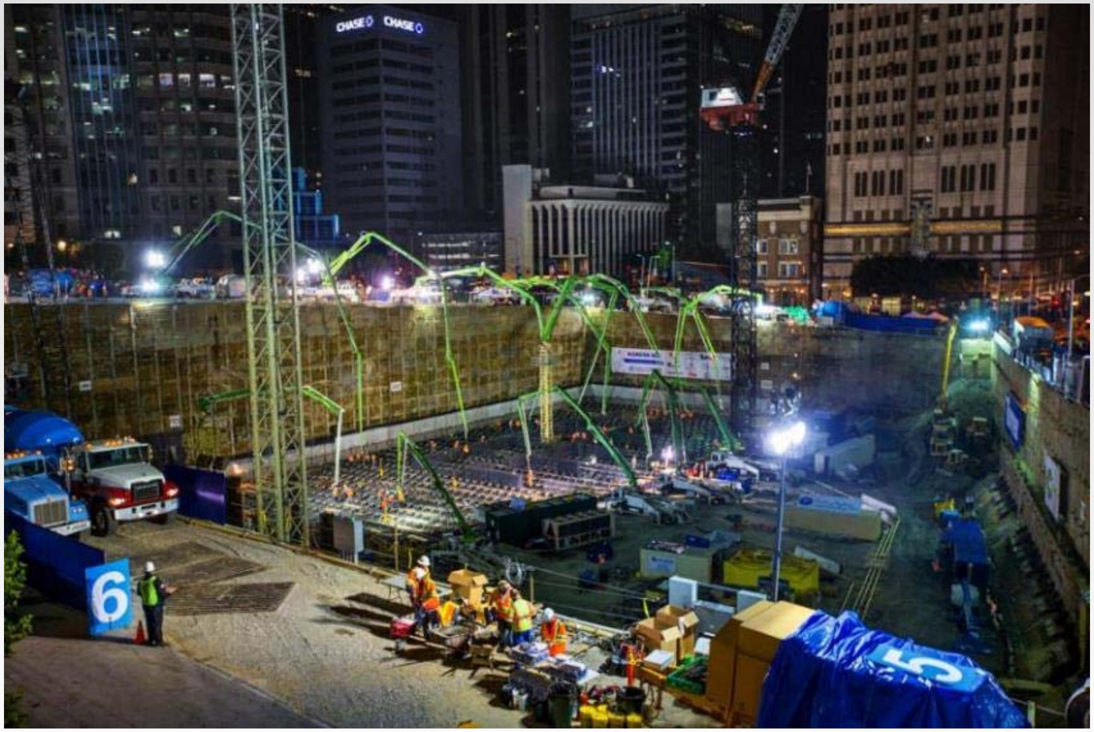
Mass Concrete Fundamentals

Everything You Ever Wanted to Know... plus a little bit more!



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About the Presenter

- John Gajda, FACI, PE/PEng (31 jurisdictions)
  - Principal at MJ2 Consulting, PLLC
  - Former Chair of ACI 207 *Mass and Thermally Controlled Concrete* (2010 to 2016)
  - ACI 301 *Specifications for Structural Concrete* Subcommittee Chair of "Mass Concrete"
  - 1000+ Mass Concrete Projects

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Outline

- Mass concrete definition
- Why treat something as mass concrete
  - What matters and why
- Specification requirements and limits
- Strategies for success
- Questions

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What is Mass Concrete?

"any volume of concrete in which a combination of dimensions of the member being cast, the boundary conditions, the characteristics of the concrete mixture, and the ambient conditions can lead to undesirable thermal stresses, cracking, deleterious chemical reactions, or reduction in the long-term strength as a result of elevated concrete temperature due to heat from hydration"

– *American Concrete Institute (ACI), 2010 and 2016*

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Trends that lead to Mass Concrete

- Larger Elements
- Higher Strengths
- Flowable Concrete
- Rapid Construction
- Long Service Life

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These Trends can Result in …

- High Concrete Temperatures
- Thermal Cracking
  - Durability concerns
  - Reduced service life
  - Structural concerns

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What is Mass Concrete?

