Photo: Dennis Purinton

Advances in Cold-Weather Concrete Work

Rules are evolving as skill and technology improve

BY TED CUSHMAN

On a 9°F day in December 2014, Connecticut concrete contractor Dennis Purinton was pouring a slab on grade. It was the kind of work Purinton had done often enough before. But this time, he had a small audience of experts and supplier representatives from around the concrete industry—some of them, like Purinton himself, members of the consensus committee that creates ACI 306, the American Concrete Institute's *Guide to Cold Weather Concrete.*

Purinton's goal was to demonstrate for his audience—and, by extension, for the full ACI 306 committee—something that he already knew from decades of experience working in New England conditions: "Concrete performs very, very well in cold weather."

ACI 306 isn't a code, or even a standard. It's an advisory document that helps professionals in the concrete industry understand how to accomplish their goals when the outside temperature drops toward freezing. Committee insiders say the 2010 edition of the document, which incorporates advances in concrete technology and practice that have evolved since the previous update, in 1988, was a significant upgrade. Recommendations from the 1988 version remain in the book to provide grounding in the basics. But current practice continues to advance, and even the 2010 document doesn't incorporate all of the latest industry research. So the ACI 306 committee is working on yet another update. After a formal ACI review process, a new edition is likely to be released in 2016 or 2017.

Photos: 1,2, Concrete Foundations Association; 3, Dennis Purinton

COLD-WEATHER BASEMENT WALLS

Dennis Purinton's work with cold-weather slab placement follows in the footsteps of an earlier program carried out by the Concrete Foundations Association (CFA), a trade group with headquarters in Mount Vernon, Iowa (cfawalls.org). From 2001 to 2004, CFA contractors studied the practical limits of concrete basement-wall placement in winter. The association developed dozens of concrete mixes using different cements and admixtures, and tested the concrete's performance in cold conditions.

For each mix, CFA researchers developed what's called a "maturity curve"—a mathematical relationship between concrete temperature, time, and strength development—that allows a contractor to follow the strength gain of any concrete placement over time simply by observing its temperature as measured by a sensor placed into the concrete when it's poured. So rather than relying on code-mandated general rules of thumb, a contractor using the "maturity method" can gauge the strength gain of his material in real time. Contractors who understand the method, and know their concrete mixes well, may be able to place concrete in cold weather without costly measures such as tenting, heating, or even insulating. And by knowing the strength of the concrete from hour to hour, they can know to within the hour whether the concrete has reached the minimum strength required to allow the crew to strip forms, or even backfill the basement wall. This can save days on the construction schedule.

The CFA's findings helped to shape another ACI document, ACI 332 (*Residential Code Requirements for Structural Concrete and Commentary*). Unlike ACI 306, ACI 332 is written in code language, and can be referenced directly in construction contracts. On the strength of the CFA's research, ACI 332 contains language supporting the use of the maturity method during cold-weather placements as an alternative to following protection requirements that don't reflect real-time strength predictions.

But the data developed in CFA's research, and the lessons learned, don't automatically apply to the placement of flatwork—such as foundation slabs or sidewalks—because the conditions, obviously, are different. Unlike a basement wall, a slab doesn't have the protection of a wall form. When it's cold outside, a cold subbase can "suck" heat out of the fresh concrete, slowing the hardening process. And slabs have a large surface area that's exposed

to cold winter air, posing a major risk of damage due to early-age freezing. So research is ongoing to justify the application of maturity methods to exposed flatwork in cold weather conditions.

Dennis Purinton's Connecticut demonstration is a good start. But Purinton's work hasn't been published or replicated, and by itself, his data probably won't be enough to spur any further revisions of ACI 306. But other researchers are studying ways to improve cold-weather placement. And in the meantime, contractors in the field can already take advantage of the maturity method. In principle, said Purinton, "if you own a cellphone, and you own a laptop, you have the ability to do this—for a very minor amount of money."

UNDERSTANDING MATURITY

Concrete is a mixture of sand, gravel (stone), water, and cement (see "Concrete Basics," Jun/00). Some concrete mixes also include supplementary cementitious materials (such as fly ash and ground granular blast-furnace slag) and chemical admixtures. Concrete generates heat during hardening as a result of the chemical process by which cement reacts with water to form a hard,

Facing page: Concrete Foundations Association members strip forms from test walls in 2003 during experiments to verify the strength of concrete poured in sub-freezing temperatures **(1)**. The researchers took core samples from the walls **(2)** to correlate in-place strengths with the values predicted by maturity formulas. The results validated the approach used by contractors like Dennis Purinton, whose Connecticut crew is shown pouring a basement wall on a typical New England winter day **(3)**.

