.0204	918.6	0.29
3.57	0.0210	926.8	0.29

2.3. Loading Device and Measuring Scheme

This test was carried out in the Key Laboratory of Structural Engineering and Seismic Resistance of Ministry of Education, Xi'an University of Architecture and Technology. Axial compression load

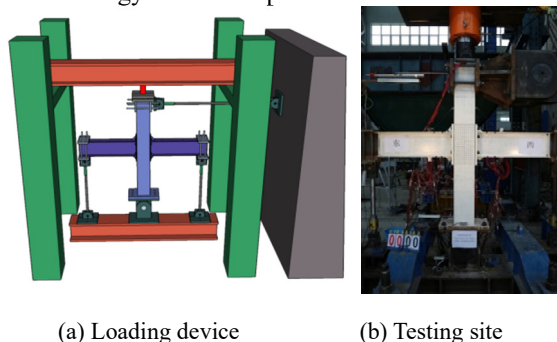


Figure 3 Loading device

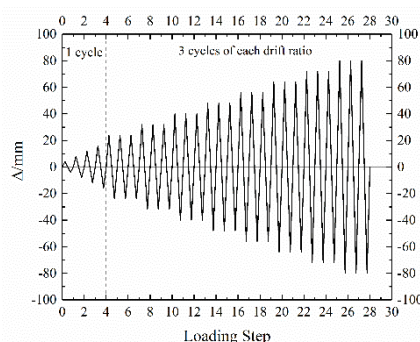


Figure 4 Loading system

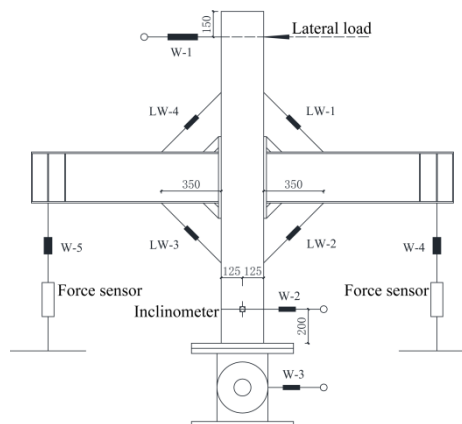


Figure 5 Layout of measuring points

is applied to the top of the column with 5000kN hydraulic jack, and lateral load is applied with 1000kN

MTS hydraulic servo actuator. The loading device is shown in Figure 3, the loading system is shown in Figure 4, and the layout of measuring points is shown in Figure 5.

3 Testing Phenomena and Failure Modes

During the loading process, for each specimen, the flange of the steel I-beam first turns drum-like, and then the web also turns drum-like. The stiffener buckles due to the increase of the joint angle. At the same time, the existence of the stiffener also makes the plastic hinge of the steel I-beam move outward, forming a plastic hinge at a position 0.5 ~ 1 times the beam height from the end plate. When each specimen is damaged, the steel beam has serious out-of-plane torsion, and the end of each specimen is slightly deformed after some high-strength bolts are removed. The test results show that the flange of the specimen buckles earlier under high axial compression ratio, and the column surface in the joint area has relatively larger drum-like curvature. The failure degree of the specimen without core column is greater. However, the failure phenomenon of the replacement beam specimen is basically the same as that of the original specimen. Figure 6 shows the failure phenomena of the typical specimen 100-8-0.6.

