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Cold-Weather Concreting

Several practices must be addressed in order to produce quality products that meet specifications.
By Evan Gurley

For most precast producers, it is that time of the year when cold weather plays an immense role in the procedures, requirements and practices that encompass precast concrete production. For manufacturers in the warmer climates, cold-weather concreting is not so much of a concern, but it is better to be prepared for extreme climatic conditions.

ACI 306 defines "cold-weather concreting" as the operations concerning the placing, finishing, curing and protection of concrete during cold weather. More specifically, it defines "cold weather" as a period of three or more successive days during which the average daily outdoor temperature drops below 40 degrees F (4 degrees C)and the air temperature is not greater than 50 F (10 C)for more than one-half of any 24-hour period.

Cold-weather concreting practices need to be addressed in order for precast manufacturers to produce quality products that meet specifications. Problems associated with cold-weather concreting are freezing of concrete at an early age; lack of required strength; improper curing procedures; rapid temperature changes; and improper protection of the structure consistent with its serviceability.

By observing a few principles, these problems can be avoided. Use discretion when deciding what is sufficient for dissimilar applications. What works for one application may not be the best for another, but generally these principles will help you make quality precast products during cold weather. The main principles that should be defined are as follows:

- Concrete that has attained a compressive strength of 500 psi or more and has been protected from freezing during this period will not be affected by a single freezing cycle.
- Concrete described above will be able to establish its potential design strength even if exposed to further cold weather. This also means that there is no need for further protection of the concrete.
- Design strengths which must be attained in a short time span (a few days or weeks) must be sheltered at temperatures above 50 F (10 C).
- Little or no added external moisture is needed for curing during cold weather, unless located in a heated enclosure.
- Take special precautions when using calcium chloride as an accelerator (hardening and setting); especially when the concrete contains embedded metals. (See ACI 318 for acceptable limits of calcium chloride in reinforced and non-reinforced concrete members.)

When faced with cold-weather concreting situations, the manufacturer must decide whether it is profitable to operate during this period of time or whether it makes more sense to wait until warmer weather. Statistics have shown that the cost of adequate cold-weather concreting is not extreme when considering the products manufactured. If one decides to follow through and manufacture precast products during cold weather conditions, do not take any shortcuts. This will ensure that the products are of the highest quality.

General requirements

To manufacture quality precast products during cold weather conditions, a number of general requirements have been established to serve as guidelines. These guidelines for cold-weather concreting include planning, protection during "non-cold" weather seasons (spring and fall), concrete temperature, temperature insights, exposure and slump.

Planning. One of the first steps when preparing for cold-weather concreting is planning. When planning for cold-weather concreting the owner, concrete contractor and concrete supplier should meet to discuss how and which specific methods should be used. Planning should take place well before any freezing temperatures are expected.

Protection during non-cold weather seasons. According to the National Oceanic and Atmospheric Administration (NOAA) , non-cold weather seasons (spring and fall) still have the potential for frost or freezing and should be considered when planning for protection of freshly exposed concrete surfaces. NOAA issues cold-weather advisories long before temperatures drop to dangerous levels. If in doubt, always take the safe route to avoid jeopardizing the quality and structural integrity. All concrete surfaces should be fully protected from possible freeze damage for a minimum of 24 hours after being placed.

Concrete temperature. During cold-weather concreting, the temperature of concrete at the time of placement (after mixing) should follow ACI 306, Table 3.1 – Recommended concrete temperatures(see Figure 1). In addition to the recommended placement temperatures in Table 3.1, these concrete placement temperatures should be controlled for a length of time (called the protection period) specified by ACI 306, Table 5.1 – Length of protection period required to prevent damage from early-age freezing of air-entrained concrete (see Figure 2). The protection period depends on factors such as cement type (Type III reduces time) and amount (higher cement content reduces time), accelerators (reduce time) and service. When concrete is placed, the temperatures should be right around the minimum temperatures described in Table 3.1. These placement temperatures should never be higher than the minimum placement values by more than 20 F (11 C). Concrete placed at lower temperatures is sheltered from freezing and can develop a higher ultimate strength and durability from the longer curing time it experiences. Placement at higher temperatures speeds up the finishing process in colder weather, but may weaken the long-term properties of the concrete

