Finite Element Analysis of the Joint Surface of Concrete Filled Steel Tubular Frame Column and Precast Shear Wall

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Abstract: In order to study the connection performance of a new type of shear key to concrete filled steel tubular (CFST) frame column and precast shear wall, a numerical model is established by using the finite element software Abaqus, the mechanical properties of the combined shear wall are studied by the strength of post-poured concrete, the yield strength of the shear key steel and the spacing between the shearing bonds. The results show that the failure modes of specimens are mainly related to the strength of post-poured concrete and the yield strength of shear keys. When the specimens are damaged by shear bonds, the bearing capacity and ductility of the specimens increase obviously with the increase of the yield strength of the shear key steel and the shortening of the spacing between the shear keys. The change of strength of post-poured concrete has little effect on the working performance of specimens. When the specimens are damaged by post-poured concrete, the stiffness of the specimens is larger and the ductility is worse.

1. Introduction

Reinforced concrete shear wall structure with CFST frame column can effectively combine the advantages of CFST and reinforced concrete respectively. Multiple seismic defense lines are formed to improve the single seismic form of shear wall structure and greatly improve the overall seismic performance of the structure[1], which has been widely concerned and gradually promoted and applied.

In many developed countries, assembled concrete building has become the most important way of building industrialization. Prefabricated reinforced concrete shear wall structure with concrete CFST frame column is formed by introducing prefabricated fabricated construction method into the structure of CFST shear wall, which is expected to effectively improve the overall seismic performance of the prefabricated shear wall structure and further promote the development of building industrialization. However, a large number of joints are connected in the precast CFST composite shear wall, and the performance and effect of these joints directly determine the overall performance of the prefabricated structure. Therefore, how to connect the CFST frame column with the precast shear wall reliably and give full play to the combined benefits of the two is the basis of the research on the mechanical performance of the precast composite shear wall.

In this paper, a new type of connection between CFST frame columns and precast shear walls is proposed, as shown in Figure 1, where the connection is that the shear keys are welded on the frame
column. After the positioning and hoisting of the prefabricated wallboard, the steel bar reserved at the prefabricated wallboard is welded to the shear key, and then the concrete is filled in the connection area to form a whole. In this paper, the finite element method is used to analyze the joint surface of CFST framed columns and prefabricated shear walls under monotonic loading. Based on the accuracy of the finite element model, the parameters affecting the shear behavior of the joint of concrete filled steel tube shear wall are studied. The load-displacement curve, bearing capacity, stiffness and ductility of the specimens under each parameter are analyzed, and the influencing factors of the joint performance of prefabricated CFST composite shear wall are further clarified.

![Figure 1. Connection method used in this article](image)

2. Parameter design

2.1 Specimen size

The dimensions of prefabricated reinforced concrete shear wall specimens refer to a project prototype [1], and the specimens adopt a 1:5 scale model. The cross-section of the CFST frame column is square, the column width is 120mm, the column height is 1200mm, and the wall thickness is 5mm. Prefabricated reinforced concrete shear wall panels are 860 mm in length, 120 mm in thickness and 400 mm in width. The base size is 1500mm in length, 700 mm in thickness and 440 mm in width. The geometric dimensions of the specimen are shown in Figure 2.

![Fig 2. Specimen Dimension Diagram (Unit: mm)](image)

2.2 Design of Reinforcement and Shear Key for Shear Wall and Base

According to the Code for Design of Concrete Structures(GB 50010-2010)[2]: The minimum reinforcement ratio of shear wall should not be less than 0.25% when the third level or below is earthquake resistant; The reinforcement of precast shear wall is as follows: The Longitudinal reinforcement is arranged in 2 rows and 4 columns with reinforcement 10@120, and the reinforcement
ratio is 0.89%; The horizontal reinforcement is arranged in 2 rows and 12 columns with reinforcement 10@75, and the reinforcement ratio is 1.8%. The base and prefabricated wall are poured as a whole to realize the loading conditions of the bottom of the shear wall.

The shear key consists of shear steel plate, stiffening ring plate and Uplift steel plate. The geometric dimensions of the shear keys are shown in Figure 3.

Figure 3 Shear connector (Unit: mm)

3. Finite element analysis

3.1 Finite element modeling

Because of the symmetry, the finite element model takes 1/2 of the wall, as shown in Figure 4. The load on the specimens is only horizontal load, so the horizontal load is directly applied to the end plate of concrete filled steel tube, which should be set as a rigid end plate that can not be deformed.

