با نام خدا

Cold-Weather Concreting

بتن ریزی در هوای سرد

آیین نامه آبا،

هوای سرد

سه روز متوالی

شرایط (الف) و (ب)

- الف) دمای متوسط هو ا در شبانه روز < ۵ درجه
- ب) دمای هوا برای بیشتر از نصف روز < ۱۰ درجه

ACI 306 Definition

- Average daily temperature <5ºC for 3 successive days
- Stays <10ºC for more than ½ of any 24h period

کانادا CSA A231.1

دمای هوا≤ ۵ درجه

یا

احتمال پایین آمدن دما ≤ ۵ درجه

۲٤ ساعت پس از بتن ریزی

Concrete Components

- Cement
- Water
- Fine Aggregate
- Coarse Aggregate

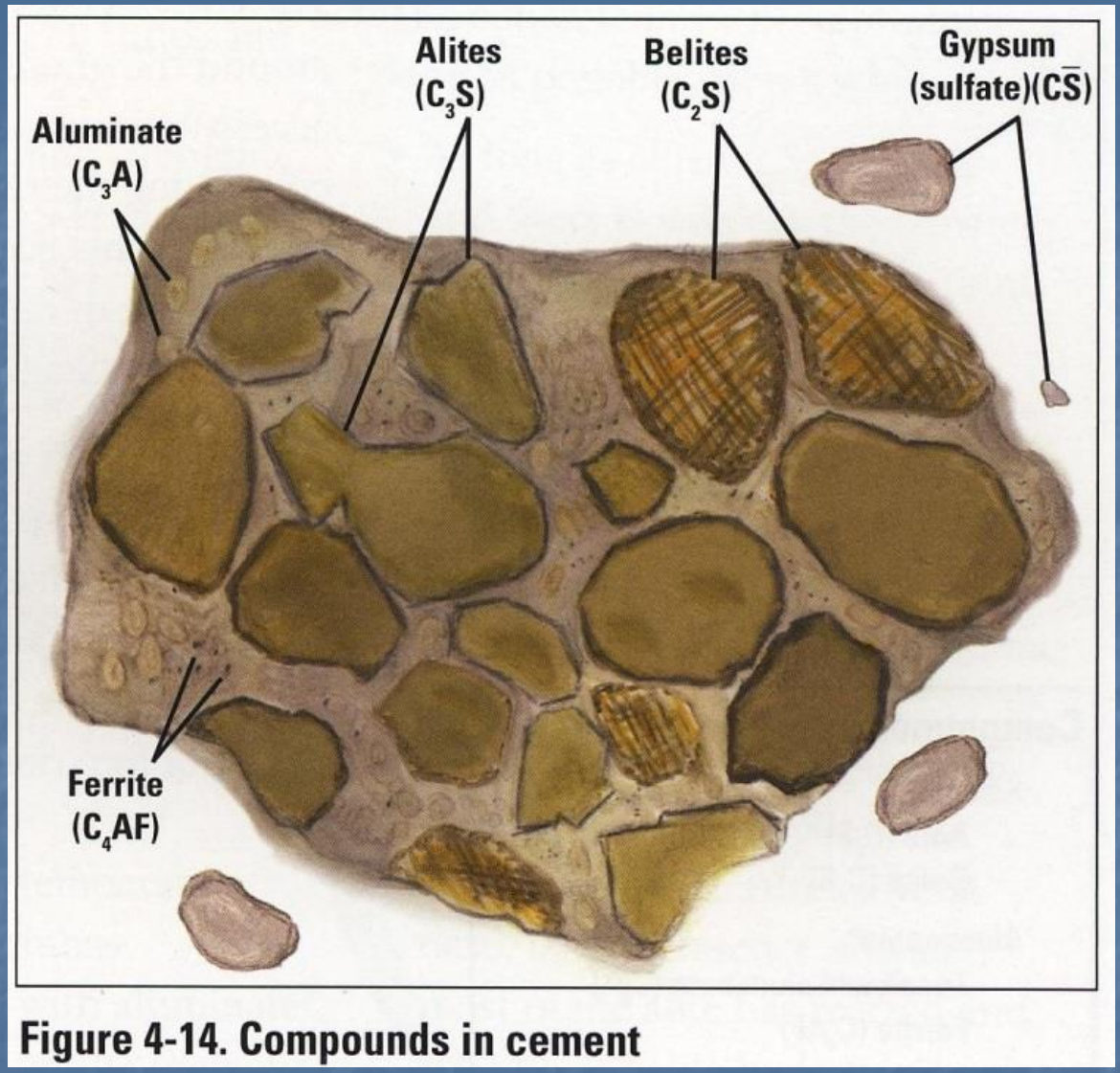
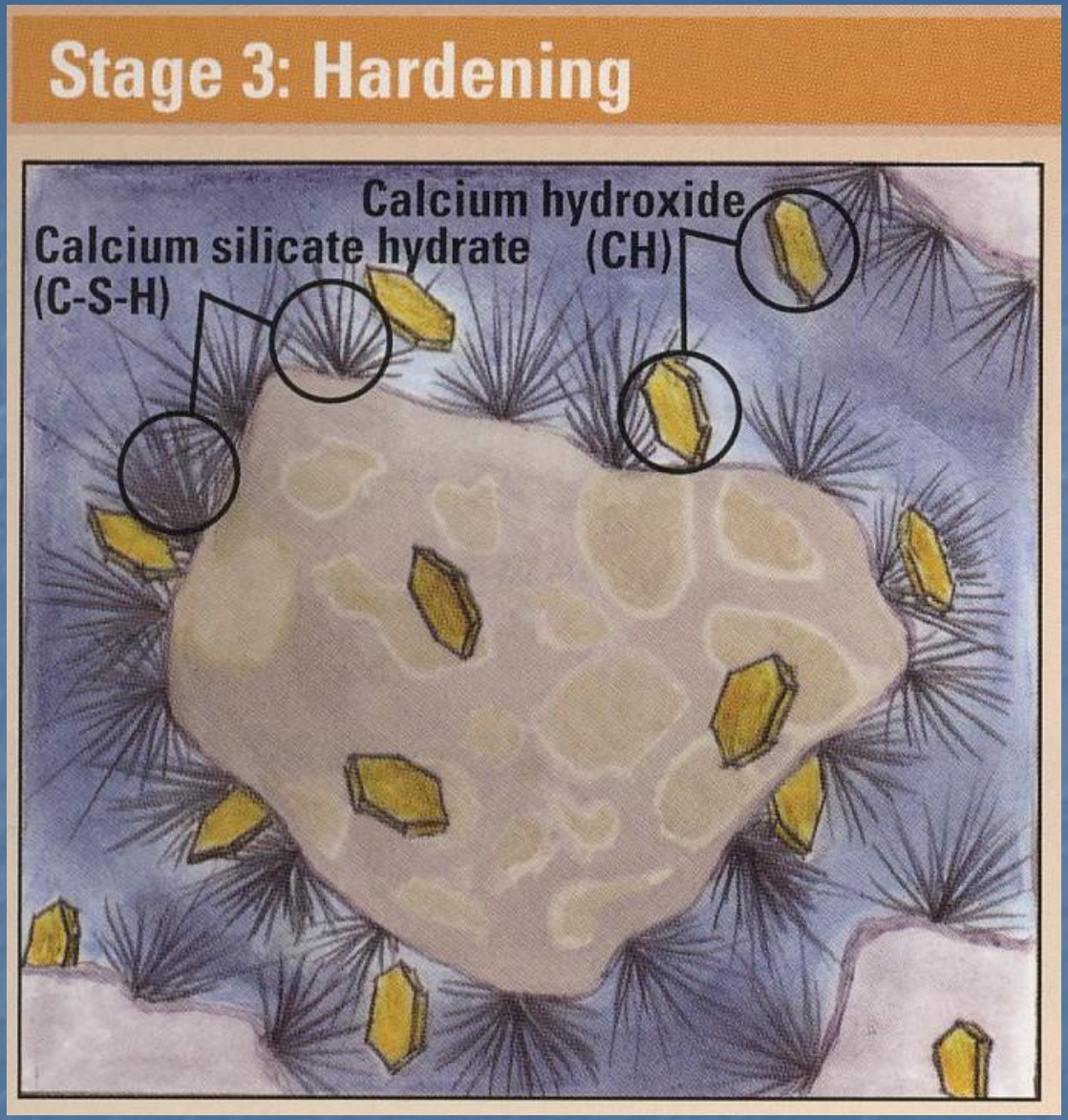


