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Analysis of Construction Technology Challenges and Countermeasures for Supertall Buildings

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Abstract: Supertall buildings are characterized by significant structural height, extended construction periods, and intensive multi-process cross-operation activities. The complexity of construction technologies increases nonlinearly with building height, making supertall buildings among the most challenging engineering projects in the construction industry. This paper systematically analyzes five major technical challenges in supertall building construction, including ultra-high-performance concrete pumping, core tube construction and hydraulic climbing formwork systems, high-altitude steel structure installation, vertical transportation systems, and tower crane selection and arrangement. Drawing upon engineering practices from projects such as Xiamen Egret West Tower and the Landmark Tower of Westlake University, targeted technical solutions are proposed from the perspectives of concrete mix optimization, synchronized staggered construction of core tubes and external frames, segmented lifting of steel structures, and coordinated scheduling of vertical transportation systems. The study aims to provide references for construction organization and technical scheme selection in supertall building projects.

Keywords: Supertall Buildings; Construction Technology Challenges; Countermeasure Analysis; Steel Structure Installation

Introduction

Supertall buildings are a product of rapid urbanization and intensive land utilization. China ranks among the world's leading countries in both the number and height of supertall buildings. Unlike conventional high-rise buildings, the construction of supertall structures involves multiple specialized technical fields, including long-distance pumping of ultra-high-performance concrete, synchronized climbing of core tubes and external structures, high-altitude installation of heavy steel components, and coordination of multi-level vertical transportation systems. Deviations in any of these processes may result in project delays or even quality and safety incidents. Based on the structural characteristics of supertall buildings, this paper systematically reviews five major construction technology challenges and proposes corresponding technical countermeasures, with the objective of providing practical references for similar engineering projects.

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1. Structural Characteristics and Construction Particularities of Supertall Buildings

1.1 Classification of Structural Systems

The structural systems of supertall buildings have continuously evolved with increasing building height. At present, the mainstream structural forms include frame–core tube structures, steel–concrete composite structures, tube-in-tube structures, and mega-frame structures. Among these, the frame–core tube system is the most widely adopted. It consists of an inner reinforced concrete core tube and outer steel–concrete composite mega-columns, which are connected through outrigger trusses to form a dual lateral force-resisting system. As building heights exceed 300 meters, a "triple lateral force-resisting system" composed of mega-columns, a core tube, and outrigger trusses has gradually become the dominant structural solution. Supertall projects such as CITIC Tower in Beijing and Ping An Finance Centre in Shenzhen have adopted this structural system. The cross-sectional area of their mega-columns can exceed 60 m^2, with multiple internal cavities that result in highly complex structural configurations.

1.2 The "Four Highs and One Multiple" Characteristics of Supertall Building Construction

The technical complexity of supertall building construction stems from its distinctive characteristics, commonly summarized as the "Four Highs and One Multiple."

High Elevation. The vertical transportation distance for construction materials is extremely long, and the pumping pressure required for concrete increases nonlinearly with building height. In the Xiamen Egret West Tower project, the concrete pumping height reached 240.4 m, requiring a 28 MPa ultra-high-pressure pumping system to achieve "single-pump delivery to the top."

High Structural Complexity. The increasing use of special structural components, such as multi-cavity mega-columns and outrigger trusses, results in intricate node configurations. Steel–concrete composite shear walls, characterized by heavy components and irregular geometries, present significant challenges in steel plate assembly and welding operations.

High Precision Requirements. Structural verticality deviations must generally be controlled within H/3000, imposing stringent requirements on surveying accuracy, positioning control, and installation precision throughout the construction process.

High Degree of Concurrent Operations. During the synchronized construction of the core tube and external frame structure, multiple construction processes and professional disciplines must operate simultaneously, creating substantial coordination challenges.

Multiple Site Constraints. Supertall building projects located in urban core areas are often restricted by limited construction space and difficulties in coordinating temporal and spatial resources with surrounding buildings and infrastructure [1].

2. Analysis of Construction Technology Challenges in Supertall Buildings

2.1 Pumping of Ultra-High-Performance Concrete

Concrete pumping in supertall buildings represents one of the most challenging aspects of construction. As building height increases, concrete must maintain adequate workability, homogeneity, and fluidity throughout long-distance transportation, while the required pumping pressure rises substantially. The industry currently faces two major challenges.

First, the shortage of natural river sand resources has accelerated the adoption of manufactured sand as the primary aggregate material. However, manufactured sand typically contains a higher proportion of stone powder and exhibits more angular particle shapes, which adversely affect the flowability and spreadability of concrete. Second, ultra-high-strength concrete possesses significantly higher viscosity, resulting in extremely high pumping resistance. The pumping difficulty of C130 ultra-high-strength manufactured-sand concrete is considerably greater than that of conventional concrete.

