PCA

Concrete Technology and Codes

Cold Weathering Concrete

Portland Cement Association

What are the Ideal Conditions for Concrete?

- Air Temperature
- Concrete Temperature
- Wind Speed
- Humidity

ACI 306 Definition

"Cold weather is defined as a period when, for more than 3 consecutive days, the following conditions exist:

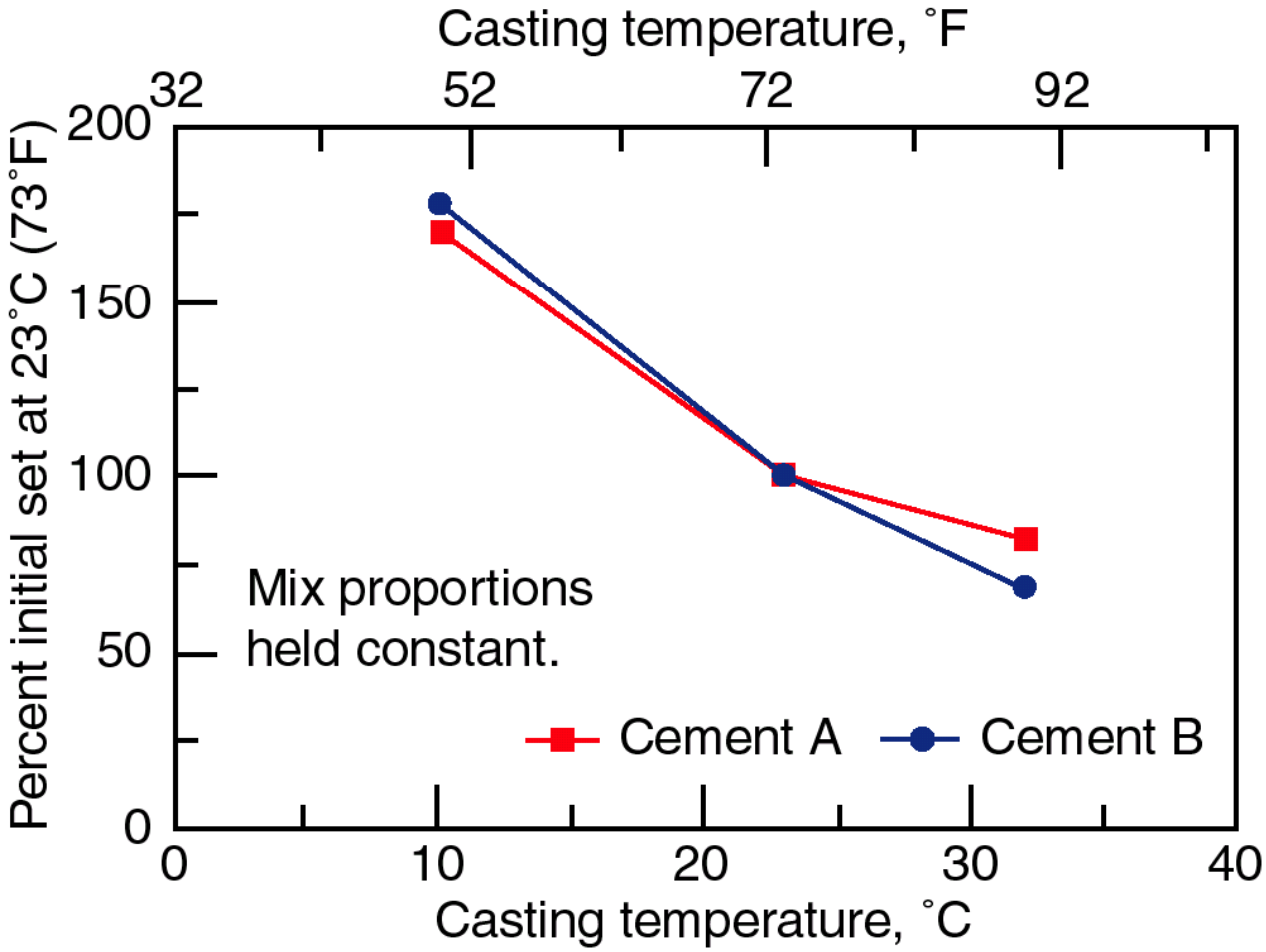
1) The average daily air temperature is less than 40° F (5°C)

2) And the air temperature is not greater than 50° F (10°C) for more than one-half of any 24-hr period."

