# COLD WEATHER CONCRETING

Hugh Martin, P.E. – National Precast Concrete Association

1

## Learning Objectives

- Know what happens to concrete when it freezes and how that affects durability
- Recognize how rapid temperature changes impact initial set, curing time, and long-term strength
- Employ practical steps to create more favorable conditions for casting in cold weather and protecting concrete from harmful exposure

2

THE PRECAST SHOW®

## Overview

- Define cold weather concreting
- What happens to concrete in low-temperature conditions
- Possible damage to hardened concrete that was cast in cold temperatures
- Steps to avoid cold weather damage

www.ThePrecastShow.com

3

THE PRECAST SHOW®

## Overview

- Define cold weather concreting
- What happens to concrete in low-temperature conditions
- Possible damage to hardened concrete that was cast in cold temperatures
- Steps to avoid cold weather damage

www.ThePrecastShow.com

4

# What is “cold” weather concreting?

Anytime it’s below 60°?




5

# What is “cold” weather concreting?

As long as it’s above zero?



6

# What is “cold” weather concreting?

When your kids will finally admit they are cold?


www.ThePrecastShow.com

THE PRECAST SHOW

7

# Defining “cold weather” concreting

NPCA QCM 18th Ed.

- A period when, for **three consecutive days**,
  - Cold weather conditions exist when the **average daily air temperature** is less than **40°F (5°C)**,
    - and -
  - The air temperature is not greater than **50°F (10°C)** for more than **one-half** of any 24-hour period.

www.ThePrecastShow.com

THE PRECAST SHOW

8

# Defining “cold weather” concreting

ACI SPEC 301.1-90

- Cold weather - A period when for more than **three successive days** the **average daily outdoor temperature** drops **below 40°F (4°C)**
- When temperatures **above 50°F (10°C)** occur during more than **half** of any 24-hr. duration, the period shall no longer be regarded as cold weather

ACI PRC 306-16

- Cold weather conditions exist when the air temperature has fallen to or **is expected** to fall **below 40°F (4°C)** during the protection period



# Defining “cold weather” concreting

Cold weather?

NPCA QCM – Yes
ACI SPEC 306.1 – Yes
ACI PRC 306 – Yes

| Scenario 1 | 2 AM | 8 AM | 2 PM | 8 PM | 24 Hr Average | Half-Day Avg. |
|---|---|---|---|---|---|---|
| Day 1 (Pouring) | 23° | 34° | 45° | 35° | 34° | 40° |
| Day 2 | 25° | 36° | 48° | 37° | 37° | 43° |
| Day 3 | 27° | 39° | 51° | 40° | 39° | 46° |

NPCA QCM – No
ACI SPEC 306.1 – No
ACI PRC 306 – Yes

| Scenario 2 | 2 AM | 8 AM | 2 PM | 8 PM | 24 Hr Average | Half-Day Avg. |
|---|---|---|---|---|---|---|
| Day 1 (Pouring) | 17° | 31° | 45° | 22° | 31° | 39° |
| Day 2 | 19° | 35° | 51° | 36° | 35° | 44° |
| Day 3 | 20° | 40° | 60° | 41° | 40° | 51° |

# Defining “cold weather” concreting

- During periods **not** defined as cold weather, but when freezing temperatures may occur, **protect concrete surfaces** against freezing for the **first 24 hrs**.
- In general, if you need protection from the cold, so does your concrete.
- Concrete can be placed in almost any weather, but without precautions, the quality will go way down.



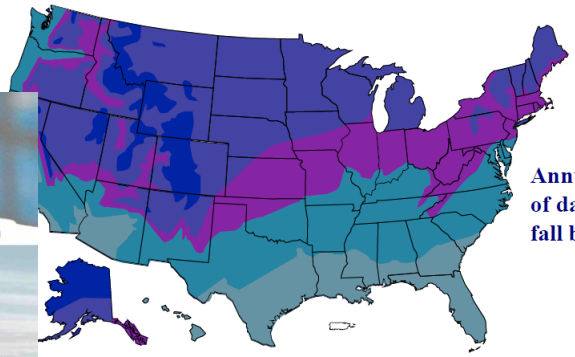
www.ThePrecastShow.com

THE PRECAST SHOW

11

# What is “cold” weather concreting?

How Often It Freezes

Annual average number of days temperatures fall below 32°F (0°C)

