IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

CONCRETE IN COLD WEATHER CONDITIONS –CHALLANGES – PRECAUTIONS

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DOI: 10.5281/zenodo.47031

ABSTRACT
In general, Concrete can be placed safely without damage from freezing throughout the winter months in cold climates if certain precautions are taken. Cold weather is defined as a period when for more than 3 successive days the average daily air temperature drops below 5°C (40°F) and stays below 10°C (50°F) for more than one-half of any 24 hour period (ACI Committee 306). Under these circumstances, all materials and equipment needed for adequate protection and curing must be on hand and ready for use before concrete placement is started. Normal concreting practices can be resumed once the ambient temperature is above 10°C (50°F) for more than half a day.

KEYWORDS: Concrete, Freezing, Temperature, Aggregate, Cylinders, Cement, Curing, Insulators

INTRODUCTION
There are two main problems with concrete in cold weather:
i. Concrete can freeze before it gains strength which breaks up the matrix
ii.Concrete sets more slowly when it is cold very slow below 50°F; below 40°F the hydration reaction basically stops and the concrete doesn't gain strength.
During cold weather, the concrete mixture and its temperature should be adapted to the construction procedure and ambient weather conditions. Preparations should be made to protect the concrete; enclosures, windbreaks, portable heaters, insulated forms, and blankets should be ready to maintain the concrete temperature (Fig 1). Forms, reinforcing steel, and embedded fixtures must be clear of snow and ice at the time concrete is placed. Thermometers and proper storage facilities for test cylinders should be available to verify that precautions are adequate

Fig. 1. When suitable preparations to build enclosures and insulate equipment have been made, cold weather is no obstacle to concrete construction.

Fresh Concrete Freezing Effect

Concrete gains very little strength at low temperatures. Freshly mixed concrete must be protected against the disruptive effects of freezing (Fig.2) until the degree of saturation of the concrete has been sufficiently reduced by the Process of hydration. The time at which this reduction is accomplished corresponds roughly to the time required

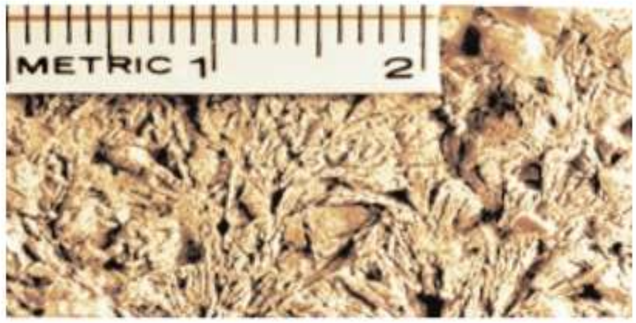


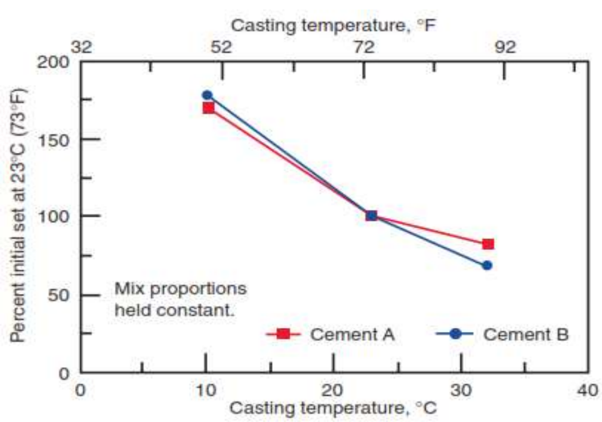
Fig. 2. Close up view of ice impressions in paste of frozen fresh concrete. The ice crystal formations occur as unhardened concrete freezes. They do not occur in adequately hardened concrete. The disruption of the paste matrix by freezing can cause reduced strength gain and increased porosity.

for the concrete to attain a compressive strength of 3.5 MPa (500 psi) (Powers 1962). At normal temperatures and water-cement ratios less than 0.60, this occurs within the First 24 hours after placement. Significant ultimate strength reductions, up to about 50%, can occur if concrete is frozen within a few hours after placement or before it attains a compressive strength of 3.5 MPa (500 psi) (McNeese 1952). Concrete to be exposed to deicers should attain a strength of 28 MPa (4,000 psi) prior to repeated cycles of freezing and thawing (Klieger 1957).

