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Innovative Models and Practical Paths of Concrete Technical Management in Construction Engineering

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Abstract: This paper focuses on concrete technical management in construction engineering. It explains the core elements, including production mix ratio, analyzes problems of traditional models, presents innovative management models like BIM + GIS and their applications, and covers aspects such as job competence standards and prefabricated modular construction regulations, emphasizing the significance and development direction of innovative models.

Keywords: Concrete technical management; Innovative models; Construction engineering

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1. Introduction

Concrete technical management is of vital importance to the quality of construction engineering. Its core elements include production mix ratio management, construction process control, and quality monitoring and evaluation. In recent years, with the development of the construction industry, China has successively issued a series of relevant policies. For example, the *Opinions on Promoting Green Development in Urban and Rural Construction*, released in 2021, emphasized the importance of construction engineering quality and sustainable development. This has set higher requirements for concrete technical management. Traditional management models have many problems, such as inaccurate material batching, non-standard construction operations, and inefficient quality control. However, the application of innovative models, such as digital management platforms based on BIM + GIS and embedded sensor network systems, has brought new opportunities and challenges to concrete technical management. At the same time, these innovations also provide strong support for improving the quality and efficiency of construction projects.

2. Theoretical basis of concrete technical management

2.1. Core elements of concrete technical management

The core elements of concrete technical management include production mix ratio management, construction process control, and quality monitoring and evaluation. Production mix ratio management requires precise calculation of the proportions of each component based on the engineering requirements and the characteristics of the raw materials to ensure that the concrete performance meets the standards [1]. Construction process control covers various stages such as pouring, vibration, and curing, and it is essential to strictly follow the construction techniques and operational standards to ensure the quality and stability of the concrete structure. Quality monitoring and evaluation involve testing the strength of concrete specimens and conducting durability tests to identify potential issues in a timely manner and take measures to resolve them. These three elements are interrelated and mutually influential, forming the core of concrete technical management and providing an important guarantee for the quality of construction projects. Effective management of these elements can help reduce material waste, improve construction efficiency, and enhance the overall durability and safety of the structure.

2.2. Analysis of current industry management status and issues

Data from typical engineering quality accidents over the past five years indicate that traditional concrete technical management models have many problems. In terms of material waste rate, a significant amount of concrete material is wasted due to the lack of precise batching and usage plans [2]. The strength qualification rate is also not satisfactory. Improper control of the mix ratio and non-standard curing during construction lead to concrete strength failing to meet the required standards. The crack occurrence rate is also high, closely related to unstable raw material quality, unreasonable construction techniques, and inadequate post-construction curing. These problems not only affect the quality of the project but also increase costs and reduce the overall efficiency of construction projects. For example, improper estimation of the required concrete volume can result in excess material that cannot be reused effectively. Insufficient vibration during pouring can result in voids within the concrete, reducing its strength and durability. Thermal cracks can form due to rapid temperature changes during curing, especially in mass concrete structures. Addressing these challenges requires innovative approaches to concrete technical management that can improve precision, reduce waste, and enhance overall quality control.

3. Construction of intelligent innovation models

3.1. Full-lifecycle intelligent control system

A digital management platform based on BIM + GIS can be constructed to form a full-lifecycle intelligent control system by integrating functional modules such as material traceability, construction simulation, and risk warning. BIM provides a building information model that accurately presents the details of each stage of concrete construction [3]. GIS endows the system with spatial analysis capabilities to locate the sources of materials and construction sites. The material traceability module can trace the information of concrete raw materials to ensure quality. The construction simulation module leverages the visual advantages of BIM to simulate the construction process, identify potential issues in advance, and optimize the construction plan. The risk warning module combines data from both BIM and GIS to provide real-time monitoring and early warning of risks during construction, such as concrete cracking and insufficient strength. By integrating these modules into a full-lifecycle intelligent control system, it is possible to achieve a closed-loop management process that ensures the quality and safety of the concrete throughout its entire lifecycle. This system not only improves the precision and efficiency of concrete management but also enhances the overall sustainability of the construction project.

3.2. Application of Internet of Things data acquisition technology

The development of an embedded sensor network system and its application in concrete technical management in construction projects can achieve real-time monitoring of key parameters such as mixing temperature, slump, and curing environment. By accurately collecting data through sensors, timely feedback on the state of concrete at different stages can be provided [4]. At the same time, an adaptive adjustment mechanism is used to automatically adjust relevant parameters based on the collected data to ensure that the quality and performance of the concrete meet the engineering requirements. On this basis, a dynamic decision-making model is established to comprehensively consider various factors and optimize the production and construction processes of concrete. This innovative mode helps to enhance the scientific and precise nature of concrete technical management and provides a strong guarantee for the quality of construction projects. For example, sensors in the mixing plant can monitor the temperature and consistency of the mix, while sensors in the formwork can monitor the curing conditions and detect any potential issues such as excessive temperature gradients. The data collected by these sensors can be transmitted in real-time to a central monitoring system, where it can be analyzed to provide valuable insights into the concrete's performance.

