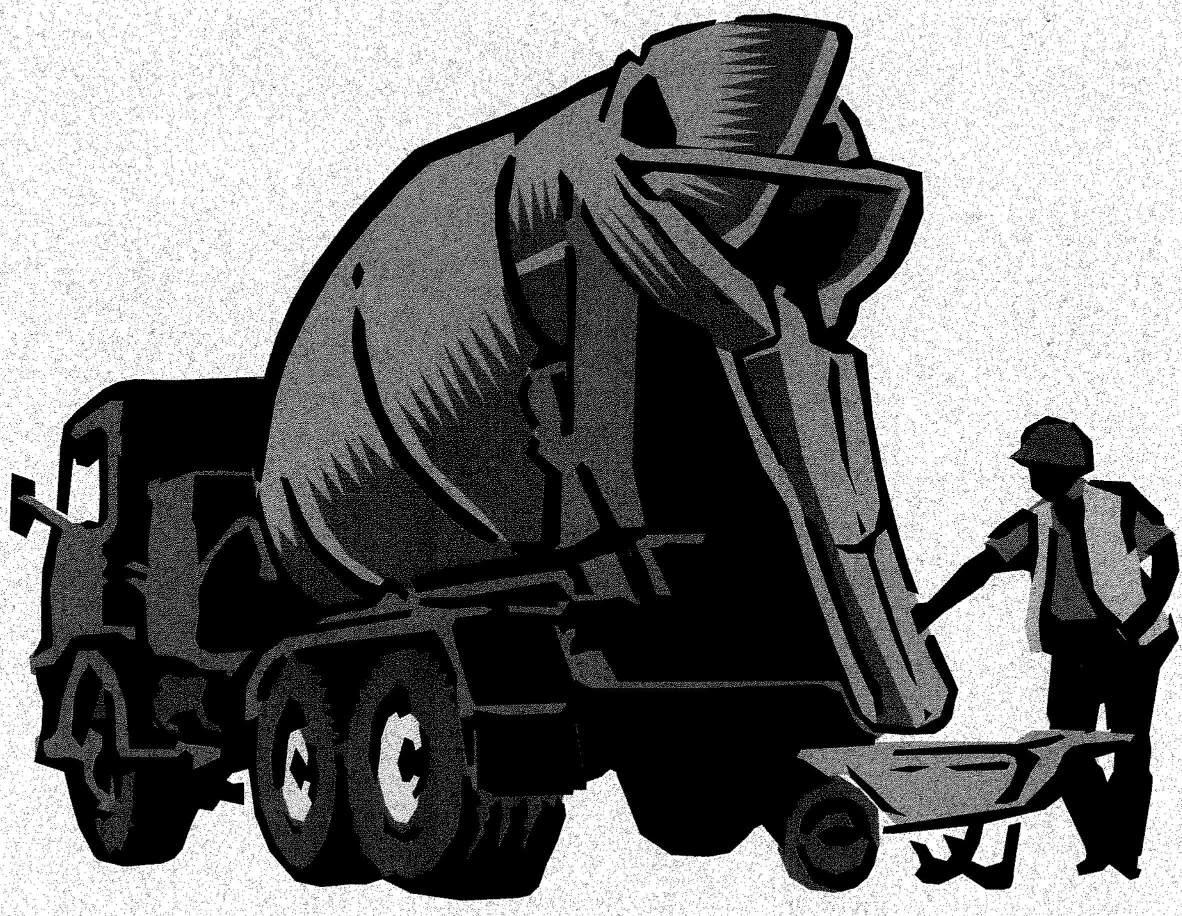
Fundamentals of Concrete

PCA - Design & Control of Concrete Mixtures

Summary of Chapters 12 - 14



Michigan Concrete Association, 2005 - 2006

Chapter 12

Curing Defined

The maintenance of a satisfactory moisture content and temperature in concrete for a period of time immediately following placement and finishing so that the desired properties may develop.

i.e. strength, durability

Curing

Curing strongly influences the following properties of hardened concrete:

1. durability
2. strength
3. watertightness
4. abrasion resistance
5. volume stability
6. resistance to freezing/thawing

Note: Exposed slab surfaces are especially sensitive to curing as strength development and freeze-thaw resistance of the top surface can be significantly reduced when the concrete is not properly cured.

