Balancing Risk in Producing Concrete in Cold Weather

The backbone of ACI 306-16

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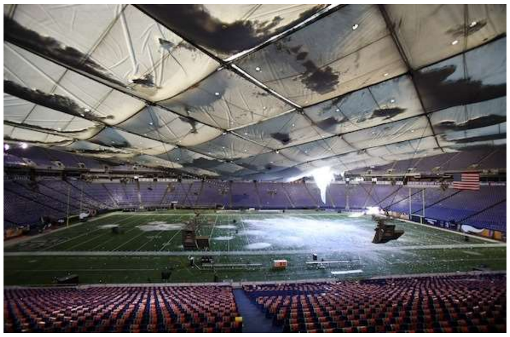
Beton Consulting Engineers LLC



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ACI 306 2016

- Cold weather exists when the air temperature has fallen to, or is expected to fall below, 40°F (4.4° C).

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Goal of ACI 306

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.

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Protection

The necessary degree of protection increases as the ambient temperature decreases.

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Risks of Cold Weather

- Neglecting protection against early freezing can cause immediate destruction or permanently weakened concrete.
- The durability of concrete can be significantly reduced

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Effect of Freezing

- Race Between the hydration of cement (Generates heat as well as strength) and heat loss
- At a point after hydration, the concrete is strong enough to resist freezing
- Little Hydration takes place below 40 °F

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Managing Risk

- The Gold Plating Issue
- Tolerance – what do you know
- Design Approach – Can we predict behavior?

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ACI 301 Requirements

- **5.3.2.1.b** *Cold weather*—Concrete temperatures at delivery shall meet the requirements of 4.2.2.6. Unless otherwise permitted, do not place concrete in contact with surfaces less than 35°F.

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ACI 301 Requirements

- 55°F for sections less than 12 in. in the least dimension;
- 50°F for sections 12 to 36 in. in the least dimension;
- 45°F for sections 36 to 72 in. in the least dimension; and
- 40°F for sections greater than 72 in. in the least dimension.
- The temperature of concrete as placed shall not exceed these values by more than 20°F.

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Objectives of Cold Weather Concreting

- Prevent damage to concrete due to early age freezing.
- Ensure that the concrete develops the required strength.

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Frozen Concrete

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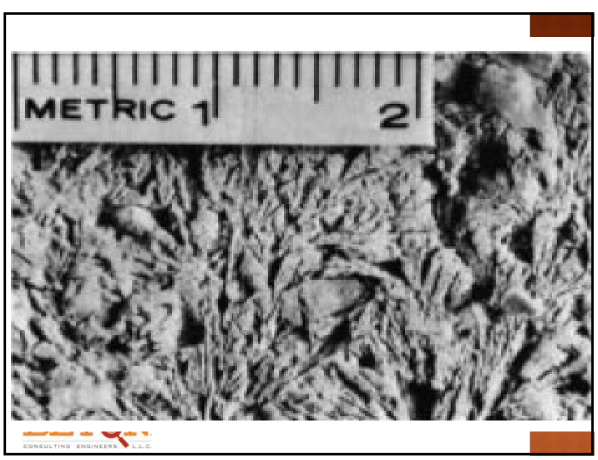
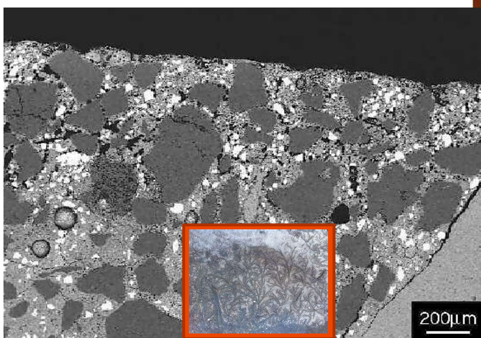

METRIC 1
2



Objectives of Cold Weather Concreting

- Maintain curing conditions that foster normal strength development.
- Limit rapid temperature changes.
- Provide protection consistent with the intended serviceability of the structure.

Principles of Cold Weather Concreting

- 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 cycle (Powers 1962).

Principles of Cold Weather Concreting

- Where a specified concrete strength should be attained in a few days or weeks, planning and protection may be required to maintain the concrete temperature

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Principles of Cold Weather Concreting

- Except within heated protective enclosures, little or no external supply of moisture is required during cold weather curing.

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Principles of Cold Weather Concreting

- 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 or other adverse effects

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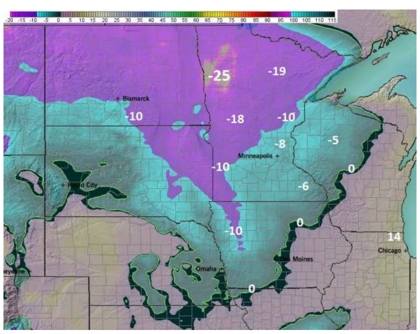
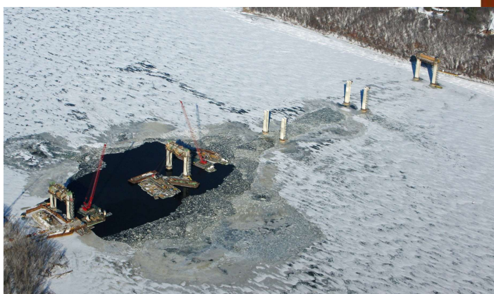
Cold Weather