Table 3.1 – Recommended concrete temperatures

Line	Temperature	Section Size, minimum dimension, in. (mm)			
		< 12 in. (300 mm)	12-36 in. (300-900 mm)	36-72 in. (900-1800 mm)	> 72 in. (1800 mm)
Minimum concrete temperature as placed and maintained					
1	——	55°F (13°C)	50°F (10°C)	45°F (7°C)	40°F (5°C)
Minimum concrete temperature as mixed for indicated air temperature*					
2	Above 30°F (-1°C)	60°F (16°C)	55°F (13°C)	50°F (10°C)	45°F (7°C)
3	0° to 30°F (-18° to -1°C)	65°F (18°C)	60°F (16°C)	55°F (13°C)	50°F (10°C)
4	0° to 30°F (-18° to -1°C)	70°F (21°C)	65°F (18°C)	60°F (16°C)	55°F (13°C)
Maximum allowable gradual temperature drop in first 24 hr after end of protection					
5	——	50°F (28°C)	40°F (22°C)	30°F (17°C)	20°F (11°C)

* For colder weather a greater margin in temperature is provided between concrete as mixed and required minimum temperature of fresh concrete in place.

Temperature insights. When concrete is placed, the concrete's surface temperature is primarily what determines the success of protection. Testing and monitoring the temperature is therefore significant. When recording and monitoring the temperature there are certain things to look and test for that could make or break the effectiveness of the protection. First you must recognize that the edges and corners of the concrete are more prone to freezing. This is simply because it is harder to maintain the corner spaces. Another important issue is the monitoring of the concrete temperature, outdoor temperature, time of readings and weather conditions. Monitor the concrete's temperature daily and choose these readings sporadically in order to gain a range of values. These readings are typically taken by thermometers under some sort of temporary cover.

Exposure. Take precautions if it is likely the concrete in its saturated condition will be exposed to freeze and thaw cycles. In order to help protect the concrete, it should be air entrained, have a water-to-cement ratio (w/c) not exceeding limits recommended by ACI 201.2R, and not be allowed to freeze and thaw (in saturated condition) before gaining a compressive strength of 3,500 psi. Depending on the intended use, this w/c value is usually between 0.30 to 0.50.

Slump. Cold-weather concreting calls for a lower slump (less than 4 inches). This is desirable because it will have less bleed water on the surface. If this bleed water remains too long, it may affect the finish. Lower slump is also desirable because if this excess bleed water is blended into the concrete during trowelling, surface strength will be lower resulting in possible dusting and freeze-thaw damage.

Temperature

Placement temperature. As mentioned earlier, the temperature of the concrete at placement has a great deal to do with the protection of the concrete during cold weather. The placement temperature should be determined by recommended limits in ASTM C 1064. For placement temperatures that are much higher than line 1 of Table 3.1(Figure 1), this does not protect against freeze-thaw as well due to the higher rate of heat loss for greater differences in the outside air and concrete temperature. In addition to the rapid heat loss, higher-temperature concrete usually calls for more mix water; as stated earlier, the lower the w/c the better. When more water is used in the mix design, more problems can arise (quick setting, increased thermal contraction).

Mixing temperature. The recommended concrete temperature during mixing is shown on lines 2, 3 and 4 of Table 3.1. The mixing temperature should not exceed 15 F (8 C) above recommend values in Table 3.1. One of the ways to offset the heat loss at the time of placement is to increase the concrete mixing temperature. This is only in correlation when the ambient air temperature is decreasing.

Heating. Heating of aggregates and water is an excellent way to obtain a desired mix and placement temperature. It is a difficult task to uniformly heat aggregates to a desired temperature and less challenging to heat mix water, but both are reasonable methods.