Recommended Curing Requirements

Duration	As long as possible (minimum 3 days). ***Begin immediately following finishing!***
Temperature	50-100°F
Moisture	Keep concrete saturated at ***all*** times. ***If curing is resumed, development strength will be reactivated but the original potential will not be achieved.***

Notes:

1. Strength development stops after the relative humidity in the concrete drops below 80%.
2. After an interruption in curing, strength development will resume but the original potential strength may not be achieved.

Curing

The results of not curing concrete include:

- increased random cracking
- dusting or flaking of surface
- crazing of surface (fine cracks)
- poor wearing surface
- reduced strength (up to 50%)

Curing
vs
Compressive Strength

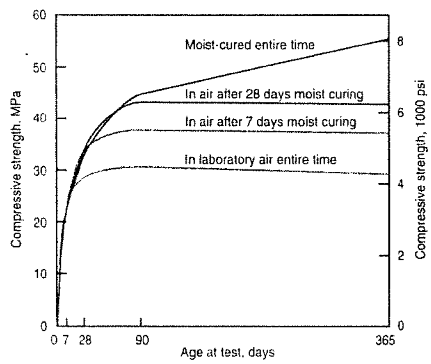


Fig. 12-2. Effect of moist curing time on strength gain of concrete (Gonnerman and Shuman 1928).

Curing Methods

Concrete can be kept moist (and in some cases at a favorable temperature) using one of the following curing methods:

1. Maintain mix water in the concrete.
   - ponding, immersion, fogging, saturated coverings
2. Reduce the loss of mix water
   - impervious paper, plastic sheets, curing compound
3. Accelerate strength gain
   - Steam, heating coils, electrically heated forms

Avoid cycles of wetting and drying!

Saturated wet coverings

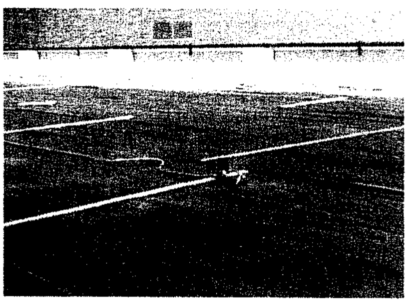


Fig. 12-5. Lawn sprinklers saturating burlap with water keep the concrete continuously moist. Intermittent sprinkling is acceptable if no drying of the concrete surface occurs. (50177)

- burlap must be free of any substance that is harmful to concrete or causes discoloration

- it must be kept moist at all times

Curing...polyethylene

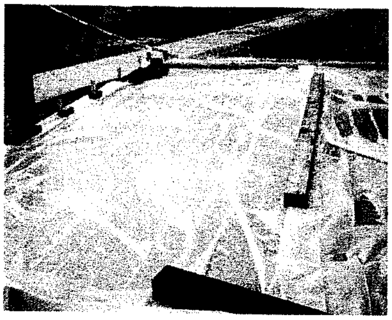
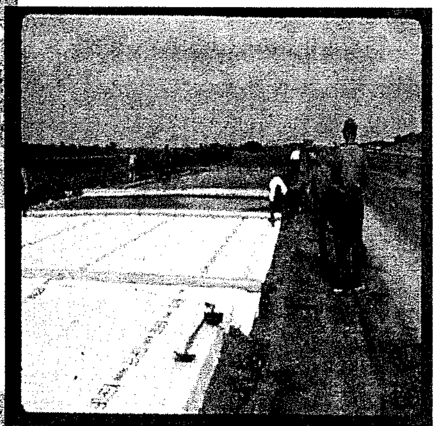


Fig. 12-7. Polyethylene film is an effective moisture barrier for curing concrete and easily applied to complex as well as simple shapes. To minimize discoloration, the film should be kept as flat as possible on the concrete surface. (70014)

- polyethylene (visqueen) is inexpensive and easy to use
- must be at least 4 mils thick for curing purposes
- discoloration may result when the film becomes wrinkled
- can be placed over wet burlap to retain water

Curing...impervious paper



- impervious paper consists of two sheets of kraft paper cemented together by a bituminous adhesive
- can be re-used if it still retains moisture and holes are repaired
- paper with a white upper surface is preferable during hot weather conditions

Curing compounds

Fig. 12-8. Liquid membrane-forming curing compounds should be applied with uniform and adequate coverage over the entire surface and edges for effective, extended curing of concrete. (69975)

Curing Compound Guidelines

- most practical and widely used curing method
- consist of waxes, resins and chlorinated rubber
- form a continuous film to seal in mix water
- can be spray or roller applied
- two general types – clear and white pigmented
- follow manufacturers recommendations for surface preparation and application rates

Caution:

Most curing compounds are not compatible with adhesives used with floor covering materials. Check with the manufacturer before applying.

