Nonlinear Finite Element Analysis on Seismic Behavior of Joints of Crisscross Section Column Composed of Core Concrete-Filled Steel Tube and Steel Beam in Different Axial Compression Ratio

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Keywords: axial compression ratio; crisscross concrete-filled steel tubular column; hysteretic behavior; finite element analysis

Abstract. This dissertation makes a study of joints of crisscross section column composed of core concrete-filled steel tube and steel beam. The study is mainly focused on the Seismic Behavior of joints. Four models are designed by using finite element structural analysis software *abaqus*, which are joints with inner stiffening ring of crisscross section column composed of core concrete-filled steel tube and I-shaped steel beam. This paper undertook and analyzed the stress nephogram, horizontal displacement hysteresis curves, horizontal displacement skeleton curves, energy dissipation capacity curves and stiffness degradation curves. The results showed that the hysteretic curves of all the joint models of the beam-columns are in plump shapes, and have no significant pinch phenomenon. It proved that the member has performed good ductility and energy dissipation that can satisfy the request of seismic design of engineering.

Introduction

At the beginning, the concrete filled steel tube is mainly used in the structure of bridge pier and industrial building. With the continuous improvement of the economic level of our country and the rapid development of urban construction, high-rise buildings, super high-rise buildings and long-span bridges are becoming more and more widely used . As a new type of building structure, steel pipe concrete has been widely used in such projects because of its high strength, good seismic performance and convenient construction[1]. The general framework of the beams and columns are exposed outside. These affect the layout of indoor furniture and the use of space, which is more and more difficult to be accepted by users. The special shaped column frame structure system has the same thickness of the column and the thickness of the wall which is more convenient and flexible. Interior of each room do not has column stare blankly out, it's convenient for interior decoration and furniture layout. It can increase the actual size of the room, so the owners and real estate developers are very fond of them[2].

As the common load bearing structure of the engineering structure, joints of the concrete filled steel tubular frame are the key parts of the beam column. Under load, they are in complex stress state, they are the weak part of the earthquake in structural engineering. The design of the joints directly affects the seismic performance of the whole frame system. A large number of earthquake disasters show that the failure of the joints is far greater than the expected estimate. This is mainly because the seismic action and the structure response is multi-dimensional, it has a big difference with the experimental conclusion of the plane joints[3].

In this paper, using the finite element analysis software *abaqus*, the pseudo static test of the crisscross section column composed of core concrete-filled steel tube and steel beam in different axial compression ratio is carried out under low cyclic reversed cyclic loading. Through the simulation results, the seismic performance of the joints is analyzed.

Establishment of nonfinite element analysis model

Dimension design of model

Steel pipe and I-beam are made of Q235 steel. Concrete column height is 1500mm, the steel tube and steel I-beam connected by reinforced ring [4]. Test piece size is shown in figure 1.

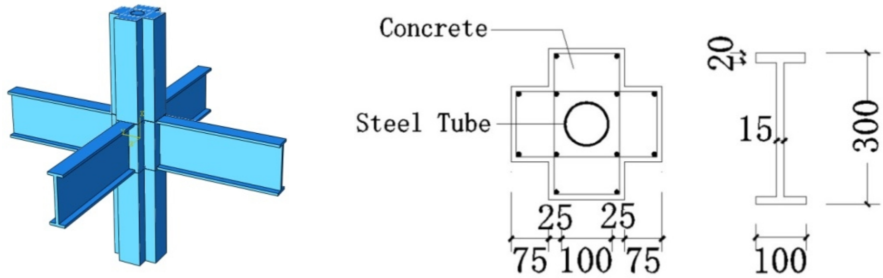

Figure 1. Sectional dimension of crisscross section column composed of core concrete-filled steel tube and steel beam

Selection of model material and variation of component parameters

From Figure 1, it can be seen that the cross section of the concrete filled steel tubular column is crisscross section. So this is not conducive to the pouring and vibrating of concrete, the actual construction of the steel pipe can be used in self-compacting concrete. Mechanical properties of materials are shown in table 1. Parameters of different components are shown in Table 2.

