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The Practice and Innovation of Construction Control Technology of Cracks in Prestressed Members in Construction Engineering

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Abstract: This article focuses on the control of cracks in prestressed concrete structures. It explains the stress characteristics, influencing factors, and causes of crack formation during construction. The article introduces advanced technologies such as intelligent prestressed tensioning, highlights key aspects like high-performance concrete mix design, and discusses various monitoring and control methods. It also covers their practical applications and achievements in real-world projects, and looks ahead to future development directions.

Keywords: Prestress; Crack control; Concrete structure

1. Introduction

With the development of the construction industry, prestressed concrete structures have been widely used in various engineering projects. The Guiding Opinions on Promoting the Coordinated Development of Intelligent Construction and Building Industrialization, released in 2020, emphasized the importance of intelligent and collaborative development in the construction industry. The stress characteristics of prestressed concrete structures are unique, and their pre stress is influenced by various factors. At the same time, concrete shrinkage and creep, temperature stress during construction, and tension control deviation can all lead to crack formation. Measures such as intelligent prestressing technology and optimization of high-performance concrete mix proportions are crucial for controlling cracks. These technologies are in line with policy guidance, aimed at improving building quality and durability, and promoting the intelligent and high-quality development of the construction industry.

1.1. Mechanism and technical principles of crack formation in prestressed components

1.1.1. Mechanical characteristics analysis of prestressed components

The stress characteristics of prestressed concrete structures are unique. The distribution pattern of pre stress is influenced by various factors, such as the arrangement of prestressed reinforcement and the magnitude of tension-controlled stress. Reasonable arrangement of prestressed steel bars can enable the structure to obtain compressive stress in advance before bearing loads, effectively improving the crack resistance performance of the structure. The impact of concrete shrinkage and creep on structures cannot be ignored. Shrinkage will reduce the volume of concrete and generate tensile stress, while creep will cause structural deformation to increase over time. In prestressed components, the shrinkage and creep of concrete can cause prestress loss, change the distribution of prestress stress, and affect the structural stress performance [1]. Therefore, in the design and construction process, it is necessary to fully consider these factors and take corresponding measures to control the occurrence of cracks.

1.2. Research on the mechanism of crack formation

Various factors during the construction phase can lead to the formation of cracks in prestressed components [2]. In terms of temperature stress, after pouring concrete, the hydration heat causes an increase in internal temperature, followed by shrinkage during the cooling process. When restrained, tensile stress may occur, which may lead to crack formation. When controlling the deviation of tensioning, the application of prestress is unreasonable. If the tensioning stress is too large or too small, it will change the stress state of the component. Excessive tensioning stress may cause the concrete to locally bear excessive tensile stress and crack, while insufficient tensioning stress cannot effectively offset the tensile stress generated by the load. Improper curing of concrete, such as insufficient humidity and curing time, can cause rapid loss of moisture, leading to shrinkage cracks, and also affecting the strength development of concrete, reducing its ability to resist cracks. These factors interact with each other and jointly affect the formation of cracks in prestressed components.

2. Core technology system for construction crack control

2.1. Pre stressing intelligent tensioning technology

In the domain of prestressed intelligent tensioning, the cornerstone is the creation of a BIM-based three-dimensional coordinate control system that governs every strand and tendon of prestressed reinforcement [3]. By embedding precise geometric and material attributes into a federated 3D model, BIM delivers millimeter-level spatial positioning data that guide installers in real time, eliminating the positional deviations that traditionally trigger early-age cracking and long-term durability loss. Concurrently, state-of-the-art intelligent tensioning rigs continuously synchronize hydraulic pressure, elongation, and anchor-set values across multiple jacks through high-frequency IoT sensors. Cloud analytics compare measured stress waves against BIM-derived target envelopes; any divergence exceeding tolerance thresholds triggers immediate, algorithmic compensation, dynamic pressure trimming, micro-timing shifts, or strand-specific re-tensioning, so that the final force distribution mirrors the design intent with sub-percent accuracy. The synergy of BIM spatial control and closed-loop stress governance not only upgrades the quality and uniformity of prestressed elements but also minimizes crack potential, extends service life, and underwrites structural safety in aggressive environments.

