Cold Weather Concreting
In the Spring

This webinar will start soon!
Cold Weather Concreting – In the Spring

Use the Question box

A link to this webinar and a PDF of the presentation will be posted online at www.ohioconcrete.org

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Cold Weather Concreting
In the Spring

Learning Objectives:

► Define Cold Weather Concrete
► Provide Specification Guidelines
► Identify Concrete Mixture Adjustments
► Describe Protection and Curing Procedures
► Explain Impacts on Strength Testing
Mark Pardi, PE, LEED GA

Mr. Pardi is the Field Engineer for Ohio Concrete and represents the Ohio Chapter of the American Concrete Pavement Association, ACPA. He has worked in the Concrete Industry for 40 years, including Highway Construction, Ready Mixed Concrete Production and the last 11 years with the Association.

Mark is an approved Examiner for ACI Certification Programs and a Past President of the ACI Central Ohio Chapter and an approved presenter for the Ohio Board of Building Standards Continuing Education Courses. Mark participates on the ACPA National task force committees for Concrete Pavement Design, Jointing, and RCC.

Mark received his BS in civil engineering from The Ohio State University in 1981 and is a registered Professional Engineer in Ohio. He is a LEED Green Associate and member of the USGBC Central Ohio Chapter’s Regional Priority Task Force.
What defines Cold Weather Concrete Construction?

- What determines if you are in cold weather conditions
- Sometimes it’s very obvious
- Has to do with temperatures less than 40° F
ACI 306R-88, (Re-Approved in 2002) defined “Cold Weather” as:

- a period when, for more than 3 consecutive days, the following conditions exist: 1) the average daily air temperature is less than 40°F and 2) the air temperature is not greater than 50°F for more than one-half of any 24-hr period.

ACI 306R-10, (2010) defined “Cold Weather” as

- when the air temperature has fallen to, or is expected to fall below 40°F during the protection period.
ACI 306R-16, defines “Cold Weather” as:

- when air temperature has fallen to, or is expected to fall below, 40°F (4°C) during the protection period;
- protection period is defined as the time recommended to prevent concrete from being adversely affected by exposure to cold weather during construction.
P3. Building codes set minimum requirements necessary to protect the public. This Standard Specification may stipulate requirements more restrictive than the minimum.

2.2 -Concrete for slabs and other flatwork exposed to cycles of freezing and thawing in a wet condition during the construction period shall be air entrained as specified in ACI 301 even though the concrete may not be exposed to freezing in service.

However, changes in ACI 306R-16 are not yet adopted into the Standard Specification for Cold Weather Concreting (306.1-90)
Concrete temperatures
Minimum concrete temps during the protection period are shown in column (2)
Temps of concrete as placed shall not exceed the Column (2) by more than 20°F.
The maximum decrease in temperature at the surface of the concrete in a 24-hour period shall not exceed the values in column (3)

Cure and protect concrete from freezing for a minimum of 3 days.
Cold Weather Concreting Objectives

- Prevent damage to concrete due to freezing at early ages
- Assure that concrete develops the required strength so that forms may be safely removed
- Maintain curing conditions to provide normal strength development without using excessive heat
- Limit rapid temperature changes
- Provide protection that is consistent with the intended use of the structure
Cold Weather Challenges

- Slower hydration
  - Retardation of set time
  - Plastic shrinkage crack potential, as surface dries before it’s ready for finishing operations
- Lower early age strength
  - Form removal slowed
- Potential for thermal cracking
- Protect from early freezing
Job site protection: Heated Enclosures

Must Vent CO₂ Exhaust Gas to prevent carbonization resulting in soft dusting surfaces
Dusting
Preparation before placement

- Remove all snow, ice, & never place on a frozen subgrade
- Surfaces in contact with the concrete should be above freezing (32° F).
- Provide insulating blankets on ground several days in advance
- Set up wind breaks
Most embedments including bars, do not need to be heated unless the air temperature is below 10° F (-12°C). Embedments with a cross-sectional area greater than 4 in² should be heated to above 32° F.

