Application of Concrete Filled Steel Tube Transfer Joints in Asymmetric Beam-Column Joints at the China National Convention Center Phase II

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Abstract. The supporting hotel of the National Convention Center Phase II employed a novel type of transfer joint for connecting steel and reinforced concrete structures, and studied geometrically regular and symmetric transfer joint. However, the mechanical properties of irregular, asymmetric joints within this hotel structure have not yet been examined. A representative asymmetric beam-column transfer joint was selected, and its failure process and mechanical performance were investigated based on a finite element model. The simulation results indicate that the construction form of the transfer joint can be applied to asymmetric beam-column joints, achieving the design goal of yielding in the upper part first.

Key words: transfer joints; RC frame; mixed structure; finite element analysis

1 INTRODUCTION

Hybrid structures can leverage the advantages of different structural forms, but research on the connections between various structural types is scarce. The existing transition and connection methods in code [1-4] do not meet the requirements of the National Convention Center Phase II project for not increasing joint size. Although some connection methods have been proposed in Ref. [5-6], they also did not consider the factor of joint size. Ref. [7] proposed a new type of transfer joint that does not increase joint size and can be used at embedded ends. However, Ref. [7] only investigated transfer joints with symmetric shapes and stiffness, while actual structures possess asymmetric transfer joints. For asymmetric joints, the theoretical design method of bearing capacity is given in the code[8], but the influence of different construction forms is not considered. In addition to the theoretical design, most of the literature mainly uses experimental or numerical methods to analyze the mechanical properties of the joints, such as [9-12]. Whether the construction form of transfer joints in Ref. [7] can be applied to asymmetric beam-column transfer joints with non-collinear beam axes, asymmetric geometric shapes, and reinforcement information requires

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further analysis and research. This paper selects an asymmetric transfer joint intended for use in the National Convention Center Phase II project and focuses on studying its failure process through numerical simulation. Since the location of the asymmetric joint is at the connection between the upper and lower parts of the structure, the strength of the lower part of the joint must be greater than that of the upper part. The main research objective of this paper is whether the upper part yields first.

2 STRUCTURAL INFORMATION AND MODELING METHOD

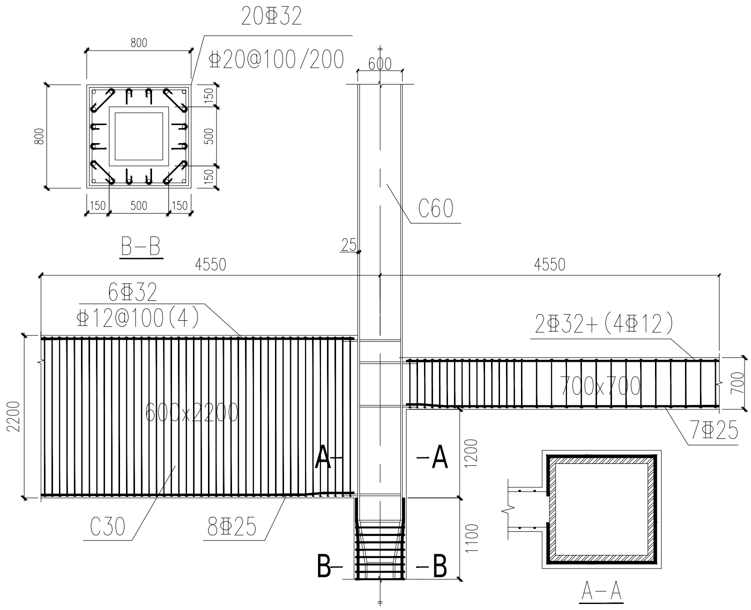
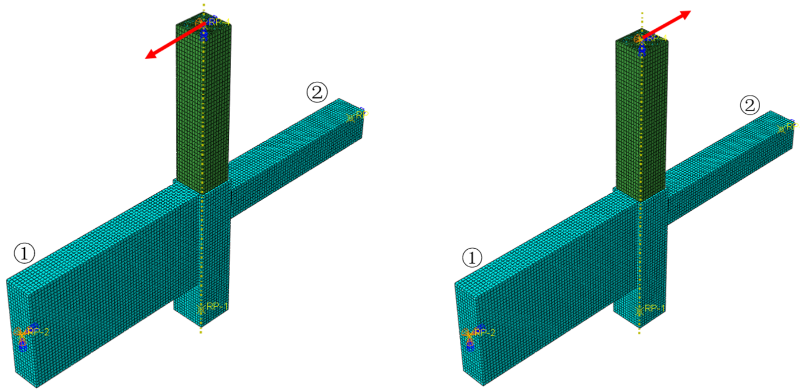