Sealing Compounds

Sealing compounds are liquids applied to the surface of hardened concrete to reduce the penetration of water and deicing salts. They are not applied until the concrete is at least 28 days old and provide an extra level of protection. Sealers are classified as follows:

1. film forming (surface) sealing compounds
   - i.e. acrylic resins
2. penetrating sealing compounds
   - i.e. silanes and siloxanes

Sealing Concrete

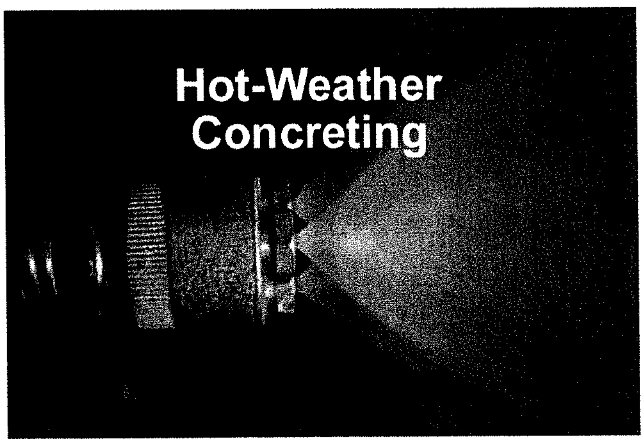
Fig 12-12. Penetrating sealers help protect reinforcing steel in bridge decks from corrosion due to chloride infiltration without reducing surface friction. (69976)

Summary

Strength and durability of concrete increase with age as long as moisture is present and temperatures remain favorable.

Lack or inadequate curing can cause a loss of up to 50% of the potential strength and decrease durability.

Chapter 13



Hot Weather Definition

American Concrete Institute (305R)

Any combination of high ambient temperature, high concrete temperature, low relative humidity, wind speed and solar radiation that tends to impair the quality of freshly mixed or hardened concrete by accelerating the rate of moisture loss and rate of cement hydration.

Hot Weather

Hot weather effects on fresh concrete include:

1. Increased water demand
2. Accelerated slump loss (water often added)
3. Increased rate of setting (finishing difficulties)
4. Difficulty in controlling entrained air
5. Increased concrete temperature
6. Increased probability of plastic shrinkage cracking
7. Increased potential for thermal cracking

There is a critical need for prompt early curing!

Temperature
vs
Water Demand

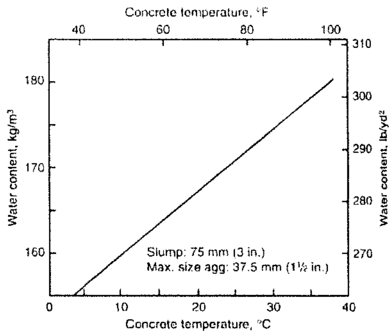


Fig. 13-2. The water requirement of a concrete mixture increases with an increase in concrete temperature Bureau of Reclamation (1981).

Adding water at the jobsite can adversely affect the concrete resulting in:

- decreased strength
- decreased durability
- increased permeability
- increased plastic shrinking potential
- reduced abrasion resistance

Temperature
vs
Compressive Strength

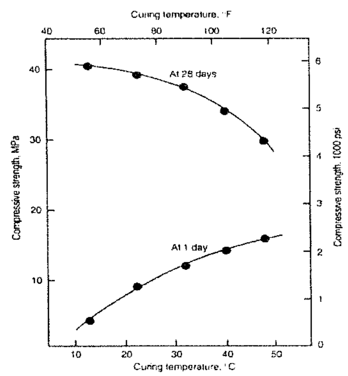


Fig. 12-11. One-day strength increases with increasing curing temperature, but 28-day strength decreases with increasing curing temperature (Verbeck and Helmuth 1968).