Table 1. Mechanical properties of materials

Material	Poisson's ratio	E	Fy(Mpa)
Concrete	0.2	33800	—
Steel tube	0.3	206000	252.9
I-shaped steel beam	0.3	206000	252.9

Table 2. Model Parameter Variations

Concrete filled steel tubular column					Steel beam	Concrete
The specimen numbering	Web height D/mm	Flange width B/mm	Steel tube thickness t/mm	Axial compressive ratio n	$h \times b_f \times t_w \times t_f$	Concrete strength grade /MPa
MJ-1	300	150	4	0.2	300×100×20×15	C60
MJ-2	300	150	4	0.4	300×100×20×15	C60
MJ-3	300	150	4	0.6	300×100×20×15	C60
MJ-4	300	150	4	0.8	300×100×20×15	C60

The selection of constitutive relation of materials

The constitutive relation of concrete

The constitutive model of concrete is provided by Plastic Damage Concrete *abaqus* model. The model considers the internal damage of concrete under compression or tension. This constitutive model is suitable for static analysis and dynamic analysis. This can be described better on the non-elastic behavior of concrete and its good convergence [5]. Concrete under the restraint of steel, strength and plastic deformation capacity has a certain increase. In this paper, the constitutive relation of concrete under compression is used for reference, and the constitutive relation model is proposed in this paper, which is based on Han Linhai's reference[6]. The concrete constitutive laws proposed by Professor Shen Jumin of the stress-strain relationship curve[7].

Constitutive relation of steel

In this paper, Von Mises yielding rule and kinematic hardening rule are commonly used in nonlinear analysis. The stress-strain curve of steel is assumed to be an ideal Elastic-Plastic, and it is described as a double line soften model. The author chooses the constitutive relation model in the reference literature[8], and the mathematical expression of this model is as follows:

$$|e_s| \leqslant e_s,\ s_s = E_s e_s \quad (\text{Which } E_s = f_y / e_y) \tag{1}$$

$$e_y < |e_s| \leqslant e_{sh},\ s_s = f_y \frac{|e_s|}{e_s} \tag{2}$$

Boundary constraints and loading system

In this paper, the boundary conditions of the specimen are simulated. According to the actual conditions: Beam end release degree of freedom, without any constraint conditions; We restrict X, Y direction of translation of the top surface of the crisscross section column composed of core concrete-filled steel tube and steel beam. We restrict bottom of the component X, Y and Z three direction of translation, but it is not restricted to the free rotation of the upper and lower column. The upper end is a free end, the lower end is a fixed end. In this paper, the author has set up two steps. We applied the axial pressure on the column top in the first step in the analysis, and set the reference point and reciprocating displacement load on the beam end in the second step. Each load control is 10mm, and the load is stopped at 50mm[9].

Analysis of finite element simulation results

The deformation map and stress chart of the specimen

In Figure 2, red is a high stress area. It can be seen that the high stress area of the external concrete, steel tube and steel beam is mainly concentrated in the joints of concrete and steel beam joints. The core area of the joint is higher, the farther the core area of the column and the stress of the beam is relatively low. The core concrete is always in the state of three to the pressure due to the restriction of the external steel tube, so that the plastic deformation of the component is improved. The existence of the steel tube not only restricts the lateral deformation of the core concrete, but also takes part of the vertical load. The existence of internal and external concrete causes the failure of the steel tube to avoid buckling in the process of force, so that the material properties of the steel tube can be fully played. It can be seen from the graph, although the model has some stress concentration area under the large load, there is no excessive yield deformation.

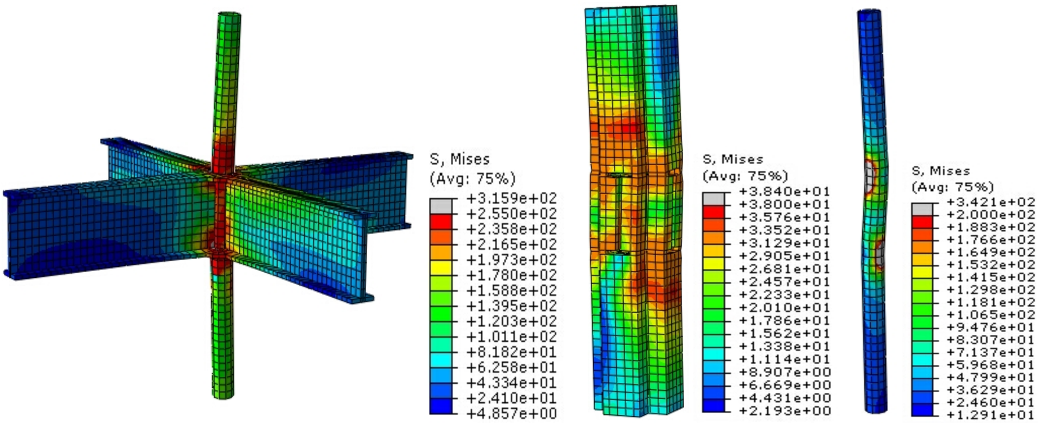

Figure 2. The stress of crisscross section column composed of core concrete-filled steel tube and steel beam

Analysis of hysteretic curve and skeleton curve of specimen

The hysteresis curve is studied in the relationship between the force and displacement of loading point of the experimental component under cyclic loading. It reflects the deformation characteristics, stiffness degradation and energy consumption of the structure in the process of repeated stress. It is the comprehensive embodiment of the seismic performance of the structure and is also an important basis for the elastic-plastic dynamic response analysis[10]. The load displacement hysteretic curves of the members under different axial compression ratios at the horizontal cyclic loading are obtained which shown in Figure 3.

