Crack mechanism and prevention measures of concrete in the initial pouring based on field temperature gradient experiment

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Abstract. To study concrete cracking, a feedback analysis on variations of surface temperature gradient has been conducted for concrete at the intermission stage of layer pouring with a precise model and finite element simulation method combined with in-situ experiments of a dry hot valley dam. This paper presents the results of concrete stresses and their development under real concrete temperature gradient and explores the internal crack mechanism and possible hidden cracks of the concrete. A discussion on effective measures for prevention of such cracking risk, particularly for construction of valley dams in a dry hot season is also given. This work is of practical reference value for construction of concrete structure in dry hot valley.

1. Introduction
In China, some regions in Yunnan, Sichuan and the Yunnan - Guizhou Plateau belong to those regions with the dry and hot weather, where some river valleys such as Jinsha River, Yuan River, Nanpan River and Nu River belong to the dry and hot river valleys. Along with development of Chinese water conservancy construction, many concrete dams were built in these regions. The typical climate characteristics of dry and hot river valleys are high temperature, lack of rainfalls, the ambient temperature in summer being often up to above 40°C, and frequent short-term extreme climates. When damming in these regions, the temperature control and crack prevention are relatively difficult (particularly, damming in high temperature season); and the cracking risks such as concrete being lowered sharply and low temperature cooling strike due to rainstorms are relatively common [1-3]. In some actual projects, cracks often occur during the construction period (Figure 1) due to many factors except for some objective weather factors, which include one key factor, namely being lack of experiment data and systematic analysis on the temperature gradient and real stress of concrete at early age; on the other hand, the previous analysis on the development variation processes of concrete surface temperature gradient during the interval is not fine to really reflect the actual temperature variation process, let alone master the actual stress variation processes of early age concrete[4-7]. Thus, the forecast of cracking risks of early age concrete is also short of objective evaluation and how to rationally select the temperature control measures for prevention of such cracking risks is free of effective basis, so cracking may be difficultly avoided.

The evaluation of the actual stress in pouring concrete in high temperature season, especially the correct analysis on the mutual relation between the surface temperature and stress variation processes
after just pouring concrete, is greatly of importance; and it is crucial to solve the current concrete surface crack prevention issue during the interval. As for concrete, pouring may give rise to the hydration reaction and the surface concrete may be influenced by the ambient temperature and hydration heat; the adiabatic temperature rise curves of indoor concrete laboratory experiments may basically reflect the actual heating processes; thus, the simulation of temperature fields is rational by using the indoor adiabatic temperature rise curves as the model in the traditional method for simulation and analysis. However, as for the stress fields, the similar method may not be used for simulation because the initial setting time is generally among 9~15 hours and concrete is plastic after pouring concrete, during which concrete temperature variation may not give rise to the stress variation; thus, the relation between the initial setting time and stress must be taken into account; especially, the early age concrete stress shall be estimated \cite{8,9}. In previous work, such relation between the initial setting time and stress is always ignored in the traditional analysis method so that the analysis results may always be not consistent with the actual results \cite{10-14}.

The study was carried out in view of such issue. Based on the temperature gradient tests, the symmetrical study was carried out to the relations between those factors such as concrete initial setting time, bad time variation, and the variation rules of temperature and stress of concrete at early age under different climate conditions; the further analysis was carried out to possible cracking risk and safety hidden dangers of the surface concrete under the interval; in addition, the corresponding measures and methods for prevention of such cracking risks in high temperature season were put forward to provide references for the crack prevention in similar subsequent projects.