Bars < No.18 ?

Warm up metal larger metal embeds
Insulated Concrete Forms
 Contractors Be Prepared!

Have plenty of blankets ready

Hydronic Heat System
Hydronic Heat System

Use system to heat concrete after placement
Concrete on a very cold subbase feels rubbery
The bottom cools rapidly and top remains warm
To reduce this differential set retardation, keep the subgrade covered until the time of concrete placement.
For **steel-troweled** floor and slab construction, **air-entrained** concrete should **not** be specified.

Finishing problems often develop when the total air content >3%

Addition of air entrainment may lead to finishing difficulties or problems with blisters, delamination, or other surface defects.

Air entrainment may be necessary for the duration of the project even though the concrete will not be exposed to freezing and thawing in final service condition. (best to use Magnesium trowel)
Finishing air-entrained slabs

- For flatwork in cold weather, lower-slump concrete minimizes excessive bleed water and allows earlier set time.
- During cold weather, bleed water may remain on the surface for extended periods, interfering with or prolonging finishing operations.
- If bleed water is finished into the concrete, the resulting surface will have lower strength and be prone to dusting and deterioration.
EFFECTS OF COLD TEMPERATURES ON FINISHING

Maximum temperature differential between the concrete interior and the concrete surface shouldn't exceed 35°F. Thermal cracks if 30°F differential between top & bottom surface of concrete

When the concrete materials are heated, the concrete temperatures should be between 50 and 70°F.

Crust forms as the surface dries and cracks may occur.
Blisters

- Bleed water and/or air sealed into concrete
Minimum required strength for concrete to freeze once

- Concrete protected from freezing until it attains a compressive strength of at least 500 psi (3.5 MPa) will not be damaged by exposure to a single freezing cycle.

- This is about 1-2 days after placement for most concrete maintained at 50F.
Effect of Freezing Fresh Concrete

Up to 50% reduction of ultimate strength can occur if frozen before reaching a strength of 3.5 MPa (500 psi)

Ice crystal impression can be seen in the frozen paste
What strength is safe to allow concrete to freeze?

- Newly placed concrete is saturated with water and should be protected from freezing and thawing cycles until it has reached a strength of at least 3500 psi.
Production Control Options w/ Materials & Mixtures

- Use Type III cement (High Early Strength)
- Increase cement amount
- Reduce percentage of SCMs (fly ash, slag cement)
- Reduce water content (lower w/cm) to mitigate problems due to excessive bleed water and delayed set time.
- Use accelerators (CaCl$_2$ if permitted or non-chloride)
- Monitor Air entrained concrete during freezing conditions
- Control temperature loss of fresh concrete
  - Hot water
  - Heated aggregates
Expected temperature loss during delivery

Temperature drop for 1 hour delivery in revolving drum mixers:
$$T = 0.25 \times (t_r - t_a)$$

- $t_r = 50^\circ F$ (Temp required at job)
- $t_a = 20^\circ F$ (Ambient Temp)
- $\Delta = 30 \times (t_r - t_a)$

$$0.25 \times 30 = 7.5^\circ F$$ temp drop

Must batch concrete at $58^\circ F$

Could be $7.5^\circ F$ for $20^\circ F$ ambient
Rules of Thumb:

- For every 20°F temperature drop, setting time is doubled
  - A change in temperature from 70°F to 50°F will double the time it takes for concrete to set
- Warm concrete on cold subgrade gets cold very fast
- Different mixes and materials have very different setting times
- Adding 1 to 2 gallons of water per cy will delay set time by 1/2 to 2 hours
Form Removal

- Based on in-place strength, not time!

