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Research progress on bolting connection of prefabricated concrete shear wall

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Abstract. Dry connection of prefabricated concrete shear wall has gradually become a hot research direction in China, and among those various of dry connections, bolted joints attract scholars' attentions with its unique advantages. This paper introduces the classifications of bolted joints of prefabricated concrete shear wall structures. Then it summarizes the latest developments of such joints in foreign countries, and the current research status in China. At the same time, this paper will give a comprehensive evaluation from the perspective of safety and cost. Finally, some suggestions are put forward for the problems still to be solved in this direction in the future.

1. Introduction

The construction industry is one of China's pillar industries, but its industrialization process has been slow in the past. On the site, the cast-in-place form of extensive operation is widely used^[1], and the traditional cast-in-place structure also has many disadvantages such as long construction period and low construction efficiency. The unique characteristic of “four reductions and environmental protection” of the prefabricated building made it an inevitable choice for the upgrading and transformation of China's construction industry.

Prefabricated building is a unitary structure which transports some or all of the components that have been produced at the factory to the construction site for assembly, and the components are connected in a reasonable manner^[2]. The prefabricated building structure includes a variety of structural forms involving wood structures, steel structures, concrete structures, and the like. In China, due to the constraints of construction costs and other factors, concrete structures are often applied to multistorey or high-rise buildings^[3].

Especially, the reliable connection of prefabricated shear walls is the key to ensure structural integrity and seismic performance^[4]. Compared with other structural systems, the fabricated shear wall structure has a larger number of joints. This paper summarizes the recent research achievements, according to whether the concrete is used on the joints or not, the bolt connections are divided into two types: wet bolt connection and dry bolt connection. Then, this paper will summarize the research progress of dry bolt connection conducted by foreign and domestic scholars. And finally, we will put forward several problems to be solved in the terms of the research and practice on dry bolt connection.



2. Classifications of prefabricated shear wall with bolt connection

2.1. Wet bolt connection

Long Libo, Ma Yueqiang, etc.^[5] applied this system to the Shanghai Zhoukanghang Resettlement Housing Project as shown in Figure 1(a), and a set of efficient construction methods suitable for bolted shear walls has been invented, which greatly reduces the cost and improves the construction efficiency.

2.2. Dry bolt connection

Sun Jian et al. of Southeast University proposed a dry bolt connection scheme for horizontal joints, which can directly display the role of bolts in prefabricated shear wall components, as shown in Figure 1(b). The upper and lower prefabricated wall panels are passed through the embedded frame, and bolt holes are reserved, and the high-strength bolts are screwed into the bolt holes to achieve the connection purpose.

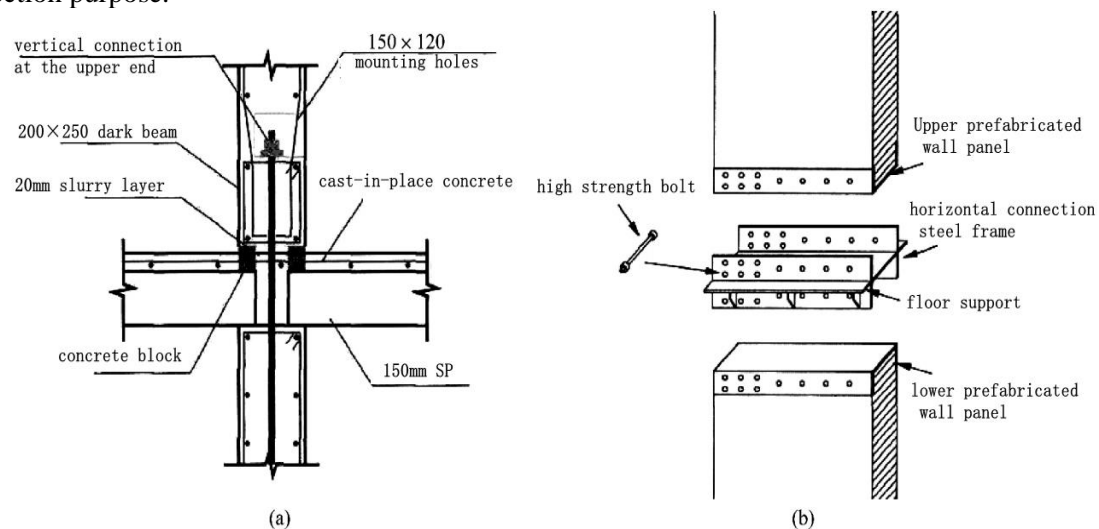


Figure 1. Classifications of bolted joints

3. Foreign research status

In 1989, Sami H. Rizkalla tested the bolt connection's level performance in prefabricated concrete shear wall panels from two different multi-keys and one plane connection angle. The connection performance reveals the performance and load carrying capacity of the multi-key bolt connection, and accurately forms the multi-bolt connection shear resistance model.