Figure 4-14. Compounds in cement

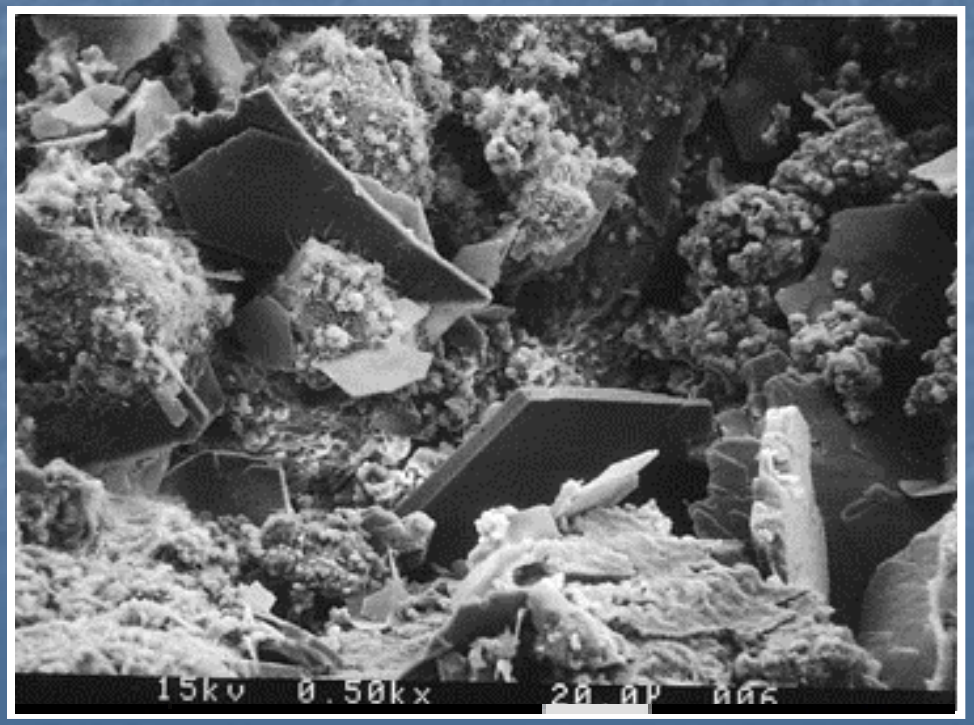
Cement Particle



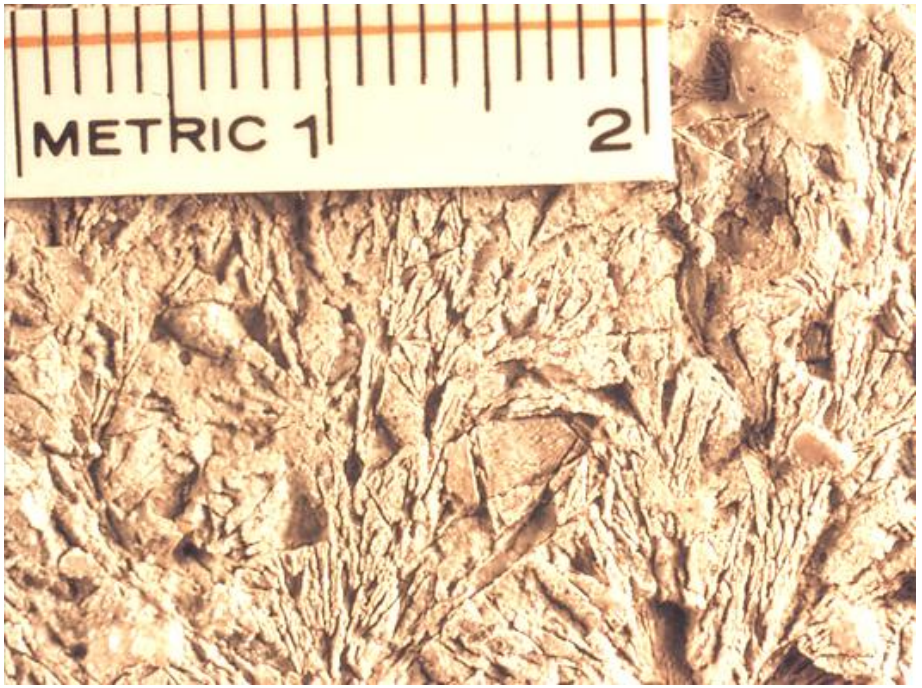
Early Stage of Hydration

Hydration

Ceases at… -10 ºC



Effect of Freezing on Fresh Concrete



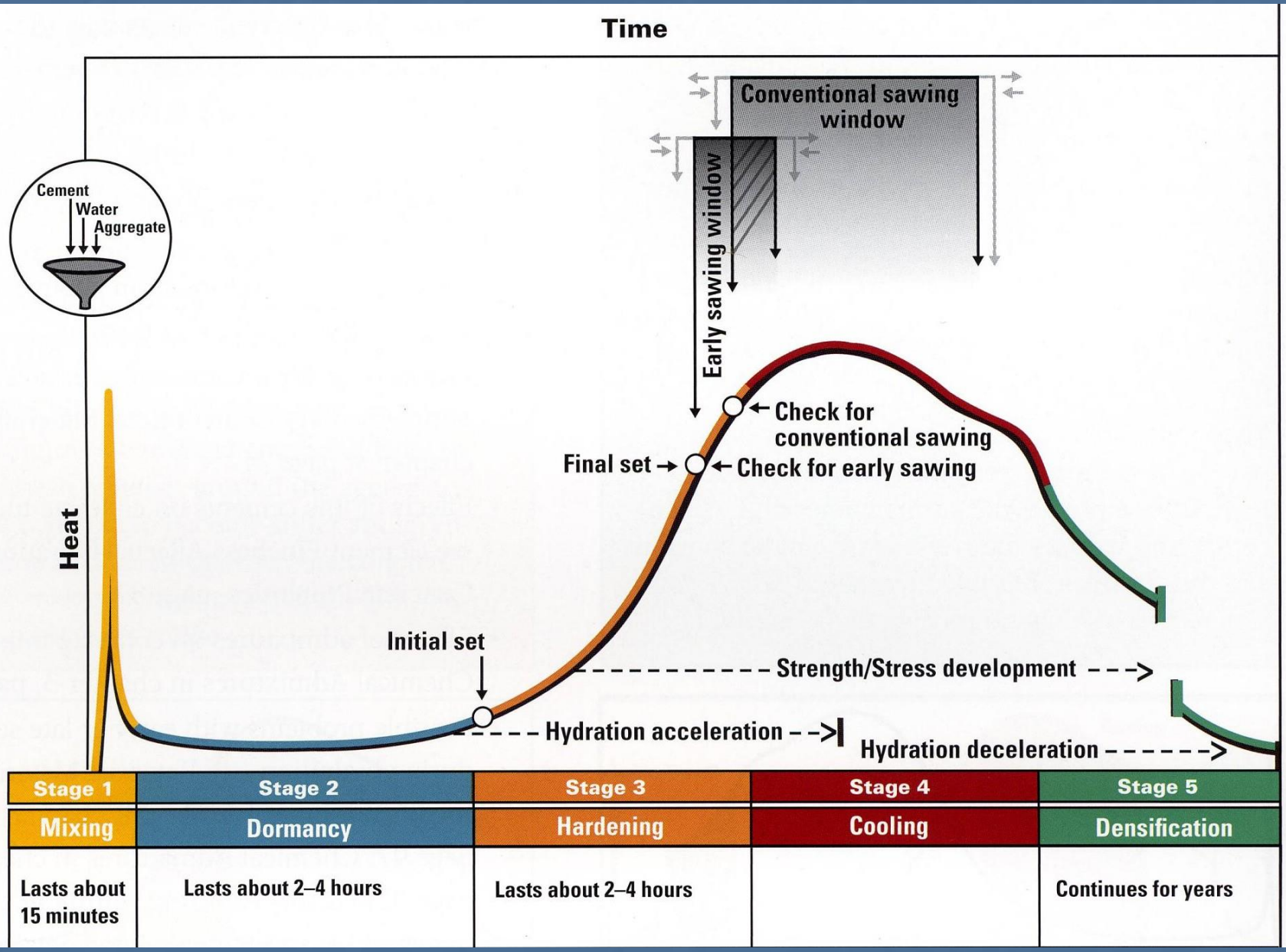
اگر بتن در

- **ساعات اولیه**
- قبل از رسیدن به **مقاومت** **35 kg/cm²**

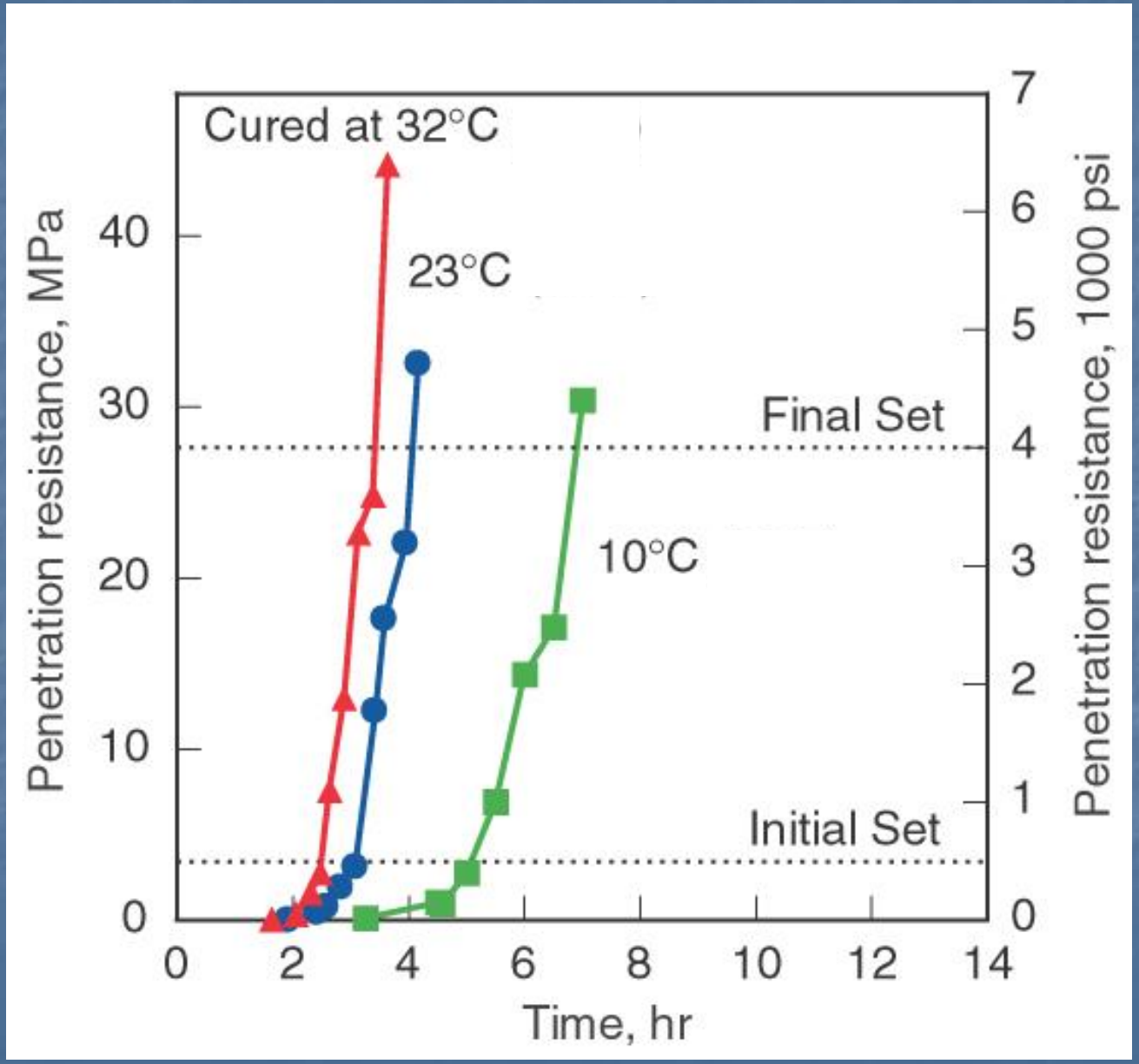
یخ بزند:

- **50% کاهش** مقاومت اتفاق میافتد.

Hydration Stages (25 ºC)



Setting Times at Different Temperatures



Final Setting Time of Concrete at Various Temperatures

Temperature, °C	Approx. Setting Time, hrs.
20	6
15	11
5	14
0	Concrete Freezes & doesn't set

CONCRETE FREEZES!

Rule of Thumb

- "every **10°C reduction**
- **times of setting**
- **double**,
- thus increasing the amount of time that the concrete is vulnerable to damage due to freezing."

A 10 degree drop in concrete temperature will DELAY set time by approximately

2 – 2 ½ hours

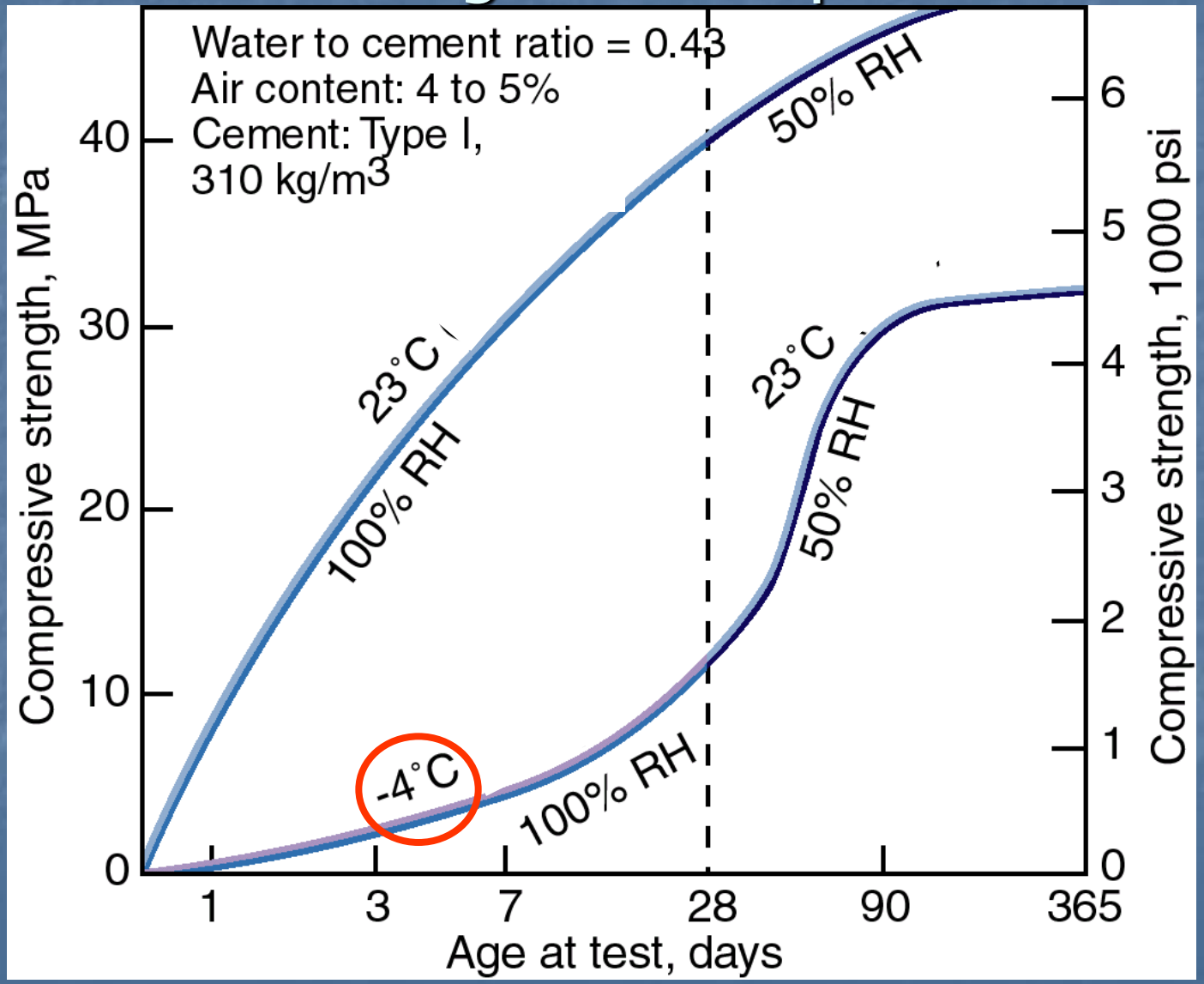
Whoops!!!

It's important to maintain adequate concrete temperatures during mixing and placing and in the first 24 hours after placement. If the temperature of undisturbed plastic concrete drops below about 29°F, freezing may occur, reducing the 28-day compressive strength by as much as 50% (see graph).

-2 °C

Source: *Behavior of Concrete under Temperature Extremes*, SP-39, American Concrete Institute.

