HIGH-EFFICIENCY PRODUCTION TECHNOLOGY OF PREFABRICATED PRESTRESSED COMPOSITE BEAMS

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ABSTRACT: This paper proposes a construction technology for the precision control of the pedestal table and the overall tensioning method of the composite beam steel strand Given because of the critical technical issues, such as the deformation and cracking of the pedestal table during the prestressed composite beam production process, group tensioning, and control of steel bar slippage. Reinforcement fixing device research and development for node reinforcement arrangement and its technologies based on BIM simulation ensures efficient tensioning of prestressed superimposed beams and avoids reinforcement slippage.

KEY WORDS: Prestressed Composite Beam, Steel Reinforcement Fixing Device, Group Tensioning Method, BIM Technology

1. INTRODUCTION

With the adjustment of the national industrial structure and the promotion of green and energy-saving buildings in the construction industry in recent years, prefabricated buildings have received increased attention for their benefits of green, energy-saving, and efficient construction. The prestressed concrete composite beam is manufactured on an assembly line using prefabricated components combined with prestressing technology, which aids in the realization of construction industrialization [1].In my country, construction technology for prefabricated prestressed composite beams is still in its early stages, and construction efficiency is low. Some domestic scholars have researched these technical issues.

Li Lei et al. [2] investigated the steel slip effect in reinforced concrete structures and proposed a bilinear steel constitutive model that considers the slip effect. Lin Gaofeng [3] analyzed the performance of prefabricated concrete structures with superimposed friction-slip surfaces. Zheng Xiaolin, Ma Dongju, Yang Hui, Wu Jiangchuan [4-7], and others studied the seismic performance of prefabricated concrete beam-column joints. It was demonstrated through low-cycle repeated load tests that the seismic performance of prefabricated concrete beam-column joints was comparable to pouring in place. Jiejing [8] investigated the common problems encountered during the tensioning of steel strands and proposed using intelligent tensioning equipment to control the quality of tensioning construction throughout the process. Tang Diwei [9] and colleagues established a method for calculating the deflection of a concrete composite beam under the action of shrinkage and creep and demonstrated that the deflection was caused by inconsistent deformation of precast and cast-in-place concrete at the composite surface is primarily caused by inconsistent shrinkage. Cao Hai, Tang Yuxuan [10-11], and colleagues investigated the mechanical properties of precast and post-cast concrete bonded specimens under static and dynamic impact loads and proposed a new type of combined closed stirrups using finite element analysis. The simulation software ABAQUS is used, and the experimental results are validated. To summarize, the main research on prestressed concrete structures in China is focused on the post-tensioning method, with relatively few studies on the pre-tensioning method, particularly group tensioning.

2. PROJECT OVERVIEW

This article relies on the "Smart Park (Phase I) Project in a City" with a total construction area of 97682.38 square meters and a building height of 23.35m. The warehouse has two floors: the first is a reinforced concrete frame structure; the second is a portal steel frame light house steel structure. This project's prefabricated beams are made by the pretensioning method. Prefabricated beams are not supported during construction and are calculated in two stages. The concrete strength grade of the precast beam is not less than C40, the concrete strength grade of the cast-in-place laminated layer is C30~C40, the diameter of the steel strand is 15.2 mm^2, s, fptk=1860 N/mm^2, and the concrete strength of the prestressed beam is not less than 75% of the precast concrete strength grade. The steel strand's tension control stress and the concrete's tensile strength are within the design parameters. Unwinding should be done evenly, symmetrically, and gradually. If unwinding in batches is required, the steel strands in the area with the lowest pre-pressure should be released first.

Fig. 1. Construction drawing of a city smart park project's prestressed beam production site

3. TECHNICAL DIFFICULTIES AND SOLUTIONS

2.1. Technical Difficulties

The main technical problems in the on-site production process of the prefabricated prestressed composite beam in this project are: during the tensioning process of the composite beam, it is difficult to control the flatness of the tension table and the elevation control between the two pieces of concrete, and the table is deformed and cracked; The steel strand of the prefabricated composite beam slips and the position deviates, resulting in a prestressed beam quality defect. The feed-through jack tensions the steel strands one at a time, inefficient; the beam-column joints and the steel bars of the primary and secondary beam joints collide.

