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Prevention and Quality Control of Temperature Cracks in Mass Concrete of High-Level Basement

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Abstract. The raft and thick base slabs of high-rise building basements often involve the one-time pouring of mass concrete, where the cumulative hydration heat of cement, combined with foundation pit constraints and diurnal temperature fluctuations, easily leads to thermal cracks. These cracks compromise structural durability and cause leakage, posing a key challenge in the construction and management of high-rise underground projects. Addressing issues such as insufficient targeted temperature control, rough construction management, and unstable crack prevention effectiveness in high-rise basement mass concrete, this paper analyzes the causes and influencing factors of thermal cracks based on practical engineering. It outlines crack prevention techniques tailored to the complex conditions of basement construction from key aspects like raw material optimization, establishes a comprehensive quality control system, and refines control standards for each construction process. Engineering verification demonstrates that this temperature control and crack prevention method, along with a quality management approach, effectively reduces internal and external temperature differentials in concrete, inhibits crack development, enhances construction quality, and ensures the stability and durability of underground structures. It provides a valuable reference for crack management and quality control in similar projects.

Keywords: mass concrete, basement, high-rise building, temperature cracks, crack prevention, temperature control, quality control in engineering

1. Introduction

Numerous scholars have conducted extensive research on crack prevention in large-volume concrete, establishing a basic temperature control system through on-site monitoring and numerical simulation. Zhu Bofang established the theory of temperature stress in large-volume concrete and proposed a temperature control calculation method and control threshold [1]. Qiu Anbing's thermal-mechanical coupling simulation shows that for every 5℃ increase in mold temperature, the peak temperature rise inside the concrete increases by 6-8 ℃, and the risk of cracking increases significantly [2]. Chen Gang proposed on-site control indicators based on raft testing projects, with an internal and external temperature difference of less than 25℃ and a cooling rate not exceeding 2 ℃/d. However, existing research mainly focuses on open-pit projects such as dams and bridges, and there is a lack of specialized research on high-rise basements. General temperature control measures

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make it difficult to form a refined control system that adapts to basement conditions, and there is insufficient analysis of crack evolution laws under multi-parameter coupling [3, 4]. International research is developing towards digitalization, with numerical simulation and machine learning capable of simulating crack evolution under complex constraints. New materials such as phase change energy storage can achieve active crack control, while fiber optic sensing and digital twins can dynamically regulate maintenance parameters. However, the mechanism model for adapting to basements is not perfect, the cost of new materials is high, and there is a lack of unified standards for digital twins. In-depth research is still needed to prevent and control crack risks throughout the entire cycle.

The hydration and heat storage of thick raft concrete cause internal expansion, and surface heat dissipation is subjected to tension, resulting in surface cracks; In the later stage, the overall cooling shrinkage is constrained by the foundation cushion layer, forming tensile stress. The cracks further develop into deep or through cracks, and in the water and soil environment, through cracks will form leakage channels, damaging the structure's self-waterproofing [5]. Based on the above research status and engineering problems, this article takes the large-volume concrete in high-rise basements as the object, analyzes the crack mechanism and influencing factors in combination with on-site working conditions, studies comprehensive prevention and control technologies, sorts out the key points of quality control throughout the entire process, summarizes the comprehensive temperature control and crack prevention control strategies that are suitable for complex conditions in basements, suppresses crack development, improves concrete construction quality, and provides practical reference for similar projects.

2. Formation mechanism of temperature cracks in large volume concrete of high-rise basement

2.1. Definition of large volume concrete and core temperature control indicators

According to the "Construction Standard for Large Volume Concrete" (GB 50496-2018), the minimum geometric size of concrete structures shall not be less than 1 0 m, and concrete structures that are prone to temperature stress and volume deformation caused by hydration heat during the construction phase and are prone to cracking are all classified as large volume concrete [6]. The raft and thick bottom plates of high-rise basements generally meet this definition standard, and under normal working conditions, the maximum temperature inside the concrete should be controlled not to exceed 75℃, the temperature difference between the inside and outside of the structure should be less than 25℃, and the cooling rate should not exceed 2℃/d, in order to avoid cracking problems caused by sudden temperature stress changes.

