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Improvement of Waterproof Performance at Joints of Prefabricated Concrete Components in Prefabricated Buildings and Construction Quality Control System Construction

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Abstract: *The waterproof failure and construction quality fluctuation of joints in prefabricated concrete components of prefabricated buildings are key issues that restrict their durability and safety. This article focuses on the two core objectives of improving the waterproof performance of joints and controlling construction quality. It systematically analyzes the influencing factors of joint waterproofing, proposes optimization paths from the aspects of materials, construction, and technology, and based on this, constructs a four-dimensional construction quality control system of "quality planning quality control quality assurance quality improvement", clarifying the control measures for the three key links of personnel, materials, and processes. Research has shown that this system can significantly improve the reliability of joint waterproofing and the stability of construction quality, providing theoretical support and practical reference for the quality assurance of prefabricated building projects.*

Keywords: *Prefabricated Building, Prefabricated Concrete Components, Seam Waterproofing*

1. Introduction

With the rapid development of the global construction industry, prefabricated buildings have gradually become an important development direction in the construction industry due to their advantages of high efficiency, environmental protection, and energy conservation. In recent years, countries have increased their promotion of prefabricated buildings, and their proportion in new construction continues to rise. In China, according to data from the Ministry of Housing and Urban Rural Development, the area of newly-built prefabricated buildings in China showed a rapid growth trend from 2012 to 2019, reaching 420 million square meters in 2019, a year-on-year increase of 44.8%. Under the promotion of the "dual carbon" goal, prefabricated buildings have ushered in a broader development space due to their significant advantages in energy conservation and emission reduction.

However, prefabricated buildings also face some challenges in their development process, among which the waterproofing problem at the joints of precast concrete components is particularly prominent. As a weak link in prefabricated buildings, if the waterproof performance is poor, rainwater can easily penetrate into the interior of the building, which not only affects the normal use function of the building, such as causing indoor walls to become damp and moldy, affecting aesthetics and living comfort, but also may cause damage to the building structure and reduce the durability of the building. Long term rainwater erosion may cause steel bars to rust, weaken the load-bearing capacity of the structure, and endanger building safety. In addition, waterproofing issues may also lead to a series of economic problems, such as increased maintenance costs and decreased property value. According to relevant research, building maintenance costs caused by waterproofing issues may account for 5% -10% of the total building cost. Therefore, improving the waterproof performance at the joints of prefabricated concrete components in prefabricated buildings and establishing a sound construction quality control system are of great practical significance for ensuring building safety, extending the service life of buildings, and improving economic benefits.

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2. Methods to improve waterproof performance at joints

2.1 Material waterproofing technology

Sealing glue is the core material for waterproofing the joints of prefabricated concrete components in prefabricated buildings [1]. Its performance directly determines the waterproofing effect. It needs to have good adhesion to form a sealing barrier, excellent elasticity to adapt to component temperature changes and structural deformation displacement, as well as weather resistance and water resistance to resist natural erosion, especially in harsh environments such as coastal areas.

The selection of sealant should follow the principle of engineering adaptation, and select the appropriate type based on the usage environment and waterproof level. Compatibility tests should be conducted to ensure adhesion with components, while also considering cost and construction convenience. During construction, it is necessary to thoroughly clean the joint impurities first, then embed the backing material to control the thickness of the adhesive layer, and then use specialized equipment to evenly inject adhesive and avoid defects. Finally, repair and maintain to ensure the curing effect.

In addition to sealant, waterproof rolls have high tensile strength and construction efficiency, but the joint treatment is complex. Waterproof coatings are easy to apply and suitable for complex joints, but their durability is poor. In practical applications, it is necessary to optimize the combination of materials according to engineering requirements: joints with high waterproof requirements and large deformation can be combined with sealant and waterproofing membrane. Complex shaped joints should be matched with waterproof coatings and sealant. At the same time, weather resistant materials should be selected based on regional climate to improve the waterproof performance of joints.

2.2 Construction of waterproof technology

Enterprise joint and high-low joint are the core waterproof structural forms of prefabricated concrete component joints in prefabricated buildings. The enterprise joint relies on a concave convex interlocking structure (similar to mortise and tenon principle) to extend the rainwater infiltration path and improve the sealing and integrity of the joint, which can resist structural deformation and seismic resistance, reduce the risk of rainwater infiltration and component displacement; The high and low joints are based on the principle of gravity drainage, guiding rainwater to flow naturally by setting a height difference, avoiding joint water accumulation, and are easy to construct and cost-effective, suitable for cost sensitive projects.