2.2. Solutions

There are four solutions:

• It is planned to solve the problem of tabletop deformation and cracks of the pedestal table during the tensioning process of the superimposed beam through the tabletop precision control technology.

- It is planned to develop a reinforcement fixing device to solve the position deviation of steel strands in prefabricated composite beams of the same type.

- It is proposed to use high-efficiency superimposed beam steel-stranding technology to ensure that steel strands of the same type of prefabricated superimposed beam have the same prestress value during the tensioning process or that the deviation value is within the allowable range.

- It is proposed to use BIM technology to simulate the reinforcement arrangement of primary and secondary beam joints to reduce collisions of beam-column joints and primary and secondary beam joints, find and solve them before site installation, reduce the amount of rework, and shorten construction time.

4. KEY TECHNOLOGIES

4.1. Construction Technology For Precision Control Of Tensioned Pedestal Surface

The precision control of the table is primarily used to control the table's flatness, elevation control between two pieces of concrete, and crack control. Using a laser levelling machine to set the elevation control points of the large-area pedestal surface, a receiving station scraper to monitor the elevation of the control points in real-time at a frequency of 10 times/s, and a vibration frequency of 4000 times/min to ensure the density of the concrete. The pedestal area is large, and the concrete must be poured in sections, and the elevations between the two concretes are inconsistent, increasing the height difference when subjected to force. For this reason, a special person is assigned to monitor the side elevation with a level. Once the concrete on the pedestal surface has reached the initial setting, use a laser leveller to control the elevation based on the elevation control points.

Fig. 2. Tensile pedestal and production line

4.1.1. Pedestal Construction Process

Pay-off positioning, pipe pile driving→Foundation pit excavation, grooved steel sheet piles→Pouring foundation pit cushion→Anchor column, bottom beam lofting→Bottom beam, anchor column, and top beam installation→Pouring foot beam concrete→backfill foundation pit→Binding countertop steel bars, pouring countertop concrete (reserved post-pouring tape in the middle)→Binding table head steel bars, installing anchor column diagonal braces→Attach the steel bars at the table head, install the anchor column diagonal braces, pour the concrete→ Pouring concrete in the tension zone.

4.1.2. Main Construction Technology

(1) Pay-out positioning and pipe pile driving: Pay out the foundation pit position line using the total station. When driving pipe piles, it is critical to verify the precision of the pile position, penetration depth, and verticality.

(2) Foundation pit excavation and grooved steel sheet piles: The foundation pit is excavated to a depth of 2m, and grooved steel sheet piles are drilled on the side away from the pipe piles. Excavate to the design elevation, level the ground, remove extra soil from the foundation pit, and double-check the height.

(3) Pouring the foundation pit cushion: After evenly placing the concrete on the foundation pit, draw a line based on the previously produced elevation mark, create a cushion height line around the foundation pit, and then manually level it to the cushion's design height. After checking that the cushion's elevation and flatness are correct, the surface of the concrete cushion must be polished to ensure the flatness of the cushion's surface for the installation of the anchor column's bottom beam.

(4) Anchor column and bottom beam stakeout: The bottom beam is staked out strictly according to the design size, with each anchor column's center line and the bottom beam's two sides pushed out. The bottom beam's edge extends beyond the length of the bottom beam to prevent the edge from getting covered during installation. After the staking is finished, double-check the elevation, size, and horizontal line.

(5) Bottom beam, anchor column, and top beam installation: vertically hoist the anchor column into the foundation pit, close to the bottom beam, and completely vertically, slowly push the side connecting channel steel into the first bottom beam's connecting bolt hole, insert the bolt into the connection hole, and tighten the nut. After bolting the first anchor column to the first bottom beam, bolt the second bottom beam to the first anchor column similarly, and so on. Make sure to be precise when installing the first sill beam. The connecting bolts of the bottom beam and the anchor column should not be tightened all at once to maintain a stable connection.

