Research on Connection Technology of Prefabricated Shear Wall

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Abstract. At present, there are two main types of connection methods used in prefabricated buildings: wet joints including grouted sleeve connection shear wall, vertical ribbed composite shear wall and Efficient Manufacture and Construction precast hollow-core composite shear wall, and dry joints including welded connection and bolted connection. Grouted sleeve technology is fast in construction and high in strength, but it requires high material quality and construction quality, and needs comprehensive consideration to ensure safety; The vertical ribbed composite shear wall structure is basically consistent with cast-in-place members in bearing capacity, failure modes, stiffness and deformation capacity. Efficient Manufacture and Construction precast hollow-core composite shear wall can improve construction quality, reduce labor, facilitate management, and optimize safety, quality, efficiency and cost through traditional connection. The welded connection improves the seismic performance and construction efficiency, but the technical requirements are high and the cost is high, which needs comprehensive consideration; Bolted connection is convenient and removable, but low bearing capacity, anti-corrosion treatment and high-precision processing are required, increasing maintenance costs and affecting construction quality.

Keywords: Prefabricated shear wall; Grouted sleeve connection; Vertical ribbed composite shear wall; Welded connection; Bolted connection.

1 Introduction

With the rapid development of society and the economy, higher demands have been placed on the construction speed in the field of building engineering. Enhancing construction speed while ensuring high-quality and high-standard project execution has become a critical development goal. Prefabricated construction is a new building construction mode in which various components or accessories of a building project are manufactured in a factory outside the construction site and then transported to the site for direct assembly. Shear walls, as one of the most important components in building structures and accounting for a significant portion of construction time, make the study

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of the construction methods and processes of prefabricated shear walls particularly important. The connection methods of prefabricated shear walls are key factors in ensuring structural stability and seismic performance. This development has undergone several stages, and with the continuous advancement of building technology, the connection methods of prefabricated shear walls are constantly being innovated and improved to meet the needs of different construction projects and enhance safety and economic efficiency. This paper will summarize the current connection methods for prefabricated shear walls and analyze which connection method should be selected for construction under different circumstances.

2 Prefabricated Shear Wall

Prefabricated shear walls are a type of precast building component commonly used to enhance the seismic performance and overall stability of structures. These walls are manufactured in a factory and then transported to the construction site for assembly, significantly improving construction efficiency and reducing the complexity of on-site work. Furthermore, the use of prefabricated shear walls can effectively shorten construction timelines, lower costs, and minimize environmental impact1. With the continuous advancement of building technology, the application of prefabricated shear walls in modern construction has become increasingly widespread, making them an important component in promoting the industrialization of the construction sector. These shear walls are primarily made of concrete, offering excellent load-bearing capacity and durability2. The design of prefabricated shear walls typically considers the structural seismic performance, ensuring stability and integrity between the walls through appropriate connection methods. Currently, there are two main categories of connection methods employed in prefabricated shear wall applications in construction projects: wet joints and dry joints. Wet joints include grouted sleeve connection shear wall, vertical ribbed composite shear wall, and Efficient Manufacture and Construction precast hollow-core composite shear wall, while dry joints primarily consist of welded connections and bolted connections3.

3 The Main Connection Modes of Wet Joints

3.1 Grouted Sleeve Connection Shear Wall

Overview. The grouted sleeve technique (Figure 1) refers to a method of reinforcing connection in which steel bars are inserted into metal sleeves embedded in precast concrete components, followed by the infusion of cement-based grouting material4. The application of grouted sleeve connection technology has a long history in Japan. The precast shear walls utilizing this connection method are structurally similar to conventional cast-in-place shear walls, with only minor differences at the reinforcement connection nodes between adjacent components. Grouted sleeve shear walls are widely used in high-rise buildings, commercial complexes, and large public facilities, particularly in regions with stringent seismic performance requirements.

