Numerical Simulation and Construction Technology of Prefabricated Columns with Steel Joints

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Abstract. This paper, based on the R&D and production base of a company, designed prefabricated concrete column components with section steel connection joints, for which a refined numerical model was established for finite element stress simulation and stress performance verification. Through the research and development of precast column node connectors, precast column positioning formwork devices and new technologies, problems such as poor concrete pouring at nodes, difficult positioning of precast columns, difficulty in setting up oblique supports and adjusting verticality have been solved. These new technologies include visual reinforcement arrangement technology, carbon dioxide gas shielded welding construction technology at the bottom of the column, two-way reserved bell mouth concrete pouring technology at the bottom of the column, etc. Through these methods, the construction quality and efficiency of the concrete prefabricated column structure are further improved.

Keywords: Prefabricated Column; Numerical Model; Construction Technology; Construction Quality

1 Overview

With high construction mechanization, fewer on-site wet construction, high construction efficiency, and fast progress, prefabricated concrete structure technology saves many molds. It has little impact on the surroundings with good social and economic benefits[1]. The new prefabricated integrated reinforced concrete structure has the advantages of standardized production and factory manufacturing and good overall stiffness, which also makes the market share of prefabricated buildings grow rapidly[2]. Yao, Zhao, et al.[3] used the ABAQUS finite element analysis software to simulate the stress-strain behavior of the beam-column joints of a prefabricated reinforced concrete frame with anchored high-strength bottom reinforcement and unfull grouting. Wu[4] utilized BIM technology to guide complex joint construction in the conversion of prefabricated integral structures to steel structures, controlling the comprehensive construction

G. Zhao et al. (eds.), *Proceedings of the 2025 8th International Conference on Traffic Transportation and Civil Architecture (ICTTCA 2025)*, Atlantis Highlights in Engineering 39,
https://doi.org/10.2991/978-94-6463-793-9_2

process and quality. Lin[5] adopted the optimization and process technology of prefabricated building construction structure joint, analyzed the construction requirements in detail and depth, focused on the key control points in the construction process, and summarized the characteristics of prefabricated buildings. Guo[6] explored the construction technology and quality control points in the prefabricated column hoisting. He first analyzed the advantages of prefabricated buildings in the construction industry, summarized the difficulties of technology implementation, and finally explored the quality control measures of prefabricated column hoisting construction technology. Zhao[7] introduced the technical characteristics and process of prefabricated column sleeve grouting, as well as the difficulties and measures of quality control, to continuously improve and optimize the construction technology. The fabrication of prefabricated components requires high accuracy, with the error of section dimension of components not exceeding 0.3 cm and the position deviation of reinforcements not exceeding 0.2 cm, to ensure the safety and stability of prefabricated building structures[8]. Concrete prefabrication construction not only stabilizes the building structure and improves the quality of the building but also effectively ensures the service life of the building, shortens the construction period, and scientifically reduces the construction cost[9]. Finnish professor Lauri Koskela applied the idea of lean construction to the production process of the construction industry[10]. Luo et al. discussed and summarized the construction technology of prefabrication components in secondary structures. Optimizing the design of prefabricated structural columns through BIM technology can improve the construction quality and ensure the construction progress, which has been applied to practical projects and achieved good results[11]. The simulation of construction with building information modeling (BIM) can fully simulate various situations that may occur in the construction of prefabricated components, such as prefabricated columns, and can also improve the quality and efficiency of the construction of prefabricated buildings[12].

2 Prefabricated Column Design and Finite Element Simulation

2.1 Prefabricated Column Design

In this paper, the structure of the prefabricated column is roughly the same as that of traditional precast concrete components, except that the I-steel connection joints are set at the top and bottom of the column for the installation of the upper and lower truncated column components. A steel corbel is set at the corresponding beam position of the steel connection joint at the column top, where bolts or welding installation is used to the corresponding prefabricated beam steel components, and the reinforcement binding, the general method of steel-concrete structure, is used to the corresponding cast-in-place beam. In addition, prefabricated columns are connected to precast concrete column components using section steel. Iron plates are embedded at the column bottom, and positioning I-steel is reserved in the column bottom joints, with the center overlapping with the column center. The I-steels penetrate 1.2 m into the interior of the column body, and the column bottom is exposed by 0.5 m. The positioning plate is installed between the I-steel bottom and substratum for welding. Meanwhile, the longitudinal reinforcements of the column are welded, of which the welding positions are adjacent and misaligned. A positioning plate with a thickness of 25 mm is installed at the structural elevation of the lower floor, of which the center coincides with the center of the column. Four sheets of shear angle steel are installed at the lower part of the positioning plate of the first layer, and the angles of the shear angle steel are flush with the projection of the I-steel, as shown in Figure 1 and Figure 2 for the installation of the prefabricated columns joints.Furthermore, the sectional dimension of the columns involved includes 600 mm, 700 mm, and 800 mm. The model of the embedded I-steel at the column bottom includes HW300 × 300 and HW250 × 250. The specifications and models of the internal reinforcement of the column are the same as those of traditional precast column components.