(6) Pouring the foundation beam concrete: Once all the bottom beams and anchor columns are linked, the top horizontal beams may be fitted, and the side beams are supported to cast the foundation beam concrete.

(7) Back**filling the foundation pit:** Layer the sand and compact it; the sand used for backfill should be coarse. Before sand filling in layers, a 120 mm thick hollow slab or a 20 mm steel plate should be set around the anchor column, with each layer 300 mm thick. After filling each layer of sand, it must be irrigated and moistened before compacting with an electric tamper.

(8) Pour the countertop cushion, bind the countertop steel mesh, and pour concrete: bind the countertop steel bars and pour concrete with accurate elevation control. Failure to finish the surface on time causes fissures in the concrete.

(9) Attach the steel bars at the table head, install the anchor column diagonal braces, and pour the concrete: The concrete surface layer must be levelled and calendared before being closed, tested, and restored as quickly as possible if it fails to meet the specifications. After the concrete has been calendared, it is covered and sprinkled with water. After the final set, a large amount of water can be sprinkled. In most circumstances, the healing duration takes no less than 7 days.

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(10) Pouring concrete in tension zone: The height difference and flatness of the floor in the tensioning region shall be kept within 3mm tolerances. The tensioning operation will be impeded if the height difference is too considerable. After pouring the floor concrete, it must be polished to ensure the surface is smooth and flat for the subsequent tensioning procedure.

4.1.3. Specific Measures For Tabletop Precision Control

(1) Setting table elevation control points: The on-site levelling control points are guided to the fixed position of the table construction work surface, a levelling route is measured and set, and the result of the adjustment calculation is used as the on-site table concrete construction elevation control point.

(2) Vibration and levelling of the laser levelling machine: Before construction, debug the laser levelling machine's base and hands, install the base in the middle of the construction site, secure it to the steel column, and then install the hands and hands. Align the device's bottom end with 0, position the pole stand vertically, and adjust the display device up and down until the reading is 0.00cm. Because of the large pedestal area, the 0 elevations at the same point shall prevail for each debugging to ensure that the elevations of the two adjacent concrete are consistent.

(3) Elevation re-measurement: When the concrete reaches the initial setting, use a laser leveller to control the elevation according to the elevation control points. The laser levelling instrument is controlled by a laser system composed of a laser transmitter, a laser receiver, and a levelling rod. First, an independent laser transmitter is installed. The laser transmitter emits laser light at a frequency of every 10 times/s to form a laser beam control Plane, and then sets up the levelling rod on the levelling control point of the ground design elevation, receives the laser beam through the levelling head on it, and finally adjust the laser receiver on the laser levelling machine; this controls the elevation of the receiver position.

(4) Water storage maintenance: On the second day after pouring, the water storage is 30mm-50mm high, and the maintenance length is no less than 7d. Simultaneously, a commissioner is appointed to test the ground's flatness, analyze the data, identify issues, and take appropriate action.

4.2. Reinforcement Fixing Device Construction Technology Research and Development

In this project, the steel strands cannot be fixed, and the steel bars slip during the tensioning process, which seriously affects the overall stress condition of the prestressed beams. In response to the above problems, the project has developed a steel bar fixing device to be used in the tensioning of steel strands to ensure that the position of the steel strands does not shift to the greatest extent possible during the tensioning process and to meet the overall stress of the prestressed prefabricated frame beams. Requirements improve installation efficiency and ensure the connection reliability of beam-column joints.

4.2.1. Installation Technique of Prestressed Beam Reinforcement Fixing Device

Construction preparation→Positioning and setting out→Steel strands and non-prestressed tendon skeletons production→Steel strand and non-prestressed steel skeleton installation→ Steel reinforcement fixing device installation.

4.2.2. Key Points of Prestressed Beam Reinforcement Fastening Device Installation

(1) Construction preparation:

(1) Clean up the residual mortar and broken concrete blocks on the pedestal and the bottom mould, paste the bottom mould leak-proof paste tape and apply the bottom mould release agent.

