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Finite Element Simulation of Precast Concrete T-beam and Column Joints with Floor Slabs

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Abstract

Precast concrete structures have become a popular option among available structural forms for their superior mechanical characteristics, economy and sustainable development as well as architectural versatility. However, some technical problem such as complex load path, uncertainty of structural stiffness of beam-column joints and inconvenience for disassembly hinders the application and development of precast concrete structures. The study wes designed to develop a new type of prefabricated concrete frame joint suitable for rapid construction. Low-cycle repeated loading tests were carried out on the T-joints of prefabricated monolithic reinforced concrete frame beams and columns, and numerical simulation analysis was carried out, including cracking process, failure mode and hysteresis characteristics, skeleton curve, ductility and energy consumption capacity, etc. All joint designs meet the requirements of "strong columns and weak beams". The findings of this study show that the two beam-column joint specimens all showed bending failure in the plastic hinge area of the beam end, and the joint area was in an elastic state. The overall performance of the joint was good, with good ductility and energy dissipation capacity.

Keywords: *Precast concrete; T-frame node; Seismic；Numerical Simulation*

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I. Introduction

The nodes of prefabricated concrete structures are divided into two categories: wet connection and dry connection. The node form certain structural measures are taken to ensure the shear resistance of the node area and the reliability of the steel connection. The precast column is a single-layer column member or a series column member, and the precast beam is generally a composite beam. In wet-connected nodes, plastic deformation often occurs in areas outside the nodes (plastic hinge area), and the connecting area should remain elastic, in line with the design principle of "strong nodes and weak members".Wu Congxiao et al.[1]studied the seismic performance difference between the seismic performance of the prefabricated concrete frame structure connection node and the cast-in-situ concrete frame structure node, and found that through reasonable design, the hysteretic energy consumption performance of the prefabricated concrete frame node is equivalent to the cast-in-place concrete frame node.Gao Lin et al.[2] used the reinforced sleeve grouting connection method and found that the prefabricated concrete frame joints have similar seismic performance as the cast-in-place joints. Yu Jianbing et al.[3] proposed a new type of steel strand anchored joint system, and found that additional steel bars contribute to the load-bearing capacity and energy consumption of the joint. Liu Lu et al.[4] proposed an assembled monolithic reinforced concrete frame beam-column node with large diameter and large-spacing HRB500 high-strength steel bars, and found that the beam-column node specimens showed bending failure in the plastic hinge area at the beam end, and the node area was in an elastic state; the overall performance of the node was good , with good ductility and energy consumption. Liu Tong et al.[5] studied the seismic performance of prefabricated frame beam-column joints connected by cement-based composite materials (ECC). They believe that the strength and stiffness of specimens in this way are slightly lower than those of ordinary concrete connections, but can be significantly improved The ductility and energy consumption of the test piece.

The numerical simulation in this paper uses ABAQUS finite element software.ABAQUS is a powerful suite of finite element software for engineering simulations that solve problems ranging from relatively simple linear analysis to many complex nonlinear problems. In addition, the damage of the specimen under each stage of load can be observed by the ABAQUS damage stress map. Nilanjan Mitra et al. [6] developed a model for simulating the response of reinforced concrete internal beam-column nodes. The new model has good stiffness and strength response parameters, and a wide range of design parameters.De-Cheng Feng et al. [7] established a finite element model method to analyze the cyclic performance of precast beam-column joints. In particular, the model takes into account the compression-softening of concrete, the bond-slip effect in the critical area, and the performance of the post-concrete interface.

XiaoyongLvet al.[8] study the influence of the constraint condition of column ends on the hysteretic behavior of the proposed beams. It is concluded that the constraint condition of column ends had a great influence on the failure mode of the proposed beams.The parametric analysis results recommended a reasonable and relatively small stirrup spacing for application of the proposed novel PC frame beams.

M. Ye et al.[9] present an innovative hybrid beam-column connection is proposed with hierarchy of strong connection and weak structural members for precast concrete structures.The experimental results showed that the new hybrid beam-column connection can reduce the stress concentration effect at the joint and achieve comparable mechanical performance with cast-in-site connections.

To better meet the requirements of building industrialization, Chenglong Wu et al.[10] proposes a Modular Prefabricated Composite Interior Joint (MPCIJ). Load-displacement curves of MPCIJ specimens are relatively full, showing high bearing capacity and strong energy consumption.

However, some technical problem such as complex load path, uncertainty of structural stiffness of beam-column joints and inconvenience for disassembly hinders the application and development of precast concrete structures.In addition,The specification requirements are too strict, resulting in the design stirrups are too dense, so it brings great difficulties to the joint assembly construction, and few scholars have improved the structural measures of the joint stirrups.