Fig. 1. The information of the joint

The information of the joint is shown in Figure 1. The simulation method is proposed in literature [13] and verified by tests. This paper uses this modeling method to model the joint based on Abaqus. The steel tube in the finite element model is S4R, the concrete part uses C3D8R, and the reinforcement is T3D2. The interface between the steel tube and the concrete of the upper column is modeled as a face-to-face contact relationship, and coefficient of friction is 0.9. The core concrete within the steel tube concrete is determined according to Ref. [13], while the concrete in other parts follows the code [14]. The damage factor of concrete is determined according to Ref. [15]. Steel materials are modeled using an ideal bilinear constitutive relationship. The Young's modulus of steel is 206000 MPa and the modulus after yielding is 2060 MPa. The steel part is insert into the concrete part, ignoring the sliding between the two. The deformation of the joints is mainly concentrated on upper column, while the lower reinforced concrete part has less deformation, so the insert interaction has less influence on the simulation results. This paper focuses on studying the damage process of the joint, thus employing a Pushover analysis for loading.

3 ANALYSIS OF THE DAMAGE PROCESS

Due to the asymmetric structural form of the joint, the damage process and mechanical performance of the joint are studied separately under loading in the directions of beam ① and beam ②, as shown in Figure 2.



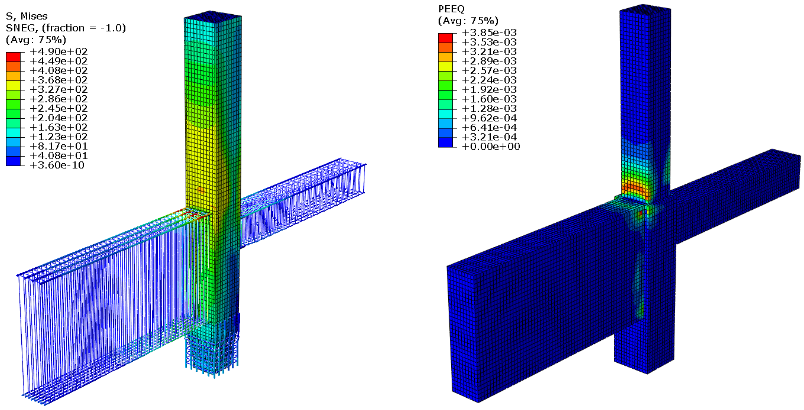
(a) Loading in the direction of beam ① (b) Loading in the direction of beam ②

Fig. 2. Schematic diagram of joint loading directions

3.1 Damage Process when Loaded in the Direction of Beam ①

When the control displacement U at the top of the column is 28.2mm, and the restoring force at the column top is approximately 2022.1kN, the stress in the steel tube at the base of the upper column reaches yield. The maximum stress in the rebars inside beams ① and ② is 245MPa and 257MPa, respectively. The maximum stress in the core area of the joint is about 226MPa, and the stress values in the steel tube and reinforcement in the diameter-changing area of the lower column are 111MPa and 109MPa, respectively. When the top column displacement U further increases to 41.3mm, the top of the web plate of the corbel enters the yield state, with the restoring force at the column top about 2543.4kN.

When the control displacement at the column top increases to approximately 74.0mm, the joint enters the ultimate load-bearing capacity state, with the restoring force at the column top about 3127.0kN. The maximum stress in the rebars inside beams ① and ② is 496MPa and 231MPa, respectively. The maximum stress in the core area of the joint is about 313MPa, and the stress values in the steel tube and reinforcement in the diameter-changing area of the lower column are 137MPa and 140MPa, as shown in Figure 3(a). Based on the equivalent plastic strain of concrete, it is observed that the damage in the concrete parts is mainly concentrated in the upper column, as shown in Figure 3(b).