Effect of Temperature on Strength Development



What Can We Influence

- Materials
- Mix Design
- Placement Conditions
- Curing conditions and length of time
- Protection

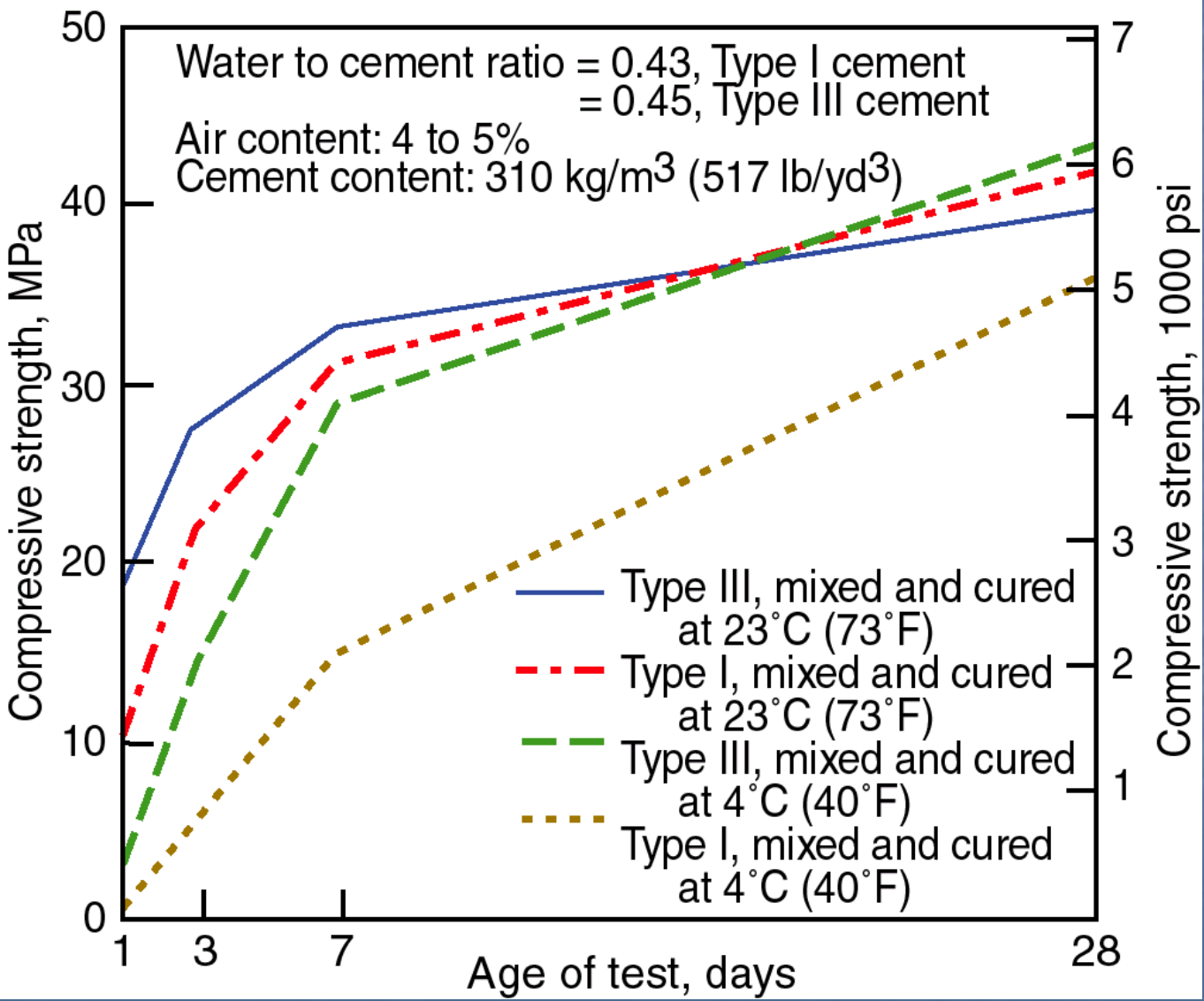
اقدامات پیش گیرانه لازم:

- استفاده از مواد افزودنی تندگیر کننده
- استفاده از سیمان های تند گیر
- استفاده از مقدار سیمان پرتلند بیشتر
- پوشش دوربند
- بادشکن
- بخاری قابل حمل
- قالب های عایق بندی شده
- پتو و ...

Methods to accelerate strength gain:

- HE high-early-strength cement
- Type I > Type I I > Pozzolanic Cement

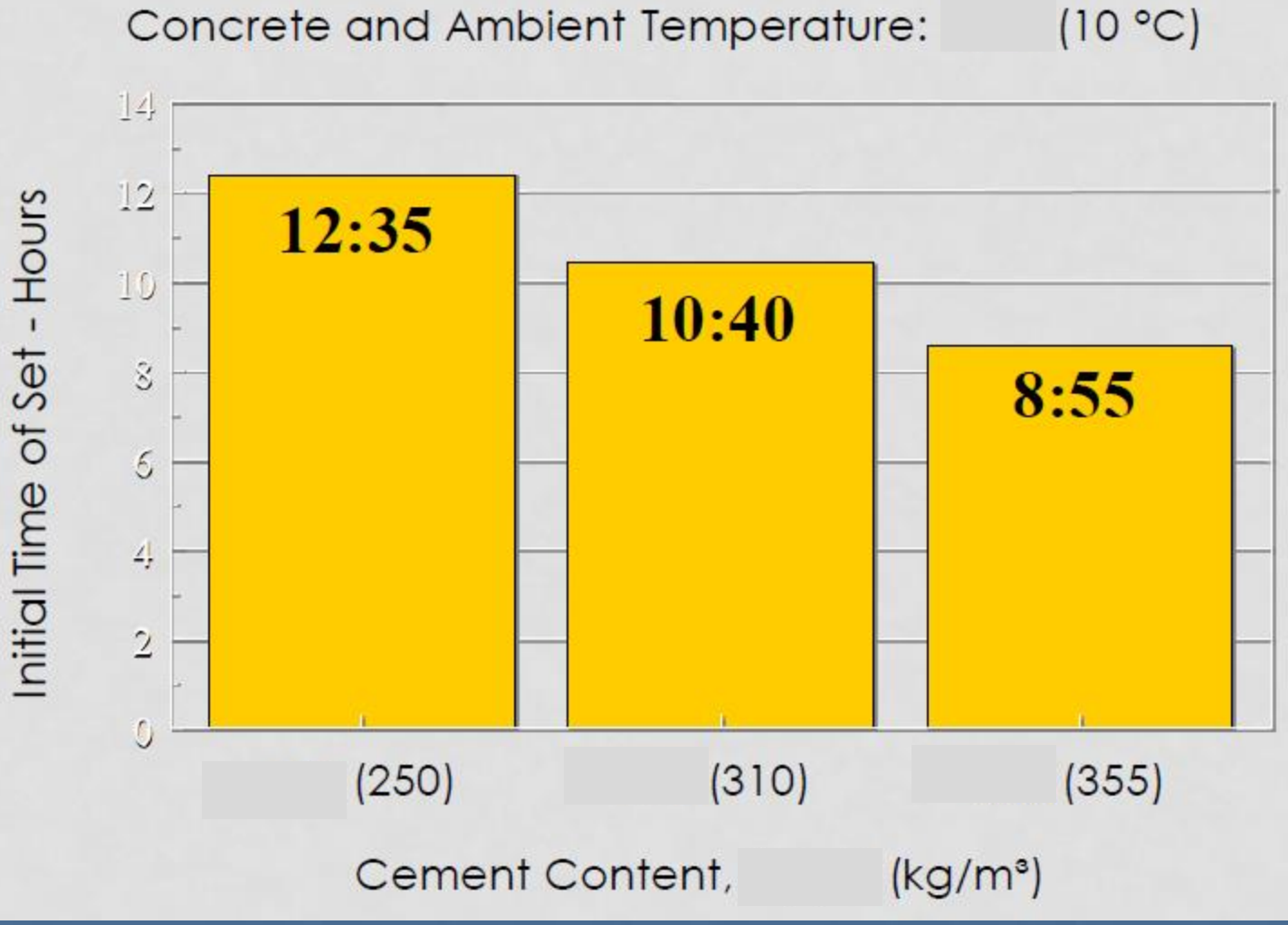
Early-Age Strength



Methods to accelerate strength gain:

- Additional portland cement (60 to 120 kg/m^3)

Effect of Cement Content on Setting Time Performance



Rule of Thumb

An increase of 1 sack of cement, will improve the set time by about 1 hour

Why?

Lower unit water content

Designation: C 494/C 494M – 05a

Standard Specification for Chemical Admixtures for Concrete[1]

Type A—Water-reducing admixtures,
Type B—Retarding admixtures,
Type C—Accelerating admixtures,
Type D—Water-reducing and retarding admixtures,
Type E—Water-reducing and accelerating admixtures,
Type F—Water-reducing, high range admixtures, and
Type G—Water-reducing, high range, and retarding

Accelerating Admixtures

ASTM C 494 or AASHTO M 194, Type C

Accelerate the rate of:

- Hydration (setting)
- Early-age strength gain

****Calcium Chloride-based accelerators:**

****Calcium Nitrate-based accelerators:**

Calcium chloride accelerators:

Increase:

- Drying shrinkage,
- Potential reinforcement corrosion,
- Potential scaling
- Darken concrete

$Ca(NO_3)_2$

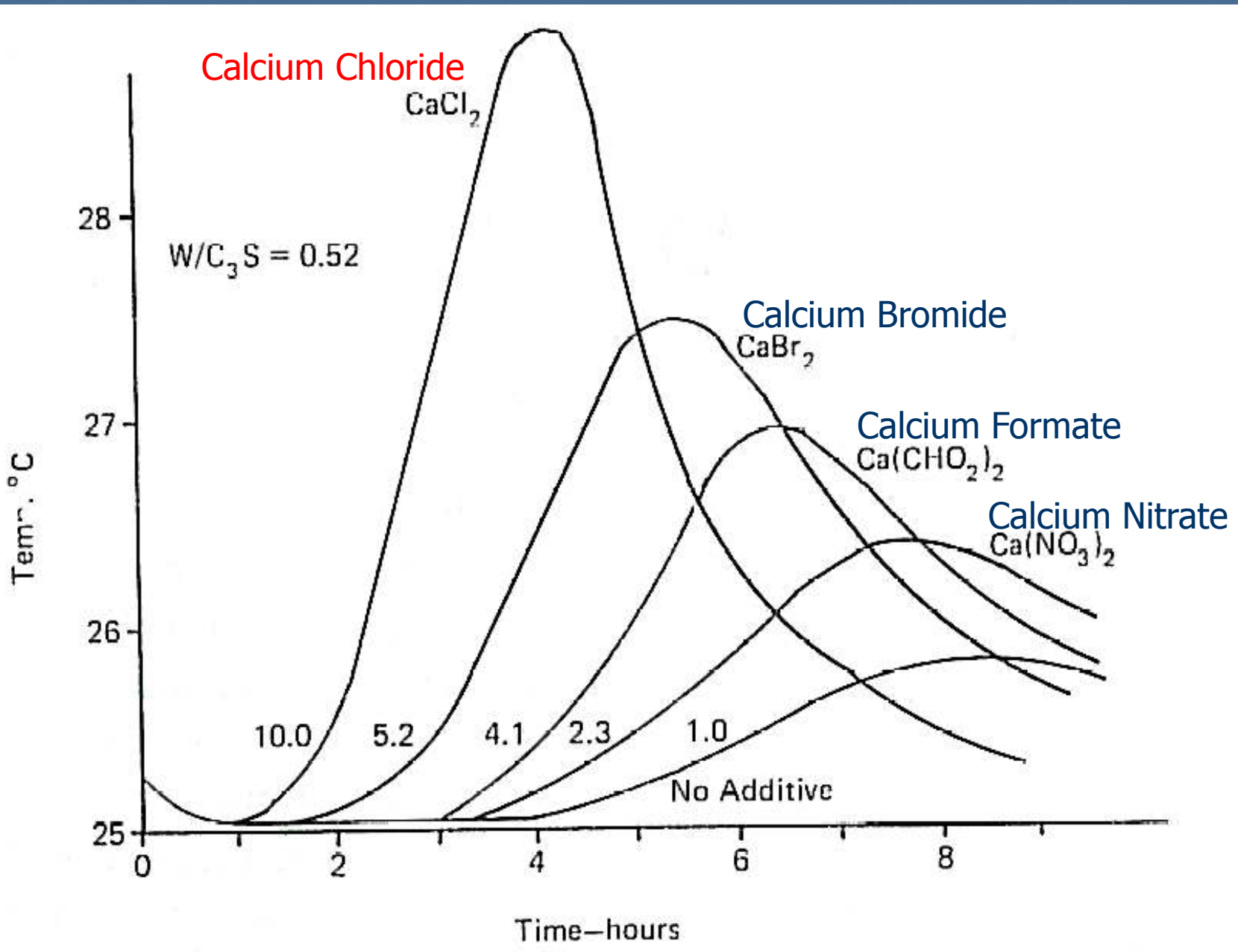
Calcium nitrate, also called Norgessalpeter, is the inorganic compound with the formula $Ca(NO_3)_2$. This colourless salt absorbs moisture from the air and is commonly found as a tetrahydrate.
Molar mass: 164.088 g/mol