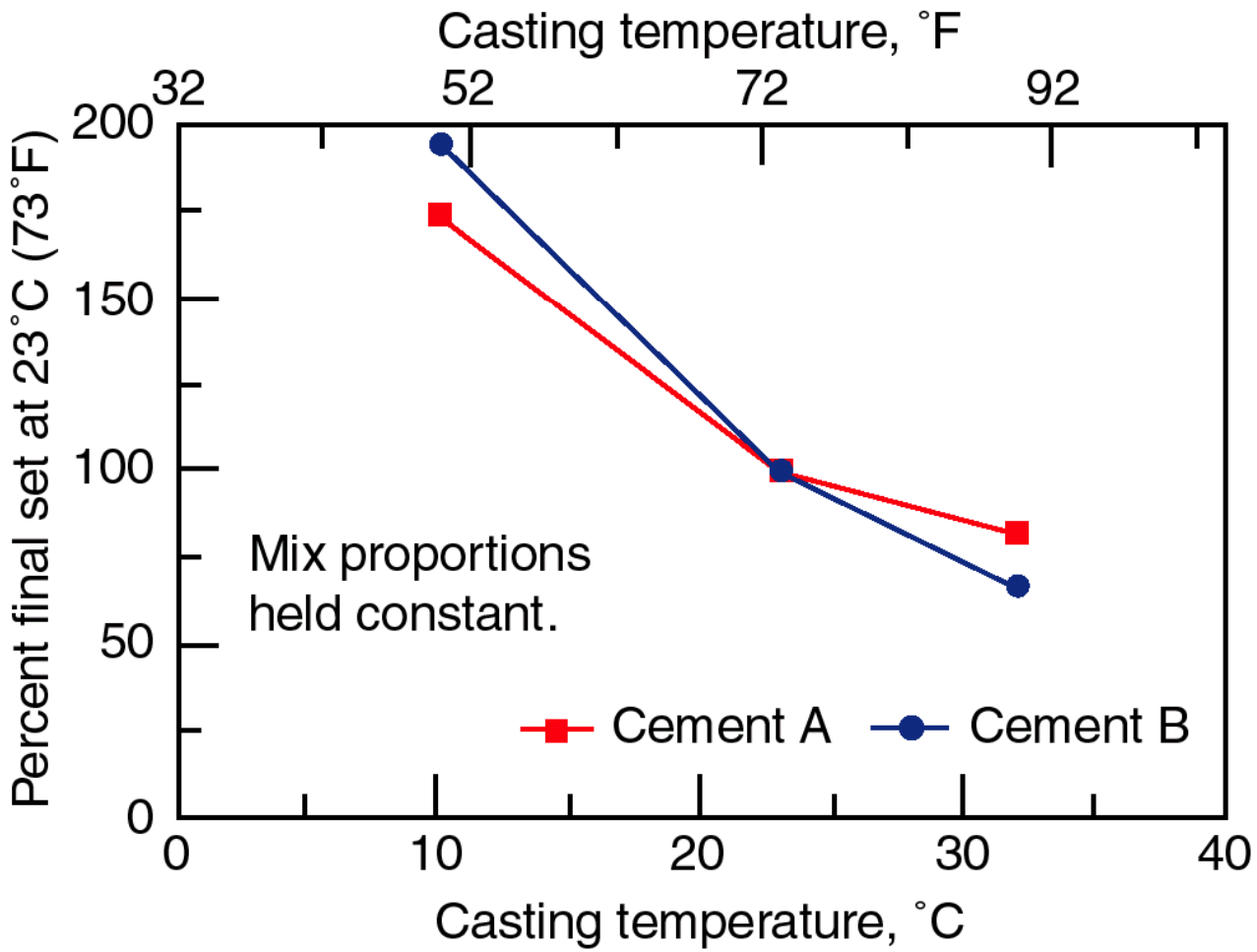
Cold Weather Concreting Problems

- Freezing
- Dusting, Crazing, Plastic shrinkage
- Slower hydration
- Slower setting times

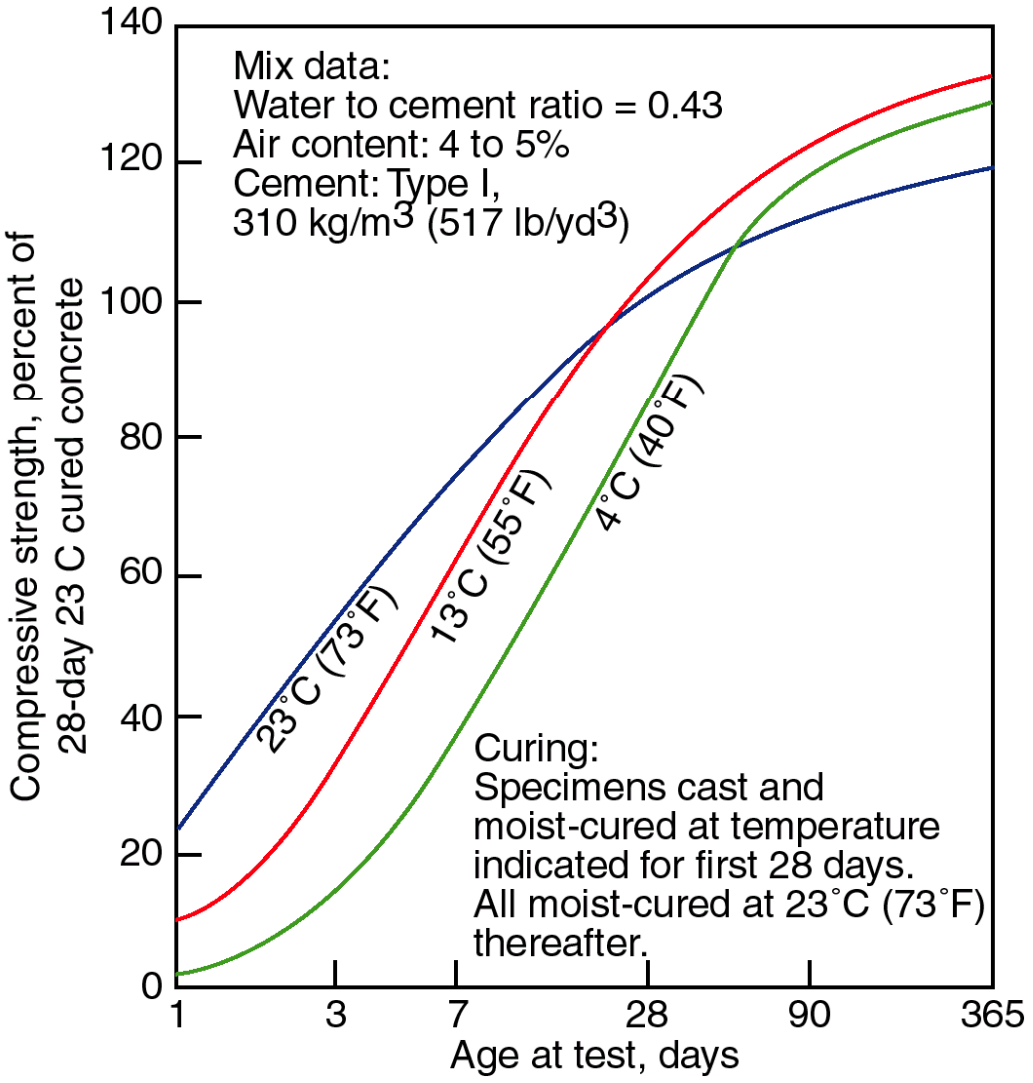
Time Relationship Between Initial Set and Casting Temperature