2.2. Mechanism of temperature cracks

After the completion of concrete pouring, cement undergoes a hydration reaction with water and releases a large amount of hydration heat. The thickness of the raft is large, and the thermal conductivity of the concrete is poor, making it difficult for heat to dissipate outward. The internal temperature of the component rapidly increases, causing volume expansion, while the surface of the component is in direct contact with the outside air, resulting in fast heat dissipation, small temperature rise, and weak expansion deformation.

Internal expansion and surface expansion are limited, and the surface concrete is subjected to internal and external tensile stress. When the tensile stress exceeds the tensile strength of concrete,

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surface temperature cracks first occur [7]. As time goes by, the overall temperature of the components begins to decrease, and the concrete shrinks as a whole. The foundation and cushion layer have a restraining effect on the bottom of the raft, which limits the shrinkage deformation of the concrete and generates significant tensile stress internally, leading to the development of deep cracks or even through cracks. At the same time, the basement floor is constantly in a water and soil environment, and through cracks, water seepage channels can form, damaging the structure's self-waterproofing [8].

3. Analysis of the main influencing factors of temperature cracks in large volume concrete

3.1. Impact of raw material performance

The type and unit dosage of cement are the core factors determining the hydration heat level of concrete. Ordinary Portland cement has a fast hydration reaction rate and concentrated heat release. The higher the unit dosage of cement, the greater the overall temperature rise inside the concrete, and the higher the risk of structural cracking [3]. Poor grading of coarse and fine aggregates and excessive mud content will directly reduce the compactness and tensile strength of concrete, weakening the structure's own crack resistance reserve. If the selection and proportion of mineral admixtures are not reasonable, the early hydration reaction of concrete will be too severe, and temperature stress will accumulate rapidly, which can easily induce early temperature cracks [4]. The compatibility defects of the cementitious material system can amplify the hydration heat effect, further increasing the probability of crack occurrence [9].

3.2. Construction process impact

The pouring process directly affects the uniformity of the temperature field inside the concrete. Excessive thickness of one-time pouring can cause a large accumulation of internal heat, resulting in excessive temperature difference between the inside and outside; If the pouring rate is too fast and the vibration operation is not dense, it will form pore defects inside the concrete, weaken the overall structure, and induce local cracks [5]. Improper control of interlayer spacing in layered pouring can easily form construction cold joints, disrupt temperature stress distribution, and promote further crack propagation. The failure of temperature control during mold insertion is a common problem on site. Under high-temperature conditions in summer, the mold insertion temperature is too high, which will increase the overall temperature rise and significantly increase the difficulty of temperature control and prevention [8].

3.3. Maintenance and environmental factors impact

The maintenance conditions are the key external factors for temperature crack prevention and control. Failure to timely implement insulation and moisture retention coverage, insufficient curing time, and inadequate water replenishment after concrete pouring can cause rapid loss of surface moisture, rapid surface cooling rate, and the formation of drying shrinkage temperature-coupled cracks [7]. In winter, there is no insulation protection for low temperatures, causing a sudden drop in the surface temperature of concrete and a sharp expansion of the temperature difference between inside and outside; Exposure to sunlight in summer and large temperature differences between day and night can also disrupt the balance of the temperature field. The special environment of sealed

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and humid foundation pits in high-rise basements can also cause uneven distribution of maintenance humidity, further increasing the risk of cracking [10].

3.4. Structural constraints and temperature control monitoring effects

The bottom plate of a high-rise basement is rigidly constrained by the foundation cushion layer, limiting the degree of structural deformation freedom and making it difficult to release temperature shrinkage stress, which is an important cause of through-temperature cracks [11]. There are defects in the temperature monitoring system at the construction site, such as insufficient layout of measuring points, low monitoring frequency, and lagging data feedback, which makes it impossible to grasp the real-time evolution characteristics of structural temperature, dynamically adjust temperature control measures, and intervene in the problem of temperature difference exceeding the standard in a timely manner, ultimately leading to crack damage.

