MASSIVE CONCRETE PLACEMENTS

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ACI 207 defines mass concrete as: “... any volume of concrete with dimensions large enough to require that measures be taken to cope with the generation of heat from the hydration of the cement and attendant volume change to minimize cracking”.
Road Map

Project Specifications → Concrete Mix Design → Ready Mix Preparation → Contractor Preparation

Quality Control on Site → Verification of Temperature & Concrete Analysis

ACTS
ADVANCED CONSTRUCTION TECHNOLOGY SERVICES
Project Specifications

Concrete Temperature

Mix Properties

Quality Control Index
Concrete Temperature

Because size does matter !!!

Maximum Concrete Temp

- Exothermic reaction
- Risk of Delayed Ettringite Formation “DEF”
- Internal Sulfate Attack

Differential Temp

- Increase core temperature
- Cooling on the surface
- Volume change, Tensile stresses and Thermal Cracks

High concrete temperature during hydration
Cooled surface and thermal cracking
High degree of restraint
Concrete Temperature
Because size does matter !!!
Practice

Common Practice
Fresh Concrete Temperature max 32°C

Good Practice
Max. Hardened Concrete Temperature
Max. Differential Temperature
Max. Fresh Concrete Temperature
( Sometimes less than 21°C )

What are the main parameters affecting the rise in temperature?
Cement composition, fineness, and content
Aggregate content and CTE (Coeff. of Thermal Expansion)
Section geometry
Placement & ambient temperatures
Concrete Mix Design & Heat of Hydration

- Cement and Cementing Materials (Cement Type, Fly Ash, Silica Fume, GGBS)
- Water for use in concrete (Warm Water, Chill Water, Ice)
- Aggregate type, size and gradation
- Water to Cementing ratio “W/Cm”
- Admixture for Concrete (Retarder, High Range Water Reducer, etc)

- Initial concrete temperature (ACI 301 – Max 21°C),
- Bleeding Rate and Setting Time

- Compressive Strength
- Durability tests (RCP, Chloride diffusion, Water Penetration, etc)
Common Practice !?

c. When air temperature is between 30 deg C and 32 deg C, delivery time from the time water is added to the mix until it is placed in its final position in the form shall not exceed 60 minutes. When air temperature is above 32 deg C, delivery time shall not exceed 45 minutes.

1. Maintain concrete temperature below 32 deg C at time of placement. Chilled mixing water or chopped ice may be used to control temperature, provided water equivalent of

F. Concrete Tests: Testing of composite samples of fresh concrete obtained according to ASTM C 172 shall be performed according to the following requirements:

1. Testing Frequency: Obtain one composite sample for each day's pour of each concrete mixture exceeding 5 cu. m, but less than 20 cu. m, plus one set for each additional 40 cu. m or fraction thereof.

Compressive-Strength Tests: ASTM C 39/C 39M; test one specimen of the field cured specimen at 7 days, and one specimen of laboratory-cured specimens at 7 days. Test one specimen of the field cured specimen at 28 days and one set of two specimens of the laboratory cured specimens at 28 days. Reserve the remaining laboratory-cured specimen for later testing if required.
Practice 😊

- Delivery of concrete shall be based on trial mixes in relation with slump and slump retention.
- Fresh concrete temperature shall be in relation to
  - Section dimension
  - Weather condition
  - Structural element

Concrete composite sample is consisted of 7 specimens for strength analysis, 2 to be tested at 7 days, 3 at 28 days and 2 spare cylinders for later use.

Samples to be taken at the average rate of 1 sample every 30 m³ of concrete or fractions thereof for the first 90 m³, Then 1 sample every 100 m³ of concrete or fraction thereof when continuous concrete production reaches up to 2000 m³ and Later of 1 sample every 200 m³ of concrete or fraction thereof when concrete production exceeds 2000 m³.
### Example: Raft Foundation
Volume 2400 m³ and Depth 3m