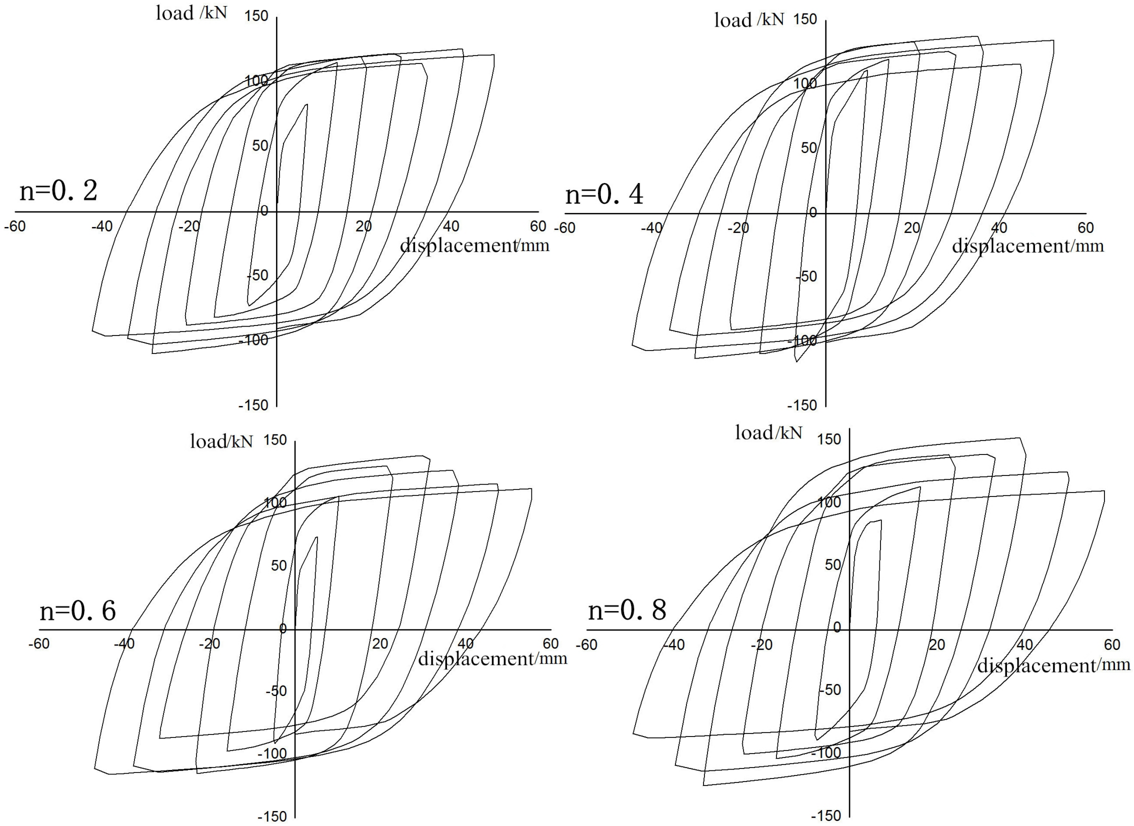

Figure 3. Hysteretic curve of component

On this basis, the load displacement skeleton curves of the specimens under different axial compression ratios are presented, as shown in Figure 4. From Figure 3, it can be seen that the curve is close to linear growth at the initial stage of loading. In the elastic stage, there is no degradation in stiffness. With the increase of the amplitude of the displacement, the specimen is included in the elastic plastic deformation stage. The stiffness of the specimen is rapidly reduced, the slope of the displacement-load curve is gradually reduced. From the graph, the rate of decline of the load carrying capacity of the specimen can be decreased with the increase of the axial pressure ratio. When the load exceeds the limit state, the load displacement curve appears to descent segment. The concrete damage in the specimen is accumulated, and the steel gradually yields. The ultimate load of each cycle is gradually reduced, and the test pieces are beginning to enter the stage of damage. As can be seen from Figure 4, in the initial stage of loading, the specimen is in the elastic stage. The rise of the skeleton curve of each specimen is linear, which shows that the axial compression ratio has little effect on the elastic stage. With the increase of the displacement load, the specimen begins to enter the plastic stage. In the late loading stage, there was a gradual decline. The yield is becoming more and more obvious, which indicates that the ductility of the specimen is getting worse and worse.