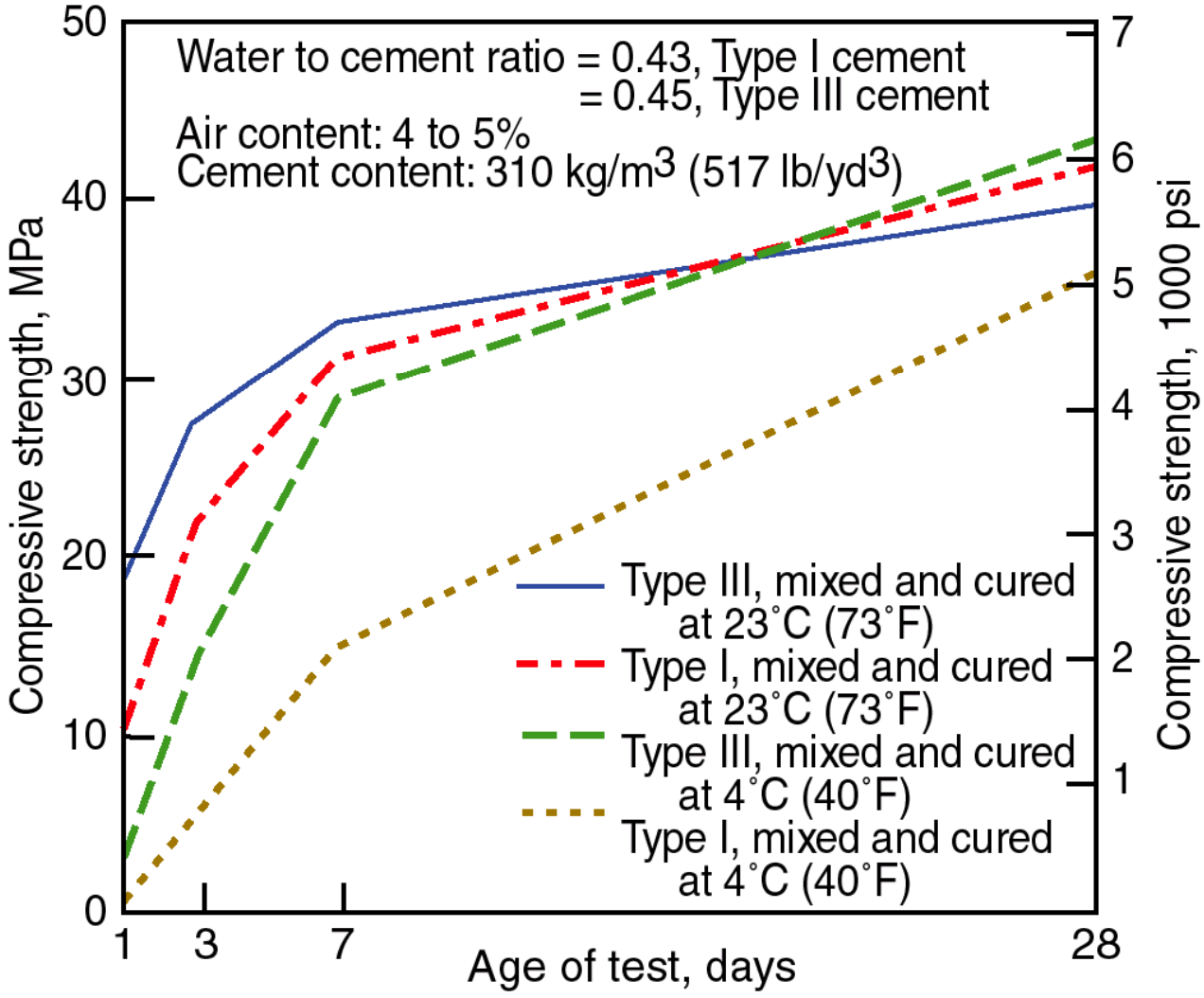
Time Relationship Between Final Set and Casting Temperature



Effect of Low Temperature on Strength

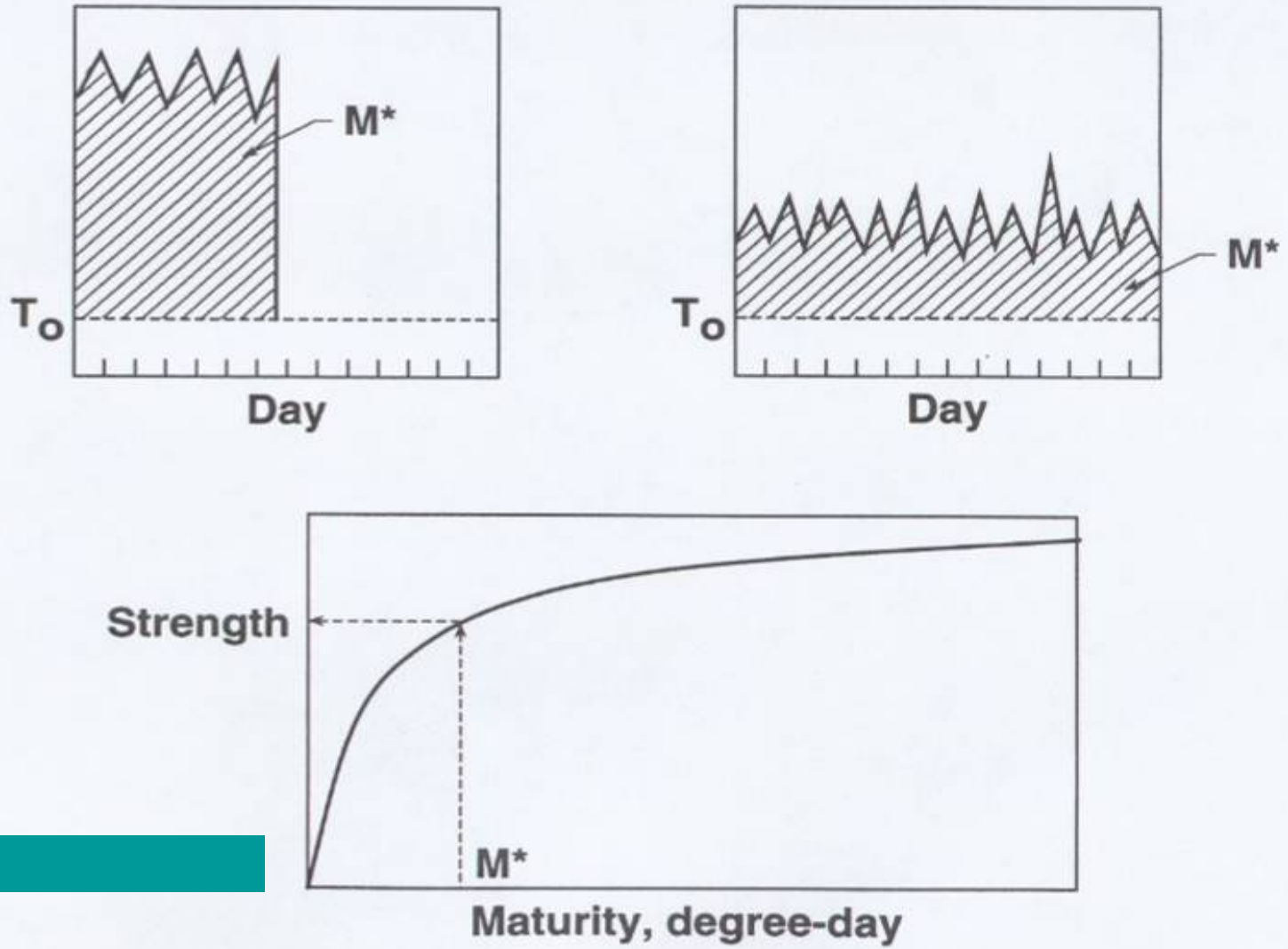


Temperature Effect on Early-Age Strength



What is Maturity?