- Definition
- Concrete will not be damaged above 500 psi
- Ice formation below that point “freeze drying”
- ACI 306 in a major revision





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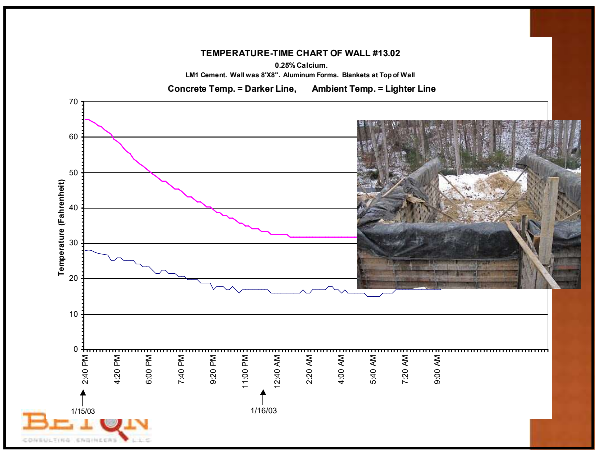
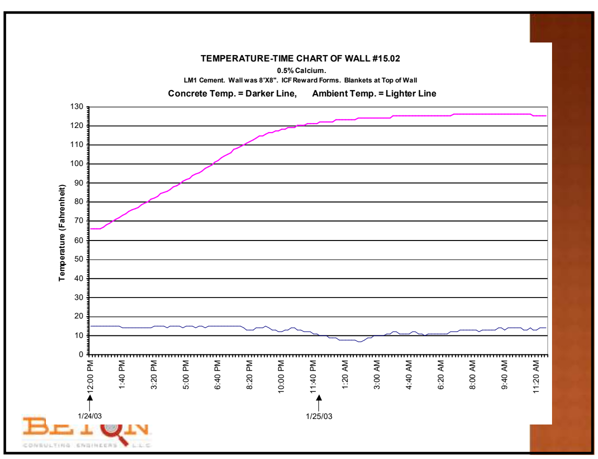
Ground
E3000 Heater
10654
ELITE 860-290-9421
Thaw Frozen Ground
Cure Concrete

32

33


TEMPERATURE-TIME CHART OF WALL #13.02
0.25% Calcium.
LM1 Cement. Wall was 8'X8". Aluminum Forms. Blankets at Top of Wall
Concrete Temp. = Darker Line, Ambient Temp. = Lighter Line
Temperature (Fahrenheit)
0
10
20
30
40
50
60
70
2:40 PM
4:20 PM
6:00 PM
7:40 PM
9:20 PM
11:00 PM
12:40 AM
2:20 AM
4:00 AM
5:40 AM
7:20 AM
9:00 AM
1/15/03
1/16/03


TEMPERATURE-TIME CHART OF WALL #15.02
0.5% Calcium.
LM1 Cement. Wall was 8'X8". ICF Reward Forms. Blankets at Top of Wall
Concrete Temp. = Darker Line, Ambient Temp. = Lighter Line
Temperature (Fahrenheit)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
12:00 PM
1:40 PM
3:20 PM
5:00 PM
6:40 PM
8:20 PM
10:00 PM
11:40 PM
1:20 AM
3:00 AM
4:40 AM
6:20 AM
8:00 AM
9:40 AM
11:20 AM
1/24/03
1/25/03

Concrete Temperature as mixed

$$T = \frac{[0.22(T_s W_s + T_a W_a + T_c W_c) + T_w W_w + T_s W_{ws} + T_a W_{wa}]}{[0.22(W_s + W_a + W_c) + W_w + W_{wa} + W_{ws}]}$$

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Heat Loss in Transit

For revolving drum mixers
$\Delta T = 0.25\ (t_r - t_a)$

For covered-dump body
$\Delta T = 0.10\ (t_r - t_a)$

For open-dump body
$\Delta T = 0.20\ (t_r - t_a)$

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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.

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PROTECTION AGAINST FREEZING AND PROTECTION FOR CONCRETE NOT REQUIRING CONSTRUCTION SUPPORTS

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 (8°C).

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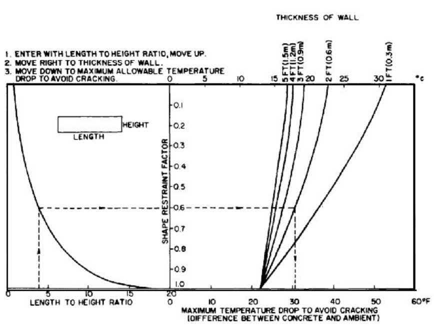

Fig. 5.6 - Graphical determination of safe differential temperature for walls (Mustard and Ghosh 1979)

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PROTECTION FOR STRUCTURAL CONCRETE REQUIRING CONSTRUCTION SUPPORTS

Table 8.8—Duration of recommended protection for percentage of standard-cured 28-day strength*

Percentage of standard-cured 28-day strength	At 50°F (10°C), days			At 70°F (21°C), days		
	Type of cement			Type of cement		
	I	II	III	I	II	III
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

*The data in this table were derived from concretes with strengths from 3000 to 5000 psi (20.7 to 34.4 MPa) after 28 days of curing at 70 ± 3°F (21 ± 1.7°C), and did not contain fly ash. The 28-day strength for each type of cement was considered as 100 percent in determining the times to reach various percentages of this strength for curing at 50 and 70°F (10 and 21°C). These times are only approximate, and specific values should be obtained for the concrete used on the job.