Heating mix water. Heating of the mix water is an easier method to obtain a higher mix temperature. While it may be easier in terms of preparation, there are many important rules to follow in order to avoid problems such as flash setting or clumping. If the temperature of mix water used is above 140 F (60 C), the order of mixing your ingredients may need to be changed. Instead of adding cement and water consecutively, water and aggregates may need to be added and then the cement.

Heating aggregates. Before heating of aggregates can take place, ice and any type of frozen materials must be removed. There are several methods of obtaining the desired temperature, but heating devices such as steam heaters and gas burners are typically used. The general consensus is that when air temperatures are consistently below 25 F (-4 C), heating the aggregates is necessary.

Overheating. Having a concrete mix with higher than recommended temperatures can cause major problems in precast products. It is impossible to have water that is too high in temperature since you can use water up to its boiling point. However, concrete temperatures must be within the limits shown in Table 3.1in order to avoid flash setting. Aggregates, on the other hand, can cause problems if overheated. The average temperature of the aggregates should not exceed 150 F (66 C) as they are placed into the mix. This excess temperature could make the overall mix temperature exceed the required limits.

Preparation before concreting

To make a quality precast concrete product during cold-weather conditions, preparation is key.

Temperatures of surfaces in contact with fresh concrete. Preparation for cold-weather concreting primarily consists of ensuring that all surfaces in contact with early aged concrete are above temperatures that will cause early freezing or draw out the setting time. As long as the surfaces that come in contact with the early aged concrete are a few degrees above freezing and within 10 F (-12 C) of the minimum required placement temperatures, you should be OK.

Removal of ice and snow. Remove all ice from the aggregates. Failure to do so can ultimately disrupt the water content in the mix design. If the concrete's temperature is too high (in cold weather, this is hard to accomplish), then crushed ice may be added to the mix. The volume of the ice should not replace more than 75 percent of the batch water. The maximum temperature reduction from the use of ice is limited to about 20 F (-7 C). If you add ice to the mixing water, then the ice must be completely melted by the time mixing is complete.

Protection against freezing

Prevention of early-age freezing. Early stages of concrete production are the most crucial when protecting against cold-weather concreting setbacks. Early-age freezing prevention must be accomplished directly after the concrete is poured. The temperature and moisture recommendations need to be achieved in order for full protection to take place. Concrete that gains initial compressive strength of 500 psi without freezing can withstand a cycle of freezing and thawing. If the precast concrete structure is larger in size or has a lower cement content, expect a longer protection period.

Additional protection. Minimum protection requirements that prevent air-entrained concrete from one cycle of freezing and thawing is defined by ACI 211.1, Table 5.1(Figure 2). This ultimately means that if early-aged concrete experiences one cycle of freezing and thawing, the concrete's durability is not affected. This is true under the conditions that proper curing has taken place, concrete did not or will not freeze when critically saturated, and the concrete is air-entrained.

Stripping of forms. Stripping of the forms is an important issue when dealing with cold-weather concreting. If the precast plant is a heated enclosure, forms also can serve the purpose of evenly distributing heat. For best results, leave the forms on for no less than the minimum protection time. This is not always possible, so forms can be removed at the earliest design age that will not jeopardize the integrity of the piece, according to ACI 347. After the forms are removed, the product needs to be covered or kept in a sheltered environment for the set time recommended in the chart "Concrete Set Time."

Concrete set time

Temperature		Approximate set time
Degrees F	Degrees C	Hours
70	21.1	6
60	15.6	8
50	10.0	10 2/3
40	4.4	14 2/3

Temperature drop after removal of protection. After the concrete has been in a protected environment for the recommended time, it is essential to let the concrete cool gradually. Concrete needs to experience gradual cooling down to the ambient temperature in order to reduce shrinkage cracking. The heat source needs to be slowly reduced and the insulation layers removed, observing the maximum temperature drops in ACI 306, Table 5.5 – Maximumallowable temperature drop during first 24 hr. after end of protection period (see Figure 4).