Concrete that has been frozen just once at an early age can be restored to nearly normal strength by providing favourable subsequent curing conditions. Such concrete, however, will not be as resistant to weathering nor as watertight as concrete that had not been frozen. The critical period after which concrete is not seriously damaged by one or two freezing cycles concrete that has been frozen just once at an early age can be restored to nearly normal strength by providing favourable subsequent curing conditions.

CONCRETE AT LOW TEMPERATURES ITS STRENGTH

Temperature affects the rate at which hydration of cement occurs low temperatures retard



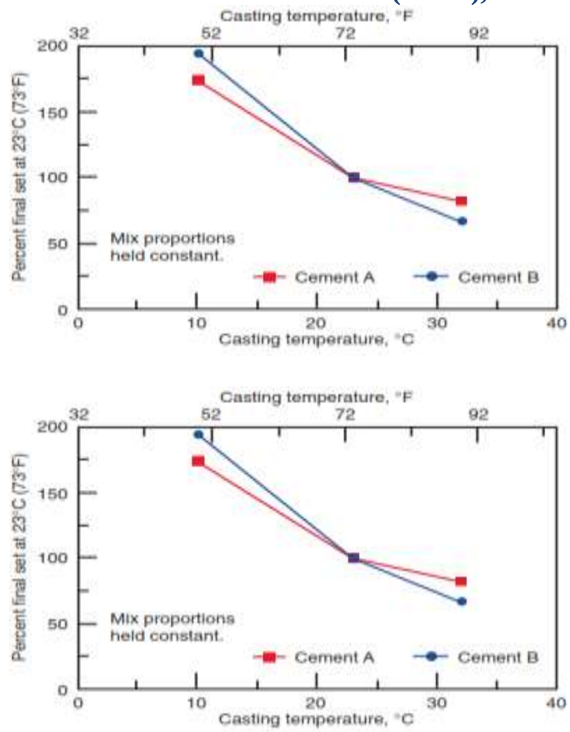


Fig. 3. Initial set characteristics as a function of casting temperature (top), and final Set and final set characteristics as a function of casting temperature (bottom) (Burg 1996).

hydration and consequently retard the hardening and strength gain of concrete. If concrete is frozen and kept frozen above about minus 10°C (14°F), it will gain strength slowly. Below that temperature, cement hydration and concrete strength gain cease. Fig. 3 illustrates the effect of cool temperatures on setting time

Fig. 4 Illustrates the effects of casting temperature on slump. Figs. 5 and 6 show the age-compressive strength relationship for concrete that has been cast and cured at various temperatures. In Fig. 6 that concrete cast and cured at 4°C (40°F) and 13°C (55°F) had relatively low strengths for the first week; but after 28 days when all specimens

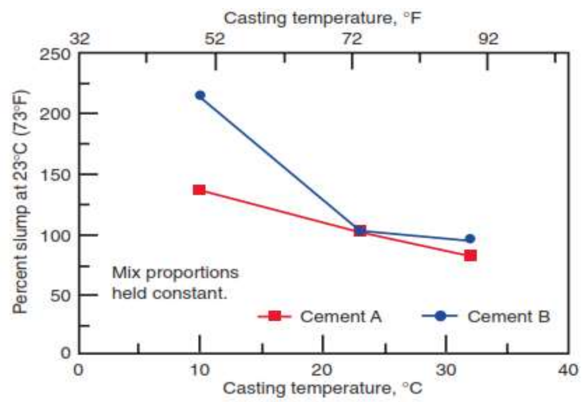


Fig. 4 Slump characteristics as a function of casting temperature (Burg 1996).