Above: Dennis Purinton organized a field demonstration of concrete placement under cold winter conditions in 2014 **(4)**. Instruments supplied by Con-Cure **(5, 6)** recorded the temperature of the concrete as it set and hardened despite the sub-freezing ambient temperatures and frozen sub-base.

Photos: John Gnaedinger/Con-Cure

stable paste. The heat generated is called "heat of hydration."

A key objective for cold-weather concreting is preventing damage to the concrete from early-age freezing. Concrete protected from freezing until it attains a compressive strength of at least 500 psi will not be damaged by exposure to a single freezing cycle. But if freezing occurs before 500 psi is reached, the final strength of the concrete could be cut in half.

Cement hydration. Science doesn't have a complete explanation for the chemical process of hydration, or a complete description of concrete's final structure. But experts do have a good working model. Cement hydration happens in stages, proceeding from "stiffening" (loss of workability) to "setting" (solidification), and on to "hardening" (strength gain). Throughout the process, water gets used up—broken into hydrogen and oxygen, which get locked into the developing compounds that form solid concrete.

But during the early stiffening and setting stages, the solidifying material is fragile, and lots of free water remains. If ice forms during that early period—before the concrete has reached about 500 psi of compressive strength—the expanding ice will fracture the weak cement, degrading the concrete's quality.

As the reaction proceeds, the free water is consumed, the concrete gets stronger, and air voids form in the concrete, so that any ice that does form will have a space to expand into. From then on, the concrete can drop below freezing temperatures, and it won't be damaged. So in winter, the key goal is to keep concrete above the freezing point until its compressive strength exceeds about 500 psi. After that, it's safe to remove the curing blankets, the heat, the shelter, and so on.

In the past, there was no way to be sure when the concrete had become hard enough in the hours or days after the pour. So the rules erred on the side of caution: You had to keep the protection in place for a set period of days, which included a healthy margin of safety.

Measuring temperature. But the modern maturity method lets contractors observe the concrete directly to know how far the hydration reaction has progressed. That's because the rate of the hydration reaction is directly related to the material's temperature: the hotter the temperature, the faster the reaction proceeds. If you measure and record the temperature over time, you can estimate how far the reaction has progressed. And for any particular mix, you can know with a fair degree of accuracy how strong the concrete has become.

To learn more about the use of maturity to guide decision-making in concrete work, *JLC* turned to John Gnaedinger, director of engineering services at Con-Cure Premiere (con-cure.com). Con-Cure manufactures the temperature probes, electronic devices, and software packages that concrete contractors use to track concrete maturity in the field.

Gnaedinger provides training and tech support for contractors who use Con-Cure's maturity system. His customers include ready-mix suppliers, precast concrete manufacturers, and post-tensioned concrete companies, as well as contractors like Dennis Purinton who work mainly in residential construction. Gnaedinger is also a member of the ACI 306 committee, and he helped Purinton with his winter demonstration program in 2014.

"First of all," explained Gnaedinger, "any maturity system has to record temperatures over time. You have to be able to look at that data and correlate it with a maturity curve that you establish ahead of time, in the laboratory."

But there's an art to applying the maturity method in the field, said Gnaedinger. "The location where you put the sensor is important," he explained. "You choose areas that you expect to be the coldest, and areas where you expect the most exposure to the elements."

In Con-Cure's "ZoneCure" maturity system, the temperature probe is protected by a plastic sleeve, so the sensor can be recovered and used multiple times. The sensor sends data to an electronic monitor that records the information on site, and also sends it wirelessly to a laptop computer. The system creates a temperature history that describes the concrete's experience and simultaneously calculates the material's maturity, supplying a real-time estimate of the concrete's in-place strength.

Cylinders. Contractors typically don't use the maturity system to determine the concrete's final strength, said Gnaedinger. For that, they use the old-fashioned method: They pour test cylinders and fracture them in the lab after a 28-day cure. But they use maturity data earlier in the job, to make daily production decisions.