Formula: $Ca(NO_3)_2$

Density: 2.5 g/cm³

Soluble in: Water

Appearance: colorless solid; hygroscopic


Calcium Chloride
CaCl2
W/C3S = 0.52
Calcium Bromide
CaBr2
Calcium Formate
Ca(CHO2)2
Calcium Nitrate
Ca(NO3)2
10.0
5.2
4.1
2.3
1.0
No Additive
28
27
26
25
0
2
4
6
8
Time—hours

Example of Non-Chloride Accelerator Effect on Set Time

Mix @ (10 °C)	Initial Set (h:min)	Difference (h:min)
Plain	13:44	REF
Accel. @ 1300 mL/100 kg cement	7:11	- 6:33
Accel. @ 2600 mL/100 kg cement	6:05	- 7:39

بتن با عیار 350 کیلو گرم سیمان تیپ دو صوفیان

(متوسط مقاومتهای فشاری دو آزمونه مکعبی 15*15*15)

	کنترل kg/cm^2	1% پودر نیترات کلسیم (3.5 کیلوگرم) kg/cm^2	3% پودر نیترات کلسیم (10.5 کیلوگرم) kg/cm^2
روکش پلاستیکی محیط آزمایشگاه 95/10/4 الی 95/10/11 هفت روزه	166	206	243
روکش پلاستیکی هوای سرد بیرون بین 1- و 16- 95/10/4 الی 95/10/11 هفت روزه	----	32	51
کاهش مقاومت 7 روزه در اثر هوای سرد	%100	%85	%79

Non-Chloride Accelerator Caution

Quote from typical accelerator literature

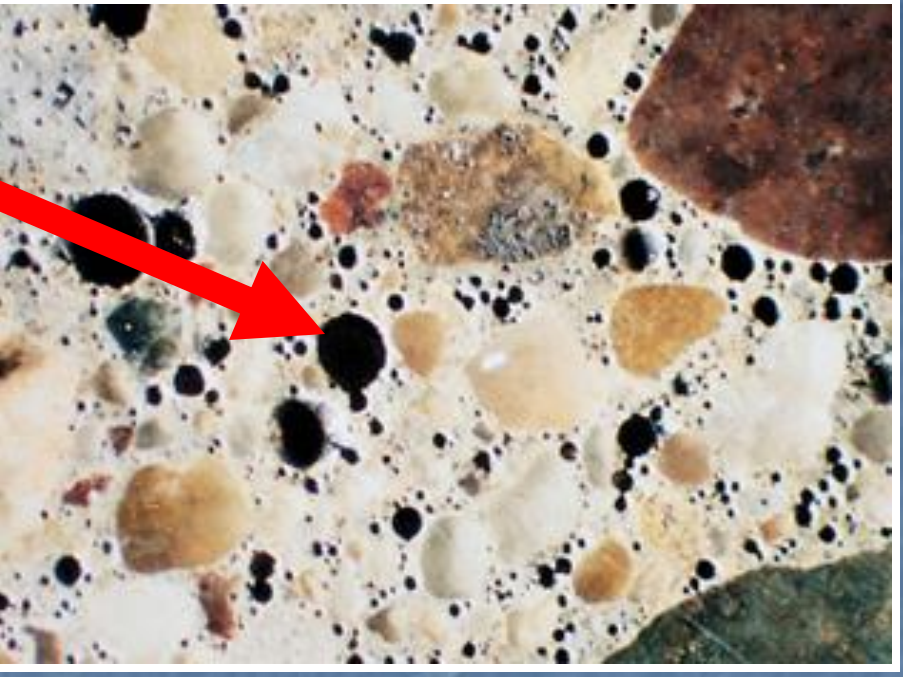
- "… the concrete producer should account for the water contained in the (accelerator). Each Liter of (accelerator) added to a concrete mix will contribute 0.78 kg of water to that mix."

Admixtures

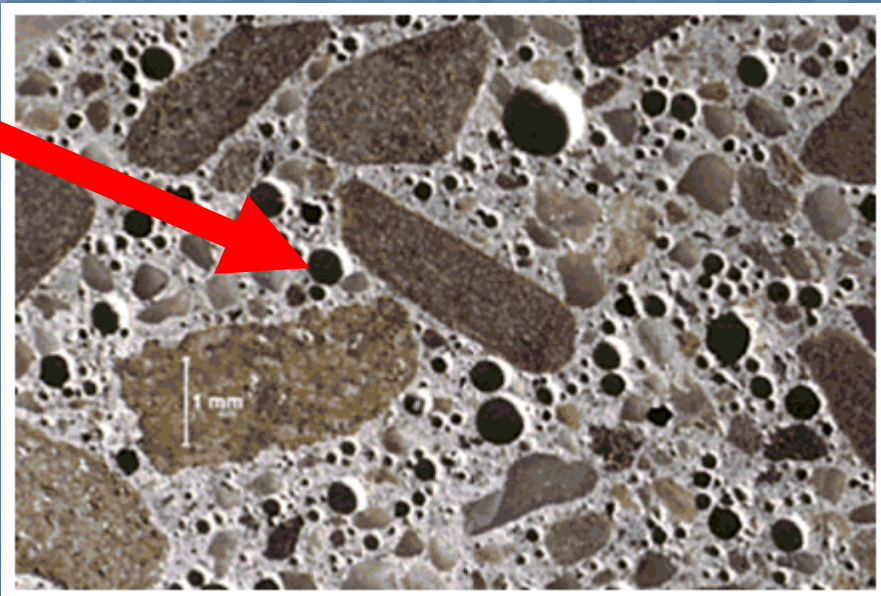
- Protect from freezing
- Agitate if necessary

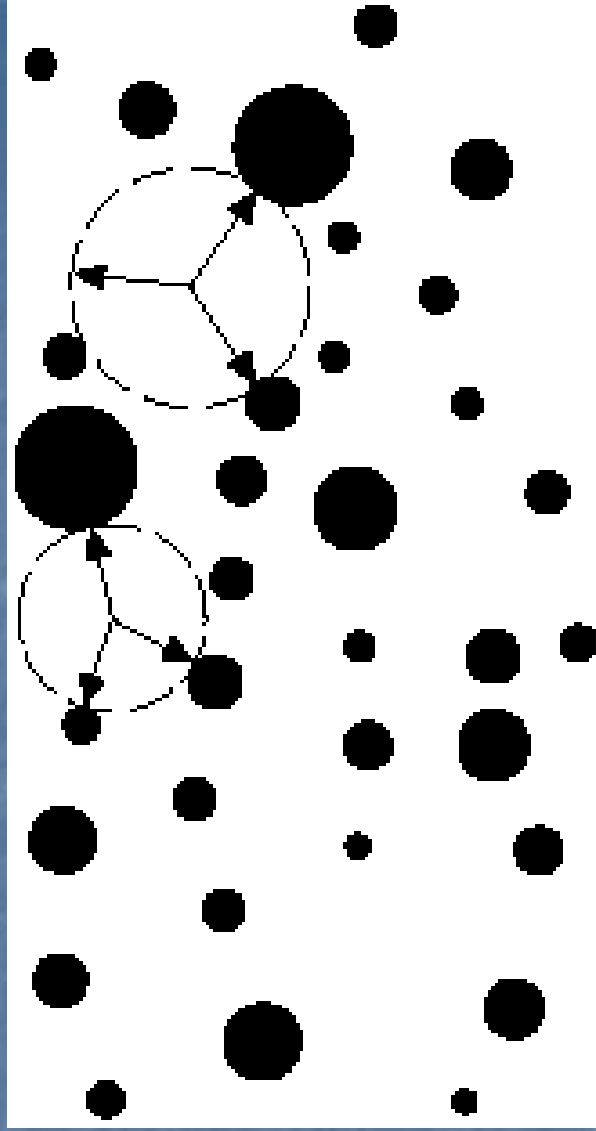
Air Entrainment for Safety

Concrete considered to ultimately be "unexposed" may well be exposed during construction.