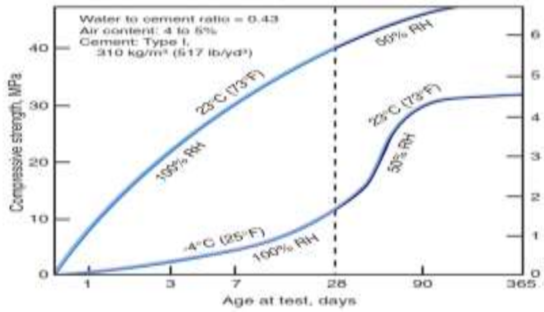


Fig.5. Effect of temperature conditions on the strength development of Concrete for the lower curve was cast at 4°C (40°F) and placed immediately in curing room at -4°C (25°F). Both concretes received 100% relative humidity curing for first 28 days followed by 50% relative humidity curing (Klieger 1958).

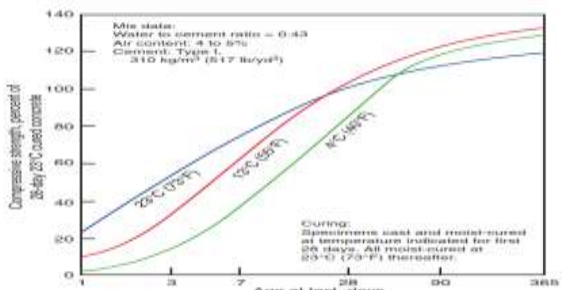


Fig. 6. Effect of low temperatures on concrete compressive strength at various ages. Note that for this particular mixture made with Type I cement, the best temperature for long-term strength (1 year) was 13°C (55°F) (Klieger 1958).

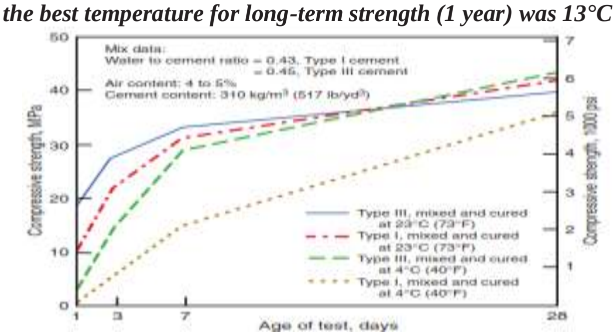


Fig. 7. Early-age compressive-strength relationships for Type I and Type III portland cement concretes mixed and cured at 4°C (40°F) compared to 23°C (73°F) (Klieger 1958).

Principal advantages occur during the first 7 days. At a 4 °C (40°F) curing temperature, the advantages of Type III cement are more pronounced and persist longer than at the higher temperature.

Heat of hydration

Concrete generates heat during hardening as a result of the chemical process by which cement reacts with water to form a hard, stable paste. The heat generated is called heat of hydration; it varies in amount and rate for different cements. Dimensions of the concrete placement, ambient air temperature, initial concrete temperature, water cement ratio, admixtures, and the composition, fineness, And amount of cementitious material all affect heat generation and build up. Heat of hydration is useful in winter concreting as it contributes to the heat needed to provide a satisfactory curing temperature; often without other temporary heat sources, particularly in more massive elements. Concrete must be delivered at the proper temperature and account must be taken of the temperature of forms, reinforcing steel, the ground, or other concrete on which the fresh concrete is cast. Concrete should not be cast on frozen concrete or on frozen ground. Fig. 8 shows a concrete pedestal being covered with a tarpaulin just after the concrete was placed. Tarpaulins and insulated blankets are often necessary to retain the heat of hydration more efficiently and keep the concrete as warm as possible.

Fig.8. Concrete footing pedestal being covered with a tarpaulin to retain the heat of hydration.Thermometer readings of the concrete's temperature will tell whether the covering is adequate. The heat liberated during hydration will offset to a considerable degree the loss of heat during placing, finishing, and early curing operations. As the heat of hydration slows down, the need to cover the concrete becomes more important.