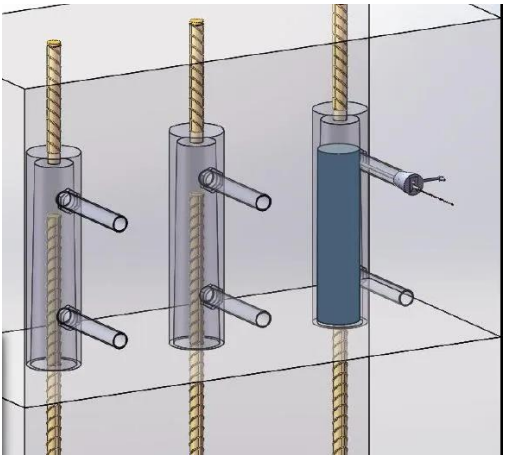

Fig. 1. Schematic diagram of grouted sleeve connection shear wall

Construction Method. The construction principle of the grouted sleeve connection involves pre-embedding a steel sleeve at the lower position within the shear wall panel. The inner diameter of the sleeve is approximately 1 centimeter larger than the diameter of the reinforcing bars to be connected. Each sleeve is equipped with two grout ports that extend outward from the wall, providing access to the interior of the sleeve for the subsequent grouting process. A portion of the reinforcing bars that need to connect with the adjacent upper shear wall is exposed at the upper part of the shear wall. When connecting two longitudinally adjacent shear walls, the exposed reinforcing bars of the lower shear wall are inserted into the reserved sleeve of the upper shear wall, ensuring that the edges of the two segments of reinforcing bars are in contact. Once all reinforcing bars are correctly positioned, a pressure grouting process is employed to inject the micro-expansive structural grout through the lower grout port. After the excess grout flows out of the upper grout port, the connection between the two shear walls is completed. Under the combined action of the steel sleeve and the expansive grout, the connected reinforcing bars exhibit excellent stiffness characteristics.

Performance Characteristics and Applicability. The advantages of grouted sleeve technology for connecting precast shear walls include ease and speed of construction, high connection strength, strong adaptability, and good fluidity of the grouting materials, which can effectively enhance construction efficiency and structural safety. However, this technology also has its disadvantages, such as the high requirements for the quality of grouting materials, limitations imposed by construction environmental conditions, and the potential for uneven grouting resulting from improper handling of connection points.

The selection of grouted sleeve connection shear walls is primarily based on their multiple advantages in structural engineering. In seismic-prone areas or buildings with high seismic design requirements, this connection method can significantly enhance the overall stability and safety of shear walls. Additionally, the use of grouting materials effectively improves the mechanical performance at the connection points, ensuring the reliability and durability of the structure during long-term use. Therefore, grouted sleeve connections have become an important method in the design of modern high-rise buildings and complex structures.

3.2 Vertical Ribbed Composite Shear Wall

Overview. The vertical ribbed composite shear wall structural system is a novel hollow precast wall panel, ribbed hollow wall panel, and sandwich insulated ribbed hollow wall panel developed based on the "vertical load-bearing reinforcement anchorage lap connection technology within cavities." These components are connected to various horizontal precast elements through reinforcement, with additional concrete poured to form an assembled integral concrete shear wall structure5. Generally, the use of ribbed composite shear walls in building structures is suitable for seismic fortification levels of 8 degrees and below. For buildings exceeding 80 meters in height, the reinforcement zone at the base of the structure should be entirely composed of cast-in-place construction. For buildings with a height of 80 meters or less, the edge components of the reinforcement zone should also be entirely cast-in-place to ensure the overall integrity and seismic performance of the building.

There are two types of cavities in ribbed composite shear walls: through cavities (Figure 2) and bottom cavities (Figure 3). These two configurations of ribbed composite shear walls are suitable for wall panels of different lengths; longer floor slabs utilize through cavities, while shorter wall panels and edge components employ bottom cavities.

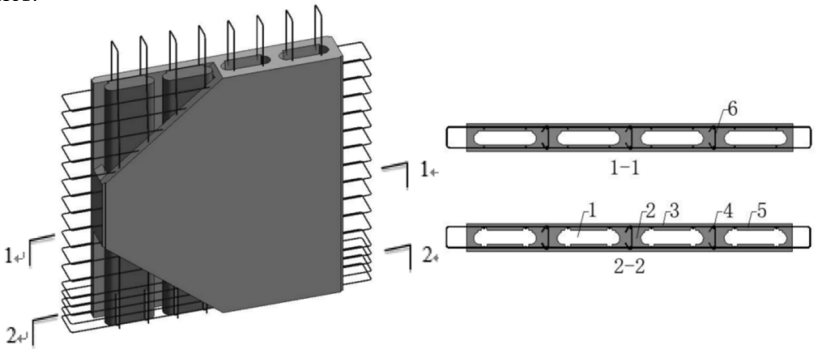

Fig. 2. Schematic diagram of ribbed hollow wall panels with through cavities
1-Cavity 2-Rib 3-Concrete slab 4-Longitudinal reinforcement 5-Laterial reinforcement 6-Tension reinforcement

