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Causes of Cracks in Large-Scale Concrete Projects and Preventive Measures

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Abstract. Large-scale concrete is widely used in large dams, super high-rise buildings, large-span bridges, and other projects, among which cracks have become the most prominent quality problem in construction and later use. Nowadays, there have been relatively complete research results on the prevention and control of concrete cracks, but a complete system has not yet been formed. This article systematically sorts out the main categories of cracks in large-volume concrete engineering and explains the reasons for their formation from four dimensions: raw materials and mix proportions, structural design, construction management, and later maintenance. The core causes of cracks are the temperature difference between the inside and outside due to hydration heat, stress concentration, non-standard construction operations, and lack of maintenance control. This article summarizes the severe engineering challenges caused by cracks, such as leakage, steel corrosion, and deterioration of structural durability, from four dimensions of prevention and control measures. Integrating existing engineering experience and research results, it aims to construct a complete and replicable prevention and control system for the entire process of large-volume concrete cracking, aiming to provide practical guidance for similar projects to reduce crack incidence and extend structural service life.

Keywords: large concrete, Hydration heat, Temperature cracks, Construction management, Crack prevention and control

1. Introduction

Nowadays, the problem of concrete cracks has become the most serious issue affecting the safety, stability, and service life of engineering structures. Cracks not only damage the integrity of the structure, but also cause water vapor to enter and cause corrosion of the steel bars, further exacerbating the damage to the structure and increasing the cost of later repair and maintenance. Therefore, it is of great significance to investigate the causes and preventive measures of large-scale concrete cracks.

At present, scholars have conducted extensive research on the problem of concrete cracks, mainly identifying triggering factors such as load effects, output effects, temperature stress effects, structural settlement effects, and construction cracks. In response to the above factors, existing research has developed mature improvement methods from four aspects: material selection and

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proportioning optimization, structural form and section design, construction technology and operation, temperature control guarantee, and post-maintenance management. Firstly, in terms of material selection and proportioning optimization, the Li Wenwei team of Yangtze Three Gorges Group Co., Ltd. has developed a new type of micro-expansion, low-heat Portland cement and high-crack-resistant dam concrete to address the problems of "low heat, expansion, and cement cracking"; the team's method is to precisely control the content of magnesium oxide within the range of 3.5% to 5%, thereby achieving later expansion compensation and effectively solving the problem of crack prevention in large-volume concrete [1]. According to public reports in 2025, no temperature cracks were found in the two dams poured using this technology within 8 years of operation. In addition, research on the optimization of material mix proportions and performance parameters based on concrete has also confirmed that adjusting the mix proportions can significantly improve the cracking problems caused by temperature changes and shrinkage, while significantly enhancing the crack resistance of concrete [2]. Secondly, in terms of structural form and section design, by optimizing the structural form of the structure reasonably, it is possible to prevent sudden changes in section size. Gradual transition sections can be set at structural changes, effectively reducing stress concentration and lowering the risk of cracking [3]. In terms of construction technology and operation, previous studies have shown that there are significant differences in the anti-seepage and crack prevention effects of dam concrete under different construction processes. The reasonable selection of construction plans has an important impact on crack control [4]. Meanwhile, by establishing standardized and refined operational requirements, human factors can be significantly reduced. The risk of cracks can be reduced. Finally, in terms of temperature control and post-maintenance management, researchers have designed a temperature control and maintenance layout plan for large-volume raft structures. By laying cooling water pipes and covering them with double-layer insulation blankets, the temperature difference between inside and outside can be controlled. At the same time, watering maintenance is carried out to ensure that the structure does not crack. After extensive comparative analysis, all measured temperature control parameters are within the recommended range, thus verifying the effectiveness of this temperature control maintenance technology [5].

Due to the significant harm of large concrete cracks in today's engineering, this article will adopt a review method to explain the types and main causes of large concrete cracks, and analyze the causes from four aspects: material ratio, structural design, construction technology, and later maintenance. And collect literature to integrate systematic preventive measures for domestic use.

