# Cold-Weather Shotcreting

*By Raymond Schallom III*

The dry-shotcrete process has a long history with placing concrete pneumatically for over 105 years. Additionally, the wet-shotcrete process has been in use for over 50 years and has expanded to all 50 states and 120 countries. The shotcrete process has a wide variety of application uses, such as new construction, tunneling, mining linings, soil (geotechnical), and repair. These proven process methods have shown great versatility and efficiency in concrete placement. Shotcrete placement has been proven to save time and money over conventional form-and-pour methods. As the industry community begins to use these processes more widely, the one constant that hasn't changed is the challenges faced during placement in cold and hot weather. This article will talk about cold weather shotcrete (concrete) practices.

This author has performed and consulted on shotcrete work in temperatures down to –45°F (–43°C), which required close attention to heat protection of the mixtures during transport, placement, finishing, curing, and protection, as well as appropriate thermal clothing for the workers. Work has a tendency to slow down in the colder climate, and there are more safety issues to contend with, that require careful consideration of production while providing full protection of the placed material. These costs are usually worked out with the owner or general contractor well in advance of the cold weather to see if it is feasible to continue work or better to shut down during the winter months.

The shotcrete industry and the American Concrete Institute (ACI) have made great strides to convince the engineering community that shotcrete is simply a placement method for concrete. Therefore, concrete—wet or dry—placed by the shotcrete process, is the same as the concrete covered in ACI 306R-10, "Guide to Cold Weather Concreting," and ACI 306.1-90, "Standard Specification for Cold Weather Concreting." ACI 306R-10 defines cold weather as:

"Cold weather exists when the air temperature has fallen to, or is expected to fall below 40°F (4°C) during the protection period. The protection period is defined as the time required to prevent concrete from being affected by exposure to cold weather."

Concrete placed during cold weather will develop sufficient strength and durability to satisfy the intended service requirements when it is properly produced, placed, and protected. The necessary degree of protection increases as the ambient temperatures decrease.

Because the shotcrete placement is often slower than form-and-pour operations and usually has one surface exposed to ambient temperatures, controlling internal and surface material heat becomes a critical task. One must protect the concrete from early-age freezing during the initial curing process until the compressive strengths reach at least 500 psi (3.5 MPa). At 50°F (10°C), most well-proportioned concrete mixtures reach this strength in a few hours or up to 48 hours in some cases. With shotcrete mixtures generally having a higher paste content and a lower water-cementitious materials ratio (*w/cm*), one can expect to reach the 500 psi (3.5 MPa) stage within a shorter time span—usually within 24 hours.

ACI 506.2-13, "Specification for Shotcrete," and ACI 506R-05, "Guide to Shotcrete," both mention that while actively shooting shotcrete, the ambient temperature needs to be 50°F (10°C) or above. At 40°F (4.4°C), it can take concrete up to 16 hours to reach initial set, while the material temperature needs to be at least 40°F (4.4°C) to start the hydration process. Most DOT work uses the minimum of 50°F (10°C) for ambient, material, and surface temperature ranges unless completely protected and heated.

This author has experienced many temperature variances over the years. The one that stands out that has been a challenge on a few projects is the rapid temperature changes within the repaired areas, particularly before the concrete has developed sufficient strength to withstand induced thermal stresses. Rapid cooling of concrete surfaces or large temperature differences between the exterior and interior (20°F [11°C] minimum change) of the patches can cause cracking and be detrimental to strength and durability. To protect the patch, or new work, the cold weather protection needs to be removed slowly once the curing and protection period has been met, allowing the concrete temperature to change gradually in a 24-hour period as long as the desired strength has been reached. This will help to prevent rapid temperature change in the new shotcrete material.

