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minnesota concrete council
Dedicated to Cast-in-Place Concrete

# Mass Concrete

## How big is big?

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Robert Howell, P.E.

1

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2

# Outline

- What is mass concrete?
- Concrete temperature
- Factors affecting mass concrete
  - Materials
  - Size
  - Construction
- Submittals (ACI 301)
- ACI documents on mass concrete

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# What is mass concrete?

*Crystal Springs Dam (completed in 1890) – located in San Mateo County, California – courtesy of nwcultural.com*

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## What is mass concrete?

*Hoover Dam (1931-1936) – near Boulder City, Nevada – courtesy of the U.S. Bureau of Reclamation*

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## What is mass concrete?

*Piers for the San Francisco-Oakland Bay Bridge, courtesy of John Gajda, CTLGroup*

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## What is mass concrete?

*Mat foundation, courtesy of Carrasquillo Associates*



7

## What is mass concrete?

*Dictionary definition of **Mass**:*

- *A coherent, typically large body of matter with no definite shape*
- *Bulk, size, expanse, or massiveness*

Mass Concrete → Size

Correct…

but incomplete



8

## What is mass concrete?

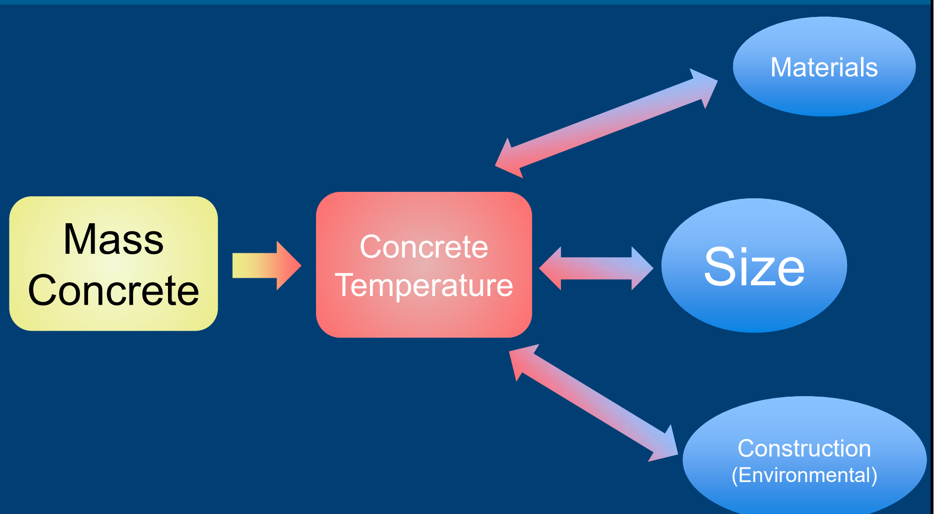
**Definition (ACI)**

any volume of structural 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 of hydration.



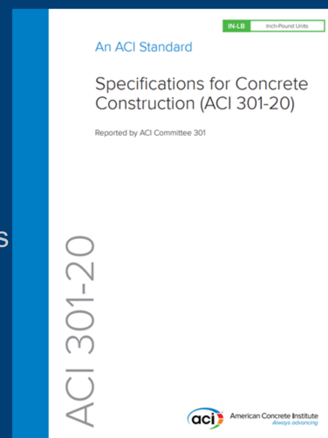


## Interpreting the Definition of Mass Concrete



## Specification Requirements (ACI 301-20)

- Section 8 of ACI 301-20 covers mass concrete
- Sections 1-5 are also applicable:
  - General requirements
  - Formwork and formwork accessories
  - Reinforcement and reinforcement support
  - Concrete mixtures
  - Handling placing and constructing
- ACI presentation on specifications

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11

## Specification Requirements (ACI 301 - 20)

- Section 8 of ACI 301- 20 covers mass concrete
  - Temperature limits
  - Thermal Control Plan
  - Methods to monitor concrete temperatures
  - Moderate to low heat-of-hydration cement
  - Monitor and control temperatures
  - Curing procedures

