IN-LB	Inch-Pound Units
SI	International System of Units

Report on Cooling and Insulating Systems for Mass Concrete

Reported by ACI Committee 207

ACI 207.4R-20

American Concrete Institute
Always advancing

First Printing
November 2020
ISBN: 978-1-64195-124-1

Report on Cooling and Insulating Systems for Mass Concrete

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

www.concrete.org

ACI 207.4R-20

Report on Cooling and Insulating Systems for Mass Concrete

Reported by ACI Committee 207

Christopher C. Ferraro, Chair

Katie J. Bartojay, Secretary

Fares Y. Abdo
Oscar R. Antommatei
Terrence E. Arnold
Teck L. Chua
Timothy P. Dolen
Barry D. Fehl
John W. Gajda
Mario Garza
Melissa O. Harrison
Michael G. Hernandez
James K. Hicks
Rodney E. Holderbaum
Ronald L. Kozikowski Jr.
Tibor J. Pataky
Jonathan L. Poole
Harry B. Prenger
Ernest A. Rogalla
Ernest K. Schrader
Kuntay K. Talay
Nathaniel F. Tarbox
Michael A. Whisonant
Fouad H. Yazbeck

Consulting Members

Jeffrey C. Allen
Randall P. Bass
Anthony A. Bombich
Robert W. Cannon
Eric J. Ditchey
Brian A. Forbes
Allen J. Hulshizer
Richard A. Kaden
William F. Kepler
David E. Kiefer

The need to control volume change induced primarily by temperature change in mass concrete often requires thermal control of concrete. This report reviews these thermal control methods such as 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.

CONTENTS

ACI 207.4R-20 supersedes ACI 207.4R-05(12), was adopted July 30, 2020, and published November 2020.

CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Scope and objective

The need to control volume change induced primarily by temperature change in mass concrete often requires thermal control such as cooling and insulating systems. This report discusses three construction procedures used to control temperature changes in concrete structures: 1) precooling of materials; 2) postcooling of in-place concrete by embedded pipes; and 3) 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 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 only 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. 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.

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 the Shapai Dam near Chengdu, China, which was the world's highest until 2004. At the 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. 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, which reduced the temperature of the concrete. 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 other structural elements where there is sufficient concern for minimizing thermal stresses.

Injection of liquid nitrogen into the concrete mixer has been used to precool concrete in recent years. Although expensive, it may be cost-effective and could result in savings associated with less insulation and shorter construction schedules. 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. Some benefits of liquid nitrogen are that it can be added as many times as required and very low temperatures can be achieved without affecting mixture proportions. 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 35°F (2°C).

Insulation has been used since the 1950s on lift surfaces and concrete faces to reduce temperature gradients and prevent or reduce the potential for cracking. Insulation reduces overall cooling and helps prevent the surface from rapidly cooling due to changes in environmental conditions. A useful practice is to apply surface insulation in layers, such as with multiple blankets, so that the insulation can be removed gradually as appropriate.

In addition to reducing thermal stresses, other benefits result from mixing, placing, and curing concrete at lower temperatures, such as enhanced long-term durability and strength, improved consistency, and longer placement time.

1.3—Types of structures and temperature controls

Cooling and insulating systems have evolved to meet engineering and construction requirements for massive concrete structures, such as concrete gravity dams, arch dams, navigation locks, nuclear reactors, powerhouses, large footings, mat foundations, and bridge piers. They are also applicable to smaller structures where high levels of internally developed thermal stresses and potential cracks resulting from volume changes cannot be tolerated or would be highly objectionable (Tuthill and Adams 1972; Schrader 1987). More information on the requirements and definitions for mass concrete is provided in ACI 207.1R.

