Finite element analysis on connection performance of prefabricated steel joints with grouting bolt sleeve

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Abstract. Under the national strategy of developing vigorously the prefabricated structure, to study the prefabrication and assembly of steel reinforced concrete shear walls, but the connection performance of the precast steel frame is the key to determine whether the prefabricated structure can be carried out. To the steel joint with grouting bolt sleeve, based on the ABAQUS finite element analysis software, the anchorage length, the thickness of sleeve wall and the bolt diameter are used as the analysis parameters, and it is to be analyzed for the influence trend of the model parameters on the joint performance. The results show that the anchorage length, the thickness of sleeve wall and the bolt diameter all have a positive influence on the tensile bearing capacity, in the meantime, the rational combination can optimize the failure state and improve the tensile bearing capacity of the joints.

1. Introduction
In view of prefabricated steel reinforced concrete shear wall structure, considering the relatively narrow construction space between upper and lower prefabricated shear wall pieces (height is about 150 MM-200 mm), in order to ensure the construction convenience and reliable performance requirements in prefabricated assembly process, this paper proposes a grouting pin-bolt sleeve prefabricated steel joint connection method. This connection method of section steel joints abandons the restriction of bolt connection on construction space and anchorage length, and the welding connection has higher technical requirements for site construction personnel, and the construction personnel need to control the welding quality strictly. The grouting pin-sleeve prefabricated steel joint connection mode is that the square steel sleeve is used to hoop the reserved ends of two profiled steels, and the pin is used to penetrate the steel sleeve and the steel sleeve area horizontally, so that the two profiled steels can achieve the effect of bolt connection. Then the high-strength fiber grouting material is poured into the steel sleeve through the grouting hole reserved on the steel sleeve, so that the steel sleeve can be connected horizontally. The grouting connection effect can be achieved in the hoop space with section steel, and the effective combination and full reinforcement of bolt connection and grouting connection can be realized to achieve the anticipated connection effect [1-2].

Based on the unidirectional tension test of steel connections with grouting pin sleeves, the influence of design parameters such as anchorage length, sleeve thickness and pin diameter on the tensile strength of steel connections is investigated. The results are as follows: 1. The anchorage length determines the stress distribution in the anchorage section; for the specimens with smaller anchorage
length, the stress concentration area is the most obvious near the pin hole of sleeve and section steel; with the increase of anchorage length, the stress concentration at the pin hole is improved, and the bonding effect of grouting material and the restraint effect on section steel are gradually strengthened. 2. The thickness of sleeve determines the mechanical properties and stress distribution of sleeve. Increasing the thickness of sleeve can improve the restraint of sleeve on grouting body and the bearing capacity around pin-bolt boreholes on sleeve. At the same time, the stress distribution of sleeve can be improved, the overall deformation of sleeve can be reduced, and the tensile bearing capacity of joint can be improved. 3. Pin bolt diameter determines the shear resistance of pin bolt, and also determines the coordinated displacement effect between sleeve and section steel. Pin bolt mainly bears shear force in the process of loading, resulting in bending deformation of pin bolt near the borehole, even shear situation. 4. The setting of shear keys helps improve the bonding effect of grouting material and the mechanical performance of joints. When the shear keys on section steel and sleeve are arranged in disorder, the corresponding two shear keys are arranged at a 45 degree angle to the horizontal direction, which can strengthen the restraint of shear keys on grouting body and give full play to the bonding and restraint effect of grouting material.

Testing is one of the most direct means to study the mechanical behavior of joints, but the content of experimental observation and the parameters of research are often limited. In this paper, a fine finite element analysis model of grouting pin sleeve connection under test conditions is established by using the general finite element analysis software ABAQUS (6.13-1). The model will take into account the influence of meshing technology, element selection, contact setting, constitutive model and other factors. According to the geometric and physical parameters of the test specimens, the model will be established and solved to obtain accurate and reliable numerical simulation results to verify the reliability and accuracy of grouting pin-bolt sleeve prefabricated steel joints.

2. Establishment of Finite Element Model

According to the design parameters of the test specimens, the finite element model of the test specimens is established in ABAQUS (6.13-1) software. It should be noted that the clearance between pin bolt and pin hole are neglected and the threaded pin bolt is simplified to a cylinder when the finite element model is established.

