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Research on the Construction Technology of Inverted Formwork Support for Ultra-Thick Factory Cast-in-place Floor Slabs

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Abstract: *This paper thoroughly investigates the application and technical details of inverted formwork support systems in the construction of ultra-thick factory cast-in-place floor slabs. Targeting construction challenges posed by large equipment size, wide room spans, and heavy floor slab loads, the inverted formwork support system presents significant advantages due to its efficiency, flexibility, and stability. This system integrates a portal frame constructed from double-channel steel and steel beams mounted on wall corbels, forming an innovative support structure, further reinforced by the design of central columns. The paper elaborates on the process, including key steps such as positioning and alignment, installation of wall embedded parts, steel corbel and inverted formwork beam-column installation, high-strength tie rod installation, and the dismantling of the support frame, offering valuable insights and guidance for the relevant field.*

Keywords: *Ultra-Thick Factory; Cast-in-Place Floor Slab; Inverted Formwork Support; Construction Technology; Stability*

1. Introduction

In In the modern construction industry, the construction of cast-in-place floor slabs in ultra-thick industrial buildings faces numerous technical challenges due to their unique structural and functional requirements [1-3]. Especially in scenarios where equipment sizes are large, room spans are wide, and floor slab loads are heavy, traditional floor slab construction methods often prove inadequate. To overcome these challenges, the inverted formwork support system construction technology has emerged, exhibiting significant advantages in terms of efficiency, flexibility, and stability in the construction of floor slabs in ultra-thick industrial buildings [4].

The inverted formwork support system ingeniously combines portal frames constructed from double-channel steel with steel beams securely placed on wall steel corbels, creating an innovative support structure [5]. When dealing with larger room spans, the technology further enhances the stability of the entire support system by introducing central columns. These columns penetrate through the floor slab and are firmly established on the ground level of the underlying structure. With this layout, each portal frame is arranged in a predetermined sequence and securely connected to the wooden members beneath the floor slab through high-strength tie rods, forming a solid and reliable inverted formwork support system [6-7].

The objective of this paper is to delve into and extensively study various aspects of the inverted formwork support construction technology for cast-in-place floor slabs in ultra-thick industrial buildings. This includes technical details, implementation procedures, practical application effects in real-world projects, and potential areas for optimization. Through a systematic analysis of the components and key construction points of this technology, this paper aims to provide valuable references and guidance for practitioners in related fields, hoping to promote the wider application and development of this technology.

2. Process Characteristics

The process of inverted formwork support construction demonstrates unique characteristics in the construction of cast-in-place floor slabs for ultra-thick industrial buildings. Centered on double-slot steel-processed portal steel frames, this technique cleverly utilizes the combination of steel beams and steel corbels to construct a stable and efficient construction support system. When faced with the challenge of large-span rooms, the inclusion of central columns becomes crucial in enhancing the stability of the support system. These columns are firmly established on the underlying structure's ground, ensuring the overall robustness and reliability of the support system.

This process emphasizes precision and efficiency. Through careful positioning and setting out, every pre-embedded part, steel corbel, and steel beam is precisely installed in its designated location, laying the foundation for the smooth progress of subsequent operations. Furthermore, the utilization of high-strength tie rods enhances the overall stability of the construction system, guaranteeing the safety of the construction process.

3. Process Principles

The principles underlying the inverted formwork support construction technique are a perfect blend of mechanical principles, materials science, and construction technology. Firstly, from a mechanical perspective, this technique achieves balanced stress distribution and stable support during construction through precise structural design and force analysis. The selection and layout of key components such as steel corbels, steel beams, and high-strength tie rods follow mechanical principles, ensuring the stability and reliability of the support system.

In terms of materials science, this process employs high-strength and high-toughness steel as the primary load-bearing components, effectively elevating the bearing capacity of the support system. Simultaneously, advanced welding techniques and materials guarantee the robust and reliable connections between steel components. Additionally, post-installation operations such as the embedding of expansion bolts enhance the integrity and stability of the structure.

From a construction technology perspective, this process emphasizes precision and continuity. Accurate measurement and positioning techniques ensure that every component is installed precisely in its intended location. Scientific construction organization and management guarantee the continuity and stability of the construction process. Furthermore, the introduction of advanced construction techniques and equipment, such as liquid penetration testing, provides robust assurances for the reliability of construction quality.

In summary, the principles underlying the inverted formwork support construction technique are the intertwining and coordination of mechanical principles, materials science, and construction technology. The application of these principles ensures the efficiency, stability, precision, and safety of the construction process, providing solid technical support for the construction of cast-in-place floor slabs in ultra-thick industrial buildings.

4. Construction Process and Technical Requirements

The inverted formwork support system ingeniously combines a portal frame made from double-channel steel with steel beams firmly placed on wall-mounted steel corbels, creating an innovative support structure. When facing large room spans, the introduction of central columns to enhance the stability of the entire support system becomes a necessary measure. These columns, passing through the floor slab and firmly standing on the lower structure's ground, ensure the robustness of the entire support system. The portal frames are arranged in a predetermined sequence and connected to the lower part of the floor slab through high-strength tie rods, forming a solid and reliable inverted formwork support system.