SPECIAL CONCRETE MIXTURES

High strength at an early age is desirable in winter construction to reduce the length of time temporary protection is required. The additional cost of high-early-strength concrete is often offset by earlier reuse of forms and shores, savings in the shorter duration of temporary heating, earlier setting times that allows the finishing of flatwork to begin sooner, and earlier use of the structure. High-early-strength concrete can be obtained by using one or a combination of the following:

1. Type III or high-early-strength cement
2. Additional Portland cement (60 to 120 kg/m or 100 to 200 lb/yd)
3. Chemical accelerators

Small amounts of an accelerator such as calcium chloride (at a maximum dosage of 2% by weight of Portland cement) can be used to accelerate the setting and early-age strength development of concrete in cold weather. Accelerators containing chlorides should not be used where there is an in-service potential for corrosion, such as in concrete members containing steel reinforcement or where aluminum or galvanized inserts will be used. Cold Weather Concrete Objectives When concrete is being managed under cold weather, concrete must be protected from freezing shortly after being poured. Also concrete must be able to develop required strength for the safe removal of forms while reducing the circumstances where excessive must be applied to help concrete develop the required strength. Other important factors that must be considered are the proper curing conditions that prevent cracking and provide the intended serviceability of the structure.

Chlorides are not recommended for concretes exposed to soil or water containing sulphates or for concretes susceptible to alkali-aggregate reaction. Accelerators must not be used as a substitute for proper curing and frost protection. Specially designed accelerating admixtures allow concrete to be placed at temperatures down to -7°C (20°F). The purpose of these admixtures is to reduce the time of initial setting, but not necessarily to speed up strength gain. Covering concrete to keep out moisture and to retain heat of hydration is still necessary.

Fig. 9. Finishing this concrete flatwork can proceed because a windbreak has been provided, there is adequate heat under the slab, and the concrete has low slump.

Since the goal of using special mixtures during cold weather concreting is to reduce the time of setting, a low water-cement ratio, low-slump concrete is particularly desirable, especially for cold-weather flatwork; concrete mixtures with higher slumps usually take longer to set. In addition, evaporation is minimized so that finishing can be accomplished quicker (Fig. 9).

Air-entrained concrete

Entrained air is particularly desirable in any concrete placed during freezing weather. Concrete that is not air entrained can suffer strength loss and internal as well as surface damage as a result of freezing and thawing (Fig.10). Air entrainment provides the capacity to absorb stresses due to ice formation within the concrete. Air entrainment

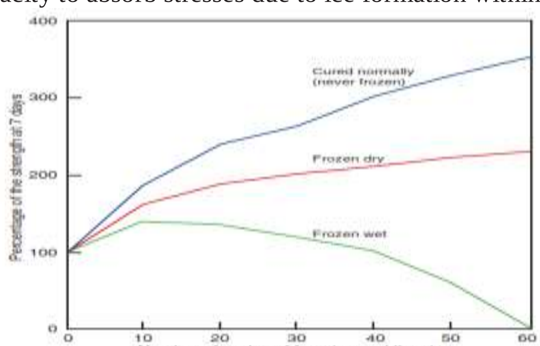


Fig.10. Effect of freezing and thawing on strength of concrete that does not contain entrained air (cured 7 days before first freeze)

should always be used for construction during the freezing months. The exception is concrete work done under roof where there is no chance that rain, snow, or water from other sources can saturate the concrete and where there is no chance of freezing. The likelihood of water saturating a concrete floor during construction is very real.

TEMPERATURE OF CONCRETE WHEN MIXED

The temperature of fresh concrete as mixed should not be less than shown in Lines 1, 2, or 3 of Table 1 for the respective thickness of section. Note that lower concrete temperatures are recommended for more massive concrete sections because heat generated during hydration is dissipated less rapidly in heavier sections. Also note that at lower ambient air temperatures more heat is lost from concrete during transporting and placing; hence, the recommended Concrete temperatures as mixed are higher for colder weather.