4. Design of management practice pathways

4.1. Organizational structure optimization strategies

4.1.1. Multi-professional collaboration mechanism

To effectively manage concrete technology in construction projects, a multi-professional collaboration mechanism must be established. A triple-helix cooperation architecture involving civil engineers, material experts, and data scientists should be designed. Civil engineers provide concrete application requirements from a structural design perspective, material experts develop suitable materials based on these requirements, and data scientists use data analysis to optimize concrete mix ratios and other parameters. Additionally, a project-based knowledge-sharing cloud platform should be established to promote the exchange and sharing of knowledge among different professions. Through this platform, professionals from various fields can promptly access the information they need, such as material performance data, engineering design requirements, and data analysis results. This breaks down professional barriers, improves collaboration efficiency, and enhances the level of concrete technical management [5].

4.1.2. Job competency standard system

The job competency standard system for concrete technology management in construction engineering should cover multiple aspects. Firstly, in terms of BIM operation ability, relevant personnel are required to be proficient in the application of BIM software in concrete engineering, including model construction, collision detection, etc., in order to better simulate and optimize construction [6]. The ability to analyze data is also crucial, as it can effectively analyze data on concrete raw materials, mix proportions, and strength, providing a basis for quality control. Furthermore, the ability to respond to emergency plans is indispensable. Personnel need to be familiar with various problems that may occur during the concrete construction process, such as cracks and insufficient strength, and be able to quickly take effective emergency measures to ensure that the quality and progress of the project are not affected. At the same time, a comprehensive talent training program and certification standards should be developed to ensure that personnel in the position possess these comprehensive abilities.

4.2. Standardized operation process re-engineering

4.2.1. Prefabricated modular construction standards

It is crucial to establish precision control standards and error compensation schemes for component lifting and positioning in prefabricated construction specifications. The lifting accuracy requirements for different types of components, such as columns, beams, slabs, etc., should be clearly defined, and reasonable positioning accuracy standards should be determined based on their stress characteristics and connection methods [7]. At the same time, corresponding compensation plans should be formulated for possible errors to ensure accurate installation positions of components and guarantee structural safety.

In addition, developing technical specifications for modular interface processing is also crucial. The specifications should cover the form, size, tolerance, and fit of interfaces, clarify the connection methods and requirements between different modules, ensure the compatibility and reliability of interfaces, and improve the overall quality and construction efficiency of prefabricated buildings.

4.2.2. Special concrete construction guidelines

For self-compacting concrete, it is necessary to improve the database of pouring parameters. Data on pouring parameters, including pouring speed, height, and temperature, should be collected under different engineering environments and concrete mix ratios to provide accurate references for subsequent construction [8]. Additionally, in the construction of super-high-rise buildings using pump-fed concrete, verticality correction is crucial. A detailed correction process should be established, with precise measurement of allowable verticality deviation ranges before construction. During construction, high-precision measuring instruments should be used to monitor verticality in real-time, and any deviations should be promptly corrected by adjusting the angle and position of the pumping equipment to ensure that the concrete is accurately delivered to the designated location and to guarantee the construction quality of super-high-rise structures.

5. Empirical research and benefit analysis

5.1. Case of the Shanghai Center project

5.1.1. Application of C80 high-strength concrete

The application of C80 high-strength concrete in the Shanghai Center project involves comprehensive research on its performance. Through intelligent curing systems, the strength development curve is optimized to better meet the engineering expectations and provide reliable strength support for super-high-rise building structures [9]. Effective control of early-age shrinkage and deformation is also critical. In this project, precise monitoring and analysis of relevant data ensure that the shrinkage and deformation of the concrete during the early-age period are within a reasonable range, avoiding structural cracking and other issues caused by excessive shrinkage and deformation. This improves the durability and stability of the concrete structure and provides valuable practical experience and data support for the application of similar high-strength concretes in high-rise buildings in the future.