Allowable temperature differential. Typically the concrete is cooled down to the ambient temperature, but a temperature difference is permitted. Using ACI 306 Figure 5.6, the maximum allowable difference between the ambient temperature and concrete temperature can be determined.

Protection for structural concrete

Structural concrete requires a higher level of design strength than non-reinforced concrete. Cold-weather concreting requires more protection beyond the minimum requirements shown in Table 5.1. For structural members, the requirements change in the duration of the removal of forms and shores. The difference is that removal of forms from structural concrete is now solely based on the in-place strength and not the duration for which they are secured.

Testing of field-cured specimens. To ensure that the concrete is holding up to standards, testing should be administered to concrete cured in the field. Test for in-place strength before the forms are removed and curing takes place. Testing should conform to ASTM C 31 standards.

In-place testing. Non-destructive strength testing can be performed on concrete that is cured in place and in the field using hand-held, portable instruments. Methods such as the pullout test (ASTM C 900) and the probe penetration test (ASTM C 803) are the most common.

Attainment of design strength. Ultimate design strength is attained when certain factors come together to produce a structurally sound member. One of the main reasons that concrete does not meet its specified design strength during cold weather is due to improper or lack of curing. Concrete must be cured for a specified amount of time in order to meet design strength. Tests have shown that when concrete specimens have been removed from the curing process before the required duration, full design strength is jeopardized. In cold-weather concreting, precast structural members need to gain a sufficient high early strength so that they will be protected from exposure to freezing weather.

Holding early strength. The most important factors when determining when to remove forms and shores are those that affect strength development. These are concrete initial placement temperature, type of cement, temperature at which the concrete is maintained after placing, type of admixtures and accelerator admixtures (if any), and curing and protection. There are many instances when accelerated manufacturing of precast members is essential to running an efficient plant, and in this case the duration of protection may be reduced.

Cooling of concrete. Gradual cooling of the concrete member after the setting period is also essential for structural precast applications. This is explained in Table 5.5, which defines maximum cooling rates. Concrete needs to experience gradual cooling down to the ambient temperature to reduce shrinkage cracking.

Estimating strength development. In cases where no testing was performed to determine the strength of the concrete, you can estimate it. However, this is true only if the concrete was properly cured and protected. ACI 306 Table 6.8 provides the duration of recommended protection for a standard-cured, 28-day-strength specimen.

Removal of forms and supports. Removal of forms and shoring must be in accordance with ACI 347.

Methods of protection and materials

Protection is a crucial aspect of cold-weather concreting. First, the placement temperatures should represent Table 3.1 as well as the recommended protection period discussed in Table 5.1. Protection of early age concrete can range from one extreme to another. Applications may need only insulating blankets covering the concrete for a short amount of time, or in other applications enclosures and heating devices may be needed to protect the concrete and maintain the desired temperature for longer durations of time. The key is that if you manufacture concrete products in colder weather, do not jeopardize the integrity of the member because of cost or any other restraints.

Insulating materials. One of the nice things about concrete is the fact that it generates heat when going through its chemical reaction (hydration), hardening the concrete. So in most applications, if the heat generated from hydration is contained (insulating blankets, etc.), outside heating sources may not be needed to prevent freezing. This is generally true for the first three days, and then if the protection period calls for a longer cover time, then additional insulating blankets are generally adequate. Some typical concrete insulators include polystyrene foam sheets, urethane foam, mineral wood/cellulose fibers, foamed vinyl blankets, batt insulation or even straw. Different applications call for different insulating materials (ACI 306).

