COLD-WEATHER CONCRETING

by Kim Basham

When it's cold outside, placing, finishing, and curing concrete calls for extra care. In cold weather, concrete sets up more slowly, takes longer to finish, and gains strength more slowly. Worst of all, there's a risk that the fresh concrete will freeze — and if it does, the damage done by ice formation can reduce its final compressive strength by as much as 50 percent.

Avoid cracking, settling, and strength loss by protecting fresh concrete from the cold

To avoid the delays and quality problems that cold weather can cause, contractors have to be careful in site preparation, concrete placement, and protection of the concrete while it is curing. Before you pour in cold weather, you should be sure you're prepared for it.

What do I mean by cold weather? According to the American Concrete Institute, if the air temperature averages less than 40°F, and if it's below 50°F more than half of each day for three days in a row, you've got cold weather and you should take precautions.

Freezing: A Major Risk

Ice starts to form in fresh concrete when the concrete temperature approaches 27°F. If there are admixtures in the mix, the freezing point may be as low as 20°F.

When the water in fresh concrete freezes, the ice takes up more space than water. Ice crystal growth causes an overall volume expansion of the concrete. This expansion weakens the concrete by creating void spaces and disrupting the bond between the cement

Figure 1. The subgrade must be thawed out before concrete is placed. If the frost is only a few inches deep, an insulating layer of straw (top) or an insulating blanket (bottom) will allow the earth's heat to thaw the ground.

paste and the aggregate. If freezing is slow, water may move to the growing ice crystals and then freeze, forming *ice lenses* — growing pockets of ice which create pressure on surrounding materials as they get larger. Later, when the concrete thaws, voids left by melting ice lenses make the concrete porous, and can cut concrete's 28-day compressive strength in half.

Freezing is only a threat, however, for a limited time. Once internal drying has nearly emptied the water-filled void spaces, there's enough room for ice crystals to grow without creating expansive pressures. If you keep your concrete at 50°F, two days after placement it should have a compressive strength of at least 500 psi. By that time, the concrete will be safe from damage if it freezes — as long as you keep it dry (see "Inspecting for Ice Damage").

Preparation: Thaw Out the Site

Before you place concrete in cold weather, you need to make sure your forms and subgrade are ready. Never place concrete on frozen subgrade. The subgrade will probably thaw unevenly, resulting in uneven settlement. Frozen subgrades also pull heat out of fresh concrete, slowing down setting and strength gain. Some parts of a pour may set up more slowly than others, making finishing difficult. So thaw the subgrade out first.

Never place concrete on snow and ice. Besides adding water and lowering concrete temperature, snow and ice will take up space intended for concrete. Clear the snow and ice from both forms and subgrade before you pour.

The subgrade should be at least 35°F before you place the concrete. If the subgrade is frozen to a depth of only a few inches, covering the ground with insulation for a few days before concreting or spreading hot sand or gravel will usually thaw it (Figure 1). For deeper frost, you may need to use windbreaks and heated enclosures. Once the subgrade has thawed, recompact it to avoid uneven settlement and cracked concrete. For flatwork, use a layer of absorbent base material, such as pea gravel or sand, to reduce finishing times. Absorbent bases reduce bleed water and decrease set time.

Table 1. Concrete Temperature vs. Set Time

Concrete temperature	Set time
70F	6 hrs.
60	8
50	11
40	14
30	19

Note: *Set time (the time it takes for concrete to harden enough so that finishing can begin) increases by a third for every 10°F drop in concrete temperature. Source: Aberdeen's* Concrete Construction.

Cold-Weather Checklist

Preparation

- ☑ Plan ahead for cold-weather concreting. Be prepared when the temperature starts dropping.
- ☑ Remove snow and ice from forms.
- ☑ Don't place concrete on frozen subgrade — thaw the subgrade or wait for warmer weather.

Placement

- ☑ Order air-entrained concrete.
- ☑ Order a cold-weather concrete mix using either Type III cement, an extra 100 lbs/cu.yd. of cement, or a chemical accelerator.
- ☑ Place concrete at temperatures between 55°F and 75°F.
- ☑ Place concrete with a slump of 4 inches or less.
- ☑ Place concrete late in the afternoon, during the warmest part of the day.