![Figure 1](image)

**Figure 1.** Schematic diagram of the crack occurred at the interval during the construction period

1.1. **Feedback analysis on observation results of temperature gradient tests and temperature fields for construction in high temperature season of some certain dam**

Some high arc dam is located in a dry and heat river valley in China South - West Region, which was under the annual continuous construction, the maximum air temperature is often above 40°C in high temperature season and such region belongs to the typical dry and heat river valley climate. In accordance with the project crack prevention requirements, the comprehensive control temperature control measures such as low temperature pouring, flowing water cooling and surface heat preservation were taken for pouring such dam. For accurately obtaining the temperature gradient and the corresponding stress variation rules of the surface concrete at the interval during the dam construction period, the temperature gradient field tests were carried out. Such concrete lift is located in the elevation (361.8m - 364.8m) and is equipped with two layers of water pipes (1.5x1.5 layout). The cooling water temperature, water flowing rate, pouring temperature and ambient temperature are actual monitoring data in the field. Six thermometers are equipped along the elevation direction, whose specific positions are shown in Figure 2. The temperature gradient is monitored by a automatic temperature monitoring and recording device developed by our research group\cite{5}. At the same time, a refined simulation model was established for simulation of temperature fields in other regions of such concrete lift, in which the grid size for the surrounding tube walls is in mm - level; and the calculation model is shown in Figure 3.
The inverting analysis was carried out to the temperature field of each lift of concrete for this dam; moreover, the refined feedback was carried out to the testing temperature variation processes. The interval of the concrete lift is 7 days; and the monitoring temperature was mainly from those data during such 7 testing days. As shown in monitoring data in Figure 4, the temperature variation rules for different locations along the elevation direction are obviously different. The locations (5# and 6#) near the surface are influenced by the surface ambient temperature, water curing and other boundary conditions; the temperature of 5# location was maximum after about 1 day and then it was basically maintained in the subsequent 3 days; on the other hand, the temperatures of those locations (1#～4#) relatively far away from the surface basically gradually rose a long time. Figure 5 shows the obvious inside and outside temperature differences for concrete after 3~4 days. The comparison curves of the monitoring temperature values and the inversion temperature values for the typical locations are shown in Figures 6(a)～(d), from which it may be seen the feedback simulation results may relatively well reflect the actual temperature field distribution rules for this project; and the accuracy of simulation results of temperature and stress fields may provide the guarantee.
1.2. Simulation of stress fields based on the field temperature gradient tests and analysis on the cracking mechanism

Based on the field temperature gradient tests and the feedback analysis on temperature fields, the simulation and analysis were carried out to concrete temperature and stress fields; moreover, the possible cracking mechanisms were analyzed.

As shown the feedback temperature results in Figure 7(a), concrete temperature variation is independent on the initial setting time. After concrete pouring completed, the temperatures of inner locations were gradually increased along with the hydration reaction, and the inner temperature is more than the surface temperature after about 3 days; the peak temperature occurred at the age of about 5~6 days. The temperature of locations in different elevations changes variously with the flowing water cooling effect; and their temperatures are slightly different. In addition, the temperature of each surface location is greatly dependent on the ambient temperature; and the daytime and night temperature shows a trend of fluctuation.

With corresponding to the temperature processes, there is no inner stress in newly pouring concrete within the initial setting time (12 hours); and after such initial setting time, the inner stress in concrete changes along with the temperature variation. The inner stress is generally compressive when the temperature rises; on the other hand, the temperature of each surface location is remarkably dependent on the ambient temperature; the stress is compressive when the temperature rises and the stress is primarily tensile when the temperature drops. The main cause for there being tensile stress in the surface locations is the temperature drop process due to the temperature difference between day and night. As shown in Figure 7(b), the surface temperature is more than the inner temperature within 2 days after concrete pouring completed; on the other hand, the daily temperature drop process gives rise to the tensile stress in the surface. After the age of 3 days, the outer surface temperature is lowered below the inner concrete temperature; at this time, the superposed effect from the temperature difference between day and night and the difference between the inner and outer temperatures occurs. As shown in the comparison results between the surface concrete stress process and the allowable stress, concrete early age tensile stress is basically near or even more than the allowable tensile stress; such case shows that there may generally be relatively large cracking risk in the early age concrete surface. If the field prevention measure is not proper, cracks may possibly occur in the surface concrete.