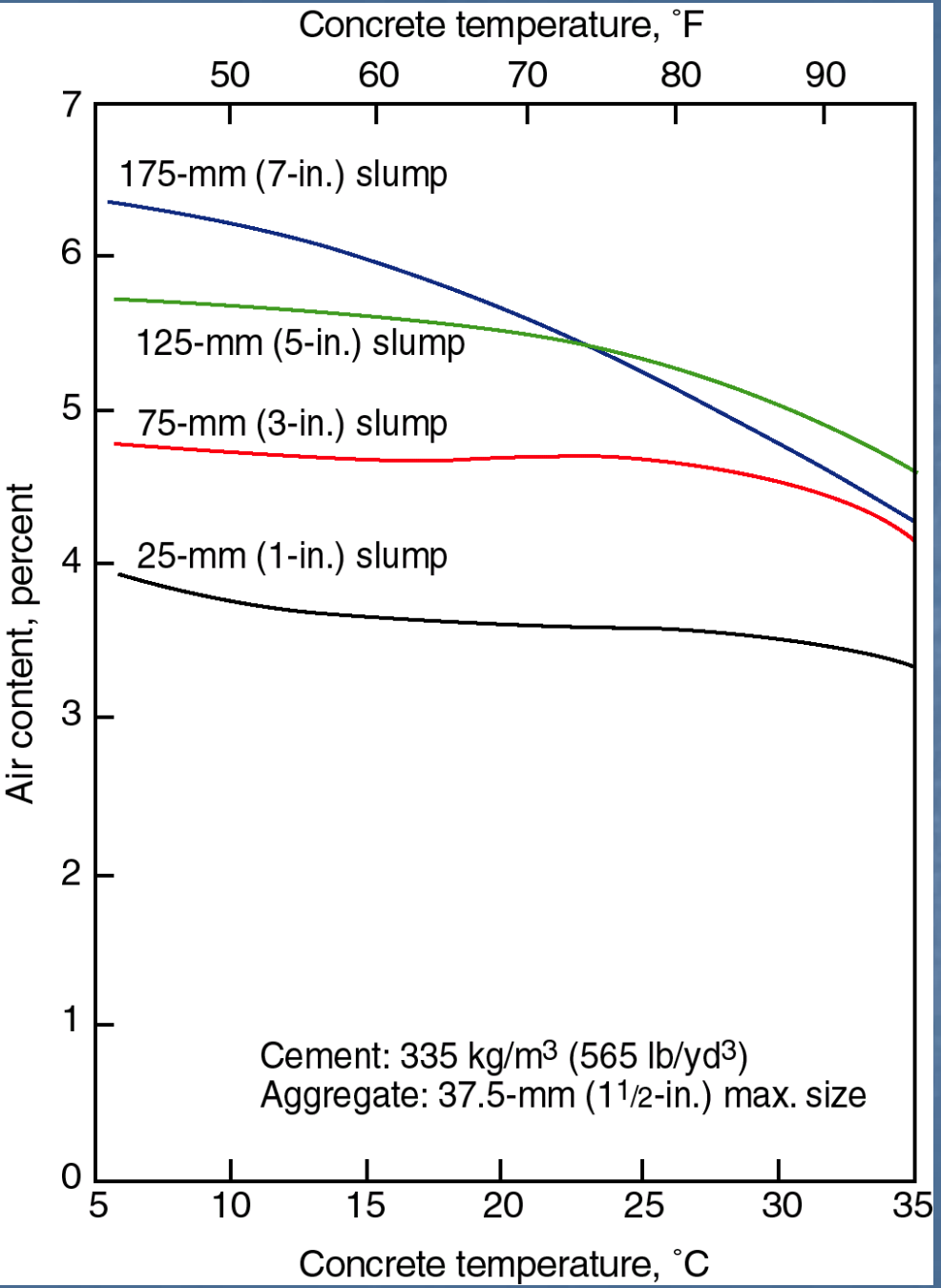
Air-Entrained Concrete





Air-Void System

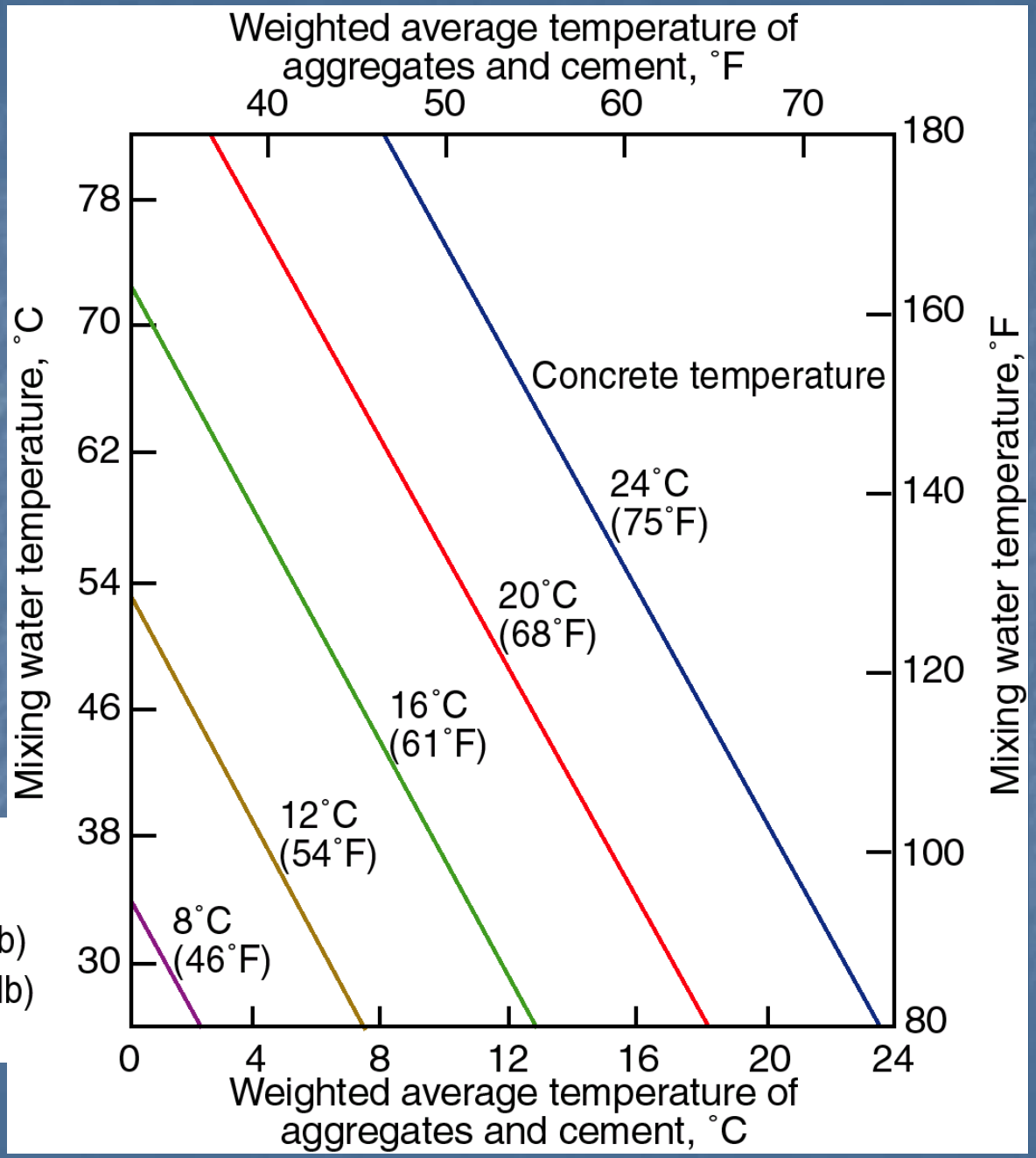
Relationship Between Temperature, Slump and Air Content



Heating Materials

- Water

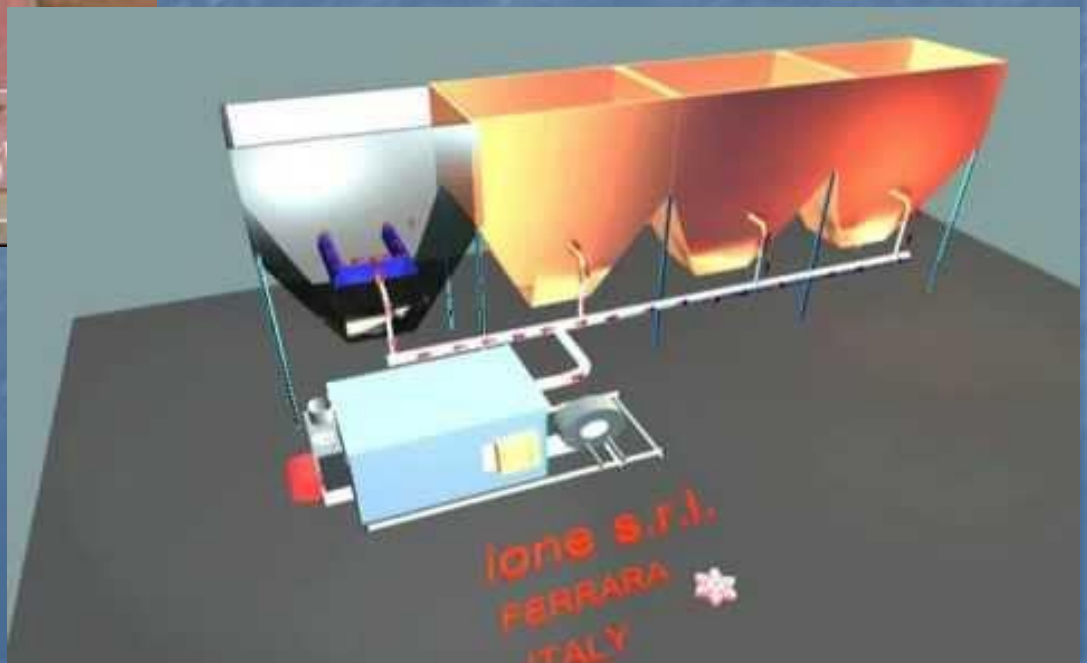
Heating Mix Water

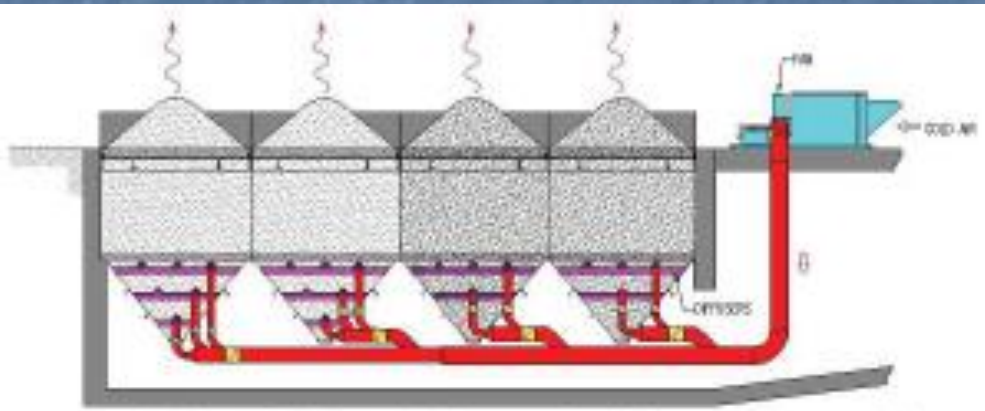


Mix data:
Aggregate = 1360 kg (3000 lb)
Moisture in aggregate = 27 kg (60 lb)
Added mixing water = 108 kg (240 lb)
Portland cement = 256 kg (564 lb)

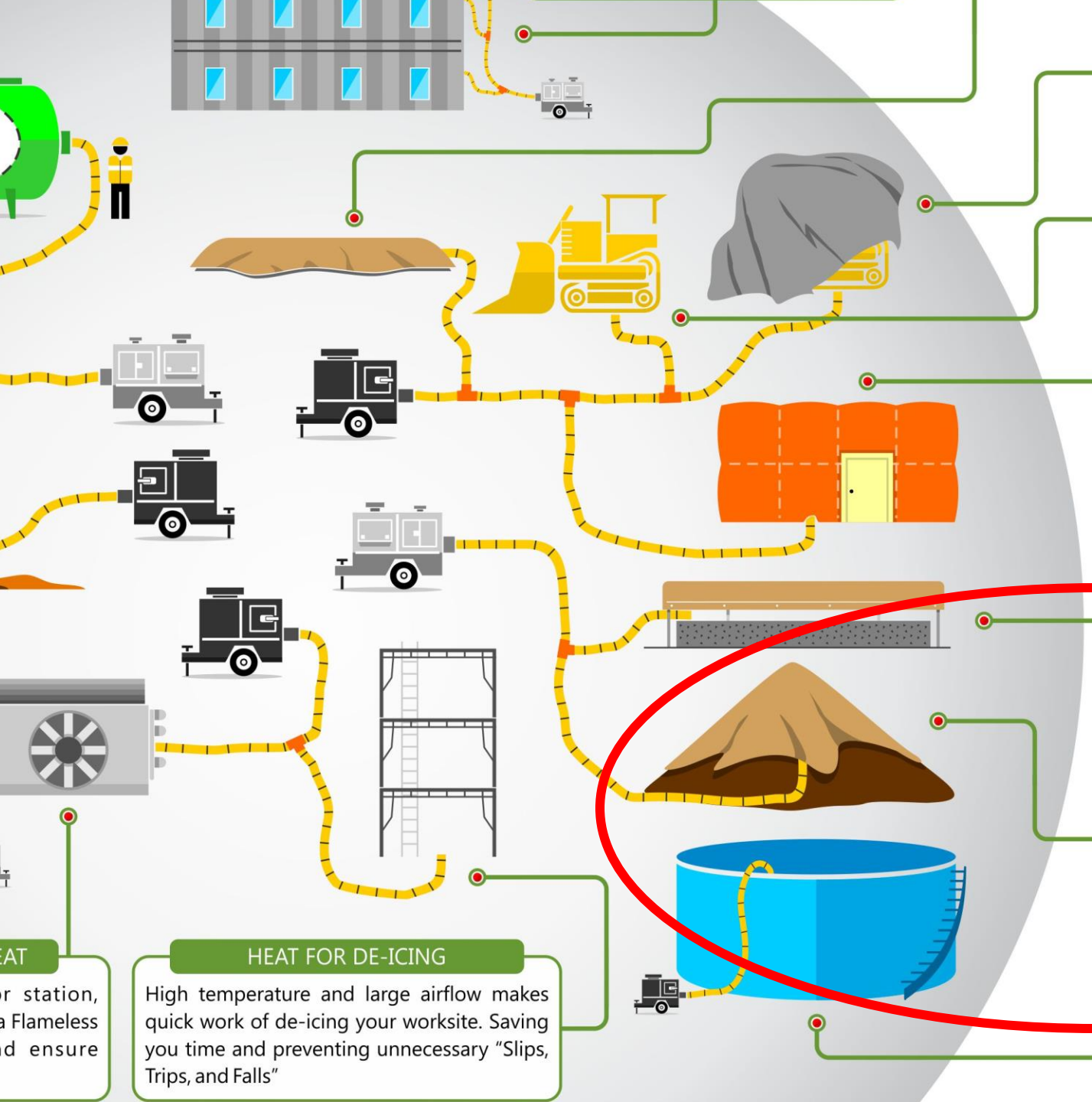
Heating Materials

- Aggregates





Aggregate is heated with hot air in the overhead bins, or in the receiving hoppers. A high pressure, industrial fan distributes the heated air via pipes and diffusers into the material in the bins.



FIELD EQUIPMENT REPAIR

No need for another heater, just us
ducting "Y" and easily inflate a heati
parachutes to facilitate quick repairs

EQUIPMENT THAW

Thaw equipment faster reduci
downtime

HEATING HOARDINGS

One JetHeat unit has been used
replace 15 frost fighters, and with t
heated air meeting OSHA and NIOSH
standards, there is no risk of irritants
eyes and lungs

CONCRETE CURING

The Heatmeister's ability
automatically control the ambie
temperature around the concrete allo
for a perfect cure every time... regardl
of changing weather conditions. Wha
your concrete pour worth?