The core concrete of steel tube and reinforced concrete are simulated by the three-dimensional solid element C3D8R with the linear reduction integral format of 8-node hexahedron; Steel pipe and shear key parts are simulated by S4R shell element, the reinforced part is simulated by T3D2 3d linear rod element, concrete adopts plastic damage model, and steel adopts isotropic elastoplastic model. The compressive constitutive structure of core concrete filled steel tube is based on the core concrete model modified by Liu Wei [3]. The compressive constitutive structure of reinforced concrete adopts the ordinary concrete model proposed by Attard and Setunge[4]. The steel pipe and shear bond constitutions adopt the secondary plastic flow model proposed by Han Linhai [5]. The material properties of reinforcing bar are similar to those of high strength steel, so the stress-strain relationship of reinforcing bar is defined by using the two-fold line model.

Tie contacts are set between steel tube and end plate, concrete filled steel tube and end plate, steel tube and shear key, shear key and steel bar respectively. Normal hard contact and tangential coulomb friction were respectively set between steel tube and concrete-filled steel tube, steel tube and post-poured concrete, and post-poured concrete and reinforced concrete, and the friction coefficient was set as 0.6 [6].
3.2 Case verification

In order to verify the reliability of the finite element analysis of the shear behavior of the combined surface of CFST column and shear wall in this paper, the necessary example verification must be carried out. Since the main research object of this paper consists of concrete-filled steel tubular columns and reinforced concrete shear walls, this paper separately simulates the reinforced concrete shear walls collected in the existing literature and compares them with the experimental results.

The finite element analysis of the mechanical properties of a reinforced concrete shear wall by Cao Wanlin et al. [7] under horizontal loads is carried out by using the finite element software ABAQUS. The upper part of the model is subjected to constant uniform axial load, the middle part of the loading beam is subjected to horizontal displacement, and the bottom of the specimen is subjected to fixed constraints so as to achieve the same loading conditions as in the test.

Figure 5 shows the finite element model of the ABAQUS of the shear wall specimen. The constitutive relation of the model, the type of element and the setting of its contact interface are shown in Section 2.1. Figure 6 shows the comparison between the finite element calculation results and the experimental results. It is found that the stiffness variation and ultimate bearing capacity are consistent.

4. Parameter analysis

Using the finite element model mentioned above, the shear ultimate bearing capacity of prefabricated shear wall joints with frame under different parameters is calculated, and which parameters have a greater impact on the joint performance of specimens is determined.

Table 1 shows the specific parameters of each calculation model, where $f_{cu}$ represents the standard value of concrete compressive strength, $f_y$ represents the standard tensile strength of steel used for shear key, $n$ represents the number of shear key layout on the bonding surface, $SC$ represents the spacing of shear key. In the model number, $P$ (Precast) represents prefabrication; $SC$ (Shear Connector) represents shear keys, followed by the number of shear keys; $Q$ represents the tensile strength of steel shear bonds; $C$ and subsequent figures represent the strength of post-poured concrete.

| Analysis parameter | Specimen label | $f_{cu}$ (MPa) | $f_y$ (MPa) | $n$ | $SC$ (mm) |
|--------------------|----------------|----------------|-------------|-----|-----------|
| $f_{cu}$           | P-SC5-Q345-C40 | 40             | 345         | 5   | $L_w/6$   |
|                    | P-SC5-Q345-C50 | 50             | 345         | 5   | $L_w/6$   |
|                    | P-SC5-Q345-C60 | 60             | 345         | 5   | $L_w/6$   |
| $f_y$              | P-SC5-Q235-C60 | 60             | 235         | 5   | $L_w/6$   |
|                    | P-SC5-Q345-C60 | 60             | 345         | 5   | $L_w/6$   |
|                    | P-SC5-Q420-C60 | 60             | 420         | 5   | $L_w/6$   |
| $SC$               | P-SC1-Q345-C60 | 60             | 345         | 1   | $L_w/2$   |
4.1 Influence of post-concrete concrete strength
Post-poured concrete strength $f_{cu} = 60$ MPa, yield strength $f_y = 345$ MPa, and spacing $SC = LW/6$ of shear keys are the basic parameters. By changing the strength of post-pouring concrete, relevant models are established for analysis. Figure 7a. shows the load-displacement curve obtained by numerical calculation. Table 2. gives the calculation results of specimens with different strength of post-poured concrete.