- Method to estimate in-place concrete strength
- Based on TIME and TEMPERATURE
- Increased strength gain at elevated temperatures
- Slower strength gain at lower temperatures

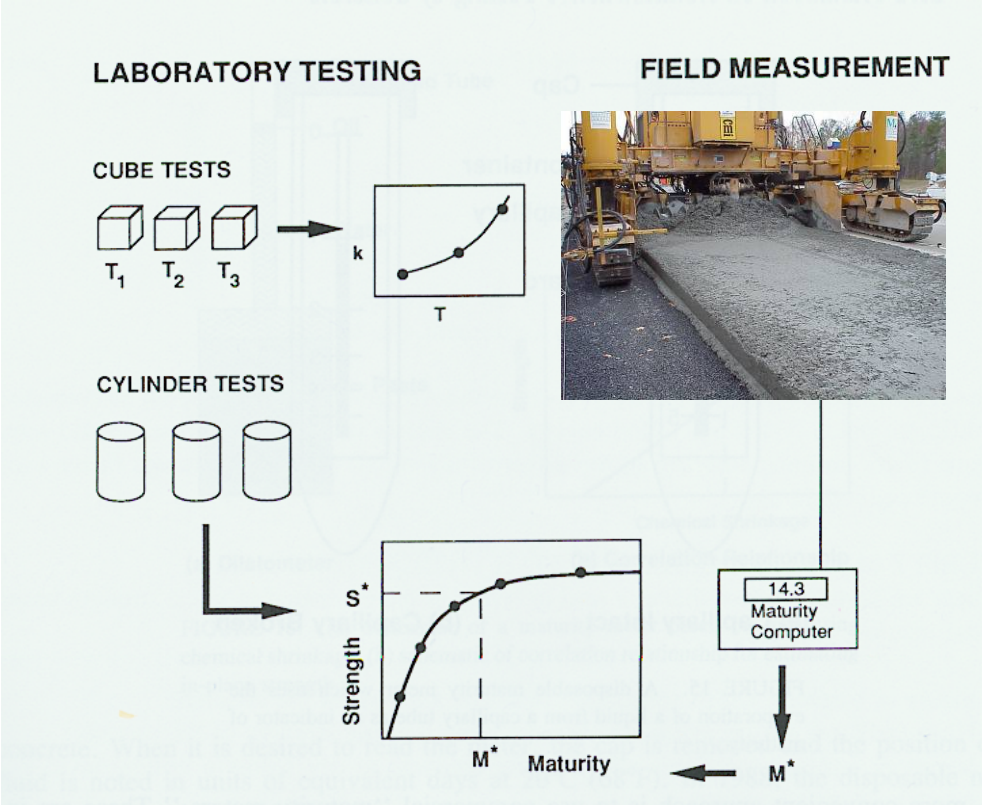

M*
T_o
Day
M*
T_o
Day
Strength
M*
Maturity, degree-day

Why Use Maturity?

- Reduces construction time
- Replaces temperature-matched curing of cylinders in thermal control plans
- Required information is mostly available
- Simple and very popular!

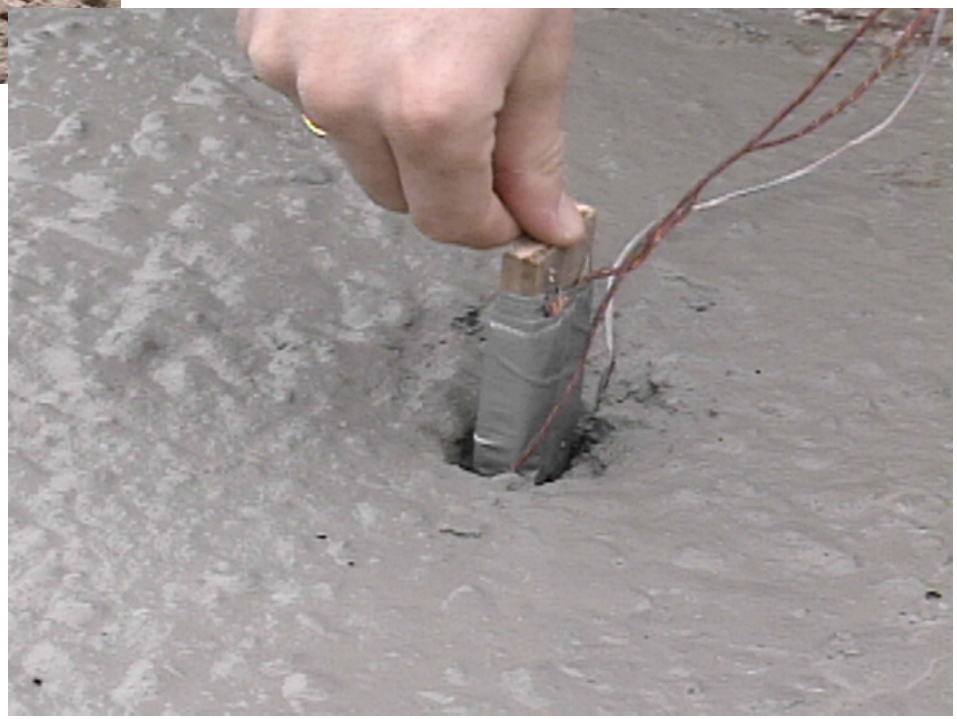
Maturity Approach

- Laboratory testing, using project materials, is required to develop a relationship
- Concrete is monitored using temperature probes



Note: Maturity testing does not indicate quality of concrete, only that it has reached strength