Traditional multi-stage relay pumping methods are associated with high costs, low efficiency, and increased risks of pipeline blockage and bursting. Furthermore, the placement of mass concrete must proceed continuously without interruption. If the lower layer begins to set before the subsequent layer is placed, cold joints may form, thereby compromising the structural integrity and long-term durability of the building.

2.2 Core Tube Construction and Hydraulic Climbing Formwork Technology

The core tube serves as the primary vertical load-bearing and lateral force-resisting component of a supertall building. Its construction progress often determines the overall project schedule. Core tube construction faces two principal challenges.

First, under conditions of extremely limited floor area, the installation space for formwork and support systems becomes highly constrained, making material turnover and construction operations difficult. Consequently, traditional floor-by-floor construction methods often result in slow progress and extended project durations. Second, the presence of irregular structural features, such as setbacks in core tube walls and numerous cantilevered corbels, complicates the control of formwork positioning accuracy and platform stability. Although hydraulic climbing formwork systems have been widely adopted in supertall building construction, they continue to encounter difficulties when dealing with complex and continuously changing cross-sectional configurations. Common issues include lengthy climbing cycles and insufficient positioning accuracy after climbing operations. In addition, inadequate control of the elevation difference between the core tube and the external frame structure may adversely affect the connection quality of outrigger trusses, thereby posing risks to the overall structural safety and performance of the building.

2.3 High-Altitude Steel Structure Installation

Supertall buildings extensively employ steel–concrete composite structural systems, making high-altitude steel structure installation one of the most hazardous and technically demanding construction activities. The primary challenges can be summarized as follows.

First, structural components are often extremely heavy and geometrically irregular. In particular, the assembly and welding of steel plates used in embedded steel plate–concrete composite shear walls present considerable technical difficulties. Second, special structural elements, such as large cantilevered transfer steel trusses, exhibit significant differences between their actual construction-stage stress conditions and their final design-state behavior when installed at high elevations. Consequently, comprehensive construction-stage simulations and real-time monitoring throughout the installation process are required.

Third, wind loads become increasingly significant as building height increases. The limited duration of safe weather windows for lifting operations substantially increases construction complexity. As a result, exceptionally high standards are imposed on lifting accuracy, operational control, and the technical competence of construction personnel [2].

2.4 Vertical Transportation Systems

Vertical transportation serves as the “lifeline” of supertall building construction and is often the most critical bottleneck affecting project progress. Construction personnel and materials must be transported to elevations of several hundred meters through construction elevators, tower cranes, and other lifting equipment. However, transportation efficiency declines sharply as building height increases. During the synchronized upward construction of the core tube and external frame structure, competition for vertical transportation resources among different trades becomes particularly intense. Construction elevators often require segmented installation and operation, making transfer organization increasingly complex. At the same time, tower crane lifting schedules must be precisely coordinated with concrete pouring operations and steel structure installation activities to maintain overall construction efficiency. The application of Building Information Modeling (BIM) technology has created opportunities for intelligent scheduling and optimization of tower cranes and construction elevators. Nevertheless, practical implementation still faces challenges related to data integration, information interoperability, and the dynamic optimization of transportation resources.

2.5 Selection and Arrangement of Tower Cranes for Supertall Buildings

Tower cranes are the most important lifting equipment used in supertall building construction, and their selection and arrangement directly affect project efficiency and operational safety. Several key challenges are involved in this process.

First, the foundation reinforcement of internal climbing tower cranes, as well as the coordination between crane climbing sequences and the progress of the main structural works, require extremely precise planning and execution. Second, significant interaction exists between tower cranes and the core tube structure. The crane support system must climb synchronously with the core tube, while the design of connection nodes between support beams and shear walls is highly complex and demands rigorous engineering analysis. Third, a fundamental conflict often exists between crane coverage radius and lifting capacity. Supertall building projects typically involve large structural components and extensive operating radii, making it difficult for a single tower crane to satisfy all lifting requirements. Although multiple cranes can be deployed to address this issue, coordinated operations introduce the risk of crane interference and collision. Furthermore, the limited construction space commonly encountered in urban central business districts significantly restricts crane placement options, thereby increasing the complexity of tower crane layout design and management.

3. Key Technical Countermeasures

3.1 Countermeasures for Concrete Pumping

Addressing the challenges of concrete pumping in supertall buildings requires a coordinated approach encompassing three aspects: mix design, equipment selection, and pipeline arrangement.

Mix design serves as the fundamental solution. Given the high stone powder content and angular particle characteristics of manufactured sand, aggregates should be carefully selected and homogenized before use. Systematic adaptability tests should be conducted based on workability, strength, and durability requirements to determine the optimal types and dosages of mineral admixtures. The objective is to ensure adequate pumping performance while simultaneously satisfying strength and durability specifications.