<table>
<thead>
<tr>
<th>Common Practice</th>
<th>Good Practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete will be waiting in queue and lots of trucks will be rejected</td>
<td>Concrete will have enough workability to avoid cold joint and placed</td>
</tr>
<tr>
<td>High possibility of thermal and DEF cracks</td>
<td>Low possibility of cracks</td>
</tr>
<tr>
<td>Each set is consisted of 4 cylinders (2 at 7 and 2 at 28 days)</td>
<td>Each set is consisted of 7 cylinders (2 at 7, 3 at 28 days &amp; 2 spare for late strength)</td>
</tr>
</tbody>
</table>
| Total number of sets 61  
Total number of cylinders 244 | Total number of sets 24  
Total number of cylinders 168 |
| Not in accordance with standard and high fluctuation | As per standard with low fluctuation |
Concrete Mix Design

Materials

Fresh Properties

Hardened Properties
Concrete Mix Design

Aggregates:
- Coarse and fine

Cement & Cementitious materials

Water

Admixtures
Aggregates:
Coarse and Fine

1- Availability
2- Large size aggregates shall be used to reduce surface area and the use of cementing content
3- Aggregate size shall meet spacing requirements
4- Aggregates shall be combined to produce maximum compactability and reduce air void
5- Coarse Aggregates shall be from single source to limit temperature differential to avoid cracking

<table>
<thead>
<tr>
<th>Aggregate Type</th>
<th>Gravel</th>
<th>Granite</th>
<th>Limestone</th>
<th>Lightweight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limiting $\Delta t$ ($^\circ$C)</td>
<td>20</td>
<td>28</td>
<td>39</td>
<td>55</td>
</tr>
</tbody>
</table>
Cement and Cementing materials

1. Cement type shall be in relation with durability consideration of the project (Type I, Type II or Type V)
2. Less C3A and C3S,
3. Reduce the Fineness of cement
4. Do not use hot cement and record the temperature of cement
5. Use of cementitious materials in the mix such as Fly Ash and GGBS

<table>
<thead>
<tr>
<th>NMAS, mm</th>
<th>Min. cementitious materials content, Kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>37.5</td>
<td>280</td>
</tr>
<tr>
<td>25.0</td>
<td>310</td>
</tr>
<tr>
<td>19.0</td>
<td>320</td>
</tr>
<tr>
<td>9.5</td>
<td>360</td>
</tr>
</tbody>
</table>
## Cement and Cementing materials

<table>
<thead>
<tr>
<th>Property</th>
<th>Fly ash</th>
<th>Slag</th>
<th>Silica fume</th>
<th>Natural Pozzolans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Requirements</td>
<td>↓</td>
<td>↓</td>
<td>↑</td>
<td>☐</td>
</tr>
<tr>
<td>Workability</td>
<td>↑</td>
<td>↑</td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td>Bleeding and Segregation</td>
<td>↓</td>
<td>⇑</td>
<td>↓</td>
<td>⇑</td>
</tr>
<tr>
<td>Air Content</td>
<td>↓</td>
<td>⇑</td>
<td>↓</td>
<td>⇑</td>
</tr>
<tr>
<td>Heat of Hydration</td>
<td>↓</td>
<td>↓</td>
<td>⇑</td>
<td>↓</td>
</tr>
<tr>
<td>Setting Time</td>
<td>↑</td>
<td>↑</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Finishability</td>
<td>↑</td>
<td>↑</td>
<td>⇑</td>
<td>↑</td>
</tr>
<tr>
<td>Pumpability</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>Plastic Shrinkage Cracking</td>
<td>⇑</td>
<td>⇑</td>
<td>↑</td>
<td>⇑</td>
</tr>
</tbody>
</table>
Water

- Water shall be tested for physical requirement (ASTM C1602 - EN 1008)

<table>
<thead>
<tr>
<th>Test Description</th>
<th>Limits</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength, min % control at 7 days</td>
<td>90</td>
<td>C31, C39</td>
</tr>
<tr>
<td>Time of set, deviation from control, h:min</td>
<td>From 1:00 early to 1:30 later</td>
<td>C403</td>
</tr>
</tbody>
</table>

- Water temperature can be cooled by the use of a chiller
- Replacement of water with ice (shall be tested as well)
- Temperature of water and ice shall be recorded
- The ice must be completely melted by the completion of mixing time and before discharging concrete
Water-Cementitious Ratio

• Selection of W/Cm shall meet with project specification to achieve Strength and Durability

• Strength can be relaxed to 56 and 91 days when:
  – Delay in setting time is required
  – Reduction for the heat of hydration will affect the sustainability of concrete
  – Reduction in the cementitious content to reduce shrinkage and cracks
Admixtures