In 1991, Abdul-Wahab H M S, Saram S Y H and others respectively from post-tensioned unbonded prestressed shear wall^{[6][7][8][9]}, large plate structure system^[10], sandwich panel shear wall and other angles^[11], by testing the energy consumption and overall stability of the bolted joints, revealing that its overall stability needs to be improved^[12].

In 1995, the National Institute of Standards and Technology's Soudki K A and his team^{[13][14][15]}, took a low-cycle reciprocating loading experiment of vertical cracks in bolted joints. Experimental studies have shown that bolted joints with the type of sliding friction energy-consuming connections have high energy consumption capacity. In 2004, James F et al.^[16] studied the nonlinear lateral force-displacement behavior of a fabricated structure using a bolted connection when it is loosened and turned into a loosely connected structure. And a formula representation of the dynamics of node connection dynamics is given. From the theoretical perspective, it reveals the high energy consuming of the bolted connection.

In 2008, Technical Council of Fib Conference's report^[17] introduces the use of bolted joints in prefabricated shear wall components is a very simple and safe connection, but it requires high

precision, thread wear or skew of the hole will directly affect whether the bolt can be successfully connected.

In 2016, Lim et al. developed a new type of C-type shear wall panel system that can be modularly assembled by bolting. Figure 2 highlights the distribution of pre-embedded sheets in the prefabricated board. The outer ends of the force-receiving ribs are provided with a wire head, which can be directly used with the nut, which greatly reduces the construction difficulty and cost of the bolt connection. In order to confirm its lateral load and seismic resistance, a reverse cycle test of two third-size PC T-walls was carried out under displacement control^[18].

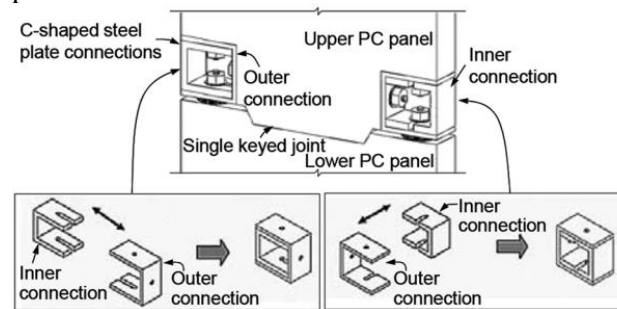


Figure 2. C-type steel plate bolted connection

4. Research state in China

Domestic research on fabricated architecture has started late, and the concept of “equivalent cast-in-place” is still widely used in researchers. Therefore, the method of wet connection is often used for fabricated building nodes in China. But for the dry-dry bolting, it was only until a few years ago that scholars have begun to study.

In 2006, Huang Xianghai^[19] tested the prefabricated beam through the Belgian project. As shown in Figure 3(a) and the dark ox leg connection as shown in Figure 2(b), the key drawback of the bolt connection is that the bolt position must be prefabricated. Once the bolts are deformed, repairs and replacements can be complicated.

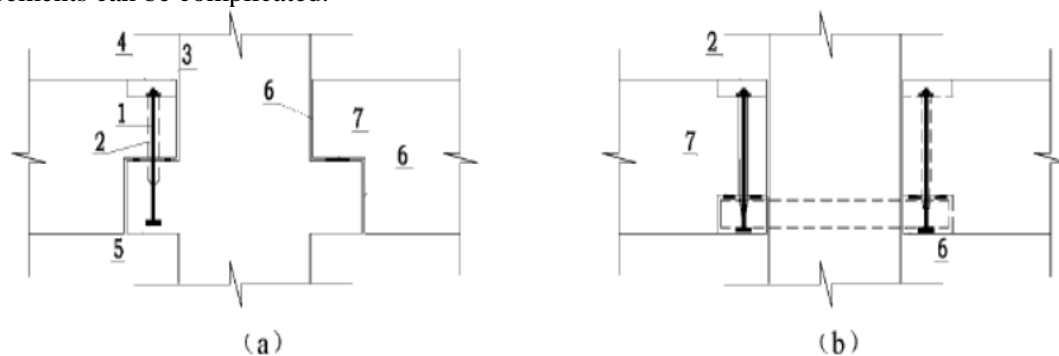


Figure 3. Bob and prefabricated beam bolting

1, Bolt; 2, grouting; 3, pad; 4, nut; 5, poured screw and screw sleeve; 6, grouting; 7, adjustable support

In 2012, Liu Jixin, Li Wenfeng and others^[20] initially explored the seismic performance of the new assembled monolithic wall in China. When assembling, one group uses welded and bolted walls as shown in Figure 4(a), and the other group uses traditional wet working methods as shown in Figure 4(b). It is found that the fully assembled structural joint can effectively transmit the shear force on the section, so that the web wall and the flange wall work in harmony, and the overall seismic performance can achieve the function of “equivalent cast-in-place”.