(2) According to the design drawings, the specifications and types of prefabricated beams are counted, the prefabricated beams of each specification are sampled, and the section size, length, number of prestressed ribs, tension control stress, embedded parts, and notch sizes of the prefabricated beams are clarified.

(3) According to the requirements of the ribbed floor and other formwork, set out the reserved holes for the supporting steel pipes on the prefabricated beams of various specifications.

(4) According to the specification and quantity of the pedestal production line, the construction schedule, and the pedestal flow construction requirements, each pedestal production line's prefabricated beam production plan shall be typeset, and the prefabricated beams shall be numbered according to the design drawings and production editions.

(5) According to the layout design of prefabricated beams, determine the product positioning of each beam on each production line.

(2) Positioning and setting out: The bottom form of each beam on the production line is positioned according to the construction layout drawing, and the steel strand support frame is placed between the beams, as shown in Fig. 3.

(3) Steel strands and non-prestressed tendon skeletons production: Steel strands and non-prestressed tendon skeletons are produced following the cutting size requirements of steel bars.

(4) Steel strand and non-prestressed steel skeleton installation:

(1) Brush a release agent layer on the table formwork for future demolding before laying prestressed steel bars. A cushion block must be placed in advance at the position of the prestressed steel bar to prevent contamination and prevent the steel bar from sagging and contacting the release agent, which will decrease cohesion.

(2) Place the trapped strand behind the pedestal in the strand installation cage. The hoist is used to pull the steel strand to finish wiring it, and the cutting machine is used to cut the end steel strand.

(3) Connect the steel strand and the finishing threaded steel with the wire rod connector and ensure a reliable connection between the anchor and the steel strand, as shown in Fig. 4. The anchor nut and the end anchor plate hold it to the pedestal anchor column.

Fig. 3. Strand support frame

Fig. 4. Pole connector

(4) Install the safety nut on the side of the anchor column's steel strand, the stirrups at the beam end, the bending steel bars, the mesh bars, the shear steel plates, the steel wire mesh at the bottom, the stirrups on the beams, and the pre-buried pipes in the hoisting holes, reserve the secondary beam shelving hole. Figures 5 and 6 depict the installation of steel bars and embedded parts.

Fig. 5. Steel bars installation

Fig. 6. Embedded parts installation

(5) Steel reinforcement fixing device installation:

(1) Accurately lay out each production line according to the construction layout. The actual beam pay-out size plus the size of the reinforcement fixtures at both ends of the beam, that is, "the design size of the beam + the thickness of the reinforcement fixtures at both ends = the size of the actual accurate pay-out beam".

(2) When the line is accurately laid out, subtract the distance between the beam and the beam from the thickness of the head plate added by the previous one.

(3) A recheck should be performed after the pay-out, and the top and bottom rows of steel strands should be used to mark the outside of the reinforcement fixing device with a square ruler to ensure that the pay-out is accurate.

(4) Install the reinforcing steel fixing device positioning card and the reinforcing steel fixing device according to the punctuation on the steel strand, as shown in Fig. 7.

Fig. 7. Steel reinforcement fixing device installation

4.3. High-Efficiency Tensioning Construction Technology of Prestressed Prefabricated Composite Beam Steel Strands

The prestress adjustment must follow the design drawings after fitting the steel strand. Use the through-core jack to apply small tension to the steel strands one at a time until they all achieve the required beginning stress value. Using jacks, all threads are then tensioned at the same time. Compared to typical small-scale tensioning, individual and group tensioning can tension more than ten beams simultaneously, reducing the need for multiple tensioning processes. Furthermore, flow construction can be adopted between multiple manufacturing lines, saving time and ensuring the main structure's hoisting construction.

4.3.1. Adjustment of Initial Stress by a Bundle-By-Beam Small Tension

Through the small sheet of the steel strand, check that the steel strand is installed correctly, that the wire rod connector connection between the steel strand and the rebar is reliable, and that the connection between the anchor and the steel strand is reliable by the wire rod connector so that each steel wire is connected reliably. The strands are all straight and pulled to the specified beginning stress. Manually tighten the wire with a wire tensioner, then install the jack support beam, jack, and movable anchor beam in sequence to ensure that the jacks are arranged horizontally. Check whether the steel strand anchor piece slips, the anchor ring is cracked, and the steel strand is displaced.