- Retarding admixture is used to delay setting time
- High Range Water Reducer to compensate for reduction of water
- Pumping aids to facilitate pumpability of concrete when needed
- Air Entraining Admixture for volume change and sulfate attack

_Do not use calcium chloride or any other accelerating admixture!!_
Selection of Mix Design

**CONCRETE**

- **Economical**
  - Chloride Resistance
  - Sulfate Resistance
  - Free Crack
  - Abrasion
  - Fire Resistance
  - Water Penetration

- **Strength**
  - Compressive Strength
  - Tensile Strength
  - Flexural Strength
  - Modulus of Elasticity

- **Durability**

- **Workability**
  - Slump
  - Pumping
  - Cohesion
  - Consolidation
  - Finishability

- **Availability**
  - Cost of materials
  - Reducing Cementing content
  - Highest W/Cm
Planning and Preparation at Concrete facility

Materials availability:
- Water source (Well, tankers, etc.)
- Chiller
- Aggregate stockpiles
- Cement silo and bulker

Store materials 2 days before placement for QC and Temperature Control

Sufficient team to ensure proper quality in production, at least:
- 1 QC Engineer
- 2 concrete technicians

Calibration of the scale in the range of use
- Inspect trucks for defects.
- Control the effect of sunlight on trucks
- Check mixer performance
- Uniformity test

Batch trial to check the mixing time needed
- Ensure the desired slump is achieved
- Verify mix proportioning to yield 1m³

Mix design
Machinery
Manpower
Materials
Factors Affecting the Placement Rate

- Mixing and truck loading
- Delivery to site
- Quality Control Check
- Park-Placement Set-up
- Pumping
- Return to Plant

Roundtrip

- Calculate the Placement rate
- Provide No. of trucks
- Number of pumps
- Standby machinery and spare parts
- Total working hours to place concrete
How to Calculate the Initial Concrete Temperature

The initial concrete temperature:

\[ T^\circ C = \frac{0.22(T_a M_a + T_c M_c) + T_w M_w + T_w a M_w a}{0.22(M_a + M_c) + M_w + M_w a} \]  \hspace{1cm} \text{.... Equ 1}

\[ T^\circ C = \frac{0.22(T_a M_a + T_c M_c) + T_w M_w + T_w a M_w a - 80M_i}{0.22(M_a + M_c) + M_w + M_w a + M_i} \]  \hspace{1cm} \text{.... Equ 2}

- \( T_a, T_c, T_w, \) and \( T_w a = \) temperature in \( ^\circ C \) of aggregates, cement, added mixing water and free water on aggregates

- \( M_a, M_c, M_w, M_w a \) and \( M_i = \) mass in Kg of aggregates, cementitious materials, added mixing water, free water on aggregates and mass of ice

As per ACI 301, the temperature of concrete at placement shall not exceed 21\(^\circ C\) or be less than 2\(^\circ C\).
### Effect of Ice on Temperature of Concrete

<table>
<thead>
<tr>
<th>Materials</th>
<th>Mass, M Kg</th>
<th>Specific Heat Kj/Kg. K</th>
<th>Kilojoules to vary temperature 1°C</th>
<th>Initial Temperature T, °C</th>
<th>Total Kilojoules in materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>350</td>
<td>0.92</td>
<td>322</td>
<td>65</td>
<td>20,930</td>
</tr>
<tr>
<td>Water</td>
<td>110</td>
<td>4.184</td>
<td>460</td>
<td>30</td>
<td>13,807</td>
</tr>
<tr>
<td>Total Aggregates</td>
<td>1850</td>
<td>0.92</td>
<td>1702</td>
<td>30</td>
<td>51,060</td>
</tr>
<tr>
<td>Ice</td>
<td>45</td>
<td>4.184</td>
<td>188</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Minus</td>
<td>45 (Mi)</td>
<td></td>
<td>2672</td>
<td></td>
<td>85,797</td>
</tr>
</tbody>
</table>

45 (Mi) x heat of fusion (335 KJ/Kg) = -15075

Total: 70,722
Initial Fresh Concrete Temperature

• Equ 1 assumes no ice = $34.2^\circ C$
• Concrete Temperature (with ice) = $70,722 / 2672 = 26.5^\circ C$
• Equ 2 assumes 45 Kg of ice = $26.5^\circ C$ (*Ice replaces partial mixing water*)