Plastic Shrinkage Cracks

Cracks that appear mostly on horizontal surfaces (in freshly mixed concrete) soon after it has been placed. Plastic shrinkage cracks are frequently associated with hot weather conditions and develop when water evaporates from the surface faster than it can replaced by the bleeding process. The following conditions, singly or collectively, increase surface evaporation and the probability of crack formation:

1. Low air temperature
2. High concrete temperature
3. Low humidity
4. High wind speed

Plastic Shrinkage Cracking

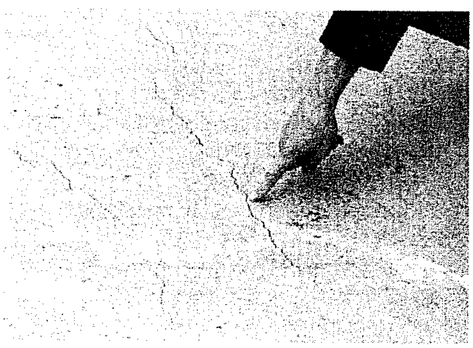
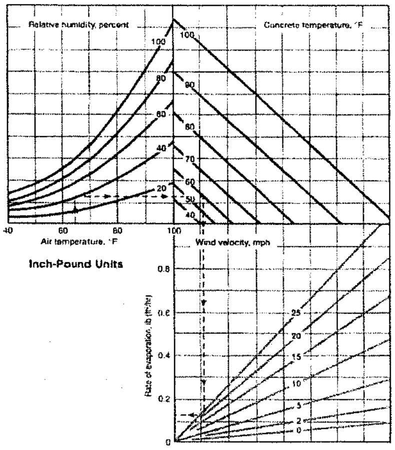


Fig. 13-7. Typical plastic shrinkage cracks. (1311)

Evaporation Chart



- when the evaporation rate exceeds 0.2/lbs/ft^2/hr precautionary measures are mandatory

Plastic Shrinkage Cracks

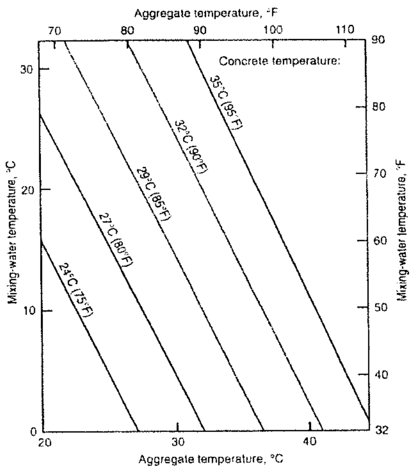
One or more of the precautions noted below can be implemented to minimize the occurrence of plastic shrinkage cracks.

1. Moisten concrete aggregates that are dry.
2. Keep aggregates and mix water cool.
3. Dampen the subgrade and forms prior to placing.
4. Erect temporary windbreaks to reduce wind velocity.
5. Erect temporary sunshades.
6. Protect concrete with temporary coverings during any appreciable delay in placement and finishing.
7. Fog the slab immediately after placing and before finishing.
8. Add fibers (polypropylene) to the mix.

Note: Spraying the surface with an evaporation retarder can be very effective.

Soaking Aggregate Stockpiles

Producing 'Cool' Concrete



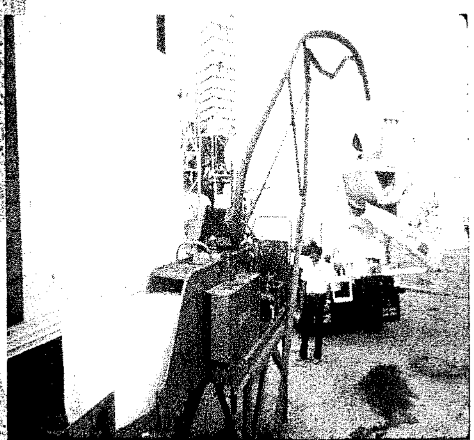
Material Effects

Always keep aggregates and water as cool as possible. To change the temperature of concrete by 1°F it takes a:

1. 1.5 - 2°F change in coarse agg. temperature
2. 3.5 - 4°F change in water temperature or
3. 9°F change in cement temperature

Note: Temperature effects are dependent on the mass (weight) of the material in the concrete mix design.