| Model number       | $P_y$(kN) | $P_{max}$(kN) | $P_u$(kN) | $\Delta_y$(mm) | $\Delta_{max}$(mm) | $\Delta_u$(mm) |
|--------------------|-----------|---------------|-----------|----------------|-------------------|--------------|
| P-SC5-Q345-C60     | 292.5     | 355           | 306       | 1.95           | 4.1               | 6.6          |
| P-SC5-Q345-C40     | 252       | 380           | 323       | 1.9            | 6.6               | 8.2          |
| P-SC5-Q345-C50     | 282       | 395           | 335.8     | 2.1            | 6.8               | 8.6          |
| P-SC5-Q345-C60     | 342       | 415           | 352.8     | 2.6            | 7.5               | 9.4          |

It can be seen that the strength of post-poured concrete has little effect on the connection performance when the specimens are damaged by shear keys; the ductility of the specimens decreases obviously when the specimens are damaged by post-poured concrete; and the increase of the strength of post-poured concrete has little effect on the shear bearing capacity of such structures.

4.2 Influence of shear key yield strength
Finite element analysis was carried out on the specimens with different yield strength of shear keys. All the specimens with different parameters were damaged by shear keys. Fig. 7b shows the influence curve of yield strength of shear bond on $P-\Delta$ curve of specimens. Table 3. gives the calculation results of specimens under different yield strengths of shear keys.

| Model number       | $P_y$(kN) | $P_{max}$(kN) | $P_u$(kN) | $\Delta_y$(mm) | $\Delta_{max}$(mm) | $\Delta_u$(mm) |
|--------------------|-----------|---------------|-----------|----------------|-------------------|--------------|
| P-SC5-Q345-C60     | 297       | 356           | 302.6     | 2.4            | 6.2               | 8.3          |
| P-SC5-Q345-C60     | 342       | 415           | 352.75    | 2.6            | 7.5               | 9.2          |
| P-SC5-Q420-C60     | 398       | 446           | 379.1     | 2.9            | 6.0               | 8.9          |

It can be seen that the yield strength of shear bonds has a great influence on the bearing capacity and stiffness of specimens, and the ultimate bearing capacity of specimens increases obviously with the increase of shear bond strength because the specimens are damaged by shear bonds.

4.3 The influence of shear key spacing
Finite element analysis of parametric specimens with different spacing of shear keys. Figure. 7c shows the influence of the spacing between shear keys on the $P-\Delta$ curve ($L_w$ is the length of the interface). Table 4. gives the calculation results of specimens with different spacing of shear keys.

| Model number       | $P_y$(kN) | $P_{max}$(kN) | $P_u$(kN) | $\Delta_y$(mm) | $\Delta_{max}$(mm) | $\Delta_u$(mm) |
|--------------------|-----------|---------------|-----------|----------------|-------------------|--------------|
| P-SC5-Q345-C60     | 126       | 152           | 129.2     | 1.1            | 2.3               | 3.75         |
| P-SC3-Q345-C60     | 238       | 305           | 259.25    | 1.9            | 7.5               | 6.6          |
| P-SC5-Q345-C60     | 342       | 415           | 352.75    | 2.6            | 7.5               | 9.2          |

It can be seen that the spacing of shear keys has a great influence on the bearing capacity of specimens. With the shortening of the spacing of shear keys, the number of shear keys on the joint surface is increased, and the shear capacity, stiffness and ductility of the specimens are obviously improved.
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5. Conclusion
In this paper, the numerical simulation analysis is carried out to study the joint performance of the joint between the CFST frame column and the prefabricated reinforced concrete shear wall, and the following results have been achieved:

- The reliability of the finite element calculation for the shear performance of the joint between the CFST frame column and the shear wall is verified by the verification of the relevant examples.

- The parameters are analyzed by using the above finite element model. The results of parameter analysis show that when the specimens are damaged by shear bonds, the bearing capacity and ductility of the specimens are obviously improved with the increase of yield strength of steel and the shortening of the spacing between shear bonds. However, the change of the strength of post-poured concrete has little effect on the working performance of the specimens. When the specimens are damaged by post-poured concrete, the stiffness of the specimens is bigger and the ductility is worse. This kind of failure mode should be avoided in practical engineering.

Acknowledgements
The research reported in the paper is supported by the National Natural Science Foundation of China (Grant No. 51578152), The financial support is highly appreciated.

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