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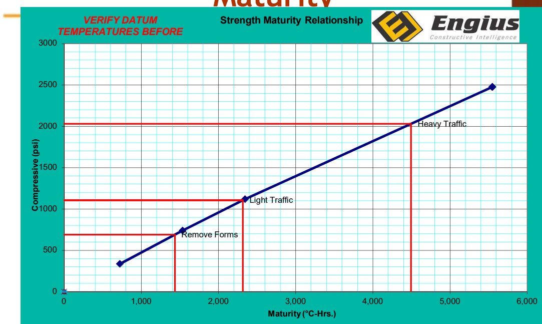
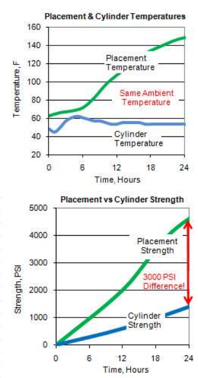
Determine In-Situ Strength

- Field Cured Cylinders
- Pullout strength testing (ASTM C900)
- Penetration resistance (ASTM C803)
- Pulse velocity measurements (ASTM C 597)
- Rebound hammer (ASTM C 805)

Maturity





Where to Measure Strength?

Estimating strength development: Modeling of cold weather placements

Temperature Effect

Table 6.8 - Duration of recommended protection for percentage of standard-cured 28-day strength*

Percentage of standard-cured 28-day strength	At 50 F (10 C), days			At 70 F (21 C), days		
	Type of cement			Type of cement		
	I	II	III	I	II	III
50	6	9	3	4	6	3
65	11	14	5	8	10	14
85	21	28	16	16	18	12
95	29	35	26	23	24	20

*The data in this table were derived from concretes with strengths from 3000 to 5000 psi (20.7 to 34.4 MPa) after 28 days of curing at 70 ± 3 F (21 ± 1.7 C). The 28-day strength for each type of cement was considered as 100 percent in determining the times to reach various percentages of this strength for curing at 50 F (10 C) and 70 F (21 C). These times are only approximate, and specific values should be obtained for he concrete used on the job.

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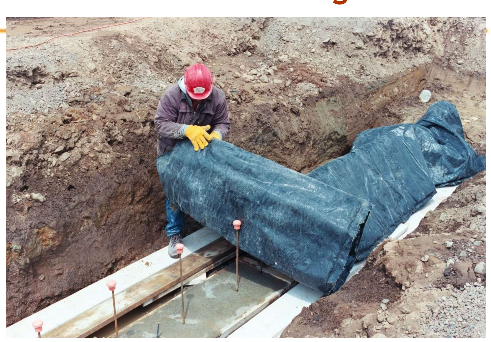
How much is enough?



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COLD WEATHER CONCRETING 306R-15

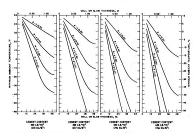

Fig. 7.3.1—Minimum exposure temperatures for concrete slabs above ground and walls as a function of member thickness, R-value, and cement content. Concrete placed and surface temperature maintained at 50 F (10 C) for 7 days

Table 7.3.1—Minimum exposure temperatures for concrete slabs above ground and walls for concrete placed and surface temperature maintained at 50 F (10 C) for 7 days

Wall or slab thickness, in. (m)	Minimum ambient air temperature, deg F (C) allowable when insulation having these values of thermal resistance R, hr·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 = 300 lb/yd³ (178 kg/m³)				
6 (0.15)	48 (9)	46 (8)	43 (6)	40 (4)
12 (0.30)	45 (7)	39 (4)	32 (0)	25 (−4)
18 (0.46)	41 (5)	31 (−1)	21 (−6)	11 (−12)
24 (0.61)	38 (3)	24 (−4)	10 (−12)	−2 (−19)
36 (0.91)	32 (0)	12 (−11)	−8 (−22)	−28 (−33)
48 (1.2)	26 (−3)	3 (−16)	−17 (−27)	−37 (−38)
60 (1.5)	26 (−3)	3 (−16)	−17 (−27)	−37 (−38)
Cement content = 400 lb/yd³ (237 kg/m³)				
6 (0.15)	47 (8)	44 (7)	40 (4)	36 (2)
12 (0.30)	43 (6)	35 (2)	26 (−3)	17 (−8)
18 (0.46)	39 (4)	25 (−4)	11 (−12)	−2 (−19)
24 (0.61)	34 (1)	16 (−8)	−2 (−19)	−20 (−29)
36 (0.91)	25 (−4)	−1 (−18)	−27 (−31)	−53 (−47)
48 (1.2)	18 (−8)	−10 (−23)	−38 (−39)	*
60 (1.5)	18 (−8)	−10 (−23)	−38 (−39)	*
Cement content = 500 lb/yd³ (296 kg/m³)				
6 (0.15)	47 (8)	43 (6)	38 (3)	33 (1)
12 (0.30)	42 (6)	31 (−1)	20 (−7)	9 (−13)
18 (0.46)	36 (2)	19 (−7)	2 (−17)	−15 (−26)
24 (0.61)	30 (−1)	7 (−14)	−16 (−27)	−39 (−39)
36 (0.91)	18 (−8)	−15 (−26)	−46 (−43)	−79 (−62)
48 (1.2)	10 (−12)	−25 (−32)	−60 (−51)	*
60 (1.5)	10 (−12)	−25 (−32)	*	*
Cement content = 600 lb/yd³ (356 kg/m³)				
6 (0.15)	46 (8)	41 (5)	35 (2)	29 (−2)
12 (0.30)	40 (4)	28 (−2)	14 (−10)	0 (−18)
18 (0.46)	33 (1)	13 (−11)	−7 (−22)	−29 (−34)
24 (0.61)	26 (−3)	−1 (−18)	−28 (−33)	−55 (−48)
36 (0.91)	12 (−11)	−27 (−31)	−66 (−54)	*
48 (1.2)	4 (−16)	−40 (−40)	*	*
60 (1.5)	4 (−16)	−40 (−40)	*	*