In engineering practice, the exterior wall of a prefabricated residential building adopts tongue and groove joints. Through precise design of dimensions and strict control of construction quality, there has been no leakage for a long time; The high and low joints used in the floor joints of a certain prefabricated commercial building have excellent drainage effects, effectively protecting the floor structure and confirming the practicality of both types of structures.

The drainage system is a key guarantee for joint waterproofing, which can timely drain rainwater and avoid component corrosion and damage. The design needs to control the drainage slope (not less than 2%, uniformly set according to the shape of the components and the direction of water flow, such as dividing the drainage area on the roof) and drainage pipes (determine the diameter and quantity according to the building scale to ensure smooth flow). Optimization strategies include: installing filter screens/grilles at drainage outlets to prevent blockages, conducting regular inspections and maintenance (comprehensive maintenance before the rainy season), and adopting intelligent systems (sensor monitoring+automatic adjustment of drainage) to improve efficiency and reliability.

2.3 Application and development of new waterproof technologies

With technological innovation, new waterproof technologies provide a new path for improving the waterproof performance of prefabricated building joints [2]. The intelligent waterproof monitoring system collects real-time parameters such as humidity, temperature, and displacement by installing sensors at the joints, and automatically alarms in case of abnormalities. A large-scale project applied this system to detect and repair leakage hazards in advance through humidity monitoring, achieving real-time monitoring and warning of joint waterproofing, improving management efficiency and accuracy, and ensuring building safety.

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The nanometer waterproof material relies on the nanometer level microstructure, and can form an ultra-thin waterproof protective film when coated on the joint surface, which has both high waterproof and breathability - the former is waterproof, the latter is moisture repellent and structural damage resistant, and has excellent durability and aging resistance. In projects with high waterproof requirements, its long-term application has no leakage and significant waterproof effect.

In the future, new waterproof technologies will develop towards diversification and intelligence. At the material level, self-healing waterproof materials (which can automatically repair micro cracks) and intelligent color changing waterproof materials (which change color according to the waterproof state) will gradually be developed; At the level of technological integration, waterproofing technology will be deeply integrated with the Internet of Things, big data, and artificial intelligence: the Internet of Things realizes cloud transmission of monitoring data, big data supports waterproofing decisions, artificial intelligence automatically adjusts system parameters, promotes intelligent management and remote control of waterproofing systems, provides more reliable solutions for prefabricated building joint waterproofing, and helps the healthy development of the industry.

3. Key points of construction quality control

3.1 Quality control during the production stage of prefabricated components

The quality of raw materials for prefabricated components directly determines the performance, durability, and overall quality of the building. Cement, as the core cementitious material, should have a uniform gray/light yellow powder appearance and no clumping. Its quality must meet the requirements of GB/T 175-2023 for setting time, stability, and strength grade. Each batch needs to be tested for strength. In a certain project, the component strength was insufficient due to an oversight in cement strength inspection, which affected the project progress and structural safety.

Aggregates should be clean and free of harmful substances, with uniform color. Coarse aggregates should have controlled particle size distribution and needle like content, while fine aggregates should have controlled fineness modulus and mud content (excessive mud content can reduce concrete strength and durability). In practical engineering, quality problems with aggregates often lead to concrete cracks and a decrease in strength.

The quality of steel bars is related to the load-bearing capacity of the components, and it is necessary to inspect the appearance (no cracks, scars, etc.) and mechanical properties (yield strength, tensile strength, elongation) according to GB 1499.1 and GB 1499.2. Due to negligence in the inspection of the mechanical properties of steel bars in a certain prefabricated bridge project, the use of steel bars was interrupted, endangering the safety of the bridge; Admixtures (such as water reducers and early strength agents) need to be tested for composition and water reduction rate, while admixtures (such as fly ash and slag powder) need to be tested for fineness and loss on ignition to ensure compliance with design requirements.