The purpose of the experiment was to develop a new type of fabricated concrete frame joint suitable for rapid construction.The stirrup limb distance of the core area of T-beam and column nodes was enlarged to study the seismic performance of this joints to analyze the possible adverse effects of this method. Through finite element simulation, a set of research data is provided for the study of seismic performance of T-beam and column joints.

II. Materials And Methods

2.1 Prototype

The prototype structure of the test piece is taken from the actual assembled monolithic concrete frame structure, the T-byte point is taken from the side-span beam-column node.

2.2 Specimen design

2.2.1 The main parameters of the test piece

As an important structural member, the seismic performance of beams and columns is very important to the safety of the structure. In the experiment, one assembled node specimen with normal stirrup distance was designed as a comparison specimen, numbered BJD1, and one assembled node specimen with enlarged stirrup distance was designed, numbered BJD2, the stirrup distance was increased from 163mm to 305mm.The test axial compression ratio of the test piece is taken as 0.25, which can meet the requirements of the limit of the axial compression ratio of frame columns specified in the GB 50011-2010 "Code for Seismic Design of Buildings". The measured mechanical properties of concrete and rebar are shown in Tables 1 and 2.

Table 1 Concrete Compression Test Results

Concrete strength grade		component	f_{cu}/MPa
The first batch	C50	Precast columns	56
	C30	Precast beams and precast panels	41
The second batch	C50	Core	54
	C30	Overlay layers	46

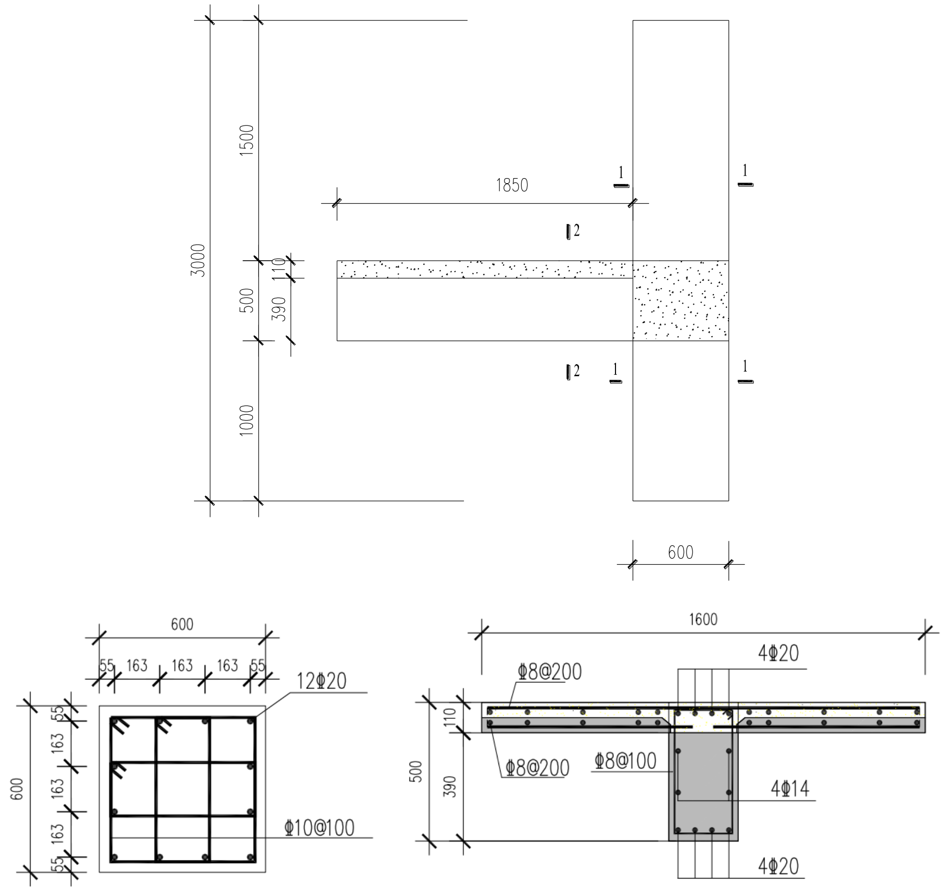
Table 2 Rebar Tensile Test Results

Rebar diameter	f_y/MPa	f_u/MPa	E_s/MPa
20mm	401.68	605.91	2.0×10^5
14mm	429.86	621.55	2.0×10^5
10mm	475.78	696.65	2.0×10^5
8mm	458.48	657.03	2.0×10^5

2.2.2The actual geometric size of the test piece

The actual geometric dimensions required for the test piece are determined, as shown in Figure 1 below.