2. Analysis of the causes of cracks in large-volume concrete

2.1. Material factors

The ratio of concrete raw materials and their own properties are the core internal factors that induce early cracks, such as the imbalance of any additive components such as cement and aggregates, which can pose a great risk of cracking. The most significant impact of materials is temperature, first and foremost the phenomenon of cement hydration heating. Cement hydrates when it comes into contact with water, releasing a large amount of heat. At the same time, the surface cement directly contacts the air and dissipates heat quickly. However, the internal cement, due to poor heat dissipation, has a higher temperature than the outside, resulting in a significant temperature difference between the inside and outside. According to the principle of thermal expansion and contraction, the internal concrete expands at high temperatures, while the external concrete shrinks at low temperatures, resulting in tensile stress caused by deformation of both. When the tensile

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stress exceeds the tensile strength of concrete, temperature cracks will appear on the surface [6]. In addition to temperature factors, the control of sand content in the raw material ratio is particularly critical. Research has shown that sand ratio has a significant threshold effect on the shrinkage and crack resistance of concrete. Taking specific experimental data as an example, when the sand ratio is between 42% and 43%, the flowability and cohesiveness of concrete reach their optimal state; And once the sand ratio exceeds the threshold and reaches 44%~45%, the total specific surface area of the aggregate increases sharply, causing the mixture to quickly transform into a "viscous and fast collapsing" state, and the plastic shrinkage cracks of the concrete significantly increase [7]. Therefore, in engineering practice, it is necessary to strictly control the sand ratio within this threshold range to avoid early cracking caused by insufficient or excessively dry slurry. In addition, the particle size specification of coarse aggregate is also an important factor affecting crack control. When the maximum particle size of coarse aggregate is too large, it is not only prone to being blocked by steel bars, resulting in incomplete pouring, but also becomes a trigger for crack initiation due to the weak transition zone between the aggregate and cement slurry interface. According to the current national standard "Pebbles and Crushed Stones for Construction" (GB/T 14685-2022), the maximum particle size of coarse aggregate shall not exceed 1/4 of the minimum size of the structural section, and shall not exceed 3/4 of the minimum net distance of steel bars. In engineering practice, commonly used continuous particle size specifications include 5-16mm, 5-20mm, 5-25mm, and 5-31.5mm. Among them, the 5-31.5mm particle size specification is most conducive to suppressing shrinkage cracks in large volume concrete due to its strong skeleton support and low porosity [7].

2.2. Structural and structural design defects

Defects in structural and construction design are one of the important causes of cracks. In some projects, the spacing between expansion joints is set too large. For example, the temperature joints of a gravity dam are set at 30m, which exceeds the recommended range of 15- 20 m [6]. This results in excessively long pouring blocks, which are prone to developing longitudinal cracks running through the middle under the effects of temperature contraction and restraint. In addition, when the design does not incorporate effective temperature stress relief measures, or when the orientation of construction joints does not align with the direction of temperature stress, stress transfer cannot be blocked. Inconsistent deformation of concrete on both sides can also induce cracking [6]. The concrete gravity dam in Revelstoke, Canada, serves as a typical example: it stands at a height of 175 meters, spans 457 meters in length, and comprises approximately 1.9 million cubic meters of concrete. After the dam began to impound water in October 1983, large areas of vertical and transverse cracks appeared, and the seepage rate once reached 174L/min [8]. After emergency sealing treatment, the leakage was finally stopped. According to the initial analysis by Zhu Bofang, a CAE Member, such "head cracks" are closely related to the continuous casting method: since there are no longitudinal joints inside the dam, there is no secondary water pipe cooling before joint grouting. When the reservoir is filled with water, the temperature inside the dam remains high, while the water temperature is relatively low, resulting in a large temperature difference between the inside and outside. This makes it easy for a continuous casting normal concrete gravity dam to develop head cracks [8].

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2.3. Construction process issues

Improper construction on site is the direct factor inducing cracks in mass concrete. The risk of concrete cracking will be significantly increased if the vibration operation is not in place at the concrete pouring stage, the pouring rate is too fast, the pouring sequence is not properly planned, and the stiffness of the formwork support system is insufficient [1, 9]. Specifically, it is mainly reflected in the following three aspects: first, the transit and interruption time is too long. The measured data show that if the parking time of the mixture from mixing to the site exceeds 120min, the slump and component compactness will be reduced, and the later cracking probability is 28% higher than that in other areas [10]. If the interruption time of a single pouring exceeds 4 hours, the interface bonding strength decreases significantly, and it is very easy to form through cracks in the follow-up. The second is improper vibration control. Excessive vibration will cause the aggregate to sink and the mortar to float up. When the stacking thickness of the surface mortar exceeds 15mm, the surface shrinkage will be concentrated and a network of fine cracks will be generated; However, if the vibration is insufficient, internal loose defects will occur, and the defect will crack first after the stress. The third is the deviation between formwork and protective layer construction. The formwork was dismantled more than three days in advance, and the early strength was insufficient, resulting in the detection rate of surface microcracks reaching 41% [10]. The deviation between the actual thickness of the reinforcement protective layer and the design value is more than 8mm, which will also change the stress state of the surface layer. On this basis, the protective layer is too thin, which is prone to steel corrosion. Expansion cracking and thicker concrete will reduce the tensile properties of the surface layer [10]. Guoyonghui and others took a water-rich railway tunnel in Southwest China as an example. After the rain, they found that the lining structure was damaged and displaced. They found that the pouring interval exceeded the initial setting time, resulting in the formation of a condensation surface between the new and old concrete. The subsequent rainstorm led to a sudden increase in the pressure of the groundwater level rise on the outside after the lining, resulting in an increase in the axial force in the cold joint, and the shear dislocation of the structure along the cold joint surface [11].