Production process control is the key to component quality. Mold making requires the use of high-strength steel to ensure stability, reasonable design to cope with pouring pressure and vibration, strict control of dimensional tolerances. Due to insufficient mold accuracy, a prefabrication factory produced components with large dimensional deviations that could not be installed, resulting in material waste and project delays. Before pouring concrete, it is necessary to clean the mold debris, check the position of the steel reinforcement skeleton and embedded parts, control the speed and height during pouring to prevent segregation, and use an inserted/flat plate vibrator to compact the material (to avoid excessive vibration causing the aggregate to sink). In a residential project, due to insufficient compaction, honeycomb and rough surface appeared on the components, reducing strength and durability. Maintenance is crucial for the development of concrete strength, and timely maintenance is required after pouring. Natural maintenance requires adjusting the frequency of watering according to temperature and humidity (increasing frequency in summer and insulation in winter), while steam maintenance requires controlling the temperature rate according to the heating constant temperature cooling curve (to prevent temperature stress cracking). Due to the uncontrolled temperature of steam maintenance in a certain prefabrication plant, the strength of the components was insufficient and cracks appeared.

3.2 Quality control of transportation and stacking of prefabricated components

The protective measures during the transportation and stacking stages of prefabricated components

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directly affect their quality and subsequent use. In the transportation process, it is necessary to select transportation vehicles with sufficient load-bearing capacity and high stability based on the size, weight, and shape of the components. Large and heavy components should be transported by flatbed trucks or specialized transport vehicles, while ultra-high and ultra wide components require transportation permits; Due to improper selection of transportation vehicles, the components of a certain project were tilted, collided, and partially damaged, resulting in a delay in the project schedule.

At the same time, it is necessary to cover the surface of components with protective film/cushion blocks, and place foam boards/sponges between components for buffering to avoid direct collision damage; Use straps, ropes, and other tools to fix components according to specifications, controlling the fixing force to prevent damage or shaking caused by excessive tightness or looseness. In a certain transportation case, due to inadequate fixation, the components displaced and collided with the carriage during turning, causing damage to the corners.

The stacking process should be carried out in a dry and ventilated area, away from high-risk areas of the construction site. Before stacking, the site should be leveled and hardened to support the weight of the components and prevent deformation caused by ground settlement; A construction site experienced tilting and cracking of components due to ground subsidence after rain, as the site was not hardened. The stacking of components should follow the principle of "heavy on the bottom and light on the top", with reserved spacing for easy inspection and lifting, and signs indicating the model, specifications, and production date; Due to confusion and lack of labeling, the retrieval of components at a certain storage yard took a long time, which affected the construction progress. During storage, it is necessary to regularly check the condition of the components, clean and repair surface damage and pollution in a timely manner, and regularly maintain the components that are stored for a long time (such as painting protective paint and checking fixation); In a certain case, due to lack of regular inspection and maintenance, some components were corroded on the surface, reducing durability.

3.3 Quality control during on-site construction phase

The joint treatment process directly determines the waterproof performance of precast concrete component joints, and the quality of each link needs to be strictly controlled [3]. Basic cleaning requires thorough removal of dust, oil stains, and other impurities, repair of defects such as peeling and honeycombing (such as repairing with cement mortar), and ensure that the base is flat and solid; Due to incomplete cleaning of the base layer in a certain project, the sealant bonding failed and water leakage occurred.

Before applying sealant, it is necessary to select the appropriate type and conduct compatibility tests. The construction environment should be controlled at a relative humidity of 40% -80% and a temperature of 4 ℃ -40 ℃ - high temperatures can cause the sealant to sag and bubble, while low temperatures can reduce its adhesion; Due to excessive construction temperature, the sealant flowed and foamed, resulting in damage to the waterproof effect of a certain project. During construction, the backing material (such as polyethylene foam rod, with a diameter of 1-2mm wider than the joint) shall be embedded first, and then the special equipment shall be used to evenly inject glue, control the speed and pressure to prevent defects, and finally the surface shall be trimmed to be flat and even. The water spraying test is the key to testing the waterproof effect. Before the test, cover the area around the joint, use specialized equipment to continuously spray water for no less than 2 hours, and assign a dedicated person to observe the leakage; A certain project was found to have leakage through a water immersion test, and after repair, it was retested to meet the standard.

