

Concrete at the Extremes

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Presentation Goals

- Introduction
- Cold weather issues and solutions
- Hot weather issues and solutions
- Odd scenarios
- Questions



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COLD WEATHER



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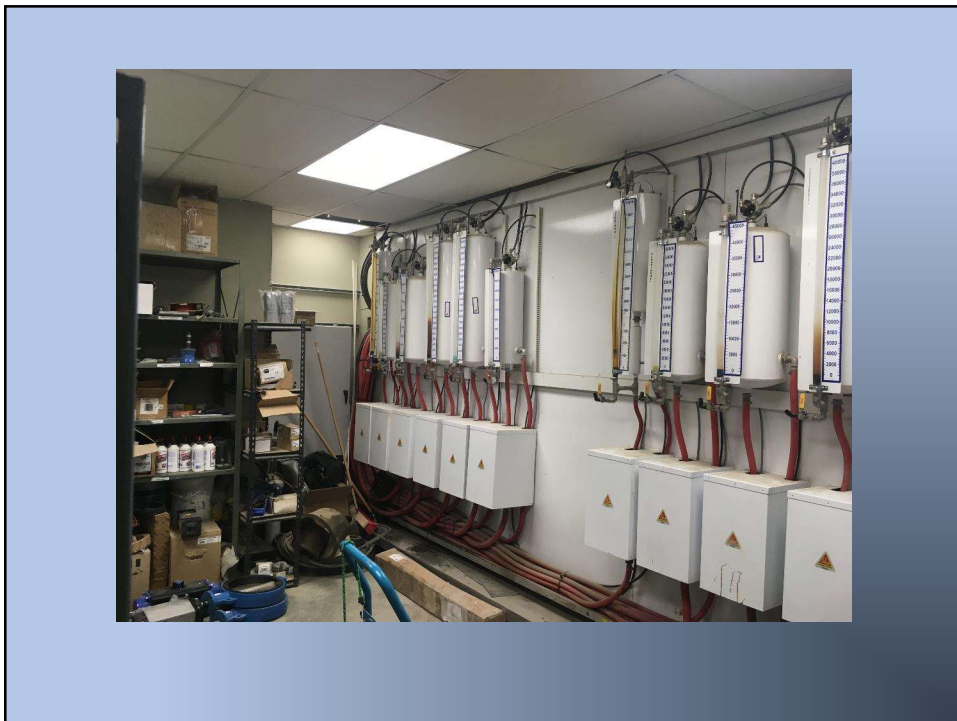
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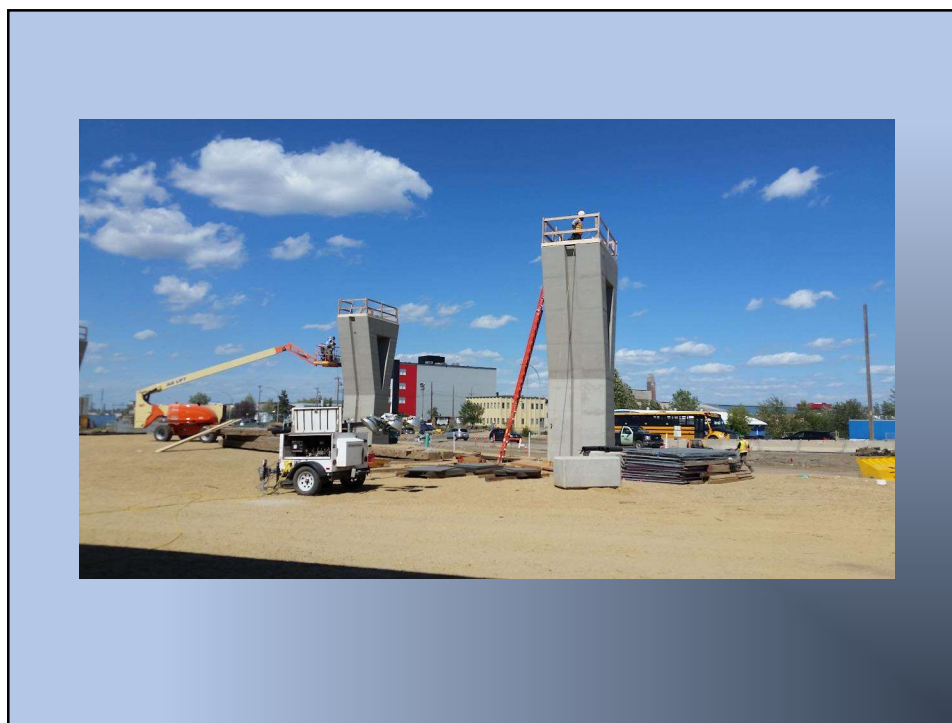
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Mixer reading	0 A	Scale	Target	Actual	% Error						
Aggregate water	241 l	Water	409	425	3.91%						
Water density	1.000	Concrete	1800	1783	0.75%						
Total Weight	11323 kg	Alarms									
Actual Vol.	1011.5 l	Component	Description	Quantity							
Concrete Temp. (tar 23.0 °C)		WATER #2	OUT OF TOLERANCE	11 l							
		SILO #4	OUT OF TOLERANCE	20 kg							
Materials											
Component	Material	Mix	Target	Actual	% Error	Density	Temp	Moisture	Trim	Rank	Cum. Err. %
WATER #1	COLD WATER	142	205	210	2.44%	1.000	5.0	0.00	100.0	2	3.91%
WATER #2	HOT WATER	0	204	215	5.39%	1.000	5.0	0.00	100.0	1	5.39%
SILO #1	SUNDANCE	120	600	592	-1.33%	2.050	10.0	0.00	100.0	2	-0.75%
SILO #4	TYPE-10	360	1800	1790	-0.56%	3.150	10.0	0.00	100.0	0	-0.56%
BIN #2	14 5mm	625	3180	3200	0.63%	2.600	10.0	2.78	100.0	1	0.63%
BIN #4	28-14mm	327	1663	1750	5.23%	2.600	10.0	2.72	100.0	3	0.83%
BIN #3	SAND	670	3508	3470	-1.08%	2.600	10.0	5.76	100.0	2	-0.27%
DRY ADMIX #01	SIKA AER CA	20	480	490	2.08%	1.010		0.00	100.0	1	2.08%
DRY ADMIX #05	VISCOCRETE2100	261	6300	6300	0.00%	1.200		0.00	100.0	5	0.00%
DRY ADMIX #06	SIKA 4R	783	18800	18850	0.27%	1.020		0.00	100.0	6	0.27%
MAN025	SIKATARD440	130	3120	3120	0.00%	1.152		0.00	100.0	0	
MAN026	SIKA CNI	2083	49992	49992	0.00%	1.300		0.00	100.0	0	
Production Volume		14.50 m3	Return	3.00 m3	Reset	0.00 m3	Void	3.00 m3			