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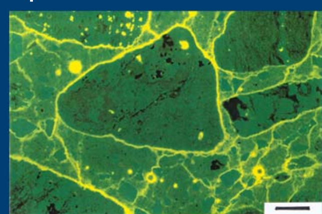
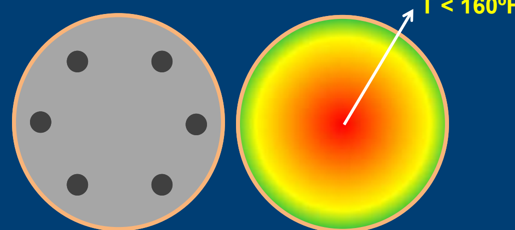
12

## Concrete Temperature: ACI 301- 20

- Maximum temperature in concrete after placement shall not exceed 160ºF
- Reason for limit: Delayed Ettringite Formation (DEF) which is a form of internal sulfate attack
- Expansion and formation of gaps around aggregate particles



*DEF, courtesy of CTLGroup*




concrete pier cross-section (*mid-height*)

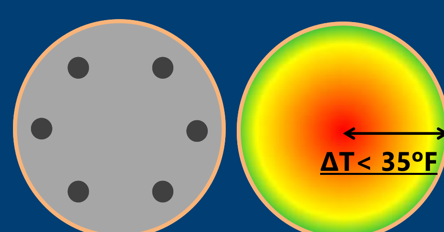




## Concrete Temperature: ACI 301- 20

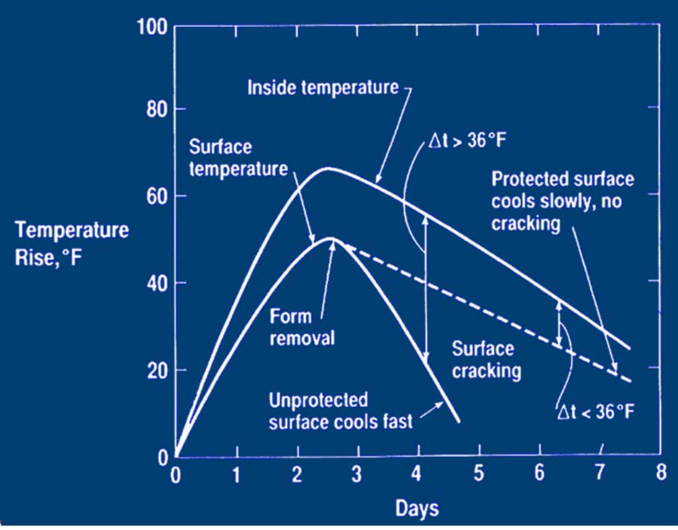
- Maximum temperature difference between center and surface of placement shall not exceed 35ºF
- Thermal gradient creates thermal stresses.
- Thermal stress > concrete tensile strength → cracking

*Cracked bridge pier, courtesy of TxDOT*




concrete pier cross-section (*mid-height*)

## Thermal Deformation – Mechanism

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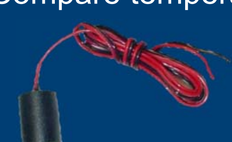
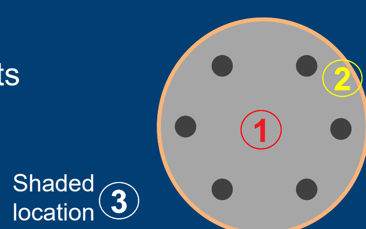
## Concrete Temperature: ACI 301- 20

- Mass concrete temperature must be **monitored**
- Place 1 sensor and a backup at:
  1) The center of the largest portion of placement
  2) 2 to 3 in. from center of nearest exterior surface
  3) Shaded location to monitor ambient temperature
- Monitor temperatures hourly
- Compare temperatures with limits



*temperature sensor, courtesy of www.FLIR.com.*




*mid-height of pier*

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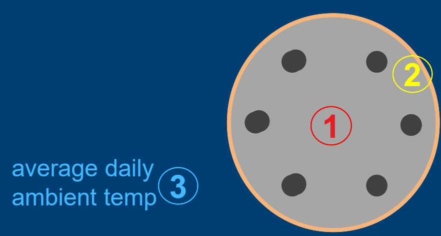
16