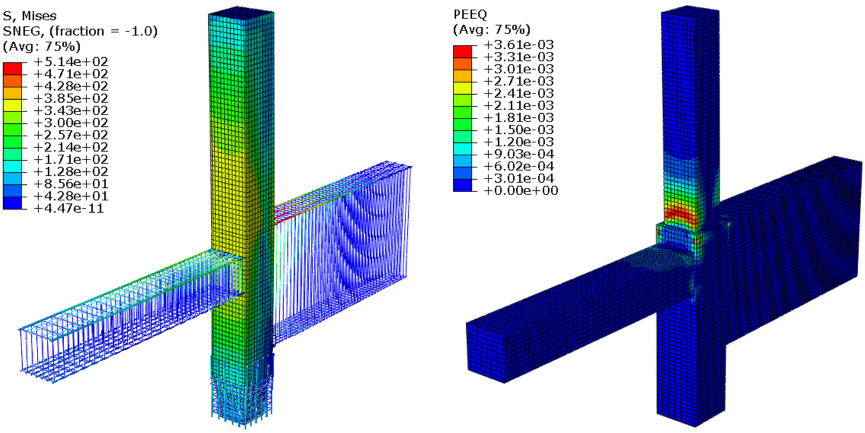


(a) Stress cloud of steel and reinforcement (b) Equivalent plastic strain of concrete

Fig. 3. Ultimate load-bearing capacity stage when loaded in the direction of beam ①

3.2 Damage Process when Loaded in the Direction of Beam ②

When the control displacement U at the top of the column is 30.6mm, the steel tube at the base of the upper column yields, with the restoring force at the column top about 520.5kN. The maximum stress value inside beam ① is approximately 396MPa, and inside beam ② is about 219MPa; the maximum stress in the core area of the joint is about 255MPa; the stress values in the steel tube and reinforcement in the diameter-changing area of the lower column are 119MPa and 121MPa, respectively.



(a) Stress cloud of steel and reinforcement (b) Equivalent plastic strain of concrete

Fig. 4. Ultimate load-bearing capacity stage when loaded in the direction of beam ②

When the horizontal control displacement at the top of the column increases to approximately 80.8mm, the joint enters the ultimate load-bearing capacity state, with the restoring force at the column top about 3083.4kN. The reinforcement inside beam ① had already yielded, with its stress value about 513MPa, the maximum stress value inside beam ② is about 392MPa; the maximum stress in the core area of the joint is about 345MPa, other parts are still in the elastic state; the stress values in the steel tube and reinforcement in the diameter-changing area of the lower column are 153MPa and 154MPa, as shown in Figure 4(a). The damage to the concrete at the base of the upper column is significantly greater than in other parts, as shown in Figure 4(b).

3.3 Summary and Analysis of the Damage Process

The damage process of the joint under different loading directions is as follows:

When loaded in the direction of column ①: Yielding at the base of the upper column → Yielding at the top of the corbel web plate → Ultimate load-bearing capacity state

When loaded in the direction of column ②: Yielding at the base of the upper column → Yielding at the top reinforcement of beam ① → Ultimate load-bearing capacity state

From the damage process, it is evident that the steel plate at the base of the upper column yields and significant concrete damage occurs, meeting the design goal of the upper column yielding first. Additionally, the floor slabs in actual engineering can enhance the strength of the lower part of the joint, but this beneficial factor was ignored in the simulation. From this perspective, the safety of the joint in actual engineering is higher than that predicted by the finite element simulation results, ensuring a certain level of reliability.

4 SEISMIC PARAMETER ANALYSIS

The mechanical parameters such as yield load, yield displacement, and ultimate load-bearing capacity under different loading directions are shown in Table 1. The ultimate load-bearing capacity and ductility coefficient of the joint under different loading directions do not vary significantly, indicating that the lower part of the joint possesses sufficient strength to fully utilize the strength reserve of the upper column. However, the stiffness under different loading directions shows certain discrepancies due to the asymmetry in geometric shape and reinforcement information.

Table 1. Supplemental simulation values of joint strength and stiffness

Loading Direction	Yield Point			Ultimate State		Ductility Coefficient
	Yield Load (kN)	Yield Displacement (mm)	Yield Stiffness (N/mm)	Ultimate Load (kN)	Ultimate Deformation (mm)	
Beam ①	2022.1	28.2	71619.7	3127	74	2.04
Beam ②	1990	30.6	65075.1	3083.4	80.8	2.07

5 CONCLUSION

(1) The joints all exhibit the characteristic of yielding in the upper column first, and during the force process before reaching ultimate load-bearing capacity.

(2) The steel tubes and reinforcement in the diameter-changing area of the joint remain in the elastic state, preliminarily indicating that the construction method of the new transfer joint can be applied to asymmetric types of joints.

(3) When loaded in different directions, the variations in mechanical parameters such as ductility coefficient and ultimate load-bearing capacity of each joint are small, indicating that despite the asymmetry at the lower part of each joint, the embedding effect under different loading directions is basically similar.

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