*<< −60 F (−51 C).

A Couple of Examples

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ACI Standard

Recommended Practice for Winter Concreting Methods (ACI 604-48)*

Reported by ACI Committee 604

Curing temperature

Newly-placed concrete should be kept at a temperature of not less than 40 F for 14 days. The temperature of the concrete surface should not be permitted to exceed 100 F at any time during the curing period. The methods of protection and curing should be such that the loss of moisture from the concrete is not excessive during the curing period.

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604-48

ditions specified in the paragraph on curing. When air temperatures do not fall below 30 F, artificial heat will not be required if the concrete surface is covered with forms or with canvas arranged so that an air space is maintained between the canvas and the concrete. For lower temperatures, sufficient well distributed artificial heat should be provided inside the coverings or enclosures around the concrete to maintain a temperature of 40 F or above at the coldest point without exceeding 80 F at the hottest point.

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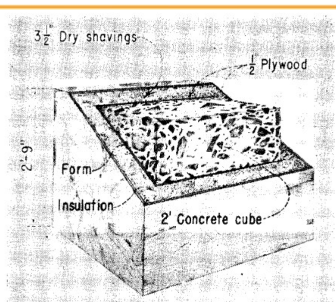
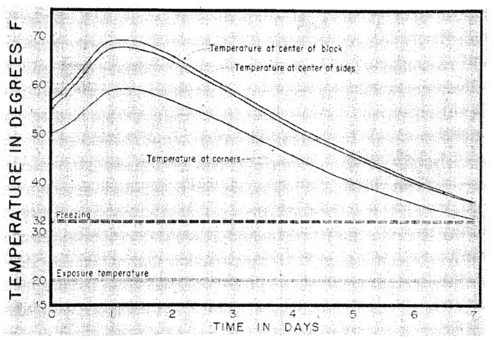
Insulation for Protection of New Concrete in Winter*
By L. H. TUTHILL, R. E. GLOVER, C. H. SPENCERt and W. B. BIERCE

Tuthill 1948

Recent investigations show that new concrete with 1 percent calcium chloride, if kept from dropping below 50 F for 3 days, has sufficient protection from freezing. As an extra precaution, 3 more days protection from dropping below 32 F may be required





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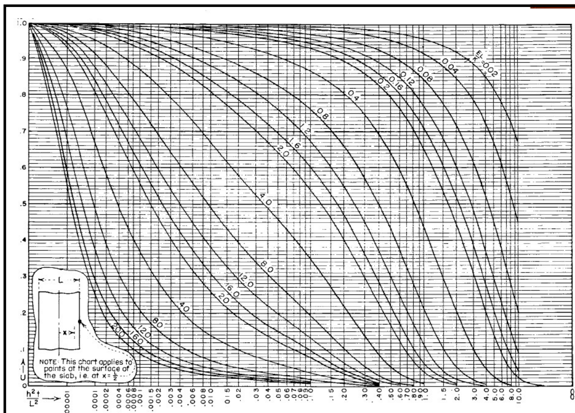

Fig. 9—Plot of U versus h^2t/L^2 for points at the surface of a slab

Progress - A technical approach

ACI Standard
Recommended Practice for Winter Concreting [ACI 604-56]
Reported by ACI Committee 604
LEWIS H. TUTHILL Chairman

ACI Standard
Recommended Practice for Cold Weather Concreting [ACI 306-66]
Reported by ACI Committee 306
LEWIS H. TUTHILL Chairman

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TABLE 7.2.1—INSULATION REQUIREMENTS FOR CONCRETE WALLS AND FLOOR SLABS ABOVE GROUND
Concrete placed at 50 F (10 C)