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What is Mass Concrete?

Other Stuff: Self Consolidating Concrete (SCC), Drilled Shaft Concrete, Grout, High Early Strength Highway Patching Material, etc.

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When is it Mass Concrete?

- When rate of heat generation and thickness is such that heat is generated faster than it escapes.
- No requirements in ACI 207
- Per ACI 301:
  - Only when the EOR specifies it to be mass concrete
    - Thickness ≥4 ft.
    - >660 lbs/yd^3 cementitious (2010 edition; not in current edition)
- DOTs: ≥2.5 to >7 ft.

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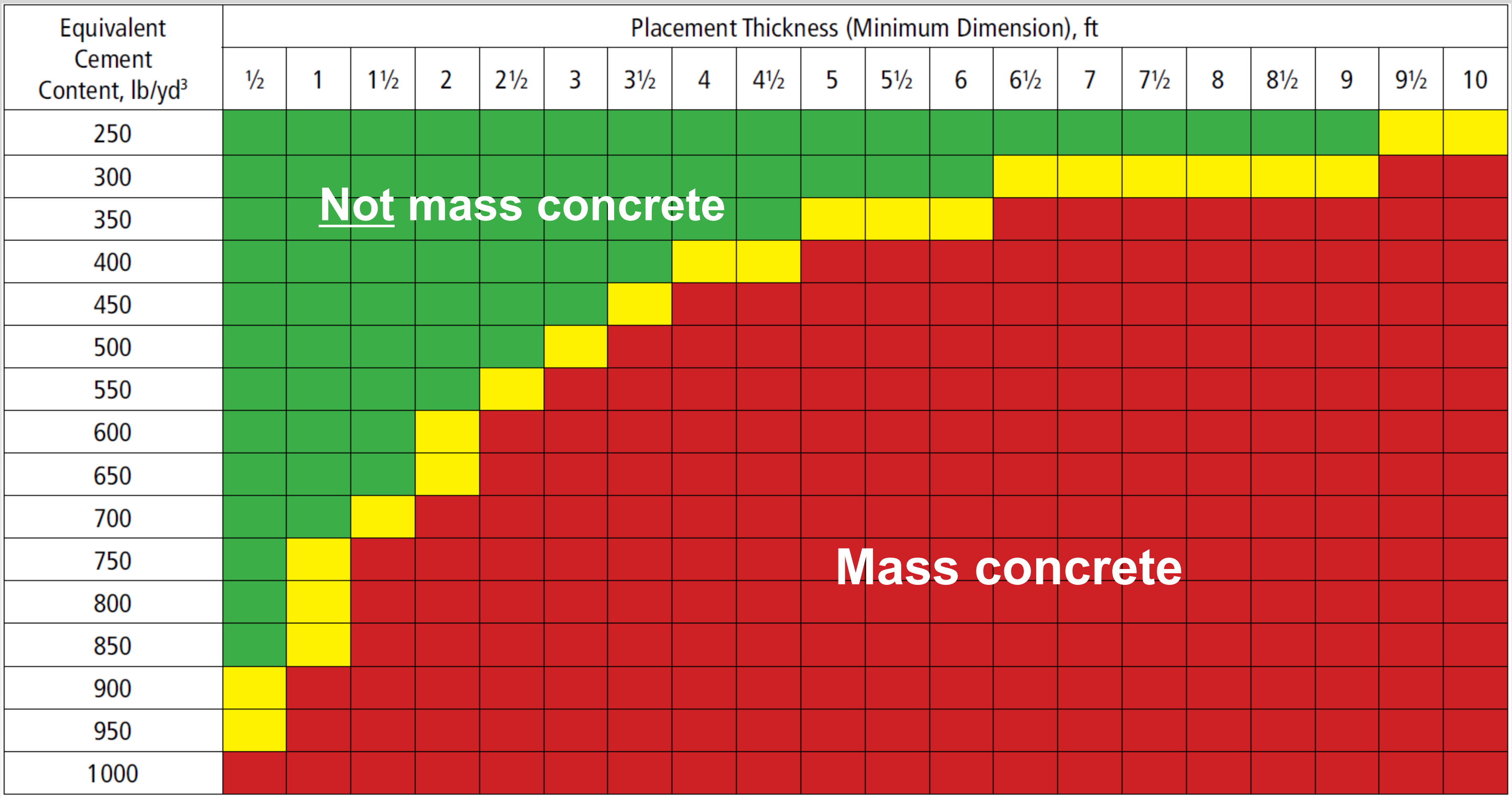
When is it Mass Concrete?