Protection

- ☑ Uses membrane curing compound or polyethylene sheets for curing. Don't use ponding, spraying, or wet coverings.
- ☑ Use insulation or enclosures to protect concrete for a minimum of three days (two days for a special cold-weather mix).
- ☑ Provide triple insulation at corners and edges of walls and slabs.
- ☑ In heated enclosures, use vented heaters or electric heaters and take necessary fire precautions.
- ☑ During the protection period, maintain concrete curing temperatures between 55°F and 75°F.
- ☑ If newly place concrete is to be partially loaded at an early age, extend the protection period to six days (four days when using a special cold-weather mix).
- ☑ Don't expose saturated concrete to freezing temperatures — allow the concrete to partially dry before exposing.
- ☑ Gradually remove insulation or reduce enclosure temperature. Don't expose concrete to sudden drops in temperature.

Place concrete late in the afternoon, after the sun has heated the subgrade and forms. The concrete forms, like the subgrade, should not be colder than 35°F. Placing concrete in the warmest part of the day will reduce the amount of heat loss from the fresh concrete.

Placement Problems

If your concrete freezes, it can be disastrous — the strength loss may be unacceptable, and tearing out concrete and doing it over is not light work. But even when your concrete doesn't freeze, letting it get too cold as it sets up can cause problems because *hydration*, the chemical reaction between water and Portland cement that produces hard concrete, goes more slowly at lower temperatures. For every 10°F drop in concrete temperature, set times increase by approximately a third (see Table 1). Hydration grinds to a halt at 14°F, although it will recommence when the temperature warms up. Prolonging set time delays your finishing operation and increases labor costs.

During cold weather, concrete should be at or above 55°F when it is placed, but no warmer than 75°F. Try to place concrete as close to the 55°F temperature as possible. Higher temperatures may speed finishing in cold weather, but this will require more mixing water, which weakens the concrete, and may increase the potential for shrinkage cracking. Placing concrete at temperatures below 50°F to 45°F can seriously increase the potential for freezing within the first three days after pouring. (If the minimum section size is greater than 12 inches, then the temperature can be less than 55°F.)

Ready-mix suppliers can deliver concrete at the right temperature by heating the mix water or aggregates, or both. Measure the fresh concrete temperature with a glass or metal concrete thermometer. You can buy a suitable thermometer from a construction equipment supplier for as little as $10. I even sometimes use a digital cookware thermometer I picked up at a hardware store. Knowing the fresh temperature can help you predict the setting characteristics of the concrete — the colder it is when you pour it, the longer you'll be waiting for it to set.

Order the Right Mix

You can shorten the set time and improve the early strength of your concrete if you order it with extra cement, Type III cement, chemical accelerators, or any combination of the three.

Type III cement is chemically similar to ordinary Type I cement, but its particles have been ground finer. Concrete made with Type III cement is almost 50% stronger after 24 hours than concrete made with Type I cement. However, Type III cement is not as readily available as Type I in some areas, because smaller companies don't always have the space to store all the different types.

Adding extra cement, usually an additional 100 pounds per cubic yard of concrete, provides about the same early strength as using Type III cement. Adding cement improves finishability, as well as the strength, durability, and watertightness of the final product. Finishing can also be started sooner.

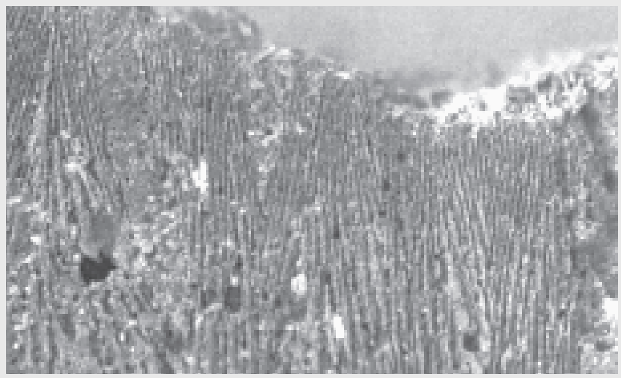
Chemical accelerators provide the same benefits as using Type III cement or adding an extra 100 pounds of cement per cubic

Inspecting for Ice Damage

Suppose your concrete sub pours your foundation during a cold snap. He tells you there's no problem, he does it all the time, and anyway he'll protect the concrete from freezing. Then, after the job is finished, the homeowner calls to complain about cracking — and you begin to have your doubts.