4.3.2. Integral Tension Method Tensioned Steel Strand

Check the working range of the upper and lower jacks with a spirit level before overall tensioning the steel strand and adjust the initial stress in advance to make the stress consistent. During the tensioning process, check the prestress value randomly so that the deviation should not be greater than or less than 5% of the total prestressed value of all steel strands of a member. Tension adopts the double control method of controlling stress and checking elongation. After tensioning one by one, the jack is used for overall tensioning after the steel strands are all in the specified initial stress state.

The overall tensioning process of the jack is the process by which the stress exerted on the prestressed steel bar gradually approaches the maximum control stress from zero, as shown in Figure 9. In practical engineering, hypertension is frequently used to compensate for stress loss. The prestressed tendon should apply a load for more than 2 minutes during overstretching to offset as much as possible the stress loss of the steel bar due to its toughness, ensuring that the final stress of the steel bar when the deformation is completed in the natural state after the load is removed. The value meets the design requirements. Alternatively, apply 103% of the typical control stress to the prestressed steel bar at once, leaving a 3% stress loss zone. The over-tension control stress cannot be more than the yield strength of the steel bar itself when utilizing the over-tension method to minimize stress fatigue on the steel bar.

Fig. 8. One-by-one steel strands of the feed-through jack

Fig. 9. Overall tensioning of the push jack

4.4. BIM-Based Simulation of Primary and Secondary Beam Joint Reinforcement Arrangement

Prefabricated building components have high precision requirements. If the precision is not accurate, especially in complex parts such as primary and secondary beam joints, beam-column joints, etc., the problem of steel bar collision will not only fail to install on-site but also lead to the possibility of the entire batch of components. Scrap directly affects the construction progress and cost. Based on BIM technology, this project performs in-depth design of primary and secondary beam joints, pre-arranges steel bars, simulates the construction and hoisting process, and detects the problem of collision between beam-column nodes, primary and secondary beam nodes, and laminated plate nodes in advance, reducing the on-site construction workload. The construction period is guaranteed.

4.4.1. Construction Process of Reinforcement Arrangement

Node Detailing Model Creation→Collision detection→Determine the reinforcement arrangement at the nodes→Adjusting the Detailing Model→Determine the final reinforcement arrangement and optimize the construction drawings→Node construction.

4.4.2. Key points of Reinforcement Arrangement Operation

In this project, before the production of prestressed composite beams in this project, the BIM model of 4D steel bars at the primary and secondary beam nodes was established using Revit software, the steel bars at the nodes were arranged, collision points were identified, and the spatial position of the steel bars was adjusted over time. Determine the best construction sequence for component installation with Mark. Use BIM technology to deepen prefabricated components, reduce errors and omissions, optimize the construction process, and realize 3D roaming and visualization models to solve potential construction problems and reduce rework.

(1) Node BIM model creation. According to the drawings, determine the nodes where the primary and secondary beams are handed over, use BIM software to create a detailed design model of the nodes, and arrange the reinforcing bars of the nodes reasonably according to the construction specifications, as shown in Fig. 11.

(2) Collision detection. The node is checked for a collision based on the completed BIM detailed design model, and the content of the check includes the name, type, material, collision position, and object quantity. Collision entities are highlighted in the model, making it simple to locate the collision points that affect the actual construction and generate the collision report.

(3) Determine the reinforcement arrangement at the nodes. Display the rebar arrangement at the node in a plan view, directly modify the type, specification, connection method, and position of the rebar, the thickness of the reinforcement cover at the beam end, the length of the reinforcement bending anchor, and other rebar cutting parameters, and the software will automatically lock the modified rebar. The optimization of the reinforcement arrangement is realized through the adjustment of the relevant parameters of the reinforcement arrangement, and the goal of meeting the design documents and facilitating construction is achieved.