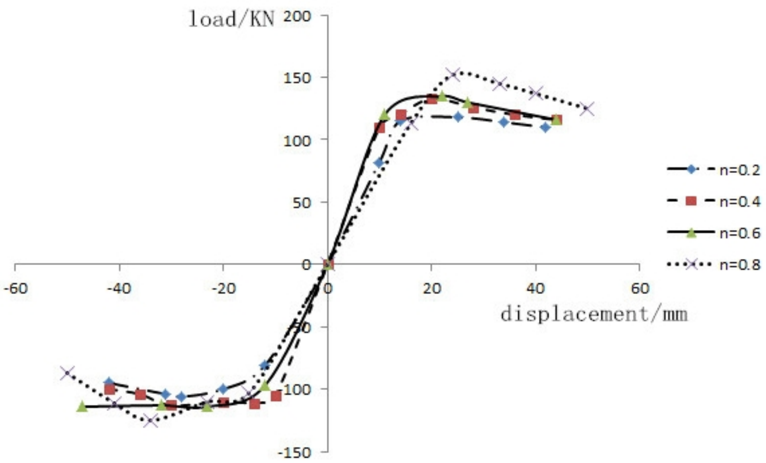

Figure 4. The skeleton curve of the model with different axial compression ratio

Energy analysis

During the earthquake, the buildings need to rely on their own elastic plastic deformation to consume seismic energy. The dissipation of seismic energy depends mainly on the plastic deformation of steel and the friction sliding between steel tube and concrete. The energy dissipation capacity is an important index to evaluate the seismic performance of buildings. In this paper, the energy dissipation capacity of the specimens is discussed by the energy dissipation coefficient E and the equivalent viscous damping coefficient ζ_{eq}. The area of the hysteresis loop can be represented in a specimen of the dissipated energy in a cyclic loading process. The more dissipated energy, the more favorable to the structural seismic performance. The energy dissipation coefficient E and the equivalent viscous damping coefficient ζ_{eq} provided by the literature[11]. The energy consumption index of each sample is shown in Table 3.

Table 3. Energy consumption index of test pieces

Number of specimen	Ultimate bearing capacity/KN	Ultimate displacement/mm	Energy dissipation coefficient（E）	Equivalent viscous damping coefficients（ζ_{eq}）
MJ-1	122.02	28.49	2.513	0.399
MJ-2	135.29	31.66	2.477	0.394
MJ-3	137.67	35.00	2.464	0.392
MJ-4	152.49	38.81	2.320	0.369

In normal circumstances, the average value of reinforced concrete joints is 0.1. Ordinary steel reinforced concrete joint is about 0.3[12]. As can be seen from the table, the equivalent viscous damping coefficient of each specimen is 0.369~0.399. The model of equivalent viscous coefficient ζ_{eq} final average value is 0.389. It is better than ordinary steel reinforced concrete joints of energy consumption. And it reflects the good energy dissipation capacity of joints of the crisscross section column composed of core concrete-filled steel tube and steel beam. With the increase of the axial compression ratio, the energy dissipation efficiency of the specimen is decreased. It is showed that the seismic resistance of the axial pressure ratio test pieces is too large, and the axial compression ratio should be properly controlled in the design of actual engineering.

Conclusions

Abaqus finite element analysis software is used in this paper, the influence of axial compression ratio on the seismic performance of the model is studied, and we can have some conclusions.

According to the *abaqus* finite element analysis software, the component is applied to the repeated load. Finally, we can see from the stress cloud of the simulation component, The high stress zone of the external concrete, steel tube and steel beam is mainly concentrated in the joints of concrete and steel beam.

Regardless of the axial compression ratio, the load displacement hysteretic curves of the specimens are all full. There is no obvious phenomenon of pinch phenomenon. Joints can effectively absorb the energy released by the earthquake and show a good seismic performance and have a wide range of applications.

The load displacement skeleton curve can be compared，With the in-crease of the axial compression ratio, the ultimate bearing capacity of the specimen decreases, and the corresponding limit displacement in-creases. It shows that the lower axial compression ratio not only can give full play to the performance of the material, but also delay the arrival of the peak load of the joints.

With the increase of the axial compression ratio, the ultimate bearing capacity and the stiffness of the specimens are decreased. When the specimen reaches the yield state, the stiffness degradation rate is accelerated. And the bearing capacity of the specimens is significantly decreased after the ultimate state, ductility performance is gradually reduced. With the increase of displacement, the failure of the specimen under high axial compression ratio has been earlier, and the bearing capacity decreased more quickly, and the total energy of the specimen is also reduced.

Acknowledgements

This work was financially supported by China Scholarship Program (201308210105) and the Research Project of Liaoning Provincial Educational Bureau (L2014238).

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