Concrete Technologist Middle East (CTME) Certification

A NRMCA Certification Program
Goal

- Knowledgeable employees
- Defined scope of responsibilities
- Employee Retention
- Recognition
  - Customers
  - Specifying Authorities
Needs Assessment

- Product Knowledge
- Mixture Proportioning and Adjustments
- Performance based concrete
- Understanding of Specifications and Project Requirements
NRMCA Technical Certification

- NRMCA Technical Short Course (1 week)
  - Since 1965
  - Concrete Technologist Level 2
  - Concrete Technologist Level 3

- NRMCA Concrete Durability Course (2 days)
  - Since 2007
  - Concrete Technologist Level 4
  - Online version available – 2 h/day – 3 weeks
NRMCA CTME Certification

- From NRMCA Course Content
  - Both courses
- Unit conversion
- Eliminate information not relevant to Middle East
- Can be updated with info more relevant to ME.
NRMCA CTME Training

- Self Study
- Develop training program
  - NRMCA will develop/provide annotated slides
- Offer certification exam
  - 2 hours
Descriptive Notes

Slag and Silica-Fume

Ground Granulated Blast Furnace Slag (GGBFS)

Slag is a by-product from the manufacture of iron in a blast furnace. Slag from other metal manufactures (copper, steel, lead, etc.) are not used as cementitious materials in concrete.

Manufacture

In the blast furnace, iron ore, scrap metal, fuel, and limestone or dolomite (slagging stone) are loaded into layers. Liquid metal from the furnace and slag flow on the top of it. The molten slag at about 1500 °C is periodically removed from the blast furnace and cooled.

- Air-cooled slag is discharged on the ground, cools slowly, and is used as aggregate or as a base in asphalt concrete.
- Expanded blast furnace slag is made porous during cooling and is used as a lightweight aggregate.
- Granulated blast furnace slag results from rapid cooling of the liquid slag with water. Only granulated slag is useful as a cementitious material.

Quenching (rapid cooling) of the slag produces slag granules, done by one of the following methods:

- Drumming the molten slag in water – older process, does not give uniform product.
- Pelletizing (or granulation) – molten slag is cooled with water sprays as it falls over a vibrating apron plate, creating a series of small balls, which are then broken into the air and cooled. Smaller particles are rapidly cooled granules, while the larger particles are separated and used as lightweight aggregate.
- Wet-process granulation – the molten slag is hit with large amounts of water using high-pressure jets, which is the most efficient method of granulating but uses large quantities of water.

Slag granules look similar to cement sand. It is de-watered and dried, and then ground to a fineness similar to or greater than that of Portland cement – 450 to 650 m slag Blaine, depending on the source. Slag is harder to grind than Portland cement. When integrated with cement to make a blended cement, slag particles may be coarse.

The ground product is referred to as Ground Granulated Blast Furnace Slag, which is a buff-colored powder. It is referred to as “slag” in this guide.

Slag is transported similar to Portland cement and stored in silos at the ready mixed concrete plant. Care should be taken in identifying the product during storage and handling.

Slag is typically used as a separately bagged cementitious ingredient in concrete. It can also be used in concrete as a blended cement (Types IFSM and I5 in ASTM C 595).

Composition and Reactivity

Composition of slag results from the fusible stone (limestone or dolomite) and impurities in iron ore. While composition is reported as oxides, it does not exist as oxides in slag.

Typical chemical composition of slag (from ACF 2329):

<table>
<thead>
<tr>
<th>Chemical Components</th>
<th>Range of Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>40-50%</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>15-20%</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>5-15%</td>
</tr>
<tr>
<td>MgO</td>
<td>1-3%</td>
</tr>
<tr>
<td>CaO</td>
<td>3-10%</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.5-1%</td>
</tr>
</tbody>
</table>

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2010 International Concrete Sustainability Conference, Dubai, UAE
# Problems and Solutions

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A1</strong></td>
<td>Slump 1-2 in.; nominal maximum aggregate size 1 1/2 in.</td>
<td></td>
</tr>
<tr>
<td><strong>A2.1</strong></td>
<td>Select the basic mixing water from Table A1, 250 lb.</td>
<td></td>
</tr>
<tr>
<td><strong>A2.2</strong></td>
<td>Correct for rounded sand shape (250) - (20) = 230 lb</td>
<td></td>
</tr>
<tr>
<td><strong>A2.3</strong></td>
<td>No correction for cement content</td>
<td></td>
</tr>
<tr>
<td><strong>A2.4</strong></td>
<td>A/E concrete with total 4.5 percent air.</td>
<td></td>
</tr>
<tr>
<td><strong>A2.5</strong></td>
<td>Added air = 4.5 - 1.0 from Table A1 = 3.5%.</td>
<td></td>
</tr>
<tr>
<td><strong>A2.6</strong></td>
<td>Cement content is given as 470 lb/cu.yd. Use 2.1 for 3.5 percent added air and 4/7 of cement water reduction of 30 lb is required. Mixing water = (230) - (30) = 200 lb/cu.yd.</td>
<td></td>
</tr>
<tr>
<td><strong>A3</strong></td>
<td>Not applicable since cement factor is specified.</td>
<td></td>
</tr>
<tr>
<td><strong>A4</strong></td>
<td>Cement content given</td>
<td></td>
</tr>
<tr>
<td><strong>A5.1</strong></td>
<td>From Table A2 b/b, = 0.70 (in between 0.71 for 2.80 F.M. and 0.69 for 3.00 F.M.)</td>
<td></td>
</tr>
<tr>
<td><strong>A5.2</strong></td>
<td>No modification for b/b required</td>
<td></td>
</tr>
<tr>
<td><strong>A5.3</strong></td>
<td>Draw given as 100 lb/cu.ft.</td>
<td></td>
</tr>
<tr>
<td><strong>A5.4</strong></td>
<td>Dry weight of C.A. = (0.70) x (100) x (27) = 1890 lb/cu.yd.</td>
<td></td>
</tr>
<tr>
<td><strong>A6.1</strong></td>
<td>Air content = 4.5 percent (Step A2.4)</td>
<td></td>
</tr>
<tr>
<td><strong>A7</strong></td>
<td>Absolute volumes in cubic feet</td>
<td></td>
</tr>
<tr>
<td><strong>A7.1</strong></td>
<td>Cement = (4/7) x [(3.15) x (64.4)] = 4.39 cu.ft.</td>
<td></td>
</tr>
<tr>
<td><strong>A7.2</strong></td>
<td>Water = (230) - (62.4) = 3.21 cu.ft.</td>
<td></td>
</tr>
<tr>
<td><strong>A7.3</strong></td>
<td>Dry C.A. = (1890) - [(2.60) x (64.4)] = 11.65 cu.ft.</td>
<td></td>
</tr>
<tr>
<td><strong>A7.4</strong></td>
<td>Air = (0.045) x (27) = 1.22 cu.ft</td>
<td></td>
</tr>
<tr>
<td><strong>A7.5</strong></td>
<td>Sum of cement + water + C.A. + air = 18.47 cu.ft.</td>
<td></td>
</tr>
<tr>
<td><strong>A8.1</strong></td>
<td>Abs. Vol. of F.A. = (27.00) x (18.47) = 8.53 cu.ft.</td>
<td></td>
</tr>
<tr>
<td><strong>A8.2</strong></td>
<td>Dry FA weight = (2.60) x (8.53) x (62.4) = 1384 lb/cu.yd. (Since dry weight was needed the bulk-dry specific gravity was used.)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Weight</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A9</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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*2010 International Concrete Sustainability Conference, Dubai, UAE*
Instructor notes