2.2. Collaborative control of concrete pouring quality

Optimizing high-performance concrete mix proportions is the linchpin of collaborative quality control during placement. Leveraging machine-learning algorithms and multi-objective genetic optimization, the system simultaneously evaluates fineness, reactivity, and particle packing of cement, aggregates, micro-silica, nano-clays, super-plasticizers, shrinkage-reducing and viscosity-modifying admixtures to predict strength, modulus, and autogenous shrinkage with laboratory-grade accuracy *in silico*. The resulting recipe is continuously refined by feeding real-time rheology and temperature data from the batch plant back into the model, ensuring crack-resistant performance under site-specific curing regimes. Concurrently, a dynamic coupling control framework integrates wireless compaction meters embedded in poker vibrators with strain-gauged formwork shores. An edge-computing module correlates vibration energy, concrete density, and formwork deflection in a closed loop, automatically modulating vibration amplitude and sequentially tightening or loosening shore screws to neutralize local stress concentrations. This real-time synchronization between mix design intelligence and placement mechanics secures uniform stress distribution, suppresses plastic settlement and thermal cracking, and delivers defect-free, durable concrete elements [4].

3. Dynamic monitoring technology for construction process

3.1. Real time monitoring system for stress field

3.1.1. Layout of fiber bragg grating sensing network

Designing the topology structure of the sensor array for prestressed critical sections is an important step in the layout of fiber Bragg grating sensing networks. The distribution position of sensors needs to be determined based on the stress characteristics of the components and key parts to accurately obtain stress information [5]. At the same time, the spacing between sensors should be considered to avoid information loss or resource waste caused by sparsity or density. Establishing a stress field data acquisition and transmission system is also crucial. The collection system needs to ensure stable and efficient acquisition of sensor data, while the transmission system needs to ensure real-time and accurate data transmission. Suitable communication protocols and transmission media can be used to timely transmit the collected data to the monitoring center for subsequent analysis and processing.

3.1.2. Multi source data fusion analysis

It is crucial to construct a numerical analysis model that couples temperature, stress, and strain multiple physical fields in order to effectively control cracks in prestressed components. Through this model, the influence of temperature changes on stress and strain can be comprehensively considered, thus more accurately simulating actual working conditions. At the same time, sensor technology is used to collect real-time multi-source data such as stress, strain, and temperature at the construction site, and these data are fused into a numerical analysis model. The process of data fusion requires the use of advanced algorithms and analysis techniques to ensure that the model can reflect the actual state of the structure in real time. On this basis, by setting reasonable thresholds and warning mechanisms, when the model calculation results show that the risk of cracks reaches a certain level, timely warning information is issued to provide a basis for construction personnel to take corresponding measures, thereby effectively preventing the occurrence and development of cracks [6].

3.2. Digital construction management platform

3.2.1. Construction of digital twin model

To establish a robust construction-process visualization system that seamlessly merges 3D laser scanning with BIM, the workflow begins by deploying high-speed, phase-based terrestrial laser scanners to capture dense, millimeter-accuracy point clouds of the evolving site. These point clouds, enriched with intensity and RGB values, are automatically registered through iterative-closest-point algorithms that leverage both target-based and targetless geo-referencing, yielding a cohesive 3D snapshot of every structural member, tendon duct, and temporary support. Next, the point cloud is aligned to the federated BIM model via a cloud-to-BIM matching engine that employs vowelized cross-correlation and semantic surface descriptors, allowing dynamic verification of as-built versus as-designed geometries.[7] Discrepancies exceeding predefined tolerances, such as misaligned anchor plates, displaced reinforcement cages, or formwork offsets and are instantly flagged in an augmented-reality dashboard, enabling crews to rectify deviations before concrete is cast or tendons are stressed. The same fusion platform continuously feeds updated geometric data to predictive crack-control modules that recalculate prestress losses and early-age restraint stresses in real time. Consequently, the integrated system not only safeguards dimensional accuracy and schedule adherence but also provides the precise, data-rich feedback loop required to prevent cracking in prestressed components throughout the entire construction cycle.

3.2.2. Design of quality traceability mechanism

In construction, establishing a construction parameter blockchain certification system is the key to quality traceability mechanism. Through this system, various parameters during the construction process, such as material properties of prestressed components, construction process parameters, etc., can be recorded and stored in real time. These data are guaranteed to be authentic and complete by the tamper proof nature of blockchain. During the construction process, data from every stage is accurately recorded, from the incoming inspection of raw materials to the processing and production of components, and then to on-site installation. This forms a traceable quality control chain throughout the entire process. Once quality problems such as cracks occur, they can be quickly traced back to the source of the problem, determining whether it is caused by material issues, construction operation issues, or other factors. Effective corrective measures can be taken to improve construction quality and management efficiency [8].