Figures 1 through 3 show some of the approaches needed for cold weather protection and heat needed to perform shotcrete work during the cold weather months. Concrete construction in cold weather must meet these objectives:

- Prevent damage to concrete due to early-age freezing;
- Ensure that the concrete develops the required strength for safe removal of forms, shores, reshores, and safe loading of structure during and after construction;
- Maintain curing conditions that further normal-strength development without using excessive heat and without causing critical saturation of the concrete at the end of the protection period;

*Fig. 1: Cold weather protection Lake Placid bobsled and luge track, which had a fast-track build from 1998-1999 through the winter. The track needed one season to operate before the Goodwill games in 2000*

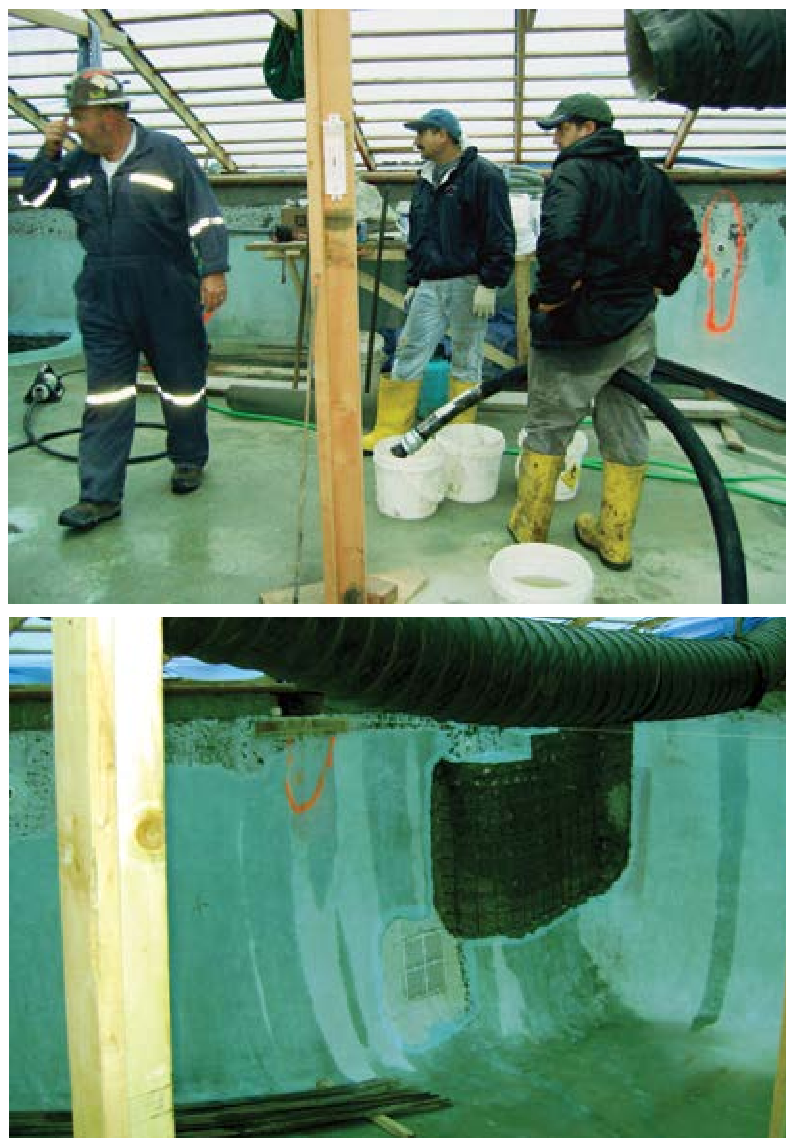

*Fig. 2: High-low thermometers for monitoring the 50°F (10°C) heating within the tenting of the pool structures. The 50°F (10°C) was maintained during the shotcrete placement and curing*

*Fig. 3: Blankets and thermometers were placed on the concrete surface to monitor the temperatures through the cool night and curing period*

- Limit rapid temperature changes particularly before the concrete has developed sufficient strength to withstand induced thermal stresses; and
- Provide protection consistent with the intended serviceability of the structure.