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WHAT IS COLD, THEN?

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Cold Weather Concrete

ACI 306 Definition: *when air temperature has fallen to, or is expected to fall below, 40°F (4°C) during the protection period; protection period is defined as the time recommended to prevent concrete from being adversely affected by exposure to cold weather during construction.*

TxDOT Item 420 Paragraph 4.7.11: Do not place concrete when the ambient temperature in the shade is below 40°F and falling unless approved. Place concrete when the ambient temperature in the shade is at least 35°F and rising or above 40°F.



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PROBLEMS WITH COLD WEATHER CONCRETE

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Problems in Cold Weather

- Delayed strength gain
- Safety
- Delayed schedule
- Freezing concrete
- Surface damage



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Set Time and Temperature

If the measured set time in laboratory (75°F) is:	For an average (in-place) concrete temperature of:	Set time estimated to be as follows:
Initial Set: 4.0 hrs. Final Set: 6.0 hrs.	35°F	Initial Set: 12.6 hrs. Final Set: 18.9 hrs.
	45°F	Initial Set: 9.3 hrs. Final Set: 13.9 hrs.
	55°F	Initial Set: 6.9 hrs. Final Set: 10.4 hrs.
	65°F	Initial Set: 5.2 hrs. Final Set: 7.9 hrs.
	75°F	Initial Set: 4.0 hrs. Final Set: 6.0 hrs.



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COLD WEATHER – INDUSTRY PRACTICE

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Concrete Mix Guidelines

- Aggregate stockpiles
 - Freely draining
 - Avoid excessive accumulation of snow or ice; cover if necessary
 - Do not batch aggregates that have ice or snow on them.
- No salt, chloride-based accelerators, chemicals (such as anti-freeze) or other materials in the concrete mixture to prevent freezing
 - These can cause damage to the concrete.
- Avoid significant revisions to mixture proportions (e.g. Type III cement or adding cement)
 - Periods of cold weather can be followed by warm periods where these revisions would be counter-productive.



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Fresh Concrete 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).