Cooling Concrete



- crushed ice must be included as water in w/c ratio calculation
- mixing time must be long enough to melt ice
- volume of ice should not replace more than 75% of the total batch water
- maximum temperature reduction is 20°F

Subgrade Preparation

Fig. 13-9. Dampening the subgrade, yet keeping it free of standing water will lessen drying of the concrete and reduce problems from hot weather conditions. (69955)

Fog Spraying

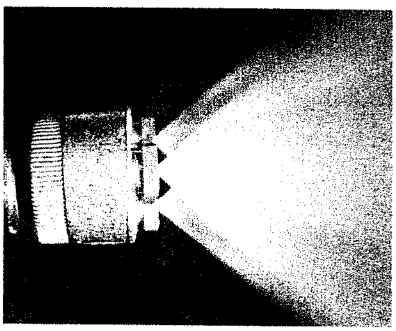


Fig. 13-10. Fog nozzle. (9853)

Fogging cools the air and increases the relative humidity above the flatwork to lessen rapid evaporation from the concrete surface.

Hot Weather Concreting

Role of ready-mixed concrete producer:

1. Incorporate retarding admixtures in the mix.
2. Use water reducing admixtures to offset the higher water demand.
3. Avoid delays in concrete delivery.
4. Keep aggregates cool by sprinkling.
5. Incorporate crushed ice, if necessary.
6. Hot climates - liquid nitrogen, cool drum of truck

Hot Weather Concreting

Contractor responsibilities

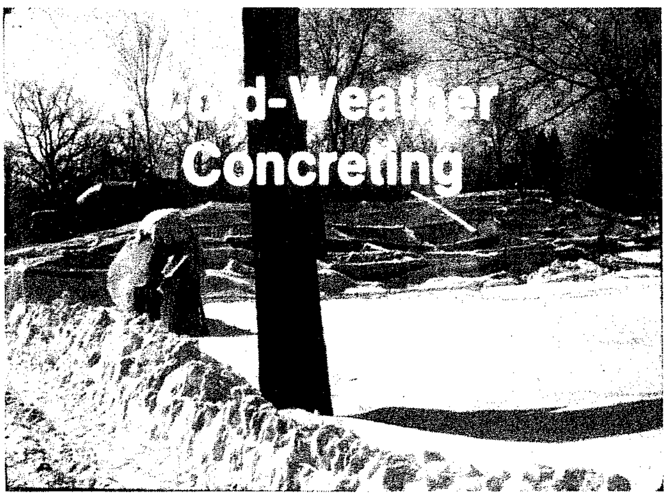
1. During placement
   - avoid delays in placement and finishing
   - dampen subgrade and forms
   - provide sun and wind protection
2. After placement
   - cover concrete and cure immediately

Hot Weather Summary

Hot weather conditions effect both the plastic and hardened properties of the concrete. The ready mix concrete supplier and the contractor play critical roles in constructing the best possible product.

Concrete must always be cured!

Chapter 14



Cold Weather Definition

American Concrete Institute (306R)

A period when, for more than 3 consecutive days, the average daily air temperature drops below 40°F and stays below 50°F for more than one-half of any 24 hr time period.

Cold weather, as defined by ACI, typically starts during the fall and continues until spring.

Cold Weather Placement

Provided the necessary precautions have been taken, concrete can be placed year round. For this project a windbreak has been provided, there is adequate heat under the slab and the concrete has low slump.

Temperature Effects

Temperature affects the rate at which hydration occurs – low temperatures retard the rate of hardening and strength gain of concrete.

Note: Significant strength reductions (up to 50%) can occur if concrete freezes within a few hours of placement or before reaching a compressive strength of 500 psi.

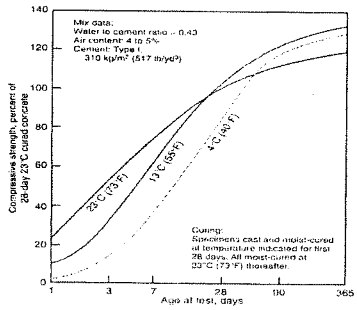


Fig. 14-6. Effect of low temperatures on concrete compressive strength at various ages. Note that for this particular mixture made with Type I cement, the best temperature for long-term strength (1 year) was 13°C (55°F) (Klieger 1958).