Published: *When Should Mass Concrete Requirements Apply?*, Aspire Bridge Magazine, Summer 2015.
Proposed Mass Concrete Definition Based on Concrete Constituents and Minimum Dimension, ACI SP325, Fall 2018.

Adopted: Not yet but in draft versions of ACI 207.1R and ACI 207.2R.

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Equivalent Cement Content (ECC)

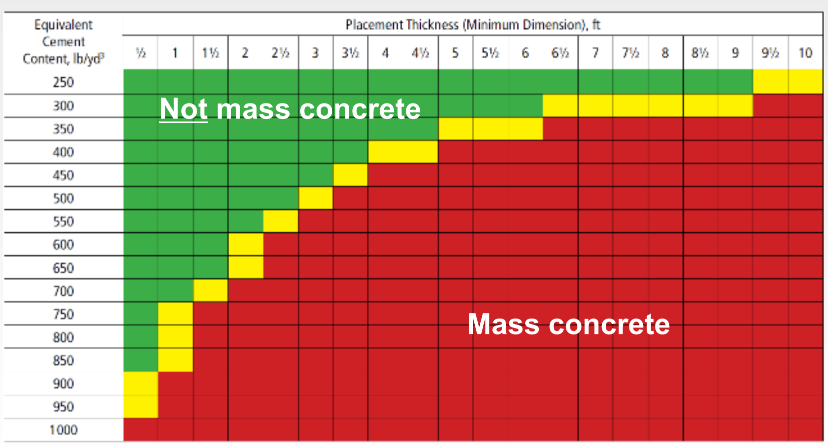
ECC = *portland cement* +

factor**slag cement* +

0.5**fly ash (class F)* +

0.8**fly ash (class C)* +

1.2*(*silica fume* + *metakaolin*)



Slag (0-20%)	1.0-1.1
Slag (20-45%)	1.0
Slag (45-65%)	0.9
Slag (65-80%)	0.8

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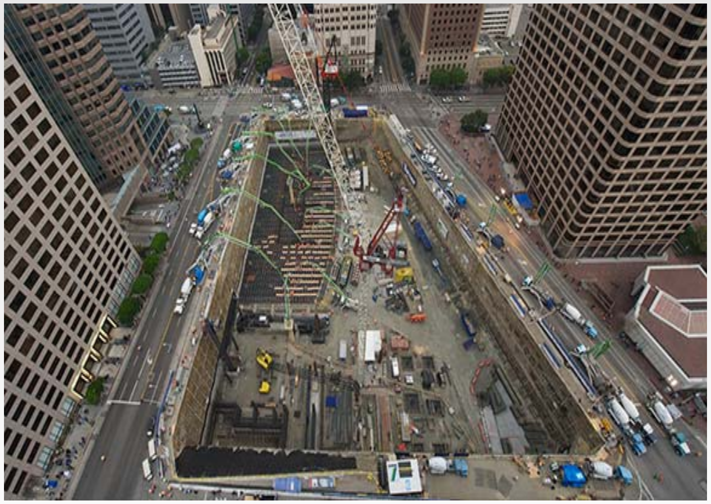
Main Considerations

- Maximum Temperature
  - Can reduce strength and durability
- Temperature Difference
  - Can result in thermal cracking
  - During thermal control and just after thermal control ends



- Thermal Shock
  - Don’t stop thermal control too soon

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Maximum Temperature

- Often limited
  - No consensus in specifications
  - Safe limit: 158/160°F (70°C)
  - Europe uses 149°F (65°C)
- Concrete mixture design
  - Cement (type and quantity)
  - SCMs (type and percentage)