- Less than 30
- 30 to 90
- 91 to 150
- 151 to 210
- More than 210

www.ThePrecastShow.com

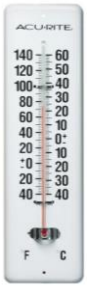
THE PRECAST SHOW

12

# Three Keys to Curing

**Time**

**Temperature**




**Moisture**

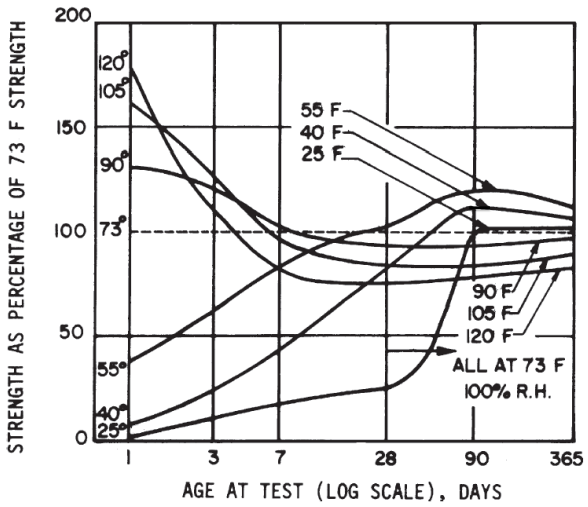


13

# Time vs. Temperature

Protection Period

- Concrete can resist the effects of **one** freezing-and-thawing cycle if it is air-entrained, not exposed to an external water source, and has reached a compressive strength of approximately **500 psi (3.5 MPa)**.






14

THE PRECAST SHOW

## Overview

- Define cold weather concreting
- What happens to concrete in low-temperature conditions
- Possible damage to hardened concrete that was cast in cold temperatures
- Steps to avoid cold weather damage




15

# Concrete in low temperatures

- Cement hydration reactions occur at slower rate and continue to get slower and slower as temperature continues to drop
  - VERY slow below 40°F (4°C), stops completely at 32°F (0°C)
- Accordingly, concrete strength development takes longer
- The curing process requires more time and additional precautions
- Supplementary Cementitious Materials (SCMs) such as coal ash (fly ash) generate less internal heat than cement
- Portland Limestone Cement (PLC) such as Type IL have less cement and are therefore more sensitive to cold…and drying



THE PRECAST SHOW

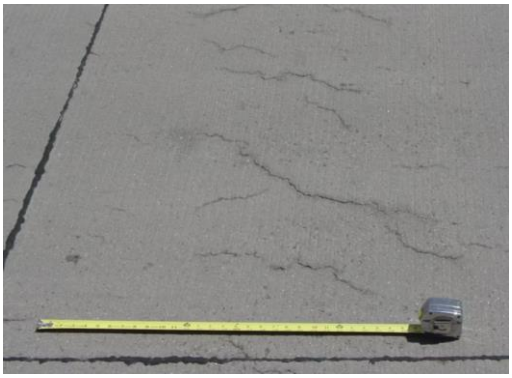
16

# Concrete in low temperatures

- Little or no added external moisture is needed for curing during cold weather…

Unless…

- Heated enclosures
- Dry ambient air, low humidity can increase rate of mix water evaporation
  - Insufficient moisture and humidity can result in unhydrated cement
  - Plastic shrinkage cracks can develop
- PLC (e.g., Type IL cement) more sensitive to relative humidity at time of placement





THE PRECAST SHOW

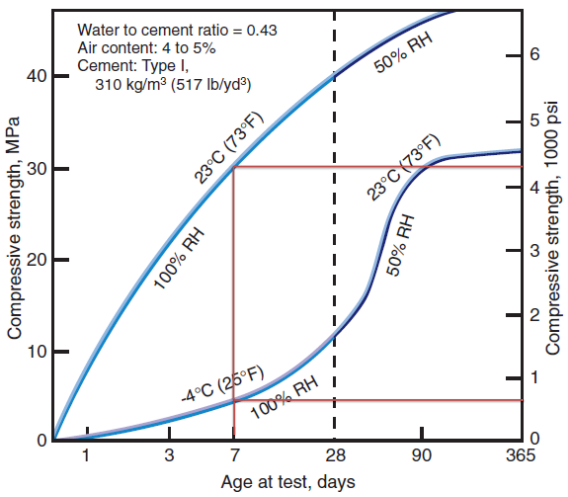
## Overview

- Define cold weather concreting
- What happens to concrete in low-temperature conditions
- **Possible damage to hardened concrete that was cast in cold temperatures**
- Steps to avoid cold weather damage