Line	Condition		Thickness of sections, mm (in.)			
			Less than 300 (12)	300 to 900 (12 to 36)	900 to 1800 (36 to 72)	Over 1800 (72)
1	Minimum temperature of fresh concrete as mixed for weather indicated.	Above -1°C (30°F)	16°C (60°F)	13°C (55°F)	10°C (50°F)	7°C (45°F)
2		-18°C to -1°C (0°F to 30°F)	18°C (65°F)	16°C (60°F)	13°C (55°F)	10°C (50°F)
3		Below -18°C (0°F)	21°C (70°F)	18°C (65°F)	16°C (60°F)	13°C (55°F)
4	Minimum temperature of fresh concrete as placed and maintained.**		13°C (55°F)	10°C (50°F)	7°C (45°F)	5°C (40°F)

***** Placement temperatures listed are for normal-weight concrete. Lower temperatures can be used for lightweight concrete if justified by tests.***

There is little advantage in using fresh concrete at a temperature much above 21°C (70°F). Higher concrete temperatures do not afford proportionately longer protection from Freezing because the rate of heat loss is greater. Also, high concrete temperatures are undesirable since they increase thermal shrinkage after hardening, require more mixing water for the same slump, and contribute to the possibility of plastic-shrinkage cracking (caused by rapid moisture loss through evaporation). Therefore, the temperature of the concrete as mixed should not be more than 5°C (10°F) above the minimums recommended in Table 1.

Aggregate temperature.

The temperature of aggregates varies with weather and type of storage. Aggregates usually contain frozen lumps and ice when the temperature is below freezing. Frozen aggregates must be thawed to avoid pockets of aggregate in the concrete after batching, mixing, and placing. If thawing takes place in the mixer, excessively high water contents in conjunction with the cooling effect due to the ice melting must be avoided. At temperatures above freezing it is seldom necessary to heat aggregates, the desired concrete temperature can usually be obtained by heating only the mixing water. At temperatures below freezing, in addition to heating the mixing water, often only the fine aggregate needs to be heated to produce concrete of the required temperature, provided the coarse aggregate is free of frozen lumps. Three of the most common methods for heating aggregates are:

(1) storing in bins or weigh hoppers heated by steam coils or live steam;

(2) storing in silos heated by hot air or steam coils; and

(3) stockpiling over heated slabs, stem vents or pipes.

Mixing water temperature.

Of the ingredients used to make concrete, mixing water is the easiest and most practical to heat. The mass of aggregates and cement in concrete is much greater than the mass of water; however, water can store about five times as much heat as can cement and aggregate of the same weight. For cement and aggregates, the average specific heat (that is, heat units required to raise the temperature 1°C (1°F) per kg (lb) of material) can be assumed as 0.925 kJ (0.22 Btu) compared to 4.187 kJ (1.0 Btu) for water. Fig.11 shows the effect of temperature of materials on temperature of fresh concrete. The chart is based on the equation

$$T = \frac{0.22(T_a M_a + T_c M_c) + T_w M_w + T_{wa} M_{wa}}{0.22(M_a + M_c) + M_w + M_{wa}}$$

Where

T= temperature in degrees Celsius (Fahrenheit) of the fresh concrete

T_a, T_c, T_w, *and* T_{wa} = temperature in degrees Celsius T (Fahrenheit) of the aggregates, cement, added mixing water, and free moisture on aggregates, respectively;

generally = $Ta = Twa$ Ma,Mc,Mw, and Mwa = mass in kilograms (pounds) of the aggregates, cement, free moisture on aggregates, and mixing water, respectively.

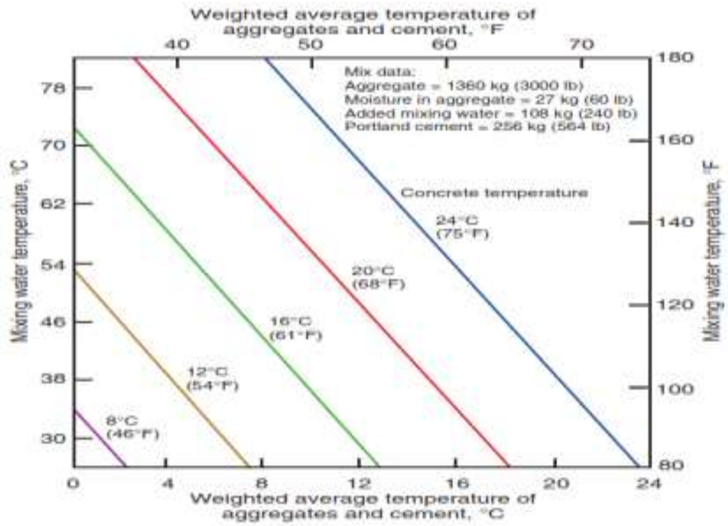


Fig. 11. Temperature of mixing water needed to produce heated concrete of required temperature. Temperatures are based on the mixture shown but are reasonably accurate for other typical mixtures.