- Options include:
  - Field cured cylinders (not very reliable)
  - In-place testing (in-place strength is generally better than field cured cylinders)
  - Pull-out testing, penetration resistance, pulse velocity measurement
  - Maturity testing

Avoid rapid temperature drop when removing blankets (temperature shock)
Maturity Testing (Time & Temperature)

Case History - Willow Island, WV
Cooling Tower Collapse April 27, 1978
Wet Concrete Possible Cause Of 51 …
Protection of Acceptance Samples

ACI Guidelines
Initial cure at 60-80°F
=> 6000 PSI at 68-78°F
Concrete shall be assigned to exposure classes in accordance with ACI 318-11, Section 4.2, based on:

1. Exposure to freezing and thawing in a moist condition or deicer chemicals; (F3-Very Severe)
2. Exposure to sulfates in water or soil; (S)
3. Exposure to water where the concrete is intended to have low permeability; (P)
4. Exposure to chlorides from deicing chemicals, salt, saltwater, brackish water, seawater or spray from these sources, where the concrete has steel reinforcement. (C)
1905.6.3 Strength test specimens. Specimens prepared for acceptance testing of concrete in accordance with Section 1905.6.2 and strength test acceptance criteria shall comply with the provisions of ACI 318-11, Section 5.6.3.

1905.6.4 Field-cured specimens. Where required by the building official to determine adequacy of curing and protection of concrete in the structure, specimens shall be prepared, cured, tested and test results evaluated for acceptance in accordance with ACI 318-11, Section 5.6.4.
8.2 – Field-cured cylinders
The use of field-cured cylinders is inappropriate and should not be allowed in cold weather concreting. In-place testing, maturity testing, or both, should be used.

8.3 – In-place testing
A number of techniques are available for estimating the in-place strength of concrete (ACI 228.1R).

8.4 – Maturity testing
Concrete maturity is based on the concept that the combination of curing time and temperature of the concrete yields a specific strength for a given concrete mixture.
Concrete Cylinders at jobsite.

Date: March 17 2011, 7:30 a.m.

Ambient Temperature at the time the photo was taken: 38°F

Curing conditions of deck: Heated & Covered, with full jacketing.

Field Cure Cylinders?
Maturity Concept

- \[ M = \sum (T - T_o) \Delta t \]

where
- \( M \) = maturity factor, deg-hr
- \( T \) = temperature of concrete, deg F (C)
- \( T_o \) = datum temperature, deg F (C) (approx. 32°F)
- \( \Delta t \) = duration of curing period at temperature \( T \), hr

Cold-Weather Concreting
Example of a Match Cure System
Benefits of Using Set Accelerating Admixtures

The reduction of setting time and the acceleration of strength gain often result in substantial savings due to:

- shorter protection periods
- faster form reuse
- earlier removal of shoring
- and less labor in finishing flatwork

Acceleration may be encouraged by using:

- Type III Portland Cement
- additional cement (normally 20% addition = Type III performance)
- heated materials
- set accelerating admixtures
**Calcium Chloride:**

- The most cost effective accelerator available; provides improved finish in some cases
- Very effective performance in both powder or solution
- Dosage based on % by weight of cement (Typ. 1% or 2%, 2% is max)

**Limitations:**

- 1. It causes corrosion of reinforcing steel in presence of oxygen and moisture.
- 2. It tends to result in a darker appearing surface
Calcium Chloride Admixture
Non-chloride accelerators

- Type E (ASTM C494)
- May contain a small amount of calcium chloride
- More expensive than calcium chloride
- Will not darken surface
- Not as effective as CaCl2
- 2% Non-chloride is about 1 gal / cu yd of water replacement
To prevent early age freezing

- Provide protection immediately after concrete placement
- Don’t allow concrete to freeze when saturated
- Set accelerators are not used as substitute for proper curing and protection
### Table 5.1 – Recommended concrete temperatures

<table>
<thead>
<tr>
<th>Line</th>
<th>Air temperature</th>
<th>Section size, minimum dimension</th>
<th>Minimum concrete temperature as placed and maintained</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&lt; 12 in. (300 mm)</td>
<td>12 to 36 in. (300 to 900 mm)</td>
</tr>
<tr>
<td>1</td>
<td>—</td>
<td>55°F (13°C)</td>
<td>50°F (10°C)</td>
</tr>
<tr>
<td>2</td>
<td>Above 30°F (−1°C)</td>
<td>60°F (16°C)</td>
<td>55°F (13°C)</td>
</tr>
<tr>
<td>3</td>
<td>0 to 30°F (−18 to −1°C)</td>
<td>65°F (18°C)</td>
<td>60°F (16°C)</td>
</tr>
<tr>
<td>4</td>
<td>Below 0°F (−18°C)</td>
<td>70°F (21°C)</td>
<td>65°F (18°C)</td>
</tr>
</tbody>
</table>

*For colder weather, a greater margin in temperature is provided between concrete as mixed and required minimum temperature of fresh concrete in place.