Wall thickness, ft (m)	Minimum air temperature allowable for these thicknesses of commercial blanket or bat insulation, deg F (deg C): 0.5 in. (1.3 cm)	1.0 in. (2.5 cm)	1.5 in. (3.8 cm)	2.0 in. (5.1 cm)
Cement content—300 lb per cu yd (178 kg per cu m)				
0.5 (0.15)	47 (8.3)	41 (5.0)	33 (0.56)	28 (−2.2)
1.0 (0.30)	41 (5.0)	29 (−1.7)	17 (−8.3)	5 (−15)
1.5 (0.46)	35 (1.7)	19 (−7.2)	0 (−18)	−17 (−27)
2.0 (0.61)	34 (1.1)	14 (−10)	−9 (−23)	−29 (−34)
3.0 (0.91)	31 (−0.56)	8 (−13)	−15 (−26)	−35 (−37)
4.0 (1.2)	30 (−1.1)	6 (−14)	−18 (−28)	−39 (−39)
5.0 (1.5)	30 (−1.1)	5 (−15)	−21 (−29)	−43 (−42)
Cement content—400 lb per cu yd (237 kg per cu m)				
0.5 (0.15)	46 (7.8)	38 (3.3)	28 (−2.2)	21 (−6.1)
1.0 (0.30)	38 (3.3)	22 (−5.6)	6 (−14)	−11 (−24)
1.5 (0.46)	31 (−0.56)	8 (−13)	−16 (−27)	−39 (−39)
2.0 (0.61)	28 (−2.2)	2 (−17)	−26 (−32)	−53 (−47)
3.0 (0.91)	25 (−3.9)	−6 (−21)	−36 (−38)	
4.0 (1.2)	23 (−5.0)	−8 (−22)	−41 (−41)	
5.0 (1.5)	23 (−5.0)	−10 (−23)	−45 (−43)	
Cement content—500 lb per cu yd (296 kg per cu m)				
0.5 (0.15)	45 (7.2)	35 (1.7)	22 (−5.6)	14 (−10)
1.0 (0.30)	35 (1.7)	15 (−9.4)	−5 (−21)	−26 (−32)
1.5 (0.46)	27 (−2.8)	−3 (−19)	−33 (−36)	−65 (−54)
2.0 (0.61)	23 (−5.0)	−10 (−23)	−50 (−46)	
3.0 (0.91)	18 (−7.8)	−20 (−29)		
4.0 (1.2)	17 (−8.3)	−23 (−31)		
5.0 (1.5)	16 (−8.9)	−25 (−32)		
Cement content—600 lb per cu yd (356 kg per cu m)				
0.5 (0.15)	44 (6.7)	32 ((0)	16 (−8.9)	6 (−14)
1.0 (0.30)	32 (0)	8 (−13)	−16 (−27)	−41 (−41)
1.5 (0.46)	21 (−6.1)	−14 (−26)	−50 (−46)	−89 (−67)
2.0 (0.61)	18 (−7.8)	−22 (−30)		
3.0 (0.91)	12 (−11)	−34 (−37)		
4.0 (1.2)	11 (−12)	−38 (−39)		
5.0 (1.5)	10 (−12)	−40 (−40)		

Insulation equivalents*

Insulating material	Equivalent thickness, in. (mm)
1 in. (31 mm) of commercial blanket or bat insulation	1.000 (25.4)
1 in. (31 mm) of loose fill insulation of fibrous type	1.000 (25.4)
1 in. (31 mm) of insulating board	0.758 (19.2)
1 in. (31 mm) of sawdust	0.610 (15.5)
1 in. (31 mm) (nominal) of lumber	0.333 (8.45)
1 in. (31 mm) of dead-air space (vertical)	0.234 (5.94)

Table 7.3.1 - Minimum exposure temperatures for concrete slabs above ground and walls for concrete placed and surface temperature maintained at 50 F (10 C) for 7 days

Wall or slab thickness, in. (mm)	Minimum ambient air temperature, deg F (C) allowable when insulation having these values of thermal resistance R, hr•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 = 300 lb/yd³ (178 kg/m³)				
6 (0.15)	48 (9)	46 (8)	43 (6)	40 (4)
12 (0.30)	45 (7)	39 (4)	32 (0)	25 (-4)
18 (0.46)	41 (5)	31 (- 1)	21 (-6)	11 (-12)
24 (0.61)	38 (3)	24 (-4)	10 (- 12)	- 2 (-19)
36 (0.91)	32 (0)	12 (-11)	- 8 (-22)	-28 (-33)
48 (1.2)	26 (- 3)	3 (-16)	-17 (-27)	-37 (-38)
60 (1.5)	26 (-3)	3 (-16)	-17 (-27)	-37 (-38)
Cement content = 400 lb/yd³ (237 kg/m³)				
6 (0.15)	47 (8)	44 (7)	40 (4)	36 (2)
12 (0.30)	43 (6)	35 (2)	26 (-3)	17 (-8)
18 (0.46)	39 (4)	25 (-4)	11 (-12)	- 2 (-19)
24 (0.61)	34 (1)	16 (-8)	-2 (-19)	-20 (-29)
36 (0.91)	25 (-4)	-1 (-18)	-27 (-31)	-53 (-47)
48 (1.2)	18 (-8)	-10 (-23)	-38 (-39)	*
60 (1.5)	18 (-8)	-10 (-23)	-38 (-39)	*
Cement content = 500 lb/yd³ (296 kg/m³)				
6 (0.15)	47 (8)	43 (6)	38 (3)	33 (1)
12 (0.30)	42 (6)	31 (- 1)	20 (-7)	9 (-13)
18 (0.46)	36 (2)	19 (-7)	2 (-17)	-15 (-26)
24 (0.61)	30 (-1)	7 (-14)	-16 (-27)	-39 (-39)
36 (0.91)	18 (-8)	-15 (-26)	-46 (-43)	-79 (-62)
48 (1.2)	10 (-12)	-25 (-32)	-60 (-51)	*
60 (1.5)	10 (-12)	-25 (-32)	*	*
Cement content = 600 lb/yd³ (356 kg/m³)				
6 (0.15)	46 (8)	41 (5)	35 (2)	29 (-2)
12 (0.30)	40 (4)	28 (-2)	14 (- 10)	0 (-18)
18 (0.46)	33 (1)	13 (-11)	- 7 (-22)	-29 (-34)
24 (0.61)	26 (- 3)	-1 (-18)	-28 (-33)	-55 (-48)
36 (0.91)	12 (-11)	-27 (-31)	-66 (-54)	*
48 (1.2)	4 (-16)	-40 (-40)	*	*
60 (1.5)	4 (-16)	-40 (-40)	*	*

