Cold Weather Concreting & Review of ACI 306

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Objectives/ Intent of Cold Weather Concreting

1. Normalize set of concrete
2. Limit rapid temperature change
3. Prevent damage from freezing at early stages
4. Provide protection consistent with serviceability of structure
Discussion Points:

1. Risks
2. Potential Problems
3. Principles
4. Objectives
5. Goals
6. Freeze Resistant Concrete
7. Cold Weather Concrete Plan
Goal of ACI 306

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 Key to Proper Cold Weather Concrete is Managing Risk
Risks of Cold Weather

1. Neglecting protection against early freezing can cause immediate destruction or permanently weakened concrete.

2. The durability of concrete can be significantly reduced
Effect of Freezing

1. Race Between the hydration of cement (Generates heat as well as strength) and heat loss

2. At a point after hydration, the concrete is strong enough to resist freezing

3. Very little hydration takes place below 40 ºF
Bladed ice crystals cast in cement paste- concrete froze while still plastic
Potential Problems for Freshly-Mixed Concrete in Cold Weather

1. Delayed set times
2. Frozen sub-grade
3. Ice in bottom of forms
4. Cold formwork
5. Over/early finishing
6. Plastic shrinkage cracking
7. Crazing
## Setting Time of Concrete at Various Temperatures (Delay)

<table>
<thead>
<tr>
<th>Temperatures</th>
<th>Approximate Setting Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 °F (38 °C)</td>
<td>2 hours</td>
</tr>
<tr>
<td>90 °F (32 °C)</td>
<td>3 hours</td>
</tr>
<tr>
<td>80 °F (27 °C)</td>
<td>4 hours</td>
</tr>
<tr>
<td>70 °F (21 °C)</td>
<td>6 hours</td>
</tr>
<tr>
<td>60 °F (16 °C)</td>
<td>8 hours</td>
</tr>
<tr>
<td>50 °F (10 °C)</td>
<td>11 hours</td>
</tr>
<tr>
<td>40 °F (4 °C)</td>
<td>14 hours</td>
</tr>
</tbody>
</table>
ASTM C-1622 / C-1622M-05
Standard Specification for Cold Weather Admixture Systems

• Determine the placement temperature of concrete according to ASTM C 1064/C1064M
• The more massive the concrete section, the less rapidly it loses heat.
Potential Problems for Freshly-Mixed Concrete in Cold Weather

1. Delayed set times

2. Frozen sub-grade

3. Ice in bottom of forms

4. Cold formwork

5. Over/early finishing

6. Plastic shrinkage cracking

7. Crazing
Frozen subgrade
Subgrade Has Previously Been Thawed With Hoses, Blankets & Tarps
Potential Problems for Freshly-Mixed Concrete in Cold Weather

1. Delayed set times
2. Frozen sub-grade
3. Ice in bottom of forms
4. Cold formwork
5. Over/ early finishing
6. Plastic shrinkage cracking
7. Crazing
Ice/snow in forms
Potential Problems for Freshly-Mixed Concrete in Cold Weather

1. Delayed set times
2. Frozen sub-grade
3. Ice in bottom of forms
4. Cold formwork
5. Over/ early finishing
6. Plastic shrinkage cracking / Crazing
Over/ early finishing

1. Because of drying conditions, concrete may appear to be ready to finish or, require additional finishing effort

2. Results:
   A. Detrained air in the top ¼”
   B. High potential for scaling
Over/ early finishing
Potential Problems for Freshly-Mixed Concrete in Cold Weather

1. Delayed set times
2. Frozen sub-grade
3. Ice in bottom of forms
4. Cold formwork
5. Over/ early finishing
6. Plastic shrinkage cracking / Crazing
Plastic Shrinkage Cracking

1. Low relative humidity
2. Wind
3. Absorbent subgrade or formwork
4. Prolonged set times
5. Lack of early protection from drying
When water evaporates off the surface too rapidly, cracking usually occurs. Plastic shrinkage occurs when the rate of evaporation of surface moisture exceeds the rate at which the rising bleed water can replace it.
Potential Problems for Freshly-Mixed Concrete in Cold Weather

1. Delayed set times
2. Frozen sub-grade
3. Ice in bottom of forms
4. Cold formwork
5. Over/ early finishing
6. Carbonation
7. Plastic shrinkage cracking / Crazing
How to avoid plastic (or any other kind of) shrinkage cracks:

1. Accelerate the set (different from high-early concrete)
2. Use micro-fibers
3. Use temporary evaporation control
   1. Use evaporation retarder
   2. Use poly/plastic sheeting
4. Cut joint as soon as feasible - DO NOT WAIT!!
5. Use a high quality curing compound, sooner rather than later
6. Use curing/insulating covers
7. Protect & Cure!!
Curing!
Issues that often arise in Cold Weather

1. Don’t skimp / forget curing
2. Concrete Cylinders
Principles of Cold Weather Concreting
Principles of Cold Weather Concreting:

1. Concrete protected from freezing until it attains a compressive strength of at least 500 psi (3.5MPa) will not be damaged by exposure to a single freezing cycle (Powers 1962).

2. Where a specified concrete strength should be attained in a few days or weeks, planning and protection may be required to maintain the concrete temperature
Principles of Cold Weather Concreting

Under certain conditions, CaCl$_2$ should not be used to accelerate setting and hardening because of increased chances of corrosion of metals embedded in concrete or other adverse effects.
Required for Durability

Concrete exposed to freeze/thaw while saturated requires lower w/cm than required for strength

1. w/cm .50 (4,000 psi) moderate to severe freeze/thaw

2. w/cm .45 (4,500 psi) deicing salts

3. w/cm .40 (5,000 psi reinforced concrete subject to brackish water, sea water or deicing chemicals
Guide to Cold Weather Concreting ACI 306R-16

* The word “required” is now changed to “recommended.”
DEFINITION 306R-88

Cold weather is defined 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 (5 C) and 2) the air temperature is not greater than 50 F (10 C) for more than one-half of any 24-hr period.* The average daily air temperature is the average of the highest and the lowest temperatures occurring during the period from midnight to midnight. Cold weather, as defined in this report, usually starts during fall and usually continues until spring.
Cold Weather Concreting
ACI 306R-10

• **Definition:** “Cold weather exists when the air temperature has fallen to, or is expected to fall below 40 F during the protection period. The protection period is defined as the time required to prevent concrete from being affected by exposure to cold weather.”
Guide to Cold Weather Concreting
ACI 306R-16

This document guides specifiers, contractors, and concrete producers through the selection processes that identify methods for cold weather concreting. The objectives of cold weather concreting practices are to: a) prevent damage to concrete due to freezing at early ages; b) ensure that the concrete develops the recommended strength for safe removal of forms; c) maintain curing conditions that foster normal strength development; d) limit rapid temperature changes; and e) provide protection consistent with intended serviceability of the structure. Concrete placed during cold weather will develop sufficient strength and durability to satisfy intended service requirements when it is properly proportioned, produced, placed, and protected.

Balancing Risk in Producing Concrete in Cold Weather
Chapter 3: Objectives, Principles and Economy

- 3.1 – Added – “The temperature of concrete is measured in accordance with ASTM C1064.”

- 3.1.3 – Rewritten - “Maintain curing conditions that promote strength development without exceeding the recommended concrete temperatures in Table 5.1 by more than 20 F and without using water curing, which may cause critical saturation at the end of the protection period, thus reducing resistance to freezing and thawing when protection is removed (Section 5.1).”

- 3.3 – Economy – “Cold weather concreting results in extra costs because of potentially lower worker productivity and additional needed products such as insulating blanket, tarping and heaters. But it may also allow a project to stay on schedule.”
Chapter 4: General Recommendations

4.3 Concrete Temperatures

Deleted – Concrete placed at lower temperatures (40-55F), protected against freezing, and properly cured for a sufficient length of time, has the potential to develop higher ultimate strength and greater durability than concrete placed at higher temperatures. (Klieger 1958)
1. Where hard troweled finish is specified, the addition of air entrainment may lead to...In this case magnesium trowels should be used instead of steel tools.

