Technical Analysis of Concrete Crack Prevention and Control in Construction Engineering

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Abstract: This paper addresses the issue of concrete cracks in construction engineering, which affect structural safety and durability. By analyzing the three core causes of cracks—material, construction process, and environmental factors—it explores corresponding technical prevention and control approaches. Adopting a "problem-oriented - technology adaptation" approach, it summarizes a three-dimensional prevention and control system consisting of optimizing material proportions, standardizing construction processes, and adapting environmental measures. The paper elucidates the roles of each technology in reducing crack risks and enhancing concrete performance. The research results aim to provide practical prevention and control solutions for engineering practice, helping to minimize concrete cracks and ensuring the long-term stability of building structures.

1. Introduction

In construction engineering, concrete cracks are a common quality issue that not only affects the appearance of buildings but also potentially weakens structural load-bearing capacity and shortens service life. Crack formation is closely related to material proportions, construction operations, and environmental conditions. If not properly prevented and controlled, cracks can easily lead to subsequent issues such as water leakage and steel reinforcement corrosion. To address this pain point, it is necessary to systematically sort out the causes of cracks, conduct targeted research on prevention and control technologies, and clarify key technical points at each stage. The following will explore concrete crack prevention and control solutions from a technical analysis perspective, aiming to prevent cracks from weakening structural load-bearing capacity, ensure building safety, prevent rainwater and harmful substances from infiltrating and causing steel reinforcement corrosion, extend structural service life, reduce later repair costs, enhance engineering economic benefits, ensure engineering quality meets standards and complies with regulations, and lay a solid foundation for the long-term stable operation of construction engineering.

2. Causes of Concrete Cracks in Construction Engineering

2.1 Unreasonable Material Proportions

There is a contradiction between the amount of cementitious materials and hydration heat. If the cement content in the mix proportion is too high, a large amount of heat will be released during cement hydration, causing the internal temperature of the concrete to rise rapidly, while the surface temperature is lower due to faster heat dissipation. When the temperature stress caused by the internal-external temperature difference exceeds the tensile strength of the concrete, irregular temperature cracks will form on the structural surface. Especially in mass concrete, cracks caused by this internal-external temperature difference are more likely to penetrate deep into the structure [1]. Improper control of the water-cement ratio is another factor. If the water-cement ratio is too large, significant dry shrinkage deformation will occur during concrete hardening due to water evaporation. At the same time, excess water will form pores inside the concrete, reducing structural density and tensile properties. In dry environments, dry shrinkage cracks that follow the direction of

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steel reinforcement or are randomly distributed are prone to appear. Deviations in aggregate gradation and dosage also contribute to crack formation. If the aggregate gradation is discontinuous or the amount of fine aggregate is excessive, the workability of the concrete mixture will decline, making segregation more likely during construction. Moreover, after hardening, the bonding area between aggregates will decrease, weakening the overall tensile capacity of the structure. Fine cracks are prone to form during setting shrinkage, and these cracks will gradually expand over time, affecting structural durability.

2.2 Non-standard Construction Processes

During the pouring process, improper vibration operations can cause problems. If the moving spacing of an immersion vibrator is too large or the vibration time is insufficient, air bubbles and voids will remain inside the concrete, forming local weak areas. These areas are prone to cracks first when subjected to loads or temperature changes. Excessive vibration, on the other hand, can cause aggregate to sink and cement paste to float up, forming an "segregation layer." The surface cement paste layer has a high shrinkage rate and is prone to net-shaped cracks after hardening. Neglect in the curing process can also lead to cracks. If the concrete surface is not covered for moisture retention within 12 hours after pouring or if the frequency of water spraying during curing is insufficient, the surface water of the concrete will evaporate rapidly. The surface shrinkage rate will be much faster than that of the interior, creating "surface tensile stress." When this tensile stress exceeds the tensile strength of the surface concrete, parallel surface shrinkage cracks will form along the pouring direction. Although these cracks are shallow in depth, they can damage the integrity of the concrete surface and provide channels for the penetration of harmful substances [2]. Improper timing of formwork removal can also cause cracks. If the load-bearing formwork is removed prematurely before the concrete strength reaches 75% of the design value, the concrete structure will be unable to bear its own weight and construction loads, resulting in bending cracks at the mid-span or supports. These cracks are mostly distributed perpendicular to the direction of the applied force and can cause structural deformation in severe cases.