Cylinders often cure in different conditions than the actual structure, and cylinder strength can lag behind the strength of the in-place concrete. "With the maturity system, you can actually know what that strength is in the structure, at any moment, without having to break a cylinder," said Gnaedinger, "and you know that the structure itself passes the strength so that you can strip forms. I've been on jobs where that time difference is three days."

Controlling costs. Connecticut contractor Dennis Purinton doesn't put maturity sensors in every slab he pours. But he does use the system often, he said—especially if he needs to document the quality of his work for a customer or a third party.

With experience, Purinton has learned how to use maturity information to manage costs. "ACI 306 gives you options of what to do in the winter," he said. "Do you use hot water, do you use accelerators, do you use blankets, do you use heating units? What do you do? By monitoring the strength gain and the temperature of the concrete as the season goes on, you know how your concrete is performing. Then as it gets colder, you add some sort of performance enhancer to the concrete. But you can put a cost on every one of these enhancers. So as time goes by, you can make yourself much more cost-effective by using a maturity meter system."

ARCTIC CONCRETE

There's another organization interested in cold-weather concrete: the U.S. military. In cooperation with several state highway departments (who have their own interest in extending the concrete season and shortening the time it takes to get pavements into service), researchers at the Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL) in New

Hampshire have been studying ways to push the freezing point of concrete lower using off-the-shelf admixtures that contain calcium nitrate, calcium nitrite, and sodium thiocyanate.

Unlike calcium chloride, the admixture that's typically used to accelerate concrete set in cold weather, these alternatives don't corrode rebar—and in fact, may provide some protection against steel corrosion.

Also, the "antifreeze" method CRREL is evaluating doesn't depend on heating up the concrete during early set; instead, the focus is on preventing freezing of the water even at cold temperatures. When the concrete sets and cures at lower temperatures (but doesn't freeze), its long-term strength is improved.

CRREL's "antifreeze concrete" has shown itself to be a practical approach to placing concrete in cold weather without heated enclosures or insulating blankets. For a 2010 demonstration near Fairbanks, Alaska, CRREL poured five sections of parking slab using its recipe and watched the fresh concrete temperatures drop below 30°F without any damage to the finished slabs (which eventually reached compressive strengths of 7,000 psi, after a 28-day cure).

In the testing of small samples to identify the freezing point, one of CRREL's mixes reached 23°F before water in the mix froze. "If the minimum concrete temperature was lowered to 23°F, instead of the current limit of 40°F," a CRREL report on the testing noted, "it is estimated that an additional 3 to 4 months could be added to the construction season within the continental United States."

But you don't have to max out the antifreeze method in order to apply it, CRREL engineer Lynette Barna told *JLC*. "There are five test slabs at the site," Barna explained. "The dosages we are using are all within the manufacturer's recommendations, but one of the slabs was at the higher dosage range. At the other end of the site, we put a slab in at the lowest dosage rate. Even at the lowest dosage, we are still getting very good performance out of that slab."

Barna said that antifreeze concrete also appears to be more durable than concrete placed in a heated enclosure. "Being able to lower the temperature and not have to heat it, you're creating more uniform conditions for the concrete to cure," said Barna. "We did a side-by-side comparison of curb repair in New Hampshire. On the west side we used the antifreeze approach, and on the east side they did a tent and heat. The conventional side is now starting to spall and crack after 10 years. On the antifreeze side, the condition is still very good, and any cracks are narrow and there is no spalling. So by being able to have a more uniform condition, we've created a more durable concrete."

CRREL researchers also suspect that the antifreeze concrete has a better internal void structure that offers greater protection against freeze-thaw damage in service. The antifreeze admixture becomes more concentrated as water in the mix is consumed during setting and hardening; CRREL engineers think that some antifreeze may stay available in the cured concrete in service, providing ongoing freeze-thaw protection for many years. These ideas, said Barna, are matters for future study.

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Above: A crew from a local concrete contractor in Fairbanks, Alaska, places concrete slabs in freezing weather at nearby Fort Wainwright, raking out the concrete **(7)** and bull-floating it **(8)**, just as they would in summer weather. CRREL researchers report they have designed freeze-resistant concrete mixes that can be handled, placed, and finished just like typical mixes, even in very cold weather.

Photos: USACE