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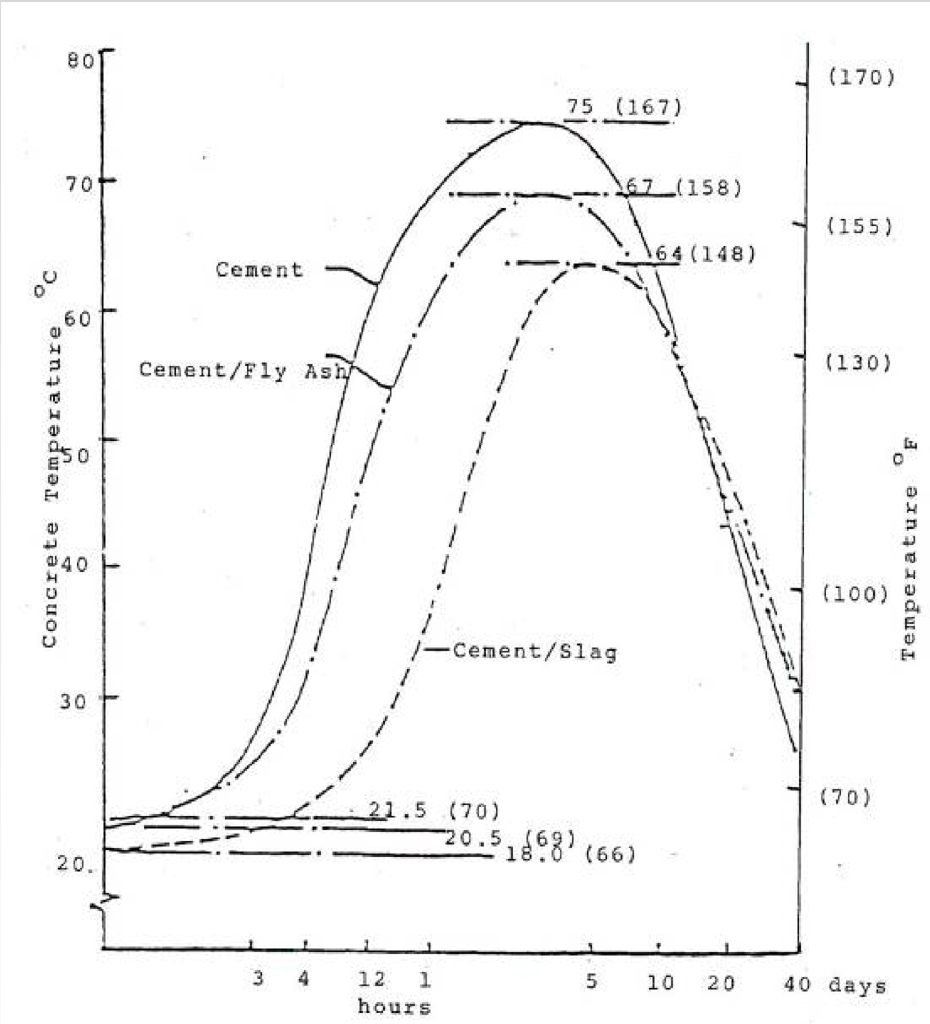
Maximum Temperature (cont.)



- 100% Cement
- 70/30 Blend of Cement and Fly Ash
- 25/75 Blend of Cement and Slag

Delayed Ettringite Formation (DEF)

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Maximum Temperature Estimation

Max. Temp. = Initial Temp. + Temp. Rise

- Initial Temperature
  - As low as economically practical (Payback of 1:1)
- Temperature Rise depends on Mix Design
  - Equivalent cement content (ECC)
- For placements >5 ft. thick

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Ballpark Temperature Rise

Estimated Rise (°F) = 0.16*ECC

ECC = *portland cement* +
factor**slag cement* +
0.5**fly ash (class F)* +
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1.2*(*silica fume* + *metakaolin*)

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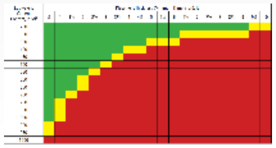


