Cold Weather Concrete and Concrete Repair Practices

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Winter Time Reading:
Cold Weather Concreting...
Cold Weather Concrete - Defined

- **cold weather**—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.

- Most repair mortar manufacturers recommend against placement of prepackaged repair mortars at temperatures below 40 deg F (4 C).
Objectives

1. Prevent damage due to early age freezing.
   - Critical Saturation
   - Concrete - Minimum 500 psi for single freeze (3500 psi for multiple)

2. Ensure required strength development for safe removal of forms, shores, reshores and for safe loading.

3. Maintain curing conditions without exceeding recommended concrete temperature by more than 20 deg F, and without using water. (Critical Saturation)

4. Limit rapid temperature changes.

5. Provide protection consistent with the durability of the structure during its design life.
   - Short-term gains in construction economy on concrete protection should not be obtained at the expense of long-term durability
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
Cold Weather Discussion

1. Risks
2. Potential Problems
3. Cold Weather Plan
4. Objectives
5. Goals
Risks of Cold Weather Concrete and Repairs

1. Freezing is the number 1 risk for cold weather concrete and concrete repair mortars.

2. Neglecting protection against early freezing can cause immediate destruction or permanently weakened concrete and repair mortars.

3. The durability of concrete and repair mortars can be significantly reduced.
Effect of Freezing – The Race is On

• At a certain point after hydration, the concrete/repair mortar is strong enough to resist freezing
• Very little hydration takes place below 40 °F
  • True of all concrete and most repair mortars.
  • Chemical reactions of polymers also slow dramatically
• Race Between the hydration of cement (Generates heat as well as strength) and heat loss
  • The thinner the section the faster the heat loss
  • Many repairs involve thinner sections.
Bladed ice crystals cast in cement paste- concrete froze while still plastic
• Critical saturation is the level at which a single cycle of freezing can cause damage. The degree of saturation falls below critical saturation at the approximate time the concrete attains a compressive strength of 500 psi (3.5 MPa).

• 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-and-thawing cycle. It will mature to its potential strength and will not be damaged, despite subsequent exposure to cold weather. No further protection is necessary unless a minimum strength at a minimum time is specified.
Concrete/Repair Mortar Freezing

Hydration of the cementitious fraction is needed to develop properties relating to durability, such as strength. If repeated exposure to freezing and thawing is anticipated, reaching 500 psi (3.5 MPa) is not sufficient protection. Concrete with a compressive strength less than 3500 psi (24.5 MPa) and exposed to repeated freezing-and-thawing cycles while critically saturated may be damaged. Consider the addition of air entrainment in the concrete (Table 4.1 of ACI 201.2R) and monitoring the concrete strength gain so that 3500 psi (24.5 MPa) is reached before the protection is removed.

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.

Many prepackaged repair mortars call for higher compressive strength attainment, i.e. 1,000 psi (7 MPa), or above prior to allowing freeze.
Protect the Concrete from Freezing

- Concrete temperature
  - Heating water and aggregates
- Increase cement content
- Type III high early cement
- Set accelerating admixtures
- Insulated covers until 500 psi (2 days at 50 deg F)
- Insulated forms
- Insulated edges and corners
- Heated enclosures
An Example:
Recommended Concrete Temperatures

ACI 306-16 (Table 5.1)

<table>
<thead>
<tr>
<th>Line</th>
<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 hours after end of protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>—</td>
<td>55 F (13 C)</td>
<td>50 F (10 C)</td>
<td>45 F (7 C)</td>
</tr>
<tr>
<td>2</td>
<td>Above 30°F (-1°C)</td>
<td>60°F (16°C)</td>
<td>65°F (18°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>
<td>55°F (13°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>
<td>60 F (16 C)</td>
</tr>
<tr>
<td>5</td>
<td>—</td>
<td>50°F (28 C)</td>
<td>40° (22 C)</td>
<td>30°F (17 C)</td>
</tr>
</tbody>
</table>

SECTION 4.3: The concrete temperature during placement should be near the temperature values in Table 5.1 and should not be higher than these values by more than 20°F (11°C).

SECTION 5.2: While it is difficult to uniformly heat aggregates to a predetermined temperature, mixing water temperature can be adjusted easily by blending hot and cold water to obtain a concrete temperature within 10°F (5°C) of the recommended temperature.
Mix Cold Weather Concrete Design Keypoints

- Proper cement content (no SCMs)
- Low W/CM ratio (reduce excess water)
- Water reducing admixtures
- Air entraining admixtures (for freeze/thaw)
- Set accelerating admixtures (non-chloride)
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
4. Air entrainment is also required.
Cold Weather Concrete

KEEP IT SIMPLE!

