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Selection and Analysis of Beam Column Joints of Multilayer Reinforced Concrete Frame Based on Finite Element

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At present, there are many tests on the joints of reinforced concrete frame beams and columns, and the corresponding measures have been taken to ensure the strength and ductility of the joints. In this paper, the nonlinear finite element analysis of reinforced concrete beams and reinforced concrete frame beam column joints is carried out from the simple to complex principles. The method of analysis and study of beam column joints with finite element method is discussed, and the force performance of beam column joints is analyzed and studied. This paper briefly introduces the characteristics, research status and development trend of reinforced concrete structure, the significance of research on the force performance of joints and the research progress at home and abroad. According to the characteristics of prefabricated steel frame structure system and how to deal with the connection of beam column joints in design, four kinds of form of bolted end plate connection beam column joints are put forward for on-site construction. The finite element method is used to analyze the stiffness, strength and bolt tension distribution of the beam column joints of each structure.

1. Introduction

The application scope of concrete structure has been expanded from the industrial and civil buildings, transportation facilities, water conservancy and hydropower construction and infrastructure projects to expand offshore engineering construction, under construction, submarine, nuclear power plant containment areas even has ideas and experiments for lunar building (Mohr et al., 2011; Nogueira, 2013; Zhang et al., 2016). With the use of light and high strength materials, more and more concrete structures are in large span and high rise buildings. The beam column node of the frame structure, also known as the core area of the node, is an important part of the main body structure. It is proved that most of the earthquake damage in the frame structure occurs in the beam column joint area. The "quality" of the node is the main factor that determines the force characteristics of the frame. In the seismic fortification area, the ductility frame design, in addition to the strength and ductility of the beam and column, must also ensure the ductility of the frame joints (Jukić et al., 2013). The force of frame joints is rather complex, but it mainly bears the combined action of shear and pressure. Only by preventing the premature failure of shear and compression of joints, the ductility design of beam column members is of practical significance.

2. Properties of reinforced concrete materials

The use of concrete structures has been about 0 years old. Compared with steel, wood and masonry structure, because of its many advantages in physical and mechanical properties and material sources, its development speed is very fast, and its application is the most extensive (Sung et al., 2013; Mazza, 2014; Seyhan et al., 2013).

The advantages of concrete structure are:

(1) Sand, stone is the main ingredient of concrete, which can use local materials. Where industrial waste is more, industrial waste can be used to make adult aggregate for concrete structure.

(2) Under normal environment, the durability of concrete is good, and the durability of high-strength concrete is better. In the concrete structure, the reinforcement is not easy to be corroded, so the concrete structure has

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good durability. For a concrete structure under corrosive environment, after reasonable design and effective measures, it can generally meet the engineering needs.
(3) The concrete is a poor thermal conductor, and the steel embedded in the concrete is far less exposed to the high temperature than the exposed steel structure. As long as the reinforced concrete protective layer on the surface of a certain thickness, in case of fire bars will soon soften, which can avoid the collapse of structure (Bui et al., 2014).
(4) Cast or prefabricated concrete structure has the advantages of good integrity, so that the structural stiffness and stability are good, which is conducive to the seismic resistance, vibration and shock wave.
(5) New mixing concrete for plastic, so it can be made into any shape according to the structure and size of need, which is conducive to building modeling.
(6) Reinforced concrete structure and reasonable use of the performance of the material play the advantages of steel and concrete respectively, compared with the steel structure can save steel and reduce cost (Costa et al., 2015).
There are also shortcomings in the concrete structure:
(1) It is of great importance. The concrete structure itself has a larger gravity, so that the effective load it can afford is relatively small. This is unfavorable to the large span structure and the high-rise building structure. In addition, the weight will make the seismic structure increase, so the seismic.
(2) Poor crack resistance. The reinforced concrete structure is usually cracked under the normal service condition. If the crack is too wide, it will affect the durability and application scope of the structure (Yang et al., 2016; Dhayalan et al., 2008).
(3) Template is needed. The production of concrete structure needs formwork. If the wood template is used, the number of repeated use will be less, and the cost of the project will be increased.
In addition, the construction process of concrete structure is complex, with a long cycle and is affected by seasonal climate. For existing concrete structures, it is difficult to repair if damaged, and the insulation and sound insulation performance is also poor. However, with the continuous development of science and technology, the shortcomings of the concrete structure are being gradually overcome or improved. A typical stress-strain full curve of concrete under uniaxial compression is shown as shown in figure 1.