The installation accuracy of components affects waterproofing and structural safety. Insufficient accuracy can lead to uneven and misaligned joints, increasing the risk of leakage and weakening structural stability; Due to significant installation deviation, a certain project still experiences water leakage even after sealing the joints. To improve accuracy, it is necessary to first accurately measure and set out, establish a measurement control network using a total station and a level, and strictly verify the data; A large-scale project utilizes advanced measurement technology to improve installation accuracy and reduce waterproofing issues. During installation, we use positioning pins and plates for initial positioning, control verticality and flatness through fine-tuning devices, and strengthen process supervision to ensure construction is carried out in accordance with regulations; A residential project achieved uniform width of wall panel joints and improved waterproof performance based on this.

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4. Construction quality control system construction

4.1 Objectives and principles of quality control system

The construction quality control system for prefabricated concrete components in prefabricated buildings has two core objectives. Firstly, to ensure that the waterproof performance of joints fully meets the standards, it is necessary to strictly control the quality of sealing materials, construction technology, and structural waterproof design and construction to prevent moisture infiltration in various environments. For a certain project, sealant screening and fine construction control are used to achieve long-term no leakage of joints; The second is to improve the overall quality of the building, covering the production accuracy and strength guarantee of prefabricated components, transportation and stacking damage prevention, and high-precision on-site construction (such as accurate component installation and perfect joint treatment). A large commercial building has significantly improved its overall quality and social evaluation through full process quality control.

The construction of the system follows three principles: firstly, prevention is the top priority. Before construction, quality risks are comprehensively predicted and measures are formulated. For example, during the production stage of prefabricated components, a certain component factory reduces material and process defects through a raw material inspection system and production monitoring; The second is full process control, covering all aspects of component production (raw material procurement and inspection, mold making, pouring and maintenance), transportation and stacking (protective measures), and on-site construction (component installation, joint treatment). A residential project solves problems in each link in a timely manner to ensure efficient and high-quality progress of the project; The third is full participation, requiring management personnel, technical personnel, and construction personnel to assume quality responsibility. Through quality training, awareness is strengthened. A certain construction site regularly organizes training to clarify the responsibilities of construction personnel and promote them to construct according to quality requirements.

4.2 Framework design of quality control system

The framework of the quality control system for prefabricated construction consists of four interrelated links: quality planning, quality control, quality assurance, and quality improvement, which work together to ensure the quality of the project.

Quality planning is the starting point of the system. Before project implementation, a quality plan should be developed based on the characteristics and requirements of the project: clarifying quality objectives such as joint waterproofing indicators and overall quality acceptance standards, determining quality control points, inspection standards, and methods for each construction process, and developing quality assurance measures such as personnel training, material inspection, and process monitoring. During the planning phase of a certain project, the requirements for joint waterproofing and quality control processes are clearly defined by combining functional and climatic conditions, providing guidance for subsequent construction.

Quality control is the core of the system, and each link is controlled according to the planning requirements during construction: strict inspection of raw materials and monitoring of processes during component production to ensure component accuracy and strength; Take protective measures during transportation and stacking to prevent damage; Real time monitoring and adjustment of component installation accuracy and joint treatment quality during the on-site construction phase. The production process of a certain component is monitored through the establishment of quality control points, focusing on processes such as concrete pouring and curing, and timely correction to ensure the quality of the component.

Quality assurance aims to establish trust, and it is necessary to establish a quality management system that clarifies the quality responsibilities of each party, and provides quality certification documents such as raw material inspection reports, component qualification certificates, and construction inspection records. A certain project has won the trust of the owner and regulatory authorities through a comprehensive quality management system and detailed supporting documents.

Quality improvement is the key to enhancing the level of quality control. This study collects and analyzes construction quality data, identifies problems and improvement opportunities, develops improvement measures such as optimizing processes and strengthening training, and tracks their effectiveness. After data analysis of a certain project, it was found that the construction of sealant caused poor waterproofing. After optimizing the process and strengthening training, the quality of joint waterproofing was significantly improved.

4.3 Key links and measures of quality control

The key links of quality control in prefabricated building construction focus on personnel management, material management, and construction process management, and targeted control measures need to be taken. At the personnel management level, the professional quality of construction personnel directly affects the quality, and it is necessary to strengthen training (covering construction technology, quality standards, safety regulations) and regularly organize skill assessments. Only those who pass the assessment can be employed. A certain project has significantly improved the operational level of construction personnel and effectively ensured construction quality through regular training and assessment.