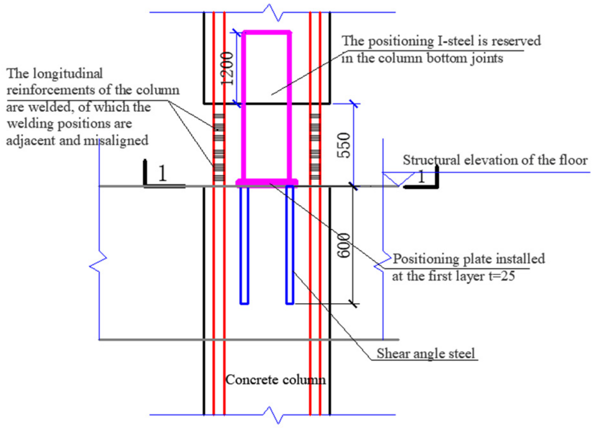


Fig. 1. Installation for Prefabricated Column Component Joints

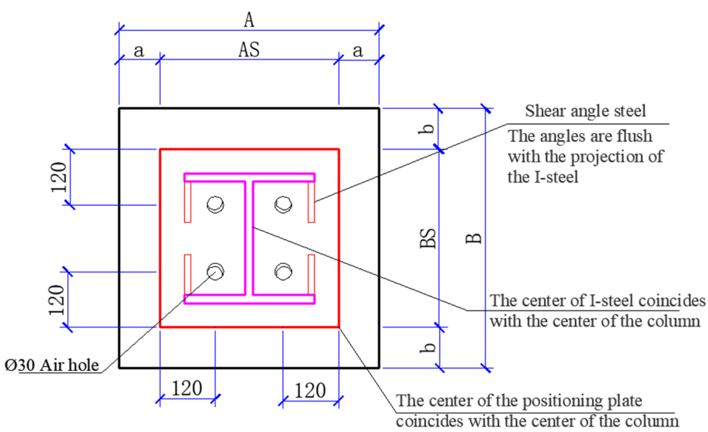


Fig. 2. Section 1-1 of Prefabricated Column Joints

2.2 ABAQUS Model Establishment

For the performance differences between prefabricated reinforced concrete columns embedded with partial I-steel and traditional prefabricated reinforced concrete columns, a refined model was established based on the ABAQUS platform software for finite element simulation analysis. In terms of material selection for components, C30 is selected for concrete, of which the stress-strain curve is shown in Figure 3. The longitudinal reinforcement adopts HRB400, the stirrup adopts HRB300, and the constitutive reinforcement model adopts the bilinear model, as shown in Figure 4. The section steel adopts I-steel Q345. Based on experimental data, the nominal stress and strain of the section steel are shown in Figure 5. The cross-section of the column is 600 mmX800 mm. The column bottom is fixed at the periphery. The load is applied with displacement loading, increasing with an amplitude of 0.1. A 10 mm vertical and 100 mm horizontal displacement are applied at the column top, as shown in Figure 6.The features of the I-steelare shown in Table 1.