Establish Curve



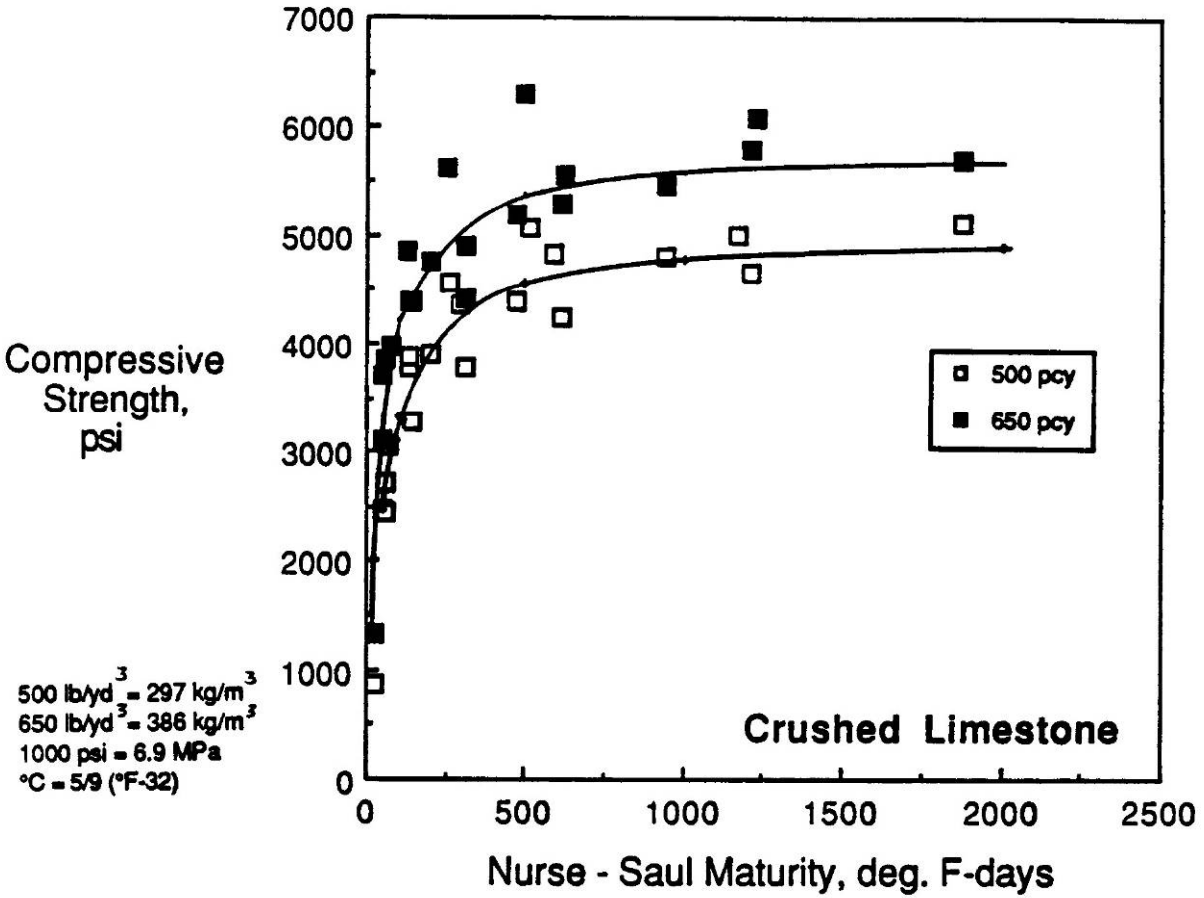
ASTM C1074 Maturity

- Time-Temperature Factor (°F·hr)

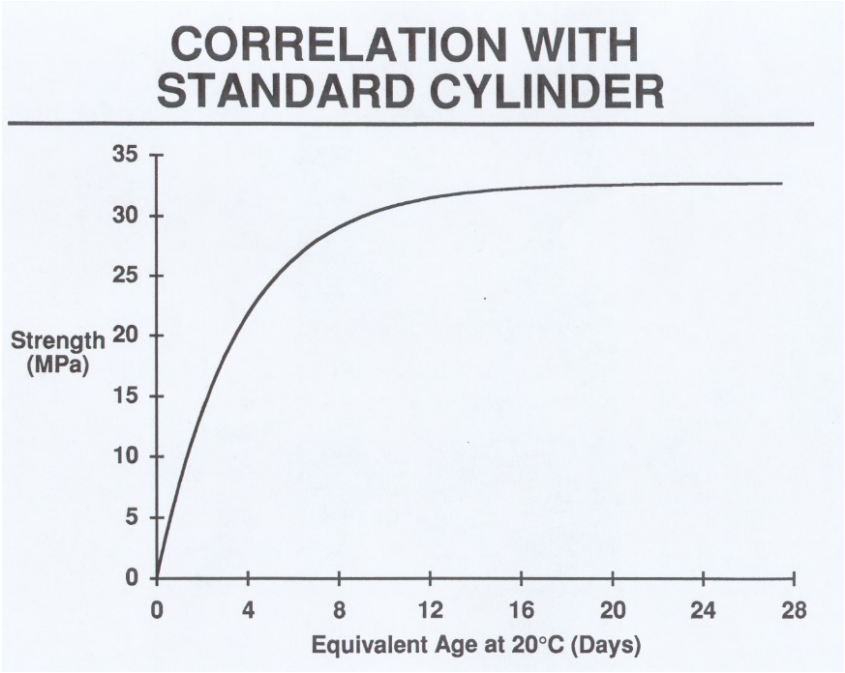
$$M = \sum_{t=0}^{t} (T - T_o)\Delta t$$

- Equivalent Age (days)

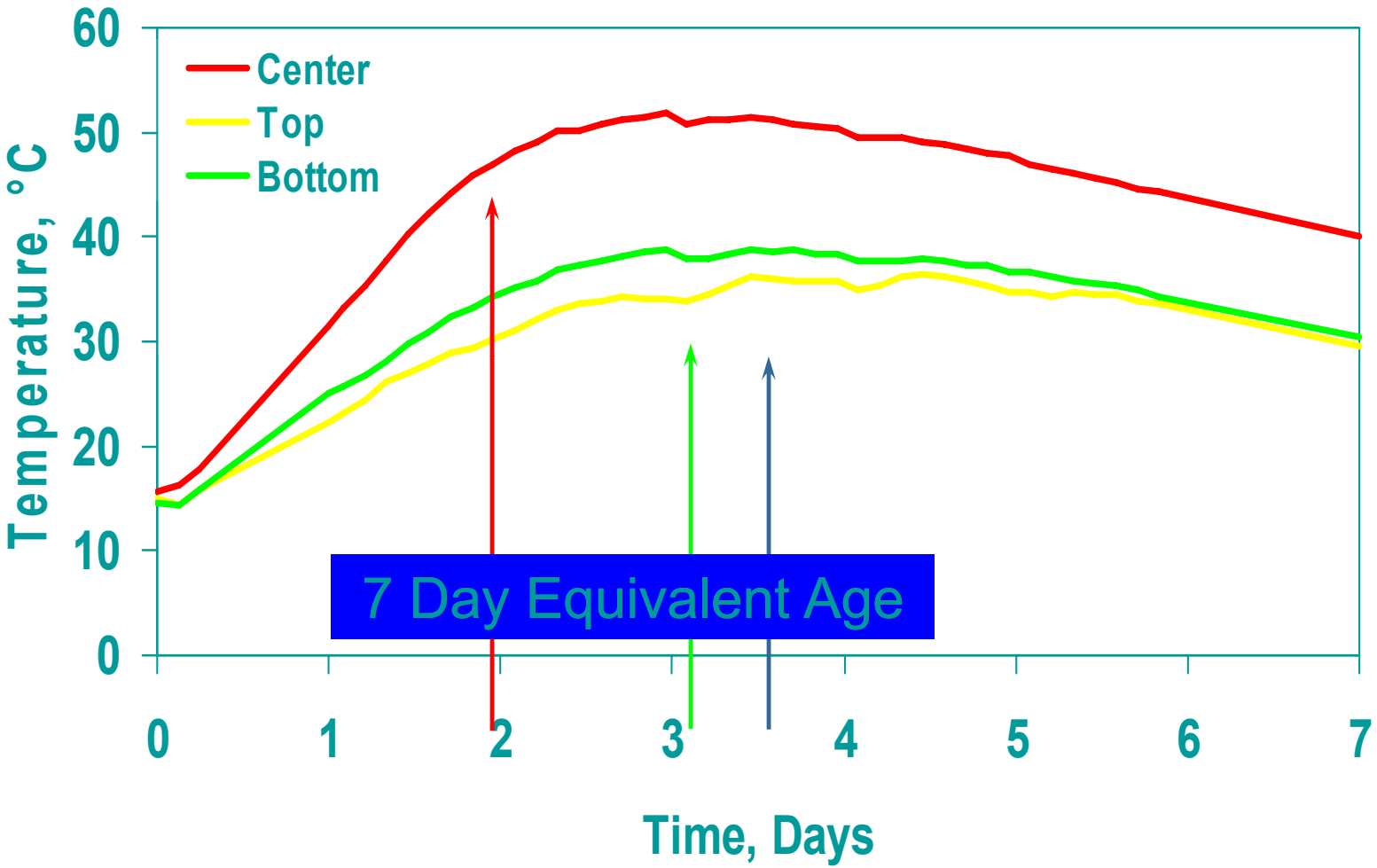
$$M = \sum_{t=0}^{t} e^{-Q\left(\frac{1}{T_a} - \frac{1}{T_s}\right)}\Delta t$$