29% Replacement of water by ice $\Rightarrow$ 7.7°C Reduction in freshly mixed concrete temperature

Aggregate occupies 60 to 80% by volume of concrete
Maximum Hardened Concrete Temperature

\[ T_{\text{max}} = T_{\text{initial}} + \left( T_{\text{rise}} \times \frac{\text{Equivalent Cement Content}}{100} \right) \]

Example:

- Cement Type I,
- \( T_{\text{initial}} \) 22\(^\circ\)C,
- \( T_{\text{rise}} \) 13\(^\circ\)C for every 100 Kg/m\(^3\) of cementing, and
- Total equivalent cementing content is 400Kg/m\(^3\)

\[ T_{\text{max}} = 22 + \left( 13 \times \frac{400}{100} \right) = 74\,^\circ\text{C} \]

1kg/m\(^3\) of cement is counted as 1kg/m\(^3\) cement
1Kg/m\(^3\) of GGBS (as 60% replacement) is counted as 0.85kg/m\(^3\)

- For detailed calculation check ACI 207.2
Limitation on the Differential Temperature $\Delta T$

$\Delta T = \frac{\varepsilon_{tsc}}{K \alpha c R}$

- Where
- $\Delta T$ = Differential temperature $^\circ$C
- $\varepsilon_{tsc}$ = Strain capacity under short-term capacity
- $\alpha c$ = Coefficient of thermal expansion CTE
- $R$ = Restraint factor (0 = unrestrained; 1 = full restraint)
- $K$ = Modification factor, 0.8, for sustained loading and creep

Assume

- $\varepsilon_{tsc} = 90 \times 10^{-6}$
- $\alpha c = 8.0 \times 10^{-6}/^\circ$C
- $R = 0.38$
- $K = 0.8$

$37^\circ$C
Ready Mix Supplier

• Maintain the plant in good performance
• Reduce mixing time
• Choose the most appropriate track from the batching plants to the construction site with respect to traffic and road accessibility
• Travel time ↑ Fresh Concrete Temperature ↑
• Provide fleet summary
• Provide Attention to the coordination of the truck agitators to provide the appropriate rate of placement in order to avoid delays in delivery to avoid cold joints
Contractor Preparation

- QC & Analysis
- Weather Precautions
- Finishing & Curing
- Consolidation
- Accessibility
- Pre-Placement meeting
- Placing concrete
Accessibility

- Gate passes and easy access to site
- Determine the flow of work and trucks
- Study the locations of the pumps or conveyor belts
- Study the sequence of placing concrete
- List the safety measures
- Provide sampling area and check points
Pre-Placement Meeting

• Agree on the mix design and mixing time
• Plants location, fleet summary (trucks and pumps)
• Date and time of placement
• Precautions for weather conditions
• Troubleshooting analysis and project preventive actions
• Agree on placement rate and checklists
• Provide curing and finishing procedure
• Provide list of employee with time line to accomplish the placement
Placement

- The **location** of the pump depends on the site conditions and on the optimal placement procedure.
- The **number** of pumps depends on the volume to be poured and the pump rate.
- The pumping sequence shall be made in a way decreasing the **surface exposure** to less than one hour avoiding possibility of cold joints.
- Municipality laws **limit** working time.

**Stair-step** is the process used for placement:
- Place concrete in layers not more than **450 mm** thick.
- Extend vibrator heads into the previously placed layer of plastic concrete.
- Immediately return to place on the freshly consolidated concrete before initial set and construct the placement in a stair stepped fashion.
Consolidation

- Ensure accessibility for vibrators through the top mat steel
- Enable proper consolidation around the steel and at faces and corners.
- Insertion spacing is 1-1/2 times radius of action

ACI 309
Curing

• Curing will start immediately after finishing.
• Essential to reduce the potential occurrence of thermal crack and achieve higher strength and durability of concrete.
• The top layer of concrete will first be covered by wet burlap.
• Concrete will be cured with tapped water.
• The concrete shall remain under curing for:
  – At least 14 days after the last placement of concrete
  – Until a differential temperature between the surface layer of concrete and ambient temperature is no more than the maximum allowable
Curing