4.1. Process Flow

The overall process includes: positioning and alignment → installation of wall embedded parts → steel corbel installation → inverted formwork beam and column installation → high-strength tie rod installation → installation of primary and secondary purlins, plywood laying → dismantling of the support frame.

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4.2. Positioning and Alignment

In the preparatory phase of construction, to ensure precise installation of components, the positioning axis and installation elevation control lines of the embedded parts are accurately laid out according to the construction plan. These control lines serve as crucial references for subsequent construction, ensuring the accuracy of the embedded parts' placement. Moreover, the axis lines and installation elevation control lines for beams, columns, and steel corbels, crucial for the overall stability and load-bearing capacity of the structure, are precisely laid out. Additionally, the position axis lines for the steel beams must be clearly marked to ensure their accurate alignment during installation. The elevation control lines for the plywood and primary and secondary purlins are also marked on the surrounding walls, providing accurate positioning for the installation of wall decoration materials.

4.3. Installation of Wall Embedded Parts

Before the concrete wall casting, specific steel plate embedded parts are installed to provide a base for subsequent welding operations of the steel corbels. The selection of these steel plate embedded parts must consider their shear resistance capacity, ensuring compliance with construction safety and stability requirements. The choice of embedded parts should be based on the "Embedded Parts Standard Diagram" to determine the appropriate type to meet the overall project needs. For the base of the central columns, they should be placed on top of the raft plate and reinforced with steel plates of specific thickness. Additionally, post-installed anchor bolts are used to ensure the solidity of the central columns.

The corbels are made from specified profile steel, and their length must not be less than the minimum size stipulated. First, the positioning axis of the corbels is marked on the wall embedded parts, with the deviation of the axis position controlled within a certain range. A certain proportion of the welding parts requires layered liquid penetrant testing (secondary welds), while other welds are performed according to the third-level standards, following GB50661. Internal stiffeners are set on the corbels, and steel pads of specific sizes are installed on the top of the corbels and welded to the embedded parts.

4.4. Steel Corbel Installation

Corbels made from specified profile steel are used, with their length meeting the minimum required size. The positioning axis of the corbels is first marked on the wall embedded parts, with the axis position deviation kept within a specific range. Part of the welding requires layered liquid penetrant testing (secondary welds), while other welds follow third-level standards as per GB50661. Stiffeners are placed inside the corbels, and steel pads of specific sizes are installed on the top and welded to the embedded parts (see Figure 1).

Figure 1: Steel Corbel Installation

4.5. Inverted Formwork Beam and Column Installation

In steel structure construction, steel beams are composed of channel steel back-to-back with a certain spacing to facilitate the passage of high-strength bolts. The steel columns are not less than a certain

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specification and are arranged with flanges adjacent, also maintaining a certain spacing. Rib plates set on the flanges connect the two channel steels, with the specifications and spacing of these rib plates carefully designed to ensure the stability and strength of the structure. Each beam-column connection point has at least two such rib plates.

Before installing the steel columns, lifting lugs made from specific diameter round steel are welded on the upper end of the column's web. The processing form of the lifting lugs and their welding length to the steel column must meet construction requirements. When installing the central columns, they are hoisted to the predetermined position above the base embedded parts, and after stabilization, the embedded bolts are inserted. By adjusting the bolts, fine-tuning of the central columns is achieved, ensuring the error in the elevation between the top of the column and the steel plate surfaces on both ends of the corbels is minimal. After adjustment, the bolts are tightened and the steel column secured. During this period, the lifting points must not be removed, and the steel columns should be securely fixed on the operation frame using scaffolding steel pipes and clamps. Only after tightening the nuts and ensuring the stability of the steel columns can the lifting points be removed. Finally, after confirming the position, elevation, and verticality of the steel columns are correct, angle steel and steel plates are welded on the side of the column base to further enhance the structure's stability.

During the installation of the steel beams, tower cranes with slings are used for hoisting operations. The lifting points are set at a certain proportion of the beam length from the beam ends, and lifting lugs, similar in form to those on the steel columns, are welded on the upper flanges of the double-channel steels. For safety, the beams and columns are initially lifted a short distance off the ground, kept stable and motionless to confirm the firmness of the lifting points and the balance of the steel beams, and then lifting, luffing, slewing, and hook lowering actions are observed for any abnormalities before proceeding. During hoisting, safety ropes are set at the ends of the steel beams, with designated personnel controlling them to prevent collisions with walls, rebars, and other components. When the steel beams are hoisted close to the installation position, the descent is paused, the positioning axis carefully observed, and then the beams are manually assisted into place. After positioning, fine-tuning is carried out according to the axis, and the beams are spot-welded to the steel corbels to ensure stability before the lifting hooks are removed.