In the Xiamen Egret West Tower project, dozens of rounds of mix proportion optimization were carried out, resulting in the successful development of a C60 self-compacting concrete mixture with a water-to-binder ratio of 0.29 and a sand ratio of 45%. This mix design not only satisfied the requirements for high strength and durability but also maintained excellent flowability and homogeneity under ultra-high pumping conditions.

Equipment selection is critical for ensuring reliable pumping operations. Pumping system parameters should be determined through repeated calculations of pumping pressure requirements. Dual-power ultra-high-pressure pumps, such as 28 MPa-class pumping systems, should be adopted to achieve “single-pump delivery to the top,” thereby avoiding the high costs, operational inefficiencies, and elevated blockage risks associated with traditional multi-stage relay pumping methods.

Pipeline arrangement is another key factor. Horizontal pipelines should be installed around the core tube to mitigate the static pressure generated by the self-weight of concrete within vertical pipelines. In addition, dedicated embedded pipe-clamping devices should be designed and installed at pumping and placing levels to control severe pipeline vibrations under high-pressure pumping conditions.

For mass concrete foundations, a construction strategy combining layered continuous pouring with wireless automatic temperature monitoring and warning systems is recommended. Real-time monitoring of hydration heat development can effectively control temperature rises and prevent thermal cracking, thereby ensuring the quality and durability of foundation concrete placement [3].

3.2 Countermeasures for Core Tube Construction

To overcome efficiency bottlenecks in core tube construction, improvements can be pursued through both construction process innovation and formwork system upgrading.

From the perspective of construction process optimization, a staggered synchronized construction method can be adopted. Under this approach, the core tube and external frame structure advance upward ahead of other works, while cast-in-place staircases within the core tube are constructed in a staggered and synchronized manner. This method effectively resolves the conflict between limited formwork turnover space and stringent schedule requirements under conditions of extremely small floor areas. Practical experience from the Westlake University Landmark Tower project has demonstrated that this construction technique can significantly shorten the cycle time of standard floors and improve overall construction efficiency.

From the perspective of formwork system enhancement, integrated self-climbing steel platform formwork systems, commonly referred to as “aerial building machines,” should be widely adopted. When combined with telescopic trusses and intelligent deviation-correction systems, these platforms can effectively address positioning difficulties caused by structural irregularities, including numerous cantilevered corbels and substantial dimensional changes resulting from core tube wall setbacks.

The intelligent climbing system utilizes synchronized hydraulic control technology and high-precision displacement sensors to achieve stable and coordinated climbing of the entire formwork platform. Compared with conventional systems, the climbing duration can be reduced from the industry average of approximately four hours to around 1.5 hours, while positioning accuracy is substantially improved.

In addition, meticulous control of the elevation difference between the core tube and the external frame structure is essential. Appropriate height coordination ensures that the connection nodes of outrigger trusses can be installed within the optimal construction time window, thereby guaranteeing the integrity of structural connections and the overall load-bearing performance of the completed building.

3.3 Countermeasures for Steel Structure Installation

High-altitude steel structure installation should be addressed through three key dimensions: optimization of lifting schemes, implementation of high-precision measurement and control throughout the construction process, and stringent quality management of thick-plate welding.

With respect to lifting scheme optimization, large-tonnage irregular components such as multi-cavity mega-columns and giant belt trusses should be installed using rational segmentation and staged lifting strategies. Structural members should be scientifically divided into manageable lifting units to reduce the weight of individual lifts and minimize the complexity of aerial assembly operations. This approach can significantly improve construction efficiency while reducing safety risks associated with high-altitude operations.

Regarding measurement and positioning control, a combined surveying system utilizing total stations and laser trackers should be employed to establish a high-precision spatial positioning reference framework. The installation position of each structural component should be verified in real time to ensure that deviations remain within the allowable design tolerances. For critical load-bearing elements, including cantilevered transfer floors and outrigger truss levels, comprehensive construction-stage simulation analyses should be conducted prior to installation. These analyses should identify the stress conditions associated with each construction phase, while real-time monitoring and feedback mechanisms should be implemented throughout installation to ensure structural safety and stability.

In terms of welding quality management, specialized welding procedure qualification tests should be developed for thick steel plates. Appropriate measures, including preheating before welding, interpass temperature control, and post-weld thermal insulation with slow cooling, should be adopted to minimize welding defects. Furthermore, non-destructive testing (NDT) should be performed after welding to detect potential defects and prevent problems such as lamellar tearing and cold cracking. Through comprehensive quality control measures, weld integrity can be ensured and the required design-grade welding standards can be achieved.