- Water shall comply with ASTM C1602
- The temperature of tapped water shall not be higher than the concrete temperature and not less than the surface concrete temperature by more than 20°C.
- This curing regime will be done by placing a 70mm layer of wet sponge (or wet sand) on top of the burlap.
- The sponge shall be kept wet at all times.
Insulation

• Above the sponge, a **100 mm** thick foam insulating board will be placed to cover the whole surface area.
• The final top layer consists of transparent or white polyethylene sheets.
• After removing the insulation, the concrete shall remain wet at least 21 to 28 days by using wet burlap and spraying water on the surface of concrete.
• Remove protection in such a manner that the maximum decrease in temperature measured at the surface of the concrete in a 24h period shall not exceed:

  • **22°C** for sections from 300 to 900 mm in the least dimension
  • **17°C** for sections 0.9 to 1.8 m in the least dimensions
  • **11°C** for sections greater than 1.8 m in the least dimension
Curing and Insulation

- Wet Sponge
- Wet Burlap
- Polyethylene Sheet
- ISOBOARD Foam Insulation Sheet 50mm thick
Weather

Rate of evaporation > Rate of bleeding

→ Plastic and Drying Shrinkage

Rate of evaporation affected by:
- Ambient temperature
- Relative humidity
- Concrete temperature
- Wind speed
- Solar radiation

Rate of bleeding affected by:
- Type of cement
- Cementing materials
- Fineness and setting time of cement
- ASTM C232
• The parameters can be measured
  – Onsite by using specialized equipment such as “Kestrel wind and weather instrument”
  – Using Equation from ACI 305.1
  – Using the evaporation chart

• The wind speed is measured 0.5 m above the concrete surface level.

• Measures should be taken to decrease the rate of evaporation to below 0.75 kg/m²/h.
Weather Considerations

1/3

Wet Weather

– Do not begin to place concrete while rain, sleet, or snow is falling unless adequate protection is available on site
– Do not allow rain water to increase mixing water or to damage the surface of concrete
– Cap the hopper of the truck mixers
Cold Weather

- Concrete and ambient temperatures shall meet the minimum temperature requirements.
- These requirements will not be necessary when temperatures above 10°C occur during more than half of any 24h duration, the concrete temperature shall be at least:
  - 10°C for sections between 300 to 900 mm in the least dimension
  - 7°C for sections between 0.9 to 1.8 m in the least dimension
  - 5°C for sections greater than 1.8 m in the least dimension
- The temperature of concrete as placed shall not exceed these values by more than 11°C. The temperature of concrete shall not exceed 32°C when hot aggregates, hot water and materials are used.
Weather Considerations 3/3

Hot Weather

- In general the fresh concrete temperature shall not exceed 21°C (32°C)
- Study the effect of hot weather on the hydration of the concrete and maximum concrete temperature
- Fog steel reinforcement, embedment, and forms with water immediately before placing concrete.
- Remove standing water before placing concrete
Temperature Control

- Use of **Thermocouples** to monitor temperature development linked to the rear panel of the digital thermometer.
Temperature Control

- The maximum hardened temperature of mass concrete usually occurs between 3 to 7 days after placement.
- It will then gradually decrease.
- Temperature shall be recorded every 1 hour for the first 48 hours then every 3-4 hours for at least 7 days or else a reduction in temperature occurs.
Temperature Control

- Possibility of shading the area
- Fog spraying the steel with water
- Shading the aggregates in bins
- Replacing added water and partially mixed water by flaked ice or chilled water
- Reducing mixing time without jeopardizing the quality and uniformity
- Spraying cold water on the drum of agitator
Quality Control

• The individual strength test shall be the average of the strength of the specimens tested at the age specified.

• If a specimen shows definite evidence (other than low strength) of improper sampling, molding, handling, curing, or testing, it shall be discarded and the strength of the remaining cylinder shall then be considered as the test result.
Quality Control

- To conform to the requirements of ASTM C94 and ACI 318, strength tests representing each class of concrete must meet the following requirements:

  - The average of any three consecutive strength tests shall be equal to, or greater than, the specified strength, f 'c, and

  - No individual strength test (average of at least two specimen tests) shall be less than 0.90f 'c when strength is more than 35MPa or

  - Be less than 3.5MPa below the design strength
Thank You

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