Frozen Concrete

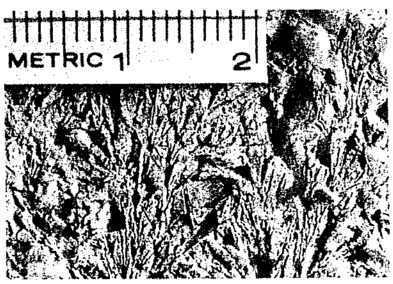
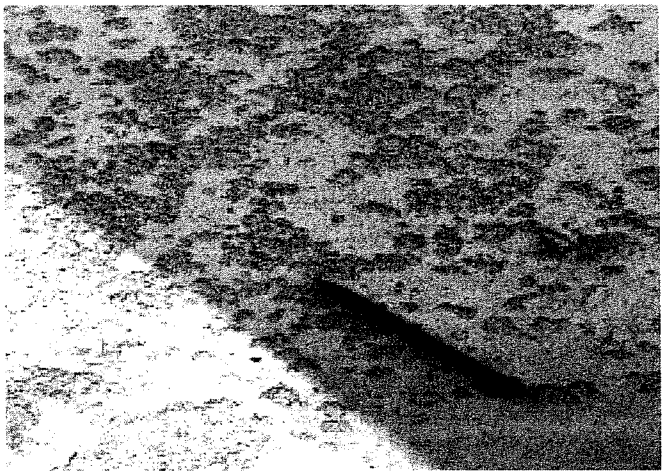


Fig. 14-2. Closeup view of ice impressions in paste of frozen fresh concrete. The ice crystal formations occur as unhardened concrete freezes. They do not occur in adequately hardened concrete. The disruption of the paste matrix by freezing can cause reduced strength gain and increased porosity. (44047)

Concrete that has froze at an early age can be restored to nearly normal strengths by providing a proper curing environment. Such concrete, however, will not be as resistant to weathering nor as watertight as concrete that had not froze.

Cold Weather Damage



Mix Design Considerations

High strength at an early age is desirable during winter construction to reduce the length of time that protection is required. High early strength can be obtained by using one or a combination of the following:

1. high early strength cement - Type III
2. add additional Type I - approx. 1 bag
3. add accelerating admixtures
   - chloride or non-chloride

Note: Accelerators must not be used as a substitute for proper curing and protection.

Calcium Chloride

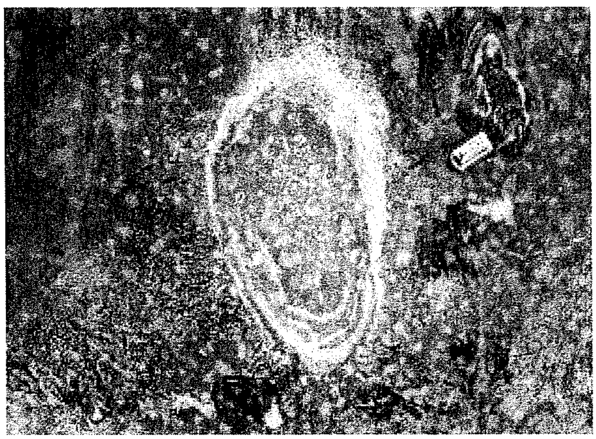
Calcium chloride can be used to accelerate the setting and early age strength development of concrete in cold weather. When used, calcium chloride accelerators may contribute to the following:

1. corrosion of reinforcing steel
2. discoloration of concrete
3. increase in shrinkage cracking

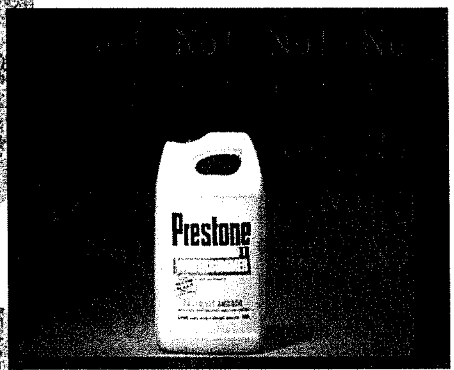
Do not add flakes directly into mixer

- always dissolve in water first

Chloride Discoloration



Anti-freeze Agents



Traditional anti-freeze agents should never be used. The quantity of material required to appreciably lower the freezing point of concrete is so great that strength and other properties are greatly affected.