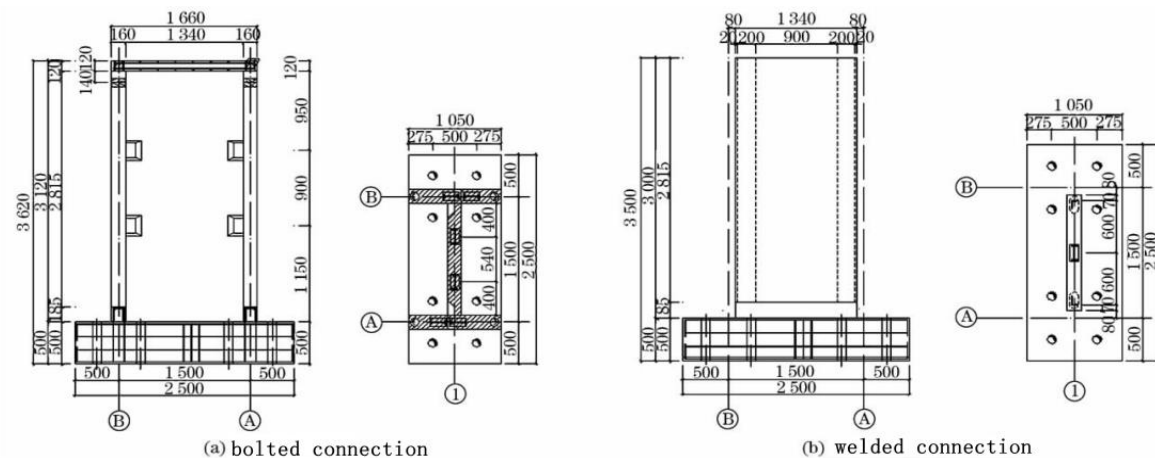


Figure 4. Test model diagram

In 2013, Wang Xiaowei, Wang Tao, etc. Four sets of pseudo-static tests were carried out for the prefabrication method of the jacket in the reinforcement project. Three different sizes of prefabricated shear wall members were designed and tested. The strength and rigidity of the bolted joints were determined by applying low-cycle reciprocating loads. The study of ductility and energy dissipation performance shows that the pre-embedded bolt connection can effectively transmit the vertical stress and shear force in the prefabricated shear wall, which can basically achieve the design goal of “strong node-weak component”.

In 2016, Sun Jian, Qiu Hongxing and others from Southeast University^{[21][22][23]}. The basic mechanical properties of concrete RC wallboards with high-strength bolted joints and the working mechanism of horizontal joints were studied. By measuring the horizontal load-side shift curve and steel strain of the specimens, the bolts were analyzed. With the addition, the horizontal joints transmit the load together by friction and bolting^[24], the RC wall panel's ductility performance has been greatly improved. Simultaneously reducing the high-strength bolt diameter and pre-tension will increase the relative slip between the horizontal joint connectors and reduce the safety reserve.

5. Analysis of research status at home and abroad

It can be seen from the above that foreign research on prefabricated concrete shear wall bolt joints is at a relatively developed level, and most scholars and institutions in China are still in their infancy, mostly focusing on the basic seismic performance of ordinary dry bolt connections. However, there are few studies on the bolting of the new combination form. In the case of domestic construction projects, a series of dry connection applications such as bolting are less, and laboratory research is mostly in the theoretical stage, and more full-scale model tests are still needed.

Regardless of the type of connection, the ultimate goal is to ensure the stability, safety and durability of the structure as a whole. Nowadays, various connection forms emerge in an endless stream. The mechanical properties and economic costs are worthy of further study. The finite element analysis software is fully utilized and the full-scale test and practical engineering application are applied to make the research of fabricated building nodes more perfect.

6. Evaluation and recommendations

From the existing research results, it can be seen that the bolting connection is an advanced concept. The wet operation is almost unnecessary on site and the construction efficiency is extremely high. Construction quality is easy to control and check, and it conforms to the development concept of the prefabricated building^[25]. As the assembly design concept based on BIM gradually replaces the traditional CAD split mode^[26], the dry bolt connection will inevitably be used in civil buildings in a large area.

But at present, there are some problems in its research and practical application to be solved, which

can be divided into the following aspects: (1) From the perceptive of research on Chinese scholars at present, they always study on the structural performance based on the material constitutive relationship. It is recommended to strengthen the mechanical properties analysis of component-based structural nodes. (2) At present, the finite element analysis software is mainly used for the pure bolt dry connection, and the full scale model test is rarely involved. It is recommended to strengthen the prefabricated shear wall joint bolt joint full-scale model test, and improve the theory and popularize further through full-scale test.

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