*<< -60 F (-51 C).

306-76, 88,10

Walls minimum temperature

Cement content—600 lb per cu yd (356 kg per cu m)				
0.5 (0.15)	44 (6.7)	32 ((0)	16 (−8.9)	6 (−14)
1.0 (0.30)	32 (0)	8 (−13)	−16 (−27)	−41 (−41)
1.5 (0.46)	21 (−6.1)	−14 (−26)	−50 (−46)	−89 (−67)
2.0 (0.61)	18 (−7.8)	−22 (−30)		
3.0 (0.91)	12 (−11)	−34 (−37)		
4.0 (1.2)	11 (−12)	−38 (−39)		
5.0 (1.5)	10 (−12)	−40 (−40)		

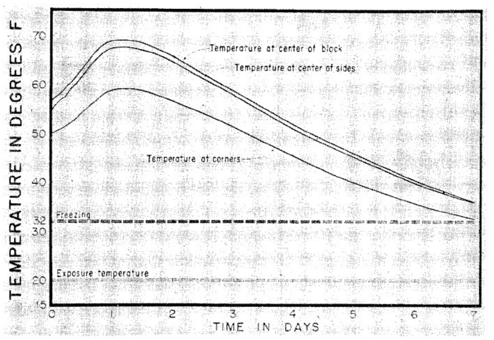
Insulation equivalents*

66

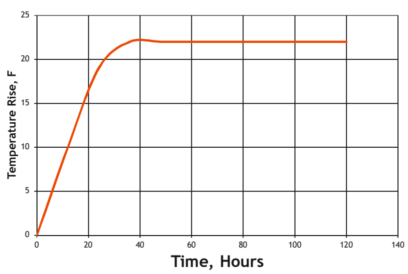
Cement content = 600 lb/yd³ (356 kg/m³)				
4 (0.10)	*	*	*	*
8 (0.20)	*	*	*	*
12 (0.31)	38 (3)	26 (-3)	14 (-10)	2 (-17)
18 (0.46)	24 (-4)	0 (-18)	-24 (-31)	-48 (-44)
24 (0.61)	14 (-10)	-16 (-27)	-46 (-43)	-82 (-63)
30 (0.76)	10 (-12)	-20 (-29)	-62 (-52)	†
36 (0.91)	7 (-14)	-30 (-34)	†	†

* > 50°F (10°C): additional heat required.
† << -60°F (-51°C).

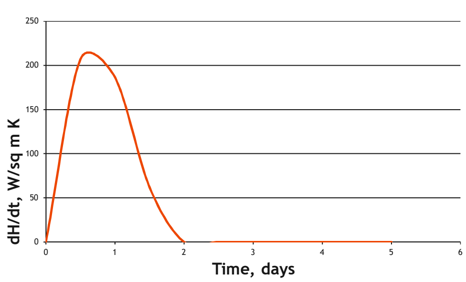
10



Adiabatic Rise



Rate of heat evolution



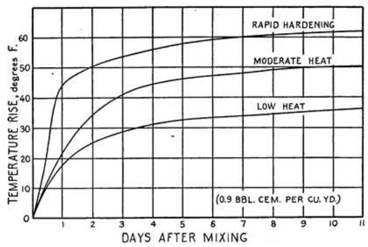


FIG. 1—ADIABATIC, TIME TEMPERATURE CURVES OF CONCRETES CONTAINING DIFFERENT TYPES OF CEMENT

Carlson, R.W. JACI, v34

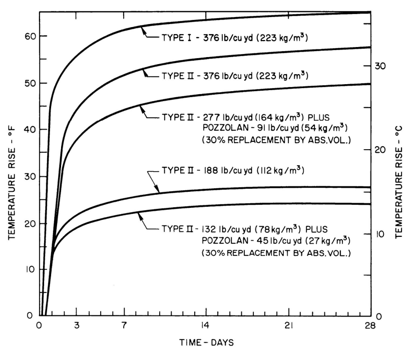
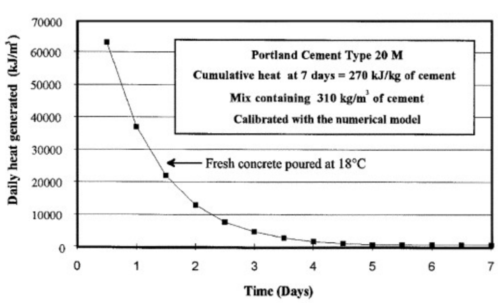
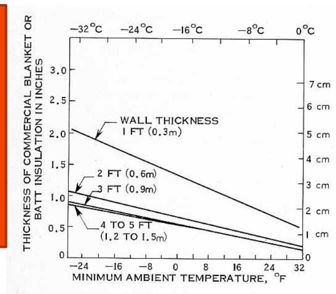