## Concrete Temperature: ACI 301-16




*mid-height of pier*

1 :should not exceed 160 ºF
1 − 2 :should not exceed 35 ºF
} Temperature limits

1 − 3 :is less than 35 ºF → stop temperature control

Basis of thermal control plan



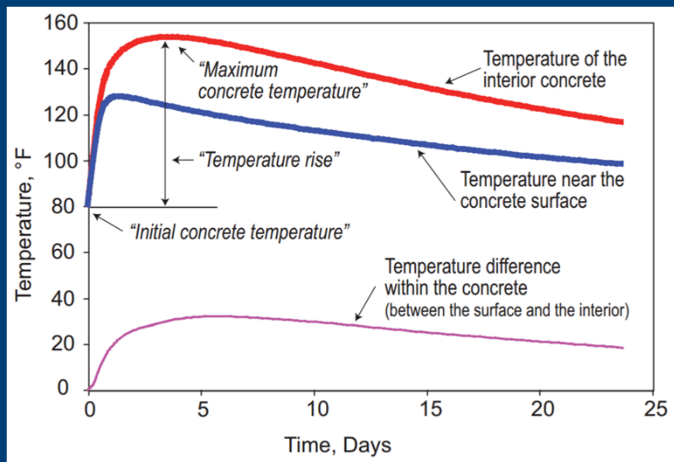


## Concrete Temperature: ACI 301-20

- Mass concrete temperature must be **controlled**
- If limits are exceeded during construction, immediate actions have to be taken
- Do not place additional concrete until cause of problem is identified and corrected
- Temperature control measures must be maintained until:

(internal or core temp.) – (avg. daily ambient temp.) < 35ºF

## Monitoring Concrete Temperature




*Source: John Gajda & Ed Alsamsam, "Engineering Mass Concrete Structures"*

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## Factors Affecting Mass Concrete

| | |
|---|---|
| Concrete Temperature | ✓ |
| Materials | |
| Size | |
| Construction | |

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## Materials:

- What is needed for mass concrete mixture designs?
  - Strength & durability
  - Workable design
  - Economical design
  - Low temperature rise
- Heat is generated by cementitious materials
- Adjust mixture ingredients to reduce heat generation (cement)

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## Materials: ACI 301 - 20

- Meet general material requirements (ACI 301)

Use:

- Moderate to low heat of hydration cement (Type II)
- Cement + Class F fly ash (or Class C fly ash)
- Cement + slag
- Cement + Class F fly ash + slag

Do not use:

- Type III or ASTM 1157 HE (High Early-Strength)

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## Materials: Cementitious Materials

- Use cementitious material that generates low heat

| SCM | Fly Ash Class F | Fly Ash Class C | Slag Cement | Silica Fume | Metakaolin |
|---|---|---|---|---|---|
| Effect on heat energy | ↘ | ↘ | ↘ | ↗ | ↗ |

- Quantity and type of cementitious material affect heat generation
- Reduce mass of cement in a mixture

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## Predicting Peak Temperature Rise

- How do we predict peak temperature rise?
  - Prediction (thermal) model
  - Trial blocks - Tests mixture proportions
  - Or both
- When should either be used and why?

*Courtesy of John Gajda, CTLGroup*

*Courtesy of Christopher Bobko*

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## Simplistic Method for Determining Temperature Rise

Temperature rise = (Cement + SCM x $f_{SCM}$) x $f_{cement}$

Equivalent Cement Content

| $f_{SCM}$ | | | |
|---|---|---|---|
| Class F Fly ash | 0.5 | Slag (0-20%) | 1.0-1.1 |
| Class C Fly ash | 0.8 | Slag (20-45%) | 1 |
| Silica Fume | 1.2 | Slag (45-65%) | 0.9 |
| Metakaolin | 1.2 | Slag (65-80%) | 0.8 |

| $f_{cement}$ |
|---|
| 0.14 - 0.16 |

All units are in US customary units ($lb/yd^3$, ºF, etc…)

*Adapted from John Gajda & Ed Alsamsam, "Engineering Mass Concrete Structures"*

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25

## Simplistic Method

| $f_{SCM}$ | | | |
|---|---|---|---|
| Class F Fly ash | 0.5 | Slag (0-20%) | 1.0-1.1 |
| Class C Fly ash | 0.8 | Slag (20-45%) | 1 |
| Silica Fume | 1.2 | Slag (45-65%) | 0.9 |
| Metakaolin | 1.2 | Slag (65-80%) | 0.8 |

Concrete mixture:
- 550 $lb/yd^3$ cementitious materials content
- 25% Class F fly ash
- Type II cement (low heat)