The range of concrete temperatures in the chart corresponds with the recommended values given in Lines 1, 2, and 3 of Table 1.

COOLING AFTER PROTECTION

To avoid cracking of the concrete due to sudden temperature change near the end of the curing period, the source of heat and cover protection be slowly removed (ACI Committee 306). The maximum allowable Temperature drop during the first 24 hours after the end of the protection is given in Table 2. The temperature drops apply to surface temperatures. Notice that the cooling rates for surfaces of mass concrete (thick sections) are lower than for thinner members.

Table 2. Maximum Allowable Temperature Drop During First 24 Hours After End of Protection Period*

Section size, minimum dimensions, mm (in.)			
Less than 300 (12)	300 to 900 (12 to 36)	900 to 1800 (36 to 72)	Over 1800 (72)
28°C (50°F)	22°C (40°F)	17°C (30°F)	11°C (20°F)

Control Tests

After the concrete has hardened, temperatures can be checked with special surface thermometers or with an ordinary thermometer that is kept covered with insulating blankets. A simple way to check temperature below the concrete surface is shown in Fig.12. Instead of filling the hole shown in Fig.12 with a fluid, it can be fitted with insulation except at the bulb.

Concrete test cylinders must be maintained at a temperature between 16°C (60°F) and 27°C (80°F) at the jobsite for up to 48 hours until they are taken to a laboratory for curing (ASTM C 31 or AASHTO T 23). For concrete mixtures with a specified strength of 40 MPa (6,000 psi) or greater, the initial curing temperature shall be between 20°C and 26°C (68°F and 78°F). During this period, cylinders should be kept in a curing box and covered with a nonabsorptive,

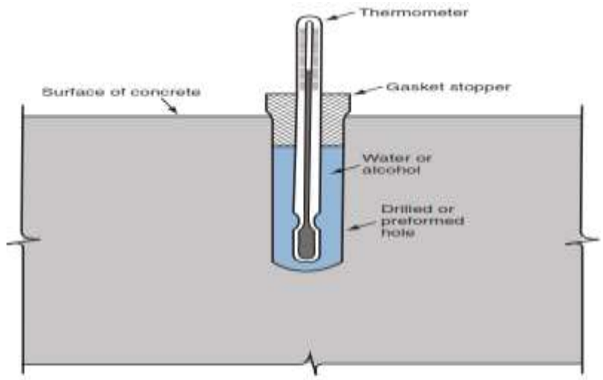


Fig.12. Scheme for measuring concrete temperatures below the surface with a glass thermometer.

nonreactive plate or impervious plastic bag; the temperature in the box should be accurately controlled by a thermostat (Fig. 13).

Fig.13. Insulated curing box with thermostat for curing test cylinders. Heat is supplied by electric rubber heating mats on the bottom. A wide variety of designs are possible for curing boxes.

In addition to laboratory-cured cylinders, it is useful to field-cure some test cylinders in order to monitor actual curing conditions on the job in cold weather.

Particular care should be taken to protect compressive strength test cylinders from freezing; their small mass may not generate enough heat of hydration to protect them. Molds stripped from cylinders after the first 24 ± 8 hours must be wrapped tightly in plastic bags or laboratory curing started immediately. When cylinders are picked up for delivery to the laboratory, they must be maintained at a temperature of 16°C (60°F) to 27°C (80°F) until they are placed in the laboratory curing room.