Uniformity of Cement - ASTM C 917

ASTM C 917 is a standard that provides for the concrete manufacturer to report the uniformity of concrete from only one source, based on strength. Typically, C 917 evaluation is only conducted for the primary producer of a concrete plant. The C 917 strength test concretes are sampled prior to shipping. All concretes are then production samples obtained from the grading plant. Samples used for C 917 testing consist of masonry of slow, high-range and some the 7-day and 28-day strength of ASTM C (100) over a period of 66 weeks.

Results:
- Individual strength, running average of 5, and overall average during the composite
- Standard deviation (ultimate strength variance) which represents the variability of concrete strengths; a parameter that addresses the confidence of the C 917 scores
- C 917 scores are useful to evaluate the strength level and variability of concrete mix, allowing the user to make informed decisions about the concrete without errors caused by the concrete
Fundamentals – an overview

- Brief history
- Terminology
- Ingredient materials
- Basic characteristics of fresh concrete
  - Consistency, setting time...
- Basic characteristics of hardened concrete
  - Curing; Strength and Durability
Why use concrete?

- Local raw materials
- Relatively economic
- Cast into any shape; texture; color
- Strength and durability can be customized

Challenges:
- To make uniform high quality concrete
- Many people involved such as:
  - Owner, designer, specification writer, material supplier, RM concrete producer, Contractor, Testing lab.
A typical cubic yard of concrete

Volume
- Air: 6%
- Cement: 10%
- Water: 18%
- Sand: 25%
- Coarse Aggregate: 40%

27 cubic feet

Weight
- -- lb.
- 500 lb.
- 300 lb.
- 1200 lb.
- 1800 lb.

~4000 lb.
Brief History of Cement & Concrete

  - Stephen Stepanian
- 1958: Patent for Front Discharge
  - Jack Willard
Typical Cubic Yard of Concrete (2008)

LOWER QUARTILE
Avg Selling Price $88 cyd

$48.54 85.2%
$16.93 19.2%
$5.46 6.2%
$16.04 18.2%
$1.49 1.7%

UPPER QUARTILE
Avg Selling Price $97.57 cyd

$63.08 54.4%
$15.11 15.5%
$4.95 5.1%
$14.31 14.7%
$10.42 10.7%

TYPICAL MEMBER
Avg Selling Price $91.88 cyd

$51.06 55.0%
$15.49 16.9%
$4.80 5.2%
$14.76 16.1%
$6.06 6.6%

Source: NRMCA Industry Data Survey, 2008

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Basic Characteristics of Fresh Concrete

- Workability
  - Slump and slump loss
- Consolidation
- Segregation
- Finishability
- Bleeding
- Setting time
- Air entrainment
Basic Characteristics of Hardened Concrete

- **Strength Development**
  - Effect of curing RH, temperature

- **Durability**
  - Permeability
  - Freeze Thaw
  - Sulfate Attack
  - Shrinkage
  - Alkali Aggregate Reaction
  - Thermal Effects
  - Resistance to Chemicals
  - Carbonation
  - Corrosion
  - Abrasion
Portland and Blended Cement

- Manufacture of portland cement
- Cement composition phases
- Types of cements their uses.
- ASTM C 150 requirements and related tests
- Quality Control of cement
  - ASTM C 917 reports
- Blended cements in C 595 and C 1157
## Manufacture of Portland Cement

### Raw Ingredients

<table>
<thead>
<tr>
<th>Component</th>
<th>Formula</th>
<th>Percentage</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime</td>
<td>CaO (C)</td>
<td>60%</td>
<td>Limestone, calcite</td>
</tr>
<tr>
<td>Silica</td>
<td>SiO₂ (S)</td>
<td>20%</td>
<td>Clay, shale, fly ash</td>
</tr>
<tr>
<td>Alumina</td>
<td>Al₂O₃ (A)</td>
<td>10%</td>
<td>Clay, shale, bauxite</td>
</tr>
<tr>
<td>Iron</td>
<td>Fe₂O₃ (F)</td>
<td>10%</td>
<td>Iron ore, clay, mill scale</td>
</tr>
<tr>
<td>Sulfate</td>
<td>SO₃ (S)</td>
<td>3% to clinker</td>
<td>gypsum, anhydrite</td>
</tr>
</tbody>
</table>
Manufacture of Portland Cement
Uniformity of Cement - ASTM C 917

28-day Strength

Average = 6170 psi
Corr. Std. Dev. = 310 psi

Running Average of 5

Cement Samples
## Portland Cement composition

<table>
<thead>
<tr>
<th>Phases</th>
<th>Amount, %</th>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₃S</td>
<td>50 – 55</td>
<td>Early strength</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heat</td>
</tr>
<tr>
<td>C₂S</td>
<td>20 – 25</td>
<td>Later strength</td>
</tr>
<tr>
<td>C₃A</td>
<td>5 – 12</td>
<td>Heat</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sulfate resistance</td>
</tr>
<tr>
<td>C₄AF</td>
<td>~ 8</td>
<td>Color</td>
</tr>
<tr>
<td>CSH₂</td>
<td>~ 5</td>
<td>Setting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strength/shrinkage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Admixture performance</td>
</tr>
</tbody>
</table>
## Types of Portland Cement