For example…

Concrete Foundation

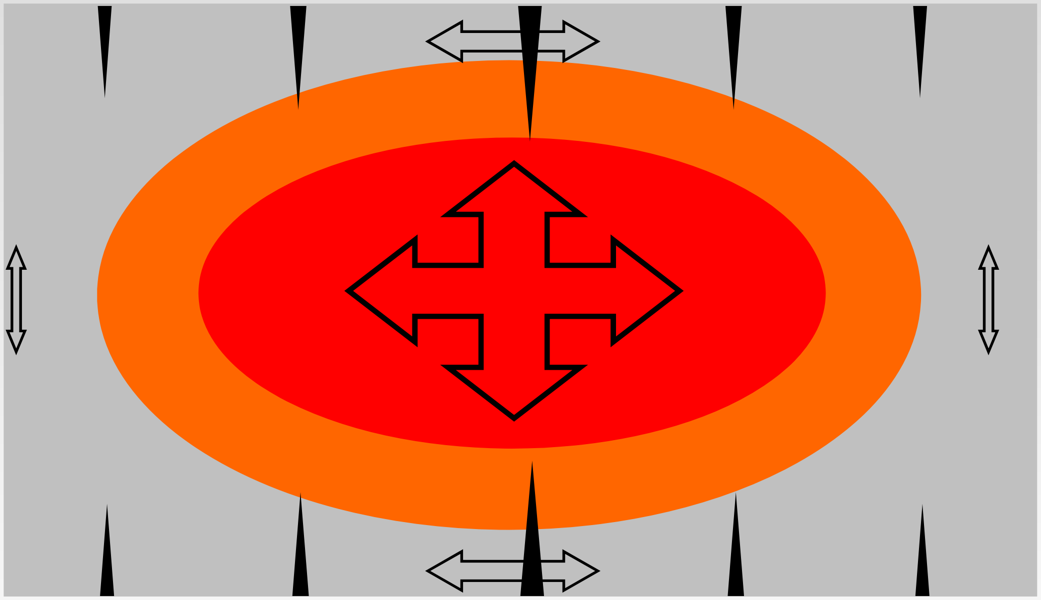
- Concrete with 400 lb/yd^3 cement and 300 lb/yd^3 class F fly ash
- 70°F delivered concrete
- 6 ft. thick

Temperature Rise =
0.16*(400 + 0.5*300) = 88°F

Max. Initial Temperature =
160°F - 88°F = 78°F

Temperature Difference

- Limited to prevent/minimize thermal cracking



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Extreme Thermal Cracking

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Typical Thermal Cracking

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Typical Thermal Cracking

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Typical Thermal Cracking

Temperature Difference

- Limited to prevent/minimize thermal cracking
- ACI 224R has cracking limits

Table 4.1—Guide to reasonable* crack widths, reinforced concrete under service loads

Exposure condition	Crack width, in.	Crack width, mm
Dry air or protective membrane	0.016	0.41
Humidity, moist air, soil	0.012	0.30
Deicing chemicals	0.007	0.18
Seawater and seawater spray, wetting and drying	0.006	0.15
Water-retaining structures†	0.004	0.10

* It should be expected that a portion of the cracks in the structure will exceed these values. With time, a significant portion can exceed these values. These are general guidelines for design to be used in conjunction with sound engineering judgement.
†Exclusing nonpressure pipes.

Temperature Difference Limit

- Often limited to a maximum of 35°F (20°C)
  - Generalized "rule-of-thumb"
  - "Discovered" during construction of unreinforced dams in Europe 75+ years ago
  - May not prevent thermal cracking
  - Simple to use and understand
  - Extends construction time
- Stepped limit
  - Steps up with age (20-30-40-50°F)
  - Shortens construction time
  - Simple to use and understand