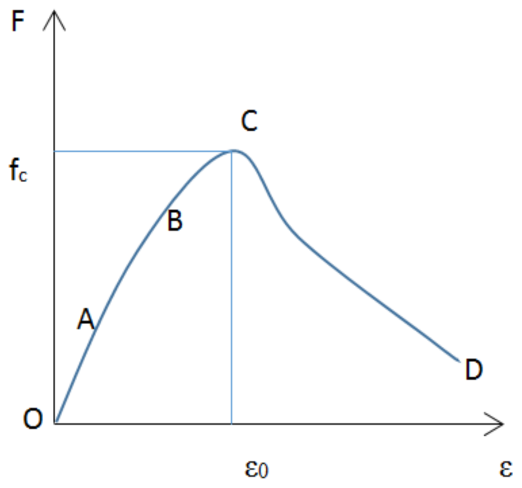

Figure 1: Typical stress strain curve of concrete under compression

$$f_{up} = f_0\left[2\left(\frac{\varepsilon}{\varepsilon_0}\right)-\left(\frac{\varepsilon}{\varepsilon_0}\right)^2\right],\ \varepsilon \le \varepsilon_0 \tag{1}$$

$$f_{\mathrm{down}} = f_0\left[1-0.15\left(\frac{\varepsilon-\varepsilon_0}{\varepsilon_u-\varepsilon_0}\right)\right],\ \varepsilon \le \varepsilon_0 \le \varepsilon_u \tag{2}$$

f_{up} represents the rising segmen and f_{down} represents a decline.

3. Brief Introduction of Finite Element Method

Finite element method (FEM) is a method of computing with the wide application of electronic computer. It is a numerical method to approximate the general continuum problem. From the physical point of view, it is a unit combination which is connected only to unit nodes to replace the continuum to be analyzed, and the continuum to be analyzed is also divided into several related units. The characteristics of the whole continuum are solved by the analysis of the characteristics of the unit (Ning et al., 2016). From a mathematical point of view, it makes a continuous infinite degree of freedom a discrete finite degree of freedom problem, which greatly simplifies the problem, or solves the problem that can not be solved. After solving the unknown element of the unit, the interpolation function can be used to determine the field function on the continuum. Obviously, as the number of units is increased, that is, the size of the unit is reduced, the approximate degree of the solution will be constantly improved. If the element is satisfied with the requirement of convergence, the approximate solution will converge to the exact solution.

The finite element method is used in two important tools: the matrix method is adopted in the theoretical deduction, and the computer technology is used in the actual calculation. The basic steps of the finite element method are as follows:

(1) The discretization of the structure. Discretization means splitting the structure to be finite elements, and setting nodes at the specified points of the unit, so that the adjacent parameters have continuity and form a unit aggregate instead of the original structure. When the structure is discretized, the size and number of the division units should be determined according to the requirements of the calculation precision and the capacity of the computer.

(2) The displacement interpolation function is selected. In order to represent displacement, strain and stress of unit body with node displacement, we must make certain assumption of displacement distribution in element when analyzing continuum problem, that is, pseudo location shift is a simple function of coordinates. The key to the finite element analysis is to choose the appropriate displacement function, and polynomial is usually used as a displacement function (Cotsovos, 2013).

(3) The mechanical properties of the unit are analyzed, and the element stiffness matrix is finally obtained by using the geometric equation, the constitutive equation and the variable component.

(4) The equilibrium equation of all elements is set up and the equilibrium equation of the whole structure is established. First, the stiffness matrix of each element is integrated into the integral stiffness matrix, and then the equivalent nodal force array of each element is set into the total load array.

(5) The equilibrium equations are used to solve the displacement of the unknown node and the stress of the calculation unit.

