

Cold Weather Concrete

Subhead:

Take precautions and follow guidelines to help ensure success

EXAMPLE:

Weather is a key factor in the placement of concrete and shotcrete because it affects how quickly the material matures and gains strength. Cement hydration is an exothermic reaction; that is, it gives off heat. In hot weather, concrete stiffens quickly, especially when the concrete temperature exceeds 90°F. This reduces the length of time it remains workable and can cause difficulties in placing and finishing it.

Cold temperatures have the opposite effect. Chemical reactions are slower at lower temperatures, so the objective during winter concrete construction is to maintain a rate of cement hydration sufficient to avoid freezing of the fresh concrete. This allows the cement paste to gain sufficient strength to withstand exposure to freezing conditions. Concrete may need protection so it can gain enough strength to allow timely form stripping and to provide the durability required by the project specifications.

With proper care and technique, concrete and shotcrete work is routinely done successfully in cold weather. In fact, it sometimes can result in better concrete quality than work done in hot weather. Cooler concrete temperatures generally have an effect similar to a retarder, resulting in more thorough cement hydration over time. (A petrographic examination would yield a low value for unhydrated cement clinker particles.) Thorough hydration also improves other concrete characteristics such as long-term strength and permeability.

When Are Precautions Needed?

The American Concrete Institute (ACI) Committee Report 306, "Cold Weather Concreting" answers this question. ACI 306 defines cold weather as

"...a period when, for more than 3 consecutive days, the following conditions exist:

- 1) the average daily air temperature is not greater than 40°F and
- 2) the air temperature is not greater than 50°F for more than one-half of any 24-hour period. [T]he average daily temperature is the average of the highest and lowest temperatures occurring from midnight to midnight."

How do cold temperatures affect concrete setting time?

For every 10°F reduction in concrete temperature, setting time is increased by about one-third. For example, a mix that usually sets in six hours when placed at 70°F would not set for 11 hours when placed at 50°F. This delay increases the available time for placing and finishing, but it also extends bleeding duration, delays slab finishing, and requires longer crew hours.

Once the concrete achieves a compressive strength of 500 psi, the free water within the mix is being used in hydrating the cement, and saturation of the concrete begins to drop below the level where damage due to freezing will occur (91.7% saturation). After the concrete reaches the 500 psi strength, curing conditions need be maintained only to achieve required compressive strength for stripping, loading or other project-specific requirements. ACI 306 Chapter 5 provides protection duration guidelines as well as allowable temperature drops after concrete protection is removed.

If there is any doubt as to whether cold weather will arrive on the day of concrete placement, be prepared to protect the concrete as ACI 306 recommends. Cold-weather conditions can occur anytime from early fall through spring, so a wise contractor will pay attention to extended weather forecasts. The preparation and planning should begin in the bidding phase. If they are not included in the bid, costs related to extra personnel, mix design modifications or alternate mixes, insulation materials, heaters, etc., will eat up profits.

Choosing Protective Measures

Protection methods vary, but the object is always the same: to protect the concrete at the early age when it is critically saturated and not strong enough to withstand damage by the formation of ice within the concrete matrix. Choose appropriate protective measures, as dictated by the expected low temperatures, cost, schedule, size, and complexity of the structure being cast.

Among the approaches discussed in ACI 306 are changing the mix design and protecting work areas.

Possible Mix Design Adjustments

Here are possible mix adjustments.

- Warm the concrete by using warm water or heated aggregates in batching. However, avoid excessive temperatures. Target concrete temperatures to stay within 15 or 20 degrees of the minimum placement temperatures presented in ACI 306 Table 3.1. Overly warmed concrete can lead to “summer problems” such as rapid stiffening, increased water demand, shrinkage cracking, or subsequent thermal cracking. Also note that thicker concrete sections can be placed with lower temperatures, since the heat of hydration will provide warmth after placement.
- Stay with Type I cement, but increase the quantity by approximately one bag and keep a low water-to-cementitious materials ratio. Low water-to-cementitious ratios also minimize total bleed-water capacity, which is desirable in cold weather finishing operations. Shotcrete mixes inherently have low w/cm ratios to prevent sloughing during placement.
- Use a high-early-strength cement (Type III) in the mix design.
- Use an accelerating admixture conforming to ASTM C 494 Type C or Type E (water reducing and set acceleration). See Chapter 9 in ACI 306 for cautions concerning the use of calcium chloride where corrosion and long-term durability are important. If corrosion of reinforcing steel is a consideration, a non-chloride accelerator may be a better option.

Protecting the Work Area

Whether you are placing a slab, wall, or structural slab, protecting the casting or shooting area offers several benefits. If the contact surface is warm or at least relatively close to the placement temperature, it helps prevent retardation of concrete in contact with the cold surface.

Finishers know that late fall slab-on-grade placements can become difficult to finish, due to the disparity in setting rates between concrete in contact with the cold subgrade and concrete at the slab surface on a sunny afternoon. Simply keeping insulating materials (blankets, straw, etc.) on the excavation can often capture enough heat to keep the ground from freezing. If snow or ice has already formed in the excavation, it must be removed, and the area thawed and recompact as needed.

