Key Technologies and Applications of Intelligent Construction in the Maiwan and Tianjiaotan Water Conservancy Hubs

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Abstract. To ensure the efficient and high-quality construction process of major water conservancy projects, the innovative integrated control technology for dam construction materials in tropical regions is applied. An intelligent construction management platform applicable to the Maiwan Water Conservancy Hub Project and the Beimen River Tianjiaotan Water Conservancy Hub Project is established. The platform utilizes advanced Internet of Things sensing technology to monitor the temperature, compaction quality, test curves, and other information throughout the dam construction process, providing real-time control suggestions to ensure overall dam construction efficiency and quality. The intelligent compaction system was officially put into operation on March 22, 2022, during the initial concrete construction of the dam at the Maiwan Water Conservancy Hub. The intelligent monitoring system for compaction quality of the Maiwan Water Conservancy Hub completed monitoring for the 56th compartment, while the Tianjiaotan Hub's intelligent monitoring system for compaction quality completed monitoring for the 27th compartment on September 16, 2022. The intelligent construction management platform significantly reduces the incidence of problems and effectively improves the problem-solving efficiency of construction units during the application process. The intelligent construction process of the Maiwan Water Conservancy Hub Project and the Tianjiaotan Water Conservancy Hub Project represents a significant application of intelligent key technologies and theories, with the developed key technologies providing better technical support for major water conservancy projects in tropical regions.

Keywords: Intelligent Construction Technology of Dams in Tropical Regions, Concrete Temperature Control , Intelligent Technology.

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1 Introduction

During the era of digital dams, with the application of network technology, databases, and computational simulation techniques in dam construction, the construction quality has been effectively enhanced. For instance, the "digital construction monitoring" and simulation analysis systems were applied in the Nuozhadu and Xiaowan hub projects. In the construction process of the Xiluodu arch dam, along with the improvement of the digital dam system, the concept of intelligent construction was introduced for the first time[1]. In recent years, both domestic and international experts and scholars have actively conducted research and exploration around the theory and technology of intelligent dam construction. Zhang Guoxin et al.[2] suggest that the comprehensive implementation of automation in collecting construction, temperature control, monitoring, and other information data can effectively promote the transformation of digital dams into intelligent dams. Zhong Denghua et al. [3,4] define a smart dam as one established on the basis of a digital dam, utilizing advanced technologies such as the Internet of Things, big data, and cloud computing. Building upon the construction of the Jinsha River large-scale hydropower project, Fan Qixiang et al. [5,6] have successfully introduced and applied the "intelligent construction closed-loop control theory," achieving favorable application results. Li Qingbin et al. [7-9] have provided a detailed analysis of the relationship between intelligent construction and intelligent control of dams, proposing and gradually refining theories of intelligent construction.

Both the Maiwan Water Conservancy Hub Project and the Beimenjiangtiantan Water Conservancy Hub Project are part of the State Council's "13th Five-Year Plan," comprising 172 significant water conservancy projects. They are classified as Grade II large (2) projects, with the primary objective of balancing irrigation and power generation needs while ensuring water supply and flood control functions.The normal storage level of the Maiwan Water Conservancy Hub is 101 meters, with a total storage capacity of 522 million cubic meters. This key water source project plays a crucial role in ensuring water supply, flood control, and ecological water use safety for Haikou City, Ding'an County, and Chengmai County.The Beimenjiangtiantan Water Conservancy Hub Project provides essential water source security for Danzhou City and Yangpu Economic Development Zone, with a total storage capacity of 194 million cubic meters.

The Maiwan Water Conservancy Hub Project and the Tianjiaotan Water Conservancy Hub Project are located in tropical regions with consistently high temperatures. Crack prevention is a crucial task in the construction of concrete dams and remains a global challenge. Modern theoretical research and engineering practices on temperature control and crack prevention have gradually established a relatively complete system of temperature control and crack prevention theories. This has resulted in a systematic set of measures for concrete temperature control and crack prevention. However, the industry widely acknowledges the fact that "no dam is without cracks" [10,11].Innovatively, an integrated control technology for dam construction materials in tropical regions has been introduced, covering the entire process from the production of the mixing building to the compaction and pouring of the dam. Utilizing advanced IoT sensing technology, the technology monitors the temperature, compaction quality, test curves, and other information throughout the entire process. It promptly provides measures to address issues such as feedback on water flow, alerts for areas with potential leakage or compaction errors, and notifications for concrete exceeding specified proportions. This ensures the overall efficiency and quality of the dam construction process.