**ASTM C 150 (AASHTO M 85)**

<table>
<thead>
<tr>
<th>Type</th>
<th>Use</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>General Purpose</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Moderate Sulfate Resistance</td>
<td>Max C$_3$A = 8% (C$_3$S + C$_3$A), Heat</td>
</tr>
<tr>
<td></td>
<td>Moderate Heat of Hydration</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>High Early Strength</td>
<td>1 &amp; 3 day strength limits</td>
</tr>
<tr>
<td>IV</td>
<td>Low Heat of Hydration</td>
<td>7 &amp; 28 day strength limits</td>
</tr>
<tr>
<td>V</td>
<td>High Sulfate Resistance</td>
<td>Max C$_3$A = 5%</td>
</tr>
</tbody>
</table>
### ASTM C 595 (AASHTO M 240)

<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>% Pozz or Slag</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP (X)</td>
<td>Portland-pozzolan cement</td>
<td>X</td>
</tr>
<tr>
<td>IS (X)</td>
<td>Portland blast-furnace slag cement</td>
<td>X</td>
</tr>
<tr>
<td>IT (AX)(BY)</td>
<td>Ternary blended cement</td>
<td>X and Y</td>
</tr>
</tbody>
</table>

**Options - MS, HS, MH, A**

**Type IT – A is primary SCM; B is secondary**

**Example:** Type IT(S25)(P15) contains 25% slag and 15% pozzolan
### ASTM C 1157

<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>GU</td>
<td>General purpose (default)</td>
</tr>
<tr>
<td>HE</td>
<td>High Early Strength</td>
</tr>
<tr>
<td>MS</td>
<td>Moderate Sulfate Resistance</td>
</tr>
<tr>
<td>HS</td>
<td>High Sulfate Resistance</td>
</tr>
<tr>
<td>MH</td>
<td>Moderate Heat of Hydration</td>
</tr>
<tr>
<td>LH</td>
<td>Low Heat of Hydration</td>
</tr>
<tr>
<td>Option R</td>
<td>Low Reactivity with Alkali-Reactive Aggregates</td>
</tr>
</tbody>
</table>
Fly ash and Natural Pozzolans

- Sources, characteristics, and uses
- Specification requirements of ASTM C 618
- Fresh and hardened concrete properties
- Quality control and mixture proportioning
Fossil Fuel Power Plant
Physical and Chemical Characteristics

- Loss on Ignition
- Fineness
- Chemical Composition
- Uniformity
- Reactivity - Fineness, glass content, Ca-glass
Workability

Workability improves - Size and shape of fly ash. Spherical shape will act as ball bearing.

Improved finishability
Improved pumpability
Strength Development

Compressive strength, PSI

Time, Days

0 1000 2000 3000 4000 5000 6000 7000 8000 9000

1 7 28 365

Plain
-20%
-50%

WWW.NRMCA.ORG
Alkali Aggregate Reactions

Fly ash – CaO / Na$_2$Oeq.

Shehata, Thomas, 2000
Slag Cement

- Sources, manufacture and characteristics
- Requirements of Specification ASTM C 989
- Fresh and hardened concrete properties
- Quality control and mixture proportioning.
Slag Manufacture - Iron Blast Furnace

[Diagram of an iron blast furnace with labeled components such as hot air stoves, blast furnace, ladle, molten iron, slag drain, charge, iron ore and limestone, blast furnace waste gas, refractory, skip (dump car), bosh, coke, air, and hot air blast.]
Grades of Slag - ASTM C 989

Slag Activity Index = \[
\frac{\text{Strength of } 1:1 \text{ Slag + Cement Mortar}}{\text{Strength of Control Cement Mortar}}
\]

<table>
<thead>
<tr>
<th>Grade</th>
<th>7-day Index</th>
<th>28-day Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>-</td>
<td>75</td>
</tr>
<tr>
<td>100</td>
<td>75</td>
<td>95</td>
</tr>
<tr>
<td>120</td>
<td>95</td>
<td>115</td>
</tr>
</tbody>
</table>

Requirements for average of 5 consecutive
Compressive Strength

Grade 120 Slag
w/cm = 0.55

Portland Cement
40% Slag
50% Slag

Ref: ACI 233R
Chloride Permeability

![Graph showing chloride permeability with varying water-cement ratios and cement types.](image-url)
Slag - Proportioning

- Typical - 35 to 50%
- Lower early age strengths, delayed initial set
- w/c ratio = w/(cement + slag) ratio
- Water demand - 1 to 5% lower
- Adjust sand content
- Admixture dosage
  - Similar for air entraining admixtures
Silica Fume

- Sources and available forms;
- Requirements of Specification ASTM C1240
- Fresh and hardened concrete properties
- Quality control and mixture proportioning
Silica Fume - Mechanism

Physical – Particle packing

Chemical - Pozzolanic
Silica Fume - High Strength

311 South Wacker, Chicago

Key Bank Tower, Cleveland
Silica Fume - Low Permeability

Bridge Deck Overlay

Parking Garages
Silica Fume – Placing and Finishing

One-Pass Finishing
Mixing Water – ASTM C 1602

- Potable water
- Non-potable sources – needs to be qualified for use
- Water from ready mixed concrete operations
  - Needs to be qualified for use and quality monitored
- Combined – mixtures of the above
Hydration, Microstructure and Permeability

- Fundamentals of cement hydration
- Impact of supplementary cementitious materials
- Role of SCMs and w/cm on pore structure and permeability
Hydration

- Cement reacts with water to form cementitious compounds
Hydration
Hydration

Cement + Water $\rightarrow$ C-S-H + CH  Hydraulic

Pozzolan + CH $\rightarrow$ C-S-H  Pozzolanic

Slag + Water $\rightarrow$ C-S-H (no CH)  Hydraulic

Slag + CH $\rightarrow$ C-S-H  Pozzolanic
General principle

Low Permeability

Good Durability
Aggregates

- Types of aggregates
- Requirements for aggregates-ASTM C 33
- Stockpiling and sampling
- Effects of Aggregates on Concrete properties
- Quality control for aggregates
- Lightweight aggregates
- Heavyweight aggregates
Types of Aggregates used in Concrete