4. Technological innovation and engineering practice

4.1. Research on the application of new materials

4.1.1. Self-compacting compensating shrinkage concrete

Self-compacting compensating-shrinkage concrete (SCCSC) is a next-generation engineered material that merges two synergistic technologies: high-flowability self-compacting concrete and controlled expansive mineral systems. The mix is proportioned with optimized powder content, comprising low-heat Portland cement, finely ground slag, and limestone micro-filler, to achieve plastic viscosity below 250 Pa·s and slump-flow above 650 mm, enabling complete gravity-driven filling of congested reinforcement, thin webs, and intricate tendon profiles without any vibration [9]. Simultaneously, a precisely calibrated blend of calcium sulfa-aluminate-based Type K expansive agent, crystalline waterproofing admixture, and shrinkage-reducing polymer is incorporated to generate restrained expansion of 0.02–0.04 % within the first 7 days. This early-age expansion counteracts autogenous and drying shrinkage that typically develop later, effectively neutralizing tensile stresses that initiate micro-cracking. Real-time wireless maturity sensors embedded in the pour validate that expansion peaks before initial set, ensuring that prestressing strands remain fully bonded and that long-term prestress losses are minimized. Field trials on post-tensioned box girders show a 70 % reduction in surface crack density and a 25 % increase in chloride diffusion resistance compared with conventional vibrated concrete. By integrating SCCSC into critical prestressed elements, segmental bridges, containment vessels, and offshore platforms, where engineers secure superior durability, extended service life, and enhanced structural safety while accelerating construction schedules through elimination of vibration operations.

4.1.2. Research and development of intelligent prestressed reinforcement

The design of intelligent steel strands with built-in sensing units is the key to the development of intelligent prestressed reinforcement. This intelligent steel strand can sense its stress state in real time by cleverly integrating sensing technology. The sensing unit can accurately capture various changes in the steel strand during the stress process and convert this information into readable data. This has brought many advantages to engineering practice, such as allowing construction personnel to timely understand the stress situation of steel strands in prestressed components during the construction process, thereby more accurately controlling the construction process and avoiding problems such as cracks caused by improper stress. At the same time, real-time data feedback also helps to dynamically evaluate the safety and stability of the entire structure, providing reliable guarantees for the long-term use of buildings [10].

4.2. Innovation in construction technology

4.2.1. Pre stressing timing optimization technology

Establishing a graded tensioning timing control strategy based on the mechanical characteristics of the construction phase is the key to prestressing timing optimization technology. Through in-depth analysis of the mechanical properties of components during the construction phase, determine the appropriate timing and intensity of prestressing application at different stages. In practical operation, considering the setting and hardening process of concrete and the changes in structural stress state, accurately plan the time nodes and stress levels for graded tensioning. This strategy can effectively avoid the problem of component cracks caused by applying prestress too early or too late, and improve the quality and durability of prestressed components. At the same time, with the help of advanced monitoring technology and numerical simulation methods, real-time monitoring and feedback of mechanical parameters during the construction process are carried out to further optimize the graded tensioning timing control strategy, ensure that the construction process meets the design requirements, and achieve effective control of cracks in prestressed components.

4.2.2. Active temperature field control technology

Active temperature-field control technology has become indispensable in modern construction, especially for massive prestressed elements whose early-age thermal gradients can trigger through-section cracking and long-term durability loss. At its core lies an intelligent temperature-control and curing system that continuously monitors both the evolving hydration-heat signature of the concrete and the fluctuating ambient conditions. Embedded sensor arrays that comprising thermocouple strings, fiber-optic DTS cables, and wireless humidity probes, feed millisecond-resolution data to an edge-computing gateway. Machine-learning algorithms fuse these readings with weather forecasts and mix-specific thermal models to predict temperature trajectories up to 48 hours ahead. When the core-to-surface differential approaches a preset threshold, which typically 20 °C for high-performance mixes, and when the system autonomously triggers targeted interventions. Excessive hydration heat is dissipated via atomized misting nozzles integrated into the formwork, variable-flow embedded cooling pipes, or phase-change panels that absorb latent heat. Conversely, when ambient temperatures drop below a calibrated set-point, resistive heating blankets, infrared emitters, or circulated warm glycol loops are activated to maintain isothermal curing. The closed-loop controller continuously recalibrates valve positions, pump speeds, and heater duty cycles, ensuring that concrete remains within the optimal 10–35 °C envelope throughout the critical first 72 hours. By maintaining a dynamic equilibrium between internally generated heat and external thermal loads, the system mitigates tensile stresses in prestressed components, suppresses delayed ettringite formation, and ultimately enhances structural safety, service life, and construction quality.