During the connection and installation process between the steel beams and central columns, each steel column and beam are hoisted one by one and bolted together firmly. Subsequently, adjacent steel columns and beams are connected into a whole using steel rebars of a certain diameter, enhancing the stability of the entire system. The transverse spacing of the connecting rebars is also carefully designed. To facilitate the subsequent removal of the steel columns, secondary casting openings are reserved at the positions where the central columns pass through the floor slabs, with the main reinforcement of the slab broken and mechanical joints left, positioned at a certain distance from the rib plates of the steel columns (see Figure 2).

Figure 2: Installation of Steel Beam to Steel Corbel Connection

4.6. High-Strength Tie Rod Installation

After the installation of the inverted formwork beams and columns, high-strength tie rods are inserted in the middle of the steel beams. The upper part of the tie rods is connected to specific double three-claw nuts and washers, while the lower part uses steel plates of specific sizes with double three-claw nuts, and a round hole is opened in the middle of the steel plates. Next, according to the elevation of the floor slab, the position of the three-claw nuts is adjusted. Finally, the main purlins are installed, with each set including two, placed at both ends of the high-strength tie rods and tied with wire at regular intervals. If

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the tie rods conflict with the position of the embedded parts, their position can be adjusted appropriately, but the adjustment range should be within certain limits. If the size of the embedded parts is too large, tie rods can be set on both sides of them (see Figure 3).

Figure 3: High-Strength Tie Rod Installation

4.7. Installation of Primary and Secondary Purlins, Plywood Laying

In laying out the primary and secondary purlins, they are arranged from high to low according to the sequence of construction sections. The primary purlins are set up using wooden beams of specific dimensions, arranged in pairs, with spacing and overhang length meeting the requirements. The secondary purlins, made of smaller-sized wooden beams, are laid out perpendicular to the direction of the primary purlins, with their spacing and overhang length also controlled within specified ranges. Both primary and secondary purlins, as well as the plywood, are laid from one side of the slab to the other. All joints in the primary and secondary purlins must be set on adjustable supports or pads, ensuring that the joints are staggered to avoid concentrated stress at weak points.

During the plywood laying, plywood of specific thickness is cut and laid as the bottom formwork, fixed to the secondary purlins with steel nails at consistent intervals. At the joints, an additional secondary purlin is added to enhance the structural stability. When installing the plywood, holes are drilled at the positions of the tie rods to facilitate the subsequent installation of high-strength tie rods and other components. The joints of the formwork should be tightly sealed to prevent leakage of slurry during concrete pouring.

4.8. Dismantling of the Support Frame

In the dismantling process, strict adherence to the "Concrete Structure Construction Specification" is maintained. The dismantling of the bottom formwork can only proceed once the concrete strength reaches a certain standard. Specifically, when the span of the slab exceeds a certain threshold, the concrete strength must fully meet the design requirements, i.e., 100% strength, before the bottom formwork can be dismantled; for shorter spans, the concrete strength must also reach at least 75% of the design strength to meet the safety requirements for dismantling.

Based on these specifications, a rigorous dismantling sequence is established: firstly, the high-strength tie rods are removed to release the main support; then the beam-column connection nodes are dismantled to further release structural stress; followed by the removal of plywood and purlins, gradually reducing the load on the floor slab; subsequently, the steel corbels are cut to completely separate the support structure; and finally, the central columns are dismantled and materials transported away.

In terms of dismantling methods, a step-by-step, area-by-area strategy is adopted. For the upper part of the floor slab, key components on the upper part of the steel beams, such as the three-claw nuts and washers, are first removed, the high-strength tie rods are cut with a professional cutting machine, the connecting bolts between beams and columns are removed, and the steel corbels are cut along the surface of the embedded parts, with the waste material immediately removed from the site. For the lower part of the floor slab, the bottom nuts are loosened first, the primary and secondary purlins and plywood are removed and transported away, and then the remaining high-strength tie rods are cut. When dismantling the central columns, they are first cut and separated from the ground embedded parts, carefully hoisted out with a tower crane, and the floor slab openings are promptly sealed to ensure site safety.

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5. Conclusion

With the continuous progress and development of the construction industry, the challenges faced in the construction of ultra-thick factory cast-in-place floor slabs are increasing. Against this backdrop, the inverted formwork support system, with its unique advantages, provides a strong guarantee for stability, efficiency, and safety during the construction process. This paper, by deeply analyzing the technical details, implementation process, and application effects in actual engineering of this technology, aims to provide valuable references and guidance for practitioners in the relevant field. However, there is always room for continuous optimization and improvement in any technology, and the same applies to the inverted formwork support system. Future research and practice can further explore its adaptability in different scenarios, innovation and optimization of structural materials, and in-depth application of mechanical principles, contributing more to the broader application and sustained development of this technology. It is hoped that the research findings of this paper will contribute to the advancement of the construction industry, jointly pushing construction technology to new heights.

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