Application and Optimization of High-Performance Concrete in Super High-Rise Building Structural Design

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Abstract: With the advancement of urbanization, supertall buildings are constantly emerging, and the application of High-Performance Concrete (HPC) in its structural design is very important. This article studies the application of HPC in supertall building structure, discusses its structural characteristics and adaptation principle, analyzes its application mode in vertical, horizontal and foundation structure, and puts forward optimization strategies from aspects of mix proportion, structural design and construction technology. It is found that HPC meets the structural requirements of supertall buildings because of its excellent performance, but it needs reasonable design and construction in application. The results show that the advantages of HPC can be brought into full play and the safety, durability and economy of supertall buildings can be improved by optimizing the mix proportion, combining the structural characteristics, and strictly controlling the construction technology. The research in this article provides a useful reference for the scientific application of HPC in the structural design of supertall buildings.

1. Introduction

With the continuous acceleration of urbanization, land resources are increasingly scarce. As an effective way to solve urban space problems, supertall buildings have sprung up in major cities around the world [1]. Ultra-high-rise building is not only a symbol of urban modernization, but also a great challenge to building technology and material science [2]. HPC, because of its excellent mechanical properties and durability, plays an important role in the structural design of supertall buildings [3].

From a global perspective, the number and height of supertall buildings have hit record highs in recent years. For example, the Burj Khalifa in Dubai is 828 meters high and the Shanghai Tower is 632 meters high [4]. The successful construction of these supertall buildings is inseparable from the application of HPC. HPC has the characteristics of high strength, high durability and high workability, which can meet the strict requirements of supertall buildings on structural materials under vertical load, lateral wind load and earthquake [5-6]. However, the application of HPC in the structural design of supertall buildings is not always smooth [7]. On the one hand, the unique structural form and mechanical characteristics of supertall buildings put forward higher requirements for HPC performance; On the other hand, if the mix design and construction technology of HPC are not handled properly, it may not give full play to its advantages and even affect the safety and durability of the structure [8]. Based on this reason, it is of great practical significance to study the application and optimization of HPC in the structural design of supertall buildings. Through the in-depth analysis of the principle of HPC adapting to supertall building structure, it can provide a more solid theoretical basis for the structural design of supertall building; The research on its application mode and optimization strategy will help to improve the construction quality and economic benefits of supertall buildings and promote the sustainable development of the construction industry.

The purpose of this article is to systematically discuss the application and optimization of HPC in the structural design of supertall buildings, and provide useful reference for the structural design of supertall buildings through theoretical analysis, so as to promote the scientific application of HPC in the field of supertall buildings.

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2. Characteristics of supertall buildings and HPC adaptation principle

Because of its unique structural characteristics, supertall buildings face many challenges in design and construction. Its large vertical height makes the vertical load increase significantly, which requires extremely high compressive performance of structural materials [9]. Futhermore, the influence of lateral wind load and earthquake on supertall buildings is more prominent, and the structure needs to have good lateral stiffness and ductility to resist deformation and destruction under horizontal force. In addition, the service life of supertall buildings is usually long, and strict requirements are put forward for the durability of structural materials.

With its excellent performance characteristics, HPC just meets the structural requirements of supertall buildings. Because of its high strength, it can effectively bear the huge vertical load of supertall buildings, reduce the cross-sectional size of structural members and increase the building use space [10]. For example, the bearing capacity of the structure can be significantly improved by using high-strength HPC in the bottom vertical members of supertall buildings. HPC has good durability and can meet the requirements of long-term use of supertall buildings. In the complex natural environment and use environment, HPC can effectively resist the invasion of external corrosive media, reduce the cost of structural maintenance and reinforcement, and ensure the long-term safety of the structure.

From the point of view of mechanical principle, HPC's high elastic modulus makes it less deformed under load, which is helpful to maintain the overall stability of supertall building structure [11]. Its good ductility can dissipate energy through its own deformation under extreme loads such as earthquakes, so as to avoid brittle failure of the structure and provide protection for personnel evacuation and structural safety.