3.4 Countermeasures for Vertical Transportation Systems

The optimization of vertical transportation systems should be based on an integrated management mechanism encompassing planning, dynamic scheduling, and real-time monitoring.

During the pre-construction stage, a comprehensive vertical transportation plan should be developed. This plan should scientifically determine tower crane lifting allocations, construction elevator transportation capacities, and concrete pouring schedules for each construction phase. Such advance planning can effectively prevent resource competition, operational conflicts, and workforce idleness during later stages of construction.

During project execution, dynamic scheduling should be implemented through the integration of Building Information Modeling (BIM) and smart construction site platforms. Sensors installed on tower cranes and construction elevators can continuously collect operational data, load information, and equipment status parameters. The management system can then automatically identify transportation bottlenecks and generate optimization recommendations, enabling project managers to adjust transportation strategies in real time according to actual site conditions.

For construction elevators, a segmented installation and transfer operation strategy is recommended. Refuge floors or mechanical equipment floors can be utilized as transfer platforms, dividing excessively long vertical transportation routes into multiple sections. This approach can significantly improve transportation efficiency over long distances while reducing waiting times for personnel and materials.

During the synchronized upward construction of the core tube and external frame structure, transportation schedules for different construction activities should be carefully coordinated. Major logistics operations—including concrete delivery, steel structure lifting, and masonry material transportation—should be arranged during staggered time periods to avoid excessive concentration of transportation demands. By implementing peak-shifting transportation strategies, competition for vertical transportation resources can be minimized, ensuring a continuous and orderly supply of materials to all construction processes and enhancing overall project efficiency [4].

3.5 Countermeasures for Tower Crane Selection and Arrangement

The selection and arrangement of tower cranes should comprehensively consider four key factors: coverage radius, lifting capacity, climbing sequence, and structural safety, thereby achieving multi-objective optimization.

During the selection stage, the tower crane model should be determined according to the maximum component weight and required operating radius. Given the large component weights and extensive working radii involved in supertall building projects, a single tower crane is often unable to satisfy all lifting requirements. Therefore, the coordinated deployment of two to three internal climbing tower cranes is recommended to ensure full coverage of the core tube area and critical locations within the external frame structure.

During the layout planning stage, Building Information Modeling (BIM) technology should be employed to simulate lifting paths and conduct interference analyses. Potential spatial conflicts between tower cranes, structural components, and adjacent cranes can thus be identified in advance, enabling optimization of crane positioning and avoiding costly adjustments during later construction stages.

The support system for internal climbing tower cranes should be designed as an integrated component of the core tube structure. Connection nodes between support beams and shear walls must satisfy both load-bearing capacity and stiffness requirements. Where necessary, finite element analysis should be conducted to verify the structural performance and safety of these critical connection details.

Regarding the climbing sequence, a detailed climbing schedule should be established and accurately coordinated with the construction rhythm of the main structure. Such coordination ensures that tower crane climbing operations do not impede the progress of core tube construction.

For projects involving multiple tower cranes, each crane should be equipped with an anti-collision system. Safety-distance warning thresholds should be established to maintain adequate clearance between adjacent crane jibs and operating zones. Through continuous monitoring and automatic warning functions, potential collision risks can be effectively eliminated, thereby ensuring the safety of multi-crane operations.

Conclusion

The construction of supertall buildings represents one of the most technically demanding and high-risk sectors within the construction industry. This study demonstrates that ultra-high-performance concrete pumping, core tube construction and hydraulic climbing formwork systems, high-altitude steel structure installation, vertical transportation systems, and tower crane selection and arrangement constitute the five primary challenges affecting construction efficiency and safety in supertall building projects. The technical complexity associated with these challenges increases nonlinearly as building height rises. With the rapid advancement of intelligent construction technologies, innovations such as BIM-integrated smart construction site platforms, AI-assisted construction scheduling, and digital twin technologies are becoming increasingly embedded in the management of supertall building projects. These technologies are expected to transform construction management from a predominantly experience-driven approach to a data-driven paradigm, thereby enhancing project efficiency, quality control, and safety performance.

References

[1] Wang, X. F. Analysis of Key Challenges and Optimization Strategies for Mechanical and Electrical Engineering Construction in Supertall Buildings[J]. Model World, 2025(8): 165–167.

[2] Li, K. S. Analysis of Key Challenges and Optimization Strategies for Mechanical and Electrical Engineering Construction in Supertall Buildings[J]. China Construction Metal Structure, 2024, 23(12): 180–182.

[3] Ouyang, C. Z. Analysis of Construction Technologies for Supertall Steel Structure Crowns[J]. Construction Materials & Decoration, 2024, 20(34): 1–3.

[4] Wang, J. Difficulties and Countermeasures in Construction Drawing Design of Supertall Office Buildings[J]. Real Estate Guide, 2025(15): 109–111.