All specimens are fully dimensioned. Precast beams and laminates are designed to have a strength rating of C30, and column concrete is designed to be rated C50.The column section size is 600×600, and the beam section size is 250×500. The strength grade of longitudinal reinforcement is HRB400. The longitudinal reinforcement of beam and column section is 4×20+4×20, 12×20. Stirrup reinforcement (HRB400) is 10@100.



1-1

2-2

Fig. 1. Geometric size of T-byte point test piece

2.2.3 Loading system

This test uses the pseudo-static test method to apply low-cycle level repeated loading to the precast joints, and conducts the test according to the "Building Seismic Test Method Regulations" (JGJ101-2015). The loading process is mainly divided into the following two steps:

Preload

Before the formal test, in order to ensure the normal operation of all parts of the equipment and eliminate the unevenness of the internal organization of the test piece, preloading should be carried out. The pre-loaded column top axial force is taken as 20% of the predicted maximum axial force, loading and unloading each time; then the horizontal load is pre-loaded, the column end horizontal force is taken as 30% of the calculated value of the cracking load, and the cycle is performed once.

Formally loaded

The formal loading is carried out in two steps. First, the axial force is applied to the top of the column by applying prestress. When loading, it should first be applied to 40% of the predetermined vertical load, and then gradually loaded to the predetermined vertical load. Keep the vertical load stable; then use a horizontal actuator to apply a horizontal low-cycle repeated load to the column end, and use a load-deformation dual-control loading method for horizontal loading. Before the specimen cracks, load according to the load control, and cycle once in positive and negative directions until the bottom of the column cracks; after the specimen cracks, load according to displacement control, load should be reduced before approaching the yield load, and load cycle once for each level before yielding ; After the specimen yields, control loading is performed with the multiple of the yield displacement as the step difference, and each step is cycled three times until the component is damaged or the horizontal bearing capacity drops to 85% of the ultimate bearing capacity, and the loading is stopped.

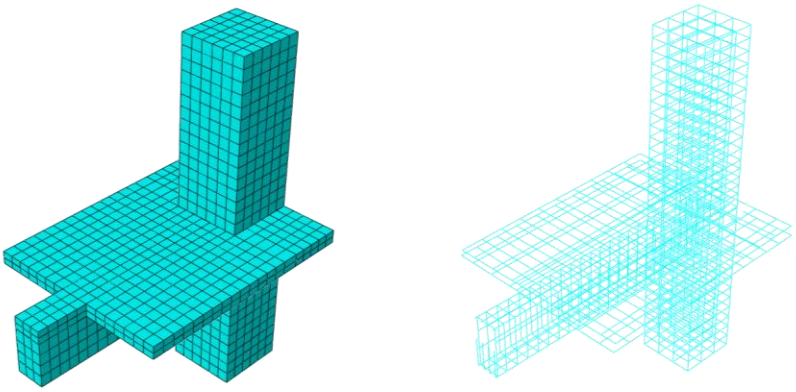
2.2.4 Main measurement content

The load applied on the beam end is automatically recorded by the data acquisition system. Strain gauges are arranged on the main bars of the cast-in-situ area to measure the strain of the steel bars, and strain gauges are arranged on the surface of the concrete in the cast-in-situ area to measure the strain of the concrete. In addition, a series of displacement meters are arranged at the loading point, column top, node area and column bottom to monitor the displacement of each key point during the test.

III. Analytical model

3.1 Cell selection and meshing

The model components of precast concrete beam and column joints mainly include: precast concrete beams, precast concrete columns, precast concrete slabs, post-cast concrete overlays and core areas and reinforced skeletons. The concrete of the finite element model concrete precast beam, precast column, superimposed layer and core area are simulated by continuous solid elements, and the reduction integral unit is used to improve the computing efficiency, that is, the C3D8R unit (eight-node hexahedral linear reduction integral unit), which has the characteristics of low stress accuracy, high displacement accuracy, less time-consuming, fine mesh, and high accuracy of calculation results. Since the steel bar is mainly subjected to tensile force and pressure during the actual force process, the influence of shear is ignored, and the T3D2 element (two-node three-dimensional truss element) is used to simulate its axial stress and strain state. The model reinforcement arrangement is shown in Figure 2.



(a) Concrete (b) Rebar

Fig.2.Simplified model diagram

IV. Results and discussion

4.1 Experimental phenomenon

When the two specimens finally fail, it is manifested as bending failure at the end of the beam, the concrete in the core area is basically intact, which meets the "strong column and weak beam", and the failure phenomenon and failure mode of the specimen are basically the same.