2.3 Environmental Factors

Temperature changes can cause cracks. In summer, under high-temperature conditions, the surface of the concrete is rapidly heated by direct sunlight after pouring. If there is a sudden heavy rain or rapid cooling at night, the surface concrete will shrink rapidly due to the "temperature shock," while the internal concrete is still expanding due to slower heat dissipation. This stress difference between internal expansion and external shrinkage will cause irregular temperature cracks on the surface, which are mostly radial or net-shaped. In winter construction under low-temperature conditions, if no insulation measures are taken after concrete pouring, when the ambient temperature drops below 0°C, the free water inside the concrete will freeze and expand, increasing the volume by about 9%. This will damage the internal structure of the concrete. After thawing, pores and micro-cracks will form inside, and these micro-cracks will gradually expand into macro-cracks under subsequent loads. Uneven foundation settlement can also lead to cracks. If the foundation is not fully compacted before construction or the soil layers of the foundation are unevenly distributed, the foundation will experience uneven settlement after the concrete structure is poured. The structure bottom will be subjected to "differential settlement forces," causing inclined settlement cracks at weak stiffness positions. These cracks mostly extend upward from the foundation and can penetrate the entire structural layer in severe cases, affecting structural stability [3]. Humidity changes can cause dry shrinkage cracks. If the concrete is exposed to a dry environment for a long time, internal moisture will continuously diffuse to the outside, causing overall dry shrinkage deformation of the concrete. When the structure is restrained and unable to shrink freely, "restraint tensile stress" will be generated. When this tensile stress exceeds the tensile strength of the concrete, parallel dry shrinkage cracks will form along the direction of the restraint. These cracks are mostly straight and evenly distributed.

3. Application Strategies of Concrete Crack Prevention and Control Technologies in Construction Engineering

3.1 Optimizing Concrete Material Proportions

Firstly, optimize the cementitious material system. After determining the benchmark mix proportion according to the engineering type (mass concrete or ordinary beam-slab concrete), reduce the cement content (it can be controlled below 300 kg/m³ for mass concrete). Add Class I fly ash (accounting for 20%-30% of the total cementitious materials) or S95 ground granulated blast furnace slag (accounting for 30%-40%) in proportion. These admixtures can not only replace part of the cement to reduce hydration heat, lowering the maximum internal temperature by 8-12°C, but also fill the gaps between cement particles, improving concrete density [4]. At the same time, control the water-binder ratio. For ordinary concrete, it should not exceed 0.55, and for mass concrete, it should not exceed 0.5. Improve the workability of the mixture and reduce the unit water consumption by adding polycarboxylate superplasticizers (at a dosage of 0.8%-1.2%), thereby reducing the risk of dry shrinkage deformation from the source. Secondly, adjust the aggregate gradation and dosage. Select continuously graded aggregates (such as 5-25 mm crushed stone) and ensure that the aggregate gradation curve meets the specification requirements. The proportion of medium-coarse aggregates (particle size 10-25 mm) should be no less than 60%, and the amount of fine aggregates (medium sand) should be controlled within 30%-40% of the total aggregate amount to avoid an excessive amount of fine aggregates leading to an increased shrinkage rate. Before aggregates enter the site, their silt content should be tested (the silt content of crushed stone should not exceed 1%, and that of sand should not exceed 3%). High silt content will weaken the bonding force between aggregates and cement paste, and water washing treatment should be carried out to reduce the silt content to the standard range [5]. Thirdly, add functional admixtures. For structures prone to cracks, add polypropylene fibers with a length of 6-12 mm at a dosage of 0.9 kg/m³ to the mix proportion. The fibers form a three-dimensional network structure inside the concrete, which can disperse shrinkage stress, improve the tensile strength of the concrete (by 15%-20%), and inhibit the formation and expansion of micro-cracks. For underground structures with crack resistance requirements, calcium aluminate expansive agents can also be added at a dosage of 8%-10% to compensate for concrete dry shrinkage through their expansion effect and further reduce crack risks.

