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Research and Application of Intelligent Construction in Prefabricated Building Construction

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Abstract

The rapid development of emerging technologies such as BIM has greatly promoted the intelligent development of prefabricated building construction. This paper adopts a research method that combines on-site investigation, field testing, and technological development to explore quality control in prefabricated building construction and the integration of prefabricated buildings with intelligent construction. Focusing on three key technologies in prefabricated building construction - component installation, on-site layout, and steel connection—the paper examines the technical principles, operational processes, and application effects. It also studies and develops intelligent construction-related technologies such as, accurate alignment of prefabricated components, intelligent layout technology and simultaneous self-locking connection technology for multiple steel. Additionally, two types of rapid steel layout equipment are developed. These findings provide references for the further integration of prefabricated concrete construction with intelligent construction.

Keywords

Prefabricated Building, Intelligent Construction, Key Technologies

1. Introduction

Prefabricated construction plays a significant role in promoting sustainable economic development and improving the level of urbanization in China. However, the traditional construction industry is increasingly constrained by enormous environmental and resource pressures. As a core driver of the transformation and upgrading of the construction industry, modular construction is receiving more and more attention. It refers to concrete structures assembled from prefabricated concrete components through reliable connection methods, including assembled integral concrete structures and fully assembled concrete structures. In the field of construction engineering, it is referred to as modular construction, and in the field of structural engineering, it is referred to as modular structures. Modular construction has the following advantages due to its characteristics of standardized design, factory production, assembly construction, integrated decoration, and information management: fast production speed, stable quality of components, high construction efficiency, less labor resource consumption, and sustainable development.

Intelligent construction is a new construction method that has emerged as a result of the low construction efficiency, serious environmental pollution, and rough construction methods in the traditional construction industry. It is an inevitable result of the rapid development of emerging technologies such as the Internet of Things, Building Information Modeling (BIM), blockchain, artificial intelligence, big data, and smart robots. Combining with the actual construction of modular construction, the definition of intelligent construction can be given as follows: Intelligent construction is based on the industrialization of construction, comprehensively using next-generation information technologies such as BIM, big data, artificial intelligence, the Internet of Things, and blockchain. It develops intelligent equipment with perception, judgment, and decision-making capabilities, constructs a new intelligent system framework, achieves integrated lifecycle management, gradually transforms the construction methods, and provides intelligent building products for society.

2. Precast Component Accurate Alignment Technology

2.1 Technical Principle

This article presents the development of a precise alignment device for prefabricated components, which mainly includes two parts: equipment intelligent positioning and component intelligent alignment. The equipment intelligent positioning part consists of a walking mechanism and a platform auto-leveling system. The walking mechanism is embedded with wheels that can rotate 360° and move freely up and down within the base plate. It can be driven by a power source to move and rotate the wheels. The platform auto-leveling system utilizes an auto-leveling system developed by China Construction Science and Technology Co., Ltd., which continuously reduces the angle between the equipment base plate and the floor slab using an industrial-grade nine-axis gyroscope and electric cylinders.

The component intelligent alignment part mainly consists of electromagnets, pressure sensors, and adjustable push plates. To ensure construction safety, the back of the “L”-shaped vertical plate is equipped with counterweights to guarantee equipment stability, diagonal supports, and ladders for operators to access. The attractive force of the electromagnets can be adjusted by controlling the current through a current controller. The adjustable push plates and the transverse plate where the pressure sensors are located can move independently up and down, and the adjustable push plates can also move back and forth.

2.2 Operation Technology

Based on the technical principles of the precise alignment device for prefabricated components and the actual site lifting, the operating process of the device is derived as follows:

1) Prepare the work area by clearing obstacles and inspecting the power system.

2) Connect the power supply and move the precise alignment device for prefabricated components to the lifting area using the walking mechanism, ensuring that the "L"-shaped vertical plate is aligned with the axis line.

3) Retract the wheels into the base plate using the power source, and then drive the auto-leveling system to level the base plate to ensure a 90° angle between the "L"-shaped vertical plate and the ground.

4) Gradually increase the current while using a tower crane to lift the prefabricated component near the device.

5) Use the magnetic force between the electromagnet and the magnet (pre-embedded inside the prefabricated component) to pull the component onto the surface of the "L"-shaped vertical plate.

6) Reduce the current intensity, and use the power source to drive the adjustable push plate to push the component until signals are received from both upper and lower pressure sensors, indicating precise horizontal alignment of the prefabricated component.

7) Slowly lower the sling, allowing the component to descend under its own gravity. Align the upper component's reserved holes with the lower component's reserved reinforcement bars to confirm precise alignment of the prefabricated component.

