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Axial compression performance research on large diameter CFST column-beam connection after cycle reversed loading

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Abstract. In order to study the mechanical properties of large diameter CFST column-beam connection after earthquake, axial compression test was carried out on the connection specimens that experienced low cycle reversed loading. The failure shapes, ultimate bearing capacities and strains characteristics of the connection were investigated. The results show that the improved interior diaphragm CFST column-H-shaped steel beam joints show waist drum failure modes. The column-beam joints still have high axial bearing capacity after cycle reversed loading. The interior diaphragms and linking reinforcing bars effectively restrain the transverse deformation of the steel tube of the connection zone.

1. Introduction
The concrete-filled steel tube (CFST) structure has superior mechanical properties and construction performance, and is widely used in civil engineering such as high-rise, ultra-high-rise and long-span bridge. The study of CFST column members is more mature from theory to related design [1]. However the research on the connection of CFST column-beam joints has been lagging behind the study of CFST column members.

On the basis of the traditional interior diaphragm joints [2-5], the reference [6] proposed an improved interior diaphragm CFST column-H-shaped steel beam joint. The CFST column is the through type, and the interior diaphragms are set up on the H-shaped steel beam corresponding parts of the upper and lower flanges. The thickness of the interior diaphragm is the same as the thickness of the flange of the H-shaped steel beam. In order to avoid the eccentricity caused by single side welding, the bars are arranged symmetrically on the upper and lower surface of the interior diaphragm, and the vertical short stiffeners are set up between the upper and lower interior diaphragms, and the other parts are evenly arranged except for the position corresponding to the web of the H-shaped steel beam. The width of the end flange of the H-shaped steel beam is changed. Through the low cyclic reversed loading test of the new joints, the results show that the linking reinforcing bars can improve the efficiency of the interior diaphragm transfer force, and the stress of connection is reduced effectively. When the flange width is expended 1.5 times and the widened angle is 1:6, the maximum stress on connection zone is significantly lower than H-shaped steel beam, and the earthquake-resistant design philosophy of ‘strong-joint and weak member’ is satisfied.

As the results of the test are mainly shown the seismic performance of the steel beam, in order to understand the mechanical properties of the new connection after the earthquake, the axial compression test is carried out on the new types of joint specimens that have experienced the effect of
the low cyclic reversed loading. The failure modes, ultimate bearing capacity and strain characteristics of the new joint under axial compression loading are discussed.

2. Overview of the tests

2.1. Specimens design and mechanical properties of materials

Two improved interior diaphragm CFST column-H-shaped steel beam joint specimens are designed and produced. The specimen numbers are JD-1-8 and JD-2-12. The detailed configuration and dimensions are shown in Figure 1. The diameter of the CFST column is 600 mm, the tube thickness is 16 mm. The steel grades of steel tube and H-shaped steel beam are all Q345. A vertical reinforcement cage is arranged in the CFST column, and studs having a diameter of 13 mm and a length of 60 mm are welded on the inner wall of the tube. The concrete grade in the tube is C60. The cube compressive strength measured at the beginning of the test is 65 MPa, the prism compressive strength is 50 MPa, and the elastic modulus is 36.6 GPa. The main difference between JD-1-8 and JD-2-12 is the number of the linking reinforcing bars. The linking reinforcing bars of the JD-1-8 and JD-2-12 are 8C12 and 12C12, respectively. The properties of steel materials are shown in Table 1.

![Figure 1. Dimension and details of JD-2-12](image)

(a) Horizontal sectional drawing  
(b) a-a sectional drawing  
(c) b-b sectional drawing

| Thickness(Diameter) /mm | Steel grade | Yield strength /MPa | Ultimate strength /MPa | Elongation after fracture/% |
|------------------------|-------------|---------------------|------------------------|-----------------------------|
| Steel tube 16          | Q345        | 388                 | 529                    | 29.2                        |
| Steel plate 10         | Q345        | 309                 | 445                    | 31.1                        |
| Longitudinal           | HRB400      | 454                 | 596                    | 21.3                        |
| reinforcement          | HRB335      | 370                 | 540                    | 22.8                        |
| stirrups               |             |                     |                        |                             |
The two joint specimens have undergone low cyclic reversed loading tests, and the load-displacement hysteresis curves of the beam ends are shown in Figure 2. The failure of the test specimens occurs at the beam end. The hysteresis curves are plump, which indicate good energy dissipation capacity and ductility. Figure 3 shows the measured strain on the surface of the steel tube in the core region of JD-2-12 specimen. It can be seen that the strain on the surface of the steel tube is roughly linear and does not reach yield.