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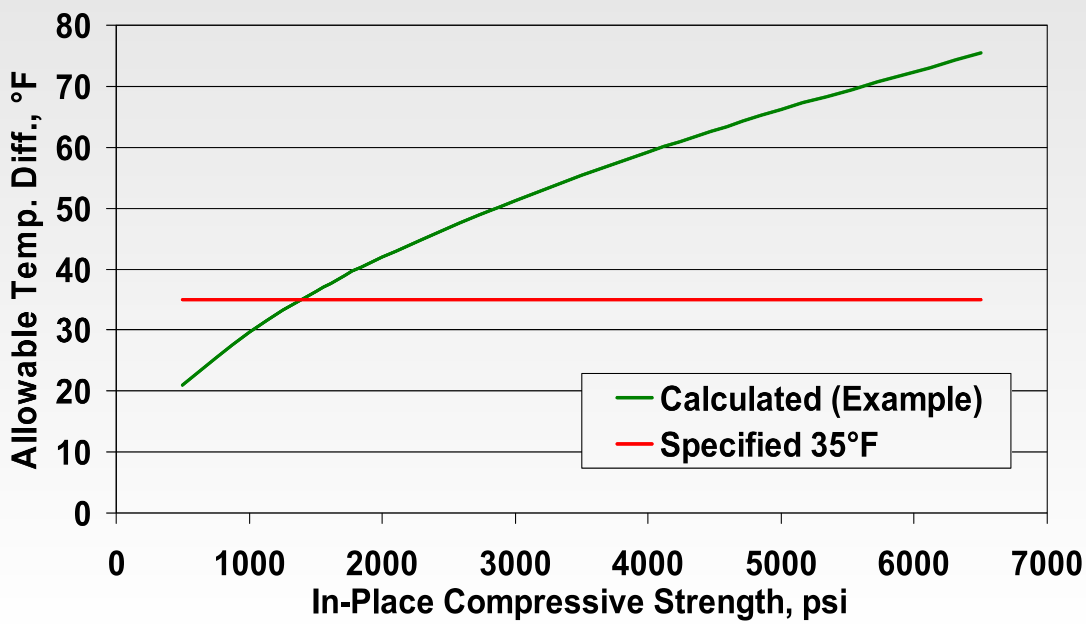
Temperature Difference Limit (Cont.)

- Engineered (tailored) limit
  - Accounts for concrete's ability to withstand higher thermal stresses as strength increases
  - Based on concrete properties and structure
  - ACI 207.2R-95 and CIRIA C660