# Concrete allowed to freeze

When concrete is allowed to freeze before it reaches 500 psi (3.5 MPa):

- Concrete for the lower curve was cast at 40°F (4°C) and immediately placed in a below-freezing curing room at 25°F (-4°C)

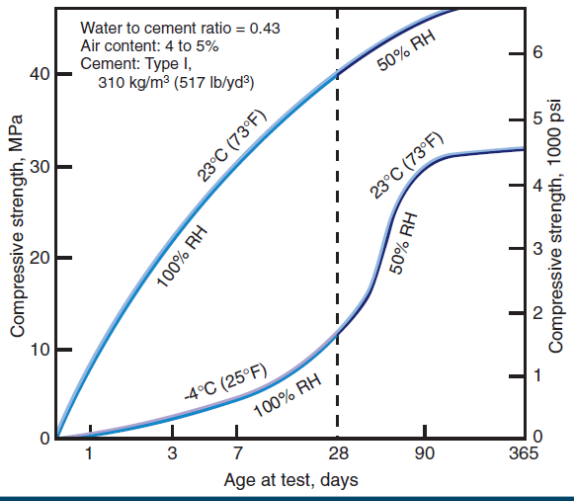





# Concrete allowed to freeze

When concrete is allowed to freeze before it reaches 500 psi (3.5 MPa):

- Concrete for the lower curve was cast at 40°F (4°C) and immediately placed in a below-freezing curing room at 25°F (-4°C)
  - Unable to achieve its intended design strength
  - Less strength gain over time



# Concrete in freezing temperatures

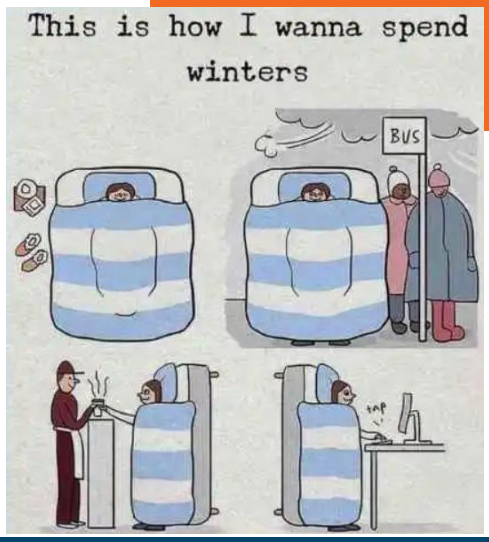
- Mix water freezes and ice forms in the paste
  - Increased porosity
  - Increased permeability
  - Less freeze-thaw resistance
  - Increased vulnerability to abrasion
- Cement hydration essentially stops, as does strength gain
- Concrete that freezes before reaching **500 psi** compressive strength will never attain its design characteristics and **should be discarded**




THE PRECAST SHOW

## Overview

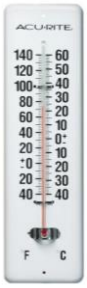
- Define cold weather concreting
- What happens to concrete in low-temperature conditions
- Possible damage to hardened concrete that was cast in cold temperatures
- **Steps to avoid cold weather damage**



# Three Keys to Curing

**Time**

**Temperature**




**Moisture**



# Strategies for cold weather

- Increase curing time
- Increase temperature
  - Concrete
  - Formwork
  - Enclosure
- Control temperature loss
- Control moisture loss
- Test frequently

# Strategies for cold weather

Protection Period

- To ensure that the concrete has reached **500 psi (3.5 MPa)**, protect the concrete temperature as described in Table 5.1 for the time periods in Line 1 of Table 7.2

**Table 7.2—Length of protection period for concrete placed during cold weather**

| Line | Service condition | Protection period at minimum temperature indicated in Line 1 of Table 5.1, days* | |
|---|---|---|---|
| | | Normal-set concrete | Accelerated-set concrete |
| 1 | No load, not exposed | 2 | 1 |
| 2 | No load, exposed | 3 | 2 |
| 3 | Partial load, exposed | 6 | 4 |
| 4 | Full load | Refer to Chapter 8 | |

*A day is a 24-hour period.