Material management requires the establishment of a strict procurement and inspection system, selecting suppliers with good reputation during procurement to ensure material quality and supply stability. At the same time, raw materials (such as cement strength, stability, and steel mechanical properties) must be strictly inspected and used only after passing the inspection; In addition, standardize the storage and use of materials to prevent moisture and deterioration. A prefabricated component factory ensures the quality of raw materials through long-term cooperation with high-quality suppliers and strict inspection systems.

Construction process management is the core, and quality control points need to be established to focus on monitoring the production of components (molds, pouring, maintenance), transportation, stacking, and on-site construction (installation accuracy, joint treatment). A certain project ensures installation quality by monitoring the verticality and flatness of components in real-time, correcting deviations in a timely manner; At the same time, strengthen process inspection and acceptance, conduct comprehensive inspection (appearance, size, strength) of components after production, and only proceed after the on-site process is completed and accepted as qualified. A certain project follows this system to ensure that the engineering quality meets the standards.

4.4 Quality inspection and acceptance standards

The quality inspection of joint waterproofing includes two core methods: water immersion test and sealing material performance testing. The water spraying test shall be carried out in accordance with the Technical Regulations for Building Waterproofing Engineering. The water spraying time shall not be less than 2 hours and the pressure shall not be less than 0.1 MPa. During the test, the leakage of the joints shall be closely observed and marked and recorded; A certain project discovered leakage through this experiment, and after resealing and retesting, it was found to have no leakage, ensuring the waterproof effect.

The performance testing of sealing materials should refer to the "Test Method for Building Sealing Materials", using tensile bonding test to test the bonding strength, and observing the elastic recovery through compression test to verify key indicators such as bonding and elasticity; A certain project has passed this test to ensure that the sealing material meets the standard, providing a guarantee for joint waterproofing.

The construction quality acceptance strictly follows national and industry standards: the production of prefabricated components is carried out in accordance with the "Code for Acceptance of Construction Quality of Concrete Structures", and the dimensional deviation, appearance (without honeycomb or rough surface), and strength (compressive strength of concrete test blocks meets the standard) are inspected. A certain component factory returns substandard components to ensure factory quality; On site construction shall be carried out in accordance with the Technical Standards for Prefabricated Concrete Buildings, and the accuracy of component installation (verticality deviation of prefabricated wall panels $\leq$ 3mm, flatness deviation of adjacent components $\leq$ 2mm) and the quality of joint treatment (full and smooth sealant, no bubbles or cracks) shall be inspected. A certain project shall rectify the non-compliant parts to ensure the compliance of construction quality.

5. Conclusion

This article focuses on the improvement of waterproof performance at the joints of prefabricated concrete components in prefabricated buildings and the construction of a quality control system. A series of important theoretical and practical achievements have been made.

In terms of improving the waterproof performance of joints, the key factors affecting waterproof performance were deeply analyzed, covering multiple aspects such as materials, construction, and construction. At the material level, through detailed research on the performance of various sealants, it has been clarified that sealants should have key performance indicators such as good adhesion, elasticity, weather resistance, and water resistance. Based on the specific needs of different projects, scientific and reasonable selection principles for sealants have been proposed. At the level of structural design, the design principles and waterproof advantages of structural forms such as tongue and groove joints and high-low joints were elaborated in detail, and the effectiveness of these structural forms in improving the waterproof performance of joints was verified through practical engineering cases. At the level of construction technology, strict construction processes and quality requirements have been established, including key links such as base cleaning, sealant construction, and water spraying tests, to ensure that the construction quality meets high standards.

In terms of building a construction quality control system, a comprehensive, systematic, and scientific construction quality control system has been successfully established. The core goal is to ensure that the waterproof performance of the joints meets the standard and improve the overall quality of the building, following the basic principles of prevention first, whole process control, and full participation of all staff. This system covers key links such as quality planning, quality control, quality assurance, and quality improvement, which are interrelated and work together to form an organic whole. By strengthening the control of key links such as personnel management, material management, and construction process management, the construction quality has been effectively improved. At the same time, scientific and reasonable quality inspection and acceptance standards have been formulated, providing reliable basis for the evaluation of construction quality.

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