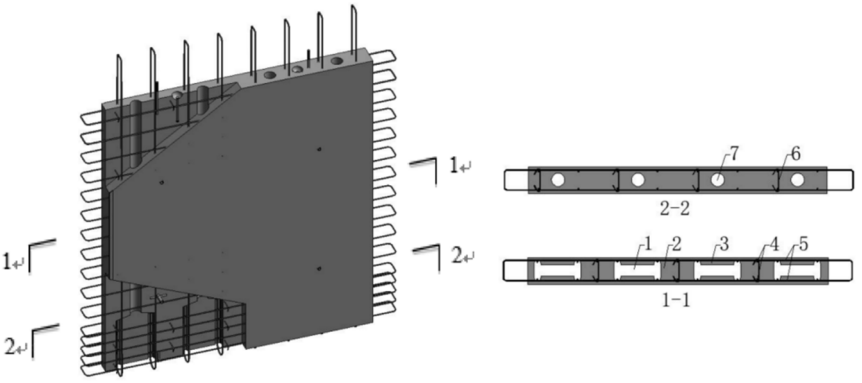

Fig. 3. Schematic diagram of ribbed hollow wall panels with bottom cavities
1-Cavity 2-Rib 3-Concrete slab 4-Longitudinal reinforcement 5-Lateral reinforcement 6-Tension reinforcement 7-Pouring hole

Construction Method. In the vertical ribbed composite shear wall system with through cavities, the arrangement of vertical and lateral reinforcement within the wall panels is located around the upper and lower through cavities of the precast wall. A segment of longitudinal reinforcement is exposed at the bottom of the precast wall panel to facilitate the lap connection with the reinforcement inserted into the cavity of the next layer of wall panels. For ribbed hollow wall panels designed with bottom cavities, a pouring hole is provided at the top solely for casting concrete. The internal lateral and longitudinal reinforcement is positioned within the sides of the precast wall panels, with a segment of reinforcement exposed at the bottom to connect with the reinforcement of the lower wall panel. All the exposed reinforcement from the upper section of the lower wall is inserted into the corresponding cavity of the upper wall panel. Simultaneously, the exposed reinforcement of the upper wall at the bottom cavity overlaps with the annular lap reinforcement of the lower wall, achieving a lap connection after the concrete pouring is completed. This method allows for the simultaneous pouring of concrete during the installation of various building components, enabling the concurrent placement of concrete in both the overlapping floor slabs and the precast shear walls, thereby significantly enhancing the integrity of the structure in both vertical and horizontal directions6.

Performance Characteristics and Applicability. After conducting experimental research on the vertical ribbed composite shear wall structure, the results indicate that, both in the elastic and elastoplastic phases, the performance of the ribbed composite shear wall is generally consistent with that of cast-in-place walls. The cast-in-place portion of this composite structure forms a good bond with the precast elements, with no occurrence of separation. The lap connections of the longitudinal reinforcement between adjacent wall components are highly reliable, and their characteristics—such as load-bearing capacity, failure mode, stiffness, and deformation capacity—are essentially consistent with those of cast-in-place components.

The selection of longitudinal ribbed composite shear walls is primarily suited for high-rise buildings, complex-shaped structures, and designs with diverse functional requirements. In seismic-prone areas, these shear walls can meet high seismic performance demands. Additionally, projects that require high construction efficiency, particularly those that involve factory-prefabricated components, are also suitable for the use of longitudinal ribbed composite shear walls.

3.3 Efficient Manufacture and Construction(Abbreviated as EMC) Precast Hollow-core Composite Shear Wall

Overview. EMC precast hollow-core composite shear wall structure (Figure 4) incorporates metal threaded pipes embedded within the wall panels to create a composite shear wall system with vertical holes. The vertical longitudinal reinforcement within the wall panels is mechanically connected or lap-connected inside the corrugated pipes, with additional concrete poured into the pipes afterward.