3. Application mode of HPC in building structure design

HPC has diverse application methods in the structural design of supertall buildings based on the functional requirements and stress characteristics of different structural parts. The vertical structure of supertall buildings, such as columns and walls, bears the majority of vertical loads and requires extremely high strength and stability of materials. HPC has become an ideal material for vertical structures due to its high strength and high elastic modulus. At the bottom floor, due to the concentration of vertical loads, high-strength grade HPC is often used to reduce the cross-sectional size of components and increase the building's usable space. For example, the core tube wall at the bottom of a supertall building is designed using C80HPC. Through reasonable mix design and construction technology, it ensures that the concrete can quickly reach the design strength after pouring. The application characteristics of HPC in vertical structures of supertall buildings are shown in Figure 1:

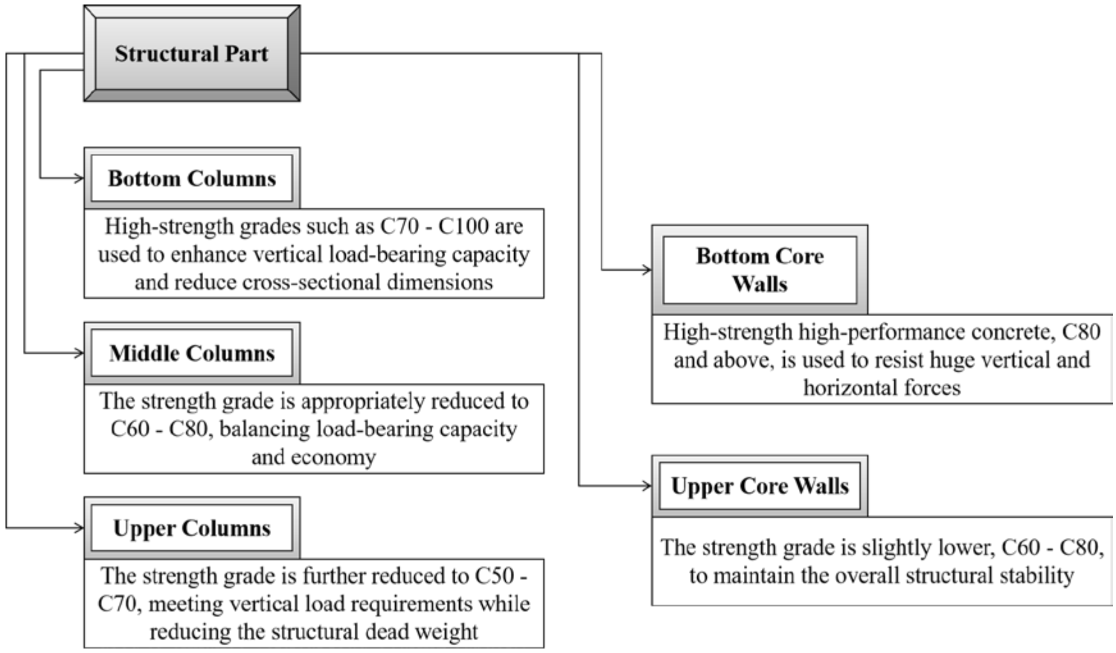

Figure 1 Application Characteristics of HPC in Vertical Structures of Super High-Rise Buildings

In the horizontal structure of supertall buildings, such as beams and slabs, the application of HPC needs to comprehensively consider its bending and shearing performance and structural deformation control. As the main stress component of horizontal structure, beam bears the vertical load from the floor and transfers it to the vertical structure. The high toughness and good crack resistance of HPC are helpful to improve the bending capacity and durability of beams. In the design of long-span beams, high-performance fiber reinforced concrete can be used to further enhance the tensile and crack resistance of beams and reduce the deflection of beams. For the floor slab, HPC should not only meet the basic bearing requirements, but also have good workability to ensure the construction quality of concrete in large-scale pouring.

As a key part of bearing the weight of the whole building, the foundation structure of supertall building requires unique performance of HPC. Foundation concrete should have good impermeability and corrosion resistance to resist the influence of corrosive media in groundwater and soil. Futhermore, due to the large volume of foundation concrete, the hydration heat problem is more prominent, which easily leads to temperature stress in concrete and cracks. For this reason, when HPC is applied in infrastructure, it is needed to optimize the mix design, select low-heat cement and add mineral admixtures, such as fly ash and slag powder, to reduce the temperature rise of hydration heat.