3.2 Standardizing Construction Process Operations

During the pouring process, strictly control the vibration quality. Determine vibration parameters according to the concrete slump (such as 180±20 mm). Select a Φ50 immersion vibrator, control the moving spacing within 300-400 mm, and set the vibration time to 20-30 s until the concrete surface shows floating slurry, no longer sinks, and no bubbles escape. Insert the vibrator 50 mm into the lower layer of concrete to ensure tight bonding between the upper and lower layers. Avoid touching the steel reinforcement and formwork with the vibrator during vibration to prevent steel reinforcement displacement or formwork damage, which could lead to insufficient density of local concrete. For areas with dense steel reinforcement, use a Φ30 small vibrator and cooperate with manual tamping to ensure proper vibration in these areas and avoid voids due to vibration blind spots [6]. In the curing process, implement the requirements of "timely covering and continuous moisture retention." After concrete pouring, cover it with geotextile or plastic film within 4 hours in summer and within 8 hours in winter. Ensure that the film or cloth is tightly attached to the concrete surface without air pockets. Control the ambient humidity during curing. Spray water 3-4 times a day in summer to keep the geotextile moist, and use double curing with film covering and insulation quilts in winter to avoid rapid water evaporation. The curing time for ordinary concrete should be no less than 14 days, and for mass concrete, due to its long hydration heat release period, the curing time should be extended to more than 28 days. Regularly detect the surface temperature of the concrete during curing to ensure that the internal-external temperature difference does not exceed 25°C [7]. During formwork removal, follow the principle of "strength compliance and orderly removal." Before removal, detect the strength of the concrete specimens cured under the same conditions. The load-bearing formwork can only be removed when the specimen strength reaches 75% of the design value, and the formwork for cantilever structures can only be removed when it reaches 100% of the design value. Remove the formwork in the order of "non-load-bearing formwork first, load-bearing formwork later, and side formwork first, bottom formwork later." Use special tools to slowly loosen the formwork during removal to avoid violent removal that could damage the concrete surface or cause vibration cracks. After formwork removal, inspect the concrete surface. If fine cracks are found, promptly seal them with cement-based permeable crystalline waterproof coatings to prevent further crack expansion.

3.3 Adapting Construction Measures to Environmental Conditions

In summer high-temperature construction, take measures from two aspects: "temperature reduction and rhythm control." For raw material temperature reduction, build sunshades over the aggregate stockpiles to avoid direct sunlight. Use ice water to mix with aggregates, with the ice water temperature not lower than 5°C. Crushed ice can be added during concrete mixing, with the amount not exceeding 20% of the total mixing water, to ensure that the concrete placing temperature is controlled below 30°C. For pouring rhythm control, avoid pouring during the high-temperature period at noon (11:00-15:00) and choose the morning and evening periods. Pour in sections, with each section length not exceeding 5 m, and cover immediately after pouring to reduce surface exposure time [8]. Embed temperature sensors inside the concrete to monitor the internal temperature in real-time. When the internal-external temperature difference exceeds 25°C, cover the surface with insulation quilts to reduce temperature difference stress by "insulating to delay heat dissipation." In winter low-temperature construction, implement three-step measures: "raw material preheating, pouring insulation, and later curing." For raw material preheating, heat the mixing water to a temperature not exceeding 80°C and heat the aggregates with steam to a temperature not lower than 5°C to ensure that the concrete discharge temperature is not lower than 10°C and the placing temperature is not lower than 5°C. During pouring, speed up the construction rhythm to reduce the residence time of the concrete on site and avoid rapid temperature drop. Cover the poured concrete immediately with insulation quilts and electric blankets, and if necessary, install heating pipes on the outside of the formwork to maintain the concrete temperature above 0°C. Regularly detect the concrete strength during curing, and do not remove the insulation until the strength reaches 75% of the design value and the ambient temperature stabilizes above 5°C [9]. To address the risk of foundation settlement, carry out layered compaction treatment of the foundation before construction. The compaction thickness of each layer of backfill soil should not exceed 300 mm, and the compaction degree should reach 93% or more (detected by the ring knife method). For soft soil foundations, use replacement methods (replace with graded sand and gravel) or lime soil lime soil compaction piles for reinforcement. Set settlement observation points at the four corners and middle positions of the structure during concrete pouring and observe them every 3 days. If the settlement difference between adjacent observation points exceeds 5 mm, adjust the pouring sequence from the area with less settlement to the area with more settlement and slow down the pouring speed to allow the foundation enough time to adapt to the load, avoiding structural cracks caused by uneven settlement.

4. Conclusion

The above analysis shows that concrete crack prevention and control require the construction of a full-process technical system based on the causes of cracks. Optimizing material proportions can reduce internal stress from the source by adjusting cementitious materials, aggregate gradation, and adding admixtures. Standardizing construction processes involves controlling key links such as pouring vibration, curing, and formwork removal to avoid cracks caused by improper operations. Adapting environmental measures requires targeted control of temperature and settlement influences according to the characteristics of summer and winter seasons and foundation conditions. The synergistic effect of these three types of technologies can effectively reduce crack formation, ensure the quality and safety of concrete structures, and provide reliable technical references for crack prevention and control in similar projects.

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