(4) Adjust the design model to generate the construction model. The BIM detailed design model of the node is further adjusted to reach the optimal state and create the construction model based on the reinforcement arrangement diagram at the node and the result of the collision detection.

(5) Complete node construction. According to the model, after solving the collision problem, determining the arrangement sequence and position of the steel bars, and optimizing the construction drawings, the node construction is carried out in the actual situation of the site, and the construction process is strictly controlled to ensure the quality and structural safety of the nodes.

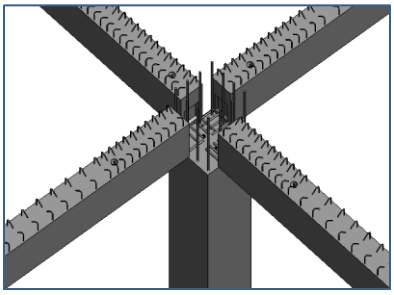

Fig. 11. Reinforcement arrangement at BIM technology nodes

5. CONCLUSION

This project employs the tension pedestal table's precision control construction technology, as well as the construction technology of the reinforcement fixing device and the efficient tension construction technology of the prestressed superimposed beam steel strand. The reinforcement arrangement of the primary and secondary beam nodes is simulated using BIM technology, which effectively reduces the table size. Cracks ensure steel strand fixation, anti-slip and efficient tensioning, pre-emptive collision of the joint steel bars, and improved prestressed composite beam production efficiency. The technology has been applied to many projects, and practice has proved that significant benefits have been achieved in the production technology and management of prestressed composite beams, ensuring prestressed beam construction quality and shortening the production period. This process is good for education and training [12].

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REFERENCES

[1] Yu Chun, Zhu Guozheng, Pang Tao. Production technology of prestressed pre-tensioned prefabricated prestressed composite beams [C]//Proceedings of the 2020 National Civil Engineering Construction Technology Exchange Conference (Volume 2), 2020:447- 450. DOI:10.26914/c.cnkihy.2020.057929.

[2] Li Lei, Wang Zhuohan, Zhang Yixin, Zheng Shansuo. Research on Constitutive Model of Steel Reinforcement Considering Slip Effect in Concrete Structures [J]. Engineering Mechanics, 2020,37(03):88-97.

[3] Lin Gaofeng. Performance and analysis method of prefabricated concrete structures considering friction and slip of superimposed surfaces [D]. Zhejiang University, 2015.

[4] Zheng Xiaolin. Seismic performance of improved integral post-cast prefabricated concrete beam-column joints [D]. Wuhan University of Technology, 2019.

[5] Ma Dongju. Seismic analysis of cast-in-place beam-column joints of fabricated monolithic frame structures [D]. Changsha University of Science and Technology, 2017.

[6] Yang Hui, Guo Zhengxing, Xu Aoyi, Guan Dongzhi, Feng Jiansen. Seismic test research on beam-column joints of locally post-tensioned prestressed concrete frame [J]. Journal of Southeast University (Natural Science Edition), 2019,49(06) :1101-1108.

[7] Wu Jiang Chuan. Research on the seismic performance of a new type of prefabricated prestressed beam assembled monolithic frame [D]. Southeast University, 2018.

[8] Jie Jing. Prestressed tension control and detection technology of concrete beams [J]. Construction Mechanization, 2019, 40(03): 40-42.

[9] Tang Diwei, Jin Weiliang, Mao Jianghong, Zhao Yuxi, Dialect. Effects of Shrinkage and Creep on the Deflection of Prefabricated Concrete Composite Beams [J]. Chinese and English Journal of Civil and Environmental Engineering, 2019,41(06):127 -134.

[10] Cao Hai. Experimental study on mechanical properties of prefabricated concrete bonding surface and composite beam[D]. Anhui University of Science and Technology, 2018.

[11] Tang Yuxuan. Research on mechanical properties of a new type of fabricated concrete beam-slab structure system [D]. South China University of Technology, 2017.

[12] Wortley, D. J., Lai, P. C., (2017) The Impact of Disruptive Enabling Technologies on Creative Education, 3rd International Conference on Creative Education, Mar 3-4.