PRECAUTIONS

Concrete on ground:

Concrete on ground during cold weather involves some extra efforts and expensive. In winter, the site around the structure may be frozen rather than a morass of mud. Placing concrete on the ground involves different procedures from those used at an upper level:

(1) the ground must be thawed before placing concrete; (2) cement hydration will furnish some of the curing heat; (3) construction of enclosures is much simpler and use of insulating blankets may be sufficient; (4) in the case of a floor slab, a vented heater is required if the area is enclosed; and (5) hydronic heaters can be used to thaw sub-grades

using insulated blankets or to heat enclosures without concern for carbonation. Once cast, footings should be backfilled as soon as possible with unfrozen fill. Concrete should never be placed on a frozen sub-grade or backfilled with frozen fill; otherwise once they thaw, uneven settlements may occur causing cracking. It is required that concrete not be placed on any surface that would lower the temperature of the concrete in place below the minimum values shown on Line 4 in Table 14-1(ACI Committee 306). In addition, concrete placement temperatures should not be higher than these minimum values by more than 11°C (20°F) to reduce rapid moisture loss and the potential development of plastic shrinkage cracks. When the sub-grade is frozen to a depth of approximately 80 mm (3 inches), the surface region can be thawed by (1) steaming; (2) spreading a layer of hot sand, gravel, or other granular material where the grade elevations allow it; (3) removing and replacing with unfrozen fill; (4) covering the sub-grade with insulation for a few days; or (5) using hydronic heaters under insulated blankets which can thaw frozen ground at a rate of 0.3 m (1 ft) per 24 hours to a depth up to 3 m (10 ft) (Grochoski 2000). Placing concrete for floor slabs and exposed footings should be delayed until the ground thaws and warms sufficiently to ensure that it will not freeze again during the protection and curing period. Slabs can be cast on ground at ambient temperatures as low as 2°C (35°F) as long as the minimum concrete temperature as placed is not less than shown on Line 4 of Table 14-1. Although surface temperatures need not be higher than a few degrees above freezing, they also should preferably not be more than 5°C (10°F) higher than the minimum placement temperature either.

Concreting above ground

Working aboveground in cold weather usually involves several different approaches compared to working at ground level:

1. The concrete mixture need not be changed to generate more heat because portable heaters can be used to heat the undersides of floor and roof slabs. Nevertheless, there are advantages to having a mix that will produce a high strength at an early age; for example, artificial heat can be cut off sooner (Table 2), and forms can be recycled faster.
2. Enclosures must be constructed to retain the heat under floor and roof slabs.
3. Portable heaters used to warm the underside of formed concrete can be direct-fired heating units (without venting)

Table 2

A. Recommended Duration of Concrete Temperature in Cold Weather–Air-Entrained Concrete*

Service category	Protection from early-age freezing		For safe stripping strength	
	Conventional concrete,** days	High-early strength concrete,† days	Conventional concrete,** days	High-early-strength concrete,† days
No load, not exposed‡ favorable moist-curing	2	1	2	1
No load, exposed, but later has favorable moist-curing	3	2	3	2
Partial load, exposed			6	4
Fully stressed, exposed			See Table B below	

B. Recommended Duration of Concrete Temperature for Fully Stressed, Exposed, Air-Entrained Concrete

Required percentage of standard-cured 28-day strength	Days at 10°C (50°F)			Days at 21°C (70°F)		
	Type of portland cement			Type of portland cement		
	I or GU	II or MS	III or HE	I or GU	II or MS	III or HE
50	6	9	3	4	6	3
65	11	14	5	8	10	4
85	21	28	16	16	18	12
95	29	35	26	23	24	20

Adapted from Tables 5.1 and 5.3 of ACI 306. Cold weather is defined as that in which average daily temperature is less than 4°C (40°F) for 3 successive days except that if temperatures above 10°C (50°F) occur during at least 12 hours in any day, the concrete should no longer be regarded as winter concrete and normal curing practice should apply. For recommended concrete temperatures, see Table 14-1. For concrete that is not air entrained, ACI Committee 306 states that protection for durability should be at least twice the number of days listed in Table A.

Part B was adapted from Table 6.8 of ACI 306R-88. The values shown are approximations and will vary according to the thickness of concrete, mix proportions, etc. They are intended to represent the ages at which supporting forms can be removed. .

