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Research on Construction Technology of Node Connection and Seismic Resilience Improvements of Prefabricated Buildings

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Abstract— **In order to improve the rapid assembly efficiency of beam-column nodes of assembled buildings, this paper proposes a new type of beam-column node connection structure for assembled buildings with " embedded steel plate + H-beam joint " and describes the assembly construction process and conducts an experimental study on the seismic performance of this new node. The research shows that the use of embedded steel plates avoids conventional sleeve grouting and solves the problem of dense connections.The H-beam structure can realize prefabricated products, which significantly saves construction time, and has greater stiffness and smaller deformation, which meets the design standard of strong nodes.In addition, the beam-column assembled nodes exhibit excellent seismic resilience.**

Index Terms— **prefabricated building; seismic resilience; beam-column joints**

I. INTRODUCTION

As China's urbanization continues to advance, environmental issues are becoming more and more concerned. While the state vigorously promotes the industrialization of construction, it also vigorously promotes green building, and assembly building has the advantages of both.Since the popularization and use of assembled structures at home and abroad, it has been found through studies after earthquake disasters that the damage of precast concrete frame structures is mainly manifested in the destruction of the connections between the members and the resulting overall disintegration and collapse of the structure[1-3]. In an assembled concrete frame structure, structural lateral stiffness is provided by the rigid frame. Under horizontal loading, energy is dissipated through plastic hinges at beam ends or column ends to satisfy the principle of " strong nodes, weak components ". The bearing capacity of building nodes should exceed that of the bars to enhance the deformation capacity and seismic performance of the structure[4]. Currently, there are two main types of beam-column frame node connections in prefabricated buildings[5]: one involves prefabricated beam-column nodes produced in factories, with components connected within the beam span; the other type features prefabricated frame beams and columns separately in component plants, with connections made in the node area of the beam-column nodes. While factory-fabricated beam-column nodes ensure connection integrity, their large size poses challenges for transportation and lifting. As a result, the connection of beam-column nodes has garnered broader research and application.

Nevertheless, practical construction poses challenges with beam-column nodes in terms of reinforcement congestion, collision risks, and construction inefficiencies. Additionally, various issues arise with connections between stacked beams, stacked beams and floor slabs, as well as shear walls, impacting the assembly structure's construction. These connections represent structural weak points, with their performance directly influencing the integrity and seismic resilience of the assembly structure. Hence, the development of prefabricated buildings should prioritize component node connections, production, seismic performance, and key construction technologies. Many experts and scholars have proposed a variety of joint design measures[6]. For example, Liu Bingkang et al.[7] studied the connection shape of post-tensioned prestressed joints and showed that this connection shape can improve the rigidity of the core area of the joint and has a good recovery ability. In the study conducted by Lv Xilin et al.[8], the bolt connection node form was examined, and it was demonstrated that the nodes of this type of connection form exhibit optimal seismic performance and operational conditions. Gao Xiangling et al. [9] conducted a comparative study of steel node forms and sleeve node forms, thereby demonstrating that the hysteresis curve of steel nodes is fuller and possesses a higher ultimate load carrying capacity. In the study by Liu Xudong et al. [10], a node form with column longitudinal bars lapped in the core area of the node was proposed. The study demonstrated that the reinforcement within the lapped range of the core area did not pull out and met the engineering requirements.

The primary hindrance to advancing residential industrialization in my country stems from the unpredictability of node seismic performance. Consequently, addressing the seismic technology of beam and pillar nodes is a pressing necessity to propel the development of prefabricated buildings. In light of this, this article introduces an innovative prefabricated building beam and column node connection structure, specifically the " H-beam joint ", and outlines the corresponding rapid-assembly construction technology. Furthermore, an in-depth analysis of the seismic resilience of this beam-pillar assembly node is conducted, offering invaluable insights and guidance for the construction of prefabricated steel-concrete beam structure nodes.