![Figure 2. Load-displacement hysteresis loops](image)

![Figure 3. Measured strain of the steel tube in the core region](image)

2.2. Axial compression test method and test contents

The tests were carried out on the 40 MN multifunction electrohydraulic servo loading system of the Key Laboratory of Urban Security and Disaster Engineering of the Education Ministry at the Beijing University of Technology. The loading device is shown in Figure 4. Both the ends of the CFST column are ball-hinge supports to reduce eccentricity during loading. A force sensor is added between the top ball-hinge and the specimen to accurately measure the applied axial load.

![Figure 4. Test set-up](image)

![Figure 5. Measuring point arrangement](image)
The main test contents include: (1) Axial deformation within two-thirds of the specimen height (Figure 5a). (2) Radial deformation. Two radial extensometers are arranged within two-thirds of the specimen height, which are respectively 300 mm from the central axis of the beam web (Figure 5a). (3) Vertical and horizontal strain gauges are arranged on the surface of the steel tube, which are 50 mm and 400 mm from the upper and lower flange of the beam web respectively (Figure 5a). (4) The strain change of the linking reinforcing bars (Figure 5b).

3. Failure mode
In the initial stage of the loading, both specimens are in the elastic stage and the appearance is basically unchanged. When the load reaches 90% of the peak load, the surfaces of the steel tube drum slightly at each position of 100 mm above and below the interior diaphragm. At the peak load, the surfaces of the steel tube have been severely drummed at each position of 150 mm above and below the interior diaphragm, and then the load is basically kept unchanged. The two specimens finally show waist drum failure mode.

(a) JD-1-8
(b) JD-2-12

Figure 6. Failure pattern of specimens

4. Analysis of results

4.1. Axial compression-longitudinal deformation curves
As the load increases, the vertical deformation of the concrete tubular column increases gradually, and the axial load-deformation curve is shown in Figure 7. From the load-deformation curves, it can be seen that:

(1) CFST column specimens have good ductility. The whole working process of the specimen can be divided into three stages: elastic stage, elastoplastic stage and failure stage. In the initial stage of the loading, the load-deformation curve is almost a straight line, and the specimen is in the elastic stage. With the increase of the load, the steel tube is pressed into the yield state, and the load-deformation curve shows obvious nonlinear properties because the strength of the core concrete is strengthened under the restraint effect of the steel tube. The bearing capacity of the specimen will exceed the simple superposition of the individual carrying capacity of the steel tube and concrete. This stage is the elastoplastic stage. Exceeding the peak bearing capacity of the specimen, the deformation in the figure increases rapidly and the bearing capacity decreases. This stage is the failure stage of the specimen.

(2) The peak loads of the JD-1-2 and JD-2-12 specimens are 3000 t and 3056 t, respectively. It can be seen that the number of linking reinforcing bars has a certain influence on the axial compressive bearing capacity of the CFST column.
4.2. Axial compression-transverse deformation curves

The transverse deformation of the CFST column is measured by extensometers, and the load-deformation curves of the JD-1-8 and JD-2-12 specimens are shown in Figures 8a and 8b. It can be seen that during the loading process, the transverse deformation is very small in the initial stage of loading. When the axial load increases to 50% - 60% of the peak load, the change rate of transverse deformation is accelerated.

![Figure 7. Axial compression-longitudinal deformation curves](image)

![Figure 8. Axial compression-transverse deformation curves](image)

4.3. Transverse strain of steel tube

Figures 9a and 9b show the transverse strain changes of steel tube of the JD-1-8 and JD-2-12 specimens. It can be seen from the figures that the transverse strain of the steel tube 200 mm away from the center of the column is less than 600 mm away from the center of the column. This is due to the restraining effect of the interior diaphragm and the linking reinforcing bars, which increases the bearing capacity of the connection area. This is also the reason why the specimen produced the failure modes shown in Figures 6c and 6d.

![Figure 9. Transverse strain of steel tube](image)
4.4. Strain of the linking reinforcing bars

Figure 10 shows the measured strain of the linking reinforcing bars. When the ultimate load is reached, the linking reinforcing bars yield and effectively constrain the transverse deformation of the CFST column. The linking reinforcing bars act as constraints to strengthen the connection area of the joints.

![Figure 10. Measured strain of the linking reinforcing bars](image)

(a) JD-1-8  
(b) JD-2-12

5. Conclusions

Through the axial compression test of three CFST column-beam joints specimens subjected to cyclic reversed loading and one CFST column specimen, the failure modes, bearing capacities and strains characteristics of CFST column-beam joints under axial compression loading were investigated. The conclusions are as follows:

1. Under low-cycle reversed loading, the steel tube is in the elastic stage, and the joint specimens show the failure of the beam end, and the connection area is basically free of damage.
2. The improved interior diaphragms CFST column-beam joints show waist drum failure modes. The CFST columns still have high axial compression bearing capacity.
3. The interior diaphragms and linking reinforcing bars effectively restrain the transverse deformation of the steel tube of the connection zone, and improve the bearing capacity of the CFST column.

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