Note: The size, specifications, quantity, and distribution of the electromagnets should be determined based on the characteristics of the components. The electromagnetic attraction design value is related to the quality of the component. During the lifting and positioning process, the application of electromagnetic force can be adjusted using a current controller. The larger the current, the greater the electromagnetic force. After the component is attached to the "L"-shaped vertical plate, control the movement of the adjustable push plate to ensure it does not touch the side reinforcement bars of the prefabricated wall. Rubber protective pads should be installed at the ends of the adjustable push plate to avoid damaging the component during the pushing process. The transverse plate where the two pressure sensors are located should also move up and down according to the position of the side reinforcement bars of the prefabricated wall to avoid damaging the pressure sensors.

2.3 Application Analysis

The precise alignment technology for prefabricated components has made significant improvements compared to traditional precise alignment techniques for prefabricated components, and it has the following beneficial effects:

Traditional precise alignment techniques for prefabricated components typically require a team consisting of a crane operator, a ground hook personnel, and 3-5 workers in the lifting area. However, with the precise alignment technology for prefabricated components, the team can be reduced to a crane operator, a ground hook personnel, and one worker in the lifting area. With the help of the precise alignment device, the worker in the lifting area can independently perform component calibration and alignment work, followed by subsequent work by the diagonal support installation personnel. The optimized design of the precise alignment technology for prefabricated components reduces labor costs and minimizes the risks associated with multiple workers working in close proximity to each other.

The precise alignment technology for prefabricated components is operated by skilled workers throughout the entire process. This greatly reduces installation deviations, improves installation efficiency, and eliminates component damage caused by human forces. It reflects the principles of lean construction management and intelligent construction.

In conjunction with a specific project, the precise alignment technology for prefabricated components developed in this study can be used for 54 exterior wall panels and 4 interior wall panels, excluding the PCF panels, on each floor. Since this equipment directly feeds back signals through pressure sensors, the deviation accuracy can reach the millimeter level, which is a significant improvement compared to the results of the deviation analysis obtained in analysis of installation deviations of component parts.

3. Intelligent Lofting Technique

3.1 Technical Principle

Intelligent layout technology is an intelligent technology that integrates BIM 3D models, layout robots, 3D laser scanners, total stations, and other tools to achieve real-time measurement and updating of the model on-site. Its main technical principles include the creation and deepening of BIM models. The creation and deepening of models are carried out through Autodesk Revit software for 3D coordinated design. A 3D coordination design team is formed, including architectural, structural, MEP (mechanical, electrical, and plumbing) professionals. Different disciplines coordinate their designs by linking models or worksets. Designers upload updated content within designated time frames, and other designers can view and design their own models in real-time based on this information. Designers can also send real-time requests to other disciplines through worksets to optimize the design model. Through these methods, designers can coordinate their designs while completing their own professional design tasks. At the end of the modeling phase, to ensure full coordination between disciplines, the models are linked together for automatic collision detection. Based on the collision detection report, coordination and refinement of the design are carried out to resolve conflicts and issues in the model.The application of layout robots and 3D laser scanners allows for on-site measurement and layout work, which is then compared in real-time with the BIM model.

3.2 Operation Technology

Based on the principles of intelligent layout technology and the actual on-site layout process, a key flowchart for intelligent layout technology is obtained.

1) The BIM consulting firm creates a 3D model based on the two-dimensional drawings provided by the design firm. The model undergoes collision detection, analysis, and review to generate a refined

design model.

2) The refined design model is imported into the layout robot, which automatically performs measurement and layout. The construction team then proceeds with the construction work accordingly.

3) Using a combination of a 3D laser scanner and a total station, the coordinates of the constructed components on-site are scanned and processed into high-quality point cloud data. This data is then imported into the BIM model for dynamic calibration (the layout robot can also collect on-site data to a certain extent).

4) The next round of intelligent layout work can then begin. The model data and on-site data from each cycle can be added with time information and stored in a block chain network as process information.

Please note that the flowchart mentioned above is a general representation of the process and may vary depending on specific project requirements and the technologies and tools used.

3.3 Application Analysis

The intelligent layout technology, which integrates BIM models, 3D laser scanners, and layout robots (total stations), offers several beneficial effects:

1) Building and refining the BIM model based on multi-disciplinary coordination allows real-time updates of model content to be shared with all professionals working on the project. This reduces rework and improves efficiency.

2) Precise layout can be achieved by controlling the layout robot through a tablet device. Compared to traditional layout methods, this approach significantly improves accuracy. Moreover, only one person is required to operate the measurement and layout process, reducing labor costs.

