t_a = ambient air temperature, °F (°C)
t_r = concrete temperature upon delivery to the jobsite, °F (°C)
T = concrete temperature, °F (°C)
T_a = coarse aggregate temperature, °F (°C)
T_c = cement temperature, °F (°C)
T_d = drop in temperature to be expected during a 1-hour delivery time, °F (°C). (This value should be added to t_r to determine the recommended temperature of concrete at the plant after batching.)
T_o = datum temperature, °F (°C)
T_s = fine aggregate temperature, °F (°C)
T_w = temperature of added mixing water, °F (°C)
W_a = saturated surface-dry weight of coarse aggregate, lb (kg)
W_c = weight of cement lb (kg)
W_s = saturated surface-dry weight of fine aggregate, lb (kg)
W_w = weight of mixing water, lb (kg)
W_{wa} = weight of free water on coarse aggregate, lb (kg)
W_{ws} = weight of free water on fine aggregate, lb (kg)
Δt = duration of curing period at concrete temperature T, deg-h

2.2—Definitions

ACI provides a comprehensive list of definitions through an online resource, "ACI Concrete Terminology," https://www.concrete.org/store/productdetail.aspx?ItemID=CT16. Definitions provided herein complement that resource.

carbon monoxide—a colorless and odorless gas in the exhaust of fossil-fuel heaters and internal combustion engines that can cause dusting of concrete surfaces that are less than 24 hours of age.

cold weather—when air temperature has fallen to, or is expected to fall below, 40°F (4°C) during the protection period; protection period is defined as the time recommended to prevent concrete from being adversely affected by exposure to cold weather during construction.

freezing—the development of solid water ice within the paste that disrupts the paste, causing frost lenses to develop in the paste.

hydronic heater—mobile energy-exchanging system used to heat frozen ground, formwork, or concrete surfaces by pumping heated fluid through closed-circulation tubing and a heat exchanger.

liquidus temperature—the minimum temperature at which all components of a solution can be in a liquid state. Below the liquidus temperature the mixture will be partly or entirely solid.

maturity testing—tests performed to estimate in-place concrete strength using in-place concrete temperature history and strength-versus-temperature history functions derived from tests of concrete with comparable mixture proportions.

protection—the materials and environmental conditions in place to prevent concrete from being affected by exposure to cold weather.

CHAPTER 3—OBJECTIVES, PRINCIPLES, AND ECONOMY

3.1—Objectives

The objectives of cold weather concreting practices are to:

(a) Prevent damage to concrete due to early-age freezing. When no external water is available, the degree of saturation of newly placed concrete decreases as the concrete matures and the mixing water combines with cement during hydration. Additionally, mixing water is lost to evaporation even at cold temperatures. Under such conditions, the degree of saturation falls below the critical saturation. Critical saturation is the level at which a single cycle of freezing can cause damage. The degree of saturation falls below critical saturation at the approximate time the concrete attains a compressive strength of 500 psi (3.5 MPa) (Powers 1962). At 50°F (10°C), most well-proportioned concrete mixtures reach this strength within 48 hours. The temperature of concrete is measured in accordance with ASTM C1064/C1064M.

(b) Ensure that the concrete develops the required strength for safe removal of forms, shores, and reshores, and for safe loading of the structure during and after construction.

(c) Maintain curing conditions that promote strength development without exceeding the recommended concrete temperatures in Table 5.1 by more than 20°F (–7°C) and without using water curing, which may cause critical saturation at the end of the protection period, thus reducing resistance to freezing and thawing when protection is removed (5.1).

(d) Limit rapid temperature changes, particularly before the concrete has developed sufficient strength to withstand induced thermal stresses. Rapid cooling of concrete surfaces or large temperature differences between the exterior and interior region of structural members can cause cracking and can be detrimental to strength and durability. At the end of the required period (Chapter 7), gradually remove insulation or other protection so the surface temperature decreases gradually during the subsequent 24-hour period (7.5).

(e) Provide protection consistent with the durability of the structure during its design life. Satisfactory strength for 28-day, standard-cured cylinders is of no consequence if the structure has surfaces and corners damaged by freezing, dehydrated areas, and cracking from overheating because of inadequate protection, improper curing, or careless workmanship. Similarly, early concrete strength achieved by the use of calcium chloride ($CaCl_2$) is not serviceable if the concrete cracks excessively in later years because of disruptive internal expansion due to corrosion of reinforcement (11.2). Short-term gains in construction economy on concrete protection should not be obtained at the expense of long-term durability.