4. Optimization strategy of HPC in structural design of supertall buildings

Mix proportion is the key factor to determine the performance of HPC. By reasonably adjusting the proportion of each component material, the advantages of HPC can be fully exerted. As a cementing material, the variety and dosage of cement directly affect the strength and hydration heat of concrete. Generally, cement with high strength grade and good stability is selected. Futhermore, in order to reduce the hydration heat, the dosage of cement can be appropriately reduced, and some cement can be replaced by mineral admixture. Mineral admixtures such as fly ash and slag powder can not only reduce the cost, but also improve the workability, durability and later strength growth of concrete. In addition, the rational use of superplasticizer is also very important, which can greatly reduce the water-cement ratio on the premise of ensuring the workability of concrete, thus improving the strength and durability of concrete. Figure 2 shows the influence of HPC mix parameters on performance.

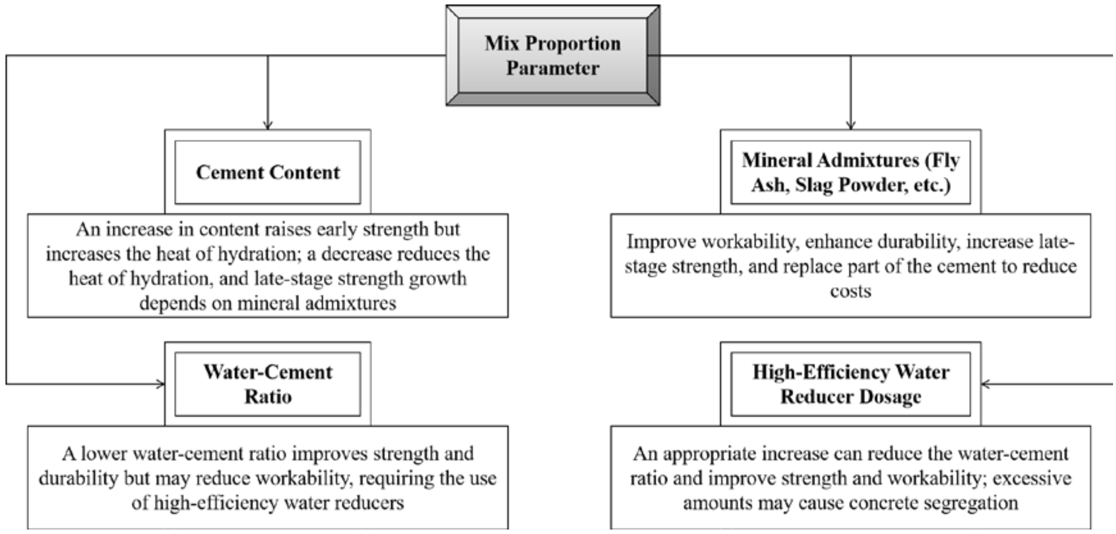

Figure 2 Influence of Mix Proportion Parameters of HPC on Its Performance

In the structural design of supertall buildings, the characteristics of HPC should be fully considered, and the structural layout and component design should be optimized. For vertical structures, due to the high strength of HPC, the cross-sectional dimensions of columns, walls and other components can be appropriately reduced, which not only increases the building use space, but also reduces the self-weight of the structure and the foundation load. However, it should be noted that reducing the section size may affect the lateral stiffness of the structure, so it is needed to ensure that the structure meets the lateral stiffness requirements through reasonable structural system selection and component arrangement. In terms of horizontal structure, the design of beams and slabs should be combined with the mechanical properties of HPC.

Construction technology plays a decisive role in the realization of HPC performance. In the process of mixing, it is needed to ensure the uniform mixing of all components, strictly control the mixing time and speed, and ensure the workability and homogeneity of concrete. In the process of transportation, measures should be taken to prevent concrete segregation and slump loss, and mixer trucks can be used for transportation, and the mixture ratio should be adjusted appropriately according to the transportation distance and time. When pouring, the appropriate pouring method should be selected according to the characteristics of components and the performance of concrete. For the mass concrete foundation, layered pouring and layered vibrating should be adopted to facilitate the heat of hydration and prevent temperature cracks.