# Strategies for cold weather

**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) |
| 5 | — | Maximum allowable gradual temperature drop in first 24 hours after end of protection | | | |
| | | 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.

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).

# Strategies for cold weather

Make "hotter" concrete

- Type III or HE high-early strength cement
- Lower w/cm ratio
  - Additional cement (100 to 200 lb./yd.) (60 to 120 kg/m³)
  - Reduce water
- Use chemical accelerators
  - Non-chloride-based
    - Calcium Formate (hardening)
    - Calcium Nitrate (setting)
  - If using +10% ash, +20% slag, heat activation should be physical rather than chemical



# Strategies for cold weather

Make "colder" concrete

- Antifreeze concrete (FHWA-HIN-21-010)
  - Outside the scope of ACI PRC 306…and most project specifications
  - Minimum concrete temperature lowered to around 23°F to 25°F (-5°C to -4°C)
  - Strength curve slower than 73°F (23°C) but faster than 40°F (5°C)
  - Stiff, sticky consistency, 3 in. to 5 in. slump
  - Compare cost of admixture(s) to cost of heating and protection
  - Test, test, test

# Strategies for cold weather

Heat mix water

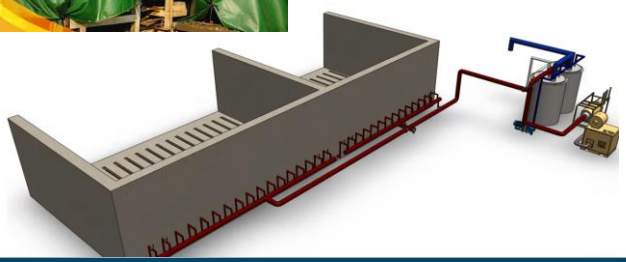
- Typically no higher than **140°F (60°C)**
- Do not exceed 180°F (82°C)
  - Heat equivalent to hot cup of coffee
- Premix to equalize water & aggregate temperatures as much as possible before adding cement
- ACI recommends measuring the temperature of each batch
- WARNING: It **is** possible to create hot weather conditions in the concrete, even when casting in cold weather



# Strategies for cold weather

Heat aggregates

- No frozen aggregates (per NPCA QCM)
- More generally, when air temperatures are consistently below 25°F (–4°C), it will be necessary to heat the aggregates
- Heat coarse up to 60°F (15°C), fine aggregates up to 105°F (40°C)
- Heating aggregates to higher temperatures generally not necessary if the mixing water is heated to 140°F (60°C)
- Heating aggregates with steam is more efficient but can also lead to moisture variations



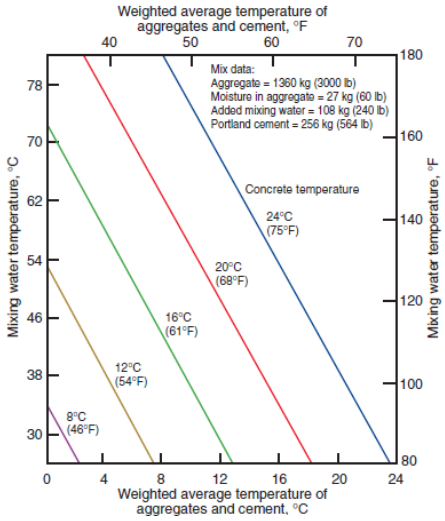
# Strategies for cold weather

Heating Water & Aggregates

- Temperature of mixing water and aggregates needed to produce heated concrete

Table 5.1—Recommended concrete tempera

| | | |
|---|---|---|
| | | < 12 in. (300 mm) |
| Line | Air temperature | |
| 1 | — | 55°F (13°C) |
| | | Minir |
| 2 | Above 30°F (–1°C) | 60°F (16°C) |