5.1.2. Economic benefit assessment

In the Shanghai Center project, the innovative model significantly reduces labor costs compared to traditional methods. By adopting advanced concrete technical management innovation models, unnecessary manual operation links are reduced, and work efficiency is improved, effectively controlling labor costs [10]. In terms of rework rate, the innovative model shows a significant advantage. Traditional methods may result in higher rework rates due to poor technical management, while the innovative model, with its precise control of concrete technology, greatly reduces the occurrence of rework, thereby minimizing the economic losses caused by rework. In terms of construction period reduction, the innovative model optimizes the construction process, avoiding delays caused by concrete technical issues, enabling the project to be completed ahead of schedule. This not only reduces indirect costs during the construction process but also allows the project to be put into use earlier to generate economic benefits.

5.2. Practice of the Hong Kong-Zhuhai-Macao Bridge project

5.2.1. Improvement of marine concrete durability

The Hong Kong-Zhuhai-Macao Bridge project has conducted in-depth practice in improving the durability of marine concrete. By comparing the monitoring data of chloride ion permeability coefficients, the effectiveness of the triple-protection system is verified. In the actual project, special concrete mix ratio designs are used, and high-performance admixtures and mineral admixtures are added to enhance the chloride ion permeability resistance of the concrete from a material perspective. At the same time, a protective coating is applied to the surface of the concrete structure to further prevent the ingress of chloride ions. Moreover, the construction process is optimized to ensure the density of the concrete, reducing porosity and thereby decreasing the channels for chloride ion permeation. Monitoring data shows that the chloride ion permeability coefficient is significantly reduced after the implementation of the triple-protection system, effectively demonstrating its ability to enhance the durability of marine concrete and providing a guarantee for the long-term safe use of the bridge.

5.2.2. Environmental benefit calculation

In the environmental benefit calculation of the Hong Kong-Zhuhai-Macao Bridge project, the improvement in green construction indicators such as waste recycling rate and carbon emission intensity is statistically analyzed. Through proper planning and the application of advanced technologies, waste generated during the bridge construction is effectively recycled and reused, increasing the waste recycling rate. At the same time, energy-saving and emission-reduction measures are taken in the production, transportation, and construction of materials, reducing carbon emission intensity. These improvements reflect the positive contributions of the Hong Kong-Zhuhai-Macao Bridge project to environmental protection and provide a reference for the green construction of subsequent large-scale construction projects, promoting the sustainable development of the construction industry.

5.3. Wuhan Yangtze River Shipping Center project

5.3.1. Temperature control scheme for mass concrete

In the temperature control scheme for mass concrete in the Wuhan Yangtze River Shipping Center project, distributed fiber-optic monitoring data is analyzed. This monitoring method can obtain key data such as the internal temperature changes of the concrete in real time. At the same time, based on these data, the crack-prevention effect of the intelligent water-cooling system is assessed. The intelligent water-cooling system plays an important role in temperature control. Reasonable water-cooling parameter settings and system operation can effectively reduce the internal temperature gradient of the concrete, decrease the generation of temperature stress, and thus minimize the possibility of crack formation. Analysis of the monitoring data shows that the system has achieved good crack-prevention effects in this project, ensuring the quality and stability of the mass concrete structure and providing useful references for temperature control and crack prevention in similar projects.

5.3.2. Technology innovation diffusion model

To deeply study the diffusion of technological innovation in the Wuhan Yangtze River Shipping Center project, it is crucial to construct a regression equation of the correlation between the technology adoption rate and project scale and enterprise qualifications. First, a large amount of data related to the adoption of concrete technology in the project should be collected, including the adoption situation at different construction stages, project scale, and enterprise qualification information. Then, using scientific statistical analysis methods, these data are processed and analyzed. Through regression analysis, the specific correlation between technology adoption rate and project scale and enterprise qualifications is determined. This not only helps to understand the diffusion law of concrete technology in the project but also provides references for the technical management of subsequent similar projects, better promoting the innovation and application of concrete technology in construction projects and improving the overall efficiency of the projects.

6. Conclusion

In construction projects, the innovative models of concrete technical management are of great significance. The new management models can effectively improve the quality of concrete, ensuring the stability and safety of the project, while also achieving cost savings and improving economic benefits. In terms of process innovation, it also has a positive driving effect. For better development, it is necessary to improve the industry standard system to make it more standardized and scientific, providing clear guidance for concrete technical management. With the advancement of technology, the application prospects of digital twin technology in the full-lifecycle management of concrete are broad. It can achieve precise simulation and monitoring of the entire process of concrete from production to use, identify problems in a timely manner, and optimize management, further improving the efficiency and quality of concrete technical management and promoting the sustainable development of the construction industry.

Disclosure statement

The author declares no conflict of interest.

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