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Prior to Placement

- Remove snow/ice from reinforcement and other surfaces that will come in contact with the concrete. Surfaces must be above freezing.
- Ensure that drainage is good so standing water is minimized.
- Do not place concrete on frozen subgrade or base. Frost, ice, and/or snow shall be removed from the subgrade prior to placement.
- Have heating equipment (and backup) staged ahead of time.
- Make a go/no go criteria. May be more strict than cold weather limits (e.g. below 45°F, have cold weather protection measures in place).



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During/After placement

- Insulation, heaters, or other appropriate heat source may be used to raise the subgrade temperatures above freezing, if necessary.
- After placement, and if freezing temperatures (at or below 32°F) are anticipated, use insulation blankets.
- Insulation materials must be installed so that the effectiveness of the insulation is not compromised by the weather (rain or snow) or air movement (wind). The insulation should be installed when the concrete has sufficient strength so that the surface is not damaged.



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Protection Period

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.



Calculate in-place strength using maturity

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Heated Enclosure



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Moveable enclosures



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Propane-Fired or Diesel Indirect Heaters

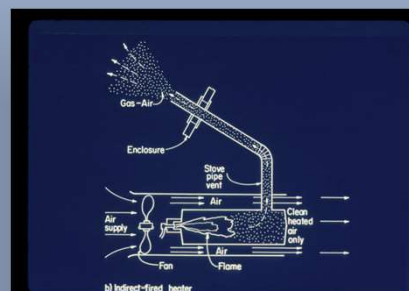
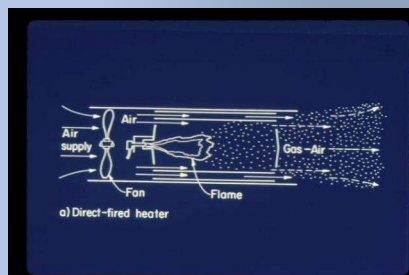


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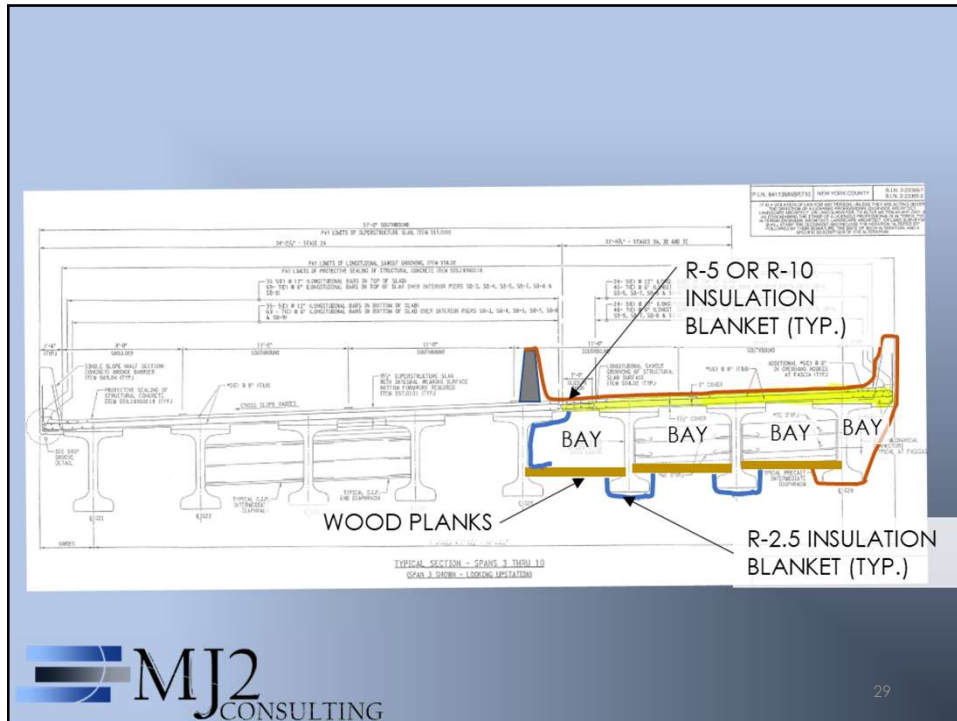
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Ground Thaw Heaters/ Hydronic Heaters



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Ground Thaw Heaters/ Hydronic Heaters



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Insulation



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What if the concrete freezes? ACI 306 says:

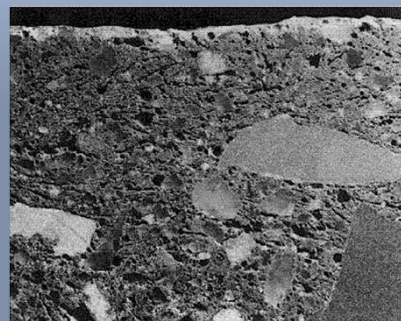
- Concrete can resist the effects of one freezing-and-thawing cycle as long as it is air-entrained, not exposed to an external water source, and has reached a compressive strength of approximately 500 psi
- If repeated exposure to freezing and thawing is anticipated, reaching 500 psi (3.5 MPa) is not sufficient protection. Concrete with a compressive strength less than 3500 psi (24.5 MPa) and exposed to repeated freezing-and-thawing cycles while critically saturated may be damaged.



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Frozen Concrete – note orientation of ice imprints



FHWA-HRT-04-150 Petrographic Methods of Examining Hardened Concrete: A Petrographic Manual



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What can you do?

- Require contractor to develop a cold weather placement plan.
- Reference ACI 306
- Harmonize minimum temperatures and protection periods with Table 5.1 and 7.2 of ACI 306R-16 (or owner requirements)
- Don't reject concrete solely for going below temperature values in ACI 306 Table 5.1. Longer curing time may be required.
- Use of temperature sensors in cold or freezing weather can avoid expensive investigations



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HOT WEATHER



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What is “Hot Weather”



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Hot Weather Concrete

ACI 305 Definition: one or a combination of the following conditions that tends to impair the quality of freshly mixed or hardened concrete by accelerating the rate of moisture loss and rate of cement hydration, or otherwise causing detrimental results: *high ambient temperature, high concrete temperature, low relative humidity, and high wind speed.*



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PROBLEMS WITH HOT WEATHER CONCRETE

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Hot Weather Concrete Problems

- Placement and delivery issues
 - Early stiffening
 - Shorter initial and final set time
 - Difficulty controlling entrained air
 - Plastic shrinkage cracking
 - Surface finish Issues – e.g. addition of water
- Conflicts with other project requirements (e.g. mass concrete)
- High curing temperatures
- QA/QC Issues
- Cost of non-compliance



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Plastic Shrinkage Cracking

- Plastic Shrinkage Cracking
 - Stress due to evaporation of bleed water – occurs right at time of setting (just when concrete is developing mechanical properties)
- Problem is evaporation rate higher than bleed rate

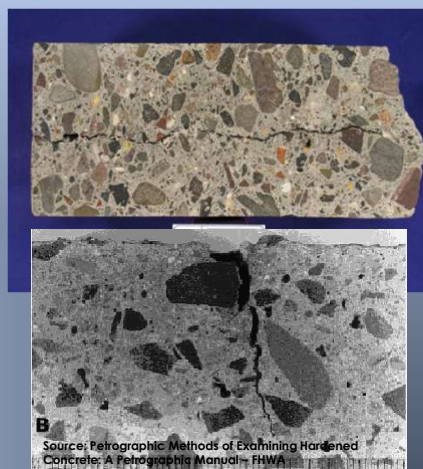


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Plastic Shrinkage Cracking Features

- Cracking occurs just before/after screeding
 - Orientation with wind direction
 - Mortar may bridge cracks
- Cracks go around aggregate
- Cracks have a tearing pattern
- Cracks may occur with drying shrinkage cracks



Source: Petrographic Methods of Examining Hardened Concrete: A Petrographic Manual - FHWA



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Example – Wind Turbine Foundation



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Plastic Shrinkage?



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Plastic settlement/subsidence cracking and plastic shrinkage cracking look very similar.



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Cracking stops at steel.



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Placement and Delivery Issues

- Slump loss
 - Contractor may add water
 - Consolidation problems
- Shorter time of set
 - Reduced window of finishability
 - Poor finish, possible durability problems
 - Cold joints
- Rejected trucks



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Set Time and Temperature

If the measured set time in laboratory (75°F) is:	For an average (in-place) concrete temperature of:	Set time estimated to be as follows:
Initial Set: 4.0 hrs. Final Set: 6.0 hrs.	55°F	Initial Set: 6.9 hrs. Final Set: 10.4 hrs.
	65°F	Initial Set: 5.2 hrs. Final Set: 7.9 hrs.
	75°F	Initial Set: 4.0 hrs. Final Set: 6.0 hrs.
	85°F	Initial Set: 3.0 hrs. Final Set: 4.4 hrs.
	95°F	Initial Set: 2.3 hrs. Final Set: 3.4 hrs.
	105°F	Initial Set: 1.7 hrs. Final Set: 2.6 hrs.



