Performance Analysis and Optimization of Prefabricated Frame Connection Nodes

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Abstract. Structural connection and seismic capacity were key technologies in assembly reinforced concrete structure. In this paper, the connection form, transmission force and the seismic performance of fabricated connection nodes were analyzed. Based on the analysis, a kind of assembled steel pipe restrained energy dissipation frame joint with good seismic performance was put forward to realize the seismic requirement of "strong node, weak component", "strong shear and weak bending ". Besides, The influence on the core area is reduced by plastic hinge migration. At last, the construction process of the connection node is introduced.

Keywords: Assembly; Frame structure; Joint; Seismic performance; Optimization.

1. Introduction
During the 13th Five-Year Plan period, China will take the development of green building and intelligent building as the direction. Prefabricated reinforced concrete structure has the advantages of high production efficiency and green environmental protection. In addition, the standardized and refined construction of prefabricated components can also improve the reliable guarantee of project quality, which is a construction method with promotion value. Among all kinds of structural systems, frame structure is suitable for prefabricated construction because of its flexible plane layout, and beam, column and other components are easy to be standardized and typed. America, Europe, Japan and so on began to use prefabricated frame structure as early as the 1950s, has developed to today's super-high prefabricated frame structure.

2. Connection Form and Transmission Force Analysis of Fabricated Frame Structure
2.1. Fabricated Frame Structure Connection Form
Frame connection node is the key factor for the safety and reliability of prefabricated frame structure. In the great earthquake of Tangshan, China in 1976, the prefabricated structure was generally severely damaged and the damage was mainly concentrated in the joints. In order to ensure the rationality of the joint, the researchers studied the methods and structural measures of the joint from the aspects of mechanical performance and construction convenience [1-5]. The assembled frame structure can be divided into four types according to the position of beam-column split, the connection method of members and the position of reinforcement joints, etc.: the joint inside form, the beam mid-span form, the integrated form of beam-column joint, and the fully assembled form.

The internal connection form of beam-column joint refers to the connection of precast beam in the core area of the joint, in which the core area and the composite beam and plate are all made of cast-in-place concrete, and the precast upper column is connected with the precast lower column through the
grouting sleeve. The internal connection form of beam-column nodes is also one of the recommended forms in the current national standards. The purpose of “equivalent in-situ” is achieved by casting frame nodes in situ. Its advantage is that the component is easy to make, the site template installation amount is less, the disadvantage is that the joint reinforcement is complex, the construction quality is difficult to guarantee.

The difference between the connection form of beam mid-span and the connection form of beam and column joints is mainly that the connection position of precast beam is moved out from the core area of the node and the connection section is set near the middle of the span. The connection section adopts the traditional method of cast-in-place concrete. Its advantage is to reduce the difficulty of reinforcing steel bar construction at the joints, but its disadvantage is to increase the workload of beam bottom formwork.

The integrated form of beam-column joints is that “node core area – beam-end” adopts the form of factory prefabrication, with perforation holes reserved in the core area. After the steel reinforcement of the prefabricated lower column passes through the perforation hole in the reserved core area and is connected with the grouting, it is then connected with the prefabricated upper column through the grouting sleeve. Cast-in-place concrete is used to connect the precast beam with the core section of the precast joint. Its advantage is that node core precast, construction quality can be guaranteed; The disadvantage is to increase the beam bottom formwork.

The fully assembled type means that the connection between the precast column and the precast beam is connected through the grouting sleeve or the steel element embedded in the precast member. Its advantages are high precast rate, no concrete pouring on site, and its disadvantages are high precision and small allowable deviation of steel components. For example, although the bolt connection installation is fast and agile, but in the production accuracy requirements are high, small allowable deviation, transportation and installation process is prone to bending, damage and pollution. Because the steel components are embedded in precast concrete components, it is very difficult to replace the embedded parts if the processing is not accurate or the steel components are damaged during transportation.