FIG. 1 - TEMPERATURE RISE OF MASS CONCRETE

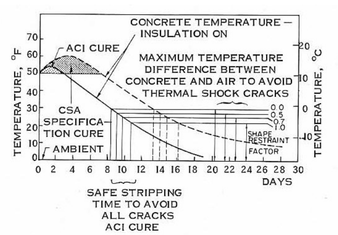


Mustard and Gosh 1979

600 lb per cubic yard cement
No accelerator



Mustard and Gosh



Carlson's Method

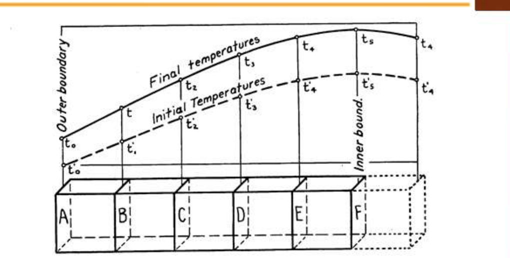


FIG. 1—DIAGRAM OF ELEMENTAL PRISM SHOWING NOMENCLATURE

Carlson Method

TABLE 6—SUMMARY OF EQUATIONS

At Junction of Two Materials "a" and "b": $Z_j = 1/(S_a + S_b + 2 - Z_{(j+1)})$	$C_j = t'_{j-1} + (S_a + S_b - 2)t'_j + t'_{j+1} + (S_a + S_b)\Delta\theta$	$L_j = (C_j + L_{j+1})Z_j$
At Inside Boundary: $Z_B = 1/(S+1)$	$C_B = 2t'_{B-1} + (2S-2)t'_B + 2S\Delta\theta$	$L_1 = C_n Z_n/2$
Beyond Effect of Heat in Mass: $Z_n = 1/(2S + 2 - Z_{n+1})$	$C_n = 2St'$	$L_n = t'(1-Z)$
At All Other Stations: $Z_n = 1/(2S + 2 - Z_{n+1})$	$C_n = t'_{n-1} + (2S-2)t'_n + t'_{n+1} + 2S\Delta\theta$	$L_n = (C_n + L_{n+1})Z_n$

Fixed Equations: $S = X^2/h^2T$ and $t_n = L_n + Z_n t_{n-1}$

t'_n and t_n are initial and final temps. at Sta. "n", $\Delta\theta$ is adiabatic temp. rise in time T, X is space interval in ft., T is time interval in days, and h^2 is diffusivity in ft.²/day

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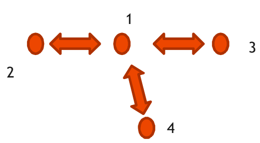

$$\left(q_i + \sum_j \frac{T_j^{\;p} - T_i^{\;p}}{R_{ij}}\right)\frac{\Delta\tau}{C_i} + T^p{}_i = T^{p+1}$$

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Finite Difference Method

$$C_i = \rho_i c_i \Delta\forall_i$$

$$R_\infty = \frac{1}{hA}$$

$$R_m = \frac{\Delta x}{kA}$$

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So What?

- The current requirements in 306-10 are based on data from 1951
- The change in 1976 was not in data but rather in terms of acceptable temperature
- Modelling was done using Heisler charts – pre computer availability
- We must update this data for modern concretes.
- The conservative nature of the model impacts sustainable construction practices

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Winter Concrete

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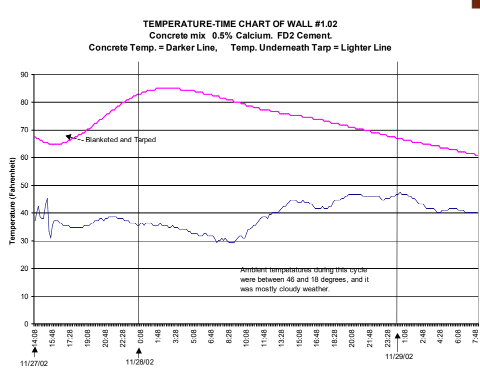