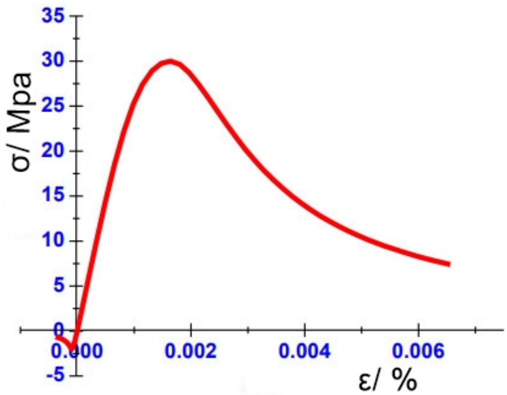


Fig. 3. Stress-strain Curve of Concrete

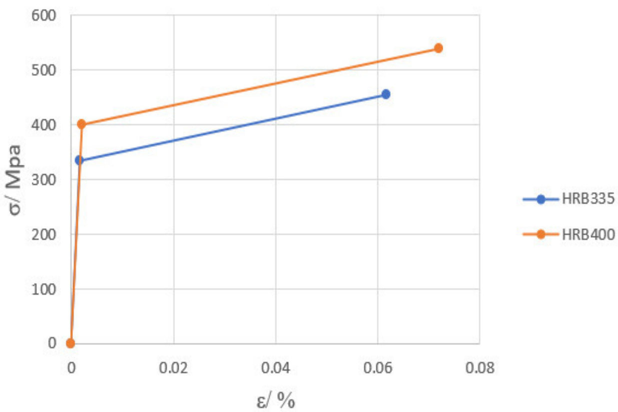


Fig. 4. Constitutive Relation of Reinforcement

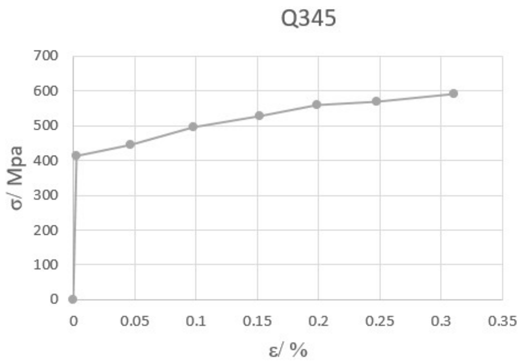


Fig. 5. Constitutive Relation of Section Steel

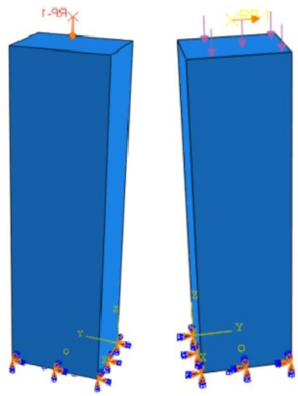


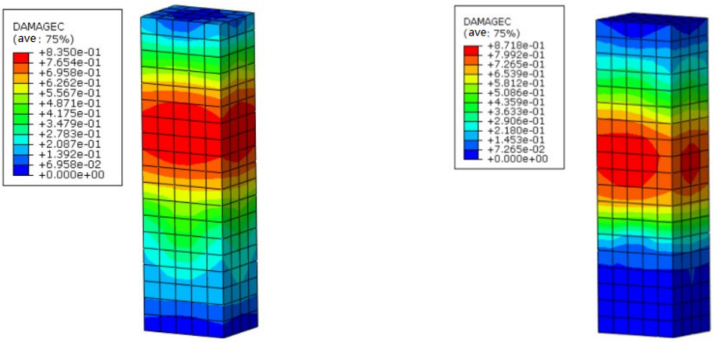
Fig. 6. Displacement Loading Form

Table 1. I-steel features

I-steel specification	I-steel type	Exposed Length of I-steel	Length of I-steel
HW300×300	Q345	500mm	1700mm

2.3 Results Analysis

The compressive damage of two types of reinforced concrete columns under vertical displacement loading is shown in Figure 7. A damage factor of 0 represents no damage; A damage factor greater than 1 indicates complete failure; Generally speaking, if the compressive damage is greater than 0.3 and the tensile damage is greater than 0.5, it can be considered a unit failure. The figure shows that the area where the concrete damage factor of partial section steel reinforced concrete columns is greater than 0.5 is smaller than that of traditional concrete columns. Therefore, reinforced concrete columns with partial section steels can effectively reduce the degree of concrete cracking.