2 Intelligent Construction Technology Route for Maiwan and Tianjiaotan

Applying next-generation information technologies such as cloud computing, big data, the Internet of Things, mobile internet, artificial intelligence, regional blockchain, and Internet Plus, based on the construction and design schemes of the Maiwan Water Conservancy Hub Project and the Tianjiaotan Water Conservancy Hub Project, as well as the changing environmental conditions and human, equipment, and other resource factors during the construction process [12-14], the intelligent construction of the Maiwan Water Conservancy Hub and the Tianjiaotan Water Conservancy Hub is integrated with dam construction. This research focuses on the intelligent construction technology of dams in tropical regions.

The intelligent construction of the Maiwan Water Conservancy Hub Project and the Tianjiaotan Water Conservancy Hub Project follows the technological route of "Comprehensive Sensing - Intelligent Analysis - Real-time Control," as illustrated in Figure 1.

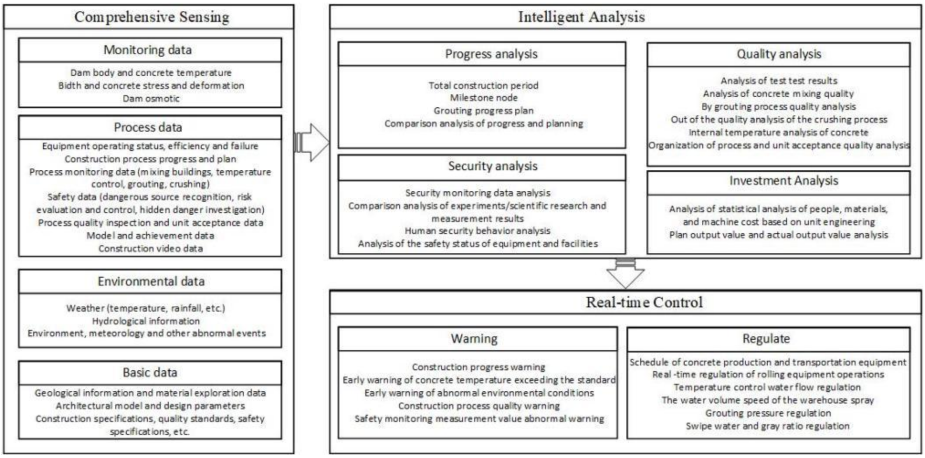

Fig. 1. The "Comprehensive Perception - Intelligent Analysis - Real-time Control" Technical Route of Maiwan Water Conservancy Hub Project and Tianjiaotan Water Conservancy Hub Project.

"Comprehensive Sensing" involves the use of corresponding data monitoring and collection devices during dam construction to aggregate various data, integrate them into the intelligent construction platform, and ensure the accuracy, authenticity, and timeliness of the data [12].

"Intelligent Analysis" entails analyzing the entire process, all elements, and the overall state of dam construction across dimensions such as progress, quality, safety, and investment. During the "Real-time Control" stage, the analysis results guide dam construction, promoting precision construction and management [14].

The project is located in a tropical region with consistently high temperatures, making crack prevention a significant task in the construction of concrete dams. Focusing on the integrated control technology for dam construction materials in tropical regions, the process is monitored throughout, from the production of the mixing building to the compaction and pouring of the dam, using advanced IoT sensing technology. It monitors information such as dam temperature, compaction quality, and test curves. Timely measures, such as feedback on water flow, alerts for areas with potential leakage or compaction errors, and notifications for concrete exceeding specified proportions, are provided to ensure the overall efficiency and quality of the dam construction process.