2. The water-cementitious materials ratio (w/cm) should not exceed the limits recommended in ACI 201.2R, and the concrete should be protected from freezing and thawing for the duration of the protection period. For steel-troweled floor and slab construction, air-entrained concrete should not be specified, and the concrete should be protected from freezing and thawing for the duration of the protection period.
New sidewalks and other flatwork exposed to melting snow and cold weather should be air-entrained and protected from freezing and thawing for the duration of the protection period. Removed ...Until attaining at least 3500 psi.
## Concrete Temperature Requirements

<table>
<thead>
<tr>
<th>Air temperature</th>
<th>Minimum concrete temperature as placed and maintained</th>
<th>Minimum concrete temperature as mixed for indicated air temperature*</th>
<th>Maximum allowable gradual temperature drop in first 24 hrs after end of protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above 30 °F</td>
<td>55 °F (13 °C)</td>
<td>50 °F (10 °C)</td>
<td>50 °F (28 °C)</td>
</tr>
<tr>
<td>(0 to 30 °F</td>
<td>55 °F (13 °C)</td>
<td>50 °F (10 °C)</td>
<td>45 °F (22 °C)</td>
</tr>
<tr>
<td>(-18 to –1 °C)</td>
<td>60 °F (16 °C)</td>
<td>45 °F (7 °C)</td>
<td>30 °F (17 °C)</td>
</tr>
<tr>
<td>Below 0 °F</td>
<td>65 °F (18 °C)</td>
<td>55 °F (7 °C)</td>
<td>20 °F (11 °C)</td>
</tr>
<tr>
<td>(-18 °C)</td>
<td>70 °F (21 °C)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*— Maximum allowable gradual temperature drop in first 24 hrs after end of protection
6.2 Massive Metallic Embedments –

Most embedments including bars, do not need to be heated unless the air temperature is below 10 F (-12C). Embedments with a cross-sectional area greater than 4 in\(^2\) should be heated to above 32deg F. Reinforcing bars smaller than No. 18 in size are not considered massive embedments.
Chapter 6

6.3 Subgrade Condition – In accordance with ACI 302, slabs should not be placed on frozen base or subgrade....

2nd paragraph

Limit surface temperatures of supporting materials beneath slabs on ground and the concrete to a temperature differential of less than 20 F to avoid any inconsistent setting, rapid moisture loss, delaminations and plastic shrinkage cracking.

Removed When the concrete temperature is more than 10F cooler or 5F warmer than the subgrade, differential rates of setting between the top and bottom of the slab...
Chapter 7. Concrete elements that do not use required construction supports are those elements that will not be needed for significant structural performance during the construction schedule that would otherwise be delayed by lack of design strength due to temperatures below 40F. To frozen conditions
Chapter 7 (Cont.)

• Added 7.3 Protection Period for Durability.
• Added this last paragraph: Concrete intended to provide low permeability or high resistance to chloride ion ingress, identified in the contract documents as being exposure Class F3, C2, or P1 as defined by ACI 318, should be protected from freezing until the mixture design compressive strength has been achieved.
8.2 Field-Cured Cylinders intended to be cured with the structure were once widely accepted to represent the lowest likely strength of the concrete. Field cured cylinders can cause confusion and unnecessary delay in construction. The use of field cured cylinders is inappropriate and should not be allowed in cold weather concreting. This is mainly related to the difficulty in maintaining the cylinders in any approximation of the conditions of the structure. In-place testing, maturity testing, or both should be used instead.
In-place testing & Maturity testing

Figure 1 - intelliRock Reader and Logger
Concrete Cylinders at jobsite.

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

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

Curing conditions of deck: Heated & Covered, with full jacketing.
Chapter 8: Protection *(Against Freezing)*

for Structural Concrete Requiring Construction Supports. *(retitled)*

- 8.6 Increasing Early Strength added the following bullets
  - Type, amount, and properties of cementitious materials
  - w/cm
  - Reducing the w/cm to increase the 28 day strength, thus increasing the early strength
  - Increase the volume of cement used in the mixture
  - Increase the use of various supplementary cementitious materials to increase early-age strength development.
  - SCM’s
Chapter 10: Curing Requirements
Recommendations and Methods

• Measures should be taken to inhibit prevent evaporation of moisture from concrete. Freshly placed concrete is vulnerable to freezing when it is critically saturated. Therefore concrete should be allowed to undergo some drying before being exposed to temperatures below 32 F (0°C)

• 10.2 3rd paragraph

• Added: If the relative humidity is less than 40 percent inside the enclosure, it is necessary to add moisture to the air to maintain at least 40 percent relative humidity, and inhibit desiccation of the exposed surface.
Chapter 11: Acceleration of Setting and Strength Development