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II. Overview of Beam-Column Nodes in Prefabricated Buildings

The prefabricated beam node based on " embedded steel plate + H-beam joint " is a steel plate of a certain thickness embedded at both ends of the prefabricated concrete columns and prefabricated concrete beams, and the H-beam joint is prefabricated. The central portion of the connector is composed of a cylindrical steel pipe, which is welded with H-beam, and the base is welded with steel plates that correspond to the steel plates at both ends of the prefabricated beams, as shown in Figure 1.During the construction period, the steel plate located at the superior and inferior extremities of the H-beam joint cylinder is welded with the steel plate at both terminal points of the prefabricated column, thereby facilitating expeditious assembly. Moreover, H-beam facilitates the rapid assembly of prefabricated beams through its provision of steel interfaces, whilst simultaneously providing "tempered" nodes, thereby enhancing the overall stiffness of the prefabricated building structure.

III. Beam-Column Node Assembly Construction Technology

In order to enhance the rapid assembly efficiency of the assembled frame structure beam node, a set of fast-assembly construction technologies was proposed for the new type connection node of the "embedded steel plate + H-beam joint". The construction process is delineated in Figure 2. The pre-embedded steel plate design has been shown to be effective in circumventing the grouting step in the reinforcement sleeve connection and solving the problem of intensive node connection. The H-beam structure is characterised by pre-batch production, which significantly reduces the construction period. The joint meets the design criteria for strong nodes due to its high stiffness and low deformation. Additionally, the H-beam joints can be installed on site by bolting and welding, thereby fulfilling the function of a bracket. This effectively simplifies the construction procedure and enhances construction safety.