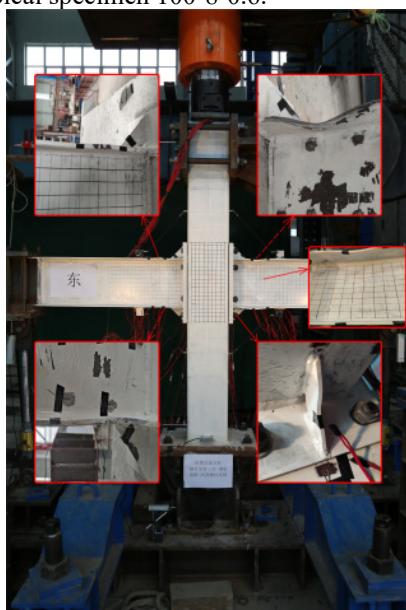


Figure 6 Failure mode of specimen 100-8-0.6

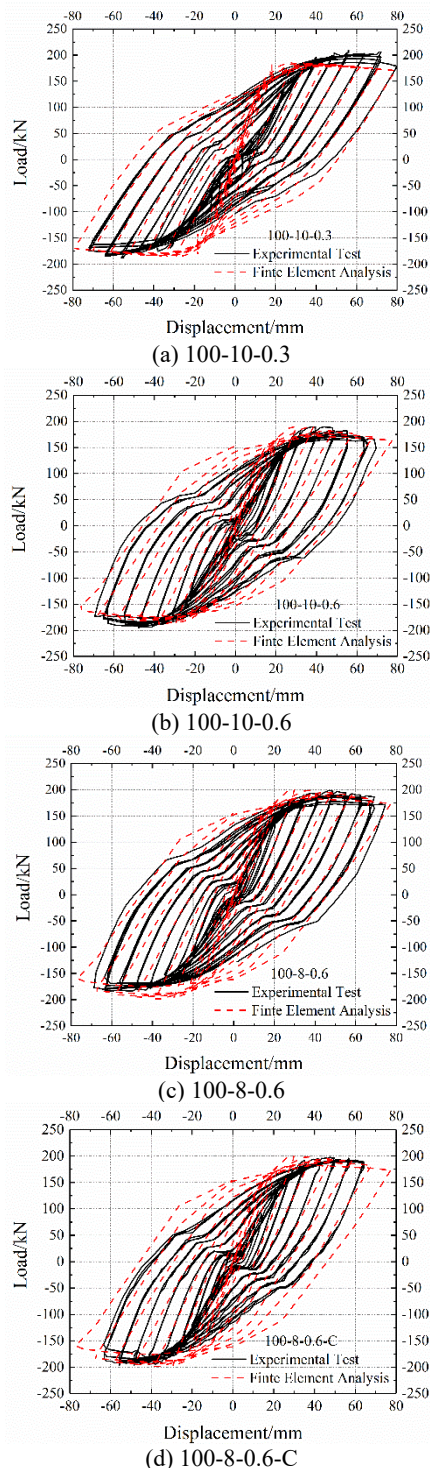
4 Testing Data and Analysis

4.1. Hysteretic Curves

Hysteretic curves of specimen are shown in Figure 7. It can be seen from the figure that the hysteretic curves of each specimen are fully spindle-shaped without pinching, which indicates that the seismic performance of the joints with core columns is good. The hysteretic curve of specimens with high axial compression ratio is relatively plumper, indicating that the energy dissipation capacity

is better. The hysteretic curve of specimen 100-8-0.6 is plumper than that of specimen 100-8-0.6-C, because the FRP-UHPC column replacing beam specimen has certain plastic damage of steel tube and concrete cracking, and thus the energy dissipation capacity is reduced.

Because the specimen can't be perfectly tight during installation, a "stair" curve with displacement changing and load unchanged appears during the loading process.



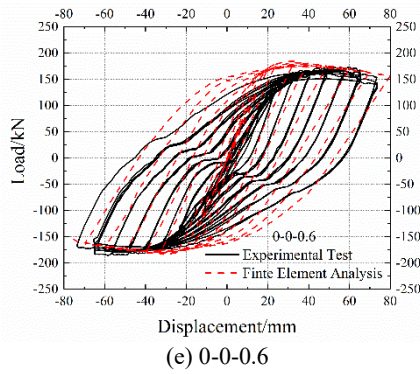


Figure 7 Hysteretic curves

4.2. Skeleton Curves

The skeleton curve of each specimen has basically similar trend, which consists of three stages: elastic stage, plasticity strengthening stage and softening stage. The axial compression ratio is increased from 0.3 to 0.6, the peak lateral load changes little, but the flexural capacity improves, because the constraint effect of FRP on UHPC core columns is excited earlier under high axial compression ratio. With the increase of lateral displacement, concrete cracking leads to the enhancement of constraint effect, the bending moment of joints is increasing, and the P-Δ effect is getting stronger, which leads to the growth of peak load reaching the bottleneck and thus the softening stage starts. As shown in Figure 8.