![Figure 6. Comparison of the measured temperature results and feedback simulation results](attachment://image.png)
2. Study on influencing factors of early age concrete stress and crack prevention measures

For further understanding those influencing factors of concrete temperature and stress in the surface at the interval under different boundary conditions and easily providing the basis for adopting the corresponding temperature control and crack prevention measures, comparison and analysis of several schemes were carried out and the main results are listed as follows:

2.1. Influencing of the initial setting time for concrete stress

As shown in those results in Figure 8, the initial setting time may greatly influence the surface concrete stress; and the actual completed time for this concrete lift was about 3:00 in the morning. As shown in the measured ambient temperature, the subsequent temperature was always in the growth trend; if the initial setting time for concrete is not taken into account, the compressive stress occurs along with the growth of the ambient temperature; and the early compressive stress may be favorable for the crack prevention subsequently. On the other hand, there is no actually such reservation process for such compressive stress due to there being the initial setting time. After concrete has been initially set within 12 hours, concrete surface ambient temperature is up to the maximum value among one whole day and then it always drops; therefore, the initial tensile stress initially primarily occurs in concrete after its peak temperature but there is no any compressive stress reservation. Thus, if the initial setting time is not taken into account, the simulation results may possibly result in misled or weaken our understanding to the cracking risk of concrete at early age.

As shown in test results in Figure 9, different initial setting times, pouring completed time and the occurrence time for the daily maximum and minimum temperatures may comprehensively influence the development and variation rules of the surface stress in concrete at early age, and the optimization control shall be carried out by combining the actual conditions during the construction period.

Figure 8. Stress compared when considering the initial setting time or not

Figure 9. Initial setting time vs. concrete stress

2.2. Influencing of the pouring completed time for concrete stress
With assuming concrete initial setting time being 12 hours and the temperature difference between day and night being 10°C, the maximum and minimum temperatures occur in 3:00 o’clock and 15:00 o’clock. Comparison and analysis were carried out to the influence of concrete temperature and stress when concrete pouring completed at the daily maximum and minimum temperatures respectively. As shown in Figure 10, if concrete pouring is completed under the daily minimum temperature, the initial setting for concrete is completed in the corresponding maximum temperature; and then the ambient temperature is lowered and the initial stress is the tensile stress; on the other hand, if concrete pouring is completed under the daily average maximum temperature, the concrete surface stress will first manifests for the compressive stress after the initial setting, and such case should be favorable for crack prevention. In contrast, if concrete lift completed under the maximum concrete temperature, it is obviously favorable for lowering the surface tensile stress and the cracking risk. Therefore, how to hold the pouring completed time to more favorable for concrete temperature control and crack prevention in accordance with the field pouring capacity and concrete initial setting time is very important.

2.3. Crack prevention measures and scheme
By combining the above analysis, reasonable planning the concrete lift completed time is favorable for reducing the surface cracking risk, when concrete is initially set and the ambient temperature is the minimum value among one day, the optimal effect may be achieved; on the other hand, the pouring completed time of concrete may be deduced inversely in accordance with the initial setting time. In addition, the surface heat preservation and curing maintenance work must also be carried out to concrete at early age so as to lower the unfavorable effects due to the temperature difference between day and night or short-term temperature drop as can as possible; at the same time, the occurrence of local defect due to improper curing maintenance shall be avoided; thus, the cracking risk of concrete at early age at the interval may be effective prevented.

3. Conclusions and suggestions
(1) The tested field temperature gradient may be used to well reflect the distribution of temperature gradient of the surface concrete at the interval; thus it is favorable to reasonably evaluate the actual stress situations and risks of concrete at early age.

(2) As for the general concrete, once concrete is initially set under the comprehensive effect of the temperature difference between day and night and the inner and outer surface temperature difference, the relatively large cracking risks possibly occur; thus, the early surface curing and thermal insulation shall be well performed.

(3) The initial setting time must be taken into account for evaluation of the stress safety status of concrete at early age; otherwise, the judgment of cracking risks of concrete may possibly be weakened or misled.

(4) The best time for completion of initial setting of concrete is the time when the ambient temperature is the minimum value per day; and the corresponding inverse deduction may be carried

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Figure 10. Concrete stress vs. different pouring completed time
out to the optimal beginning and closing placed times. As shown in the calculation results, the cracking risks of concrete at the early age may be effectively lowered through the rational optimization of the pouring completed time.

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