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Local 'Customs'



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Cold Joints



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Water Addition



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Other Issues

- Cost of controlling as-delivered temperature
 - Precooling (liquid nitrogen, ice, etc.)
 - Evaporation reduction measures
 - Thermal control measures



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Mass Concrete – More Challenge

- High placement temperatures = higher curing temperature
- For mass concrete, hot weather can cause temperatures and temperature differences greater than ACI 301 limits for maximum; higher risk of thermal cracking
- Possible reduced strength at high curing temps.



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Mass Concrete



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Element Size, Mix Proportion Example

Strength	Cement	Fly Ash	Adiabatic Temp. Rise	Placement Temp.	Temp. Rise - 5 ft. Section	Temp. Rise - 7 ft. Section
psi	pcy	pcy	°F	°F	°F	°F
3000	360	72	73	75	138	140
4000	440	88	89	75	153	156
5000	520	104	105	75	168	172
6000	600	120	122	75	184	189



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HOT WEATHER – INDUSTRY PRACTICE

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Typical Concrete Specifications/Guidance

- Placement Temperature <95°F (ACI 305)
- Maximum Temperature <160°F (ACI 301)
- Maximum Temperature Differential <35°F (ACI 301)
- Evaporation Rate > 0.20 lbs/sq ft/hr - Hot weather measures apply (ACI 305)
- Other, agency/owner specifications may apply



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PLACEMENT TEMPERATURE

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Higher Delivered Temperature of Concrete

- ACI 305.1-14 Requirements
 - 95°F measured at time of discharge unless higher is approved by Architect/ Engineer
 - Can qualify higher temps. by lab or field mixes
 - Lab testing requirements follow ASTM C192 with modifications
- Other limits
 - TxDOT – 90°F for pavements, 70°F for mass
 - COE – 50°F for mass



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Lab or field validation can allow higher temperatures

- Lab test procedures are a modification of ASTM C192 – intended to correlate with slump loss similar to a 30-40 minute delivery time
- Field testing is preferred if extended slump life is needed
- See ACI 305R-10 Guide for more detail

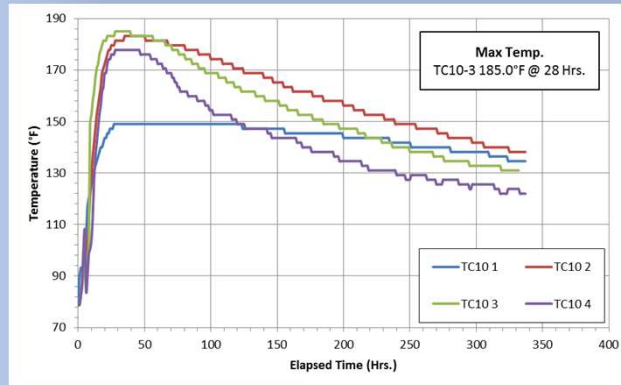


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MAXIMUM TEMPERATURE

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Max. temperature > 160°F – What now?



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Higher Than 160°F?

- Review chemistry – 170°F is often allowable when sufficient SCMs of the right chemistry are used
 - FDOT allows 180°F if chemistries are favorable
- Temperatures higher than 180°F require laboratory investigation
 - Petrography + SEM/EDX
 - Length change of mortar bars, cores
 - Still debate on methodology
- Careful on ACI 201/308 guidance



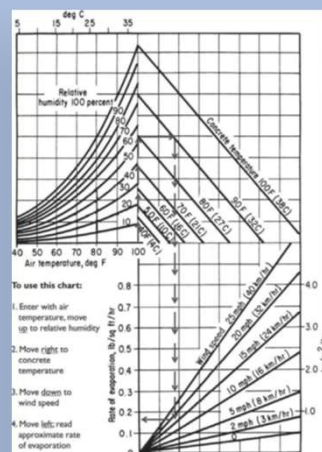
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EVAPORATION RATE

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Nomograph (Menzel) – The old way to calculate evaporation rate



Source: ACI 305, NRMCA, Menzel 1954, Lerch 1957

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Uno – the new way to calculate evaporation

- $E = (T_c^{2.5} - r \cdot T_a^{2.5})(1 + 0.4V) \times 10^{-6}$
 - Where: E = Mass of water evaporated per hour (lb/ft²)
 - T_c = Temperature of evaporating surface (°F) – i.e. concrete
 - T_a = Temperature of air (°F), measured 4 to 6 ft. above surface, on windward side, shielded from sun
 - r = relative humidity of air (0 to 100%), measured 4 to 6 ft. above surface, on windward side, shielded from sun
 - V = Wind speed (mph), measured 20 in. above surface
- Nomograph is attached as Appendix – not in Spec.