1.4—Construction practices for temperature control

Practices that have evolved to control temperatures, and consequently reduce thermal stress and cracking, are listed in the following. Some of these require minimal effort whereas others require substantial initial expense:

a) Cooling batch water
b) Producing, handling, and stockpiling aggregate during cold seasons or cool nights
c) Replacing a portion of the batch water with ice
d) Shading aggregates in storage
e) Shading aggregate conveyors
f) Spraying aggregate stockpiles for evaporative cooling
g) Immersion in cool water or saturation of coarse aggregates, including wet belt cooling
h) Vacuum evaporation of moisture in coarse aggregate
i) Nitrogen injection into the mixture and at transfer points during delivery
j) Using light-colored mixing and hauling equipment, and spraying the mixing, conveying, and delivery equipment with a water mist
k) Scheduling placements when ambient temperatures are lower, such as at night or during cooler times of the year
l) Cooling cure water and the evaporative cooling of cure water
m) Postcooling with embedded cooling pipes
n) Controlling surface cooling of the concrete with insulation
o) Avoiding thermal shock during form and insulation removal
p) Protecting exposed edges and corners from excessive heat loss
q) Cooling aggregates with natural or manufactured chilled air
r) Monitor ambient and material temperatures

1.5—Instrumentation

The monitoring of temperatures in concrete components such as stockpiles and in fresh concrete can be adequately accomplished with commercially available temperature measuring devices with typical resolution of 2°F (1°C). The ease of gathering temperature sensor data has been improved by the availability of wireless transmitters. The data acquisition is a temperature sensor started prior to the placement of concrete and provide updates wirelessly to a computer at the project job site, and if an internet connection is available, the data can be reviewed remotely or the computer can send alerts to team members when approaching the maximum allowable temperature or differential. This system improves safety at the job site because it is no longer necessary to site visits during off hours to a acquire data manually. In addition, some temperature sensors have built-in dataloggers that eliminate the need to run temperature sensor leads from the concrete structures to external dataloggers, thus reducing safety hazards on site and improving reliability of the temperature recording system. These temperature sensors have leads that only project above the concrete surfaces, and temperature data can be downloaded by connecting these leads to portable handheld devices.

Postcooling systems require embedded temperature-sensing devices (temperature sensors or resistance thermometers) to provide special information for the control of concrete cooling rates. It is considered best practice to monitor temperature of concrete components, fresh concrete, and post-cooling system temperatures. Various technologies are available for monitoring temperatures. Typical methods include manual thermometers, wired temperature sensors, wired temperature sensor/datalogger systems, and wireless temperature sensor/datalogger systems. Typical resolution of these devices is 2°F (1°C). Similar instruments provide data to evaluate the degree of protection afforded by insulation. Other instruments used to measure internal volume change, stress, strain, and joint movement have been described (Carlson 1970; USACE EM 1110-2-4300).

CHAPTER 2—PRECOOLING SYSTEMS

2.1—General

Reducing the temperature of the fresh concrete at placement is one of the most important and effective ways to reduce thermal stresses and cracking. Generally, the lower the temperature of the concrete when it passes from a plastic or as-placed condition to an elastic state upon hardening, the lower the tendency toward cracking. In massive structures, the reduction of the placing temperature will lower the peak temperature of the hardened concrete by a similar amount (ACI 207.2R).

2.2—Heat exchange

2.2.1 *Heat capacities*—The heat capacity of concrete is defined as the quantity of heat required to raise a unit mass of concrete one degree in temperature. In those systems of units where the heat capacity of water is established as unity, heat capacity and specific heat are numerically the same. Typical specific heat capacity values for concrete and its components are provided in Table 2.2.1a. The temperature of the fresh concrete mixture is influenced by each component of the mixture and the degree of influence depends on the individual component's temperature, specific heat, and proportion of the mixture (Lamond and Pielert 2006). Because aggregates comprise the greatest part of a concrete mixture, a change in the temperature of the aggregates will affect the greatest change in the temperature of the concrete, except where ice is used. Because the cementitious materials make up a relatively small volume of the concrete, cooling the cementitious materials may not result in significant temperature reduction, even when these materials are rela-