1. 600# TYPE 1 CEMENT minimum
2. 6% AIR
3. Set accelerating admixture
Why Use Set Accelerating Admixtures in 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
Set Accelerating Admixtures

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.
Set Accelerating Admixtures

- ASTM C494 Type C and E admixtures can be used to accelerate the set of concrete helping it to reach 500 psi sooner.
- Some non-chloride accelerating admixtures can be used to actually lower the freezing point of the water in the mix.
- Work closely with local ready mix producers and admixture suppliers.
- Most repair mortar manufacturers do not recommend adding admixtures to their products.
Insulated Covers

- Polystyrene foam sheets
- Urethane foam
- Insulation blankets
- Straw

- Do not use insulation beyond the recommended amount because it could raise the internal temperature of the concrete above recommended levels, which lengthens the gradual cooling period, increases thermal shrinkage, and increases the risk of cracking due to thermal shock.
Insulated Covers and Forms

• Corners and edges are particularly vulnerable to cold weather damage.

• Thickness of insulation should be approximately 3 times the thickness recommended for walls and slabs.
Heated Enclosures
Heated Enclosures

• Generally needed for placing operations when the air temperature is lower than –5°F (–20°C)
Heaters

• Direct fired
• Indirect fired
• Hydronic
Direct Fired Heaters

• Unless concrete is protected carbon dioxide combines with calcium hydroxide in fresh concrete to create soft dusting surfaces.
Indirect Fired Heaters

- Indirect fired heaters can vent carbon dioxide outside the enclosure.
- Do not blow heat directly on concrete or concrete repair mortars.
Hydronic Heat

• Hydronic heater provide heated water hoses. Combustion units are typically located outside enclosure.
Potential Problems for Concrete and Concrete Repairs in Cold Weather

1. Delayed set times
2. Over/early finishing
3. Frozen sub-grade
4. Ice in bottom of forms
5. Cold formwork and Reinforcing Steel
6. Plastic shrinkage cracking
7. Crazing
8. Thermal shock
9. Hurried and/or poor workmanship
## 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>
Prepackaged Repair Mortars

• Most repair mortar manufacturers use the 20 deg F rule.
• For every 20 deg F temp change up or down from 70 deg, set time is either increased (colder) or decreased (hotter) by 50%.

Set Time vs. Temperature
(20° rule)

![Bar chart showing set time vs. temperature]
Prepackaged Repair Mortars

• Most manufacturers recommend minimum of 40 degrees and rising for application of repair mortars.

• Store materials in warm temperatures and mix with warm (Not Hot) water.

• Do not apply to frozen or frost covered surfaces.
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9. Hurried and poor workmanship
Over/ early finishing

1. Because of drying conditions and delayed set, 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
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Frozen subgrade
Subgrade Has Previously Been Thawed With Hoses, Blankets & Tarps
Elevated Deck Placements

Most Common Application For Freeze Resistant Concrete
Potential Problems for Concrete and Concrete Repairs in Cold Weather

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Ice/snow in forms
Preparation Before Concreting

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 in² should be heated to above 32deg F. Reinforcing bars smaller than No. 18 in size are not considered massive embedments.
Repair Surfaces

• All surfaces in contact with repair mortars should be maintained to temperatures between 35 deg F and 90 deg F (2 C and 32 C).
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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.
How to avoid plastic (or any other kind of) shrinkage cracks:

1. Accelerate the set (different from high-early concrete)
2. Use micro-fibers in concrete
3. Use low-shrinkage repair mortars
4. Use temporary evaporation control
   1. Use evaporation retarder
   2. Use poly/plastic sheeting
5. Cut joints as soon as feasible - DO NOT WAIT!!
6. Use a high quality curing compound, sooner rather than later
7. Use curing/insulating covers
8. Protect & Cure!!
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Rapid Cooling – Thermal Shock

- Rapid temperature drop can result in damage
- Removal insulation slowly over time.
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Hurried Poor Workmanship

- Freezing cold workers can often rush or make mistakes
Issues that often arise in Cold Weather

ACI 306 - 8.2—Field-cured cylinders. 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 condition of the structure. In-place testing, maturity testing, or both, should be used instead.
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.

The deck is hot
The cylinders are not
Curing!
Chapter 10: Curing Recommendations and Methods

• Measures should be taken to inhibit 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).

• Avoid curing methods that add water to the surface except in heated enclosures.

• 10.2 - 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.
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 – Level I

1. No single mix answer.
2. Selection of a few mix designs supported by maturity testing to confirm local performance.
   • Some repair mortars are more friendly to cold applications than others.
3. Pour earlier in the day – solar gain on concrete mass
4. Type III cements over Type I for performance
5. Set accelerating admixtures
6. 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
   c. Frequency and location of T monitors
   d. Rate of T decrease to minimize thermal cracking
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
   1. Clear – expectations and goals
   2. Clear – process and procedures.
   • 3. This is Contractor’s Day.
   • 4. Specification overview
     1. Have the difficult conversation!
Pre-Placement Meeting

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

1. Plan ahead!
2. Suppliers & Consultants – model the plan
3. Understand the goals
4. Mix Design
   a. Have options!
5. Monitor
   a. Temperatures
   b. Maturity
   c. Tie temperature measurements to action if temps drop below allowable minimum
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.
Questions?

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