Heated work areas or enclosures, even heat pumped within forms, works well. On a winter rehabilitation project in the St. Lawrence Seaway, heat pumped into the 3-ft-thick forms for a new lock wall facing allowed workers to set reinforcing steel in relative comfort, while ambient temperatures were near 10°F. When all pre-placement activities were complete, the reinforcing steel was well above freezing and the concrete required only minimal warming at placement. After casting, the heat of hydration and insulated blankets placed outside the forms were sufficient to keep the concrete protected. This allowed the contractor to keep up with a rigorous project schedule.

When heating work enclosures, do not allow direct-fired heaters to exhaust directly onto freshly placed concrete. Such a reminder may seem unnecessary, but floor dusting problems associated with CO₂ emissions still occur from time to time. Any heater burning fossil fuel produces carbon dioxide (CO₂). This gas combines with calcium hydroxide on the surface of the fresh concrete to form a weakened layer of calcium carbonate. This interferes with cement hydration and results in a weak and dusted surface. Indirect-fired or hydronic heaters are a better option, and any heater used should vent CO₂ to the outside to prevent reaction with the fresh concrete surface.

Don't Rush Form Removal

Measuring temperatures at the concrete surface after placement provides direct feedback on the effectiveness of the protection used and helps determine how soon protective measures can be safely phased out. Once the concrete has gained enough strength to allow stripping, insulation can be removed. But don't rush to remove forms; when surface temperature drops too quickly, thermal-related cracking can occur. Removing protection during the warmest part of the day may be helpful. Pull off insulating blankets first, and then remove forms after the internal concrete temperature has begun to drop. As a general rule of thumb, avoid creating a temperature differential of 35°F or more between the center of the concrete section and the outer surface. Thermocouples embedded at the mid-section and near the surface will provide the information you need to effect a gradual cool-down of a new placement. Table 5.5 of ACI 306 gives guidelines for maximum temperature drops. Thicker sections require a slower cool-down, because they generate greater internal heat of hydration.

Conclusion

As a troubleshooting engineer who sees many problems in the field, I understand that some contractors may find my views on the need for protection to be too conservative. A recent report by the Concrete Foundation Association (CFA) asserts that ACI 306 seems too restrictive for residential concrete construction. The CFA has conducted research on the effects of cold temperatures and has posted the results on its website, www.cfawalls.org. Contractors who commonly work in cold weather should review this work in conjunction with the proven performance guidelines in ACI 306, then come up with bids that include the kinds of protection and mix adjustments that you are comfortable with. Your goal should be not just to meet minimum requirements, but to leave behind quality work that ensures repeat business and continued profits.

In summary, think ahead and come to the jobsite prepared for cold weather. If it doesn't come today, you will still be ready for tomorrow. Being prepared will always be less costly than resolving potential disputes, providing extra testing, or repairing damage to concrete.

EXAMPLE:

I would define cold weather where precautions should be taken at any time the temperature will go down to 29°F and stay there for two or three hours, and then only get up to 35°F to 40°F during the day. I've made a practice of using high early cement starting when the nighttime temperature drops to the low 30°s and gets up to the 50°s during the day.

When the concrete companies heat their water, I usually start using a quick drying additive. I know calcium chloride is not recommended, but I've used it on many a pool through the late 1950's and into the 1960's and have not had a problem with these pools. About 20 years ago after reading some of the reports on bridges affected by calcium chloride, I changed to a less corrosive additive.

Depending on conditions, I have also added one bag of cement per yard to increase or at least to hold the strength I need for the project. One of the common mistakes people make is that they feel that some of these additives will frost proof the mix. Nothing is an anti-freeze for concrete. All you can do is dry the water out as fast as possible using several methods including heat, additives, extra cement per yard, and high early cement. Reduce the water used per yard.

Proper preparation of the base is important. As the weather gets colder, we use more stone in the base of the pool. Usually, in late afternoon we will sprinkle rock salt into the stone base. Then cover it with four mill plastic. If it's really going to be cold, we might put straw over it if we're not going to shoot it for a couple of days as that's cheaper than using heat.

For heat, we use propane gas because there is less carbon in the exhaust and a plastic cover with both ends open so that the air will blow through changing the humidity and keeping the heat up at least to 50°F.

After the concrete is shot, we will put plastic over it to maintain 50° for at least 24 to 48 hours, depending on the air temperature. We will not strip the forms for at least several days and keep it covered so the concrete cures properly.

Once the concrete cures, we then lay the plastic into the pool and put two to three feet of straw on the floor of the pool. This will insulate the floor of the pool and protect against the weather. In fact, where pools may take over a year to get completed you may want to clean the old straw out and replace it with new straw each year. Remember, a good base under the concrete that does not hold water will not allow cold temperatures to penetrate the concrete and create ice or frost.