COLD WEATHER CONCRETING

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The American Concrete Institute defines cold weather as "…a period where for more than three successive days the average daily outdoor temperature is less than 5.5°C. The average daily temperature is the average of the highest and the lowest temperature during the period from midnight to midnight. When temperatures above 10°C occur during more than one-half of any 24 hour duration, the period shall no longer be regarded as cold weather."

Cold weather has an adverse affect on concrete for several reasons which include:

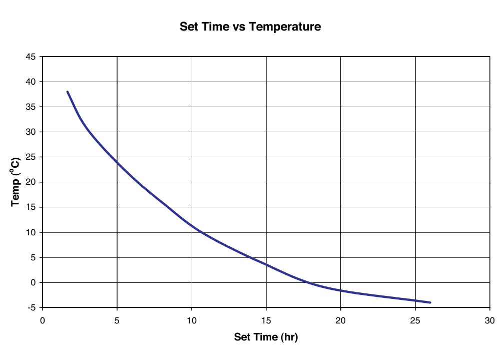
- Fresh concrete will freeze when the temperature drops to -4°C to -6°C (note: hydration probably continues slowly to -10°C).
- Cement hydration slows drastically and thus, strength gain is slow.
- Slow setting increases bleeding of concrete and hampers surface finishing.

Concrete hardening is a time and temperature process in the presence of adequate moisture. The chemical reaction between cement and water is an exothermic reaction, that is, heat is given off during the reaction. In spite of the exothermic reaction, external heat will accelerate concrete set. Regardless of the strength of the concrete, in cold weather the dormancy period of the concrete is increased. However, concrete can be placed safely in cold weather.

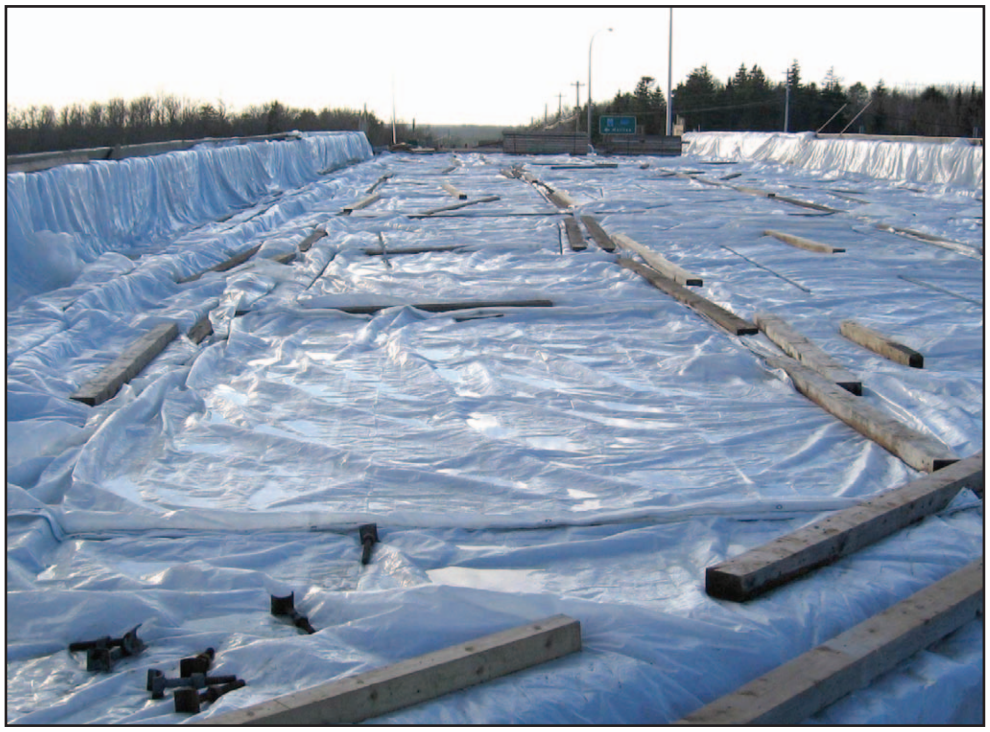
Good cold weather concreting practice requires advance planning. Typically the formwork, reinforcing steel, and embedded fixtures must be free of ice and snow and preferably be heated; the concrete must be protected from freezing for 24 hours or about 3.5 MPa (at which time the degree of saturation of the concrete has reduced to 90 percent); a strength of 25 MPa should be achieved prior to cyclic freezing and thawing; use warm concrete ingredients; use set controlling admixtures (do not consider admixtures as an antifreeze); cycle the transit mix trucks to reduce waiting time; and use insulation and external heat as required.