3 Real-time Monitoring of the Entire Process of Dam Concrete Construction

This paper focuses on the intelligent construction of the Maiwan Hydraulic Hub Project and the Beimen River Tianjiaotan Hydraulic Hub Project, specifically targeting the production, transportation, and compaction processes of concrete. The monitoring system employs intelligent mixing control to analyze concrete mix proportions, optimize transportation routes, and facilitate on-site operations. The paper further discusses the key components of the intelligent mixing, intelligent vehicle transportation, intelligent compaction, and real-time image capture for the entire concrete construction process. Additionally, it delves into the real-time monitoring of concrete temperature throughout the construction process[13].

3.1 Intelligent Mixing

Intelligent mixing is divided into three components: the industrial control system, production batching system, and data acquisition system. The industrial control system contains information such as project name, pouring location, discharge time, mixing time, theoretical mix ratio, concrete strength grade, etc. The production batching system generates instructions by accessing theoretical mix ratio information from the industrial control system and sends them to relevant hardware. The data acquisition instrument wirelessly uploads data to the industrial control system after encryption, automatically compiling real-time data on mixing time, material usage, actual production mix ratio, and auxiliary production information into the database. It automatically analyzes data beyond the specified range, compares real-time data with theoretical mix ratio information, and reports to relevant personnel[13-16].

3.2 Intelligent Vehicle Transportation

The vehicle transport management system accesses information such as project names and geographic coordinates from the intelligent mixing control system. The system analyzes the optimal route and assigns vehicles for transportation. Upon departure of concrete, the system's terminal software can print a concrete transport order with a QR code attached. Drivers carry the transport order with them to the site, where on-site personnel can receive it using a mobile app, thus facilitating concrete transport management. Additionally, GPS positioning systems installed on transport vehicles monitor the vehicles' routes and whether they exceed the prescribed speed limit, thereby achieving the purpose of alerting for "route deviation" and "vehicle speed limit" [17].

3.3 Intelligent Compaction

By installing a vibration-resistant monitoring device integrated with a high-precision GNSS receiver and vibration force sensor on the compactor, real-time collection of dynamic coordinates, vibration status, and other parameters of the compactor is achieved. Through the installation of a vibration-resistant data transmission device on the compactor, the monitoring information of the compactor's operation status is compiled into the database in real-time, serving as the source data for calculating and analyzing parameters such as operating trajectory, speed, vibration force, number of compaction passes, compaction elevation, and compacted thickness. The compaction situation is visualized and displayed in real-time. When compaction parameters of the compactor, such as vehicle speed or vibration force status, fail to meet standards, the system automatically sends alarm messages to relevant personnel, providing detailed information on deviations from standards and spatial location for prompt guidance on rework or adjustments. Furthermore, to prevent oversights or deviations during the compaction process, alarm information is recorded in an abnormality database for future reference [4,18].

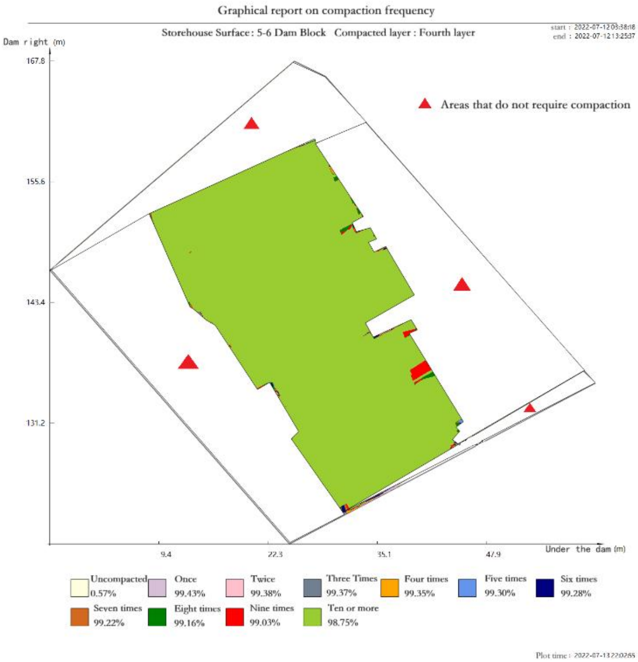

Fig. 2. Intelligent Compaction Layer Report for Maiwan Water Conservancy Hubs

3.4 Concrete Construction Process Imaging Collection

By installing monitoring systems at the construction site, image data is collected to monitor the on-site construction conditions. The collected image data is then organized and archived in real-time, thereby achieving full control and traceability of the concrete construction process for dams. By associating the monitoring system with each construction site and adjusting parameters such as focal length and viewing angle of the cameras, it is possible to compare real construction scenes with design models and progress models. Furthermore, historical image data can be queried to review the appearance of various construction stages and trace quality issues encountered during the construction process, thereby enhancing the management level of construction personnel [18, 19].