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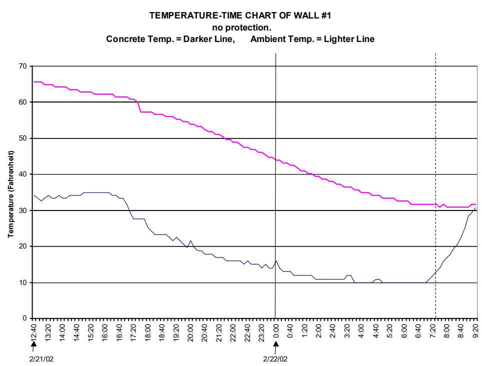
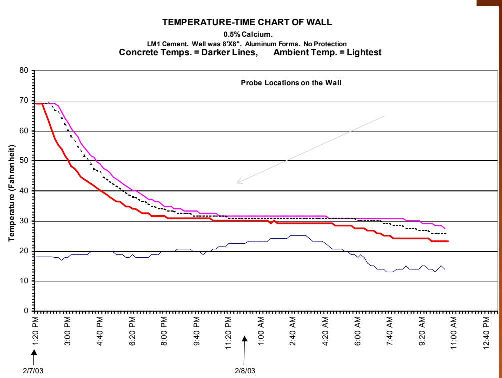
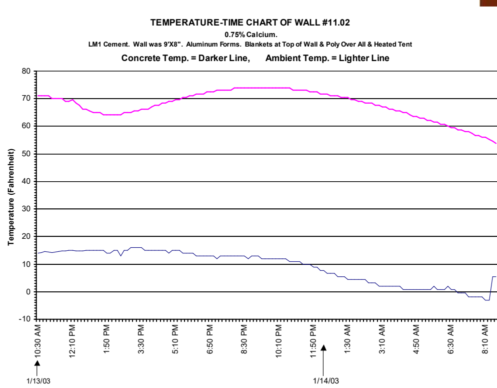
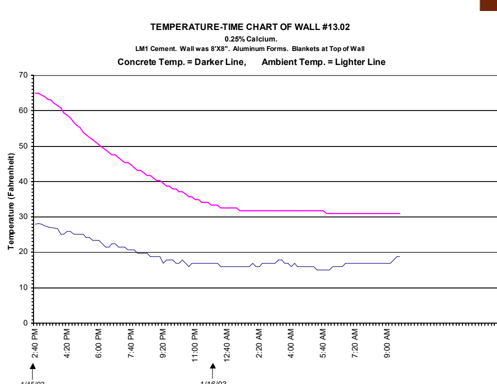
Cold Weather





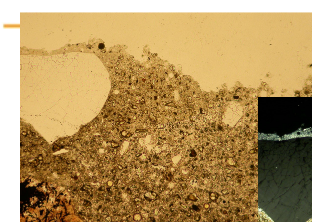
Bring the Outside Indoors

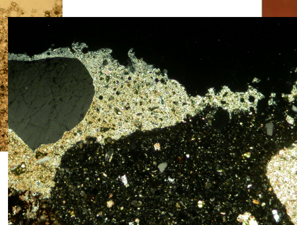




Dusting

Carbonation





Thermodynamics

Definitions

- Heat The amount of energy associated with the motion of atoms or molecules in matter
- Temperature a measure of the degree of hotness in matter.
- Heat Capacity The amount of heat required to increase the temperature of matter
- Mass The amount of matter present

Thermodynamics

- Four Laws (or three?)
- You can't win,
- you can't break even
- you can't get out of the game

Heat Transfer

- Heat Transfer
- Modeling - solution of Fouriers equation, usually by numerical means
- In-Out +Generation = Accumulation

Convective Heat Transfer

Wind increases the rate of heat loss – will quickly reach the Ambient temperature

Conductive Heat Transfer

Increasing Protection Requirements

Plan Components

- Concrete temperature during mixing and placing,
- Temperature loss during delivery
- Preparation for cold weather concreting
- Estimating strength development,
- Methods of protection,
- Curing requirements, and
- Admixtures for accelerating setting and strength gain and antifreeze admixtures.

Preparation for Cold Weather

- Plans should be made well before freezing temperatures are expected to occur.
- Equipment and materials should be at the work site before cold weather is likely to occur

Concrete Temperature Requirements	Section size minimum dimension, in. (mm)			
	< 12 in. (300 mm)	12-36 in. (300-900 mm)	36-72 in. (900-1800 mm)	> 72 in. (1800 mm)
Air temperature	Minimum concrete temperature as placed and maintained			
—	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*			
Above 30 °F (-1 °C)	60 °F (16 °C)	55 °F (13 °C)	50 °F (10 °C)	45 °F (7 °C)
0 to 30 °F (-18 to -1 °C)	65 °F (18 °C)	60 °F (16 °C)	55 °F (13 °C)	50 °F (10 °C)
Below 0 °F (-18 °C)	70 °F (21 °C)	65 °F (18 °C)	60 °F (16 °C)	55 °F (13 °C)
—	Maximum allowable gradual temperature drop in first 24 hrs after end of protection			
	50 °F (28 °C)	40 °F (22 °C)	30 °F (17 °C)	20 °F (11 °C)

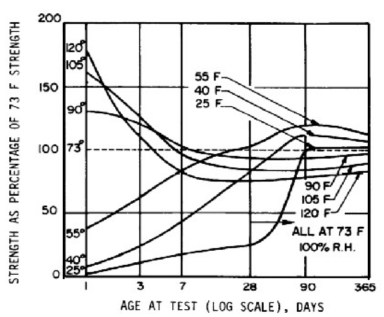


Fig. 6.6.1 - Effect of temperature conditions on the strength development of concrete (Type I cement) (Kleiger 1958)

Risk Management

- If we can predict the concrete temperature, hydration heat and insulation, an estimate of the weather can allow prediction of the temperature and strength of the concrete at any time after placement.
- ACI 306 is very conservative, and will always work. For fast track, sustainable construction we need to do better to manage the risk to deliver safe, durable concrete.

Questions?

- Thank you for the time and attention.