Before the cast-in-place concrete specimen reaches yield, there is no crack in the cast-in-place area. However, when the specimen was continuously loaded, shear cracks appeared in the cast-in-situ area. As the load increased, the old cracks continued to develop, and some new cracks appeared. When the loading displacement reaches 30mm, only fine shear cracks appear at the top of the core area. As the load increases, a large number of fine cracks appear in the cast-in-situ area. As the load continues to increase, old cracks continue to develop, and some new cracks appear. The load-bearing capacity of the specimen remains at a relatively high level. When the bearing capacity is 85%, the specimen is considered to be damaged.

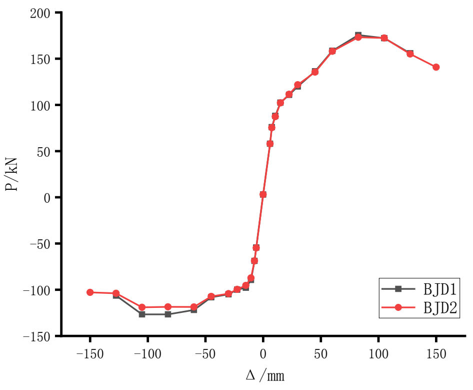
4.2 Hysteresis performance

The skeleton curve of the specimen is shown in Figure 3. The skeleton curves in the positive and negative directions of all specimens are asymmetrical, which is due to the presence of superimposed floor slabs that increases the stiffness of the upper part of the beam and shifts the neutral axis of the beam upward.

When positive and negative loading, the skeleton curves of the two specimens are highly coincident, and both have a yield step, which shows more reliable bearing capacity and ductility, which is conducive to earthquake resistance. Overall, the skeleton curve trend of BJD1 and BJD2 is the same.

4.3 Stiffness degradation

The equivalent stiffness(K) of the specimen is shown in Figure 4. The attenuation of the stiffness of the specimen increases with the increase of displacement; as the specimen cracks, yields, and reaches the ultimate load, its stiffness decreases rapidly. After reaching the ultimate load, the attenuation of stiffness tends to be gentle. The stiffness degradation rate of the specimen after the stirrup limb distance is enlarged is close to that of the normal specimen, and it is relatively smooth.



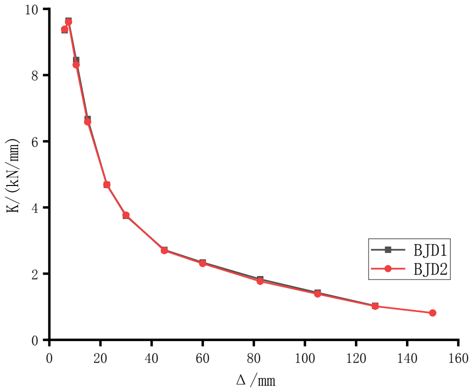


Fig.3.Skeleton curveFig.4.Equivalent stiffness

4.4 **Energy dissipation capacity**

Energy dissipation capacity(E) is an important index to evaluate the seismic performance of structures. The stronger the energy dissipation capacity, the better the seismic performance. For comparison, the cumulative energy consumption is generally converted into a dimensionless quantity for comparison. The energy consumption of the ideal elastomer of the two test pieces is calculated. This is shown in Figure 5.

The energy consumption of the specimen with stirrup pitch enlargement is close to that of the normal specimen, and on the whole, the stirrup pitch enlargement has no obvious effect on the energy consumption of the node.

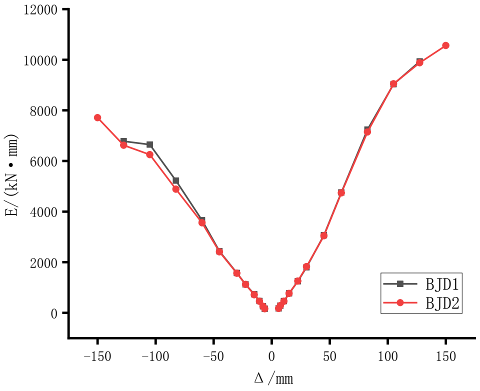


Fig.5.Energy dissipation capacity

V. Conclusions

Compared with the normal stirrup pitch, the enlarged stirrup pitch has no effect on the failure mode of the T-joint of the prefabricated concrete frame, and the final failure is manifested as beam end bending failure.After the stirrup distance is enlarged, the bearing capacity, stiffness degradation and energy dissipation capacity of the T-shaped node of the prefabricated concrete frame are relatively close, and the overall stirrup distance amplification measure has no obvious effect on the performance of the T-shaped frame node.Finite element simulation provides a set of data for the optimization design of T-shaped beam and column joint stirrup limb distance to meet the "strong column weak beam". The specification can appropriately relax the restrictions on the distance between the joints of the nodal stirrups.

There is no innovation in node connection in this experiment. Wet connection is an important node connection method for prefabricated buildings, and the depth and breadth of the research are insufficient. It needs to be strengthened in the future to carry out research to improve the seismic performance of nodes.

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