3) By collecting on-site data through 3D laser scanners and layout robots, feedback mechanisms ensure the coordination and consistency between on-site data and model data, thus avoiding conflicts between the refined model and the actual site conditions. Additionally, the comparison between on-site and model data can visually display construction deviations, aiding in improving construction quality.

4) With synchronized updates of on-site and model data, the BIM model in the final stages of construction reflects the actual site conditions accurately. This enables the use of the as-built model for project acceptance, streamlining the acceptance process. The as-built model, which links to the project's process documentation, can also be delivered for future maintenance and operation, laying the foundation for post-construction management.

By utilizing intelligent layout technology, construction projects can benefit from improved coordination, enhanced accuracy, reduced labor costs, and streamlined acceptance procedures, ultimately leading to higher construction quality and efficient post-construction management.

4. Multiple Steel Bars Simultaneously Self-Locking Connection Technology

4.1 Technical Principle

The research in this paper has developed a multi-steel self-locking connection device, which mainly consists of a steel connection part and a steel clamp part. The steel connection part is processed into a tapered thread shape. The outer part of the dedicated sleeve is a ductile iron protective zone, and the inner part is an elastic keyway made of high-strength elastic material. The dedicated sleeve also has a partition in the middle.

The steel clamp part is made of steel and is 50mm thick. Depending on the number and distribution of the connected steels, the steel clamp has pre-drilled semi-circular rough holes. The upper steel clamp has rectangular recesses, while the corresponding position of the lower steel clamp is welded with protruding blocks. The recesses are slightly larger than the protruding blocks. Both the upper and lower steel clamps are connected by fastening bolts. This multi-steel self-locking connection device provides a secure and reliable connection for multiple steels simultaneously. The tapered thread shape and elastic keyway ensure a tight and self-locking connection, while the steel clamp securely holds the steels in place. The device is designed to withstand the forces exerted by the connected steels, providing structural stability and integrity.

4.2 Operation Technology

Before construction, precise processing of the steels, sleeves, clamps, etc. is carried out. During construction, the lower steel clamp tightly secures the lower steels by fastening bolts. After determining the orientation of the dedicated sleeve, the sleeve is placed on the steels through the elastic keyway, allowing the special threaded section of the steels to fit into the elastic keyway of the sleeve.

Simultaneously, the upper steel clamp tightly secures the upper steels using fastening bolts.

Finally, the upper steels with the clamps are inserted into the dedicated sleeve. The steel steel connection is considered complete when the recesses of the upper steel clamp are fully fitted onto the protruding blocks of the lower steel clamp.

This method of steel connection simultaneously satisfies the connection of multiple steels. The bite force between the elastic keyway and the special threaded section of the steels ensures a high-quality connection, and the complete fit between the protruding blocks and recesses indicates the completion of the steel connection. With this steel connection technique, multiple steels can be connected simultaneously, and automatic locking can be achieved. For prefabricated wall panels and composite panels, which are the main components of prefabricated structures, the operating process is as follows:

For vertical components like prefabricated wall panels: In the component factory, the dedicated sleeve and special threaded steels are pre-embedded in the component, with the dedicated sleeve protruding upwards. During lifting, the first steel of the upper component is inserted into the dedicated sleeve of the lower component through gravity.

For horizontal components like composite panels: Customized steel clamps are made according to the number and position of steels. After inserting the dedicated sleeve into the clamp, it is tightened. The clamp with the dedicated sleeve is firmly placed on top of the multiple steels. Simultaneously, another clamp is placed on the steels of the other component, and by moving the other component, these steels are also inserted into the dedicated sleeve.

4.3 Application Analysis

The multi-steel simultaneous self-locking connection technology has made significant improvements compared to traditional steel connection methods, and it offers the following beneficial effects:

1) Taking a wall panel with 20 steels at the bottom as an example, when using traditional steel connection methods, each steel needs to be connected one by one, resulting in low connection efficiency. However, with the multi-steel simultaneous self-locking connection technology, all 20 steels can be connected simultaneously. Corresponding clamps are made for different quantities and distribution patterns of the two-sided steels. The clamps are placed on the processed steels, and with the force of gravity or external power, multiple steels on both sides can be connected simultaneously.

2) It enables automatic self-locking of the steel connection. The steels gradually approach the middle partition of the sleeve through the elastic keyway. When the recesses and protruding blocks of the two clamps are fully engaged, it can be determined that the self-locking is successful and irreversible.

4. Conclusion

In this paper, the related equipment and construction method of intelligent construction are researched and developed. Specifically: precast component precise alignment technology, precast component precise alignment technology and multiple steel bar simultaneously self-locking connection technology. For each intelligent construction technology, the technical principle and operation process are introduced respectively, and the simulation application and effect analysis are carried out, and the integration of intelligent construction and prefabricated building is preliminarily explored.

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