4. Comprehensive prevention and control technology for temperature cracks in large volume concrete of high-rise basement

4.1. Optimization technology for raw materials and mix proportions

Priority should be given to using low hydration heat retarding ordinary Portland cement, while meeting the requirements of structural strength and durability, and the benchmark cement dosage should not exceed 220 kg/m ^{3}; Using a binary composite admixture of fly ash and mineral powder to replace some cement, the total dosage of the dual admixture should be controlled at 20% to 40%, with fly ash accounting for 15% to 25% of the cementitious material and mineral powder accounting for 10% to 15% of the cementitious material, in order to delay the release rate of hydration heat and reduce the peak temperature rise of the concrete as a whole [3]. Strictly control the quality of coarse and fine aggregates, strictly adhere to the specified limits for sand and gravel mud content (stone mud content $\leq$ 1%, sand mud content $\leq$ 3%), and improve the compactness and tensile performance of concrete. Add a high-efficiency retarding polycarboxylate superplasticizer at 1.2% to 2.0% of the quality of the cementitious material to improve the workability of concrete, prolong the initial setting time, avoid short-term concentrated release of hydration heat, and reduce the risk of cracking from the source of the material [9].

4.2. Layered and segmented pouring construction technology

For thick basements, the inclined layered pouring process is adopted, with a single-layer pouring thickness controlled at 300-500 mm. The interlayer pouring interval is strictly controlled, and the upper layer of concrete must be poured before the lower layer of concrete sets to prevent construction cold joints. Implement layered vibration during pouring to achieve dense and uniform compaction, prevent missed or excessive vibration, and reduce internal defects in the concrete. Control the pouring rate, strictly control the temperature of concrete entering the mold to $\leq$ 30℃, and further control it within 28℃ during high-temperature construction in summer to stabilize the initial temperature conditions and reduce the initial temperature rise of concrete [10].

4.3. Internal water circulation cooling technology

When the thickness of the component is greater than 1.5 meters, a pre-embedded serpentine circulating cooling water pipe is used to carry out internal forced cooling. The horizontal spacing of

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cooling water pipes is 800- 1000 mm, the vertical layer spacing is 1000mm, and the distance between water pipes and the edge of the structure is not less than 500mm, achieving full coverage of cooling inside the components. After the concrete pouring is completed, circulating cooling water should be promptly introduced, and the water flow rate and flow rate should be dynamically adjusted based on on-site temperature measurement data to remove the accumulated heat inside, control the temperature rise rate, reduce the temperature difference between the inside and outside of the component, and avoid local concentration of temperature stress [5].

4.4. Whole process temperature monitoring technology

Establish a temperature monitoring system for the entire process, deploy temperature sensors at key locations such as the center, surface, bottom, and corners of the concrete, and collect temperature data at different locations. Encrypt monitoring within 48 hours after pouring is completed, and collect one set of data every 2 hours; After 48 hours, the monitoring frequency is dynamically adjusted based on the temperature rise curve, and the internal temperature, surface temperature, and environmental temperature changes of the foundation pit are continuously tracked. When the monitoring results approach the standard control threshold (maximum internal temperature of 75℃, temperature difference between inside and outside of 25℃, cooling rate of 2℃/d), adjust the cooling water flow rate in a timely manner, synchronously thicken the surface insulation layer, and ensure that all temperature control indicators are within the allowable range [6].

5. Construction of a quality control system for the entire construction process

5.1. Quality control during construction preparation stage

Strictly carry out technical work in the early stage of construction, and prepare a special temperature control and crack prevention construction plan based on the structural dimensions of the project basement, construction season, and foundation pit conditions. Strictly inspect the performance indicators of raw materials and eliminate the use of unqualified materials. The layout and debugging of cooling water pipes and temperature measurement points on the construction site should be completed in advance, and supporting facilities for drainage, shading, and insulation should be improved. The risk of temperature differences and constraints during the construction process should be predicted in advance, and targeted emergency response measures should be formulated.

5.2. Quality control during construction pouring stage

Strictly control the pouring temperature, pouring thickness, and vibration quality during the pouring process, arrange dedicated personnel to be on duty throughout the entire process, and monitor the on-site temperature and construction status in real time. Strictly implement the layered pouring and layered vibration process to ensure that the concrete is formed densely. Synchronize the operation and maintenance of the cooling water circulation system to ensure smooth and leak-free pipelines, and stable operation of the cooling system. Standardize the retention of construction images and temperature measurement raw data, eliminate illegal and extensive construction issues, and ensure controllable construction quality during the pouring stage.