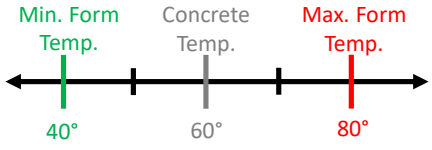



31

# Strategies for cold weather

Heating forms & embedded items

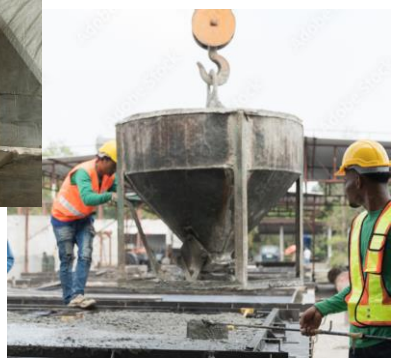
- All formwork and embedded items must be **at least 32°F (0°C)** at the time of fresh concrete placement
- Recent work has shown that most embeds, including reinforcing bars, do not need to be heated unless the air temperature is below **10°F (–12°C)**
- Formwork should be within **±20°F (±11°C)** of fresh concrete temperature
- No deicing chemicals on forms/molds






32

# Strategies for cold weather



Control Heat Loss

- Time is your enemy
- Heat is expensive, as well as time-consuming; preserve it at much as possible
- Pour while ambient temperatures are **rising**
  - Start pouring as early as possible
- External heat should not be applied until **after** initial set



# Strategies for cold weather

Control Heat Loss

- ACI PRC 306-16
  - Minimum exposure temperatures maintained for 50°F* (10°C*) for 3 days
- Insulating Materials
  - Polyethylene, Polyurethane, Polystyrene
  - Fiber blankets
  - Loose fill

| Wall or slab thickness, in. (m) | Minimum ambient air temperature, °F (°C), allowable when insulation having these values of thermal resistance $R$, h·ft²·°F/BTU (m²·K/W), is used | | | |
|---|---|---|---|---|
| | $R$ = 2 (0.35) | $R$ = 4 (0.70) | $R$ = 6 (1.06) | $R$ = 8 (1.41) |
| Cement content = 500 lb/yd³ (296 kg/m³) | | | | |
| 6 (0.15) | 43 (6) | 35 (2) | 28 (–2) | 20 (–7) |
| 12 (0.30) | 34 (1) | 18 (–8) | 3 (–16) | –12 (–24) |
| 18 (0.46) | 25 (–4) | 2 (–16) | –21 (–29) | –44 (–42) |
| 24 (0.61) | 18 (–8) | –10 (–23) | –38 (–39) | –68 (–56) |
| 36 (0.91) | 12 (–11) | –23 (–31) | –60 (–51) | * |
| 48 (1.20) | 10 (–12) | –25 (–32) | * | * |
| 60 (1.50) | 10 (–12) | –25 (–32) | * | * |
| Cement content = 600 lb/yd³ (356 kg/m³) | | | | |
| 6 (0.15) | 41 (5) | 32 (0) | 23 (–5) | 14 (–10) |
| 12 (0.30) | 31 (–1) | 12 (–11) | –7 (–22) | –26 (–32) |
| 18 (0.46) | 21 (–6) | –7 (–22) | –35 (–37) | –63 (–53) |
| 24 (0.61) | 11 (–12) | –24 (–31) | –59 (–51) | * |
| 36 (0.91) | 4 (–16) | –36 (–38) | * | * |
| 48 (1.20) | 4 (–16) | –40 (–40) | * | * |
| 60 (1.50) | 4 (–16) | –40 (–40) | * | * |

*Minimum is 40°F (4°C)

# Strategies for cold weather

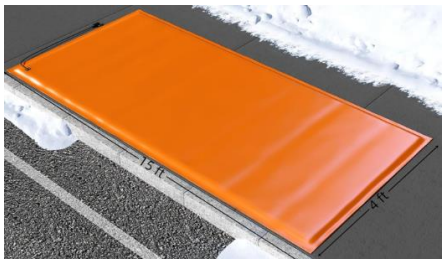


Heat Application

- Plant heat
  - +50°F (10°C) for 3+ days
- **After** initial set:
  - Indirect Heating
    - Larger, requires more energy, lowers humidity
    - Liquid fuel, natural gas/propane or electricity
    - Exhaust separate from heat
  - Direct Heating
    - "Torpedo" heater (most common) – portable, highly effective
    - Kerosene/Diesel
    - Heat = exhaust, workspace must be well ventilated