Compressive Strength, psi
7000
6000
5000
4000
3000
2000
1000
0
0
500
1000
1500
2000
2500
Nurse - Saul Maturity, deg. F-days
500 pcy
650 pcy
Crushed Limestone
500 lb/yd3 = 297 kg/m3
650 lb/yd3 = 386 kg/m3
1000 psi = 6.9 MPa
°C = 5/9 (°F-32)

Field Monitoring



Initial Lift in Footing 15E



Pitfalls

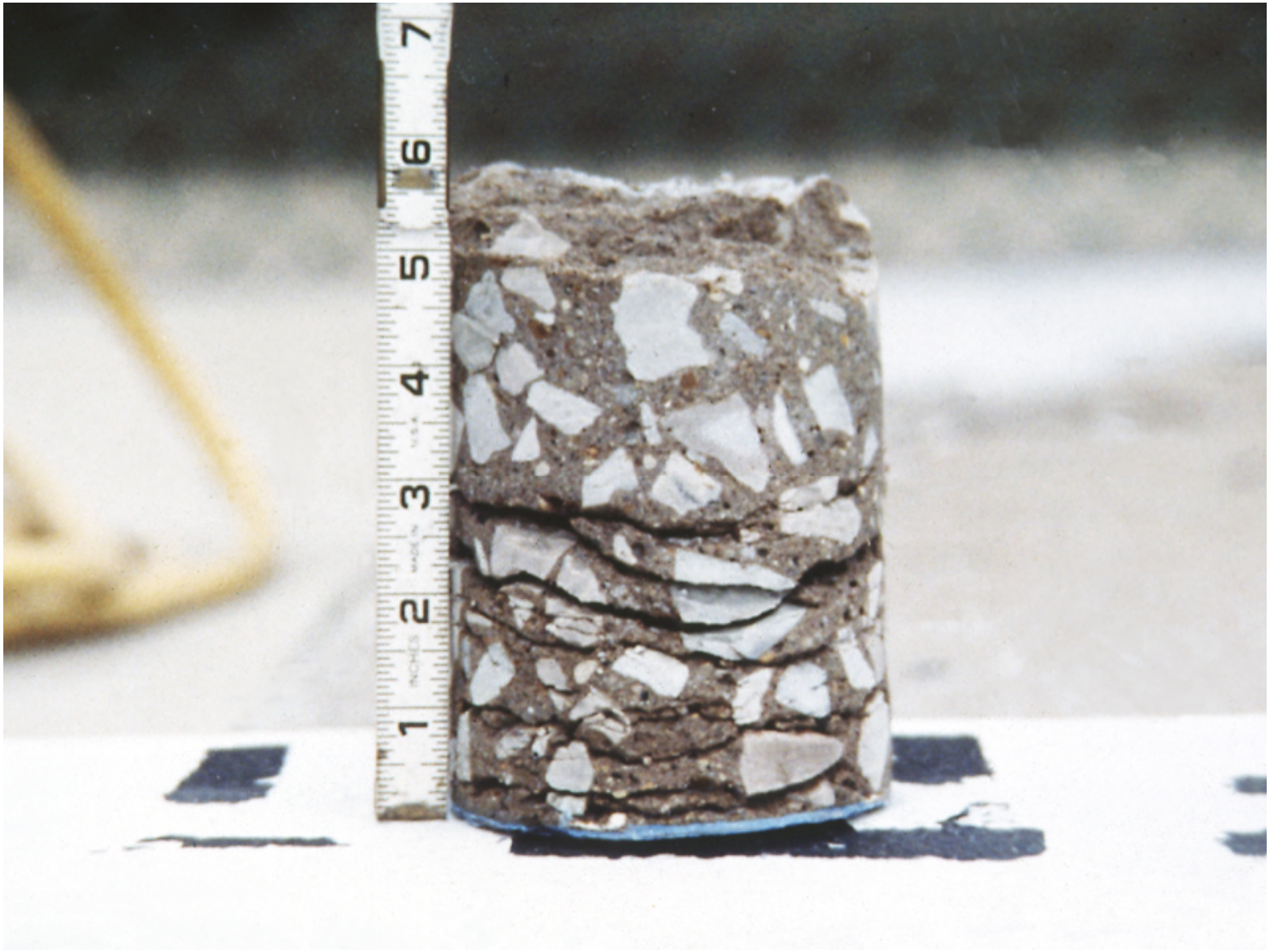
- Any changes to the concrete mix requires new maturity relation to be developed
- Its an estimate based on indirect measurements
- Continuous permanent record of strength gain