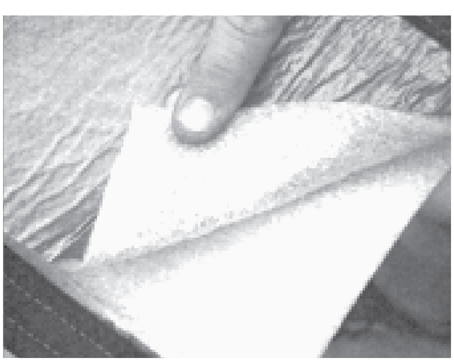
In a situation like this, it's possible to inspect for ice damage in hardened concrete, but you'll need to take a sample of the concrete. For visual inspection, all you need is a chunk of the concrete. But it's probably worth the relatively low cost of calling a concrete test lab to take a 4-inch core sample. Then, if you still have questions after a visual inspection, you can have that core crushed in a lab to measure compressive strength. Concrete that freezes before curing sufficiently will have tiny ice crystal imprints in it (see photo below) — a good damage indicator. You can see them with a magnifying glass in cores or sawed specimens, especially in pockets where coarse aggregate particles have pulled out. When you're looking for the imprints, wetting the concrete surface can make them more visible.

If you see ice lens voids in the sample, it's best to hire an engineer to determine whether your concrete's final strength will be acceptable. But, if there were no ice lenses, your concrete probably reached 500 psi before it froze, and it will continue to cure with only minimal strength loss.



Tiny grooves left behind by melting ice lenses, visible with a magnifying glass, are a sign of damage from freezing. Concrete that freezes soon after placement can lose as much as half of its compressive strength.

Figure 2. The most common way to protect freshly poured concrete is with insulation blankets. Make sure the edges of the blankets are weighted down to prevent convection currents.



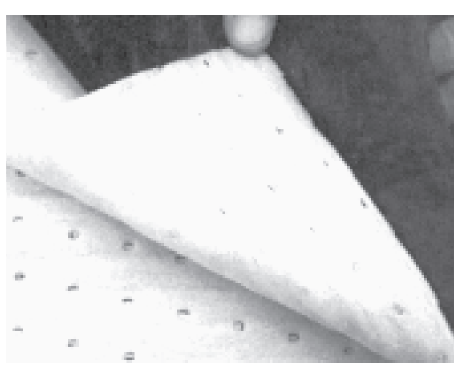


Figure 3. There are two types of manufactured insulation blankets — fiberglass (left) and closed-cell polypropylene foam (right). The author prefers closed-cell foam because it stays flexible at low temperatures, lies flat on slabs, and doesn't soak up water.

yard. There are two main types of accelerators, Type E and Type C. Type E is a water reducer and accelerator, while Type C is only an accelerator. Both Type E and Type C are available in either chloride-based or nonchloride-based formulations.

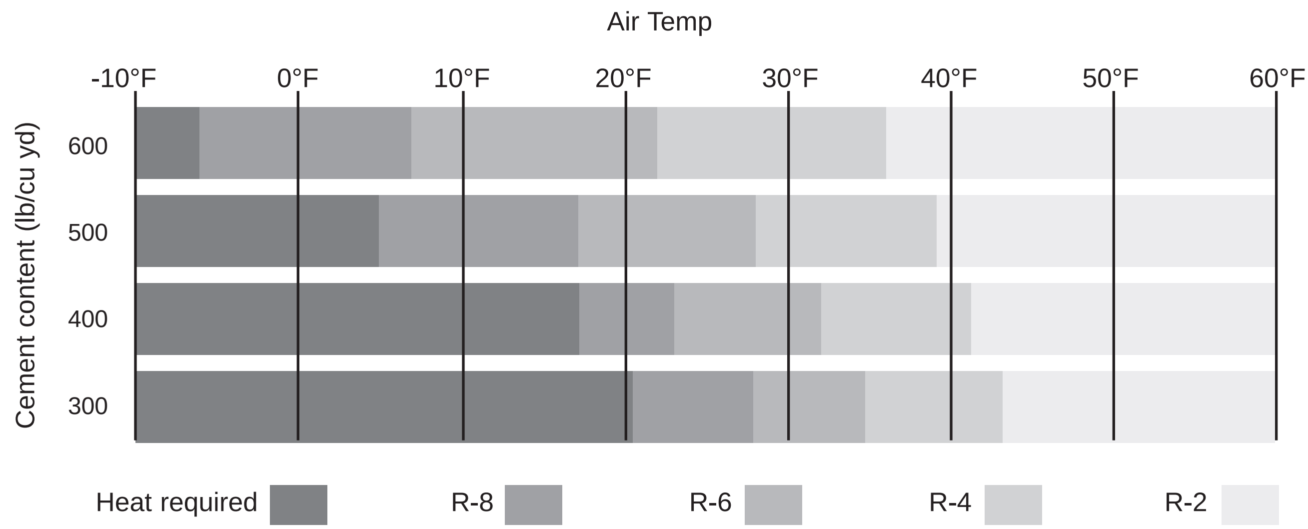
The most common accelerator is *calcium chloride*, a Type C accelerator. Calcium chloride increases the rate of hydration; it is not an antifreeze.