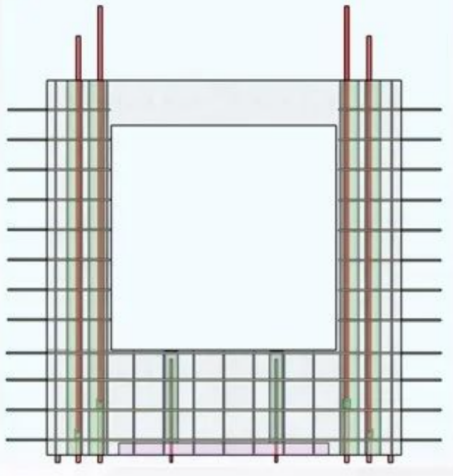

Fig. 4. EMC Schematic diagram of the EMC precast hollow-core composite shear wall structure

Construction Method. The prefabricated concrete wall features only vertical structural reinforcement and edge component ties, forming a reinforcement cage. The edge components utilize a few large-diameter longitudinal bars arranged continuously, with mechanical connections made between the large-diameter longitudinal bars of the upper and lower edge components. The prefabricated wall includes radially distributed extended connection bars, with the lower reinforcement extending from the top of the precast wall panel into the corrugated pipes of the upper precast wall panel for lap connections. This shear wall structure addresses several issues associated with traditional sleeve grouting connections in fully prefabricated shear walls, such as high requirements for precast and installation accuracy, high connection costs, challenges in grout quality control, and difficulties in winter construction. Additionally, it resolves problems related to dense lap reinforcement within the cavities of traditional composite shear walls, such as difficulties in achieving compact concrete during pouring, high production process requirements, and significant limitations on the locations of mechanical and electrical points.

Performance Characteristics and Applicability. EMC precast hollow-core composite shear wall structure system utilize traditional mechanical connections or lap connections, thereby avoiding potential construction quality issues related to rebar joints that may arise from inadequate worker skills and management. This approach enhances the controllability of construction quality and effectively reduces on-site labor requirements, facilitating construction management. The practicality and scalability of this process are notable, as it requires simple processing equipment and can be produced using existing traditional precast component production lines, ensuring capacity.

The structural design methods and construction measures are straightforward, employing equivalent cast-in-place structural analysis methods that allow designers to quickly and accurately understand the requirements. The EMC series structural system can achieve the objectives of improving work efficiency and reducing costs while ensuring safety, quality, and performance.

The selection of this system is primarily suitable for construction projects that require high efficiency, such as high-rise residential and office buildings. This structure is

particularly well-suited for sites with low foundation bearing capacity, as it can effectively address the need for weight reduction. Furthermore, its flexible design adaptability allows it to meet a variety of functional and architectural requirements.

4 The Main Connection Modes of Dry Joints

4.1 Welded Connection

Overview. Welded connections are a common type of dry connection that is very convenient during the construction process. However, the potentially excessive amount of structural welding may impact construction costs, and the quality of the structure after completion is largely influenced by the quality of the welding7.

Construction Method. At the node locations of the shear walls, welded connections are made between the walls and other components such as beams and columns, with common types including corner welds and butt welds. The surfaces of the shear walls are welded to other components like floor slabs to enhance the integrity of the connections. Localized welding is performed at critical locations of the shear walls to improve their load-bearing capacity. The specific construction method involves the following steps: First, prepare the materials and equipment, and conduct on-site measurements and layout according to the design drawings. Next, clean the welding surfaces and perform beveling. During welding, preheating treatment must be considered; spot welding is conducted to fix the position before proceeding with full welding, while monitoring welding parameters to ensure quality. After welding, visual inspection and non-destructive testing are carried out, with mechanical property testing performed if necessary. Subsequently, the welds are cleaned and treated for rust prevention. Finally, parameters and test results from the construction process are recorded for future reference and improvement.

Performance Characteristics and Applicability. After welding connections are made in prefabricated shear walls, the structural performance is notably enhanced, primarily reflected in improved seismic resistance, increased load-bearing capacity, and durability. Welded connections provide excellent integrity and ductility, effectively absorbing and dissipating seismic energy while withstanding greater loads. Additionally, this connection method enhances construction efficiency, reduces on-site operation time, and lowers construction costs. However, it also presents challenges such as high technical requirements for welding, issues related to the heat-affected zone, difficulties in quality control, challenges in repair, and potentially higher costs. Therefore, when choosing to utilize welded connections, it is essential to consider these factors comprehensively to ensure that the specific requirements of the project are met.

The selection of welded connections for prefabricated shear walls is primarily suitable for construction projects with high load-bearing requirements, as well as structures with complex shapes or special designs. This connection method is particularly advantageous for buildings in seismic zones, as it enhances the overall stiffness and seismic performance of the walls. Additionally, welded connections are suitable for use in harsh construction environments or in situations with significant spatial constraints, making them common in projects that demand high construction efficiency. Therefore, welded connections for prefabricated shear walls are widely applied in various architectural designs.