- Manufactured Sand
- Sand
- Manufactured Stone
- Gravel
ASTM C 33

Standard Specification for Concrete Aggregates

- Ordering Information
- Fine and Coarse Aggregate Characteristics
- Grading
- Soundness
- Abrasion resistance
- Deleterious materials
Aggregate Properties for use in Concrete

- Freeze-thaw durability
## Harmful Materials in Aggregate

<table>
<thead>
<tr>
<th>Substance</th>
<th>Effect on Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic Impurities</td>
<td>May cause deterioration, effects setting &amp; hardening</td>
</tr>
<tr>
<td>Material Finer than 75 μm</td>
<td>Increases water requirement, may affect bonding</td>
</tr>
<tr>
<td>Coal, lignite &amp; other lightweight materials</td>
<td>Affects durability, may cause popouts, color change</td>
</tr>
<tr>
<td>Soft particles, chert</td>
<td>Affects durability, may cause popouts</td>
</tr>
<tr>
<td>Clay lumps, friable particles</td>
<td>Affects workability and durability, may cause popouts</td>
</tr>
<tr>
<td>Alkali reactive aggregates</td>
<td>Abnormal expansion, map cracking and popouts</td>
</tr>
</tbody>
</table>
Lightweight Aggregate (ASTM C 330)

- Expanded
  - Shale
  - Clay
  - Slate
  - Slag

Produce structural lightweight concrete 1350 to 1850 kg/m³ (90 to 120 lb/ft³)
Heavyweight Aggregate
ASTM C 637, C 638 (Radiation Shielding)

- Barite
- Limonite
- Magnetite
- Ilmenite
- Hematite
- Iron
- Steel punchings or shot

Produce high-density concrete up to 6400 kg/m³ (400 lb/ft³)
Aggregate tests and calculations

- Sampling - field and lab
- Moisture
- Grading and fineness modulus
- Specific gravity and absolute volume
- Bulk density
- Other tests
Sampling Aggregates ASTM D 75
Fine Aggregate
Aggregate Moisture Content

**DRY**

**SSD**

**WET**

Total moisture = Free + Absorbed

Free Moisture = Total - Absorbed

Free Moisture is included in Mixing Water
Particle Distribution of Aggregates
ASTM C 136 Sieve Analysis
## Particle Distribution of Aggregates

### ASTM C 136 Sieve Analysis

<table>
<thead>
<tr>
<th>Sieve</th>
<th>Wt. retained, g</th>
<th>Ind. % retained</th>
<th>% Retained</th>
<th>% Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8 in.</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>100.0</td>
</tr>
<tr>
<td>No. 4</td>
<td>40.5</td>
<td>8.1</td>
<td>8.1</td>
<td>91.9</td>
</tr>
<tr>
<td>No. 8</td>
<td>65.5</td>
<td>13.0</td>
<td>21.1</td>
<td>78.9</td>
</tr>
<tr>
<td>No. 16</td>
<td>82.7</td>
<td>16.4</td>
<td>37.5</td>
<td>62.5</td>
</tr>
<tr>
<td>No. 30</td>
<td>96.3</td>
<td>19.2</td>
<td>56.7</td>
<td>43.3</td>
</tr>
<tr>
<td>No. 50</td>
<td>111.7</td>
<td>22.2</td>
<td>78.9</td>
<td>21.1</td>
</tr>
<tr>
<td>No. 100</td>
<td>87.2</td>
<td>17.3</td>
<td>96.2</td>
<td>3.8</td>
</tr>
<tr>
<td>No. 200</td>
<td>15.2</td>
<td>3.0</td>
<td>99.2</td>
<td>0.8 (W&amp;D</td>
</tr>
<tr>
<td>Pan</td>
<td>0.6</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200 W</td>
<td>3.3</td>
<td>0.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Bulk Density of Aggregates - ASTM C 29

Unit Weight

- Weigh the empty bucket
- Fill in three equal layers
- Rod each layer 25 times
- Level the final layer with rod & fingers
Organic Impurities - ASTM C 40
Specific Gravity & Absorption - C 127

Coarse Aggregate
- Soak sample for 24 hours
- Towel dry to SSD condition
Specific Gravity & Absorption - C 127
Fine Aggregate
L.A. Abrasion – ASTM C 131

Steel Charge:
11 spheres = 4584 g
500 revolutions
Sieve over No. 12
Weigh material retained
Chemical Admixtures

- Requirements in Specification ASTM C 494
- Air-entraining admixtures-ASTM C 260
- Effective use of admixtures
- Cement-admixture compatibility
- Special Admixtures and uses
- Fibers
Purpose of Admixtures

- Improve characteristics of Fresh Concrete
  - Increase workability
  - Reduce water requirement
  - Setting time control
  - Bleed and / or segregation control
  - Hydration control
  - Pumpability
  - Finishability

- Improve characteristics of Hardened concrete
  - Increased Strength
  - Increased Durability (Corrosion, ASR, Permeability, Freeze-thaw)
  - Economy
Types of Chemical Admixtures

- Air Entraining Admixtures (ASTM C 260)
- Water Reducing/Plasticizing
  - ASTM C 494 – Type A, Type D (retarding), Type E (accelerating)
  - ASTM C 1017 – Type I, Type II (retarding)
- High Range Water Reducing
  - ASTM C 494 – Type F, Type G (retarding)
- Set Controlling
  - ASTM C 494 – Type B for retarding
  - ASTM C 494 – Type C for accelerating
Mechanism of Water Reducers
Specialty Chemical Admixtures

- Hydration Control
- Corrosion Inhibitors (ASTM C 1582)
- Shrinkage Reducing Admixtures
- Alkali-Silica Reactions
- Anti-Washout
- Viscosity Modifying Admixtures
- Color
- Fibers
Proportioning Concrete Mixtures

- Selecting mixture characteristics
- Required information on material properties
- Proportioning by absolute volume method
- Adjustments to trial batches
- Proportioning with pozzolans and slag
- Yield, calculated batch quantities
Proportioning Concrete Mixtures

Before we proportion concrete mixtures, we need to know:

- Application (pavement, slab)
- Strength requirement
- Durability requirements - w/cm, other
- Characteristics of the materials
  - Cementitious materials – types and relative density
  - Sand – fineness modulus, relative density, absorption, moisture
  - Stone – nominal max size, relative density, bulk density, absorption, moisture
  - Water
  - Admixtures
Sequence in Mixture Proportioning