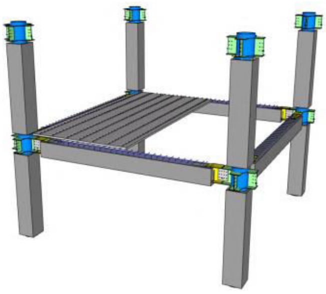

Figure 1. " Embedded steel plate + H-beam joint " connection node

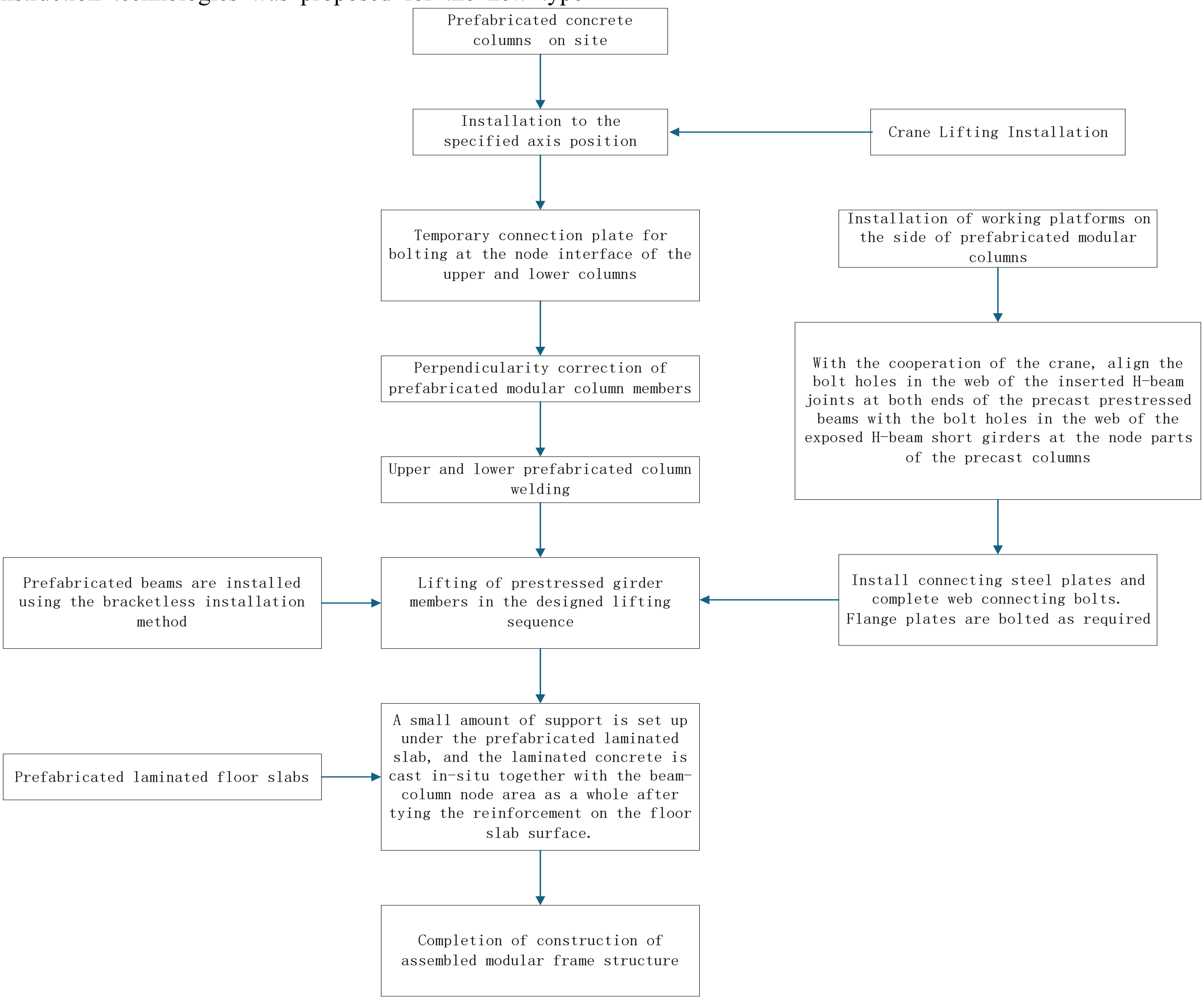

Figure 2. Construction Flowchart

The trial assembly of the beam-column nodes of the assembled frame structure was conducted with the objective of verifying the construction feasibility and effectiveness of the new type of tooling. The data pertaining to the trial assembly statistics is presented in Table 1, which is compared with the existing level of the project. The purpose of this comparison is to ascertain whether the new type of tooling achieves the desired improvements in construction speed, ensures the quality of assembly and reduces the cost of the project.

Table 1. Comparison of efficiency analysis

Number	Present level	Improved level
1	Lifting from the top of prefabricated columns, slings are prone to collision with column bars	Lateral lifting of prefabricated columns to avoid collisions
2	Restricted view angle for workers during positioning of prefabricated columns, making operation difficult	Convenient view for workers to manoeuvre when prefabricated columns are in place
3	The complete lifting time of a single column is about 12min	Increased speed of prefabricated columns in place by more than 10 percent
4	Single beam bottom vertical support spacing 1m each way	Reduce the amount of prefabricated girder bottom support by more than 70 percent
5	The adjustment time for lifting a single girder into position is about 17 min	Improvement of prefabricated girder positioning adjustment speed by more than 10%
6	Each beam-column node supporting and dismantling time of about 60 minutes	Increase the speed of node supporting and dismantling by more than 50%

4. EXPERIMENTAL STUDY ON SEISMIC PERFORMANCE OF BEAM-COLUMN NODES

4.1 Test Methods

A significant body of research has been dedicated to the comparison of assembled and cast-in-place buildings with regard to the quality of their connection nodes and the seismic performance of these connections. It has been demonstrated that the seismic performance of node connections is a key indicator of construction quality. In order to comprehensively assess the seismic capacity of the novel assembled beam-column nodes, beam-column node models were fabricated for load testing[10] and then subjected to a comparative analysis with the load tests of nodes in the conventional grouting sleeve connection method. The fabrication was adjusted by scaling down, resulting in a final prefabricated beam size of 300mm×350mm, with a length of 2,000mm, and a prefabricated column size of 450mm×450mm, with a height of 2,800mm.The assembly of beam-column nodes of the newly assembled building was completed by using the rapid assembly process mentioned above. Then, the specimens were placed on the hydraulic servo loading system MTS to carry out the low-cycle repeated loading test. The vertical load applied to the top of the member is realised by tensioning the jack strand. The horizontal loading device is a 150-tonne actuator, the horizontal cyclic loading is 36 times, and the maximum horizontal displacement is 150 millimetres. The test system records the loading displacement and the corresponding loading data in real time. Meanwhile, the strain data of the steel structure and the concrete interior can be observed using the DH3816 Static Strain Gathering Instrument.