2.4. Later maintenance

The lack of concrete maintenance measures or inadequate control is an important factor inducing cracks in mass concrete. If the curing cycle is insufficient, the temperature control in the curing stage is not perfect, and the surface moisturizing measures are not in place, the structure will eventually crack [1]. Specifically, improper maintenance can induce cracks in two ways: one is that the temperature gradient is out of control. After the mass concrete is poured, the cement moisture continues to release heat, and the internal temperature rises sharply, while the heat dissipation on the surface is faster, forming a temperature gradient between internal heat and external cooling. When the internal and external temperature difference exceeds 25 °C, the surface concrete will produce tensile stress due to internal binding force from shrinkage. Once the tensile stress exceeds the tensile strength at that time, the surface area will produce cracks. If temperature control measures such as watering and moisturizing are not taken in a high-temperature environment, the hydration heat accumulation inside the concrete will lead to a significant increase in the temperature gradient; if thermal insulation and curing are not in place under a low-temperature environment, the temperature stress generated by the rapid cooling of the concrete surface may also exceed its early tensile strength, and both will cause cracking. This will lead to excessive internal temperature stress in the concrete and cracks [1]. The second is surface dehydration and shrinkage. After final setting, if the

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concrete is not covered with moisture in time, the evaporation rate of water on the surface exceeds the migration rate of internal water, forming a humidity gradient, causing the drying shrinkage stress on the surface and generating irregular network shrinkage cracks. Under the continuous effect of subsequent shrinkage, creep, and temperature changes, the early cracks will gradually expand into deeper structural cracks, even through the whole structure [1]. Taking the RCC gravity dam of Baishi Reservoir in Liaoning Province as an example, the foundation cushion concrete of the dam section 17#～26#was poured before the winter of 1996. After pouring, it was directly put into the river for overwintering. Because the temperature difference between inside and outside during overwintering was as high as 27.37 ～ 29.9 ℃, which was far higher than the 19 ～ 22 ℃ allowed by the specification, the foundation cushion concrete produced penetrating cracks [12]. However, the temperature difference between the inside and outside of the6# ～ 9# dam section poured in spring is only 14.06~17.9 ℃, within the allowable range, without cracks. This comparison fully shows that the key factor leading to cracks is the inadequate control of temperature difference during curing [12].

3. Crack prevention and optimization measures for large concrete engineering

3.1. Raw material selection and mix design optimization

In view of the above causes of cracks, it is also aimed at these four points to prevent and optimize. The core goal is to reduce the release of hydration heat and concrete shrinkage, so as to prevent and control the occurrence of temperature cracks. For mass concrete structures, slag Portland cement or fly ash Portland cement should be preferred. This kind of cement has a lower hydration heat level and can effectively reduce the temperature accumulation inside the concrete. On this basis, the technical scheme of using fly ash and slag to replace 30% -50% of cement in the total cementitious material can not only further optimize the comprehensive working performance of concrete, but also directly reduce the amount of cement [1]; This method can reduce the drying shrinkage of concrete by about 25%, and can significantly reduce the probability of cracks [1]. The aggregate link also needs to be optimized and adjusted: the category of continuous grading is preferred for coarse aggregate, and the mud content of sand and gravel is strictly controlled to reduce the shrinkage deformation of concrete. If necessary, retarding water reducer can also be added to delay the release rate of hydration heat, delay the occurrence time of internal temperature peak, and relieve the cracking pressure caused by internal and external temperature difference [1].

3.2. Optimization of structural design

In the design stage, the structural form of the structure should be reasonably optimized to avoid sudden changes in the section size. The transition section should be set at structural changes to reduce stress concentration and increase the reinforcement ratio, especially in parts prone to cracks, such as the junction of the pool wall and the bottom plate and around the hole; the appropriate amount of reinforcement should be configured. According to the climatic conditions of the project location and the characteristics of the structures, expansion joints and post-cast strips shall be reasonably set. The spacing of expansion joints shall not exceed 30m. The width of post-cast strips is generally 800 to 1000mm. The post-cast strips shall be closed after two months of concrete pouring on both sides [1]. A water cooling device is set inside the concrete to take away the heat inside the concrete and reduce the temperature difference between inside and outside by taking advantage of the large specific heat capacity of water.