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Evaporation Rate

- ACI 305.1-14
 - 0.2 lb/sq. ft./hr. – May be revised by Engineer/Architect
- Lower evaporation rate (such as 0.1 lb/sq ft/hr) often appropriate for slow bleeding mixes (i.e. modern concrete!)
- Research still needed on further refinement of this limit



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Typical evaporation protection measures

- Fogging
- Evaporation retarders
- Wet burlap
- Wind breaks
- Don't forget to protect QC specimens!
- Don't forget to coordinate with other project requirements

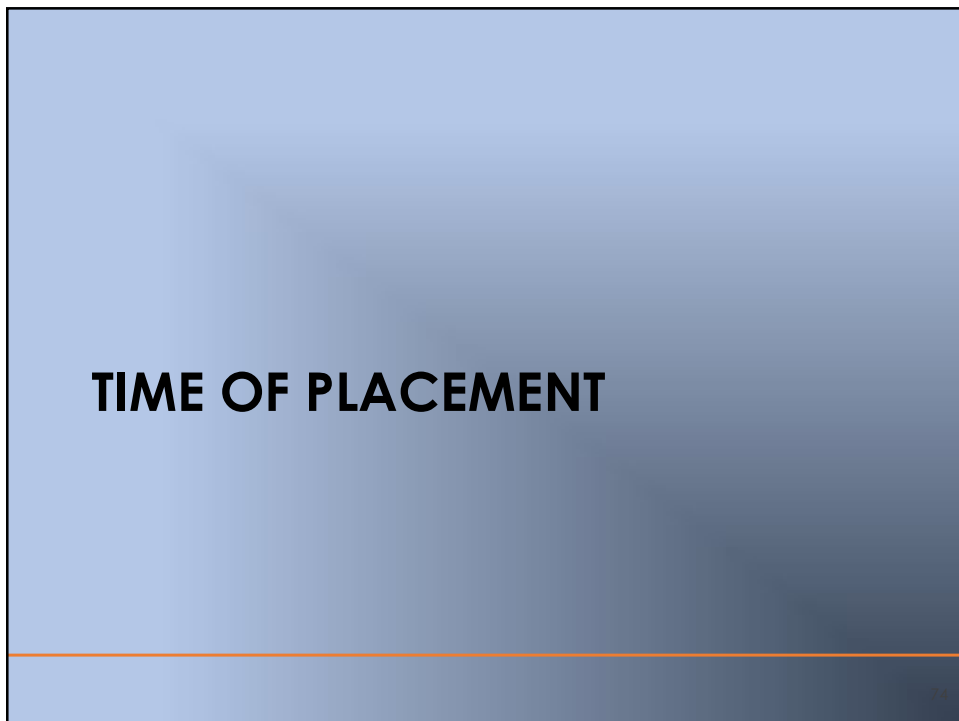


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Time of Placement: Use Judgement

• 2006 Spec.

- *In hot weather, a time of less than 1-1/2 hours, such as 1 hour, may be specified. The limitations of ASTM C 94/C 94M, Paragraph 11.7, are permitted to be waived by the purchaser if the concrete is of such slump that it can be placed without the addition of water. With extended set control admixtures, concrete slump can be maintained*

• 2014 Spec.

- *Any limitations on elapsed time of the concrete mixture prior to discharge may be waived by the purchaser if the concrete is of such slump that it can be placed without the addition of water. With extended set control admixtures, concrete slump is maintained without the addition of water indefinitely with no detrimental effect to the concrete once placed. It is strongly recommended that the mixture and any set-control admixtures are tested prior to use in a project.*



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What can you do?

- Harmonize temperature requirements with ACI 301 and 305 (or owner requirements).
 - Don't be overly strict unless needed.
 - There are economic costs to cooling.
- Require contractor to develop a hot weather placement plan.
 - Contractor should address evaporation control measures (e.g. fogging, evaporation retarder)
 - Address high performance, slow bleed rate concrete
- Reference ACI 305
- Don't reject concrete solely for going over 90 minutes.
- Have a repair spec for the inevitable plastic shrinkage crack occurrence.



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Questions?

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