- Water requirement
- Air content
- Cementitious materials
- Coarse aggregate
- Sand
**Required Average Strength**

With past test record

\[
\begin{align*}
    f'_{cr} & = f'_c + 1.34 S \\
    f'_{cr} & = f'_c + 2.33 S - 500
\end{align*}
\]

Without past test record

<table>
<thead>
<tr>
<th>$f'_c$, psi</th>
<th>$f'_{cr}$, psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>less than 3000</td>
<td>$f'_c + 1000$</td>
</tr>
<tr>
<td>3000 to 5000</td>
<td>$f'_c + 1200$</td>
</tr>
<tr>
<td>over 5000</td>
<td>$1.10f'_c + 700$</td>
</tr>
</tbody>
</table>
Nominal Max. Aggregate Size

28-day Compressive Strength, psi

Non Air Entrained

Air Entrained

Water-cement Ratio

w/cm to strength
## Select mixing water

<table>
<thead>
<tr>
<th>Slump, inches</th>
<th>Non-Air Entrained Concrete No. 4 (Mortar)</th>
<th>3/8 in.</th>
<th>1/2 in.</th>
<th>3/4 in.</th>
<th>1 in.</th>
<th>1½ in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 2</td>
<td>310</td>
<td>295</td>
<td>280</td>
<td>265</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>3 - 4</td>
<td>420</td>
<td>335</td>
<td>325</td>
<td>310</td>
<td>295</td>
<td>280</td>
</tr>
<tr>
<td>6 - 7</td>
<td>375</td>
<td>355</td>
<td>335</td>
<td>320</td>
<td>305</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Slump, inches</th>
<th>Air-Entrained Concrete</th>
<th>3/8 in.</th>
<th>1/2 in.</th>
<th>3/4 in.</th>
<th>1 in.</th>
<th>1½ in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 2</td>
<td>280</td>
<td>270</td>
<td>260</td>
<td>245</td>
<td>235</td>
<td></td>
</tr>
<tr>
<td>3 - 4</td>
<td>380</td>
<td>305</td>
<td>300</td>
<td>290</td>
<td>275</td>
<td>265</td>
</tr>
<tr>
<td>6 - 7</td>
<td>345</td>
<td>330</td>
<td>315</td>
<td>300</td>
<td>290</td>
<td></td>
</tr>
</tbody>
</table>
Paste Content
Effect of Aggregate Grading
Trial Batches

- Verify and make adjustments
Typical Cost of Concrete

- Material: 54%
- Delivery: 18%
- Plant: 15%
- Fixed: 8%
- Profit: 5%
Production, Delivery & ASTM C 94

- Overview of concrete production
- Requirements of Specification ASTM C 94
- Requirements for mixing water
- Weighing and batching equipment and tolerances
- Mixing Concrete - Batching Sequences; Mixing Concrete; Evaluating mixing Uniformity
- Plant recorders, records and delivery tickets
- Delivery requirements - Jobsite adjustments
Flow of Materials
Revolving Tilt-Drum Mixer
Truck Mixers
Types of Scales

Load cell

Lever-
Volumetric Measurement

- Water meters
- Admixture dispensers
- Accuracy
  - Verified every 90 days
  - Calibrated every 6 months
Accuracy of Batching

- Aggregates
- Storage should maintain distinct types / sizes
- Handling procedures to minimize segregation
- Batching accuracy
  - Individual Batchers ± 2% of required weight
  - Cumulative Batchers ± 1% of intermediate and final cumulative wt.
Batch Records

- **Batch Recorders**
  - Non-tamper able record of actual batch quantities
  - Identified to delivery tickets

- **Delivery Tickets**
  - Record of mix furnished
  - Jobsite notes / purchaser acceptance
Specifications

ASTM C 94 Specification for Ready Mixed Concrete

- Address joint and separate responsibilities of:
  - Owner, purchaser, or specifier
  - Producer and contractor
  - Testing agency

- Project specification requirements govern
Basis of Purchase

Sold by Volume -- cubic yard or cubic meter

\[
\text{Yield} = \frac{\text{Total weight of batch}}{\text{Unit weight of concrete}}
\]

When ordering account for:
- Waste
- Spillage
- Over excavation
- Form Deflection
- Loss of air
- Settlement
Ordering Information

Purchaser Specifies:
- Coarse aggregate size
- Slump
- Air content

**Option A - Performance**
- Strength

**Option B - Prescriptive**
- Cement Content
- Maximum water
- Admixtures

**Option C - Mixed**
- Strength
- Minimum Cement
- Admixtures
Delivery Requirements

- Max 100 revs initial mixing
- Max 300 revs. - mixing and agitation
- 90 minute time limit - batching to end of discharge
- Slump tolerances
  - ± Tolerance depending on slump
  - Producer responsible for slump later of:
    - 30 minutes from time ordered
    - 30 minutes after arrival at jobsite
- Air content requirements
  - ± 1.5%
  - Permitted to adjust air a the jobsite
- Job-site Water Addition
  - 1 addition - after arrival at the job-site + 30 revs
  - Do not exceed maximum water
Shrinkage and Cracking

- Types of physical volume change in concrete
  - Shrinkage in plastic and hardened states
- Controlling and minimizing cracking
- Testing and identifying conditions that result in cracking
Concrete Never Cracks!

Always
Why does concrete contract?

- Chemical shrinkage - Hydration
- Moisture loss (drying shrinkage)
- Temperature
Chemical vs. Autogenous Shrinkage

- **Chemical Shrinkage**
- **Autogenous Shrinkage**

- **H = 0%**
- **H = 100%**
- **w/c = 0.45**

- **Cement**
- **Water**
- **HCP**
Minimizing Drying Shrinkage

- Minimize paste (water) content
- Minimize moisture loss to the system (evaporation retarders, curing compounds)
- Supply extra water (burlap)
- Adjust timing of drying
Concrete Temperature – Placement time

![Graph showing temperature changes over time](image)

- **7:30 AM**
- **11:15 AM**
- **3:30 PM**

**Time (September 9, 1947)**

**Temperature (°F)**
- 120
- 110
- 100
- 90
- 80
- 70

9:00 AM to 12:00 AM
Measuring Shrinkage & Cracking

- C157 – prism length change
  - Initial is at 24 hours
  - Drying only starts at 28 days (or other)
- C1581 – ring shrinkage test
  - Readings start immediately
  - Drying starts at selected age
Cracking