2.2. Force Transfer Performance of Fabricated Frame Connection Nodes

The transmission path and mechanism of frame nodes are directly related to the form of frame nodes, and the transmission mechanism of frame nodes in different connection forms is not the same. At present, the force transmission mechanism of beam-column joints is divided into rigid connection, semi-rigid connection and hinge joint according to the structure form and rotation capacity of the joints. The bending resistance and shear resistance of frame joints are two important indexes to reflect the reliability of joint connections. The bending resistance reflects the main indexes to resist deformation or failure [6-9]. The shear resistance is a key factor to ensure that no sliding occurs between each other.

At present, there is no obvious difference between cast-in-place structure and fabricated structure in the research methods and indexes of the bending performance of beam-column joints, and researchers mainly study the influence of the form and construction of joints on the bending performance of joints. Wang Tao (2013) [6] studied the influence of bolt diameter, grade, slip coefficient of anti-slip surface and adding some T-shaped parts at the beam-column joint on the joint bending performance by combining finite element method with static bending test. Chen Jian-jia (2014) [8] made a scale specimen of steel sub-beam penetration joint in the proportion of 1:2 and carried out static loading test on it to study the stress process and failure mechanism of the joint. Zhang Pei (2007) [9] analyzed the mechanical properties of three kinds of beam-column joints, which were slotted with tooth, slotted with external steel plate and planted with bent steel bar after straight slotted without tooth. The shear properties of nodes usually include the shear properties of the core area of nodes and the shear properties of the connections of prefabricated components. The shear strength of core area is basically the same as that of cast-in-place concrete structure. But some scholars use steel fiber concrete instead of ordinary concrete in the core area, so as to improve the shear resistance of the core area. Vasconez ’s test results show that the incorporation of steel fiber into concrete in the core area can not only reduce the amount of stirrup in the core area [7], but also improve the shear resistance and
energy dissipation capacity of the core area. 3% steel fiber volume content can reduce the amount of stirrup in node core area by 50%. And the beam midspan connection form and beam column joint integration form, the connection of the shear is mainly artificial gouge, keyway, planting bars to ensure the way.

2.3. Seismic Performance of Fabricated Joint

The experimental results of most researchers at present show that the seismic performance, including ductility and energy consumption, can be equivalent to that of cast-in-place[10-16]. The Precast Seismic Structural System Research Program (PRESS), a cooperative project between the United States and Japan, proposed three ductility nodes of prestressing technology. The test results show that, using the framework of these ductility nodes, the lateral deformation can reach 1/25 of the height of the structure, and the structure can even maintain the elastic state under the horizontal load exceeding the ultimate wind pressure. Ertas(2006)[10] made 5 fabricated beam-and-column joints and carried out low-cycle loading tests, including 1 cast-in-place node, 1 welded node with bracket column, 1 bolted frame node and 2 cast-in-place integral nodes. The test results showed that: these prefabricated joints showed good strength, ductility and energy consumption, etc. In addition, some researchers use the good ductility and energy consumption of steel to improve the energy consumption or rotation capacity of the joint by setting up connecting steel elements in the joint area. Huang Xianghai (2005)[11] proposed a new type of fully precast prefabricated concrete frame joint. This new type of frame joint is to use the legs or dark legs with high vertical bearing capacity as the vertical load-bearing member and adopt the steel plate with good ductility as the horizontal force transmission member, so as to effectively transfer the shear force and bending moment. Li Xiangmin (2013)[14] used the connection node embedded with low yield and high ductility connecting rod in the node core area and effectively anchored through the middle flange. The test results showed that: the connecting rod first yielded and had sufficient plastic deformation, and the beam and column basically remained elastic, so as to achieve the purpose of ductility connection design. Cheng Wanpeng (2015)[15] proposed to place steel bones locally in the connection area of members and the core area of beams and columns, and conducted a hysteresis test study on the hysteretic performance of partially fabricated steel bone concrete frame structures. The research results showed that the bearing capacity and energy dissipation capacity of the joints were significantly better than that of cast-in-place concrete structures.

However, individual researchers also point out that the ductility and energy consumption of prefabricated joints may not reach the level of cast-in-place. Kaya(2009)[16] showed that, although the strength of non-bonded post-tensioned prestressing joint is basically the same as that of the cast-in-place joint, its energy consumption is not as high as that of the cast-in-place joint. The effect of form and construction on ductility and energy consumption of various fabricated joints is the focus of attention.