4.2 Bolted Connection

Overview. Bolt connections involve embedding reinforcement bars in precast wall panels, using pre-embedded steel components and high-strength bolts to connect the upper and lower shear wall sections3. Bolt connections are one of the commonly used dry connections abroad and are widely applied in projects such as high-rise buildings, public facilities, industrial plants, residential communities, infrastructure, and green buildings. This connection method provides excellent seismic performance and construction efficiency, making it suitable for rapid construction and enhancing safety. Additionally, it aligns with sustainable development requirements by reducing material waste.

Construction Method. Bolt connections form a cohesive structure by linking different shear wall components using bolts, washers, and nuts. The principle of bolt connections in prefabricated shear walls primarily relies on mechanical connections and the transfer of forces. Bolts secure the shear walls to the structure by aligning with the hole positions in the walls and foundation, generating friction to resist shear and tensile forces while distributing loads across multiple bolts to enhance overall stability.

Performance Characteristics and Applicability. The bolt connections in prefabricated shear walls offer advantages such as ease of construction, strong disassemblability, and high adaptability, allowing for rapid installation and flexibility in various environments. However, they have relatively lower load-bearing capacity, constrained by the strength of the bolts, and may encounter fatigue issues under long-term loads and vibrations. Additionally, bolt connections require corrosion protection to prevent rust, which increases maintenance costs, and the positioning and machining precision of the connection holes are critical, impacting construction quality.

Bolted connections for prefabricated shear walls are primarily suitable for construction projects that require high speed, such as high-rise residential and commercial buildings. Moreover, this connection method is appropriate for designs that necessitate on-site adjustments in position or angle, which are often found in complex structures or buildings that need to adapt to the terrain. Additionally, bolted connections are widely used in temporary structures or movable buildings, especially when considering future dismantling or reuse. Furthermore, bolted connections are compatible with various materials, making them suitable for architectural designs that incorporate different material combinations. Consequently, they play an important role in modern construction applications.

5 Conclusions

The advantages of grouted sleeve technology for connecting prefabricated shear walls include rapid construction, high connection strength, and strong adaptability, which can enhance efficiency and safety. However, it also has drawbacks, such as high quality requirements for grouting materials and constraints related to the construction environment. Therefore, it is essential to weigh these pros and cons to ensure that the connections are reliable and safe. It is widely applied in seismic-prone areas, as well as in the design of modern high-rise buildings and complex structures.

The performance of vertical ribbed composite shear wall structures is fundamentally consistent with that of cast-in-place walls. The cast-in portion of the composite components integrates well with the precast sections, preventing separation. The lap con-

nections of the longitudinal reinforcement in adjacent walls are reliable and demonstrate similarities to cast-in-place components in terms of load-bearing capacity, failure modes, stiffness, and deformation capacity. It is suitable for high-rise buildings with complex shapes, designs with diverse functionalities, and seismic-prone areas, particularly demonstrating good adaptability in projects that require factory-prefabricated components.

The steel reinforcement connections in the EMC precast hollow-core composite shear wall utilize traditional mechanical or lap connection methods, avoiding construction quality issues and improving controllability. This process reduces labor requirements, facilitates management, and is highly practical, easily scalable, and can be rapidly produced using simple equipment and existing production lines, with a straightforward design that is easy to master. It is suitable for construction projects that demand high efficiency, particularly in sites with low foundation bearing capacity and in seismic-prone areas.

Welded connections in prefabricated shear walls enhance seismic performance, load-bearing capacity, and durability, strengthening overall integrity and ductility, effectively absorbing seismic energy while improving construction efficiency and reducing costs. However, they also present challenges such as high technical requirements, difficulties in quality control, and challenges in repair. It is suitable for construction projects with high load-bearing requirements, complex shapes, or special designs.

Bolt connections in prefabricated shear walls are convenient to construct, easily disassembled, and highly adaptable; however, they have lower load-bearing capacity, which may be affected by fatigue over long-term use. Additionally, bolts require corrosion protection, increasing maintenance costs, and there are high precision requirements for the connection holes, which can impact construction quality. It is primarily suitable for construction projects that require high speed, complex structures, and designs that need to adapt to the terrain. It is also widely used in temporary structures and architectural designs that involve the combination of different materials.

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