The actual temperatures of the concrete surface determine the effectiveness of protection regardless of the ambient temperature. Therefore, it is desirable to monitor and record the concrete temperature at the surface of the concrete (Fig. 4). During the temperature recording and monitoring process, consider the following:

- Concrete corners and edges are vulnerable to freezing and are usually more difficult to maintain at required temperatures;
- Maintain the internal temperature of concrete to ensure that excessive heating does not occur;
- Inspection personnel should record the date; time; outside air temperatures; temperature of

*Fig. 4: Winter protection for the Volcano skin repair. Temperatures were kept between 47 and 50°F (8 and 10°C) on both sides of the shell. Concrete blankets were placed as added protection. Compression Strengths exceeded the specification for 7 and 28 days. Kings Dominion (Doswell, VA,) November 1, 2015 to March 15, 2016*

**Table 5.1—Recommended concrete temperatures**

| Line | Air temperature | Section size, minimum dimension | | | |
|---|---|---|---|---|---|
| | | < 12 in. (300 mm) | 12 to 36 in. (300 to 900 mm) | 36 to 72 in. (900 to 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 | Below 0°F (–18°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 hours after end of protection | | | |
| 5 | — | 50°F (28°C) | 40° (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.

*Fig. 5: Recommended concrete temperatures—ACI 306R-10, Table 5.1*

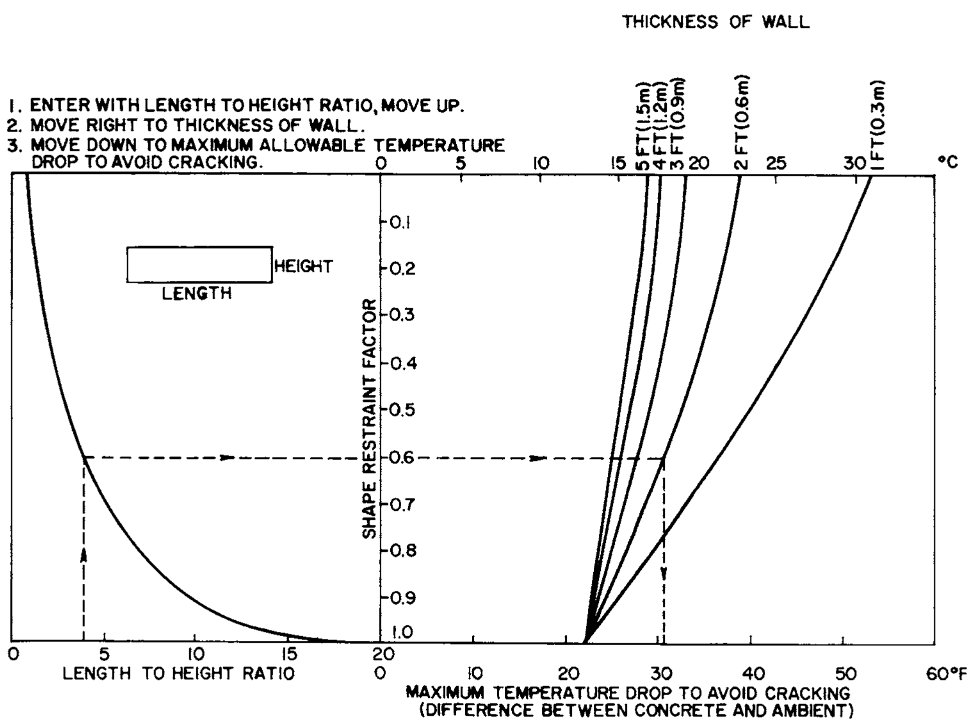


*Fig. 6: Graphical determination of safe differential temperature for walls (Mustard and Gosh 1979)*

concrete as placed; and weather conditions, such as calm, windy, clear or cloudy; and

- Record maximum and minimum temperature reading at the concrete surface and ambient conditions in each 24-hour period.