Calcium chloride can increase the potential for corrosion of reinforcing steel if water is present. So any time your concrete has reinforcing steel in it, a nonchloride accelerator is a better choice — especially when water intrusion is possible. For example, when a foundation wall is poured on a footing, water sometimes enters at the joint between footing and wall. If the concrete contains chloride, increased corrosion can weaken the steel in this joint and damage the concrete-to-steel bond. Then frost action or soil movement can more easily cause foundation movement or cracking, or the joint may open up and let water into the basement.

As the concrete temperature drops, accelerators become less effective. In cold weather, concrete producers increase the dosage rate to compensate.

Table 2. Insulation Required to Keep Concrete at 55°F

(8-inch-thick wall protected for three days)



Note: As outside air temperature drops, it becomes harder to keep concrete at the correct temperature using insulation alone. A mix that contains more cement will set up faster and generate more internal heat of hydration, allowing the concrete to gain strength properly at lower air temperatures. Adding insulation keeps more of the concrete's heat in — another way to lower the minimum outdoor temperatures you can work in. Below a certain point for any given mix, you will need to provide a heated enclosure to prevent the concrete

Air-entrained concrete is less susceptible to damage caused by freezing and thawing than non-air-entrained concrete, because the tiny air spaces in the mix allow some ice crystals to form harmlessly. For exterior concreting exposed to freezing and thawing, always use air-entrained concrete. Also, use air-entrained concrete for interior concreting if there's a chance it will be exposed to cold weather during construction.

A low-slump mix — that is, one with as little water as possible — has several advantages. During cold weather, bleed water is slow to evaporate and usually interferes with proper finishing. For flatwork, a slump of 4 inches or less will minimize bleeding and decrease finishing delays. Do not mix bleed water into the surface during troweling — the resulting surface will have lower strength and will be prone to dusting and subsequent freeze-thaw damage. If bleed water is present on flatwork, skim it off using a rope or hose before troweling.

Also, don't add water to the mix. Adding a gallon of water per cubic yard can increase set time by up to 30 minutes and can lower compressive strength by 200 psi. Adding 2 gallons per cubic yard can increase set time by as much as an hour.

The extra cost of a special cold weather concrete mix varies from about $1.25 to $7 a cubic yard, depending on the method used. Calcium chloride is often the cheapest option, with extra cement a close second. Type III cement or Type E accelerators are usually the most expensive options. Using Type III cement, extra cement, or a chemical accelerator reduces the needed protection period by one day. Compared with the cost of replacing damaged concrete, or even the cost of one day's protection, the extra cost for a special mix is a bargain.

Protection: Cover It Up

In addition to thawing the substrate and pouring the concrete at the right temperature, in cold weather it's important to protect fresh concrete from freezing, and to maintain curing conditions to ensure adequate strength development. There are two ways to achieve this: insulating the concrete, or "tenting it out" and heating it.

Insulation. The most common and easiest way to protect concrete against the cold is by insulating. During the first three days after placement, the chemical reaction between Portland cement and water generates heat, called the "heat of hydration." If you can keep that heat in, you often won't need to supply extra heat.

Six inches of straw held in place with tarps or polyethylene sheeting will keep heat from escaping. But straw has disadvantages: It's bulky, it's flammable, and if it gets wet, it loses its insulating value. For light construction, insulating or curing blankets are the most practical way to maintain heat and moisture during cold weather (Figure 2). Insulating blankets are easy to install: You can anchor them with weights or tie them onto slabs and walls.

Most blankets are made of fiberglass or closed-cell polypropylene insulation, attached or laminated to an outer cover of woven polyethylene, canvas, nylon, or vinyl (Figure 3). Blankets made of closed-cell foam are more effective than fiberglass blankets, as the fiberglass tends to mat and can soak up water, lowering its insulating value. Polypropylene foams remain flexible at low temperatures, lay flat on slabs, and won't soak up water.