The real trick with cracks is to get them where we want them.
Fundamentals of Durability

- Corrosion
  - Mechanisms, tests and measurements, and strategies for minimizing

- Sulfate attack (chemical, physical, DEF, thaumasite)
  - Mechanisms, tests and criteria and strategies for minimizing

- Alkali Aggregate Reactions
  - Mechanisms, tests and criteria and strategies for minimizing
Where can corrosion occur?
Corrosion is an Electrochemical Process

\[ \text{Fe(OH)}_2 \rightarrow \text{Fe(OH)}_2 \]

\[ \text{FeCl}_2 \rightarrow 6\text{Cl}^- \rightarrow 2\text{H}_2\text{O} \rightarrow \text{O}_2 \]

\[ 2\text{Fe}^+ + 4\text{e}^- \rightarrow \text{Fe} \]

\[ 4\text{OH}^- \rightarrow 2\text{H}_2\text{O} \]

\[ 4\text{e}^- \rightarrow 2\text{H}_2\text{O} \]
Options for Delaying Corrosion

- Provide a sufficient barrier of protection
  - Adequate concrete cover
  - Low permeability concrete
  - Good concreting practices
  - Sealer, membrane

- Modify corrosion behavior of reinforcing steel
  - Reinforcement less prone to corrosion
  - Corrosion-inhibiting admixtures in concrete
  - Cathodic protection or electrolytic chloride removal
Low Permeability Concrete

- Use low w/cm
  - 0.40 and 5000 psi strength (Table 4.2.2 ACI 318)
  - Is w/cm = 0.33 better?

- Use fly ash, silica fume, slag

- Rapid Chloride permeability (ASTM C 1202) test is ideal for specification even though it does not measure permeability
Chemistry of Sulfate Attack

- $\text{C}_3\text{A} + \text{C}_3\text{S} + 12\text{H} \rightarrow \text{C}_4\text{A}_3\text{SH}_{12}$ (monosulfate)
- $\text{C}_4\text{A}_3\text{SH}_{12} + 2\text{C}_3\text{S} + 20\text{H} \rightarrow \text{C}_6\text{A}_3\text{S}_3\text{H}_{32}$ (ettringite)
- $\text{Na}_2\text{SO}_4 + \text{Ca(OH)}_2 + 2\text{H}_2\text{O} \rightarrow 2\text{NaOH} + \text{CaSO}_4.2\text{H}_2\text{O}$ (gypsum)
Ettringite crystals
Sulfate Resistance

Bridge columns in North Dakota in sulfate soils.
Sulfate Attack Preventive Measures

- Use of appropriate cements
- Utilize low w/cm
- Utilize an appropriate mineral admixture (essential for very severe sulfate environment)
Alkali Aggregate Reactions

- Reactive Silica
- Sufficient Alkali
- Sufficient Moisture
ASR map cracking / leaching on a bridge abutment

Built in New Brunswick in 1937
ASTM tests for ASR

- C 295 (petrographic analysis of aggregate)
  - indicates presence of potentially expansive minerals
- C 289 (quick chemical test for aggregate)
  - not reliable
- **C 1260** - (rapid mortar bar for aggregate)
  - Fast – very severe, might fail non-reactive aggregate
- **C 1293** (concrete prism)
  - slow, may be the most reliable test
- C 227 (mortar bar)
  - may pass potentially reactive aggregate
- C 441 (mortar bar-pyrex to qualify effectiveness of SCM)
  - no standardized limits
- **C 1567** - (rapid mortar bar for SCM)
  - Fast, qualifies a cementitious material-aggregate combination
ASR Preventative Measures

- Use non-reactive aggregate
- Limit alkali (<0.6% alkali cement) – must not be only solution (migration, deicer appln.)
- Use supplemental cementing materials
- Use suitable chemical admixtures
Alkali Carbonate Reaction

- Certain carbonate rock (dolomitic)
- Uncommon (IL, IN, IA, MI, MO, NY, SD, VA, TN, WI)
- Mechanism not well understood

- Avoid aggregate or dilute it or use smaller size
- Use very low alkali cement
- Pozzolans not effective
Basic statistical computations

- Average
- Standard Deviation and Coefficient of Variation
- Normal Distributions and properties
- Statistical concepts for mixture overdesign and strength test results
- Applications to quality control
Statistical Concepts

Inaccurate Variable

Inaccurate Precise

Accurate Precise
Measure of Variability - Standard Deviation

\[ S = \sqrt{\frac{\sum (X_i - \bar{X})^2}{n - 1}} \]
Frequency Distribution

Strength, psi

- 2200
- 2400
- 2600
- 2800
- 3000
- 3200
- 3400
- 3600
- 3800
- 4000
- 4200
- 4400
- 4600
- 4800

Number of Tests

- 0
- 1
- 4
- 8
- 7
- 12
- 16
- 18
- 14
- 9
- 7
- 3
- 1
- 0

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## Percentage of Tests Less Than

### Table 2

<table>
<thead>
<tr>
<th>Strength Level</th>
<th>Percent Less than</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{X} - 0.43 S$</td>
<td>33</td>
</tr>
<tr>
<td>$\bar{X} - 0.84 S$</td>
<td>20</td>
</tr>
<tr>
<td>$\bar{X} - 1.00 S$</td>
<td>16</td>
</tr>
<tr>
<td>$\bar{X} - 1.28 S$</td>
<td>10</td>
</tr>
<tr>
<td>$\bar{X} - 1.64 S$</td>
<td>5</td>
</tr>
<tr>
<td>$\bar{X} - 1.96 S$</td>
<td>2.5</td>
</tr>
<tr>
<td>$\bar{X} - 2.00 S$</td>
<td>2.25</td>
</tr>
<tr>
<td>$\bar{X} - 2.33 S$</td>
<td>1.0</td>
</tr>
<tr>
<td>$\bar{X} - 3.00 S$</td>
<td>0.10</td>
</tr>
</tbody>
</table>

**Example**

$\bar{X} = 4000$ psi; $S = 350$ psi

10% of tests less than? Or

90% of tests greater than?