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5.3. Quality control during maintenance and operation stage

Implement a responsibility system during the maintenance phase, strictly implement the maintenance plan, and eliminate problems such as missed maintenance, insufficient maintenance period, and inadequate coverage. Real-time tracking of temperature monitoring data, dynamically adjusting maintenance and cooling parameters; Regularly inspect the surface of the structure, identify subtle cracks and hidden dangers, and strengthen insulation and moisture retention in weak areas. After the maintenance is completed, the insulation layer should be removed layer by layer, and it is forbidden to remove it all at once to ensure smooth cooling of the concrete and prevent cracks caused by sudden temperature differences.

There are abundant studies on temperature control and crack prevention of large-volume concrete, but there are still deficiencies in systematic research on strong constraints, closed foundation pits, and thick raft conditions in high-rise basements. Temperature cracks are controlled by hydration heat, internal and external temperature differences, constraint conditions, cooling rate, and maintenance measures. The focus of prevention and control is to suppress internal temperature rise, reduce internal and external temperature difference, release temperature stress, and curb early crack propagation.

In terms of temperature stress research, scholars combined finite element simulation and on-site monitoring to reveal the development law of cracks. Qiu Anbing confirmed through thermal coupling finite element analysis that the key influencing factors of cracking are the mold temperature, hydration heat temperature rise, cooling rate, and constraint conditions, providing a theoretical basis for raft temperature control. In engineering practice, technologies such as raw material optimization, layered pouring, cooling water pipe cooling, and insulation maintenance are widely used. Chen Gang, Xiao Zhixue, and others combined raft engineering to propose multidimensional control ideas and support crack prevention processes.

Overall, although existing research has achieved many results, the shortcomings are still evident. Most of the computational models and engineering experience come from water conservancy and bridge engineering, and there is insufficient specificity for the strong constraint conditions of thick raft slabs in high-rise basements; The research on the evolution law of cracks under multi-factor coupling is not systematic enough, and the integration degree of monitoring data and numerical simulation needs to be improved. Although intelligent monitoring and digital simulation are gradually developing, their systematic and engineering applicability in complex excavation environments is limited. Therefore, it is necessary to focus on the characteristics of high-rise basement engineering, carry out refined temperature control and crack prevention research, and construct a quality control system that is suitable for the complex working conditions of basements.

5.4. Engineering application examples

5.4.1. Project overview

Selecting the underground raft engineering of a 33-story high-rise residential project as the verification object, the total height of the building is 99.6 meters, the size of the basement raft is 38 meters×25 meters, and the thickness of the raft is 2.2 meters. It belongs to a typical large-volume concrete component, with a concrete design grade of C40P8 and a one-time overall pouring volume of 3800 cubic meters. The construction time is May, and the on-site foundation pit is sealed. The temperature difference between day and night environments is 12-15℃, and the rigid constraint of the foundation cushion layer is strong, with a high risk of cracking. This project adopts the complete

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technical system proposed in this article, including optimized raw material mix ratio, inclined layered pouring, internal circulating cooling water pipes, temperature monitoring throughout the entire process, and quality control throughout the entire construction cycle.