Fresh concrete can be heated effectively by heating the ingredients, principally the mixture water (mix water has approximately five times the specific heat as the dry materials); extra cement may be added to increase temperature; a temperature of 16°C can be achieved at the plant.

Set accelerators reduce the dormancy period of the cement at all temperatures. These admixtures are generally based on calcium chloride or calcium nitrate. Calcium chloride is the most efficient accelerator; however, it may promote corrosion of embedded ferrous metals (including reinforcing steel) whereas calcium nitrate, which is more costly, inhibits steel corrosion. Insulated blankets are very effective in retaining heat; however, they generally cannot be used until after final finishing.



Most project specifications with a proper QA/QC management plan will require a submittal on procedures to be implemented for cold weather concreting. These procedures will of course bear little resemblance to concrete placed in warmer weather. The cold weather plan will include such items as formwork preparation, insulation type and when applied, methods to retain moisture in the concrete, use of set accelerators, thermal monitoring, etc.



The Exit 4 bridge on Highway 103 was covered in insulated tarps after the concrete deck was finished. This provided a warm environment to allow for proper curing of the final product. This, in turn, allowed the bridge to achieve its full strength and load capacity.

Heated enclosures over slabs are difficult to maintain in winter conditions, and the large open space allows for surface drying of the slabs. Also, there is a risk of surface carbonation of the concrete. Moisture barriers and insulation on the top of slabs, and heating from enclosures below is effective cold weather curing in most instances.

The objectives of cold weather concreting are to:

- Extend the concrete construction season into a year round opportunity;
- Prevent damage to concrete at early ages;
- Assure concrete develops required strength;
- Maintain curing to ensure structural requirements are met; and
- Limit rapid temperature changes in the concrete to prevent thermal shock and subsequent cracking.

The first principle in winter concreting is to "use warm concrete and keep it warm."

Moist curing is generally not a favorable option in cold weather, nor is fogging or misting concrete surfaces. To provide sufficient workability, concrete at the time of placement has more than sufficient water to promote hydration. In cold weather, the key is to reduce the moisture loss and keep it in the concrete. Evaporation is generally lower in winter months.

A Case Study

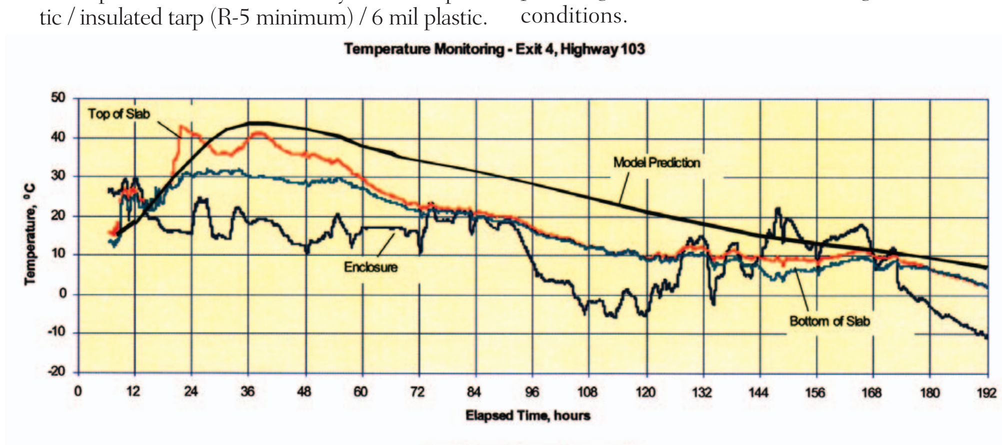
Dexter Construction requested W.S. Langley Concrete & Materials Technology Inc. to provide recommendations for cold weather concreting on a bridge structure at Exit 4 on Highway 103. The existing Quality Management Plan accepted by the Nova Scotia Department of Transportation for bridge deck construction was not applicable to construction during sub-zero weather. In particular, the normally required misting or fogging could not be performed in freezing temperatures. In the absence of early misting during placement of silica fume concrete, it was considered important to retain surface moisture, protect the concrete surface from low temperatures and commence curing as early as practical.