Enclosures. If you are looking for the best type of protection for an application, then an enclosure is what you want. Enclosures offer the best type of protection, but with the best of anything comes a higher price tag and therefore they may not be cost effective for certain applications. The need for an enclosure depends on certain variables such as the nature of the structure and the weather conditions. In cases where the ambient air temperature is less than -5 F (-21 C), enclosures are generally required for placing operations. Generally if you are operating in those types of conditions, then you may experience larger problems (equipment failure, etc.) in the manufacturing of your precast products.

Internal electric heating. Another method used to keep the concrete temperature at a steady median above minimum requirements is by internal electric heating. This is accomplished by using embedded coiled and insulated electrical resistors. A low-voltage current is passed through the coils, which in turn raises the temperature of the concrete internally.

Covering. As soon as the concrete has been poured and placed in cold-weather conditions, the concrete needs to be protected. An easy way to do this is by covering the concrete with some type of insulated material. Layering is an effective way to insulate the concrete, as this helps retain any heat that is generated.

Insulated forms. Insulated forms are used alongside enclosures. When insulated forms are used, the concrete's temperature needs to be closely monitored so that the concrete does not become heated beyond the recommended temperature.

Curing requirements and methods

Curing refers to the natural phenomenon that happens within concrete. When water is added to a concrete mix, a chemical reaction takes place. The reaction forms a calcium silicate hydrate gel that "glues" everything together. As this glue hardens, the cement hydrates and the concrete cures. Curing directly affects concrete strength.

The 28-day strength is defined as the standard design strength or specified strength. So another important factor that comes into play when cold-weather concreting is proper curing. Proper curing techniques must be established in order for the newly placed concrete to be protected from drying. When the temperature is below 50 F (10 C), in most geographic areas excess drying will not be a major concern. Although excess drying may not be a major concern, freezing of the concrete when it is critically saturated becomes a problem. Protection is needed so that critically saturated concrete will not be exposed to freezing conditions.

Curing during the production period. Although excessive drying is not a major concern in most geographic regions, concrete that is being protected from the cold-weather conditions may be a different story. When warmer concrete (60 F/16 C) is in contact with warmer air (50 F/10 C or higher), then precautions must be taken in order to prevent drying. The most frequently used method in preventing drying in this case would be by steam heating. Other methods such as dry heating and warm-water heating are also options, although they are practiced less often.

If using the steam curing technique, it should be terminated 12 hours before the end of the temperature protection period, because it will need to follow the recommended gradual adjustment defined in Table 5.5.

NPCA curing requirements. NPCA's Quality Control Manual lists its target curing temperatures in correlation with the concrete being produced (heavyweight, lightweight). For precast/prestressed concrete, the target maximum curing temperature is 150 F (66 C). The NPCA QC Manual states that when curing is done at too high a temperature, it kills the formation of ettringite while the hydration process is going on later. If the concrete is exposed to a moist environment, ettringite can form and then crack the product.

Curing following the protection period. After the protection insulation has been removed, additional protection from drying is not typically needed as long as the temperature remains below 50 F (10 C) and it is not windy. The drying of concrete members is typically defined by four main factors, which are temperature of the concrete, ambient temperature, relative humidity and wind speed. If excessive drying is probable, then water curing is acceptable as long as the temperature remains above freezing.

Acceleration of setting and strength development

It is permissible to expect shortening of the required strength setting times by the addition of cement, type of cement or admixtures. This is often used in cold-weather concreting because it shortens the protection period, allows forms to be reused more quickly and requires less labor to finish the work. Accelerated setting can also raise the heat of hydration, which could come in handy when keeping the concrete's temperature up to the required temperature. Additional information on accelerated setting can be found in ACI 212.

Admixtures. There are many accelerating admixtures available. A couple of the most common accelerating admixtures used today are calcium chloride and those that conform to Type E (ASTM C 494). Calcium chloride, which reduces the setting time and increases the rate of early-age strength development, is a very popular accelerating admixture. It must be limited in use, since too much can be detrimental to the integrity of the concrete. ACI 318 defines the calcium chloride limits and regulations. Some Type E accelerating admixtures have also been found to increase strength gain and accelerate setting time.

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