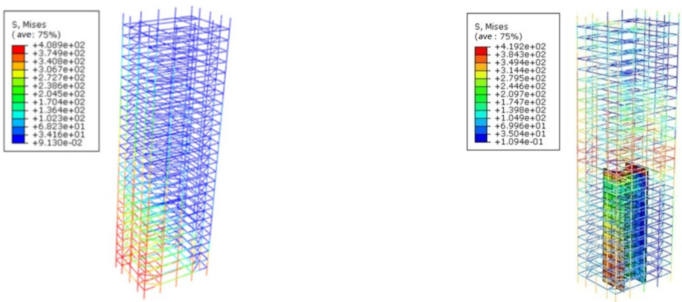


(a) Traditional Reinforced Concrete Columns

(b) Reinforced Concrete Columns with Partial Section Steels

Fig. 7. Damage of Reinforced Concrete Columns

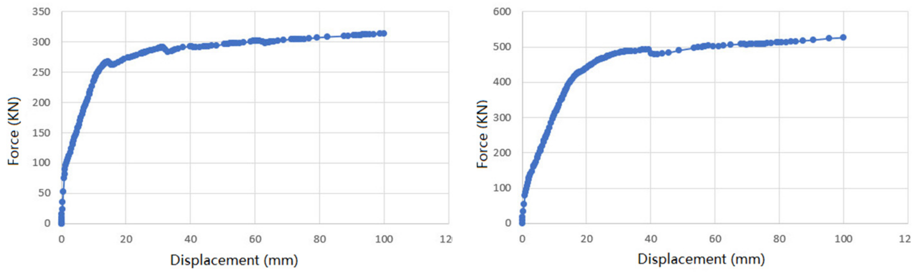
The steel stress nephogram of two types of reinforced concrete columns under horizontal displacement loading is shown in Figure 8. The figure shows that the stress on the reinforcement cage at the bottom of the reinforced concrete column with partial section steels has significantly decreased. At the same time, after extracting the base shear of two types of columns, the base shear of traditional reinforced concrete columns is 299.9 KN, and that of reinforced concrete columns with partial section steels is 687.1 KN, 2.29 times that of traditional reinforced concrete columns. Therefore, under the same horizontal displacement loading, reinforced concrete columns with section steels can bear greater shear, indicating that adding a certain length of section steel into the traditional reinforced concrete column can effectively improve the horizontal force resistance of the column. The stress-displacement curve of the extracted column top loading point is shown in Figure 9. When the loading displacement is 100 mm, the force of traditional reinforced concrete is 313.80 KN, while the force of reinforced concrete with partial section steels is 525.77 KN, increased by 211.98 KN compared to the former, indicating that the latter can significantly enhance the horizontal resistance of the column.



(a) Traditional Reinforced Concrete Columns

(b) Reinforced Concrete Columns with Partial Section Steels

Fig. 8. Stress Nephogram of Reinforced Concrete Columns



(a) Traditional Reinforced Concrete Columns

(b) Reinforced Concrete Columns with Partial Section Steels

Fig. 9. Stress-displacement of Reinforced Concrete Columns

3 Construction Technology And Key Points of Prefabricated Column

Prefabricated column construction process: BIM-based joint reinforcement layout → embedment embedding at column bottom → pouring and curing of structural slab concrete → entry acceptance of prefabricated columns → hoisting preparation of prefabricated columns → positioning of prefabricated columns → flipping and hoisting of prefabricated columns → initial fixation of prefabricated columns → diagonal bracing installation and perpendicularity adjustment → section steel welding at column bottom shielded with CO_2 → binding by putting stirrup later → joint area mold sealing and bidirectional bellmouth reserving → concrete pouring and vibration in joint area → mold removing from column bottom and cleaning of bellmouth.

1. BIM-based Joint Reinforcement Layout

Based on the determined joint positions, a 3D model is created using the BIM software to deepen the design of the joints, conduct collision checks on the reinforcements at the joints, and simulate and analyze the dimension and position of the embedded steel plates at the column bottom based on the model.

2. Embedment Embedding at Column Bottom

(1) For prefabricated column control line layout, first are two control lines for left and right positioning, then one for front and rear positioning, enabling the component to be 1 m above the elevation. The elevation of the column joint should be verified with the left and right positioning control lines.

(2) The reinforcement installation and the layout of embedments should comply with the *Construction Operation Instructions* and *Operation Procedures,* confirmed by the self-inspector, who then fills out the *Work Order* with a signature before proceeding to the next process. The stacking of prefabricated columns and the embedded steel plates at the bottom of the cast-in-place floor slab are shown in Figure 10 and Figure 11, respectively.