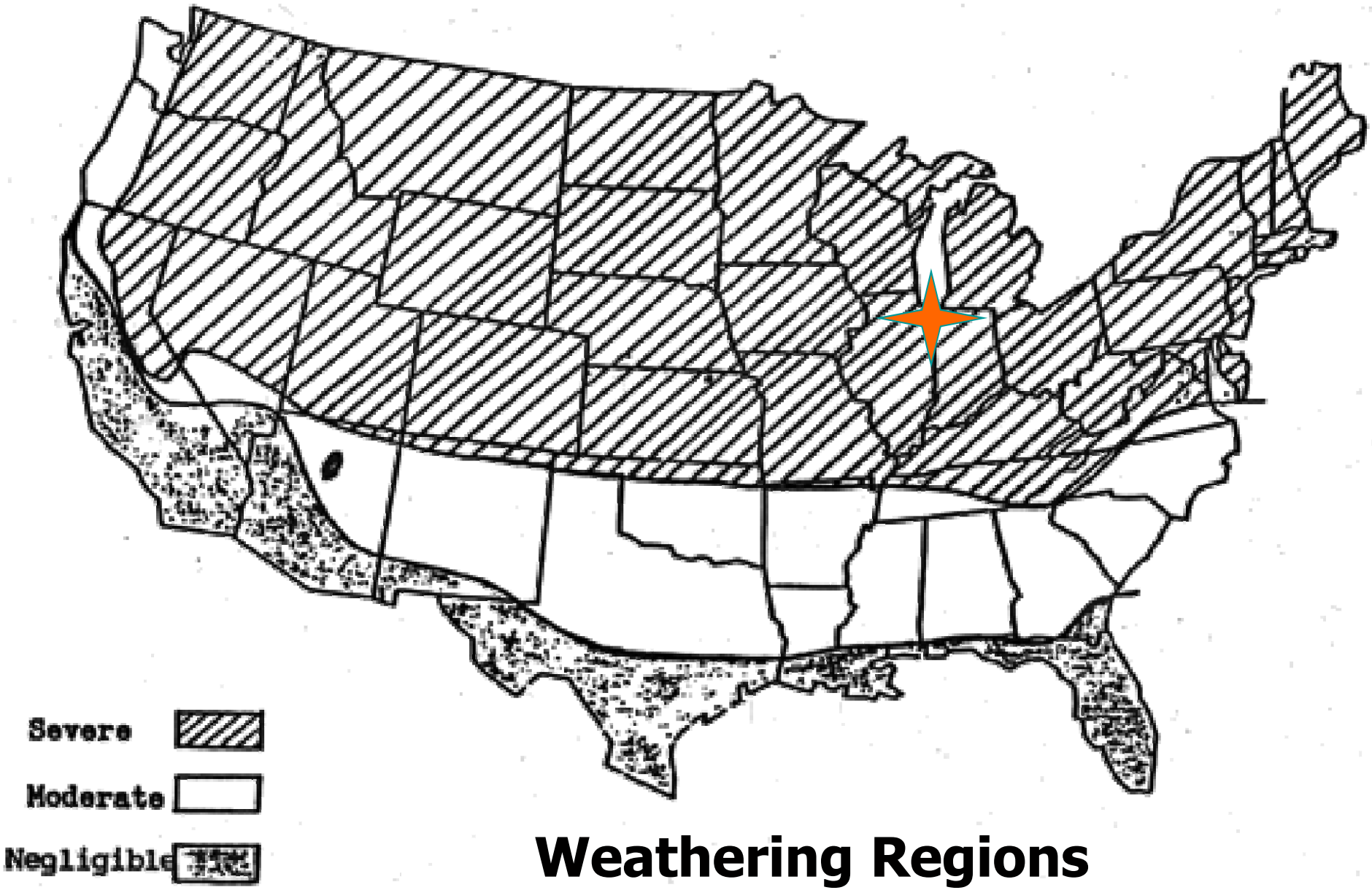
Recap

- Method to estimate in-place concrete strength
- Based on TIME and TEMPERATURE
- Requires upfront laboratory testing
- Eliminates daily testing
- Saves time and effort

Consequences of Freezing Fresh Concrete

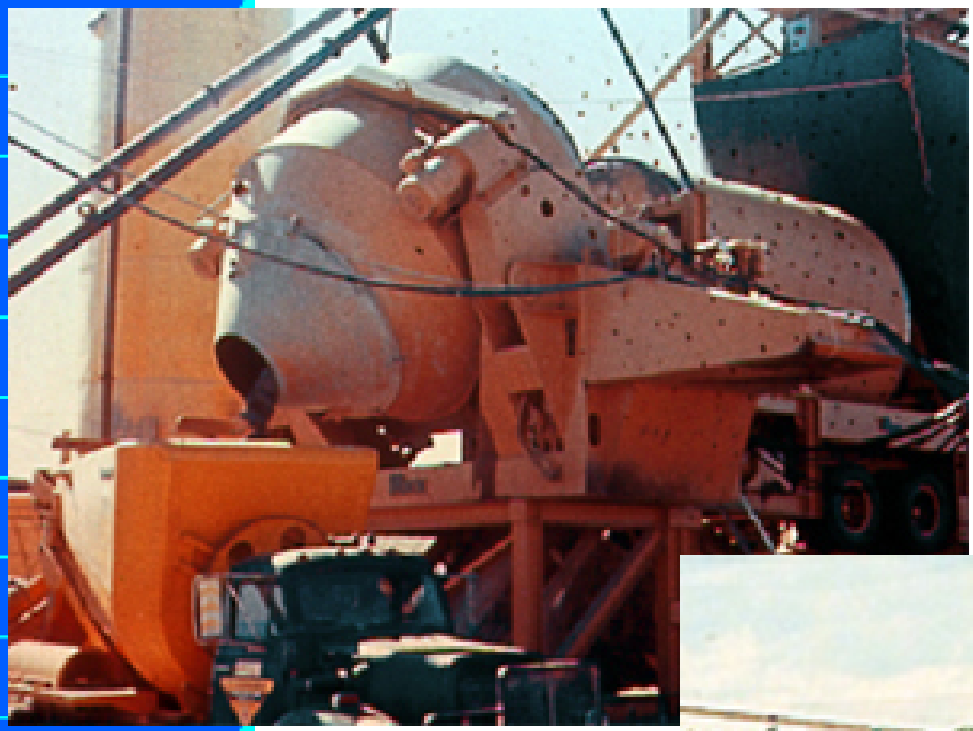
- Up to 50% reduction of ultimate strength can occur if frozen
  - Within a few hours
  - Before reaching a strength of 3.5 MPa (500psi)
- Frozen only once at an early age
  - With curing nearly all strength can be restored
  - May lower resistance to weathering
  - Higher permeability