Note 1: For Line 1, maximum placement temperature is minimum temperature in the table plus 20°F (11°C).

Note 2: For Lines 2-4, maximum temperature is minimum temperature in the table plus 15°F (9°C).

<table>
<thead>
<tr>
<th>Line</th>
<th>Minimum allow. gradual temperature drop in first 24 hours after end of protection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 12 in. (300 mm)</td>
</tr>
<tr>
<td>1</td>
<td>50°F (28°C)</td>
</tr>
</tbody>
</table>

### Table 7.2 - Length of protection period for concrete

<table>
<thead>
<tr>
<th>Service Condition</th>
<th>Normal Concrete</th>
<th>Accelerated Set Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not exposed</td>
<td>2 days</td>
<td>1 day</td>
</tr>
<tr>
<td>Exposed</td>
<td>3 days</td>
<td>2 days</td>
</tr>
</tbody>
</table>
Removing thermal protection

CAUTION!

- Remove curing blankets slowly
- Do not “shock” the concrete
- Allow it to acclimate to the cold temperatures
- Slide 2x4s under the blankets to allow some air circulation for a day or two
What is Curing?

Definition:
maintenance of a satisfactory moisture content and temperature in concrete for a suitable period of time immediately following placing & finishing so that the desired properties may develop...offer ample condition for hydration to occur.

Minimal Requirements

Time: 3-7 days
Temp: 50-100 F
Moisture: Saturated at all times
Caution on Curing Compounds

- Not suggested after about October 1st
- Seals the excess moisture in the concrete
- Will actually cause scaling if excess water in the concrete freezes
- Use blankets instead
Item 451.07

When the air temperature is 35 °F (2 °C) or below, ensure the concrete has a temperature of between 50 and 80 °F (10 and 27 °C) at the point of placement.

When the air temperature is greater than 35 °F (2 °C) before placing, maintain a concrete temperature of not more than 95 °F (35 °C).

Do not place concrete on any surface that is frozen or has frost.
**Contractor Communication**

Communicate to the Ready Mixed Supplier:

- Design Strength and early age strength requirements
- Air Entrainment, Agg Size, W/C ratio, slump
- Exposure condition and ambient temperatures
- Required set time – need for accelerators
- Section Thickness – dictates minimum concrete temp as placed
- Placement method – slump modification admixtures
- Producer assumes the contractor will have proper cold weather protection and concrete curing
Resources

- American Concrete Institute, *ACI 306R-16 Guide To Cold Weather Concreting*
- American Concrete Institute, *ACI C873-15 Compressive Strength by Cast-In-Place Molds*
- American Concrete Institute, *ACI 228*
- National Ready Mixed Concrete Association, *Concrete in Practice (CIP) 13, Concrete Blisters and (CIP) 20, Delamination of Troweled Concrete Surfaces, (CIP) 27 Cold Weather Concreting, (CIP) 42 Thermal Cracking of Concrete (www.nrmca.org)*
- Ohio Concrete, *Technical Tips for Residential Concrete, #4 Cold Weather Concreting*
- Ohio Concrete, *Industry Recommendation for Exterior Concrete Flatwork, 2014*
- *Design and Control of Concrete Mixtures, Portland Cement Association, Skokie, IL, 16th Edition, 2016*
Thank you for Listening!
Questions??
Upcoming Future Webinars

- Stay tuned for future webinars by Ohio Concrete
  - We welcome suggested topics
Your opinion matters!

Please take a moment to complete the brief survey following today’s presentation to help us improve future webinars.

THANK YOU!