The deck slabs were 225 mm in thickness and were supported on 6 precast girders for Exit 4. The concrete was specified as follows:

- Compressive strength of 45 MPa at 28 days (minimum)
- Air content of 6-8 percent
- w/c of 0.35 (maximum)

W.S. Langley Concrete & Materials Technology Inc. completed thermal modeling of the structure and determined that concrete could be placed safely under the following conditions:

- Concrete delivered to the site at a temperature of 16°C;
- The area below the deck to be enclosed in tarps and heated to a minimum temperature of 10°C;
- Plywood formwork on sides and bottom (with 6 mil plastic cover if ambient air temperature was below -6°C); and
- The top surface covered with a layer of 6 mil plastic / insulated tarp (R-5 minimum) / 6 mil plastic.



In our recommendations to Dexter Construction, W.S. Langley Concrete & Materials Technology Inc. recommended that the concrete placement be monitored by thermocouples as a means to verify that the concrete as placed was in conformance with the model and to verify that it met the Department standards. It was recommended that readings be taken by SmartReaders and downloaded at regular intervals to monitor concrete temperatures and make site adjustments as necessary (i.e., additional top surface insulation, adjust temperature below deck, etc.). Regular monitoring would also permit the evaporation rate from the deck surface to be calculated, thus providing guidelines for curing and protecting the surface, in an effort to avoid cracking.

The supply of 327m^3 of concrete by Bedford Ready Mix commenced at approximately 10 a.m. on 13 January 2005 and finished 13 hours later. W.S. Langley Concrete & Materials Technology Inc. was on site to install thermocouples before the placement began. Thermocouples were attached to the underside of rebar where possible to protect the thermocouple wire from damage due to foot traffic, vibration equipment, etc. Thermocouples were located 2" below the top of the slab, and 2" above the bottom of the slab. The temperature inside the enclosure below the deck was monitored as well.

A SmartReader data logger was connected to the thermocouples, and readings were taken at 10 minute intervals. Readings were downloaded from the data logger onto a laptop computer at hourly intervals during the placement, once during each 24 hour period for duration of three days after the placement finished, final readings taken five days after the placement finished.

During the concrete placement, ambient air temperatures approximately four feet above the deck surface were monitored, as well as relative humidity and wind speed. The temperature of placed concrete was also monitored to aid in determining when to place insulated tarps on the surface. After the insulated tarps were placed, concrete temperatures and relative humidity were measured near the edge of the deck using a hand-held thermometer.

Monitoring data was recorded between 13 January 2005 and 18 January 2005. The actual site conditions and boundary conditions were used in the prediction model and the model re-run for a prediction of temperatures up to a period of 192 hours from the commencement of the concrete placement. All actual ambient conditions (temperature, wind speed, etc.) were input into the model.

The model prediction was very similar to that which was observed on the site with a peak concrete temperature of 43°C.

The bridge deck at Exit 4 of Highway 103 demonstrates that concrete bridge decks can be successfully placed in cold weather with proper planning and careful monitoring of in situ conditions.

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