2.1. Model Size and Material Properties

In the model, steel density is 7.8 *10-9 t/mm³, Poisson’s ratio is 0.3, Mises yield criterion is selected, isotropic strengthening model is selected under monotonic load, and elastic-strengthening double-fold line model is selected for constitutive model. In this model, considering the confinement of square steel pipe to grouting material, the confined concrete constitutive model proposed by Han Linhai is selected as the constitutive model[3]. In ABAQUS software, the damage plastic constitutive model of concrete is selected to define the plastic parameters of grouting material, the compressive behavior of grouting material and the tensile behavior of grouting material. The density is 2.4 x 10-9 t/mm³, the elastic modulus is 2.95 x 104 MPa, and the Poisson’s ratio is 0.3[4].

2.2. Contact and constraints

In contact problems, there is a normal interaction force along the contact surface between two objects in contact. If there is friction on the contact surface, shear force along the tangent direction of the contact surface will also be generated to resist tangential sliding between objects[5]. The positions of contact pairs in the model include the following parts: 1) contact between pin bolt and pin hole and grouting material; 2) contact between grouting material and casing. When setting contact pairs, the contact property tangential behavior chooses "penalty" friction formula, the friction coefficient is 0.4, the normal behavior is set to hard contact, and the slip formula is limited slip. When defining contact pairs, we need to pay attention to: 1) choose the surface with large stiffness as the main surface; 2) choose the surface with similar stiffness as the main surface; 3) try not to let the node from the surface
fall out of the main surface when there is limited slip; 4) the position of the grid node can correspond to the result one by one more accurately[6].

The built-in constraints are used to simulate the relationship between H-beam and grouting material.

In order to facilitate the application of load and boundary conditions, and to prevent the problem of excessive local stress during loading, reference points are established at the end center of H-section steel and sleeve as constraint control points respectively, and then motion coupling constraints are established with the whole end surface.

2.3. Load and boundary conditions
The load in the model is the axial tension at the end of the sleeve. In order to make the calculation convergent, displacement is applied to the coupling point at the end of the sleeve.

The boundary condition is the same as that of the test, and the boundary condition is applied to the coupling constraint points. Firstly, all degrees of freedom of H-section steel end face constraints U1, U2, U3, UR1, UR2 and UR3 are restrained in the initial analysis step to ensure that the H-section steel end face is fixed; secondly, axial displacement is applied to the sleeve end face in the first analysis step.

2.4. Elements and grids
Because there are a lot of non-linear contact problems in the model, the 8-node hexahedral linear reduction integral element C3D8R with good contact analysis effect is chosen. When the grid is distorted, the analysis accuracy will not be greatly affected. It should be noted that in order to prevent the occurrence of hourglass numerical problems, the component thickness direction is divided into at least two elements.

The quality of meshing directly affects the accuracy of finite element calculation results. All components are divided into regular hexahedron elements by structured Meshing Technology after datum cutting. In the model, the mesh is divided into three parts, which can increase the efficiency of computer solution and refine the mesh in the area with large deformation.

3. Finite element analysis results

3.1. Analysis of Tensile Bearing Capacity
Through the comparative analysis of finite element curves, it can be seen that:

(1) All curves show three stages of development, i.e. initial deformation, rapid increase and stable load-bearing.
(2) The relative slip between the section steel and the sleeve of all the specimens is about 14 mm. The reason is that the shear keys can not be set accurately in the process of establishing the model. The friction coefficient between the sleeve and the grouting body, the section steel and the grouting body can only be set.
(3) The ultimate tensile bearing capacity of each anchorage length group is higher than that of the ordinary sleeve curve, which indicates that the increase of sleeve wall thickness can effectively improve the tensile bearing capacity of the joints; when the pin diameter is 12 mm, the tensile bearing capacity of the specimens with 90 mm anchorage length is significantly higher than that of 70 mm anchorage length group, indicating that the increase of anchorage length can also be effectively raised. Tensile bearing capacity of elevated joints; Compared with 80 mm group and 90 mm group, the tensile bearing capacity of 80 mm group is slightly higher than that of 90 mm group. This is because the bolt diameter of 80 mm group is 14 mm, while that of 90 mm group is 12 mm, which shows that the increase of bolt diameter has a more obvious effect on improving the tensile bearing capacity of joints.
(4) The slope of curve ascending stage is positively correlated with bolt diameter. The bolt diameter of 80 mm bolt is set to 14 mm, the slope of curve ascending stage is the largest, the bolt diameter of 100 mm bolt is set to 10 mm, and the slope of curve ascending stage is the smallest. The
smaller the relative slip between steel and grouting body is, the more obvious the effect of increasing the tensile capacity of joints is.