Equiv. cement = 0.75 x 550 + 0.25 x 550 x 0.5 ≈ 481 $lb/yd^3$

Temperature rise = 481 x 0.14 ≈ 67ºF

| $f_{cement}$ |
|---|
| 0.14 - 0.16 |

Concrete Temp = 80ºF + 67ºF ≈ 147ºF

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26

## Simplistic Method for Determining Temperature Rise

| | *Mixture 1* | *Mixture 2* | *Mixture 3* | *Mixture 4* |
|---|---|---|---|---|
| ***Cementitious Materials Content*** | 650 lb/yd$^3$; Type II cement; no SCM | 550 lb/yd$^3$; Type II cement; no SCM | 550 lb/yd$^3$; Type II cement; 25% Class F fly ash | 550 lb/yd$^3$; Type II cement; 70% slag cement |
| ***Equivalent Cement Content*** | 650 lb/yd$^3$ | 550 lb/yd$^3$ | 481 lb/yd$^3$ | 473 lb/yd$^3$ |
| ***Temperature Rise*** | 91ºF | 77ºF | 67ºF | 66ºF |
| ***Maximum Internal Concrete Temperature*** | 171ºF | 157ºF | 147º | 146ºF |

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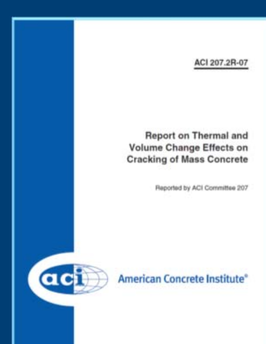
27

## Materials: Determining Temperature Rise

- More advanced methods are available
- Chapter 4 of ACI 207.2R (Schmidt Method)
  - Predicts temperatures, temperature differences, cooling rates, etc…
  - Takes into account other factors such as the volume-to-exposed surface ratio (*V*/*S*)
- Commercial Software

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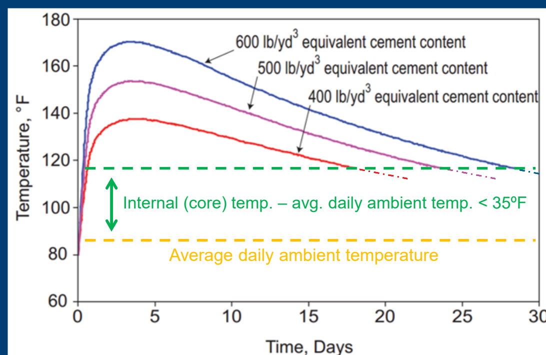
## Cement Content & Temperature Control Time

- Reducing cement content reduces temperature control time




*Source: John Gajda & Ed Alsamsam, "Engineering Mass Concrete Structures"*

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## Materials: Aggregates

Aggregate:

- Use the largest maximum size aggregate
- Optimize aggregate gradation (use denser gradations)

→ Reduce cementitious content of mixture

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30

## Materials: Aggregate

- Thermal stresses are a function of the coefficient of thermal expansion of concrete
- The coefficient of thermal expansion of concrete is a function of the mineralogy of the aggregate

| | Coefficient of thermal expansion of concrete (per millionths per ºF) |
|---|---|
| **Quartzite, Cherts** | 6.6-7.1 |
| **Sandstone** | 5.6-6.6 |
| **Granite and Gneisses** | 3.8-5.3 |
| **Limestone** | 3.1-5.1 |

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## Materials: Admixtures

- Water-reducing admixtures
- Air-entraining admixtures

→ Improve workability
Reduce cement content

- Retarding admixtures

→ Reduce the likelihood of cold joints

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## Factors Affecting Mass Concrete

| | |
|---|---|
| Concrete Temperature | ✓ |
| Materials | ✓ |
| Size | |
| Construction | |





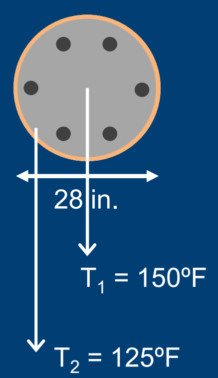
## Size – Placement Dimensions

- For placements with large minimum dimensions, internal heat cannot escape as rapidly as it is generated

| ACI 301-20 Optional Requirements | Commonly prescribed in specifications |
|---|---|
| 48 in. (4 ft) | 36 in. (3 ft) |

- Size alone is not sufficient to identify “mass concrete”