$\bar{X} - 1.28 S$

### Note

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**Strength over-design**

Example

Specified = 4000 psi

Acceptable: 5\% less than spec.

\[ \bar{X} = \text{Spec} + 1.64 \cdot S \]

\[ S = 550 \text{ psi} \]

\[ \bar{X} = 4902 \text{ psi} \]

\[ S = 350 \text{ psi} \]

\[ \bar{X} = 4574 \text{ psi} \]
Requirements of ACI 318, 301

- Durability Requirements – Exposure Classes
- Strength Overdesign
- Mixture submittals
- Evaluation and acceptance of concrete
- Investigation of low strength results
Code vs. Specification

- **Building Code**
  - Minimum requirements for design and construction to protect the public
  - Legally adopted (police power)

- **Specification**
  - Owner-established requirements for materials and construction
  - Project contract documents
ACI 301 Specification for Structural Concrete

Core

- Section 1 — General Requirements
- Section 2 — Formwork and Formwork Accessories
- Section 3 — Reinforcement and Reinforcement Supports
- Section 4 — Concrete Mixtures
- Section 5 — Handling, Placing, and Constructing

Additional by option

- Section 6 — Architectural Concrete
- Section 7 — Lightweight Concrete
- Section 8 — Mass Concrete
- Section 9 — Prestressed Concrete
- Section 10 — Shrinkage Compensating Concrete
Step 2 (a) Calculate Average Strength, $f'_c$

Equation 5-1

$$f'_c = f'_c + 1.34 \times S$$

Example

$$f'_c = 4000 \text{ psi}$$
$$S = 400 \text{ psi}$$

$$f'_c = 4000 + 1.34 \times 400 = 4536 \text{ psi}$$

Equation 5-2

$$f'_c = f'_c + 2.33 \times S - 500$$

$$f'_c = 4000 + 2.33 \times 400 - 500 = 4432 \text{ psi}$$

Use the higher value
Step 3 Mix Design and Submittal

Furnish data showing mix design will obtain required average strength, $f'_c$

- Field Tests between 10 and 30 tests
- Can use same data used for calculating $S$
- Laboratory Trial Batches
- Three point curve
- Water-cement ratio
- Cement content
ACI 318-08 Acceptance

During the Job - Should meet both criteria

1. Average of 3 consecutive $\geq f'_{c}$

2. Single test $\geq (f'_{c} - 500)$

For $f'_{c} > 5000$ psi – Single test $\geq 0.9f'_{c}$
ACI 318-08 Exposure Classes

- Category F
  - Exposure to freezing and thawing cycles

- Category S
  - Exposure to water-soluble sulfates

- Category P
  - Conditions that require low permeability concrete

- Category C
  - Conditions that require additional corrosion protection of reinforcement
### Exposed to water-soluble sulfates

**Exposure Category S** – Exposure to water-soluble sulfates

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
<th>Water-soluble sulfate (SO$_4$) in Soil, percent by weight</th>
<th>Sulfate (SO$_4$) in Water, ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>S0</td>
<td>Negligible</td>
<td>SO$_4$ &lt; 0.10</td>
<td>SO$_4$ &lt; 150</td>
</tr>
<tr>
<td>S1</td>
<td>Moderate</td>
<td>0.10 ≤ SO$_4$ &lt; 0.20</td>
<td>150 ≤ SO$_4$ &lt; 1500 Seawater</td>
</tr>
<tr>
<td>S2</td>
<td>Severe</td>
<td>0.20 ≤ SO$_4$ &lt; 2.00</td>
<td>1500 ≤ SO$_4$ &lt; 10,000</td>
</tr>
<tr>
<td>S3</td>
<td>Very severe</td>
<td>SO$_4$ &gt; 2.00</td>
<td>SO$_4$ &gt; 10,000</td>
</tr>
</tbody>
</table>
## Requirements for Concrete - Exposure Class S

<table>
<thead>
<tr>
<th>Exposure Class</th>
<th>Max w/cm</th>
<th>Min $f'_c$ psi</th>
<th>Cementitious Materials - Types</th>
<th>Additional Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>C 150</td>
<td>C 595</td>
</tr>
<tr>
<td>S0</td>
<td>-</td>
<td>2500</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S1</td>
<td>0.50</td>
<td>4000</td>
<td>II</td>
<td>IP(MS), IS(&lt;70)(MS)</td>
</tr>
<tr>
<td>S2</td>
<td>0.45</td>
<td>4500</td>
<td>V</td>
<td>IP (HS) IS(&lt;70)(HS)</td>
</tr>
<tr>
<td>S3</td>
<td>0.45</td>
<td>4500</td>
<td>V + pozz or slag</td>
<td>IP (HS) IS(&lt;70)(HS) + pozz or slag</td>
</tr>
</tbody>
</table>

Additional Requirements:
- MS: No calcium chloride admixtures
- HS: No calcium chloride admixtures
Overview of Fresh Concrete Tests

- Sampling;
- Slump;
- Unit Weight (density),
- Air Content;
- Temperature;
- Making and Curing Cylinders
Testing Hardened Concrete

- Compressive and flexural strength tests
- Factors affecting strength
- Precision of strength tests
- Core testing
- Nondestructive testing
Analysis of Test Report

- Tabulate the test reports in the order of date made
- Date of pour
- Ambient temperature
- 7 & 28 day strengths
- Slump, air content and temperature
- Duration of initial curing
Strength Round Robin Testing

Data for Medium Strength 4 x 8 Specimens

Strength, psi

Lab ID
Sampling Concrete  ASTM C 172

Pay Attention to:
- How the sample was taken
- Sample Container
- Segregation / Re-mixing
- Delays in Sampling
- Loss of air / Sampling from a Pump
ASTM C 31 Compressive Strength

- Specimens made in accordance with C31 or C192
- Made in 3 layer when rodded, 2 layers when vibrated
- Standard size, 6” x 12” or 4”x8”
- Curing depends on how the compressive strength data is used
- Standard Curing
- Field Curing
Effects of Initial Curing

Variables:
- Ambient Temperature 60-80°F
- Prevent Moisture Loss
- Immersed in Limewater
Grinding Cylinders – High Strength
What if you have Low Test Results?