4 Real-Time Monitoring of Concrete Temperature Throughout the Entire Process of Dam Construction

The design of the concrete intelligent temperature control system employs advanced technologies such as automation monitoring, GPS, and wireless transmission. It integrates dynamic intelligent monitoring, analysis, and control systems for temperature control construction, to comprehensively monitor the production, transportation, pouring, temperature control, and water cooling processes of dam concrete [4, 13, 18-21].

(1) Real-Time Collection and Transmission of Construction and Temperature Control Information

Through real-time collection devices for temperature control information, relevant data such as aggregate temperature, pouring information, water cooling information, and surface temperature of concrete materials are recorded. This construction-related information and temperature control elements can be automatically transmitted to the server via on-site networks and compiled into the database.

(2) Efficient Management and Visualization of Temperature Control Information

Efficient management and information sharing of temperature control information are achieved through network and permission allocation. Corresponding visualization management platforms are established to visualize and manage data, facilitating efficient management and intuitive display of large amounts of temperature control data. Additionally, the platform can provide real-time outputs such as statistics on the highest temperature compliance rate of dam concrete, statistics on temperature during pouring into the warehouse, and statistics on the cooling water flow for various phases of dam concrete projects.

(3) Simulation Analysis and Reverse Analysis of Temperature Stress

Based on the efficient management and visualization platform of temperature control information, timely analysis and reverse analysis of temperature stress are conducted according to measured data and on-site requirements, providing intelligence for system prediction and decision-making.

(4) Evaluation and Early Warning of Temperature Control Construction Effects

Assessment of concrete temperature control construction is achieved through efficient management of temperature control information and analysis of temperature stress, enabling real-time early warning of deviations from standards based on a large amount of measured data and analysis results. After classifying and grading deviations, suggestions and recommendations can be sent to construction and management personnel based on their permissions.

(5) Intelligent Control of Temperature Control Construction

An intelligent water cooling method considering the temperature of cooling water is adopted for precise control of water flow. Based on measured data and validated predictive analysis models, construction instructions for water cooling are formulated according to idealized temperature control construction requirements. Subsequent temperature control work is then completed through automated control equipment or manual operation.

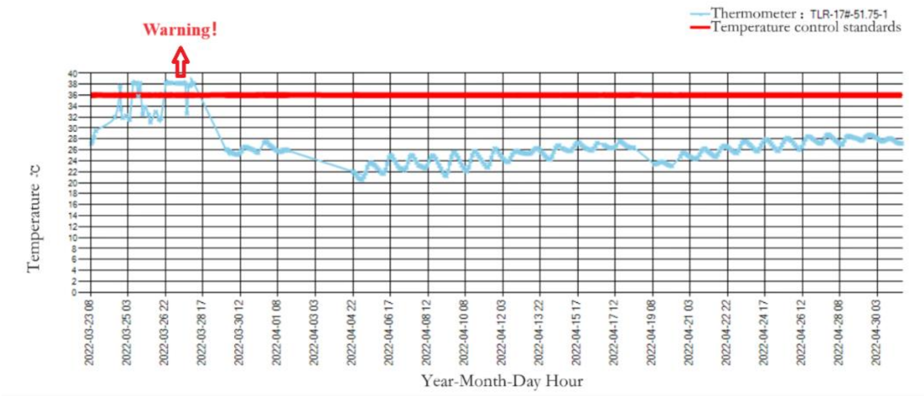

Fig. 3. Maiwan Water Conservancy Hubs 17 # Dam block-51m Storehouse temperature Warning - Control Process

5 Real-time Monitoring of Grouting throughout the Entire Process

The large amount of data and complexity of construction processes, coupled with the significant challenge of controlling construction quality, pose great challenges to on-site quality control personnel in the consolidation grouting and anti-seepage curtain holes of the Maiwan Reservoir Project and the Tianjiaotan Reservoir Project. The intelligent grouting management module utilizes BIM technology and information processing techniques to achieve the informatization, visualization, and intelligence of grouting data management, ensuring controlled quality of grouting projects[16].