Fig. 10. Stacking of Prefabricated Columns

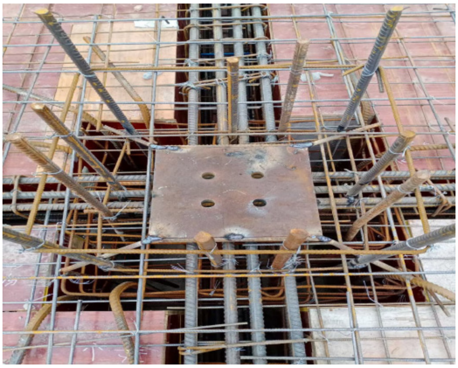


Fig. 11. Welding of Embedded Steel Plates at Column Bottom

3. Pouring and Curing of Structural Slab Concrete

After the formwork system, reinforcement binding, and embedments are completed and passed the acceptance of concealed works, the structural slab concrete is poured and cured according to standard requirements.

4. Entry Acceptance of Prefabricated Columns

According to the construction drawings, the dimension, quality, and quantity of the components and corresponding component numbers are checked, the prefabricated columns are checked for deviations in the embedded I-steels and reserved bellmouth, and details are recorded.

5. Hoisting Preparation of Prefabricated Columns

(1) Technical preparation: The concrete surface layer is clean, and the column position is marked; Quality inspection of prefabricated columns is required before hoisting; It is necessary to select an appropriate spreader according to the component form and weight and determine the number of hoisting points by the anchor number; The component weight and installation direction is confirmed, and the ceiling is prepared.

(2) Preparation of hoisting operators: Before hoisting the prefabricated components, the corresponding hoisting command operators are arranged, with each building or construction segment on the site no less than four operators.

(3) Preparation of hoisting tools and materials: Before hoisting, equipment required for installation, such as diagonal bracing, fixing irons for diagonal bracing, bolts, and

soft gaskets for the bottom of the prefabricated columns, are prepared, and a list of tools and materials are provided.

6. Positioning of Prefabricated Columns

The hoisting of prefabricated columns adopts a self-developed installation positioning and guide device for prefabricated concrete columns, which is composed of four bolted vertical plates, electric telescopic rods, telescopic supporting mechanisms, guide mechanisms, etc. The prefabricated column is clamped by extending the active plate with the electric telescopic rod. The prefabricated column perpendicularity is corrected by adjusting the length of the telescoping supporting mechanism. In the prefabricated column installation, color lamps are installed on the active base plate to facilitate the adjustment of the installation personnel.

7. Flipping and Hoisting of Prefabricated Columns

When the prefabricated column is flipped, two layers of 100 mm×100 mm laminated timbers are laid at the column bottom, with soft gaskets placed above it. The hoisting direction and sequence of the prefabricated column are according to the on-site crane position, ensuring the construction quality of the prefabricated column. The hoisting of prefabricated columns is shown in Figure 12.

8. Initial Fixation of Prefabricated Columns

The gasket is placed on the fixed part of the prefabricated column, with measurement done. Then the prefabricated column is placed on the gasket, and the diagonal bracing is fixed on the column and the floor slab embedment. Both sides of the column are provided with diagonal supports to fix the prefabricated column initially.

9. Diagonal Bracing Installation and Perpendicularity Adjustment

After the prefabricated column is hoisted, the diagonal bracing is fixed on the column and floor slab embedment in time. The diagonal bracing is set on both sides of the column, and the perpendicularity is adjusted through the adjustable diagonal bracing until the perpendicularity meets the requirements. The installation of diagonal bracing on the prefabricated column is shown in Figure 13.

Fig. 12. Prefabricated Column Hoisted in Place

Fig. 13. Setting up of Diagonal Bracing on Prefabricated Columns

10. Section Steel Welding at Column Bottom Shielded with CO_2

(1) Welding technology: The strength of the selected welding material and parent metal, and the material of the starting weld tab and run-off weld tab should be consistent with the parent metal to be welded; During welding, the welding continuity should be paid attention to, and the welding slag and spatter should be cleaned up in time; After the completion of welding, the starting weld tab and run-off weld tab is removed.

(2) Construction steps: The I-steel reserved at the column bottom and the embedded iron plate on the plate surface are welded on a single side, with a welding length not less than 12 times the diameter; The reserved I-steel at the column bottom and the embedded iron plate on the plate surface are fully welded on both sides. Subsequently, the connected reinforcements of the upper and lower layers are welded with carbon dioxide for the shield, ensuring that the I-steel and vertical stressed reinforcements at the column bottom are reinforced. The welding effect is shown in Figure 14.

Fig. 14. Welding Effect of Vertical Reinforcements

11. Binding by Putting Stirrup Later

In the installation of the prefabricated column in this project, the reinforcements protruding from the vertical column are welded, with the reinforcements protruding from the ground. The collision between the vertical reinforcements and the stirrup is solved by putting the stirrup later. The binding effect of the stirrup at the prefabricated column bottom is shown in Figure 15.