## Size – Placement Dimensions



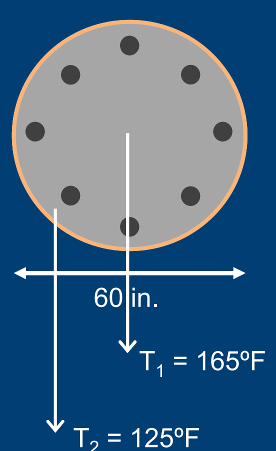

- 28 in. column
- Cement content = 560 lb/yd$^3$

- Measured $T_1$ & $T_2$ < 160ºF limit
- $\Delta T = T_1 - T_2$ = 25ºF < 35ºF limit

Not Mass Concrete



## Size – Placement Dimensions

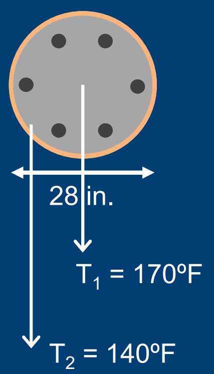



- 60 in. column
- Cement content = 560 lb/yd$^3$

- $T_1$ = 165ºF > 160ºF limit
- $\Delta T = T_1 - T_2$ = 40ºF > 35ºF limit

Mass Concrete

## Size – Placement Dimensions




- 28 in. column
- Cement content = 700 lb/yd$^3$

- $T_1$ = 170ºF > 160ºF limit
- $\Delta T = T_1 - T_2$ = 30ºF < 35ºF limit

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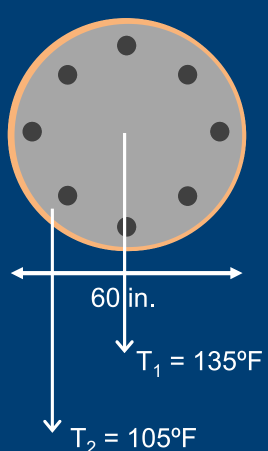
37

## Size – Placement Dimensions




- 60 in. column
- Cement content = 380 lb/yd$^3$

- $T_1$ = 135ºF < 160ºF limit
- $\Delta T = T_1 - T_2$ = 30ºF < 35ºF limit

Not Mass Concrete

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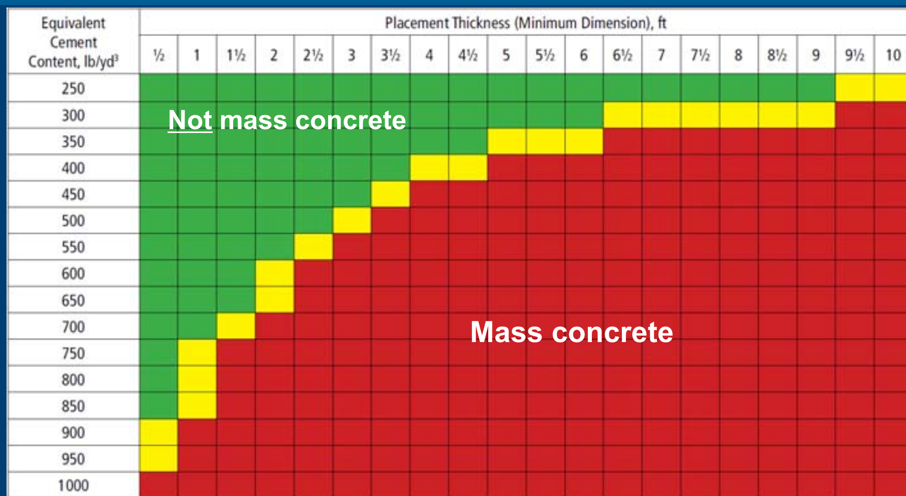
38

## Placement Thickness vs. Equivalent Cement Content




Source: John Gajda, "When Should Mass Concrete Requirements Apply?", Aspire Magazine, Summer 2015

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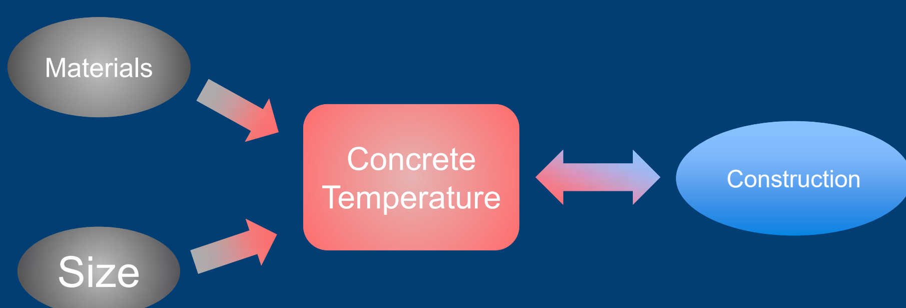
39