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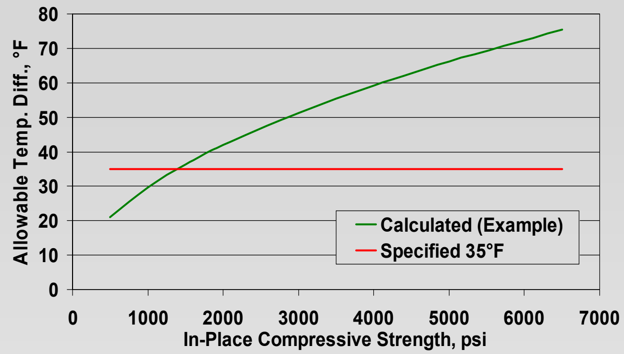
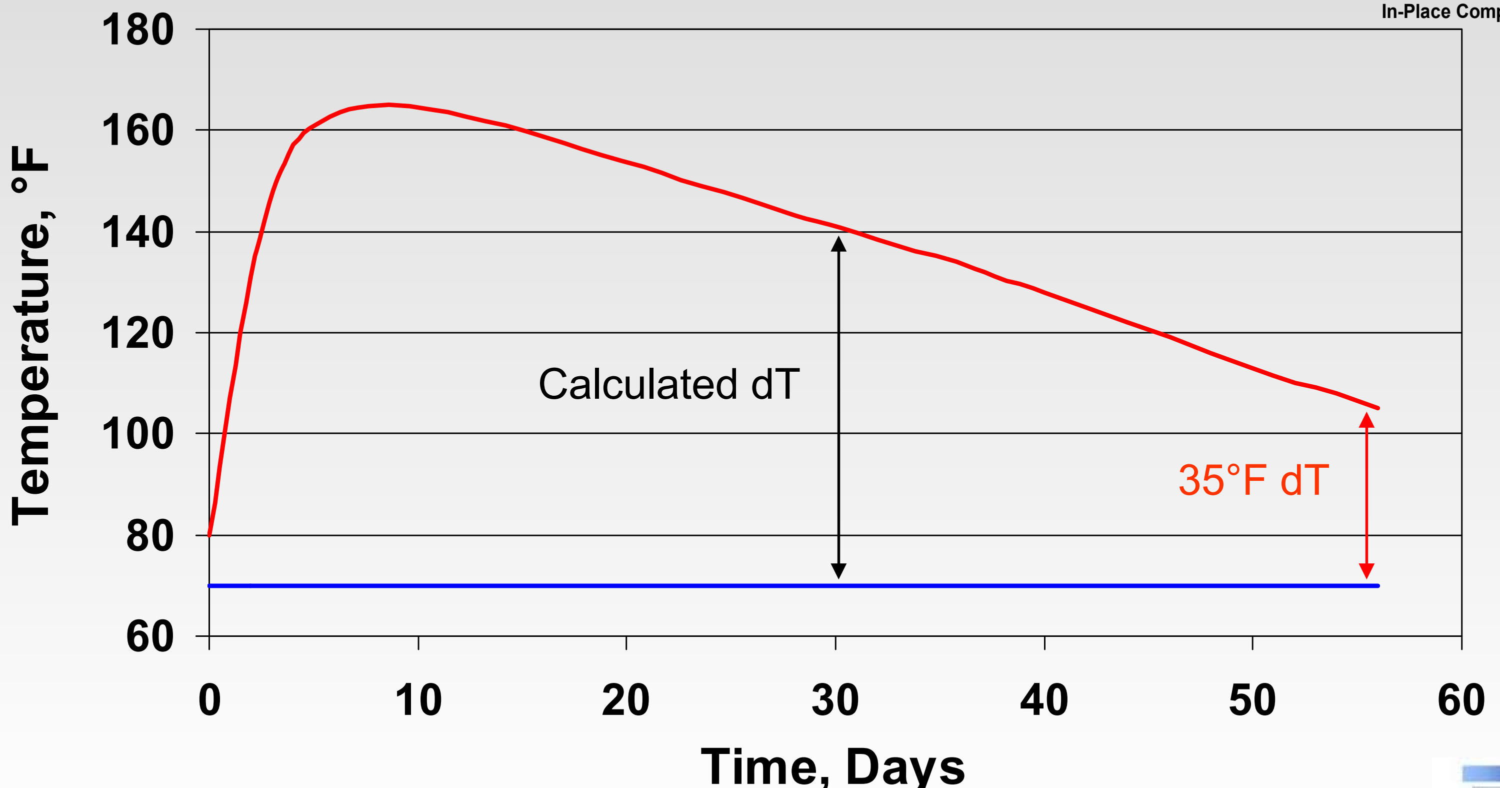
Temp. Difference and Time Savings





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Thermal Control Strategies

- Thermal control plan (TCP)
  - Document that demonstrates contractor’s methods to:
    - Comply with mass concrete specifications
    - Ensure maximum temperature doesn’t exceed 158°F/160°F
    - Limit the temperature difference to minimize/prevent thermal cracking
  - Based on modeling and/or mockups

Control Strategies (Cont.)

- Low temperature rise concrete
  - Less cementitious
  - Higher SCMs and/or low heat cement

	Mass Mix
Cement, Type II/V, pcy	320
Fly Ash, Class F, pcy	320
Concrete Sand, pcy	1544
#8 Coarse Aggregate pcy	365
#57 Coarse Aggregate, pcy	1460
w/cm	0.34
Est. Temp. Rise, °F	72

Comp. Strength, psi	Mass Mix
7 days	5955
28 days	8570
56 days	10,840
90 days	10,980
Air Content	3%
Slump, in.	9¾
C157 Shrinkage, 28 days	0.33%

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Control Strategies (Cont.)

- Reduced placement sizes
  (with adequate time for cooling)

Control Strategies (Cont.)

- Keep the surface warm
  - Surface insulation
    - Time ≈ ¾*Thickness-1
    - No exposed steel!
  - Added heat?