5.4.2. On-site implementation plan

Low-hydration heat ordinary Portland cement is selected, with a cement content of 170 kg/m³, combined with binary composite admixtures of fly ash and mineral powder, with fly ash content of 130 kg/m³and mineral powder content of 90 kg/m³. Additionally, 6.5 kg/m³ of high-performance slow-setting carboxylic acid water reducer is added. During the construction phase, strict control is maintained over the silt content of aggregates, and the temperature of concrete as it enters the mold is measured on-site and stabilized at 28 ℃ [12]. The project adopts a sloping layered pouring method, with each layer maintained at a thickness of 400 to 500 mm, ensuring that the upper layer is poured before the initial setting of the lower layer. During the construction process, vibrations are applied in layers to avoid issues of missed or excessive vibrations. Φ40 mm serpentine cooling water pipes are embedded inside the raft, with horizontal and vertical spacing of 1000 mm, and the pipe wall is no less than 500 mm away from the component edge. After pouring, circulating cooling water is introduced, and the flow rate of cooling water is dynamically adjusted based on temperature measurement data collected on-site [13]. The project deploys 32 wireless temperature sensors at the center, corners, surface, and bottom of the raft, collecting temperature data every 2 hours within 48 hours after pouring. After 48 hours, the monitoring frequency is adjusted, and the internal, surface, and foundation pit ambient temperatures of the concrete are simultaneously collected. When the monitoring indicators approach the specification limits, the flow rate of cooling water and the number of layers of surface insulation covering are promptly adjusted. After the initial setting of the concrete, plastic film is used in conjunction with two layers of insulation blankets for heat and moisture retention. A dedicated maintenance personnel system is implemented, with a maintenance period set at 21 days. After maintenance, the insulation layers are gradually removed, and it is prohibited to remove them all at once to avoid the risk of cracking caused by sudden temperature drops [1]. The on-site temperature measurement statistics show that the maximum temperature inside the center of the concrete reaches 59 ℃, which is below the project's internally controlled limit of 75 ℃. The temperature peak occurs 62 hours after pouring, and the maximum temperature difference between the interior and surface of the component is 21 ℃, which is less than the control threshold of 25 ℃ specified in GB50496-2018. After implementing these temperature control measures, no harmful through cracks appeared in the raft structure [12].

5.4.3. Actual monitoring data and crack observation results

The on-site measured temperature statistics are as follows:

1) Peak temperature: The maximum temperature at the center of the concrete is 59 ℃, which is lower than the control limit of 75 ℃ in the specification. The temperature peak appeared 62 hours after pouring.

2) Internal and external temperature difference: The maximum temperature difference between the interior and surface of the component is 21 ℃, which is less than the control threshold of 25 ° C.

3) Cooling rate: The measured average cooling rate during the cooling stage is 1.2 ℃/d, which meets the standard requirement of ≤ 2℃/d, and there is no sudden temperature drop phenomenon.

After the maintenance period, a crack survey was conducted on the entire area of the raft using visual observation and a crack width detector. Only two shallow microcracks with a width of 0.1

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mm were found at local corner positions, and no deep or penetrating temperature cracks were found. The solid anti-seepage test of the raft meets the P8 design level requirements, and there is no water seepage or moisture regain disease in the basement. The average measured compressive strength of the 28-day concrete cube is 48.5 MPa, which meets the C40 strength design requirements and the overall construction quality is controllable.

5.4.4. Example analysis

The practice of high-rise basement raft engineering under the condition of a sealed foundation pit shows that the comprehensive prevention and control system proposed in this paper, including raw material optimization, layered pouring, water pipe circulation cooling, whole-process temperature measurement, and whole-process quality control, can effectively reduce the peak hydration heat, stabilize the temperature difference and cooling rate inside and outside within the allowable range of the specifications, and significantly suppress the occurrence of harmful temperature cracks. The actual test results of the project confirm the feasibility of the aforementioned temperature control and crack prevention technology, which can provide practical reference for the construction of similar thick basement raft slabs.

6. Conclusion

This article reviews the current research status of temperature crack prevention and quality control in large-volume concrete of high-rise basements, analyzes the formation mechanism and main influencing factors of temperature cracks, and systematically summarizes comprehensive prevention and control technologies such as raw material mix ratio optimization, layered and segmented pouring, internal water circulation cooling, and whole-process temperature monitoring, as well as the key points of whole process quality control. Strictly implementing and dynamically adjusting the above-mentioned conventional temperature control measures for special working conditions such as strong constraints on high-rise basement foundations and sealed foundation pits is a practical way to suppress crack initiation and ensure structural durability.

With the continuous iteration of numerical simulation, intelligent sensing, and new material technology, existing research results and engineering techniques can effectively deal with temperature cracking problems under conventional construction conditions, effectively suppress the initiation and expansion of harmful cracks inside concrete, significantly improve the forming quality of high-rise basement concrete structures, and improve the structural impermeability and long-term waterproof durability. However, there are special conditions such as strong foundation constraints and enclosed foundation pit environments in high-rise basements, and the adaptability of the existing comprehensive prevention and control system in such complex working conditions still needs further deepening and improvement.

Authors contribution

All the authors contributed equally and their names were listed in alphabetical order.

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