The maintenance link is also critical, and the early strength of HPC increases rapidly, which requires high maintenance conditions. Moisturizing and curing should be carried out in time to prevent concrete surface moisture from evaporating too quickly, leading to shrinkage cracks. Covering with plastic film, watering and curing can be used to ensure the concrete to harden under suitable temperature and humidity conditions and give full play to its performance advantages.

5. Conclusions

This study focuses on the application and optimization of HPC in the structural design of supertall buildings. In terms of application, HPC has targeted applications according to the characteristics of different structural parts of supertall buildings. The vertical structure bears huge vertical load with its high strength, the horizontal structure exerts its high toughness and crack resistance to meet the requirements of bending and shearing, and the foundation structure resists external erosion with its good impermeability and corrosion resistance.

In terms of optimization strategy, the mix design takes into account the cost and hydration heat control while ensuring the performance by adjusting the dosage of cement, mineral admixture, water-cement ratio and superplasticizer. According to HPC characteristics, structural design optimizes vertical and horizontal structural layout and component design, and balances bearing capacity, space utilization and lateral stiffness. The construction technology is strictly controlled from mixing, transportation, pouring to maintenance to ensure the performance of HPC.

However, there are still some limitations in this study. The long-term performance evolution of HPC, such as the durability change in complex environment for decades, has not been monitored by in-depth long-term tests. Future research can be carried out in this direction to further improve the application theory and technology of HPC in supertall buildings. Reasonable application and optimization of HPC is of great significance to promote the development of supertall buildings, and continuous research is needed to ensure the high-quality construction and long-term use of supertall buildings.

References

[1] Deng Jiezhen. Influence of Aggregate on Crack Resistance of Mass Concrete in Mega Columns of Super High-Rise Buildings[J]. Architecture Technology, 2024, 55(8): 1003-1006.

[2] Wang Dingxin, Huang Liming, Zhang Chen. Key Construction Techniques for Mass Concrete in Ultra-Thick Foundation Slabs of Super High-Rise Buildings[J]. Architecture Technology, 2023, 54(16): 1965-1968.

[3] Tang Jianyu, Pan Wen, Dong Weiqing. A Case Study on Vibration Damping in a Super High-Rise Frame-Reinforced Concrete Core Tube Structure[J]. Industrial Safety and Environmental Protection, 2021, 47(07): 55-59.

[4] Su Hengqiang, He Jun, Liu Jinsong. Research and Application of Steel Box-Concrete Shear Walls in Super High-Rise Structures[J]. Building Structure, 2020, 50(10): 23-27.

[5] Zhang Yanbo, Hu Kexu, Hu Xiaoyi. Cause Analysis and Treatment of Concrete Beam Cracking in a Super High-Rise Building[J]. Structural Engineers, 2024, 40(1): 72-80.

[6] Tang Min, Liu Yongtian, Chen Chen. Key Techniques in the Structural Design of a Steel Frame-Concrete Core Tube Super High-Rise Building[J]. Building Structure, 2021, 51(15): 18-22+75.

[7] Duan Changli, Wu Chen, Li Hui. Application Research of Aerated Concrete Slabs in Super High-Rise Buildings[J]. New Building Materials, 2021, 48(07): 48-51+162.

[8] Qin Feifei, Xie Nan, Hao Jianbing. Study on Impact Load of Concrete Pump Pipes in Construction Platforms of Super High-Rise Buildings[J]. Construction Technology, 2021, 50(03): 66-68+75.

[9] Gao Su, Xu Ziguo, Wan Yixiu. Post-Tensioned Prestressed Design with Slow-Bonding Tendons for Concrete Shear Wall Structures in a Super High-Rise Building[J]. Building Structure, 2021, 51(11): 59-65.

[10] Li Tao, Li Dongxiao, Xu Chaozhuo. Study on Vertical Deformation of Steel-Reinforced Concrete Frame-Core Tube Hybrid Super High-Rise Structures[J]. Journal of Building Structures, 2020, 41(3): 93-104.

[11] Li Zhaofeng, Niu Zhongrong, Wu Jian'an. Strength Analysis and Reinforcement of Steel-Reinforced Concrete Transfer Joints in High-Level Transfer Floors of Super High-Rise Buildings[J]. Building Structure, 2020, 50(24): 61-68.