4.2 Test Results and Analyses

Cumulative energy consumption is a significant metric for evaluating a node's capacity to dissipate energy under vibratory loading, thereby influencing the node's seismic performance. This index is typically determined by calculating the area enclosed by the hysteresis curve in each loading cycle. The results of the cumulative energy consumption of the beam-column assembled nodes of this new assembled frame structure and the nodes of the traditional grouting sleeve connection method are shown in Figure 3. As is evident from the figure, the cumulative energy consumption of the beam-column nodes of the two connection methods exhibits a similar trend of change, with both demonstrating a significant exponential growth. Upon reaching the 20th cycle, both specimens demonstrated a transition into the yielding stage. However, a discrepancy was observed in the ultimate cumulative energy consumption of the two specimens. Specifically, the ultimate cumulative energy consumption of the beam-column assembly node of the new assembled frame structure reached 9.84×106J, and that of the node of the traditional grouting sleeve connection method was 3.44×106J. Consequently, the seismic performance of the assembled frame structure beam-column assembly node is significantly enhanced, and its ultimate cumulative energy consumption is 2.8 times higher than that of the node of the traditional grouting sleeve connection method.

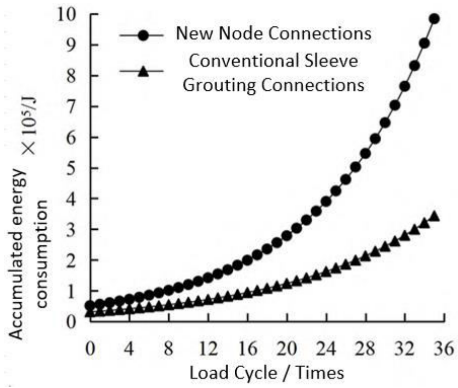

Figure 3. Accumulated energy consumption of new node connections vs. conventional sleeve grouting connections

CONCLUSION

In the contemporary era, there is an imperative for transformation within the construction industry. Whilst the field of assembly building has undergone rapid development in recent years, fundamental research is yet to be adequately supported by adequate technical resources for production and construction. A programme of systematic research and innovation in structural systems, node connection, informatised production, prefabrication and installation of components is to be initiated. The objective is to identify and overcome the key technical difficulties in the design and construction of connecting nodes of assembled concrete structural components. The ultimate aim is to establish a complete set of application technology with enterprise characteristics and to lead the domestic professional field. In addition, the new type of assembled building structural technological system will be promoted.

In light of the challenges and issues encountered during the implementation process of the existing assembly frame structure, a novel approach has been proposed. This approach involves the introduction of a new type of prefabricated beam and column components rapid assembly node connection structure, along with a corresponding rapid assembly construction process. To assess the seismic performance of the node, an indoor test method has been utilised, leading to the following conclusions:

(1)The pre-embedded steel plate employed in this study has been shown to effectively obviate the grouting process when connecting the reinforcement sleeve, thereby resolving the issue of intensive connection at the node. The H-beam structure can be manufactured in advance in batches, a process which is known to be highly time-efficient. The H-beam joints possess the advantages of large stiffness and small deformation, thus meeting the design requirements of strong nodes. The installation process is highly efficient and safe.

(2)The construction process of the beam-column assembly node of the assembled frame structure includes the lifting of precast concrete columns, the welding of embedded steel plates and the installation of precast concrete beams. This process is of high construction efficiency and safety, and has good engineering application prospects. The findings demonstrate that this set of tooling can effectively facilitate the lifting of precast columns, enhance the lifting speed and accuracy of precast beams, minimise the requirement for precast beam bottom support, and improve the efficiency of sealing the beam-column node and the quality of concrete pouring. This study can serve as a valuable reference for analogous projects.

(3)The cumulative energy consumption of the beam-column assembly node of the novel assembly frame structure and the node of the traditional grouting sleeve connection method demonstrate a marked exponential growth pattern. The specimen enters the yielding stage when loaded up to 20 times. The beam-column assembly node of the novel assembly frame structure exhibits excellent seismic performance, with its ultimate cumulative energy consumption being 2.8 times that of the node of the traditional grouting sleeve connection method. This is in accordance with the seismic resistance of nodes of assembled building components. The performance requirements of toughness are of paramount importance.

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