4. The results of finite element calculation

4.1 Bending moment curve

The extraction results of finite element method in loading force and calculated bending moment of beam end column position of the surface, and the extraction of a finite element model of the column surface u_1, u_2 and the vertical displacement of the beam flange at the center line of 3 points, 4 of the horizontal displacement of u_3, u_4 . The formula (3) is used to calculate the relative rotation angle θ of the node:

$$\theta=\frac{u_3-u_4}{h_2}-\frac{u_1-u_2}{h_1} \tag{3}$$

The h_1 is the horizontal distance between 1 and 2 points, that is, the section height of the column; h_2 is the vertical distance between 3 and 4 points, that is, the height between the upper and lower flange center lines.

On the basis of the above calculation, the bending moment and relative angle of the beam are obtained, and the bending moment curve of each node is obtained, as shown in figure 2. It can be seen from the figure, four kinds of nodes in the form of a joint initial rotational stiffness and flexural capacity are small; the initial node four rotational stiffness and flexural capacity are compared; node two and node three initial stiffness similar to the initial node two rotational stiffness is slightly higher than the three node. The bearing capacity is obviously higher than that of node three (Ganesan et al., 2014).

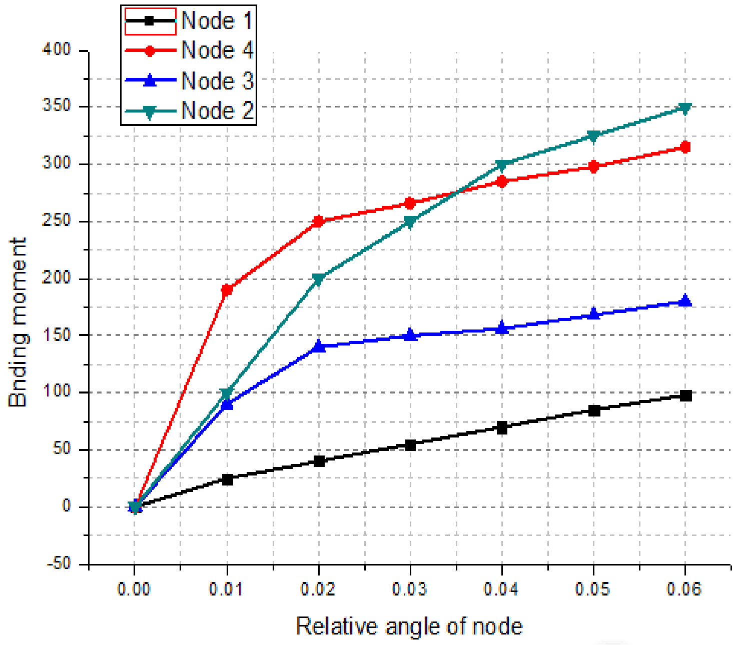

Figure 2: The relationship between the bending moment and the angle of the node

According to the European standard, according to the ratio of the rotational stiffness of the node to the line stiffness of the connected beam, the nodes can be divided into rigid nodes, semi-rigid joints and articulated joints. According to the support frame, the dividing line of the stiffness classification of the node is drawn according to the stiffness of the beam, that is, the line A and B in figure 2. The moment rotation coordinate system can be divided into three parts: the initial section of the bending moment of the node -- the initial section of the angle curve in the 1 area is the rigid node, the semi-rigid node in the 2 area, and the articulated joint in the 3 area. According to the initial stiffness of each node, it can be seen that one of the nodes belongs to the hinges, and the other nodes are semi rigid connections.

4.2 Stress and deformation of connected components

When the displacement of the beam to the beam end is 100mm, there is a larger yield region in the models of the 4 nodes. The stress and deformation of the beam column and end plate at this time. When the node rotates and the cylinder is seriously deformed, the connecting part between the extended cylinder and the tension bolt is partially concave connected with the compression flange, and the end plate is partly connected with the tensile deformation part. There is also a certain deformation on the surface of the column of node two, but the deformation of the column surface is more than that of the node because of the restriction of the column diaphragm (Shankar and Suji, 2014). Node three column end plate and column outer ring plate was affected by deformation, near the tensile flange of beam column end plate was torn off in the beam, the beam web and column overhanging section in tension bolt corresponding to large area within the height range of yield. The deformation of the end plate and the end plate of the four beams is smaller, and the plastic hinge is formed in the part of the cylindrical plate near the surface of the column, and the plastic deformation is mainly concentrated in this area.