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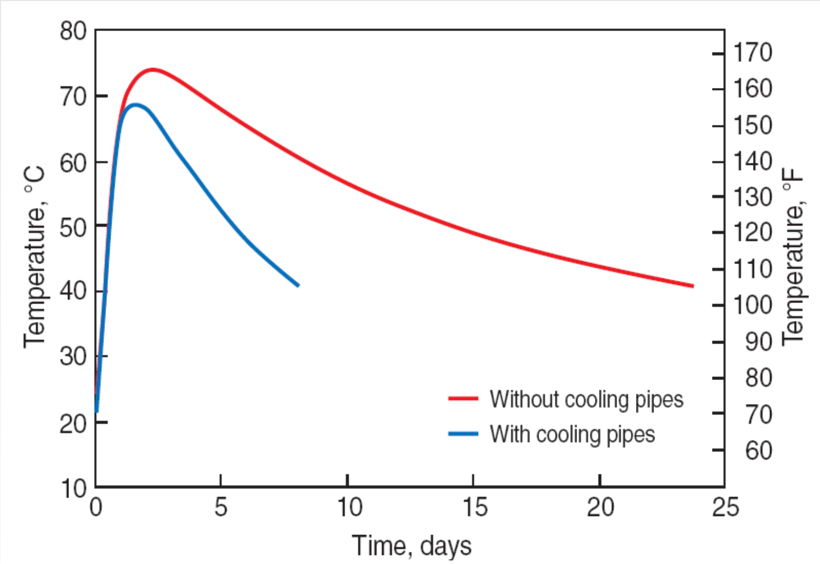
Control Strategies (Cont.)

- Precool the concrete
  - Use cold batch water
    - 2-3°F reduction
  - Replace batch water with ice
    - Up to 20°F reduction
  - Liquid nitrogen precooling
    - Unlimited precooling

Control Strategies (Cont.)

- Post-cool with cooling pipes
  - Remove internal heat after placement
  - Reduces the overall temperature rise and maximum temperature
  - Reduces the time of thermal control
  - ¾” or 1” plastic pipe
  - Typically uses water
  - Filled with grout afterwards



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Cooling Pipes

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Cooling Pipes

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Temperature Monitoring

- Monitor temperatures to ensure (prove) limits not exceeded
- Typical locations
  - Geometric center of placement
  - 2-3” below the surface at center of large surface
- Hourly data

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Things to Avoid

- Poor insulation
- Uninsulated steel
- Water curing

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Summary

- Mass concrete is not always massive!
- Cracking can be minimized/prevented through control of temperatures and temperature differences.
- Insulation is (almost) always required.
- Increased time of construction (but this can be minimized).
- Helps ensure service life is achieved.

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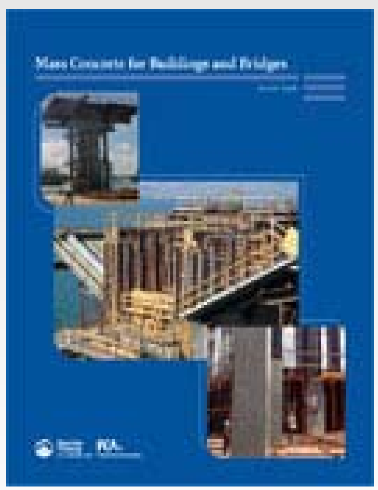
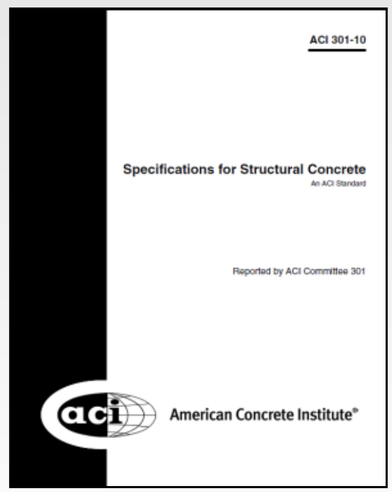
Resources

- ACI 301-10 or ACI 301-16 (www.concrete.org)
- PCA Publication EB547 (www.cement.org)
- ACI 207.7R (to be published “soon”)
- www.ThermalControlPlan.com





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Thank you!

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