# Strategies for cold weather




Heat Application and Retention

- Heated curing blankets
- Use tarps to cover the curing products and create an enclosure to trap the heat
- Protect corners and edges of product
- No hot spots inside enclosure; monitor temperature throughout
- **Never** point direct-fired heaters at the formwork
  - Uneven heating
  - Delayed Ettringite Formation (DET)
  - Carbonation

# Strategies for cold weather


Heat and Moisture Retention

- Rise in ambient curing temperature shall be limited to a maximum of 40°F (22°C) per hour
- Maintain moisture (40% humidity)
  - Consider heat source
  - Tip: wet the floor underneath enclosure
  - Curing compound
- Minimize convection
  - Concrete **warmer** than 60°F (16°C) **exposed to air** 50°F (10°C) or higher is susceptible to surface desiccation
- Air temperature inside enclosure should not be more than **20°F (11°C) more** than concrete placement temperature



# Strategies for cold weather

Monitoring and Cooling

- Monitor and record concrete surface temperature during curing
- Max. concrete temperature **150°F (65°C)**
- Monitor the maximum internal concrete temperature once every three (3) months
- Remove heat gradually after protection period
  - 50°F (28°C) per day, or per ACI PRC 306 Table 5.1

# Time vs. Temperature

Table 5.1—Recommended concrete temperatures

| | | 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) |
| Line | Air temperature | 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) |
| 5 | — | Maximum allowable gradual temperature drop in first 24 hours after end of protection | | | |
| | | 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.

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).

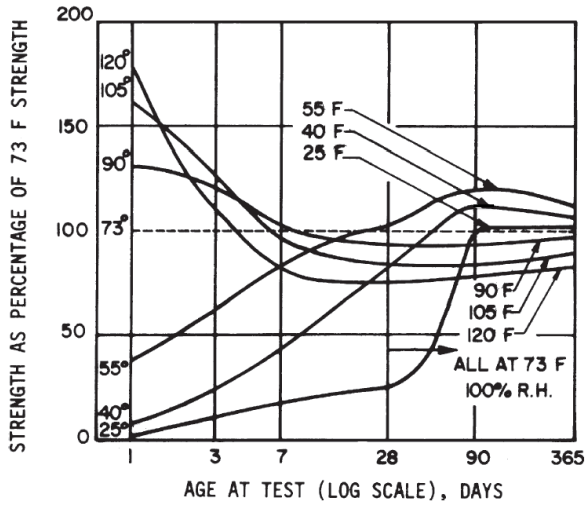


39

# Time vs. Temperature

Hot Weather Conditions Created in Cold Weather

- While frozen concrete is bad, concrete that is overheated has lower later-age strength, as well as lower durability



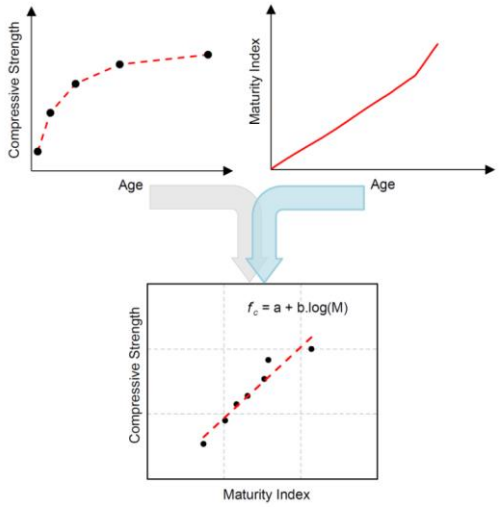



40

# Strategies for cold weather

Maturity Curve using Time-Temperature Factor (TTF)

- Requires multiple test cylinders (16+) from a test batch
- Temperature and strength of each cylinder recorded as they age
- Results plotted as function of maturity vs. time
  - Time-temperature function, or factor (TTF)
  - Area under the curve
  - 1° F = 10 min., 10° F = 1 min.
- Per mix design using exact same materials and proportions




www.ThePrecastShow.com

THE PRECAST SHOW

41

# Strategies for cold weather

Frequent Testing

- Compare test results from several sources
  - Maturity meter (Requires TTF curve)
  - Lab-cured vs. plant-cured cylinders
  - Rebound hammer (ASTM C805)
- Plan for cold weather before it hits
  - Be prepared for weather changes
  - Keep extra blankets, heaters, hygrometers
- DO NOT strip product until adequate strength is attained
- Monitor concrete temperatures during curing
- Have a contingency plan in place

www.ThePrecastShow.com

THE PRECAST SHOW

42

# Strategies for cold weather

- Increase curing time
- Increase temperature
  - Concrete
  - Formwork
  - Enclosure
- Control temperature loss
- Control moisture loss
- Test frequently