Table 5.1 in ACI 306R-10 lists the recommended concrete temperatures at various ambient temperatures during and after the protection period (Fig. 5).

Oftentimes a crew will remove protection immediately after the 7-day curing and protection period, not knowing the concrete should be exposed gradually over a 24-hour period to the ambient temperature. If a crack occurs, it's almost always overlooked or is blamed on the live traffic on the highway bridge, railroad bridge, or even attributed to cold joints/cracks in the structure that run through and behind the repair. Using the material compression strength test results from the preconstruction testing (3-, 7-, and 28-day) will help with the decision regarding when the protection and formwork should be removed. The colder the ambient temperature, the longer the protection stays on.

Proper preparation before placement in cold weather often requires a temperature increase of the formwork, reinforcement, and other surfaces that contact fresh concrete so the temperature of the freshly placed concrete will not decrease below the minimums as placed and maintained found in Fig. 5. There are many techniques for warming formwork, mixing water, concrete materials, and embedded items. This may include one or more approaches, such as heated enclosures, electric blankets, hydronic heating systems, forced air heat, or other acceptable systems. Other methods of accelerating concrete reaching the 500 psi (3.5 MPa) threshold against freezing damage can be provided by concrete mixture acceleration, such as a chemical admixture, decreasing the *w*/*cm*, increasing the cement content, pozzolan quantity, cold weather admixtures, or going to a Type III cement (high early).

Figure 6 shows the safe differential temperatures for walls as found in ACI 306R-10. Chapters 8 through 11 in ACI 306R-10 provide much greater detail on protection, curing, and acceleration of concrete set and strength, along with many helpful graphs dealing with different exposure temperatures.

When setting up a project, one has to weigh the costs for cold weather shotcreting to see if it is worth the money spent. Some projects have no choice and run right through the winter. Safety of the crew comes first; the added wear and tear on the equipment—as well as the winter protection and heating costs—all play an important role in deciding to continue work or shut down for winter. Since shotcrete is just a placement method for concrete protection and curing of shotcreted sections is the same as for concrete in the winter.

## References


ACI Committee 306, 2010, "Guide to Cold Weather Concreting (ACI 306R-10)," American Concrete Institute, Farmington Hills, MI, 26 pp.

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Mustard, J.N., and Ghosh, R.S., 1979, "Minimum Protection and Thermal Stresses in Winter Concreting," *Concrete International*, V. 1, No. 1, Jan., pp. 96-101.



***Ray Schallom III*** *is an underground shotcrete application specialist and President of RCS Consulting & Construction Co., Inc. He has 40 years of experience as a Project Manager, Owner, and Superintendent. Schallom works with State DOT departments with their shotcrete specifications and trains engineering companies' inspectors in the field of shotcrete. He is a Past President of ASA, past Chair of the ASA Education Committee, and is a member of the ASA Publications, Underground, Marketing, Sustainability, and Pool & Recreational Shotcrete Committees. Schallom is also a member of ACI Committees 506, Shotcreting, and C660, Shotcrete Nozzleman Certification, and ACI Subcommittees 506-A, Shotcreting-Evaluation; 506-B, Shotcreting-Fiber-Reinforced; 506-C, Shotcreting-Guide; 506-E, Shotcreting-Specifications; 506-F, Shotcreting-Underground; and 506-G, Shotcreting-Qualification for Projects. Schallom is a retired ACI Certified Nozzleman in the wet- and dry-mix processes for vertical and overhead applications with over 40 years of shotcrete nozzling experience in wet- and dry-mix handheld and robotic applications. He is an ASA-approved ACI Shotcrete Examiner for wet and dry applications. Schallom is also a member of ASTM Committee C09, Concrete and Concrete Aggregates, and ASTM Subcommittee C09.46, Shotcrete.*