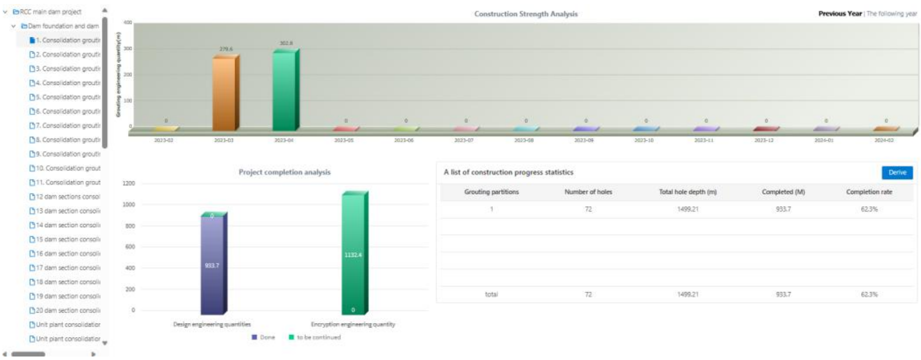

Fig. 4. Intelligent grouting system progress display page

The intelligent grouting module automatically uploads massive data generated during the construction process to the system and organizes it systematically. It visually displays the construction intensity of grouting and the progress of the project through graphs such as histograms and pie charts. For instance, the graphical display area of geophysical exploration shows the changes in pre- and post-grouting acoustic wave detection values for each grouting unit project. This area intuitively illustrates the effect of consolidation grouting on the increase in rock acoustic wave velocity. The display area for the list provides a clear view of the pre- and post-grouting acoustic wave velocity values of each grouting unit, and analysis indicators include average value, average of maximum values, average of minimum values, acoustic wave distribution ratio, deviation, and the rate of increase in acoustic wave velocity before and after grouting. It also supports the export function of detection results.

Furthermore, the intelligent grouting module is combined with a three-dimensional BIM model. It utilizes data transmitted in real-time by the grouting recorder as the basis to drive the BIM model, providing a visual representation of the construction progress, grouting-related data, and grouting quality and analysis. Additionally, by integrating grouting lifting monitoring recorder data into the system and leveraging its powerful warning capabilities, it provides early warnings based on indicator parameters. It promptly sends warning messages to key project management personnel, accelerating feedback and enhancing control capabilities[16,18,19].

6 Conclusion

The intelligent compaction system was officially put into operation during the concrete construction of the first warehouse of the dam on March 22, 2022. The intelligent monitoring system for compaction quality of the Maiwan Reservoir Dam completed the monitoring of the 56th warehouse, while the Tianjiaotan Reservoir Dam's intelligent monitoring system for compaction quality completed the monitoring of the 27th warehouse on September 16, 2022.

The application effects of key intelligent construction technologies and intelligent construction management platforms in the Maiwan Reservoir Project and the Tianjiaotan Reservoir Project mainly manifest in the following aspects:

(1) Specialized research on standards and measures for compaction, temperature control, and other aspects is conducted based on the characteristics and difficulties of dam construction in tropical regions. Through comprehensive monitoring and real-time adjustment of dam temperature, compaction quality, test curves, and other information, the overall dam construction process is ensured to proceed efficiently and with high quality.

(2) The application of intelligent construction systems such as intelligent mixing, intelligent vehicle transportation, intelligent compaction, and intelligent temperature control effectively support project construction management and promote high-quality construction of the projects.

The intelligent construction processes of the Maiwan Reservoir Project and the Tianjiaotan Reservoir Project represent important applications of intelligent key technologies and theories. The critical technologies developed can provide better technical support for major water conservancy projects in tropical regions.

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