Temperature of Concrete

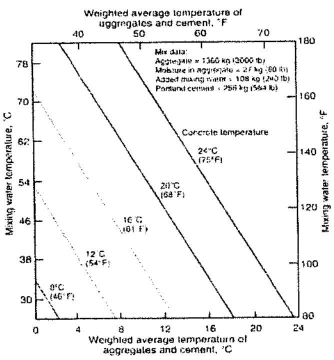


Fig. 14-12. Temperature of mixing water needed to produce heated concrete of required temperature. Temperatures are based on the mixture shown but are reasonably accurate for other typical mixtures.

Aggregates usually contain frozen lumps and ice that must be thawed before using. Besides being the easiest and most practical to heat, water stores five times as much heat as cement and aggregates at the same weight. The recommended maximum concrete temperature is 70°F.

Insulating Materials

Heat and moisture can be retained by covering the concrete with insulating blankets or with straw/hay that is covered by tarps or polyethylene. Corners and edges are most vulnerable to freezing. The material selected for providing cold weather protection must be moisture-proof and able to withstand exposure to the weather.

Protection with Straw

A minimum of 1 ft. is required to provide the necessary R or insulation value. Straw or hay must be covered and securely held in place.

Caution:

Hydration occurs very slowly at temperatures below 40°F.

Protection with insulating blankets

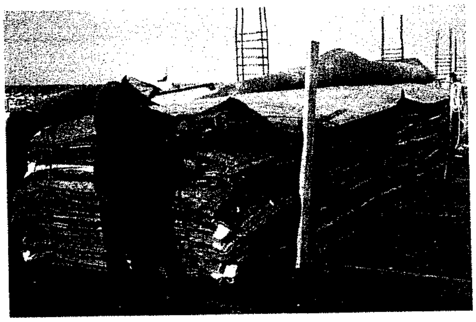


Fig. 14-19. Stack of insulating blankets. These blankets trap heat and moisture in the concrete, providing beneficial curing. (43460)

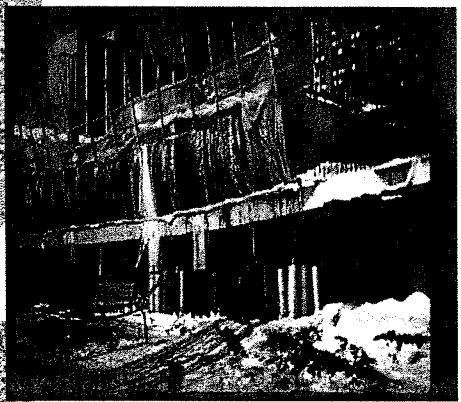
R-Values

R VALUES OF INSULATION

(°F · hr · ft²) / Btu - 2 in. thick

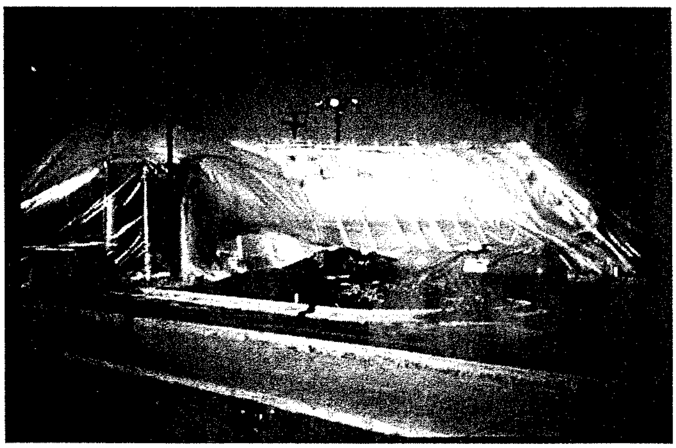
Polyurethane extruded:	12.4	Fiberglass blanket:	7.0
Polystyrene extruded:	8.0	Mineral fiberboard:	6.4
Polypropylene foam:	7.4	Plywood:	2.4