3.2. Stress analysis

The stress distribution diagram of joint failure shows that:

(1) Compared with the thicker sleeve, the stress concentration near the pin-bolt borehole of the ordinary sleeve is more obvious, and the thickness of the sleeve determines the stress distribution and deformation characteristics of the sleeve. The reason for the analysis is that the thickness of the sleeve increases, the lateral bearing capacity of the pin-bolt borehole is enhanced, the shear effect of the pin-bolt borehole area sleeve on the pin-bolt is strengthened, and the restraint of the sleeve on grouting material is strengthened. With this method, the deformation of sleeve is reduced, and the stress distribution of sleeve in pin bolt drilling area is obviously improved.

(2) Compared with the specimens with anchorage lengths of 70mm, 80mm and 90mm, under the same sleeve wall thickness, the larger the anchorage length, the weaker the stress concentration near the pin-bolt borehole, and the stress concentration area is changed from flaky state to point state. For the specimens with anchorage lengths of 100mm, due to the relatively small influence of pin diameter and sleeve wall thickness, the stress distribution near the pin-bolt borehole is weakened. The force concentration distribution is obvious, but the stress concentration area is still discontinuous and flaky compared with the anchorage length of 70mm and 80mm specimens. The reason is that the increase of anchorage length enhances the bonding between sleeve, section steel and grouting body, enlarges the distribution area of stress in the anchorage area, improves the stress distribution on sleeve, and it is beneficial to improve the tensile bearing capacity of nodes.

(3) For pin bolt diameter, pin bolt with diameter of 10 mm has obvious bending deformation, pin bolt with diameter of 12 mm has slight bending deformation, while pin bolt with diameter of 14 mm basically has no bending deformation, and the smaller the diameter, the stress distribution on pin bolt is more concentrated, and the stress value on pin bolt is higher; for specimens with the same pin bolt diameter, sleeve wall thickness is smaller or anchorage length is smaller. The bending deformation of pin bolt is more obvious, and the stress distribution on pin bolt is more complex, and the stress value is higher. The reason is that the pin bolt is responsible for the majority of the joint tensile bearing capacity, and the pin bolt diameter determines the joint tensile bearing capacity, but it is also affected by the sleeve wall thickness and anchorage length. At the same time, the pin bolt diameter can be set reasonably and effectively. At the same time, the reasonable setting of pin diameter can effectively improve the contact between pin and borehole side wall of pin and improve the stress distribution in the borehole area of pin.

(4) The phenomenon of grouting pull-out occurs in all specimens. Under the three conditions of anchorage length, sleeve wall thickness and pin diameter, when any two of them are fixed, the phenomenon of pull-out decreases with the increase of another condition; the phenomenon of pull-out of all specimens is within a reasonable range of deformation; the reason is that the anchorage length, sleeve wall thickness and pin diameter are all within a reasonable range of deformation. The diameter of pin bolts has a decisive influence on the tensile bearing capacity of joints. The three factors need to coordinate and work together to ensure the tensile bearing capacity of joints.

4. Conclusion

According to the results of finite element analysis, it can be seen that the ABAQUS finite element analysis software can effectively simulate the connection performance of grouting pin-bolt sleeve prefabricated steel joints, and the results are consistent with the theoretical analysis, which shows that the finite element analysis model is reasonable and reliable. At the same time, the following conclusions can be drawn:

(1) The anchorage length, sleeve wall thickness and pin diameter are positively correlated with the tensile bearing capacity of the joints.
(2) To further determine the decisive role of pin diameter on joint performance, anchorage length and sleeve wall thickness should be limited within a reasonable range.

(3) The stress distribution shows that the stress concentration area is near the pin-bolt borehole. It is suggested to set up reinforcement measures in the joint design to ensure that the pin-bolt borehole area of sleeve does not appear weakening or destructive.

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