## Factors Affecting Mass Concrete




- Assume size and mixture proportions cannot be changed
- Predicted temperatures exceed limits

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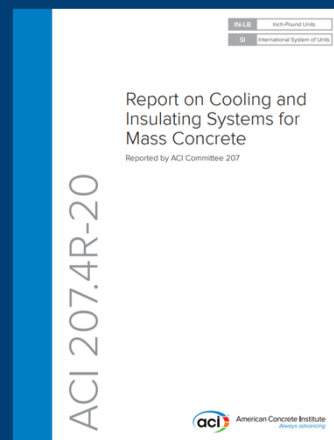
40

## Construction

- Batching, mixing, placing, and curing
- Temperature control could be achieved through:
  - Construction Management
  - Insulation
  - Precooling
  - Postcooling








## Construction Management

Protecting the structure from excessive temperature differentials by:

1. Placing concrete during cool weather or at night
2. Use of lifts

*Courtesy of John Gajda, CTLGroup*

## Insulation

- Used to control temperature differential
- Slows escape of heat at the exposed surfaces
- Formed surfaces:
  - Cover forms with blankets
  - Build insulated forms (foam insulation, etc…)
- Unformed (horizontal) surfaces –
  - blankets

*Courtesy of Mark Bloschock*

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## Insulation

*Courtesy of John Gajda, CTLGroup*

*Courtesy of Carrasquillo Associates*

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# Precooling

- Involves reducing concrete temperature during batching/mixing – prior to placement
- Precooling aggregate by misting or sprinkling water
- Using chilled water or shaved/crushed ice

*Courtesy of Qanbar Ready Mix*

*Courtesy of Portland Cement Association*



45

# Precooling: Liquid Nitrogen

Cooling concrete using liquid nitrogen

*Courtesy of Portland Cement Association*



46

## Postcooling: Cooling Pipes

- Consists of circulating a cool liquid through thin-walled pipes
- Accelerates heat removal:
  - Reduces peak temperature
  - Reduces temperature control time
- Cooling pipes
  - Uniformly distributed
  - Closer pipe spacing more rapidly removes heat

*Courtesy of John Gajda, CTLGroup*

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47

## Postcooling: Cooling Pipes

*Courtesy of Gerard M. Nieblas*

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# Postcooling: Cooling Pipes


*Courtesy of John Gajda, CTLGroup*



# Construction: Temperature Control

- Which temperature control method should be used?
- Main factors
  - Cost
  - Expected temperature rise

| | |
|---|---|
| **Insulation** | Controls temperature differential |
| **Precooling** | Reduces concrete temperature before concrete is placed (at the batch plant) |
| **Postcooling** | Actively reduces concrete temperature after the concrete is placed |

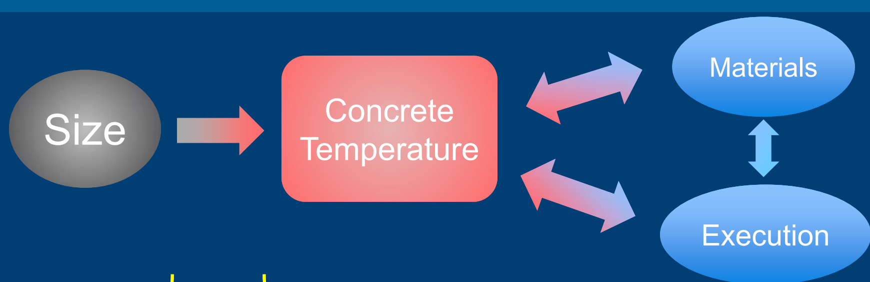
## Construction: Temperature Control - Curing

- Monitor and control temperature
- Preserve moisture by maintaining forms in place
- Use water-retention sheeting materials or membrane-forming curing compounds
- water curing should not be used
- Conditions for early termination of curing measures (ACI 301-20, Section 8)