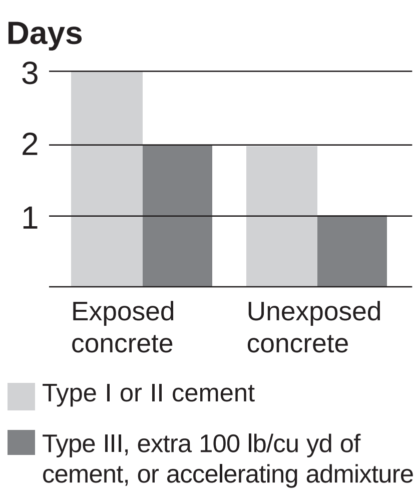
Blankets come in standard sizes — 6x25-foot and 12x25-foot are typical, but any size is available by special order.

Figure 4. A heated enclosure made of wood and poly can be used to keep concrete at the ideal 55°F temperature.

Thickness of the insulation varies from 2 inches for fiberglass to 1/2 inch for closed-cell polypropylene foam. A 1/2-inch-thick polypropylene foam blanket has an R-value of 1.85. By comparison, 1 inch of dry straw has an R-value of 2, and 6 inches gives R-12.

Depending on the type, blankets cost from about 15¢ to 55¢ a square foot. A good blanket, if not mistreated, can last up to ten years. Also, many concrete supply stores rent insulating blankets for about 9¢ per square foot per week. Considering the cost of replacing concrete damaged by cold weather, these costs are very reasonable.

Table 3. Curing Time Required to Prevent Freezing Damage



Note: Concrete made with Type I or Type II cement needs two days of curing at 55°F to 75°F before it is dry enough and hard enough to be safe from freezing. Concrete that will be exposed in service, such as sidewalks or outdoor slabs, should be given a third day of protection before uncovering. But using a special cold-weather mix will cut a day off those required protection times.

To be effective, insulating blankets have to lie flat on concrete surfaces, and the edges must be weighted down to prevent air movement under the blanket. Always triple-insulate corners and edges of walls and slabs: These areas offer more surface area to the cold air, so they're more vulnerable during cold weather.

To measure concrete surface or curing temperatures, place a thermometer under the blanket. If it's between 55°F and 75°F under the blanket, you're in good shape.

Heated enclosures. The colder the weather gets, the harder it gets to maintain adequate curing temperatures by relying on insulation and the heat of hydration (Table 2). When outdoor temperatures drop below 40°F, it is very hard to maintain a 55°F concrete temperature using insulation alone. When adequate cure temperatures can't be maintained, and you can't wait for warmer weather, you'll have to tent out — use heated enclosures to protect your concrete. You can build enclosures with wood and polyethylene sheeting (Figure 4). Or rent a large party tent — it makes a great winter enclosure.

When you heat enclosures, be sure to use vented heaters or electric heaters. Heaters burning gas, oil, or kerosene produce carbon dioxide and carbon monoxide. Carbon dioxide reacts with the surface of the concrete, causing a soft chalky layer to form. Later, this weak layer will dust under traffic. And carbon monoxide, of course, is dangerous and can be deadly to workers placing and finishing the concrete.

When to uncover. Your first goal is to keep the concrete from freezing until it reaches a strength of 500 psi and most of the water is gone. This takes longer if the concrete gets cold. Temperatures below 50°F slow the hydration process, extending the time when there is a risk of freezing. Temperatures above 75°F speed up curing, but decrease final strength and cause other problems in quality. So the key is to keep the concrete between 55°F and 75°F for at least two days before letting it cool. However, exposed concrete such as a sidewalk should be protected for longer — three days at least (Table 3).

To be on the safe side, protect *all* fresh concrete from freezing for three days. After that, protect the concrete from rain, snow, or any other source of water for a few days before exposing it to freezing temperatures. Also, do not cure the concrete by ponding, spraying, or applying wet coverings. These techniques work well in warm weather, but will cause problems in subfreezing temperatures. Instead, use membrane curing compounds or polyethylene sheets.

At 500 psi, your concrete is safe from freezing, but it may not be strong enough to carry the loads it's designed for, or to hold up when backfill is dumped against it. How long you must protect concrete depends on the mix you use, but in general, the longer you protect it the stronger it will be.

Cool down slowly. Whether you insulate or tent out, do not allow the concrete to cool too fast at the end of the protection period. Sudden drops in temperature will cause thermal shrinkage cracking. Remove the protection system in a way that lets the concrete cool gradually — no faster than a 50°F drop in 24 hours. ■

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