Fig. 15. Binding of Stirrups at Prefabricated Column Bottom

12. Joint Area Mold Sealing and Bidirectional Bellmouth Reserving

During the construction of this project, the position of various reinforcements and members should be strictly controlled. When setting up molds at the bottom joints of prefabricated columns, bidirectional bellmouth should be reserved symmetrically on both sides of the column for concrete pouring devices at joints. The mold installation for column bottom joints and reserved bellmouth are shown in Figure 16.

Fig. 16. Mold and Bellmouth Installation for Joint

13. Concrete pouring and Vibration in Joint Area

For areas with dense and overlapping reinforcements such as beam-column joints, symmetrical bellmouth are set up for pouring concrete into both sides of the column, while small vibrating rods are used to ensure the concrete compactness at the joints, followed by a self-inspector filling out the *Work Order* with a signature before proceeding to the next process.

14. Mold Removing from Column Bottom and Cleaning of Bellmouth

After the concrete pouring is completed and reaches the standard according to the temperature and the concrete curing condition, the device is removed, and excess concrete is leveled. The effect of the concrete column bottom after the mold was removed is shown in Figure 17.

Fig. 17. Effect of Concrete Column Bottom after Mold Removed

4 Construction Quality Control

4.1 Entry Acceptance of Prefabricated Column

1. When prefabricated columns enter the site, factory certificates, relevant quality certification documents, and performance testing reports should be provided, with factory identification clearly marked on the noticeable parts. The product quality should meet the requirements of the design and relevant standards.
2. The appearance of prefabricated columns should not have serious defects. The components with serious appearance defects should be returned to the component processing factory for processing, then reinspected and accepted before reentering the site. The appearance of prefabricated components should not have general defects. The components with general defects should be processed according to the technical treatment plan and reinspected and accepted.
3. Prefabricated columns should not have dimensional deviations that affect structural performance, installation, and use. Components with dimensional deviations should

be returned to the component processing factory for processing, then reinspected and accepted before reentering the site.

4. Rings, anchors, and embedded nuts should be reserved for prefabricated column hoisting. Welded and embedded I-steel embedment should be installed firmly without loose. The specifications, positions, and quantities of embedments, reinforcements, embedded I-steels, and reserved bellmouth on prefabricated columns should meet the design requirements.
5. The rough joint surface between prefabricated columns and post-poured concrete and grout should meet the design requirements.

4.2 Installation And Acceptance of Prefabricated Columns

1. The temporary fixation and support measures for the installation of prefabricated components should be effective, reliable, and in accordance with relevant technical standards and construction technical scheme requirements.
2. When prefabricated components are connected with reserved reinforcements anchorage, the variety, grade, specification, quantity, spacing, anchorage length, and strength and performance of the poured concrete should meet the design requirements.
3. The welding connection of prefabricated components should comply with design requirements and carbon dioxide shielding welding construction process standards. The surface of the weld seam should be free from defects such as cracks, weld flash, burn-through, and arc craters. The components shall be numbered and coded according to the requirements of the drawings and relevant regulations. The allowable deviation of weld leg dimension and surplus seam height should comply with the specifications.
4. After the installation of prefabricated components, the position, elevation, dimensional deviations, perpendicularity, and flatness of the components, as well as their inspection methods should comply with the specifications and design requirements. The inspection batch should be divided according to the floor, structural joint, or construction section. In the same inspection batch, 10% and no less than three components should be checked.

5 Conclusions

This paper established an ABAQUS model to study the stress performance of prefabricated reinforced concrete columns embedded with I-steel.Simulate the construction site through BIM technology to achieve accurate production and construction installation. Scientific research and development of devices to solve key technical problems such as positioning, hoisting, installation, welding, joint concrete pouring, and vibration during the assembly construction process of steel concrete joint prefabricated columns. This paper optimizes the hoisting process of prefabricated columns, which ensures the quality, saves the construction period, speeds up the image progress of the project, saves energy and protects the environment, and has obvious social, economic and environmental benefits and broad promotion and application value.

Acknowledgment

Fund Projects: School-level scientific research platform of Guangdong Polytechnic of Water Resources and Electric Engineering: Green Construction and Intelligent Detection Platform for Prefabricated Building (Project Number: XK202202)

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