**Time**

**Temperature**

**Moisture**

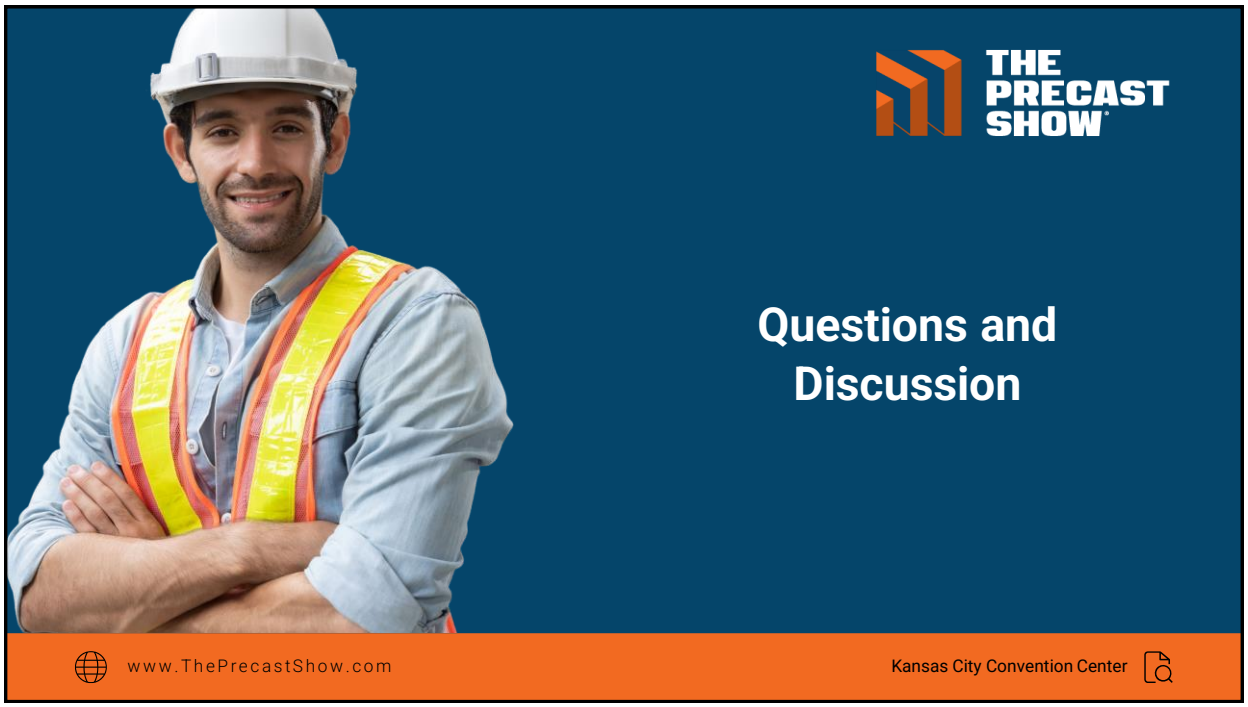


THE PRECAST SHOW

# Takeaways

## Cold Weather Concreting

- ❑ Not one-size-fits-all; it can vary from day to day.
- ❑ Short-term production convenience should not be prioritized at the cost of long-term strength or durability.
- ❑ Every step in the process is crucial.
- ❑ Carefully monitor concrete during the protection period.
- ❑ Prepare. Review cold weather procedures before it happens.


THE PRECAST SHOW
Questions and Discussion
www.ThePrecastShow.com
Kansas City Convention Center

45


THE PRECAST SHOW
CONTACT US
Before We Go...
Hugh Martin, P.E.
Director of Technical Resources
1320 City Center Drive
Suite 200
Carmel, IN 46032
(317) 582-2323
(800) 366-7731
hmartin@precast.org
www.ThePrecastShow.com
Kansas City Convention Center

46


47