NRMCA Pub 133:

- Was cylinder tested properly
- Is $f'_{c}$ needed for the structure
- Try non-destructive testing
- Try core tests
- Try load testing
- Corrective Measures
Rebound Hammer ASTM C 805

- It is not a substitute for compressive strength !!!!
- Variables
  - Moisture
  - Hardness of Surface
  - Smoothness of the surface
  - Corrective Measures
  - Aggregate Type
Windsor Probe  ASTM C 803

- It is not a substitute for compressive strength !!!!
- Variables
  - Different Probes for Lightweight
  - Moisture
  - Hardness of Surface
  - Smoothness of the surface
  - Mohs Hardness of Aggregate
Concrete Core Testing

ASTM C 42 Obtaining and Testing Drilled Cores

- Do you really need to core the structure?
  - When?
  - Where?
  - How Many?
Quality Control Procedures

- Review of quality control program
- Material Handling and Storage
- Quality control monitoring - charts
Definitions

- **Quality control.** Actions taken by a producer or contractor to provide control over what is being done and what is being provided so that the applicable standards of good practice for the work are followed.

- **Quality assurance.** Actions taken by an owner or his representative to provide assurance that what is being done and what is being provided are in accordance with the applicable standards of good practice for the work.
Scope of QC activities

- Sampling and testing
  - Concrete materials
  - Concrete
- Plant and field control of concrete production
- Evaluation and procurement of new equipment and tools to improve quality
- Specification review
- Concrete mixture optimization
- Research and development
  - Optimization
  - Innovation
- Evaluation of concrete performance
- Failure analysis and prevention
Control Charts

- Visual Check
- Establish points for corrective action

Control Chart for Average for No. 50 Sieve (Percent Passing)

Specification Limits

Historical Data

Average Percent Passing No. 50

Apr-97 May-97 Jun-97

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Material Storage and Handling

- Aggregates

Unloading, stockpiling, and moving without segregation

Sizes stored in separate bins

Sizes separated to avoid contamination

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Plant control of concrete production

- Maintenance
  - Batch plant equipment
  - Truck mixers
- Replacement schedule
- Calibration of scales and volumetric devices
  - Frequency
  - Evaluation of batching accuracy
- Plant and truck mixer certification
- Selection and investment in new equipment
Concrete mixture optimization

- Specification criteria and on-going historical data
- Periodic review of mix performance - statistical
- Broad range water/cement ratio relationship for basic mixes, with and without fly ash
- Quantifying the efficiency (strength or otherwise) of supplementary cementitious materials
- Evaluate new mixes - trial lab or field batches to confirm performance
- Mixtures for high performance
  - Self consolidating concrete
  - Low permeability
  - Shrinkage
Quality Assurance

- Submittals
- Mixtures and construction procedures will comply with contract documents
- Test records
  - Past records
  - Trial batches
- Prequalification tests of materials and concrete
  - Performance based
- Request variance from specification requirements
Handling, Placing; Finishing and Curing concrete

- Site Preparation
- Placement Methods
- Finishing Procedures
- Curing
Dampen Subgrade

- Dampen when there is danger of plastic shrinkage cracking
- No ponding or standing water

ACI 302 now recommends that the sub-grade normally be dry
Vapor Retarders/Barriers

- Vapor retarders when floor covering installation is anticipated – directly under slab

CIP 29
Placing Concrete
Cranes and Buckets

- Above ground placements
- Clean discharge.
- Bucket capacity - compatible with delivered load and placement capacity
Avoid Segregation

- Baffle
- Mortar
- Rock
- Mortar
- Shallow hopper
- Rock
- Mortar
- Belt Scraper
- No Separation

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Vibration

Radius of Action

Radius of Action

Vibrator

\[ R \]

\[ d \]

\[ 1\frac{1}{2} R \]
Concrete Finishing Tools
Bullfloating
Machine Troweling
Super-flat Industrial Floor
Curing Paper / Plastic Sheets
Concrete in Extreme Weather

- Conditions and affects on concrete
- Estimating concrete temperature
- Plastic shrinkage cracking
- Delivery and jobsite precautions
Hot weather concreting problems….

- Increased plastic shrinkage
- Handling, compacting and finishing difficulties
- Controlling air content
- Cement-admixture interactions like very delayed setting times, poor strengths
  - $\text{SO}_3 - \text{C}_3\text{A}$ imbalance slows $\text{C}_3\text{S}$ hydration
Control of Temperature

- Is there a temperature limit?
- For reducing $1^\circ F$ concrete temperature reduce:
  - Cement by $9^\circ F$
  - Aggregates by $1.6^\circ F$
  - Water by $4^\circ F$
Control of temperature ….

- Cool the water
  - Chiller – 100°F; Ice – 200°F; Liquid nitrogen – 200°F+
Effect of chilled water (45 F) and ice
Control of temperature .... Liquid Nitrogen

Hoover Dam By-pass
Minimize Plastic Shrinkage Cracking

- Provide proper equipment and man power
- Fogging and Misting or evaporation retardants
- Use vapor barriers under slabs, dampen sub-grade
- Set up wind barriers
- Use synthetic fibers
- Accelerate set time
Troubleshooting Concrete

- Causes and Prevention
  - Surface defects
  - Cracking
  - Strength
  - Discoloration

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Can we correct a problem?

Depends when we see it

- Concrete in the truck – return it
- Fresh concrete - maybe
  - Correct the next batch
  - Dig it out
- Hardened concrete – probably not
  - Fill cracks
  - Repair surfaces
  - Retrofit
  - Remove

First find the cause!!!!!!!
Reasons for troubleshooting problems

- Fresh properties
  - Too stiff / wet / variable between loads
  - Placement method – loss of air, etc.
  - Setting time

- Workmanship
  - Construction tolerances
  - Surface finish

- Tensile stresses exceed strength
  - Cracking

- Deterioration
  - Chemical attack
  - Physical distress
Strength Problems

- Ensure proper testing
  - Certified technicians
  - Proper initial curing
  - Specimen Care
Cracking

Joint pattern

Timing the cut

Joint depth

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Cracking – Later Age

Freeze-Thaw

Internal Expansion
Chemical or Physical
Surface Defects – bug holes

Results from Improper Consolidation
Concrete mixture too stiff during placement
Delamination

- Improper Finishing - timing
- Hard Troweled Finishes
Dusting

- Unvented heaters
- Water on surface during finishing
- Weak surface
Curling

Slab Surface is Cooler and Drier than Base

A. Upward Curling – Typical in Internal Slabs

Slab Surface at a Higher Temperature and Moisture than Base

B. Downward Curling

Differential drying shrinkage or temperature
Discoloration

- Improper timing and finishing
- Calcium Chloride
- Hard Trowelled finishes
- Slag Concrete
- Polyethylene burns
Concrete Technologist Middle East (CTME) Certification

A NRMCA Certification Program