3. The Utility Model Relates to an Assembled Steel Tube Constrained Energy Dissipation Joint

In order to further improve the application range of precast prefabricated concrete frame structure in earthquake zone, better connection mode is an urgent problem to be solved, and is also a hot research topic at present. Put forward a kind of prefabricated steel pipe constraints of the core concrete connection nodes, prefabricated in the factory and the connection node in the core area reserved through hole, prefabricated under column of reinforced through the core area reserved through hole, down from a precast connection node in the middle of the grouting hole, grouting slurry filling of precast column and precast connections under the connection between the overflow from the through hole up after layer, ensure the reliability of reinforced and the shear bond; Then the reinforcement is connected with the precast upper column through the grouting sleeve. The joint between the precast joint and the precast beam is cast-in-place steel fiber self-compacting concrete. Precast joint structure schematic is shown in figure 1, and this kind of prefabricated steel tube - beam end constraint core concrete cast-in-situ steel fiber reinforced concrete beam-column connection mode referred to as "prefabricated steel pipe constraint link node energy consumption", based on the node of precast frame structures is called "prefabricated steel pipe constraint energy dissipation frame structure".
Figure 1. Assembled steel tube constrained energy dissipation joint.

The steel pipe provides lateral constraint for the core concrete and improves the strength and ductility of the concrete, thus realizing the seismic design concept of "strong joint and weak member". Steel-fiber self-compacting concrete combines the advantages of traditional steel-fiber concrete and self-compacting concrete. Adding steel fiber into self-compacting concrete not only enhances the energy dissipation capacity and ductility of concrete, but also restrts the shrinkage of self-compacting concrete. Cast-in-place steel fiber self-densifying concrete at the connection part of the beam end can better exert the energy dissipation capacity of the plastic hinge at the beam end and delay the degradation rate of the plastic hinge stiffness, so as to achieve the purpose of performance-based seismic resistance. In addition, the prefabricated node core area is embedded with outreaching steel elements to improve the shear capacity of the beam end, so as to achieve "strong shear and weak bending", and at the same time, the plastic hinge is moved outward to reduce the adverse impact of plastic hinge on the core area of the node. On the construction level, the longitudinal reinforcement of the surrounding beam can be connected by the overhanging steel elements, which overcomes the problem of dense reinforcement in the core area of the traditional beam and column joints, and at the same time, the good fluidity of steel fiber self-comping concrete reduces the difficulty of concrete placement at the beam end.

4. The Construction and Installation Process of the Assembled Steel Tube Constrained Energy Dissipation Frame Structure

The frame structure based on the fabricated steel tube constrained energy dissipation joint is called the fabricated steel tube constrained energy dissipation frame structure. The assembling process are mainly: core connection node prefabrication, precast beams and columns, three components such as factory to transport to the construction, installation of prefabricated column connection and installation of prefabricated core nodes under installed to install prefabricated composite beams, composite plate - casting precast beams connected with core sections - casting composite beams and composite plate - on the installation of prefabricated column - connection installed on a layer of prefabricated core node - >... . Figure 2 is the connection diagram of the connection node of the prefabricated lower column and the prefabricated core area, Figure 3 is the connection diagram of the prefabricated beam and the core area, and Figure 4 is the connection diagram of the prefabricated upper column and the core area.
5. Conclusion
At present, there are many forms of fabricated connection nodes, and the main goal is to achieve the effect of "equivalent to cast-in-place". Based on the assembly characteristics and the advantages of high performance concrete and steel structure, it is the trend of future development to study the assembly-type joint with better seismic performance and more efficient construction.

In the assembled steel pipe constrained energy dissipation joint, the steel pipe not only provides lateral constraint for the core concrete, but also improves the strength and ductility of the concrete, thus realizing the seismic design concept of "strong joint and weak member". In the core area of prefabricated joints, the embedded protruding steel element can improve the shear capacity of beam end, realize "strong shear and weak bending", and at the same time move the plastic hinge outward to reduce the adverse impact of plastic hinge on the core area of joints.
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