AGGREGATE HEATING

The high static pressure and CFM all
for even heat distribution over t
aggregate. Eliminating hot and co
spots created by smaller heat sources

DRYING AND DEHUMIDIFYING

With the highest rise in temperatu
available, Nakoda's heaters are able
dry and dehumidify faster than any oth
technology

HEAT FOR DE-ICING

High temperature and large airflow makes quick work of de-icing your worksite. Saving you time and preventing unnecessary "Slips, Trips, and Falls"

EAT

r station,
a Flameless
nd ensure

Effect of Temperature of Materials on Concrete Temperatures

$$T = \frac{0.22(T_a M_a + T_c M_c) + T_w M_w + T_{wa} M_{wa} - 80 M_i}{0.22(M_a + M_c) + M_w + M_{wa} + Mi}$$

T = temperature of the freshly mixed concrete, °C

T_a, T_c, T_w, and T_{wa} = temperature in °C of aggregates, cement, added mixing water, and free water on aggregates, respectively

M_a, M_c, M_w, and M_{wa} = mass, kg, of aggregates, cementing materials, added mixing water, and free water on aggregates, respectively

Effect of Temperature of Materials on Concrete Temperatures

$$T = \frac{0.22(T_a M_a + T_c M_c) + T_w M_w + T_{wa} M_{wa}}{0.22(M_a + M_c) + M_w + M_{wa}}$$

T_a =2 °C	M_a= 1730 kg/m^3	دما و جرم سنگدانه ها
T_c =5 °C	M_c= 325 kg/m^3	دما و جرم سیمان
T_w =5 °C	M_w= 170 kg/m^3	دما و جرم آب اختلاط
T_{wa}=2 °C	M_{wa}= 50 kg/m^3	دما و جرم آب سطحی سنگدانه ها

T = temperature of the freshly mixed concrete=3 °C

Effect of Temperature of Materials on Concrete Temperatures

$$T = \frac{0.22(T_a M_a + T_c M_c) + T_w M_w + T_{wa} M_{wa} - 80 M_i}{0.22(M_a + M_c) + M_w + M_{wa} + Mi}$$

$T_a = 0$ °C	$M_a = 1730$ kg/m^3	دما و جرم سنگدانه های **یخزده**
$T_c = 5$ °C	$M_c = 325$ kg/m^3	دما و جرم سیمان
$T_w = 5$ °C	$M_w = 170$ kg/m^3	دما و جرم آب اختلاط
$T_{wa} = 0$ °C	$M_{wa} = Mi = 50$ kg/m^3	دما و جرم آب سطحی **یخزده** سنگدانه ها

T = temperature of the freshly mixed concrete= - 4 °C

Effect of Temperature of Materials on Concrete Temperatures

$$T = \frac{0.22(T_a M_a + T_c M_c) + T_w M_w + T_{wa} M_{wa}}{0.22(M_a + M_c) + M_w + M_{wa}}$$

T_a =2 °C	M_a= 1730 kg/m^3	دما و جرم سنگدانه ها
T_c =5 °C	M_c= 325 kg/m^3	دما و جرم سیمان
T_w =**70 °C**	M_w= 170 kg/m^3	دما و جرم آب اختلاط
T_{wa}=2 °C	M_{wa}= 50 kg/m^3	دما و جرم آب سطحی سنگدانه ها

T = temperature of the freshly mixed concrete=20 °C

Effect of Temperature of Materials on Concrete Temperatures

$$T = \frac{0.22(T_a M_a + T_c M_c) + T_w M_w + T_{wa} M_{wa}}{0.22(M_a + M_c) + M_w + M_{wa}}$$

T_a =10 °C	M_a= 1730 kg/m^3	دما و جرم سنگدانه ها
T_c =5 °C	M_c= 325 kg/m^3	دما و جرم سیمان
T_w =5 °C	M_w= 170 kg/m^3	دما و جرم آب اختلاط
T_{wa}=10 °C	M_{wa}= 50 kg/m^3	دما و جرم آب سطحی سنگدانه ها

T = temperature of the freshly mixed concrete=8 °C

Effect of Temperature of Materials on Concrete Temperatures

$$T = \frac{0.22(T_a M_a + T_c M_c) + T_w M_w + T_{wa} M_{wa}}{0.22(M_a + M_c) + M_w + M_{wa}}$$

T_a =10 °C	M_a= 1730 kg/m^3	دما و جرم سنگدانه ها
T_c =5 °C	M_c= 325 kg/m^3	دما و جرم سیمان
T_w =70 °C	M_w= 170 kg/m^3	دما و جرم آب اختلاط
T_{wa}=10 °C	M_{wa}= 50 kg/m^3	دما و جرم آب سطحی سنگدانه ها

T = temperature of the freshly mixed concrete=25 °C

-Temperature loss during delivery

For revolving drum mixers:

$$T_d = 0.25(t_r - t_a)$$

دمای هوا= t_a = -7 ˚C

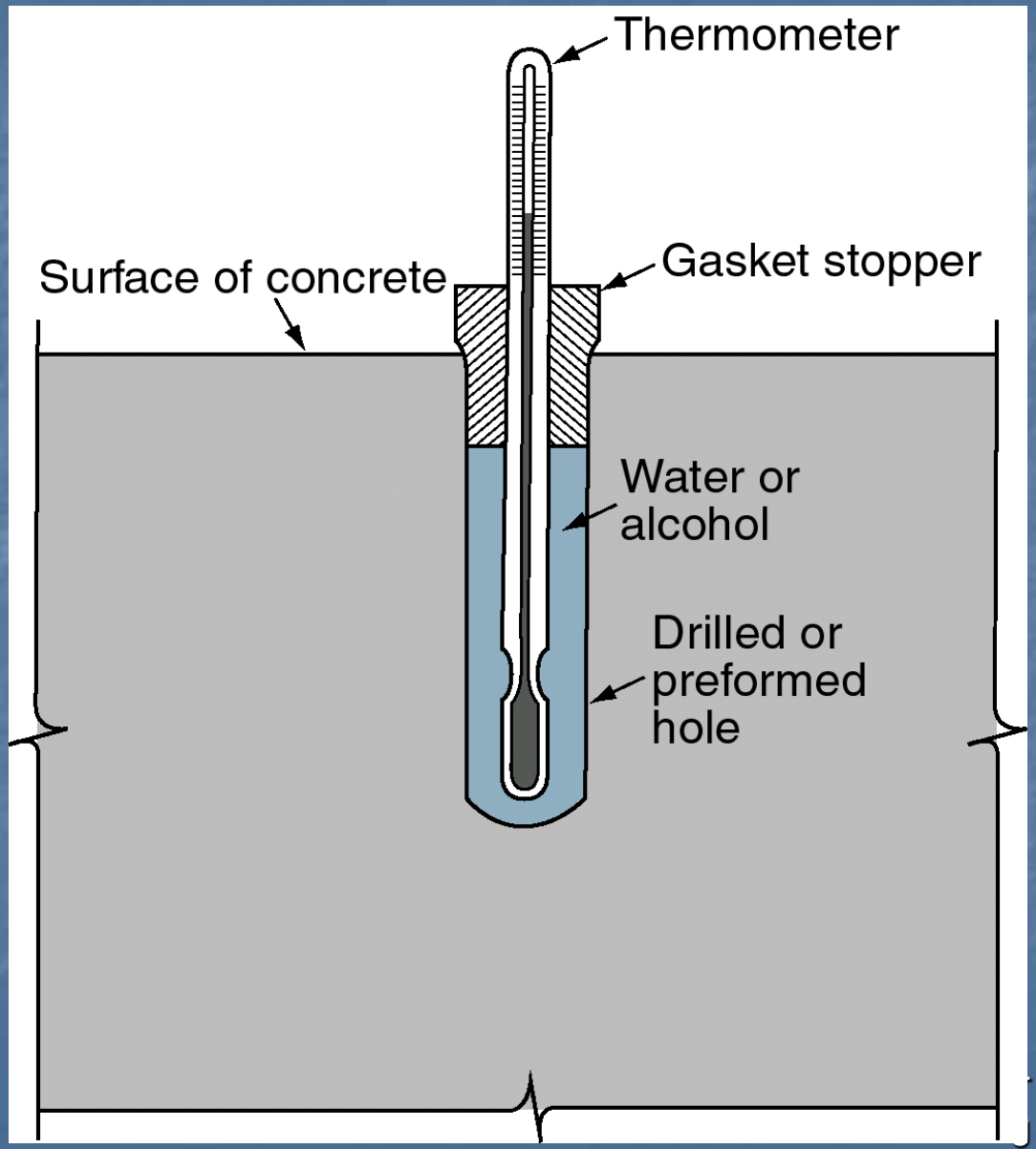
دمای بتن در کامیون مخلوط کن = t_r = 10 ˚C

بعد از یک ساعت حمل در کامیون

افت دمای بتن = T_d = 0.25x[10-(-7)]=**4.25 ˚C**

Checking Fresh Concrete Temperatures

Checking Hardened Concrete Temperatures



Recommended Concrete Temperatures—Air-Entrained Concrete (ACI 306)

Line	Condition		Thickness of sections, mm	
			Less than 300	300 to 900
1	Minimum temperature of **fresh** concrete as mixed for weather indicated.	Above -1°C	16°C	13°C
2		-18°C to -1°C	18°C	16°C
3		Below -18°C	21°C	18°C
4	Minimum temperature of fresh concrete as placed and maintained.		13°C	10°C

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).

Surface Temperature Limitations (ACI 306)

- Above freezing (at least 2°C)
- No more than 11 °C higher than minimum placement temp.

Rapid moisture loss can occur from surfaces exposed to cold weather because of the low absolute humidity of the cold air (ACI 302.1R).

Permissible Concrete Temperatures at Placing

CSA A23.1

Thickness of Section, m	Temperature, °C	
	Minimum	Maximum
Less than 0.3	10	35
سقف-ستون-پی 0.3-1	10	30
پی گسترده 1-2	5	25
More than 2	5	20

Max. Permissible Temp. Differential Between Concrete Surface and Ambient Air — Wind up to 25 km/hr.

Thickness of concrete, m	Max. permissible temp. differential, °C				
	L to H ratio of structure				
	0	3	5	7	20 or more
0.3	29	22	19	17	12
0.6	22	18	16	15	12
0.9	18	16	15	14	12
1.2	17	15	14	13	12
1.5	16	14	13	13	12

CSA A23.1 – TABLE 21

Maximum permissible temperature differential between concrete surface and ambient (wind up to 25km/h)

(see Clauses 7.4.2.3 and 7.4.2.5.3.4)

	Maximum permissible temperature differential, °C				
	Length to height ratio of structural elements*				
Thickness of concrete, m	0†	3	5	7	20 or more
< 0.3	29	22	19	17	12
0.6	22	18	16	15	12
0.9	18	16	15	14	12
1.2	17	15	14	13	12
> 1.5	16	14	13	13	12

** Length shall be the longer restrained dimension and the height shall be considered the unrestrained dimension.*
† Very high, narrow structural elements such as columns.

ACI 306R-16

Guide to Cold Weather Concreting

Reported by ACI Committee 306

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.

Recommended Duration of Temperature

Air-entrained concrete

Service category	Protection from early-age freezing		For safe stripping strength	
	Convent. concrete, days	High-early strength concrete, days	Convent. concrete, days	High-early-strength concrete, days
No load, not exposed, favorable moist-curing	2	1	2	1
No load, exposed, but later has favorable moist-curing	3	2	3	2
Partial load, exposed			6	4
Fully stressed, exposed			See next slide	

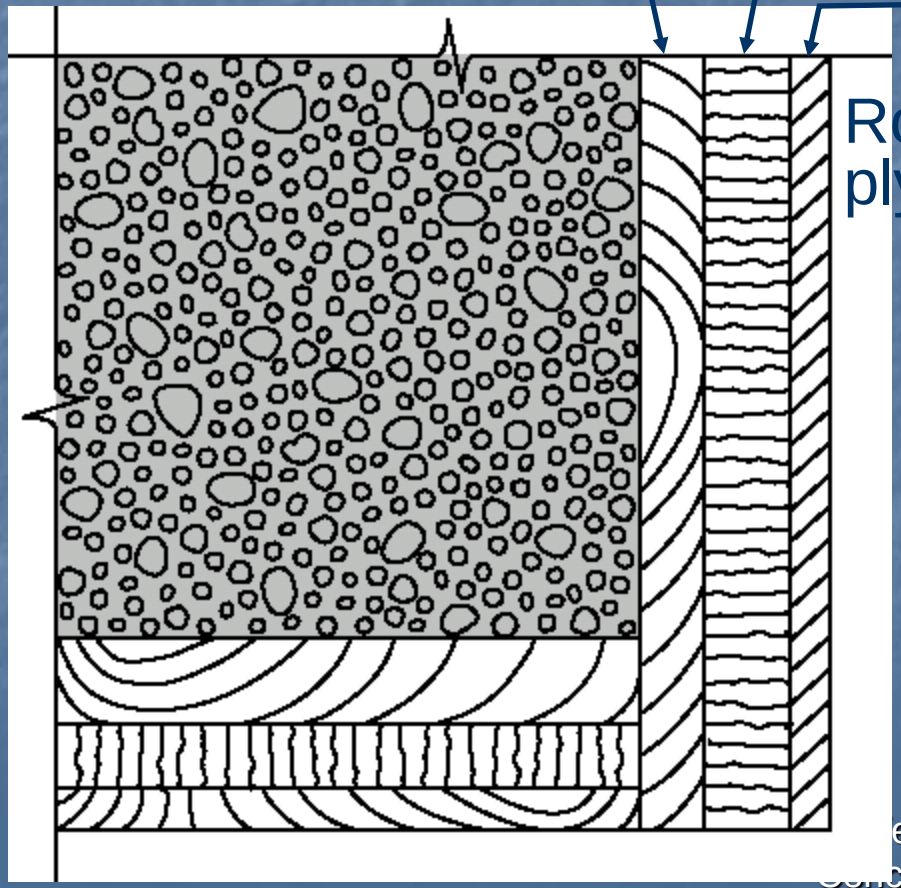
Recommended Duration of Temperature

Fully stressed, exposed, air-entrained concrete

Required percentage of standard-cured 28-day strength	Days at 10°C (50°F)			Days at 21°C (70°F)		
	Type of portland cement			Type of portland cement		
	I or GU	II or MS	III or HE	I or GU	II or MS	III or HE
50	6	9	3	4	6	3
65	11	14	5	8	10	4
85	21	28	16	16	18	12
95	29	35	26	23	24	20