• 11.2.2 – rewritten - Calcium Chloride

The amount of water soluble chloride ion should consider all other sources of chlorides ions in the concrete mixture. ACI 318 and ACI 332 provides the maximum water-soluble chloride ion content based on exposure class. All statements about calcium chloride added to concrete in permissible quantities...To avoid misplaced confidence in this practice, it is removed.
Chapter 11: Acceleration of Setting and Strength Development

• Removed from document
• 11.2.5 Non chloride accelerating admixtures for use in sub-freezing ambient temperatures
• 11.2.6 Antifreeze Admixtures
  a) Background
  b) Composition
  c) Strength
  d) Freezing & Thawing Resistance
  e) Reactive Aggregates
  f) Corrosion
  g) Batching
  h) Cost Benefits
  i) Summary
Chapter 11: Acceleration of Setting and Strength Development

11.3 Cold Weather Admixture Systems (CWASs)  
Follows ASTM C 1622/C1622M as an admixtures or group of admixtures that depresses the freezing point of mixing water and increases the hydration rate of cement
Freeze Resistant Concrete

IS IT POSSIBLE?

IS IT AFFORDABLE?
Bring the Outside Indoors
Why Should We Use Freeze Resistant Concrete?

1. Reduces initial set
2. Concrete placing cycle is accelerated
3. Improves early strength gain
4. Allows same-day finishing
5. Maintain Schedule
6. Emergency Situations
Important Points

1. Keep the design method simple
2. Not all non-chlorides accelerators can make freeze resistant concrete
3. Cannot be done with calcium chloride
4. Many types of application
5. Work very closely with your RM producer & admixture supplier
KEEP IT SIMPLE!

1. 600# TYPE 1 CEMENT minimum
2. 6% AIR
3. 60 oz./cwt of freeze protection admixture
4. PREVENT THE INGRESS OF MOISTURE
   – a. cover with visqueen or insulated blankets
   or
   – b. apply solvent based cure and seal
Metal Deck Placements

Most Common Application For Freeze Resistant Concrete
An Example:
Hudson Lights Fort Lee NJ
What To Do When The Show Must Go On?

1. You have a Critical Placement!
2. The Weather does not Cooperate!
3. The Concrete Placement is critical to the Time Line of Construction!
4. There is no Easy Method for Winter Protection!
5. What Is Your Option????????
6. **Create a plan
Basic Recommendations –

1. No single mix answer.
2. Selection of a few mix designs supported by maturity testing to confirm local performance.
3. Pour earlier in the day – solar gain on concrete mass
4. Type III cements over Type I for performance
5. Slower strength gain in cold weather – use caution when removing support.
Cold Weather Concreting Plan

1. Contingencies
   a. For equipment failure
   b. Abrupt changes in weather
Cold Weather Concreting Plan

1. Curing
   a. Insulating blankets, leave forms in place, curing compounds

2. Temperature Monitoring
   a. From plant to point of placement
   b. In place testing
   c. Frequency and location of T monitors
   d. Rate of T decrease to minimize thermal cracking
Cold Weather Concreting Plan
Cold Weather Concreting Plan

1. Transportation & Placement
   1. Schedule deliveries to minimize truck waiting times
   2. Tie temperature measurements to action if temps drop below allowable minimum
   3. Means for thawing, heating or insulating subgrade and forms

2. Protection (Different for different temp ranges)
   1. Blankets, enclosures (lumber, plastic sheeting, vents, hardware), means of heating (vents, fuel)
Pre-Placement Meeting

1. Timing – Not the day before

2. Goals of the meeting
   a) Clear – expectations and goals
   b) Clear – process and procedures.

3. This is Contractor’s Day.

4. Specification overview
   a) Have the difficult conversation!
Pre-Placement Meeting

Attendees

a. Owner
b. Design Engineer
c. General Contractor – Supt or PM
d. Concrete Supplier
e. Testing Agency
f. Foreman / Superintendent – All concrete trades
g. Other Suppliers – Pump, admix, fiber, etc.

** Accurate minutes to be distributed within 5 days
Plan Components

1. Concrete temperature during mixing and placing,
2. Temperature loss during delivery
3. Preparation for cold weather concreting
4. Estimating strength development,
5. Methods of protection,
6. Curing requirements,
7. Admixtures for accelerating setting and strength gain and antifreeze admixtures.
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