Cooling and Insulating Systems for Mass Concrete

Reported by ACI Committee 207

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The need to control volume change induced primarily by temperature change in mass concrete often requires cooling and insulating systems. This report reviews precooling, postcooling, and insulating systems. A simplified method for computing the temperature of freshly mixed concrete cooled by various systems is also presented.

Keywords: cement content; coarse aggregate; creep; formwork; heat of hydration; mass concrete; modulus of elasticity; precooling; postcooling; pozzolan; restraint; specific heat; strain; stress; temperature rise; tensile strength; thermal conductivity; thermal diffusivity; thermal expansion; thermal gradient; thermal shock.

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CHAPTER 1—INTRODUCTION

1.1—Scope and objective

The need to control volume change induced primarily by temperature change in mass concrete often requires cooling

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and insulating systems. This report discusses three construction procedures used to control temperature changes in concrete structures: precooling of materials, postcooling of in-place concrete by embedded pipes, and surface insulation. Other design and construction practices, such as selection of cementing materials, aggregates, chemical admixtures, cement content, or strength requirements, are not within the scope of this report.

The objective of this report is to offer guidance on the selection and application of these procedures for reducing thermal cracking in all types of concrete structures.

1.2—Historical background

Major developments in cooling and insulating systems for concrete began with postcooling systems for dams. Later gains were made in developing precooling methods. The use of natural cooling methods has increased with the use of better analytical methods to compute thermal performance. Similarly, insulating systems expanded beyond just cold weather protection and into control of thermal gradients during other weather conditions.

The first major use of postcooling of in-place mass concrete was in the construction of the Bureau of Reclamation's Hoover Dam in the early 1930s. The primary objective was to accelerate thermal contraction of the concrete monoliths within the dam so that the contraction joints could be filled with grout to ensure monolithic action of the dam. Cooling was achieved by circulating cold water through pipes embedded in the concrete. Circulation of water was usually started several weeks or more after the concrete had been placed. Since the construction of Hoover Dam, the same basic system of postcooling has been used in the construction of many large dams and other massive structures, such as powerhouses, except that circulation of cooling water is now typically initiated immediately after placing the concrete.

In the early 1940s, the Tennessee Valley Authority used postcooling in the construction of Fontana Dam for two purposes: to control the temperature rise, particularly in the vulnerable base of the dam where cracking of the concrete could be induced by the restraining effect of the foundation; and to accelerate thermal contraction of the columns so that the contraction joints between columns could be filled with grout to ensure monolithic action. Postcooling was started coincidently with the placing of each lift of concrete. The pipe spacing and lift thickness were varied to limit the maximum temperature to a predesigned level in all seasons. In summer, with naturally high (unregulated) placing temperatures, the pipe spacing and lift thickness for the critical foundation zone was 2.5 ft (0.76 m); in winter, when placing temperatures were naturally low, the pipe spacing and lift thickness for this zone was 5.0 ft (1.5 m). Above the critical zone, the lift thickness was increased to 5.0 ft (1.5 m), and the pipe spacing was increased to 6.25 ft (1.9 m). Cooling was also started in this latter zone coincidently with the placing of concrete in each new lift.

In the 1960s, the Corps of Engineers began the practice of starting, stopping, and restarting the cooling process based on temperatures measured with embedded resistance thermometers. At Dworshak Dam and at the Ice Harbor Additional Power House Units, the cooling water was stopped when the temperature of the concrete near the pipes began to drop rapidly after reaching a peak. Within 1 to 3 days later, when the temperature would rise again to the previous peak temperature, cooling would be started again to produce controlled, safe cooling.

Generally, arch dams were constructed with postcooling systems to expedite the volume change of the mass concrete for joint grouting. The first roller-compacted concrete (RCC) arch dam was Knellpoort Dam in South Africa, completed in 1988. Due to the height and rapid construction of RCC arch dams, design engineers paid close attention to the heat-of-hydration issues due to their effect on the final stress state of the dam. In China, several arch dams have been completed, including Shapai Dam near Chengdu, China, which was the world's highest until 2004. At Shapai Dam, and others since, cooling pipes were embedded between some of the RCC lifts to circulate cool liquid to control the maximum internal temperature of the RCC. Testing showed that high-density polyethylene cooling pipes worked quite well with RCC. The controls and operation procedures for the RCC arch dams were the same as used in conventional concrete dams in the past. By late 2003, 14 RCC arch dams had been completed or were under construction, mainly in China and South Africa.

The first reported use of precooling concrete materials to reduce the maximum temperature of mass concrete was by the Corps of Engineers during the construction of Norfork Dam from 1941 to 1945. A portion of the batch water was introduced into the mixture as crushed ice. Placement temperature of the concrete was reduced by approximately 10 °F (6 °C). The concrete was cooled as a result of the thermal energy (heat of fusion) required to convert ice to water and from the lowered temperature of the water after melting. Since then, precooling has become very common for mass concrete placements. It also is used for placements of relatively small dimensions, such as for bridge piers and foundations where there is sufficient concern for minimizing thermal stresses.

Injection of cold nitrogen gas into the mixer has been used to precool concrete in recent years. Practical and economical considerations should be evaluated, but it can be effective. As with ice, additional mixing time may be required. Minor amounts of concrete cooling have been achieved by injecting it at transfer points on conveyor delivery systems, in gob hoppers, and in the mixing chamber. Nitrogen's main inefficiency is losing gas to the atmosphere if the mixer or transfer is not well enclosed.

Various combinations of crushed ice, cold batch water, liquid nitrogen, and cooled aggregate are used to lower placement temperature to 50 °F (10 °C) and, when necessary, to as low as 40 °F (4.5 °C).

RCC projects have effectively used "natural" precooling of aggregate during production. Large quantities of aggregate produced during cold winter months or during cold nighttime temperatures and stockpiled in naturally cold conditions can remain cold at the interior of the pile well into the warm