Heated enclosures

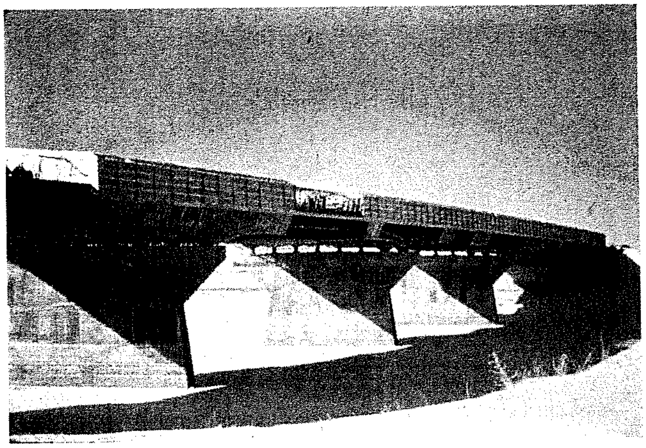


Heated enclosures are very effective for protecting concrete in cold weather, but are the most expensive to construct and operate.

Heated enclosures



Heated enclosures



Heaters

The three types of heaters used in cold-weather concrete construction include:

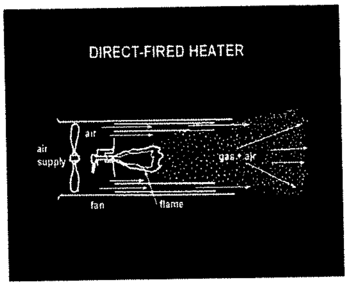
1. Direct-fired (unvented)
2. Indirect-fired (vented)
3. Hydronic systems

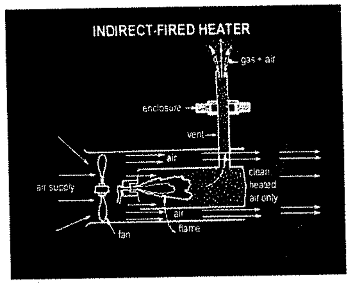
Carbon dioxide (CO_2) in the exhaust of heaters must be vented to the outside and prevented from reacting with the fresh concrete surface or carbonation will occur.

Mild carbonation

Severe carbonation

Direct vs. Indirect Fired Heaters





Indirect Fired Heater

Fig. 14-23. An indirect-fired heater. Notice vent pipe that carries combustion gases outside the enclosure. (43459)

The solution to carbonation

Avoid the use of direct fired (unvented) heaters.

If direct fired heaters are used:

- avoid using older, less efficient heaters
- provide good air exchange and circulation
- minimize period of exposure
- if carbonation occurs, clean surface then apply a hardener (depends on depth)

Hydronic Heaters

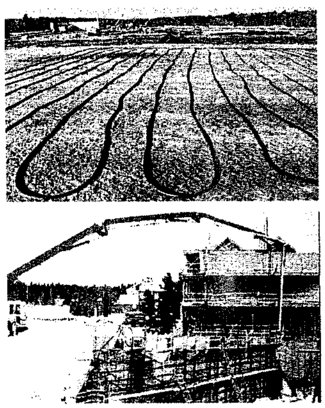
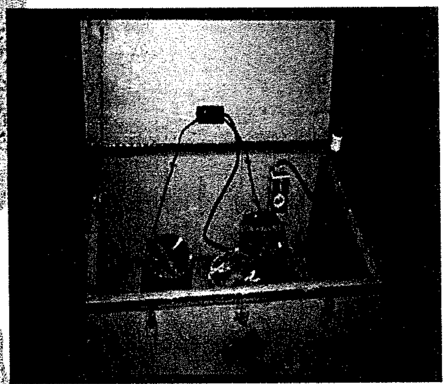


Fig. 14-25. Hydronic system showing hoses (top) laying on soil to defrost subgrade and (bottom) warming the forms while fresh concrete is pumped in. (68345, 68344)

Hydronic systems transfer heat by circulating a glycol/water solution in a closed system of pipes or hoses. Typical applications include thawing and pre-heating subgrades.

Cold Weather Cylinder Protection



Concrete test cylinders must be maintained at a temperature between 60-80°F for a period up to 48 hrs.

Cylinder protection???

Cold Weather

Role of the ready-mixed concrete producer:

- provide heated concrete (60-70°F)
- supply a cold weather mix design
    - Type III cement
    - additional Type I ~ 1 bag
    - chloride/non-chloride accelerators

Cold Weather

Contractor responsibilities:

- check the weather forecast
- never place concrete on a frozen subgrade
- incorporate a cold weather mix design
- after placement, cure and protect concrete
- protect cylinders, if applicable

QUESTIONS?