Insulating Concrete Forms (ICF)

Insulated Column Forms



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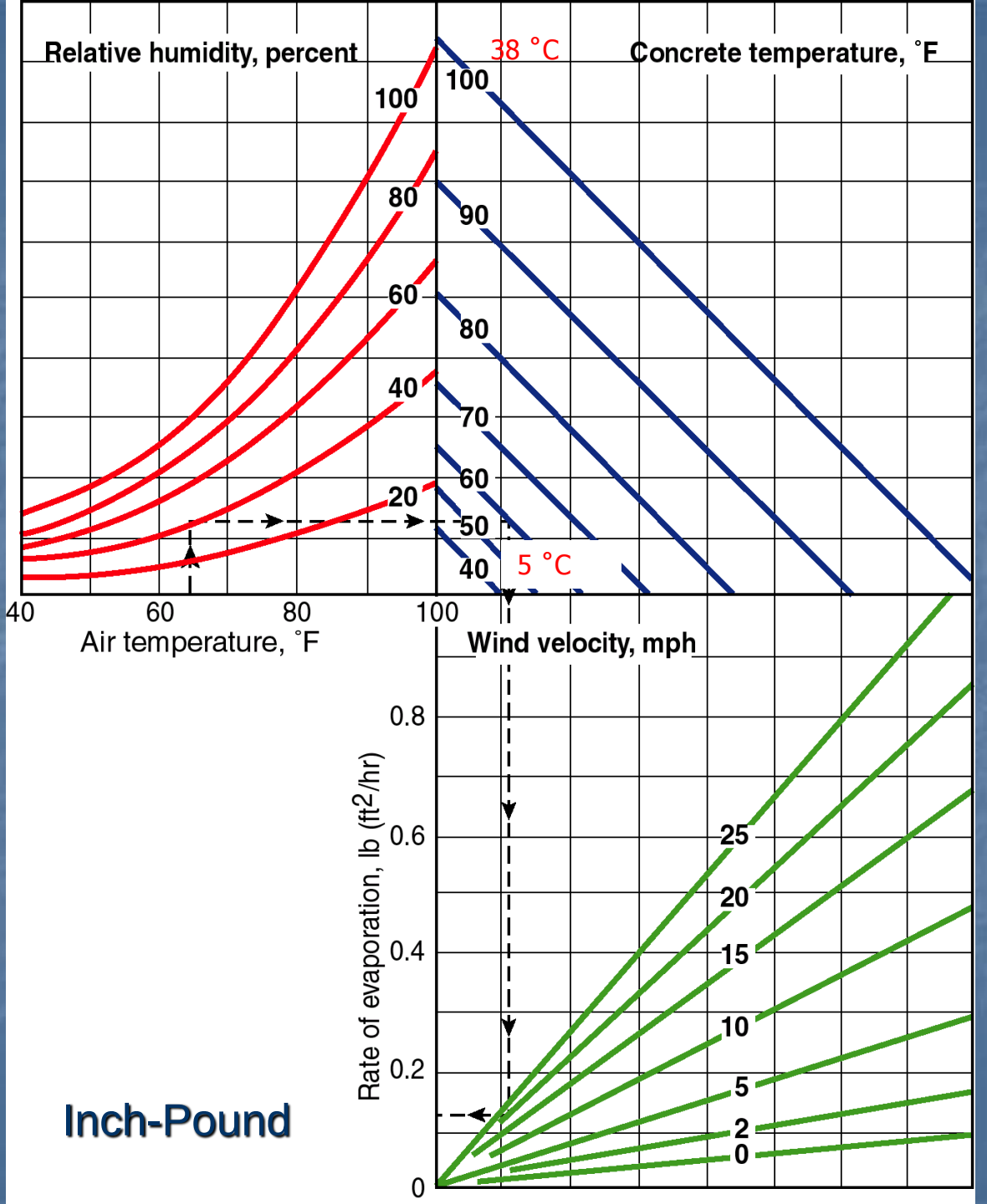
creting

When the air temperature within the enclosure falls to 50°F (10°C), the concrete can be exposed to the air, provided the relative humidity is not less than 40 percent. 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.

Protect from Thermal Shock

Evaporation of Surface Moisture from Concrete



Inch-Pound

Retaining Heat of Hydration

Insulating Blankets

Thermal resistance of mineral fibre blanket (50 to 70-mm thick)	1.2 $(m^2 \cdot °C)/W$

Thermal Resistance (R) for 10-mm Thickness of Material

Board and Slabs	**Density kg/m³**	**(m² · °C)/W**
Expanded polyurethane	24	0.438
Expanded polystyrene	29	0.277
Mineral fiberboard	256 - 272	0.204
Plywood	545	0.087
Loose fill		
Wood fiber, soft woods	32 - 56	0.231
Vermiculite	112 - 131	0.148

Enclosures

- Wood
- Canvas
- Tarpaulins
- Polyethylene Film

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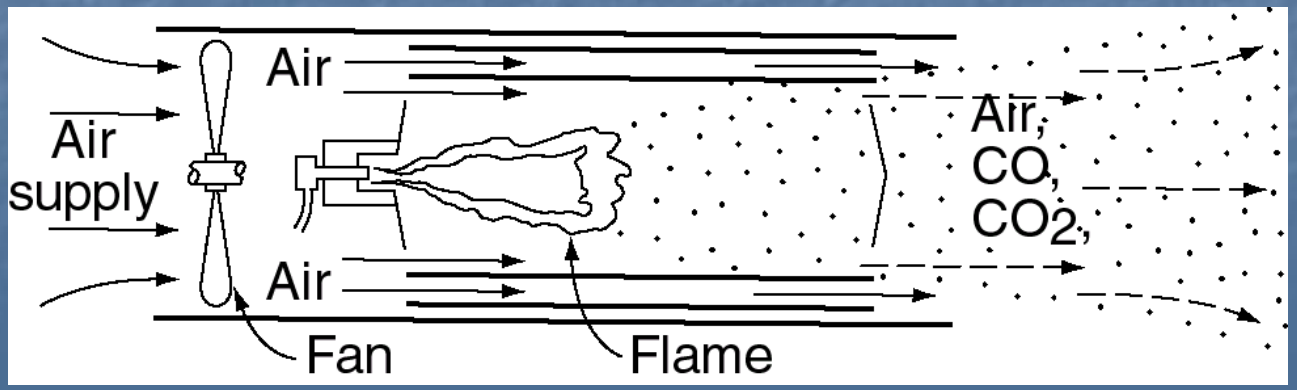
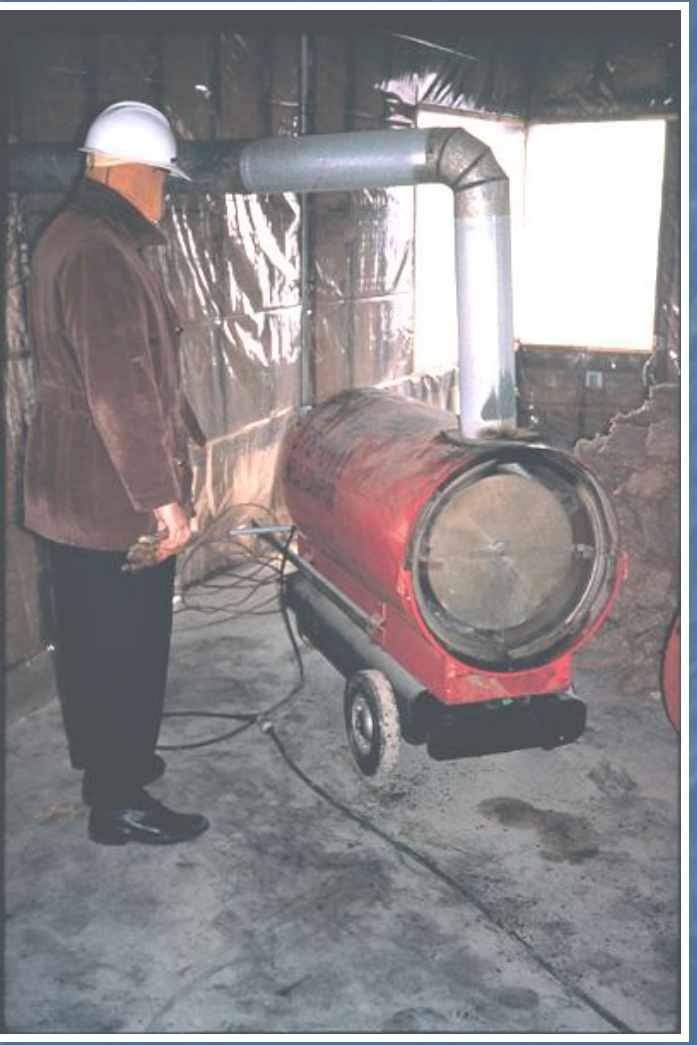
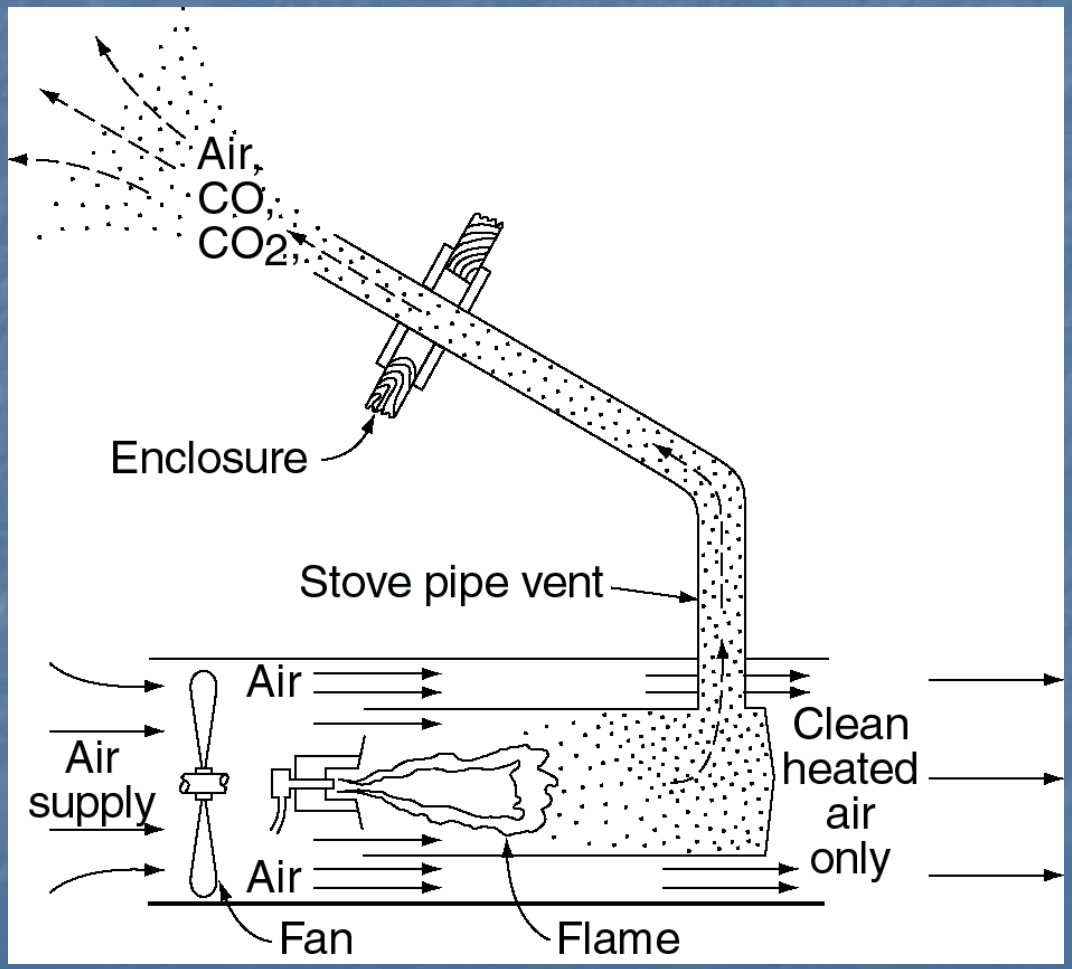
Photo courtesy of Lafarge Canada Inc.