4.3. Engineering application verification

4.3.1. Case study of large-span bridge engineering

Crack control technology played a key role in the construction of prestressed box girders for a certain cross sea bridge. In this project, strict control over the quality of raw materials ensured the stability of concrete performance and reduced the possibility of cracks caused by material problems. At the same time, advanced prestressing technology is adopted to precisely control the magnitude and distribution of prestressing, effectively avoiding cracks caused by uneven stress. During the construction process, real-time monitoring of temperature and humidity is carried out, and construction techniques are adjusted based on the monitoring results, such as arranging pouring time and maintenance measures reasonably to prevent cracks caused by temperature stress and shrinkage deformation. Through the comprehensive application of these crack control technologies, the crack situation of the prestressed box girder of the cross-sea bridge has been effectively controlled, improving the quality and durability of the box girder, and providing useful reference and inspiration for similar large-span bridge projects.

4.3.2. Practice of super high-rise buildings

In the practice of super high-rise buildings, the construction of the core tube prestressed transfer layer faces many challenges. Through technological innovation, the design of prestressed components has been optimized to better adapt to the complex stress conditions of super high-rise structures. During the construction process, advanced prestressing equipment and technology are used to strictly control the tensioning stress and elongation, ensuring the accuracy of prestressing application. At the same time, strengthen the quality control and mix design of concrete raw materials to improve the crack resistance of concrete. A specialized construction sequence and quality control points have been developed for the special structural form of the core tube, such as strict inspection of the steel reinforcement layout and anchoring of key parts. Through the comprehensive application of these measures, the occurrence of cracks in prestressed components has been effectively controlled, the construction quality of the core tube prestressed conversion layer has been improved, and strong guarantees have been provided for the structural safety of super high-rise buildings.

5. Summary

The construction control technology for cracks in prestressed components has achieved significant results in practice. In terms of innovation, a series of effective crack control technologies have been developed, which have significant advantages in both technology and economic benefits compared to traditional processes. Technically, it can more accurately control the occurrence of cracks; Economically, it has reduced maintenance costs caused by crack problems. At the same time, a quality management system for the entire life cycle of prestressed structures based on intelligent construction technology has been proposed, which will further enhance the ability to control cracks in prestressed components. Looking ahead to the future, digital and intelligent technologies have broad development prospects in the field of crack prevention and control. Through intelligent sensors and other devices, the status of components can be monitored in real time, and crack risks can be warned in advance. By utilizing big data analysis, crack control strategies can be continuously optimized, providing more efficient and accurate solutions for crack control of prestressed components in construction.

Disclosure statement

The author declares no conflict of interest.

References

[1] Sanabra Loewe M, Capellà Llovera J, 2014, The Four Ages of Early Prestressed Concrete Structures, PCI Journal, 59(4): 93–121.

[2] Fei D, 2023, Research and Analysis on Technological Innovation of Prefabricated Building Construction, in: Advances in Urban Construction and Management Engineering, CRC Press: 447–452.

[3] Yousefpour H, Gallardo J, Helwig T, et al., 2017, Innovative Precast, Prestressed Concrete Network Arches: Elastic Response During Construction, Structural Concrete, 18(5): 768–780.

[4] Fleischman R, Seeber K, 2016, New Construction for Resilient Cities: The Argument for Sustainable Low Damage Precast/Prestressed Concrete Building Structures in the 21st Century, Scientia Iranica, 23(4): 1578–1593.

[5] Dawood M, Taher H, 2021, Various Methods for Retrofitting Prestressed Concrete Members:1A Critical Review, Periodicals of Engineering and Natural Sciences (PEN), 9(2): 657-666

[6] Bonopera M, Chang K, Lee Z, 2020, State-of-the-Art Review on Determining Prestress Losses in Prestressed Concrete Girders, Applied Sciences, 10(20): 7257.

[7] Vijayan D, Sivasuriyan A, Devarajan P, et al., 2023, Development of Intelligent Technologies in SHM on the Innovative Diagnosis in Civil Engineering—A Comprehensive Review, Buildings, 13(8): 1903.

[8] Anay R, Lane A, Jáuregui D, et al., 2020, On-site Acoustic-Emission Monitoring for a Prestressed Concrete BT-54 AASHTO Girder Bridge, Journal of Performance of Constructed Facilities, 34(3): 04020034.

[9] Life-cycle Civil Engineering: Innovation, Theory and Practice: Proceedings of the 7th International Symposium on Life-Cycle Civil Engineering (IALCCE 2020), October 27–30, 2020, Shanghai, China, 2021, CRC Press.

[10] Kaur H, Singh J, 2017, A Review on External Prestressing in Concrete, International Research Journal of Engineering and Technology, 4: 1801–1805.