## Factors Affecting Mass Concrete




Design phase, governed by design codes

Construction phase, governed by material and construction specifications

- Temperature control is part of the construction phase
- Contractor must identify mass concrete before placement

## Specification Requirements (ACI 301 - 20)

- Section 8 of ACI 301 - 20 covers mass concrete
  - Temperature limits
  - Thermal Control Plan
  - Methods to monitor concrete temperatures
  - Moderate to low heat-of-hydration cement
  - Monitor and control temperatures
  - Curing procedures

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## Submittals: ACI 301 - 20

The contractor shall submit a **thermal control plan**:

- Mixture proportions
- Calculated or measured concrete temperatures
- Equipment and measures to monitor and control temperature
- Curing plan and duration
- Formwork removal procedures and how curing will be maintained to not exceed temperature limits

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54

## Submittals: ACI 301 - 20

The contractor shall submit a **thermal control plan** which includes information and data about:

- Concrete mixture proportions
- Calculated or measured concrete temperatures
- Equipment and measures to monitor and control temperature
- Curing plan and duration
- Formwork removal procedures and how curing will be maintained to not exceed temperature limits

Refer to section 8.1.4 of ACI 301-20 for details





## What If Temperature Limits are Exceeded

- What if the maximum temperature limit of 160ºF is exceeded during construction? → DEF?
- What if the maximum temperature difference limit of 35ºF is exceeded during construction? → Thermal cracking?

**PLAN AHEAD**

- Avoid exceeding temperature limits
- Factor of safety

# How big is big?

# It's not a **BIG** Deal

*Control Temperature*

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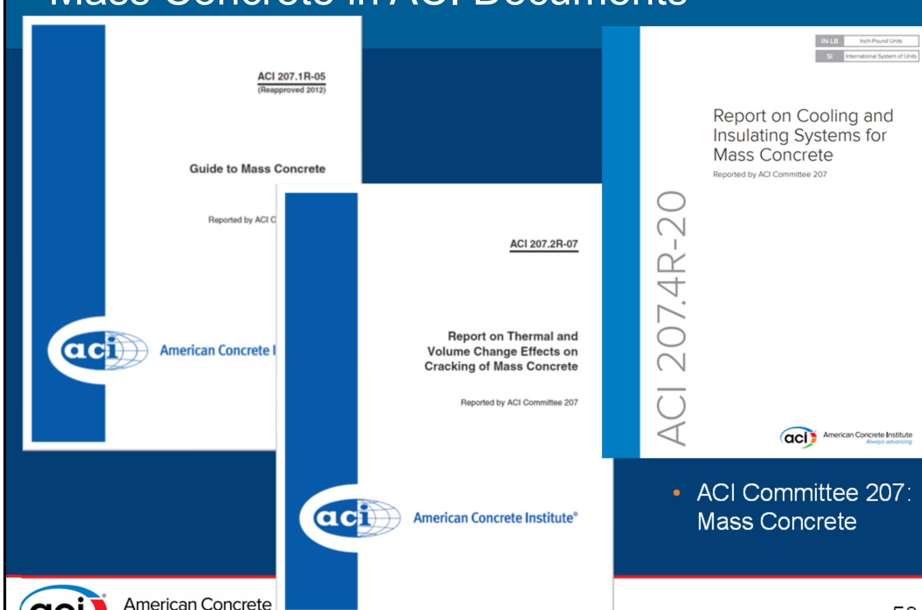
## Mass Concrete in ACI Documents




- ACI Committee 207: Mass Concrete

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58

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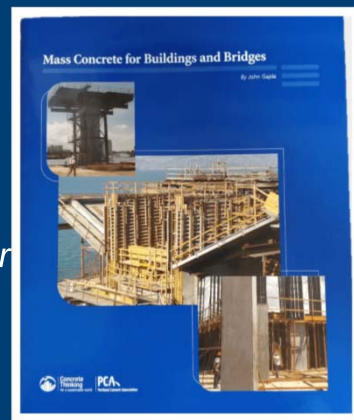
## Mass Concrete – Other References

- “Mass concrete for Buildings and Bridges”, *Portland Cement Association*
- “When Should Mass Concrete Requirements Apply?”, *John Gajda, Aspire Magazine, Summer 2015*
- *“Engineering Mass Concrete Structures”, John Gajda & Ed Alsamsam*








## *Thank you*

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