Direct-Fired Heater



Indirect-Fired Heater





بادشکن

Cooling After Protection

Maximum Temperature Drop in 24 Hours

Section size, minimum dimensions, mm			
Less than 300	300 to 900	900 to 1800	Over 1800
28°C	**22°C**	**17°C**	**11°C**

Maturity Concept

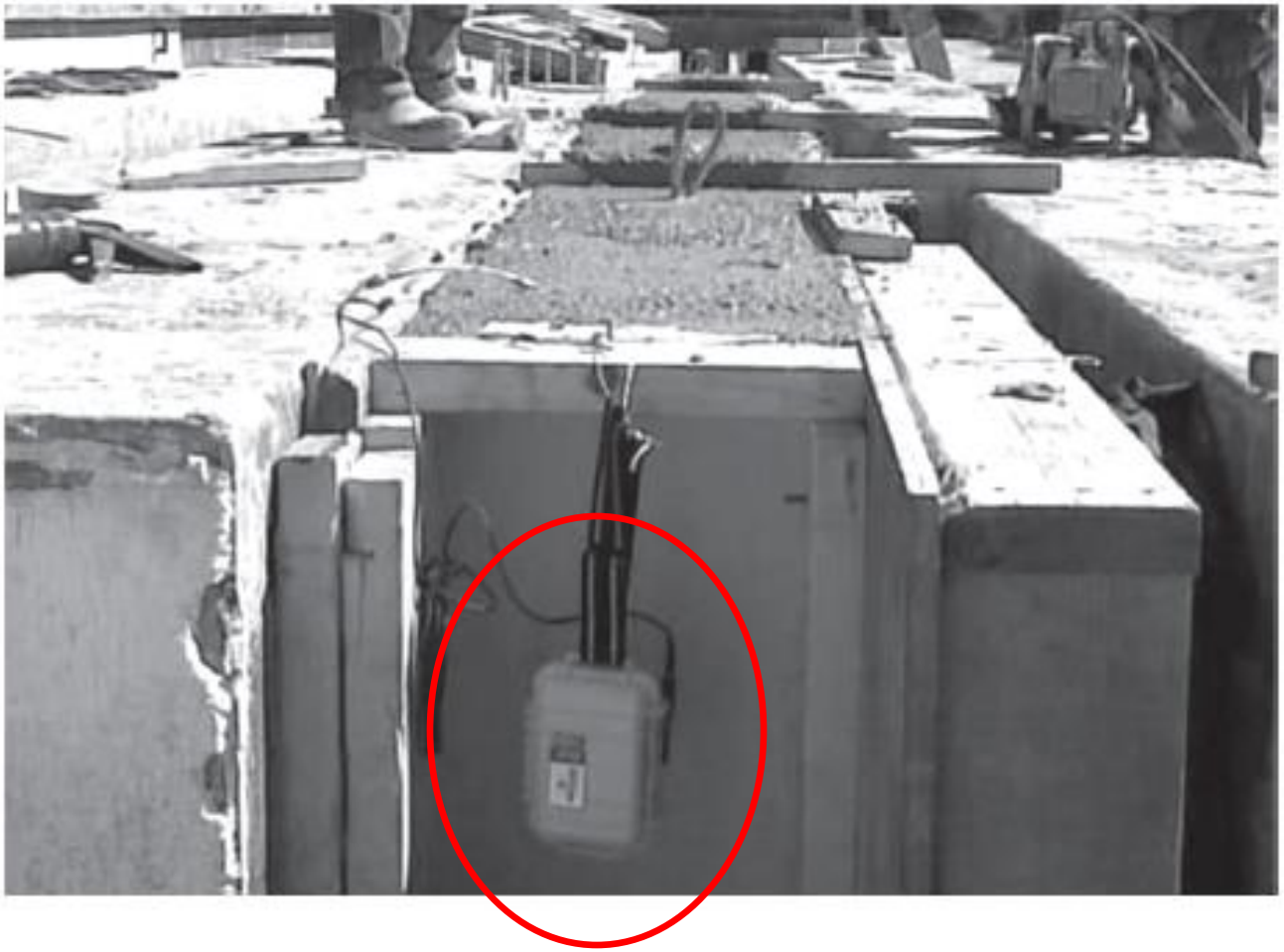


Fig. 8.4—Maturity meter suspended from structure.

Maturity Concept

GUIDE TO COLD WEATHER CONCRETING (ACI 306R-16)

The principle of the maturity method is that the strength of a given concrete mixture can be related to the concrete temperature and time.

Temperature should be measured at locations determined and specified by the licensed design professional. The maturity method develops a relationship between time-temperature history and concrete compressive strength. As detailed in ASTM C1074, it is required that a maturity relationship be developed for each specific concrete mixture.

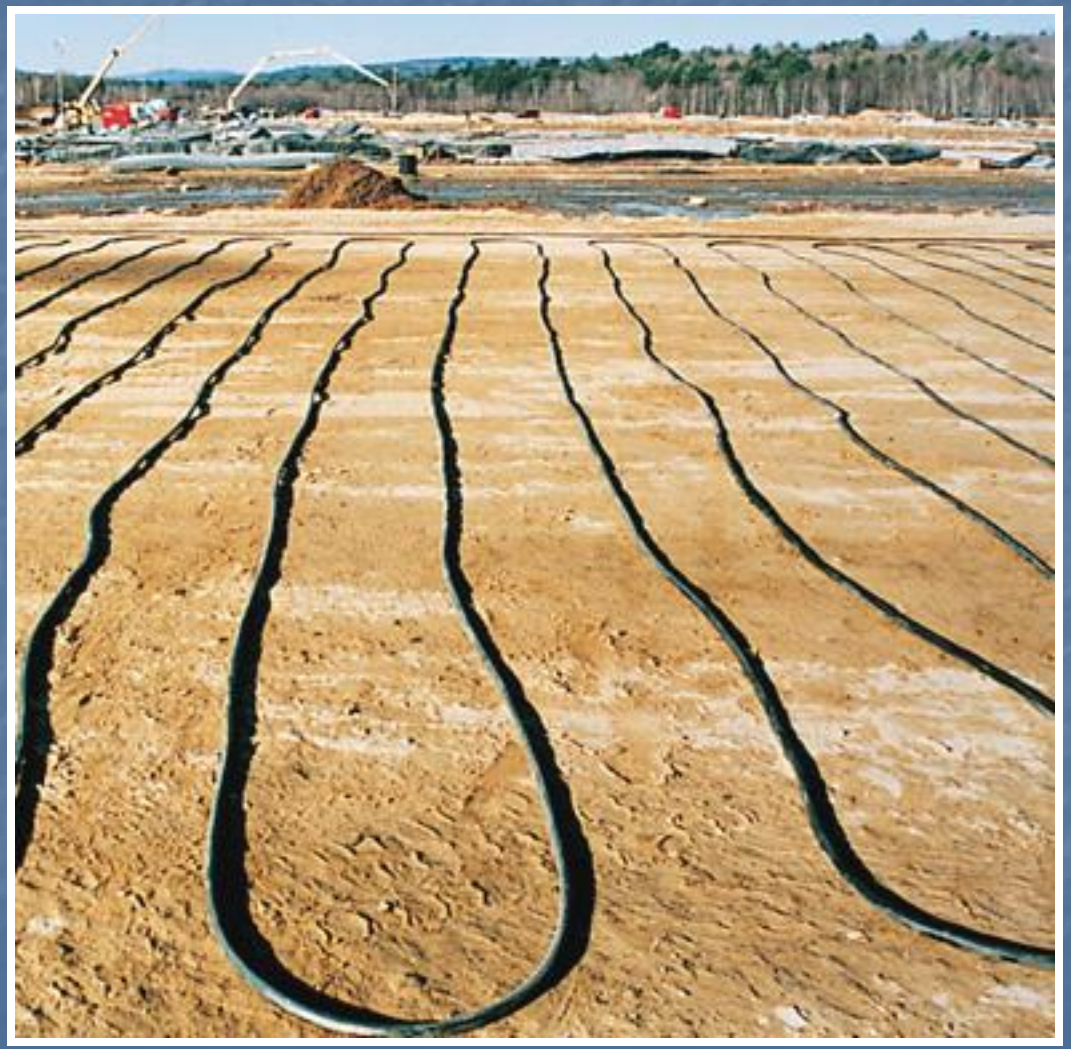
$$M = \sum (T - T_o)\Delta t$$

Maturity Concept

$$M = \sum (T - T_o)\Delta t$$

where M is temperature time factor (maturity index), deg-h; T is temperature of concrete, °F (°C); T_o is datum temperature, °F (°C); and Δt is duration of curing period at temperature T, h.

Hydronic Systems



Hydronic Systems

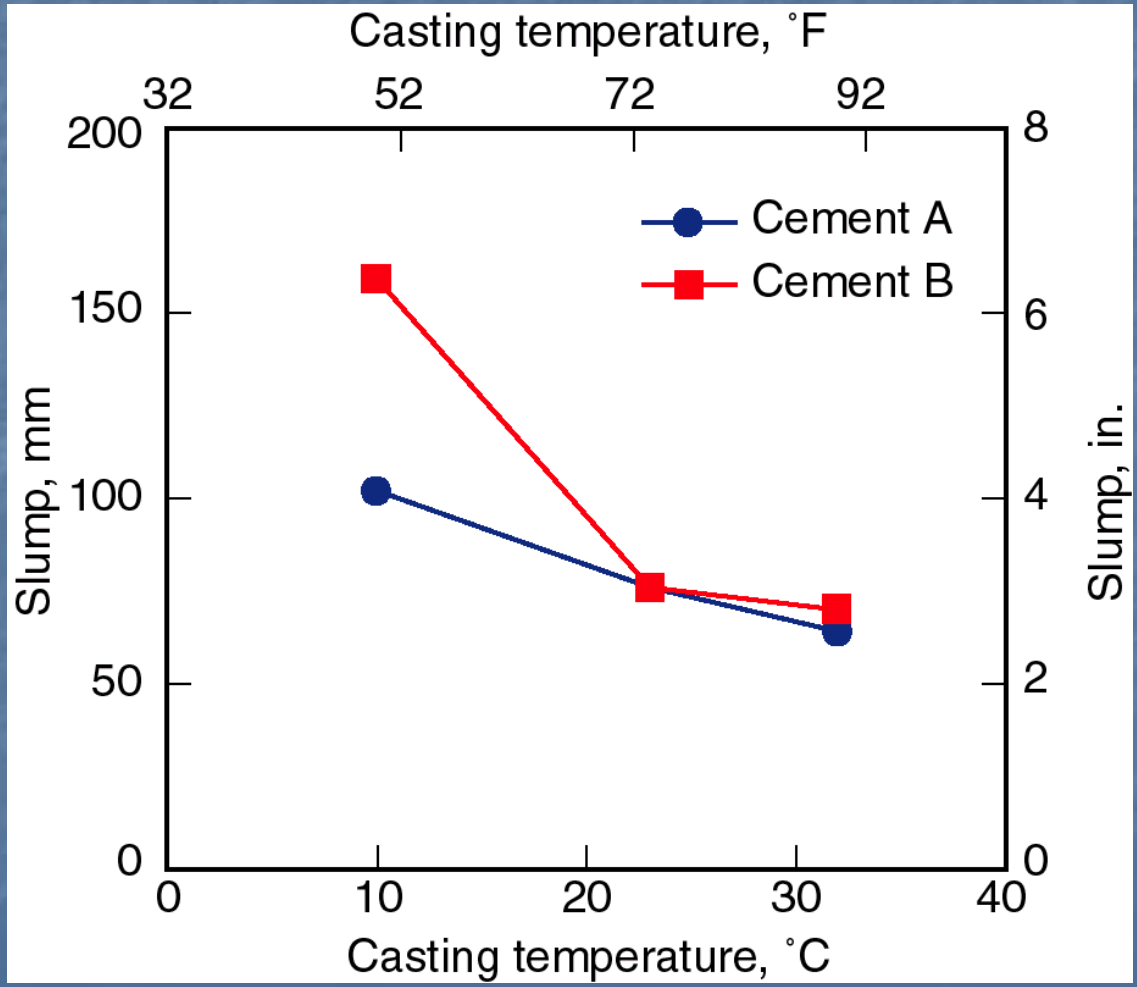
Hydronic Systems

Hydronic Systems

Curing Concrete in Cold Weather Using Cable Heaters.

با تشکر

Effect of Casting Temperature on Slump



Relationship Between Temperature, Slump and Air Content