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3.3. Optimization of construction management

In order to effectively prevent cracks, it is necessary to implement refined control over the whole construction process. First, strictly control the access of raw materials, establish a regular sampling inspection mechanism, and ensure that the incoming materials and various indicators strictly match the mix design requirements. Secondly, in the mixing process, it is necessary to accurately calibrate the metering system, strictly control the water-binder ratio and the amount of admixtures; the water-binder ratio of mass concrete should not be greater than 0.45, and enforce a concrete mixing time of no less than 120 seconds to ensure the uniformity and stability of the concrete mixture. At the same time, the flow direction and advancing speed of pouring should be scientifically planned at the stage of pouring operation to prevent cold joints formed due to too long an interval. For mass concrete, the method of layered pouring and layered vibration shall be adopted to control the thickness and time of each layer, strictly limit the thickness of single-layer pouring and the duration of vibration, prevent missing vibration or excessive vibration, and ensure the compactness of concrete. In addition, special acceptance shall be strictly carried out before the completion of pouring to confirm that the support is stable. At the same time, a special person shall be arranged to monitor the status of the formwork in real time during the pouring. Once deformation or displacement is found, the operation must be suspended immediately, and reinforcement measures must be taken to eliminate potential safety hazards [1]. At the same time, the formwork is one of the important parts that affect early concrete cracking. In the early stage, the cracks can be controlled by changing the heat exchange length of the formwork and the surface volume ratio of the structure. The conductivity of formwork materials and the length of removal time play a vital role in concrete cracking. With the improvement of the conductivity of the template material, the risk of cracking in the construction stage will gradually reduce, but the risk of cracking in the later stage of demoulding will increase [13].

3.4. Optimization of maintenance methods

In view of the lack of maintenance, it is necessary to introduce refined maintenance optimization measures in the construction, so as to block the source of cracks. First of all, the traditional single watering maintenance mode should be changed, and the double standards of temperature control and humidification should be adopted. The geotextile or plastic film should be covered immediately after the final setting of the concrete, which can not only prevent the water on the surface from evaporating too quickly, but also use the hydration heat for internal insulation to control the temperature difference. In addition, the fixed curing days should be abandoned, and dynamic adjustment should be made according to the field-measured temperature and humidity data: for mass concrete mixed with fly ash or slag, the curing time for moisture preservation and insulation should not be less than 14 days; For ordinary Portland cement, the curing time shall not be less than 7 days. Especially in areas with abundant groundwater or high wind speed, the curing time shall be appropriately extended. When removing the formwork, confirm that the concrete strength meets the corresponding requirements according to the component type and span, and the temperature difference between the surface of the concrete pouring body and the atmosphere should not be greater than 20°C; then remove the formwork and turn to natural curing. For the parts easy to crack, such as the side wall and bottom plate of the tunnel, spray curing or spraying a curing agent should be used to ensure the wettability of internal and external corners and construction joints, and avoid plastic cracks due to local rapid water loss [14, 15].

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3.5. New crack self-healing and repair technology

As the current social traditional cost of repairing cracks is gradually rising, such as labor cost and road closure cost of repairing pavement, the paper points out that concrete self-healing technology is a very promising new technology. Through self-healing repair of cracks, it reduces crack damage and repair costs. This new method uses Pasteurella, a serotonin-degrading bacterium. Based on the alkaline environment of concrete, researchers have developed a protective carrier for bacteria by using calcium aluminate sulfate cementation, which has a very obvious effect on the preservation of bacteria. Bacteria can enhance the local pH value by secreting catalysts, promote mineralization reactions inside the crack to fill the crack gap, and closely integrate with concrete [16].

4. Conclusion

The main causes of large-scale concrete cracks are caused by material factors, structural factors, construction factors, and maintenance factors. Since concrete cracks have not been studied as a complete system, the solutions are analyzed and integrated from these four aspects according to the existing research and analysis. In terms of materials, reduce the total hydration heat by optimizing the raw materials and mix proportion, and control the temperature difference by adjusting the use of aggregates and water-reducing agents to suppress cracks. In terms of structure, the risk of cracking is reduced by increasing the reinforcement ratio in places prone to cracking, and the internal water cooling device is installed to reduce the temperature difference between the inside and outside of the concrete. In terms of construction management, human risks are reduced through refined and standardized operations. In terms of maintenance, relevant rules and regulations should be specified to ensure the quality of maintenance. In the future, it can focus on the research of an intelligent maintenance system to automatically adjust the temperature and humidity by detecting the state of concrete, reduce the labor cost and improve the accuracy of maintenance. Finally, a new type of self-healing and repair technology is recommended to reduce crack damage and maintenance costs.

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