1
2
3
4
5
6
7



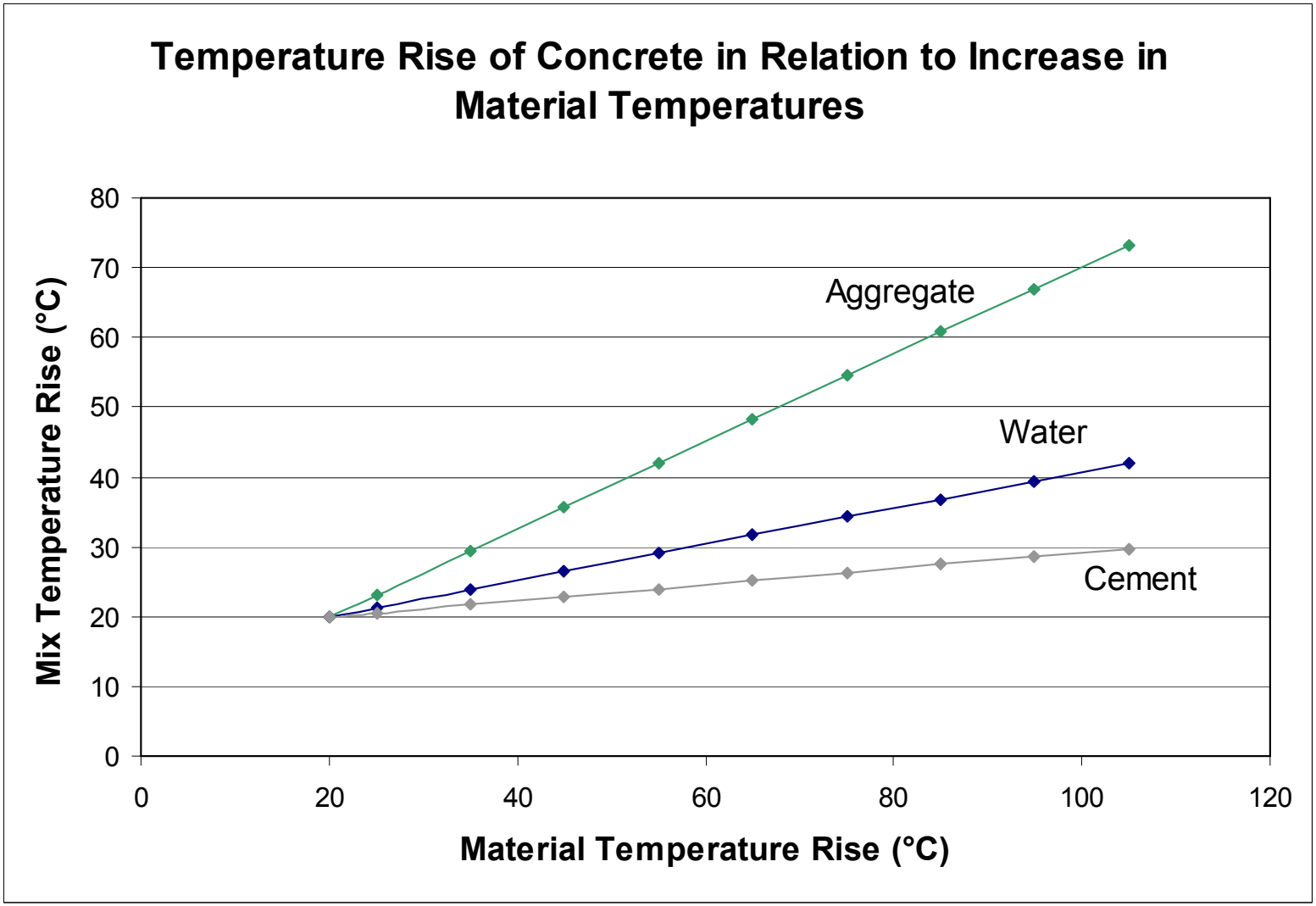
Weathering Regions

Adjusting The Mix for CWC



- Consider accelerators
- Increase Cement Content
- Heat the ingredients
  - Heat the water
  - Heat the aggregate

Relative Effect of Heating the Concrete Mix



Placing and Finishing Concrete in Cold Weather

- Never place concrete on frozen ground
- Use wind breaks
- Protect the concrete temperature with Insulation during curing
- consider heated enclosures in extreme conditions

Hydronic Systems

Enclosures

- Wood
- Canvas
- Tarpaulins
- Polyethylene Film

Use Ventilated Heaters

Consider using insulated forming systems

Maximum temperature drop after Protection per 24 hour period

Section size, minimum dimensions, mm (in.)			
Less than 300 (12)	**300 to 900 (12 to 36)**	**900 to 1800 (36 to 72)**	**Over 1800 (72)**
28°C (50°F)	22°C (40°F)	17°C (30°F)	11°C (20°F)

Recommended Protection Period

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	

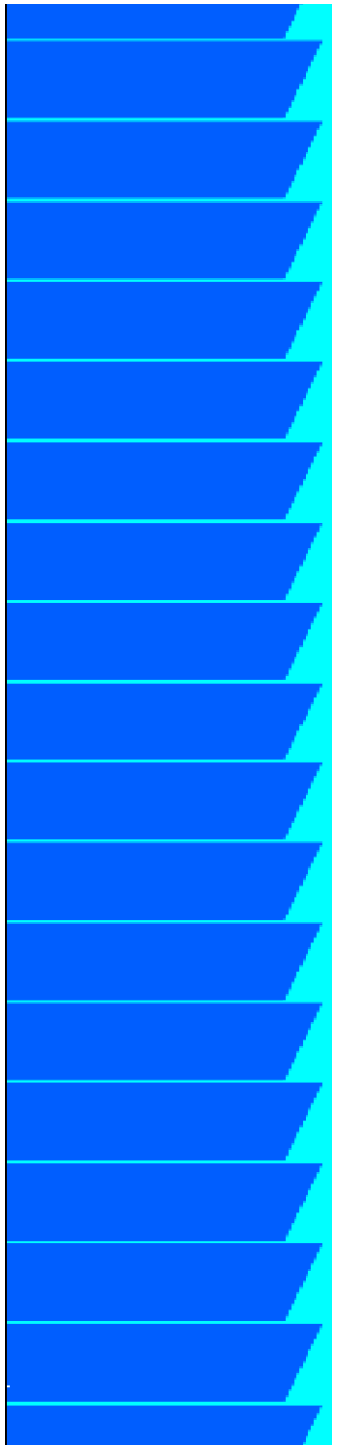
Recommended Duration of Temperature

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

Summary

- ACI 306
- Effects of cold weather
- Precautionary methods



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