3.2—Principles

This guide presents recommendations to achieve the objectives outlined in 3.1(a) through (e). The practices and procedures in this guide stem from the following principles concerning cold weather concreting:

(a) Concrete protected from freezing until it attains a compressive strength of at least 500 psi (3.5 MPa) will not be damaged by exposure to a single freezing-and-thawing cycle (Powers 1962). It will mature to its potential strength and will not be damaged, despite subsequent exposure to cold weather (Malhotra and Berwanger 1973). No further protection is necessary unless a minimum strength at a minimum time is specified.

(b) Where a specified concrete strength should be attained in a few days or weeks, planning (including mixture proportion alterations and revisions to construction practice) and protection could be required to maintain the concrete temperature needed to attain the specified strength (Chapters 7 and 8).

(c) Except within heated protective enclosures, little or no external supply of moisture is recommended during cold weather curing (Chapter 10).

(d) Under certain conditions, $CaCl_2$ should not be used to accelerate setting and hardening because of increased chances of corrosion of metals embedded in concrete (Chapter 11).

Times and temperatures in this guide are not exact values for all situations and should not be used as such. The user should consider the primary intent of these recommendations and use judgment in deciding what is adequate for each particular circumstance.

3.3—Economy

Although cold weather concreting results in extra costs because of potentially lower worker productivity and additional needed products such as insulating blankets, tarping, and heaters, it most likely will also allow a project to stay on schedule. The owner should decide whether the extra costs of cold weather concreting operations are a profitable investment, or if it is more cost-effective to wait for mild weather. Neglecting protection against early freezing could result in immediate destruction or permanently weakened concrete, making it essential that adequate planning, protection from low temperatures, and proper curing are performed with cold weather concreting.

CHAPTER 4—GENERAL RECOMMENDATIONS

4.1—Planning

The general contractor, construction manager, concrete contractor, concrete supplier, specific materials suppliers, testing laboratory representative, and owner or architect/engineer should meet in a preconstruction conference to define what cold weather concreting methods will be used. This document guides the specifier, contractor, and concrete producer through recommendations that identify methods for cold weather concreting.

Plans to protect fresh concrete from freezing and maintain temperatures above recommended minimum values should be made well before freezing temperatures are expected to occur. Equipment and materials such as tarping or blankets should be at the worksite before cold weather is likely to occur.

4.2—Protection during unexpected freezing

During periods not defined as cold weather, such as fall or spring in cold climates or winter in temperate climates, precautions to protect all concrete surfaces from unexpected freezing should be provided for at least the first 24 hours after placement or until the minimum compressive strength is achieved for protection from damage using techniques detailed in Chapter 7. Concrete protected in this manner will be safe from damage by freezing at an early age. However, protection from freezing during the first 24 hours does not ensure a satisfactory rate of strength development, particularly when followed by colder weather. Concrete that will be subjected to applied loads should be continuously protected and cured long enough, and at a temperature recommended by Table 5.1, to produce the strength specified for form removal or structural safety (Chapters 7 and 8).

4.3—Concrete temperature

During cold weather, the concrete temperature during placement should not be lower than the values recommended in Chapter 5. To prevent freezing at early ages, maintain the concrete temperature at or above the recommended placement temperature for the length of time given in Chapter 7. The length of this protection period depends on cement type, dosage of accelerators, and the service conditions defined in 7.4.

The concrete temperature during placement should be near the temperature values in Table 5.1 and should not be higher than these values by more than 20°F (11°C). The recommended minimum placement temperatures given in Table 5.1 apply to normalweight concrete. While placement temperatures of lightweight concrete are equivalent to normalweight concrete, experience indicates that freshly mixed lightweight concrete loses heat more slowly than freshly mixed normalweight concrete. Lightweight insulating concretes lose heat even more slowly. However, when exposed to cold temperatures, some lightweight concretes are still susceptible to damage from surface freezing.

4.4—Temperature records

The surface temperature of concrete determines the effectiveness of protection, regardless of ambient temperature. Therefore, it is desirable to monitor and record the concrete surface temperature. During the surface temperature recording and monitoring process, consider:

(a) Concrete corners and edges are vulnerable to freezing and usually more difficult to maintain at the temperatures given in Table 5.1. Monitor the concrete surface temperature in these areas to evaluate and verify the effectiveness of the protection provided.

(b) Monitor internal temperature of concrete to ensure that excessive heating does not occur (9.8). Expendable thermistors or thermocouples cast in the concrete can be used for internal temperature monitoring.

(c) Inspection personnel should record the date, time, outside air temperature, temperature of concrete as placed, and weather conditions such as calm, windy, clear, or cloudy. Record concrete temperatures at regular time intervals, but