***** Made with ASTM Type I, II, GU, or MS portland cement.***

† Made with ASTM Type III or HE cement, or an accelerator, or an extra 60 kg/m 3 (100 lb/yd) of cement.

‡ "Exposed" means subject to freezing and thawing.

Before placing concrete, the heaters under a formed deck should be turned on to preheat the forms and melt any snow or ice remaining on top. Metallic embedments at temperatures Below the Freezing point may result in local freezing That decreases the bond between concrete and steel reinforcement. (ACI Committee 306) suggests that a reinforcing bar having a cross-sectional area of about 650 mm) should have a temperature of at least -12°C (10°F) immediately before being surrounded by fresh concrete at a temperature of at least 13°C (55°F). Caution and additional study are required before definitive recommendations can be formulated. When slab finishing is completed, insulating blankets or other insulation must be placed on top of the slab to ensure that proper curing temperatures are maintained.

A correlation between curing temperature, curing time, and compressive Strength can be determined from laboratory testing of the particular concrete mix used in the field ACI 306 States that with a compressive strength of 3.5 MPa (500 psi), concrete will normally have sufficient strength to resist early frost damage. If the concrete will be in a saturated condition when frozen, the concrete should be properly air entrained and must have developed a compressive strength of 28 MPa (4000 psi).

Corners and edges are particularly vulnerable during cold weather. As a result, the thickness of insulation for these areas, especially on columns, should be about three times the thickness that is required to maintain the same for walls or slabs. On the other hand, if the ambient temperature rises much above the temperature assumed in selecting insulation values, the temperature of the concrete may become excessive. This increases the probability of thermal shock and cracking when forms are removed. Temperature readings of insulated concrete should therefore be taken at regular intervals and should not vary from ambient air temperatures by more than the values given in ACI 306. In addition, insulated concrete temperatures should not be allowed to rise much above 27°C (80°F). In case of a sudden increase in concrete temperature, up to say 35°C (95°F), it may be necessary to remove some of the insulation or loosen the formwork. The maximum temperature differential between the concrete interior and the concrete surface should be about 20°C (35°F) to minimize cracking. Columns and walls should not be cast on foundations at temperatures below 0°C (32°F) because chilling of concrete in the bottom of the column or wall will retard strength development. Concrete should not be placed on any surface that would lower the temperature of the as placed concrete below the minimum values shown on Line 4 in Table 1.

ENCLOSURES

Heated enclosures are very effective for protecting concrete in cold weather. Enclosures can be of wood, canvas tarpaulins, or polyethylene film Prefabricated, rigid-plastic Enclosures are also available.

CONCLUSION

It is necessary to protect the concrete until it can handle the cold on its own. The general rule is that once the concrete has gained strength to about 500 psi then it is ok. When the concrete achieves 500 psi compressive strength, hydration of the cement has consumed enough of the water in the original mix so that even if it does freeze, there is not enough water left in the pores to damage the concrete. With most concrete, even at 50°, this happens during the second day. To help it reach that 500 psi strength, then, there are two things we can do in cold weather: Change the mix to get it to set more quickly or protect the concrete from the cold or more likely, both.

ACKNOWLEDGMENT

The Article presented in this paper has been funded by several organizations. Mainly, Prof. SK. Mohan Rao, Principal of Siddhartha Institute of Engineering and Technology, Hyderabad, Telangana, India, through the strategic institute program SITREP should be acknowledged. Special thanks goes to the Prof. Appa Reddy, Dean, Civil Engineering department, RGMCET, Nandyal, AP, India, for helping in providing various suggestions for completing this paper.

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did B.Tech (Civil), M.Tech (Structural engineering) got PhD, and having 15 years teaching and 13 Years Industrial experience in Middle East countries. He is having Immense knowledge on RCC structures, Cementing Materials, and wrote several articles which published in various journals and magazines. Presently he is working as Professor and Head of Department of Civil Engineering in Siddhartha Institute of Engineering and Technology, Hyderabad, Telangana, India.