Compared with the stress and deformation of node two and node, it can be seen that the column diaphragm can significantly reduce the deformation of the flange with the end plate. Comparing the stress and deformation between node two and node four, it can be seen that the end plate of the welded column can move the bolt connection position outside the outer ring plate, so that the deformation of the end plate decreases. Node one, node two and node four pull the side plate end plate stiffener into yield, indicating that the beam end plate stiffener has obvious transfer force, which can reduce the deformation of the end plate to a certain extent and affect the distribution of bolt tension.

4.3 Bolt tension distribution

In order to study the influence of structural form on the bolt tensile force distribution, the tension of each bolt was extracted from the state of each node loaded to the limit load 2/3, and the bolt tension distribution map was drawn according to its location on the end plate, as shown in figure 3. In this state, the four forms of the joints are in the elastic stage, which can be used as the basis for calculating the tension distribution of the bolt when the elastic design is designed.

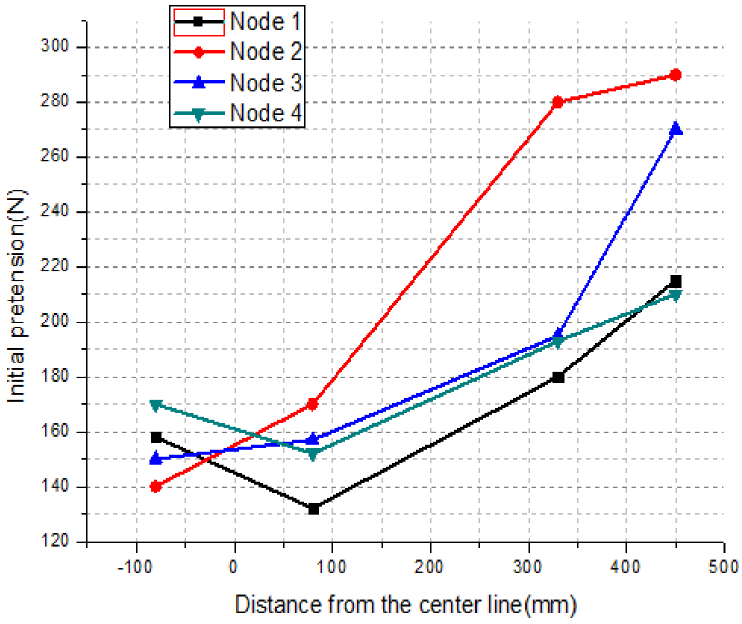

Figure 3: Bolt tension distribution

According to the bolt tension distribution of each node in figure 3, the pull force on the outside flange of the tension flange of the node is 15.6% larger than the inner bolt. When designing, the tension between the inside flange and the outer side of the tension flange should be considered. There is little difference between the tensile force of the tensile area of node two and node four, and the pulling force between the outer bolt and the inner bolt is less than 5%, so it can be designed according to the uniform distribution of tensile force of the tension bolt. The tensile force difference between tension bolts and node three is larger, and increases with the distance from the bolt to the flange, and does not have a linear relationship. The bolt tension near the tensile flange increases significantly, and the influence of nonlinear distribution of tension should be considered in the design.

At the same time, the tension distribution of four nodes can also be obtained. Under the same safety degree, the maximum pull force of nodes four bolts is 32.8% and 25% smaller than that of node two and node three respectively.

5. Conclusions

According to the results of the finite element analysis of the four kinds of nodes, we can draw the following conclusions: the connection between the cold-formed square steel tubular column and the steel beam can increase the stiffness and bearing capacity of the joints significantly, while the stiffness of the end plate connections without diaphragms and outer ring plates is smaller. Setting the outer ring plate and welding the end plate outside the steel tube can move the end plate connection position to reduce the bending moment of the end plate connection position, so as to reduce the deformation of the end plate and the pulling force of the bolt. The extended end plate connection, flange lateral stiffener and a force transmission effect can be restricted to a certain extent, the end plate deformation and influence the distribution of bolt tension, but it will have a higher level of stress. In the four node forms analyzed, the stiffness of node four is the largest, the bearing capacity is higher, and the end plate deformation and bolt tension are relatively small. It is a more reasonable prefabricated steel frame beam column joint form.

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