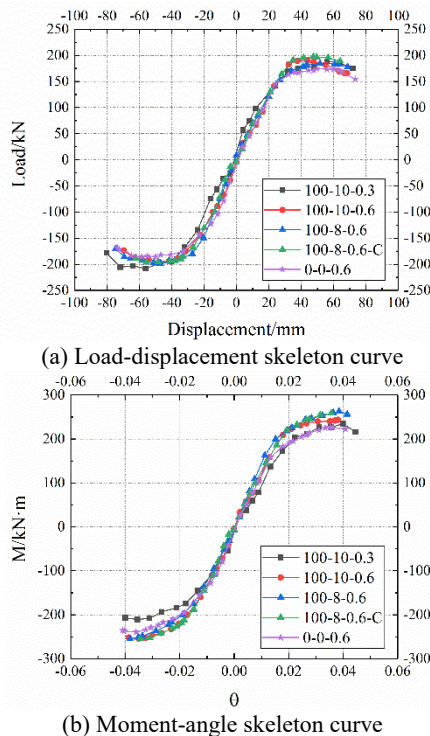


Figure 8 Skeleton curves

4.3. Ductility and Energy Dissipation

Table 4 shows the ductility coefficient of each specimen. Except for the replacement beam, the ductility

coefficient of all the other specimens is greater than 2. The ductility of specimens with high axial compression ratio is lower, which is due to the fact that specimens with high axial compression ratio bear more bending moments. Moreover, the constraint

Table 4 Ductility coefficient

Specimen No.	$\bar{\mu}$
100-10-0.3	2.50
100-10-0.6	2.28
100-8-0.6	2.24
100-8-0.6-C	1.59
0-0-0.6	2.56

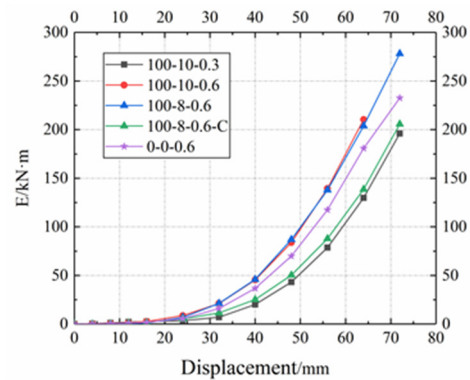


Figure 9 Cumulative energy dissipation

effect of FRP pipe and steel pipe in the joint area is excited earlier under high axial compression, and after the peak load, the constraint fails in advance, resulting in premature failure. Due to the plastic damage and concrete cracking of FRP-UHPC columns after the first loading, the ductility coefficient of specimens after replacing beams is lower than that of original specimens. The number of FRP layers has no significant influence on the ductility coefficient.

Figure 9 shows the cumulative energy dissipation per stage of each specimen. It can be seen from the figure that when loading at the same stage ($\Delta = 64\text{mm}$), the axial compression ratio increases from 0.3 to 0.6, and the cumulative energy dissipation increases by 61.5%, indicating that the axial compression ratio has a significant impact on the energy dissipation capacity and the energy dissipation capacity of the core column is also obviously improved.

5 Conclusions

Through the seismic test of Concrete-filled square steel tube column with core column -Steel Beam Joints, the following results are obtained:

- This kind of joint can work well under high axial compression ratio and has good seismic hysteretic

performance. At the same time, most parts of the joint can be prefabricated in the factory, which improves the construction efficiency.

- The inter-story drift is between $1/29$ and $1/22$ when each specimen is damaged, which is far beyond the specification limit. It proves that the concrete-filled steel tubular column-steel beam joints with core columns has good collapse resistance capacity.

- The bearing capacity and energy dissipation capacity of the replacement beam specimen are good, which proves that the joint is removable and repairable after earthquake.

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